ASSESSMENT OF EQUIPMENT PERFORMANCE AND ENVIRONMENTAL EFFECTS DURING THE DEBRIS REMOVAL PILOT STUDY AT GOWANUS CANAL

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ABSTRACT

The Gowanus Canal (Canal) is a 2.9 kilometer (km) man-made canal in Brooklyn, New York constructed in the 1850s that supported industry and commerce until the late 20th century. A long history of industrial releases, stormwater discharges, and combined sewer overflows has resulted in several feet of impacted sediment. Deemed a Superfund Site in 2010, the US Environmental Protection Agency issued a Record of Decision in 2013 mandating the cleanup and dredging of the Canal.

Large quantities of debris were identified throughout the Canal, including within the 4th Street Turning Basin (TB4). Debris in the Canal will hinder planned remedial operations; therefore, a debris removal pilot study was conducted in TB4 during Fall 2016 to evaluate the effectiveness of several types of equipment and management processes. The pilot study included (i) large debris removal, (ii) debris field dredging, and (iii) debris/sediment processing and disposal. Since over 100,000 people live in the census tracts abutting the Canal, water quality, air/odor and noise/vibration monitoring was conducted to identify appropriate control measures for mitigating community impacts during full scale construction.

The pilot study began with the removal of 25 debris targets larger than 1.5 meters (m) in at least one dimension with either a five-tined grapple or rake. The largest debris target removed, approximately 19.2 m by 4.0 m, was a World War II Aircraft Rescue Boat converted to a community gathering location before it sank in TB4. Since the community was concerned that artifacts of historical significance could be lost, a trained archeologist was present during debris removal.

Following large debris removal, approximately 250 cubic meters (CM) of mixed debris and sediment were dredged from an area near the mouth of TB4. The effectiveness of two different buckets and three scow loading techniques were evaluated. In addition to testing dredging techniques, removal of the mixed debris and sediment provided access for future bulkhead stabilization work. Experience was gained in dealing with the major challenges of dredging within 3.0 m of an active pedestrian promenade along the bulkhead and controlling potential sediment and sheen releases with turbidity and air curtains.

All removed debris larger than 10 centimeters (cm) was offloaded at an upland staging site along the Canal for sorting and cleaning prior to examination by an archaeologist. Sediment was treated to pass paint filter test requirements for transport. Both sediment and debris were transported to a permitted landfill for disposal. As described in this paper, collected field data and experience gained during the pilot study provided insights on dredging method, logistics, environmental controls, and project implementation that will inform the full scale design and aid in the prevention of environmental and societal impacts during future remediation.

KEYWORDS

Environmental Monitoring, Water Quality, Dredging Methods, Production Rate, Community Relations

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INTRODUCTION

The Gowanus Canal (Canal) is a 2.9 kilometer (km) man-made canal constructed within the former Gowanus Creek in Brooklyn, New York (Figure 1). While development of the Canal began as early as 1767, the Canal was officially authorized in 1848 by the State of New York for the dual purposes of draining the wetlands of South Brooklyn and opening the area to development (Hunter Research, Inc., et al., 2004). Constructed between 1853 and 1869, the Canal was designed as a conveyance channel for barges (NYC Department of City Planning, 1985). It consists of the main portion of the Canal along with six turning basins, some of which have since been abandoned. The Canal was the primary mode of transportation for bulk materials such as coal, petroleum, asphalt, and lumber to support the rapid growth of industry in Brooklyn and surrounding areas. During its peak period of operation in the 1920s, there were an estimated 23,000 to 25,000 vessel trips per year through the waterway to 60 dock facilities (WFB Engineering, 2016). Use of the Canal started to decline by the early 1960s due to relocation of many industries. By 2000, there were only five active dock facilities along the waterway, with current estimates of only 400 to 500 vessel trips annually (WFB Engineering, 2016).

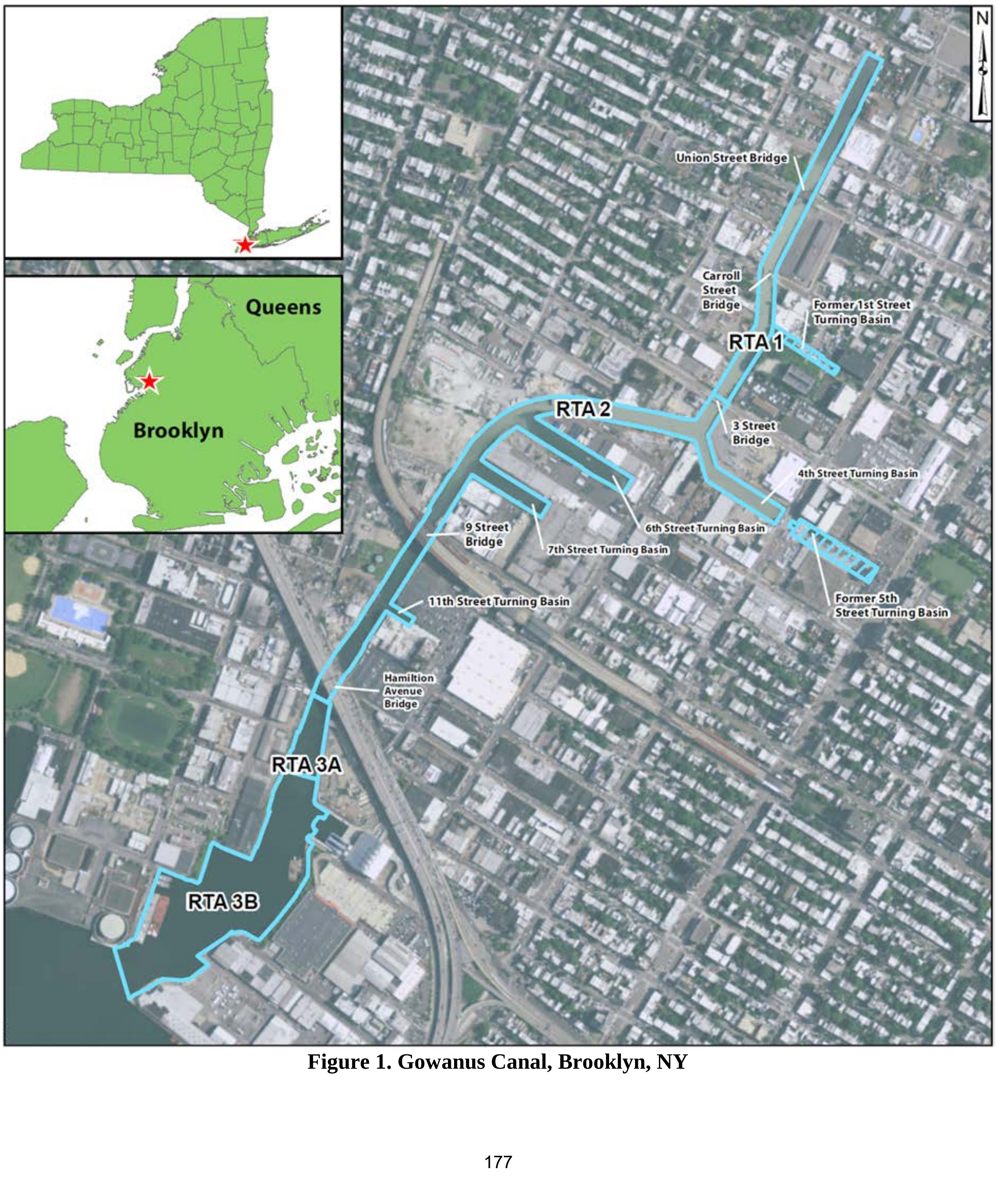

Figure 1. Gowanus Canal, Brooklyn, NY

Since the development and industrialization of the area, the Canal has also served as a conveyance for sewage and industrial wastes. During wet weather conditions, a mixture of sewage and stormwater enter the Canal via eleven combined sewer overflow (CSO) outfalls (NYCDEP, 2008). In addition to the study completed by the New York City Department of Environmental Protection (NYCDEP) in 2008, a United States Environmental Protection Agency (EPA) survey identified 231 private pipes that potentially discharged to the Canal (HDR, et al., 2011). Due to the confined nature of the Canal and limited tidal exchange, these discharges have resulted in deposition of several feet of impacted sediment along with water quality degradation throughout the Canal.

In April 2009, the New York State Department of Environmental Conservation (NYSDEC) requested that the Canal be included on the National Priorities List (NPL) pursuant to the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA). EPA commenced a remedial investigation following the proposal for inclusion on the NPL, and placed the Canal on the NPL on March 2, 2010. In April 2010, EPA issued Administrative Orders of Consent to perform work in support of EPA’s remedial investigation (RI)/feasibility study (FS). The RI was completed in January 2011, draft FS in December 2011, and addendum report to the FS in December 2012. Following the RI and FS, EPA issued the Record of Decision (ROD) on September 27, 2013 (EPA, 2013).

The ROD mandates the remediation and cleanup of the Canal. It requires the dredging of soft sediments that contain elevated levels of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and heavy metals. Dredged soft sediment will be treated and used for beneficial reuse. In some areas of the Canal with contaminated native sediment, in-situ stabilization (ISS) will be required. Following dredging, cap layers will be placed along the bed of the Canal including both an active treatment layer and an armoring layer.

DEBRIS REMOVAL PILOT STUDY OVERVIEW

To aid in the remedial design of the Gowanus Canal, a pilot study in the 4th Street Turning Basin was developed to evaluate the effectiveness of several types of debris removal equipment and environmental control measures. The pilot study was designed in three phases: (I) site staging area preparation; (II) evaluation of large debris and debris field removal; and (III) dredging of soft sediment, bulkhead stabilization, capping, ex-situ dredge material management, and dredge water treatment. The first two phases were completed in Fall 2016, with the final phase set to occur in the latter half of 2017. This paper will focus on the second phase of the pilot study: evaluation of large debris and debris field removal.

Sidescan sonar surveys performed by SeaVision Underwater Solutions in 2015 and 2016 identified various forms of debris present throughout the Canal. Specifically, the 4th Street Turning Basin (Figure 2) had 36 large debris (greater than 1.5 meters (m) in any direction), 10 tires, and a debris field (area with excess coverage of smaller debris). Debris in the Canal obstructs planned remedial operations; therefore, efficient debris removal and management is critical to ensuring the success of Phase III remedial activities. The key objectives of the 4th Street Turning Basin Debris Removal Pilot Study included:

- Clear large obstructions that prevent navigational access and hinder future dredging operations;
- Remove debris fields to allow navigational access for bulkhead upgrades prior to full scale pilot study;
- Evaluate the ability of different types of equipment to efficiently remove debris; and
- Evaluate the processes for managing debris, including:
    - Debris cleaning, handling, and storage;
    - Archaeological profiling;
    - Wash water reuse and recycling; and
    - Limited sediment processing.

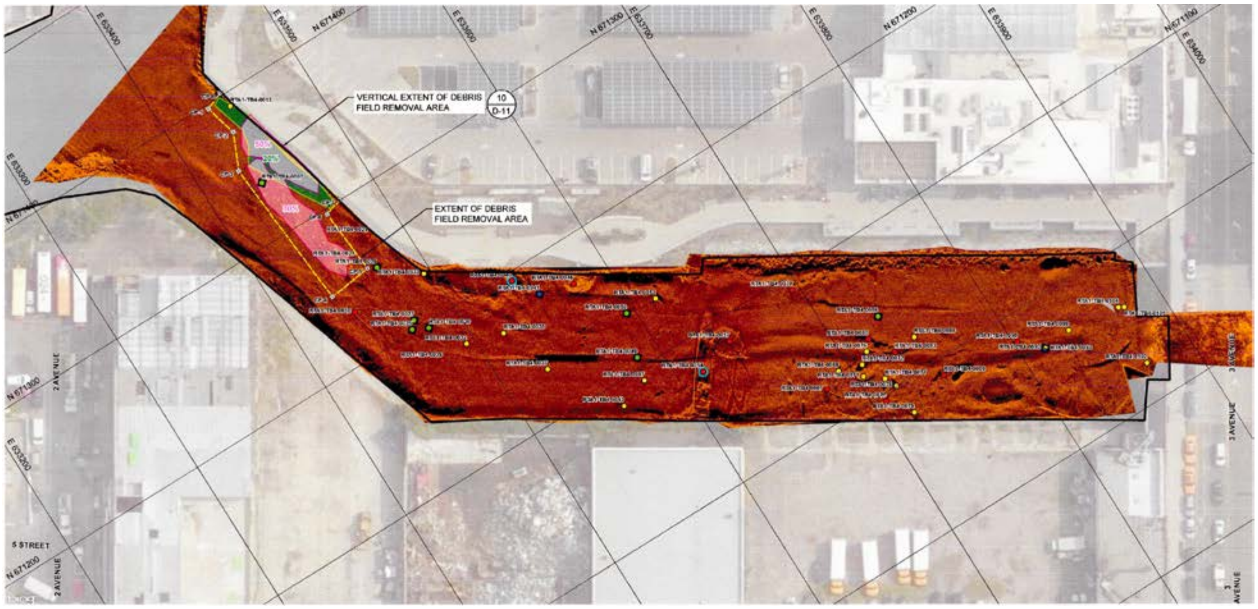

Figure 2. Observed Debris Locations in the 4th Street Turning Basin – Prior to Debris Removal Operations

Sevenson Environmental Services, Inc. (Sevenson), was selected to conduct the debris removal phase of the 4th Street Turning Basin Pilot Study in October 2016. Debris removal work started in October 2016 and lasted through December 2016. Sevenson’s scope of work included the following elements:

- Site preparation and installation of sediment and floatable containment controls;
- Removal of large debris using a grapple or a rake;
- Removal of 250 cubic meters (CM) of sediment and comingled small debris from a debris field with a conventional and environmental clamshell bucket;
- Transportation of recovered debris and sediment via barge to the staging site;
- Preservation of potential cultural resources for assessment;
- Classification and sorting of debris; and
- Transport of debris, sediment, and wash water to offsite permitted treatment or disposal facilities.

Sevenson furnished the following equipment (Figure 3) to conduct the work: 30.5 m x 9.1 m deck barge (equipped with a Komatsu PC450 long reach excavator on the front, Komatsu PC240 excavator placed on the back, a water tank, office/storage trailer, environmental clamshell bucket, conventional clamshell bucket, conventional excavator bucket, rake, and 5-tined grapple), another 30.5 m x 9.1 m deck barge to collect large debris, four pocket scows for sediment, one water scow, a push boat, a work boat, turbidity/air curtains, and a front end loader for use at the staging site area.

Figure 3. 4th Street Turning Basin Debris Removal Pilot Study Equipment

LARGE DEBRIS REMOVAL

Removal Operations

Removal operations began with the 36 large debris targets (greater than 1.5 m in any dimension) and 10 tires identified by sidescan sonar survey within the 4th Street Turning Basin. Two different attachments (a five-tine grapple and a rake) were used during the large debris removal operation (both shown in Figure 4). The advantage of the grapple is that it could rotate more easily to gather debris from the Canal. However, while working to remove an Aircraft Rescue boat, submerged debris severed one of the small exposed hydraulic lines at the fitting to the cylinder, rendering the grapple nonoperational. Thus, the grapple had to be replaced with the rake, resulting in lost time. The rake was larger and more durable than the grapple, but could not provide the same rotational movement. Additionally, the rake retrieved more sediment with the debris than the grapple. Debris covered in excess sediment was held over the Canal and was washed with Canal water using a fire hose prior to placement on the debris barge. Due to concerns with pathogens in the Canal water, this method was used sparingly. Some washing with the fire hose was also conducted once the material was placed on the debris barge, and a switch was made from Canal water to potable water for later stages of the project.

Figure 4. Large Debris Removal Attachments: Five-Tined Grapple (Left) and Rake (Right)

Production Data

Large debris removal spanned 37.5 hours (hrs) over the course of four days. Of that time, there were 9.75 productive hours for a time efficiency of 26%. The time efficiency observed during large debris removal was much lower than could be expected during full scale debris removal along the Gowanus Canal due to the short duration of the project (four days). A detailed breakdown of the removal activities and the number of occurrences of each activity are presented in Table 1. The longest activity was mobilization for 9.50 hrs, which accounts for 25% of the four-day duration. During full scale implementation, a similar mobilization time can be expected, but with much less impact to the overall time efficiency. The other major activities were safety meetings/crew boat rides, barge moves, and tidal delays. Looking ahead to full scale implementation, safety meetings/crew boat rides, barge moves, and lunch delays should be assumed to be the same duration as those observed during the Pilot Study. Tidal delays should only be a factor in the shallower, upper reaches of the Canal. It can be reasonably assumed that during full scale implementation, a time efficiency for large debris removal would be on the order of 65% (e.g. during a 10-hr day, the following would be expected delays: 1.25 hrs for safety meeting and crew boat travel, 1 hr for barge movement, 0.75 hrs for tidal delays, and 0.50 hrs for lunch).

Table 1. Large Debris Removal Activities During 4th Street Turning Basin Pilot Study

	Time (hrs)	Occurrences	Time/Occurrence (hrs)
Debris Removal	9.75	22	0.44
Mobilization	9.50	2	4.75
Safety Meeting & Crew Boat	5.25	4	1.31
Barge Moves	4.17	17	0.25
Tidal Delay	3.42	3	1.14
Change Attachment	2.83	1	2.83
Lunch	2.00	4	0.50
Mechanical Repairs	0.58	1	0.58

All 36 large debris targets were attempted, but only 25 were located and removed. Five out of the ten tires were located and removed. Eleven of the targets that were identified by sidescan sonar were not able to be located during large debris removal. At each of these locations, at least 5 minutes were spent trying to locate the target. The largest debris target removed, approximately 19.2 m by 4.0 m, was a World War II Aircraft Rescue Boat converted to a community gathering location before sinking. This vessel took 2.67 hours to remove. Excluding the Rescue Boat, 10-15 minutes were spent on each target location. Table 2 presents the removal efficiency and duration for both attachments. Both attachments removed around 70% of the targets, with similar time duration per target.

Table 2. Large Debris Removal by Attachment Type

Attachment	Targets Attempted	Targets Removed	Removal Rate	Total Duration (min)	Duration per Target (min)
Grapple	14	10	71%	165	12
Rake	32	21	66%	450	14

DEBRIS FIELD REMOVAL

Removal Operations

Following completion of large debris removal, Sevenson conducted the debris field removal. Approximately 250 CM of material were removed and loaded into four pocket scows. Two different bucket types and three different loading techniques were used during the debris field removal, as shown in Figures 5 and 6. The first two scows were loaded with a 1.1 CM environmental bucket and the second two with a 1.9 CM conventional clamshell bucket. One scow was loaded using the first loading technique in which buckets of commingled sediment and debris were emptied directly onto a 10-centimeter (cm) screen. To improve efficiency, a second loading technique was evaluated in which buckets were loaded directly into a scow and subsequently transferred to another scow through grizzly bars with 10-cm spacing. The final scow was loaded using the third loading technique in which buckets were emptied directly through the 10-cm grizzly bars into the scow.

Figure 5. Debris Field Removal Attachments: 1.5 CY Environmental Bucket (Left) and 2.5 CY Conventional Clamshell Bucket (Right)

Figure 6. Debris Field Removal Scows: Screen (Left) and Grizzly Bars (Right)

Production Data

Debris field removal occurred between November 1 and November 8, 2016. Over the course of the six workdays, 48.5 total hours were worked, of which, 15.67 hours were productive for a time efficiency of 32%. Activity durations and occurrences are presented in Table 3. The main activity was barge movements. Due to tight quarters in the 4th Street Turning Basin, the activities observed during the Pilot Study are longer than can be expected during full scale debris field removal. Tidal delays would not be expected during this portion of work, as the dredge would work from the deeper portions of the Canal into the shallower areas. During full scale debris field removal, a time efficiency around 65% can be expected (e.g. during a 10-hr day, the following would be expected delays: 1.50 hrs for barge/scow movements, 1.25 hrs for safety meeting and crew boat travel, and 0.50 hrs for lunch).

Table 3. Debris Field Removal Activities During 4th Street Turning Basin Pilot Study

	Time (hrs)	Occurrences	Time/Occurrence (hrs)
Debris Field Removal	15.67	23	0.68
Barge Moves	10.00	22	0.45
Safety Meeting & Crew Boat	7.08	6	1.18
Mobilization	5.42	1	5.42
Lunch	3.25	6	0.54
Mechanical Repairs	2.92	7	0.42
Change Bucket	2.58	1	2.58
Rehandle Material	1.08	1	1.08
Wash Debris	0.50	1	0.50

Noticeable differences between the two bucket types was observed during the debris field removal. Due to the size and quantity of debris, typically the environmental bucket did not completely close allowing for spillage of dredged material. Since the conventional bucket was not fully enclosed, it allowed for heaping buckets of sediment. The operator drained all buckets prior to emptying the contents to reduce water in the scow. Production numbers for each of the four scows are presented in Table 4. Bucket size and scow loading techniques were as follows:

- Scow 1: 1.1 CM Environmental Clamshell Bucket onto 10-cm Screen
- Scow 2: 1.1 CM Environmental and 1.9 CM Conventional Clamshell Bucket directly into Scow
- Scow 3: 1.9 CM Conventional Clamshell Bucket directly into Scow
- Scow 4: 1.9 CM Conventional Clamshell Bucket onto 10-cm Grizzly Bars

Table 4. Debris Field Removal Production Numbers

	Scow 1	Scow 2	Scow 3	Scow 4
Scow Volume (CM)	55	60	68	70
Total AVG Cycle Time (sec)	193	92	127	137
AVG Cycle w/o Cleaning Screen (sec)	101	N/A	N/A	114
Total Scow Load Time (hr)	4.45	2.79	2.68	3.63
Total Lost Time (hrs)	2.18	N/A	N/A	0.63
Total Productive Time (hrs)	2.27	2.79	2.68	3.00
Total Buckets	81	109	76	95
Number with Lost Time	36	N/A	N/A	18
Percent Buckets w/ Lost Time	44%	N/A	N/A	19%
Average Bucket Percentage	58%	40%	47%	38%
Average Bucket Volume (CM)	0.67	1.12	0.89	0.73

Since both Scows 1 and 4 were loaded through a screen and grizzly bars, respectively, lost time refers to the time required to push material through and remove material from on top of the screen or bars. Not accounted for in the table is the time required to rehandle the material in scows 2 and 3. This material was removed from the loaded scow and passed through the 10-cm grizzly bars into a new scow. It took the long reach excavator just over 1 hr to rehandle both scows. Accounting for this time, total scow load times are as follows: 4.45 hrs for Scow 1, 3.29 hrs for Scow 2, 3.18 hrs for Scow 3, and 3.63 hrs for Scow 4. Load times show that a 10-cm screen significantly impacts debris field removal production. Similar load times were observed when comparing loading directly into a scow with rehandling through 10-cm grizzly bars or loading directly through 10-cm grizzly bars.

SEDIMENT AND DEBRIS DISPOSAL

Following large debris and debris field removal, debris and sediment were transported to the site staging area for sorting and disposal. The long reach excavator removed the debris and sediment from the barges, while the excavator sorted the material on the asphalt pad with the rake. Separate debris piles were made for rocks, wood, tires, metal, and general debris. Dredged sediment was stabilized in each scow with Portland cement (approximately 5% by weight). Following stabilization to pass the paint filter test, the sediment was offloaded to the asphalt pad at the staging area. Water decanted from the sediment scows was pumped to a frac tank on the staging site for later disposal. Photos of the debris and sediment offload are presented in Figure 7.

Figure 7. Debris and Sediment Offload to Pad (Left) and Loading of Debris and Sediment to Trucks for Disposal at Permitted Landfill (Right)

All debris and stabilized sediment was transported and discarded at three different permitted landfills in Pennsylvania. Due to the limited quantities of tires and potentially recyclable material recovered during the debris removal operations, recycling was not attempted as planned. Between December 14, 2016 and December 19, 2016, 316 metric tons of stabilized sediment and 1,029 metric tons of debris were loaded into tractor trailers for transport offsite and disposal as non-hazardous waste. An additional 6 metric tons of stabilized sediment were transported for disposal on January 5, 2017. A total of 2.12 CM of water used for debris washing and water decanted from sediment scows was pumped from the frac tank to a tanker truck and transported offsite.

ENVIRONMENTAL MONITORING

Over the course of the debris removal pilot study, both a turbidity curtain and air curtain were tested for sediment and floatable containment during dredging (Figure 8). The turbidity curtain was deployed upon mobilization and during large debris removal. The air curtain was installed prior to debris field removal. During debris field removal, the air curtain was operated and the turbidity curtain was tied to the bank. At night, the air curtain was shut off and the turbidity curtain was redeployed. This saved costs by reducing fuel and eliminating the need for an air curtain operator overnight. Low fuel and other mechanical issues with the air curtain compressor regularly caused delays, but were usually resolved quickly. While the air curtain was much faster and easier to use compared to the difficulties associated with opening and closing the turbidity curtain, the reliability and added cost of the air compressor and fuel may limit the air curtain as a sole sediment and floatable containment device.

Figure 8. Turbidity Curtain (Left) and Air Curtain (Right)

Minimal sheen and minor odor were observed during the large debris removal. BioSolve Pinkwater solution was applied, when necessary and noticeably mitigated any odor issues. Debris on the barge was either covered with plastic sheeting or RusFoam® LM (RusMar Foam Technologies, Incorporated) was applied to effectively control odor from the debris pile. Once on the asphalt pad at the staging site, all debris and sediment was covered with plastic sheeting.

Water quality monitoring was conducted throughout the Pilot Study to evaluate the effectiveness of deployed engineering controls (turbidity and air curtains), monitor the impact of construction activities within the work zone on sediment resuspension and sheen production, evaluate best management practices, and develop a correlation between turbidity and total suspended solids (TSS). The correlation between turbidity and TSS could be used in future stages of work to easily estimate TSS directly from field turbidity readings. Two turbidity buoys, sentinel (just outside of the work area) and ambient (upstream away from activities to provide background data) were deployed to record turbidity on 15 minute intervals. Average daily readings and turbidity ranges during working hours are presented in Table 5. Negligible differences between the ambient and sentinel buoy turbidity readings indicate the effectiveness of both the turbidity and air curtain engineering controls.

Table 5. Turbidity Buoy Measurements During 4th Street Turning Basin Pilot Study

Date	Ambient AVG Turbidity (NTU)	Sentinel AVG Turbidity (NTU)	Difference (NTU)	Ambient Range (NTU)	Sentinel Range (NTU)	Engineering Control
10/24/2016	2.3	3.4	1.0	1.9 - 2.9	2.3 - 4.8	Turbidity curtain
10/25/2016	1.6	4.4	2.9	1.0 - 2.4	2.1 - 9.4	Turbidity curtain
10/26/2016	2.3	3.9	1.6	1.4 - 5.0	2.0 - 7.1	Turbidity curtain
10/27/2016	2.6	5.0	2.5	1.7 - 7.8	1.9 - 13.6	Turbidity curtain
10/28/2016	3.0	3.9	0.9	2.3 - 3.9	2.3 - 6.9	Air curtain
10/31/2016	4.5	5.7	1.1	2.9 - 6.5	1.9 - 20.4	Air curtain
11/1/2016	5.7	4.6	-1.1	3.3 - 10.4	2.0 - 7.6	Air curtain
11/2/2016	5.7	7.9	2.1	3.8 - 10.7	2.5 - 16.2	Air curtain
11/3/2016	4.9	6.9	2.0	4.3 - 6.0	2.8 - 10.2	Air curtain
11/4/2016	6.4	4.3	-2.2	4.3 - 13.6	1.2 - 9.8	Air curtain
11/7/2016	6.5	4.1	-2.4	4.8 - 13.8	1.2 - 7.9	Air curtain
11/8/2016	5.3	3.2	-2.1	3.9 - 8.6	1.8 - 5.7	Air curtain

Samples were also collected manually, measured for turbidity, and sent to the laboratory for TSS analysis. Table 6 indicates the turbidity measurements within the plume of turbid water from the debris removal operations. The most turbid plumes were detected not during removal operations, but during movement of barges. The propeller wash was the most impactful due to the shallow depths of the turning basin. A linear correlation between turbidity and TSS was observed (Figure 9).

Table 6. Handheld Turbidity Measurements within Plumes

Description of In-Canal Activity	AVG Turbidity in Plume (NTU)	MAX Turbidity in Plume (NTU)	AVG Distance from Source of Sediment Resuspension (m)	Number of Measurements
Large Debris Removal with Grapple	21.8	25.0	18	2
Large Debris Removal with Rake	23.6	32.0	18	4
Debris Field Removal with Environmental Clamshell Bucket	9.9	26.9	9	87
Debris Field Removal with Conventional Clamshell Bucket	16.8	27.1	13	35
Movement of Barges with Push Boat	46.3	155	30	28

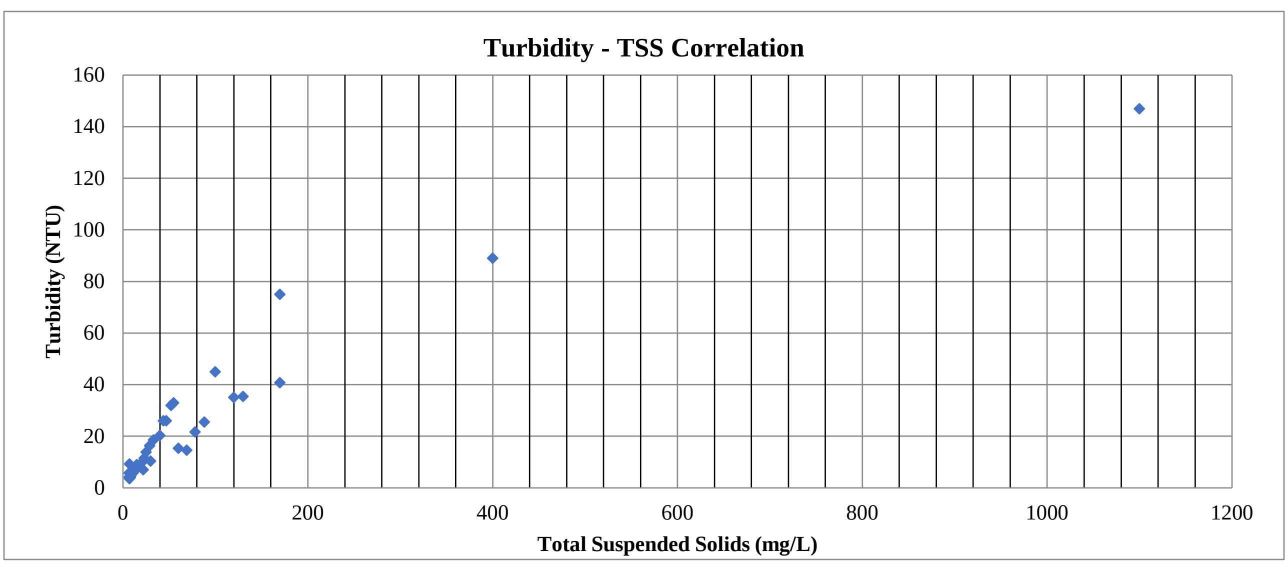

Figure 9. Turbidity and TSS Correlation

ARCHEOLOGICAL MONITORING

An archeological contractor was retained to develop and implement the Cultural Resources Monitoring Plan. A professional archaeologist was on site to monitor large debris and debris field removal, along with debris decontamination at the staging site. The archeological contractor did not identify any significant historic or archaeological resources during monitoring. The Aircraft Rescue boat was deemed ineligible for the National Register due to the number of vessels preserved, and the lack of unique construction (AHRS, 2017). Several fragments of stamped Hudson River Valley bricks likely dating back to the nineteenth and twentieth centuries were stored onsite.

CONCLUSIONS

Upon completion of the 4th Street Turning Basin Debris Removal Pilot Study, 25 large debris targets were removed throughout the turning basin, and 250 CM of sediment were removed from the debris field area at the mouth of the turning basin. Debris targets that could not be located may have been covered up by sediment while removing other targets nearby or by barge movement in the turning basin. Targets could also have been moved while attempting removal. Remaining targets within the 4th Street Turning Basin will be removed in 2017 during dredging in Phase III of the pilot study.

Equipment and Vessel Considerations

Grapple and rake attachments were tested to evaluate which attachment was more effective for large debris removal. An advantage of using the grapple was that the tines could be rotated to easily remove debris. One disadvantage was the number of small hydraulic lines that could be severed while trying to remove submerged debris. This happened on the first full day using the grapple causing a minor hydraulic leak and forcing an attachment change to the rake. Grapples did not seem effective in removing tires from Canal. The rake attachment was more durable than the grapple, but could not rotate as easily to retrieve debris. There were still hydraulic lines on the rake, but they were fewer and more protected. The rake was less precise than the grapple and picked up more sediment with debris than the grapple which adds to processing time. Additionally, a shear attachment was onsite for the pilot study, but was not needed as the timber and bulkhead pieces were easily picked and placed on the debris barge. While the grapple and rake each have advantages and disadvantages, they showed similar effectiveness during the short duration of the pilot study. Thus, the future Contractor will most likely be allowed to specify which attachment they prefer to use in their means and methods.

Based on experience during the pilot study, tugboat size should be limited to fit within constraints of the Canal. Large tugboats not only have difficulties maneuvering in the tight quarters of the Canal, but are also the biggest factor in increased turbidity during the operations. Small pocket scows with walkways worked well as larger debris could be placed on the walkways.

Debris and Sediment Removal Considerations

Both a 1.1 CM environmental and 1.9 CM conventional clamshell bucket were evaluated. The environmental bucket did not completely close, usually due to debris, and drained water. The conventional bucket drained as much water as the environmental bucket, closed sometimes, and allowed for heaping buckets. For future work, it is recommended that an environmental clamshell bucket be used for dredging initially. If the environmental clamshell bucket is deemed ineffective, then a switch could be made to a conventional clamshell. A conventional excavator or backhoe bucket was not tested in this study and is not planned for use during full scale operations.

As shown by the scow loading durations, the 10-cm screen over the scow significantly impacts dredge production and is not planned to be used in the future. Similar load times were observed when comparing loading directly into a scow with rehandling through 10-cm grizzly bars or loading directly through 10-cm grizzly bars. Similar to the attachment for large debris removal, for future work, the Contractor will be able to determine which one of these loading techniques they will use in their means and methods. To further reduce the impact of debris sorting, while still preserving archeological artifacts and not sending debris to sediment stabilization, it is recommended that the grizzly bar spacing be increased to 15 cm for future work.

While a low time efficiency around 30% was observed during the debris removal pilot, the full scale operations can except to see more efficient operations. The longer project duration will alleviate the high mobilization times. Tidal delays and delays due to barge movements will decrease after work begins in the main Canal. Future debris removal operations are expected to have a 55-70% time efficiency.

Sediment and Floatables Containment Considerations

During the pilot study, both a turbidity and air curtains were deployed. Once the ties holding up the boom on the turbidity curtain were removed to lower the curtain to approximately 30.5 cm from the bottom of the Canal at low tide, the curtain became difficult to open and close. The air curtain was easier to work around than the turbidity curtain as it allowed for vessels to enter and exit the work area without delay. Turbidity data from the water quality monitoring buoys showed a negligible difference between the sentinel and ambient buoys, showing that both the turbidity and air curtains were effective at containing sediment and floatables.

The air curtain was unsuccessful in containing sheen when the dredge barge was straddling the air curtain. The dredge barge should not straddle the air curtain unless additional containment measures are applied such as setting up the turbidity curtain around the barge to contain the sheen. The recommended approach for future work is to deploy an air curtain during dredging or debris removal operations and deploy a turbidity curtain during non-working hours. The turbidity curtain will also provide redundancy in case the air curtain becomes nonoperational.

Environmental Management Considerations

Odor control mist and foam were both applied during the work to compare the effectiveness of each option. BioSolve Pinkwater solution mist mitigated odors, but there was concern about the spray and mist impacting pedestrians downwind. It was not applied on windy days for these reasons. RusMar long-duration foam was applied to debris and sediment stockpiles to mitigate odors and is the preferred odor control method for future work.

Turbidity measurements from the turbidity buoys and handheld measurements both indicated that barge movements cause the most substantial sediment resuspension. Despite frequent observation of sediment resuspension in the work zone by handheld turbidity measurements, data from the sentinel turbidity buoy demonstrated that both the turbidity curtain and air curtain were successful in containing resuspended sediment. Even when debris removal activities occurred at the mouth of the turning basin with the barge straddling the air curtain, turbidity measured by the sentinel turbidity buoy remained low. However, sheen was observed outside of the turning basin when the barge was positioned straddling the air curtain. This observation should be considered when developing future best management practices.

Final Conclusions

Experience gained in dealing with the major challenges of removing debris and debris field areas within 3.0 m of a heavily used pedestrian area and controlling potential sediment and sheen releases with turbidity and air curtains will prove valuable in full scale design. Field data collected and experience gained during the pilot study provided insights on dredging methods, logistics, environmental controls, and project implementation that will carry through to future design work and will aid in the prevention of environmental and societal impacts during remediation.

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NOMENCLATURE

CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act*
cm	Centimeters
CM	Cubic Meters
CSO	Combined Sewer Overflow
EPA	United States Environmental Protection Agency
FS	Feasibility Study
hrs	hours
ISS	In-situ Stabilization
km	Kilometers
m	Meters
min	minutes
NPL	National Priorities List
NTU	Nephelometric Turbidity Unit
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
RI	Remedial Investigation
ROD	Record of Decision
sec	Second
TB4	4th Street Turning Basin
TSS	Total Suspended Solids