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A comparison of methods used to measure suspended sediment in Canada's federal monitoring programs

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ABSTRACT Different sectorial monitoring programs within Environment Canada collect suspended sediment data for their own purposes. To address their particular needs they have adopted different sampling methods. Consequently, these methods do not produce similar results. This paper highlights the knowledge which has been gained from various intercomparisons in an effort to address the issue of data compatibility.

INTRODUCTION

Canada, like many other countries in the world, has had a sectorial approach to monitoring the fluvial environment. For example, the physical aspects of sediment transport (concentration, particle size, load) have been traditionally measured by an engineering-oriented organization (Water Resources Branch). Water quality monitoring, on the other hand, has been the mandate of a chemically-focused group (Water Quality Branch), which collected suspended sediment (non-filterable residue - NFR) as one of many parameters. Although these two groups are located within one federal government department (Environment Canada) only limited collaborative efforts have taken place between them.

By the early 1980s it became increasingly apparent that sediment played a major role in the transfer, fate and effect of many priority contaminants (Chapman et al. 1982). In fact, the major contaminants of concern (i.e. toxics) were acknowledged to be primarily associated with the sediment component (Allan, 1986). This in turn has prompted these two agencies to undertake comparison studies that focused on the review and evaluation of samplers, sampling methods and laboratory procedures. This paper highlights the results of some of these efforts and elucidates the knowledge which has been gained and some of the implications to future sediment monitoring.

METHODS USED IN FEDERAL MONITORING PROGRAMS

The Water Resources Branch (WRB) sediment program was initiated in the early 1960s to collect data for various engineering applications. The network next expanded to major river systems to document the sediment regime. To collect these data the program adopted the universally accepted US-series of samplers (e.g. USDH-48, USP-61) and followed the procedures of isokinetic sampling. In the late 1970s, samplers such as the USD-77 were field tested in a growing effort to find a suitable sampler for obtaining uncontaminated water quality samples. The water quality compatible (epoxy painted, silicon rubber gasket) version of the US-sampler series were introduced into the program in the 1980s. This effort to move towards common sampling methods has proven to be unsuccessful so far. The complete sample (minus 100 ml for total dissolved solids) is used by WRB for suspended sediment analyses. Filtration (AP2O prefilter and Whatman 934AH) is the most common method of determining concentration and bottom withdrawal is used to determine particle size (WRB, 1988).

The Water Quality Branch (WQB) collection program also started in the early 1960s with a mandate to document water quality in Canada's inland waters. The program focused on water chemistry. WQB used pseudo-depth integrating sampling techniques and dip sampling where conditions necessitated. In the program, a number of samplers are used (WQB, 1983), the most common of which are the sampling iron and multiple sampler (Fig. 1). The volume of water filtered is dependent on the turbidity of the stream. As much as a litre may be used, but typically an aliquot (100-500 ml), obtained by splitting, is the requirement. The sample is filtered (Whatman GF/C) following standard procedures for suspended sediment (non-filterable residue) analysis (WQB, 1986). To collect larger sediment samples for sediment quality purposes, WQB introduced centrifuges by the 1980s and currently are testing passive sediment samplers.

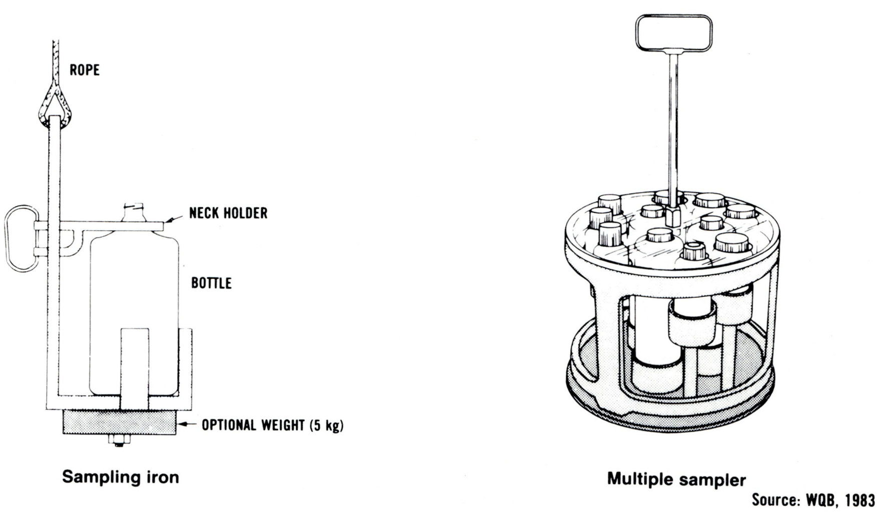

FIG. 1 Water quality samplers used to sample suspended sediment.

DATA COMPATIBILITY STUDIES

In Canada there is limited spatial and temporal information available on fluvial sediments in many of our river systems. In many cases it has been necessary to use the data from both these programs to address an environmental concern in a particular river system. Therefore it was decided by these two programs to work on a collaborative basis to address the issue of data compatibility. A number of studies have been initiated over the last decade in an effort to resolve this issue.

In a review of all available sediment data for the Lower Fraser River, Kellerhals (1984) drew attention to fact that the data collected by these two programs were not equivalent. Using long term data sets from the same site to derive rating curves, he noted that WQB data tended to be lower by a factor of 2-5 times. He concluded this difference was a direct result of field sampling procedures. Since the multiple sampler only collects a pseudo-depth integrated sample, Kellerhals speculated it was underestimating the sand fraction in suspension. Sands comprise approximately 30% of the suspended sediment load of the Fraser River.

Kellerhals findings prompted a more extensive evaluation. Using data collected on six different prairie rivers by these two programs, Linton et al. (1988) attempted to evaluate the extent of this difference, the possible cause of the difference and to determine if adjustments could be applied that would make these data more directly comparable. Samples collected on the same day by these two programs were used for direct comparison (Fig. 2). Statistically it was shown that there is a distinct proportional negative bias (it was assumed that WRB's methods produces more accurate results) associated with WQB's data. Analysis of particle size data indicated

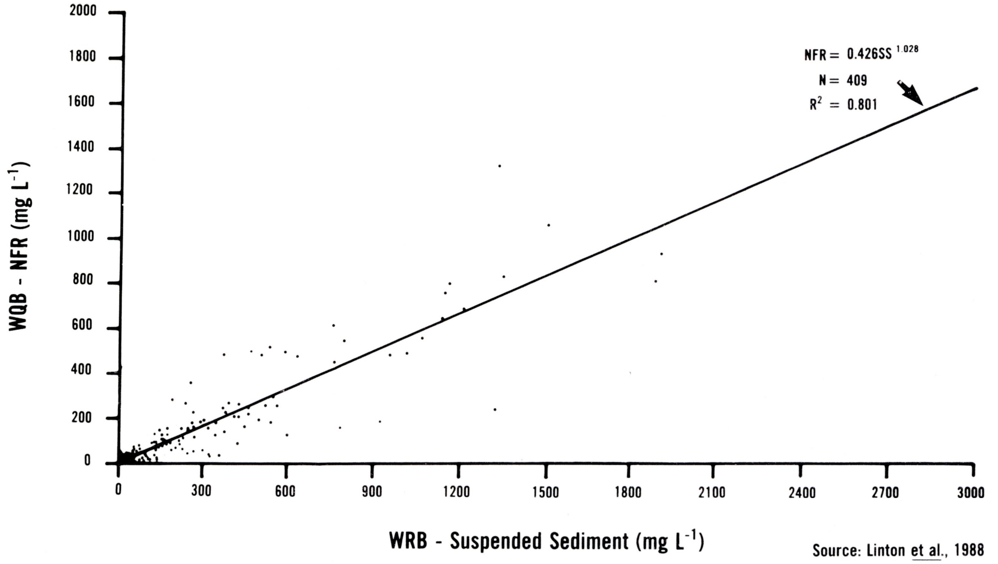

FIG. 2 NFR vs. suspended sediment from six prairie streams.

that this difference could not be explained by just underestimation of the sand fraction. The exact cause of the bias could not be isolated. Individual regression relationships were found to vary significantly from site to site, indicating the differences are a function of flow and sediment characteristics. The report concluded that site specific relationships were required and that no universal correction was applicable. The report also recommended that the programs move towards adopting common methods.

Of the suspended sediment, it is the fine-grained sediments (silts and clays) that are generally associated with the contaminants. Thus for sediment quality purposes, undersampling of sands is not considered to be a concern. It also has been assumed that silts and clays tend to be evenly distributed in the cross section and that a mid-stream surface or near-surface sampling will provide acceptable results. To test this hypothesis WRB's point-integrating data were analyzed. Six sites from four major river systems were used for the study (Ongley et al., 1990). This data set (436 verticals) cannot be considered to be truly representative as it is biased towards mid to high flows. Surface sampling tended to produce lower values (≈10%) when compared to the vertical mean. However, at 5 of the 6 sites, 89% of the time the surface value was within ±15% of the vertical mean (Table 1). The individual vertical distribution of silts and clays, however, commonly displayed inconsistent and variable patterns of concentration. Horowitz et al. (1989) suggest that even when the silts and clays are uniformly distributed the sediment chemistry can be variable. Thus, results obtained from less rigorous sampling protocols (i.e. surface or pseudo-depth integrating) may provide misleading information.

TABLE 1 Cumulative probability (ΣP) of suspended sediment concentration of surface sample being within ±X% of concentration of vertical mean.

	± Difference (%) from vertical mean						
Location X =	5	10	15	20	25	30	>30
Red River							
ΣP: silt	35.8	71.7	83.0	86.8	94.3	96.2	100
ΣP: clay	43.4	67.9	84.9	94.3	96.2	100	
ΣP: silt + clay	73.6	94.3	100				
South Saskatchewan River							
ΣP: silt	51.1	80.0	93.3	97.8	100		
ΣP: clay	62.2	88.9	93.3	100.0			
ΣP: silt + clay	66.7	86.7	93.3	97.8	100		
North Saskatchewan River							
ΣP: silt	55.3	78.8	91.8	95.3	97.6	97.6	100
ΣP: clay	42.4	63.5	71.8	76.5	80.0	84.7	100
ΣP: silt + clay	64.7	88.2	94.1	96.5	97.7	97.7	100
Fraser River (Marguerite)							
ΣP: silt	50.0	76.7	85.1	91.7	95.1	98.4	100
ΣP: clay	18.3	35.0	43.3	51.7	63.3	73.3	100
ΣP: silt + clay	58.3	78.3	90.0	95.0	95.0	96.7	100
Fraser River (Hope)							
ΣP: silt	52.7	76.4	89.3	96.8	97.9	97.9	100
ΣP: clay	19.4	35.5	54.9	65.6	69.9	75.3	100
ΣP: silt + clay	62.4	78.5	89.3	95.7	98.9	98.9	100
Fraser River (Mission)							
ΣP: silt	22.0	50.0	72.0	85.0	94.0	96.0	100
ΣP: clay	15.0	36.0	53.0	67.0	78.0	81.0	100
ΣP: silt + clay	23.0	56.0	79.0	93.0	96.0	99.0	100

Source: Ongley et al., 1990

METHODS (FIELD AND LABORATORY) EVALUATIONS

There are a number of potential sources that can contribute to the data differences discussed above. Potential sources are: field methods (protocol), samplers, sample handling (splitting), sample preparation and analytical procedures (filters).

Crosley (1985) as part of a study on mercury transport collected replicate samples to define the precision of various analytical methods. A composite sample was collected and placed in a 4-litre pyrex mixing flask. Mixing, splitting and preservation procedures were completed within three hours of sampling. A 500 ml sample was sent for NFR analysis to a WQB lab and a 600 ml sample to a WRB laboratory. The results show basically a 1:1 relationship for the range of concentration (5-722 mg L^{-1}). This study concluded that the difference in laboratory procedures (preparation and filter size) is not a significant factor in terms of accounting for the data differences between the programs.

Gaskin and Block (1987) undertook one of the first systematic evaluations of these two different types of samplers (USD-77 vs. sampling iron). Based on a suite of paired data collected from two prairie streams they found the results produced were not statistically different for certain water quality parameters: turbidity, particulate nitrogen and particulate phosphorus. However, for sediment there were differences primarily associated with the ability of the samplers to measure the sand fraction. Even though the USD-77 was found to have a higher degree of precision, it was not endorsed by WQB. Sample splitting was not found to be a significant factor, based on tests conducted as part of this study.

To try and address the data discrepancy identified by Kellerhals (1984), Churchland (1991) undertook some extensive field testing on 6 different streams. She noted that NFR data were consistently lower than WRB's data by 10-55%. Even when a more elaborate data set (9 samples collected at various depths) using a peristaltic pump was compiled, the results were still in the order of 50% lower than WRB's values. Attention was then focused on the analytic methods, starting with sample splitting to try and account for this difference. Even though vigorous mixing procedures were employed (method A), it was not possible to obtain a representative subsample from a larger sample (Table 2). Sample

TABLE 2 Effect of analytical technique on determination of suspended sediment.

Location	Date Sampled	Concentration (mg L^{-1})			
		Non-filterable Residue (WQB)			Suspended Sediment (WRB)
		A	B	C	
Liard River	16/05/84	107 ± 8	165 ± 14	172 ± 21	187 ± 10
Swift Current Creek	28/07/84	488 ± 10	561 ± 9	540 ± 15	549 ± 9
Squamish River	07/06/83	83 ± 3	137 ± 7	142 ± 9	137 ± 10
Fraser River at Mission	22/06/83	100 ± 12	157 ± 15	148 ± 17	156 ± 33
Greely Creek	29/07/84	180 ± 18	437 ± 90	455 ± 57	390 ± 92
Sumas River	16/11/83	25 ± 4	29 ± 4	35 ± 6	32 ± 1

Source: Churchland, 1991

Note: Numbers are arithmetic means and 95% confidence limits; sample size is ten.
A is the non-filterable residue analysis of a 100 ml subsample from a 250 ml bottle.
B of the total contents of a 250 ml bottle.
C of the total contents of a 100 ml bottle.

splitting appears to have been a major contributing factor in accounting for the data difference between the programs. Sample size did not appear to be an important factor. Even when a small sample size of 100 ml was used (method C), it tended to produce more comparable results. This conclusion appears to contradict the findings of previous studies (Crosley, 1985; Gaskin and Block, 1987), but when viewed in terms of the fluvial environment can be explained. Fast settling times of sands make splitting more difficult; the streams Churchland studied had a high sand fraction in suspension.

A major environmental assessment of the Churchill River Diversion in Northern Manitoba is currently being completed. Sparsity of data in this remote setting necessitated the use of all available data. Concerns were raised about combining suspended sediment data collected by a number of different agencies (NHCL, 1988). A field study was thus designed to determine data compatibility and the overall precision of various methods in this environmental setting. Lapointe et al. (1989) determined through an intensive field study (30 sets of samples collected over a 5-hour period) that the sampling iron produced a lower estimate (≈12%) of suspended sediment when compared with the USD-74 (Fig. 3). Sample splitting procedures for WQB may contribute a further ≈10% to this negative bias. Therefore an adjustment of ≈20% would be required for wash load dominated streams in northern Manitoba. The results of this study are currently being applied to help develop a more comprehensive sediment budget for the Churchill River Diversion.

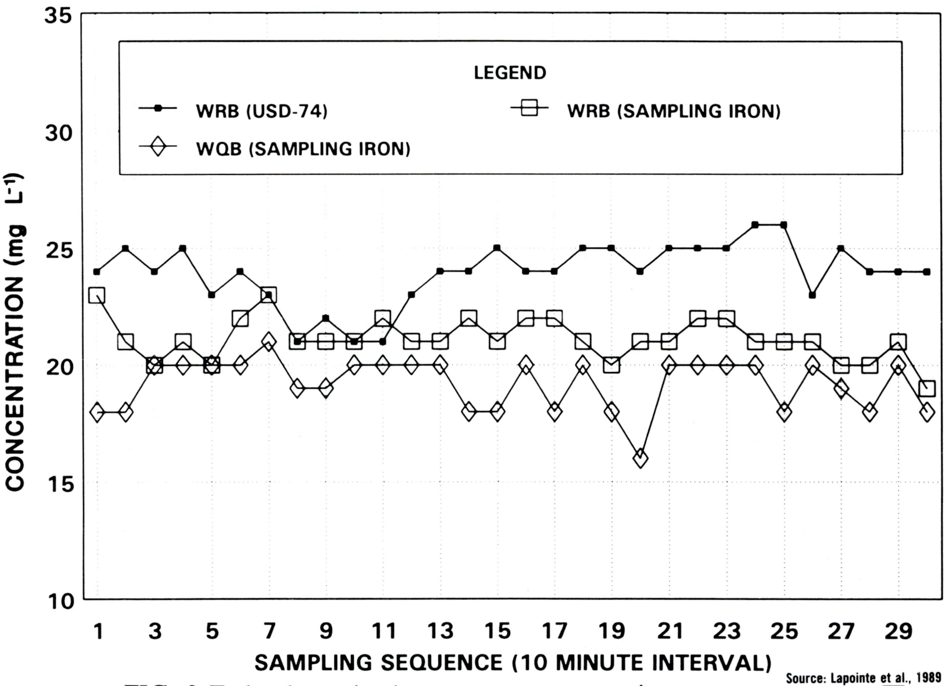

FIG. 3 Federal monitoring programs comparison.

INTEGRATION OF THE FEDERAL MONITORING PROGRAMS

The objectives of these two programs were distinctly different and as such has resulted in the methodological differences used to measure suspended sediment. WQB collected sediment as a "general" indicator of water quality conditions; while WRB measured sediment to quantify sediment transport. The latter required more elaborate (isokinetic) methods and sampling technology. Contamination problems associated with the original US-series of samplers made it inappropriate for water quality purposes and subsequently alternative methods were adopted.

The US-series of samplers (trace metal versions) and other isokinetically-designed water quality samplers (e.g. USD-77) have been unsuccessful in replacing the existing WQB sampling technology. Even though the intercomparison studies discussed in this paper indicate that depth-integrating samplers are more appropriate, movement in this direction has been slow. Some of the reasons given for this are:

(a) the existing WQB sampling technology does provide a reasonable estimate of the wash load, and it is deemed that it is only the fines (silts and clays) that are of significance to water quality;
(b) efforts with regards to sampling, especially for sediment quality, have focused on centrifuges and passive samplers; which are capable of providing the mass of sediment required for analysis;
(c) the quality of the data gained using isokinetic samplers still needs to be weighed against the increase in resources (e.g. sampler replacement, increased field sampling time, etc.);
(d) the integrity of the WQB data base would be impacted by a major change in methodologies and perhaps render the historical data base useless for trend assessment;
(e) it is only in recent years that WQB monitoring stations are being co-located with the hydrometric (and sediment) stations and therefore the importance of flow and sediment data for interpretative purposes are now more fully being appreciated.

The adoption of an ecosystem approach to the assessment of the aquatic environment will necessitate integrated planning and monitoring of physical, chemical and biological components. Some of the steps required to more closely align these two programs have already been identified (Blachford and Day, 1988). Although progress has been slow to date, actions such as establishing integrated network evaluation and planning committees across the country, making organizational adjustments, and re-focussing monitoring needs, are currently underway that will aid the integration of sediment and water quality monitoring conducted by Environment Canada.

CONCLUSION

These studies have helped to provide us with a better understanding of the implications of using the sediment data collected by these two monitoring programs. It is apparent that the current WQB sampling methods provide an underestimate of suspended sediment, the bias being largely dependent on the amount of sand in suspension. In terms of wash load (silts and clays), the pseudo-depth integrating samplers used by WQB tend to provide an acceptable estimate (10-20%). The data discrepancy between these two programs is a function of both field sampling and sampling handling (splitting), with the degree of difference being dependent on the sand fraction.

With a country the size of Canada and the sparsity of sediment data, resource managers often find it necessary to combine any and all available data. However, users of sediment data in Canada must exercise caution when combining data obtained using different methods such as those employed by the Water Resources and Water Quality Branches of Environment Canada. The studies discussed in this paper illustrate the magnitude of the problems which can be encountered.

Environment Canada is currently pursuing an integrated monitoring approach to the aquatic ecosystem, which will inevitably lead to the resolution of this methodological issue.

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