Appendix C

Stream Crossing Assessment Procedure

The Stream Crossing Quality Index: A Water Quality Indicator for Sustainable Forest Management

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Abstract
One of the goals of sustainable forest management is the maintenance of water quality. One of the biggest forestry related impacts to water quality is accelerated sediment delivery to streams at road crossings. Good road building and maintenance practices will minimize the erosion hazard and related negative impacts to water quality. Based on this, several divisions of Canadian Forest Products Ltd. have recognized that a good water quality indicator should be based on a field-survey that evaluates effectiveness of controlling accelerated erosion and sediment delivery at stream crossings. This has led to the development of a sediment source hazard assessment procedure called the Stream Crossing Quality Index (SCQI). The procedure evaluates and scores the size and characteristics of road-related sediment sources at crossings and the potential for the eroded sediment to reach the stream environment. A high score infers that there is a significant erosion problem which may in turn cause sediment-related water quality problems. The SCQI is a good management tool because it identifies specific problems in the landscape and provides future direction to minimize them.

Introduction

One of the goals of sustainable forest management (SFM) is to implement best management practices so that water quality is maintained within natural ranges of variability (CCFM 2000). Within an SFM framework there is a requirement for a set of clearly defined performance criteria and indicators to gauge progress towards the goal of maintaining water quality. Designing a meaningful indicator to address this goal is not an insignificant challenge. Forestry activities are an extensive type of disturbance that generally cover many hundreds of square kilometers and numerous watersheds. Forest harvesting activities can affect many water quality characteristics, but increased sediment loading has been identified as one of the most detrimental (MacDonald *et al.* 1991). Several forest harvesting activities can cause increased erosion rates and sediment delivery to aquatic environments. However, road building and maintenance, particularly at stream crossings, is the dominant point source for forestry-generated sediment in landscapes where landslides are not a dominant process (Beaudry 2001, Beschta 1978, Bilby *et al. 1989,* Cafferata and Spittler 1998) (Figure 1).

Figure 1. Ditches, road surfaces and cut/fill slopes can be significant sources of sediment at stream crossings.

Within any given watershed, there may be dozens or even hundreds of stream crossings, each being a potential source of sediment. Although the impacts of forestry disturbances on water quality can be relatively small and subtle at any given point within a watershed, the sum of the impacts may add up to significant downstream cumulative effects. If good road building and maintenance practices can minimize (or eliminate) accelerated erosion and sediment delivery to streams, then negative impacts to water quality will be minimized. Based on this assumption, several B.C. and Alberta Divisions of Canadian Forest Products Ltd. (Canfor) have decided that a good water quality indicator should be based on a field survey that evaluates how well accelerated erosion and sediment delivery are being controlled in the vicinity of stream crossings. The stream crossing quality index (SCQI) was developed as an SFM indicator to provide a meaningful measure of the potential hazard that a stream crossing may present for water quality.

Development and Refinement of the SCQI

In 2000, the Prince George Division of Canfor considered a variety of SFM indicators for use in its forestry certification program. As an indicator of protection of water quality, Canfor was considering the concept of the stream crossing density used in the BC Watershed Assessment Procedure (WAP), i.e. # of stream crossings counted on a map divided by the watershed area (BC Government 1995). We suggested that although the stream crossing density is very simple and inexpensive to measure, a better alternative would be to complete a field assessment of the crossing and score its real potential for accelerated erosion and sediment delivery to the stream. Such a procedure would provide accurate field-based information and would be a large improvement on the stream crossing density concept that assumes that all crossings produce the same amount of sediment to the stream environment. Thus was born the concept of the SCQI, a field-based hazard assessment of the potential for accelerated erosion and sediment delivery at stream crossings.

The origins of the SCQI methodology were based on the concepts of the sediment source survey (SSS) presented in version 2.01 of the WAP (B.C. Government 1999). In the WAP, the road-related SSS is used as an indicator of the level of hazard that forestry roads have for delivering sediment to the aquatic ecosystem and thus potentially reducing water quality. One of the major refinements provided by the SCQI methodology is the systematic description and evaluation of all individual sediment sources at a crossing that have the potential to deliver sediment to the stream network.

As an SFM indicator, the basic assumption that underlies the SCQI is that if erosion and sediment delivery in the vicinity of stream crossings is minimized, through proper road building and maintenance practices, then the potential impact to water quality from increased sediment delivery is also minimized (Figure 2). The SCQI is a useful management tool because it provides a clear incentive to improve erosion and sediment control (ESC) practices in the vicinity of stream crossings since it documents practices that create a water quality hazard and those that minimize it. Improvement of forest management practices over time is a clearly explicit goal of all forest certification schemes. The Canadian Council of Forest Ministers (CCFM 2000) clearly recognizes the potential negative impacts to water quality associated with road crossings. In their sustained forest management program they have defined one of the aquatic indicators as being: "percentage of forest area having road construction and stream crossing guidelines in place" (Indicator 3.2.2).

Figure 2. Hay mulch used effectively for both erosion and sediment control.

Method

The execution of an SCQI survey begins with the mapping of current access within the watershed and planning an effective way of completing a 100% sampling of stream crossings with that watershed. In many situations 100% sampling is not possible but at least 90 to 95% sampling is usually achieved. Stream crossings are accessed using trucks, quads or by walking.

Once the surveyor has arrived at the stream crossing, the procedure begins by evaluating the size and characteristics of all sediment sources that can potentially contribute sediment to the aquatic environment. Each stream crossing is divided into eight distinct and independent "elements". These include four road ditches that run into the stream, two road fill slopes and two road running surfaces, each of these potential sediment sources being assessed independently. The sediment source hazard score for each individual element is a product of the *erosion potential* and the *delivery potential* of that source. The *erosion potential* is calculated as a function of several factors which are:

1. the size of the sediment source
2. the soil texture of the source
3. the slope gradient of the source
4. the percentage of non-erodible cover
5. the level of road use (for road surface) and
6. the shape of the ditch (for ditch elements)

The cornerstone of the SCQI procedure is the measurement of the size of the sediment source (m^2). The other variables act as modifiers to increase or decrease the hazard associated with the size of the sediment source (Appendix 1). Each of the modifiers is scaled from 0 to 1, where zero (0) represents a condition that would eliminate the hazard (e.g. coarse gravel, no slope or an abandoned fully revegetated road) and one (1) represents a condition that would maximize the hazard (e.g. silt, slope greater than 15% or active mainline). The size of the sediment source (m^2) is multiplied by the value of each modifier to generate an *erosion potential* score for the particular element being assessed. This is then multiplied by the *delivery potential* (scaled from 0 to 1) to obtain the element score. The *delivery potential* represents a qualitative assessment of the percentage of the eroded material that will likely reach the stream. A series of definitions are provided to assist in the determination of the delivery potential, e.g. 0 means that there is no connection between the erosion source and the stream and no delivery is possible, 0.5 means that the delivery is indirect and filtered through trees grasses and/or sediment control structures, 0.8 is used when sediment is weakly filtered through a sparse grass cover and most of the material reaches the stream and 1.0 means that delivery is evident, direct and uninterrupted with no obvious depositional zones before reaching the stream. The total score for the crossing is simply the sum of the eight scores for each of the individual elements. The final SCQI crossing score generates five hazard classes as defined in Table 1.

Table 1. Correspondence between SCQI score and hazard class.

Score	Sediment Source Hazard Class
0	None
0< score <0.4	Low
0.4 ≤ score ≤ 0.7	Moderate
0.7 < score ≤ 1.6	High
Greater than 1.6	Very High

The values for each of the modifiers are based on the concepts and values developed for the Revised Universal Soil Loss Equation (RUSLE) presented by Wall *et. al*. (2002). The universal soil loss equation was initially developed by Wischmeier and Smith (1965). The objective of the RUSLE was to provide a quantitative tool to assess the potential for soil erosion at a given site.

The SCQI procedure is a useful management tool because it identifies the specific location and magnitude of erosion problems. If scores are high, the crossing can be improved through remedial actions and current practices can be altered to avoid high scores in the future. If scores are low, then it shows that good erosion and sediment control practices are being implemented and by extension water quality is being protected. The procedure has been presented to numerous field practitioners in a series of field workshops and received a favourable response because it clearly identifies the specific location of the problem and the practice that generates the problem.

It is important to note that the SCQI method was designed to be quick (about 15 minutes per crossing) so that a maximum number of crossings can be assessed, thus providing a better landscape level perspective. The SCQI has evolved over the last three years from its initial structure based mostly on subjective assessments. The procedure is now more objective, repeatable and transparent, using values based on the RUSLE.

It must be noted that the whole SCQI approach is largely a conceptual model, based on the general concepts of the RUSLE, and was not developed based on an experimentally acquired set of empirical relationships. It provides a score in a consistent way that can be compared with other crossings in a given watershed and evaluated for how "good" or "bad" the crossings are. The SCQI does not provide a quantitative evaluation (e.g. kg/ha/yr) of exactly how much sediment is entering the stream or what the impact of that sediment has on the stream environment. The SCQI approach tells you where there are erosion and sediment control problems, how frequent in the landscape those types of problems appear and provides a basis of information to judge the magnitude of the problem and how to fix it so that impacts to water quality will be minimized. It is important to emphasize that the SCQI focuses exclusively on the evaluation of the sediment source and the potential of that sediment to reach a stream (i.e. the “hazard”). It does not in any way attempt to measure, evaluate or score the sensitivity of the stream or the impact of increased sediment delivery to the aquatic environment (i.e. it does not evaluate “consequence”). Work is currently underway to develop a methodology to evaluate the sensitivity of a stream to increased sediment loads. If this effort is successful, it could be combined with the SCQI approach to produce a true risk assessment procedure.

Evaluation of the SCQI Procedure

In 2001 an evaluation program was initiated by Canfor, Prince George Division, to test the validity of the SCQI procedure by monitoring stream turbidity levels at selected stream crossings. Several hundred stream crossings ranging over a variety of topographic and climatic conditions across the Prince George Timber Supply Area (TSA) were surveyed in the spring of 2002 to generate a population of possible sampling sites. From this database, we eliminated all large streams (relatively rare occurrence in the landscape) and streams that were too small to be instrumented. Our objective was to focus the measurements on "small" streams with an average bankfull width of 1 to 3 metres (Figure 3) since about 90% of stream crossings in the Prince George region occur on small streams (P. Beaudry and Associates Ltd. 2002). The crossing scores were then grouped into one of three hazard levels, i.e. low, moderate or high (see Table 1). A random selection of seven stream crossings, per hazard level, was selected to serve as our experimental sample (i.e. total of 21 crossings).

Figure 3. Example of size of stream monitored and instrument set-up for measurement of turbidity. Note water is turbid as a result of rainstorm.

Each crossing was instrumented with electronic continuous turbidity sensors in an "upstream-downstream" experimental design. The assumption behind this approach is that the difference between the upstream and downstream measurements can be attributed to the erosion and sediment delivery at the stream crossing (i.e. induced turbidity). An example of the induced turbidity results, obtained from one of the monitored crossings, is provided in Figure 4. The objective was then to compare the measured induced turbidity with the hazard score generated by the SCQI procedure to see if there was an acceptable correlation.

Both the provincial (Government of BC 2001) and federal (DFO 2000) governments have produced some guidelines that relate increases in turbidity to the risk to the aquatic environment. We used an adaptation of these guidelines to define five hazard classes for our SCQI scores. The classes range from no hazard to very high hazard (Table 2). As an example, a hazard level of "high" is defined as a site that generates enough sediment to the stream that it will consistently cause an increase in turbidity between 70 NTU and 130 NTU, when significant rainfall occurs. The maximum induced turbidity for every rainfall-turbidity event measured during the field season was tabulated and crossing averages were calculated. The event-frequency distributions for each crossing were analyzed and the right tail 10% of the distributions were removed to account for extreme events occurring at very low frequencies (i.e. one large event over the entire field season) that might skew the average. It is also our opinion that most of these extreme events do not actually represent increases in turbidity, but rather an anomaly caused by debris passing over the turbidity sensor, and thus should be removed from the database.

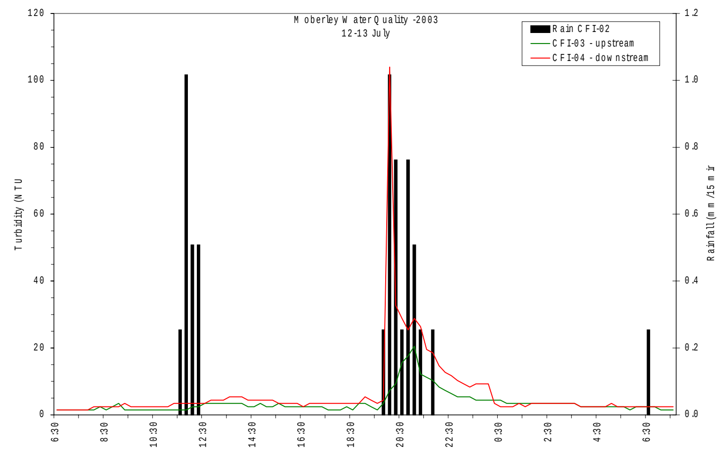


Figure 4. Example of measurement of induced (red) turbidity, where the downstream turbidity peak is about 80 NTU greater than the upstream peak (green).

Results from the 2002 turbidity measurements generally showed a good correspondence between the assessed hazard level and induced turbidity measurements. The validation process also identified some specific problems with the procedure and improvements were made accordingly during the 2003 field season. One of the major refinements was the introduction of an objective measurement of the actual size of each of the sediment sources, rather than the previously used subjective assessment of the "level of erosion". This refinement provided an opportunity to generate a more quantitatively-based score with no pre-defined upper limit. The individual crossing scores for each of the 21 sites were related to the average induced turbidity of the entire monitoring site to determine if the SCQI score was a reasonable predictor of induced turbidity.

Table 2. Levels of risk associated with increases in turbidity (adapted from Fisheries and Oceans, 2000)

Induced Turbidity (NTU)	Risk to Fish Habitat	Sediment Source Hazard Class
0	None	None
1 to 8	Low	Low
8 to 70	Moderate	Medium
70 to 130	High	High
>130	Unacceptable	Very High

The regression analysis has shown that indeed the relationship is quite good, at least for SCQI score less than 3.5 (Figure 5). Two of the monitored crossings had scores greater than 8, and yet did not generate turbidity levels as high as the scores suggest they should have. These two points were not included in the dataset as they render the linear relationship insignificant. Based on these two "outliers", it appears that the SCQI procedure needs to be further refined for situations where the sediment source is very large. Currently, we think that as a sediment source increases in size (e.g. > 150 m^2) and the complexity and variability of the characteristics of the sediment source also increase, it becomes increasingly difficult to predict how much of the eroded material will actually reach the stream.

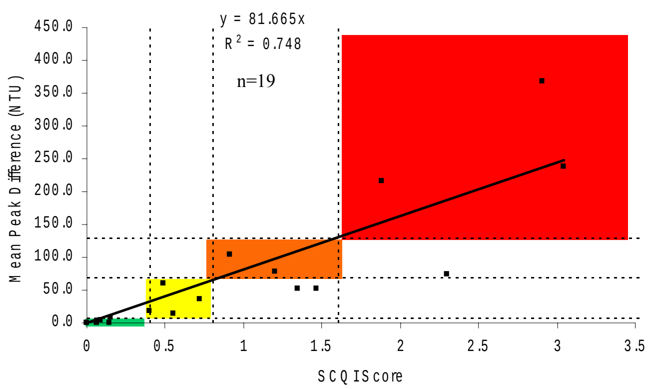
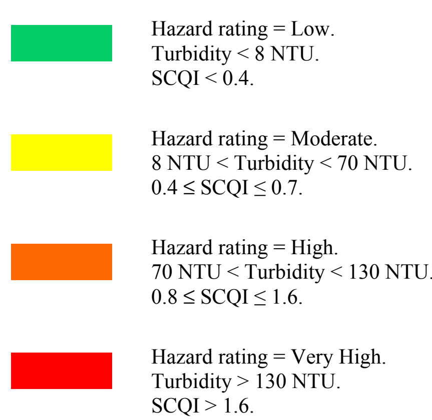


Figure 5. Relationship between SCQI score and induced turbidity (mean peak difference NTU).

Further improvements to the SCQI procedure are necessary to accommodate the complexities of larger sediment sources. Another related issue is that the upper limit of the induced turbidity scale is dependent on the sediment saturation potential of the volume of water transported in the stream and when the water is very dirty the relationship between delivery of sediment and increases in turbidity may no longer be linear.

In Figure 5, we added coloured rectangles to illustrate the areas on the graph that represent the different hazard rating classes used in the SCQI procedure and how these relate to the expected range of induced turbidity. These results clearly suggest that the procedure is very good at predicting induced turbidity (within the expected range) for the low and moderate hazard levels, and although somewhat less accurate, also good for the high and very high classes (up to scores of about 3). The three points that are outside of the coloured areas all represent the same situation, i.e. the SCQI score is predicting a situation that is a little bit worse than the actual problem, but only for situations where a significant problem already exists. Thus, for a proportion of crossings surveyed, the SCQI procedure may be overstating the size of a problem where a significant problem exists, but it accurately predicts the size of the problem where the problems are small or non-existent. Consequently, we believe that the SCQI is a good tool to identify the proportion of problem and non-problem crossings across the landscape and is thus a good SFM indicator to address the goal of protection of water quality. Work is continuing on the development and refinement of this procedure.



Conclusions

Canfor has completed SCQI surveys over a wide range of their operating areas as part of their forest certification programs (well over 3,000 crossings). These include areas within central and northern B.C. and eastern Alberta. Several independent certification audits have identified this approach as a meaningful and well structured process to objectively document the extent of effective erosion control practices in the landscape. Road construction and maintenance supervisors find this a useful tool because it locates and identifies specific problems and provides direction for remedial action with the built-in incentive of obtaining a better SCQI score in the future. The SCQI tool is also useful to show improvements in erosion control practices over time, a requirement of many forestry certification schemes.

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Appendix 1. **Modifier score values** (subject to change with further validation work)

Table A1. Sediment Source Area Scores

Size (m^2)	Score	**Size (m^2)**	Score
0	0	**50-100**	2
0-1	0.1	**100-150**	3
1-2	0.2	**150-200**	4
2-4	0.3	**200-250**	5
4-8	0.4	**250-300**	6
8-14	0.5	**300-350**	7
14-20	0.6	**350-400**	8
20-26	0.7	**400-450**	9
26-32	0.8	**450-500**	10
32-40	0.9	**500-550**	11
40-50	1	**550-600 etc**	12, etc

Table A2. Soil texture class modifier scores.

Soil Textural Class	***Score/Compactness Level***		
	M	***L***	***H***
Very Fine Sand	1.0	0.90	0.80
Silt	0.97	0.86	0.77
Silt -Loam	0.88	0.80	0.70
Silty Clay Loam	0.74	0.70	0.60
Clay	0.51	0.46	0.41
Sandy Loam	0.3	0.27	0.24
Medium Sand	0.16	0.14	0.13
Coarse Sand	0.014	0.013	0.011
Stones and Gravel	.007	0.006	0.006

Table A3. Slope modifier scores.

Gradient	**Score**
>12%	1.0
9-12%	.97
7-9%	.85
5-7%	.75
3-5%	0.60
1-3%	0.25
<1%	0.15
away from stream	0.00

Table A4. Road use level modifier scores.

Road Use Level	***Score***
Active mainline	1.0
Active branch line	0.99
Moderate activity (occasional grading)	0.95
Low activity (no grading, x-ing structure still present)	0.96
De-activated (xing structures removed)	
-used extensively by 4 wheelers	0.98
-minor use by 4 wheelers	0.92
-no 4 wheeler use evident	0.85
Abandoned – no access (too much veg)	0.80

Table A5. Ditch shape modifier scores

Ditch shape	***Score***
"V"shape-V.steep&V.steep	1.55
"V"shape-Steep&V.steep	1.45
"V"shape-Gentle&V.steep	1.35
"V"shape-Flat&V.steep	1.10
"V"shape-Steep&Steep	1.35
"V"shape-Gentle&Steep	1.25
"V"shape-Flat&Steep	1.00
"V"shape-Gentle&Gentle	1.15
"V"shape-Flat&Gentle	0.90
"U"shape-V.steep&V.steep	1.40
"U"shape-Steep&V.steep	1.30
"U"shape-Gentle&V.steep	1.20
"U"shape-Flat&V.steep	1.10
"U"shape-Steep&Steep	1.20
"U"shape-Gentle&Steep	1.10
"U"shape-Flat&Steep	1.00
"U"shape-Flat&Gentle	0.90
"U"shape-Flat&Flat	0.85
"U"shape-Gentle&Gentle	1.00