Sediment Quality Analysis and Related Management Approaches in Halifax Harbour

By

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ABSTRACT

Halifax Harbour is one of the world's deepest harbours (AMEC Earth & Environmental, 2011). It is sheltered, spacious, and has minimal currents and tides (Robinson, Hui, Soo, & Hellou, 2009). The ice free port leaves the harbour accessible year round, and it is the closest port of call for ships operating the North Atlantic, Round-the-World and Suez routes (AMEC Earth & Environmental, 2011). These advantageous natural conditions have made Halifax Harbour one of the largest commercial ports in Canada and home of Canada's east coast Navy. In addition to being a major shipping port, industrial centre, naval centre and research centre, Halifax Harbour is surrounded by one of the fastest growing urban regions in Atlantic Canada (Chairpefkon, Thirumurthi, Parker, & Griffiths, 1993). Increasingly, the Harbour's ecosystems have been placed under stress as a result of intensive human activities along its shorelines. Since the colonization of the area 250 years ago, Halifax Harbour has been a receptacle for raw sewage and industrial wastes (Federico & Henderson, 2001).

Environmental assessments show that acute chemical components in the water and sediments still have great potential hazards to the health of human and biota (AMEC Earth & Environmental, 2011). Harbour sediments have historically tended to be hotspots of contamination due to direct and indirect cause related to anthropogenic activities developed in the area such as shipping-related activities, industries, presence of highly populated areas, rivers and other discharges. Dredging and disposal processes can release pollutants bound to contaminated sediments and make them available to the biota.

The purpose of this research is to contribute to the efforts focused on minimizing the level and exposure to contaminants in Halifax Harbour by both humans and marine organisms linked to the harbour environment. This will be done by understanding the importance of sediment quality for a costal ecosystem, analyzing how it is affecting environmental and human health, identifying the potential contributing sources of these contaminants, and the current monitoring and evaluation strategies and governance frameworks aimed at controlling contaminant levels in Halifax Harbour.

This research findings will be relevant in assisting with recovery plans for threatened and endangered species frequenting the harbour. It will also provide needed information to assist identified sources of the contaminants to mitigate against the continued pollution of these contaminants into the harbour. Similarly, regulators will be provided with recommendations aimed at improving management of priority contaminants through the use of best practices.

Keywords: Halifax Harbour, sediment quality, contaminants, integrated coastal management, coastal environment

1. INTRODUCTION

Occupying 71% of the Earth's surface, the ocean has been supporting human activities in a variety of ways, including marine transportation, resource developments, fishing and aquaculture, residential developments, as well as sewage inputs. Starting from the 1860s, with the industrial revolution, human activities expanded to the world of ocean. Within a century, these activities have dramatically changed the characters of the oceans. Marine industry has grown rapidly: maritime transportation of oil has reached more than 2 billion tons annually (El-Said, 2013). For fisheries industries, annual catch of the fish and shellfish is nearly 100 million tons (Stewart & White, 2001; Dahlen, Hunt, Emsbo-Mattingly, & Keay, 2006), and has become the major source of protein intakes for daily lives. Nowadays, over 60% of the world population lives within 60 km of the sea, and depend directly or indirectly on coastal and marine ecosystem for their livelihood (UNEP-WCMC, 2011; Velmurugan, Swarnam, & Lal, 2015). Along with the development of science and technology, the awareness of health conditions of ocean has increased, especially for the coastal areas along harbour cities.

It is well known that the ocean is linked to the global environment and human activities in various ways. Therefore, a healthy coastal environment is crucial for the health of human and marine biota. In recent decades, among a wide range of global environmental issues, ocean pollution is causing a surge in attention and has become one of the heaviest pressures faced by human beings and the environment.

The importance of sediment quality and its intimate connection to the sustainable coastal environment has been acknowledged and studied since early 1990s (Munawar, Dermott, McCarthy, Munawar, & Stam, 1999; Crane, 2003; Branch, 2013). In recent years, scientists has revealed the important role played by marine sediments more comprehensively. Compared to water quality, sediment quality in harbour areas are affecting the health of the coastal ecosystem in a more powerful way (Willford, Mac, & Hesselberg, 1987; Forbes, Forbes, Giessing, Hansen, & Kure, 1998; Munawar et al., 1999; Ghada Farouk El-Said, 2013).

1.1 RESEARCH PURPOSE

The purpose of this research is to contribute to the efforts focused on minimizing the level and exposure to contaminants in Halifax Harbour by both humans and marine organisms linked to the harbour environment. This will be done by understanding the importance of sediment quality for a costal ecosystem, analyzing how it is affecting environmental and human health, identifying the potential contributing sources of these contaminants, and the current monitoring and evaluation strategies and governance frameworks aimed at controlling contaminant levels in Halifax Harbour. By analyzing gaps and mismatches in the monitoring strategies for identified priority contaminant, management recommendations will be developed so as to improve the existing governance framework, thereby contributing to the requirement to protect both human health and marine biota using the harbour environment, particularly those that are legally-protected species at risk.

Halifax Harbour is chosen to be the focus of the case study, as it is the major port city on the east coast of Canada with multiple ocean related activities. By identifying potential contributing sources, discussing the impacts of contaminated sediments, and evaluating existing policies and management plans, this research is intended to find management gaps and opportunities to recommend solutions for improvements. Data and information will be obtained primarily from desktop research (primary, secondary and ‘grey literature’ documentation), supplemented by governmental information on monitoring processes currently in place for assessing and responding to current contaminant levels in the harbour. Research to identify monitoring procedures undertaken in other jurisdictions, such as San Francisco, U.S., will be undertaken to identify best practices which may contribute to recommendations for Halifax Harbour.

2. THE BROAD CONTEXT OF SEDIMENT QUALITY

Prior to discussing the research focus and analysis, it is essential to fully understand the role sediment is playing in a coastal ecosystem by answering the following questions: Why is sediment important? How can sediment affect environmental and human health? Where do contaminants come from? What are the priority and new emerging pollutants?

2.1 THE IMPORTANCE OF SEDIMENT QUALITY

First of all, most contaminants released to the water will eventually end up in the sediments. Research and studies using a variety of designs in the field are critical to prioritizing pollutants of concern in contaminated areas, devising mitigation strategies and documenting environmental responses (Borja et al., 2004; Morales & Ross, 2015). Sediments have been routinely used to evaluate integrated pollutant inputs into aquatic environments, as they are regarded as both ‘sinks’ and potential ‘sources’ for adjacent food webs (Adams, Kimerle, & Barnett, 1992; Tolun et al., 2001; Moreira, Lima, Ribeiro, & Guilhermino, 2006; Grant et al., 2011; Burd, Macdonald, Macdonald, & Ross, 2014). Studies show that harmful contaminants, such as pathogens, nutrients, metals, and organic chemicals, tend to sorb onto both inorganic and organic materials that eventually settle and lead to accumulation in the sediments of rivers, reservoirs, lakes, estuaries, and marine waters (Burton Jr, 2002; Robinson et al., 2009).

Second, there is a variety of ways for humans and the biota to be exposed to the contaminants in sediments. Starting from the benthos from the sediment, contaminants will be accessed through the consumption of seafood and local foods (Kelly & Gobas, 2001; Koenig et al., 2008; Kelly, Mattson, McDonald, Nielsen, & Weir, 2014). If the loading of these contaminants into the waterways is large enough, the sediments may accumulate excessive quantities of contaminants that directly and indirectly disrupt the ecosystem, causing significant contamination and loss of desirable species (Burton Jr, 2002). The impacts on the ecosystem from sediment-associated contaminant have been found to have a wide range (Burton Jr, 2002), from direct effects on benthic communities (Canfield et al., 1994; Swartz et al., 1994) to substantial contributions to contaminant loads and effects on upper trophic levels through food chain contamination (e.g., for tree swallows, Bishop, Mahony, Trudeau & Pettit, 1999; McCarty & Secord, 1999; for mink, Foley, Jackling, Sloan & Brown, 1988; for Caspian terns Ludwig et al., 1993). According to Mackay (1991) and Burton (2002), “the ecosystem is an interconnected series of pathways whereby chemical, physical, and biological contaminants move between the four primary compartments of air, surface and ground waters, land, and biota (MacKay, 1991)” (P.66). Therefore, the sediment quality will eventually affect the health situation of the whole marine ecosystem. More significant harmful effects can be observed at higher tropic levels, such as sharks and marine mammals (killer whales, sea lions, sea otters, etc.). In this sense, tracing and ensuring the quality of the sediments is crucial and fundamental from a management perspective in order to protect the endangered and threatened marine species listed under the Species at Risk Act (SARA) (EC, 2008). For human health issues, when contaminants bioaccumulate in food sources such as shellfish, trout, salmon or ducks, they pose a threat to human health (El-Said & Draz, 2010; El-Sikaily & El-Said, 2010; Qiao et al., 2010; US EPA, 2012; El-Said, 2013). Possible long-term effects of eating contaminated fish include cancer and neurological defects (US EPA, 2012). Therefore, it is highly possible for human and biota to have acute exposures to multiple harbour contaminants in a wide range.

Third, in recent decades, urbanization and the expanding population in coastal areas have increased the sources of pollutants entering harbour environments, triggering more challenges in terms of effective management approaches and risks for environmental health (McCauley, DeGraeve, & Linton, 2000; Long, 2006). Human activities in coastal areas, such as harbours, usually involve an input of contaminants to the natural environment that becomes evident in the decreased quality of coastal sediments (Morales-Caselles et al., 2008). The importance of the environmental quality of the sediments and its intimate connection to the sustainable coastal environment has been acknowledged and studied since early 1990s (Munawar et al., 1999; Crane, 2003). Five major pollutant sources are: industry, shipping and harbour, agro-forestry, urban developments, and home and garden. Pollutants such as trace metals, plastics, oils, pesticides, household chemicals herbicides and cleaning agents, Pharmaceuticals and Personal Care Products (PPCPs), radioactive substances, nutrients and solid waste may come from industry waste discharge, urban sewage, shipping and harbour activities, aquaculture and agriculture, run-offs, as well as tourism businesses among others (Buckley, Smith, & Winters, 1995; Federico & Henderson, 2001; Dahlen et al., 2006; Ruus et al., 2013). Compared to the low rate of natural decomposition, the daily metabolic wastes from the cities are far higher than what nature can bear. Moreover, many chemicals will transform or react with each other into more complex and toxic contaminants, which makes it even more difficult to predict and anticipate the risk of pollutants (El-Said & Draz, 2010).

Moreover, the effects of sediment contaminants are long-term and chronic (Tueros et al., 2009; Elhakeem & Elshorbagy, 2013). After World War II, a large number of chemical weapons were dumped and buried into the ocean as a way of disposing of the excess military uses, most of them are along harbour areas (Burton Jr, 2002). It remains unclear the amounts of pollutants released through this type of activities. In addition, prior to 1990s, there was a lack of information and understanding of marine pollution and sediment contamination among researchers and managers. The absence of sewage treatment at the initial period of urbanization has led to the discharge of large amounts of untreated waste waters directly into the ocean. Halifax, for example, did not have any sewage treatment program before 2000 (Buckley et al., 1995; Timoney, 2007), and all of the urban sewage and industrial waste water were poured directly into the harbour without any prior treatment. Once in the water column, contaminants might settle and accumulate into the sediments at certain areas, such as those where the water flows slowly (Burton Jr, 2002). Studies in these types of lotic systems have detected toxicity in both the bottom and mobile suspended seston components (Munawar et al., 1999). The natural decomposition process takes a long time, and some contaminants such as trace metals and microplastics can be considered as non-degradable. The risk posed by historical contaminated sediments is that they might resuspend due to a storm, a boat propeller or dredging activities (Carmen Morales-Caselles, Gao, Ross, & Fanning, 2015). The resuspension of contaminated sediments into the water column will directly expose other organisms, not just the bottom-dwelling organisms, to toxic contaminants (US EPA, 2012).

Last but not least, up until now, there has not been a completely safe and effective way to purify contaminants from sediments. A variety of remediation technologies exist for cleanup, but they tend to be expensive and the most common method is still dredging (Averett, Perry, Torrey, & Miller, 1990; Burton Jr, 2002). The downside of this technique is that dredging will disrupt the bottom of the ocean and release a certain amount of contaminants that will become available to other organisms in the aquatic system (Long, 2006; Mamindy-Pajany et al., 2011). Therefore, dredging works may sometimes increase the exposure of human and biota to the contaminants. As such it is important that research and management efforts focus on preventing the contaminants from entering the harbours as a more effective approach.

2.2 ANTHROPOGENIC SOURCES OF CONTAMINANTS

In order to solve the problem of tracing and regulating the harbour environment, it is essential to identify and control the sources of pollutants. Five categories of human activities: industry, shipping and harbour, urban, home & garden and agri-forestry cause pollutants to enter terrestrial, atmospheric and marine ecosystems, which then contributed to major sources of sediment contaminants (Shahidul Islam & Tanaka, 2004; Dagnino & Viarengo, 2014).

Harbour contaminants might include sewage, oil, heavy metals, pesticides, PCBs, radioactive substances, nutrients and solid waste among others (Belan, 2004; Morales-Caselles et al., 2008). Several classes of contaminants have been previously identified as potentially related to port activities, while others may originate from external sources (Table 1).

Table 1: Putative contaminants of concern in a harbour

CONTAMINANTS OF CONCERN		
Known – Port related activities	Likely – Port related activities	Likely – external sources
Metals	Flame retardants	Organochlorine Pesticides
Hydrocarbons	Perfluorinated compounds	Current Use Pesticides
Polychlorinated biphenyls	Dioxins	Pharmaceuticals
Organotins (TBT)	Furans	Personal Care Products
	Alkylphenols	Microplastics
		Neonicotinoid pesticides
		Phthalate ester
		Chlorinated paraffins

(Source: Morales-Caselles et al., 2015)

For terrestrial ecosystems, effects are from urban developments, home and garden activities, industrial growth and agri-forestry uses. Related sources including solid contaminants, ground water and upstream water pollutions, run-offs, urban and industrial sewage, pesticides etc., which contains contaminants such as oil, heavy metals, pesticides, Polychlorinated Biphenyls (PCBs), PPCPs, radioactive substances and micro-plastics (Belan, 2004; Morales-Caselles et al., 2008). Trace metals might come from industrial pollution such as the burning of coals and municipal waste incinerations (Je, Belan, Levings, & Koo, 2004). Pesticides and cleaning agents are mainly derived from agriculture, forestry and aquaculture, as well as urban sewage and run-off. Based on the combined drivers of analytical chemistry and emerging toxicity profiles, certain classes of chemicals are increasingly featured within the peer-reviewed literature (Hernández-Arana, Rowden, Attrill, Warwick, & Gold-Bouchot, 2003; Roose, Yocum, & Popelkova, 2011). Attention continues to focus on persistent, bioaccumulative and toxic substances and as scientific knowledge advances, the scope of concern goes beyond what it is currently covered by international programs (IMO, 2015a). In recent years, the increasing population and urbanization, PCBs, PPCPs, solid waste, micro-plastics and other substances have increased dramatically (Federico & Henderson, 2001; Belan, 2004; AMEC Earth & Environmental, 2011; Ruus et al., 2013), leading to higher safety risks for marine environment and human health. Newly emerging contaminants such as pharmaceuticals and personal care products (PPCPs) still need to be examined for their potential to bioaccumulate and biomagnify (Lachmuth & Canadian Science Advisory Secretariat, 2010; Morales & Ross, 2015). Many of the compounds in these products are common in waste water effluent and may affect the health of living organisms (Appendix 1).

For marine ecosystem, human activities such as aquaculture, shipping and harbour loading, ship painting and cleaning, naval uses, the release of ballast water and dredging works are now seriously affecting the balance of nature (Morales-Caselles et al., 2015). Hydrocarbon contamination poses a particular concern, especially in areas with high maritime traffic, and has caught the attention of scientists, the public and the social media. According to statistics, 45% of hydrocarbon inputs in the marine environment come from marine transport whereas 32% are spilled through routinely loading operations and boat cleaning (Morales-Caselles et al., 2008).

All five categories of human activities are going to release pollutants into the atmosphere. With the emission and dissolve processes, contaminants from the air are about to enter the harbour marine ecosystem and finally end up into the sediments.

For Halifax Harbour, studies show that the main sources of pollution are approximately 100 untreated sewage outfalls that come from private homes, light industry, government and university laboratories, military bases, and hospitals (Buckley et al., 1995; Scott et al., 2005; Dabbous & Scott, 2012). These outfalls discharge 181 ML/day of organic and inorganic pollutants into the harbor (Halifax Regional Municipality, 2006; Dabbous &

Scott, 2012). PAHs, one of the most widespread organic compounds recorded in the sediments, are considered persistent pollutants with levels above the minimum established by environmental quality guidelines (Tay et al., 1992; Hellou, King, Steller, & Yeats, 2002). It is estimated that the annual input of the heavy metals to Halifax Harbour are as follows: copper (10,700 kg/yr), zinc (36,000 kg/yr), lead (34,600 kg/yr), and mercury (185 kg/yr). These amounts are among the highest recorded in marine harbors worldwide (Buckley et al., 1995; Dabbous & Scott, 2012). These contaminants are able to affect the human health and marine biota, and give an odorous smell to the harbor, diminishing its recreational value (Arvai, Levings, Harrison, & Neill, 2002; Halifax Regional Municipality, 2006; Timoney, 2007).

In addition to the three major sources and five categories of human activities, other factors are also drawing scientists' attentions in recent years. For instance, the effects of global warming including gradual increase of water temperature and ocean acidification, might lead to the release of the contaminants and secondary reactions. (Timoney, 2007; Morales-Caselles et al., 2015). Many of these contaminants, especially organic components, are potentially able to react with each other in aquatic environment to form new, unpredictable chemicals (Lachmuth & Canadian Science Advisory Secretariat, 2010; Morales & Ross, 2015).

Nowadays harbour areas are facing multiple, wide range of challenges. Through the development of comprehensive, high quality and harmonized monitoring, harbours and other hotspots of contamination can provide early warning signs of emerging contaminants in a very useful way. Historical problems combined with newly emerging contaminants makes the coastal environment more vulnerable than ever before, and thus are urgently in need of better scientific understandings, public awareness, and regulatory approaches (Lachmuth & Canadian Science Advisory Secretariat, 2010; Onorati, Mugnai, Pulcini, & Gabellini, 2012).

3. INTRODUCTION TO HALIFAX HARBOUR

Halifax Harbour, as one of the most important harbours in Canada, is chosen to be the focus of this research. It is Canada's major shipping port, industrial centre, naval centre, research centre, and tourism attraction. The harbour ecosystem is highly influenced by multiple human activities, which means that a well-developed coastal management method is crucial for the sustainability of the harbour area.

3.1 OCEANOGRAPHY

Halifax Harbour is one of the world's deepest harbours at a depth of 18 metres at low tide (AMEC Earth & Environmental, 2011). It is sheltered, spacious, and has minimal currents and tides. The ice free port leaves the harbour accessible year round and it is the closest port of call for ships operating the North Atlantic, Round-the-World and Suez routes (AMEC Earth & Environmental, 2011). "The harbor receives a high influx of freshwater from the Sackville River, which flows into the northern end of the Bedford Basin (Figure 1), and through sewage outfalls along its margins."(Dabbous & Scott, 2012, P.188). Because of this influx and the semi-enclosed shape, Halifax Harbour ideally has a two-layered-flow estuarine circulation model in which marine water enters through the harbor mouth below the fresh water that in turn flows over the denser seawater out of the harbor (Figure 2) (Dabbous & Scott, 2012). Stormy weather disrupts this circulation pattern, during which ocean waters will enter near the surface and fresh waters exit near the bottom (Fader, 2008), especially during tropical storms and hurricanes (Shan, 2010; Dabbous & Scott, 2012)."

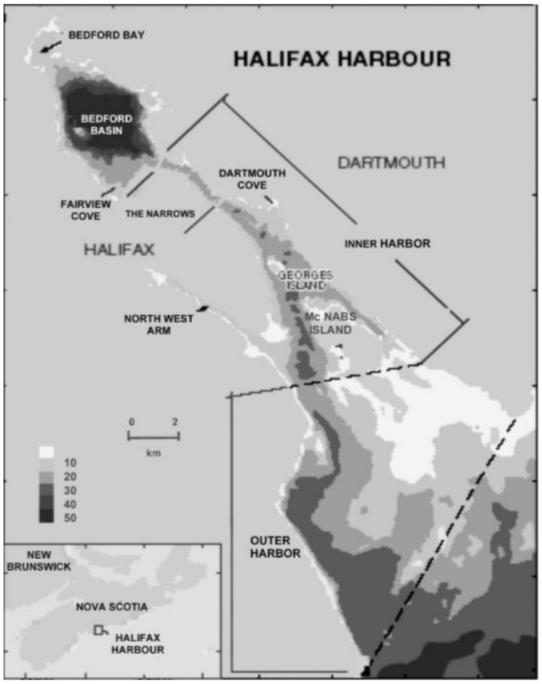

Figure 1. Map showing location, geographic divisions, and water depths of Halifax Harbour (Sources: Fader, 2008; Dabbous & Scott, 2012).

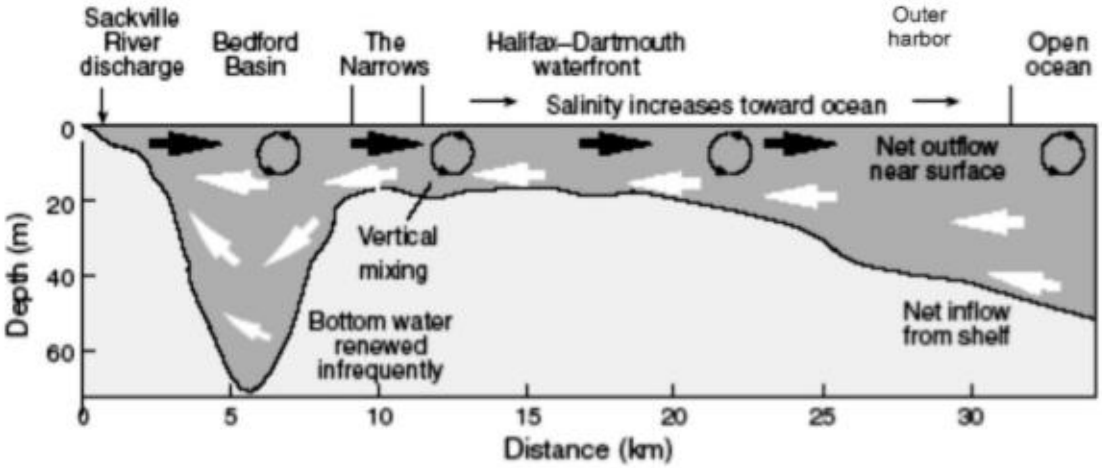

Figure 2. Simplified water circulation model of Halifax Harbour from Bedford Basin to the harbor mouth (Sources: Fader, 2008; Dabbous & Scott, 2012).

3.2 Human Activities

The advantageous natural conditions have made Halifax Harbour one of the largest commercial ports in Canada and home of Canada's east coast Navy (Dabbous & Scott, 2012). In addition to being a major shipping port, industrial centre, naval centre and research centre, Halifax Harbour is surrounded by one of the fastest growing urban regions in Atlantic Canada (Chairpefkon et al., 1993; AMEC Earth & Environmental, 2011). Nova Scotians and tourists value the Harbour's recreational opportunities and the aesthetic dimension it adds to this urban centre. The population of Halifax is booming, year 2007 to 2013 has witnessed the population growth from 223,000 to 504,000 in five years (The Greater Halifax Partnership, 2014). A 3.8% increase was calculated from year 2001 to 2006, and reached 8.1% from 2005 to 2010 (The Greater Halifax Partnership, 2014). Shipping activities are also becoming busier. In May 2009, The CKYH Alliance, which are five Southeast Asia shipping lines, commenced service with the Port of Halifax from Asia, via the Panama Canal, with eight Panamax vessels, which are one of the world's biggest ships (The Greater Halifax Partnership, 2014). Two major oil companies are putting more into offshore exploration in Nova Scotia than any other offshore in the world (The Greater Halifax Partnership, 2014). In addition, the local businesses have increased and is expected to keep accelerating within 10 years. One of the area's urban plan including building a vibrant and attractive Regional Centre that attracts $1.5 billion of private investment and 8,000 more residents by 2016 (HRM, 2014). As a result of all these changes, sediment quality and management approaches in Halifax region need to be better examined.

3.3 BIOLOGY

Halifax Harbour is a diverse environment being the home of low trophic-level organisms such as phytoplankton, seaweeds and benthic invertebrates as well as individuals higher in the food chain including fish, birds and marine mammals. In short, this harbour has an extraordinary ecological value. According to related government reports, the harbour environment supports a variety of species at all level, including microbes, plankton, macrobenthos (lobster, mussels, polychaetes, etc.), fish and mammals (HRM & DFO, 2001a, 2001b). The existence of these species highlights the values for coastal biodiversity and for commercial fisheries. Therefore, a biologically healthy harbour represents a healthy harbour ecosystem, as well as healthy food sources for human. However, the Harbour's ecosystems have progressively been placed under stress as a result of intensive human activity along its shorelines. Since the colonization of the area 250 years ago, Halifax Harbour has been a receptacle for raw sewage and industrial wastes (Federico & Henderson, 2001) that has impacted the ecological equilibrium of the area. Studies from 1990s show that the contaminants detected in the organisms are generally below the human health levels (Fournier, 1990; HRM & DFO, 2001b), but further research needs to be done to assess multiple levels of risks after thirty years of developments.

3.4 HISTORICAL OVERVIEW

The harbor has been a disposal site for urban waste materials since the founding of the city of Halifax in 1749 (Dabbous & Scott, 2012). Targeting the environmental health of Halifax Harbour, projects and scientific research have been launched by multiple organizations both governmental and non-governmental.

At the governance level, two main projects were launched in 1990s and the early 2000s for environmental monitoring. In November 1990, the federal and provincial Ministers of the Environment jointly appointed an independent Environmental Assessment Panel to conduct a review of the proposal by Halifax Harbour Cleanup Inc. (HHCI) to design and construct a Halifax-Dartmouth Metropolitan Sewage Treatment Facility (the "Halifax Harbour Cleanup Project", also known as Halifax Harbour Task Force) (Chairpefkon et al., 1993). The implementation of this program has made dramatic improvements on the source control of Volatile Organic Compounds (VOC) and other chemical contaminants to Halifax Harbour, and thus has improved the water quality (JWEL, COAI, & ARTM, 2001).

Halifax Harbour started the Harbour Solutions Project in the 2000s. In 2007, the Halifax Regional Municipality (HRM) began construction of a three-plant treatment system (one in downtown Halifax, downtown Dartmouth, and Herring Cove on the southwest side of the harbor, as well as extensive collector piping to close all sewage outfalls into the harbour and redirect sewage into the treatment plants) to provide advanced primary treatment of the sewage outfalls that pour into the harbour. The three facilities, projected to cost $400 million (Canadian), were expected to improve conditions in the harbor dramatically (Figure 3). The first to open on February 11, 2008, was the Halifax Waste-Water Treatment Facility (WWTF). "The Halifax plant incurred a massive failure after one year of operation, and raw sewage flowed again into the harbor, causing extensive odor and large floater problems. By June 2010, the three WWTFs were fully operational and began treating sewage" (Dabbous & Scott, 2012, P.189-191). However, other than WWTF, the present operating approaches are still raw and immature. Environmental assessments show that acute chemical components in the water and sediments still present great potential hazards to the health of human and biota (AMEC Earth & Environmental, 2011).

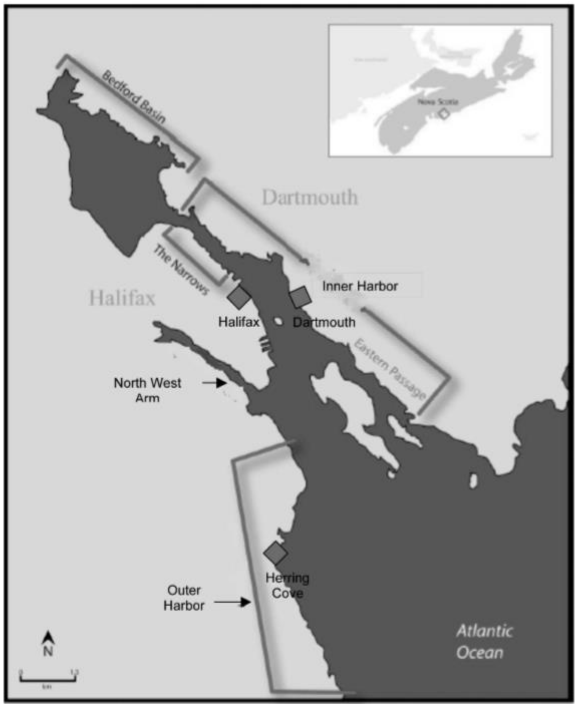

Figure 3. Location of waste-water treatment facilities (WWTFs) in Halifax, Dartmouth, and Herring Cove (Sources: Dabbous & Scott, 2012)

At the non-governmental level, much scientific research have been done to address the importance of sediment quality to the harbour environment. The majority of these studies targeted contamination but focused mainly on the geochemistry of the sediments and water analyses (e.g., Buckley, 1989; Winters & Atlantic Geoscience Centre, 1991; Fader & Buckley, 1995; Williams, 2010). In 1995, Buckley et al., did a historical review of the concentrations of contaminants in sediment samples, and concluded that historical trends in the changing dominance of these environmental factors reflect changes in industrial activity, urban growth, and changes in the use of metals in paints, domestic and industrial chemicals, and in the combustion of fuels (Buckley, Smith & Winters, 1995). Microscale Toxicity Tests method was explored by Wells et al. in 1996, 1999 and 2001 as a fast and affordable way to assess the toxicity of harbour sediments (Cook & Wells, 1996; Wells, 1999; Wells, Depledge, Butler, Manock, & Knap, 2001). In the article *Trends in the Distribution of PCBs Compared to PACs in Sediments and Mussels of Halifax Harbour* and *Distribution of PACs in surficial sediments and bioavailability to mussels, Mytilus edulis of Halifax Harbour*, Hellou et al. (2002 a, b) compared the concentration of contaminants in mussels and sediments, and concluded that food could represent a substantial source of contaminants for mussels (Hellou, Steller, et al., 2002; J. Y. Hellou, King, et al., 2002). J. Hellou et al., (2010) evaluated the wastewater treatment in Halifax Harbour based on the studies of marine sediment chemistries, and concluded that there are no substantially changes on the concentrations of polycyclic aromatic hydrocarbons (PAHs), lead, zinc, and copper in the past two decades, while there are decreases in the concentrations of mercury and increases in the concentrations of alkylated PAHs. In 2012, research on short-term monitoring of Halifax Harbour pollution remediation using benthonic foraminifera as proxies by Dabbous and Scott (2012) show that the inner harbour and North West Arm of Halifax Harbour is highly polluted, and that even though changes can be detected after the sewage treatment facilities have been built, long-term environmental assessments are still needed. Numerous studies suggested that a baseline is needed for sediment contaminants in Halifax Harbour (Tay et al., 1992; Scott et al., 2005; Robinson & Hellou, 2009; Robinson et al., 2009); Bioaccumulation factors and long-term risk assessments are suggested in other research (Burton Jr, 2002; McLachlan, Czub, MacLeod, & Arnot, 2011; Benedetti et al., 2012; El-Said, 2013; Burd et al., 2014). Recent studies done by Mathalon & Hill (2014) aimed at detecting microplastics in Halifax Harbour by testing mussels, showed that more microplastics were enumerated in farmed mussels compared to wild ones.

3.5 THE SITUATION NOW

In the meantime, related management vulnerabilities are increasingly prominent. Studies show that about 80% of Halifax Harbour sewershed still entered Halifax Harbour untreated (AMEC Earth & Environmental, 2011). Under the present advanced primary sewage operating approach, only the solids are removed, dewatered and transported, other chemical components which are dissolved in the liquid, such as pharmaceuticals and agrochemicals, are still not well managed (Figure 4). According to Hellou et al. (2010), water quality has improved sufficiently after the launch of waste water treatment facilities in Halifax, while no evidence of improvements to marine sediment quality were observed. This indicate the need to monitor sediment quality as part of harbour quality screening programs (Hellou et al., 2010). A study in 2009 indicate that open-ocean conditions in the outer harbour except inside Herring Cove that is polluted by a waste-water outfall discharge of ~15 ML/day, and that little significant environmental change are observed in untreated areas of Halifax Harbour (Robinson & Hellou, 2009; Dabbous & Scott, 2012).

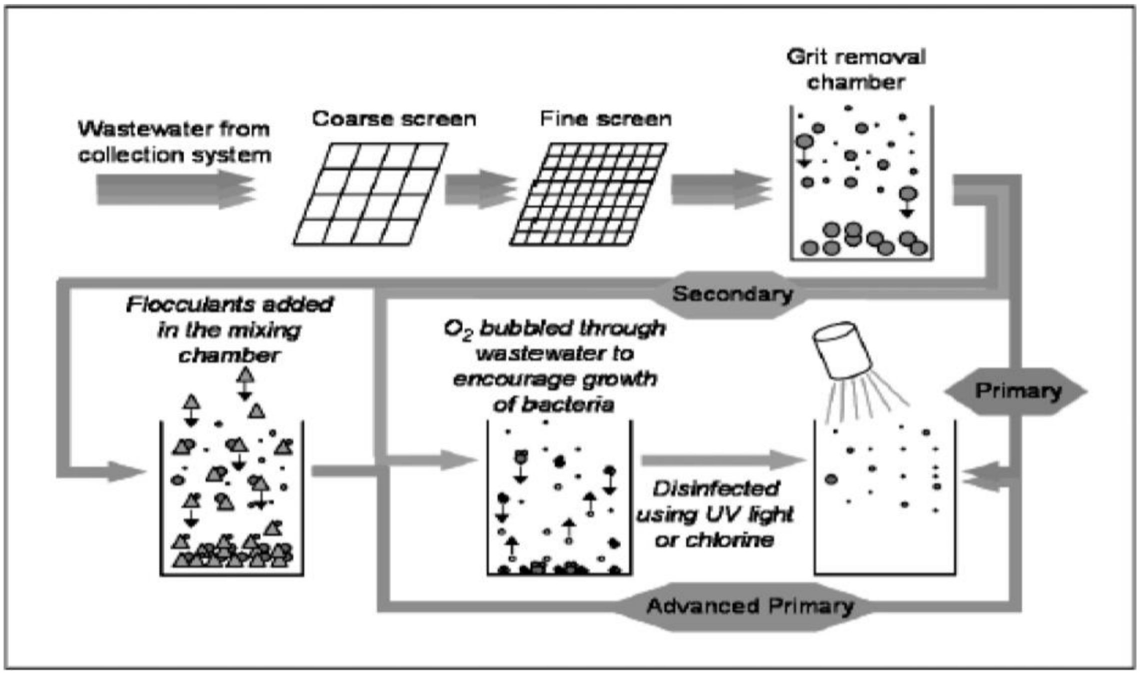

Figure 4. WWTF processes in Halifax Harbour
(Source: Williams, 2010)

It is suggested that in order to improve the water and sediment quality in the harbour, it is essential to control and monitor the potential sources (Fournier, 1990). In the case of Halifax Harbour, the multiple uses of harbour areas lead to various potential contaminant sources. Thus comprehensive and systematic management strategies are urgently in need to satisfactorily protect the sediment and water column quality, as well as the public health. However, up until now, depending on the existing policies, the controls of contaminant sources are mainly focusing on land-based pollution, which is important but not enough. Even though it is well studied that shipping is a major source of hydrocarbons and other anthropogenic contaminants, relative regulation approaches are weak. According to Stewart and White (2001), "Associated with ship traffic are incidental and accidental releases of hydrocarbons from tank and ballast water clearing and bilge operations; releases of metals from sacrificial anodes (plates of metals such as lead and zinc which corrode preferentially in seawater and leave other ship metal intact) and antifouling paints;

marine litter and garbage disposal from routine disposal from routine disposal practices; and spills of fuel chemicals, and ship debris and cargoes from ship accidents. Accidental releases of hydrocarbons from vessel and tanker traffic account for more hydrocarbons reaching the marine environment than the occasional major oil spills." (P.20)

In addition, among various shipping activities, the military use of the harbour for navy activities is another important and unique component. Studies show that water and sediments in many bays, harbours and coastal waters used by navies are contaminated with potentially harmful metal and organic compounds (Chadwick & Lieberman, 2009).

These unique conditions of Halifax Harbour discussed above have increased the sensitivity and vulnerability of the Harbour environment, leading to concerns for both the health of the public and the marine biota that frequent the harbour, including any threatened and endangered species that fall under Canada's Species at Risk Act. However, the existing regulatory approaches in Halifax Harbour have poorly addressed monitoring the contaminants in order to protect the public health or quality of the marine environment.

4. HALIFAX HARBOUR SEDIMENT QUALITY ANALYSIS

Based on the previous studies, the sediment quality in Halifax Harbour is in a process of dynamic change. Even though there is no complete database of sediment contaminants for Halifax Harbour, related information can be collected by the published documents. The sediment quality analysis in this research summarizes data from previous studies to have an understanding of historical changes and trends (Table 2). To assess the level of contamination, the sediment quality guideline used in the analysis is Sediment Quality Guidelines for the Protection of Aquatic Life (Freshwater and Marine ISQG/PEL)

(CCME, 1998) from Canadian Council of Ministers of the Environment (CCME), and Sediment Quality Guideline from Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) which is the national guideline for sediment quality in Canada, Australia and New Zealand. For Sediment Quality Guidelines for the Protection of Aquatic Life, ISQG means Interim Sediment Quality Guideline, and PEL is Probable Effect Level. In ANZECC/ARMCANZ, the two levels, low and high, represents trigger level and high risk level. Further in-situ research is requested when the sediment contaminants reach the trigger level.

Table 2: Inner Harbour Sediment Contaminants in Halifax Harbour, Related Sediment Quality Guidelines and On-Going Activities

Contaminant	Halifax Harbour	Date	Source of Data	Environmental Quality Guideline (Canada)	Concentration for Human Health (Canada)	ISQG-Low /ISQG-High (Australian Department of the Environment, 2000)
METALS (mg/kg dry wt)						
Antimony				No data		2/25
Cadmium	0.1 0.4 0.34	1992 1999 2010	Tay et al. (1992) HRM J. Hellou et al. (2010)[a]	0.7/4.2	400-500 µg/week	1.5/10
Chromium	28	2010		52.3/160		80/370
Copper	30 ±8 53 66 55 100	Pre 1890[b] 1992 1999 2010 20th century[b]	Buckley et al. (1995) Tay et al. (1992) HRM J. Hellou et al. (2010) Buckley et al. (1995)	18.7/108	100 (marine and freshwater animal products)	65/270
Lead	5 ±39 134 110 68 130	Pre 1890 1992 1999 2010 20th century	Buckley et al. (1995) Tay et al. (1992) HRM J. Hellou et al. (2010) Buckley et al.	30.2/112	0.5 (fish tissue)	50/220

Contaminant	Halifax Harbour	Date	Source of Data	Environmental Quality Guideline (Canada)	Concentration for Human Health (Canada)	ISQG-Low /ISQG-High (Australian Department of the Environment, 2000)
			(1995)			
Mercury	0.5 ±0.4 0.6 0.55 0.42 2.9	Pre 1890 1992 1999 2010 20th century	Buckley et al. (1995) Tay et al. (1992) HRM J. Hellou et al. (2010) Buckley et al. (1995)	0.13/0.70	0.5 (fish tissue)	0.15/1
Nickel				No data		21/52
Silver				No data		1/3.7
Zinc	101 ±14 608 170 125 280	Pre 1890 1992 1999 2010 20th century	Buckley et al. (1995) Tay et al. (1992) HRM J. Hellou et al. (2010) Buckley et al. (1995)	124/271	100 (fish tissue)	200/410
METALLOIDS (mg/kg dry wt)						
Arsenic	34	1992	Tay et al. (1992)	7.24/41.6	5 (Fish Tissue) 3.5 (Fish Protein)	20/70
ORGANOMETALLICS						

Contaminant	Halifax Harbour	Date	Source of Data	Environmental Quality Guideline (Canada)	Concentration for Human Health (Canada)	ISQG-Low /ISQG-High (Australian Department of the Environment, 2000)
Tributyltin (µg Sn/kg dry wt)				No data		5/70
ORGANICS (µg/kg dry wt)						
Acenapthene	<6	1992	Tay et al. (1992)	6.71/88.9		16/500
Acenaphthalene				5.87/128		44/640
Anthracene	<10	1992	Tay et al. (1992)	46.9/245		85/1100
Fluorene	190	1992	Tay et al. (1992)	21.2/144		19/540
Naphthalene	<10	1992	Tay et al. (1992)	34.6/391		160/2100
Phenanthrene	<4	1992	Tay et al. (1992)	86.7/544		240/1500
Low Molecular Weight PAHs[b]				No data		552/3160
Benzo(a)anthracene	400	1992	Tay et al. (1992)	74.8/693		261/1600
Benzo(a)pyrene	690	1992	Tay et al. (1992)	88.8/763		430/1600
Dibenzo(a,h)anthracene	<1	1992	Tay et al. (1992)	6.22/135		63/260
Chrysene	<7	1992	Tay et al. (1992)	108/846		384/2800
Fluoranthene	1130	1992	Tay et al. (1992)	113/1494		600/5100

Contaminant	Halifax Harbour	Date	Source of Data	Environmental Quality Guideline (Canada)	Concentration for Human Health (Canada)	ISQG-Low /ISQG-High (Australian Department of the Environment, 2000)
Pyrene	1450	1992	Tay et al. (1992)	153/1398		665/2600
High Molecular Weight PAHs				No data		1700/9600
Total PAHs	4370 4617	1992 2010	Tay et al. (1992) J. Hellou et al. (2010)[c]	No data		4000/45000
Total DDT				1.19/4.77		1.6/46
p.p’-DDE				2.07/7.81		2.2/27
o,p’- + p,p’-DDD				2.26/4.79		2/20
Chlordane				0.71/4.3		0.5/6
Dieldrin				2.67/62.4[d]		0.02/8
Endrin				0.32/0.99		0.02/8
Lindane				21.5/189		0.23/1
Total PCBs	0.84 0.3	1999 2002	HRM Hellou et al.	0.85/21.5	2 (fish tissues)	23/-
PCDD/Fs (ng ·kg-1 dw)						

a: data source: mean level of chemical concentrations at location D2 from J. Hellou et al. (2010)

b: maximum concentration in 20th century estimated by Buckley et al. (1995)

c: data source: total PAH concentrations from station 8 at the depth of 15 meters from J. Hellou et al. (2010)

d: Provisional guideline, adoption of freshwater ISQG/PEL (CCME, 1998)

Usually, sediment quality assessments for Halifax Harbour are based on samples from more than five locations. In this research, data are focusing on the chemical concentrations of the inner harbour for the following reasons: 1) water flow and mixture is at medium level which indicates the mean level of geographical situation; 2) it is at the location of cargo ships and cruise ships, so that shipping related activities are able to have impacts on sediment qualities; 3) it is close to the industrial centre of both Halifax and Dartmouth region, with a long history of sewage discharges; 4) it is located next to, but not too close to the sewage treatment facility, which means that the launch of the sewage treatment plans may or may not have impacts on changing the sediment qualities. These factors make the inner Harbour able to represent the mean level of the sediment situations in Halifax Harbour.

As shown in Table 2, sediment contaminants at the inner harbour area in Halifax Harbour shows dramatic increases from 1890s to 2000s. For metals and metalloids, the level of Copper, Lead, Mercury, Zinc, and Arsenic in sediment samples are all above the Interim Sediment Quality Guideline (CCME, 1998). For organics, Fluorene, Benzo(a)anthracene, Benzo(a)pyrene, Fluoranthene, Pyrene and total PCBs level are above the quality guideline (CCME, 1998), indicating hazards to the health of aquatic environment and humans. Moreover, compared to the quality guideline of Australia and New Zealand, Canadian sediment quality guide shows problems of lacking important chemical data guidelines.

Table 2 also indicates the lack of data for sediment quality. Even though numerous studies have been done to assess the chemical levels in Halifax Harbour, the majority of them are focusing on water quality. While among the studies that focus on sediment quality, different authors adopt different approaches in instrumentation and methodology (Hellou et al., 2010). Several studies collect sediment samples in the Harbour (i.e. Tay et al., 1992, Buckley et al., 1995; Ginn, Rajaratnam, Cumming, & Smol, 2015), some are detecting the concentration in benthic organisms (i.e. mussels: Hellou et al., 2002; foraminifera: Murray, 1971, Dabbous & Scott, 2012; lobster: Buckley et al., 1989), some are using Microscale Toxicity Tests method(Cook & Wells, 1996; Wells, 1999; Wells et al., 2001). Therefore, it is difficult to get a lineal background information for sediment contaminants to compare with each other. In addition, studies are always focusing on different contaminants. For example, Buckley et al. (1995) and Tay et al. (1992) focus their research on metals, while Hellou et al. (2002) focuses on PACs and PCBs. In summary, individual projects or studies are not able to provide enough information for the general overview for management purposes. A complete baseline or database is in need for scientific references as well as monitoring purposes.

5. CURRENT GOVERNANCE AND MANAGEMENT EFFORTS

The highly integrated harbour activities and the involvement of multiple stakeholders make the situation in Halifax unique and complex. No single government agency is completely responsible for addressing the problem of contaminated sediments. A variety of laws give municipal, regional and provincial, and federal agencies authority to address sediment quality issues. Private industry and the public also have roles to play in contaminated sediment prevention (US EPA, 2012). The following environmental related governance frameworks are contributing to achieve a healthy ecosystem. Even though some are not targeting sediment quality, they are still been concerned in this research as the approaches are able to contribute to sediments indirectly.

5.1 FEDERAL

Multiple federal legislations are related to environmental health. Related government sectors are taking responsibilities and regulations to implement the law and by-laws. At this level, legislation is the major tool to provide guidance. Related legislation and regulation frameworks are listed in Table 3. It shows that the system to ensure human and environmental health in Canada involves multiple agencies, projects and complex policies. Federal department include Environment Canada (EC), Department of Fisheries and Oceans (DFO), Department of National Defence (DND), Transport Canada (TC), Halifax Port Authority (HPA), Health Canada (HC). The regulation net is crossing multiple jurisdictions, which shows the need for an efficient collaboration between the agencies.

Table 3: Overview of General Management guidelines for Human Health, Ecological Risk Assessment, and Their Key Features (Canada)

Government Agency	Legislations and Policy Frameworks	Description and key features
The Interdepartmental Committees on Oceans	Oceans Action Plan (OAP)	It includes federal departments and agencies involved in the oceans, to promote collaboration, synergies and economics
Environment Canada	Canadian Environmental Protection Act (CEPA 1999)	An act respecting pollution prevention and the protection of the environment and human health in order to contribute to sustainable development. The Canadian Environmental Protection Act, 1999 came into force on March 31, 2000 and has been updated to include all amendments.
	Canadian Environmental Quality Guidelines	
	Federal Contaminated Sites Action Plan (FCSAP)	
	Persistence and Bioaccumulation Regulations (2000)	
	Canadian Marine Sediment Quality Guidelines	
	Canadian Freshwater Sediment Quality Guidelines	
	Canadian Sediment Quality Criteria	
	Ontario Ministry of Environment Screening Level Guidelines	
	Tissue Residue Guidelines	
	Regulations and the Storage of PCB Material Regulations	
Department of Fisheries and Oceans	Oceans Act 1997	Three principles: Sustainable development; integrated management; the precautionary approach (DFO, 2015a)
	Fisheries Act	Key Priorities: Environmental sustainability; economic viability; the inclusion of stakeholders in decision-making processes
	Species at Risk Act (SARA)	To protect wildlife species at risk, including fish, reptiles, marine mammals and molluscs.
	Aboriginal Fisheries Strategy/An Integrated Aboriginal Policy Framework	

Government Agency	Legislations and Policy Frameworks	Description and key features
	A Fishery Decision-Making Framework Incorporating the Precautionary Approach	
	Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas	
	Ecological Risk Assessment Framework (ERAF) for Coldwater Corals and Sponge Dominated Communities	
	Vessel Replacement Rules and Procedures on Atlantic Coast – Discussion Paper	
	Large Ocean Management Areas (LOMAs)	LOMAs are established to advance collaborative management. For each LOMA, all levels of government, Aboriginal groups, industry organizations, environmental and community groups and academia work together to develop a strategic, long-term plan for sustainable management of resources within its boundaries (DFO, 2015b).
	Marine Protected Areas (MPAs)	To protect and conserve: commercial and non-commercial fishery resources and their habitats; endangered marine species and their habitats; unique habitats; marine areas of high biodiversity or biological productivity; any other marine resource or habitat necessary to fulfill the Minister's mandate
Transport Canada	Canada Transportation Act (2014)	The government of Canada's commitment to meeting the transportation challenges and opportunities of the next decade in a sustainable manner
	Canada Shipping Act (2001)	To protect the health and well-being of individuals, vessels; promote safety in marine transportation; protect the marine environment from damage due to navigation and shipping activities…
	Marine Environmental Protection	The environmental protection division is responsible for the development and management of regulations, guidelines, various official Transport Canada Publications (TPs), programs and initiatives that focus on the prevention of pollution in maritime operations.
	National Environmental Man-	The NEMS includes everything TC do

Government Agency	Legislations and Policy Frameworks	Description and key features
	agement System (NEMS)	to manage the environmental obligations. By determining and understanding how TC's operations, services and products impact the environment, objectives and targets to be set to reduce those impacts.
	Marine Pollution Prevention in the Atlantic Region	
	Canadian Ballast Water Program	
	Marine Pollution Sources and Regulations	Air pollution; anti-fouling systems; ballast water; garbage; marine pollutants in package form; noxious liquid substances and dangerous chemicals; oil; sewage
	Canadian Marine Advisory Council (CMAC) – a member of the Canadian delegation at the IMO Marine Environmental Protection Committee.	Transport Canada's national consultative body for marine matters. Meetings are normally held twice a year in the spring and fall, nationally in Ottawa.
Canadian Coast Guard	Marine Spills Contingency Plan	The Canadian Coast Guard is responsible for ensuring the clean-up of all oil, and other noxious substance spills in Canadian waters.
	Tank truck to marine vessel oil transfer manual	
	CCG Environmental Response Program	
Natural Resources Canada	Natural Resources Canada's (NRCan) Adaptation Platform	Brings together Canada's institutional, financial and knowledge resources to enable development and widespread use of adaptation information and tools.
Canadian Council of Ministers of the Environment (CCME)	Canadian Environmental Guidelines	
	Federal Contaminated Sited Action Plan (FCSAP)	
Health Canada (Jardine et al., 2003, P.581-582)	Decision-Making Framework for Identifying, Assessing and Managing Health Risks (Health Canada, 2000)	Based on the Framework for Risk Management (US), replacing the 1990 framework
	Health Risk Determination: The Challenge of Health Protection (Health and Welfare Canada, 1990; Jardine et al., 2003)	Used as the model for health risk assessment and management by the federal government until 2000

Government Agency	Legislations and Policy Frameworks	Description and key features
	CSA-Q850 Risk Management: Guidelines for Decision-Makers (Canadian Standards Association, 1997)	Provides generic guidance to government and industry for many types of risk
	CSA-Z763 Introduction to Environmental Risk Assessment Studies (Canadian Standards Association, 1996)	Published as a companion to CSA-Q850, and based on CSA-Q634-91; stresses that environmental risk assessment is part of good corporate environmental policy
	CSA-Q634-91 Risk Analysis Requirements and Guidelines (Canadian Public Health Association, 1991)	Developed primarily to address the occupational risk from exposure to hazardous materials or processes
	Integrated Risk Management Framework (Treasury Board of Canada, 2011)	Designed to provide guidance to advance the use of a more corporate and systematic approach to risk management, and to assist public service employees in their decision making

(Source: adapted from Jardine et al. (2003))

5.2 REGIONAL AND PROVINCIAL

The Government of Nova Scotia is the main actor at this level. In 2010, the Government of Nova Scotia published the document *Water for Life*: Nova Scotia's water resource management which aims to integrate different levels of government work. According to the document, the provincial government intends for Nova Scotia to have one of the most environmentally and economically sustainable ways of life in the world by 2020. The water resources in the province can be managed by municipal, provincial, or federal governments. This creates complex and overlapping responsibilities which can make managing water resources difficult. The water strategy aims to integrate water management to ease this problem. It is proposed in the document *Water for Life* that Nova Scotia Environment (NSE) is going to be the leading agency for pollution prevention. The following are the legislation and regulations which govern contaminated sites in Nova Scotia – *En-*

vironment Act (amendments); Contaminated Sites Regulations; Petroleum Management Regulations; Environmental Emergency Regulations.

5.3 MUNICIPAL

Halifax Regional Municipality (HRM), specifically the department of Halifax Water, is the leading agency for the sewage treatment project launched in 2000s. It is now playing a role in regulating water quality, "to provide our customers with high quality water, wastewater, and stormwater services" ("Mission Statement | Halifax.ca," 2015.). Under the regulation of Halifax Water, two programs are launched to improve the system performance, *Stormwater Inflow Reduction (SIR) Program* for infiltration reduction and *Pollution Prevention Program* for pollution prevention. Related legislation and regulations include *Halifax Regional Water Commission Act*, *Halifax Regional Municipality Charter and Halifax Water Rules and Regulations*.

5.4 INTERNATIONAL

At the international level, multiple countries and organizations have contributed their efforts to integrate science and technology into management frameworks and international agreements. International Maritime Organization (IMO), for example, keeps addressing on ocean based environmental issues. Under the regulation of IMO, several international treaties have been signed globally, including "London Convention" and International Convention for the Prevention of Pollution from Ships (MARPOL). The "*Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972*", the "*London Convention*" for short, is one of the first global conventions to protect the marine environment from human activities and has been in force since 1975 (IMO, 2015a).

In 1973, IMO adopted the International Convention for the Prevention of Pollution from Ships, now known universally as MARPOL, which has been amended by the Protocols of 1978 and 1997 and kept updated with relevant amendments (IMO, 2015b). The MARPOL Convention addresses pollution from ships by oil; by noxious liquid substances carried in bulk; harmful substances carried by sea in packaged form; sewage, garbage; and the prevention of air pollution from ships (IMO, 2015b).

Another significant international agreement is the Stockholm Convention, which is a global treaty to protect human health and the environment from persistent organic pollutants (POPs) (UNIDO, 2015). The Global Environmental Facility (GEF) is the designated interim financial mechanism for the Stockholm Convention (UNIDO, 2015). The United Nations Environment Programme (UNEP) coordinated the organisation of the Stockholm Convention, which was originally signed by 92 nations and the European Community on the 23 May 2001 in Stockholm, Sweden (UNIDO, 2015). Over 150 countries signed the Convention and it entered into force, on 17 May 2004, 90 days after the ratification by the fiftieth country (UNIDO, 2015). The Stockholm Convention established an initial list of 12 key POPs chemicals (the socalled dirty dozen) for which signatories are required to reduce the risks to human health and the environment arising from their release (UNIDO, 2015). Enlisted parties are required to take measures (legal and/or administrative) to eliminate or heavily restrict the production and use of POP pesticides and PCBs, and to minimise the unintentional production and release of POPs (UNIDO, 2015).

Internationally, different countries have developed their own management processes for sediment quality. Good examples can be learned from the U.S., Hong Kong, the Netherland, Australia and New Zealand, etc. Though there are differences between the methods adopted by different agencies, Hong Kong, the Netherland, and Australia and New Zealand are all using "hazard region" and multiple environmental assessment tools instead of a simple hazard guideline (Simpson et al., 2010). In the U.S., the US Environmental Protection Agency (USEPA), National Oceanographic and Atmospheric Administration (NOAA), US Army Corps of Engineers (USACE), US Geological Survey (USGS) and the Federal Government are now working together to regulate works to ensure a healthy level of sediment quality. The strong multi-governmental management method offers sediment related services in a highly efficient way. San Francisco Public Utilities Commission (SFPUC) for example, has developed intergovernmental regulation networks to achieve high standard performances on "*Customers, Environment & Natural Resource, Infrastructure, Community, Governance & Management, Workplace*" levels. The success examples will be discussed in details in the recommendation section of this paper. Table 4 lists the overview of general management frameworks internationally. US, Australia, the Netherland, Hong Kong and the UK are listed in the table, since they have developed a relatively mature system for coastal environmental assessment approaches.

Table 4: Overview of General Management Frameworks for Human Health, Ecological Risk Assessment, and Their Key Features (International)

Framework	**Description and key features**
Framework for Risk Management (U.S. Presidential/ Congressional Commission on Risk Assessment and Risk Management, 1997)	Perhaps the most influential framework. Considered to reflect the international "state of the art" in risk management
Risk Assessment in the Federal Government: Managing the Process (U.S. National Research Council, 1983)	Represents the first formalized effort to describe the health risk assessment and management process in a structured way consolidates earlier efforts at developing a comprehensive framework, and has since been widely endorsed throughout the world it has been the most influential framework in risk assessment
Science and Judgement in Risk Assessment in	Expert panel publication characterizing the

Framework	Description and key features
(U.S. National Research Council, 1994)	scope of judgement and uncertainty involved in risk assessment
Understanding Risk: Informing Decisions in a Democratic Society (U.S. National Research Council, 1996)	Based on an “analytic-deliberative process” for risk characterization
Guidelines for Ecological Risk Assessment (U.S. EPA, 1998)	Designed to provide a consistent approach in the application of U.S. EPA environmental laws
Guidelines for Carcinogenic Risk Assessment (U.S. EPA, 1986)	Designed to set forth principles and procedures to guide U.S. EPA scientists in the conduct of cancer risk assessments, and to inform U.S. EPA decision makers and the public about these procedures
Proposed Guidelines for Carcinogenic risk Assessment (U.S. EPA, 1996)	Designed to replace 1986 guidelines; underwent revision in 1999; still considered draft after several years of feedback
Risk Characterization Handbook (U.S. EPA, 2000)	Based on the premise that, to be effective, risk characterization must be transparent, clear, consistent, and reasonable (TCCR)
U.S. DOE Risk Integration Framework (2000)	Recognized that the integration of risk information and issues into decision-making and the integration of program activities across various projects and sites are critical to be credibility and accountability o their Environmental Management Program
Integrated Framework for Population Health Risk Management (Birkwood & Hogan, 1999)	One of the few frameworks for population health risk assessment and management; includes key aspects from the fields of health promotion
Australian/New Zealand Risk Management Standard (AZ/NZS 4360) (1999)	Jointly developed by Standards Australia and Standards New Zealand, the standard is intended to provide a “generic guide for the establishment and implementation of the risk management process involving establishing the context and the identification, analysis, evaluation, treatment, communication and ongoing monitoring of risks”
Australian Health and Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards (2002)	An Australian national approach to environmental health risk assessment; brings together the standard risk assessment components of issues of identification, hazard assessment,

Framework	Description and key features
	exposure assessment, risk characterization, and risk management; engagement of stakeholders, risk communication, and community consultation is seen to "envelope" the process
Health Council of the Netherlands: Environmental Risk Management Approach (1996)	Conceptual framework for evaluating and deciding about risks in the Netherlands
Hong Kong Interim Sediment Quality Guidelines (ISQG)	
United Kingdom Framework for Environmental Risk Assessment and Risk Management (2000)	Based on a tiered approach to environmental risk assessment and risk management where the level of effort put into assessing each risk is proportionate to its priority (in relation to other risks) and its complexity (in relation to an understanding of the likely impacts)

(Source: adapted from Jardine et al. (2003))

6. GAPS AND OPPORTUNITIES

a) THE GUIDELINE NEED TO BE UPDATED.

The Canadian Environmental Protection Act, 1999 (CEPA 1999) is an important part of Canada's federal environmental legislation aimed at preventing pollution and protecting the environment and human health. The goal of CCME guideline is to contribute to sustainable development. However, the guidelines and references for current studies are based on documents in the 1990s and early 2000s. This means that related scientific studies are at least 10 years earlier in the 1970s or 1980s. Even though there are some related documents updated in the 2000s under CCME guideline, the Environmental Assessment methods, decision making processes, and guidelines are out of date now.

First, In CCME guideline, the baselines are drawn from benthic organism's studies, which means that they are not predictive of bioaccumulative effects that may affect higher trophic levels (Aldenberg & Jaworska, 2000; Burton Jr, 2002). According to Burton (2002) “Chemical data (e.g., SQGs) have been the primary decision-making tool, with little or no site validation of biological effects”. In the case of Halifax Harbour, and the connected aquatic systems, it is questioned if the current Canadian guidelines are appropriate enough for the safety of marine mammals.

Secondly, the guidelines are based on studies of mean diets and mean health level. Whereas it cannot be well applied to everyone, especially indigenous people who rely for food mostly from the aquatic system. For example the guideline on chemical concentration for human health, individual exposure to Cadmium should be lower than 400-500 μg/week. However, the risks can be different based on diet habits. Therefore, a general sediment quality guideline may not be acceptable for all. In US, studies show that the current Sediment Quality Guideline have errors of 25% or greater (Burton Jr, 2002). In Canada, studies in British Colombia highlights the need for government agencies to conduct risk assessments and make decisions that are culturally sensitive, requiring a full analysis of the potential exposed populations and how they may be impacted by different management options (Wiseman & Gobas, 2002).

Thirdly, chemicals entering marine ecosystems undergo various weathering processes that may alter their bioavailability and toxicity, reducing the reliability of the chemical approach for assessing environmental quality (Jonker, Brils, Sinke, Murk, & Koelmans, 2006). Coupling exposure and effects lowers the uncertainty in the determination of environmental risks due to contamination (Dagnino et al., 2008; Lyons et al., 2010; Borja et al., 2011; Benedetti et al., 2012; Dagnino & Viarengo, 2014; Morales & Ross, 2015)

Fourth, the guideline is not complete for chemical data. Contaminants such as Antimony, Nickel, Silver, Tributyltin and total PAHs have no data in the guideline (CCME, 1998). Others such as Dieldrin has no data for marine environment, so that the guideline is using the data from fresh water, which may be inappropriate.

b) ENVIRONMENTAL ASSESSMENT PROCESSES NEED TO UPGRADED

According to Burton (2002), once the chemical contamination concentration reaches a point at which it causes adverse effects to biota, it is considered polluted. The question then comes to what exactly is the “point”? The reference level for sediment contaminants varies from place to place. Scientific research also does not have a unified standard, so that results and conclusions can be very different, especially when the concentration of sediment contaminants are at a relatively low to middle level (Arblaster, Ikonomou, & Gobas, 2015). In addition, the bioaccumulation rate can be different depend on specific situations, so that a precise evaluation should depend on more in-depth analyzes (Bakke, Källqvist, Ruus, Breedveld, & Hylland, 2010; Arblaster et al., 2015). According to Munawar et al. (1999), three reasons make the risks of sediment contaminants different from one place to another: “1) the complex geochemistry of sediment makes understanding chemical speciation and kinetics difficult; 2) aquatic organisms interact with the sediment in a myriad of ways, influencing contaminant fate and their own exposure to the pollutants; 3) biological variability is substantial due to numerous biochemical responses that occur once the contaminant has entered the organism, making simple assumptions based on sediment contaminant analysis difficult” (P.368). This means that a general reference level may not be suitable for each case, and that referencing only general guidelines can cause serious mistakes. Burton Jr (2002) argues that SQGs may not be accurately developed for national and wide geographic areas; rather, they will be most useful on a site-specific basis where they can be optimized and verified through multiple assessment approaches. Therefore, only by the use of multiple assessment approaches can accurate assessments be conducted where the likelihood of false positive and false negative conclusions is rare (Burton Jr, 2002).

For Halifax Harbour, the large volume of daily water exchanges and the pattern of turbulent flow is able to bring fresh water into the harbour every day. The physical condition like this can also affect the bioaccumulation rate, and makes it complicated for environmental risk assessments. For example, when the water flows slow, and the bioaccumulation rates are higher, same amount of contaminants can have a much higher possibility to flow into the food web and then threaten biotas and human beings. In other words, the same level of contaminates in sediments, if located in different coastal systems, can have very different consequences. In this way, one general environmental assessment can lead to miscalculations and cause poor decisions to be made.

c) CURRENT REGULATORY NETWORK IS NOT VERY WELL DEVELOPED

The health of the harbour indicates good water quality, sediment quality, shipping activities, industrial developments, food safety issues, well managed aquaculture and agriculture, navy uses, and public behaviours. While all of these are under the regulation of different government sectors, they are not strongly combined and connected. As discussed above, there in not a regulatory network nor influential information exchanges among multiple government departments and other stakeholders currently for Halifax Harbour.

The overlap of authority is causing the entire system to be inefficient, making it difficult for problem solving. This phenomenon can also lead to other problems, such as government departments “passing the buck” to each other when it comes to environmental issues.

d) PUBLIC AWARENESS AND STAKEHOLDER INVOLVEMENT IN HALIFAX ARE LOW.

In Canada, when it comes to pollution problems, most of the effect (especially relating to government assessment) is aimed at water quality, while less attention is being paid on assessing sediment quality (Borja et al., 2004). Especially for the public, sediment quality is not considered as important as water quality, which reflects the low awareness of the public and an urgent need of further outreach and education approaches.

e) WASTE WATER TREATMENT FACILITIES NEED TO BE UPGRADED

In Halifax, most works that have been done focused mainly on industrial and urban sewage treatments. Even though after the two environmental programs (Halifax Harbour Task Force and Halifax Solutions Project), the inner harbour showed environmental improvements during the treatment period, other areas show little significant environmental change (Dabbous & Scott, 2012). Moreover, the Waste Water Treatment Facilities processes are now limited to advanced primary treatment method (Dabbous & Scott, 2012), during which only the solids are removed, dewatered and transported, other chemical components which dissolved in the liquid. Pollutants such as pharmaceuticals and agrochemicals are still not well managed.

f) LACK OF DATABASE AND BASELINE INFORMATION

Baseline information and a database is lacking in Halifax Harbour. Although scientific research has been done by independent programs, the lack of database is a great hazard for future developments. The importance of a database has been examined in other cases. For example, in April 2015, a serious oil spill happened in Vancouver Harbour, and the regional ecosystem was effected. The lack of a baseline has made many related environmental assessment work hard to process. It is difficult to measure the damage caused by the oil spill because there are no baselines to be compared to. The lack of baseline information also makes it hard to trace the source of the pollutant. Though some modern technologies have been developed to trace the sources, no work can be done without the baseline sediment data. Therefore, the lack of database makes it difficult for tracing pollutions. Same problem exists in Halifax Harbour. Thus it is urgent to establish a chemical database for information storage, to avoid the mistakes that happened in other areas.

7. RECOMMENDATIONS FOR IMPROVEMENTS

In this section, several recommendations are raised for the further development of Halifax Harbour based on the gaps and opportunities discussed above. Efforts from all involved stakeholders are in need to achieve the goal of sustainable development. No single government department or organization can do it alone. The suggestions involve multiple levels of management. For an integrated coastal management network, top-down approaches should combine with bottom-up approaches to form an efficient and effective system. This can be accessed by three major approaches: regulatory network, best practices, and outreach and education.

a) LEGISLATION – USE MULTIPLE TOOLS FOR ENVIRONMENTAL ASSESSMENT AND DECISION MAKING

The CCME (Canadian Council of Ministers of the Environment) guideline is the most important piece of environment legislation in Canada for many years and will substantially influence the environmental regulation of chemicals, including human and veterinary pharmaceuticals. As the major document that guides sediment quality, CCME guideline should be updated based on recent studies. Based on the gaps and problems discussed above, related changes such as bioaccumulation factors and a complete chemical monitoring database should be added in the document.

It is suggested that sediment quality guidelines be used for screening in conjunction with other assessment methods (Brown, 2002; Grifoll, Jordà, Borja, & Espino, 2010; Grifoll, Jordà, Espino, Romo, & García-Sotillo, 2011; Grifoll et al., 2013). Although it is apparent that national guidelines will continue to improve in accuracy and applicability in geographic areas around the world, they will probably always be relegated to be used as screening tools, given the complexity of sediments and mixture interactions (Burton Jr, 2002). Referencing from Hong Kong, the Netherland, and Australia and New Zealand, one effective way to solve this problem is to use an area of uncertain toxicity instead of a solid standard. In this way, a low and severe effect threshold was set. The range of concentrations between the two was deemed an area of uncertain toxicity, and therefore further biological testing was required before the sediment could be classified as a hazard (Burton Jr, 2002; Wenning, 2005). For a contaminated area that is higher than the low threshold, further monitoring programmes will test factors including. Thus, ideally, investigations should combine assessments of persistence, laboratory and in situ toxicity and bioaccumulation testing, toxicity, hydrodynamic characterization (low vs. high flow, surface-ground water transition zones), relevance at the large scale (river basin, high fluxes (tendency to increase concentrations/ fluxes on a long-term basis), habitat analyses, and addition or replacement of pollutants (Burton Jr, 2002; Brils, 2008; He, Peng, Zhai, & Xiao, 2011). Only with these multiple tools and an understanding of their interactions can reliable determinations of sediment pollution and long-term consequences be made (Burton Jr, 2002). Then cost-effective, environmentally protective management decisions can be made about the type, extent, and need for sediment remediation (Burton Jr, 2002).

For environmental assessment, a comprehensive tool that combines water quality and sediment quality assessment, uncertain toxicity, and bioaccumulation factors to identify the situation of contaminated sites is suggested (Borja et al., 2004; Droppo, Krishnappan, Liss, Marvin, & Biberhofer, 2011; Furlan, Poussin, Mailhol, Le Bissonnais, & Gumiere, 2012; Tixier, Rochfort, Grapentine, Marsalek, & Lafont, 2012). In Australia and New Zealand, the ANZECC/ARMCANZ (2000) guidelines, a similar method is adopted. It indicates that lower SQG values were termed “trigger values” to imply that further action is triggered if the values are exceeded (Australian Department of the Environment, 2000; Wenning, 2005). The upper values (termed “interim SQG-high”) were, however, included in the guideline documentation to provide an indication of a value at which toxicity is more likely (Wenning, 2005).

For decision making processes, it is argued that ANZECC/ARMCANZ (2000) guidelines is currently the best approach to assessing sediment quality (Wenning, 2005). This can be achieved by extending the current ANZECC/ARMCANZ decision framework to include bioaccumulation and ecological assessments, or by combining these and other factors in an integrated framework. Figure 5 and Figure 6 show the Environmental Assessment in the Netherland and Decision Making processes adopted in ANZECC/ARMCANZ (2000) guideline. The common theme of these two is addressed in the multiple assessment approaches that include in-situ assessments, bioaccumulation factors, and detailed and special analysis, which can increase the accurate rates of environmental assessments.

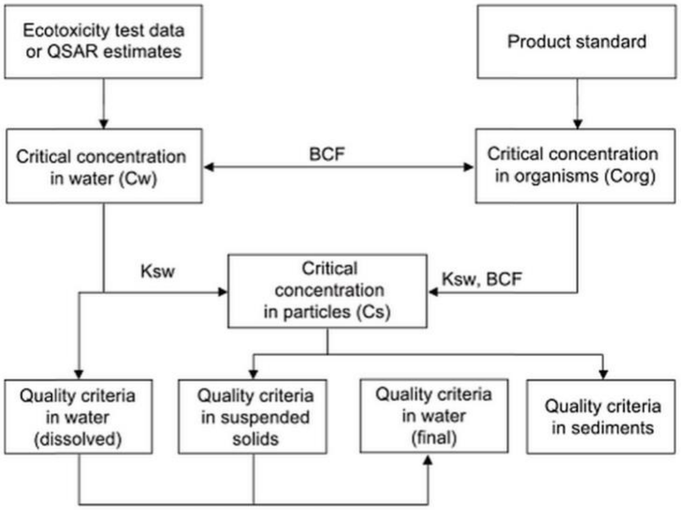

Figure 5: Derivation of sediment quality criteria in the Netherlands (Reprinted from Water Research 25(6), Van Der Kooij et al., Deriving quality criteria for water…, p 679-705, copyright 1991, with permission from Elsevier). BCF = bioconcentration factor; Ci = concentration in medium i; w = water; org = organism; s = sediment particle; Ksw = partition coefficient between sediment and water

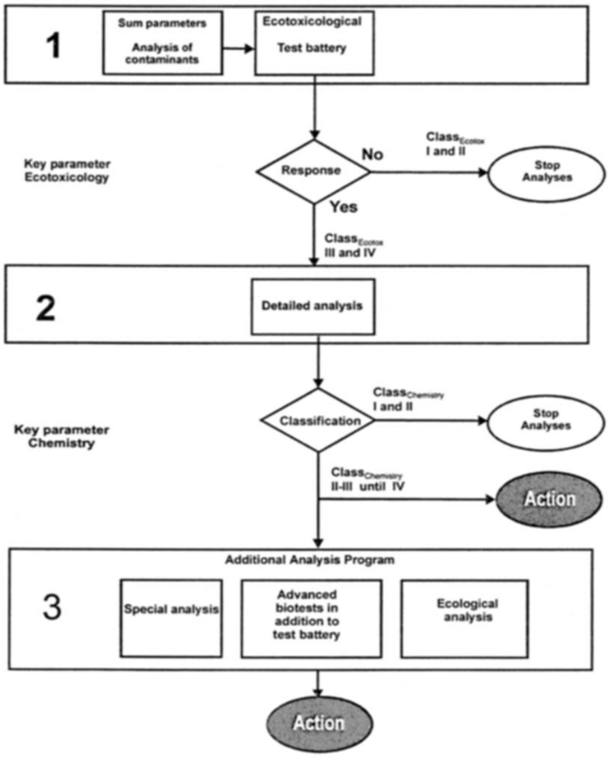

Figure 6: Hierarchical assessment of contaminated sediments
(Ahlf, Hollert, Neumann-Hensel, & Ricking, 2002)

b) REGULATION – USE COLLABORATION AS A MANAGEMENT STRATEGY

The regulatory approaches for a healthy sediment quality involves multiple levels of stakeholders. From the governance perspective, federal, regional and provincial, and municipal government departments share responsibilities on environmental issues. Related departments include but not limited to Halifax Regional Municipality, Halifax Port Authority, Nova Scotia Environment, Industries Canada, Environmental Canada, Transport Canada, Department of Fisheries and Oceans, Department of National Defence, Health Canada, and US Coast Guard. Other non-governmental stakeholders include universities, Non-Governmental Organizations, as well as industrial companies that are using the coastal resources. Therefore, it is crucial for the stakeholders to collaborate at all levels for sustainable harbour development. An integrated coastal zone management method is ideal to achieve this goal (Souchère et al., 2010; Spencer, Droppo, He, Grapentine, & Exall, 2011; Tiller, Brekken, & Bailey, 2012). San Francisco Public Utilities Commission (SFPUC, 2014) has developed a multi-governmental management method, which is one of the most advanced system in the world, and thus is recommended in this research to be referenced for regulating Halifax Harbour. Even though the legislation and political environment are different in Canada, much can be learned from SFPUC's successful cases.

In the case of SFPUC, the agency is a multi-governmental department, which is responsible for all water related activities at multiple levels. At the governmental level, it launches programs to improve the quality of drinking water and the health of urban watersheds, monitors ocean and beaches, supports clean energy developments, regulates San Francisco shipyards, and manages sewage treatment facilities. At the community level, it works closely with local groups to engage the public for pollution prevention projects such as *Pollution Prevention Calendar, Only Rain Down the Drain, Cooking Oil Recycling, To Flush or Not to Flush?, Expired Medications, Less-Toxic Products, Garden Workshops, Classroom Presentations, Proper Copper*. The active media team and outreach programs make the society work efficiently for the bottom-up approaches.

The SFPUC also publishes annual reports to analyze its sustainability performance. It uses six major categories to frame its Strategic Sustainability platform, which are Customers, Community, Environment & Natural Resources, Governance & Management, Infrastructure & Assets, and Workplace. Detailed criteria is highlighted for each category. Each year, the committee examines its performances by analyzing data and doing surveys, and summarize them by using scoring scale of 1 to 5 (best). By comparing with former years' performances and the target goals, the Committee is able to understand how well it worked in the past year and where to improve for the upcoming years. All the data and reports are accessible by the public. By using this method, the overall performance of SFPUC is showing a positive trend in the past five years.

SFPUC is a successful case that can be referenced to form a regulation framework in Halifax Harbour. The unique cultural, environmental, and economical background of Halifax Harbour makes it urgently in need of an efficient management system to achieve sustainable coastal development goals. The barrier of achieving this strategy may be the lack of political will and financial support. Under this circumstance, Nova Scotia Environment or Halifax Water is potentially suitable for acting as a leading agency to form the multi-governmental framework.

c) BRIDGE THE DATA AND KNOWLEDGE GAP

The importance of building a database is well accepted. According to Tay et al. (1992), “without collection of baseline data, including biological response studies, it is impossible to monitor the results of any population control programs designed to clean up the marine environment” (P. 1579). The situation of Halifax Harbour is changing in a dramatic way. During the past decade, the population has doubled, shipping activities is becoming more active, and economic is increasing with the urban development. All these changes have the potential to affect the sediment quality. Without a baseline, it is difficult to analyze the impacts of human activities on marine contamination situations. At this point, Environment Canada should be the leader for data collection and the establishment of a systematic database.

As discussed, in Table 2, the lack of data makes it difficult to compare the sediment qualities during the past centuries. Separate individual projects are not comprehensive enough for environmental assessments or decision makings. A complete database with Geographical Information System (GIS) for sediment contaminants in Halifax Harbour is urgently in need. In this case, DFO can be the leader for data collections and regular monitoring activities. Once the systemic database is established, regular monitoring work (i.e. seasonal or yearly) should follow up to keep the database updated. Only in this way, information can be used for further regulatory approaches such as environmental assessments, risk assessments, and coastal development plans.

d) CULTURAL CHANGES – OUTREACH AND PUBLIC EDUCATION

Increasing public awareness of the problem is crucial to developing an effective solution (US EPA, 2012). According to McKenzie-Mohr (2000), changing individual behavior is central to achieving a sustainable future. In some cases, in addition to legislation, regulation and scientific approaches, sustainable urban environment can be achieved more efficiently with the supports of the public. Unlike policy and legislation approaches, which are in need of complex processes and government approvals, outreach activities can be achieved in multiple ways (Greiner, 2014).

In Halifax region, the education organizations that have ocean education programs include universities, the Discovery Centre, and other NGOs. However, as a coastal city and one of the most important port harbours in Canada, Halifax is not the leader of sediment quality education. The public lacks awareness of the importance of sediment quality. Water is recognized as a vital ingredient to a healthy and prosperous economy, however, little public awareness is focusing on the sediment quality. Most sediment related works are limited in scientific research and academic levels.

Traditional education programs, such as school programs and NGO outreach events are the most popular ways to increase the public awareness and to change individual behaviours. In addition to this, educators can be more creative to find more effective ways for public education (McKenzie-Mohr, 2000). This can be practiced by using multiple tools such as marketing based instruments and social media outreach. For example, one successful case of using marketing based instruments is environmental certifications (i.e. sustainable seafood, sustainable wood products). This method can be addressed for products such as Personal Care Products which can contain toxic chemicals. In addition to using environmental labeling, smart phone Apps are also valuable as they are playing important roles in public outreach, especially for youth and teenagers. *Think Dirty* for example, is one smart phone App that can simply show customers the harmful chemicals in beautiful products by scanning the QR code. *Think Dirty* will pull up a “dirty meter,” which gives users a health impact rating between zero (harmless) and 10 (serious health impact) on each rated category. From there, users can check out the ingredient list on a particular product, and find out what each is used for and why is a threat to health. With the increasing users of the App, more customers tend to purchase “safe” products. In this way, health product companies tend to change because of the market pressure.

8. CONCLUSION

In summary, ensuring sediment quality is crucial for a healthy harbour environment. Sediments are supporting the coastal ecosystem, acting as the source of contaminants, and being used by scientists as a critical tool for environmental behaviours. Sediment quality is affecting human and biota in a variety of ways. Harmful contaminants can enter the food web and accumulate in the body of coastal organisms; long term and chronic effects are potential hazards for the environmental health; indigenous people have a higher risk to be exposed to the contaminants. As a key player in the harbour ecosystem, sediment can be easily affected by human activities from water, territory and atmosphere related activities, which makes the health of sediment fragile.

From the perspective of legislation, Canada, the CCME guideline is out dated and problematic. Scientific research show that a simple guideline that does not consider bioaccumulation factors, geographic differences, diverse diet behaviours and long-term effects is not accurate enough to make conclusions on sediment quality. From a regulation perspective, as a fast growing coastal area, Halifax Harbour is lacking of efficient networks that integrate multiple government departments, non-governmental organizations and other stakeholders. From the perspective of science and technology, the effectiveness of sewage treatment facilities for Halifax is questionable; the absence of sediment quality monitoring and a chemical database is a potential hazard for future harbour developments and environmental assessments. Moreover, the community level, the education and outreach approaches are weak in increasing the public awareness of the importance of sediment quality, and changing individual behaviours that have impacts on the harbour environment.

After analyzing the importance of the sediment quality, the legislative environment in Canada, and the specific case of Halifax Harbour, this research suggested several ways to improve for sustainable developments in the region of Halifax. Targeting the legislation issue, referenced from successful cases from other countries, this research suggests that CCME guideline and other related documents should be updated by using multiple tools for Environmental Assessments and Decision Making processes. In order to improve the regulation approaches, this research recommends a multi-governmental network should be established. An active management system can be referenced from the case of San Francisco Public Utilities Commission. For science and technology developments, the sewage treatment facilities may need to be upgraded; a comprehensive database urgently needs to be established. Last but not least, it is crucial to increase the public awareness on the issue of sediment quality. The public should know more about the importance of sediment quality, and learn in what ways they can participate to become more environmental friendly. Such cultural changes can be achieved by using multiple and creative outreach methods.

The sustainable development of Halifax Harbour and a healthy sediment quality involves stakeholders multiple levels and perspectives. It is important to realize that active participations of all stakeholders, the government departments to the individuals, is the key for a balanced coastal management system. This research suggests that the changing of the political and social environment is urgently in need for ensuring the sediment quality, protecting the whole coastal ecosystem, as well as benefiting the human interests.

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APPENDIX

Appendix 1: A brief description of priority contaminants of concern in harbours, including existence or not of Canadian Sediment Quality Guidelines for the protection of aquatic life

CONTAMINANT	SOURCE	PERSISTENCE AND TOXICITY	LEGISLATION	CCME SQGs
Trace Metals	Heavy metals occur naturally, but are also products or by-products of human activities. Common anthropogenic sources include mining and industrial wastes, vehicle emissions, lead-acid batteries, fertilizers, paints and treated woods.	Metals can accumulate in marine life and can be locally problematic. Metals vary in their toxic effects. Some effects include oxidative stress and carcinogenicity. For example lead interferes with a variety of body processes and is toxic to many organs and tissues including the heart, bones, intestines, kidneys, and reproductive and nervous systems. The organometallic forms methylmercury and tetraethyl lead can be extremely toxic.	Regulations in food and environmental guidelines	Some
PAHs	Polycyclic Aromatic Hydrocarbons are often byproducts of petroleum processing or combustion; some PAHs are used to make dyes, plastics, and pesticides. Forest fires and prairie fires, agricultural burning, and fossil-fuels are the major contributors of PAHs to the environment.	There exist thousands of PAHs in the environment, with individual PAHs varying in behaviour. Lighter PAH compounds are generally more water soluble and can therefore be more bioavailable to aquatic life where they may pose risk of acute toxicity. However, breakdown times are much shorter than for heavier compounds. PAHs with more than four rings, being less volatile and soluble, favor adherence to solid particles. They are generally found in soil and sediment as complex mixtures. Alkylated PAHs are more persistent than their parent PAHs. Many of these compounds are highly carcinogenic at relatively low levels. The heavier PAH compounds tend to be associated with more chronic health	CEPA 1999 Schedule 1 - List of Toxic Substances: new restrictions in Europe (ECHA: EU No 1272/2013).	Total, some congeners

CONTAMINANT	SOURCE	PERSISTENCE AND TOXICITY	LEGISLATION	CCME SQGs
		effects. US EPA has identified 16 priority PAHs that are thought to be carcinogenic through multiple routes of exposure, and can affect the immune, reproductive, nervous and endocrine systems. The most toxic PAH is benzo(a)pyrene		
PCBs	Polychlorinated biphenyls have been used as heat exchange fluids, in electric transformers and capacitors, and as additives in paint, carbonless copy paper, and plastics.	Their persistence in the environment corresponds to the degree of chlorination, and half-lives can vary from weeks to decades. Of the 209 different types of PCBs, 13 exhibit a dioxin-like toxicity. PCBs are toxic to fish, causing reproductive failures at relatively low doses. Large numbers of people have been exposed to low to moderate levels of PCBs through food contamination. Since PCBs are persistent, bioaccumulative and toxic, they accumulate in aquatic food webs and attain high levels in some marine mammals. PCBs have been associated with toxic effects in marine mammals such as endocrine disruption, which can cause impairment of reproduction, development, and other hormonally mediated processes, and immunotoxicity, giving rise to an increased susceptibility to infectious diseases and cancers.	Listed under Annex A with specific exemptions and under Annex C of the Stockholm Convention. The import, manufacture, and sale (for re-use) of PCBs were made illegal in Canada in 1977 and release to the environment of PCBs was made illegal in 1985. However, Canadian legislation has allowed owners of PCB equipment to continue using PCB equipment until the end of its service life. The storage of PCBs has been regulated since 1988. Handling, transport and destruction of PCBs are also regulated, mostly under provincial regulations. Canada is signatory to several international agreements on the phase-out of a number of persistent toxic substances including PCBs. Environ-	Total, some congeners

CONTAMINANT	SOURCE	PERSISTENCE AND TOXICITY	LEGISLATION	CCME SQGs
			ment Canada has therefore repealed the *Chlorobiphenyls Regulations* and the *Storage of PCB Material Regulations* on September 5, 2008 and made the *PCB Regulations* under the *Canadian Environmental Protection Act*, 1999 (CEPA 1999) that set specific dates for the destruction of PCBs in service and in storage.	
PCDDs	Polychlorinated dibenzo-p-dioxins are produced unintentionally due to incomplete combustion, as well during the manufacture of pesticides and other chlorinated substances. They are emitted from the low-temperature incineration of hospital, municipal, and hazardous wastes, and also from automobile emissions, peat, coal, and burning of salt laden wood in coastal pulp and paper boilers, iron sintering and electric arc furnace steel manufacturing. There were releases of large amounts of dioxins from pulp and paper mills in Canada prior	There are 75 different dioxins, of which seven are considered to be of concern. High capacity to accumulate in biological tissues. Dioxins have been associated with a number of adverse effects in humans, including immune and enzyme disorders and chloracne, and they are classified as possible human carcinogens.	Listed under Annex C of the Stockholm Convention. Dioxins and furans are slated for virtual elimination under the Canadian Environmental Protection Act, the federal Toxic Substances Management Policy and the CCME Policy for the Management of Toxic Substances.	Total

CONTAMINANT	SOURCE	PERSISTENCE AND TOXICITY	LEGISLATION	CCME SQGs
	to regulations restricting the use of elemental liquid chlorine.			
PCDFs	Polychlorinated dibenzofurans are produced unintentionally from many of the same processes that produce dioxins, and also during the production of PCBs. They have been detected in emissions from waste incinerators, automobiles and from pulp mills. There were releases of large amounts of dioxins from pulp and paper mills in Canada prior to regulations restricting the use of elemental liquid chlorine.	Furans persist in the environment for long periods. High capacity to accumulate in biological tissues. Furans are structurally similar to dioxins and share many of their toxic effects. There are 135 different types, and their toxicity varies. Furans are classified as possible human carcinogens. Food, particularly animal products, is the major source of exposure for humans. Furans have also been detected in breast-fed infants.	Listed under Annex C of the Stockholm Convention. Dioxins and furans are slated for virtual elimination under the Canadian Environmental Protection Act, the federal Toxic Substances Management Policy and the CCME Policy for the Management of Toxic Substances.	Total
Brominated Flame Retardants	Brominated Flame Retardants appear in manufactured materials, such as furnishings, electronics, plastics and textiles; a major source is diffuse leaching from products into wastewater streams from users, households and industries.	Many of the BFRs are considered toxic, persistent and bioaccumulative. Largely distributed in organisms (including marine mammals) from various geographic regions. Long-range atmospheric transport and deposition. PBDEs bioaccumulate in blood, breast milk, and fat tissues. Health effects of PBDE exposure include damage to the neurological, reproductive, immune, and hormonal systems. The most widely used chemical in this group, decaBDE, is also a suspected carcinogen. HBCD causes reproductive toxicity. TBBPA degrades to bisphenol A and to TBBPA dimethyl	PBDEs "toxic", as defined under the Canadian Environmental Protection Act, 1999. Regulations prohibit the manufacture of all PBDEs in Canada, and restricting the import, use and sale of PBDEs found in commercial mixtures of greatest concern (Penta- and OctaBDE). DecaBDE is under assessment. Stockholm Convention on Persistent	NO

CONTAMINANT	SOURCE	PERSISTENCE AND TOXICITY	LEGISLATION	CCME SQGs
		ether; TBBPA has demonstrated toxicity in a variety of aquatic and terrestrial species, its chronic toxicity is predicted at very low concentrations.	Organic Pollutants decided in May 2013 to list hexabromocyclododecane in Annex A (for elimination) to the Convention with specific exemptions. TBBPA is currently in the pre-registration phase of REACH. The Government of Canada is considering the implementation of risk management measures to reduce releases of TBBPA from industrial source if required, while maintaining the use of TBBPA where deemed necessary	
PFCs	Perfluorooctane sulfonic acid (PFOS) and its salts, perfluorooctane sulfonyl fluoride and Perfluorooctanoic acid (PFOA) are known as perfluorinated compounds. They can be found in electronic parts, firefighting foam, photo imaging, hydraulic fluids and textiles. PFOS was the key ingredient in Scotchgard, a fabric protector made by 3M, and numer-	PFCs are persistent in the environment. PFOA and PFOS are considered to be resistant to degradation in soil. Bioaccumulate and persist in protein-rich compartments of fish, birds, and marine mammals. PFCs are toxic including neonatal mortality. Studies of PFOA indicate that it can cause several types of tumors and neonatal death and may have toxic effects on the immune, liver, and endocrine systems.	Added to Annex B of the Stockholm Convention on Persistent Organic Pollutants in May 2009. EPA has designated rules for the use of PFCs. EU and other countries developing strategies to reduce their use. The Government of Canada added PFOS, its salts, and its precursors to the Toxic Substances List under Schedule 1 of the Cana-	NO

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	ous stain repellents.		dian Environmental Protection Act, 1999.	
Alkylphenols	Alkylphenols including nonylphenol, are used to make alkylphenol ethoxylates (APEs), chemical compounds that are mainly used as synthetic surfactants used in detergents and cleaning products. Used as antioxidants, oil additives, detergents, emulsifiers, and solubilizers, precursors of non-ionic surfactants, cosmetic, pesticides.	Alkylphenols can take months or longer to degrade in surface waters, soils, and sediments. Long distances transportation and global reach. Alkylphenols are endocrine disruptors due to their ability to mimic estrogen and in turn disrupt the natural balance of hormones in affected organisms. Prenatal and perinatal exposure to nonylphenol has been linked with developmental abnormalities. Nonylphenol exposure has also been associated with breast cancer.	European Union and Canada have banned the use of nonylphenol ethoxylates (NPEs) in detergents	NO
OCPs	Organochlorine Pesticides; also known as legacy pesticides; they were widely used in agriculture and pest control until research and public concern regarding the hazards of their use led to government restrictions and bans. Despite restrictions and bans on the use of many organochlorine pesticides in the 1970s and 1980s, they continue to persist in the environment today.	Despite restrictions and bans on the use of many organochlorine pesticides in the 1970s and 1980s, they continue to persist in the environment today. Organochlorine pesticides are hydrophobic, lipophilic and extremely stable. Toxicity appears to be via disruption of neural function and specific disturbances vary by chemistry. Studies support both acute and chronic effects of OC pesticides, potentially via damage to reproductive and neurological functions, carcinogenesis and endocrine disruption	Nine of the 12 most hazardous persistent organic pollutants (POPs) targeted by the Stockholm Convention in 2001 are OC pesticides.	Some
Neonicotinoid pesticides	During the 1970s and 1980s after the detrimental	Long-term persistence in soil and water. The neonicotinoids show reduced toxicity	Temporary suspensions and bans on the use of	NO

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	effects of pesticides like DDT became known, OC pesticides were replaced with less persistent pesticides. These new pesticides had different physical-chemicals properties than OCs and different environmental fates.	compared to previously used organophosphate and carbamate insecticides. The use of neonicotinoids was linked in a range of studies to a number of adverse ecological effects, including honey-bee colony collapse disorder (CCD) and loss of birds due to reduction in insect populations.	different neonicotinoids in several countries.	
CUP	Current use pesticides.	Current use pesticides are generally more target specific and are less persistent in the environment than legacy pesticides. They may be more acutely toxic than old pesticides. Studies have shown that exposure to OP pesticides can affect the neurological and immune systems in animals. Once in the body, many OP compounds metabolize into dialkyl phosphate metabolites. Atrazine is linked to ovarian cancer and can be toxic to freshwater fish, invertebrates, and aquatic plants.	Some banned in the EU	NO
TBTs	Tributyltins is a pesticidal compound applied to the hulls of ships and small boats to protect against an accumulation of barnacles and other fouling organisms on underwater surfaces. TBT is one of a class of compounds called organotins and was introduced in the 1960s. Ships painted with TBT needed repaint-	Highly persistent, bioaccumulative and biomagnifies in the food chain. Compared to earlier copper-containing antifouling coatings, TBT was more toxic to fouling organisms and lasted longer. Toxic effects at all trophic levels. Endocrine disruptive (i.e. masculinization of gastropods), it affects immune system in vertebrates.	Completely banned in 2008 by the International Convention on the Control of Harmful Anti-fouling Systems on Ships of the International Maritime Organization.	NO

CONTAMINANT	SOURCE	PERSISTENCE AND TOXICITY	LEGISLATION	CCME SQGs
	ing every 4-5 years.			
Phthalate esters	Plastics that contain phthalates are commonly used in applications that include building materials, clothing, cosmetics, perfumes, food packaging, toys, and vinyl products; primarily used to make polyvinyl chloride (PVC) or vinyl flexible and pliant	They will tend to persist for long periods in anaerobic sediments. Endocrine disruptors, teratogenic effects, mortality.	Lower-molecular-weight phthalates (3-6 carbon atoms in their backbone) are being gradually replaced in many products in the United States, Canada, and European Union over health concerns.	NO
Chlorinated paraffins	Short-Chain Chlorinated Paraffins (SCCP)s are used as lubricants and coolants in metal cutting and metal forming operations and as secondary plasticizers and flame retardants in plastics.	They can remain in the environment for a significant amount of time and can bioaccumulate in animal tissues, increasing the probability and duration of exposure. Even relatively small releases of these chemicals from individual manufacturing, processing, or waste management facilities have the potential to accumulate over time to higher levels and cause significant adverse impacts on the environment. They are classified as toxic to aquatic organisms.	CEPA 1999 Schedule 1 - List of Toxic Substances. The EU has restricted SCCP use in metalworking fluids. Currently EPA is taking an action plan, under which regulations to restrict or even ban all short-chain paraffins (together with eight phthalates, and two types of perfluorinated compounds: perfluorinated sulfonates and perfluoroalkyl carboxylates) are being considered.	NO
PPCP	Pharmaceuticals and Personal Care Products get into the marine environment from wastewaters from areas of intense ur-	Although some degrade quickly, they can be considered pseudo-persistent in the environment because of continual inputs. The ability of triclosan (and others) to bioaccumulate is affected by its ionization	BPA considered "toxic substance" and added it to schedule 1 of the Canadian Environmental Protection Act, 1999. The	NO

CONTAMINANT	SOURCE	PERSISTENCE AND TOXICITY	LEGISLATION	CCME SQGs
	banization and animal production.	state in different environmental conditions. Their toxicity varies, and it can affect hormone levels, carcinogenicity, etc. Triclosan is toxic to aquatic bacteria at levels found in the environment. It is highly toxic to various types of algae and has the potential to affect the structure of algal communities, particularly immediately downstream of effluents from wastewater treatment facilities that treat household wastewaters. Triclosan has been observed in multiple organisms, including algae aquatic blackworms, fish and dolphins.	Risk Assessment by EC proposed that triclosan meets the criterion as set out under paragraph 64(a) of CEPA 1999; it was also proposed that triclosan meets the criterion for bioaccumulation but not the criteria for persistence as set out in the Persistence and Bioaccumulation Regulations (Canada 2000).	
Microplastics	Micro-plastics have a range of compositions and can be demarcated by usage and origin as: i) 'primary', pellets used as a feedstock in the plastics industry, and in certain applications such as abrasives; and, ii) 'secondary', fragments resulting from the degradation and breakdown of larger items. Artificial particles < 5mm. wastewaters (Land-based sources are considered to contribute the largest input of plastics), marine litter, shipping, fishing and the military transport. Microplastic particles can arise through four separate pro-	Their persistency is high. Microplastics can be ingested by marine organisms. Entanglement and ingestion with the potential for: physical disruption and abrasion; toxicity of chemicals in the plastic; and, toxicity of absorbed persistent, bioaccumulative and toxic (PBT) substances.	No regulations. Some companies have promised a voluntary phase-out of plastic microbeads. Some US Sates (e.g. Michigan) are banning microbead-containing products.	NO

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	cesses: i) deterioration of larger plastic fragments, cordage and films over time, with or without assistance from UV radiation, mechanical forces in the seas (e.g. wave action, grinding on high energy shorelines), or through biological activity (e.g. boring, shredding and grinding by marine organisms); ii) direct release of micro particles (e.g. scrubs and abrasives in household and personal care products, shot-blasting ship hulls and industrial cleaning products respectively, grinding or milling waste) into waterways and via urban wastewater treatment; iii) accidental loss of industrial raw materials (e.g. prefabricated plastics in the form of pellets or powders used to make plastic articles), during transport or transshipment, at sea or into surface waterways; iv) discharge of macerated wastes, e.g. sewage sludge.			

(Sources: CCME, 1998; Morales-Caselles et al., 2015)