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Boston Children's Hospital Construction Management Plan

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Boston Children’s Hospital Construction Management Plan
Stantec, Boston Project Center

A Major Qualifying Project submitted to Stantec, Suffolk Construction, and the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Bachelor of Science Degree by

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This report represents the work of one or more WPI undergraduate students. WPI routinely publishes these reports on its web site without editorial or peer review.
Abstract

This Major Qualifying Project was completed for Stantec. The project analyzed the construction plans for the Boston Children’s Hospital Additions in Brookline, Massachusetts and designed possible alternatives for these plans. Cut-and-fill calculations were completed that considered the contaminated soils on site. Three alternative plans were developed that altered duration, costs, soil reuse, and phasing start dates. These plans were then evaluated using a weighted decision matrix. The provided recommendation focused on maximizing efficiency of project cost and time.
Acknowledgements

The team would like to formally thank everyone who helped with the completion of this project. In particular, the team would like to send a sincere thanks to Professor Leonard Albano and Professor Suzanne LePage for their leadership, time commitment, and support throughout the project. A special thanks to the staff at the Stantec office in Boston, and especially to Lucilla Haskovec, Project Manager, for her guidance and engagement in our project to ensure its completion. We would also like to thank Denis Garriepy, Suffolk Construction Project Executive, and Jesse Keefe, Boston Children’s Hospital Construction Manager, for their time and assistance while on-site.
Capstone Design Statement

The Accreditation Board for Engineering and Technology (ABET) requires a capstone design experience be included as part of all accredited engineering programs. Students at Worcester Polytechnic Institute (WPI) fulfill this requirement through the Major Qualifying Project (MQP) program, which affords students an opportunity to research a problem and develop a solution given real world constraints. This MQP involved designing and evaluating various phasing options for the construction of Boston Children’s Hospital’s (BCH) Brookline Place additions, and considered the following eight design constraints:

Economic

Overall project cost was one of the criteria considered during the evaluation of the developed phasing options. The relative costs associated with each phasing option were assumed, as little cost information about the project was available. Increased costs were assumed when considering the use of weekend shifts or the export of large amounts of contaminated soil; decreases in project cost were assumed when proposing a greater use of on-site materials as fill.

Environmental

An important challenge to the development of the phasing options was the contamination of on-site materials. Strategies were developed to utilize these contaminated materials as fill without impacting the well-being of the surrounding community and environment.

Sustainability

The partial reuse of on-site materials as fill was incorporated into the design of one of the phasing alternatives as a means of not only reducing the cost of construction, but also increasing the sustainability of the project. This reuse would decrease the amount of shipping required for export and import of fill materials. Additionally, less space at landfills would need to be utilized for the disposal of contaminated materials.

Constructability
Evaluation of the phasing options had to take into account site specific limitations, such as the limited amount of space available for stockpiling.

**Ethical**

Although decreasing the overall cost of the project was the goal of several phasing options, no attempt was made to disregard the impacts involved with unethical use of contaminated materials. All designs for this project were consistent with the American Society of Civil Engineers’ (ASCE) code of ethics.

**Health and Safety**

Design of the phasing options maintained the highest regard for the safety of the community during construction. Parameters such as the possible transport of contamination through the fill materials, access through and around the site for workers and members of the community, and mitigation of the effects of noise and vibration caused by construction were some of the main aspects that were considered.

**Social**

Concern for the surrounding community and how the impacts of construction would affect it were taken into account during all decisions of this project. The evaluation of phasing options took into account the impact that noise, vibrations, pollution, and traffic disruptions would have on the surrounding community.

**Political**

This project took into account regulations on soil contaminants imposed by the Massachusetts Department of Environmental Protection, as well as limitations on working hours and other impacts of construction that were imposed by the Town of Brookline. These limitations guided the development of phasing options, and were taken into account when evaluating each option.
**Professional Licensure Statement**

The goal as a Civil Engineer and/or Environmental Engineer is to attain Professional Licensure. Professional Licensure can be obtained by first earning a degree from an ABET-accredited engineering program, and then taking and passing the Professional Engineer (PE) Exam, although additional requirements may vary by state. The PE Exam can only be taken after successfully passing the Fundamentals of Engineering (FE) Exam and having at least four years of experience under a licensed PE. The title of PE displays an expertise in the given field and shows clients that the work can be trusted; many engineering plans require the signature or stamp of a registered PE in order to be approved for construction. Obtaining Professional Licensure also provides the PE with the individual feeling of accomplishment within their field. The licensure also comes with a greater amount of responsibility and authority within the workplace, and less experienced engineers often look to PE’s for guidance or supervision. To maintain the professional licensure, PE’s must periodically renew their license and continue to pursue further education.
Executive Summary

Boston Children’s Hospital (BCH) is a not-for-profit pediatric healthcare center that provides healthcare services in a variety of specialties. BCH is currently redeveloping their investment properties in Brookline in an effort to accommodate a growing demand in complex pediatric care. This construction will expand the current healthcare center at 1 Brookline Place, increase the amount of parking available and upgrade the landscaping of the surrounding campus. The new facility at the adjacent 2 Brookline Place will afford BCH with more capacity for additional patients, and will serve as a new center for neurodevelopmental care.

This Major Qualifying Project (MQP) was completed in conjunction with Stantec to develop and recommend a phasing option that saves BCH time and money. To achieve this goal, cut-and-fill calculations for volumes of materials required were completed. One major challenge to these tasks was the varying levels of soil contamination found throughout the site. This made the process of trying to reuse on-site materials, as requested by BCH in an attempt to lower construction costs, more difficult. Three phasing plans for the construction to be completed on 2 Brookline Place were developed. After the phasing plans were developed, they were evaluated using a weighted decision matrix. These tasks were completed so as to provide Stantec with a final recommendation.

The first phasing option focuses on decreasing the duration of construction. This option calls for little to no reuse of on-site materials as fill, as reusing materials requires that they be stockpiled on-site to be used as fill in a different area. The purchase of new materials, as well as the shipping costs involved in the removal of contaminated soils, present greater expenses, but would effectively reduce the amount of time required to complete earthwork.

The second phasing option focuses on decreasing the overall cost of construction. This option looks to maximize the reuse of on-site materials by increasing the elevation of the site by an average of 0.5 feet using on-site materials. This would reduce the total amount of contaminated soil being shipped off site and, in turn, diminish the cost of the project.

The third phasing option focuses on maximizing efficiency in both duration and overall costs. The main difference in this plan is that it requires the start date of construction on the 1 Brookline Place addition be delayed for about 20-22 weeks, so that the available space on that
site can be used for the stockpiling of materials. With the delay, 1 Brookline Place would be completed at about the same time as the 2 Brookline Place construction.

The three options were evaluated using a comparative weighted decision matrix. The options were given a score of three, for most effective option, two for second best option, and one for the least effective option of the three. The criterion for which the options were weighted were cost, time, noise, vibrations, pollution, and traffic disruptions. After rating each option, the score was multiplied by the weighting factor for each criterion. The resulting highest weighted score is the best option. The first option received a weighted score of sixteen, the second option scored a twenty-six, and the third option received a score of thirty.

The third plan was deemed the most effective phasing strategy for this site. The first option would effectively cut the time of duration of construction, but would be too costly for BCH. The second option reduced the cost of construction. The one drawback to the second option was the higher risk of exposure to contamination. The third option did not focus on reducing either the time or cost, but effectively decreased the cost of construction while not increasing the duration.
Authorship

This project was completed collaboratively by all team members. The approach, techniques, and plans were determined together. In an effort to maximize efficiency, each member was allocated specific tasks and wrote the respective sections. After completion, all group members reviewed and edited one another's work and writing. Below is an overview of the primary responsibilities of each team member.

**Tyler Leighton:** Composed cut-and-fill calculations and created all marked up site maps using Bluebeam Revu. Compared with the Civil 3D cut-and-fill results to ensure accuracy and calculate takeoffs.

**Kenuel Lopez Rivera:** Researched construction project manager responsibilities and the construction phasing plans. Evaluated the cut-and-fill calculations and site plans that detailed the areas of contamination to design the alternative plans. Evaluated the phasing options.

**Tyler Van Nostrand:** Researched extent of contamination on-site and the developed site plan detailing sections of contaminant concentration exceedances.

**Kevin Wormer:** Researched Boston Children’s Hospital, Stantec, and the impacts of construction. Conducted cut-and-fill calculations using Autodesk AutoCAD Civil 3D. Verified calculations with those from Bluebeam Revu, and utilized this information to conduct takeoffs. Evaluated the alternative phasing options.
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1.0 Introduction

The Boston Children’s Hospital is currently redeveloping their two adjoining investment properties in Brookline, MA, less than a mile from their main campus in the Longwood Medical Area of Boston. The project consists of the construction of a new eight-story, 180,000-square-foot outpatient facility at 2 Brookline Place; a 47,000-square-foot addition to the existing six-story, 105,000-square-foot 1 Brookline Place medical office; and a replacement of the four-story parking garage with a new seven-story garage. Stantec is serving as the Owner’s Representative and Project Manager for the project; they are managing the project team, budget, and schedule.

The Brookline Place site is heavily contaminated. Stantec has expressed the need for the construction team to efficiently and cost effectively control the movement of contaminated materials on-site throughout the construction phase.

The goal of this Major Qualifying Project (MQP) is to provide Stantec with possible alternatives to their current Construction Management Plan, with the goal of decreasing construction duration and expenses. This project sought to achieve this goal by completing the following tasks:

1. Cut-and-fill calculations,
2. Project phasing plans,
3. An evaluation of the alternative plans.

A final recommendation on the best option to minimize cost and duration was developed utilizing the information gathered from the aforementioned tasks.
2.0 Background

This section of the report provides the reader with information that is essential to understanding the focus of this MQP. A description of the Boston Children’s Hospital institution, as well as of the renovation project and Owner’s Project Manager (Stantec), is included in this chapter. In addition, background information is given on construction project management exercises such as cut-and-fill calculations, phasing, and cost estimations. A discussion about construction impacts concludes this section of the report.

2.1 Boston Children’s Hospital

Boston Children’s Hospital (BCH) is a pediatric health care center that provides health care services to children from birth to the age of twenty-one. The mission of BCH is to “Provide the highest quality health care, be the leading source of research and discovery, educate the next generation of leaders in child health, and enhance the health and well-being of the children and families in the local community.” Central to their mission is the 404-bed health care center which performs over 26,500 surgical procedures and 158,700 radiological examinations a year, located in the Longwood Medical Area of Boston. Other services performed by BCH include a full-time emergency room, medical training, education, and extensive research programs. These services enable BCH to operate with a not-for-profit status and provide added value to not only the citizens of Boston, but also the country as a whole.

Boston Children’s Hospital is nationally ranked by U.S. News in ten different pediatric specialties, and they are ranked first in the following eight pediatric specialties: Cancer, Cardiology, Gastroenterology, Neonatology, Nephrology, Neurology, Orthopedics, and Urology. To compile these rankings, U.S. News gathered data from 183 pediatric centers. The rankings were determined using reputational surveys, supplemental information from sources

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including the National Cancer Institute, and other surveys investigating factors such as hospital resources, delivery of healthcare, and clinical outcomes.\(^7\)

The new Boston Children’s Hospital campus at Brookline Place is planned to accommodate a growing demand in complex pediatric care. The redevelopment of the Brookline Place site will enable BCH to expand their services outside of their main Longwood campus. Although located adjacent to each other, the 1 Brookline Place and 2 Brookline Place reside on separate property lots. At 1 Brookline Place, patients and visitors will have access to upgraded amenities, including an improved and expanded parking garage and enhanced landscaping across the campus. The 2 Brookline Place facility will serve as a new center for neurodevelopmental care for BCH.\(^8\) Figure 1 shows the architect's rendering of the completed site. These improvements and additions will support improved care for patients and their families.

![Aerial View from SE](image)

**Figure 1: Rendering of completed Brookline Place campus**

The unique Brookline Place location is steps away from the Brookline Village Massachusetts Bay Transportation Authority (MBTA) stop, and is designated as a Transit-

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Oriented Development (TOD) which enables the project to have a positive impact on the surrounding community. As shown in Figure 2, the public will have access to a large walkway cutting diagonally through the site between 1 Brookline Place and 2 Brookline Place, providing easy access to the MBTA stop. Other publicly accessible features of the site are a new plaza and garden space. In total, forty percent of the completed site will be space that is open to the community. A storage space will also be available to the public and town that can be used to store materials or items needed for special events. Additionally, the ground floor of 2 Brookline Place will include retail space to promote street-level activity.

![Figure 2: Pedestrian Flow Diagram](image)

### 2.2 Stantec’s Role

Stantec was founded in Alberta, Canada in 1954 by Dr. Don Stanley and has grown to over 22,000 employees at over 400 locations. Originally focused on water and sewage projects, Stantec has evolved into a diverse firm with architecture, engineering, interior design, landscape

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10 PDF. (2015, January 22). Brookline, Massachusetts: Boston Children's Hospital. presentation to the Brookline Planning Board
architecture, surveying, environmental science, and project management divisions.\textsuperscript{11} In the first decade, Dr. Stanley grew the company to 30 employees that worked on projects throughout Alberta and British Columbia. After a series of acquisitions, including the first U.S. acquisition in 1991, Stantec had grown to over 800 employees by 1993.\textsuperscript{12}

Stantec is organized into several different ‘Business Lines’ including: Buildings, Community Development, Energy and Resources, Environmental Services, Infrastructure, Mining, Oil and Gas, Power, Project Delivery, Transit/Rail, and Water. Each Business Line has its own separate leadership and structure. Several of these Business Lines have their own subgroups that work collaboratively on projects.

Stantec’s Program and Project Management division is within the Project Delivery Business Line. This division manages projects across sectors ranging from buildings to infrastructure. The division was hired by Boston Children’s Hospital to serve as the Owner’s Representative on the Brookline Place project. Specifically, they are managing the project team, budget, and schedule for BCH.

2.3 Construction Project Manager Responsibilities

Construction Project Managers (CPM) have many responsibilities to a construction project. The CPM for the BCH Brookline project is Suffolk Construction, a national construction management firm headquartered in Boston, Massachusetts. Project managers must maintain effective communication with all project teams throughout the project to ensure the client is satisfied and the project is completed on schedule and within budget. Before construction begins, a project manager must perform a series of services, called pre-construction services. Three major pre-construction exercises a CPM must complete are cut-and-fill calculations, phasing, and cost estimations.

2.3.1 Contaminated Soil Regulations

The handling of contaminated soils must be considered during cut-and-fill calculations. Contaminated soils must follow regulations imposed by the state in which the project is based. The Massachusetts Department of Environmental Protection (MA DEP) developed the

Massachusetts Contingency Plan (MCP) to define procedures for assigning responsibility of any groundwater or soil contamination, as well as the procedures to follow for handling these materials during construction so as to limit any further spread of the contamination. Once a release of any contaminant at a concentration greater than the MCP’s Reportable Concentrations is reported to the MA DEP, it is assigned a Release Tracking Number (RTN) and entered into the MA DEP’s RTN database.\textsuperscript{13} The contamination is then characterized by Licensed Site Professionals and MA DEP staff. If it is characterized as not posing an immediate threat to the surrounding community or environment, an Activity and Use Limitation (AUL) is placed on the site to limit transport pathways of contaminants.

Two different RTNs have been assigned to 1 and 2-4 Brookline Place, with a third to the abutting property to the west, 10 Brookline Place. Soil contamination at 1 and 2-4 Brookline Place exists because of “a manufactured gas plant, a gasoline service station, several light industries, and an upgradient underground storage tank” that all previously existed on the sites.\textsuperscript{14} As a result of these various releases, on-site materials have exhibited levels of lead, arsenic, mercury, nickel, petroleum hydrocarbons, benzene, and naphthalene that exceed MCP Reportable Concentrations. A characterization of the site performed by Sanborn, Head & Associates (Sanborn), has determined that this contamination, however, does not pose any immediate threat to the community or environment.\textsuperscript{15} The on-site materials have been approved for reuse in construction, but with AULs that prevent activities, such as gardening, that would provide a direct pathway for the transport of contaminants to members of the community. The AUL also states that any material removed from six feet beneath grade must be returned to a similar depth from which it was removed, as well as to an area of similar levels of contamination.

Additionally, the MCP identifies required protocols for the storage of excavated materials on site, as well as for any necessary transportation of these materials when exported from the site. With regards to storage, all materials must be stockpiled on top of polyethylene sheeting to prevent transport of contaminants to the soils beneath. The stockpile must also be covered with

\textsuperscript{13} Massachusetts Department of Environmental Protection. Massachusetts department of environmental protection. Retrieved from http://www.mass.gov/eea/agencies/massdep/


\textsuperscript{15} Release Abatement Measure Plan 2-4 Brookline Place (December 2015), Sanborn, Head & Associates.
polyethylene sheeting to prevent transport of the contaminants by means of rain or wind. When transported by means of public roadways, the materials must be covered to prevent the formation of dust. Further details on these regulations and protocols can be found within the MCP on the MA DEP website.\footnote{Massachusetts contingency plan, MA 310 CMR 40.0000 (2014).}

### 2.3.2 Cut-and-Fill

Cut-and-fill computations are essential to the understanding of on-site soil management throughout a project’s cycle. The calculations determine the elevations throughout the site before, during, and after construction to gauge the amount of on-site soils that must be removed, or if extra material needs to be purchased and brought to the site.

These calculations can be completed by hand or using computer programs. Although there are many different computer programs that can be used, there are some which are considered standard within the civil engineering industry. Bluebeam Revu and Autodesk AutoCAD Civil 3D are two programs that are considered standards within industry, and widely used by contractors and designers for cut-and-fill calculations.

#### 2.3.2.1 Bluebeam Revu

Bluebeam Revu (Bluebeam) enables users to alter various file types, including Microsoft Office, CAD, and PDF, for demonstration or measurement purposes.\footnote{Bluebeam Revu. Bluebeam Revu. Retrieved February 10, 2017, from http://www.bluebeam.com/us/products/revu/} Bluebeam can also be used to measure elements in a file, such as section areas or the perimeter of a site. Using the area information of the site, volumes can be accurately computed to produce cut-and-fill estimates. The program also enables collaboration by allowing multiple users to access and make edits to a file simultaneously.\footnote{Bluebeam Revu. Bluebeam Revu. Retrieved February 10, 2017, from http://www.bluebeam.com/us/products/revu/}

#### 2.3.2.2 Autodesk AutoCAD Civil 3D

Autodesk AutoCAD Civil 3D (Civil 3D) is a program focused on enhancing the design of civil infrastructure. It is compatible with Building Information Modeling (BIM) and is used mainly for “civil engineering design and construction documentation.”\footnote{Autodesk. (2016). Why AutoCAD civil 3D. Retrieved from http://www.autodesk.com/products/autocad-civil-3d/overview} It is a powerful tool that, among numerous other features and uses, can also be used to make measurements and
perform cut-and-fill calculations. Civil 3D creates different surfaces that track location and elevation. These surfaces can serve as existing conditions and proposed conditions to allow users to calculate needed quantities for cut-and-fill. This technique can be extremely accurate, especially when compared to hand calculations.

### 2.3.3 Phasing

Phasing of a construction project allows construction managers, before starting work, to maximize efficiencies of the project and minimize construction impacts on the surrounding community. The site and surrounding areas are studied to determine options to minimize impacts and the best plans to implement construction. Construction plans are separated into several stages and are documented and detailed using drawings for each phase of the project. Some of the details that are illustrated in the phasing plans include pedestrian and vehicular traffic management, safety equipment placement, preliminary completion dates, and the main objective during the phase.

Before construction at Brookline Place could begin, BCH was required to provide the Town of Brookline Building Commissioner with their complete Construction Management Plan (CMP) as a condition of the special permit they obtained on May 21, 2015. The BCH CMP outlines a three-phase approach to complete the project which began in September of 2016 and is scheduled to finish in October of 2019. The phasing was developed to enable the continued occupation of 1 Brookline Place throughout construction by utilizing a temporary parking lot. The three phases are detailed in the succeeding subsections.

#### 2.3.3.1 Phase One

Phase One of construction began with site preparation and mobilization. These two tasks included guidance of pedestrian and vehicular traffic, as well as placement of street signs and perimeter safety fencing. The existing 2-4 Brookline Place buildings were then demolished to make room for a temporary parking lot. Figure 3 displays the demolition plan for 2-4 Brookline Place. While the demolition was ongoing, preparation for the demolition of the parking garage began. The final task before moving on to the second phase of the project was the installation of the temporary parking lot on the 2 Brookline Place property. Throughout construction, the

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20 Boston Children's Hospital, & Stantec. (2015). *Brookline place redevelopment construction management plan.*
medical office building at 1 Brookline Place is to be fully operational. To provide space for patients of 1 Brookline Place to park while the existing garage was demolished and a new one constructed, the temporary parking lot was constructed. Table 1 outlines the main tasks of Phase One of the project.

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration (weeks)</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Preparation and Mobilization</td>
<td>4</td>
<td>September 2016</td>
</tr>
<tr>
<td>Demolition of 2-4 Brookline Place and Garage Enabling Work</td>
<td>6</td>
<td>September 2016 - October 2016</td>
</tr>
<tr>
<td>Construct Temporary Parking Lot</td>
<td>10</td>
<td>October 2016 - December 2016</td>
</tr>
</tbody>
</table>

Figure 4 shows the completed temporary parking lot in use. The image was taken by the MQP team, facing west, from the sixth floor of the BCH building at 1 Brookline Place.

2.3.3.2 Phase Two

Phase Two of the project consists of the demolition of the current garage on the 1 Brookline Place lot and the construction of the garage that will replace it. The previous parking garage, a four-story, 359-parking space, steel and precast concrete structure, was demolished to make way for a seven-story, 683-space, precast concrete parking garage. The replacement garage will be built in the same location as the previous one. The following table summarizes the time period in which each task is occurring during Phase Two of the construction. Figure 5 displays the parking garage demolition plan.

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration (weeks)</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garage Demolition</td>
<td>12</td>
<td>December 2016 - February 2017</td>
</tr>
<tr>
<td>Construction of New Garage</td>
<td>46</td>
<td>March 2017 - February 2018</td>
</tr>
</tbody>
</table>
2.3.3.3 Phase Three

Once the replacement garage is completed and occupied by BCH, Phase Three can begin. The first activity will be the demolition of the temporary parking lot. After it is demolished, the construction of 2 Brookline Place and the 1 Brookline Place Addition will begin. The site will also be landscaped during this phase. An outline of the tasks for this phase is detailed in Table 3. Figure 6 shows the site plan for 1 and 2 Brookline Place after construction is finished.

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration (weeks)</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction of 1 Brookline Place Addition</td>
<td>60</td>
<td>March 2018 - April 2019</td>
</tr>
<tr>
<td>Construction of 2 Brookline Place</td>
<td>82</td>
<td>March 2018 - October 2019</td>
</tr>
</tbody>
</table>

Figure 5: Brookline Place Parking Garage Demolition Plan

Table 3: Phase Three Main Tasks

2.3.4 Evaluation of Alternatives

There are countless ways to accomplish the same end product. In construction, a major task of the CPM is to decide on the ‘best’ manner to complete construction to achieve the desired product. The ‘best’ manner may vary depending on the particular group deciding, due to differences in goals and special interests. The owner wants a completed project that will serve their own interests, whether that is making a profit by selling the property, or having a new facility to occupy. The designer wants a completed project that pleases the owner, but also one that they are proud of and can use to display their expertise and enhance their reputation. The CPM wants the project to be completed on time and under budget to please the owner, while still making a profit on the project. The CPM also hopes to perform well and please the owner so that they are hired back on future projects. It is the job of the CPM to attempt to balance these competing interests and ensure successful completion of the project.

In order to select an approach, the CPM must take several factors into consideration. These factors are used to evaluate different approaches. Such factors include costs, duration,
environmental and community impacts. Evaluations can be conducted using decision matrices that assist in “identifying, ranking, and rationalizing decisions.” A weighted decision matrix approach can be utilized which takes into account the importance of different factors and incorporates that importance into the ranking of each alternative.

2.3.5 Cost Estimations

Accurate preliminary cost estimates are crucial to identify the feasibility of a construction project. This is important to ensure the project does not go over budget. In some cases, the contract may be a Guaranteed Maximum Price or Construction Manager at Risk which places the burden of project overages on the CPM. The best method to avoid these extra costs is to provide an accurate cost estimate, which is possible using the correct cost estimating techniques.

A widely accepted and accurate technique to estimate the cost of a project is Case-Based Reasoning (CBR). This concept makes use of prior experiences with a similar project to learn and solve current problems or uncertainties. When a project team is preparing cost estimates, and is unsure of a certain aspect of the estimate, it can refer to CBR to solve the discrepancy. Solutions developed using CBR must then be adapted to the current project and documented for future use. Using the CBR technique when cost estimating is effective because it can predict some of the effects of construction that can result in a loss of funds.

2.4 Construction Impacts

Construction projects will always have an impact on the surrounding area and must be considered by the CPM during pre-construction phase planning. These impacts will vary depending on proximity to the site, type of construction, and a variety of other factors such as different construction methods and mitigation efforts utilized by the builder. Known impacts of construction that should be considered include: noise, vibration, pollution, dust, displaced dirt/mud, litter, light pollution, road closures, increased traffic, disrupted pedestrian routes,

limited parking, and pavement obstructions.\textsuperscript{29,30,31} This section will discuss these impacts and practices that can be used to limit their impact.

\subsection*{2.4.1 Noise}

Noise, defined as unwanted sound, poses a known and expected impact on all construction projects. Due to the extreme and separate impact that construction noise can have on a community, it is often considered separately from other types of pollutions. As an environmental stressor, noise has physiological and psychological effects, and has the ability to impair health if exposure is prolonged.\textsuperscript{32,33} Additionally, construction noise can lead to troubles associated with stress, concentration, sleep, and relaxation.\textsuperscript{34,35} Heavy equipment, and backup alarms are common causes of construction noise in urban areas.\textsuperscript{36}

Often times, towns and cities have specific ordinances regulating noise levels, and allowed times for construction activities to occur. Brookline, MA has a By-law, the Noise Control By-law of the Town of Brookline, which places limits on all sound originating within the Town.\textsuperscript{37} This By-law limits the use of all devices used for construction or demolition that exceed set maximum Noise Levels to only operate between seven A.M. and seven P.M. Monday through Friday, and eight-thirty A.M. to six P.M. on Saturdays, Sundays, and holidays. See Appendix E for specific noise level restrictions, as specified in Section 8.15.6b and 8.15.6c of the Noise Control By-law of the Town of Brookline. If these provisions are violated, fines can be issued up

\begin{thebibliography}{99}
\bibitem{29} U.S. Department of Transportation Federal Highway Administration, \& The State of California Department of Transportation. (2001). \textit{SAN FRANCISCO OAKLAND BAY BRIDGE EAST SPAN SEISMIC SAFETY PROJECT on interstate 80 between yerba buena island and oakland in san francisco and alameda counties FWAL ENVIRONMENTAL IMPACT STATEMENT/ STATUTORY EXEMPTION AND FINAL SECTION 4(f) EVALUATION}. Sacramento, CA: Federal Highway Administration.
\bibitem{37} Town of Brookline, Noise control by-law 8.15, (2008).
\end{thebibliography}
to $200.00. Special permits can be issued for exemptions from this By-law. These permits are issued by the Board of Selectmen, or a designee of the Board.

There are many ways to manage and reduce the impact of noise. Generally, mitigation techniques are focused on limiting the impact of noise to the greatest extent possible. Some of these techniques include limiting extremely noisy operation to be performed simultaneously, erecting noise barriers to limit the travel of noise out of the site, and restricting noisy operations to certain hours. A key measure to manage the impact of construction site noise is communication with impacted parties, residents, and community directly surrounding the site. Specifically, selecting specific and limited working hours that are communicated to the community is important. These are the only hours during which construction work, and therefore noise, will occur. This allows those impacted to prepare for the disturbances. Although not a requirement, it is a proven best practice to also provide notice to the community and residents.

There are three main techniques to limiting noise: controlling noise at the source, controlling the path, and controlling the receptor. Controlling the noise from the source is the most effective option in that it reduces noise emanating in all directions rather than picking a specific path or end location to control. A variety of techniques exist to control noise from the source, but most are focused on proactively choosing equipment, methods, or materials that will produce the least amount of noise as possible. The path of noise can be controlled by using acoustical barriers that absorb and reflect sound back to the source. When setting up barriers, positioning is integral because they should be placed overlapping and as close to the source as possible. The last technique is controlling the noise at the receptor; however, it is the least desirable due to complexity and cost. Some possible solutions include sound dampening curtains, or more drastic options such as relocating those sensitive to noise.

Construction projects in urban areas often require a noise control program to ensure that the surrounding community is not exceedingly disturbed. Although each noise control program is

different, there are multiple responsibilities that are generally covered. Before construction begins, noise studies should be completed that evaluate the impact the project will have on noise in the area. Specifications should be established restricting the sound levels and limiting times of the day for noisy operations to be conducted. Training should be provided to the field staff and subcontractors on issues relating to noise, measurement, and control techniques. Lastly, specific noise mitigation strategies and programs should be developed and implemented such as acoustical barriers or window treatments.  

2.4.2 Vibration

Vibrations generated during construction activities can cause damage to structures, annoyance and even added levels of stress in humans. Since typical construction traffic does not generate large levels of vibration, and is temporary in duration, the overall impact can be considered minimal. Other activities, such as pile driving, can generate significant vibrations and often require vibration monitoring.

There are several different methods in construction to achieve the goal of minimizing produced vibrations. The available methods depend on factors such as the operation, and the nature of the soils in which the work is being completed. When driving piles, pre-drilling is useful for reducing vibrations by overcoming the high penetration resistance in upper levels of soil. Reducing the energy of the hammer driving the piles can also reduce vibrations. Additionally, when driving piles near existing buildings, driving should start closer to the building and proceed away to utilize the previously driven piles as a shield for vibrations and soil movements, as well as increase bearing capacity. An increased bearing capacity can help reduce the depth of the pile driving or the amount of piles needed. Other general practices include requiring vibration monitoring if there will be ongoing vibration-intensive activities.

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43 U.S Department of Transportation/Federal Transit Administration, & Alameda Contra Costa Transit District. (2012). *AC transit east bay bus rapid transit project in alameda county, final environmental impact statement/environmental impact report*. (No. 1). California:
44 Hadi, M. (2001). *DTI construction industry directorate project report: working with the community; impacts report for general dissemination*. Watford, UK:
limiting the hours of vibration-intensive activities, and avoiding the usage of equipment that is known to cause annoying vibrations.47

2.4.3 Pollution

Pollution created by construction projects can be significant if not managed properly. The impacts can range from severe health and safety risks, to environmental, to creating concerns among the community. Projects that contain hazardous materials such as asbestos or produce dust can pose serious risks to the surrounding community if not properly managed. Specifically dust can aggravate health issues such as asthma, and bronchitis. Dust, dirt, and mud also pose an annoyance or inconvenience to the surrounding community if not properly managed. Dust, dirt, and mud can cover nearby homes, roads, walkways, vehicles causing annoyance and inconvenience. Litter can also be an issue on construction sites. In some cases, workers may drop litter around the site while eating, smoking, and other activities. This can cause a significant impact on the community and can lead to complaints.48

Proper handling of hazardous materials is the main method to limit their impact. Following regulations and plans developed to control the contaminants is extremely important.49 The primary method to control dust is watering it down. Dust, dirt, and mud control methods usually involved the usage of plastic sheeting as barriers to limit the amount leaving the site. When those methods do not work, compensation to neighboring residents or attempts to clean their cars and windows is common.50 Other methods to control dirt and mud from leaving the sites are truck wheel wash stations. There are a variety of types available for use that vary in strengths and abilities. On the low end, wheel wash stations are capable of dust removal. More expensive options are capable of removing thick layers of dirt and mud.

Light created as a result of construction can also pose issues to those near the site. Specifically in the winter months when it may be dark while construction operations are

47 U.S Department of Transportation/Federal Transit Administration, & Alameda Contra Costa Transit District. (2012). AC transit east bay bus rapid transit project in alameda county; final environmental impact statement/environmental impact report. California:


49 U.S. Department of Transportation Federal Highway Administration, & The State of California Department of Transportation. (2001). SAN FRANCISCO.OAKLAND BAY BRIDGE EAST SPAN SEISMIC SAFETY PROJECT on interstate 80 between yerba buena island and oakland in san francisco and alameda counties FINAL ENVIRONMENTAL IMPACT STATEMENT/STATUTORY EXEMPTION AND FINAL SECTION 4(f) EVALUATION. Sacramento, CA: Federal Highway Administration.

beginning, light generated can cause irritation. In some cases residents may even be impacted by light from headlights of vehicles if they are pointed towards resident windows. In such cases care must be taken to turn off headlights of parked or unloading vehicles.

### 2.4.4 Traffic Disruptions

Construction activities can cause numerous disruptions to both vehicular and pedestrian traffic, especially in dense urban areas. Construction logistics and timing can lead to road closures, increased traffic, reduced parking, and disruptions to pedestrian routes. Road closures can cause annoyance to residents and abutters, especially when limiting access to their homes. Deliveries, slow moving trucks, and increased amount of vehicles in the area lead to increased congestion which may cause residents inconvenience as well as frustration, and even lead to access issues for emergency vehicles. Parking issues can include inconsiderately parked cars, large increases in parked cars, the blocking of handicap accessible spaces, and reduced visibility. Disrupted pedestrian routes may cause annoyance for residents, but may also pose issues for elderly or disabled if the routes are not accessible.\(^5\)

Before construction begins, it is important to conduct traffic studies and develop a traffic management plan to maintain traffic flow and minimize the impact on the surrounding areas.\(^6\) A comprehensive traffic management plan will take efforts to minimize the impact of numerous issues by designating areas for activities such as subcontractor parking and vehicle unloading. Additionally, the plan will take into account the need for accessible pedestrian routes, and ensure that ramps and sidewalks are provided and maintained where needed.\(^7\) Other methods to limit parking issues include bussing in workers, permit parking, and utilization of local workers who can walk to the site. To control increased traffic volumes, material deliveries to the site should be closely coordinated with limits placed on timing to mitigate potential interference with rush hour or schools.\(^8\)

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\(^7\) U.S Department of Transportation/Federal Transit Administration, & Alameda Contra Costa Transit District. (2012). *AC transit east bay bus rapid transit project in alameda county, final environmental impact statement/environmental impact report*. California.

\(^8\) Hadi, M. (2001). *DTI construction industry directorate project report: working with the community*; *impacts report for general dissemination*. Watford, UK.
3.0 Methodology

This section of the report covers the steps followed to complete this Major Qualifying Project (MQP). Before beginning to design phasing plans for the construction on 2 Brookline Place, an analysis of the soil on-site and cut-and-fill calculations had to be completed. The phasing plans created were then evaluated to provide recommendations to Stantec and Suffolk Construction. The recommended plan, along with the information gathered throughout the project, was presented to Stantec for review.

3.1 On-Site Soil Limitations

A review of the construction management plans and other city documents was completed to fully understand the soil limitations before proposing any construction plans. The limitations include the location of the contaminated soil on-site and the requirements for moving, storing, and disposal of the soil. This information was used to identify the on-site soil that can and/or cannot be reused for construction purposes, which would affect the cut-and-fill calculations.

The contamination found within a large portion of the on-site materials varies greatly in both types and levels of contaminants throughout the site. To determine the locations of on-site contamination, an Exploration Location Plan (ELP) developed by the Environmental Engineer, Sanborn, Head & Associates (Sanborn Head), was utilized. This site plan displays the locations of numerous soil borings located throughout the site. By cross referencing this site plan with a data chart of contaminant levels at the various exploration locations, also gathered from Sanborn Head, a more clearly defined diagram was developed using Bluebeam Revu. This diagram was a modification of the site plans and was utilized in the phasing portion of this project to develop strategies for reusing on-site materials as fill.

3.2 Cut-and-Fill

Cut-and-fill calculations were performed to determine the amount of soil on-site through the remainder of construction. The cut-and-fill calculations were completed using Bluebeam Revu and AutoCAD Civil 3D. The calculated values were compared to the CPM’s Construction pre-bid package to ensure the accuracy of the calculations. The values were then used to produce alternative phasing plans, which are described in Section 3.3 of this report.
3.2.1 Bluebeam Revu

Bluebeam Revu (Bluebeam) was utilized to measure the areas and volume calculations for different sections of the landscape architect’s plans. The architect’s landscape plans can be found in Appendix C: Layout and Material Plans and Appendix D: Planting Plans.\(^{55,56}\) Markup editing tools, like lines and shading, were used to assign different zones in the architect's plans. The zoning was assigned depending on the type of plant and soil type the plans required. The zones were then color coded to clearly differentiate the areas on the plans.

Before making any measurements, the plans were scaled in Bluebeam to ensure accurate results. The square footage tool was used to determine the area of each assigned zone. Volume calculations were completed by cross referencing the specifications of fill material in the architect’s plans of each zone with the areas calculated using Bluebeam. Quantity takeoffs were conducted for specific plants and materials. The specifications of plant types, which take up a certain amount of space as well, were also taken into account when computing the fill volume calculations. The information and calculations were organized by the assigned zones and material codes specified in the landscape designs.

3.2.2 Autodesk AutoCAD Civil 3D

AutoCAD Civil 3D (Civil 3D) was used to assist with cut-and-fill calculations. Stantec provided a Progress Set of Construction Documents (PSGD), dated July 12, 2016, for 2 Brookline Place.\(^{57}\) This set broke up the site into four areas detailed on separate sheets. Pages L201-L204, of the PSGD, contained the Landscape Grading Plans for Areas one through four. Appendix B contains the Grading Plans for site.\(^{58}\) These drawings were imported into Civil 3D. Once imported, the separate sheets were aligned together to create one large, cohesive site plan. To conduct the calculations, surfaces were created that corresponded with the existing site elevations, and the elevations of each proposed section of the site. A proposed surface was created for each separate area denoted on the Layout and Material Plans and the Planting Plans. Appendix C contains the Layout and Material Plans and Appendix D contains the Planting Plans.

The existing surface was generated using the existing point elevations indicated on the provided Grading Plans. These point elevations were added as points to the existing surface with a specific elevation. Contours were not used to create the existing surface because no existing contours were indicated on the Grading Plans. Due to the construction of the temporary parking lot, the site was largely flat resulting in minimal need for contours. Once all existing spot elevations were added to the surface, the surface was smoothed to enable it to mirror real site conditions more accurately. The smoothing method used was ‘Natural neighbor interpolation’. Natural neighbor interpolation (NNI) works by using the elevation and location of existing points to calculate a weighted average of elevations of neighboring points. The point interpolation output was specified as a ten-foot by ten-foot grid to balance accuracy without creating an overwhelming amount of interpolated points.

Each proposed surface was generated using both spot elevations and contours. Spot elevations were added to the surface in the same manner they were when creating an existing surface. Once the surface was defined with points, contours were added. Contours were added to the proposed surface in a two-step process. First, the polylines representing the proposed contours in Civil 3D were updated to ensure that the elevations indicated on the Grading Plan matched their specific elevations. This was done using edit polyline elevation function, and then selecting the polyline representing a proposed contour. Once selected, the elevation for that polyline was entered according to what was specified on the Grading Plan. The second step utilized the add contours function. Once the proposed surface was selected, the add contours function could be used. The add contour data function used weeding factors of a five-foot distance, and a four degree angle. The supplementing factors used were a distance of fifty feet and a mid-ordinate distance of one foot. To minimize flat areas, the following options were selected: filling gaps in contour data, adding points to flat triangle edges, and adding points to flat edges. Then the desired polyline contours could be selected and added to the surface.

To calculate the cut-and-fill volumes, a volume surface needed to be created for each proposed surface. This was done in the volume dashboard. The existing surface acted as the base surface. The proposed surface acted as the comparison surface. Once the volume surface was created, it could be added to the volume dashboard. The add volume surface function was used,

and the desired surfaces could be selected. Once added, the volume dashboard calculated the area, cut, and fill needed to create the proposed surface.

### 3.2.3 Comparison of Calculated Quantities

The takeoff calculations for the quantities for materials were verified by comparing the overlapping surface area values in both Bluebeam and Civil 3D. The calculated values, such as cubic yards of gravel fill, were also compared to the values provided by the CPM for materials in their design development pre-bid package.

Bluebeam and Civil 3D were used to verify the calculations accuracy for square footage of each zone for the material components of the cut-and-fill calculations. The square footage parameter was vital in finding the net quantities for material estimates and allowed for the calculation of volumes required for landscaping and on-site support.

The calculations were also verified through a comparison to the CPM’s design development pre-bid proposal, which contained estimates for general quantities and square footage. A common estimating practice is to add ten to fifteen percent of the value for materials, such as soil and concrete, to account for human error and on-site discrepancies from the plans.

### 3.3 Phasing

The goal of this MQP was to provide Stantec with recommendations about how to most effectively manage the on-site soil throughout the remaining phases of construction on 2 Brookline Place. Specifically, Phases Two and Three of the construction, as outlined in the background chapter of this report, were investigated since the first phase of construction was already completed. Three different strategies were developed: one that focused on completing the project in the shortest time possible, one that was aimed at decreasing the overall cost of the project, and one that combined the previous two approaches to maximize efficiency.

To decrease the duration of the project, several parameters of the building and landscaping developments were investigated. The parameters included the time necessary to export and import soil, as opposed to reusing it on-site, fast tracking various tasks using second shifts and extra crews, as well as any additional construction impacts caused by expediting the project that may affect the surrounding environment.
Cost-saving opportunities were researched in regards to the management of soil throughout a project’s lifespan. Focus was placed on developing a sequence that allows for the reuse of materials without seriously impeding the final plans for the site.

A third option was created considering both the cost and time while managing the soil throughout the rest of construction. The criterion considered both time and cost saving methods mentioned above.

3.4 Evaluation of Alternatives

The three proposed phasing plans were evaluated to determine the most effective plan to utilize. This evaluation was conducted from the perspective of the best option for BCH. Factors that were considered include: cost, time, noise, vibrations, pollution, and traffic disruptions. This list of factors was developed after meeting with Denis Garriepy, Suffolk Construction Project Executive, Jesse Keefe, Boston Children’s Hospital Construction Manager, and Lucilla Haskovec, Stantec Project Manager. A weighted decision matrix approach was utilized to evaluate the different phasing plans. Each factor was assigned a weighted importance to place emphasis on the factors that are more valuable to BCH. Each option was rated for specific factors relative to one another on a scale of one to three. A one indicated the plan was the worst of the three options for that factor, and the three indicated the plan was the best of the options for the factor. Figure 7 below shows the decision matrix without ratings for each phasing option.

3.4.1 Cost (Weight = 3)

The impact of cost for BCH is the most important factor. A large portion of the cost to BCH is related to the length of time that Stantec and the CPM work for BCH; the longer they
work, the more BCH must pay them. As a result, a weighted importance factor of three was
selected.

3.4.2 Time (Weight = 2)

The impact of time for BCH is also an important factor. The longer the project continues,
the longer it takes before they can occupy 2BP, and begin to consolidate their offices. As a result,
two was selected for the weighted importance factor.

3.4.3 Noise (Weight = 1)

The impact that noise has is important to BCH largely due to the impact it will have on
the community. BCH wants to ensure that they minimize annoyance to abutters. However, it is
not nearly as important as the cost of construction. As a result, one was selected for the weighted
importance factor.

3.4.4 Vibrations (Weight = 2)

The impact of vibrations can be significant due to the potential damage they may cause to
surrounding structures. If damage to abutting structures did occur, BCH could be liable for the
costs. Additionally, they can cause annoyance or even disturbances to the care of patients in the
occupied 1BP. As a result, two was selected for the weighted importance factor.

3.4.5 Pollution (Weight = 3)

The impact of pollution varies depending on the type of pollution. Due to the large
variety of possible pollutants, and the contaminated soils on site, pollution control is extremely
important. As a result, efforts taken to control pollution for each phasing plan are weighted
heavily. The weighted importance factor selected for pollution was three.

3.4.6 Traffic Disruptions (Weight = 1)

Disruptions to traffic, parking, and the roadways can have a significant impact on nearby
residents and the community. Therefore, it is important that the plans take into account this
impact, and make efforts to minimize disruptions. These impacts will largely affect the
surrounding community, similarly to noise. As a result, the selected weighted importance factor
was one.
4.0 Results

4.1 On-Site Soil Limitations

Using documents developed by Sanborn Head, a site plan detailing the various areas of contaminant concentrations that exceeded MCP Reportable Concentrations, as well as the depths at which these contaminants are located, was developed. This plan, which could not be included due to the sensitive nature of the information to Boston Children’s Hospital’s site, made information regarding the usability of on-site materials more apparent, and aided in the phasing of earthwork.

The thirteen zones created in this plan represent areas of contaminant concentrations that are assumed to be similar to the concentrations found at the individual soil explorations within each zone. The size and shape of the thirteen zones were determined by making assumptions using the relative distance between soil explorations. Zones with smaller distances from neighboring soil explorations were allotted a smaller size. The areas with more distance between explorations would have larger zones. These assumptions were made to conservatively characterize the contamination in larger areas where concentration data was not available. The majority of the contamination discovered was six feet beneath grade, and the contaminants found were mainly lead, total petroleum hydrocarbons (TPH), and various volatile organic compounds (VOCs).

As discussed in section 2.3.2, any materials with an exceedance of an MCP Reportable Concentration that are to be reused on-site must be returned to a similar depth and a similar level of contamination. Additionally, these materials may only be reused if there is a barrier preventing the transport of contaminants to people who may use the hospital. These barriers may be paved surfaces or, such as in the case of the 2 Brookline Place addition, a sub-slab vapor intrusion barrier. This barrier will be a layer of crushed stone, with a network of perforated pipes that will passively collect any contaminants that may volatilize and redirect them above the building to be released into the air. This layer will be placed beneath the concrete foundation slab, and the slab will likely be sealed using a liquid vapor barrier, such as Liquid Boot or GeoSeal. The exact plans and specifications for this vapor intrusion barrier have yet to be finalized by Sanborn Head.
4.2 Cut-and-Fill

4.2.1 Bluebeam vs. Civil 3D

Table 4 displays the square footages of the designated locations that were calculated in both Bluebeam Revu and AutoCAD Civil 3D. Figures 8 and 9 show the location of the corresponding zones on the site from Table 4. These area values were used to generate the takeoff quantities.

<table>
<thead>
<tr>
<th>Table 4: Square Footage Calculations</th>
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<tbody>
<tr>
<td>Location</td>
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<td>Lawn</td>
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<td></td>
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<tr>
<td>Shrubs/</td>
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<tr>
<td>Ground</td>
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<tr>
<td>Lawn</td>
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<tr>
<td>Shrubs/</td>
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<td>Lawn</td>
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<td>Shrubs/</td>
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<td>Concrete</td>
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<td>Pavement</td>
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<td>Type 1</td>
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<tr>
<td>Concrete</td>
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<tr>
<td>Pavement</td>
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<tr>
<td>Type 2</td>
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<tr>
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<td>Concrete</td>
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<tr>
<td>Pavement</td>
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</tr>
<tr>
<td>Type 1</td>
</tr>
<tr>
<td>Concrete</td>
</tr>
</tbody>
</table>
As seen in the table, the total square footages calculated were within one percent of each other. Additionally, a majority (31 of 36) of the values calculated were within fifteen percent of each other. This is an acceptable factor of accuracy, as it is an industry standard for ten to fifteen
percent excess of materials to be ordered for contingency during a project to account for human error and discrepancies in the field.\textsuperscript{60}

One factor that may have contributed to the additional differences between the values calculated is human error in determining and marking the boundaries of the individual locations, which may have altered the sizes of the zones. Additionally, the irregularly curved boundary lines increased the margin of error when marking and measuring the locations in both programs. There were five locations that had higher than 15 percent of a difference between the two values calculated, which is believed to be due to differences in the zoning of the locations. The similarity of the two total values, however, accounts for these larger differences; the total amounts of materials calculated by both programs account for nearly all of the area of the project site.

\textbf{4.2.2 Comparison of MQP results to CPM’s bid package}

Table 5 shows the comparison of the calculated material areas to the material areas provided in the Construction Project Manager (CPM) bid package.

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|l|l|l|l|}
\hline
\textbf{Material} & \textbf{Bluebeam} & \textbf{Civil 3D} & \textbf{Avg} & \textbf{Suffolk Bid} & \textbf{Unit} & \textbf{Difference (SF)} & \textbf{\% Difference} \\
\hline
\textbf{Total Concrete Pavement} & 13412 & 13300 & 13356 & 14482 & sf & 1126 & 8\% \\
\textbf{Concrete Paver Type 1} & 3142 & 3191 & 3167 & 3225 & sf & 58 & 2\% \\
\textbf{Concrete Paver Type 2} & 2723 & 2434 & 2578 & 2750 & sf & 172 & 6\% \\
\textbf{Shrubs & Ground cover} & 13103 & 12891 & 12997 & 12935 & sf & -62 & 0\% \\
\textbf{Lawn} & 10827 & 10898 & 10862 & 10750 & sf & -112 & -1\% \\
\hline
\end{tabular}
\caption{Calculated Material Areas vs CPM Material Areas}
\end{table}

As seen in the table, the calculated totals for concrete pavement, concrete pavers, shrubs and ground cover, and lawn are all within a ten percent margin of the quantities the CPM generated for their bid package. This indicates that the calculations are reliable and accurate. Therefore, the volumes generated using the square foot areas will also be accurate. Table 6 shows the comparison of the calculated fill volumes for soil profile type one. It shows that the calculated volumes are within one percent of the fill quantities generated by the CPM for their bid package.

\textsuperscript{60} Makepeace, J. (1997). \textit{DOE G 430.1-1, cost estimating guide}. (No. 11).
4.2.3 Volumes

The cut-and-fill volumes for the site were calculated using Civil 3D. Table 7 shows the required cuts needed to be made to the site to allow for the addition of the landscaping. See Figures 8 and 9 for the locations of each zone. The net total cut is 2,684 cubic yards of soil. This is the total volume of soil that is required to be removed across the site to allow for the landscaping to be completed as specified in the Landscape Grading Plans of the Progress Set of Construction Documents, available in Appendix B.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Material</th>
<th>Calculated</th>
<th>Suffolk Bid</th>
<th>Unit</th>
<th>Difference (cy)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Profile</td>
<td>Topsoil</td>
<td>538</td>
<td>530</td>
<td>CY</td>
<td>-8</td>
<td>-1%</td>
</tr>
<tr>
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Table 7: Cut-and-fill Calculations

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<th>Zone</th>
<th>Area (Sq. Ft.)</th>
<th>Cut (Cu. Yd)</th>
<th>Fill (Cu. Yd)</th>
<th>Cut or Fill</th>
<th>Net (Cu. Yd)</th>
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<td>14</td>
<td>-124</td>
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</table>

Total  -2684 Cut

4.2.4 Takeoff Quantities

When investigating the quantities of materials necessary for the landscaping, the two forms of takeoffs completed were quantities of plants and quantities of materials, such as soil and concrete. The specification for the plants detailed the soil requirements. The site was separated
into areas specified by the soil requirements using Bluebeam. The mapped zones created in Bluebeam can be seen in Figure 10. The specific quantities for the takeoffs can be found in Appendix F. Appendix F displays the descriptions of the plants on the architect’s design plans, as well as the attributes of the plants, shrubs, and trees for the site.

4.3 Phasing

4.3.1 Option One

The first option for the management of on-site materials focuses on decreasing the duration of construction. This option involves shipping all of the excavated materials off site, as opposed to storing and reusing it on-site. Additionally, the small amount of available on-site space limits the possible areas for stockpiling, and would impede heavy machinery from efficiently maneuvering throughout the site. New fill materials would be ordered and used to account for the increased elevation that is defined in the architect’s design plans. These fill materials vary across the site, but include materials such as gravel, sandy loam, and planting soil.
Additional strategies that will be used involve continuous work through the weekends. The added two working days gained by working through the weekends would result in approximately a 36-week decrease in construction duration.

4.3.2 Option Two

The second phasing option would focus on decreasing the overall cost of construction. This option would prioritize the reuse of some of the on-site soil to avoid the cost of shipping all of the excavated materials off-site. Because the designs indicate no areas of required fill, reuse of on-site materials would effectively raise the overall elevation of the site. This proposed raising of elevation would occur gradually throughout the site, and only in areas utilized for landscaping, as the aesthetics and functionality of these areas would not be excessively hindered by the proposed 0.5-foot increase in elevation. Areas near the 2 BP building and sidewalks would not experience this increase in elevation, as doing so would impair both the visual aesthetic of the newly constructed building and the ease of access through the site to the general public. This option requires much more movement and storage of materials across the site, and stockpiles would impede the movement of heavy machinery throughout the site.

4.3.3 Option Three

The third phasing option incorporates ideas from the previous two options in an attempt to maximize efficiency in terms of duration and cost. This plan involves delaying the start date of construction on the 1 Brookline Place addition for it to be completed at the same time as 2 Brookline Place, so that the 1 Brookline Place area may be used for the stockpiling of materials. This would allow the construction on 2 Brookline Place to proceed without the hindrance of stockpiling materials on the site, allowing heavy machinery to move more freely throughout the 2 Brookline Place site.

4.4 Evaluation of Alternatives

The evaluation criterion presented in section 3.4 of this report was used to evaluate the different proposed soil management strategies. The scores can be seen in Table 8. The raw score of three is given to the option with the best effect on the specific criterion being evaluated. A raw score of one is assigned to the worst option for the criterion, and a two is given to the second-
best option for the certain criterion. Each raw score is then multiplied by the weighting factor for the specific criterion to calculate the total score. Option Three had the highest total score with 30.

<table>
<thead>
<tr>
<th>Phasing Option</th>
<th>Cost (Raw Score)</th>
<th>Cost (Wtd Score)</th>
<th>Time (Raw Score)</th>
<th>Time (Wtd Score)</th>
<th>Noise (Raw Score)</th>
<th>Noise (Wtd Score)</th>
<th>Vibrations (Raw Score)</th>
<th>Vibrations (Wtd Score)</th>
<th>Pollution (Raw Score)</th>
<th>Pollution (Wtd Score)</th>
<th>Traffic Disruptions (Raw Score)</th>
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<td>3</td>
<td>3</td>
<td>30</td>
</tr>
</tbody>
</table>

**4.4.1 Option One**

Option One received the lowest score (1) for the cost. This is because this option involved working weekends and longer hours. It also calls for shipping most, if not all, excavated materials off site and ordering new materials. This will result in the largest cost of the three options. By reducing the amount of time spent stockpiling and moving materials, this option would decrease the overall duration of the project, generating the highest rating (3) for time. Longer working hours cause longer periods of noise and vibration generation for the community. This option also calls for the use of more heavy machinery to complete the project quicker, leading to increased noise, vibrations, and pollution. Consequently, this option received a rating of one for noise, vibration, and pollution. Since this option involves shipping soils off site, importing all new soils, and working weekends, it will have a significant impact on the traffic. Therefore, it received a rating of one for traffic. After applying the weights for each factor, Option One received a score of sixteen.

**4.4.2 Option Two**

Option Two received a raw score of three for the cost because it prioritizes reusing on-site soils. This option received a score of one for time because it is not as time efficient as either of the other two options. The increased use of on-site soils decreases the number of trucks needed for soil transportation. This leads to a lower amount of noise generated, resulting in a rating of three for noise. This also leads to lower vibrations, pollution, and traffic disruptions.
than option one. Therefore, this option received a rating of two for vibrations, pollution, and traffic disruptions. The extended occupation of Pearl Street for material storage will also increase the disruption of traffic. After applying the weights for each factor, Option Two received a score of twenty-six.

4.4.3 Option Three

Option Three received a raw score of two for cost because it strikes a balance between shipping soil off site and reusing some of it as fill. It also received a rating of two for the time required for completion, as it is not the most time efficient option, but still represents a decrease in duration when compared to option two. This option received a rating of two for noise because there will still be a greater amount of heavy machinery used than in Option One, which will generate slightly more noise. Since this option does not call for the immediate removal of the temporary parking lot in its entirety, there will be more space available to store materials without requiring the occupation of Pearl Street. The delayed start date for the construction of the 1 Brookline Place addition also allows extra room for the storage of construction equipment, soil, or construction materials. The impact of vibrations will be lowest due to the coordination of construction activities between 1 and 2 Brookline Place, resulting in concurrent construction activities. Therefore, the rating for vibrations was three. The pollution will be lowest for this option because of the increased use of on-site materials, which will be stored on the paved parking lot. This ensures safe storage of materials, leading to the rating of three for pollution. This option calls for the shortest occupation of Pearl Street, and very few trucks to transport soils. Option three received a rating of three for traffic disruptions. After applying the weights for each rating factor, Option Three received a score of thirty.
5.0 Conclusions

The goal of this project was to provide Stantec with a recommendation for a possible alternative to their construction management plan. This goal was achieved by completing cut-and-fill calculations that were used to develop three phasing plans. These phasing plans were then evaluated using a weighted decision matrix. The evaluation of the proposed plans proves that Option Three would be the most efficient phasing plan for this construction project. The following conclusions have been made for each of the designed options:

Option 1

This plan is feasible in a planning stage and would be done in the shortest amount of time, but it may not be possible with a limited budget. Cost is important to Boston Children’s Hospital (BCH) and this option may be too expensive. The MQP team recommends analyzing the budget for BCH for the feasibility of utilizing this option. The team also suggests completing a cost-benefit analysis for finishing construction early compared to completing the construction as it is currently scheduled. This cost benefit analysis will investigate specific costs associated with accelerating the schedule, savings on office space that BCH is leasing throughout the city, and benefits of earlier occupation.

Option 2

This is a viable option which could save BCH a large amount of expenses. Increasing the elevation by an average of 0.5 feet throughout the site would cut the amount of on-site soil being off by almost a third of the total. Sidewalks nor buildings would experience this increase in elevation. The increased amount of contaminated soils at the site pose a larger risk of possible exposure of contaminants. Also, the stockpiles could impede the movement of heavy machinery throughout the site.

Option 3

The third method for soil management was the most efficient. Delaying the start date for of the construction for the 1 Brookline Place addition for about 20-22 weeks, will provide room for the storage of materials, construction equipment, and soils. This provides space that could eliminate the need for the occupation of Pearl Street, which is very costly (paying daily for the parking spaces taken up), especially over a lengthy period of time. The Pearl Street occupation and 1 Brookline Place addition take up approximately the same amount of area (~7500 square feet). The lack of available information to complete a cost-benefit analysis comparing the benefit
versus cost of delaying the start date of the 1 Brookline Place addition represents a limitation for this project.

**Future Work**

The MQP team suggests analyzing the costs and benefits of delaying the start date of 1 Brookline Place. The team did not have access to important cost information while performing the evaluation of alternatives. Some important information to consider includes leasing agreements that BCH currently holds for their staff working out of various locations, as well as the possible value that leasing space in the 1 Brookline Place addition may provide.
6.0 References


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7.0 Appendix

Appendix A: Project Proposal

MAJOR QUALIFYING PROJECT
PROPOSAL
STANTEC, BOSTON-PROJECT CENTER

TEAM:
NAUMILDA COMO
TYLER LEIGHTON
KENUEL LOPEZ RIVERA
TYLER VAN NOstrand
KEVIN WORMER

ADVISORS:
LEONARD ALBANO
SUZANNE LEPAGE
STEVEN VAN DESSEL

PROJECT SPONSOR:
STANTEC
Introduction

The project consists of the construction of a new 180,000 square foot outpatient facility, an addition to current hospital building at 1 Brookline Place, and a replacement of the current parking garage at the Boston Children’s Hospital. Stantec is serving as the Owner’s Representative and Project Manager for the project. Specifically, they are managing the project team, budget, and schedule. Stantec has expressed that they would like to efficiently and cost effectively control the contamination of the dirty material throughout the different phases of the construction process. Our team will provide Stantec with:

1. A project phasing analysis, with proposed alternatives to the current plan,
2. An analysis of the material used in construction, with proposed changes to the current plans,
3. Cut-and-fill calculations for the proposed alternatives,
4. Cost estimations,
5. And a final recommendation on the best option to minimize cost, duration, waste, and site disturbances.

Design Statement

We will produce alternatives to the various aspects of the construction process for the Boston Children’s Hospital additions, with the goal of reducing both the overall cost and duration of the project.
Background

2.1 Project Overview

The new design of the Boston Children’s Hospital will be incorporated to accommodate the growing demand in complex care. The development of the property at 1 Brookline Place and the creation of the new 2 Brookline Place will enable Boston Children’s Hospital to continue to provide ambulatory clinic care in a more convenient neighborhood setting. Patients and families will be able to access upgraded amenities, an improved and expanded parking facility and enhanced landscaping throughout the campus. Additionally, the new building will allow the hospital to update and replace current double rooms with individual rooms to better accommodate parents and medical staff. These changes will support improved care and privacy for patients and their families.

2.2 Challenges

The project has been controversial because it resulted in the demolition of a half-acre healing garden in the Boston campus, and because of concerns on how the expansion will affect healthcare costs. The main concern regarding the expansion was that “the new project will lead to higher health care costs in the state, as patients are drawn to the expanded Children's Hospital from lower-cost pediatric hospitals.” Even though the Massachusetts Public Health Council approved the project, some opponents say that they will appeal the decision, and are currently in the process of a lawsuit to block the project.

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The Brookline Campus is in a congested area of the city that is currently undergoing roadway construction and other infrastructure projects. Figure 1 shows the Boston Children’s Hospital Campus in Brookline, Massachusetts, circled in red.

Figure 1: Brookline Boston Children’s Hospital Campus Location

Further challenges are posed due to the site remaining in operation while construction is ongoing. Other issues are that current parking and pedestrian walkways will be closed and detours will need to be utilized. Additionally, the soils at 2-4 Brookline Place are currently contaminated because of previous use of the site as “a manufactured gas plant, a gasoline service station, several light industries, and an upgradient underground storage tank”.

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Methodology

This project will analyze the various phases of the construction process, including site specific concerns, the project schedule, the usage and handling of any on-site materials, and the construction method that will be used for the project. Additionally, we will develop a strategy for construction, excavation and filling using cut-and-fill calculations, and provide a cost estimation for the alternative solutions.

3.1 Develop a Set of Limitations

Our team will begin the project with a review of the plans for construction and other city documents to fully understand the designs and considerations when proposing changes to the current plans. The review will include investigating any limitations that can affect the phasing of the construction, cut-and-fill calculations, and/or project materials.

3.2 Compare Existing Design and Limitations

Once we have a full understanding of the construction of this project and its limitations, our team will analyze the existing designs and determine areas for improvement. Afterwards, our team will look to make improvements within the construction phasing process to make the project more cost and/or time efficient.

3.3 Phasing

The current phasing plans and construction methods will be analyzed in comparison to concerns listed below. Information such as the project schedule and construction methods will be used to guide the analysis.
3.3.1 Project Schedule

Given the information available when we begin our work in January, we will identify tasks within the construction schedule to focus on that we will have the most impact on. This will be done by taking a variety of factors into consideration. The impact on traffic and pedestrian access, as well as their safety, around the site will need to be considered throughout. Additionally, signage is important to communicate changes of access and relocation of parking to the public. Other factors to consider are working around ongoing road construction, inclement weather concerns, and deadlines required by the Boston Children’s Hospital for completion. Construction progress will be assessed for compliance with the baseline schedule, and re-evaluated to maximize efficiency. An Earned Value Analysis (EVA), which measures project performance, will be conducted to look for areas for improvement and focus when proposing alternatives.

3.3.2 Construction Methods

Our team will analyze the defined construction method in terms of budget, construction duration, and waste produced on-site. Based on our study, we will propose different construction methods, such as prefabricated construction, to mitigate construction time, cost, and waste.

3.3.3 Produce Alternatives

Our team will use the analysis conducted to develop potential different phasing alternatives for the project. These options will be developed with the goal of lowering the overall price, expediting the project schedule, minimizing the impact on the surrounding site, and minimizing waste. Alternative options will be produced utilizing a scheduling tool such as Primavera P6 and a Building Information Model (BIM). This information and the model will be
used to conduct an EVA on the various phases to determine the best option. The BIM and schedule produced using Primavera will be linked together in Autodesk Navisworks to visually show the alternatives.

### 3.3.4 Location Specific Concerns

Due to the close proximity that pedestrians and the general public will have to the site, it is integral that all phases of the project be planned and monitored to minimize potential risks and hazards. As construction progresses and the actual location of work moves, the specific concerns will change. Figure 2 shows the first phase of construction which includes the plan to direct pedestrians and traffic around the site. We will periodically reevaluate the plan, ensure it is being followed, and determine if improvements to it can be made to minimize time of construction.

![Figure 2: Phase One, Enabling Works](http://www.childrenshospital.org/~/media/microsites/brookline-place/cpr_10809_brookline_phase_r_1.ashx?la=en)

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3.4 Cut-and-Fill

3.4.1 Analyze Current Plans

After determining the phases of the project, we will begin the cut-and-fill process with a review of the construction plans to establish an inventory of the fill materials throughout the different project phases we will be addressing. We will also investigate topics ranging from storage requirements to transportation of the materials to and from the site.

Additionally, we will research the limitations on use of any contaminated soils on site. In an effort to maximize the reuse of on-site materials, we will research to verify the areas of the site that contain reusable soil.

3.4.2 Produce Alternatives

After determining the necessary quantities of materials and determining phases of construction, we will identify different scenarios for the management of fill materials. These alternatives will include variations of the amount of on-site and off-site materials used for the project, as well as a variety of different vendors. The different vendors may be able to provide the same materials at a lower cost or a shorter delivery time, which will affect both the cost and the time efficiency of the project.

A similar strategy will be applied to the reuse of on-site materials. The information gathered on the specifics of the on-site contamination will be used to develop alternative methods for the use of contaminated materials. These alternatives will factor into the timelines for excavation during the phasing section of our project.
3.5 Recommendations

Using the information collected from the phasing and cut-and-fill sections of our project, we will assemble a final recommendation which incorporates cost estimation calculations, suggested schedule changes, cut-and-fill calculations, and comparisons of the proposed scenarios. The recommendations will be a part of the final report and presentation for Stantec to review.

3.6 Finalize and Present

We will review our research, analysis, and other materials to refine our report. With the information from our report, a presentation will be created and presented to Stantec. Finally, we will present our findings and submit a report to Stantec. At the conclusion of this project, our team will have designed alternatives to the various aspects of the construction process for the Boston Children’s Hospital additions, with the goal of reducing both the overall cost and duration of the project. Individual contributions to this design component are listed below:

1. Naumilda Como - Work on the Architectural/Structural component of the project.
2. Tyler Leighton - Work on cut-and-fill calculations, help with on-site material management plan, cost estimation of variations of material management plans
3. Kenuel Lopez Rivera - Cut-and-fill calculation, propose changes to schedule to minimize challenges being faced by project managers, and develop alternate plans to manage the materials on-site
4. Tyler Van Nostrand - Determine alternative uses for any contaminated soils that may be deemed reusable by the Licensed Site Professional (LSP), produce alternatives to on-site material management plan, cost estimation of variations of material management plans
5. Kevin Wormer - Assist on cut-and-fill calculations, propose phasing schedule changes taking into account cut-and-fill, and develop schedule and cost analysis of alternatives
Major Qualifying Project Schedule

Figure 3 shows the preliminary schedule for what our team plans to accomplish. The projected end date to our project is March 2, 2017.

![Figure 3: Expected List of Tasks]
Appendix B: Grading Plans
Appendix B.1: Grading Plan, Area 1

GRADING PLAN KEY
1.0 Cutting Contours
2.0 Fills
3.0 Proposed Grade
4.0 Existing Grade
5.0 Proposed Excavation
6.0 Existing Excavation

GRADING NOTES
A." Existing Grade /
B. Proposed Grade
C. Grading Slope
D. Elevation
E. Proposed Excavation
F. Existing Excavation

L201

Appendix C.3: Layout and Materials Plan, Area 3
Appendix D: Planting Plans

Appendix D.1: Planting Plan, Area 1

PLANTING PLAN KEY

1. Shrub Plantings
   1.1. Deciduous Shrubs
   1.2. Evergreen Shrubs
   1.3. Ground Cover

2. Tree Plantings
   2.1. Deciduous Trees
   2.2. Evergreen Trees

3. Site Furniture
   3.1. Site Furnishings

PLANTING PLANT KEY - CONT.

PLANTING PLANT KEY - CONT.

PLANTING NOTES

- Planting Species:
  1. Tree Species
  2. Shrub Species
  3. Ground Cover Species

- Planting Details:
  1. Planting Density
  2. Planting Method
  3. Site Condition

- Planting Specifications:
  1. Planting Size
  2. Planting Care
  3. Planting Maintenance

- Planting Schedules:
  1. Planting Season
  2. Planting Date
  3. Planting Time
Appendix D.3: Planting Plan, Area 3
Appendix E: Construction and Demolition Noise Level Restrictions

Appendix E.1: Maximum Vehicular Noise Levels\textsuperscript{69}

\begin{quote}
(b) Vehicular Sources: Maximum Noise Levels Measurements shall be made at a distance of 50 (fifty) feet from the closest point of pass-by of a Noise source or 50(fifty) feet from a stationary vehicle.
\end{quote}

\begin{center}
\begin{tabular}{|l|c|c|}
\hline
Vehicle Class & Stationary Run-up or Speed Limit 35 mph or less & Speed Limit 35-45 mph \\
\hline
All vehicles over 10,000 lbs. GVWR or GCWR & 83 & 87 \\
\hline
All motorcycles & & 79 \\
\hline
Automobiles and light trucks & 75 & 75 \\
\hline
\end{tabular}
\end{center}

\textsuperscript{69} Town of Brookline, Noise control by-law 8.15.6b, (2008).
Appendix E.2: Maximum Construction Equipment Noise Levels

(e) Construction and Maintenance Equipment:

<table>
<thead>
<tr>
<th>Construction Item</th>
<th>Maximum Noise Level dBA</th>
<th>Maintenance Item</th>
<th>Maximum Noise Level dBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backhoe, bulldozer concrete mixer dumptruck, loader, roller, scraper, pneumatic tools, paver</td>
<td>90</td>
<td>Wood Chipper running concrete mixer, leaf vacuum</td>
<td>90</td>
</tr>
<tr>
<td>Air compressor</td>
<td>85</td>
<td>Chainsaw, solid waste compactor, tractor (full-size)</td>
<td>85</td>
</tr>
<tr>
<td>Generator</td>
<td>80</td>
<td>Home tractor, snow blower</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lawn mower, trimmer,</td>
<td>75</td>
</tr>
<tr>
<td>Electric drills, power tools, sanders, saws, etc.</td>
<td>75</td>
<td>Leafblowers</td>
<td>67</td>
</tr>
</tbody>
</table>

70 Town of Brookline, Noise control by-law 8.15.6c, (2008).
## Appendix F: Takeoff Charts

### Appendix F.1: Plant Takeoff Chart

<table>
<thead>
<tr>
<th>Plants</th>
<th>Quantity</th>
<th>sf' coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS</td>
<td>674</td>
<td>594</td>
</tr>
<tr>
<td>CR</td>
<td>87</td>
<td>475</td>
</tr>
<tr>
<td>CP</td>
<td>152</td>
<td>824</td>
</tr>
<tr>
<td>IV</td>
<td>14</td>
<td>875</td>
</tr>
<tr>
<td>OS</td>
<td>64</td>
<td>490</td>
</tr>
<tr>
<td>PA</td>
<td>161</td>
<td>314</td>
</tr>
<tr>
<td>PL</td>
<td>374</td>
<td>724</td>
</tr>
<tr>
<td>VV</td>
<td>58</td>
<td>1338</td>
</tr>
<tr>
<td>RS</td>
<td>58</td>
<td>1338</td>
</tr>
<tr>
<td>MS</td>
<td>516</td>
<td>1338</td>
</tr>
<tr>
<td>LS</td>
<td>2450</td>
<td>1352</td>
</tr>
<tr>
<td>HH</td>
<td>223</td>
<td>913</td>
</tr>
<tr>
<td>VM</td>
<td>1760</td>
<td>1458</td>
</tr>
<tr>
<td>SOD</td>
<td>0</td>
<td>14688</td>
</tr>
<tr>
<td><strong>total excluding sod</strong></td>
<td></td>
<td><strong>12033</strong></td>
</tr>
</tbody>
</table>

### Fills

<table>
<thead>
<tr>
<th>plant beds</th>
<th>cy</th>
</tr>
</thead>
<tbody>
<tr>
<td>leaf mold mulch</td>
<td>2006</td>
</tr>
<tr>
<td>(&quot;varies&quot; assume 2&quot;)</td>
<td></td>
</tr>
<tr>
<td>Soil mix (6&quot;-8&quot;)</td>
<td>8022</td>
</tr>
<tr>
<td>Soil profile 1 (4')</td>
<td>48132</td>
</tr>
<tr>
<td>Soil profile 2 (sandy loam)(1')</td>
<td>8362</td>
</tr>
</tbody>
</table>
## Appendix F.2: Tree Takeoff Chart

<table>
<thead>
<tr>
<th>Trees</th>
<th>Quantity</th>
<th>Planting</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZS</td>
<td>25</td>
<td>4.1 (11), 4.2 (5), 4.3 (5)</td>
</tr>
<tr>
<td>UA</td>
<td>3</td>
<td>4.2</td>
</tr>
<tr>
<td>GB</td>
<td>8</td>
<td>4.1</td>
</tr>
<tr>
<td>BN</td>
<td>3</td>
<td>4.4</td>
</tr>
<tr>
<td>AR</td>
<td>14</td>
<td>4.2</td>
</tr>
<tr>
<td>AC</td>
<td>4</td>
<td>4.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Planting Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>19</td>
</tr>
<tr>
<td>4.2</td>
<td>22</td>
</tr>
<tr>
<td>4.3</td>
<td>9</td>
</tr>
<tr>
<td>4.4</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.1</th>
<th>cy</th>
</tr>
</thead>
<tbody>
<tr>
<td>soil profile 1 (1')</td>
<td>538</td>
</tr>
<tr>
<td>profile 1 sandy loam</td>
<td>1076</td>
</tr>
<tr>
<td>planting soil mix (1.5')</td>
<td>807</td>
</tr>
<tr>
<td>sand pedestal (# of units)</td>
<td>19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>soil mix (3')</td>
<td>1245</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>soil</td>
<td>977</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.4</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>pea gravel (4&quot;)</td>
<td>28</td>
</tr>
<tr>
<td>bio retention media (2')</td>
<td>170</td>
</tr>
<tr>
<td>coarse sand (4&quot;)</td>
<td>28</td>
</tr>
<tr>
<td>crushed gravel (4&quot;)</td>
<td>28</td>
</tr>
<tr>
<td>storage rock (10&quot;)</td>
<td>71</td>
</tr>
</tbody>
</table>
### Appendix F.3: Shrubs Takeoff Chart

<table>
<thead>
<tr>
<th>Shrubs</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>756</td>
</tr>
<tr>
<td>FG</td>
<td>262</td>
</tr>
<tr>
<td>TV</td>
<td>37</td>
</tr>
<tr>
<td>IG</td>
<td>72</td>
</tr>
<tr>
<td>IV</td>
<td>14</td>
</tr>
<tr>
<td>HV</td>
<td>64</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand pedestal</td>
<td>1205</td>
</tr>
</tbody>
</table>
Appendix F.4: Planting Descriptions

### Plant List

<table>
<thead>
<tr>
<th>KEY</th>
<th>Plant Type</th>
<th>Common Name</th>
<th>Qty</th>
<th>Root</th>
<th>Size</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trees</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZS</td>
<td>Zelkova serrata</td>
<td>Japanese Zelkova</td>
<td>25</td>
<td>B+B</td>
<td>9&quot; cal.</td>
<td>Umbod @ 7'</td>
</tr>
<tr>
<td>UA</td>
<td>Ulmus americana</td>
<td>Princeton American Elm</td>
<td>3</td>
<td>B &amp; B</td>
<td>7&quot; cal.</td>
<td>Umbod @ 7'</td>
</tr>
<tr>
<td>GB</td>
<td>Ginkgo biloba</td>
<td>Ginkgo Tree</td>
<td>8</td>
<td>B+B</td>
<td>9&quot; cal.</td>
<td>Umbod @ 7'</td>
</tr>
<tr>
<td>BN</td>
<td>Betula nigra</td>
<td>River Birch</td>
<td>3</td>
<td>B+B</td>
<td>4&quot; cal.</td>
<td>Umbod @ 9'</td>
</tr>
<tr>
<td>AR</td>
<td>Acer rubrum</td>
<td>Red Maple</td>
<td>14</td>
<td>B+B</td>
<td>4&quot; cal.</td>
<td>8&quot; cal.</td>
</tr>
<tr>
<td>AC</td>
<td>Amelanchier canadensis</td>
<td>Shadbrown sugarbush</td>
<td>4</td>
<td>B+B</td>
<td>16-18&quot; HG</td>
<td>Clump form, white flower</td>
</tr>
</tbody>
</table>

| **Shrubs** | | | | | | |
| CA | Cistus albidus | Summersweet cistus | 767 | B+B | 2-4'H | |
| FG | Forsythia x intermedia | Dwarf Forsythia | 262 | B+B | 2-3'H | White flower |
| TV | Itea virginica | Virginia sweetspire | 37 | B+B | 3-4'H | White flower |
| F3 | Leucodendron argenteum | Silverberry | 70 | B+B | 3-5'H |
| IV | Viburnum x carlcephalum | Winterberry | 14 | B+B | 3-5'H |
| HV | Hamamelis virginiana | Common Witch-Hazel | 93 | B+B | 4-6'H |

### Plant List - Cont.

<table>
<thead>
<tr>
<th>KEY</th>
<th>Plant Type</th>
<th>Common Name</th>
<th>Qty</th>
<th>Root</th>
<th>Size</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Perennials/Groundcover</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS</td>
<td>Anemone sylvestris</td>
<td>Snowdrop Anemone</td>
<td>674</td>
<td>Pot</td>
<td>#1</td>
<td>Plant 12&quot; OC</td>
</tr>
<tr>
<td>CR</td>
<td>Cimicifuga racemosa</td>
<td>Beesphoon</td>
<td>87</td>
<td>Pot</td>
<td>#1</td>
<td>Plant 30&quot; OC</td>
</tr>
<tr>
<td>DP</td>
<td>Comptonia peregrina</td>
<td>Sweetfern</td>
<td>152</td>
<td>Pot</td>
<td>#1</td>
<td>Plant 30&quot; OC</td>
</tr>
<tr>
<td>PI</td>
<td>Iris versicolor</td>
<td>Blue Flag Iris</td>
<td>23</td>
<td>Pot</td>
<td>#1</td>
<td>Plant 24&quot; OC</td>
</tr>
<tr>
<td>OS</td>
<td>Onoclea sensibilis</td>
<td>Silver Fern</td>
<td>64</td>
<td>Pot</td>
<td>#1</td>
<td>Plant 40&quot; OC</td>
</tr>
<tr>
<td>PA</td>
<td>Polystichum acrostichoides</td>
<td>Christmas Fern</td>
<td>161</td>
<td>Pot</td>
<td>#1</td>
<td>Plant 18&quot; OC</td>
</tr>
<tr>
<td>PL</td>
<td>Pennisetum alopecuroides</td>
<td>Fountain Grass</td>
<td>374</td>
<td>Pot</td>
<td>#1</td>
<td>Plant 18&quot; OC</td>
</tr>
<tr>
<td>WV</td>
<td>Veronicastrum virginicum</td>
<td>Culver's root</td>
<td>58</td>
<td>Pot</td>
<td>#1</td>
<td>Plant 36&quot; OC</td>
</tr>
<tr>
<td>RS</td>
<td>Perovskia atriplicifolia</td>
<td>Russian Sage</td>
<td>58</td>
<td>Pot</td>
<td>#1</td>
<td>Plant 36&quot; OC</td>
</tr>
<tr>
<td>MS</td>
<td>Salvia sylvestris</td>
<td>Meadow Sage</td>
<td>516</td>
<td>Pot</td>
<td>#1</td>
<td>Plant 12&quot; OC</td>
</tr>
<tr>
<td>IS</td>
<td>Liriope spicata</td>
<td>Blueboy Lilyturf</td>
<td>2,447</td>
<td>Flat</td>
<td>3'H</td>
<td>Plant 9&quot; OC</td>
</tr>
<tr>
<td>HH</td>
<td>Hedera helix</td>
<td>English Ivy</td>
<td>223</td>
<td>Pot</td>
<td>#2</td>
<td>Plant 9&quot; OC</td>
</tr>
<tr>
<td>VM</td>
<td>Vinca minor</td>
<td>Periwinkle</td>
<td>2,720</td>
<td>Pot</td>
<td>#3</td>
<td>Plant 12&quot; OC</td>
</tr>
<tr>
<td>SOD</td>
<td>Poa pratensis</td>
<td>Kentucky Bluegrass</td>
<td>14,244</td>
<td>Sod</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---