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# COHESIVE SEDIMENT TRANSPORT: EMERGING ISSUES FOR TOXIC CHEMICAL MANAGEMENT

by

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# MANAGEMENT PERSPECTIVE

Many toxical chemicals in aquatic systems are associated with the cohesive sediment phase (silt & clay). In rivers, chemical management and the prediction of chemical pathways and fate requires a significant improvement in knowledge of the physics, chemistry and microbiology of cohesive suspended and bottom sediments.

The principal knowledge gaps are identified and specific examples of importance of the cohesive fraction for toxicology flocculation, modelling and chemical partitioning are provided.

# PERSPECTIVE GESTION

Bien des substances chimiques toxiques présentes dans les réseaux aquatiques sont associées à la phase des sédiments fins (silt et argile). La prévision des voies de transformation et du devenir des substances chimiques dans les fleuves et les rivières ainsi que leur gestion nécessitent une bien meilleure connaissance de la physique, de la chimie et de la microbiologie des sédiments fins, tant en suspension que déposés sur les fonds fluviaux.

Les principales failles dans les connaissances sont identifiées et des exemples spécifiques sont fournis de l'importance de la fraction des sédiments fins dans la floculation, la modélisation et le partage chimique des agents toxiques.

## COHESIVE SEDIMENT TRANSPORT: EMERGING ISSUES

#### FOR TOXIC CHEMICAL MANAGEMENT

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#### ABSTRACT

For environmental monitoring, prediction and management purposes in rivers and their basins, the association of many environmentally sensitive chemicals and their transformation products with mineral and organic substrates assumes great importance. Our understanding of these relationships is, however, modest to unknown. Of particular concern (and to which we address ourselves in this paper) are: the physical behaviour of fine-grained (<63um) sediment in freshwater; the role of flocculation as a transport vector; the processes that control freshwater flocculation including microbiological factors; the uncertainty in conventional sediment transport models for predicting pathways of sediment-associated chemistry; the relationship between suspended sediment and toxicity in the water column; and the partitioning of chemicals between the sediment, organic and water phase, including the significance of these in predicting chemical transport on suspended matter.

Keywords: cohesive sediment, flocculation, toxicity, partitioning, rivers, chemistry, transport, bacteria

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RÉSUMÉ

Pour fins de contrôles environnementaux, de prévision et de gestion. un rôle très important revient à l'association de maintes substances chimiques sensibles dans les conditions environnementales qui prévalent dans les fleuves et les rivières ou leurs bassins et de leurs produits de transformation en présence de substrats minéraux et organiques. Notre compréhension de ces relations est cependant modeste, voire nulle parfois. Les principales questions qui se posent (auxquelles nous tentons de répondre dans le présent article) sont : le comportement physique des sédiments à grains fins ( < 63  $\mu$ m) dans les eaux douces; le rôle de la floculation comme agent de transport; les processus qui régissent la floculation en eaux douces (entre autres, les facteurs microbiologiques); l'incertitude des modèles classiques décrivant le transport des sédiments pour ce qui est de prévoir les voies de transformation chimique liées aux sédiments; la relation entre les sédiments en suspension et la toxicité dans la colonne d'eau; finalement, le partage des substances chimiques entre les sédiments, les matières organiques et l'eau, y compris l'importance de ce partage dans la prévision de leur transport sur des matières en suspension.

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Mots clés : sédiments fins, floculation, toxicité, partage, fleuves, rivières, chimie, transport, bactéries.

#### INTRODUCTION

Toxic chemicals, including most heavy metals and the majority of the US-EPA Priority Pollutants (including 96% of categories #1 and #2 -- most toxic and persistent pollutants; Chapman et al. 1982) and many other unlisted but environmentally sensitive chemicals, have environmental pathways that are primarily or exclusively associated with sediment and biological substrates. For environmental monitoring, prediction and management purposes in rivers and their basins, the association of parent compounds and their transformation products with mineral and organic substrates assumes great importance. Our understanding of these relationships and of the physical and biogeochemical processes that govern transport and pathways between environmental compartments is, however, modest to unknown. Here we address the knowledge gaps that exist in our understanding of:

 physical behaviour of the cohesive (<63um) fraction of suspended sediment vis-a-vis freshwater flocculation, including microbiological controls of this process

uncertainty in predicting sediment transport for the <63um fraction</li>
role of suspended solids in toxicity assessment of river water
chemical partitioning on suspended sediment

In this paper we chiefly address the cohesive (<63um) fraction of the suspended sediment load. Although many authors have identified this size-class

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as the most significant in terms of chemical adsorption processes, detailed studies of sediment-chemical relationships by size class indicate substantial differences between size class. depending on the chemistry under investigation. Horowitz and Elrick (1987), for example, found that the <63um and <120um size classes most closely correlated with bulk (metal) chemistry for a wide variety of stream sediments from 17 geographically and hydrologically diverse areas of the United States. Experimental data on phosphate adsorption/desorption on sediments from two streams in Ontario suggest that, while, particle size per se is not important, the mineralogical and chemical composition of the finest fraction (<13um) produced the largest measured adsorption (Stone & Mudroch, 1989).

Sediment-associations for many organic chemical contaminants are not so well known as for trace metals and phosphorus. Karickhoff (1981) and others have shown that the particulate organic carbon (POC) content of suspended solids plays a central role in organic contaminant association and transport. Umlauf and Bierl (1987) demonstrate that about 60% of PAHs are associated with the middle to coarse silt fractions of suspended sediments of the river Rotmain; they show that this association is mainly related to the organic carbon content of these size classes. Umlauf and Bierl conclude that PAH transport must take into account the transport characteristics of the silt fraction. Carey <u>et al</u> (in press) found in the Mackenzie River that individual PAHs displayed differing affinities for sediment and aqueous phases.

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Focus on the <63um fraction should not obscure the fact that total loadings of chemistry associated with larger size fractions can be significant. Horowitz et al. (in press) demonstrate for the Arkansas and Cowlits Rivers that metal chemistry associated with the >63um particle-size classes can be significant and can contribute substantial loadings. Also, in cases where the chemical concentration on the >63 fraction is small, sites having a large suspended load in the >63um fraction can produce substantial chemical loads in non-cohesive sediment.

### FLOCCULATION AND PHYSICAL BEHAVIOUR OF COHESIVE SUSPENDED SEDIMENT IN RIVERS

Flocculation of suspended matter in estuarine and marine environments is well known (Kranck, 1973; Krone, 1978). Although the flocculated state of fine-grained suspended matter in freshwater fluvial systems has been suggested and/or inferred by many researchers (e.g. Ongley <u>et al</u>. 1981; Partheniades, 1986; Umlauf & Bierl, 1987) and has been experimentally studied (e.g. Tsai <u>et</u> <u>al</u>. 1987), we could find only one paper that explicitly examined flocculation of suspended sediment in river systems (Droppo & Ongley, 1989). The absence of information on freshwater flocculation undoubtedly relates both to traditional sediment sizing techniques that include chemical or ultrasonic sediment dispersion and carbon elimination in order to reduce particles to their primary mineral size distribution, and to the absence of non-destructive techniques for in-situ measurement of particle aggregates.

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Flocculation of particles is a dynamic phenomenon controlled by a variety of physico-chemical and biological processes. Aggregation phenomena include: suspended sediment concentration together with particle collision mechanisms such as Brownian motion, fluid shear, and differential settling of particles (Tsai <u>et al</u>. 1987); van der Waals forces; salinity; control over particle size and settling velocity by absorbed organic carbon (Kranck, 1975); and biological processes. In salt water, flocculation is promoted by suppression of repulsive charges of the electron field surrounding each particle. According to Tsai <u>et al</u>. (1987) high valent cations such as Ca+2 and Mg+2 have the greatest capacity for promotion of chemical flocculation in freshwater. Nevertheless, chemical flocculation in freshwater is probably subordinate to other physical and biological mechanisms.

Biological processes reflect two principal phenomena -- bacterial bonding and bacterial "glue". Research has demonstrated that bacteria have a high affinity for <63um soil particles (Marshall, 1971); this promotes flocculation by increasing the surface area and by bonding two or more mineral particles together. Floc stabilization is likely enhanced by secretion of extracellular polymeric exudates by certain bacteria (Biddanda, 1986; Muschenheim <u>et al</u>. 1989).

Although the relative importance of bacterial processes in freshwater flocculation has not been conclusively demonstrated, there is ample circumstantial evidence that suggests that this may be the most important flocculating process. Work of Paerl (1973), Muschenheim <u>et al</u>. (1989), Zabawa

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(1978) and others indicate the importance of bacterial processes in the formation and stabilization of flocculated material. Kranck's (personal communication) speculation that unflocculated suspended matter in cold environments such as in northern rivers and downstream from glaciers, is a result of low bacterial populations, seems consistent with experimental evidence.

### Field Studies of Freshwater Flocculation

Understanding of freshwater flocculation and the measurement of in-situ particle sizes ("effective" particle size; Ongley et al., 1981) has suffered from the lack of instrumentation for direct and nondestructive measurement of suspended particles. Flocs are generally regarded as sufficiently fragile that the act of sampling may cause floc breakage. Conventional sizing apparatus, Coulter Counter, Sedigraph and laser devices, require sample including pretreatment and/or agitation to pump the suspension past the sensor. Bale and Morris (1987) demonstrated that particle-size distributions in pumped samples were different from those measured in-situ. Floc breakage is likely with pipette analysis. It is not known if, or to what extent, flocs stabilize in flowing waters to achieve an equilibrium between aggregation forces/mechanisms and turbulent shearing forces. Even in the sanitary engineering field where flocculation is commonly used for water and wastewater treatment, questions of floc stability and physical characteristics are still the subject of research (Glasgow, 1989).

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Following the example of Bale and Morris (1987), we have adapted a bench-top Malvern laser particle analyser for routine under-water use. Preliminary data suggest that we are able to detect substantial differences in particle-size distribution across the St. Lawrence River. Instrumentation, such as our field Malvern, does not permit analysis of floc characteristics other than particle-size distribution. Other in-situ techniques such as the Benthos Camera permit quantification of individual particles but are unable to resolve flocs less than 90um. Droppo and Ongley (1989) developed a technique of direct analysis of freshwater flocs using techniques adapted from plankton studies. Using a combination of settling chambers, inverted microscopy and digitization, they were able to quantify floc sizes and numbers for a Southern Ontario river. Droppo and Ongley were also able to demonstrate bacterial associations with flocs using staining and fluorescence techniques of Rao et al. (1984). Rao et al. (1988) experimented with low pressure cascade filtration with subsequent verification by Malvern analysis, as a technique both for separating floc sizes and for quantifying floc-bacterial relationships by particle-size class. Each technique has unique advantages but suffers inherent limitations.

Although many authors have commented on riverine flocculation, a recent survey of the freshwater literature found no references (other than Droppo and Ongley, 1989) of empirical studies of in-situ flocculation. Droppo and Ongley found that although flocs comprised only 10-27% of the total number of particles, they represented from 92-97% of the total volume of suspended particles over a complete water year. They found that the median floc size

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(measured as equivalent spherical diameter) was only 9um with few flocs exceeding 60um. Although Droppo and Ongley experimentally determined that their sampled flocs were relatively stable, their results are so much smaller than those reported for the marine and estuarine literature that one may question whether their sampling protocol was disruptive, or whether riverine flocs are inherently smaller and represent a limiting growth process in a turbulent riverine environment. In comparison, using the cascade filtration procedure on a 5L Yamaska River (Quebec) water sample we found the dominant floc size to be 20-40um (Table 1).

### - Approx. here for TABLE 1 -

# Empirical Studies of Bacteria and Suspended Particulates

There is a rich albeit inconsistent literature in the field of bacteriaparticle associations. Bell and Albright (1981) reported that 60% of bacterial biomass was associated with suspended particulates in the turbid Fraser River Estuary, but declined to 15-39% as salinity increased. Droppo and Ongley (1989), using fluorescence techniques, found that bacteria were primarily associated with flocs in 16 Mile Creek. Using Rao's techniques noted above, our preliminary results indicate that bacterial densities are greatest in the dominant floc size class (20-40um) for a 5L Yamaska River sample (Table 1); this preliminary result requires further confirmation to establish if it can be replicated or is representative of a wider range of river samples.

### UNCERTAINTY IN PREDICTING COHESIVE SEDIMENT TRANSPORT

Knowledge of physical processes in fine sediments in rivers is of fundamental importance for predicting the transport of sediment-associated contaminants and nutrients. Although a few researchers have been investigating cohesive sediment transport processes for more than twenty years, conventional wisdom in the sediment transport field holds that suspended fine-grained sediment is transported in rivers in a continuous mode without significant deposition. However, field and laboratory evidence suggest that sedimentation and resuspension leading to discontinuous transport of the cohesive fraction are very probable and may be a major component of transport. Indeed, it is this evidence that has prompted our own focus on flocculation processes and particle physics in order to predict fine particle transport together with associated nutrients and contaminants.

Verhoff <u>et al</u>. (1979) inferred discontinuous transport in time and space in their study of phosphorus flux in Ohio. Blachford and Ongley (1984) found that sediment-associated concentrations of metals in the Bow River, Alberta, declined systematically downstream. Unpublished work of our own in the North Saskatchewan River found similar downstream declines in sediment-associated metal concentrations which appear to be related to in-stream processes of sedimentation and replacement during transport.

In virtually all of the existing models of fine-sediment transport (e.g. Onishi <u>et al.</u> 1979 & 1984; Ziegler & Lick, 1986; Thomas & McAnally, 1985;

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US-EPA, 1988) the process of flocculation is neglected and the fine sediment particles are assumed to behave as individual (primary) particles. Flocculation can change the physics of particle behaviour, mainly through significant changes in the settling velocities of flocs relative to their primary constituents. As shown by Krishnappan (in press) and many others, there is a substantial change in settling velocity when dispersed mineral sediment is allowed to flocculate. A second transport characteristic that can be affected by flocculation is the nature of particle interactions at the bed/water interface, resulting in substantial differences in critical shear stresses required for erosion and deposition.

Determination of potential error in cohesive sediment transport models due to flocculation of particles, has never been quantified. Here, we incorporate the flocculation model of Krishnappan (in press) into the dispersion model of Krishnappan and Lau (1982) in order to predict the sediment concentration and sediment flux in a natural stream with, and without, the flocculation component. Krishnappan's flocculation model has been tested against the still water settling data of Kranck (1980) and found to be in good agreement. Kranck's data are from a marine situation but are applied here to freshwater only in order to simulate the effects rather than the processes of flocculation. Extending the model to a flowing medium also requires additional information such as the effect of turbulence on the size distribution of sediment flocs. Because such information is non-existent we have made certain simplifying assumptions in order to demonstrate the potential magnitude of error in excluding the flocculation component. We assume that the effect of turbulence is only to promote particle collision and not floc breakage. Also, the flow field is in the depositional regime, i.e. the regime in which only sedimentation occurs but not resuspension. Both assumptions are reasonable for a flow with low turbulence intensity.

We applied this model to a stretch of the Grand River near Kitchener, Ontario, for which the hydraulic characteristics are documented (Krishnappan & Lau, 1982). An hypothetical sediment with the size distribution of a dispersed sediment enters the Grand River from a small tributary (Figure 1). Sediment transport, downstream of Transect #1 is predicted by specifying an initial concentration distribution across the river at Transect #1. Model prediction is based on (1) primary particle transport in unflocculated form, and (2) in flocculated form. The predicted lateral distributions of suspended sediment are illustrated in Figure 1 and the calculated downstream sediment flux in Figure 2.

- approx. here for Figures 1 and 2 -

It is readily apparent that the predicted behaviour of the cohesive suspended material is radically different if one assumes flocculation. Whereas unflocculated material is largely transported through the reach, flocculated material is virtually entirely deposited over a distance of 713m. Given that there is, in practice, no net change in suspended sediment concentration in rivers over lengthy reaches (in the absence of tributary inputs), these

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results raise additional important questions about the nature of interactions between suspended sediment and the bed. Also, our observations in other river systems of systematic reductions in sediment metal chemistry in the downstream direction imply that there is particle replacement occurring during transport.

According to Partheniades (1977), there cannot be deposition of flocculated sediment and resuspension of fine sediment at the same location for any given flow (shear) condition. Moreover, Partheniades considers that strong flocs can settle through the shear layer whereas weak flocs will be broken and the constituent components resuspended. Alternatively, Lick (1982) hypothesizes that deposition and resuspension can occur simultaneously. If the spatial variability of bed shear is such that areas of deposition and resuspension are small and randomly distributed along the bed, the practical differences between these two models are inconsequential. Alternatively, if flocs are relatively homogeneous in size and strength (as per our initial data) and respond primarily to major variations in shear stress that correspond to riverbed geomorphology, the Partheniades model would lead to a type of contaminant focusing within specific areas of the bed. Lick's hypothesis would lead to a more uniform distribution of contaminated sediment along the river bed. The difference between these two hypotheses has implications both for the nature of the downstream continuum of contaminant transport, as well as ecological impacts where contaminants are focused into localised areas.

Other consequences of particle/bed interactions relate to the role of periphyton and benthic invertebrates in biochemical cycling. Carey et al.

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(1984) suggest that periphyton plays an important role in cycling certain organic compounds such as chlorophenols. Our unpublished data on organic contaminant transport in the North Saskatchewan River demonstrates an inability to track compounds downstream during Lagrangian (time-of-travel) sampling, suggesting that physical or biochemical mechanisms are at work which eliminate or store the chemicals in the system. Although these in-river processes are poorly known, the nature of supply of chemically enriched fine-grained sediments to the biotic complex living at the sediment-water interface may prove to be important to biodegradation processes that lead to in-situ decontamination.

### TOXICITY OF SUSPENDED FINE PARTICLES

Although there has been much research on toxicity of bed sediments, there has been relatively little work in the field of suspended particles. As we note above, not only are fine sediments extremely important as a transport vector, they are also likely to be important in the biochemical cycling of contaminants by riverine organisms. Using bioassays on large volumes of raw water and on suspended and bed sediment, Ongley <u>et al</u>. (1988) demonstrated that most of the observed toxicity in the North Saskatchewan River during their summer sampling period was associated with the suspended sediment fraction.

Preliminary data from the Yamaska River (Table 1) indicate that toxicity, as measured by Microtox, is greatest (EC50 = 4.62) for the dominant size class.

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We also find that this size class has the highest bacterial densities and the largest amount of particulate organic carbon and nitrogen. Although Droppo (1989) was unable to analyse chemical and bacterial data by floc size class in 16 Mile Creek, he inferred a relationship between flocculated material, bacterial densities and particulate organic carbon. Bacteria are one of many biological contributors to biodegradation of contaminants. It remains to determine whether flocculated particles, because of the apparently high bacterial densities associated with the flocculation process, play a significant role in biotransformation of sediment-associated (organic) contaminants during downstream transport.

### CHEMICAL PARTITIONING ON SUSPENDED SEDIMENT

Adsorption to suspended solids and sediment is the most important distribution pathway in aquatic ecosystems for many chemicals. Nevertheless, and despite simplifying assumptions and operationally-defined extraction schema by chemists and chemical modellers, the nature of chemical partitioning under <u>in-situ</u> environmental situations remains poorly understood, especially for organic contaminants. Chemicals may bind to mineral surfaces or to organic material of either biotic or abiotic nature, or to both types of substrates. The nature of the binding may be through ionic attraction or exchange in the case of metals and charged organic species, or by solution in the organic matter "pool" of suspended solids and sediments in the case of lipophilic chemicals (Baughman & Lassiter, 1978; Karickhoff et al., 1979, Karickhoff, 1981).

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Quantitative measures of the extent of adsorption of chemicals from solution to surfaces are developed from earlier work on physical chemistry in the field of gas adsorption to surfaces -- e.g. the well-known Langmuir adsorption isotherm. The commonly used Freundlich isotherm (Moore, 1962) has no theoretical significance and predicts an ever-increasing adsorption with increasing solute concentration. Moreover, no fundamental significance can be attached to the constants in the Freundlich equation. Simple equilibrium processes often best describe the distribution between the "dissolved" and sediment-associated phase of many lipophilic chemicals at trace concentrations in water. However, the "dissolved" phase is operationally defined as that which passes a 0.45um filter, or that which passes through a continuous-flow centrifuge. Yet, it is recognised that lipophilic chemicals in the dissolved phase may be either truly dissolved, bound to soluble macromolecules, or to colloids. Work of Servos & Muir (1989) and others demonstrate that sorption to colloids (dissolved organic carbon or nonsettling particulates) results in an overestimation of the "dissolved" phase as the suspended solids concentration increases.

Because the organic carbon content of suspended solids appears to be the most important consideration in the partitioning process for lipophilic chemicals, Karickhoff (1981) has defined an organic carbon-corrected partitioning coefficient ( $K_{oc}$ ) which is derived from the organic content of the sediment and is related to the octanol-water partition coefficient (Kow) of the chemical in question. However,  $K_{oc}$  was derived for sediment, not for suspended solids, and the accuracy with which it applies to aquatic systems is not

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clear. Nevertheless, assuming  $K_{oc}$  generally applies to suspended solids, we can use Karickhoff's equations to calculate (Figure 3) the proportion of the chemical that is partitioned to the suspended solids under differing suspended solids concentrations and for different values of  $K_{ow}$  ( $K_{ow}$  is well-known for most environmentally important chemicals). Most chemicals of environmental interest have log  $K_{ow}$  values between 2 and 7. Examples are:

Atrazine 2.6	Lindane 3.9
Hexachlorobenzene 5.2	DDT 5.8
chlordane 6.0	Mirex 6.9
various PCB's 5-7	

#### - Approx. here for Figure 3 -

Figure 3 indicates for waters of relatively low suspended solids concentrations such as those of the Great Lakes, that even though relatively lipophilic chemicals with log  $K_{ow} = 3 - 7$  may be concentrated in suspended matter, the bulk of the chemical will be in the "dissolved" phase. In river systems of temperate continental areas, the bulk of the annual sediment transport occurs during very short periods of time when discharge and sediment concentrations are high. At such times, the majority of the chemical transport will be associated with the solid phase; nevertheless, annual loadings must factor in potentially large "dissolved" loads transported over the rest of the runoff period. In such calculations and ensuing discussions of annual environmental significance, the temporal variability of the source conditions

that control release of the chemical into the aquatic system (e.g. point versus diffuse sources) becomes highly significant.

Another difficulty in predicting chemical transport is the uncertainty in values of rate constants that are assumed in transport models. Most models assume equilibrium conditions; nevertheless, the kinetic processes that lead to sorption and desorption equilibria are not well known for metals or for lipophilic organic compounds. Lau et al. (1989) showed that periods of hours to days may be required before equilibrium is established between the dissolved and sediment-bound phases for selected chemicals in the Detroit and St. Clair Rivers. Theis et al. (1988), in resuspension experiments for selected sediment-associated metals, determined that desorption equilibria were strongly influenced by pH, mass transfer, and diffusion phenomena. Young et al. (1987) found that partition coefficients for Cu, Zn and Cr varied widely and that values determined in the water column were different from those in pore water. Moreover, these authors found that desorption was very slow for these metals (>24 days to achieve metastable equilibrium). For contaminant prediction in lakes with long residence times, the rate constants may not be important in practical terms; however, in rivers with transit times typically in the order of days, assumption of equilibrium partitioning may provide quite erroneous conclusions concerning medium of transport, transfer coefficients and rates between environmental compartments (water, sediment, biota), environmental effects that are contingent upon the nature of transport -- e.g. biological uptake by membrane exchange (i.e. fish gills) for the dissolved phase versus ingestion of the sediment-associated phase, and environmental fate.

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### CONCLUSIONS

Managing the environmental consequences of chemicals that are released or by design (e.g. pesticides) requires knowledge of the accidentally transport characteristics of these contaminants. For most metals, phosphorus and lipophilic (organic) compounds, cohesive sediments are a primary transport vector. Our work, and that of others, shows that cohesive sediment transport is not the simple, one-dimensional problem usually portrayed in engineering models. Freshwater flocculation appears to have a profound impact on chemical transport in time and space. Empirical studies of flocculation in riverine environments are, however, few. Important questions of flocculation processes, settling velocities, stability, size, and chemical relationships, remain poorly known. The role of sediment-associated bacteria in flocculation processes seems now to be fairly well documented; however, the role of these bacteria in in-situ biochemical processing is not known. We show that there is the potential for very large errors in transport models if flocculation is not taken into account.

Cohesive sediments have been shown to be the principal transport vector for toxicity in the water column for one major river in prairie Canada; if this is generally true, conventional water monitoring programs which sample small volumes of water, are missing most of the environmentally important chemical information from their data base. Substantial knowledge gaps remain in our understanding of chemical partitioning between suspended and "dissolved" phases, both in sorption and desorption modes. Transport models conventionally

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use equilibria assumptions in pathways and fate modelling. Yet, such assumptions are often invalid and can lead to erroneous conclusions about pathways, fate and effects of environmental contaminants.

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FIGURE CAPTIONS

Figure 1. Predicted distribution of flocculated and unflocculated suspended sediment across the Grand River at successive downstream transects.

Figure 2. Predicted suspended sediment flux along the Grand River.

Figure 3. Partitioning of chemicals of varying lipophilicity between dissolved and adsorbed phases as a function of suspended solids concentration.



Figure 1: Distribution of suspended sediment across the river at different transects



Figure 2: Suspended sediment flux variation along the river



FIGURE 3



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