The Planning & Implementation of Trenchless Technologies to Restore the St. James Avenue, Boston, Interceptor

Using a variety of construction methods reduced negative impacts on groundwater levels, abutters, maintaining service, and vehicular and pedestrian traffic.

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The New St. James Avenue Interceptor Project, with a construction cost of $15.6 million, utilized a combination of various types of trenchless technology applications for the installation or replacement of the sanitary, storm drain and combined sewer systems located within the St. James Avenue area in the historic Back Bay district of Boston. The project commenced in May 1995 and was completed in December 1996.

History & Purpose of the Project: A Summary of Planning Studies & Data Collection

In the spring of 1990, after more than sixty years of continuous and repetitive maintenance problems associated with the St. James Avenue sewer system, the Boston Water and Sewer Commission (BWSC), contracted with an engineering consultant to prepare a comprehensive design study report for the restoration of that sewer system (see Figure 1). The St. James Avenue system is a complex network of interconnected sanitary sewers, storm drains, combined sewers and underdrains between

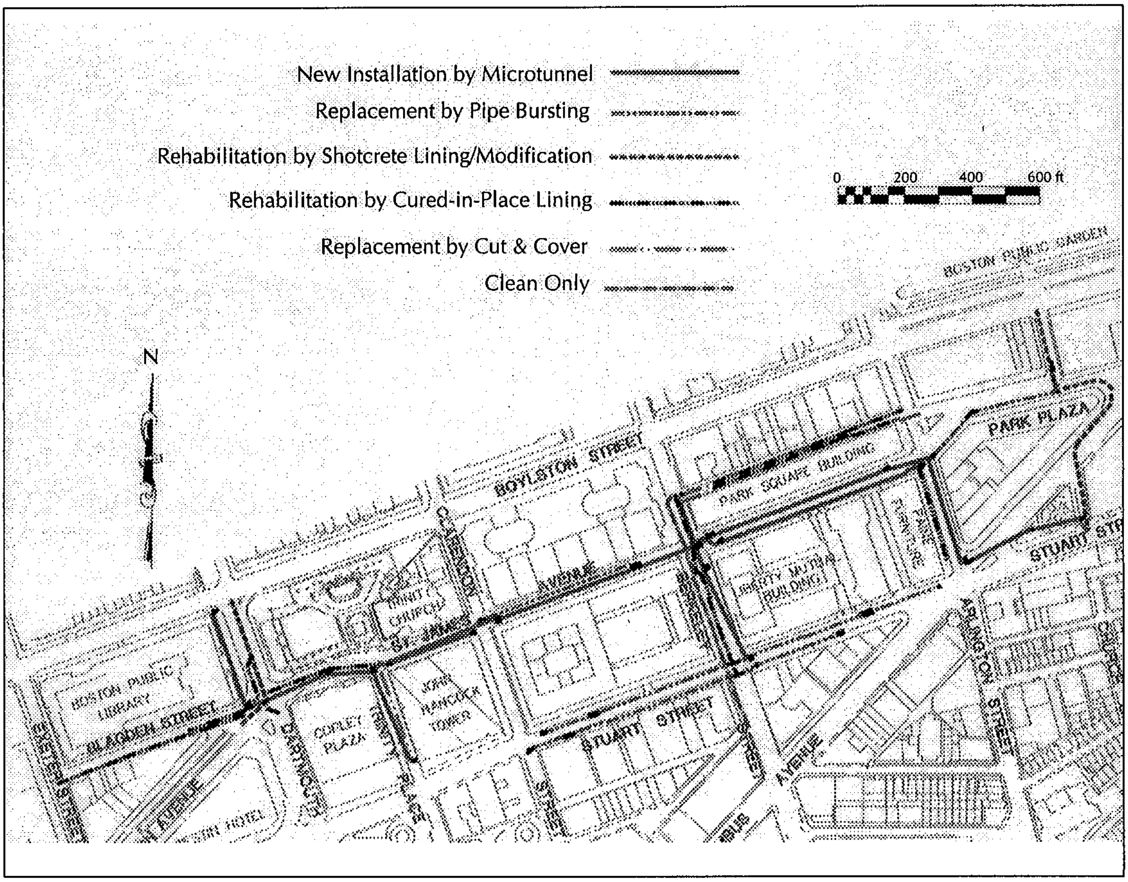

FIGURE 1. Project area map.

Copley and Park squares. The Massachusetts Bay Transportation Authority's (MBTA) Green Line and Orange Line subway systems and the Massachusetts Turnpike border this area and provided significant constraints to the design of the project and, as well, restrict groundwater movement within it. The primary objective of the study was to review the physical conditions of the St. James Avenue sewer system and to identify an economically, environmentally and socially acceptable solution for the rehabilitation and/or replacement of the system.

The project area was a former tidal estuary that was subsequently filled between 1836 and 1871. The soils consist of sandy gravel material deposited without significant compaction. As a result, the soils are of an unconsolidated nature and are not suitable for extensive loads. The oldest pipe in the study area was built in 1847; however, most of the sanitary and storm systems were installed in the early 1900s to improve an original system of wooden box conduits. The existing sanitary sewer of varying sizes carried approximately 1.75 million gallons of flow per day and was, on average, 20 feet below street grade. The project area included the old and new John Hancock Insurance buildings, numerous hotels, substantial office developments and retail establishments, as well as historic establishments such as the Trinity Church and the first Boston Public Library.

As part of the design phase, an extensive groundwater study was performed to determine areas of groundwater depletion caused by infiltration into the system and to understand the relationship of groundwater flows and groundwater depletion rates. Many of the older buildings within the area — including Trinity Church and the Boston Public Library, which were built between 1876 and 1912, respectively — were constructed with wood pile foundations. The tops of most of the piles were cut off at, or driven below, elevation 5.0± Boston City Base (BCB) Datum. When groundwater is lowered below the tops of the wood piles, exposing the piles to air, the piles begin to decay. If the piles are exposed to air, underpinning is usually required to restore bearing capacity for the buildings' foundations. To ensure that the system did not cause groundwater to fall below elevation 5.0 (BCB), the city of Boston installed a dam to maintain the flow within the system at or above that elevation. Unfortunately, the invert elevation of the sanitary sewer system was well below the dam elevation, which resulted in extensive maintenance and hydraulic problems with the system.

During the study, the sewers and storm drains were evaluated by using a video inspection system where feasible and from previous video and physical investigations. Since the system was continually degrading, and present-day inspection was not feasible in certain areas, the older video inspection tapes became an important source of information for the planning of the course of replacement or repair. Overall, the system was found to be in a deteriorated condition both physically and hydraulically. This degraded state was a combination of several issues, including consolidation of the underlying soils that caused non-uniform settlement of the pipe, sags and structural deficiencies, surcharging in the system and extensive groundwater infiltration.

The lowering of the groundwater from infiltration, which impacted the foundations and/or the piles of adjacent buildings, resulted in the installation of a man-made dam in 1933 at a downstream manhole to prevent the lowering of the groundwater in the area. However, the dam, while alleviating infiltration problems and groundwater issues, aggravated sediment and organic grease build-up in the system due to the creation of the surcharged condition. As a result of the grease and sediment problems, the BWSC was required to undertake a weekly maintenance program in the area to minimize the adverse impact of flow restrictions and the resulting customer complaints.

As part of the project, a detailed geotechnical boring program was conducted to evaluate soil conditions and to identify the geotechnical parameters for the design. The boring program determined that approximately 20 feet of sandy/gravelly fill with cobbles overlies sandy marine deposits, organics and clays for most of the project area. One area was also found to be heavily contaminated with fuel oil.

Plans were prepared that depicted the project area, including all surface and known subsurface features. Records were researched to identify the sizes and types of all utilities, present and abandoned, as well as all roads, railways and buildings in the project area. The current and future system hydraulic needs were analyzed and a base hydraulic flow model prepared. Based on a review of the system and the hydraulic requirements, the project limits were increased and evolved beyond the initial project area of St. James Avenue. The adjoining pipes that tied into the St. James Avenue system required replacement or rehabilitation to ensure proper hydraulic conditions for the area.

With the project limits defined and all of the surface and subsurface constraints identified, methods for the rehabilitation and/or replacement of the system had to be selected that would solve the sewer system problems. Any remediation needed to be done by limiting the impact of construction on surface activities, abutters and underground utilities. The methods reviewed included conventional open-cut construction, jacking, a non-gravity installation, trenchless techniques or a combination of these methods.

An evaluation of each method was performed to decide which techniques were practical and cost effective for the construction constraints imposed within the project area. Various alternatives were developed and presented to the BWSC. Some of the alternatives, such as jacking and extensive open-cut excavation, were eliminated because of the potential impact of lowering the groundwater table for an extended period during the construction process and for potential surface disruption. The non-gravity option, which included the installation of pump stations, was not attractive due to the long-term maintenance issues with operating a pressure system and the lack of suitable locations to install the pump stations.

Further review and analysis was performed comparing several trenchless technologies based on the existing hydraulic condition and types of pipes used in the original construction. The project was geared to incorporate several methods emphasizing the use of trenchless technologies for the replacement or rehabilitation of the system and to select the specific techniques in conjunction with the system characteristics and the capabilities of the selected methods.

Existing Flow Characteristics: Removal of Infiltration & Separation of the System

The project area has an average dry weather flow rate of 1.75 million gallons per day. The system within the project area consists of a combination of sanitary sewers, storm drains and combined sewers that are interconnected in several areas to relieve the system during peak rainfall events. The project goals were to separate the system where economically feasible, provide a sound hydraulic system and remove groundwater infiltration. In removing the groundwater and inflow, significant cost savings associated with treatment would be realized. The artificial surcharge of the system at the downstream end would be eliminated by removing the dam once the infiltration was controlled. Once the infiltration into the existing system was removed, the groundwater should not be influenced by the system within the project area, thus providing protection for the wood piles.

In addition to the artificial surcharging of the system, the conduits were found to have settled in various locations, creating sags that resulted in the settlement of solids, the accumulation of grease and a decreased hydraulic capacity (which caused significant surcharging during peak flow periods). As a result, the combined sewer overflows occurred more frequently than should have been expected and customer complaints regarding backups became more numerous. Major separation work previously undertaken in the South End district of Boston, which abuts the Back Bay area, was tied in with this project so that there would be further separation in the combined sewers and reduced combined sewer overflows.

Existing Pipe Materials & Impact on Construction Techniques & Flow Capacity

In order to evaluate the methods of rehabilitation or replacement, the materials, sizes, shapes and design capacities of the conduits were compiled using a field investigation as well as a study of recorded documents. The investigation determined that there were numerous types, shapes and sizes of conduits, including vitrified clay pipe, cast-in-place concrete, formed brick, cast iron, concrete encased clay and ductile iron with several portions of the conduits being pile supported. Given all of these varying pipe materials and the need to increase the capacity of parts of the existing system, using one specific construction method was not considered to be practical. In order to limit the range of proposed pipe sizes and to standardize where possible, one size of pipe was primarily selected for some of the rehabilitation methods to achieve economy of installation. It become apparent (as a result of all of the site constraints) that this project would require a combination of trenchless technologies.

Trenchless Methods: Microtunneling, Pipe Bursting, Cured-in-Place Lining & Shotcrete Lining

A number of trenchless methods were evaluated against the project conditions and design parameters. The results of this evaluation concluded that no one method would satisfy all of the project objectives. Therefore, it was determined that four main trenchless techniques would need to be utilized.

Microtunneling. Microtunneling was utilized for the majority of the mainline pipe installation. This method was selected for pipes that required replacement where the physical condition for rehabilitation was suspect but could not be verified due to the field conditions or where extensive settlement was known to have occurred. During the planning stage, it was discovered that in the early 1900s the project area contained a major train terminal where the present roadway system exists. Within this area there was a high potential to encounter abandoned wood piles and granite block foundations. As a result, the concept to replace the existing system in its existing (in-line) location wherever possible was specified to minimize the potential for encountering the abandoned foundations and wood piles. In-line replacemement appeared to be the only feasible trenchless construction method even though it had not been attempted in the United States previously.

In addition, microtunneling was also selected where clay pipes existed. The portions of the existing system that were encased in concrete were not conducive for microtunneling. The size of the pipe for microtunneling was standardized at 36 inches, even though a smaller diameter could have been utilized in certain areas. One standard size allowed for the mobilization of only one microtunneling machine for the entire project. In order to provide greater competition at bid time, both reinforced concrete and fiberglass pipes were considered as acceptable materials for use with microtunneling.

Cured-in-Place. Cured-in-place rehabilitation was utilized for the pipes that had cracked (thereby allowing groundwater infiltration), but had not totally lost their structural integrity (as was verified by video inspection). The circular pipe sizes ranged from 10 to 36 inches. Irregularly shaped cast-in-place or brick pipes ranging from 27 by 27 inches to 42 by 42 inches were also rehabilitated in this manner. The existing system was cleaned and active services were confirmed by video inspection. The existing, or "host," pipe was then lined with a resin-impregnated structural liner and the services reopened by remote controlled cutters. While other types of liner systems such as fold and form rehabilitation methods were evaluated, the shapes, sizes and ovality of the conduits did not permit these methods to be utilized.

Pipe Bursting. For the clay pipes that had lost their shape but had maintained a positive gradient, and could not be cleaned and inspected by video camera, pipe bursting was the method chosen for replacement. The major benefit of pipe bursting is the ability to increase the hydraulic capacity of the system by increasing the pipe size where necessary. The project's contractor was allowed to utilize either high-density polyethylene or fiberglass pipe ranging from 12 to 24 inches in diameter. The actual type of pipe bursting equipment utilized was selected by the contractor, which resulted in the lengths of runs being maximized and also increased competition at bid time.

Shotcrete Lining. In the largest conduits where physical personnel entry was feasible, the combined sewers were lined with shotcrete and a polyvinyl chloride half-pipe invert was installed. This scheme provided a hydraulically efficient means for both low (sanitary only) and wet weather (sanitary and storm run-off) flows.

Ensuring Adequate Experience With Trenchless Technologies

Since numerous trenchless technologies were going to be employed on the project and, in some instances, were methods that had never been used in Boston, the BWSC opted to prequalify the contractors for the microtunneling, pipe bursting and cured-in-place methods of work. The firms that had been determined to meet the minimum experience levels were listed as prequalified firms in the contract documents. The general contractor was required to specify at the time of bid which prequalified subcontractors would be utilized for these specialized areas.

The BWSC also conducted a value engineering workshop utilizing four outside specialty consultants to review the contract documents. The purpose of the review was to provide an independent assessment of the methodologies selected and the feasibility of the proposed methods. The results of the workshop was reviewed with the panel, BWSC and the project designer. The conclusions that they reached were incorporated into the contract documents.

Open Cut Excavation: Access Shafts, Service Connections & Mainline Replacement

The pipe bursting and microtunneling methods required 32 access shafts to be excavated in order to install the new pipes. These shafts were constructed so that they could accommodate the necessary equipment to install the new pipes by either microtunneling or pipe bursting. These access shaft excavations were generally small, with a surface area of 40 to 45 square yards each. The average depth of the sanitary sewer system was 20 feet and the average depth of the storm drain system was 15 feet. The contractor was required to pre-excavate each of the shafts to locate utilities. This method ensured that both utility and earth support systems were properly drained for each of the shafts. The shafts were constructed sequentially and decked with wood beams and then were paved over until needed. The jacking and pipe bursting insertion shafts were located in such a manner so that they could limit impacts to vehicular traffic movement, while still providing building access. Work areas were defined in order to reduce the impact on other surface activities. The shafts were primarily constructed of wood sheeting and soldier piles with lagging due to the required configuration of the shafts. Many of the shafts had unique shapes in order to support utilities or to circumvent the relocation of utilities.

There were two types of service connections that required additional excavations:

- The first was the excavation and reconnection of over 100 existing service connections that were replaced in their existing locations by either microtunnelling or pipe bursting.
- The second included the extension and reconnection of over 30 existing service connections that needed to be reconnected to the new microtunneled pipes that were in new locations from the existing pipes.

In certain areas, conventional open-cut excavation had to be employed to replace the pipe because of the need to connect to existing manholes or to replace pipes that could not be replaced by one of the trenchless methods. Open-cut excavation was also specified where the depth of installation was shallow. Even though these shallow installations could have been microtunneled, that method was not preferred since it was not the most economic solution. Each location on the project initially was analyzed for its hydraulic needs and then the impacts of the construction were evaluated to determine the best construction method.

The contractor utilized wood sheeting with wood or steel internal bracing, trench boxes, steel (vertical) roadway plates, wood lagging or a combination thereof to provide the earth support system for all open-cut work.

Existing Utility Networks & Utility Relocations Required for Open-Cut Components

As part of the design, a complete utility inventory was assembled for the entire project area. All surface features were horizontally located and plotted on the base survey plans. Rims and invert elevations were obtained by a combination of field survey, record information and actual manhole investigations. Record plans of all utilities were obtained and added into the base plans. These utilities included sanitary sewers, storm drains, combined sewers, water mains, gas lines, telephone and other telecommunication systems, cable television, steam lines, subway traction power, electric, street lighting and traffic signals. Private utilities between commonly owned buildings were also present in the project area. In addition to the "active" utilities, there were numerous abandoned utilities that were identified during the research process.

The locations for shaft and pipe excavations were determined based on the design requirements of the system and an attempt to minimize utility relocations. Due to the cost and time typically associated with relocating electric, communications and steam systems, a concerted effort was made to produce a design that did not impact these utilities. Water and gas lines are generally more easily relocated and, where necessary to provide access to the excavations, these utilities were specified to be relocated outside the shaft construction. There was only one "unplanned" relocation of a 20-inch diameter gas line in one of the microtunnelling receiving shafts due to the location of other existing utilities that prevented the installation of the system. Numerous utilities were supported in situ by the contractor within the limits of excavation.

Vehicular & Pedestrian Traffic Maintenance & Coordination With Abutters

It was found that approximately 20,000 vehicles per day traverse each of the streets in the project area's grid-like pattern. Other surface activities included an open-air farmers market (held during the spring, summer and fall), cultural activities such as musical groups playing for the public in Copley Square Park, and the constant flow of many tourists. A method of construction was needed that would limit the impact on surface traffic and other surface activities.

Roadway occupancy locations for construction activities had to be strategically sited since an important consideration of the project's design and construction was to limit the project's impact on surface traffic. The different trenchless construction methods required different work zone strategies and the work zones were optimized based on several criteria, including methods of control for pedestrian and vehicular traffic movement, building access areas and other impacts. For example, the location of an abutters' loading dock, as well as entrances to parking areas and public access points to the building, had to be evaluated.

Any disruption of business could cause economic loss not only to that business but also to the general public by the loss of tax revenue for local and state governments (especially important in an area with high tourist traffic). As a result of the extensive amount of work being performed by Boston's Central Artery/Tunnel Project, it was prudent to minimize negative impacts on traffic in the project area. One of the major benefits of trenchless construction is a reduction in the surface area required to perform the work.

Numerous project meetings and individual meetings were held with building owners and abutters in the project area. Each had expressed concerns with maintaining public and commercial access to their buildings. Most understood the need for the project, and were very cooperative with the project team during the planning, design and construction phases. A monthly project update was mailed to all abutters, impacted agencies and individuals to provide them with the projected work for the following month and the progress to date. Individual telephone conversations, letters and meetings were held to provide additional information. In addition, the construction schedule was reviewed and modified to incorporate the abutter's concerns and needs. However, loading dock deliveries and individual tenant and building matters were coordinated separately.

To minimize any other negative impacts on abutters, the contract documents also required the contractor to provide street sweeping and snow removal within the project area. A rodent control program was also implemented and maintained during the construction phase.

In addition, the project area was the site for two important public events. The finish line for the Boston Marathon was adjacent to the project area and many of the hotels played important roles in staging the event. Construction took place during the 1996 marathon, which was the 100th running of the event. The project had to have minimal effects on the nearly 50,000 participants and one million spectators. Boston's First Night Celebration (New Year's Eve) also held numerous activities, including ice sculptures, in the project area. The impact on these activities was minimized through continuous coordination with the organizers of the various events, local businesses and the community.

Groundwater: Existing Conditions During Construction & Through Project Completion

The direction of groundwater flow in the project area was evaluated during the design phase. The groundwater levels were determined with the dam in place and also with the dam removed. Areas of the greatest and most rapid groundwater lowering were along St. James Avenue between Arlington and Berkeley streets, west of Clarendon Street and the area beyond St. James Avenue along Blagdon Street towards Exeter Street. The results of this exercise confirmed that the groundwater depletion in the study area was directly correlated to the poor condition of the existing conduits.

Based on the results of the groundwater study and the location and configuration of the wood-pile-supported building foundations, the contract documents established the minimum groundwater level that the contractor needed to maintain during construction. Different groundwater levels were established for the Boston Public Library and the Trinity Church, two of the more historic and groundwater-sensitive structures within the project area.

During the construction phase, groundwater levels were monitored and recharge wells were utilized when the water levels dropped below those specified. After the project was completed and the existing system was abandoned, the groundwater was still monitored and the data compiled and evaluated. In addition, the Boston Public Library and Trinity Church continuously monitor the groundwater levels with their respective monitoring systems. Data from those "external" monitors was made available to the project team and utilized throughout the project duration.

Maintaining Existing System & Service Flows by Sequencing Construction

The contract documents provided the contractor with all existing building and catch basin service connections as well as with an overall system map that indicated flow directions and approximate invert elevations. The project area has a significant amount of sewers, drains or combined sewers that allowed the contractor to bypass flows by using a combination of pumping, temporary pipes and by sequencing the construction to take advantage of the "new system" that could be installed without any flow diversion in some areas.

Obstructions: Contract Document Requirements Versus Actual Field Conditions

The one word that raises concern whenever microtunneling is mentioned is the word *obstruction*. For this project, the contract defined an obstruction as an item that stopped the forward progress of the tunnelling machine and that met other material criteria (such as granite piers, a cluster of timber piles or reinforced concrete). During the design phase, various methods for locating and identifying potential obstructions were reviewed. These methods included borings, probes, test pits, historical data research, review of inspector's daily notes from the installation of previous utilities and buildings, ground penetration radar and directional drilling of a pilot bore along the alignments.

The data gathered from these methods were identified on the contract drawings and helped establish an uninterrupted workflow. When an obstruction was known to exist, the contract documents specified that a shaft or test pit be dug in an attempt to remove the obstruction without delaying the microtunneling process.

As noted, the contract documents defined what an obstruction was; however, they further indicated the operating and standby rates for any additional equipment required prior to commencing work. Since those items were already pre-established, the only factor left to decide was the actual downtime for the microtunneling operation. That downtime would be different in each occurrence, and the associated costs to remove the obstruction would vary as well.

It is commonly said that there is theory, practice and reality. The reality of the obstruction issue on this project was that everyone's fear of the isolated piece of granite stopping the machine only occurred twice, once within 20 feet of the start of the first drive and then again 30 feet further. These two instances may have been related to an existing steam manholes' foundation, or remnants of granite blocks from the construction of the Boston Public Library.

In the fourteen drives performed on the project, the tunneling machine was stopped eleven times due to obstructions (granite blocks, abandoned piers, steel tiebacks and other unknown massive structures). In addition to the two times mentioned above, the machine encountered the remains of granite block walls/foundations eight times and a steel strand tieback from a building's subsurface earth support system (which was the most costly and frustrating obstruction encountered).

All obstructions were removed by the excavation of access pits. During the design it was assumed that some of these obstructions could be removed by installing a caisson. In actuality, the head of the microtunneling machine needed to be viewed and the size of the obstructions needed to be verified and removed prior to continuing with the microtunneling, thereby making this method impractical.

The project team spent considerable time reviewing the procedures used to determine the locations of potential obstructions. In one instance, a jacking shaft was installed at the location where an abandoned granite block railroad abutment was believed to have existed. The abutment was found and the contractor was asked to probe beyond the shaft sheeting with a 6-foot long drill to confirm if all of the granite had been removed. A 6-inch horizontal and vertical pattern of offset holes were drilled and no granite blocks were encountered. The contractor also pushed a 12-foot long reinforcing bar at a few locations through the sheeting without encountering any other granite blocks. Prior to launching the microtunnelling machine the contractor cut through the wood sheeting and to everyone's surprise found a 5-inch high, 18-inch wide and 2-foot long granite block that was neatly positioned between the probe holes. Luckily, it was easily removed and it proved to be the only piece of granite encountered on that drive.

Excavated Materials: Handling & Disposal of Hazardous Waste, Solid Waste & Sediment

During the preparation of the contract documents a review of the Massachusetts Department of Environmental Protection's (DEP) records was made to identify any potentially contaminated soil areas. In addition, the soil borings were also utilized to classify the characteristics of the existing materials that would have to be removed by the various types of construction. The contractor has excavated, tested and disposed of over 38,000 tons of material from the various items of work. This material was classified into one of eight different bid items, ranging from clean non-reusable fill to hazardous waste. Once classified, the material was appropriately disposed of at various landfills and processing facilities.

In addition to the excavated materials, portions of the project contained contaminated groundwater that required treatment using a portable treatment unit that was brought to the site. Before anything could be done with the water it had to be treated.

Another area that required disposal of material was the removal and testing of over 1,500 tons of conduit, manhole and catch basin sediments. During the design phase, representative samples of sediment were obtained, tested and the results sent to DEP for review and classification. This sediment was classified into three different types and disposed of accordingly. All testing and disposal requirements for excavated material and pipe sediment were indicated in the contract documents.

Summary of Project Features

The New St. James Avenue Interceptor Project provided a cost-effective and sensitive solution to a problem that has existed for over 60 years. The project has provided the following benefits:

- The BWSC was finally able to rehabilitate The New St. James Avenue Interceptor Project area by taking into account all aspects and impacts of the project with the use of trenchless technology. Prior to the advent of trenchless technology, the BWSC had not undertaken performing the work on this project because of the negative impacts open-cut excavation would have had on groundwater as well as on its customers, tourists, workers and other utilities.
- The project area has extensive groundwater concerns. Depletion in the past has caused damage to surrounding buildings. The project met the goal of minimal groundwater drawdown and only minor recharging was required.
- Trenchless technology was utilized to reduce the construction duration and impacts to abutters and their businesses. Trenchless technology is reducing the financial impacts to other utilities including electric, gas, telephone, steam, etc., by avoiding the need to extensively relocate or support in place these utilities for the extent of a trench that would have been required by open-cut installation of the work.
- The project removed a significant amount of groundwater infiltration that previously discharged into the sewer. The

elimination of this infiltration translates into a reduction in the cost for treatment at the Deer Island Wastewater Treatment Plant. By the separation of sanitary and storm flows, combined sewer overflows into the Charles River will also be decreased.

- The project was a massive utility undertaking in a complex urban environment with over 20,000 pedestrian trips per day. It provided minimal disruption to this traffic.
- The project was scheduled around the 100th running of the Boston Marathon, which attracted nearly one million spectators as well as a record number of participants. The project caused no disruption to the marathon.
- The project positively demonstrated the feasibility of a variety of trenchless technologies to solve infrastructure replacement/rehabilitation in a congested urban environment.

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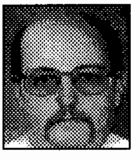

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