LONG TERM FATE OF DREDGED SEDIMENTS AT ILE MADAME DUMPING SITE (ST. LAWRENCE ESTUARY) : A BASIC ASSESMENT

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ABSTRACT
The long term fate of the dredged sediments dumped at the Ile-Madame disposal site is assessed on the basis that the texture and mineralogy of the dumped sediments is different from that of the sea floor and the tendency of the dumped sediments to form sand dunes that are outlined on sea floor imagery. The correspondence between the total volume of dumped sediments and the estimated volume of the assumed dispersal cone is verified. This approach leads to conclude that the dispersal cone is elongated and extends over a distance of 14 km with an average width of 1 km.

RÉSUMÉ
L'évolution à long terme des sédiments de dragage déversés au site de dépôts de l'Ile Madame est évaluée en considérant que la texture et la minéralogie des sédiments déversés diffère de celles qui recouvrent le fond marin de même que la tendance des sédiments dragués à former des dunes mises en évidence par l'imagerie numérique du fond marin. L'adéquation entre le volume total de sédiments dragués et le volume estimé du cône de dispersion est vérifiée. Cette approche amène à conclure que le cône de dispersion est allongé et se prolonge sur une longueur de 14 km et une largeur moyenne de 1 km.

1. INTRODUCTION

This paper is part of a multidisciplinary project aimed at assessing the impact on habitat of juvenile Atlantic sturgeon (*Acipenser oxyrhinchus*) and lake sturgeon (*Acipenser fulvescens*) of the disposal of dredged sediment in the St. Lawrence River upper estuary (Munro, 2000). The study area is located 30 km downstream from Quebec City at the upper reach of the salt wedge of the St. Lawrence Estuary (Fig. 1). The dredged sediment disposal site X-01, located S of Ile

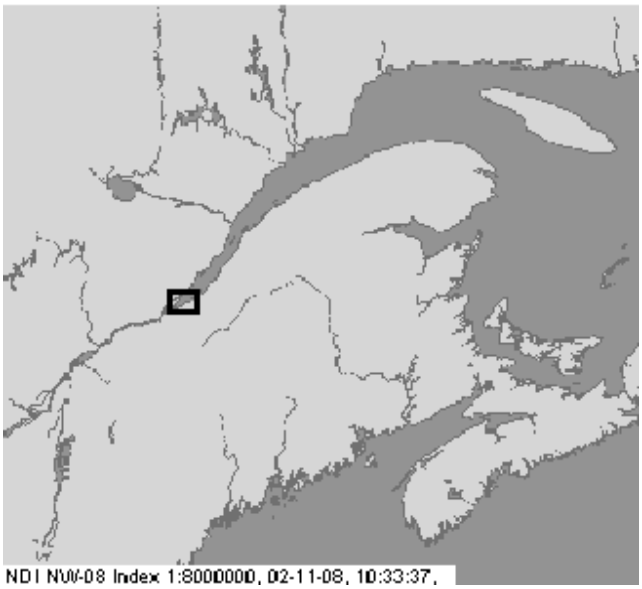

Figure 1. Location map. The study area is identified by a rectangle.

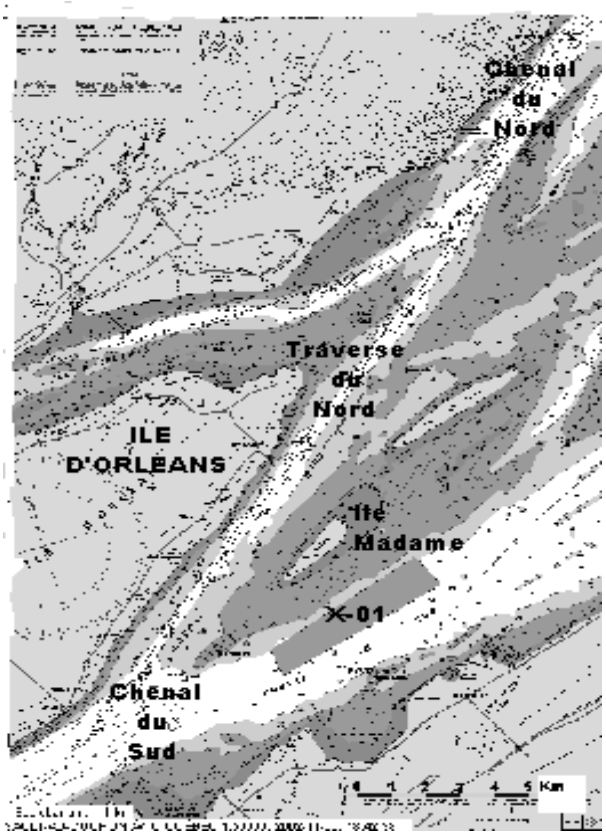

Figure 2. Map of the study area. The dump site is the rectangle south of Ile-Madame identified X-01. A kilometer scale appears in the lower right corner.

Madame (Fig. 2), is one of three disposal sites used since 1971 to dump sediment dredged from the Traverse-du-Nord, a 31 km long and 300 m wide navigation channel E of Ile d'Orléans between Chenal-du-Nord and Chenal-du-Sud (Fig. 2). The Traverse-du-Nord was initially dredged to a depth of 7.6 m (25 ft) between 1912 and 1927, and a depth of 10.7 m (35 ft) was reached by 1937 (Marine Hydraulics Branch, 1969). Deepening the channel to its actual depth of 12.5 m below normal lowest low tides (NLLT) took place between 1971 and 1974. Three new disposal sites were designated at that time: Ile-Madame (X-01), Cul-de-Sac and Sault-au-Cochon (Fig. 2).

The long term fate of the dredged sediments dumped at the Ile-Madame disposal site is assessed on a simple approach. One criterion used to identify the dispersal pattern of the dumped sediments is that the sediments dredged from the navigation channel have a texture and mineralogy different from that of the sea floor in the area of the disposal site. Another characteristic is that deposited sediments have a tendency to form sand dunes on the sea floor. And finally, the correspondence between the total volume of sediments deposited on that site and the estimated volume of the sand dunes is verified.

2. HYDRONAMICS

Semidiurnal tides are the dominant phenomenon in this portion of the St. Lawrence Estuary. The tidal range in the study area is 6.6 m for large tides and 4.5 m for mean tides (Department of Fisheries and Oceans, 1999). In the Traverse-du-Nord tidal currents reach 150 $cm \cdot s^{-1}$, and exceed 100 $cm \cdot s^{-1}$ 50 % of the time (Department of Fisheries and Oceans,1997). A current meter moored during one month at Ile-Madame disposal site showed that current direction measured on the site does not show the circular pattern typical of tidal currents in open water. The tidal currents in the Ile Madame area are lined up with the axis of the estuary . The tidal currents measured 50 cm above the sea floor reach 70 $cm \cdot s^{-1}$ during the ebbing of the tide and 50 $cm \cdot s^{-1}$ during the flood.

3. SEDIMENTOLOGY

Two assemblages of sediments are present on the sea floor in this section of the St. Lawrence Estuary. The "Laurentian" assemblage is a pinkish sand with a dominant grain size of 0.8 mm. Quartz and white feldspar represent some 60 %, pink feldspars 20 %, and dark minerals 20 % of the sediment. The pink feldspar is a mineral characteristic of the Laurentian Precambrian Shield outcropping exclusively on the North side of the St. Lawrence Estuary. The "Appalachian" assemblage is a greenish grey sand and its dominant size is 0.5 mm. This assemblage comprises 70 % quartz and feldspar and 30 % greenish minerals typical of the Appalachian shales, outcropping on the South side of the St. Lawrence Estuary, as well as on Ile d'Orléans, Ile Madame and the surrounding islands of the Montmagny Archipelago.

The sea floor in the Ile-Madame area is covered with the Appalachian assemblage sands. Variable quantities of pebbles are spread erratically on the sea floor, likely dropped by drifting ice (Dionne, 1987). This sand layer covers dense grey clays, the Goldwaith clays, which were deposited during the sea transgression that followed the Wisconsin glaciation, some 12,000 years B.P (Dionne, 1988). The sand layer covering the sea floor in the study area is thin and at many sampling locations the Shipek grab used to sample the sea floor cut through the surficial sand layer and reached the underlying Goldthwait clays.

Sand dunes are present at many locations in this sector of the estuary (Marine Hydraulics Branch, 1969, 1970), especially in the area N of Ile Madame. The strong tidal currents prevailing in this portion of the St. Lawrence Estuary induce hydrodynamic conditions leading to the development of sand dunes that seem to form wherever and whenever the sand supply is sufficient.

4. DREDGED SEDIMENT BUDGET

Between 1911 and 1970 sediments dredged from the Traverse-du-Nord were dumped at approximately one kilometer from the channel sides. Field studies (Marine Hydraulics Branch, 1970) as well as hydraulic models (Hausser et Galiana, 1972) showed that a portion of the dredged sediments were brought back into the channel by the tidal current regime. In 1971, the three new dumping sites (Fig. 2) were designated far enough to prevent any further filling of the channel. The Ile-Madame dumping site was first used when a major deepening of the Traverse-du-Nord to the nominal depth of 12.5 m NLLT was undertaken in 1971. After the deepening of the navigation channel was completed in 1974, the dump site was used for the maintenance dredging. The dredging budget of Traverse-du-Nord since it was first used in 1971 is summarized in Table 1.

Table 1. Dredging Budget (m^3) at Ile Madame Dump Site X-01

Site	Capital (1971-74)			Maintenance (1975-99)
	Clay	Sand	Boulders	Sand
Ile-Madame	2,649,800	3,748,400	133,700	953,900
Cul-de-Sac	531,100	2,472,900	49,100	1,392,200
Sault-au-Cochon	0	274, 800	0	795,800

(Canadian Coast Guard, 2002)

Different types of sediment were dredged when the channel was deepened to 12.5 m NLLT. Clays dredged are the Goldthwait relict clays described above. The boulders are either of glacial origin or dropped by drifting ice.

5. LONG TERM FATE OF DUMPED SEDIMENTS

Clays: A fundamental difference was observed between the sediment samples collected in the fresh water portion of the estuary and those collected in the salt water wedge portion. The upper limit of the salt wedge is only a few kilometers downstream from the dump site (Pellerin, 1975). In the sea floor depressions within the salt wedge reach, the sampled sediments contain loose clays, that are absent within the fresh water portion of the estuary. It indicates that the tidal turbulence in this section of the St. Lawrence Estuary is strong enough to maintain the clays into suspension until they flocculate at the contact of salt water. As no loose clay sediments were sampled at the Ile Madame dump site, located just upstream from the salt water wedge, it is assumed that the clay sediments dredged when deepening the navigation channel between 1971 and 1974, although they were compact and sticky, were eventually eroded, brought back into suspension and transported downstream. The long term fate of these dredged clays would then be that of the fine sediments that form the high turbidity zone within the salt wedge (Kranck, 1979).

Boulders: The boulders dredged during the deepening of the channel obviously remained where they were dumped.

Sand: Because of fine sediment drifting conditions prevailing at the Ile Madame dump site, the dispersal of dredged sediments is then essentially that of the sandy sediments on that site. Table 1 shows that 3,748,400 cubic meters of sandy sediments were dumped on that site during the deepening of the navigation channel between 1971 and 1974.

The maintenance dredging is comprised exclusively of sandy sediments because the strength of the tidal currents keeps the finer sediments into suspension and only sand size material is sedimenting in the navigation channel and needs to be dredged annually. From 1975 to 1999, 953,900 cubic meters of sandy sediments were dredged for maintenance of the channel. Then, the total amount of sandy sediments dumped at the Ile Madame site amounts to 4,702,300 m^3 .

Dispersal of deposited sediments: A first approximation of the dispersal of the sediments dumped at the Ile Madame dump site is based on the sampling of the sea floor sediment. As explained above, the mineralogy of the dredged sediments is different from that of the sea floor in the Ile Madame area; the dredged sediments contain pink feldspars that are absent from the other sediments. It is then possible to distinguish the dredged sediments from the surrounding different sediment and outline the maximum extension of their dispersal.

This approximation is refined using numeric imagery of continuous sea floor mapping surveyed by the Canadian Hydrographic Service in different zones of the study area. Oblique illumination of these images outlines very efficiently the sand dune fields as shown on figure 3. Sediment sampling has shown that the sand dunes covering the sea floor in the Ile Madame dump site are of the same composition as the dredged sediment sands, i.e. Laurentian sands, as exemplified on figure 3. Many more samples were collected in the dump site area, namely in the SW portion where a restricted area is designated to receive sediments from the annual maintenance dredging.

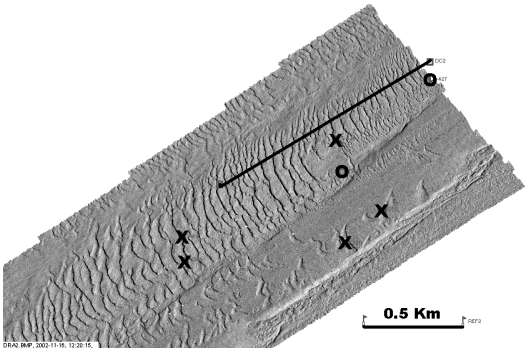

Figure 3. Raster image of the north-eastern section of the dump site (see location on Fig. 4). Dredged sand samples are identified by X and natural sea floor samples by O.

Figure 4. Raster image mosaique of dump site, lower left and adjacent zone, upper right. The dotted line outlines the dispersal cone. Location of figure 3 is is outlined by five "+".

Figure 4 is a mosaic image of continuous mapping surveys of the whole Ile Madame dump site (on the lower left side) and a zone downstream making a slight angle with the dump site. The identification of sand dune fields combined with the sediment sampling has lead to outline the assumed dispersal cone of dredged sediments as delineated on figure 4.

Thickness of dredged sediments: The thickness of the dredged sediments covering the sea floor is assumed to be essentially that of the sand dunes. Figure 3 shows details of a sand dune field spreading on the sea floor of Ile Madame dump site. It also shows that samples of the

natural sea floor were collected occasionally in the troughs and vicinity of sand dunes. These observations lead to infer that the thickness of dredged sediments is essentially that of the sand dunes covering the sea floor in the Ile Madame area.
Echosounder profiles were surveyed in the study area to complement the information on sand dunes. An example is shown on figure 5. This sea floor profile is 1260 m. long and its location is outlined on figure 3 by a straight black line. The profile is running from left to right. The sand dunes on that profile are some 2 m high and the crests are 50 m apart.

Sediment sampling has produced full grabs of dredged sediments on the dumping site and dilution of these sediments as distance increased from the dumping site, indicating the thinning of the dredged sediment cover.

Cubature of dredged sediment dispersal cone: The estimates made in the previous paragraph for the dispersal cone surface area and its thickness are approximate but their accuracy can be improved by confronting the cubature of the described dispersal cone with the known volume of sediments dumped on the site. The dispersal cone outlined on figure 4 has a surface area of some 14,000,000 m^2 . Then, if the volume of dredged sediments is divided by the surface area of the dispersal cone, the average thickness of dredged sediments would amount to 33.6 cm., if they were dispersed evenly on the whole dispersal area delimited on figure 4.

As the dispersal of dredged sediments is not uniform, different scenarios can be proposed. One is that the first 5 km of the dump site would average a thickness of dredged sediments of 50 cm and that it would then gradually diminish to zero over the remaining 9 km as the distance increases from the dumping area. Under these conditions the postulated volume adds up to 4,500,000 m^3, which is close enough from the factual volume within the framework of the present analysis.

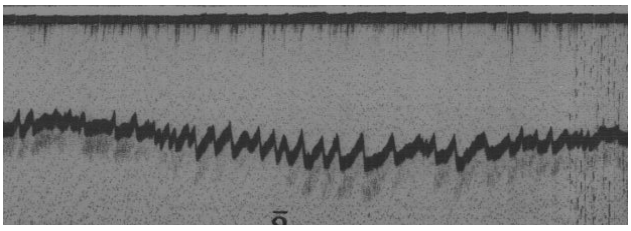

Figure 5. Echosounder profile of dune field. The location of the profile is shown on Figure 3. The profile has a length of 1250 m. The vertical scale is 0 to 20 m.

Remains to verify how these estimates fit with reality . Figure 3 reproduces a detailed image of the north-eastern portion of the dump site. Sand dunes are outstanding but they do not cover the whole area and sediment sampling confirms that the sea floor is not totally covered with dredged sediments. Figure 5 indicates that the higher sand dunes appearing on figure 3 reach a height of 2 m. Assuming that the shape of these dunes is essentially triangular, the quantity of sediments that builds the dune fields at that height is equivalent to a uniform sediment blanket half the sand dune height, that is the thickness of one meter in this case. Considering that the sand dune coverage is not total, the guess of 0.5 m as an average thickness for the whole dump site is quite reasonable. As for the postulated diminishing thickness of dredged sediments downstream, it is in concordance with the smaller dune size and the bottom sediments sampling.

6. CONCLUSIONS

This evaluation of the long term fate of sediments dumped at the Ile Madame site refers to basic parameters and simple calculations. The results are nonetheless useful because they provide a first hand estimation which is approximate but nonetheless realistic, because the results rely on the total volume of sediments dumped on the site. It provides a preliminary perspective to workers evaluating the impacts of that dump site on Atlantic and lake sturgeon and its habitats.

Nonetheless fundamental questions are yet to be answered. The present study does not provide information on the dynamics of the dump site. Some 20,000 m^3 of sandy sediments are dumped annually at the upstream end of the site. Do these sediments add up to the present dispersal cone and simply increase its volume ? Or has the dispersal cone already reach its state of equilibrium, that is a level of saturation, and the sediments added annually are either extending the actual cone or transported some distance away ? Answers to these questions are essential to deal with the impacts of dredging activities on fish populations or their habitats. Work is in progress to develop sediment transport models themselves based on hydrodynamic models of this portion of the St. Lawrence Estuary (Senneville et al. 2001).

7. ACKNOWLEDGMENTS

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