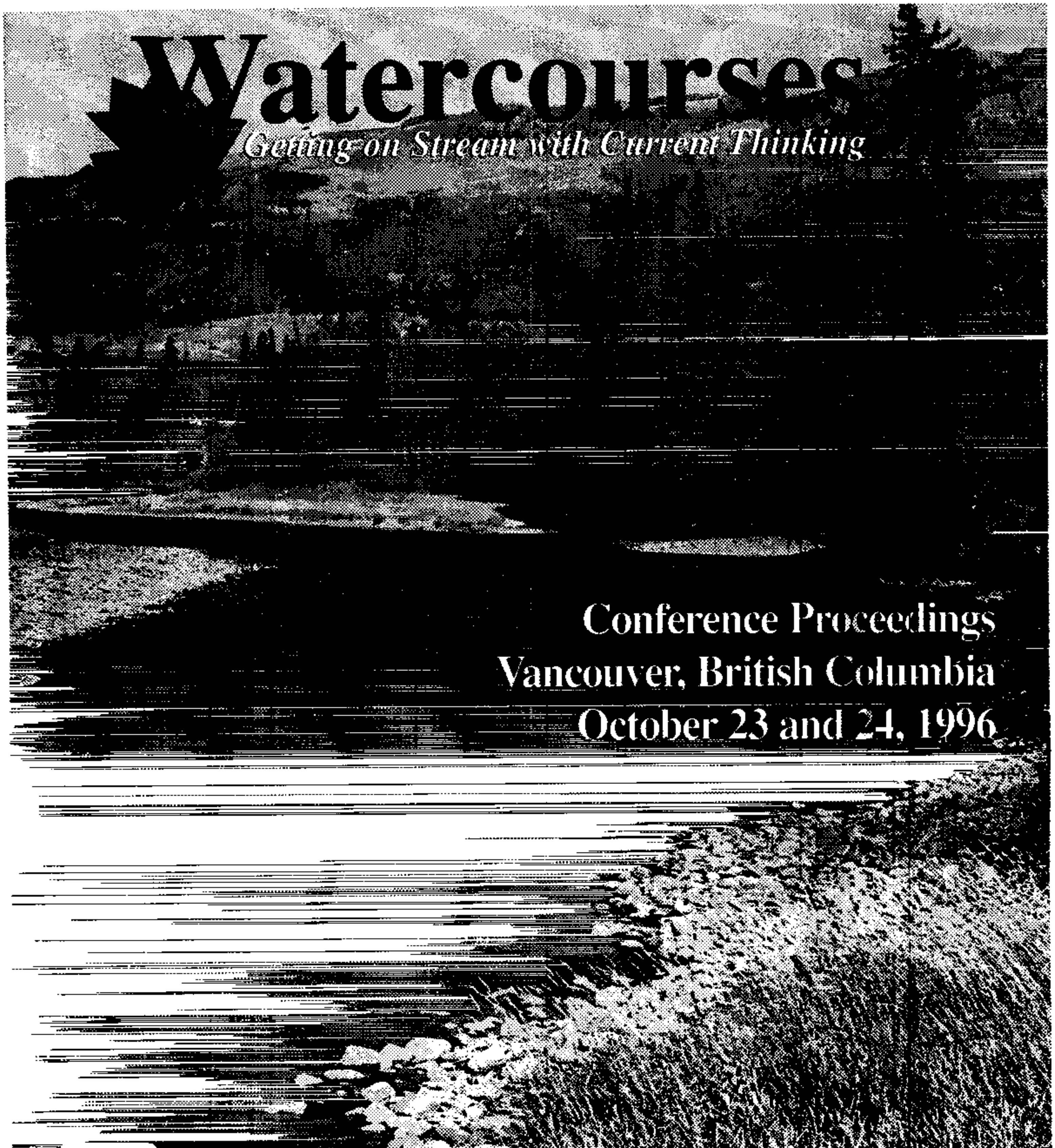
Watercourses

Getting on Stream with Current Thinking



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Turbidity Monitoring: (The EKG of Watershed Managers?)

Brian Carson, P.Geo. [1]

Introduction

The public equate clear, sparkling river water with good watershed health. If the water becomes turbid or murky, it is often assumed that negligence is involved. The lack of good historic data on turbidity of streams hampers watershed managers when determining trends in water quality. Automatic turbidity meters were installed within a number of community watersheds in B.C. in 1995, with one objective being to monitor upstream forestry activities. However, unless watershed managers are willing and capable of investigating turbidity with a concurrent assessment of ongoing sedimentation and hydrological processes within the watershed, turbidity results themselves offer no prescription. Turbidity events result from human induced watershed instability and natural hydrological processes. (Bilby, R.E. et al, 1989) Roads and road destablilized terrain are often a dominant cause of human-induced turbidity. (Rice, R.M and Jack Lewis, 1991) Those unfamiliar with the particular characteristics of a watershed may easily misinterpret the significance and cause of turbid waters. and mis-assign its cause. Like a medical doctor's use of the EKG for determining a patient's health, turbidity monitoring must not only be properly "read" but it must be taken within the context of the watershed's specific character and history. This is of particular importance with the FRBC funded Watershed Restoration Project where road deactivation is assumed to lead to substantial sediment reduction.

This paper investigates the use of turbidity monitoring as a tool to improve management decisions within Chapman Creek Watershed on the Sunshine Coast of British Columbia.

Background

Chapman Creek has, over the past 40 years been subject to heavy roading for forest harvesting which has triggered over 250 mass failures, (Thomson, 1987) many of which have had a direct impact on the main channel of the creek. Because the Sunshine Coast Regional District uses Chapman Creek as the main source of water for 20,000 residents, and because until recently there was little storage capacity, the occurrence of turbidity was immediately reflected in dirty tap water and so has been of direct concern to the community. (Jamieson, M., 1996) High turbidity levels are not conducive to providing high quality raw water for domestic use. Turbid waters interfere with its disinfection, promote unwanted regrowth of bacteria within water mains and can carry the precursors of a number of undesirable halogenated hydrocarbons when chlorinated. There is also a substantial fisheries interest in the lower reaches of the Chapman which is affected by sediments. The sources of sediments believed to generate these turbidity events in Chapman Creek include road surfaces, unstable slopes, (many of which were caused by roads and diverted drainage), and stream banks themselves. As late as 1995, no one was certain what was the dominant source of sediments, under what conditions sediments were released, or indeed, if they could be controlled at all. To further complicate matters, it was not possible to say with any certainty what portion of the turbidity measured on the lower reaches of the Chapman or Gray Creek could be ascribed to inorganic sediments. In spite of these uncertainties, at the inception of the Watershed Restoration Project there was a general consensus that watershed rehabilitation focussing on road deactivation would reduce turbidity substantially. One purpose of the monitoring program was to determine if this was true.

Methodology

The 1995/96 sampling season was designed as a broad reconnaissance survey to direct attention towards specific (possibly previously unrecognized) water quality concerns of these watersheds. Water quality, quantity and seasonal flow is being investigated in concert with terrestrial monitoring. A sediment source survey, initiated in the summer of 1995, is now reviewing the condition of the stream banks, tributaries, gully systems, landslides and road systems of Chapman Creek Watershed and is estimating the actual and potential sediment contributions.

[1] *Project Coordinator, Chapman Gray Creek Watershed Restoration Project*

Comparisons are being made between initial predictions of sedimentation from specific catchments and measurements of turbidity from streams draining that catchment during specific rainfall events.

A continuous turbidity meter provided a record for the turbidity at the Sunshine Coast Regional District water intake on Chapman Creek throughout every storm event in the 1995/96 winter season. Continuous turbidity monitoring on Chapman Creek has been carried out since the spring of 1995 with the primary purpose of activating intake closure when turbidity exceeds a set threshold. At that point the water system has two days of water storage, providing time for the creek to clear, sparing the water system from the worst of most turbidity events.

Along with this continuous meter that provided an uninterrupted measure of turbidity for one point along the creek, many grab samples were collected along the different reaches of the creek during specific turbidity events. Over 180 turbidity measurements were taken using an Orbeco-Hellige portable turbidimeter. Stream water samples were collected from selected reaches of the creek systems during eleven major storm events for the 1995/96 fall winter season. Readings were taken to the nearest 1 NTU. A "threshold" for initiation of spot sampling was 10 NTU measured in Chapman Creek at the highway crossing. During every turbidity event measured, this station had the highest turbidity within the main stream of either Chapman or Gray Creek. A regular sampling routine was carried out using the available road to access the middle reaches of Chapman Watershed. The same sites were sampled during each event. During a number of turbidity events, more remote reaches of the stream were also sampled. The exact time of sampling for turbidity was recorded so that the reading could be directly compared to the continuous meter at the intake. Samples were taken both going up into the upper watershed and on return in order to determine the dynamics of the rise and fall of the turbidity in relation to the "peak event" as recorded at the intake.

A number of water samples were also taken to investigate suspended and dissolved inorganic and organic components during different stages of flood events, during different seasons and at different locations within the watershed during a specific turbidity event. Results of these analyses were used to estimate volumes of suspended sediments being carried by Chapman Creek.

Results

Between Oct 1, 1995 and April 30, 1996, there were 29 turbidity events in excess of 5 NTU and 12 events in excess of 10 NTU. This contrasted sharply with the previous turbidity data collected between 1991 and 1993 where, after two years of random weekly spot sampling, only two of the samples exceeded 5 NTU. Without inquiring how the sampling program was carried out one might (mistakenly) surmise that the river has become more turbid between 1992 and 1996. The increase in turbidity was, in fact, related to the timing of sampling that was initiated by specific hydrological events rather than a routine weekly collection.

A closer look at rainfall events, river discharge and the nature of the turbidity event was also of considerable interest. In all of the cases measured, the peak turbidity measured was associated with the rising hydrograph. In all but one case, turbidity did not rise substantially until discharges of Chapman Creek exceeded 20 m^3/s.

However the highest turbidity event of the year was associated with a low discharge (<5 m^3/s) which initially was wrongly ascribed to a presumed massive failure and river blockage upstream. Upon investigation it was determined that this peak sediment loading at low flow was issuing from the river banks themselves. The river banks, in response to thawing after six days of sub zero temperatures were contributing large sediment loads directly into the stream in response to a minor rainfall event.

Only one major turbidity event was traced to a major landslide in the upper Chapman Creek that occurred after one of the heaviest rainfalls of the year. However, for most of the turbidity events observed, inorganic sediments were being generated by diffuse, but none-the-less small point sources of sediment, largely restricted to the main stream channel and side tributaries themselves. These events are discussed below.

Portioning of Turbidity Production within Chapman Creek Watershed

The initial hypothesis that most or at least a significant portion of the turbidity within Chapman Creek was road related was not supported by the observations made. In all of the turbidity events measured to date, surface drainage from the upper 60 % of the watershed (above the East Main bridge) , including the most unstable road grades, appears to be producing much less turbidity (during these events) than the lower parts of Chapman Creek Watershed. This 60 % of the watershed area (contributing greater than 60 % of water because of higher rainfall at higher elevations) accounted for less than 15 % of the generated turbidity noted at Chapman's mouth for the storm events monitored. The nature of sediment production in the watershed areas with major landslide failures appeared to be one of occasional isolated failures causing extreme but short lived sedimentation followed by long periods of little or no sediment production within the particular subcatchment. Sampling carried out within old debris flow tracks documented usually stable and low turbidities with occasional catastrophic responses to individual rainfall events. A large sand gully incising an old deltaic deposit at km 17.3 appears to be a chronic sediment producer. Turbidity events are produced by virtually every storm in response to stream capture of side wall glacial fluvial sands sloughed into the gully. Discharges of 50 liters/sec and associated turbidities of 50 NTU are apparently common, with roughly 1 cubic meter of sediment being supplied to Chapman Creek per moderate storm event.

The stream reach between km 16 on the East Main (above the abandoned bridge on the old Chapman Main) and the highway bridge drains less than 24 % of the watershed. However this reach was invariably the dominant turbidity producer within the whole Chapman Creek system for the events sampled. Substantial turbidity production was found to occur between the old bridge and the SCRD water intake, including turbidity from the old Chapman Mainline road, now covered with alder. Incised deep tills and glacio lacustrine sediments are found extensively along this reach. Although less than 20 % of the actual runoff is initiated in the lower reaches of the watershed, over 70 % of the suspended sediment appears to have been generated here during these storm events. From the preliminary sampling done, both inorganic and organic elements of the turbidity were found to increase substantially within the lower reaches of the watershed. On the other hand, side tributaries below the km 16 sample site had consistently low turbidities (5 NTU) during all storms measured. Most of the tributaries in the lower reaches of Chapman Creek flow through coarse textured glacial fluvial terrain. These material are porous, well vegetated and slopes tend to be gentle, so generation of surface runoff is proportionally lower than on other landscapes. This may account for the low inorganic sediment loads from surface runoff on this terrain. One must conclude that it is the main stem of Chapman Creek itself that is generating the inorganic sediments.

For the 1995/96 winter season, no discharge exceeded 80 cubic meters per second (which would correspond to the normal 2 year flood) although many lesser storms (20 -60 cumecs) occurred for the watershed as a whole, a great portion of the failures will undoubtedly occur in the more extreme events, particularly in those areas with unstable road prisms. It is expected that failures of the type that occurred (on December 11, 1995) on the upper East Main (see below) would occasionally and catastrophically overwhelm the Chapman River system. Turbidity might reach levels an order of magnitude above, and for 4 and 5 times longer than normal lower discharge turbidity events.

One of the aims of the road deactivation program is to rehabilitate unstable slopes where risk of failure directly threatens water quality. However, after assessing the rehabilitation potential of known sediment sources, it must be recognized that there are many untreatable, long term turbidity generating sources within the watershed.

The SCRD continuous turbidity monitor below the Chapman Creek Intake was used to document turbidity at one point along the creek. Results from this meter correspond well with readings taken at the river about 4 km up from the intake. The SCRD's turbidity meter is within a water pipe 1 km from the creek intake and there is a small pre-settling basin between the sensor and the stream. It was found that the SCRD turbidity meter read consistently lower (10 to 40 %) than the turbidity readings taken in the stream at the intake. This 10 to 40 % variability between the two readings may in part be explained by the nature of the sediment load during a particular event. If the suspended sediment is dominated by fine sands, it will have a chance to settle out in the small settling pond before it reaches the meter and thus lower measured turbidity. The role of different sediment sizes on turbidity is discussed at length by Holstrom and Hawkins (1980).

Approximate Correlation of Turbidity Events, Their Duration, Stream Discharge and Suspended Sediment Transport For Chapman Creek

A rough estimation was made of the amount of suspended sediment moving through the river system. While there is no universal relationship between turbidity and suspended sediment concentration, there is often a good correlation for an individual stream (Truhlar, J.F., 1978). Turbidity was measured and samples were then analyzed for total suspended sediments. Within Chapman Creek, there was a good correlation between turbidity and non-filterable concentration over a wide range of concentrations and organic matter contents. From this correlation and a review of standard discharges and their frequency of occurrence, Table 1 was compiled.

Comparison of Chapman and Gray Creek turbidity.

In terms of turbidity, Chapman Creek has shown consistently to have more than double the turbidity levels of Gray Creek (ie if Chapman Creek reads 60 NTU at the highway bridge then Gray Creek will be 30 NTU during a specific rainfall event) This might reflect the observation that mass wasting processes influence Chapman Creek Watershed to a much higher degree than Gray Creek. However initial observations indicate the higher portion of unarmoured unconsolidated sediments within stream channel walls in the lower Chapman Creek verses Gray Creek may be more important.

Table 1.
PRELIMINARY FINDINGS: CHAPMAN CREEK TURBIDITY
(based on 12 storm events of 1995/96 winter season measured at highway bridge)

Turbidity range (NTU)	Occurrence in 95/96 winter season	Approximate sediment concentration (mg/l)	Approximate sediment transport at highway bridge with stated average discharge (kg of suspended solids passing station per second)	Approximate amount of suspended sediment moved in one hour past station at given turbidity and rate of discharge (T/hr)	Approximate annual suspended sediment contribution (T)
<1	normal background level	<1	(Discharge of 2 m³/sec) <0.002	<.007 ave. (0.003) (mostly organic)	50 (mostly organic)
5 to 15	20x 8 hr events	20	(Discharge of 20 m³/sec)	1.4	224
50 to 150	3x 2 hr events	200	(Discharge of 80m³/sec) 16	57	342
500 to 1500	none so far	2000	(Uncertain whether main stem is ever so turbid)	-	

Measured rates of turbidity for the 95/96 storm events at Chapman Bridge have ranged from 1 to 120 NTU. According to rough estimates made in Table 1, major winter storm turbidity events would correspond to movement of roughly between 1 and 60 tonnes of sediment per hour under Chapman Highway bridge during peak flood events. Although peak discharges occurred for very short periods, they moved most of the suspended sediments for the past year. It must be stressed that the estimates of weight of suspended sediments over the year are crude but provide the opportunity to begin to address sediment budgets. Total suspended sediment loading estimates appear low when compared with average rates of regional denudation. What could account for the differences? Overestimating erosion and/or sediment delivery? High stream channel storage? Heavy bedload? At present we cannot say but such questions will be addressed in the future.

Influence of subcatchments

Isolated side channels have measured turbidity levels as high as 700 N.T.U. for short duration failure events and can easily transport a few cubic meters of material into the creek over a couple of hours. Repeated re-sampling of the same drainages after extreme turbidity events often fail to show any sediment in the water. This periodic delivery of extreme sediment loads over time and geographic location is undoubtedly the most difficult aspect in designing and interpreting any monitoring program in the coastal areas of British Columbia. For a program to shed light on sediment sources, a continuous turbidity meter such as is installed at the SCRD intake on Chapman Creek must be complemented by an ongoing network of turbidity samples taken at strategic positions throughout the drainage network. What makes this sampling particularly difficult is that collection must be timed to turbidity events, that may only occur 10 or 15 times a year, at any time of day or night when weather conditions are at their worst.

Importance of Major Mass Wasting Events in Characterizing Turbidity on Chapman Creek

Chapman Creek has been strongly influenced in the past by major slope failures, many of which have resulted in high levels of turbidity over a long period. Historically, these failures have had a drastic effect on water quality during peak storm events and have been a major concern for the Sunshine Coast Regional District Water Board. The occurrence of human induced mass wasting events has focussed the attention on the forest road systems within Chapman Creek and their effect on periodic heavy sediment loading.

On December 11, 1995, after two days of rain in excess of an estimated 40 mm per day, a major road induced mass failure occurred in upper Chapman Creek. Although over 2500 m^3 of material was transported downslope, amazingly, very little of it reached the creek. Most of the debris flow's energy was dissipated crossing the main logging road (where around 1000 m^3 of material was deposited) and after dropping off the road onto the side slope, the debris was quickly halted when the side slope became more gentle, (5 degrees). The debris flow was virtually all contained on the lower slope. The debris flow lobe came to rest at the toe slope and deposited another 1500 m^3 of unsorted debris. Immediately after the failure, there was a de-watering event, where around 30 m^3 of washed sands was also captured immediately downslope of the main debris lobe in thick riparian shrub vegetation. The maximum discharge immediately preceding the failure, could not have exceeded 500 L/s, the flow confined to a side drainage running parallel to Chapman Creek for 100 meters before entering the main stream. Deposition of sands and silts occurred within this side channel. Some washed gravels were found as well but it was believed that these gravels had been deposited by earlier slope failures. The amount of sediment reaching Chapman Creek was very small compared to the size of the debris flow. This sediment would be of a silt or clay size fraction.

Given that virtually all of the mass of the debris flow was accounted for down slope, and that the amount of water coming out at de-watering and from the through-drainage was small, the effect on turbidity of Chapman Creek is expected to have also been small. A peak averaging 20 NTU was recorded at the SCRD intake. The sporadic nature of the individual sediment loading events was noted in the spikiness of the turbidity graph for that day.

Role of Soluble and Suspended Organics as Turbidity Generators within the River Systems.

In the samples taken to date between 11 to 60 % of the non-filtered sample is of organic origin. Suspended organic concentrations (dry weight) ranged from 1 to 310 mg/L. (See Table 2) In certain conditions, and particularly at low flows, these organic sources of turbidity outweighed the importance of inorganic sources and obviously makes the assessment of turbidity even more complex. Gray Creek has been observed to have more of the reddish organic staining than Chapman Creek. Measured true colour reading of 70 are common on Gray Creek while during the same rainfall events Chapman Creek shows lower levels of true colour. This colouration may be responsible for the commonly held perception that Gray Creek waters are more turbid than Chapman's. (In fact, the reverse appears to be true) The heavy layer of rotted alder leaves within both Chapman and Gray riparian zone gives off a distinct black colour that can under certain conditions result in turbidity levels from contributing side channels of as high as 10 NTU. Dissolved organic carbon analysis showed concentrations of between 5.3 mg/L and 10.6 mg/L under a wide range of turbidity conditions on both Chapman and Gray Creek. Again the highest levels recorded come from Gray Creek. Gray Creek appears to carry more soluble organics but less suspended inorganics than Chapman Creek. An assessment of turbidity must always consider the importance of organic materials in normal stream dynamics.

Conclusions

Turbidity monitoring, using at least one continuous turbidity meter, combined with extensive turbidity

Table 2.
Suspended and Dissolved Load in Selected Turbid Water Samples (Chapman and Grey Creek, Winter 1995/96)

Sample No	Field Turbidity (ntu)	Lab Turbidity (ntu)	True Colour Col. Units	Residue (non filt) (mg/L)	Residue (fixed) (non filt) (mg/L)	Residue Vol. (non filt) (mg/L)	% Org	Dissolved Organic Carbon (mg/L)
1	50	24	50	112	91	21	18	8.3
2	870	340	50	1510	1200	310	20	10.4
3	6	2.5	40	7	6	1	14	7.3
4	20	8.5	40	38	34	4	10	5.3
5	35	16	50	67	59	8	12	5.9
6	41	15	50	82	66	14	17	8.1
7	22	10	70	55	47	8	15	10.6
8	35	22	60	114	103	11	10	8.7
9	12	3	50	24	20	4	17	5.9
10	20	7.7	50	30	26	4	13	6.4
11	2	0.9	40	5	2	3	60	5.6

checking along the main stream and tributaries during the periodic major turbidity events can provide valuable information about suspended sediment sources. A concurrent terrain assessment of point and non point sources of turbidity in relation to chronic sediment loading and periodic catastrophic events will greatly enhance the targeting of road rehabilitation activities.

A preliminary assessment of the value of the present road deactivation for amelioration of turbidity in Chapman Creek has been made. During normal winter flood events, the effect of road deactivation would have a small (but possibly unmeasurable) effect on the turbidity of the main channel. During extreme events, where major road side cast failure is expected, the effect of road deactivation will occasionally greatly lessen the chance of a major turbidity event.

For some watershed managers, inorganic sediment and turbidity loading are synonymous. However, in Chapman Creek an important portion of suspended particulates is of organic origin and it is these organics that have a potentially serious effect on drinking water quality. In coastal watersheds where drinking water is treated with chlorine, a be ter understanding of the nature and sources of the organics is required.

Simple field observations using crude tools ca uncover important information for watershed mar agers.

Like the EKG of the medical world, in prop hands and with sufficient background informatio turbidity monitoring can be an important diagnosti tool. Also, like the EKG, taken in isolation an unconnected with the character and history of th patient, any diagnosis made solely by turbidity moni toring might bring on a malpractice suite.

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