Action plan for the removal of sediment contaminants from St. John's Harbour through dredging

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Abstract

This paper examines a theoretical action plan for the removal of contaminated sediment deposited by untreated sewage from St. John's harbor through the use of dredging. It includes a brief summary of known contaminants present in the harbor based on previously conducted sediment sampling, and data from a series of available hydrographic surveys of the harbor. This project includes a series of maps of the harbor, highlighting potential areas of high deposition and showing the position of sediment sampling sites in order to create a visual representation of the current state of the harbor. This paper then determines the feasibility of removing contaminated sediments through the use of dredging. A brief discussion of common dredging methods and their resultant turbidity is provided in order to determine the most efficient and environmentally responsible means of removing contaminated sediments. Primary data processing has been conducted by the author for the purposes of rendering a bathymetric surface of the harbour bottom.

Executive Summary

St. John's Harbour has been continuously in use since 1630; however, there was nothing done to "address and rectify the St. John's Harbour pollution problem" (Dillon, 2002, p. iii) until the formation of the Atlantic Coastal Action Program (ACAP) in 1993. The main focus of the St. John's ACAP was the "rehabilitation and protection of the St. John's Harbour and its environs" (Dillon, 2002, p. iii). The evaluation of the harbour by the St. John's ACAP resulted in the Riverhead Wastewater Treatment facility entering production in 2009, with the final sewer outflow into the harbour being routed to the treatment facility by the end of 2014. Once the flow of untreated waste water has ended, the environmental focus can now shift to the reclamation of the harbour to its natural state. To this end, this paper examines the removal of contaminated sediments from St. John's Harbour through the use of dredging.

In order to accomplish this goal, data from a sediment sampling survey conducted by the Department of Fisheries and Oceans in 1993 was examined and a selection of fourteen contaminants that are present in the harbour were chosen to demonstrate the level of sediment contamination. For these contaminants, some of which are probable or known carcinogens, levels measured in the harbour sediment samples were up to ten thousand times the background samples taken from Robin Hood Bay. The bathymetric data from a series of surveys by the Canadian Hydrographic service in 2005 and 2006 was compared with bathymetric data collected by the Marine Institute in 2010 to establish a baseline state of the harbour and to then determine focus areas that were likely to have high levels of contaminants.

The determining factor in selecting a dredging method for this project was turbidity. Turbidity is a "measure of [the] relative clarity of a liquid" (US Geological Survey (USGS), 2014, para. 1). It can be caused by "clay, silt, finely divided inorganic and organic matter, algae, soluble colored organic compounds, and plankton and other microscopic organisms" (USGS, 2014, para. 1). The turbidity measurements for different dredging techniques are detailed in Pennekamp, Epskamp, Rosenbrand, Mullie, Wessel, Arts, & Deibel's (1996) article, *Turbidity caused by dredging: Viewed in perspective*. Based on these results, it was determined that for this specific case a pneuma-dredge would be the most effective based on the high solid content of the dredge output and the extremely low turbidity levels.

In order to treat the contaminated sediments from the harbour, three methods of waste material disposal were examined. Composting and dewatering were determined to be too expensive in this scenario, as both would require the construction of large facilities in order to properly process the dredged material. Reed beds offer a low maintenance method of removing contaminants from the sediment and composting the remaining organic material in to a usable soil additive. Reed beds still require a large area in order to be effective, but have significantly lower construction and operating costs.

Based on the 2014 city budget and the projected deficit for the 2015/16 fiscal years, this project is not recommended to proceed at this time. Projected costs for the dredging phase of the project alone are expected to be at $9.2 million, which doesn't include the construction costs for the reed bed treatment facility, wages for the work crews and other associated costs for this project. It is the recommendation of the author that additional funding will need to be secured from the provincial and federal government in order to offset the cost of this project.

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1.0 Introduction

1.1 Purpose

This project develops an action plan for the removal by dredging of contaminated sediments deposited in St. John's harbour by untreated sewage. It includes a summary of known contaminants present in the harbour based on previously conducted sediment sampling and data from a series of available hydrographic surveys of the harbour, and determines the economic and environmental feasibility of dredging as a solution. This project contains a series of maps of the harbour, highlighting areas of high deposition and sediment sampling sites for the purpose of creating a visual representation of the state of the harbour. It also examines three waste disposal methods for the removed sediments and determines the feasibility of these methods in this scenario.

1.2 Background

St. John's Harbour has been continuously in use since 1630; however, there was nothing done to "address and rectify the St. John's Harbour pollution problem" (Dillon, 2002, p. iii) until the formation of the Atlantic Coastal Action Program (ACAP) in 1993. The main focus of the St. John's ACAP was the "rehabilitation and protection of the St. John's Harbour and its environs" (Dillon, 2002, p. iii). In order to complete this mandate, the ACAP members reviewed a series of harbour surveys conducted on water and sediment quality dating back to 1974. A map showing water sampling sites can be found in Appendix A, while a map of the sediment sampling sites can be found in Appendix B. Water samples were found to contain increasing concentrations of bacteria and were excessively enriched with dissolved nitrogen, phosphorus and ammonia. These levels were higher at known sewage outfalls, indicating that untreated waste water was the dominant source of these dissolved nutrients (Powell, 1998). Sediment samples from the harbour revealed significantly elevated levels of polychlorinated biphenyls (PCBs), organic compound pesticides and polyaromatic hydrocarbons (Powell, 1998). The majority of the pollution that is present can be attributed to untreated waste water entering the harbour.

In 1999, the city of St. John's had to conduct underwater blasting in order to improve harbour navigation, so it sent divers down to do a bottom inspection. John Barry, project engineer for the City of St. John's stated in an interview that according to the divers who conducted the inspection, "The tide must have been coming out and it was just like you were in a snowstorm—and what it was, was all the toilet paper" (Breen, 2009, para. 33-34). As a means of controlling the influx of these contaminants from the city, the Riverhead Wastewater Treatment facility was built and began processing waste in 2009. The development of the Riverhead Wastewater Treatment facility has already significantly reduced the amount of untreated waste water that is being discharged directly into St. John's Harbour, and an action plan is already in place to develop a secondary treatment facility to further treat waste water. All of the current action plans are focused on limiting the introduction of new waste material into the harbour; however, there is not currently an action plan in place to remove the already present contaminated sediments. In order to determine areas of high sedimentation from sewer outflow, this project will examine multibeam sonar data for a series of surveys conducted in the harbour.

Due to the fluctuating nature of the outflow, the amount of sediment each year varies (Stoschek, 2008). This project will examine the harbour as a whole and determine if these sediments can be safely removed and disposed of. As part of the dredging operation, Pennekamp, Epskamp, Rosenbrand, Mullie, Wessel, Arts, & Deibel (1996) state that the environmental effects of the turbidity due to disturbed sediments can consist of

- Sedimentation inside or beyond the dredging area;
- Uncontrolled movements of attached pollutants;
- Pollution of clean areas;
- Release of nutrients;
- Oxygen consumption in surface water; and
- Blocking of sunlight (p.11).

Cardoso & Helleur (2004) examine a series of action plans for the collection, treatment and disposal of biosolid sludge from raw sewage. Her report details alternate disposal options for the dredged material that will comply with current provincial waste management strategies and which will decrease the current leaching situation in the harbour. As part of the dredging process section of this project, three of the options that are explored in Cardoso's report for the safe disposal of dredged material will be examined: namely composting, use of a reed bed, and dewatering.

1.3 Scope

This project will present the following topics in order to address the issue of contaminated sediment removal in St. John's Harbour:

- Background
- Current State of the Harbour
    - Hazard Assessment
    - Current Waste Water Action Plans
    - Baseline Maps
- Dredging Methods
    - Dredging Operations
    - Turbidity
    - Preferred Dredging Method
- Dredging Process
    - Focus Areas
    - Dredging Process
    - Waste Material Disposal
- Dredging Project Limitations
- Conclusions and Recommendations

1.4 Methodology

Phase I – Primary Research

The initial phase for this project is primary research that develops a baseline for the current state of the harbour. This includes developing survey maps for sediment data through the use of historical survey and sediment sampling data in St. John's Harbour. This data has been provided through an analysis of Powell's *St. John's Harbour Scientific Data Summary 1969-1997*, and a series of multibeam sonar surveys of St. John's Harbour as conducted by the

Canadian Hydrographic Service and provided to the Marine Institute for training purposes. The data processing time for this project is dependent upon the amount of noise removal and corrections that are required in order to create a usable final product.

The multibeam data required noise removal, tide corrections and a line-by-line analysis in order to create a series of temporal Bathymetry Associated with Statistical Error (BASE) surfaces of the harbour. The preparation of the multibeam data into an interpretable form took a period of four weeks based upon the condition of the data and the amount of noise removal required. This data was processed in the Computer Aided Resource Information System (CARIS) Hydrographic Information Processing System (HIPS) software, and then the BASE surfaces were exported into the Environmental Research Systems Institute (ESRI) ArcGIS software suite for the production of a series of maps showing areas of sediment deposition over the available time period for the data. This portion of the project required two weeks to produce the final products after the data had been processed fully and the final BASE surfaces prepared.

A map showing the most recently available sediment sampling sites from Powell's summary has been included for the establishment of a baseline of contaminated sediment deposits.

Phase II – Secondary Research

In order to establish an informed baseline for the state of St. John's Harbour, there is an analysis of a series of technical reports that examine the Atlantic Coastal Action Program (ACAP) and explore waste handling strategies that have been proposed for contaminated sediments. The two main papers that will be examined are Dillon's *An Evaluation of St. John's Harbour ACAP* and Cardoso & Helleur 's *Literature Review and Independent Appraisal of Biosolids Management Options for the St. John's Harbour Clean-Up Project*. These papers provide essential background data for the harbour and will be used in conjunction with the Powell's scientific data summary to highlight areas of significant deposits of hazardous contaminants as potential dredging sites. This research will form the majority of the historical data on the state of the harbour and provide an analysis of potential disposal methods for the contaminated materials. The analysis of these papers will form a solid foundation and give direction for additional research into the history of the St. John's Harbour ACAP.

The final stages of this project examine if dredging is a viable option for the removal of contaminated sediment from St. John's Harbour and will examine any dredging operations that have already been undertaken in the harbour and analyze additional dredging methods that will allow for the removal of contaminated materials in an environmentally responsible manner.

Phase III – Primary Source Summary

The primary sources of the multibeam data that are used in this project are Dr. Dominique St-Hilaire with the School of Ocean Technology and Doug Cartwright, chair of the Ocean Mapping Program. The rest of the research and primary data processing has been conducted on an individual basis by the project author with regular consultations with the supervisor. This data has been analyzed and compiled to create a baseline for the current state of the harbour.

2.0 Current State of St. John's Harbour

2.1 Hazard Assessment

St. John's has been a commercial center since the earliest days of the fishing industry in Newfoundland. The first recorded permanent residents of the St. John's area were the Oxfords, who settled on a plantation in the area west of Beck's Cove in the early 1600s (St. John's Archives, 2014). With the increasing vessel traffic for the Newfoundland fishery, St. John's Harbour has been a dumping ground for most forms of waste for over 400 years. This has resulted in the sediments of the harbour accumulating large concentrations of organic waste material, pesticides and heavy metals. Powell's *St. John's Harbour Scientific Data Summary 1969-1997* includes the scientific analysis of eight sediment sampling sites within St. John's Harbour in 1993, the exact positions of which are shown in Appendix C. For the purposes of this project, the contamination levels of nine polyaromatic hydrocarbons, four pesticides, and polychlorinated biphenyls (PCBs) will be examined. These chemicals, known biological effects and exposure limits are presented in Table 1. As is demonstrated in this table, the harbour sediments contain several probable and known carcinogens, i.e. cancer causing agents, as well as other chemicals that have documented neurological and toxic effects. The potential source for these chemical residues is the flow of untreated waste water from the St. John's storm drain and sewer system into the harbour. The positions of these outflows can be found in Appendix A and B. The sediment samples that are used for this project were collected by the Department of Fisheries and Oceans (DFO) in 1993, almost a decade and a half before the Riverhead treatment facility began production.

The positions of the sampling sites in the harbour are shown in Appendix C. In order to determine the extent of the contamination of the harbour, two sediment samples from Robin Hood Bay that were collected in the same survey have also been analyzed in order to establish baselines for the level of contamination. The following graphs present the recorded amounts of each chemical in the eight harbour sediment samples and the two control samples.
Figure 1 demonstrates the degree to which the sediments have been contaminated with polyaromatic hydrocarbons, all of which are considered possible or probable carcinogens. For all of the chemicals that are examined in this project, there are significant amounts present in the harbour, in particular on the north end, which is the location of one of the sewer outflows for the city of St. John's prior to the implementation of the Riverhead Wastewater Treatment facility. This area of increased chemical levels indicate the location of the largest sewer outflow for the city.

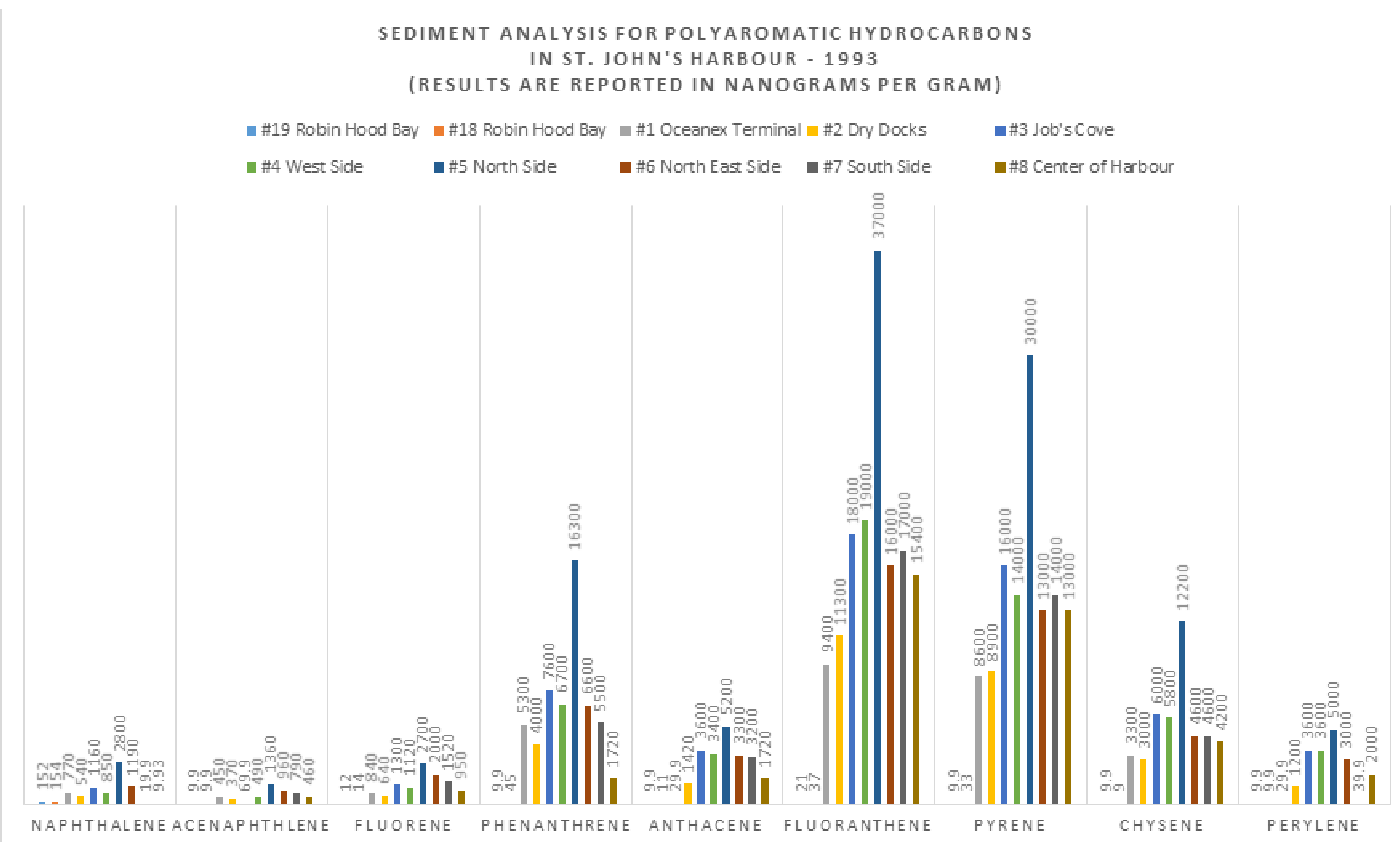
These levels also can be used to indicate potential current/drift patterns within the harbour. Of the chemicals that have been selected for this project, Naphthalene was one of the only chemicals that had values that tested lower for some locations in the harbour, namely sample locations 7 (south side) and 8 (center of harbour) when compared to the baselines. In some cases, chemical levels in the harbour samples were over ten thousand times the levels of the baseline samples from Robin Hood Bay. Of the chemicals that were tested, the highest concentration levels were Fluoranthene, a probable carcinogen for which chronic exposure is known to cause cancer of the liver, lungs and skin.

Table 1: Chemical names, biological effects and exposure levels

Chemical Name	Biological Effects	Exposure limit [Units]
Polyaromatic Hydrocarbons		
Naphthalene	Symptoms of acute exposure include headache, nausea, vomiting, diarrhea, malaise, confusion, anemia, jaundice, convulsions, and coma. Chronic effects: Cataracts, retina degradation/hemorrhage, hemolytic anemia in infants. Potential carcinogen (EPA, 2000)	0.02 mg/kg/day
Acenaphthlene [PAH][*]	Symptoms of acute exposure include skin/eye/nose and throat irritation. Chronic effects: Lung irritation, liver and kidney damage. Potential carcinogen (New Jersey Department of Health and Senior Services, 1998)	2.5 ppm [total]
Fluorene [PAH]	Symptoms of acute exposure include skin/eye/nose and throat irritation. Chronic effects: Damage to skin, body fluids and the immune system in mice. Potential carcinogen. (Agency for Toxic Substances and Disease Registry (ATSDR), 1990)	2.5 ppm [total]
Phenanthrene [PAH]	Symptoms of acute exposure include skin/eye/nose and throat irritation. Chronic effects: Damage to skin, body fluids and the immune system in mice. Potential carcinogen. (ATSDR, 1990)	2.5 ppm [total]
Anthracene [PAH]	Symptoms of acute exposure include skin/eye/nose and throat irritation. Chronic effects: Damage to skin, body fluids and the immune system in mice. Potential carcinogen. (ATSDR, 1990)	2.5 ppm [total]
Fluoranthene [PAH]	Symptoms of acute exposure include skin and eye irritation. Chronic effects: PROBABLE CARCINOGEN. Known to cause lung, liver and skin cancer in animals. (New Jersey Department of Health and Senior Services, 2001)	No safe exposure limit 2.5 ppm [total]
Pyrene [PAH]	Symptoms of acute exposure include skin/eye/nose and throat irritation. Nephropathy (kidney disease) Chronic effects: Damage to skin, body fluids and the immune system in mice. Potential carcinogen. (ATSDR, 1990)	2.5 ppm [total]
Chysene [PAH]	Symptoms of acute exposure include skin and eye irritation. Chronic effects: PROBABLE CARCINOGEN. Known to cause lung, liver and skin cancer in animals. carcinogen (New Jersey Department of Health and Senior Services, 2001)	0.2 mg/m^3 per 8 hour day (maximum recommended) 2.5 ppm [total]
Perylene [PAH]	Symptoms of acute exposure include skin/eye/nose and throat irritation. Chronic effects: Damage to skin, body fluids and the immune system in mice. Potential carcinogen. (ATSDR, 1990)	2.5 ppm [total]
Organic Compound Pesticides		
Chlordane	Symptoms of acute exposure include gastrointestinal distress and neurological symptoms, such as tremors and convulsions. Chronic (long-term) inhalation exposure of humans to chlordane results in effects on the nervous system. PROBABLE CARCINOGEN (EPA, 2000)	<1 ppm No safe exposure limit
Endrin Aldehyde	Symptoms of acute exposure include shortness of breath, cough, narrowing of airways and throat spasms. May also cause muscle twitches, spastic movements and seizures. Chronic effects: multiple nervous system infections and disorders. May cause long-term adverse effects in the aquatic environment (MSDS, 2008)	100 mg/m^3
Methoxychlor	Symptoms of acute exposure include skin irritation. Chronic effects: developmental and reproductive effects including liver, kidneys and nervous system. (EPA, 2000)	0.005 mg/kg/day
P,P'-DDE	Breakdown product of DDT. Symptoms of acute exposure include central nervous system effects. Chronic effects: liver, immune system and central nervous system effects. PROBABLE CARCINOGEN. (EPA, 2000)	0.0005 mg/kg/day
PCBs	KNOWN CARCINOGEN. Also affects immune system, reproductive system, nervous system, endocrine system. (EPA, 2013)	0.1 ppm

[*] Polycyclic aromatic hydrocarbons. Often found in groups of two or more chemicals. Exposure limit is for all PAH. (EPA, 2000) Table: Wise, 2014

Figure 1: Sediment analysis for polyaromatic hydrocarbons in St John's Harbour - 1993



(Powell, 1998, Appendix O)

Figure 2 presents the reported amounts of four organic compound pesticides that are present in the sediment samples. These pesticides and pesticide by-products affect muscle control and the central nervous system, and can result in the development of cancer or nervous system disorders.

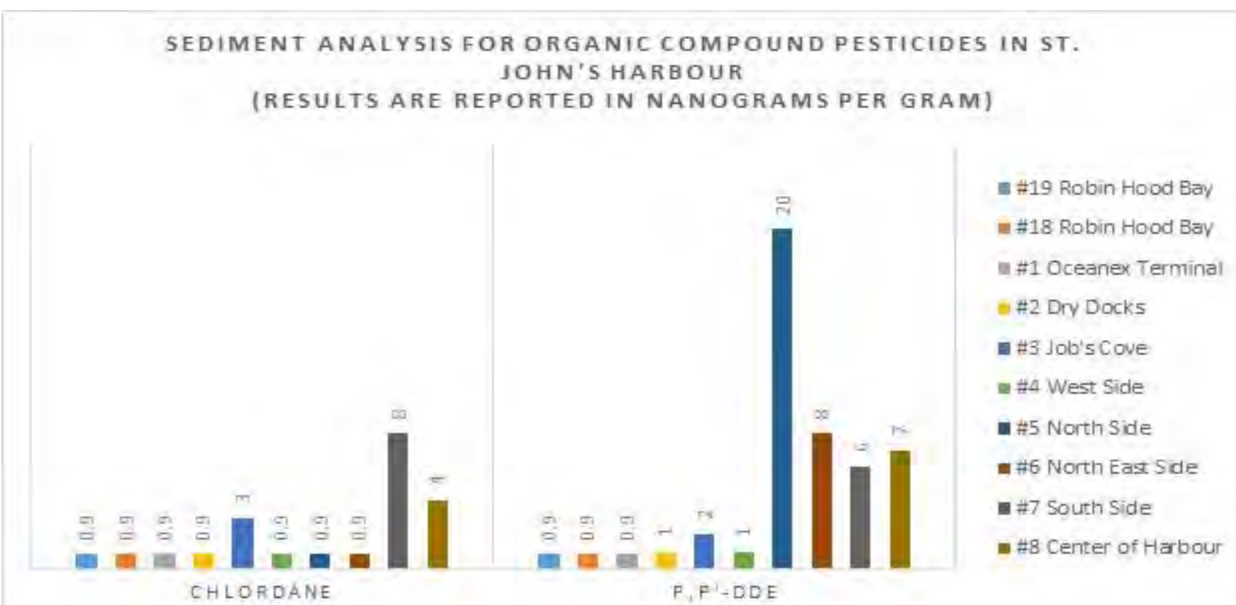
Two of the pesticides, Endrin Aldehyde and Methoxychlor, had recorded levels of up to two hundred times the baseline levels. Endrin Aldehyde has been documented to have an adverse effect on the aquatic environment (Chemwatch, 2003), and chronic Methoxychlor exposure can have developmental and reproductive effects including liver, kidney and nervous system disorders (Environmental Protection Agency (EPA), 2000). DDE is a breakdown product of DDT, and is listed as a pollutant of concern to EPA's Great Waters Program due to its persistence in the environment, potential to bio-accumulate, and toxicity to humans and the environment (EPA, 2000).

The last chemical that will be analyzed for the purposes of this project is Polychlorinated Biphenyls (PCBs). The results for the sediment analysis for PCBs in the St. John's Harbour sediment are shown in Figure 3. The adverse effects of PCBs are well documented, and they have

> "been shown to cause a number of serious non-cancer health effects in animals, including effects on the immune system, reproductive system, nervous system, endocrine system and other health effects. Studies in humans provide supportive evidence for [the] potential carcinogenic and non-carcinogenic effects of PCBs" (EPA, 2013, para. 1).

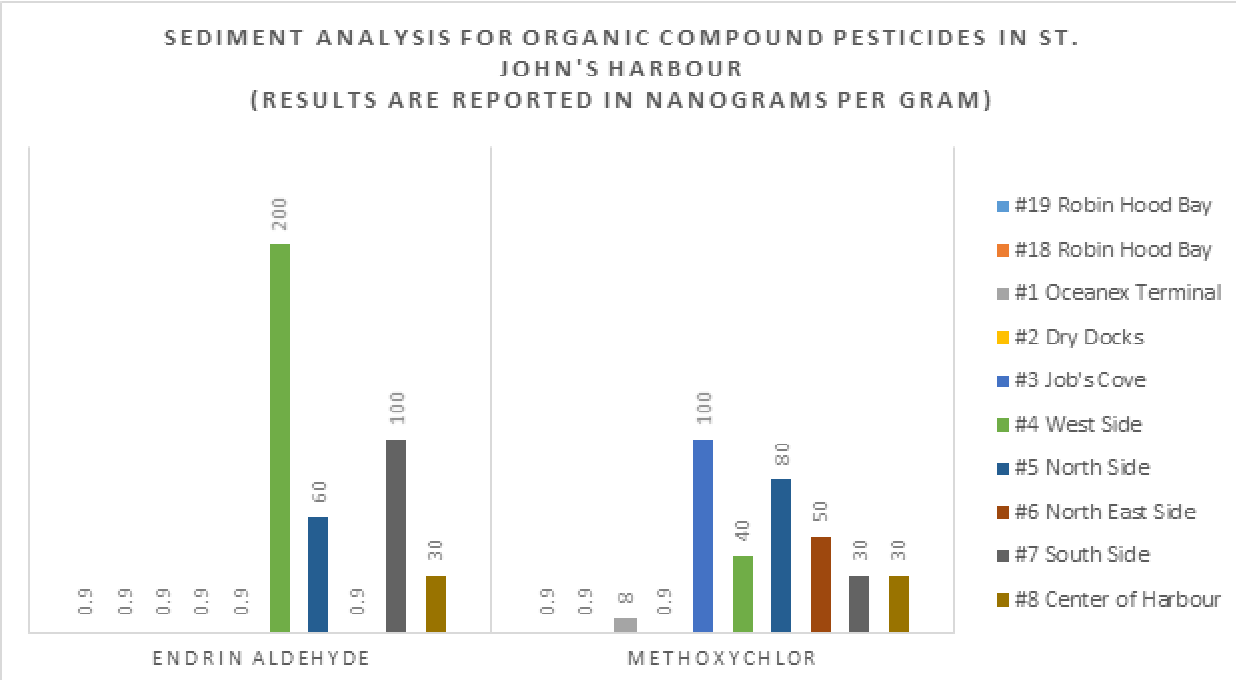
For St. John's harbour, the level of PCBs is up to twelve thousand times that of the baseline levels. It is interesting to note that the levels of PCBs vary significantly around the harbour, with areas of high concentrations focused on the northern half of the harbour.

Figure 2-A: Sediment analysis for Organic Compound Pesticides in St. John's Harbour



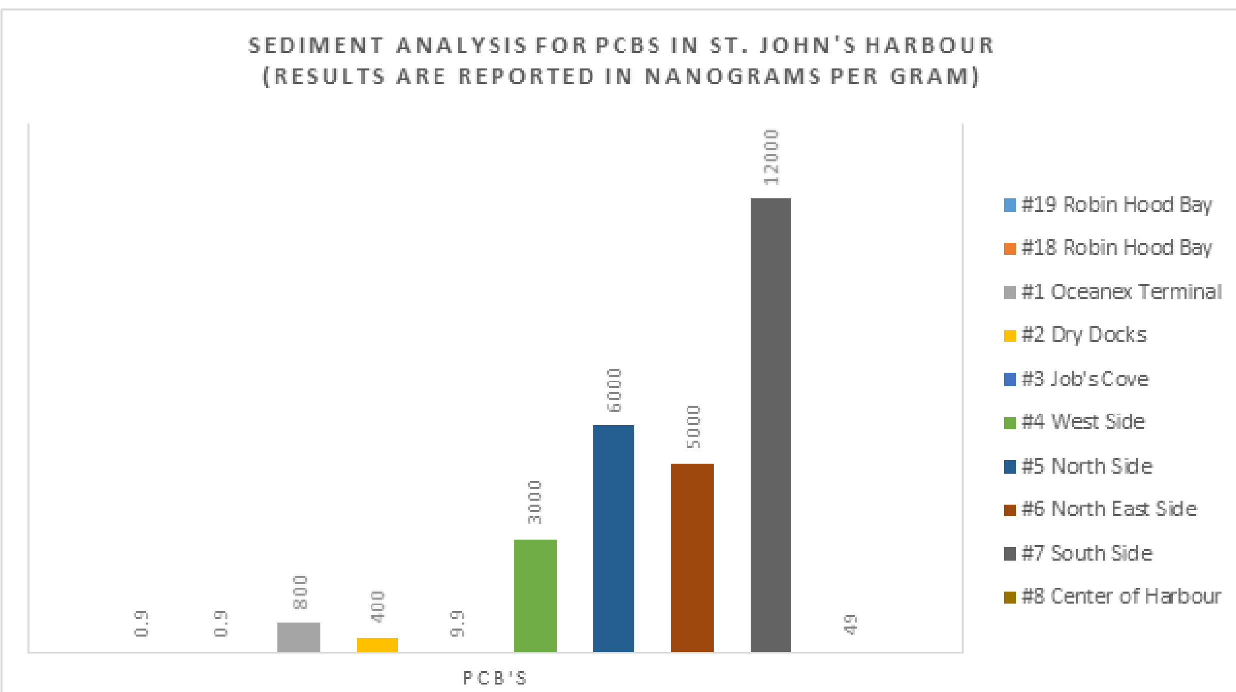
(Powell, 1998, Appendix O)

Figure 2-B: Sediment analysis for Organic Compound Pesticides in St. John's Harbour (cont'd)



(Powell, 1998, Appendix O)

Figure 3: Sediment analysis for PCBs in St. John's Harbour



(Powell, 1998, Appendix O)

Since the levels of harmful chemicals is significantly higher in the sediment samples from the harbour, it would be prudent to remove the contaminated sediment if financially and environmentally viable. Table 2 shows the common types of contaminants present in the harbour, the probable source and the environmental significance of these contaminants. These elevated levels show a pattern for which sewage outflows have the highest output, and would therefore be sites of highest potential sediment deposition. These values allow for focus areas to be created with the intent of selecting areas for potential dredging operations to remove contaminated sediments. Further analysis of the BASE surfaces should support the selection of these areas, and will highlight the extent of the area of sediment deposition over the period from 2005 – 2010.

Table 2 – Sources and Environmental Significance of Some Important Wastewater Contaminants

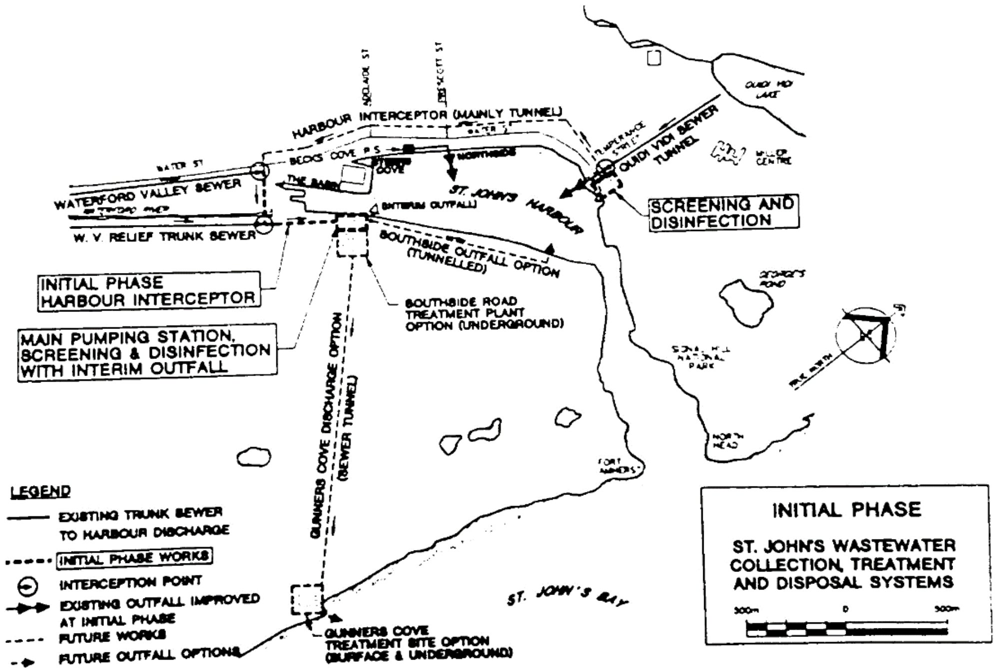
Contaminant	Source	Environmental Significance
Suspended Solids	Domestic use, industrial wastes, erosion by infiltration/inflow	Causes sludge deposits and anaerobic conditions in aquatic environments
Biodegradable Organics	Domestic and industrial waste	Cause biological degradation, which may use up oxygen in receiving water and result in undesirable conditions
Pathogens	Domestic waste	Transmit communicable diseases
Nutrients	Domestic and industrial wastes	May cause eutrophication
Refractory Organics	Industrial waste	May cause taste and odor problems, may be toxic or carcinogenic
Heavy Metals	Industrial waste, mining, etc.	Are toxic, may interfere with effluent reuse
Dissolved inorganic solids	Increases above level in water supply by domestic and/or industrial use	May interfere with effluent reuse

(St. John's Harbour ACAP, 1997, Table 2.7)

2.2 Current Waste Water Action Plans

The St. John's Atlantic Coastal Action Program (ACAP) was formed in 1993 to develop a Comprehensive Environmental Management Plan (CEMP) with the ultimate goal of the "rehabilitation and protection of the St. John's Harbour and its environs" (Dillon, 2002, p. iii). As a part of the CEMP, several waste water treatment methods have been extensively examined as a means of preventing the further contamination of the harbour. Prior to the construction of the Riverhead Wastewater Treatment facility, all sewage and storm drain runoff was diverted to the Southside of the harbour with the intent of pumping it through a tunnel under the Southside Hills into Gunner's Cove, St. John's Bay. Advanced levels of waste water treatment could then be progressively added as demand on the system increased.

Figure 4: St. John's Wastewater Collection, Treatment and Disposal Systems



(St. John's Harbour ACAP, 1997, p.iii)

This plan was suspended in the early 1980s when Federal funding was withdrawn (ACAP, 1997, p.1). The St. John's wastewater collection, treatment and disposal systems design can be seen in figure 4. These designs sought to treat sewage and waste water runoff at a facility on the South side of the harbour, or to pump it under the Southside Hills to a treatment facility in Gunner's Cove. Due to the costs of drilling a tunnel under the Southside Hills, the decisions was made to construct a wastewater treatment facility on the south side of the harbour. The project took nearly three years to complete and initially was projected to cost $93 million (Municipal and Provincial Affairs, 2005, para. 2). The Riverhead Wastewater Treatment facility entered production in 2009 and is expected to reach full production by the end of 2014, with the diversion of the final sewer outflow at Temperance Street to the facility (Breen & Mills, 2014, para. 3). With the last of the sewer outflows having been diverted, the amount of waste material entering the harbour will be severely reduced, which will allow for the reclamation of the harbour to a natural state.

2.3 Baseline Maps

In order to establish effective baselines for sediment deposition in St. John's harbour, it is important to have multiple surveys over the same geographic area over a lengthy time period. St. John's Harbour is very useful in this regard as it offers a protected area for the purposes of calibration and testing of multibeam equipment. Figure 5 shows the bathymetry for a survey conducted by the Canadian Hydrographic Service in 2005. A larger version of Figure 5 is provided in Appendix D. The sediment sampling sites from the Department of Fisheries and Oceans (DFO) survey in 1993 is shown in Appendix C, and can be used to determine the

Figure 5: St. John's Harbour – Bathymetry [2005]

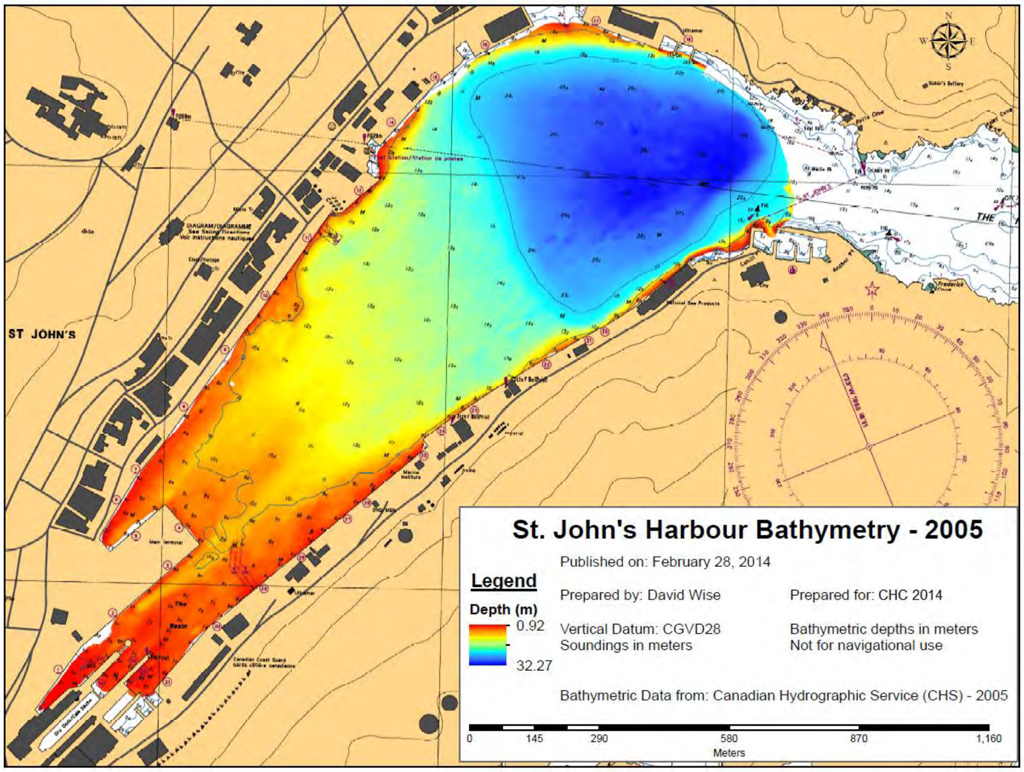
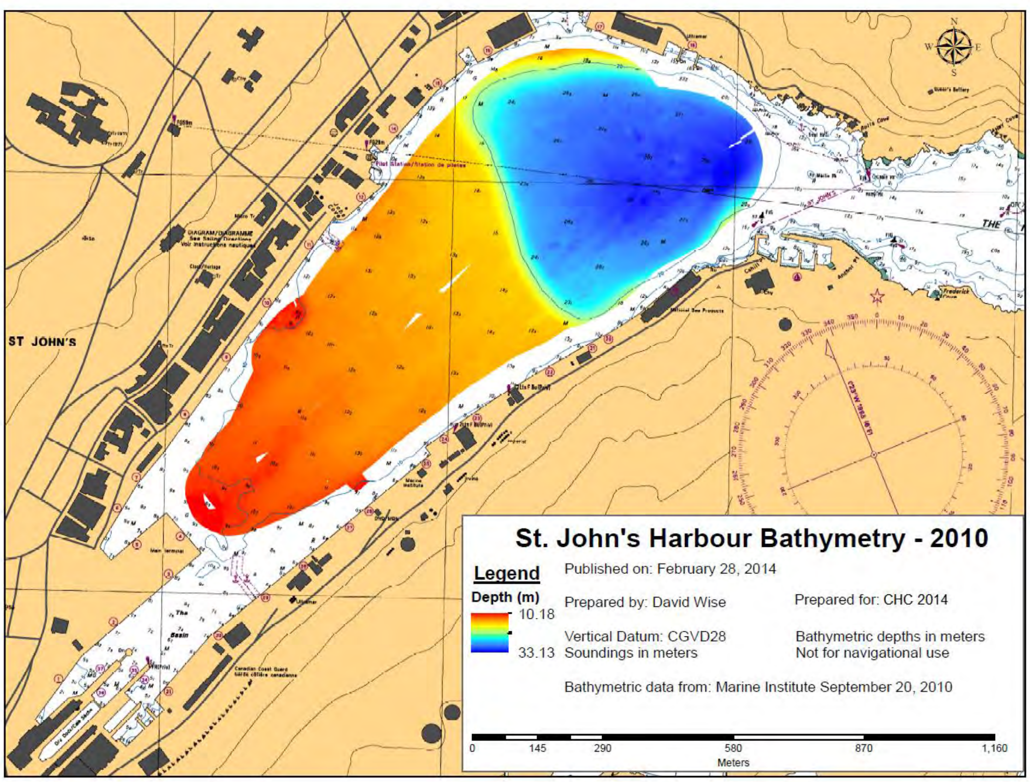


Figure 6: St. John's Harbour – Bathymetry [2010]



dimensions of the focus areas for the dredging operation

Figure 6 shows a similar survey of St. John's Harbour that was conducted by the Fisheries and Marine Institute's *M/V Atlanticat* in September 2010. This was one of several calibration surveys that were conducted by the Marine Institute as part of the multibeam system testing. A larger version of Figure 6 is provided in Appendix E. When the bathymetry for these two datasets is compared, areas of significant sedimentation can be identified as potential areas for sediment removal.

3.0 Dredging Methods

3.1 Dredging Operations

Figure 7: Grab Dredge

(Hi-Sea Marine, n.d.)

Modern dredging systems are classified based on the means by which the sediment is transported from the seabed to the surface. Mechanical (bucket) dredges use a container that is lowered to the seabed, then filled with sediment and retrieved. There are three configurations of mechanical dredges, commonly known as a grab, dipper or ladder.

Grab dredges, also known as clamshell dredges, employ a grab bucket on a derrick that is raised and lowered to the seabed by cables. The operator has a large degree of control over the placement of the bucket, meaning that this type of dredge is effective around piers and other hard to navigate spaces. Grab dredges are most effective at removing small till and other mixed soft sediments.

Figure 8: Dipper Dredge

(Technical and Maritime Services, 2014)

Dipper dredges have a similar design to the grab dredge, however the bucket is attached to the derrick, resembling an excavator. The operator again has a high level of control over the placement of the bucket, however this type of dredge is limited in its operating depth due to the length of the derrick arm. The dipper dredge is very effective at removing till and broken up rocks.

Figure 9: Ladder Dredge

(Rohr Dredge NA, 2011)

Ladder dredges consist of a chain of small buckets on a conveyor chain mounted on a dual derrick system. The ladder dredge is very limited in its range of motion, requiring frequent repositioning of the dredge in order to continue operations. Since the removed sediment is dumped into the dredge itself, operations must be regularly suspended so the dredge can be offloaded. A ladder dredge is very effective at removing soft sandy sediments.

Mechanical dredges are limited in the amount of material that can be removed from the seabed, as in most cases the grab container must be repeatedly raised and lowered to the seabed. Another limitation of the mechanical dredge is the need for a secondary method of transport for

Figure 10: Suction Dredge

(World Maritime News, 2012)

the removed sediment, either in the form of barges or trucks. For St. John's harbour, the removed sediments would likely be transported to the Robin Hood Bay Waste Management Facility for disposal, meaning large amounts of sediment would be removed and depending on the method of transport, there may be a risk of a contaminant spill in the city itself while the dredged material is being transferred to the disposal site.

Hydraulic dredges use a pump to pull water and suspended sediments from the seabed. There are two main types of hydraulic dredge, though there are multiple configurations for each type, as the suction heads are customized for different sediments.

Suction dredges consist of a forward or side facing suction pipe that extends through the hull of the vessel to a pump. The pump discharges water and suspended sediments into barges or hoppers. Modern suction dredges have high pressure water jets mounted around the head of the dredge, which are used to break up the sediment so it can be removed. Suction dredges work best when stationary and in soft sandy sediments.

Figure 11: Drag-head Dredge

(Damen Dredging Equipment, 2011)

Drag-head dredges consist of a specialized head attached to the suction pipe that is towed along by the vessel while it is underway. The head of the dredge must remain in contact with the bottom, and is customized for the expected material that is to be removed. Drag-head dredges are designed to work in rivers and in areas where there is room for the dredge to maneuver.

Modern dredges can also rely on compressed air for their operation as opposed to a water pump. Pneuma-dredges have the dredge head mounted directly to the pump, and the whole assembly is lowered into the sediment. The weight of the unit keeps it in contact with the sediment, which ensures a constant flow of material into rubber inlet pipes. The inlet pipes are flexible and not as heavy as steel, so the dredged material can be pumped over longer distances. Pneuma-dredges produce almost no turbidity, and the head is in continuous contact with the seabed. This dredge can be used in a trailing configuration, which uses the movement of the barge itself to force the dredge head into the sediment. As a result, it is possible to reach a very high solid content in the inlet mixture, up to 90 percent solids (Pneuma S.r.l. n.d. para 7). This makes the dredging more efficient, as the operation is removing mostly sediment with little water. This will result in more solid material per load being transported to Robin Hood Bay for disposal. In a trailing configuration, a pneuma-dredge is limited to a speed of "1-5 m/min depending on the compactness of the material to be dredged" (Pneuma S.r.l.,

Figure 12: Pneuma- Dredge

(Pneuma S.r.l., n.d.)

n.d. para 3). This is the main limitation for a pneuma-dredge, as the speed of the dredging process is only limited by the material to be dredged.

For all dredging operations, there is an issue with turbidity, that is, the sediments being stirred up during the dredging. In St. John's harbour, this presents an issue as the sediments that are going to be removed are contaminated with high concentrations of known carcinogens as well as heavy metals. Consequently, any dredging operation in the harbour will need to limit the turbidity of the dredging operation, but as St. John's is an active commercial port, the operation will also need to proceed quickly in order to limit the impact on commerce and tourism.

3.2 Turbidity

Turbidity is a "measure of [the] relative clarity of a liquid" (US Geological Survey (USGS), 2014, para. 1). It can be caused by "clay, silt, finely divided inorganic and organic matter, algae, soluble colored organic compounds, and plankton and other microscopic organisms" (USGS, 2014, para. 1). The results of turbidity measurements for different dredging techniques is detailed in Pennekamp et al. (1996) article, *Turbidity caused by dredging: Viewed in perspective*. The tables detailing these findings can be found in Appendix F. Turbidity is measured through four variables, depth-averaged background turbidity [C (mg/litre)], characteristic increase due to dredging [■C (mg/litre)], collapse time [■T (hours)] and suspension parameter [S (kg/m^3)]. Depth-averaged background turbidity is the regular levels of turbidity due to currents, tides and other regularly present factors. The characteristic increase due to dredging is "the average increase in turbidity on the edge of an area 50 x 50 meters around the center of the dredging" (Pennekamp et al. 1996). The collapse time is the period after the end of dredging activity until the plume is no longer observed at a height of 50 cm above the seabed. The suspension parameter is the volume of water bed material that is re-suspended in the surface water per cubic meter of dredged sea bed.

Based on the size of St. John's harbour, a smaller dredging operation will enable the removal of deposits of contaminated sediments while not significantly impacting the daily operations of the harbour.

3.3 Preferred Dredging Method

Based on the turbidity values that are presented in Appendix F, the dredging method that offers the lowest chance of dispersing the contaminated sediments during the dredging operations is the pneuma-dredge. This dredge doesn't require a large operations platform as compared to some of the other dredging types and is designed for the purposes of removing contaminated sediment. This is advantageous in St. John's Harbour as a smaller operation will not have a significant impact on commercial and tourism operations. The high solid content of this method of dredging will also allow for more sediment to be transported to Robin Hood Bay per trip for disposal, and will reduce the total dredging time for the removal of the contaminated sediments.

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4.0 Dredging St. John's Harbour

4.1 Focus Areas

Based on the location of the sewer outflows, there are three areas in St. John's Harbour that would be considered heavily contaminated and in need of dredging. The first focus area is on the north side of the harbour, between piers 16 and 17. The sediment sample taken in this area showed significant amounts of Phenanthrene, Fluoranthene, Pyrene, Chysene and DDE, as shown in figures 1-3. The second focus area is on the south side of the harbour, extending from piers 27-31. This area has elevated contamination levels that are consistent with the by-products of fuel spillage, paint and metal waste. This area is also the delta for the Waterford River, and the associated storm runoff for the Waterford River drainage basin. The third focus area is another known sewer outflow at Pier 11. This area has an area of built up sediments around the outflow that have raised the bottom height by almost a meter and a half in this area. A series of maps focusing on these areas can be found in Appendix G. Focus area 2 was the only area that had total coverage by multiple surveys, so a comparison layer indicating the change in bathymetry has been included in Appendix H.

4.2 Dredging Process

In order to dredge St. John's harbour, permits are required to be submitted to Environment Canada indicating the area to dredged, the method of dredging and the location and means of disposal. While the permit approval process is ongoing, the St. John's Harbour Authority will begin preparations to route shipping traffic around the operation. Once the permits have been approved by Environment Canada, the operation can begin. For this operation, focus area one would be dredged first, then focus area three and finally focus area two. This will allow for the most contaminated sediments to be removed first, then the area of highest sedimentation, and finally the shoal area. This dredging operation will consist of the dredge itself and 3-4 transport trucks. The flexible hose from the dredge will be attached to a shore station, and the dredged material will be pumped into a holding tank to permit dredging to continue while the transport trucks are being loaded. The advantage of the pneuma-dredge is the high solid content, which allows for the dredged material to be transported in either a covered container or a tank.

This configuration will allow for the dredge machinery to be in continuous production, with the potential for 24-hour operations, provided experienced crew and the access to the Robin Hood Bay Facility after-hours could be secured. For focus area 2, material would have to be transported to either the Oceanex main terminal or to the Canadian Coast Guard facility in order to minimize the length of hose needed to extend from the dredger to the shore. In the event that neither of these locations were available for 24-hour access, then two 20-tonne barges could be used to ferry the dredged material from the operation to a shore facility for loading onto the trucks. Once the material has reached the Robin Hood Bay Waste Management Facility, there are three potential methods that will allow for the disposal of the waste materials, consisting of composting, use of a reed bed, and dewatering.

4.3 Waste Material Disposal

The three methods of waste disposal that are mentioned in Cardoso's report, *Literature review and independent appraisal of biosolids management options for the St. John's harbour clean-up project* are, composting, reed beds and dewatering. With the composting process, contaminated sediments are dewatered, then mixed with municipal solid waste and allowed to decay in large concrete pits. After a period of 1-2 years, the solids have decomposed into a mineral rich soil which can then be used for fertilizer, erosion control, slope stabilization, roadside aesthetic improvements and land reclamation (Sylvis Environmental, n.d., Para 3).

Reed beds consist of large concrete beds with an impermeable liner, risers to distribute the waste material, a thin layer of sand or gravel to hold the reeds while the reed bed is established, and a drain to recycle the liquid (Witham, 2013, para. 3). Most reed beds use a type of marsh grass called *Phragmites communis*, a "tough adaptable plant, which can grow in polluted waters and find sustenance in sludge. This reed has a voracious appetite for water. The plant is tolerant to low oxygen levels and to waterlogged conditions" (Lagoon Systems in Maine, 2003, para. 3). Reed beds are advantageous in that they both dewater and transform the waste material into a soil-based fertilizer, and the facility can safely store sludge for a number of years.

Dewatering is a mechanical process in which excess water is removed from the waste material before it is sent for further processing in the form of composting, landfilling or incineration. The dewatering process can take several forms, depending on the amount of excess water to be removed, and the amount of material to be processed. Some common dewatering processes include air drying, vacuum filtration, centrifuges and belt filter presses (Cheremisinoff, 2003, p. 181-2).

Based on these three waste management systems, the use of reed beds would allow for heavy metals to be removed from the contaminated sediments. When combined with the composting method, dredged material from the harbour could be used for roadside aesthetic improvements or erosion control in 3-5 years (Lambert, Leven & Green, n.d. p.2). The advantage of the use of a combined composting method is that sludge from the Riverhead Waste Treatment facility could be added to the beds, extending the working life of the reed bed facility. The disadvantage of a reed bed facility is that the reeds must be harvested and composted/incinerated at the end of each growing season, in order to prevent the drainage pipes from becoming clogged with plant matter.

5.0 Dredging Project Limitations

In terms of this project, there was inordinate difficulty in attaining data that had adequate coverage to allow for the creation of comparison surfaces in order to determine areas of high sedimentation between surveys. The only area where an appropriate comparison surface was able to be generated was focus area 2, a map showing this surface can be found in Appendix H. For a dredging operation in St. John's Harbour, the critical limitation is funding. Table 3 gives a representative cost for the dredging operation, not including wages and the cost of the construction of the reed bed storage facility at Robin Hood Bay, of $9.2 million. These values are based on estimated costs from Pneuma S.r.l., one of the leading manufacturers of the pneuma-dredge system (n.d.). The maps showing the aforementioned focus areas can be found in Appendix G. The city of St. John's 2014 budget is projecting that without tax increases, the city will have a deficit of $8.1 million in 2015, and $15.6 million in 2016 (City of St. John's, 2014, p 17).

As a result of these costs combined with the projected deficit for the 2015-16 fiscal years, additional funding will need to be secured from the provincial and federal government in order to offset the cost of this project.

Table 3 – Dredging Cost by Area

Dredging Cost by Area		
Focus Area 1 [High Priority]		
	Amount	Unit
Surface to be dredged	30,560	sq.m.
Depth of sediment to be removed	0.50	m.
Total quantity of removed sediments	15,280	cu.m.
Estimated dredging cost	15.00	$/cu.m.
Total cost of dredging	229,200.00	$
Average treatment cost	150.00	$/cu.m.
Total treatment cost	2,292,000.00	$
Focus Area 2 [Low Priority]		
	Amount	Unit
Surface to be dredged	7,540	sq.m.
Depth of sediment to be removed	0.50	m.
Total quantity of removed sediments	3,770	cu.m.
Estimated dredging cost	15.00	$/cu.m.
Total cost of dredging	56,550.00	$
Average treatment cost	150.00	$/cu.m.
Total treatment cost	565,500.00	$
Focus Area 3 [Medium Priority]		
	Amount	Unit
Surface to be dredged	72,830	sq.m.
Depth of sediment to be removed	0.50	m.
Total quantity of removed sediments	36,415	cu.m.
Estimated dredging cost	15.00	$/cu.m.
Total cost of dredging	546,225.00	$
Average treatment cost	150.00	$/cu.m.
Total treatment cost	5,462,250.00	$
Total cost for Dredging		
Total amount of removed sediment	55,465	cu.m.
Total cost of dredging	9,151,725.00	$

(Wise, 2014)

6.0 Conclusion

St. John's Harbour has been used as a dumping ground for industrial and sewer waste for the past 400 years, and as a result, the sediments in the harbour have been heavily contaminated with pesticides, fuel, sewage and heavy metals. Sediment sampling that was conducted by the Department of Fisheries and Oceans in 1993, showed that contaminant levels in the harbour were up to ten thousand times the baseline samples from Robin Hood Bay. In order to remove these sediments, several dredging methods were briefly examined. Based on the amount of turbidity produced by each of the types of dredge, the dredging method that would best suit St. John's Harbour is the pneuma-dredge, which produces nearly no turbidity and has a high solid content for the output materials. This project then examined three disposal methods that could be used to neutralize the contaminants and compost the wastes into a serviceable fertilizer or nutrient rich soil additive. Based on the types of contaminants present in the harbour, the reed bed method of waste material disposal was deemed the most effective and low maintenance means of removing the contaminants and dewatering the remaining waste material. Due to projected shortfalls in the 2014-2016 fiscal years for the city of St. John's, it would not be appropriate to begin the construction of a new waste treatment facility at Robin Hood Bay and appropriate the required dredging equipment at this time.

7.0 Recommendations

Due to the projected financial shortage for the next few fiscal years, the city of St. John's will be unable to cover the associated costs linked with the dredging of contaminated sediments from the harbour at this time. With the routing of the Temperance Street outflow to the Riverhead Wastewater Treatment facility expected this year, the flow of untreated waste water into the harbour will end. As a result, the city of St. John's can start to focus on the reclamation of the harbour, the development of a secondary waste water treatment facility and begin to secure funds toward these goals. The question of the removal of contaminated sediment from the focus areas as determined by this project should be re-examined after the 2016 budget. If the city can make a significant contribution toward the total cost of the project, the remaining balance could be provided by the provincial and federal governments in the form of environmental grants.

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Acknowledgements

The author would like to thank Doug Cartwright, Paul Elliot and Christopher McCulloch from the Marine Institute for their insights and patience over the course of this paper.

Appendix A: Water Sampling Sites

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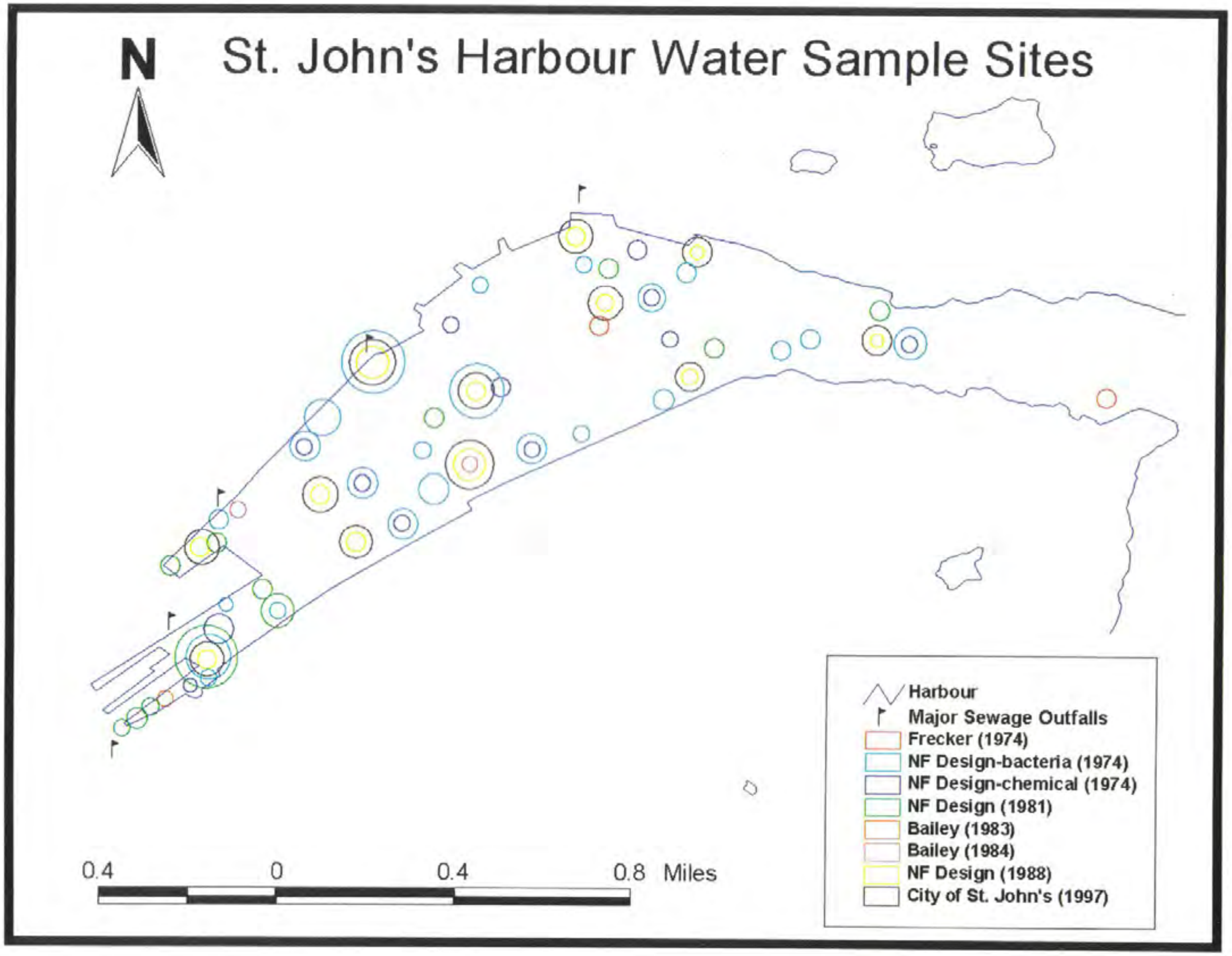

(Powell, 1998, Appendix F)

Appendix B: Sediment Sampling Sites

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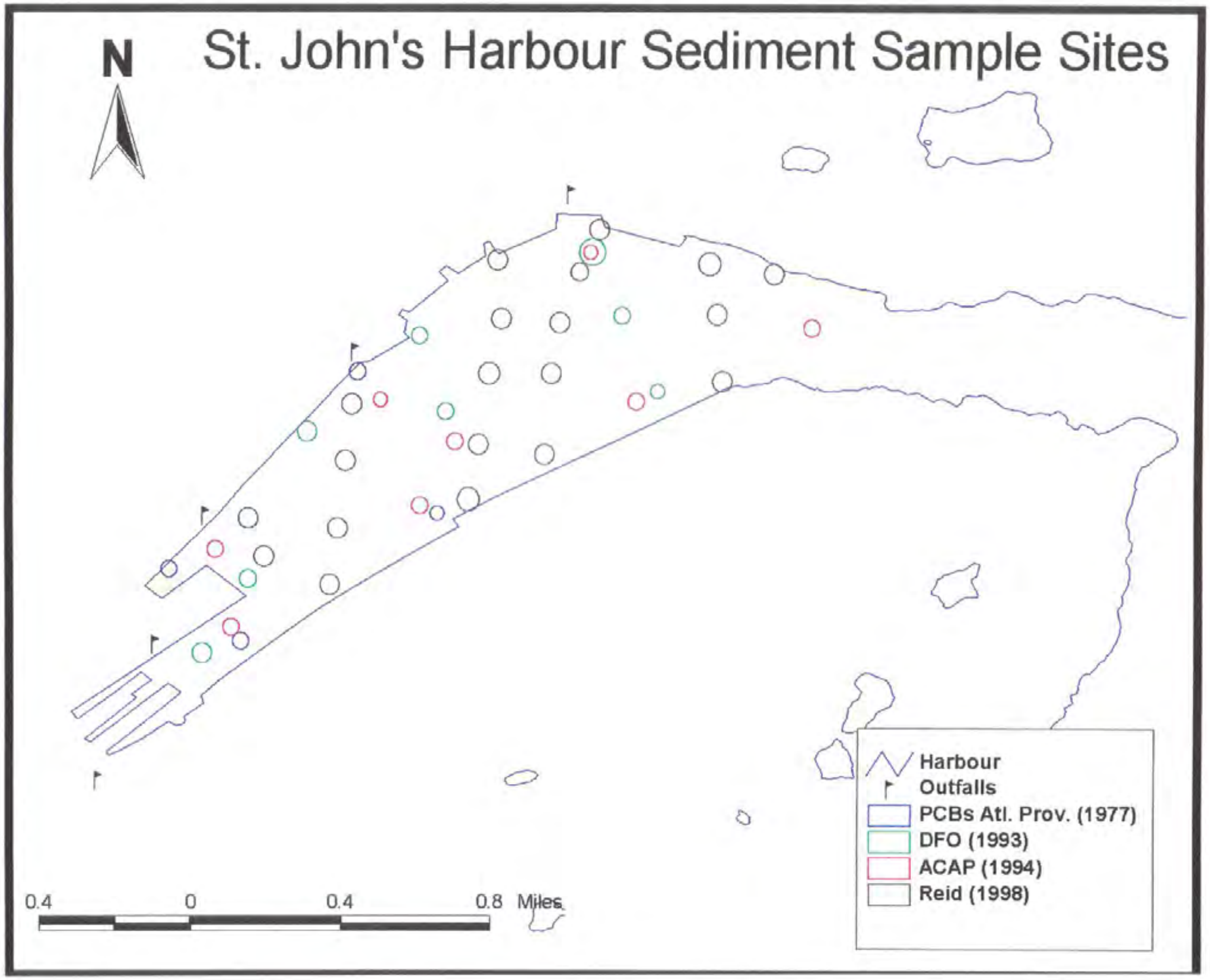

(Powell, 1998, Appendix G)

Appendix C: St. John’s Harbour Sediment Sample Sites - 1993

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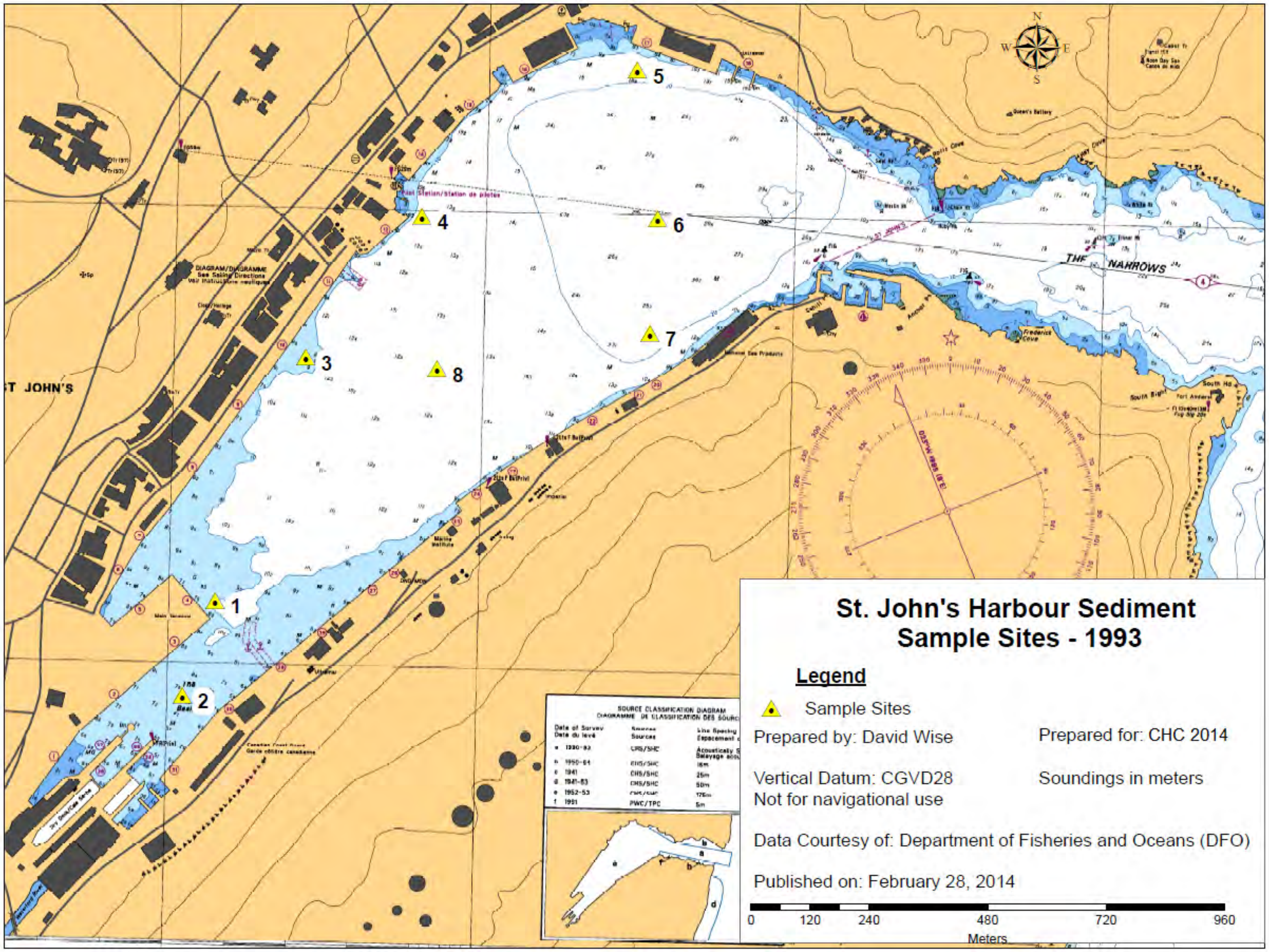

Appendix D: St. John’s Harbour – Bathymetry [2005]

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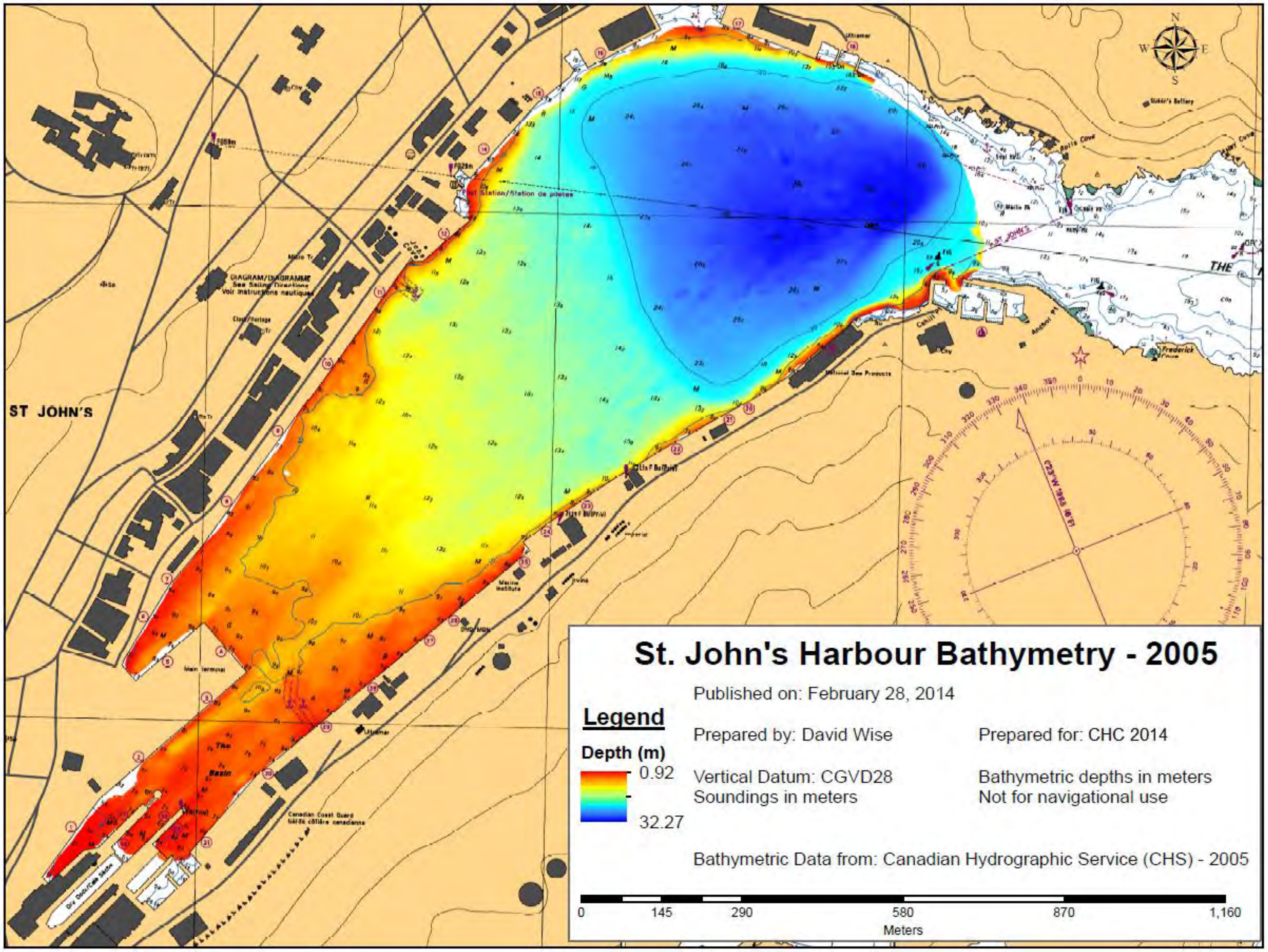

Appendix E: St. John's Harbour – Bathymetry [2010]

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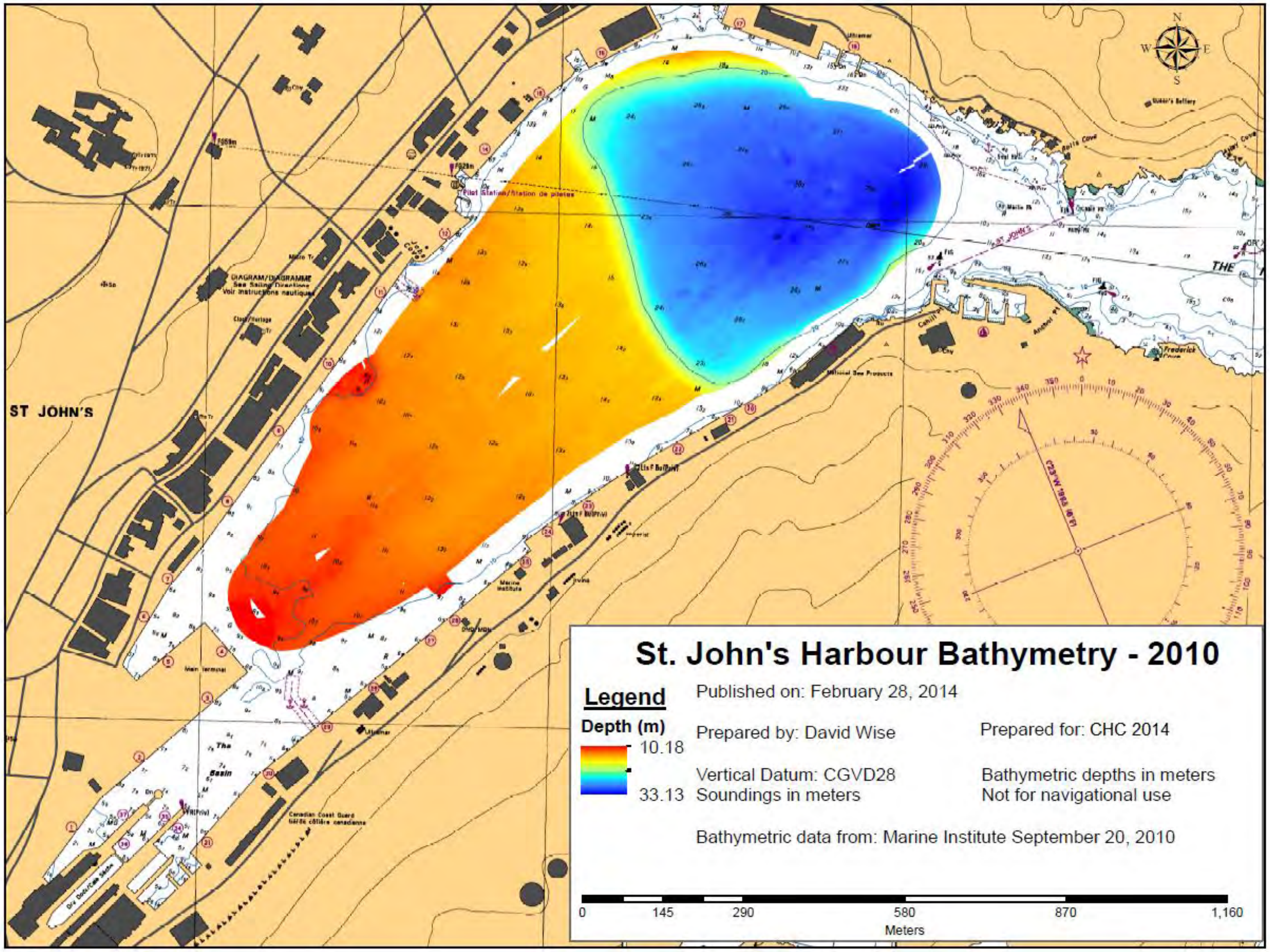


Appendix F: Turbidity by Dredging Method

Appendix F: Turbidity by Dredging Method

Table I. Turbidity parameters of the measurements dealing with hydraulic dredging techniques.

Hydraulic dredging techniques

Location	Production (m^3/hr)	C (mg/litre)	■C (mg/litre)	■T (hours)	S (kg/m^3)
Large Trailing Suction Hopper Dredge *"Cornelia"* with LMOB (Lean Mixture Over Board)					
Third Petroleum Harbour Rotterdam	5500	75	400	1	14
Large Trailing Suction Hopper Dredge *"Cornelia"* without LMOB (Lean Mixture Over Board)					
Third Petroleum Harbour Rotterdam	5400	40	150	1	3
Small Trailing Suction Hopper Dredge *"Kinhem"*, limited LMOB					
Sea Harbour Channel Delfzijl	1750	65	15	0.5	1-5
Small Trailing Suction Hopper Dredge *"Hein"*					
Laurens Harbour Rotterdam	2170	23	60	1	8-22
Pneuma-dredge system					
Berghaven Harbour Hook of Holland	59	25	0	0	0

Table III. Turbidity parameters of the measurements dealing with hydraulical/mechanical and agitation dredging techniques.

Hydraulical/mechanical and agitation dredging techniques

Location	Production (m^3/hour)	C (mg/litre)	■C (mg/litre)	■T (hours)	S (kg/m^3)
Environmental disc cutter					
Berg Harbour Hook of Holland	113	25	0	0	0
Auger "Willem Bever"					
Sea Harbour Canal Delfzijl	300	20-50	0	0.5	0
Siltcutter dredge *"Zsuzsa"*					
Industrial Harbour Heusden	115	45	10	0.5	2
Water injection dredge *"Jetsed"*					
Haringvliet Hellevoetsluis	*	20	30	0.5	*
Prototype water injection dredge *"Woelnix"*					
Merwe Harbour Rotterdam	3200	45	250	1.5	11
Bed leveller *"Pesante"*					
Waal Harbour Rotterdam	610	35	60	1	6

Table II. Turbidity parameters of measurements dealing with mechanical dredging techniques.

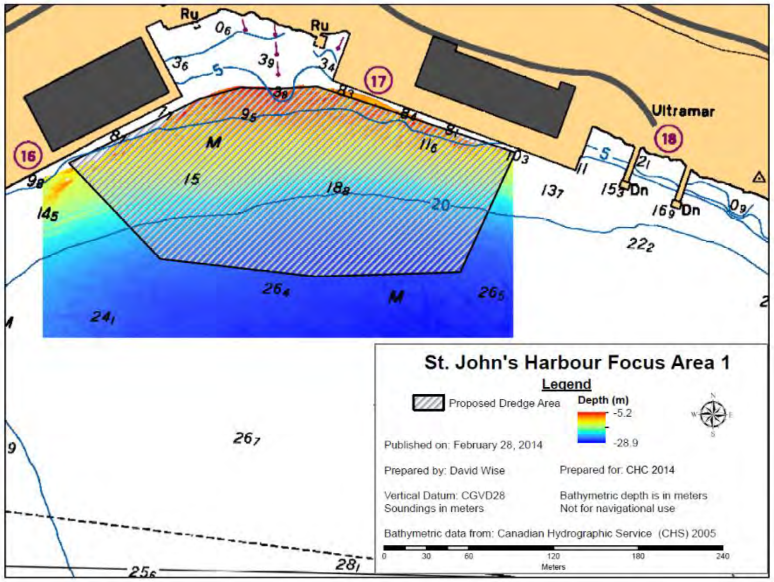
Mechanical dredging techniques

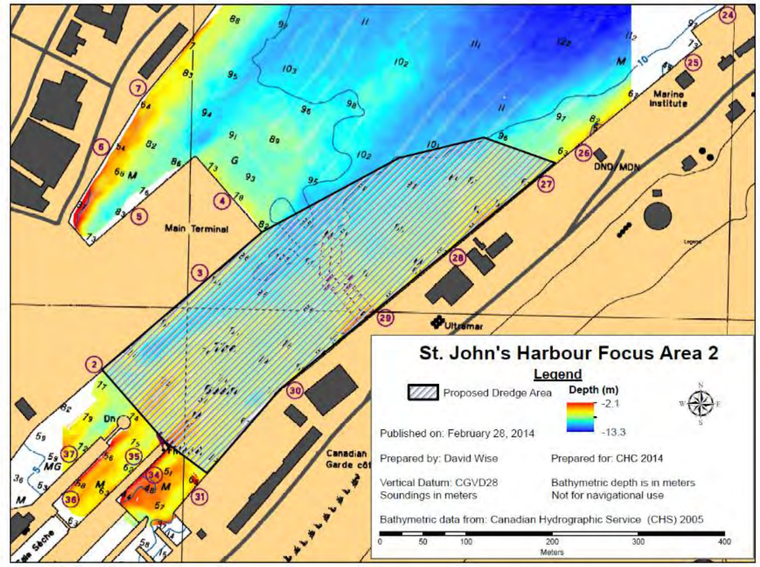
Location	Production (m^3/hr)	C (mg/litre)	■C (mg/litre)	■T (hours)	S (kg/m^3)
Dragline with open clamshell					
Merwe Harbour Rotterdam	90	20	35	1	3
Dragline with open clamshell and silt curtain					
Hollandse IJssel river Nieuwerkerk a/d IJssel	84	35	35	1	9
Dragline with watertight clamshell					
Hollandse IJssel river Nieuwerkerk a/d IJssel	166	35	100	1	19
Oude Haven 't Sas Zierikzee	220	50	90	1	11
First Petroleum Harbour Rotterdam	121	20	80	1	13
Dragline with watertight clamshell and silt curtain					
Hollandse IJssel river Nieuwerkerk a/d IJssel	102	35	20	1	3
Oude Haven 't Sas Zierikzee	204	50	105	1	11
Hydraulic crane with orange peel excavator and silt curtain					
Geul Harbour Rotterdam	130	50	100	1	6
Hydraulic crane with open backhoe					
Amsterdam-Rhine Canal, Wijk bij Duurstede	208	40	530	0.5	54
Hydraulic crane with closed visor backhoe					
Amsterdam-Rhine Canal, Wijk bij Duurstede	199	45	170	0.5	21
Bucket dredge *"Saturn"*					
North Sea Canal Amsterdam	714	15	110	1	18-21
Bucket dredge *"Aalscholver"*, adapted for environmental efficiency					
2nd Inner Harbour Scheveningen	296	48	20-35	0.5	3-5

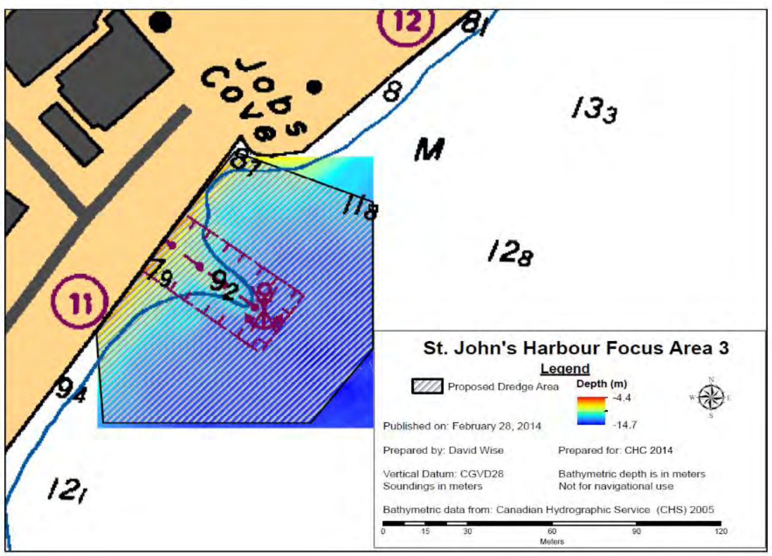
(Pennekamp et. all, 1996, pp. 15-17)

Appendix G: Focus Areas

Appendix G: Focus Areas







Appendix H: St. John’s Harbour – Focus Area 2 Comparison

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