Removal of Historic Low-Level Radioactive Sediment from the Port Hope Harbour – 13314

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ABSTRACT

At the Port Hope Harbour, located on the north shore of Lake Ontario, the presence of low-level radioactive sediment, resulting from a former radium and uranium refinery that operated alongside the Harbour, currently limits redevelopment and revitalization opportunities. These waste materials contain radium-226, uranium, arsenic and other contaminants. Several other on-land locations within the community of Port Hope are also affected by the low-level radioactive waste management practices of the past. The Port Hope Project is a community initiated undertaking that will result in the consolidation of an estimated 1.2 million cubic metres of the low-level radioactive waste from the various sites in Port Hope into a new engineered above ground long-term waste management facility. The remediation of the estimated 120,000 m^3 of contaminated sediments from the Port Hope Harbour is one of the more challenging components of the Port Hope Project. Following a thorough review of various options, the proposed method of contaminated sediment removal is by dredging. The sediment from the dredge will then be pumped as a sediment-water slurry mixture into geosynthetic containment tubes for dewatering. Due to the hard substrate below the contaminated sediment, the challenge has been to set performance standards in terms of low residual surface concentrations that are attainable in an operationally efficient manner.

INTRODUCTION

Historical Development of Harbour

Port Hope is located on the north shore of Lake Ontario, at the mouth of the Ganaraska River, approximately 100 km east of the city of Toronto, Ontario, Canada. In 1832, the Port Hope Harbour and Wharf Company started work on the creation of a Harbour that would consist of parallel wooden wharves extending out into Lake Ontario. By 1851, these wharves were in a poor state of repair, so the Town of Port Hope acquired the Harbour from the Company and vested its interest in Commissioners acting as trustees for the benefit of the Town Council. The Commissioners immediately took steps to repair and enlarge the Harbour to attract a new railroad that would connect the town to points to the north. The work of the Commissioners would result in an improved Harbour extending over 2 hectares in size and projecting over 360 metres into Lake Ontario and 250 metres along the shoreline. The Harbour would subsequently be reconstructed to include a Turning Basin, an Approach Channel and protective breakwalls. The Turning Basin walls were built in the mid 1800s as squared timber cribs set on rock or hard till and filled with stone and fill ballast. With the exception of the concrete copewalls, these walls have remained essentially unaltered since that time.

The Centre Pier was constructed during the later 1800s to service the needs of the local lumber industry and to provide additional docking space and areas for coal storage and servicing facilities for the heavy lake vessel traffic in and out of the port. The Queen's Wharf was created by filling at the southwesterly part of the Harbour. Commencing in the early 1930s, interlocking steel sheet piling and anchorage points were used to construct new Harbour walls rather than timber cribs.

Although a significant proportion of the Harbour construction work was completed by the early 1900s, the current Harbour configuration was not attained until 1953 (see Figure 1). Under the current configuration, the Harbour comprises: the Outer Harbour located between the entrance breakwaters with direct access to Lake Ontario; the Approach Channel (approximately 40 metres wide by 305 metres long); the inner Turning Basin (195 metres by 135 metres); the Queen's Wharf, located on the west side of the Approach Channel; and the Centre Pier (approximately 500 m long by 100 m wide) separating the Harbour from the Ganaraska River. The Harbour no longer receives commercial vessel traffic and is best described as a recreational Harbour that serves as a small craft mooring facility for the Port Hope Yacht Club. The Cameco Port Hope Conversion Facility has a process water intake at the Outer Harbour and a discharge point on the west wall of the Turning Basin. Figure 2 presents a recent aerial photo of the Harbour area.

The history of the Port Hope Harbour from the early 1800s to today is typical of other small-town ports along Lake Ontario that have experienced growth and decline in direct relation to Great Lakes shipping volumes and the shift in industry and commerce to larger urban areas and other modes of transportation. However, in the case of the Port Hope Harbour, the presence of low-level radioactive sediment, resulting the refining of radium and uranium by a former federal Crown Corporation, Eldorado Nuclear Limited that operated alongside the Harbour, currently limits redevelopment and revitalization opportunities. The presence of historic low-level radioactive waste is not limited to only Harbour sediments. Several other on-land locations within the community are also affected by the historic low-level radioactive waste management practices of the past. Waste placement occurred between the early 1930s and mid 1950s. These waste materials contain radium-226, uranium, arsenic and other contaminants resulting from the refining process.

To address these situations, the Port Hope Project is currently underway to implement a local, safe, long-term waste management solution. The Port Hope Project is a community initiated undertaking that will result in the consolidation of an estimated 1.2 million cubic metres of the low-level radioactive waste from the various sites in Port Hope into a new engineered above ground long-term waste management facility (LTWMF). The remediation of the estimated 120,000 m^3 of contaminated sediments from the Port Hope Harbour is one of the more challenging components of the Port Hope Project.

PORT HOPE HARBOUR CONTAMINATED SEDIMENT

Surveys of radioactivity conducted in the vicinity of the Harbour, including its sediments, during the 1970s and early 1980s identified the presence of historic low-level radioactive waste. With respect to the Port Hope Harbour, it is probable that the accumulation of this historic waste started with the commissioning of the radium refinery and resulted from direct deposition of chemical wastes in the 1930s and 1940s, discharges of aqueous process effluent, discharge of plant-site runoff, accidental spills due to plant process upsets, operating water discharges, groundwater movement and other waste management practices on the former Eldorado plant site. The residues from the refining process contained a number of primary Contaminants of Potential Concern (COPCs), most notably: arsenic; antimony; cadmium; cobalt; lead; nickel; uranium; radium-226; thorium-230; and the thorium-232 decay series [1].

Fig. 1 Current configuration of Port Hope Harbour

Contamination in the Harbour exists in a naturally-accumulated sediment layer overlying the till and bedrock throughout the Turning Basin and Approach Channel and in a portion of the Outer Harbour. The sediment is typically comprised of silty organics, soft silts and clays underlain by hard till or limestone bedrock. The thickness of the sediments varies across the site and extends to as much as 3.5 metres deep in the Turning Basin and 7 metres in the Approach Channel.

Table I presents a summary of typical and maximum contaminant concentrations measured in the Port Hope Harbour Sediments [2]. Typical and maximum contaminant concentrations for radium-226 and uranium are 41 Bq/g and 380 Bq/g respectively and 1,736 and 17,620 µg/g respectively.

Fig. 2 Aerial photograph of Port Hope Harbour (2010)

TABLE I. Typical and Maximum Contaminant Concentrations for Port Hope Harbour Sediments [2]

Contaminant	Units	Concentration	
		Typical	Maximum
Radium-226	Bq/g	41	380
Uranium	µg/g	1,736	17,620
Arsenic	µg/g	1,093	10,500
Barium	µg/g	204	670
Copper	µg/g	474	2,400
Lead	µg/g	5,532	61,700

CONTAMINATED SEDIMENT REMOVAL STRATEGY

Sediment Cleanup Criteria

A field and laboratory study was conducted to derive site-specific cleanup criteria for the contaminated sediment in the Port Hope Harbour [3]. These criteria were developed based on the protection of aquatic biota, with emphasis on the benthic invertebrates inhabiting the bottom, on or within the contaminated sediments. The recommended toxicity-based sediment criteria were as follows: arsenic, 375 µg/g; lead, 2500 µg/g; uranium, 1100 µg/g; and copper, 400 µg/g [3].

It was determined that the application of these criteria would also protect against chronic toxicity of the other COPCs associated with the Harbour sediment, including radioactive constituents [3]. However, based upon the objectives of the Port Hope Project, it was recommended that, rather than apply these site-specific criteria, the more stringent criteria applicable to residential soils be applied for Ra-226, Th-230 and uranium instead. This would ensure that if the Harbour sediments were ever dredged again in the future, after completion of the Port Hope Project, no historic low-level radioactive waste would be present that could require special management for on-land disposal due to its radioactivity. If, in the future, non-radioactive contaminants were found to be present above residential or commercial/industrial criteria, these sediments could be managed without concern for radioactivity. These Port Hope specific criteria are as follows [1]: Ra-226, 0.29 Bq/g and Th-230, 1.16 Bq/g. The criterion for arsenic is 6 µg/g, which is consistent with the 2011 MOE sediment standards [4]. The criterion for U is 23 µg/g, which is consistent with the MOE residential property standard [4] in the absence of a sediment standard.

Preferred Alternative Remediation Concept

As part of the Environmental Assessment process, alternative means of carrying out the remediation Port Hope Harbour were investigated. The first step of the alternative means evaluation process was to identify feasible concepts [5]. The options ranged from excavation in-the-dry (whereby all the water in the Turning Basin and Approach Channel would be pumped out to allow conventional construction equipment to work in-the-dry and excavate the sediment), to dredging, and to *in situ* management, whereby the entire Turning Basin and Approach

Channel would be in-filled with clean soil and the impacted sediment left in place. The alternative means were then screened with a pass/fail filter that examined technical and economic feasibility. The remaining feasible concepts were then evaluated and compared to identify a qualified concept [6]. The evaluation criteria were divided into five indicators; technical, health and safety, community, economic, and environmental. These criteria, developed through consultation with the public and other stakeholders, were assigned weighting factors.

Following a thorough review of the various options through the alternative means evaluation process, a single concept was qualified as the preferred alternative for the remediation of the Port Hope Harbour sediments. The preferred alternative method of remediation is removal of the contaminated sediment by dredging. The sediment from the dredge will then be pumped as a sediment-water slurry mixture into geosynthetic containment tubes to dewater the mixture. The dewatered material will then be excavated and transported by truck to the LTWMF. Further detail design of the dredging and dewatering approach based on the selected option had to be within the bounds of the parameters set by the environmental assessment.

DETAIL DESIGN OF DREDGING AND DEWATERING

Detail Design Process

The detail design of the contaminated sediment dredging and dewatering was initiated with completion the *Analysis of Project Requirements* [7] report, which included a review previous reports and concepts prepared for the environmental assessment. The next phase of the detail design was the *Condition Assessment* [8] which included historic drawing review, field condition surveys, bathymetric survey, sonar imaging, diving inspection, residual thickness testing investigations, and a geotechnical investigation with over 60 boreholes, bedrock coring and sediment testing. This was followed by the *Design Concept* phase [9], which examined alternative concepts that met the project criteria within the bounding parameters of preferred alternative concept selected during the environmental assessment: remove all sediments from Harbour down to hard bottom (weather limestone or hard till); deliver dredge material hydraulically to sediment dewatering tubes on the Centre Pier for subsequent removal to the LTWMF; repair, rehabilitate or replace Harbour walls structurally impacted by dredging; maintain subsequent use as recreational Harbour; maintain Cameco's ongoing use of the Harbour for process water intake and discharge; adhere to strict safety requirements for management of dust and low-level radioactive waste; and abide by construction timing restrictions due the important fisheries in the adjacent Ganaraska River. The design progressed with *Design Development and Final Detailed Design* [10] and culminated with the preparation of complete construction drawings and specifications.

Dredging

Although cleanup criteria have been developed for the cleanup of contaminated Harbour sediments, the apparent variability of the contamination distribution and impracticality of attempting to segregate the contaminated and non-contaminated sediment led to the decision that the remediation of the Harbour would be based upon the removal of the all the accessible sediment above the bedrock or till. With this approach, the estimated quantity of material to be dredged is 120,000 m^3. However, all dredging operations normally leave some of the material behind due to resuspension and residuals [11]. To achieve effective control of residuals dredging of the Harbour will proceed through a two-stage dredging program.

During the first stage (production dredging) the contractor will remove the bulk of the material to be dredged to hard bottom. Following the first stage production dredging, a sufficient period of time shall be allowed to elapse to allow re-suspended material to settle before the second stage dredging (cleanup dredging passes). The second stage cleanup dredging will remove residual material left following the first stage dredging. The surface of the till and bedrock underlying the Harbour sediment will not be uniformly smooth and will exhibit natural irregularities, fissures and depressions that will practically result in some amount of residual material. Due to the hard bottom, the dredge will not be able to perform a cleanup pass that involves overdredging of a thin layer of underlying clean sediment. The Port Hope Harbour dredging specifications require the contractor to use a plain suction or pneumatic dredge or specialty dredgehead (e.g., Vic Vac®[1]) to complete two cleanup dredging passes, each providing 100 percent coverage of the Harbour bottom, to remove as much of the residuals as reasonably practical.

For the first stage production dredging, the specific type of dredging equipment is not prescribed in the specifications thereby allowing the contractor to select the most effective equipment to meet the project objectives, specified performance standards, site-specific constraints and environmental and health and safety requirements while at the same time being able to minimize resuspension, deal with debris in the dredge material and the requirement to dredge to hard bottom and to deliver the dredge material hydraulically to the Centre Pier for dewatering within the geosynthetic tubes. The dredge rate will be primarily governed by the rate of chemical conditioning and dewatering process. While it is not uncommon to undertake dredging work on a 24 hour per day, 7 days per week basis to maximize efficiencies, the present Municipality of Port Hope by-law restricts working hours.

Debris in the Harbour sediment has been identified by sonar survey and consists of items such as tree branches, mooring anchors, discarded mooring lines, bicycles, shopping carts, tires, pieces of pipe and other miscellaneous items that cannot be passed through a hydraulic dredge and pipeline. This will impact the selection of the preferred dredge technique by the contractor since debris slows down hydraulic dredging equipment. The debris must be mechanically removed by an excavator or crane. A further pre-dredging survey will be undertaken to identify the position of objects requiring removal prior to dredging.

Allowable turbidity levels during dredging and monitoring and testing requirements will also factor into the dredge efficiency. Control of resuspended material will be achieved through the use of a fixed structural barrier that fully encloses the opening of the Harbour. Current plans call for the isolation of the Harbour from the Ganaraska River mouth and Lake Ontario by installing a cellular steel sheet pile breakwater/cofferdam in the Outer Harbour for the duration of Harbour remediation work. This isolation is necessary to minimize the release of potentially impacted

[1] *Vic Vac is a registered trademark of J.F. Brennan Company, Inc. in the United States and/or other countries.*

suspended sediments to Lake Ontario and the Ganaraska River during the dredging operation. Installation of this barrier will also prevent fish from entering the dredging area during the annual fish spawns that occur during the spring and fall of the year. A turbidity curtain will also be provided on the Harbour side of the temporary wave attenuator as an additional control measure for the release of resuspended sediment. Discharge from the Harbour will be required to meet regulatory guidelines for suspended sediments. Resident fish in the Harbour will be directed outside of the controlled area by progressive seining from the north end of the Turning Basin to the Ganaraska River and Lake Ontario just prior to the isolation of the Harbour work area. The turbidity curtain will be installed in a manner that will prevent fish from re-entering the Harbour.

The temporary breakwater will also protect the remediation work area from Lake Ontario wave action (wave heights exceeding about 2.5 m at the Harbour mouth), water level fluctuations (nearly up to 2 m), storm surge (up to about 0.4 m) and ice action.

Dredging Verification

Cleanup criteria have been established to meet the remediation project goals and objectives. Performance standards are required to measure the success in achieving compliance with the cleanup criteria and the Harbour remediation objectives. Due to the hard substrate below the contaminated sediment, the challenge has been to set performance standards in terms of low residual surface concentration that are attainable in an operationally efficient manner. It is expected that the two-stage dredging process, including the two cleanup passes will remove as much of the sediment down to hard bottom as is reasonably practical. Following the two cleanup dredging passes, the Harbour will be surveyed using a multibeam echosounder system to quantify the volume of residuals remaining on the Harbour bottom, which is estimated to be in the order of a few percent of the dredge volume. The residuals will be below any reasonable future dredging depth: -2.5 m to -3 m chart datum (CD) for Turning Basin; -3 m CD for Approach Channel; and -5 m CD for the southern portion of Approach Channel and Outer Harbour.

Once the second stage dredging has been completed the Harbour bottom will be sampled according to the *Remediation Verification Standard Operating Procedure (RVSOP) for Port Hope Harbour* [12]. The intent of the verification sampling is to characterize the concentrations of the COPCs in the residual materials. The RVSOP describes the sampling methods, the number of samples required, and the analytical methods and limits to be used. The sampling grid size will be 15 m x 15 m and three replicate samples are to be collected from each grid square. The three samples from each grid square are to be combined and tested at a minimum for uranium, arsenic, radium-226 and thorium-230. Since the Harbour sediments contain a mixture of metals and radionuclides, based on previous analysis these elements are most consistently observed in sediment samples, and are suitable analytical surrogates for the metals present.

Dewatering

Through the environmental assessment process, it was concluded that dewatering of the dredged material would take place on the Centre Pier using geosynthetic containment tubes in lined sediment dewatering areas. Dewatering of the sediment within the containment tubes will take place within the dewatering areas and the drained water will be collected and treated prior to discharge back into the Harbour.

Bench scale investigations involving the Port Hope Harbour sediments demonstrated that the sediment-water slurry can be successfully mixed with polymers to promote flocculation and consolidation of the sediment within containment tubes. Figure 3 presents a picture of the consolidated sediment in the bench scale containment bag and the form of collected sediment that will make it amenable for placement into standard haulage vehicles for transportation to the off-site long-term waste management facility.

Dewatering of sediment will be a two-phase process. An initial flush of drainage water (approximately 65%) will occur as the sediment containment tubes are progressively filled over several days. When completely filled, the sediment containment tubes will undergo a secondary dewatering period during which they will passively drain (approximately 35% of the drainage water). The quality of the drainage water is not expected to change between the initial flush and secondary dewatering.

As the entrained water drains from the sediment containment tubes, it will collect in the primary drainage water retention lagoons. When the primary lagoons are about 90% full, water will decant from the top of the water column through a perforated riser into a secondary containment lagoon. The decanted water will remain in the secondary containment lagoon prior to treatment for dissolved metals and subsequent discharge back into the Harbour. Suspended sediment is not anticipated to be present in the effluent. However, if sediment accumulates in the lagoons to the point that it affects their storage capacity, it will be removed using a conventional excavator, dewatered and hauled to the LTWMF.

When the sediment containment tubes have been filled, they will undergo a secondary dewatering period (approximately 7 days) during which minimal activity will occur within the sediment dewatering area. During this time, the sediment containment tubes will continue to naturally drain into the drainage water retention lagoons. The presence of multiple sediment dewatering areas will facilitate nearly continuous dredging operations (i.e., some tubes will be filled while others drain or are emptied and hauled to the LTWMF).

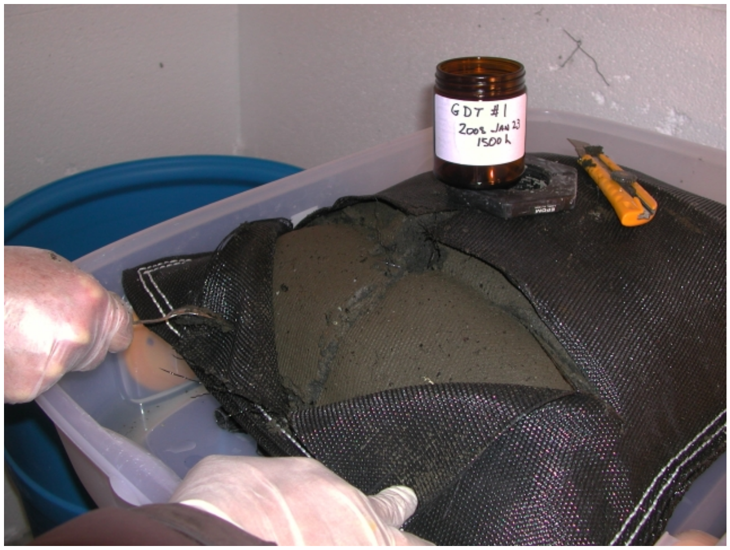

Fig. 3 Bench scale test of polymer additive and sediment containment bag dewatering system

Once the sediment has dewatered to an acceptable solids content, the containment tubes will be broken open and the contaminated sediment loaded into dedicated dump trucks for transport to the LTWMF. Odours and dust associated with the sediment will be monitored and appropriately managed to prevent off-site impacts.

Pre-Sediment Removal Enabling Activities

As noted previously, the Port Hope Harbour has undergone many upgrades over the past 200 years, resulting in walls of various construction types and other supporting structures that will present challenges for the remediation work (e.g., steel sheet pile with uncertain toe embedment conditions, tie-backs, deadheads, wooden cribbing, stone ballast, concrete cope walls, etc.).

The design of the Harbour remediation strategy has involved careful examination of the integrity and stability of the existing Harbour walls, revealing that the removal to bedrock, or hard till, of the sediment located adjacent to the walls could compromise the wall structures. To address this concern, a Harbour wall condition assessment was conducted during the summer of 2010 on over 1800 metres of existing Harbour wall structures which could be impacted by the dredging operation. The physical appearance and structural integrity of these walls were characterized.

Based on the results of this condition assessment, and the required depth of sediment removal to bedrock or hard till, a series of optional concepts for the repair, rehabilitation or replacement of specific sections of Harbour walls potentially impacted by the dredging were developed. These concepts took the following factors into consideration:

- shift in Harbour use from commercial traffic to recreational boating;
- pedestrian and light vehicle loadings rather than heavy industrial along specified wall perimeters;

- depth of small pleasure craft (sail and power) less than 3 metres below chart datum;
- depth of visiting larger vessels, such as tall ships, less that 5 metres below chart datum; and
- alongside moorings versus floating docks.

Discussions with Harbour area stakeholders (Port Hope Yacht Club, Municipality of Port Hope, Port Hope Harbour Commission, Department of Fisheries and Oceans, and Cameco Corporation) were conducted and various scenarios presented on potential rehabilitation strategies for the Harbour walls affected by the sediment dredging, as well as on-land soil remediation work planned for sites adjacent to the Harbour.

Based upon these discussions, a wall rehabilitation program involving the installation of new steel sheet pile walls, and stabilization of existing walls through the placement of new stone revetments in front of selected existing walls, was agreed as the preferred concept in principle. Aspects considered during these discussions included maintenance of an acceptable entrance width in the Approach Channel, maintenance of recreational craft alongside wall moorings, allowance for potential larger draft vessels alongside wall moorings, reduction in wave action in the Approach Channel and wave agitation in the Turning Basin, provision of a heavy lift area to position a crane to place boats in the water in spring and remove from the water in the fall, and optimization of fish habitat following removal of the contaminated Harbour sediments.

The final wall rehabilitation plan includes the removal of 270 lineal metres of contaminated timber cribs (up to 4 m below chart datum) and the construction of approximately 1760 m of new Harbour wall, including:

- 150 m - new river bank stone revetment;
- 200 m - remediated timber crib/ concrete cope wall;
- 180 m - replacement of existing tierods and anchor blocks for existing SSP wall;
- 180 m - new combination pipe pile steel sheet pile wall (up to 9 m below chart datum);
- 350 m - new steel sheet pile wall (typically 3 to 6 m below chart datum); and
- 700 m - new stone revetment.

Figure 4 illustrates a schematic cross-section of the Approach Channel depicting the new combination steel pipe pile sheet pile wall along the Centre Pier side, and new stone revetment along the Queen’s Wharf wall.

CONCLUSION

Since its original development in 1832, under the direction of the Port Hope Harbour and Wharf Company, the Port Hope Harbour has undergone many changes and reconfigurations. Once serving as a bustling port on Lake Ontario serving the shipping needs of local commerce and trade, it now serves as a recreational anchorage for the Port Hope Yacht Club.

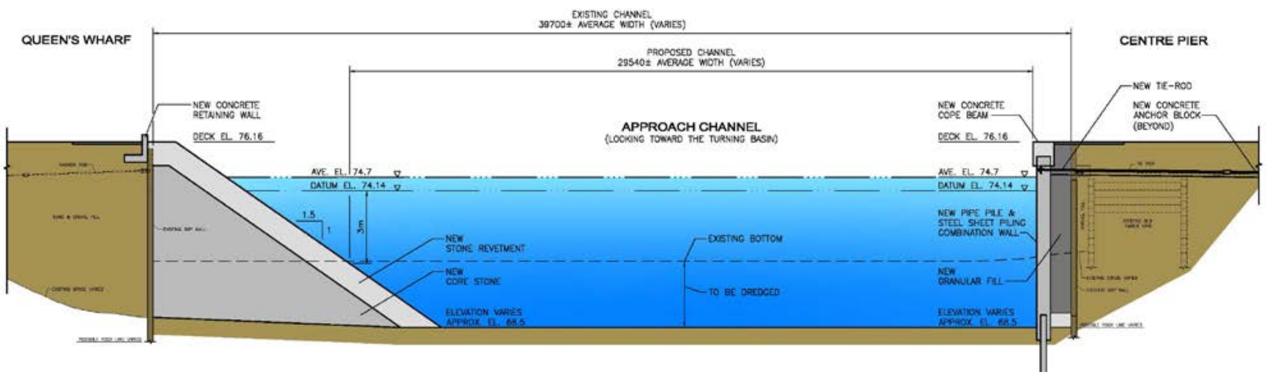

Fig. 4 Typical section through Approach Channel following wall rehabilitation (looking north)

The lack of an appropriate waste management site to receive the existing low-level, radioactively-contaminated sediment (resulting from former radium and uranium refining operations adjacent to the Harbour) has precluded Harbour remediation for more than 30 years.

The Port Hope Project – including the development of a new, long-term waste management facility – now provides an opportunity to address this impacted sediment.

But this cleanup is far from a conventional dredging operation. It will require unique and specific expertise, training and equipment – and will present unique challenges. Based on the nature of the sediment and the large volume to be removed, the remediation work for the Harbour must include:

- radiological protection for workers and the environment during the work;
- structural assessment and rehabilitation of the Harbour walls that could be structurally compromised by dredging to bedrock or hard till;
- special procedures for the dewatering and management of radioactively contaminated sediments; and
- implementation of socio-economic mitigation measures to address the temporary relocation of the Harbour's tenant, the Port Hope Yacht Club.

What may have appeared back in the late 1990s as a simple line-item – the removal of 120,000 cubic metres of contaminated sediment from the Port Hope Harbour – has, through comprehensive environmental assessment and detailed engineering design processes, evolved into a highly complex undertaking.

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