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Sediment Bound Contaminants in a Remote Northern Delta

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Deltas of major rivers are among the most productive and environmentally sensitive components of riverine systems in cold regions, and are of great hydrological and ecological importance. Much of their productivity stems from the supply of nutrient-rich sediments that rejuvenate in-channel, perched and riparian habitats. Such sediments, however, can also be a source of organic contaminants, and deltas, because of their natural tendency to accumulate sediments, may become retention zones or sinks of these. The objective of this research was to determine the nature of sediment-related organic contaminant deposition in the Slave River Delta, Canada – a remote area that is now experiencing the effects of rapid upstream development. A special focus was placed on the protracted low-flow period that characterizes the winter period during which there should be a significant deposition of fine-grained sediment – size fractions with an affinity to adsorb organic contaminants. Results of an exploratory field program conducted during the 1997 pre-breakup and pre-freeze-up periods support the concept that the under-ice period is a time of significant fine-grained sediment deposition. Moreover, the contaminant load was found to be higher at the end of the winter flow recession rather than in late autumn following the major summer flow events. Comparisons of the observed contaminant levels measured in the delta are also made with those recorded by others in the upstream river that feeds the Slave Delta and in Great Slave Lake downstream of the delta.

Introduction

Deltas are important features of many cold regions rivers: within the Mackenzie River Basin in northern Canada, for example, there are three major deltas. The Peace Athabasca Delta forms at the confluence of two major north-flowing rivers, the Peace and Athabasca Rivers, that have seen rapid industrial development over the last decade (NRBS 1996), and flows through the Slave River to the Slave Delta as it discharges to Great Slave Lake. The Mackenzie Delta is located farther north at the point where the Mackenzie River drains to the Beaufort Sea of the Arctic Ocean.

Deltas are in a constant state of evolution, morphologically and biologically. They are particularly sensitive to alterations in the flow regime that can produce significant changes to overall flow patterns and related sediment transport and deposition. The low-slope energy regime characteristic of deltas favours the retention of the finer-grained sediments (clays and silts) that would typically be transported as suspended or wash load by the concentrated flow in the main channels feeding the deltas. Because such sediments are often important carriers of organic and inorganic contaminants, deltas may also become important retention zones of these and, relatedly, a major source to biological food chains originating in the delta aquatic systems. This has added importance at a broader ecological scale since deltas are often the most biologically productive and diverse portions of large rivers, especially in cold regions.

A recent comprehensive evaluation of upstream development on the Peace and Athabasca River systems has found the presence of a number of organic contaminants related to industrial developments within water, sediment and biota. Contaminants of interest include chlorophenolic compounds (produced primarily in pulp and paper processing plants but also used as disinfectants, biocides, preservatives, dyes and pesticides), PAHs (formed almost exclusively as combustion byproducts of carbon-based fuels such as coal, wood and petroleum), dioxins and furans (formed in the production of other chlorinated compounds and in reactions involving elemental chlorine such as chlorine bleaching of wood pulp) and PCBs (mixtures of high molecular weight industrial products that have been used worldwide in transformer and capacitor oils, hydraulic and heat exchange fluids and lubricating and cutting oils). Various members of these contaminant groups were detected by in-stream surveys, approximately 100 km upstream of the Slave River Delta(McCarthy *et al.* 1997a; 1997b), and by in-lake bed surveys immediately offshore of the delta (Evans *et al.* 1996; Mudroch *et al.* 1992) but no similar research has been conducted directly in the delta. Such research is especially important given the high biological and ecological importance of the delta, particularly to local inhabitants who rely on it for traditional lifestyles (Wrona *et al.* 1996), and the need to manage properly the future development of the overall resources of this northern river system (NRBS 1996).

In view of the above, the major objective of this study was to investigate the presence of industrial contaminants in the Slave River Delta. Given the high costs of organic contaminant analyses and remote northern field surveys, it was necessary to conduct a limited exploratory field survey, strategically focussed on periods when contaminant levels were theorized to be near their potential maximum. Hence, it was decided to assess specifically whether there existed a late-winter seasonal maximum in sediment-bound contaminants, as theorized in the following background descriptions. A second objective was to compare the level of any detected contaminants to that previously reported by the adjacent in-river and in-lake surveys.

Background

Delta-Forming Processes

Deltas typically form at mouths of rivers at the point where stream velocity decreases rapidly and particulate material carried either as bed load or suspended load is deposited in lakes or seas. The active delta comprises a complex array of serpentine distributary channels, natural levees, crevasse splays and interdistributary basins including swamps, marshes and lagoons. Delta-forming processes are complex and dynamic, and the rate of delta advance is dependent primarily on fluvial and shoreline processes (erosion and deposition), the nature of transported and deposited sediments, structural basin topography (land subsidence and isostatic rebound) and climatic factors affecting vegetative growth and sediment trapping (*e.g.* Axellson 1967; Mollard 1981).

The evolution of a delta alters the hydraulic characteristics of a river, especially a reduction in the river's capacity to form alluvial channels and an associated reduction in sediment transport capacity. A reduction in river efficiency affects the sediment transport capacity of distributary channels, resulting in sandbars, cleavage and wave-built bars that form preferentially at the mouths of the largest channels. Significant bar formation at the delta front can cause distributary channels to lengthen, thereby reducing bed slope and sediment transport capacity (Mollard 1981). This reduced channel efficiency can lead to greater sediment deposition, overbank flooding and development of natural levees, new channel formation, and distributary channel splitting or closing.

Ice-Affected Sediment Transport

Although a number of advances have been made in our understanding of the physics and hydraulics of particles in motion (*e.g.* Graf 1984), the processes affecting motion and transport and the interaction between streamflow and sediment transport are often poorly understood or difficult to treat with mathematical certainty. This is particularly true for complicated distributary systems of river deltas (Simon and Sentürk 1992), especially those significantly affected by floating ice – a major feature of northern river deltas.

In general, a stable ice cover changes flow hydraulics primarily by increasing resistance to flow as the wetted perimeter and undersurface roughness of the ice cover increases, and cross-sectional area decreases (Michel *et al.* 1986). These changes in channel hydraulics can influence in-stream velocities that affect the beginning of motion and deposition processes. For example, a river-ice cover effectively acts as an additional flow boundary that produces a parabola-shaped velocity distribution: one characterized by zero velocity at the channel bed and base of the ice cover, and maximum velocity somewhere between them, the exact point depending on the relative roughness of the two boundaries (Lau 1982). Similarly, shear stresses increase linearly from the point of maximum velocity towards the upper and lower boundaries. Accompanying these changes in velocity and shear-stress parameters are alterations to mixing parameters such as vertical diffusivity and longitudinal dispersion – major mechanisms for spreading of dissolved and suspended substances. Both are believed to decrease under an ice cover, although field data are relatively meagre (Beltaos 1994). More importantly, while some research has been conducted on sediment transport under ice (*e.g.* Lau and Krishnappan 1985; Lawson *et al.* 1986; Sayre and Song 1979) and at breakup (*e.g.* Beltaos *et al.* 1994; Milburn and Prowse 1996; Prowse 1993) there is limited research on under-ice sediment deposition and retention, especially in river deltas. While under-ice transport capacity is generally unknown, it is reasonable to assume that hydraulic conditions characterizing this period will favour deposition and retention of fine-grained particles that would remain in suspension for equivalent open-water discharge. Hence, a significant quantity of fine-grained sediments should accumulate by the end of the protracted under-ice period, prior to the rising of flows that precede spring break-up of the river-ice cover.

Environmental Contaminants

Within aquatic systems, environmental contaminants are distributed among sediment, water and biota, but the greatest concentration of many elements is found in bed- and suspended-sediments. Moreover, there is a strong correlation between increasing contaminant concentration and decreasing particle size (*e.g.* Combest 1991; Horowitz 1991; Horowitz and Elrick 1988; Luoma 1989; Ongley *et al.* 1988; Warren and Zimmerman 1993). Environmental contaminants can enter aquatic ecosystems through a number of pathways, but direct discharge from industrial and other land use activities, and atmospheric deposition are the most common (Barrie *et al.* 1997; Gregor 1992). The processes affecting contaminant transport are complex and generally poorly understood, but it is known that a range of these contaminants are generally widespread in arctic aquatic ecosystems and are being transported through rivers and the atmosphere (*e.g.* Barrie *et al.* 1997; Gregor *et al. 1996*; Lockhart *et al.* 1992). Because many contaminants resist photolytic, biological and chemical degradation, and because growth rates of aquatic organisms in cold regions are low and higher trophic level animals are long lived, there is considerable potential for a greater lifelong accumulation of environmental contaminants in cold-regions aquatic ecosystems than in more temperate regions. These sediment-bound contaminants can accumulate in various hydrologic pathways, deltas, logically being a major sink. Maximum retention should be greatest in distributary channels or other areas known to be preferential deposition zones. Furthermore, as with the assumed over-winter accumulation of fine-grained sediments, it is hypothesized that late-winter should be characterized by a relative peak in contaminant levels.

Site Description

The Slave River Delta (Lat. 61 16'; Long. 113 32') is located at the mouth of the Slave River – a large regulated north-flowing river. It has been described in its broadest sense as a 170 km long, narrow alluvial plain extending from Slave River Rapids at Fort Smith to Great Slave Lake and covering a total surface and submarine area of 8,300 km^2 (Vanderburgh and Smith 1988). Only 400 km^2 of this area is considered active and significant channel bifurcation has resulted from flooding, sedi-

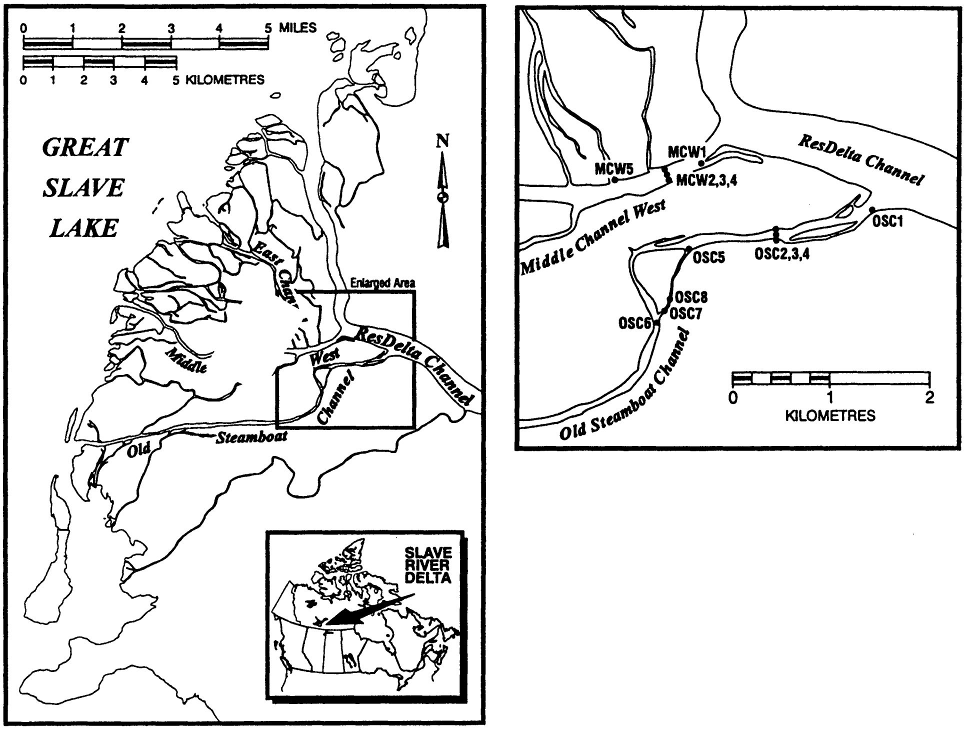

Fig. 1. The Slave River Delta, Northwest Territories, Canada. Enlarged area shows sampling locations for two field programs. Stations OS7 and MCW5 represent replicate sites; that is, they were sampled on both occasions.

ment accumulation and erosional influences of Great Slave Lake (English *et al.* 1996). Fort Resolution, with a population of 500 people, is located at the western edge of the delta and is the only community within several hundred kilometres.

The Slave River at Fitzgerald, Alberta, (Lat. 59 20'12"; Long. 111 35'00") has a mean annual flow of 3,400 m^3/s and a total mean annual discharge of 107 million dam^3. The maximum instantaneous discharge of 8,830 m^3/s was recorded on June 4, 1990 (Department of the Environment 1997). This station, located 415 kilometres upstream of the delta, is the only hydrometric gauge site on the Slave River. The period of ice cover on the Slave River at this site ranges between 173 and 203 days or approximately half the year. Typical pre-breakup and pre-freeze-up discharges are 2,200 m^3/s and 2,600 m^3/s respectively (Department of the Environment 1997)

Although the major tributary to the Slave River, the Peace River, has been controlled by a large dam since 1968, significant inter-annual variability in discharge still occurs – much of it due to tributary inflow downstream of the point of regulation. Notably, however, regulation has resulted in a post-regulation mean peak discharge of approximately 5,000 m^3/s compared to the pre-regulation peak discharge of approximately 7,500 m^3/s (Fig. 2). This reduction in peak discharge reduces sediment transport capacity and consequently, increases the sediment deposition potential. Upstream of the Slave River Delta, significant changes to river morphology and riparian processes have been observed on the Peace River and in the Peace-Athabasca Delta (*e.g.* Carson and Hudson 1997; Church 1995; Prowse and Conly 1996; Prowse *et al.* 1996). Reduced sediment-transport capacity has led, for example, to enhanced sediment deposition, channel narrowing, abandonment of secondary channels, and in-channel shoaling along the main stem of the Peace River.

Some related changes of flow regulation have been observed in the Slave River Delta (English *et al.* 1996). Annual sediment loads from the Slave River to Great Slave Lake following regulation were estimated to be 30 million tonnes (MRBC 1981), and Stone and English (submitted) suggest that regulation has reduced annual suspended sediment transport to the delta by 65 per cent. Furthermore, English *et al.* (1996) state that since regulation, bars have continued to form at the mouth of the delta, effectively narrowing channel entrances and reducing input of larger sand size material from the Slave River to the smaller distributary channels. Selective sorting of bed material by grain size seems to be occurring in the smaller channels, and combined with hydraulic changes associated with the stable ice cover, the sediment transport capacity of these channels should be favouring under-ice deposition and retention of fine grained clays and silts.

The main distributary channels of the Slave Delta are ResDelta, East, Middle, Middle Channel West, Old Steamboat and Nagle Channels. The largest of these, ResDelta Channel, has a mean width of 500 metres and depths reaching over 30 metres in some reaches. Mean channel width of some distributary channels of the Delta has changed significantly over the last 60 years (English *et al.* 1996; Hill *et al.* 1997). The cause is a combination of natural processes and flow regulation. ResDel-

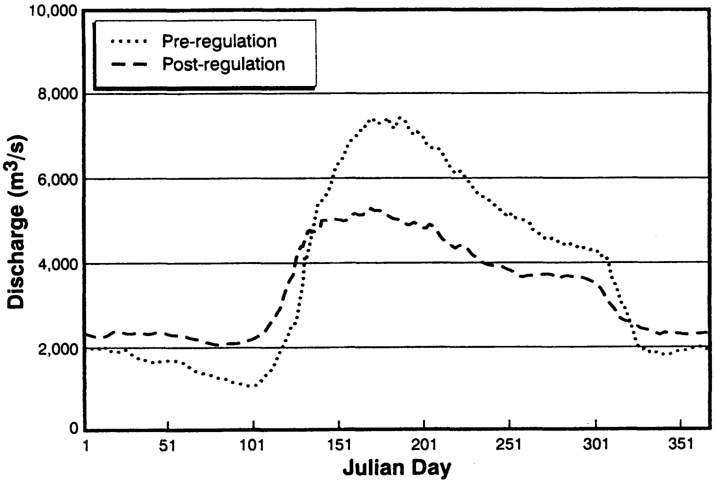

Fig. 2. Mean daily discharge hydrographs, pre- and post-regulation

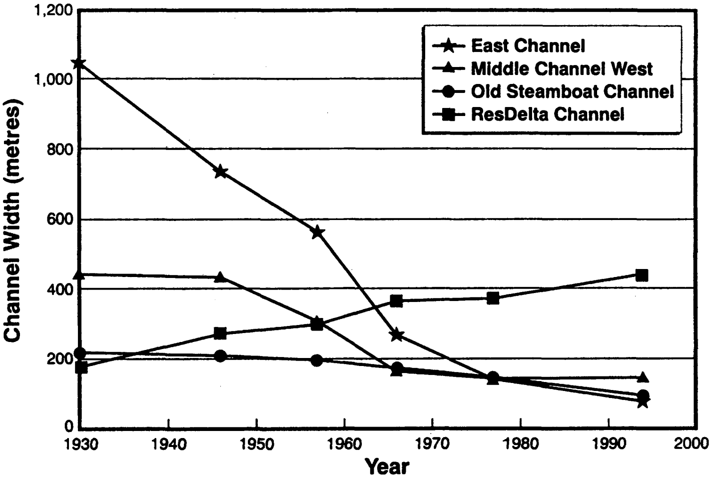

Fig. 3. Mean width of channels in Slave River Delta (adapted from Hill *et al.* 1997).

ta Channel, for example, is increasing in width, while Old Steamboat Channel has decreased in mean width by over 50% since 1930 (Fig. 3). Historical data are not available for any changes in channel depths. Further details on sediment characteristics of the distributary channels are provided in the following section.

Methods

A two-phase, sampling program, conducted in April and October, 1997, was designed to fulfill the research objectives. The original goal of the field program was to obtain pre-breakup (April 1997) and pre-freeze-up (October 1997) bed samples from a number of depositional zones in a range of distributary channels of the Slave Delta. These samples were to form the basis for quantifying basic temporal and spatial trends in composition and contaminant characteristics of deposited sediments. Unfortunately, however, logistical difficulties including remote access to the sites, river-ice conditions and long distances between sites precluded completion of the full sampling program. Therefore, a more strategic approach was used to select sampling sites that represented key depositional zones in two morphologically different delta channels at two seasonal extremes.

The two distributaries selected for study were Old Steamboat and Middle Channel West, both of which have some specific geomorphic characteristics that favour fine-grained particle deposition. For example, sills at the channel entrances, resulting from sharp decreases in water depth, form effective barriers for coarse sediment grains for most of the year and fine-grained material is preferentially transported to the distributary channels. The water depth of Old Steamboat Channel at the entrance is just over two metres, whereas ResDelta Channel just before Old Steamboat Channel ranges between seven and ten metres. Similarly, the entrance to Middle Channel West is less than six metres, while ResDelta Channel, just before the entrance to Middle Channel West, has a depth between 10 and 20 metres.

To characterize further the transport capacity of these channels, hydrometric measurements were taken in March, 1997, one month prior to the pre-breakup sampling program. Results show that both channels are primarily rectangular in form. Old Steamboat Channel at a location one kilometre downstream from its entry point from ResDelta Channel has a width of 59 metres and a mean depth of 0.9 metres. Mean under-ice velocity was 0.2 m/s and discharge was computed to be 12 m^3/s. Middle Channel West, at a location one kilometre from ResDelta Channel, has a width of 150 metres and mean depth of 3.3 metres. Discharge was 151 m^3/s, or over an order of magnitude greater than Old Steamboat Channel. Mean under-ice velocity was 0.3 m/s.

Although both distributaries have specific sediment deposition zones, they contrast in their sediment transport capacity as evidenced by the flow they carry. Based on some limited discharge measurements taken in 1978-80, ResDelta Channel was shown to account for approximately 90% of under-ice (1,945 m^3/s) and open-water (2,974 m^3/s) discharge. The second largest channel was Middle Channel West which carried approximately 5% of the open-water and under-ice discharge. Flow through Old Steamboat was approximately 1/3 of that in Middle Channel West. Although these channels have undergone some subsequent morphological change (*e.g.* English *et al.* 1996; Hill *et al.* 1997), they are still main distributary channels of the delta.

Sampling on the two channels was conducted just prior to breakup and freeze-up. The latter period occurs in the autumn recession of the hydrograph after the major summer flow events and just prior to freeze over of the river. As such, it represents the end of the period of maximum sediment mobilization and transport, and the beginning of a protracted period of under-ice sediment deposition. Pre-breakup sampling was undertaken at the annual low point in the hydrograph prior to the rising flows that cause river-ice breakup. It represents the period of lowest flow, minimum instream turbulence and bed shear stress, and the end of an almost 6-month steady recession in flow and accumulation of sediments.

In both distributaries, a set of up to six bed samples for each sampling period was obtained from a number of assumed depositional locations, one of each being from the exact same depositional feature and herein referred to as the replicate locations (OSC7 and MCW5). All samples were collected using an Ekman dredge designed to remove and keep intact the top layer of bed sediments. Although this layer may represent multi-year layers of sediment, it was reasoned that if a significant quantity of fine-grained material was deposited during the low-flow winter period, and even though it would be regularly removed by higher flows during the break-up and open-water periods, its presence should be evident in size differences between the seasonal range of samples. Furthermore, from a multi-year perspective, the quantity of fine-grained material measured in the end of winter sample should be considered a conservative estimate of total multi-year deposition because it most likely represents only a single-season accumulation, compared to the multi-year heavier material that remains after the main summer flow period.

All sediment samples were analysed for particle size distribution by Taiga Environmental Laboratory, Yellowknife, Canada, using a Malvern Mastersizer. Dioxin and furan analyses were conducted by Wellington Laboratories, Guelph, Canada according to USEPA (United States Environmental Protection Agency) Method 1613. Other analyses for organic contaminants were conducted by Water Technology International Corporation, Burlington, Canada using in-house methods based on USEPA methods as follows: Chlorophenolics- Method for the Analysis of Chlorophenolics in Solid Samples using Direct Acetylation; Base/Neutral And Acid Extractables-Method for the Analysis of SemiVolatile Organic Compounds by GC/MS (modified from USEPA SW846 Method 8270); and Pesticides and PCBs-Method for the Analysis of Polychlorinated Biphenyls and Organochlorinated Pesticides in Solids (modified USEPA SW846 Method 8080).

Results

Physical Characteristics

Although the number of samples that could be collected in this initial exploratory study was small and therefore not suitable for rigorous statistical comparison, a number of obvious spatial and seasonal contrasts were observed in the data. As hy-

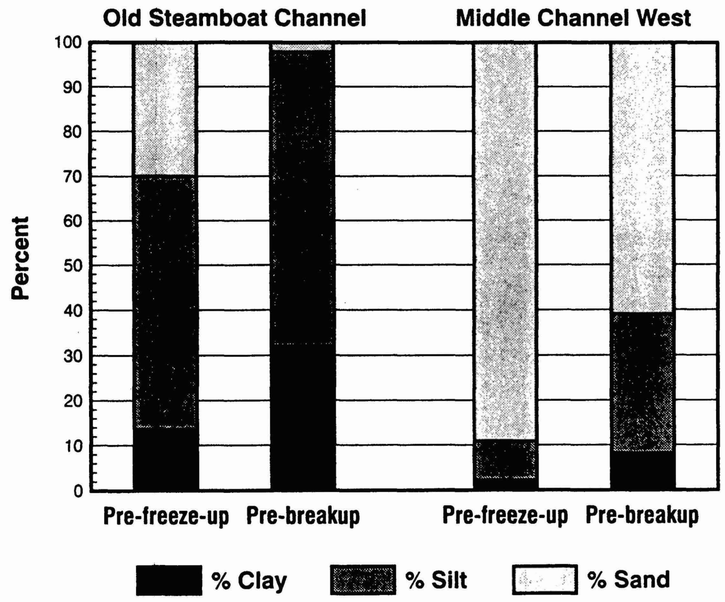

Fig. 4. Comparison of clay, silt and sand fractions in the replicate pre-freeze-up and pre-breakup samples at Old Steamboat Channel and Middle Channel West.

Table 1 – Summary of Physical Characteristics of Bed Sediment Samples

	Pre-breakup			Pre-freeze-up		
Location	% clay	% silt	% sand	% clay	% silt	% sand
OSC1				19	61	21
OSC2	33	24	44			
OSC3	25	26	49			
OSC4	37	26	38			
OSC5				10	59	32
OSC6	40	49	11			
OSC7	32	66	2	14	56	30
OSC8	35	65	0			
Mean	34	43	24	14	59	27
MCW1				8	47	45
MCW2	13	60	27			
MCW3			100			
MCW4	3	23	74			
MCW5	8	31	61	2	9	89
Mean	8	38	65	5	28	67

pothesized, the bed samples collected at the replicate sites in April, 1997 and October, 1997 in Old Steamboat Channel (OSC7) and Middle Channel West (MCW5) showed a higher proportion of clays and silts in the pre-breakup samples (Fig. 4). In Old Steamboat Channel, the smaller distributary channel, clays and silts account for almost 98% of the bed particles in the pre-breakup sample compared to 70% in the pre-freeze-up sample. Although not as striking, the pre-breakup sample in Middle Channel West contained 39% clays and silts compared to 11% in the pre-freeze-up sample.

Similar differences between sampling sites and periods are evident in all the sediment samples (Table 1). Despite the sample size, there is a significant difference (at a 95% level) in pre-breakup and pre-freeze-up fractions of clays in Old Steamboat Channel. Although the mean proportions of clay and silt in the pre-freeze-up and pre-breakup samples are similar (73% and 77% respectively), the clay fraction in the latter period is significantly (95% confidence level) greater (34% and 14% respectively). A similar pattern is found in Middle Channel West, where the proportions of clays and silts are higher in the pre-breakup samples (46% compared to 33% in pre-freeze-up). Interestingly, silts are higher, but not significantly, in the pre-freeze-up sample in Old Steamboat Channel but not in Middle Channel West.

Overall, the physical characteristics described above support the assumptions made about expected spatial and temporal differences in delta sediment deposition. In general, sediment composition in Old Steamboat Channel tends to be finer than Middle Channel West for both seasons. The physical results also confirm that the selected sampling sites are suitable for assessing the existence of temporal and spatial differences in sediment-bound organic contaminants.

Contaminants in Bed Sediments

The four contaminants of interest in this research were detected in all bed samples collected in Old Steamboat and Middle Channel West for both sampling periods. Distinct seasonal contrasts are also evident in the data for the replicate sites (OSC7 and MCW5) from the two distributaries (Table 2). With the exception of chlorophenolic compounds in the pre-freeze-up sample in Middle Channel West (MCW5),

Table 2 – Comparison of concentrations of contaminants of interest at the replicate stations (at the same sampling location) in Old Steamboat Channel and Middle Channel West.

	Old Steamboat Channel (OSC7)		Middle Channel West (MCW5)	
	Pre-breakup	Pre-freeze-up	Pre-breakup	Pre-freeze-up
Chlorophenolics (ng/g)	24	20	24	68
PAHs (ng/g)	460	20	140	130
Dioxins/Furans (pg/g)	19	6	3	3
PCBs (ng/g)	130	50	276	31

Table 3 – Summary of mean concentrations of contaminants of interest for all samples collected in Old Steamboat Channel and Middle Channel West.

	Old Steamboat Channel		Middle Channel West	
	Pre-breakup (n=6)	Pre-freeze-up (n=3)	Pre-breakup (n=4)	Pre-freeze-up (n=2)
Chlorophenolics (ng/g)	30	20	38	63
PAHs (ng/g)	224	60	155	130
Dioxins/Furans (pg/g)	27	13	11	4
PCBs (ng/g)	309	133	252	109

concentrations of all the other organic contaminants are consistently higher in the end of winter pre-breakup samples. The largest differences are seen for PAHs and dioxins/furans in Old Steamboat Channel and PCBs in both channels.

A comparison of mean concentrations of all samples shows similar temporal and spatial patterns (Table 3). With the exception of chlorophenolic compounds in Middle Channel West, mean concentrations of organic contaminants in bed sediments sampled prior to breakup are higher than in the pre-freeze-up period. The reason for the higher chlorophenolic compounds in the pre-freeze-up samples is not readily evident, but it could be related to atmospheric deposition during open-water conditions. Higher overall concentrations of PAHs, dioxins and furans, and PCBs in Old Steamboat Channel also suggest that a spatial pattern of sediment-bound organic contaminant deposition exists whereby smaller distributary channels tend to retain these contaminants.

Discussion

The above results support the general hypothesis that low-flow ice-covered conditions favour the deposition of fine-grained clays and silts, particularly within the smaller, slower moving distibutaries. A similar seasonal trend is evident for a number of important organic contaminants known to adsorb preferentially to fine-grained sediment. From a broader catchment perspective, it is useful to compare these results with other recent research conducted on the Slave River-Great Slave Lake system. In recent years, regular suspended-sediment sampling (high-volume centrifuge) was conducted on the main stem of the Slave River, approximately 100 km upstream of the delta, to develop a baseline of instream contaminants (McCarthy *et al.* 1997a). Cores were also taken from the bed of Great Slave Lake to assess the long-term accumulation of contaminants on the lake bed (Mudroch *et al.* 1992; Evans *et al.* 1996). Results from these studies are summarized with the data from this investigation in Table 4.

Table 4 – Comparison of results with other research (mean values reported; highest concentrations are shown in bold)

Location	Chlorophenolics	PAHs	Dioxins/Furans	PCBs
Fort Smith[1] (centrifuge)	21	**668**	7	not detected
Old Steamboat Channel (pre-breakup)	30	224	**27**	**309**
Old Steamboat Channel (pre-freeze-up)	20	60	13	133
Middle Channel West (pre-breakup)	38	155	11	252
Middle Channel West (pre-freeze-up)	**63**	130	4	109
Great Slave Lake[2]	not analysed	not analysed	not analysed	5
Great Slave Lake[3]	0	639	2	10

[1] McCarthy *et al.* 1997a

[2] Mudroch *et al.* 1992 (value reported is top of core section)

[3] Evans *et al.* 1996 (organochlorines only, which includes chlorophenolics)

Notably, with the exception of PAHs, concentrations of chlorophenolic, dioxins/furans and PCB contaminants in bed samples of the two distributary channels of the Slave Delta are markedly higher than those in the main-stem suspended-sediment or lake-bed samples. In the case of PAHs, McCarthy *et al.* (1997a) found that levels were significantly higher in the open-water period ($\bar{x}$ =796 ng/g, n=12) than during the winter ($\bar{x}$=8.5, n=2, January to March). This marked seasonal variation is probably attributable to runoff of atmospherically-deposited PAHs resulting from summer forest fires (*e.g.* de March, 1997) and should be considered when contrasting the annual average value noted in Table 4 with those from this study.

PCBs were not detected by McCarthy *et al.* (1997a) in any sediment sample collected at the Fort Smith river site over the four-year study period, yet these compounds were found consistently in this research and in the lake sediments reported by Evans *et al.* (1996) and Mudroch *et al.* (1992). Moreover, PCB concentrations in the distributary channels are over an order magnitude higher than those in the lake bottom sediments in Great Slave Lake. McCarthy *et al.* (1997b) did detect PCBs in fish in the Slave River but concluded that levels were consistent with ranges and concentration seen in other fish in the Arctic. One possible explanation for the finding for non-detectable PCBs in the suspended sediment samples at Fort Smith is that there is a point source located downstream of their sediment sampling site. A long-range transport atmospheric input does not seem plausible because measurable levels should show some consistency in detections. Further examination of this discrepancy is warranted.

In some cases, differing sampling methodologies and changes in analytical accuracy (detection limits) amongst the above studies conducted in the Slave River-Great Slave Lake system make intercomparisons and statistical analyses difficult.

The best example is in the comparison of PCB data. As noted by McCarthy *et al.* (1997a) changing analytical detection limits over the course of their four-year study resulted in the upper value of a "non-detect" ranging from 5 to 300 ng/g. By comparison, all but one PCB sample collected in this study fell within this earlier "non-detectable" range. There may have also been problems with an underestimation of the contaminant load because of the type of suspended-sampling equipment used. Specifically, samples collected by centrifuge preferentially capture only the finest sediment particles and may not, therefore, be truly representative of the total sediment-bearing contaminant load. In this case, a better indication of the potential load is probably provided by the accumulated bed samples. Notably, however, the order-of-magnitude difference in delta (this study) and lake (Evans *et al.* 1996; Mudroch *et al.* 1992) bed samples also points to the need to consider the effects of load distribution.

Conclusions and Future Research

This unique and exploratory study of one of Canada's remote northern deltas has confirmed that the approximately six month under-ice period of low flow leads to a winter seasonal maximum in the accumulation of fine-grained sediments – larger than that occurring at the end of the open-water period. Although the data set was too small to define overall spatial patterns, as expected, the greatest percentage of the finer fractions accumulated in the slower moving distributary channel.

The results also displayed matching spatial and temporal trends in sediment-bound contaminants. The levels of some were found to be higher that those previously observed on the main stem of the river that feeds the delta and in the sediments of the lake below the delta. There are difficulties, however, in analyzing for some contaminants because of the rapidly changing detection levels afforded by new analytical methods.

Based on the results of this initial study, it is recommended that future field explorations for organic contaminants on this river system should focus specially on sampling of the delta system – not only because of its apparent capacity to retain fine-grained sediments but also because of its high biological sensitivity. Where resources permit, sampling should be conducted on a broader spectrum of distributary channels and on more replicate sampling including the use of sediment traps. Regular seasonal sampling should be conducted, there should be a special focus on sampling of under-ice sediment accumulation. Although the flux of suspended sediment may be relatively small during the winter, the protracted period of ice cover can lead to significant accumulations of fine grained sediment. This is a period that has been previously overlooked by aquatic contaminant surveys but one that, based on the results of this study, should be a major focus of future surveys. It is important to stress, however, that sampling must occur before the late-winter rise in flow that precedes breakup. Increases in bed shear stress associated with increasing discharge will resuspend the fine-grained material and the associated contaminants within a very short period compared to the long-winter interval that leads to its accumulation. Given the potential for this initial plume of sediments to contain a seasonal load contaminants, future studies of its bio-physical fate and effect are also recommended.

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