Contaminated Sediment Management: the Canadian Experience

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Since the beginning of North America’s industrialization, the Great Lakes have been negatively impacted by the discharge of industrial, agricultural and municipal pollutants. The governments of Canada and the United States have recognized that the accumulation of pollutants within the bottom sediment and the water column has had a detrimental effect on the Great Lakes ecosystem. In 1972, Canada and the United States signed the *Great Lakes Water Quality Agreement*, which established common water quality objectives and commitments to programs and other measures to achieve these objectives. This included measures for the abatement and control of pollution from dredging activities. By 1985, the International Joint Commission, a body established by the two countries to provide advice on boundary water issues, identified 43 Areas of Concern where impaired water quality prevented full beneficial use of rivers, bays, harbours and ports. The *Great Lakes Water Quality Agreement*, amended in 1987, committed both countries to concentrate remediation efforts in these 43 Areas of Concern. This led to the development of Remedial Action Plans to assess and remediate contamination problems. Contaminated sediment was identified in all of these Areas of Concern. In 1989, the Canadian government created the 5-year $125-million Great Lakes Action Plan in support of the *Great Lakes Water Quality Agreement*. Of this, $55 million was allocated to the Great Lakes 2000 Cleanup Fund for the 17 Canadian Areas of Concern. A portion of the Cleanup Fund was designated for the development and demonstration of technologies for assessment, removal and treatment of contaminated sediment. Since its creation, the Remediation Technologies Program, established under the Cleanup Fund, has successfully performed 3 full-scale remediation projects, 11 pilot-scale technology demonstrations and 29 bench-scale tests. In addition to these projects, the program also evaluated existing sediment management practices and processes.

**Key words:** sediment, remediation, technologies, Environment Canada

**Introduction**

Sediment acts as a sink for various types of contaminants entering a watershed. The International Joint Commission (IJC) recognizes that pollutants in contact with sediment as one factor impairing water quality in the Great Lakes basin. Over the years, controls have been put into place to decrease the discharge of pollutants from point and non-point sources entering the basin from Canada and the U.S. However, contaminants exist within bottom sediment and will continue to be a source of

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pollution to overlying waters until remedial actions are focused on contaminated sediment.

Recognition of this problem led to the creation of the Contaminated Sediment Removal Program under the Great Lakes Cleanup Fund. Under this program, removal has been identified as one remedial option in dealing with the problem of contaminated sediment.

The Contaminated Sediment Removal Program (CSRP) was formed in 1990 following a request from the Great Lakes Cleanup Fund to the Environmental Protection Branch, Ontario Region (Environment Canada), to provide leadership in the identification of innovative removal technologies and procedures for contaminated sediment in the Great Lakes. The objectives of the CSRP were to identify and demonstrate innovative contaminated sediment removal technologies, which could eventually be used for full-scale cleanups in Areas of Concern (AOC). Operational and performance standards have been developed as a means to evaluate technologies and assist during the on-site technology demonstration.

In June 1990, the CSRP decided upon an approach which encompassed the basic elements of a request for proposal from vendors. A notice to vendors wishing to submit proposals or expressions of interest for the demonstration of removal technologies was published in November 1990. A list of suitable firms was prepared from those expressing interest. The firms on the list were sent a request for proposal document (RFP) in May 1991.

Responses to the RFP document were submitted in a workshop held in June 1991. About 25 proposals were received from 12 companies for three chosen demonstration locations (Collingwood, Hamilton and Port Hope harbours). Nine proposals were found to have merit.

In 1994, the CSRP became the Remediation Technologies Program (RTP) with an enlarged mandate, which encompassed not only removal technologies, but treatment technologies as well. Between 1990 and 1999, the RTP performed seven innovative contaminated sediment removal technologies demonstrations, participated in two commercial applications of demonstrated technologies and three full-scale contaminated sediment removal projects.

This paper focuses on innovative approaches for the removal of contaminated sediment in the nearshore zone of the Great Lakes. Although the experiences described herein relate to Canadian removal projects, their application is equally suitable for sediment remediation at marine and freshwater sites worldwide. This paper summarizes the demonstrations to date with the intent of highlighting the benefits accrued from each project.

**Monitoring and Auditing Methods**

The ultimate goal for finding and demonstrating new dredging technologies and procedures is to help to modernize dated equipment and techniques that have been used for over a century without today’s environmental concerns. Innovative equipment and procedures must be capable of
dealing with sediment contamination, but at the same time be affordable for both the contractor and the project proponent. A new technology must meet various environmental constraints that did not exist 50 years ago.

Recognizing these problems, the RTP developed means to evaluate the environmental and economic feasibility of modernizing this existing industry. Stringent operational and performance standards were established. Generic and site specific monitoring and auditing protocols were developed.

**Sediment Resuspension**

One of the most important environmental concerns related to environmental dredging is the resuspension of sediment-bonded contaminants. While resuspension is not the actual concern, it must be minimized in order to protect fish and wildlife habitat, water intakes and the newly exposed sediment. Some innovative dredging technologies, when used in accordance to specific procedures, may minimize the level of sediment resuspension during the actual dredging operations.

A comprehensive water quality-monitoring program may ensure that adverse impacts caused by sediment resuspension during dredging operations are minimized. To do so, a maximum allowable increase of the total suspended solids (TSS) concentration must be identified. In general, an hourly average TSS concentration increase of less than 25 mg/L from ambient level (measured at a control station located in an unaffected area) at 25 m from the actual removal operations should ensure adequate protection of the surrounding environment.

Depending upon site conditions, specific criterion may be established. The number and location of sampling stations will greatly vary. A more stringent resuspension criteria may be used in particularly sensitive environments.

**Productivity**

Conventional navigational dredging projects are usually carried out as quickly as possible with little concern for environmental requirements. Production has been the most important factor for both the contractor and the proponent.

When dealing with contaminated sediment, production does have a different meaning. In some instances, it may be more efficient to decrease the production rate in order to meet environmental requirements. Other considerations include ensuring that minimal water is added to the removed material or ensuring that only one sweep of the area will be required.

In order to provide indication of a production rate that is balanced with other factors, technology and project audits were performed by the RTP. For example, slurry/sludge samples were collected in order to determine percentage of solids. Cycle times or pumps RPMs were adjusted, depending on these samples. Production was also adjusted according to sediment resuspension data gathered during the demonstrations. Table 3
provides a turbidity comparison for the Pneuma pump and the cable arm environmental clamshell at different sediment cuts. It can be seen that optimization of the ultimate production is closely linked to the thickness of the sediment cut. Excessive turbidity levels may trigger a modification or shut down of the operation.

**Sediment Removal Demonstrations**

**Hamilton Harbour Removal Demonstration (April 1991)**

Hamiton Harbour is located at the west end of Lake Ontario, approximately 60 km southwest of Toronto (Fig. 1). It is the second largest Canadian port on the Great Lakes, serving a heavily industrialized urban area, which generates various contaminants and discharges sewage from several point sources into Hamilton Harbour. Identified as an AOC in 1985 by the IJC, sediment contamination has resulted in several impaired uses, which must be addressed through cost-effective remediation approaches.

This demonstration site was at the south end of Hamilton Harbour in Sherman’s Inlet, between piers 14 and 15. This site is in a heavily industrialized zone associated with the production of iron and steel. High concentrations of total PAHs (greater than 1200 ppm) (Murphy et al.1990) and protection from wave action and boating activity were the basis for selection of this location. Sediment samples taken prior to the demonstration had visible oil and grease residues, a black colour and a slight odour.

This project had two objectives: test the applicability of the cable arm bucket to dredge contaminated sediment and provide 8 m³ of highly contaminated PAH sediment to the Eco Logic thermal treatment plant.

A silt curtain (30 m × 10 m) was extended along the shore and attached to a boat in open water. It was anchored to the harbour bottom.

![Fig. 1. Project location.](image-url)
and suspended 1.5 m above the water surface. An 11 m³ cable-arm aggregate bucket was used in two cycles to collect 8 m³ of sediment, which was placed on shore in a 27 m³ lugger box situated on a vinyl spill pad. Pre- and post-monitoring was conducted for water clarity using a Secchi disk and water quality sampling for organic and inorganic parameters inside and outside the silt curtain. Turbidity sampling within the curtain indicated that, 1 hour after removal, conditions were returned to ambient levels (Eco Logic et al. 1991).

Following this demonstration, operational and performance standards were developed to evaluate new removal technologies. Criteria for evaluation included turbidity, suspended solids, TOC, removal efficiency, effluent quality, production rate, transportation and pretreatment requirements. Lessons learned from this first generation cable arm bucket led to the development of an environmental bucket demonstrated in subsequent years.

Welland River Removal Demonstration (November 1991)

Welland is located approximately 60 km east of Niagara Falls and is part of the Niagara River AOC. Past industrial discharges through two outfalls have resulted in localized accumulations of reef-type deposits of oily, black, fine-to-coarse granular, metallic industrial mill scale, totaling over 5,000 m³. The maximum thickness of the industrial deposits was approximately 2.5 m. Another significant volume of sediment located downstream of the outfalls was also impacted. The mill scale and the contaminated sediment contained concentrations of several metals, including copper, chromium, iron, lead, manganese, nickel and zinc, as well as phosphorus and oil and grease, which exceeded the Ontario Ministry of the Environment sediment quality guidelines.

Atlas Specialty Steels of Welland, Ontario, acknowledged its responsibility for a significant quantity of industrial contaminated river sediment, and in December of 1987, made a commitment to the community to remediate this contaminated portion of the Welland River. In June of 1991, Atlas approached the RTP with a partnership proposal for a technology demonstration. Collaboration between the RTP and this private industry led to the formation of a planning team. It should be noted that this site was not one of the original three demonstration locations. The site was deemed ideal, however, for the demonstration of one of the RTP selected technologies.

During the months of October and November 1991, the Mud Cat 915 ENV was demonstrated in the shallow waters of the Welland River. This technology was manufactured by Ellicott Machine Corporation of Baltimore, Maryland, and owned and operated by Auburn Contractors Incorporated of Sudbury, Ontario.

The dual convergence of the horizontal auger head, with an enclosed housing for the auger, were the principal components contributing to the minimization of sediment resuspension. Other components of the operation included hydraulic vibrators to supplement the excavation and removable front screens to restrict oversized material from obstructing the system. The hydraulic forward tilt and manual transverse tilt of the
truss boom and ladder were useful in accommodating the slope of the river bottom. These were some of the many modifications made to the Mud Cat 915 ENV to enhance environmental performance.

Data loggers plus OBS real-time backscatter turbidity sensors were mounted at the dredge head. Samples of water were also collected directly behind the dredge head, 10 m downstream and 10 m upstream. As a contingency measure, a silt curtain was deployed. The average TSS concentrations are presented in Table 1. These results indicate that the curtain was unnecessary. This technology has the proven ability to remove coarse mill scale material and oily residue with little resuspension, while pumping the slurry to a treatment site over a kilometer away with a vertical head of 5 m.

**Toronto Harbour Removal Demonstration (June 1992)**

With a population of over 3 million (including the Greater Metro area), and about one-third of Ontario’s population, Metropolitan Toronto is the commercial, industrial and administrative centre of the province of Ontario (Fig. 1). Port activities and development have reshaped Toronto’s waterfront through dredging, land reclamation and lake filling over the past 150 years. Extensive filling operations resulted in creation of the port lands, which transformed much of the waterfront. A 5-km headland to provide an outer harbour for port expansion is now one of Toronto’s most prominent shoreline features. Sediment contamination in Toronto Harbour consists mainly of elevated levels of total phosphorus, total Kjeldahl nitrogen, oil and grease, copper, lead, zinc and total PCBs (Metropolitan Toronto & Region Remedial Action Plan 1989).

Parliament Street slip (part of Toronto Harbour) was selected for the demonstration of the specially designed cable arm environmental bucket

<table>
<thead>
<tr>
<th>Technology</th>
<th>Location, year</th>
<th>Volume (m³)</th>
<th>Solids (%)</th>
<th>Prod. rate (m³/h)</th>
<th>Cycle time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable arm</td>
<td>Hamilton, 91</td>
<td>15</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Mud cat</td>
<td>Welland, 91</td>
<td>160</td>
<td>10–20</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Cable arm</td>
<td>Toronto, 92</td>
<td>250</td>
<td>49</td>
<td>30</td>
<td>3.5</td>
</tr>
<tr>
<td>Cable arm</td>
<td>Hamilton, 92</td>
<td>150</td>
<td>44–48</td>
<td>30</td>
<td>2.5</td>
</tr>
<tr>
<td>Pneuma pump</td>
<td>Collingwood, 92</td>
<td>1,800</td>
<td>20–40</td>
<td>25–45</td>
<td>NA</td>
</tr>
<tr>
<td>Cable arm</td>
<td>Pickering, 93</td>
<td>150</td>
<td>60</td>
<td>25</td>
<td>8.0</td>
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<tr>
<td>Pneumpump</td>
<td>Collingwood, 93</td>
<td>3,000</td>
<td>30</td>
<td>45</td>
<td>NA</td>
</tr>
<tr>
<td>Visor grab</td>
<td>Penetanguishene, 94</td>
<td>375</td>
<td>40</td>
<td>27</td>
<td>1</td>
</tr>
<tr>
<td>Amphibex</td>
<td>Scarborough, 95</td>
<td>35,000</td>
<td>20–35</td>
<td>40–50</td>
<td>NA</td>
</tr>
<tr>
<td>Amphibex</td>
<td>Welland, 95</td>
<td>7,600</td>
<td>12–30</td>
<td>13–120</td>
<td>NA</td>
</tr>
<tr>
<td>Cable arm</td>
<td>Thunder Bay, 97–98</td>
<td>11,000</td>
<td>10–40</td>
<td>10–50</td>
<td>1</td>
</tr>
</tbody>
</table>
due to low sediment contamination and appropriate particle size (74% was a mixture of silt and clay). Several important modifications were made to the bucket to satisfy the RTP’s requirements for environmental sediment removal. The bucket design was refined, from the traditional format of the aggregate cable arm bucket to the pear shape of the environmental bucket. This pear shape reduced water surface pressure during lifting, thereby minimizing water column turbulence. A venting system was also introduced. The vents remained open during descent in order to allow air and water movement through the bucket, therefore reducing the water pressure on contact with the sediment. Those vents closed during ascension, thus minimizing washout of removed material. Rubber seals were installed along the vertical edges of the bucket in order to minimize the loss of material in the water column and during its travel over to the containment vessel. Modifications of the bucket configuration were also made to allow for a wider footprint.

A silt curtain was deployed at the mouth of the slip to prevent release of resuspended sediment to the rest of the inner harbour. An apparatus called “confined work area” was put in place in order to evaluate whether full confinement would be required during work in open water. This cell was made of four pieces of 18 m × 8 m Terrafix 400, which were sewn together and hung 2 m above the water surface and 1.5 m above the sediment. A basic pretreatment process was also put in place in order to decrease the volume of water included in the sediment that was transported to the treatment facility. The containment area of the transport barge was divided into two sections using 22-foot containers welded in place to span the entire width of the boat. Five tons of 2-cm gravel formed a cove on the inside wall of the partition. Since the ship was ballasted to effect a 15 degree slope to the stern, the excess water from the sludge was able to filter through the gravel.

Two-hundred-and-fifty cubic meters of marginally contaminated sediment were removed at approximately 49% solids (dry basis). Prior to the demonstration, the percentage of in situ solids was found to be between 50 and 60%. The pretreatment process was able to extract 75 m³ of water from the removed material. This volume represents approximately 60% of the total volume of water that was present in the sediment. Cycle time was measured to average approximately 17 cycle/h with a 4.7 m³ bucket, in approximately 8 m of water. (McLellan et al. 1989) found cycle times for conventional clamshell bucket during navigational dredging to fluctuate between 22 and 50 cycle per hour.

Water quality was monitored prior to, during and after the demonstration. The results from the water quality monitoring program indicated that resuspension of material decreased as the operator became more familiar with the cable arm bucket and procedures related to environmental dredging. Other parameters such as metals and organics were also monitored during this demonstration, although no concentration variations were noted. Table 2 presents the average total suspended solids concentration and the turbidity levels measured at three stations.
This demonstration highlighted the need to evaluate the cable arm bucket in an open water area with greater sediment contamination.

**Hamilton Harbour Removal Demonstration (October 1992)**

The selected removal demonstration area was adjacent to Pier 15. In July of 1992 a sediment sampling program was conducted within the study area. Sediment cores revealed large deposits of oil on the waters surface and large deposits of tar within the core sections, producing a distinct odour. Particle size analysis indicated that approximately 65% of the material sampled were clay. Chromium, iron and zinc metals were all in exceedance of the Ontario Ministry of the Environment severe effect level guideline of 110 ppm, 40,000 ppm and 820 ppm, respectively (Persaud et al. 1994). The total PAH concentrations ranged between 1200 and 1400 ppm, with over half of the compounds composed of high molecular weight compounds.

Previous sediment sampling surveys in the study area have identified greatly depressed oxygen consumption levels for the bacteria Photobacterium. The anoxic sediment contains high levels of hydrogen sulphide, which increases the toxicity of bottom sediment and thus reducing the biodegradability of coal tar in such an environment (Murphy 1990).

In order to address the problem of anoxic sediment, a demonstration of an innovative in situ sediment treatment process was performed by Environment Canada in the early summer of 1992. Calcium nitrate was injected in the top 20 cm of the bottom sediment in an attempt to reduce hydrogen sulphide production, thus increasing oxygen levels and allowing naturally occurring organisms to biodegrade PAH molecules.

The removal area was divided into three areas. Area 1 (20 m × 15 m) and 3 (17 m × 15 m) were removed to an average depth of 45 cm. Area 2

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**Table 2. Resuspension results summary for each project**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Location, year</th>
<th>Amb. turb.</th>
<th>Turb. 25 m</th>
<th>Amb. TSS</th>
<th>TSS 25 m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(NTU)</td>
<td>(NTU)</td>
<td>(mg/L)</td>
<td>(mg/L)</td>
</tr>
<tr>
<td>Cable arm</td>
<td>Hamilton, 91</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Mud cat</td>
<td>Welland, 91</td>
<td>NA</td>
<td>NA</td>
<td>7.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Cable arm</td>
<td>Toronto, 92</td>
<td>3</td>
<td>3</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Cable arm</td>
<td>Hamilton, 92</td>
<td>2</td>
<td>3</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Pneuma pump</td>
<td>Collingwood, 92</td>
<td>10</td>
<td>20</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Cable arm</td>
<td>Pickering, 93</td>
<td>3</td>
<td>7</td>
<td>12</td>
<td>22</td>
</tr>
<tr>
<td>Pneuma pump</td>
<td>Collingwood, 93</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Visor grab</td>
<td>Penetanguishene, 94</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Amphibex</td>
<td>Scarborough, 95</td>
<td>NA</td>
<td>NA</td>
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<td>Amphibex</td>
<td>Welland, 95</td>
<td>40</td>
<td>70</td>
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<td>NA</td>
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<tr>
<td>Cable arm</td>
<td>Thunder Bay, 97–98</td>
<td>12</td>
<td>14</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>
(20 m × 15 m) was pre-injected with calcium nitrate and removed to a depth average of 34 cm. Both sediment types were separated and transported to a solid phase biological treatment facility located at Pier 27.

In October 1992, a modified version of the cable arm environmental bucket was demonstrated in Hamilton Harbour. There were five objectives of this technology demonstration project. First, to test the applicability of the bucket in an open water environment. Second, to determine if the modifications following the Toronto demonstration enhanced the operation and performance of the bucket. Third, to provide sediment to a biological treatment technology. Fourth, to determine the efficacy of the bucket to provide surgical sediment removal. Lastly, to determine the effectiveness of the in situ treatment technology by taking chemical and biological samples directly before and after treatment. The removal performance criteria included the removal of 60 m³ of pretreated sediment and 90 m³ of untreated sediment while meeting operational and performance standards and the removal of in situ treated sediment to a depth of 20 cm to achieve a minimum of 45% solids content.

Based on recommendations from the Toronto demonstration and site conditions in Hamilton the following modifications were made to the bucket: neoprene and gasket seals were added to provide a positive seal during closure; inner side plates were used to reduce the lateral movement of sediment; an external reeving system was used to eliminate sediment contact; and an epoxy coating was used on the bucket surface to reduce coal tar adhesion. Independent seal ports were used to maximize solids content for different sediment cuts. Using the lower vent, the maximum capacity was 3.2 m³, allowing removal treated sediment to a depth of 20 cm. Using the upper vent, the maximum capacity of the bucket was increased to 4.8 m³, allowing removal of 30 cm of untreated sediment.

The plant setup included a 85 m × 15 m deck barge anchored to Pier 15, which provided support to a flat deck barge (27 m × 18 m) used to support the crane, and a second flat deck barge (43 m × 12 m) used to support the sediment storage bins. A confined working area (11 m × 10 m), similar to that used in Toronto, was placed at the end of the deck barge suspended 1.5 m above the harbour bottom and 2 m above the water surface.

During the demonstration, approximately 50 m³ of pretreated sediment and 100 m³ of untreated sediment were removed at a percent solids

<table>
<thead>
<tr>
<th>Technology</th>
<th>Location, year</th>
<th>Cut thickness (cm)</th>
<th>Turbidity increase (NTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneuma</td>
<td>Collingwood, 1992</td>
<td>30</td>
<td>&gt;15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>0–5</td>
</tr>
<tr>
<td>Cable Arm</td>
<td>Pickering, 1993</td>
<td>45</td>
<td>50–100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>20–25</td>
</tr>
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</table>
between 44 and 48% (dry weight). The average cycle time was 2 min, 30 seconds. However, with proper operator training and use of a positioning system, the cycle time could be reduced (depending on water depth).

Water quality monitoring was performed throughout the entire removal demonstration. Several parameters were monitored, including turbidity and suspended solids. Table 2 provides an overview of the resuspension data. Turbidity was measured using a nephelometer and was generally within the 30% increase from background, except in a few instances where the bucket was overfilled.

Collingwood Harbour Removal Demonstration (November 1992)

The Pneuma pump #150/30 was operated at Collingwood Harbour. This was the first time this dredge was used in the Great Lakes. The demonstration of this system was developed by Pneuma s.r.l. Firenze, Italy, and modified by Voyageurs Marine Construction Company Ltd., Dorion, Quebec. The demonstration was conducted during November of 1992 in the west slip of an old shipyard in Collingwood Harbour. Based on its operational performance, an additional phase of the project continued into the month of December in the west and east slips of the harbour, and then finally in the inner harbour. The management of this second phase was carried out by the RTP. However, a consortium of partners, including user groups, private industry and regulatory groups provided funding for this remedial work. The strong community support for this project was a driving force for this additional work. This removal of contaminated sediment played a significant role toward delisting this harbour as an Area of Concern.

Operated from a barge and suspended by a crane, the optimum mode and positioning of the pump was to run it in the trailing and sweeping mode. As a result of the demonstration, it was shown that this technology has proven ability to operate among an assortment of different sized debris. Historically, ocean-going vessels were once constructed in the west slip. Over the past century, the bottom of this slip became a concealed waste site. Divers physically removed the larger sizes of debris prior to the demonstration. However, numerous ruble, including welding rods, rivets, bolts, wooden wedges, cables, steel bars, textile and plastic sheets, and barrels remained. The smaller material was readily transported through the pump and pipeline to the confined disposal facility approximately 1.2 km from the dredging site. Obstructions by larger material occurred during the demonstration. Through use of a flow meter to assess production levels, it was determined that the efficiency of the pump was limited with the presence of vast quantities of large debris. The system sustained optimum efficiency in areas free of larger debris.

Even though debris were present in the bottom sediment of the west slip, the results indicate that the Pneuma pump was able to remove 1800 m$^3$ with a production rate fluctuating between 25 and 40 m$^3$/h with a percentage of solids in the slurry varying from 20 to 40% (Table 1).
Water quality was monitored thoroughly throughout the demonstration. Parameters such as turbidity, total suspended solids concentration and total organic carbon were used as operational standards in order to evaluate the secondary pollution generated by the Pneuma pump. Table 2 presents an overview of the monitoring data. These results indicate that, even with the large amount of debris, the Pneuma pump was able to keep the increase in the total suspended solids concentration at 10 m from the pump to an average of 15 mg/L above ambient levels.

Penetanguishene Removal Demonstration (Fall 1994)

Severn Sound is located in the southeastern portion of Georgian Bay and is composed of a group of bays, including Penetang Bay, Midland Bay, Hog Bay, Sturgeon Bay and Matchedash Bay. Severn Sound was first identified as an Area of Concern (AOC) by the IJC in 1973, mainly due to excessive algal growth linked to elevated concentrations of phosphorus and other nutrients in the water column. In 1989, a survey of nearshore fish habitat in Penetang Bay was conducted. An area of shoreline in the south end portion of the bay was identified as providing poor habitat and requiring restoration. A rare wind-induced water level change occurred in Severn Sound on Monday, November 6, 1992. This seiche lowered the water level by one meter. As a result, several hectares of degraded fish habitat were exposed (approximately 300 m × 200 m) in the shallow nearshore area of the bay. Logs, wood slabs and sawdust covered the area. A subsequent borehole survey (February 1994) indicated that the debris layer was up to 1 m thick over the original lakebed.

The removal of approximately 4000 m$^3$ of wood wastes using conventional technologies and methodologies took place in October 1994. A second component of the demonstration included an innovative sediment removal technology — the Visor Grab. Effectiveness assessment in the removal of contaminated sediment in other AOCs throughout the Great Lakes basin was performed on a clay-sawdust mixture left on the bay bottom.

The Visor Grab, owned and developed by HAM Dredging, was brought from Holland to Penetanguishene to evaluate its applicability for removing sediment at a high percentage of solids while minimizing sediment resuspension. The bucket was installed on Wayne Jones Construction’s 235 Caterpillar excavator on Thursday October 20, 1994. The demonstration started the same day and lasted until Monday October 24, 1994.

In total, 19 hours were devoted to the removal of approximately 375 m$^3$ of a mixture of sawdust and clay. From those 19 hours, approximately 5 hours were devoted to transport and off-loading of material. Therefore, the total duration of the removal period was 14 hours, which leads to an average production rate of approximately 27 m$^3$/h. The average cycle time was approximately 55 seconds, with a percentage of solids averaging approximately 40%. It should be noted that performances relat-
ed to the Visor Grab are related mostly to the excavator, the operator and the water depth. The above-noted performances could be totally different under other site conditions.

Even though most of the large debris were removed from the area with the grapple fork, some pieces of wood were still present on the sediment. These leftovers prevented the Visor Grab from sealing completely. In fact, approximately 70% of the bucket loads were not sealed due to the presence of debris preventing complete closure. It was impossible to evaluate sediment resuspension using only the Visor Grab because of three major factors: 1) already extremely elevated levels of total suspended solids in the water column of the confined area, 2) effects of the current created by the tugboat propellers resuspending a considerable amount of sediment, and 3) leaks from the holding barge.

The Visor Grab, with some minor modifications, does have the potential to be used to clean up other AOCs.

Scarborough Bluffs Demonstration (1995)

Located just east of the city of Toronto, Scarborough is part of the Metropolitan Toronto and Region Area of Concern (AOC). Erosion from the Scarborough Bluffs is a major source of suspended solids to Lake Ontario. Other problems associated with the Scarborough Bluffs area are the storm sewer and combined sewer overflows that discharge into Bluffers Park and ultimately reach Lake Ontario. As part of the Water Quality Enhancement Strategy for the Brimley Road drainage area (storm sewer source to Bluffers Park), a Dunkers flow balancing system was proposed within the Bluffers Park embayment. Construction of this facility requires dredging of sediment currently in the embayment to create a retention pond to trap suspended solids. The quality of the sediment was determined using acceptable disposal methods according to the Ontario Ministry of Environment Guidelines for the Protection and Management of Aquatic Sediment Quality.

In order for the retention pond to hold a 100-year storm, it was estimated that a capacity of 40,000 m$^3$ was required. To obtain this volume, removal of 35,000 m$^3$ of marginally contaminated sediment was needed, with a water depth increase from 15 cm to 3 m. Due to the nature of the material to be removed, the shallowness of the embayment and difficulties associated with dredging in a parkland, an innovative amphibious dredging technology (Amphibex) was selected.

The Amphibex is an amphibious dredge specifically designed for shallow waters and sensitive areas such as wetlands. It is one of very few technologies that can perform work from the shoreline to water depths of up to 6 m. Equipped with an hydraulic bucket, the Amphibex first excavates the sediment in a manner comparable to a standard excavator and displaces the sediment using positive pressure pumps located directly on the excavating bucket. In contrast to standard centrifugal pumps, the process used by the Amphibex during dredging requires only minimal suction, thereby reducing the initial hydraulic head associated with the lift. This method ensures
a greater percentage of solids in the slurry, therefore reducing the amount of excess water generated during hydraulic dredging.

During the Scarborough Bluffs demonstration, the Amphibex was only audited for production. Sediment resuspension was impossible to measure due to the shallowness of the embayment and the constant external output from an active storm sewer discharging into the embayment during the work.

The production rate was measured on three different occasions by calculating the volume of sediment removed in that period of time. The maximum production rate registered was 49.5 m$^3$/h (average for 201 hours of work), while the minimum recorded was 16.24 m$^3$/h (average for 58.5 hours). The difference was mainly due to the tests of different pumps and to pump performance tests being performed. Percentage of solids in the slurry was also measured at various occasions using calculation and slurry sample collection. Knowing the actual production rate and the maximum production rate for the setup used in Scarbourough (pipeline limitation, velocity of slurry, etc.), the percentage of solids was calculated at the same three occasions as above. The maximum calculated was 35.59% while the minimum was calculated at 11.67%. Sample collection also indicated that instantaneous percentage of solids was measured at 45% (volume/volume). Tests of an infrared densitometer inserted in the pipeline were also performed during this project but were inconclusive. The limitations of the meter only allowed accurate measurements of density up to 25%. In addition, the inserted portion of the meter became damaged over time by debris. Organic matter and sediment blinding the sensors also corrupted measurements.

This project introduced a new and inexpensive innovative technology to the dredging industry and project promoters. The Dunkers flow balancing system would not be in place today without the use of the Amphibex.

Commercial Applications and Full-Scale Projects

Pickering Nuclear Generating Station (April 1993)

Pickering is located approximately 30 km east of Toronto. Since commissioning, Pickering B Nuclear Generating Station has experienced sediment entrainment problems within the cooling water intake channel, resulting in frequent problems with the nuclear reactors. A solution to the station’s sedimentation problem was to install a sediment by-pass system in 1990. The system is comprised of precast concrete slabs creating a funnel shape approximately 19 m in diameter. The sediment is pumped through a 2-m diameter fiberglass pipe to the tempering screenhouse and then into the discharge channel. In the spring of 1992, the Ontario Ministry of the Environment granted conditional approval for the sediment by-pass system to become operational. The terms and conditions associated with this approval stated that the 150 m$^3$ of sediment, which had accumulated on top of the funnel area, was to be removed before
beginning operation of the system. Due to the amount of sediment resuspension, including problems with the containment and treatment of discharge water, conventional mechanical and hydraulic dredging technologies were not chosen by Ontario Hydro. The cable arm environmental clamshell bucket was selected in order to meet both environmental regulatory standards and Ontario Hydro’s operational requirements.

It was crucial that material resuspension be kept to a minimum throughout the dredging operations since most of the cooling water intake would still be in operation. In fact, an increase of 10 mg/L from ambient levels at 25 m from the dredge was the set limit not to be exceeded. The closest water intake was located between 15 and 25 m from the dredge (depending where dredging was occurring on the funnel) with a primary current pushing the material to this intake and a secondary current pushing the resuspended material in the opposite direction. Increasing suspended particle concentration could lead to unit derating and possible shutdown of the nuclear generator since a great amount of this resuspended material would be sucked in by the water intake.

The cable arm bucket used for this first commercial application had a maximum capacity of 3.2 m³ and was equipped with an underwater camera, a closure confirmation system, an air-operated vents dewatering system and a depth transducer.

During the removal project, approximately 150 m³ of bottom material (mainly composed of organic wastes such as: tree branches, leaves, dead fish, etc.) at approximately 60% solids (dry basis) was dredged and placed in containers for transport to a temporary holding facility. In order to ensure that the level of material resuspension would be kept to a minimum, Ontario Hydro had requested a cycle time of 10 min at the beginning of the project. As indicated in Table 1, The cable arm bucket was able to achieve a cycle time averaging 8 min, and a production rate of approximately 23 m³/h.

At the beginning of the removal operations, overfilling of the bucket occurred due to the operator’s lack of training with the cable arm bucket and the depth transducer. During that operator’s on-site training process, the concentration of resuspended material did exceed the limits preset by Ontario Hydro, but at no time required shutdown of the nuclear plant operations. As the operator was gaining confidence, the frequency of overfilling events was reduced, thus decreasing the resuspension of material. From that time, the preset limit of 22 mg/L was rarely exceeded.

The most important objective of this project was successfully met when Ontario Hydro personnel noticed no effect on station operation and reactor safety. It is believed that a cost saving was realized by using the cable arm environmental bucket since no shutdown of operation was necessary.

Maintenance Dredging in Collingwood Harbour (November 1993)

The Collingwood Harbour removal demonstration and post-demonstration partnership cleanup lead to the commercial application of the Pneuma pump. In November 1993, the Pneuma pump #150/130 was
selected through a competitive bid to remove additional sediment from Collingwood Harbour. This was the first commercial application of the Pneuma system since the demonstration of November 1992.

Production levels of the demonstrated technologies are competitive with traditional equipment. This hydraulic airlift pump dredged an approximate volume of 3000 m³ of material at an average dredging depth of 0.30 m. The average hourly production rate was calculated to be approximately 45.0 m³/h, with an estimated 30.7% solids in the dredge slurry.

During this operation, the RTP undertook water quality samples to monitor the effectiveness of the dredge in minimizing sediment resuspension while operating at a commercial level. The results indicated that the Pneuma pump marginally increased the turbidity at 25 m from the dredge at both the surface and bottom waters. At 10 m from the pump, very little increase was noticed, except at four occasions when the turbidity levels were increased by more than 10 nephelometric turbidity units (NTU), mostly near the bottom. These results indicate that even when dredging for production, the Pneuma pump is able to maintain low levels of sediment resuspension.

Both the performance and the water quality monitoring results indicated that the Pneuma pump is very effective at removing contaminated sediment in areas where very minimal debris are encountered. This project also proved that the Pneuma pump could compete with conventional technologies for navigational dredging projects.

**Welland River Reef Cleanup Project (Fall 1995)**

In the fall of 1995, the RTP partnered with Atlas Specialty Steels, the Ontario Ministry of the Environment, the City of Welland and the Regional Municipality of Niagara to perform a contaminated sediment removal and treatment project. This large-scale demonstration was the result of the 1991 Welland River contaminated sediment removal demonstration. For this project, the Amphibex was selected as the preferred and most cost-efficient innovative dredging technology. Other components of the project included 1) on-line material screening; 2) sheetpiling of a portion of the remediation area in order to maintain integrity of the floodplain; and 3) backfilling a portion of the removal area with granular material in order to recreate a suitable fish and wildlife habitat and to ensure stability of the adjacent floodplain and parkland.

Sediment removal took place at two locations in the Welland River separated by approximately 0.5 km. In the first section, mill-scale deposits and contaminated sediment totaled over 3000 m³ and were removed and pumped through a fused pipeline (with the aid of booster pumps) to a screening facility located approximately 1.5 km away. In the lower section, the volume was over 6500 m³ and was again pumped to the same screening facility at a distance of 1 km.

Several factors such as distance (and associated hydraulic head) and the amount of debris affected production. Overall, the production rate in mill-scale sediment (specific gravity greater than 2.6) varied from 12.8 to
35.6 m$^3$/h with an average percentage of solids in the slurry around 10%. In lighter river sediment (clayey-silt), it reached over 100 m$^3$/h, with a solids content averaging 28%. The flow generally varied between 1000 and 1800 US gallons per min. The last day of work proved to be the most productive. During that day, 1266 m$^3$ of river sediment was removed in approximately 11 hours, which led to a production rate of 115 m$^3$/h while the solids content was maintained at 48% by weight.

For this project, the guideline for allowable sediment resuspension was set at a TSS concentration of 25 mg/L above background. Water quality monitoring was performed through the use of on-line sensors (Hydrolab) located upstream (control station) and 25 m downstream from the silt curtain. A relation between turbidity and TSS was established prior to the project with several verifications of the curve during the operations. By so doing, the turbidity readings from the hydrolabs provided instantaneous indication of TSS concentrations. An averaged increase in turbidity levels over 1 hour related to an increase in TSS concentration greater than 25 mg/L above background triggered shutdown of the operations, search for external inputs and re-evaluation of dredging methodologies.

Over the 300 hours required to dredge the 9833 m$^3$, the guideline was exceeded on three occasions, all related to either external inputs, climatic variations (increased current, rain, snow, wind), or other activities taking place in the river.

**Conclusion**

With the type of development and testing that was performed by Environment Canada and other agencies, it is believed that, eventually, a whole range of technologies will be available for all kinds of dredging projects requiring special care due to sediment contamination.

Environmental dredging is definitely an option for management of contaminated sediment. Innovative procedures and technologies can minimize environmental impacts of projects that, not so long ago, would not have been viable.

**References**


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