Perspective

Water quality sampling: An effective way to monitor watershed condition?

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Public concern about the possible effects of forest harvesting on water quality is reflected in newspaper articles, government reports, environmental group reports, and government legislation and policy. The provincial government in British Columbia has a new plan to address this issue. The government will rely, at least in part, on Water Quality Objectives (WQOs) to move from a prescriptive forest practices code to a results-based code. This plan will define the results forest licensees must achieve, while giving them broad flexibility in how they accomplish these results. In a May 2002 discussion paper, government stated three results they will expect in relation to water quality in community watersheds and high-value fish streams. Specifically, the report made the following statement:

"Forest and range practices will be conducted in a manner that will:

- not introduce deleterious substances to streams;
- meet community watershed objectives at the water supply intake;
- maintain water quality, water quantity and timing of flow within the range of natural variability." (Province of B.C. 2002: 34)

The objective of this perspective article is to examine three forestry and water quality studies to assess how practical a water quality results-based regulatory scheme will be. This is neither a review of the literature nor a critique of legislation. Rather, it is a somewhat subjective attempt to apply British Columbia research experience to an important policy issue.

Following an outline of relevant literature and introduction of key issues, we will discuss three watershed studies:

- Carnation Creek watershed study on the west coast of Vancouver Island (Hartman and Scrivener 1990; Church 1998);
- Matthew Creek watershed study in southeastern British Columbia (Gluns and Toews 1989); and
- Sediment budget studies in the Kootenays (Jordan and Fanjoy 1999; Henderson and Toews 2001; Jordan 2001).

There are many references on the subject of water quality (WQ) monitoring. We have found the publication *Monitoring Guidelines to Evaluate Forestry Activities on Streams in the Pacific Northwest and Alaska* (MacDonald et al. 1991) particularly useful. Also, Dissmeyer (2000) has edited a comprehensive multi-author report called *Drinking Water from Forests and Grasslands: A Synthesis of the Literature*—it provides a recent summary of the literature related to water quality. For guidelines specific to British Columbia policies, we direct the reader to two reports by Cavanaugh et al. (1998a, 1998b).

The Forest Practices Board (2003) recently released a report on the history and possible role of water quality objectives in a regulatory regime. The Board expressed some serious concerns about using a set of Water Quality Objectives (WQOs) as a regulatory tool. The following excerpt from the Board's report explains these reservations:

- WQOs are not well suited for routine enforcement in the specific forestry context because it is difficult to prove that a specific forest practice caused a particular violation of an objective in a waterbody.
- It is questionable whether WQOs can be adequately monitored and enforced.
- It can take a long time for results to appear, and then it may be too late to do anything to avoid problems, remediate them, or even enforce the law (Forest Practices Board, 2003:5).

The Forest Practices Board (FPB) report concludes with an appendix of appropriate uses of WQOs, including:

- setting a long-term goal for water quality,
- providing a yardstick for long-term tracking of water quality trends,
- as an effectiveness evaluation tool... an indicator of whether the overall regulatory regime is working,
- providing policy direction for resource managers and the public to determine whether new development fits long-term water goals, and whether it should be permitted (Forest Practices Board, 2003:11).

As hydrologists in the Nelson Forest Region, we find that water users often ask us to test water quality in a given stream. We must then address a number of issues: what should we test, how often we should test, and what might the results tell us? Assessing water quality is technically

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complex; there are dozens of parameters for which one can test. Furthermore, flow in a stream is almost continuously changing, and consequently so is water quality. If we apply a broad spectrum of tests to a single sample, costs can run into thousands of dollars. As we try to determine trends in water quality, the costs escalate with time. The first challenge is to set up a sampling program that determines the effects of logging on water quality. The second is to accomplish this in a manner that is both cost-effective and practical.

Known Effects Of Logging On Water Quality

Experience in a number of jurisdictions shows that the primary water-quality effect of logging is on suspended-sediment levels. Moreover, most of this effect is associated with roads required for logging. We measure suspended sediment directly by collecting a water sample from the stream. To determine sediment concentration, we send it to a laboratory to be filtered and dried. We can assess suspended sediment indirectly by measuring turbidity, which is the absorption or scattering of light through a water sample. The relationship between turbidity and suspended sediment varies by watershed depending on the quality of sediment. Turbidity is a useful, economical measurement that is usually inversely correlated with the goal we are trying to achieve: clean water.

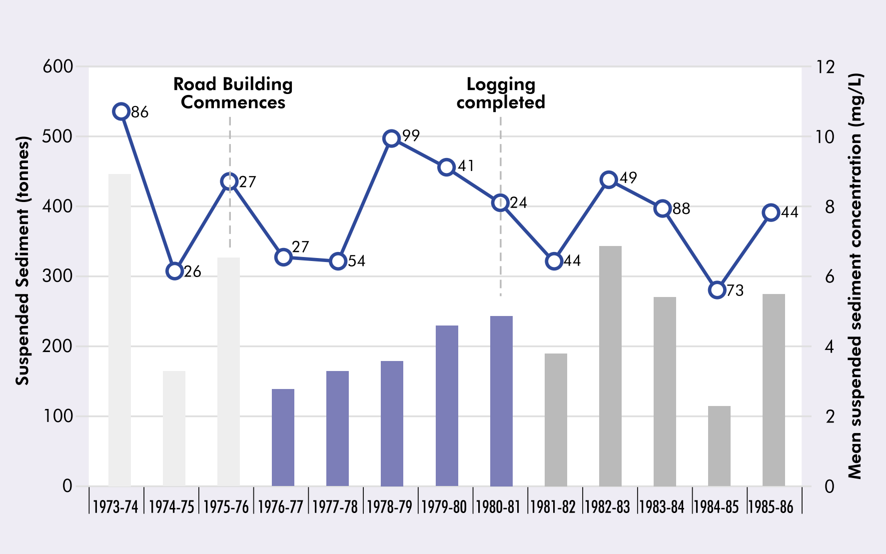

Figure 1. Total suspended sediment transported (bars) and mean annual concentration measured (lines) at B-weir, Carnation Creek for each water year (Oct. 1 to Sept. 30). Numbers adjacent to circles indicate maximum daily sediment concentration during that year. (Based on Hartman and Scrivener 1990 and Church 1998.)

Beyond turbidity, logging can affect physical water-quality parameters such as temperature, and chemical parameters such as phosphorus and nitrate. Logging can also indirectly affect biological parameters such as total and fecal coliform levels. Other forestry-related activities also affect water quality. These activities include prescribed burning or forest fertilization, as well as activities like recreation and grazing that often follow road system expansion. MacDonald et al. (1991) and Dissmeyer (2000) both offer good discussions of the relationship between various watershed activities and water-quality parameters. Nevertheless, the major concerns are suspended sediment and turbidity, which we emphasize in the case study discussion below.

Case Studies

1. Carnation Creek Watershed Study

We will begin with the suspended sediment sampling program at Carnation Creek, which investigated the effects of logging on a small coastal watershed. To determine the effects of logging on the fisheries resource, the research program had three phases: before, during, and after logging. The study was initiated in 1972, logging and road building took place between 1975 and 1981, and post-logging monitoring has continued to the present. The objective was to monitor the effects of logging at the process level. Water Survey of Canada initiated a suspended sediment monitoring program on the mainstem while the Department of Fisheries and Oceans monitored a number of tributaries. Researchers sampled water by different frequency according to stage, systematically measuring suspended sediment before, during, and after logging. As the results in Figure 1 indicate, there was no clear effect of logging on suspended sediment levels and yield. Figure 2 shows the number of days a 20 mg/L level of suspended sediment was exceeded in each year of monitoring (20 mg/L was chosen as an approximation of the Ministry of Water, Land and Air Protection's 5 NTU[1] guideline standard). Suspended sediment appeared to decrease with time.

However, other study findings indicate that sediment-related and habitat-related impacts did occur in this watershed during and after logging (Hartman and Scrivener 1990). There are two possible explanations for this apparent discrepancy. One is that the project

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[1] *A Nephelometric Turbidity Unit is a unit of measurement of light absorption or scattering in a sample.*

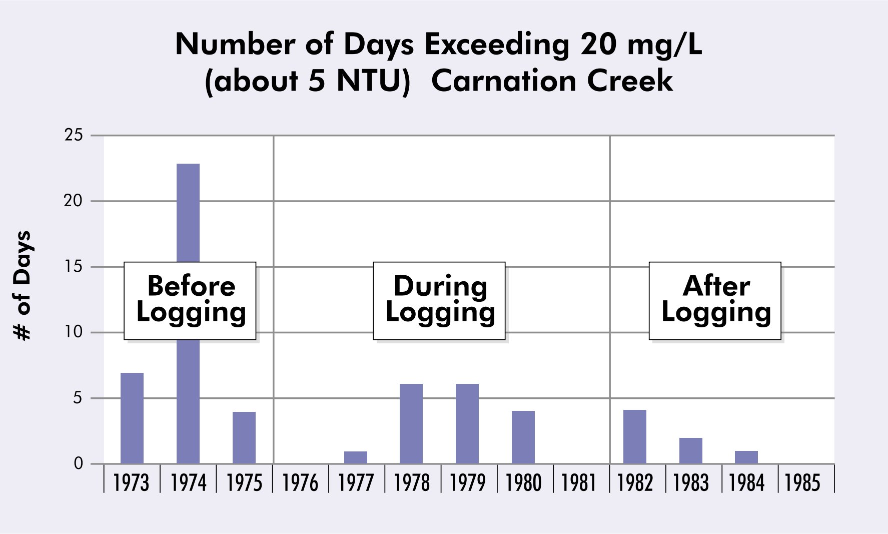

Figure 2. A graph showing the frequency of days exceeding 20 mg/L in Carnation Creek. Data is summarized from Environment Canada (1999).

team did not design the sampling regime such that it would capture the impacts. The other possibility is that the water-quality parameter of suspended sediment is not, by itself, a particularly sensitive measure of impacts. We suspect the latter is the case. Had suspended sediment been the only parameter, it would have provided no inkling of other fisheries, channel, landslide, and spawning gravel effects that this study documented.

The channel changes following the storm of January 3 and 4, 1984 illustrate this point. Some of the major logging-related changes in Carnation Creek occurred during this storm that took place several years after completion of logging (190 mm of precipitation fell during a 24-hour period). Numerous landslides in the upper part of the watershed caused a debris flow in the canyon in the middle part of the drainage. That slide caused extensive reorganization of debris jams and major movement of sediment wedges associated with those debris jams in the lower part of the drainage (Church 1998). Compared to conditions observed previously (Toews and Moore 1982) changes to the channel were dramatic. The sediment movement during the storm was the highest on record but did not persist. Although the highest individual sediment level in Carnation Creek was recorded during this storm (842 mg/L recorded at 2:18 on January 4), this result was not apparent in the annual sediment load (Figure 1) or in frequency of days with high sediment levels (Figure 2). If it were not for channel and gravel quality studies (Hartman and Scrivener 1990), there would have been no indication that this storm had created significantly more serious consequences than other storms.

The Carnation Creek case study illustrates that some of the major impacts can occur several years after logging is complete when it is too late to take any corrective action. While the program was expensive to run, it was not definitive. Church (1999) suggested that more information linking individual logging activity to specific water-quality data was needed.

2. Matthew Creek Wildfire Study

In 1985, a 2200 ha fire burned 13% of the Matthew Creek community watershed, which supplies water to the St. Mary's district of the City of Kimberley. The city was very concerned about the possible water-quality effects both of the wildfire and of the salvage logging that followed. We initiated a program to collect upstream and downstream samples on two burned tributaries, on an unburned tributary that served as a control (Figure 3), and at the intake. We continued the study for four years after the fire and came back again after the 10th year. We sampled every two weeks during the spring runoff season, and monthly or bimonthly at other times of the year. During the first three years of the study, there were small but statistically significant increases in nitrate nitrogen, phosphorus, hardness, alkalinity, calcium, magnesium, pH, and conductance (Gluns and Toews 1989). The differences in turbidity, non-filterable residue (a parameter similar to suspended sediment), and true color were not significant over this interval. The pattern for nitrate nitrogen is shown in Figure 4. This indicates a dramatic difference between the control and the two burned tributaries. Even though both the statistical and graphical analyses showed clear effects of the fire, the water met drinking-water standards of the day. For example, the highest recorded value for nitrate nitrogen was 0.9 mg/L, whereas the guideline specified a maximum of 10 mg/L for drinking water.

The fact that the study design included an unburned control and at least some replication (two burned tributaries) gave us confidence in the results for most parameters. The biweekly sampling interval was adequate for the nutrient parameters studied, but was insufficient for turbidity (Figure 5). Had we only sampled at the intake, we would have seen a small rise in nitrates and several other nutrients during spring runoff. However, we would have been unable to make any inference about the effects of the fire, other than to say

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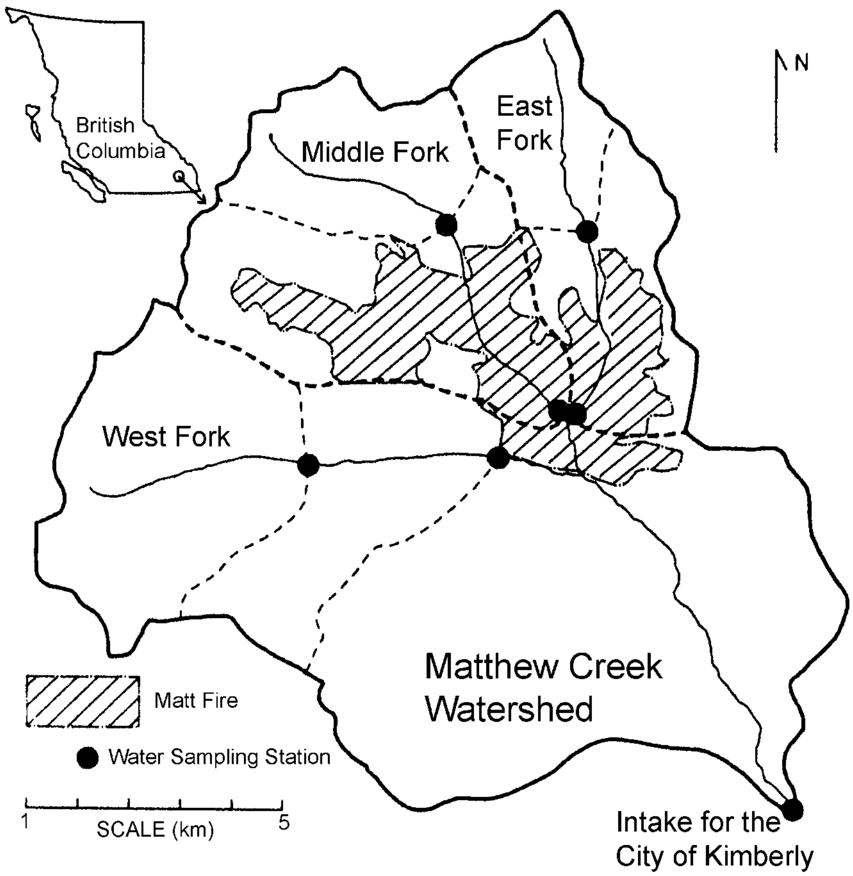

Figure 3. The Matthew Creek watershed showing the sampling locations and location of the burn (from Gluns and Toews 1989).

the water quality appeared similar to other streams in the area and most samples met water-quality standards.

Our main constraints when undertaking this study were labour and funding. Sample analysis costs about $1000 per day in addition to the considerable cost of collecting the samples. We felt our sampling frequency was insufficient to conclude anything definitive about turbidity. To make inferences about this parameter with confidence, it would have been necessary to take daily samples during freshet.

The Matthew Creek study illustrates that it is possible to demonstrate subtle changes in water quality with a proper design. It also shows that different water-quality parameters require different sampling frequencies. The sampling frequency in this study was adequate for the chemical parameters but not sufficient to characterize turbidity.

3. Sediment Budget Studies in the Kootenays

During the 1990s, researchers initiated a number of sediment and turbidity studies in the Kootenays. Jordan and Fanjoy (1999) documented typical patterns of sediment yield in a number of community watersheds. Henderson and Toews (2001) calculated sediment budgets in several watersheds with varying geology to calibrate the IWAP procedure. In Figure 6, we show a typical pattern of turbidity with time; this result indicates that most of the sediment yield happens during the two- to three-month spring freshet. The daily pattern is highly variable and there is no way of knowing when the peaks in turbidity will occur. Thus, to identify the true pattern of variation, one must sample on at least a daily basis. Sediment levels can also vary considerably in the course of a given day. Jordan (1998) demonstrated at Redfish Creek, however, that a single sample in the afternoon could provide a reasonable estimate of the daily average and total load.

No consistent relationship between amount of logging and sediment delivery was evident in 20 watersheds studied by Henderson and Toews (2001) and Jordan and Fanjoy (1999). We found that year-to-year climatic variations and other factors such as recent landslides were far better predictors of water quality than was logging activity. Figure 7 shows annual sediment yields and number of days the 5 NTU water-quality criteria were exceeded at Redfish Creek. Note that there is considerable annual variation. We attribute most of this to flow differences from year to year.

Conclusions

This paper set out to determine the practicality of using WQOs in the regulatory context of the results-based code. Having looked at three watershed studies, we conclude that this strategy is not appropriate.

Lessons Learned: Problems

Natural Variation: The interpretation of water-quality results is often ambiguous. The year-to-year, watershed-to-watershed, or sample-to-sample variation can often be much greater than the effect of a

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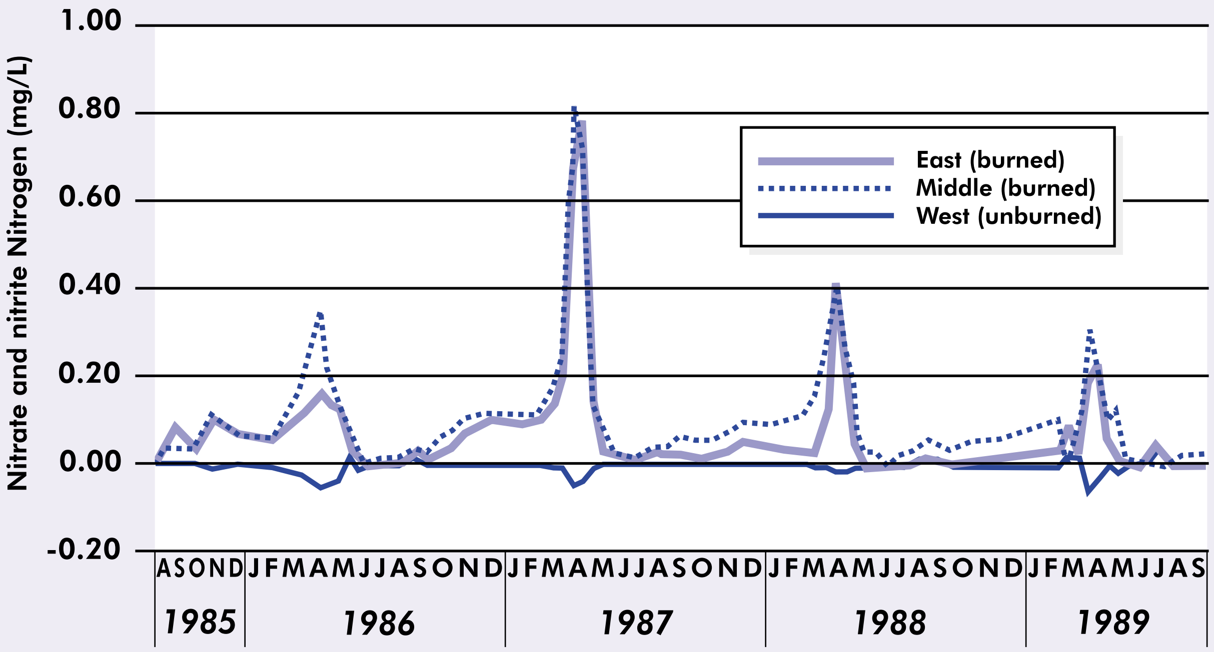

Figure 4. A graph showing nitrate nitrogen trends in two burned and one unburned tributary of Matthew Creek. The graph shows the difference between downstream and upstream sampling sites to illustrate the burn effect. The values for the control are negative during high flow reflecting higher values upstream than downstream. (Data to 1988 from Gluns and Toews 1989; 1989 data is unpublished and from the B.C. Ministry of Forests)

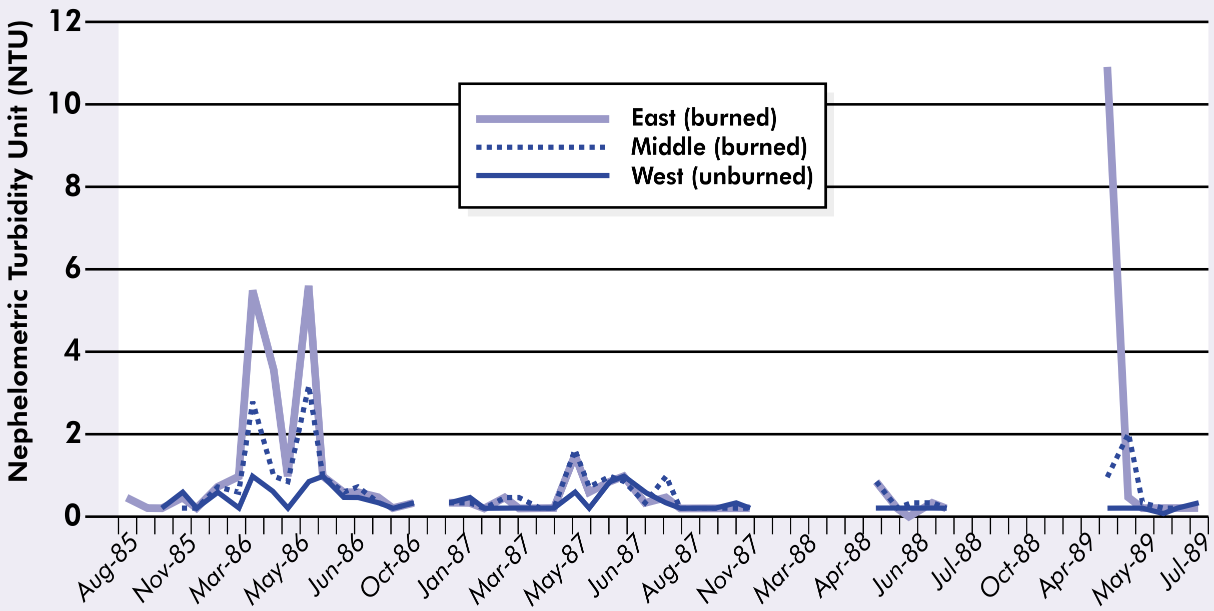

Figure 5. A graph showing the pattern of turbidity with time at downstream stations in three tributaries of Matthew Creek (unpublished data from the B.C. Ministry of Forests).

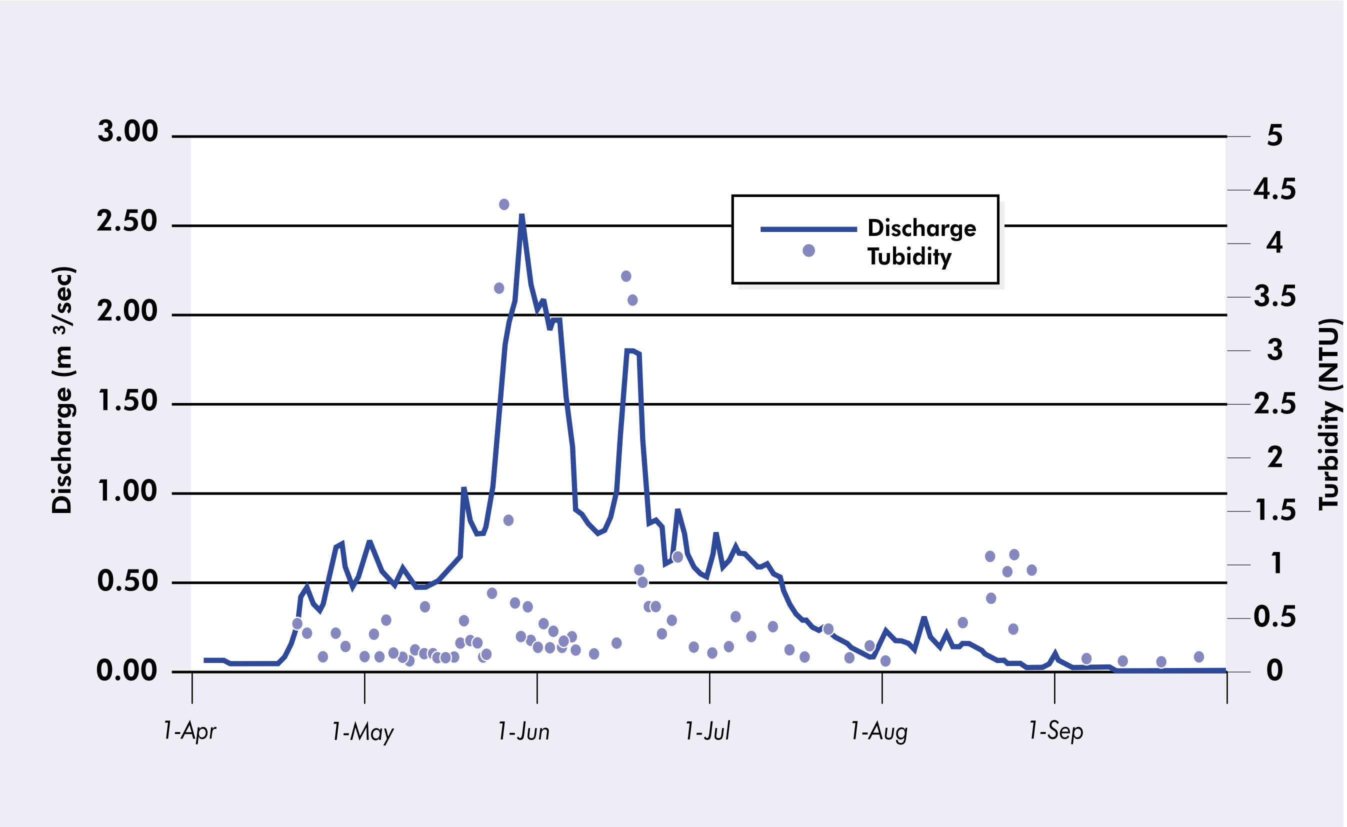

Figure 6. A graph showing the pattern of turbidity in 1999 in Trident Creek near Castlegar (Henderson and Toews 2001, Figure 2). All samples were less than 5 NTU.

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given treatment. These variations may mask the real effects of forest management on water quality. These problems can sometimes be overcome when researchers use external or internal controls. The Matthew Creek study illustrates this potential solution. When there is natural variation, we conclude that it is possible to investigate this with on-site field observations made at the time of abnormal water quality. The on-site investigation can also trigger corrective action. Note that natural variation makes it difficult to set thresholds for enforceable water quality standards.

Delayed Impacts: Many of the important land-use effects we have seen are episodic, results of a unique set of flood and land-use circumstances. It is difficult to sort out the effect of a storm from the effect of

Year	Total Runoff (mm)	Peak Daily Discharge m^3/sec	Sediment Yield t/km^2	No. of Days 5 NTU water quality criteria exceeded
1993	600	5.28	9	6
1994	695	4.79	2	0
1995	703	5.45	5	5
1996	1075	6.51	10	1
1997	1250	8.94	11	5
1998	820	6.59	6	3
1999	1077	7.14	10	4

Figure 7. Summary of streamflow data, sediment yield and number of days water quality criteria are exceeded in Redfish Creek by year (from Jordan 2001, Tables 1 and 3).

logging activity. An event such as a debris flow may occur many years after logging, yet logging may have exacerbated the damage we observe at this later date. It is always difficult to know which has the greater impact on water quality: an exceptional storm, or prior land use. This makes enforcement of regulations difficult. In Carnation Creek, the most dramatic sediment movement happened in 1984, several years after logging was complete.

Cost: Water-quality sampling is an expensive way in which to regulate the forest industry. With respect to sediment, it is far more efficient to undertake appropriate road-building practices in the first place than to try to correct poor road design after an event. Nevertheless, water users often demand proof that logging is not affecting drinking water. Our experience suggests that it is more useful to sample thoroughly in a few representative basins than to sample sparsely in a number of basins.

Lessons Learned: Opportunities

Water quality is one of a number of useful indicators of watershed condition. In Carnation Creek, water-quality testing was a valuable addition to a multi-disciplinary study. As one of several indicators, WQOs can be useful for setting long-term goals and tracking water-quality trends, as the Forest Practices Board has concluded.

The three case studies we have presented and discussed here illustrate that properly designed studies allow us to infer the effects of logging. Although the studies showed that WQOs may not be useful for enforcement, we may nevertheless use them to determine whether protective measures are meeting our goals. Those goals are to provide clean, drinkable water on an ongoing basis.

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