RISK-BASED REMEDIATION OF LEAD AND CHROMIUM IMPACTED SEDIMENTS IN LAKE WABAN, WELLESLEY, MA: A CASE STUDY

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ABSTRACT

Lake Waban is located in Wellesley, Massachusetts, USA, approximately 20 miles west of Boston. Lake Waban sediments are impacted by lead and chromium due to past disposal practices of a former paint pigment factory operating along its shoreline from 1848-1928. Sediment characterization studies and a detailed human health and environmental risk assessment were conducted to define receptors and develop risk-based remedial goals to address the contamination. Based on the information obtained, a remedial plan was designed and implemented along a portion of Lake Waban to eliminate the identified significant risks. The remedial action utilized a barge-mounted excavator outfitted with a proprietary environmental clamshell bucket, guided by a global positioning system integrated with software to provide the real-time data necessary for precise remedial dredging. Samples were analyzed on site for lead and chromium using a field portable X-ray fluorescence analyzer (XRF) in near real time to guide the dredging operation, and verify that remedial goals had been achieved. The project was a success as the innovative mechanical dredging technique minimized over-excavating while allowing the project team to achieve the goals of the remediation.

RÉSUMÉ

Le Lac Waban est situé à Wellesley, dans l'etat du Massachusetts aux Etats-Unis d'Amerique, approximativement 20 miles a l'ouest de Boston. Les sediments du Lac Waban ont été affectés par du plomb et du chrome, suite aux pratiques de disposition de déchets par une ancienne usine de peinture operant aux abords du lac de 1848 à 1928. Des études de caractérisation des sédiments ainsi qu'une évaluation du risque pour la santé humaine ont été conduites pour definir les récepteurs et développer un objectif de remèdes aux risques de contamination. D'après l'information obtenue a ce sujet et afin d'éliminer les risques significatifs identifiés, un plan rectificatif a été conçu et mis en oeuvre le long d'une partie du Lac Waban. Ce plan a engendré l'utilisation d'un excavateur chaland-monté equipé d'une benne industrielle de propriété environnementale. Celle-ci est guidée par un systeme de positionnement global intégré avec logiciel afin de fournir des données en temps réel nécessaire pour un dragage reparateur precis. Des échantillons de plomb et de chrome ont été analysés sur place en utilisant un analyseur portatif à rayons-x fluorescents et ceci en temps presque réel, afin de mener à bien l'operation de dragage et verifier l'accomplissement de rectification. Ce project a été mené avec succès, étant donné que la technique de dragage mécanique a reduit tout exces d'excavation, tout en permettant à l'equipe de ce project d'accomplir le but de cette opération de rémédiation.

1. INTRODUCTION

Lake Waban is located in Wellesley, Massachusetts, USA, approximately 20 miles west of Boston. From 1848 until approximately 1928 the Henry Wood's Sons Paint Factory manufactured paint pigments on an upland parcel of land adjacent to the lake. Historic disposal activities during paint factory operations resulted in elevated lead and chromium concentrations in Lake Waban sediments. Around 1928 the Henry Wood's Sons Paint Factory ceased operation and was abandoned, and in 1932, Wellesley College purchased the land occupied by the former factory; the College did not operate the paint factory or play a role in its abandonment. The College worked with the Massachusetts Department of Environmental Protection (MADEP) to develop the scope and objectives of both human health and ecological risk assessments completed for Lake Waban. Based on the results of the risk assessment, the College and the MADEP agreed on a risk based remedial strategy for the near shore sediments in a portion of Lake Waban.

2. SITE SETTING

Lake Waban is approximately 44 hectares (108 acres) in size with a mean depth of approximately 3 meters. The lake becomes stratified during the summer months and is considered slightly eutrophic (Carr 1984). A sediment transport study conducted by the MADEP concluded that the lake is a depositional environment with minimal sediment resuspension or migration (HydroQual 2002).

The lake is bordered to the north and east by the Wellesley College campus, to the west by undeveloped, forested land owned by Wellesley College, and to the south by private properties, owned by third parties. Lake Waban is used for recreational boating, swimming, and fishing by the public and littoral owners, including the College. The lake is classified as a Great Pond of the Commonwealth pursuant to Massachusetts General Laws Chapter 91 and its implementing regulations in 310 CMR 9.00.

Surface water from Paintshop Pond flows into Lake Waban from Upper Waban Brook along the Northern Shoreline, as shown on Figure 1. The water level of the lake is

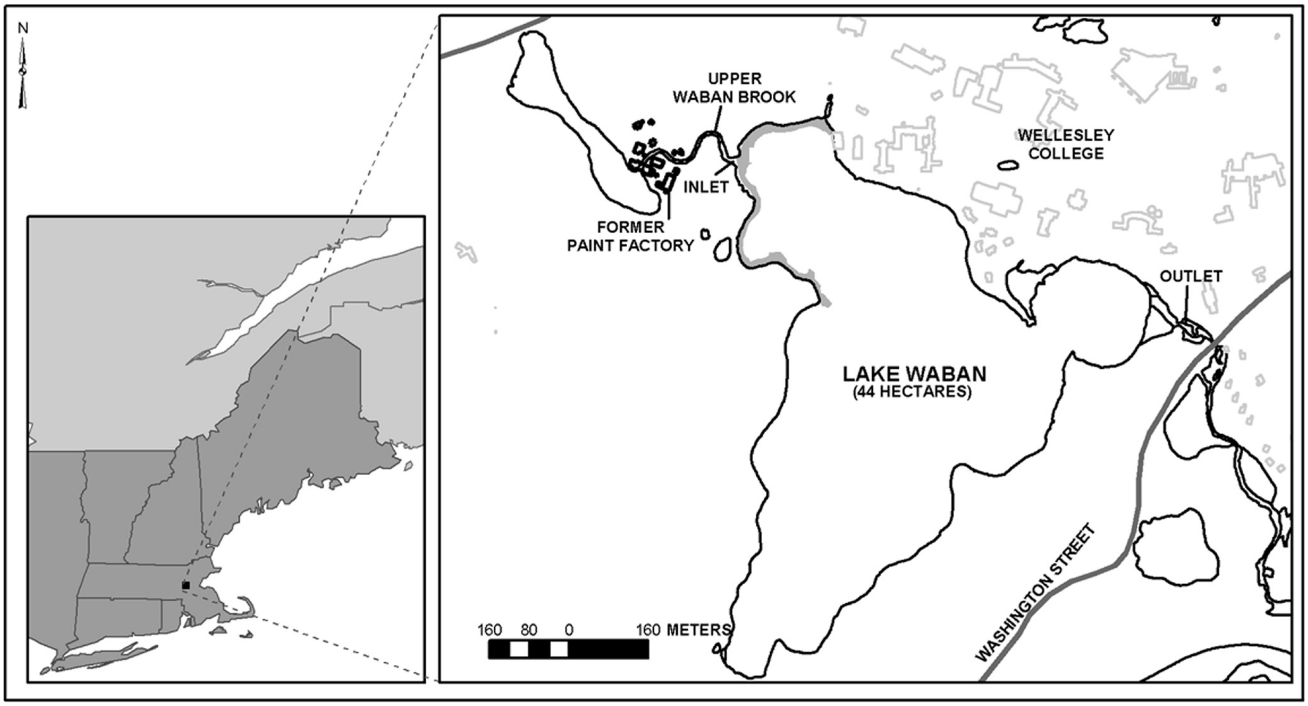

Figure 1. Location of the site and general site features. The Northern Shoreline/Western Cove (NS/WC) portion of Lake Waban is shaded gray.

maintained at approximately elevation 33.1 meters (Mean Sea Level) by a small dam located approximately 100 meters south of Washington Street (Fig. 1). Water from Lake Waban flows over this dam into Lower Waban Brook.

3. BACKGROUND

The Former Henry Wood's Sons Paint Factory manufactured paint pigments on a parcel of land adjacent to Lake Waban from 1848 until approximately the mid-1920s. The former paint factory is visible on Figure 2, which is an aerial photograph taken in 1931. During factory operations, waste was regularly discharged into Lake Waban via Upper Waban Brook. The Former Henry Wood's Sons Paint Factory used and produced pigments based on heavy metal (e.g., lead, chromium, and barium) and other inorganic compounds. Paint pigment manufacturing using metal ores began at the uplands portion of the Site in 1848. "Historical records of the Wood's factory indicate that in the early 1880s, 6 tons of pigment were produced daily" (Clark, 1912). In general, waste disposal practices used at the former paint factory caused the sediments in Lake Waban to become contaminated with metals, primarily lead and chromium.

During pigment production, the pigment was decanted and washed several times to remove salts and acid; the pigment was then sent through a filter press, packed in trays and dried. Typically, at 19th century paint factories, the decanted wastewater was discharged through a waste gate located beneath the building and into a nearby stream or brook (Bolger, 1982). As a rule of thumb, the volume of wastewater was generally five times by weight the quantity of pigment produced. The historical record confirms that the Wood's factory discharged decanted process water to Upper Waban Brook. The wastewater discharged into Upper Waban Brook was carried into the northwest corner of the lake.

A study prepared by the Massachusetts State Board of Health in 1903 (SBOH 1903) concluded that large volumes of waste liquor passed from the Wood's factory into Upper Waban Brook and then into the lake. The study found that the "Brook is often badly colored by these wastes, and the lake to some extent. With these colored wastes, large amounts of lead are carried into the Brook and lake." The SBOH found that, based on analytical data of the surface water in Lake Waban, "every acre of water, one foot deep, contains about two (2) pounds of lead." SBOH further stated that "samples taken at a depth would probably show still more lead present. At this figure, however, the upper foot of lake water contained about 282 pounds of lead." The report further stated that the sediment deposits in the upper brook, and at the entrance of the upper brook into the lake, contained a large amount of lead.

The SBOH recommended treatment of the waste stream emanating from the factory. From sometime after 1904 until cessation of the operations, a portion of the waste was discharged to filter beds, which were constructed adjacent to the factory. Liquids discharged to the filter beds infiltrated to the groundwater. During the period in which the filter beds were used, they operated with varied results. SBOH identified problems with clogging of the filter beds and overflow of wastes into the abutting wetlands.

In addition to discharging untreated or partially treated wastewater, two waste piles remained on site at the close of the factory operations until removal in 1991 (ECE, 2000). These waste piles were located on either side of Upper Waban Brook. It is believed that these piles represented off-spec waste from earlier production operations at the facility, or possibly waste pigment Wood removed from the filter beds to mitigate clogging. These piles were left unprotected in close proximity to Upper Waban Brook.

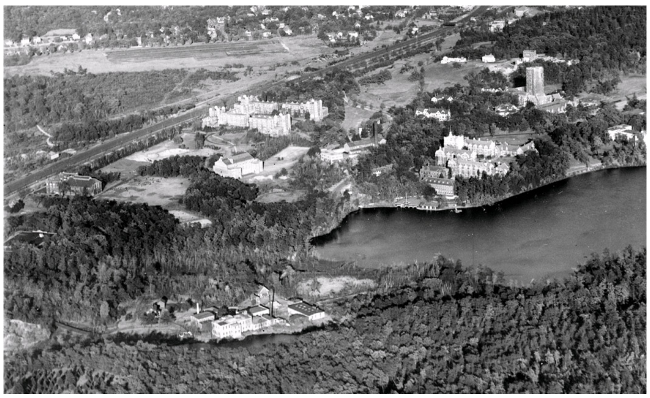

Figure 2. Aerial Photograph taken in 1931 looking east. Note the abandoned paint factory in the foreground.

4. SITE CHARACTERIZATION

Between 1994 and July 2001, 408 sediment samples were collected from Lake Waban to define the extent of contamination and to evaluate potential risks to human health and the environment. All sediment samples were analyzed for lead and chromium. Samples collected from 1998 through 2001 were analyzed for aluminum, arsenic, barium, copper, nickel, selenium, silver, zinc, and total cyanide in addition to lead and chromium. Maximum lead and chromium concentrations were 94,000 mg/kg and 15,000 mg/kg, respectively. Near shore sediments are granular in nature, consisting of sand, gravel, and cobbles. Deeper water, low-energy, environments exhibit very fine-grained organic-rich sediments. Sediment input to Lake Waban is very low due to a single small tributary (Upper Waban Brook) that discharges into the lake. This tributary also has two dam structures upstream of the lake which act as effective sediment traps. Hydrodynamic modeling conducted as part of the sediment transport study by the MADEP indicates that the lake is depositional in nature with very little sediment output. The modeling also determined that resuspension and subsequent transport of sediments is not likely to occur under conditions modeled (HydroQual 2002).

To support the human health and ecological risk characterizations, a subset of the samples were analyzed for hexavalent chromium, physiologically-available cyanide (PAC), acid volatile sulfide/simultaneously extracted metals (AVS/SEM), total organic carbon (TOC), and grain size distribution. Lake sediments were shown to exhibit reducing conditions, therefore, the chromium species present in sediment is found in its reduced form, trivalent chromium (Cr^{3+}), not hexavalent chromium (Cr^{6+}). Consequently, for the risk calculations, total chromium concentrations were assumed to be trivalent chromium.

Sampling to support the risk characterizations also included the collection of surface water and fish for analysis of fillets and whole fish. Ecological risk characterization activities also included additional sampling and analysis of plant and invertebrate tissue, a fish survey, a benthic invertebrate survey, and water column toxicity testing with fish larvae.

The human health risk assessment identified a potential condition of significant risk due to lead exposure of small children (younger than 7 years) who might wade or swim on a regular basis in the area of the lake referred to as the "Northern Shoreline/Western Cove" (NS/WC). Although these areas were not typically used for recreational activities other than boating by College students and adults, there was nothing to prevent small children from contacting (and possibly ingesting) contaminated sediment in these areas. The area(s) that posed a risk to small children was conservatively identified as being limited to a water depth of 1 meter or less, as it is unlikely that small children could come into contact with deeper sediment. No significant risks were identified for College students and adults, since they would have less contact with sediment, and the assessment assumed that adolescents and adults would not ingest sediment. As an interim risk abatement measure, signs were posted (Fig. 3) and thorny shrubs were planted along the shoreline to dissuade potential wader/swimmers from these areas.

Figure 3. Warning signs were posted along the shoreline to dissuade waders and swimmers

Food chain modeling conducted as part of the ecological risk assessment suggested a sub-lethal risk due to chromium exposure to waterfowl that might consume water lily roots (or roots of other aquatic vegetation) and sediment. Water depths where waterfowl could contact sediment were assumed to be 1 meter or less, based on the reach of a mute swan, the largest waterfowl using the lake. Lead concentrations in lake water regularly exceeded the chronic Ambient Water Quality Criterion (AWQC), which in accordance with Massachusetts regulations is an indicator of potential risk to the environment. Reduced fish growth rates were also identified in the northern end of Lake Waban but it is unclear at this time whether this is a result of lead and chromium contamination in sediments or other factors such as overcrowding.

5. RISK-BASED REMEDIAL GOALS

Using the exposure scenarios developed for the human health risk assessment, remedial goals were calculated for the contaminants identified as posing risk, — lead and chromium. The calculations resulted in concentrations at which risk would be reduced to acceptable levels (according to MADEP guidance [MADEP, 1995]). The USEPA IEUBK model (USEPA, 1994) was used to assess lead risks to children and to develop remedial goals. The calculated remedial goals to achieve a condition of no significant risk for human health are 400 mg/kg for lead and 8,635 mg/kg for chromium. These goals are applied to water depths under 1 meter where potential risks to young children were identified.

The only portion of the ecological risk assessment amenable for use in calculating numerical remedial goals was the food chain modeling. Other identified ecological risks were not directly associated with or correlated to sediment concentrations. [However, subsequent use of USEPA's (1999) draft equilibrium-partitioning guidelines for mixtures of metals indicates acid volatile sulfides and organic carbon are sufficient in sediment to bind the divalent metals (e.g., lead) and protect benthic invertebrates.] Remedial goals for swans were calculated at 7,210 mg/kg and 2,951 mg/kg for lead and chromium, respectively. For mallards (a species that can contact sediment to depths of 0.5 m), remedial goals of 1,194 mg/kg and 514 mg/kg were calculated for lead and chromium, respectively. Of the human health and ecological risk-based remediation goals, the lowest for each metal was selected for sediments in 0 to 1 meter of water, 400 mg/kg (the human health risk-based concentration) for lead and 514 mg/kg (the lowest waterfowl risk-based concentration) for chromium.

6. REMEDIAL PLAN DEVELOPMENT AND IMPLEMENTATION

Remediation of sediments presenting human health risks due to lead was limited to a specific geographic area of the lake, the NS/WC area, and risks were limited to water depths of less than 1 meter (due to lack of access of small children to sediment in deeper water). Removal of sediments in the NS/WC to address the risks to human health also addressed the risk to waterfowl, because this was the only area of the lake where elevated lead and chromium concentrations in sediments were located in shallow water (less than 1 m).

Remediation of sediment in the rest of the lake to eliminate the AWQC exceedances has been determined to be infeasible. The exceedances were small in magnitude when samples were collected in 1997 and 1998 for the ecological risk assessment (2.0 ug/L of lead versus the AWQC of 1.2 ug/L (at a hardness of 52 mg/L $CaCO_3$)). The potential remedies to eliminate these exceedances are lakewide dredging or capping. Since 2000, quarterly surface water monitoring has not resulted in an AWQC exceedance for lead. This issue is being addressed with MADEP.

Similarly, the reduced fish growth rates in Lake Waban are being reassessed as additional information on the fishery composition density and habitat is being evaluated. This issue will be addressed with MADEP in the near future.

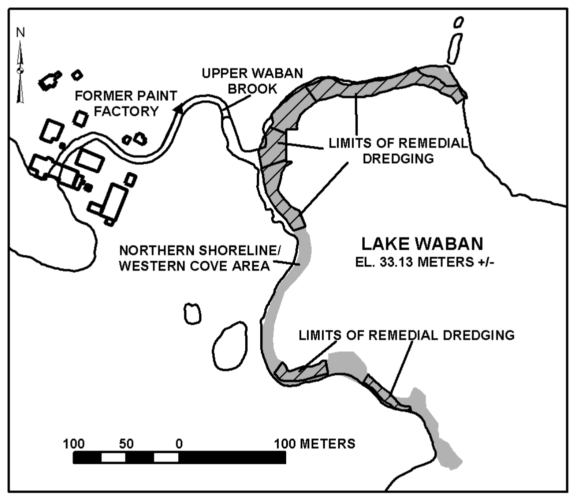

Figure 4. NS/WC portion of Lake Waban. Hatched areas identify the limits of remedial dredging.

Therefore, although sediments throughout the lake in water deeper than 1 meter are contaminated with lead and chromium, the risk assessment indicated that only the sediments in the NS/WC in water depths less than 1 meter needed to be addressed to achieve an acceptable human health risk and meet the calculated ecological risk-based remedial goals. Concurrent with the NS/WC evaluation, a large source remediation was being conducted in the "Upland" portions of the site. This remedial action included excavation of approximately 146,000 m^3 (200,000 cyds) of soils and sediment, including insitu chemical treatment of approximately 22,000 m^3 (30,000 cyds) of pigments containing soluble Cr^{6+}. Soils were consolidated on site and covered with an engineered barrier. Athletic fields were subsequently constructed on top of the consolidated soils.

Dredging of the contaminated sediments along the NS/WC was deemed the most appropriate remedy as the timing of the uplands work allowed placing contaminated sediments from the NS/WC in the consolidation area.

Hydraulic dredging was originally thought to be the most practical method of sediment removal. However the remediation contractor, Maxymillian Technologies, offered an alternative mechanical dredging approach that was ultimately accepted. The method employed is described in detail in section 6.2.

6.1 Remediation goals

The goal of sediment dredging in the NS/WC area was to reduce human health risk to acceptable levels and achieve calculated ecological risk-based goals. This would be accomplished by dredging sediments with lead and chromium concentrations above the remedial goals in the geographic area shown to exhibit risk (i.e., within the NS/WC area and in less than 1 meter of water). In addition, the area at the mouth of Upper Waban Brook was also included in the remedial plan. Although this area was not considered a risk to human health due to inaccessibility, the sediments in this area exhibited very elevated lead and chromium concentrations (94,000 mg/kg of lead in one sample), and were considered a potential source that could recontaminate adjacent areas proposed for remediation.

Sediment cores were used to delineate the vertical extent of contamination. In areas outside the mouth of Upper Waban Brook, contamination was limited to the upper 0.3-0.6 meters of sediment. At the mouth of the brook, the contamination extended approximately 1.3 meters below the lake bottom. It was also noted that there were areas within the NS/WC, typically shallow areas immediately adjacent to the shoreline with sand and gravel substrate, which had lead and chromium concentrations well below the remedial goals. The final dredging plan consisted of removal of approximately 4600 m^3 (6,300 cyds) of sediment from six discrete areas within the NS/WC. Figure 4 shows the limits of remedial dredging.

6.2 Dredging equipment and approach

Dredging was completed using a barge-mounted excavator outfitted with a proprietary environmental clamshell bucket, guided by a global positioning system (GPS). Software was integrated to provide the real-time data necessary for precise remedial dredging. Figure 5 shows the excavator configuration.

The software allowed the final dredge depth of a specific area to be entered into the program and as the excavator dredged material the LCD screen would change colors as it approached the final depth. The operator would continue dredging until the screen indicated that dredging had been completed to the appropriate depth. The LCD display is shown on Figure 6. The computer display linked to GPS ensured that all specified areas were dredged.

Figure 5. Excavator configured with an environmental clamshell dredge bucket. Note vertical GPS receiver antenna attached to bucket.

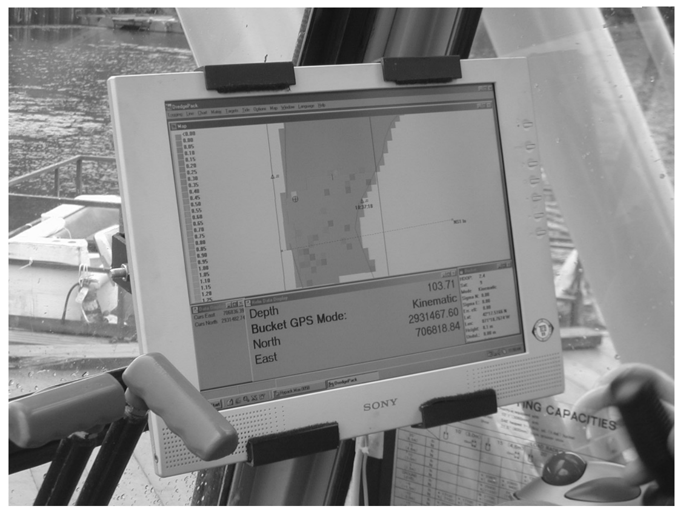

Figure 6. LCD Computer display which guides the operator and records the limits of dredging in 3 dimensions.

The rest of the lake was protected from the NS/WC dredging operation by two silt curtains. Turbidity measurements were collected at least 4 times per day and compared to an initial background measurement collected each morning prior to dredging activities.

Once the operator dredged to the appropriate depth, a confirmatory sample was collected using an Eckman dredge or a helical hand auger. Samples were collected of the upper 6 inches of sediment, placed in glass jars and analyzed at the on-site field laboratory. Sediment samples were analyzed for lead and chromium using a Niton X-ray Fluorescence (XRF) analyzer, and results were provided in near real time to guide the dredging operation. If the sample concentrations were above the remedial goals, dredging continued in 1-foot intervals until the goals were achieved. To ensure that the areas had been remediated successfully, additional samples were collected several days or even weeks after an area had been dredged to determine if settling of suspended solids or sediment migration had occurred. As a quality control measure, 50% of the samples analyzed on site were also submitted to a fixed laboratory for analysis by Inductively Coupled Plasma (ICP).

7. RESULTS

In general, all the areas that had been identified to pose risk to human health or the environment in the NS/WC area were dredged to below the remedial goals and the concentrations observed over time remained at or below the remedial goals for lead and chromium with the following exceptions.

At the initiation of the dredging project, the MADEP required a trailing silt curtain be used so that suspended solids could not migrate back into recently dredged areas. This curtain was placed between the shore and the dual silt curtain that isolated the NS/WC from the rest of the lake. It soon became apparent from post-dredge sampling and bathymetric data that the trailing curtain was dragging contaminated sediments, located in water depths greater than 1 meter (non-remediated areas), into the remediated areas. Once this problem was identified, use of the trailing silt curtain was discontinued, and the areas impacted were subsequently redredged. However, near the mouth of Upper Waban Brook, the remedial goals could not be achieved at several locations, primarily due to dramatic changes in water depth and sediment sloughing as described below.

The area at the mouth of Upper Waban Brook experienced the greatest dredge depths. Water depths in this area were increased from less than 1.05 meters prior to dredging to greater than 3 meters. In order to prevent sloughing into the dredged area at the mouth of the brook, a slope stabilization wall consisting of sand and gravel was installed along the outer limits of dredging in this area. The slope stabilization wall appeared to remain intact after dredging. However, it appears that the fine-grained sediments that were present beyond the limits of dredging may have migrated, via gravity, into the dredged areas. The abrupt change in lake bottom elevation caused by dredging was also coincident with vast differences in lead and chromium concentrations between dredged and un-dredged areas. Immediately outside of the dredged area, sediment concentrations were observed up to 50,000 mg/kg lead. A 2-meter abrupt elevation change was created in the outermost area dredged and apparently post-dredge sloughing caused lead concentrations in this outermost area to range from 1,000 to 10,000 mg/kg.

A subsequent post dredge risk evaluation including samples from these areas indicated that they do not pose risk to human health or waterfowl in the NS/WC on an average basis. Furthermore, the water depths make these sediments inaccessible to receptors that may be at risk (small children and waterfowl).

8. LONG TERM MONITORING

Quarterly monitoring along the extent of the NS/WC is being conducted for one year after completion of the dredging. Long term sediment monitoring along the NS/WC will be conducted at select locations on a quarterly basis as part of the Operation and Maintenance plan for the consolidation cell located adjacent to the lake on the Paint Factory site. This sediment monitoring will evaluate the long term reliability of the dredging operation to reduce and/or eliminate risks.

9. SUMMARY AND CONCLUSIONS

At a site heavily impacted by lead and chromium, a focused, risk-based remedial strategy provided a targeted cleanup of near shore Lake Waban sediments. Thorough human health and ecological assessments identified receptors and exposure pathways. Near real time, GPS-guided mechanical dredge data coupled with timely on-site laboratory analysis allowed for extremely efficient field operations that saved time and reduced cost. Most importantly, remedial goals were met, and stakeholder concerns were addressed for the NS/WC.

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