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Assessment of the impact of farmland erosion on sediment quality: the Saskatchewan River basin, western Canada

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ABSTRACT

The Prairie region of western Canada is one of North America's major agricultural belts, specializing in cereal crop production. The region is also one of significant soil erosion, through both runoff and wind action. Recent studies in the United States have implicated farmland erosion as an important source of sediment and sediment-associated contaminants in river water. This has prompted a similar assessment in Canada, focussing initially on the Saskatchewan River basin. Analysis of data on suspended sediment concentrations and loadings from Water Survey of Canada hydrometric stations, and on pollutant levels from Water Quality Branch sampling sites in the basin, does not, however, implicate farmland erosion in deterioration of water quality on most rivers. Any effects of farmland sediment are masked by natural erosion of sediments, especially from channel margins. A possible exception is small basins. Few data are currently available to assess the situation there, however, and this is earmarked as a priority area of monitoring in the future.

INTRODUCTION

In recent years, the impact of farmland erosion on surface water quality has attracted a large amount of attention in North America. The impact of pesticide residues carried into watercourses is one of the most obvious potential concerns with farmland runoff, but not the only one. The overall severity of impacts from farmland erosion was highlighted in a report by the The Conservation Foundation in the USA entitled "Eroding Soils: The Off-Farm Impacts" (Clark et al., 1985). The report concluded that agricultural lands accounted for almost 70% of all water-caused erosion in the USA, and for more than a third of the cost of sediment impacts on stream water. These impacts included loss of recreational water use, reduced capacity of reservoirs and navigation channels through sediment deposition, to name just a few.

A smaller, but similar study, in the province of Ontario in Canada, established that agriculture was responsible for almost 90% of sediment impacts on waterways (DCH-LRRI, 1986), particularly through recreational fisheries losses.

These and similar studies prompted the Inland Waters Directorate of Environment Canada to review its own existing database on sediment in the Prairie Provinces in order to determine:
(a) whether existing data had been collected in an appropriate manner to allow investigation of this issue; and
(b) whether the data indicated the same degree of agricultural pollution of waterbodies as found in the Ontario and American studies. The choice of the Prairie Provinces was dictated by the fact that this is the agricultural heart of Canada with almost the entire land area of the plains devoted to farming, especially the cultivation of grain crops. The annual on-farm costs of soil erosion in Alberta and Saskatchewan are only marginally less than in Ontario. The Saskatchewan River Basin was chosen as a representative portion of this land area.

It should be emphasized that this data review was not concerned with all aspects of possible agricultural pollution: it was restricted to sediment, and to those contaminants that are bound to sediment and thus enter watercourses when sediment is removed from fields into streams and lakes. A large portion of the potential array of contaminants may be expected to move primarily in association with sediment, especially organic sediment: these include nutrients, heavy metals and pesticide residues, many of which preferentially adsorb to fine grained particulate matter (Pionke and Chesters, 1973).

The data review did not examine pollutants that occupied the dissolved phase. This obviously poses certain problems of interpretation because much of the potential pollutant load that is bound up with sediment is usually assumed to be far less bioavailable than the load that is actually dissolved in the water. This does not mean, however, that contaminants bound up with sediment should be regarded as permanently removed from the aquatic ecosystem. For example, nutrients that remain incorporated in the sediment in well-oxygenated conditions, can become released to the dissolved phase as sediment settles into anoxic areas, or as the oxygen status of the water itself changes over time. Moreover, metals and pesticide residues that are bound up with fine-grained particulate matter are known to be consumed by some benthic invertebrates and by some filter-feeding zooplankton, and thus enter the food-chain in that way.

The rest of this paper deals with the three main potential groups of pollutants bound up with farmland sediment: nutrients, metals and pesticide residues, dealing with them successively.

NUTRIENTS

Nutrients, particularly, phosphorus, are of concern in the water pollution context, for many reasons, but in particular because of the problem of eutrophication, that is, the creation of algal blooms and the subsequent decomposition of this biomatter. Eutrophication is certainly encountered in some of the main rivers of the Saskatchewan River basin in the summertime, as well as in smaller, shallow waterbodies. However, present-day eutrophication in large rivers occurs immediately downstream of the major sewage treatment plants, and does not seem to be directly related to sediment.

The question of nutrient loading on the mainstem rivers, as it relates to sediment in general and farmland erosion in particular, is nonetheless still a potentially important issue. At present the huge waterbody of Lake Diefenbaker, just upstream of Saskatoon, is in good condition, but questions continue to be asked about possible deterioration in the future, in view of the large quantities of sediment-bound phosphorus that accumulate in the reservoir each year. In the present context, the important question, therefore, is how much of this particulate phosphorus is derived from agricultural land.

No precise answer can be given to this question, but the available data do suggest that farmland's contribution is probably extremely small. There are two main indicators here:

(a) limited sediment supply from farmland; and

(b) comparable level of nutrients in background sediments.

It seems that most of the sediment entering the South Saskatchewan River is not from the surface soils of farmland, but from gullying of valley slopes and undercutting of channel banks. Existing suspended sediment data indicate that more than 40% of the sediment-associated phosphorus entering the reservoir is from the Red Deer River basin (Weagle and Crosley, 1989). And within this basin, measurements of gully erosion in badland areas indicate that this process alone produces a supply of sediment equal to that actually measured in the river (Campbell, 1973). Similar conclusions have been reached for the Oldman River basin, though there are no data to quantify the importance of riparian sediment supply (FEARO, 1991).

The total phosphorus content of these subsurface sediments being eroded in channel banks and valley walls is not appreciably less than the P-content of eroding farmland soils. Data from the Saskatchewan Institute of Pedology, for example, show both subsurface sediment and surface soils to contain total phosphorus in the range of 500-600 mg P per kg of sediment (Schoenau et al., 1989). The concentration of P in the bottom sediments of Lake Diefenbaker is admittedly slightly higher (about 800 mg P per kg of sediment). This finding seems to be due to the fact that the nutrient-poor sand component settles out of suspension at the head of the reservoir, thus enhancing the nutrient status of sediment in the main area of bottom sediments.

It is therefore tentatively concluded that farmland erosion is not a major problem in the overall loading of phosphorus in Lake Diefenbaker. The same conclusion could be reached in connection with the other large rivers in the Prairies. On the other hand, this conclusion does not appear to be valid for many of the smaller watercourses. There is clear evidence that small streams and lakes do suffer eutrophication, and that a major source of the increased P loading is runoff from farmland (Mitchell, 1985).

Why should this difference exist between the large and small waterbodies? The answer appears to be that a much larger percentage of the sediment washed into small streams and lakes originates from farmland. In turn, this explanation itself, reflects two main points.

In the first place, in large river basins, a high proportion of the soil being eroded from farmland simply does not reach the river, because of the hummocky character of the terrain, and the fact that large parts of the land are internally drained. Some small river basins also fall into this category. But there are many small basins where there is good connectivity between eroding farmland surfaces and the drainage system: these can be expected to produce stream sediment that is dominated by farmland soil erosion.

Secondly, there is a general tendency in the Prairies for sediment concentrations in stream water to increase as the riverflow moves downstream: this is because additional sediment is added to the flow from landslides, gullies and bank erosion as the river water moves downstream. All this additional riparian sediment is non-farm sediment and therefore acts to dilute the effects of farmland soil. In contrast, in the upper areas of prairie catchments, the diluting effect of this non-farm sediment is at a minimum.

This distinction between large rivers (most of the water in which originates in the mountains and foothills of the Rockies) and small rivers (which drain only prairie areas) is therefore fundamental in any attempt to understand off-farm sediment impacts in the prairie region. The conclusions just reached should apply not only to phosphorus, but to all potential pollutants originating on farmland. Whether it does in fact apply to these other contaminants is hard to establish because very few data have been gathered for metal pollutants and for pesticide residues in small prairie drainage basins. Most of the data collected so far have been for the large waterbodies. This emphasis of the sediment-monitoring program on the mainstem rivers is, of course, understandable: Lake Diefenbaker supplies drinking water to a large percentage of the population of Saskatchewan and, in general, it is true that large water bodies are more intensively used by humans that the smaller ones.

The time has now come, however, when smaller waterbodies need to be investigated. These waterbodies are also used by human activity; and in terms of their use by non-humans their importance may be even greater. The sloughs and potholes, for example, are the home to large numbers of prairie nesting ducks, and attention is now being directed to acquiring data from these small water systems (Sheehan et al., 1987).

METALS

In relation to heavy metals, the existing database again tends to indicate that agricultural erosion is not a significant polluter of the large waterbodies.

One reason for this, as already noted, is that only a small portion of the sediment load in the main rivers comes from farmland, the rest being from channel and valley margins. The other point - as in the case of nutrients - is that there is not always a great deal of difference in the metal content of surface soils and that of the subsurface sediment that is subject to gullying and bank scour. Available data for surface prairie soils (Mills and Zwarich, 1975) do show some metals to be more concentrated in surface sediment, but the statistical significance of this limited comparison is admittedly questionable.

The National Water Research Institute has examined metal concentrations in sediment carried in suspension by the main rivers and noted that in springtime - the period of high flows and most sediment transport - the metal levels in suspended sediment are essentially the same as in the subsurface materials exposed in channel banks (Blachford and Ongley, 1984). In addition, they examined the metal levels of sediment being moved into streams from irrigation return flows in the summer time (Joseph and Ongley, 1986); again they found little difference between these levels and those in river water during springtime flow from natural runoff.

The one possible exception to this overall finding is mercury: Hg concentrations in suspended sediment in rivers were actually an order of magnitude higher than in levels in surface soils. But the source of this mercury is not known. Mercury was formerly used in a fungicidal treatment of crops in the 1960s and may therefore still consitute a diffuse source of metal pollution. On the other hand, mercury levels in surface soils do not appear to be significantly higher than in bank sediments. A more likely source is industrial effluent, but the matter remains unresolved.

As noted earlier, there are few data for metals in sediments of small river basins. Some intriguing data have been collected by the National Hydrology Research Institute (Warwick, 1989), however, from Tobin Reservoir on the Saskatchewan River downstream of the junction of the North and South branches. Metal levels in bottom sediments in the main body of the reservoir (where sediment collects from the mainstem Saskatchewan River itself) were generally significantly lower than in a side basin which receives sediment from a small agricultural basin.

These data support the view that sediment from large rivers contains less metal pollutant (per unit volume of sediment) than sediment from small agricultural basins. Higher metal concentrations at the bay site are, in all cases, associated with metals which have higher concentration in surface farmland soil than in river bank materials. The data are therefore consistent with the speculation that much of the sediment in the large rivers is relatively inert material from subsurface sediment, and thus able to dilute any metal-contaminated agricultural soil. Additional data for small farmland basins are needed before any acceptable generalization can be made.

PESTICIDES

Turning to pesticides, it is more difficult to address the specific issue of sediment pollution because almost all the data refer to water samples, not samples of suspended sediment. It is true that these water samples are generally unfiltered so that if there are pollutants in the sediment, they would be expected to show up in the analysis. On the other hand it has been documented that analysis of sediments directly will often reveal presence of pesticide residues, even though analysis of the whole-water sample fails to do so (Blachford and Ongley, 1984).

In examining the available pesticide data (IEL, 1989), it is certainly hard to believe that there is any problem in terms of the larger watercourses, which is where most of the data have been collected. Of 63 pesticide residues examined, 54 of them were detected in less than 2% of the samples, 22 of them never having been detected at all. Of the remaining 9, the three most prominent were the insecticide residues α-BHC and lindane, and the herbicide 2-4-D. None of these three were found in concentrations exceeding the CCREM (Canadian Council of Resource and Environment Ministers) guideline for the protection of aquatic life. As in the case of metals and nutrients, therefore, it appears that agriculturual pollution of the major rivers is minimal.

As already noted, data for smaller streams are scant. In view of the findings for nutrients and metals, the possibility of finding higher pesticide levels in these smaller water bodies must be recognized. Monitoring of small basins has now begun to this effect.

CONCLUSION

Three main conclusions would seem to emerge from this review: one primarily of local significance; one of general sedimentological relevance; and one that is methodological.

The first conclusion is that sediment in the large river systems of the Prairies shows minimal (if any) evidence of contamination by off-farm sediment; tnere is some evidence that this conclusion does not apply to small watercourses (as far as nutrients is concerned), but insufficient data exist to comment on metals and pesticides.

The second conclusion is that increased levels of sediment in stream systems can be viewed positively as well as negatively. The negative costs are well-known: increased expense of dredging, impact on fisheries, etc. The positive role is that sediment from natural (background) sources clearly acts to dilute the concentration of sediment-bound contaminants from anthropogenic sources.

Thirdly, there is a methodological issue: the results that are produced by a monitoring program will be strongly conditioned by the sampling design of that program. And since different purposes of investigation will warrant different experimental designs, great care is needed in generalizing from the results of any one such investigation. The surface water data for the Prairie Provinces has, for understandable reasons, been focussed on the large rivers: the conclusions obtained from this data set may be quite misleading if applied to other settings in the aquatic environment.

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