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SPECIAL MEETING OF THE BOARD OF DIRECTORS ON METROPOLITAN TUNNEL REDUNDANCY

to be held on

Thursday, October 6, 2016

Location: Carroll Water Treatment Plant
84 D'Angelo Drive
Marlborough, MA 01752

Time: 8:00 a.m.

AGENDA

I. INTRODUCTION

II. STATUS OF THE EXISTING TRANSMISSION SYSTEM FACILITIES

III. TUNNEL SYSTEM SHUTDOWN IMPACTS

IV. STRATEGIC GOAL FOR REDUNDANCY IMPROVEMENTS

V. EVALUATION OF ALTERNATIVES

VI. FINANCIAL CONSIDERATIONS

VII. STAFF PREFERRED ALTERNATIVE

VIII. EXECUTIVE SESSION

IX. ADJOURNMENT

STAFF SUMMARY

TO: Board of Directors
FROM: Frederick A. Laskey, Executive Director
DATE: October 6, 2016
SUBJECT: Special Meeting on Redundancy for the Metropolitan Tunnel System

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FULL BOARD

X Information
___Vote

Anandan Navanandan, Chief Engineer
David Coppes, P.E., Director of Waterworks
Prepared/Title

Michael J. Hornbrook
Chief Operating Officer

RECOMMENDATION:

For information only.

DISCUSSION:

The attached information is being provided to you in advance of the Special Board of Directors meeting scheduled for Thursday, October 6. Staff are planning a comprehensive meeting agenda and this package of information will help put the staff presentations in context.

While the information being provided to the Board is voluminous and on its face complex, the fundamental issues are in some ways simple to boil down:

The integrity of the water tunnels is not in question at this time. The risk is the failure - either catastrophic or partial - of the appurtenances of the tunnel shafts, like the valves, blow offs and pressure reducing valves. Starting with the Quabbin Tunnel in the 1930s, the Metropolitan Water System has built six tunnels over the decades. With the exception of the MetroWest Tunnel and soon the Cosgrove Tunnel, there is no redundancy to these tunnels at this time and it has not been possible to maintain and upgrade these tunnel appurtenances. For example, the City Tunnel, which carries 60% of the water we deliver on a daily basis, has been in operation for 66 years without maintenance or upgrades. The accepted useful life of this equipment is 50 years.

A failure in the tunnel system would, at best, be a very difficult challenge and more likely, a catastrophic event that could endanger the public safety and public health of those we serve. It would in all likelihood create substantial economic impact.

Staff believe that there is a compelling case that doing nothing is not a responsible option. Staff have studied over 30 different options. A critical strategic decision that the Board needs to make is what level of redundancy is necessary and what types of projects are feasible. This will lead to a discussion of the families of options.

Staff understand the magnitude of this decision and do not expect a final decision by the Board at this time. We are instead hoping for guidance on how to proceed with final approval to come at a later meeting. We realize that there is much work remaining to build a consensus of support from our member communities and state and local officials.

Readers Guide to the Briefing Book

The materials within this Briefing Book have been provided to summarize the staff presentations and to supply additional background information. It has been developed from material previously produced for the Board of Directors but also includes background or more detailed information assembled as part of the analyses conducted for the October 6, 2016 Special Board Meeting on Metropolitan Tunnel Redundancy.

The **Summary Document** is followed by the following attachments of supplemental information.

Tab 1- Chronology of Board Briefings and Key Staff Summaries

This section includes a chronology of past Board briefings on the topic of water system redundancy and copies of significant staff summaries on the topic of Transmission System Redundancy. These include:

- November 28, 1990: Sudbury Aqueduct Reconstruction and Connecting Tunnels Project; Requesting Board approval to proceed with the design of the MetroWest Water Supply Tunnel. Staff recommended that a future Northern Tunnel Loop extend from Weston to Shaft 9A in Malden.

- June 30, 2010: Metropolitan Water Transmission System Redundancy Plan; Informational staff summary presenting the findings and recommendations of the Transmission Redundancy Plan. The recommended alternative included the construction of seven miles of large diameter surface pipes, sliplining the Sudbury Aqueduct with a seven-foot diameter pipe, rehabilitation of the Chestnut Hill Emergency Pump Station and a four mile tunnel from Norumbega Reservoir to the Sudbury Aqueduct.

- June 25, 2014: A verbal update was provided to the Board at the Water Policy and Oversight Committee on Metropolitan Tunnel Redundancy highlighting possible tunnel alternatives. The attached map was presented.

- February 10, 2016: The Need for Metropolitan Tunnel Redundancy; Informational staff summary addressing the need for redundancy for the Metropolitan Tunnels. Information is provided on the condition of the current system, potential failure scenarios and system restoration information. A White Paper on Water System Redundancy is attached with information on peer utilities and policy guidance.

- July 13, 2016: Weston Aqueduct Supply Main 3 Project Update; Informational staff summary on the condition of the existing WASM 3 pipeline and issues associated with the plan to replace 7 miles of WASM 3 with 72-inch diameter pipe as part of the

Transmission system redundancy plan. The staff summary notes that WASM 3 is a critical element of the transmission system and under all redundancy alternatives, it must at a minimum, be rehabilitated.

- September 14, 2016: Chestnut Hill Emergency Pump Station Southern High Service Area Redundancy. Informational staff summary addresses use of the underground Chestnut Hill Emergency Pump Station for emergency supply to the Southern High and Southern Extra High service areas. Analysis identified capacity and pressure concerns in the surface piping that could affect operations if the Dorchester Tunnel is out of service.

Tab 2- Economic Analysis of Impact of Failure in City Tunnels

Staff developed updated information on the economic cost to business and residents of a failure of the Metropolitan Tunnels. This Tab provides information on the methodology and results of the analysis including data by community.

Tab 3 – Potential Short Term Measures-Tops of Shafts

Staff have identified a number of interim measures that should be implemented to reduce risks at the top of shaft structures. This matrix summarizes the potential measures at each location.

Tab 4 - Maps of Baseline and Alternative Projects

This section includes a matrix providing a high level summary of the evaluation of alternatives and individual maps showing Baseline projects, Northern System alternatives and Southern System alternatives. These maps show the range of potential alternatives evaluated. Each map includes a project description and an estimated Cost to Complete.

Tab 5 - Rate Impacts

Information developed showing the impact of a range of options and the preferred alternative for the redundancy project on rate revenue requirements and projected percentage increases on assessments.

Tab 6 - Map of Transmission System

Tab 7 – Power Point Presentation for Special Board Meeting on Metropolitan Redundancy

Copies of presentation materials will be provided at the meeting.

Massachusetts Water Resources Authority

Special Meeting of the Board of Directors
on
Metropolitan Tunnel Redundancy

Summary and Supporting Materials

October 6, 2016

STATUS OF EXISTING WATER TRANSMISSION SYSTEM FACILITIES

Transmission System Overview

The Water Transmission System can be divided into five major segments as shown in Figure 1. Completed or ongoing projects to achieve system redundancy for segments 1 through 4 are discussed below. The fifth segment, the Metropolitan Tunnels, represents the next challenge for the agency in improving the reliability of this great water system.

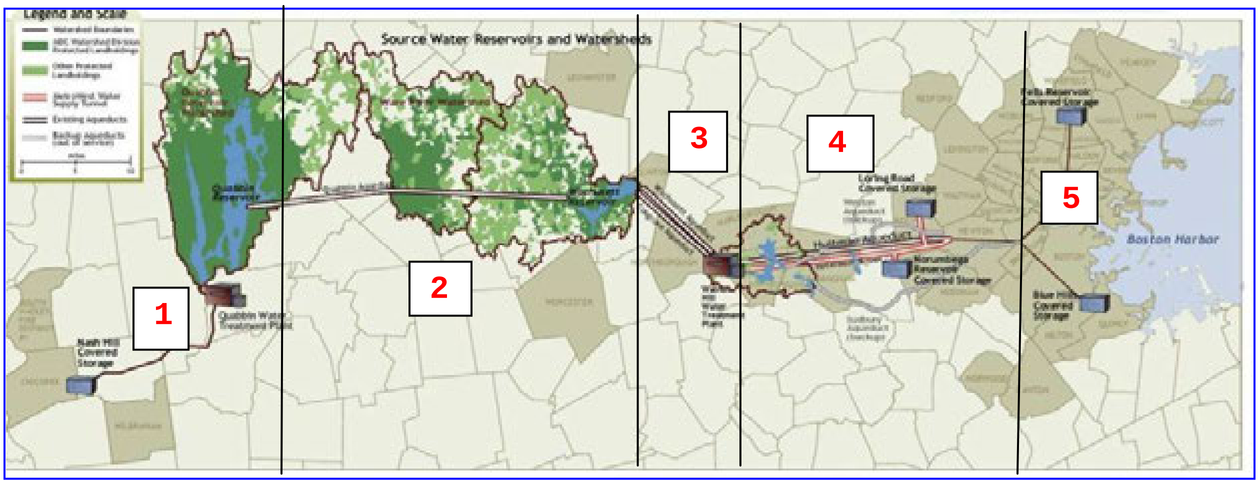


Figure 1 - MWRA Water Transmission System

1. Chicopee Valley Aqueduct. In 2007, MWRA completed construction of 8,100 feet of 30-inch diameter pipeline; 2,400 feet of 20-inch pipeline; and 3,100 feet of 16-inch pipeline to provide redundant supply for critical sections of the 14.8 mile long aqueduct.

2. Quabbin Aqueduct. The CIP includes development of an inspection plan for this tunnel and an isolation gate for the Quabbin end of the tunnel. With the exception of the Oakdale power station, which has under gone pipe and valve replacements, the shafts are un-pressurized ventilation structures with no surface piping or valves. The Wachusett Reservoir contains adequate storage to provide water supply if the Quabbin Aqueduct requires short duration maintenance (months) or emergency repair.

Wachusett Aqueduct Pump Station

3. Cosgrove Tunnel/Wachusett Aqueduct. The Wachusett Aqueduct Pump Station project (currently under construction), together with the existing Wachusett Aqueduct will provide redundant supply to the John J. Carroll Water Treatment Plant with up to 240 MGD of water, providing redundancy to the Cosgrove Tunnel during periods of low demand.

4. MetroWest Tunnel/Hultman Aqueduct. The MetroWest Water Supply Tunnel was completed in 2003 and the Hultman Aqueduct was

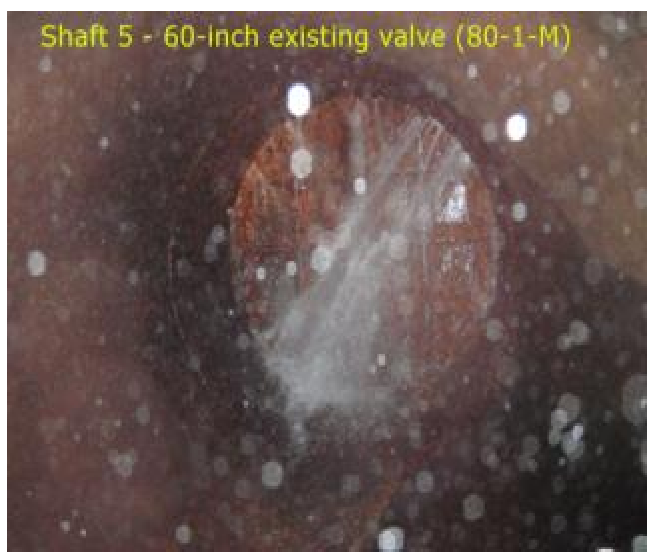
rehabilitated in 2013 and interconnected with the new tunnel, providing redundancy between Marlborough and Weston.

5. Metropolitan Tunnels. The Metropolitan Tunnels include the City Tunnel (1950), the City Tunnel Extension (1963), and the Dorchester Tunnel (1976). These three tunnels come together at Shaft 7 at Chestnut Hill. Together, these tunnels carry approximately 60% of the total system daily demand. The lack of redundancy for these specific tunnels is the subject of this presentation.

Condition and Reliability of Metropolitan Tunnels

Each tunnel consists of concrete-lined deep rock tunnel sections linked to the surface through steel and concrete vertical shafts. The tunnels and shafts, themselves, require little or no maintenance and represent a low risk of failure. The shafts are located in Weston, Chestnut Hill, Allston, Somerville, Malden, West Roxbury, and Dorchester. At the top of each shaft, cast iron or steel pipe and valves connect to the MWRA surface pipe network. These pipes and valves are accessed through subterranean vaults and chambers. Many of the valves and piping are in poor condition.

The City Tunnel (1950) appurtenances are 66 years old and can't be replaced until a back-up exists. In contrast, the original Hultman Aqueduct (1940) appurtenances were 63 years old when the MetroWest Tunnel was placed into service (2003). Most of those valves were subsequently replaced.



Leaking Gate Valve at Shaft 5

Valve reliability for the Metropolitan Tunnels is a concern. These valves can cut off a majority of the system's capacity to supply water and due to the physical condition, age, and environment in which they are installed they have not been exercised for fear of breaking them in a closed position. During the May 2010 isolation of the MetroWest Tunnel connection to Shaft 5 of the City Tunnel, two 60-inch gate valves were used to isolate MetroWest flow and allow repair to the connection. Unfortunately, one of these two valves failed to re-open due to a mechanical break-down in the interior of the valve. Another of these valves was later used to isolate the Hultman Aqueduct connection to the shaft during rehabilitation in 2013 and the valve was observed to leak badly. These valves should be, but cannot be, replaced because shut down of the City Tunnel would be required. Like the main line valves on the Hultman Aqueduct, many of the old tunnel shaft valves have reached the end of their useful life and should be scheduled for replacement as soon as an alternative means of supply is in service.

Shaft 7D chamber

Access to some of the top of valve structures and appurtenant valve chambers is hampered in some locations by high ground water or damp conditions. This is especially true at Shaft 8 of the City Tunnel Extension adjacent to the Charles River and Shaft 7D of the Dorchester Tunnel near the Neponset River. All prior pipe coatings are completely gone as pipes and valves are coated in thick layers of rust. Loss of metal thickness and structural strength is a concern. Bolts and fasteners have corroded and staff will begin replacement where feasible without increasing risk of failure. When visited, some chambers must be pumped down to allow access, which impedes emergency response times and aggravates further corrosion concerns.

At many of the top-of-shaft structures, piping and valves of varying diameters (ranging from less than an inch to several inches in diameter) are present for air and vacuum relief, drains, flushing connections, valve by-passes, and control piping for hydraulic valve actuators. These pipes and valves are in a similar deteriorated condition as the main pipes and valves themselves. Failure of one of these smaller diameter connections could require a tunnel shut down to allow a safe repair in some of these confined spaces. The amount of water that can flow out of a modest opening under high pressure can be significantly more than one might think. During the Shaft 5 connection break for example, a gap in the piping of less than an inch produced a flow of approximately 250 million gallons per day (MGD).

Some of these concerns can be mitigated somewhat through replacement of corroded bolts, wrapping or coating corroded pipeline segments, replacement of air valves, and installation of cathodic protection systems. Staff are developing a program to implement some of these ideas to reduce the risk of certain failures that would require complete tunnel shut down. However, all the potential failure points cannot be mitigated or addressed without tunnel isolation and complete replacement or maintenance of failed or failing components at some point in the future.

Even when all of these measures are completed, there are still several locations of special concern where risks cannot be easily mitigated. The location of Shaft 7 alone is a concern and its proximity to the back-up pump station that would be used in the event of the shutdown of the tunnel system. In addition, this location has special significance as it connects all three tunnels and contains the valves for their individual isolation.

Shaft 7 valve actuators

Both the City Tunnel and the City Tunnel Extension were constructed with dewatering

1959 photo of valves in Shaft 9 Chamber

provisions to allow for future removal of the tunnels from service for internal inspection or repairs. At Shaft 5, 375 feet below ground, and at Shaft 9 at a similar depth, two subterranean pump chambers were constructed with 16-inch bronze piping and valves connecting the pressurized tunnel sections to dewatering pumps and small diameter drain lines. The isolation valves have hydraulic actuators with small diameter piping that terminates in the shaft buildings at the surface. The valves were controlled by opening and closing the control piping and pumping up the lines to move the hydraulic cylinders. It is not known if these valves are in the open or closed position and whether the exposed piping is pressurized and 'live' or not. At Shaft 9, this chamber is completely under water and has been submerged for decades. In addition, the Shaft 9 site has an isolation valve 300 feet below ground, hydraulically actuated, that can shut off the tunnel section to Shaft 9A.

At the end of the City Tunnel Extension at Shaft 9A there is a pair of pipe couplings between the tunnel isolation valves and the top of the shaft. These couplings are indicated on record drawings as being 56-inch (a non-standard size). Staff are searching for shop drawing information on these couplings in order to fabricate replacements. The condition of the coupling and its bolts is unknown. Staff are hesitant to dig up this section as disturbing the pipe could lead to a failure which would require shutting down the tunnel.

TUNNEL SYSTEM SHUT DOWN IMPACTS

Planned Shutdown

While back-up systems for these tunnels exist they rely on pumping from open distribution reservoirs (Sudbury, Spot Pond and Chestnut Hill), back-up aqueducts (Sudbury), and undersized surface mains to distribute water of inferior quality and inadequate pressure to customers (along with water use restrictions during periods of high seasonal demand). Use of any of these systems would require a boil order. Partially supplied communities would be encouraged to maximize production of their own sources of supply to reduce demand on the system.

Mobile disinfection unit and chlorine tank at Gillis Station

To the north, with the City Tunnel and/or the City Tunnel Extension out of service, supply would be partly from the 60-inch WASM 3 line, though most would be pumped from the open Spot Pond by either the Gillis Pump Station or the new Spot Pond Pump Station via Fells Reservoir to the Northern High Service area. Spot Pond would be replenished by the Northern Low System, although supply could not keep pace with demand and the level in the reservoir would drop requiring water restrictions. Staff estimate that Spot Pond would last 1-2 months in average demand conditions and 1-3 weeks during high demand. Many pipe and valve closures would be required to reconfigure the system to operate in this manner. Use of Spot Pond requires emergency chlorination at high doses and a boil order in all communities potentially receiving its water.

Chestnut Hill Emergency Pump Station

To the south, in any scenario in which the Dorchester Tunnel and/or City Tunnel is out of service, supply would be pumped from the Chestnut Hill Reservoir to the Blue Hills Tanks using the Chestnut Hill Emergency Pump Station with electric pumps and no back-up power supply. This is very different from the situation when the station was utilized in the Shaft 5 break in 2010 during which the Dorchester Tunnel was available and in service. In order to push enough water through the surface mains (with the tunnel shut down) to meet demand, pressures in the vicinity of the pump station would greatly exceed current operating pressures and the possibility of leaks and breaks in MWRA and local community's systems is high. Pumping would need to run continuously to Blue Hills Tanks as the elevation in Blue Hills is inadequate to back feed through those small surface mains without an unacceptably large drop in pressure. Hence, large swings in pressure would occur. The Chestnut Hill Reservoir would be replenished from the Sudbury Aqueduct. Use of the Chestnut Hill Reservoir would require emergency chlorination at high doses and a boil order in all communities potentially receiving its water.

Unplanned Emergency Shutdown

In an emergency shut-down in which flooding causes damage or public safety concerns there may not be time to set up these back-up systems. The time to complete isolation can be very long; valve crews would be stretched thin, there are nine shaft locations and numerous valves to close, access is difficult and the valve turn counts are very high.

A large drain on the system would put large areas served by these tunnels completely out of water. Once isolated, the process of activating the back-up systems would begin which would also take a long time and further stretch crews. Additional areas would go without water during this time as local storage tanks drain and pump station suction pressures drop. Restoration of service would require refilling of pipes and evacuating air in both MWRA and community mains which would occupy MWRA and community water department staff for weeks. To accomplish this, staff would be flushing hydrants to waste while areas of the system have no water at all. A large part of the MWRA service area would be totally out of water for many days, if not weeks.

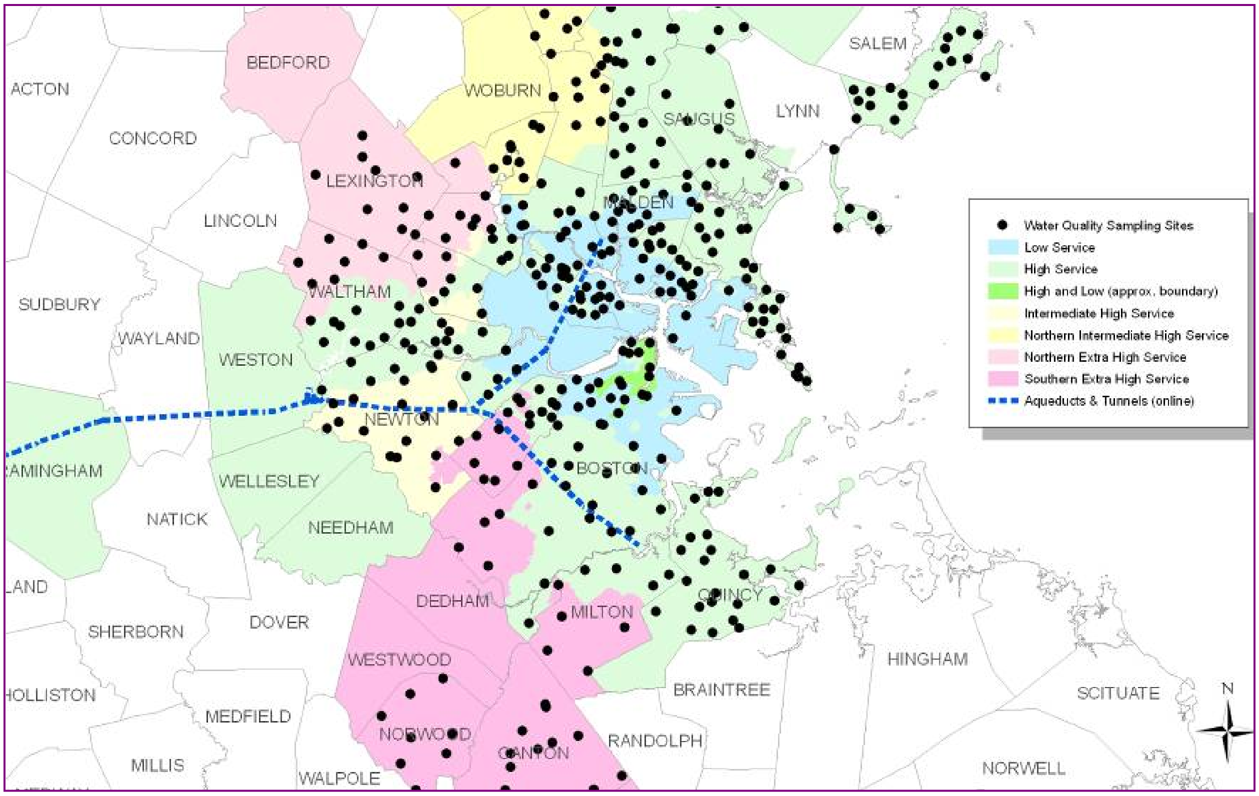


Figure 2 - Water Sample Locations

Areas with water would remain on a boil order. Before the boil order could be lifted the sanitary condition of the system would have to be restored and proven with multiple rounds of clean water quality samples.

Analysis of Economic Impact of Failure of Metropolitan Tunnels

Staff conducted an analysis of the economic impact of a failure of the Metropolitan Tunnels. This analysis utilized the Federal Emergency Management Agency's (FEMA) analysis of standard economic benefit-cost values for disaster events, and studies from California and Italy of the economic loss from water supply interruptions.

To calculate the business loss, staff calculated each community's share of the most recent Commonwealth's Gross State Product (2015). Each community's numbers were then multiplied by water and wastewater importance factors. The wastewater importance factor was utilized for periods when no water was available since the ability to use sewers would be impacted. The water factor was utilized during the anticipated boil water periods.

The economic impact to residents was calculated utilizing FEMA's guidelines and includes the loss of welfare to residents and the cost of providing replacement water.

Based on these calculations, staff estimate business loses of approximately $200 million per day for a total water loss event and an additional approximately $100 million per day for residents. The economic loss for a boil order would be somewhat less.

More detailed information about the analysis and the impact by community can be found in Tab 2.

STRATEGIC GOALS FOR REDUNDANCY IMPROVEMENTS

Reliable delivery of water is critical to protecting public health, providing sanitation, fire protection and is necessary for a viable economy. MWRA and our predecessor agencies have long recognized the value of system redundancy as a means to both provide continued service during emergencies and to allow equipment and facilities to be taken off-line for planned maintenance or rehabilitation. The objective is to seamlessly transfer to a back-up system so that the end consumer does not notice the transition or at least avoid areas with loss of service or severe disruption.

The need for transmission system redundancy is driven by two compelling interests. First, MWRA must be able to swiftly respond to a disruption in service. Failure of the deep rock tunnels is unlikely; however, the more likely failure is of surface piping or surface connection valves. This scenario may require isolation of the entire tunnel system for repair or replacement of customized equipment and could take weeks or months to complete.

A second reason for redundancy is the need to inspect, maintain and rehabilitate surface piping, key valves and tunnels on a periodic basis. At this time, some of the metropolitan tunnels, surface piping, ancillary valves and equipment are over 60 years of age and there is currently no way to schedule inspection or maintenance work while providing an alternative means of water supply. Thus, a redundant means of providing service will allow scheduled system rehabilitation as needed and also reduce the risk associated with an emergency event disrupting service.

Redundancy is reflected in different ways in different circumstances but generally, it means eliminating or managing ‘single points of failure’ within a system. Depending on the configuration of a water system, different means of providing redundancy or creating operational flexibility allows the utility to respond to emergencies or unforeseen conditions. For example, for utilities like MWRA, where there is a single water source and treatment facility that feeds the metropolitan Boston area, redundant transmission mains are critically important.

<u>National Guidance, Peer Organizations, and Redundancy at MWRA</u>

At the national level, the Recommended Standards for Water Works (the “10 States Standards” which was the basis for development of the Massachusetts Department of Environmental Protection’s Guidelines for Public Water Systems) says that designs should *“…identify and evaluate single points of failure that could render a system unable to meet its design basis. Redundancy (geographically separated) and enhanced security features should be incorporated into the design to eliminate single points of failure when possible, or to protect them when they cannot be eliminated.*” The Environmental Protection Agency’s 2011 Guidance recommends “*Reduce outage risk through system redundancy/resiliency and repair capabilities…*”

Other major utilities across the United States have taken varied approaches to this guidance. One example is San Francisco where the focus has been on being able to maintain and/or quickly recover service in the event of an earthquake. This has meant the need to develop redundant tunnels in parts of their system. The project was part of the agency's $4.8 billion Water System Improvement Program and the three new tunnel projects allow the SFPUC to take either tunnel out of service for inspection or maintenance.

Seattle's approach to redundancy is to have two different supply and transmission systems which are on opposite sides of the City. Their looped transmission system allows two ways to convey water to all parts of the system.

New York City essentially operates three separate supply and aqueduct systems which gives the City great flexibility if one needs to be shut down for any reason. The construction of Water Tunnel No.3 is intended to provide the City with a critical third connection to its Upstate New York water supply system, allowing for the repair of tunnels No.1 and No.2 for the first time in their history. The first two phases of Tunnel No. 3 are now completed at a cost of over $4.7 billion. The tunnel will eventually measure more than 60 miles long, though completion of all phases is not expected until at least 2020.

Examples of redundancy principles are evident throughout the history of the metropolitan water system. In the late 1800s there were two basins at the Chestnut Hill Reservoir; one to settle water from the Cochituate Aqueduct and the other the Sudbury Aqueduct, but both somewhat interchangeable. At the outlet of the pump station at Chestnut Hill two (east and west) supply lines carried water to Spot Pond. There were initially two Weston Aqueduct supply lines for the Boston low service system; each taking a different route with redundancy being one of the benefits provided. The Cordaville pipeline was built in 1928 to bring water in from the south Sudbury (Ashland and Hopkinton) reservoirs while Quabbin reservoir was being planned and constructed.

More recent Transmission System improvements have built on projects constructed decades ago. The Hultman Aqueduct was completed in 1940 with plans and infrastructure left behind for a second barrel. This 1940 photo shows concrete placement for a future aqueduct connection at Shaft 4 of the Hultman Aqueduct. The onset of World War II prevented completion of the second pipeline. In 2003, MWRA completed the MetroWest Water Supply Tunnel Project which provides a second means of water conveyance from the John J. Carroll Water Treatment Plant to the Norumbega Covered Storage Facility and ultimately the City Tunnel and Metropolitan distribution system at Shaft 5. The Hultman Aqueduct was then rehabilitated after 70+ years of continuous service and interconnecting structures created to provide

Provisions were left for a future Hultman Connection at Shaft 4

the ability to isolate sections of either transmission main while continuing to provide water service to the Metropolitan area. With the rehabilitation and interconnection full redundancy from Marlborough to Weston was achieved in 2013.

The Chicopee Valley Aqueduct was built on one side of its easement to make room for a second future barrel. In 2007, MWRA completed construction the CVA Redundancy Project. With these new pipelines in place, the communities are connected to Quabbin Reservoir, Nash Hill Covered Storage or both in the event of a failure along the Aqueduct.

MWRA has begun construction on the Wachusett Aqueduct Pump Station which will provide redundancy to the Cosgrove Tunnel between the Wachusett Reservoir and the Carroll Water Treatment Plant.

The MWRA's metropolitan distribution system has many examples of redundant pipelines and multiple community connections. The practice of having parallel pump stations operating in each service area (e.g., Brattle Court constructed in 1907 and Spring Street constructed in 1958) allows facilities to be taken off line for maintenance and rehabilitation and also allows service to continue in the event of a more significant equipment failure. In 1994, a catastrophic pipeline failure shut down the Spring Street Pump Station and the system was able to shift to use of the Brattle Court Pump Station, avoiding major system disruptions to Arlington, Bedford, Belmont, Lexington, Waltham and Winchester. New projects, now underway, such as the Northern Intermediate High Redundant Pipeline project and the Southern Extra High Pipe Loop will provide redundant service to those pressure zones for the first time and will allow use of the whole system on a regular basis, allowing individual elements to be taken out of service for maintenance or in an emergency.

Previous Studies and Recommendations

The original plan for the metropolitan tunnel system, which was developed in 1936, included redundancy in the form of a tunnel loop to the north beginning in Weston and ending north of the Mystic River in Everett.

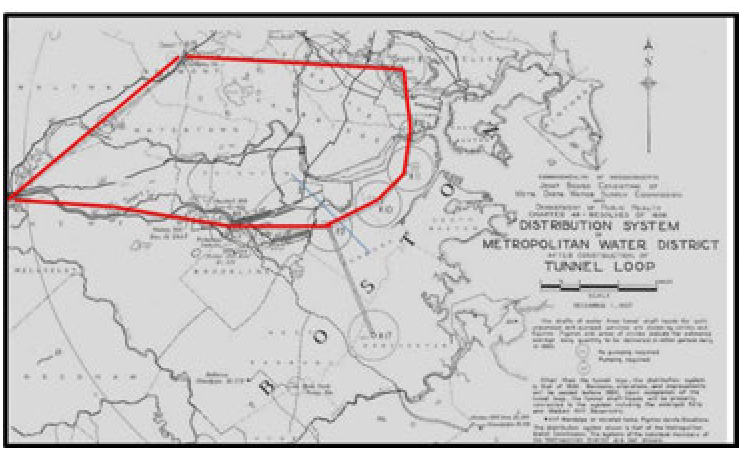


Figure 3 - Original 1936 Tunnel Loop Plan

In 1990, Staff presented a proposed redundancy program to the Board of Directors that included the proposed MetroWest Water Supply Tunnel from Shaft C in Marlborough to Weston and a proposed Northern Tunnel Loop from Weston to Shaft 9A in Malden. This plan was similar to the 1936 plan, but followed the actual alignment of the City Tunnel Extension, which ends at Shaft 9A in Malden. At the time, the Board approved the proposed MetroWest Tunnel, but deferred a decision on the proposed Northern Tunnel Loop.

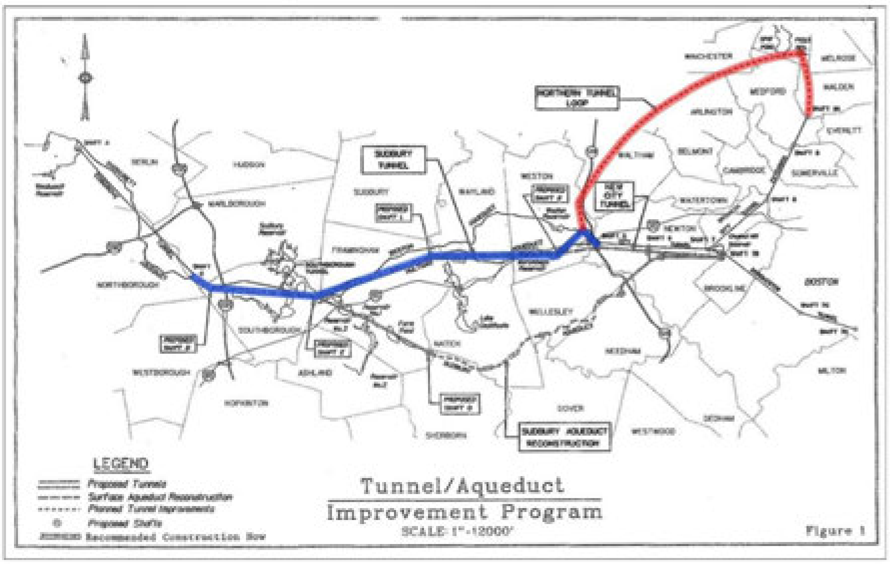


Figure 4 - 1990 Tunnel/Aqueduct Improvement Program

2011 Transmission Redundancy Plan

In September 2008, the Board approved a contract to develop a redundancy plan for the water system including the metropolitan area. The goal of the study was to develop redundancy alternatives while minimizing capital costs through integrating redundancy with MWRA's pipeline rehabilitation and asset protection program. Given MWRA's decreased demands and concern that any redundancy project be cost effective, the study was intended to review the full range of potential alternatives including a full tunnel alternative but also including an examination of existing and proposed CIP projects to determine if existing or potential surface pipelines could be optimized to provide transmission system redundancy. Fifteen alternatives were developed and evaluated. Eleven of the alternatives were designed to supply average day demands and four alternatives were designed to meet high day demands.

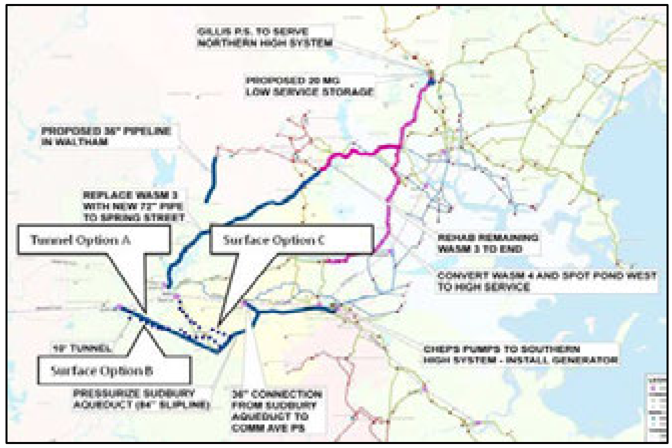


Figure 5 – 2011 Transmission Redundancy Plan

In June 2010, staff presented a proposed plan for redundancy for these facilities to the Board, which included increasing the size of approximately two thirds of the eleven mile Weston Aqueduct Supply Main 3 (WASM 3) pipeline with a new six-foot diameter water main, sliplining the Sudbury Aqueduct with a seven-foot diameter steel pipe and constructing a four mile tunnel from the MetroWest Tunnel/Hultman Aqueduct to the Sudbury Aqueduct (See Figure 2). WASM 3 is currently a 56-inch and 60-inch diameter steel pipeline that supplies the communities of Waltham, Watertown, Belmont, Arlington, Lexington, Bedford and Winchester. WASM 3 carries high service water from the 7-foot diameter branch of the Hultman Aqueduct to community connections and MWRA pumping stations serving the Intermediate High, the Northern High and the Northern Extra High pressure zones. It extends from the Hultman Branch in Weston to the Shaft 9 connection pipe in Medford and supplies approximately 250,000 customers over all. The proposed plan was designed to allow the existing tunnel system to be taken out of service to provide much needed maintenance and rehabilitation while continuing to provide uninterrupted water supply to the service area.

Challenges Implementing the 2011 Plan

On June 26, 2013 the Board approved the award of Contract 6539, Weston Aqueduct Supply Main 3: Design, Construction Administration and Resident Engineering Services. The scope of this contract includes engineering services for rehabilitation/replacement of the WASM 3 pipeline including the replacement of 7.3 miles of existing pipe through Weston, Waltham and Belmont with a new 72-inch diameter pipeline and rehabilitation of the remaining 2.7 miles of existing pipe through Arlington, Somerville and Medford. The design and construction services span a total duration of 13 years.

As work progressed with preparing for the Massachusetts Environmental Policy Act (MEPA) review, it became apparent that the disruption associated with increasing the pipe size to 72 inches created major questions of constructability. The area is densely developed with both residential and commercial districts and roads are very heavily trafficked, particularly at commuting times. To construct a larger diameter pipeline along this route would require extensive and long-term disruption including major, lengthy road closures and detours; and potentially significant losses to local businesses due to disrupted access. It was also apparent that many sections of the route would require micro-tunneling to avoid potential impacts.

Main Street (Route 20) Waltham

Waverly Oaks Rd / Pleasant St Belmont

Not only would replacement of WASM 3 be problematic; the southern projects proposed in the plan were also viewed as difficult to implement. Staff identified both surface piping and tunnel alternatives from Weston to the Sudbury Aqueduct and the surface routes were viewed as infeasible due to narrow roads and the lack of viable detour routes among other concerns. Sliplining of the Sudbury Aqueduct was also viewed as potentially infeasible. The Sudbury Aqueduct alignment sits immediately adjacent to houses along much of the alignment. Sliplining the Aqueduct for the four mile length between St. Mary's Pump Station in Needham to Chestnut Hill would require 50-foot long access pits every 1,000 feet. Use of the Sudbury Aqueduct was also considered as an initial alternative in the analyses of options to provide Hultman redundancy and the difficulties associated with work along the Sudbury Aqueduct alignment was a major factor in the selection of the MetroWest Tunnel alternative.

These impacts would most likely be impossible to mitigate to a level acceptable to local officials, business owners and residents in the affected communities. This would be a significant issue both during the MEPA review process and would also likely diminish MWRA's ability to obtain required permits including local street opening permits.

In addition to the community and permitting issues, further review also concluded that the reliance of the southern portion of the plan on the operation of the Chestnut Hill Emergency Pump Station was also of concern. Further modeling showed that the pump station could not supply sufficient water to the South in part due to the limited capacity of the surface mains, if the Dorchester Tunnel is not in service.

For these reasons, staff initiated a study of additional alternatives with fewer construction impacts, including a range of deep rock alternatives. A summary of these alternatives, along with the original alternatives evaluated, follows.

However, it is important to note that under all alternatives, WASM 3 must be rehabilitated. WASM 3 remains a critical single point of failure within the MWRA system and must be repaired. The pipe was built in the 1920s and has an extensive history of leak repair with 72 leaks reported since 1987. Rehabilitation, although difficult, results in much less impact to the communities than would replacement with a larger diameter pipe. Access pits could be constructed at 500-foot intervals and the major utility relocation and long duration street closures would not be required. Under all of the alternatives discussed below, WASM 3 is assumed to be rehabilitated as a baseline project.

EVALUATION OF ALTERNATIVES

A large number of alternatives were developed and evaluated for meeting the redundancy needs of the City Tunnel, City Tunnel Extension and Dorchester Tunnel. While organizing these alternatives for presentation it was determined that there are in fact two separate problems that staff are attempting to solve in the event of a disruption in service: providing supply to the Northern High Service Area; and providing supply to the Southern High and Southern Extra High Service Areas. This presentation groups together alternatives by commonalities or families of alternatives: three for the north and three for the south, and provides a high level summary of the evaluations. Maps of each alternative are located in Tab 4.

Northern System Alternatives

In the north, the solutions can be grouped into the following families: 1. Pushing the existing system to the limits of its capacity; 2. Increasing the capacity of the 60-inch WASM 3 pipeline; and 3. Increasing capacity through construction of a new tunnel.

1. Pushing the System to Its Limit: The first category consists of one alternative that would utilize capacity from adjacent service areas to get enough Low Service and High Service water up to Gillis Pump Station to avoid the need to pump directly out of Spot Pond. It combines all four WASM mains to serve the Boston Low, Northern Low and Northern High winter/average day demands by increasing the pressure in the Low Service System to push water to the north. It would require rehabilitation of WASM 3 and addition of new, higher capacity pressure reducing valves to feed the low system. The West Spot Pond Supply Line would need to be evaluated to determine if it is capable of being operated at higher pressure and may require replacement. The estimated cost of this alternative (beyond the baseline costs) is $10 million (if pipeline replacement is not required). However, this alternative does not provide any additional system capacity to the north, nor does it resolve the need for redundancy for WASM 3. In fact, it relies on all of the major northern distribution pipelines being in service in order to work; there are a number of single points of failure in this idea.

   When modeled on the MWRA water system hydraulic model, this alternative only barely works. Given the degree of accuracy of the model and the fact that the system is pushed beyond the model's calibration staff would not be comfortable utilizing this concept for anything beyond an emergency response when no other option exists. This alternative, therefore, would not allow for isolation of parts of the tunnel system for maintenance and rehabilitation. As such, it was determined to be not feasible as a long term solution. Since it could be used for contingency planning in the near term (the next 15-20 years) the requirements of this alternative are included in staff's interim improvement recommendations.

2. Increase the Capacity of WASM 3: The second category of northern alternatives would increase the capacity of the WASM 3 pipeline through: increase in size of the existing pipeline; addition of an on-line pump station; construction of an alternate parallel large diameter pipeline; or a combination of these three elements. There were six alternatives in this category with midpoint of construction costs ranging from $138 million to $473 million.

   Staff do not recommend this family of alternatives. One of the major concerns is that of installing miles of large diameter pipelines in dense urban areas as previously discussed. Another major concern is the idea of adding an in-line pump station to overcome the lack of capacity in the WASM 3 line. This creates the same kinds of problems for the system that was presented to the Board of Directors in September 2016 with the Chestnut Hill Emergency Pump Station pumping through the surface mains to the south (see Tab 1). High pipeline head losses, pressure swings and surges increase the risk of pipeline failures. Staff believe that local opposition to these alternatives due to significant community impacts, extensive utility relocation, and miles of street closures and disruptions makes these surface piping alternatives infeasible, and therefore do not recommend them.

3. New Tunnel: The third category of northern alternatives would increase capacity through construction of a new deep rock tunnel. There were six alternatives in this category with midpoint of construction costs ranging from $472 million to $1,292 million. Construction impacts would be limited to the shaft construction and pipeline connection sites. A tunnel could provide needed redundancy for the WASM 3 pipeline and would have adequate capacity to meet high day demand allowing for year round maintenance of the metropolitan tunnel system (in combination with a southern solution). Staff recommend this family of alternatives. A tunnel would provide the most reliable and seamless operation and would result in less community impact than other alternatives.

Southern System Alternatives

In the south, the solutions can be grouped into the following families or groups: 1. Large diameter surface pipe or new tunnel to the Sudbury Aqueduct in Newton or Needham and slip-lining of the Sudbury Aqueduct or a new tunnel to Chestnut Hill Emergency Pump Station (CHEPS); 2. Providing a new pipeline to Shaft 7C or to a new pump station south of Chestnut Hill; and 3. Increasing capacity through construction of a new tunnel to Shaft 7C.

1. Slip-lining Sudbury Aqueduct and New Connection: The first category would bring supply to the existing Chestnut Hill Emergency Pump Station through a combination of slip-lining the Sudbury Aqueduct, construction of new large diameter surface pipeline, and/or new tunnel between the Shaft 5 / Norumbega tank area and the Sudbury Aqueduct in Needham or Newton, or a new tunnel all the way to Chestnut Hill. There were ten alternatives in this category with midpoint of construction costs ranging from $293 million to $629 million.

   One of the major concerns with this group of alternatives was the reliance on the

Chestnut Hill Emergency Pump Station (CHEPS) to overcome the capacity deficiencies of the southern surface mains as presented at the September 2016 Board of Director's meeting. A copy of that staff summary is included in Tab 1 of the attachments to the meeting documents. Discharge pressures from the CHEPS would exceed normal pressures in MWRA and community water pipelines increasing risk of pipeline failures. With CHEPS pumps shut down grade lines would be inadequate at high points in the system close to the station. Additional operational concerns with coordinating pump operation with downstream pump stations and lack of emergency power are being looked at and will be part of staff's interim improvement recommendations. Lack of available space at CHEPS to make necessary improvements needed to improve reliability of operation when the Dorchester Tunnel is out of service is also a significant problem.

Slip-lining the Sudbury Aqueduct and/or construction of miles of new large diameter pipelines have the same constructability concerns previously discussed for the WASM 3 pipeline that would result in significant community impacts. The MetroWest Tunnel, originally the Sudbury Aqueduct rehabilitation project, was changed to a tunnel project in part due to these same difficulties and impacts.

Due to the significant construction impacts of new large surface mains and slip-lining of the Sudbury Aqueduct, the potential unreliability of the CHEPS with the Dorchester Tunnel out of service, the potential to cause damage to surface piping when operating the CHEPS, staff do not recommend this family of alternatives.

2. <u>New pipeline to Shaft 7C</u>: The second category of southern alternatives would eliminate the capacity deficiencies of the southern surface mains by providing additional large diameter pipeline capacity closer to Southern System demand or to a new pump station south of Chestnut Hill. There were two alternatives in the category with midpoint of construction costs ranging from $363 million to $390 million.

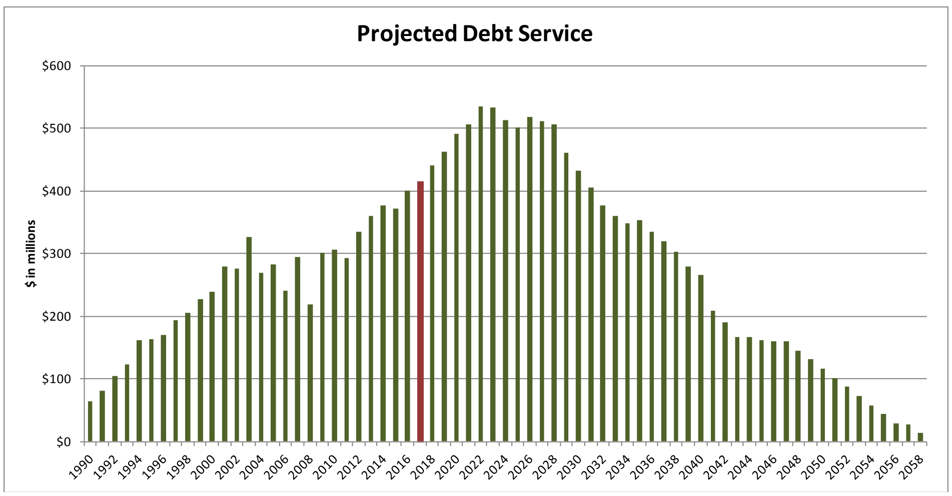
   Staff do not recommend this family of alternatives due to the inability to construct 8 to 10 miles of large diameter surface pipeline in dense urban areas (Needham, Wellesley, Newton, Brookline and Boston) as previously discussed, as well as concerns about the impact of pumping related to surges on the surface pipelines.

3. <u>New Tunnel</u>: The third category of the southern alternatives would increase capacity through construction of a new deep-rock tunnel. There were three alternatives of various tunnel lengths in this category with midpoint of construction costs ranging from $716 million to $1,034 million. Construction impacts would be limited to the shaft construction and pipeline connection sites. A tunnel would eliminate the need to pump from the Chestnut Hill Emergency Pump Station under Metropolitan Tunnel failure scenarios. In addition, it would have adequate capacity to meet high day demand allowing for year round maintenance of the metropolitan tunnel system (in combination with a northern solution).

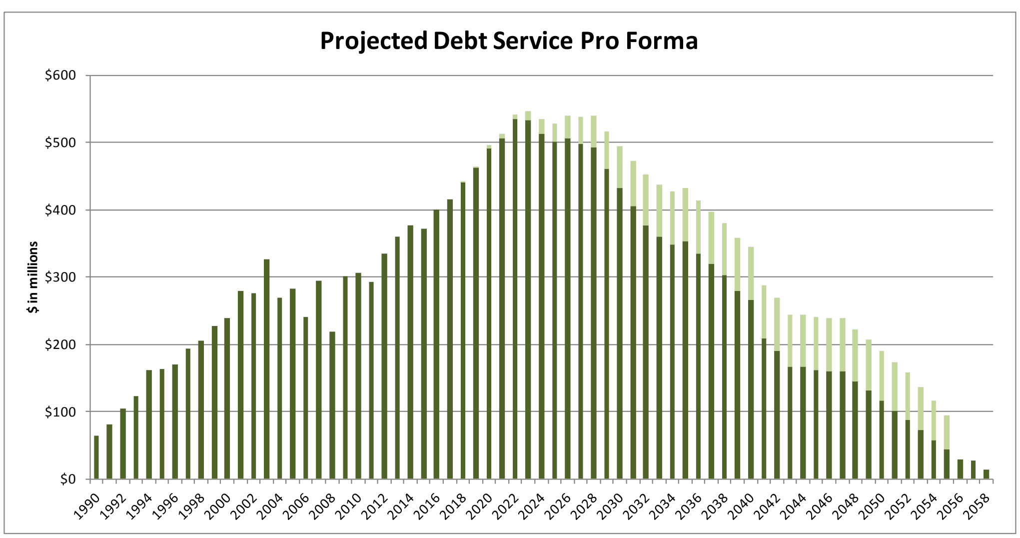
   Staff recommend this family of alternatives. A tunnel would provide the most reliable and seamless operation and would result in less community impact than other alternatives.

FINANCIAL CONSIDERATIONS

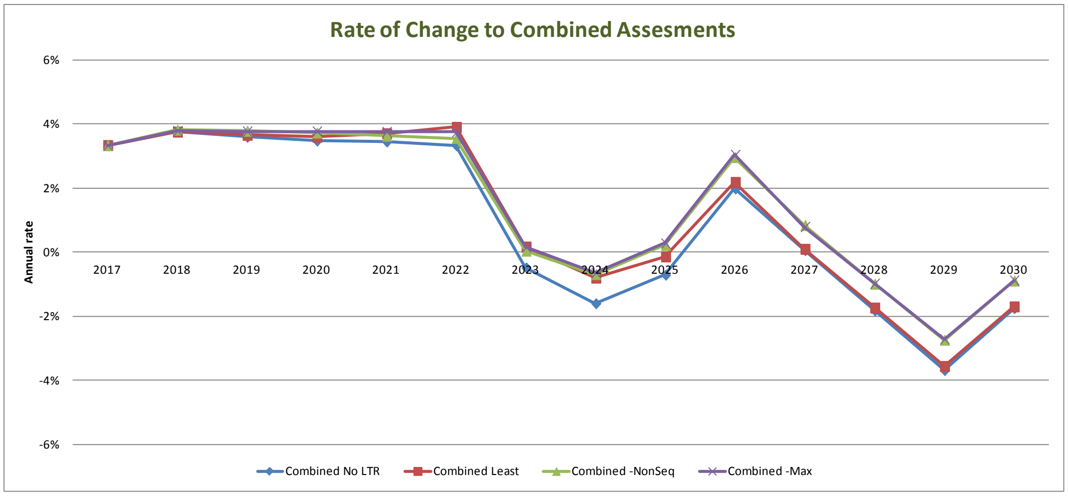
Consistent with MWRA's multi-year rates management strategy to provide sustainable and predictable assessments to our communities, staff evaluated the impact of a variety of options for the redundancy project on the Capital Improvement Program (CIP) and the debt service on the Current Expense Budget (CEB). Since 1985 MWRA has spent approximately $8.1 billion to upgrade the wastewater and waterworks systems. The majority of these improvements were funded through the issuance of tax-exempt bonds. As depicted in the graph below MWRA is projected to reach the peak of its debt service payments in fiscal 2022.



In the case of all the options, most of the new debt service will occur after MWRA's projected peak debt service year. The following graph shows a representation of where the debt service associated with the long-term redundancy would occur based on current project cost estimates.

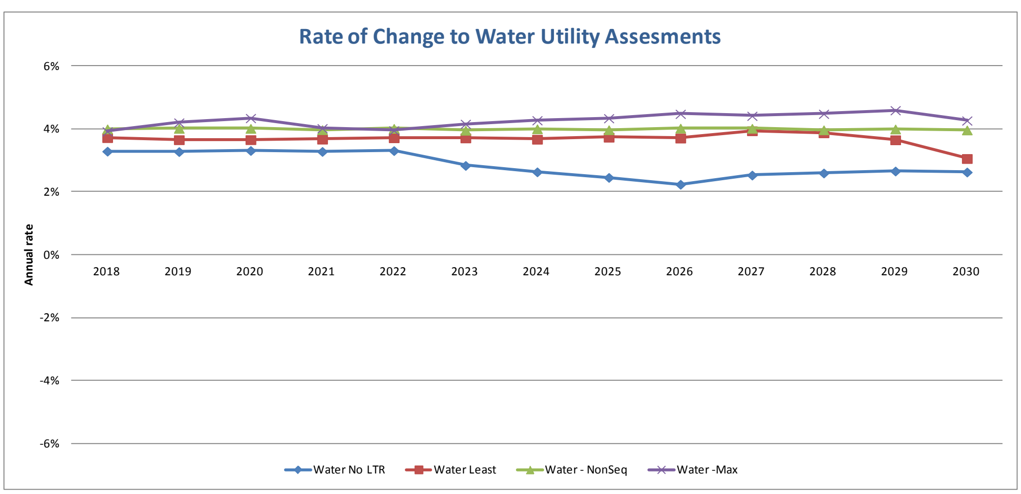


To facilitate discussion staff evaluated the impact of four different redundancy options to provide an estimated range of assessment impacts. The four options are: no long-term redundancy, a least expensive option, a midrange option, and the most expensive option. The total rate revenue requirement represents all planned CIP projects and the impact of all the options. The following graph shows the impact of the various construction options on the combined rate revenue requirement.



Depending on the option selected the combined assessment increases would range from an average of 0.7% with the lowest cost option to 1.4% with the most costly; the maximum annual increase for any option is 3.9% in 2022.

The negative combined rate changes are primarily driven by reductions to the sewer utility's debt service payments in years 2023-2024 and 2028-2030. The next graph details the impact on just the water utility assessments based on the various proposed options.



Based on current projections the average water assessment increases would range from an average of 2.9% with the lowest cost option to 4.3% with the most costly; the maximum annual increase for any option is 4.6% in 2029.

The average increase solely related to the redundancy project ranges from 0.27% to 0.64% on a combined basis and 0.83% to 1.41% on the water utility alone. More detailed information on the assessment impact of the various options is included in Tab 5.

STAFF PREFERRED ALTERNATIVE

Interim Improvements

Environmental review, design and construction of any long term redundancy alternative will take many years (potentially 15 to 20 years). Staff, therefore, recommend that interim system improvements be made to marginally reduce the risk of tunnel system failure (as previously described) and to improve system operating conditions in the event that an emergency occurs. These interim improvements include:

- Tunnel/shaft pipe and valve improvements should be made where feasible; e.g., metal thickness evaluation, replacement of corroded bolts and fasteners, coatings and or structural pipe wrapping, cathodic protection, improvement of access, and installation of new isolation valves and replacement of air valves;

- Emergency back-up power at the Chestnut Hill Pump Station should be installed and an evaluation of any improvements that could be made to minimize operational impacts such as installation of VFD drives and other modifications to the Chestnut Hill Pump Station previously described;

- Rehabilitation of the WASM 3 pipeline should proceed to improve operation in an emergency and reduce the risk of failure;

- The Commonwealth Avenue Pump Station, which gets supply directly from the City Tunnel at Shaft 6, should be modified to allow pumping directly from the Low Service Supply lines that run in the street in front of the station to provide redundancy for the City of Newton.

- Evaluation and potential installation should be undertaken of new pressure reducing valves on WASM 3 and 4 and the West Spot Pond Line capable of supplying flow adequate to serve the Boston Low, Northern Low and Northern High Service Areas and evaluate the ability to operate the West Spot Pond Supply Line at higher pressure to allow pushing the system in a manner that limits the use of the open Spot Pond Emergency Reservoir in an emergency (would require a boil order).

As these interim measures are undertaken, environmental review could begin on a preferred long-term redundancy alternative.

Long Term Preferred Alternative

Given the difficulties associated with the construction feasibility and significant community impacts associated with large diameter surface pipe as described, together with operational reliability concerns, staff preferred the all-tunnel redundancy alternative. The preferred alternative, subject to more detailed review during the public review period, is shown in the Figure 6 below.

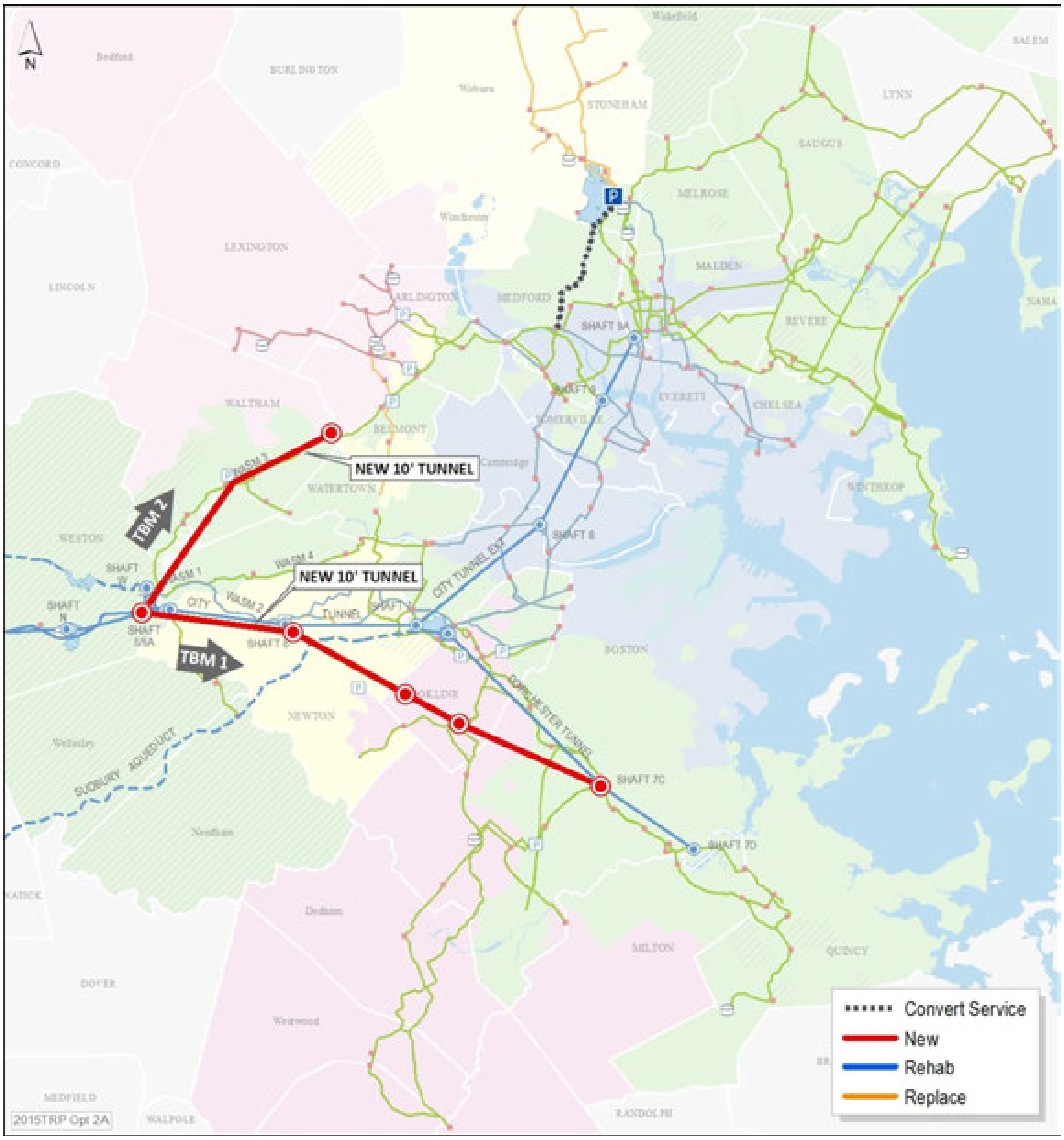


Figure 6 - Staff Preferred Tunnel Alternative

This alternative consists of two deep rock tunnels beginning at the same location in Weston near the Massachusetts Turnpike/Route 128 interchange. The Northern Tunnel generally follows the route of MWRA's existing WASM 3 transmission line to a point about midway along the pipeline near the Waltham/Belmont border allowing flow in WASM 3 in both directions. The length of the Northern Tunnel would be approximately 4.5 miles and the tunnel would have a finished inside diameter of approximately 10 feet. It would include one connection shaft to provide a redundant supply to MWRA's Lexington Street Pump Station and to allow isolation of the WASM 3 line in segments. The Northern Tunnel has an estimated midpoint of construction cost of $472 million.

The Southern Tunnel would run east to provide a shaft connection to MWRA's Commonwealth Avenue Pump Station and would then run southeast to tie into the surface connections at Shaft 7C about midway down the southern surface mains allowing flow in both directions. The length of the Southern Tunnel would be approximately 9.5 miles and would have a finished inside diameter of 10 feet. The estimated midpoint of construction cost of the Southern Tunnel is approximately $1,003 million.

This alternative limits community disruptions and construction impacts to the locations of the tunnel construction and connection shaft sites. Large diameter surface piping, over seven miles in length in the north through congested urban communities, contains a high risk of significant delays, expensive utility relocation and the inability of obtaining necessary local approvals. The all tunnel alternative meets the strategic objective of a seamless transition to a back up supply, allowing maintenance to be scheduled for the Metropolitan Tunnels, without use of a boil order, without impacting the ability to provide for local fire protection, and without noticeable changes in customers' water quality, flow or pressure. It has the ability to meet high demand conditions which extends the time frame for maintenance and rehabilitation activities.

To the north, the all tunnel alternative provides redundancy for the critical WASM 3 pipeline. To the south, it eliminates the need for the Chestnut Hill Emergency Pump Station in Metropolitan Tunnel shut down scenarios, thereby reducing operational risks associated with use of the Emergency Pump Station. The estimated total midpoint of construction cost for both the recommended north and south alternatives is $1,475 million with an estimated time to completion of 17 years. This estimate includes 30% contingency and 4% annual construction cost escalation.

Phased Approach

Construction of either the Northern Tunnel or the Southern Tunnel by itself would provide benefit to the system. The Northern Tunnel by itself provides redundancy for the City Tunnel Extension and the Southern Tunnel provides redundancy for the Dorchester Tunnel. In addition, the Northern Tunnel, if completed, could allow isolation of the City Tunnel in an emergency under certain circumstances (e.g., Shaft 7 valves available and winter/average demand). In that case, the Southern System could be supplied back through the City Tunnel Extension to the Dorchester Tunnel, while being supplemented by the Chestnut Hill Emergency Pump Station pumping treated water from the Boston Low. If phasing of the two tunnels was selected, staff would recommend the Northern Tunnel be started first and/or completed first. This is due to the relative age of the City Tunnel Extension with its cast iron surface pipes (harder to repair and more vulnerable to failure) over the Dorchester Tunnel and its steel surface pipes, and the locations of special concern at Shafts 5, 9 and 9A that could be more readily addressed with the

Northern Tunnel construction. Rehabilitation of Shaft 7 and valves and piping along the Dorchester Tunnel would be delayed until the southern tunnel was completed.

Rate Impact of Preferred Alternative

The average annual increase on the combined assessment of the preferred alternative is 1.3% with a highest single increase of 3.8%. Given the longer duration of the phased construction option, the annual required borrowings would be lower than the un-phased option. This would result in lower debt service costs which would result in smaller changes to the annual combined assessment. The average annual increase on the combined assessment for the phased alternative is 1.1% with a highest single increase of 3.8%.

The average annual increase on the water assessment of the preferred alternative is 4.0% with a highest single increase of 4.0%. The average annual increase on the water assessment for the phased alternative is 3.6% with a highest single increase of 3.7%.

The rate impacts of the preferred option on both the combined and water assessments are within the MWRA's long-term rates management strategy. The preferred option is both consistent with the Authority's core mission of providing reliable, cost-effective and high quality water, and its goal of providing sustainable and predictable assessments.

Board of Director's Briefings Regarding Redundancy Projects

Board of Director's Briefings Regarding Redundancy Projects

November 28, 1990	Board approval to proceed with design of the MetroWest Water Supply Tunnel. Staff recommended that a future tunnel extend north from Weston to Shaft 9A.
September 13, 1995	Informational briefing at a special Board meeting regarding the planning and interrelationships of the proposed MetroWest Water Supply Tunnel, Norumbega and other covered storage projects, and the Carroll Water Treatment Plant
September 20, 1995	Board approval to award the Spot Pond Pipeline (Section 99) construction contract to provide a redundant supply to the Gillis pump station.
May 22, 1996 August 7, 1997 October 21, 1998	Board approval to award the MetroWest Water Supply Tunnel construction contracts
August 7, 1997	Board approval to award the Loring Road Covered Storage construction contract
February 11, 1998	Board approval to award the Nash Hill Covered Storage construction contract
February 10, 1999	Board approval to award the Chestnut Hill Replacement Pumping Station to provide redundancy to the Southern High and Southern Extra High service areas
September 29, 1999	Board approval to award the Norumbega Covered Storage design build contract
October 12, 2005	Board approval to award the Chicopee Valley Aqueduct Redundancy construction contract
November 15, 2006	Board approval to award the Blue Hills Covered Storage design build contract
January 10, 2007	Informational staff summary on construction progress of the Chicopee Valley Aqueduct Redundancy construction project
June 27, 2007	Informational staff summary on the benefits and proposed schedule for the Hultman Aqueduct Rehabilitation and Interconnections to the MetroWest Tunnel project.

December 12, 2007	Informational Staff Summary describing the level of redundancy throughout the water transmission and distribution systems and the status of ongoing or proposed projects and studies.
March 12, 2008	Board approval to award the University Ave Water Main construction contract to provide a pipeline loop supplying Norwood
September 17, 2008	Board approval to award a contract (Transmission Redundancy Plan) to evaluate alternatives and develop conceptual design for redundancy for the metropolitan tunnel system and the Cosgrove Tunnel.
July 15, 2009	Board approval to award the Hultman Aqueduct Rehabilitation and Interconnections construction contract (CP-6A)
December 16, 2009	Board approval to award the Southern Spine Distribution Mains Section 107 construction contract to provide a redundant supply to Milton and Quincy
May 6, 2010	White paper on Water System Redundancy Planning and Construction. The white paper described completed, ongoing and planned redundancy projects throughout the water system. The white paper identified the need for redundancy for the metropolitan water system and noted that the findings of the Transmission Redundancy Plan would be presented soon.
June 30, 2010	Informational Staff Summary presenting the findings and recommendations of the Transmission Redundancy Plan. The recommended alternative included the construction of seven miles of large diameter surface pipes, Slip lining the Sudbury Aqueduct with a seven foot diameter pipe, rehabilitation of the Chestnut Hill Emergency Pump Station and a four mile tunnel from Norumbega Reservoir to the Sudbury Aqueduct.
December 22, 2010	Board approval to award the Lynnfield/Saugus Pipeline construction contract to provide redundancy to the Lynnfield Water District.
October 12, 2011	Board approval to award the Spot Pond Water Storage Facility and Pump Station design build contract
January 18, 2012	Informational staff summary on construction progress of the Hultman Aqueduct Rehabilitation and Interconnections to the MetroWest Water supply Tunnel

March 14, 2012	Board approval to award the Hultman Aqueduct Interconnections construction contract (CP-6B)
May 15, 2013	Informational Staff Summary on the completion of the Hultman Aqueduct Rehabilitation and Interconnections with the MetroWest Water Supply Tunnel. For the first time since the Hultman Aqueduct was planned in the 1930s, the transmission system has full redundancy from Marlborough to Weston.
June 25, 2014	Update to the Water Policy and Oversight Committee on Metropolitan Tunnel Redundancy highlighting possible tunnel alternatives.
November 18, 2015	Board approval to award the Wachusett Aqueduct Pump Station construction contract to provide redundancy to the Cosgrove Aqueduct.
February 10, 2016	Informational staff summary addressing the need for Metropolitan Tunnel redundancy. Information on the condition of the existing condition is included as are potential failure scenarios and system restoration information. A White Paper on Water System Redundancy with information on peer utilities and policy guidance is attached.
July 13, 2016	Informational staff summary providing a project update on Weston Aqueduct Supply Main 3 (WASM 3). The condition of the existing WASM 3 line is discussed as is the feasibility of constructing a replacement 72-inch diameter pipe along a significant part of the current WASM 3 alignment as part of the Metropolitan Tunnel system redundancy plan.
September 14, 2016	Informational staff summary addresses use of the underground Chestnut Hill Emergency Pump Station for emergency supply to the Southern High and Southern Extra High service areas. Recent Metropolitan Tunnel redundancy analysis identified capacity and pressure concerns in the surface piping that could affect operation in the event that the Dorchester Tunnel is not in service.

WA.1 +
IV.A.3
11/28/90

STAFF SUMMARY

TO: Board of Directors

FROM: Paul F. Levy, Executive Director

DATE: November 28, 1990

SUBJECT: Sudbury Aqueduct Reconstruction and Connecting Tunnels Project

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PURPOSE: ____ INFORMATION
_X_ VOTE

BOARD COMMITTEE COORDINATION
____ ADMINISTRATION & FINANCE
____ WASTEWATER POLICY & OVER.
_X_ WATER POLICY & OVERSIGHT
____ PERSONNEL
____ OTHER: ____________

James Powers, Section Manager
Preparer/Title (Type)

William A. Brutsch
Div/Unit Director Approval (Sign)

William A. Brutsch, Director, Waterworks Div.

Div/Unit Director (Type)

Paul F. Levy
Executive Director Approval (Sign)

RECOMMENDATION:

That the Board:

a) approve the selection of the deep-rock tunnel alternative for the Sudbury Aqueduct and connecting tunnels project, and

b) as part of this deep-rock tunnel alternative, approve a tunnel diameter of 14 feet from Shaft C to Norumbega Reservoir and approve a change in the tunnel route from the current alignment of Norumbega Reservoir to Chestnut Hill Reservoir to an improved alignment starting at Norumbega Reservoir and extending to Fells Reservoir/Shaft 9A, and

c) authorize staff to negotiate an amendment with Sverdrup, the Sudbury project's design engineers, to include the design and construction of the first phase of the improved tunnel route from Norumbega Reservoir to the Weston Aqueduct and to delete the design and construction phases of the tunnel from Norumbega Reservoir to Chestnut Hill, and

d) authorize staff to initiate a new procurement for the EIR of the improved tunnel route from the Weston Aqueduct to Fells Reservoir/Shaft 9A, and to include in a future CIP the design and construction of the improved tunnel route from the Weston Aqueduct to Fells Reservoir/Shaft 9A.

DISCUSSION/ALTERNATIVES:

Background

The Master Plan Study for the aqueduct/tunnel system examined ten different concepts for providing redundancy to the system. It narrowed the list of alternatives down to two:

1. Reconstruction of our existing Gravity Aqueducts.
2. Construction of an All-Tunnel System.

The most critical need for system redundancy is between Shaft C in Marlborough and the Chestnut Hill area, see fold-out map - Figure 1. The reconstruction of the Sudbury Aqueduct and the connecting tunnels was selected as the primary alternative to resolve this problem because it would provide redundancy between these locations at what was believed to be the lowest cost.

On May 9, 1990, staff informed the Board that a tunnel from Shaft C to Chestnut Hill with the same hydraulic capacity as the reconstructed Sudbury Aqueduct, could be built for about the same price, and with far less environmental impact. Staff recommended that additional investigations into a tunnel alternative be conducted to confirm this. The Board agreed and voted for staff to put a minimum of effort into further study of the Sudbury Aqueduct and instead to concentrate on a study of the tunnel alternative and then to report back to the Board with a recommendation.

This staff summary presents the progress of the Sudbury Aqueduct and Connecting Tunnels project and staff's recommendation for the future course of action.

Progress Report

Since May 1990 we have informed the public of the change in project emphasis, developed back-up data necessary to verify the preliminary cost estimate for the tunnel alternative, and we have evaluated other opportunities which arise once the decision is made to construct a deep rock tunnel instead of rehabilitating the Sudbury Aqueduct.

The advantages of tunnel construction over aqueduct rehabilitation are detailed in Appendix A. In summary, the reconstruction of the Sudbury Aqueduct would result in extensive surface disruptions through wetlands and population centers while the tunnel construction would occur at hundreds of feet below the surface. Moreover, the reliability of a deep rock tunnel is far superior to that of a surface pipeline. Above all, the cost of this superior alternative is competitive. The estimated construction cost of rehabilitating the Sudbury Aqueduct is approximately $270 million while the cost of the tunnel is $295 million. Furthermore, we anticipate that continued development along the surface route, and potentially tighter regulations on surface construction activities are likely to escalate future costs of surface construction while continued advancements in tunnelling technology may further reduce tunnelling costs in the future.

Opportunities arising from the all-tunnel option:

Given that construction of a tunnel is better than rehabilitation of the aqueduct, the remaining issue to be determined is what size of tunnel to build, how to phase it with other redundancy improvements, and where best to locate the tunnel.

The MWRA does have an opportunity to resolve a number of problems by the timely and appropriate construction of tunnel sections. If these are correctly phased and sized there will be an overall reduction in cost to the Authority. The opportunities arise as follows:

1. The MWRA Master Plan for redundancy calls for the pressurization of the Weston Aqueduct after the reconstruction of the Sudbury Aqueduct. However, because of the Safe Drinking Water Act regulations for covered distribution storage, we expect that we will be required to pressurize the Weston Aqueduct sooner to eliminate use of the uncovered Weston Reservoir. Pressurization of the Weston Aqueduct can be avoided if the new Sudbury Tunnel is constructed as a 14-foot diameter tunnel instead of a 10-foot-diameter tunnel (a 10-foot diameter tunnel is the comparable alternative to rehabilitating the Sudbury Aqueduct). A 14-foot-diameter tunnel does not cost much more than a 10-foot-diameter tunnel but it can convey more then twice as much water. A 14-foot-diameter tunnel could carry sufficient water to permit the Weston Aqueduct to be retired to an emergency reserve status.

2. The MWRA Master Plan for redundancy also calls for the eventual construction of a tunnel from Norumbega Reservoir to Fells Reservoir/Shaft 9A, the Northern Tunnel Loop. This tunnel, when fully completed, will provide redundancy for the City Tunnel and the City Tunnel Extension and will simplify planning of future distribution system improvements. If the Northern Tunnel Loop is properly phased and started now instead of later, it becomes less critical to construct an interim tunnel from Norumbega Reservoir to Chestnut Hill, the New City Tunnel. If construction of the entire Northern Tunnel Loop is delayed, the Authority would need to strongly consider building both the New City Tunnel now and the Northern Tunnel Loop later. In the long term, the New City Tunnel would become superfluous. In the short term, lack of redundancy for the City Tunnel, other than the existing Sudbury Aqueduct, would require that the Authority bear a certain level of risk.

3. Selection of a tunnel parallel to the Hultman Aqueduct, will result in a savings of $5 million on construction of the planned pipeline improvements in Framingham.

Discussion of Alternatives

Figure 1 shows the major elements of the alternative projects. Construction costs are shown on Table 1.

TABL. ISON OF PROJECT COSTS

PROJECT SEGMENTS	SUDBURY AQUEDUCT ALTERNATIVE (ORIGINAL PROJECT)	ALL-TUNNEL ALTERNATIVE	AMENDED ALL-TUNNEL ALTERNATIVE	RECOMMENDED PROJECT	COMMENTS
SHAFT C TO SHAFT 4	$80 MILLION (14 FOOT DIAMETER TUNNEL)	$80 MILLION (14 FOOT DIAMETER TUNNEL)	$80 MILLION (14 FOOT DIAMETER TUNNEL)	$80 MILLION (14 FOOT DIAMETER TUNNEL)	THIS SEGMENT IS IDENTICAL FOR ALL ALTERNATIVES
SHAFT 4 TO NORUMBEGA RESERVOIR (SEE NOTE BELOW)	$115 MILLION (10 FOOT DIAMETER RECONSTRUCTED SUDBURY AQUEDUCT AND TUNNEL)	$135 MILLION (10 FOOT DIAMETER TUNNEL)	$150 MILLION (14 FOOT DIAMETER TUNNEL)	$150 MILLION (14 FOOT DIAMETER TUNNEL)	TUNNELS HAVE LONGER LIFE AND ARE LESS SUSCEPTIBLE TO BREAKS. A 14-FOOT TUNNEL CARRIES MORE THAN DOUBLE THE WATER OF A 10-FOOT TUNNEL.
NORUMBEGA RESERVOIR TO CHESTNUT HILL	$75 MILLION (10 FOOT DIAMETER TUNNEL)	$80 MILLION (10 FOOT DIAMETER TUNNEL)	$85 MILLION (12 FOOT DIAMETER TUNNEL)	$0 NOT REQUIRED	THIS SEGMENT IS NOT REQUIRED FOR THE RECOMMENDED PROJECT BUT MUST BE BUILT IMMEDIATLY FOR THE AMENDED ALL-TUNNEL ALTERNATIVE.
WESTON AQUEDUCT (SHAFT 4 TO WESTON RESERVOIR)	$90 MILLION (11 FOOT DIAMETER RECONSTRUCTION OR TUNNEL)	$90 MILLION (11 FOOT DIAMETER RECONSTRUCTION OR TUNNEL)	$0 NOT REQUIRED	$0 NOT REQUIRED	STAFF ANTICIPATES THIS WILL BE REQUIRED BEFORE THE YEAR 2000 BASED ON SDWA REGULATIONS.
NORUMBEGA RESERVOIR TO FELLS RESERVOIR/ SHAFT 9A	$235 MILLION (12 FOOT DIAMETER TUNNEL)	$230 MILLION (12 FOOT DIAMETER TUNNEL)	$218 MILLION (10 FOOT DIAMETER TUNNEL)	$238 MILLION (12 FOOT DIAMETER TUNNEL)	STAFF RECOMMENDS ACCELERATING THE CONSTRUCTION SCHEDULE OF THIS SEGMENT TO MAXIMIZE SAVINGS.
TOTAL PROJECT COSTS	$595 MILLION	$615 MILLION	$533 MILLION	$468 MILLION	POTENTIAL SAVINGS FROM PLANNED DISTRIBUTION SYSTEM IMPROVEMENTS ARE NOT INCLUDED IN THE TOTAL PROJECT COSTS.

Note: THE JUNCTION POINT FOR THE SUDBURY AQUEDUCT IS THE PROPOSED SHAFT IN NEEDHAM JUST WEST OF ROUTE 128.

The following discussion briefly summarizes the principal alternatives in light of the opportunities detailed above. More detailed discussion of each alternative is presented in Appendix A. We have included discussion of rehabilitation of the Sudbury Aqueduct solely for the purpose of comparing costs when all opportunities are viewed together.

Alternative 1 Sudbury Aqueduct Rehabilitation. The rehabilitation of the Sudbury Aqueduct and the construction of connecting tunnels would cost $270 million; but we would also need on the order of an extra $90 million to pressurize the Weston Aqueduct within ten years, and ten years later we would need another $235 million to construct the Northern Tunnel Loop. The total cost of all elements in Alternate 1 would be $595 million. (See Table 1)

Alternative 2 All-tunnel to Chestnut Hill. If we construct a 10-foot diameter tunnel to Chestnut Hill, the basic project would cost $295 million; it would be a superior engineering alternative with greater reliability and a much longer life than the rehabilitated surface aqueduct in Alternate 1, but it would not eliminate the need to pressurize the Weston Aqueduct or to construct the Northern Tunnel Loop at a later time. The total cost would be $615 million. (See Table 1)

Alternative 3 Amended all-tunnel to Chestnut Hill. If we construct a 14-foot diameter Sudbury Tunnel from Shaft C to Norumbega, and a 12-foot-diameter New City Tunnel from Norumbega to Chestnut Hill, we would have all the advantages of the tunnel alternative plus we would avoid the necessity of pressurizing the Weston Aqueduct. The disadvantages of this alternative are that the Northern Tunnel Loop would still be needed at a later date and that in the long term, the New City Tunnel would become superfluous. The total costs would be $533 million. (See Table 1)

Alternative 4 Recommended Project. The recommended project is a 14-foot diameter Sudbury Tunnel from Shaft C to Norumbega Reservoir, and a 12-foot diameter Northern Tunnel Loop to the Fells Reservoir and Shaft 9A. The Northern Tunnel Loop would be completed in two stages to achieve the optimum trade off between affordability and risk. The recommended project will eliminate the costs of pressurizing the Weston Aqueduct, as well as the costs required to construct a New City Tunnel from Norumbega Reservoir to Chestnut Hill.

Since the Authority has a large number of projects under construction during the late 1990's, such as the SDWA Compliance Program, Secondary Treatment at Deer Island and CSOs, the Northern Tunnel Loop construction will be completed in two stages. Stage 1 construction of the Northern Tunnel Loop consists of a 12-foot diameter tunnel, approximately 12,000 feet in length, from Norumbega Reservoir to a shaft located near the Terminal Chamber of the Weston Aqueduct. At this shaft, surface piping connections and pressure regulating facilities would permit water from the new tunnel to be transferred to the Weston Aqueduct Supply Mains (WASM). Once these are in service, the Weston Aqueduct would remain available for back-up service. At this shaft a connection would be made to an existing 7-foot-diameter high service pipeline which currently connects the Hultman Aqueduct to the WASM pipelines. A new tunnel, 10-foot in diameter, and about 4000 feet long would be constructed from this shaft to Shaft 5. These improvements would provide redundancy for the eastern two miles of the Hultman Aqueduct from Norumbega Reservoir to Shaft 5.

Stage 1 construction would also include the four remaining shafts of the Northern Tunnel Loop, from the first shaft at the Weston Terminal Chamber, to the last shaft at Fells Reservoir. Construction of these portions of the Northern Tunnel Loop will begin in 1994 and be completed by 1998. Stage 2 would consist of the tunnel sections between the Weston Aqueduct and Shaft 9A of the City Tunnel Extension. This stage would be constructed between 2003 and 2007. The total cost of Stage 1 is estimated to be $43 million for construction. Engineering costs for both Stages 1 and 2 are $20 million. Construction cost for Stage 2 is $195 million.

The recommended alternate achieves the best trade-off between risk and cost. Until the entire Northern Tunnel Loop is complete, the Authority has the risks imposed by lack of adequate redundancy for the City Tunnel and the City Tunnel Extension.

Immediate construction of the Sudbury Tunnel from Norumbega Reservoir to Chestnut Hill would have provided redundancy for the eastern-most two miles of the Hultman Aqueduct and the City Tunnel. The recommended project provides immediate redundancy for the eastern two miles of the Hultman Aqueduct which are considered more vulnerable, but delays for 10 years the provision of redundancy for the more secure City Tunnel, until the Northern Tunnel Loop is completed. This approach eliminates an expenditure of $85 million for the New City Tunnel. It calls for construction of the first portion of the Northern Tunnel Loop, an expenditure that would have been made in the future in any case, and it requires construction of a short 10-foot-diameter tunnel, at a cost of approximately $8 million, which, together with this first portion of the Northern Tunnel Loop, will provide back-up capability for the eastern-most two miles of the Hultman Aqueduct.

The 14-foot diameter Sudbury Tunnel and the 12-foot-diameter Northern Tunnel Loop, as described above in Alternative 4, at a cost of $468 million provide full redundancy for the Hultman Aqueduct now and the City Tunnel and the City Tunnel Extension later. The project avoids the necessity of pressurizing the Weston Aqueduct. It reduces the volume of required covered storage at the Weston Reservoir area. It is superior from the standpoint of working within the Authority's funding limits, meeting master planning goals and reliable engineering design. A decision to proceed immediately with the recommended project would simplify planning for distribution piping improvements and covered distribution storage because it would establish the foundation for future system hydraulics. It follows our master plan for providing redundancy for our principal tunnels and aqueducts without committing funds to intermediate facilities which could become either superfluous or hydraulically inappropriate. By constructing the 14-foot-diameter Sudbury Tunnel now and starting a phased construction program for the Northern Tunnel Loop, we will save $165 million in construction costs over the long term. In the short term, the Authority will need to bear the risk for having no redundancy for the City Tunnel other than the existing Sudbury Aqueduct.

<u>Related Issues</u>

<u>Interbasin Transfer Act Implications:</u> The Department of Environmental Management has already completed a preliminary review of the original project under the Interbasin Transfer Act. They concluded that the portion of the project relating to reconstructing the Sudbury Aqueduct or providing an equivalent 10-foot diameter tunnel is not governed by the Act. The 14-foot-diameter connecting

tunnel segment between Shaft C and Shaft 4 in Southborough would, however, require a request for a determination as to whether the Act applies, regardless of which alternative is chosen. Therefore, for each of the alternatives outlined above, a review of the project under the Interbasin Transfer Act will be required. The larger the project, both in terms of diameter and scope, the more detailed the review is likely to be.

Safe Drinking Water Act Implications: Construction of a tunnel or rehabilitated aqueduct is not directly affected by any of the rules resulting from the Safe Drinking Water Act Amendments. However, the need to eliminate uncovered distribution storage at Norumbega, Weston, Spot Pond and Fells Reservoirs and the need to replace unpressurized aqueducts with pressurized tunnels does affect our planning and scheduling and is a major reason why a 14-foot-diameter Sudbury Tunnel is needed in place of the somewhat less expensive 10-foot-diameter Sudbury Tunnel.

Northern Tunnel Loop Shaft Sites: There is a better opportunity to lock in shaft sites for the Northern Tunnel Loop now rather than later. The Northern Tunnel Loop will be located mostly within the Metropolitan Boston area which is already heavily developed. Any remaining open land within the Metropolitan Boston area will come under increasingly more pressure for development in the future. Accordingly, staff recommends that, once the shaft sites for the Northern Tunnel Loop have been identified and approved through the EIR process, the Authority should proceed to purchase and construct them.

A commitment to purchase and build the shafts now will fix their location and help to simplify planning of future distribution system improvements. Construction of the shafts now will also set the stage for future tunnel construction activities at those sites.

Engineering Fees: The recommended project will require adjustments to the current contract with Sverdrup and a new procurement for the entire EIR and later on for the second phase of the design and construction of the Northern Tunnel Loop. Following approval by the Board, staff will negotiate an amendment with Sverdrup to reduce the scope of the final design, construction administration and resident inspection phases of the contract (Phases II and III) by eliminating the New City Tunnel section of the project (from Norumbega Reservoir to Chestnut Hill) and by adding the first phase of the Northern Tunnel Loop (from Norumbega Reservoir to the Weston Aqueduct with a connection to Shaft 5 and the construction of the tunnel shafts); and

Staff will also pursue a new procurement for the entire EIR and for the second phase of the final design and construction of the Northern Tunnel Loop.

We estimate that the current total budget for the Sverdrup contract will be reduced somewhat with the proposed amendment. The new procurement for the entire EIR and for the second phase of the design, construction administration and resident inspection of the Northern Tunnel Loop will require additional engineering costs.

Project Schedule: The current project schedule calls for completion of the EIR for the Sudbury Aqueduct by June 1991 and for commencement of construction by January 1993. To take advantage of the opportunities now offered by the all-tunnel option the schedule must be revisited.

We estimate that a time extension of about six months would be required to incorporate the 14 foot diameter tunnel into the EIR. Final design for the Sudbury Tunnel and the first phase of the Northern Tunnel Loop would start in the Winter of 1992. Construction would commence by June 1994 and would be completed by June 1998.

The new procurement for the EIR of the Northern Tunnel Loop would proceed immediately with a final EIR ready by December 1993. The new procurement for final design and construction services for the second phase of the Northern Tunnel Loop would begin once funds became available, but not later than 2000. Construction would begin not later than 2003 and finish by 2007.

BUDGET/FISCAL IMPACT: The FY91-93 CIP includes a 10 year forecast from FY1991 through FY2000. The recommended project includes expenditures the Authority would incur through FY2000. Although the project cost is $468 million, the second phase of the Northern Tunnel Loop construction is too large to absorb in the late 1990's, given the other scheduled projects. The Phase 2 costs are not included in the 10 year plan.

Since the approved 10 year plan includes construction of the New City Tunnel, pressurization of the Weston Aqueduct and a 27,000 foot pipeline in Framingham. The following recommended project represents a savings of $48 million through the 10 year planning period as listed below:

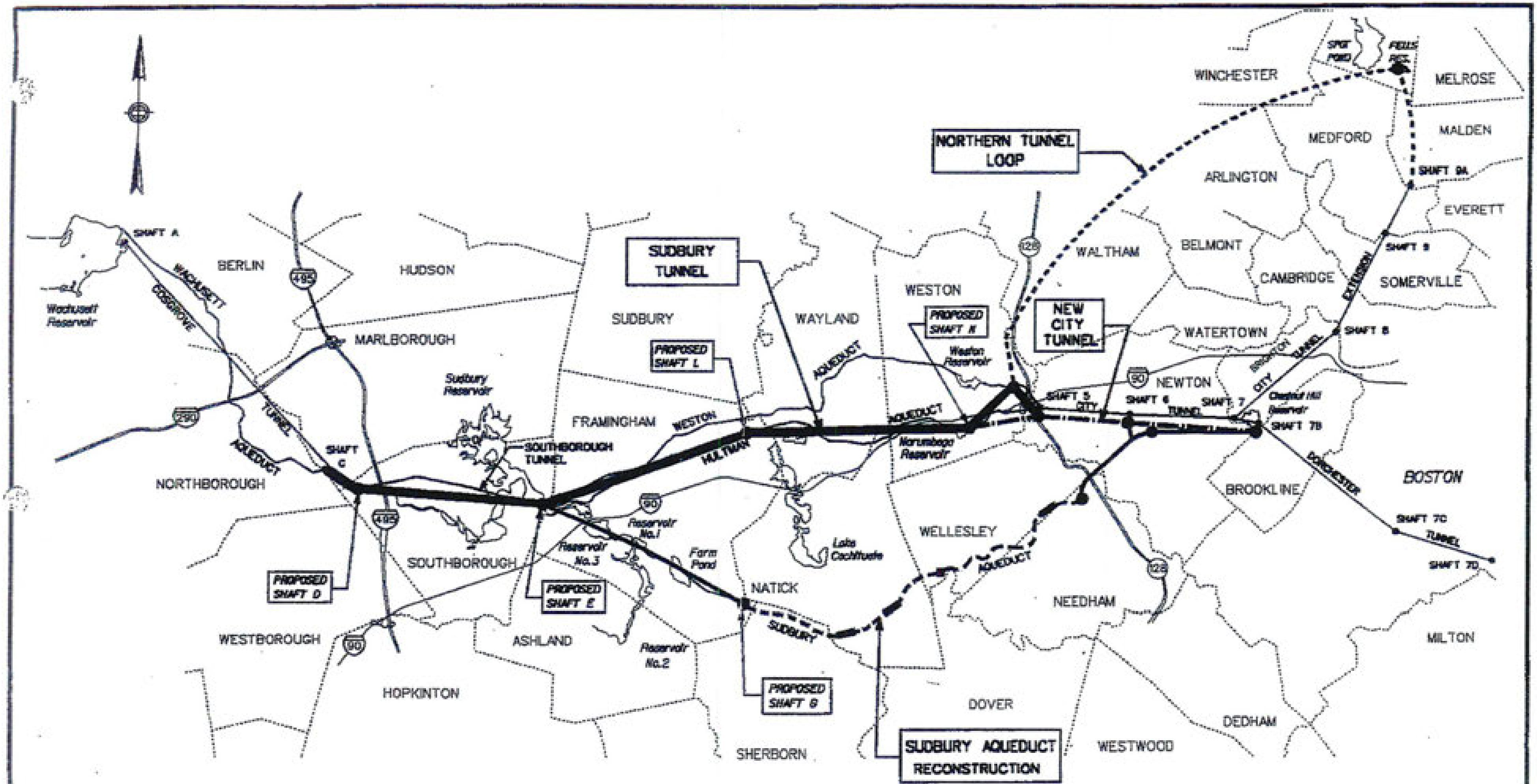
Aqueduct Improvements	1991-2000 FY91-93 Final CIP	1991-2000 Recommended Project
Sudbury Aqu. Des./Const.	260,579,863	244,000,000
Framingham Des./Const.	11,295,000	6,295,000
Northern Loop Des./EIR	0	20,000,000
Northern Loop Const. Ph.1	0	43,000,000
Safe Drinking Water Act		
Weston Aqueduct Des./Const.	90,000,000	0
Total	361,874,863	313,295,000

The proposed FY92-94 CIP does not reflect the 10 year recommended project. The final CIP will be prepared in accordance with the Board's decision.

MBE/WBE UTILIZATION: The current project requires a combined minimum MBE/WBE participation of 20 percent. A minimum 20 percent combined MBE/WBE participation will be maintained throughout the project.

Attachments:
Figure 1 - Tunnel/Aqueduct Improvement Program
Appendix A - Progress Report and Discussion on Project Alternatives

pb617-2



LEGEND

- Proposed Tunnels
- Surface Aqueduct Reconstruction
- Planned Tunnel Improvements
- Proposed Shafts
- Recommended Construction Now

Tunnel/Aqueduct Improvement Program

SCALE: 1"=12000'

Figure 1

APPENDIX A

PROGRESS REPORT AND DISCUSSION OF PROJECT ALTERNATIVES

PROGRESS REPORT

Since our staff summary in May, 1990, Amendment No. 1 was executed by the Executive Director under his delegated authority. Amendment No. 1 addressed the change in project emphasis from reconstruction of the Sudbury Aqueduct to a new tunnel. It resulted in a net reduction of $19,717 in engineering costs for Phase I. The consultant has not been authorized to proceed with Phase II - final design or Phase III - construction administration and resident inspection.

In May, a newsletter was also sent to project abutters and community officials informing them that an all-tunnel alternative to the reconstruction of the Sudbury Aqueduct was being evaluated. In early June, a Notice of Project Change was published by the MEPA Unit of the Executive Office of Environmental Affairs, and a public meeting was held to inform interested parties of the all-tunnel alternative. Community officials from Weston and Wayland were briefed by staff because neither community had been briefed earlier since they were not located within the project area of the original alternative.

To refine the initial cost estimate for the tunnel alternative, it was necessary to obtain a better understanding of the geology along the tunnel route and to identify the availability of sites for tunnel construction shafts. A state-wide search was launched to collect available data on the geology of the study area. Rock core was located from deep borings taken by the MDC in 1937 as part of the planning of the Hultman Aqueduct. The 1937 borings provided extremely useful geological information because they were located along the same general alignment as the currently proposed tunnel. To supplement the available geological data, a survey of the surface geology along the route was undertaken. Seismic surveys and deep rock borings at strategic points were also completed. Altogether, the collected data has given us significant insights into the area geology and has allowed us to establish an approximate profile of bedrock elevations.

Potential areas for tunnel construction shafts were identified and investigated. These included the area around Shaft C in Marlborough, the Shaft 4 area in Southborough, an existing sand and gravel pit at the northwest corner of Framingham, the Norumbega Reservoir area, the area around Shaft 5, the area around Shaft 6 and the Chestnut Hill Reservoir area.

Conceptual layouts of surface piping interconnections at shaft sites have been initiated. Several piping layouts are being developed and evaluated to ensure future operational flexibility and metering dependability at a reasonable cost. Alternative concepts are also being evaluated to provide redundancy to the communities along the project route. Staff will continue to work with the communities to provide them a continuous and dependable supply of water.

Based on an evaluation of the geologic information, the potential locations for tunnel construction shafts and the surface piping interconnections, the construction cost estimates for the tunnel were refined. The current estimates confirm that the all-tunnel alternative is cost competitive with the option of reconstructing the Sudbury Aqueduct. The availability of shaft sites in unpopulated areas, with excellent access to rock storage areas and major highways and/or rail lines, means that the tunnel can be constructed with minimal disruption to the environment and the community.

Reconstruction of the Sudbury Aqueduct would require at least 100,000 linear feet of surface construction with a 10 foot diameter pipe through environmentally sensitive areas and population centers; it would also require 43,000 linear feet of tunnels and at least five tunnel shafts. The tunnel alternative will require only about 15,000 linear feet of surface construction for interconnections between our existing facilities and the new tunnel, approximately 115,000 linear feet of tunnels, and eight tunnel shafts. The cost of reconstructing the Sudbury Aqueduct is approximately $270 million while the cost of constructing a new tunnel of similar capacity would be approximately $295 million. The costs are on the same order of magnitude given the level of detail available at this time. Furthermore, construction costs for the rehabilitation of the Sudbury Aqueduct are more likely to increase in the future than are tunneling costs. Recent advancements in tunneling technology have already reduced tunneling costs significantly and are likely to continue to reduce them in the near future. An article on tunneling technology in the August issue of the Engineering News Record states that "in the midst of escalating construction costs, some tunneling costs have dropped as much as 75% over the past 20 years". On the other hand, continued development along the route of the Sudbury Aqueduct, and potentially tighter regulations on surface construction activities are likely to escalate the future costs of surface construction.

DISCUSSION OF PROJECT ALTERNATIVES

In the following discussion the aqueduct/tunnel system from Shaft C in Marlborough to Shaft 9A in Malden, is broken down into four geographic segments, and the options available for each segment are discussed.

Shaft C in Marlborough to Shaft 4 in Southborough

At present, one hundred percent of the flow between these points is conveyed in a single conduit. The western most two miles of the existing conduit consists of a 12.5 foot diameter pressure pipeline, and the eastern three miles, a 14 foot diameter tunnel. There is no backup capacity whatsoever in this area, other than to reduce pressure and pass the water through the Sudbury Reservoir. The reduction in pressure would restrict flow so severely that minimal flow requirements could not be met. Water quality would also be impaired, and a boil order would be required. All of the alternatives considered recommend a new 14 foot diameter tunnel to provide redundancy for this segment of the project.

Shaft 4 to Norumbega Reservoir in Weston

For this section of the transmission system, the original plan was to reconstruct the Sudbury Aqueduct immediately and the Weston Aqueduct later. However, given that a new tunnel of the same capacity (10 foot diameter) as the reconstructed Sudbury Aqueduct can be built for close to the same price, and at far less environmental impact, a tunnel is recommended.

The foundation and configuration of the Sudbury Aqueduct are such that a 10 foot diameter is the largest size which could be built economically. At 200 million gallons per day (mgd) capacity, the reconstructed Sudbury Aqueduct, together with the existing Weston Aqueduct, would have provided the minimum required 300 mgd capacity. In the future, reconstruction of the Weston Aqueduct would have increased capacity to provide full transmission redundancy.

With the decision to construct a new tunnel, the issue of diameter or capacity must be re-examined. For a relatively small incremental cost, a large increase in capacity can be achieved. A 10 foot diameter tunnel between Shaft 4 and Norumbega Reservoir is estimated to cost $135 million; a 12 foot diameter, $145 million; and a 14 foot diameter, $150 million. For an 11 percent increase in cost, therefore, the tunnel diameter can be increased from 10 feet to 14 feet and a more than 100 percent increase in capacity can be achieved. With the additional capacity provided by a 14 foot diameter tunnel, the Authority would not have to reconstruct the Weston Aqueduct in the future. The cost of reconstructing the Weston Aqueduct is approximately $100 million.

The Weston Aqueduct needs to be reconstructed because it presents serious concerns related to the Safe Drinking Water Act (SDWA). As a gravity aqueduct of masonry construction, the Weston Aqueduct is subject to infiltration of groundwater which may not meet drinking water standards. Also, as a gravity aqueduct it requires a very large reservoir at its terminus (currently provided by the existing Weston Reservoir) which does not fluctuate much in water surface elevation. As such, the Weston Reservoir cannot be economically replaced with covered distribution storage and instead the Weston Aqueduct must be reconstructed as a pressure conduit. With a pressure conduit the required storage would be reduced to possibly a 20 or 30 million gallon tank which would then be partially or completely buried.

To pressurize the Weston Aqueduct we would undoubtedly encounter similar concerns with surface construction in environmentally sensitive areas and population center as were identified for the reconstruction of the Sudbury Aqueduct. These issues might have the effect of significantly increasing the costs of reconstructing the Weston Aqueduct, perhaps even to the point where another new tunnel might have to be considered as a substitute.

In light of these concerns and given the savings to be gained by eliminating the need for future reconstruction of the Weston Aqueduct, staff recommends that a 14 foot diameter tunnel be selected for this segment of the project.

Norumbega Reservoir to Chestnut Hill in Boston

Since 1848, the Chestnut Hill area has been the hub of the transmission system. This was the terminus of the Cochituate Aqueduct (1848), the Sudbury Aqueduct (1878), the Weston Aqueduct Supply Mains (WASM) 1903, and the high pressure City Tunnel (1951). The Dorchester Tunnel (Southern High Service) and the City Tunnel Extension (Northern High Service) start at this point. It is also the junction point between the Boston Low Service and the Northern Low Service systems. Therefore, any plan for transmission system redundancy must take these facts into consideration.

The City Tunnel brings water from Norumbega Reservoir to Chestnut Hill. The rock tunnel portions of the City Tunnel are very safe, reliable and secure facilities. However, the tunnel surface connections, valves and other control facilities are less reliable. Last year a valve which connects the City Tunnel to the

Commonwealth Avenue Pump Station in Newton failed in the shut position. It cut off 85 percent of the supply to Newton. Fortunately it was possible to repair the broken section of the valve without removing the entire valve and having to shut down the City Tunnel. It is this type of incident which demonstrates that, even with a very secure tunnel, there are relatively minor appurtenances whose failure can result in a major shut-down.

Currently, only one major on-line facility, the Weston Aqueduct Supply Main Number 4 (WASM 4), can be operated at high service to provide back-up to the City Tunnel. It has less than 15 percent of the capacity of the City Tunnel. The only other back-up at present would require drawing water of low quality and low pressure from the Framingham Reservoirs together with the activation of the Sudbury Aqueduct and the Chestnut Hill Pumping Station. Water quality would be impaired and a boil order would be required.

In the future, there could be three possible plans for providing redundancy between Norumbega Reservoir and Chestnut Hill:

- o The Sudbury Aqueduct
- o A New City Tunnel parallel to the existing City Tunnel
- o The Northern Tunnel Loop

The Sudbury Aqueduct is a less desirable solution because it would generate too much surface disruption and no significant economic advantage.

A New City Tunnel would cost $85 million and would only provide limited benefit. For purposes of comparing the 10 foot diameter reconstructed Sudbury Aqueduct to a new tunnel in the area from Norumbega Reservoir to Chestnut Hill, the new tunnel is shown as a 10 foot diameter conduit. If it were built at 12 foot diameter (the diameter of the existing City Tunnel) it would cost an additional $5 million, but it would provide full redundant capacity for the City Tunnel and it would allow the diameter of the Northern Tunnel Loop to be reduced from 12 foot to 10 foot. However, the Northern Tunnel Loop would still be required in the future. At a 10 foot diameter the Northern Tunnel Loop would cost $210 million while at 12 foot diameter it would cost $230 million.

The recommended alternative is to start building the Northern Tunnel Loop now. A 12 foot diameter Northern Tunnel Loop, when completed, would provide direct supply to the Northern Extra High, Northern Intermediate High, Northern High and Northern Low systems. The Northern Tunnel Loop would also provide redundancy to both the City Tunnel and the City Tunnel Extension with sufficient capacity to send water to Chestnut Hill to meet the demands in the central and southern areas.

<u>Northern Tunnel Loop from Norumbega Reservoir to the Fells Reservoir and Shaft 9A in Malden</u>

All of the alternatives evaluated under the Redundancy Master Plan included the Northern Tunnel Loop as the means to provide full redundancy for the City Tunnel Extension, and to provide full or partial redundancy for the City Tunnel. The basic concepts for system redundancy in this area have remained unchanged since they were first introduced in 1936. The only variations have been slight adjustments in location (so as to avoid crossing major rock fault zones, to cross faults at right angles, where crossings are unavoidable, and to locate shafts at environmentally sound sites. As described in the preceding section, the Northern Loop can have a smaller capacity if it is one of several means for providing redundancy for the City Tunnel. It must have larger capacity if it is the sole means.

If a 12 foot diameter Northern Tunnel Loop is built now, at a cost of $230 million, then the New City Tunnel between Norumbega Reservoir and Chestnut Hill need not be built ($85 million). If, however, the Northern Tunnel Loop is not built now, then a 12 foot diameter New City Tunnel must be built now between Norumbega and Chestnut Hill ($85 million), and a 10 foot diameter Northern Tunnel Loop ($210 million) must be built in the future. A full listing of construction costs is shown in Table 1.

If the New City Tunnel is not built and funding the entire Northern Tunnel Loop now is not possible, the Northern Tunnel Loop construction should be subdivided into two phases with the first phase to be built now and the second phase to begin not later than 2003. The first phase of the Northern Tunnel Loop would include construction of the first leg of the Northern Tunnel Loop from Norumbega to the Weston Aqueduct, construction of a connection to Shaft 5 to provide redundancy for the Hultman Aqueduct from Norumbega to Shaft 5, and construction of shafts for the Northern Tunnel Loop. Construction of the Northern Tunnel Loop shafts now achieves two important goals. First, it locks in the land required for construction of the Northern Tunnel loop now while also preventing future encroachments which might require re-routing the tunnel later. Second, it simplifies planning of future distribution system improvements by fixing the location of the tunnel shafts and the future location of the tunnel interconnections with the distribution system.

pb-617-21

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6/30/10

STAFF SUMMARY

TO: Board of Directors
FROM: Frederick A. Laskey, Executive Director
DATE: June 30, 2010
SUBJECT: Metropolitan Water Transmission System Redundancy Plan

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COMMITTEE: Water Policy & Oversight

X INFORMATION
___ VOTE

Jae R. Kim, Director, Water Engineering
Frederick Brandon, Senior Program Manager
Preparer/Title

Michael J. Hornbrook
Chief Operating Officer

The Metropolitan area water transmission system does not currently have redundancy for the City Tunnel, the City Tunnel Extension or the Dorchester Tunnel. The loss of these tunnels would be catastrophic.

As part of a contract with the engineering firm of Fay, Spofford and Thorndike that is studying redundancy for the overall transmission system, a plan has been developed that will provide redundancy for the transmission system within the Metropolitan area. This plan, when combined with the Cosgrove Tunnel Redundancy Pump Station and rehabilitation of the Hultman Aqueduct, will provide redundancy from Wachusett Reservoir to the heart of the distribution system within the Metropolitan area.

The details of the proposed plan to provide redundancy for the Metropolitan area water transmission system are outlined in this staff summary and in staff's presentation to the Board.

RECOMMENDATION:

For information only.

DISCUSSION:

The water transmission system within the Metropolitan area relies on the availability of the City Tunnel, the City Tunnel Extension and the Dorchester Tunnel. A shut-down of any of these tunnels would seriously compromise MWRA's ability to deliver potable water without imposing a boil water order.

In September 2008, the Board approved a contract with Fay, Spofford and Thorndike (FS&T) to study redundancy for the overall transmission system. As a result of that study, on January 13, 2010, the Board directed staff to proceed with the design and construction of a emergency pumping station at the terminus of the Wachusett Aqueduct near the Carroll Water Treatment Plant site to provide redundancy for the existing Cosgrove Tunnel. Now, a plan has been developed that will provide redundancy for the transmission system within the Metropolitan area.

The need for transmission system redundancy is driven by two compelling interests. First, MWRA must be able to swiftly respond to a disruption in service. Failure of the deep rock tunnels is unlikely. However, a more likely failure is of surface piping or surface connection valves. This scenario may require isolation of the entire tunnel system, repair of customized equipment at specific locations and take weeks or months to complete. In general, water systems across the United States use a range of strategies to eliminate such single points of failure. The general goal is to transition to a back-up system that is unnoticeable by the consumer. Another reason for redundancy is the need to inspect, maintain and rehabilitate these tunnels and key valves on a regular basis. At this time, the Metropolitan tunnels, ancillary valves and equipment are as much as 60 years old and there is currently no way to schedule inspection or maintenance work with an alternate means of providing water supply. Thus, a redundant means of providing service will allow scheduled system rehabilitation as needed and also reduce the risk associated with an emergency event disrupting service.

MWRA's predecessor agencies began considering redundancy for the tunnel system in the 1930s when a preliminary plan for a Northern Tunnel Loop was identified. Given MWRA's decreased demands and concern that any redundancy project be cost effective, the study was intended to review the full range of potential alternatives including a full tunnel alternative but also including an examination of existing and proposed CIP projects to determine if existing or potential surface pipelines could be optimized to provide transmission system redundancy.

Since award of the redundancy study to FS&T, significant work has been performed to define existing hydraulic conditions within MWRA's system and to identify the impacts of various failure scenarios of the Metropolitan tunnel system on the level of service and the hydraulic gradeline at each community meter. Alternative improvements to mitigate the impacts associated with failure of key tunnel segments were then developed and evaluated. As noted above, in the Metropolitan tunnel system, the most significant points of failure are at Shaft 5 and at Shaft 7.

Fifteen alternatives were evaluated; four alternatives, including a tunnel loop alternative, were developed for various demand scenarios and 11 alternatives were developed to meet average demands. Alternatives meeting average demands allow maintenance to be scheduled and completed during three seasons but cannot meet normal summer demands if routine work were to extend beyond the spring or in the event of an emergency during higher-demand periods. Under such circumstances, demand reductions through mandatory restrictions and possible supply limitations to some partial-user communities would be necessary.

The 15 alternatives were evaluated for a range of criteria and then narrowed down to three key alternatives:

1. A Tunnel Loop to Provide Maximum Day Demands
2. Surface Mains to Provide Average Day Demands
3. Surface Mains with a Tunnel Segment to Provide High Day Demands

Further review of these three alternatives shows that although the tunnel alternative provides full redundancy for maximum day demands, it is extremely expensive and is considerably over-designed for normal operations. Alternative 2 has the lowest cost but would require water use restrictions in the event of extended repairs or during a seasonally-occurring emergency. It also does not adequately consider potential additional water demand due to either new customers or to partial users impacted by drought or emergencies. Additionally, this alternative connects to the system at the Shaft 5 area, which is very congested and could be impacted by flooding or construction activities under certain failure scenarios.

Alternative 3 was further broken down into three options, which vary by whether they include a tunnel component (Option A) and by where the redundant system connects to the current system (Options A & B connect at Norumbega; Option C at Shaft 5), see Figure 1, attached. Staff have a selected as a preliminary recommendation, Alternative 3, Option A, because this alternative provides full redundancy for existing and projected high-day demands and it avoids the congestion of connecting at the Shaft 5 location. Option A does include a 10-foot-diameter tunnel segment from Norumbega to the Sudbury Aqueduct. Although this alternative is more expensive than Option B, which uses a 72-inch surface pipeline between Norumbega and the Sudbury Aqueduct, community disruption would be significantly lessened.

Staff plan to initiate the procurement process for a contract the Concept Design and Environmental Review phase of the Sudbury Aqueduct pressurization work during FY11 and carry out Concept Design and alternatives evaluations before returning to the Board for a detailed presentation of the recommended alternative prior to formal MEPA review in late-fall 2011.

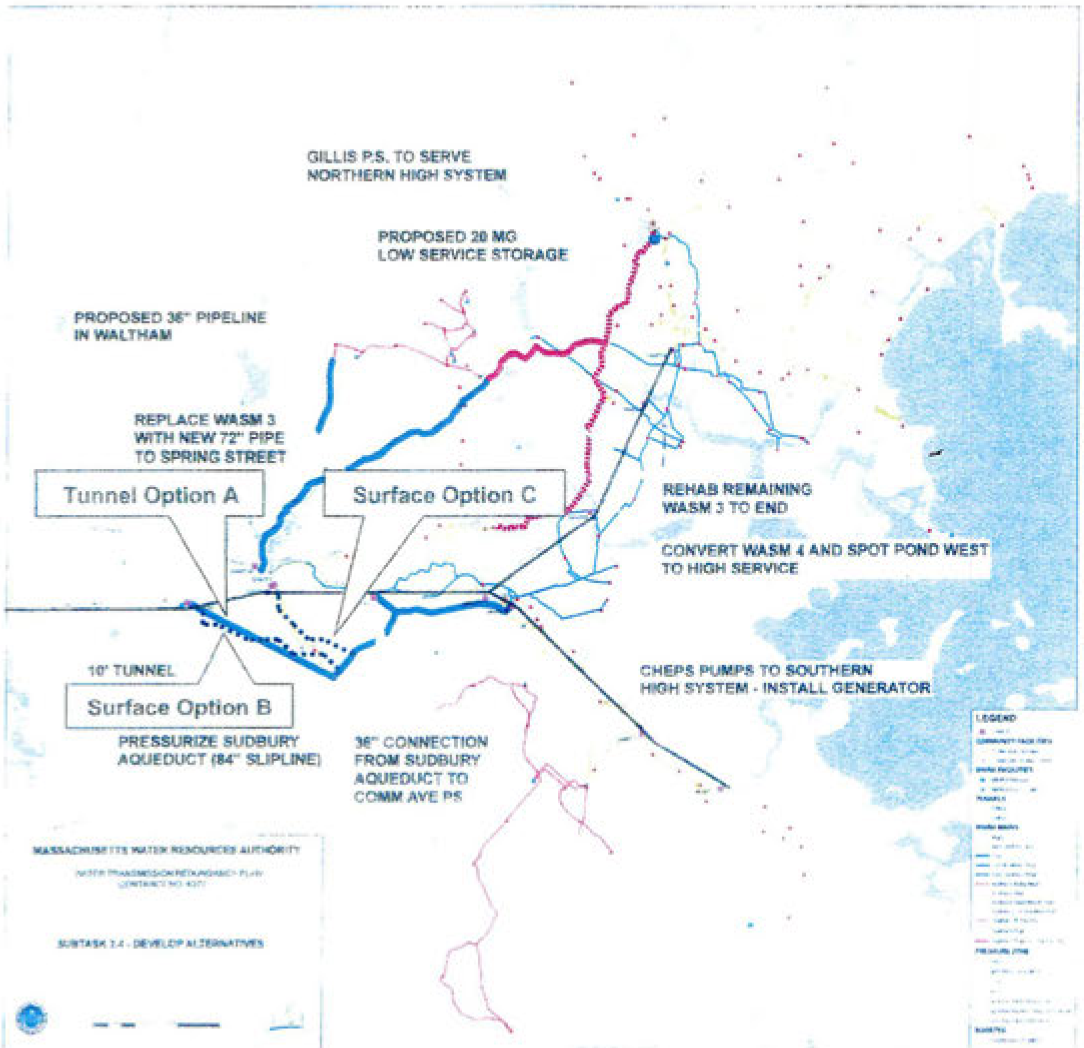
BUDGET FISCAL IMPACT:

An estimated net cost of $229 million was added for the water redundancy projects to the Draft FY11 CIP for the Alternative 3, Option A proposal.

ATTACHMENT:

Figure 1. Metropolitan Transmission System Redundancy Plan Alternative 3

Figure 1. Metropolitan Transmission System Redundancy Plan Alternative 3



Net CIP Impact*

Option A: $229 million

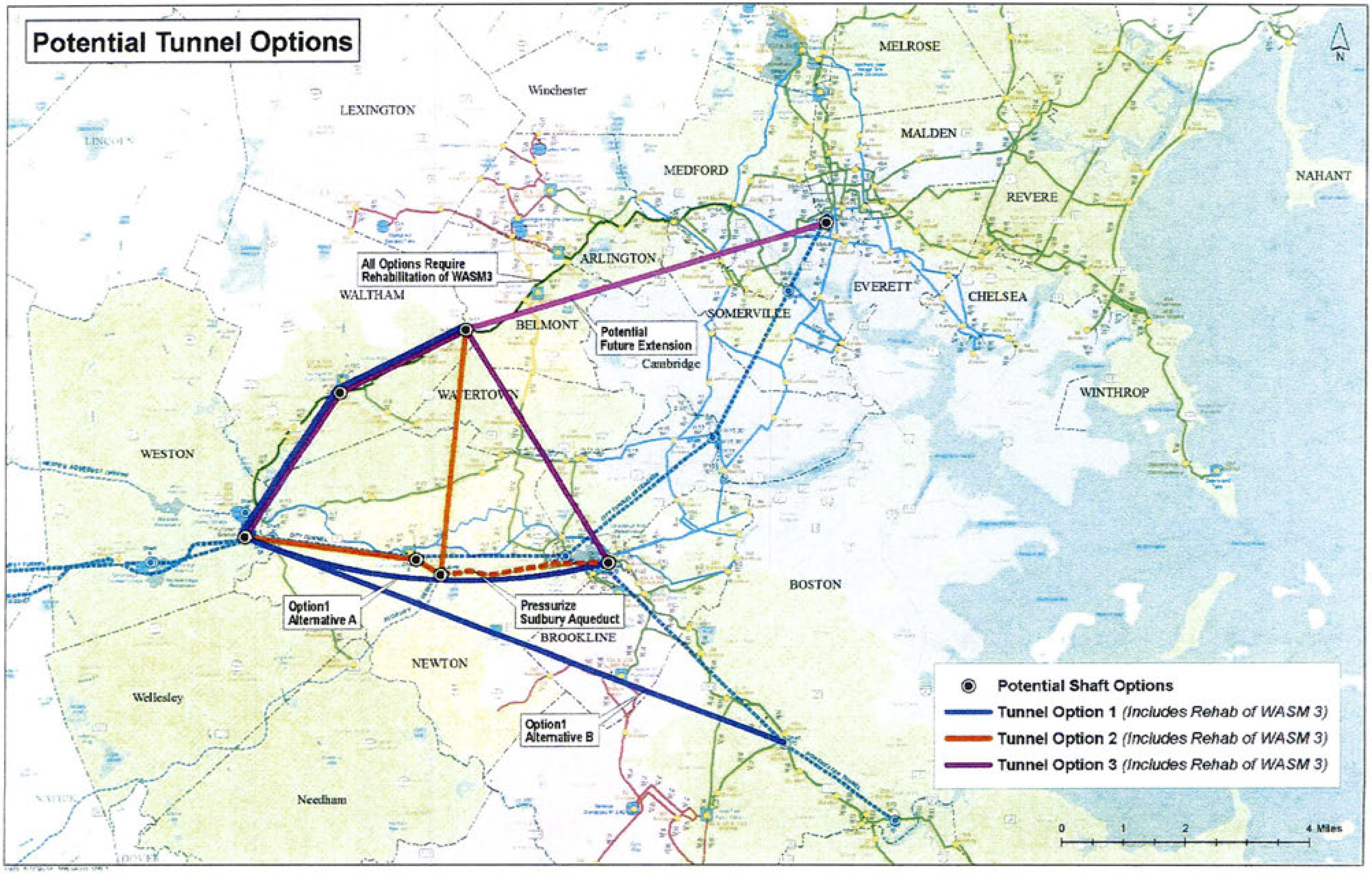
Option B: $170 million

Option C: $99 million

*Includes $52 million budget credit for Cosgrove Tunnel Redundancy Pump Station project.

Board of Directors
Water Policy and Oversight Committee
June 25, 2014

Update to the Water Policy and Oversight Committee on Metropolitan Tunnel Redundancy highlighting possible tunnel alternatives.
(map)


Potential Tunnel Options
MELROSE
Winchester
LEXINGTON
MALDEN
MEDFORD
NAHANT
REVERE
All Options Require Rehabilitation of WASM3
ARLINGTON
WALTHAM
EVERETT
CHELSEA
SOMERVILLE
BELMONT
Potential Future Extension
Cambridge
WATERTOWN
WINTHROP
WESTON
BOSTON
Option1 Alternative A
Pressurize Sudbury Aqueduct
BROOKLINE
NEWTON
Wellesley
Option1 Alternative B
Needham
Potential Shaft Options
Tunnel Option 1 (Includes Rehab of WASM 3)
Tunnel Option 2 (Includes Rehab of WASM 3)
Tunnel Option 3 (Includes Rehab of WASM 3)
0
1
2
4 Miles
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STAFF SUMMARY

TO: Board of Directors
FROM: Frederick A. Laskey, Executive Director
DATE: February 10, 2016
SUBJECT: The Need for Metropolitan Tunnel Redundancy

COMMITTEE: Water Policy & Oversight

X INFORMATION
___ VOTE

Stephen Estes-Smargiassi, Director, Planning & Sustainability
David Coppes, P.E., Director, Waterworks
Preparer/Title

Michael J. Hornbrook
Chief Operating Officer

Over the next several months staff will present three major aspects of initial planning for that project. This staff summary is the first, and will look at why redundancy for the Metropolitan Tunnels is essential, including the condition of the system, potential failure scenarios, the difficulty of recovering from any failure and restoring service, and the inability to shut down the system for either inspection or maintenance. The second, in March, will review work done over the past several years examining a wide range of alternatives to provide full or partial redundancy, including their costs, reliability of operation, constructability issues and environmental impacts. The third staff summary, in May, will examine whether and how the costs can be accommodated within the framework of maintaining predictable and sustainable rates.

RECOMMENDATION:

For information only.

DISCUSSION:

The Water Transmission System can be divided into five major segments as shown in Figure 1. Completed or ongoing projects to achieve system redundancy for segments 1 through 4 are discussed below. The fifth segment, the Metropolitan Tunnels represents the next challenge for the agency in improving the reliability of this great water system. Further detail on MWRA's and its predecessors' efforts to build redundancy into the water delivery system are contained in the attached White Paper.

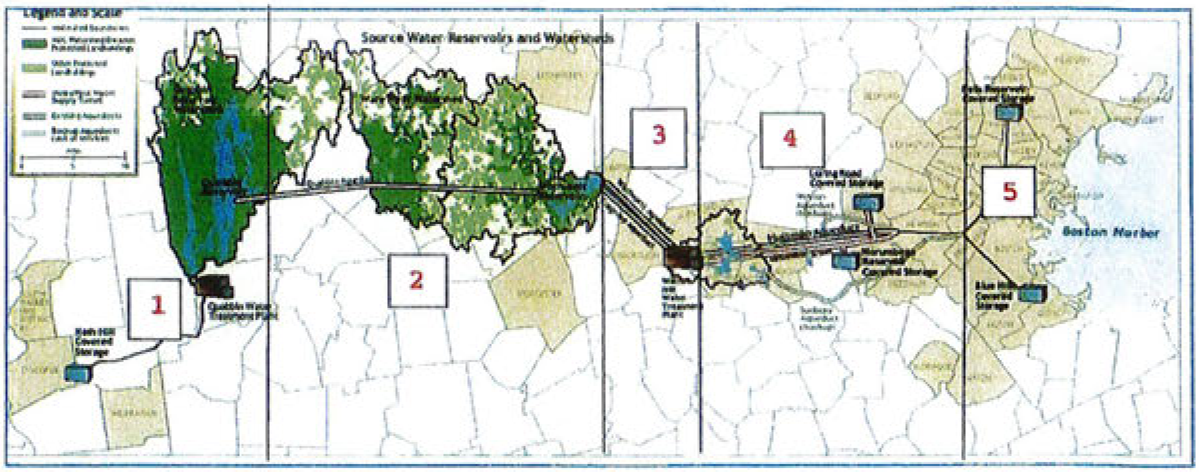


Figure 1. MWRA Water Transmission System

1. Chicopee Valley Aqueduct. In 2007, MWRA completed construction of 8,100 feet of 30-inch diameter pipeline; 2,400 feet of 20-inch pipeline; and 3,100 feet of 16-inch pipeline to provide redundant supply for critical sections of the 14.8 mile long aqueduct. Emergency connection points to the Springfield water system were created to allow connection of MWRA's mobile pumping unit to supplement Springfield's supply.

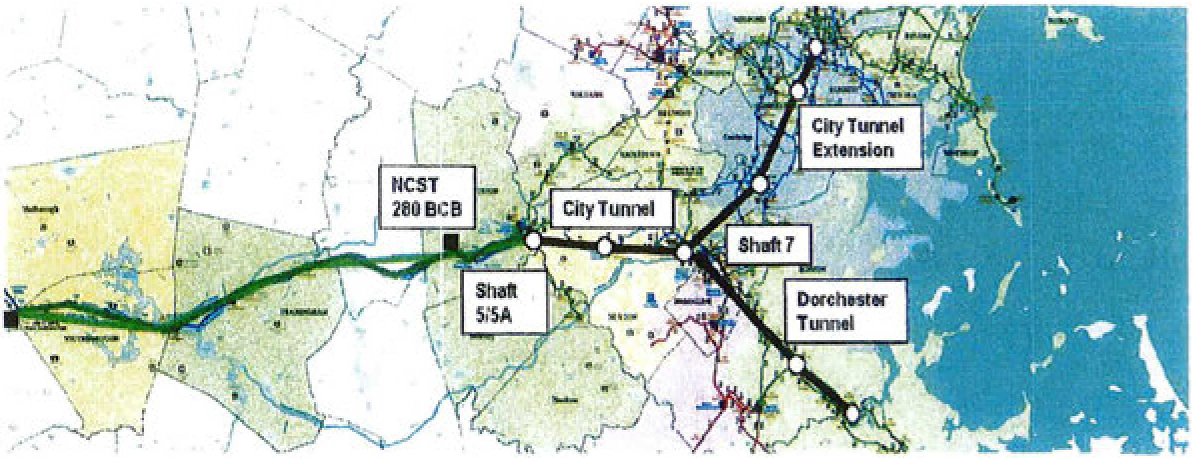
2. Quabbin Aqueduct. The Quabbin Aqueduct brings water from the Ware River to Quabbin and from Quabbin to Wachusett Reservoir. The CIP includes development of an inspection plan for this tunnel. The system can rely on the Wachusett Reservoir during winter/spring months in years with normal precipitation and staff believe that this tunnel can be inspected with minimal risk or disruption.

Wachusett Aqueduct Pump Station

3. Cosgrove Tunnel/Wachusett Aqueduct. The Cosgrove Tunnel supplies water from Wachusett Reservoir to the John J. Carroll Water Treatment Plant (CWTP). The recently awarded Wachusett Aqueduct pump station project will allow the gravity aqueduct to supply the plant allowing the Cosgrove Tunnel to be taken out of service without impacting water quality. The 240 mgd capacity would allow for unrestricted supply for at least eight months during the lower demand fall/winter/spring period.

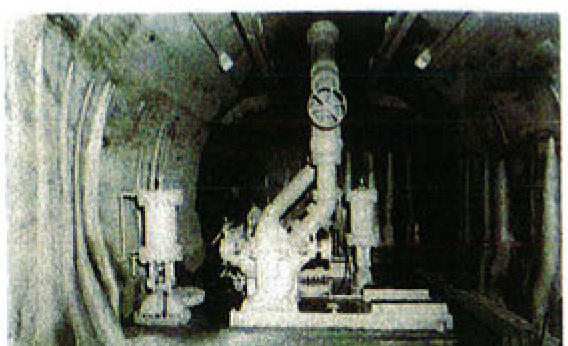
4. MetroWest Tunnel/Hultman Aqueduct. Providing the link between the CWTP and Shaft 5 of the City Tunnel, the MetroWest Water Supply Tunnel was completed in 2003 and the Hultman Aqueduct was rehabilitated in 2013. These projects provide a second means of water conveyance to the Norumbega Covered Storage Facility and ultimately the City Tunnel and Metropolitan distribution system.

5. Metropolitan Tunnels. The tunnel system to the east of the Hultman and Metrowest Tunnel includes the City Tunnel, the City Tunnel Extension, and, to the south, the Dorchester Tunnel. These three tunnels come together at Shaft 7 at Chestnut Hill.



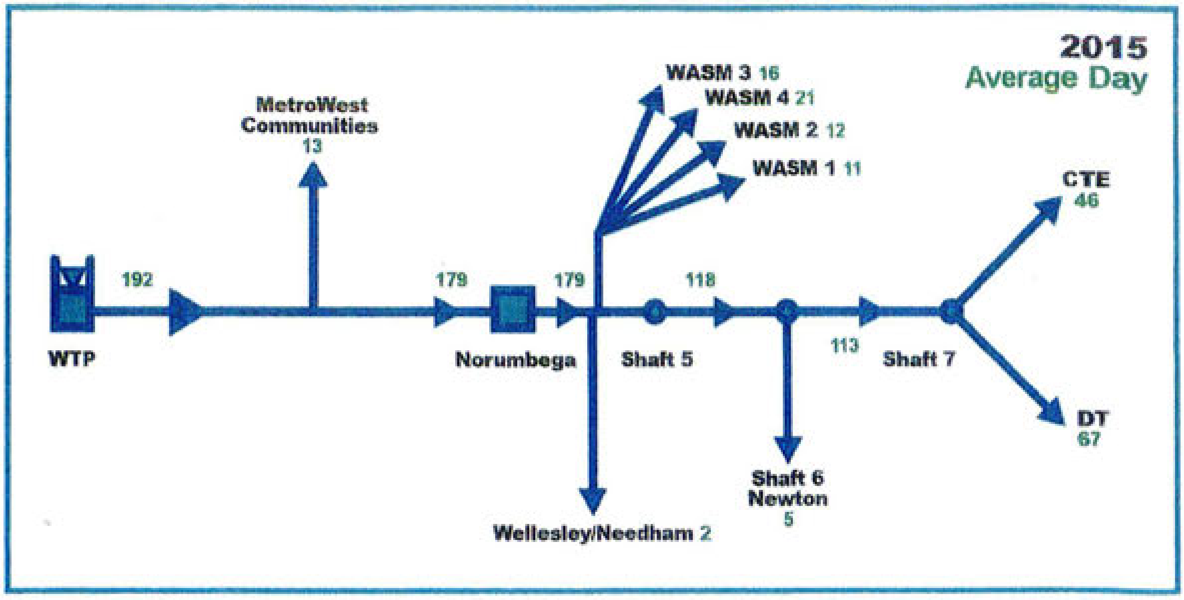
Metropolitan Tunnels

The City Tunnel is a deep rock tunnel, 5.4-miles in length, from Route 128 to Chestnut Hill that brings more than 60% of Wachusett system water to customers in the Metropolitan area. Built in 1950, it starts at Shaft 5 on the banks of the Charles River in Weston connected to the ends of the MetroWest Tunnel and Hultman Aqueduct. At Shaft 5, four 60-inch isolation valves (two for the Hultman and two for the MetroWest tunnel) are contained in a brick and concrete structure that also houses dewatering equipment, a shaft to a subsurface dewatering chamber over 300 feet underground with valves, pipes and pumps that are connected to the pressurized tunnel, and a pressurized dead-end tunnel shaft built for a future redundant tunnel. During the Shaft 5 pipe break in May 2010, one of the 60-inch gate valves used to isolate supply to the tunnel failed to open when the repaired pipe section was reactivated. This valve cannot be repaired without shutting down the City Tunnel. In Newton a riser shaft connects to the suction piping of the Commonwealth Avenue Pump Station and provides 75% of the City of Newton's water supply. The tunnel terminates at Shaft 7 at Chestnut Hill in a 25-foot-deep chamber which houses connections to the City Tunnel Extension to the north and the Dorchester Tunnel to the south. Six hydraulically activated isolation valves and three 20-inch supply lines for the Chestnut Hill area are located in this chamber.



Dewatering chamber at bottom of shaft

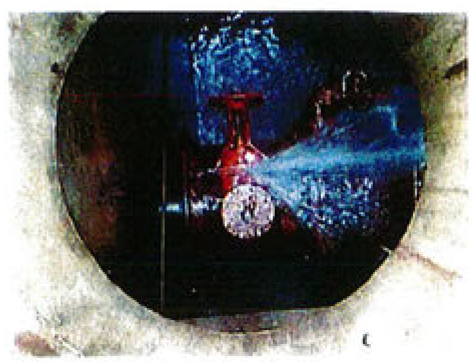
The City Tunnel Extension brings water from the City Tunnel north to Malden and supplies water to the entire northern high pressure zone. Constructed in 1963, it is 7 miles long with surface connections in Brighton and Somerville and a dewatering shaft and subsurface chamber in Somerville similar to the structure at Shaft 5 in Weston. In Somerville there is also a hydraulically actuated valve in a subsurface chamber for isolating the tunnel north of the shaft location and another connected to a pressurized tunnel stub. This chamber and associated piping has been submerged for decades and cannot be readily accessed without increasing the risk of failure or shutting down the tunnel.



The Dorchester Tunnel supplies the Southern High and Southern Extra High service areas through a 6.4 mile deep rock tunnel constructed in 1976. The tunnel has surface piping and valves at Chestnut Hill, West Roxbury and Dorchester.

Scenarios Requiring Shut-Down

There are many events that might require a shut-down of any or all of the Metropolitan tunnels. A leak or rupture in any of the piping at the surface locations or in the deep dewatering chambers (caused, for example, from material fatigue, corrosion, water hammer, freezing, etc.) would necessitate a shut down. There have been a number of near misses over the years. For example, in 2000 an air valve on the top of Shaft 9 froze and ruptured, filling the shaft house with water. Fortunately, staff were able to close an isolation valve and make a repair without shutting down the tunnel. After the incident, heat tracing was added to similar air valves on the system to prevent a similar occurrence. In another example, a recent as 2012, the bonnet on a small diameter by-pass valve at Shaft 9A broke on the right side of the tunnel isolation valve due to corroding bolts. Had the failure been on the other side of the isolation valve, the City Tunnel Extension would have needed to be shut down to repair. Staff have since replaced bolts on other by-pass valves to prevent a similar failure.



Leaking valve bonnet in 2012

Inspection of the internal condition of the tunnel liners cannot be readily made with the tunnels in service.

Replacement, repair, or exercising of the valves at any of the surface connections might require a complete shut-down. Unlike the current Deer Island valve replacement program where the plant is being shut down over night to allow strategic replacement of valves while wastewater backs up in the collection system, the water system consists of pressurized pipes that can only be shut down when a fully redundant pipeline can achieve supply. Since the MetroWest Tunnel went into service, staff have been able to shut down and isolate sections of the Hultman Aqueduct in order to do regular exercising of the valves, full inspection, and repairs. This was not possible before for fear of breaking a valve closed and shutting off water to nearly 2 million customers.

Shaft 8 Isolation valves and PRVs

Shaft 7 Hydraulic Valve Operators

For much of the MWRA system, that kind of redundancy exists (see attached White Paper for a history of MWRA's efforts to improve system reliability and redundancy). For the Metropolitan Tunnels, use of the existing back-up supply results in a major impact on the current quality and level of service.

Existing Back-up Supply

While back-up systems for these tunnels exist, they rely on pumping from open distribution reservoirs (Sudbury, Spot Pond and Chestnut Hill), back-up aqueducts (Sudbury), and undersized surface mains to distribute water of inferior quality and inadequate pressure to customers (and possible water use restrictions during periods of high seasonal demand). Use of any of these systems would require a boil order. Partially supplied communities would be encouraged to maximize production of their own sources of supply to reduce demand on the system.

To the south, in any scenario in which the Dorchester Tunnel is out of service, supply would be pumped from the Chestnut Hill reservoir to the Blue Hills Tanks using the Chestnut Hill Emergency Pump Station with electric pumps and no back-up power supply. This is very different from the situation when the station was utilized in the Shaft 5 break in 2010 during which the Dorchester tunnel was available and in service. In order to push enough water through the surface mains (with the tunnel shut down) to meet demand, pressures in the vicinity of the pump station would greatly exceed current operating pressures and the possibility of leaks and breaks in MWRA and local community's systems is high. Pumping would need to run continuously to Blue Hills Tanks as the level in Blue Hills is inadequate to back feed through those small surface mains without a large drop in pressure. Hence, large swings in pressure would occur. The Chestnut Hill Reservoir would be replenished from the Sudbury Aqueduct.

To the north, with the City Tunnel and/or the City Tunnel Extension out of service, supply would be partly from the 60-inch WASM 3 line, though most would be pumped from Spot Pond from either the Gillis Pump Station or the new Spot Pond Pump Station via Fells Reservoir to the Northern High service area. Spot Pond would be replenished by the northern low system though supply would likely not keep pace with demand and the level in the reservoir would drop requiring water restrictions. Many pipe and valve closures would be required to reconfigure the system to operate in this manner.

Emergency Shut Down

A failure could be a leak in a small pipe that allows an orderly shut-down or it could be large and uncontrollable requiring immediate shut down without benefit of pre-activation of back-up systems. For example, the failure at Shaft 5 released 250 million gallons per day of water through a gap in the pipe as small as about ¾ inch.

Shut-down and isolation of the Metropolitan Tunnel system requires closure of numerous valves located through-out the metropolitan area. Some of these valves have not been exercised in decades for fear that they may break in the closed position, shutting down supply to customers and/or necessitating a shut down and transition to the back-up system. Valves that can be operated without impacting service are exercised regularly. In an emergency shut-down valve crews would be stretched thin, the turn counts for closing the valves are extraordinarily high, and shut-down would take many hours.

Shaft 5 Break. May 1, 2010

MWRA has conducted training for various water operations, engineering and construction staff on emergency response requiring tunnel isolation and system reconfiguration in order to increase the pool of staff that can assist in such an emergency. However, the scope of the work to be done would be overwhelming. In many ways, the Shaft 5 failure was relatively easy in comparison. The number of valves required for isolation and the amount of system reconfiguration required was much simpler than would be required in a Metropolitan tunnel failure and still it took many hours to get all of the pieces into place before the pipe could be shut down.

Ground water in top of Shaft Chamber

A large drain on the system would put large areas served by these tunnels completely out of water. Once isolated, the process of activating the back-up systems would begin which would also take a long time and further stretch crews thin. Additional areas would go without water during this time as local storage tanks drain and pump station suction pressures drop. Restoration of service would require refilling of pipes and evacuating air in both MWRA and community mains which would occupy MWRA and community water department staff for weeks.

To accomplish this, staff would be flushing hydrants to waste while areas of the system have no water at all. A large part of the MWRA service area would be totally out of water for days, if not weeks. Areas with water would remain on a boil order.

Need for "Seamless" Redundancy

In contrast, the great water main break of 2010 at Shaft 5 allowed an orderly transition to the back-up systems. The City Tunnel was able to remain in service, supplemented from Chestnut Hill. The break was able to continue to flow until everything was ready due to the proximity to the Charles River. A smaller break at one of the Metropolitan Tunnel shaft locations could be devastating. The boil order that affected our system for three days had a major impact on the service area. Shut down of the Metropolitan Tunnels utilizing existing back up supplies could result in a boil order for months with wide swings in service pressure and intermittent service.

Staff have studied this problem and reported on the need to address it in the past (see attached chronology/summary of redundancy presentations). As an agency, MWRA has greatly reduced risk and improved the ability for seamless transitions through many parts of the water system. The Chicopee Valley Aqueduct improvements, the MetroWest Tunnel, Spot Pond Storage Tanks and Pump Station, and the recently awarded Wachusett Aqueduct Pump Station among other efforts improve this capability. However, this part of the system still requires a major level of effort. The CIP has several projects that have been developed to increase operational response capabilities for the Metropolitan Tunnels. However, implementation would be more than 10 years from now and the existing valves and surface piping would be that much closer to needing repair or replacement. Next month, staff will brief the Board on specific alternatives to address this part of the transmission system.

BUDGET/FISCAL IMPACT:

Budget for the Metropolitan Tunnel redundancy plan in the amount of $1.4 billion has been included in the Draft FY17 CIP as a placeholder.

ATTACHMENTS:

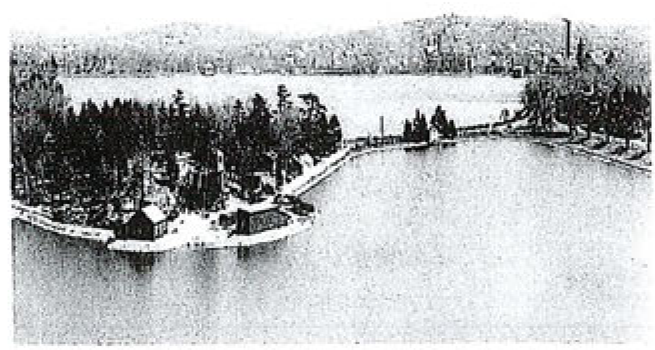
White Paper on Redundancy in Waterworks
Chronology of Briefings to the Board of Directors on Redundancy Projects

Redundancy in the MWRA Waterworks System

Reliable delivery of water is critical to protecting public health, providing sanitation, fire protection and is necessary for a viable economy. Redundancy is important in achieving a high degree of reliability for a water system. One key way that redundancy achieves this is by allowing major equipment, pipelines and appurtenant structures to be taken off line for regular inspection and rehabilitation. Redundancy is reflected in different ways in different circumstances but generally, it means eliminating or managing 'single points of failure' within a system. Depending on the configuration of a water system, different means of providing redundancy or creating operational flexibility allows the utility to respond to emergencies or unforeseen conditions. For example, for utilities like MWRA, where there is a single water source and treatment facility that feeds the metropolitan Boston area, redundant transmission mains are critically important. Intake and treatment systems are designed following an 'N+1'[1] philosophy to limit the impact of equipment failures on the ability to continue to deliver water.

Water system redundancy is not a new idea

Examples of redundancy principles in the metropolitan water system are sprinkled throughout the history of our great water system. In the late 1800s there were two basins at the Chestnut Hill reservoir (the former Lawrence Basin, now the site of Boston College's Alumni Stadium and Bradley Basin the sole remaining reservoir – see 1949 photograph showing the two basins with Lawrence Basin in foreground, Shaft 7 construction and the Chestnut Hill pump station in the background); one to settle water from the Cochituate Aqueduct and the other the Sudbury Aqueduct but both somewhat interchangeable. At the outlet of the pump station at Chestnut Hill two (east and west) supply lines carried water to Spot Pond. There were initially two Weston Aqueduct supply lines for the Boston low service system; each taking a different route with redundancy being one of the benefits provided. The Cordaville pipeline was built in 1928 to bring water in from the south Sudbury (Ashland and Hopkinton) reservoirs while Quabbin reservoir was being planned and constructed.



1 The 'N+1' strategy has a long history in waterworks and is now mandated in Department of Environmental Protection design guidelines. It provides the required number of pieces of equipment (for example chemical feed pumps) to meet the design maximum output of the facility with any (or in case of varying size equipment – the largest) piece of equipment out of service.

The Quabbin intake was constructed with two independent intake lines, one used for releases to the Swift River and the other used decades later for the Chicopee Valley Aqueduct (CVA); at Winsor power station the ability to cross over from either pipeline provided operational flexibility. The Hultman Aqueduct was completed in 1940 with plans and infrastructure left behind for a second barrel. This 1940 photo shows concrete placement for a future aqueduct connection at Shaft 4 of the Hultman Aqueduct. The onset of World War II prevented completion of the second pipeline. The Chicopee Valley Aqueduct was built on one side of its easement to make room for a second future barrel.

The MWRA's metropolitan distribution system has many examples of redundant pipelines and multiple community connections. The Northern Extra high service area has two pump stations (Brattle Court constructed in 1907 and Spring Street constructed in 1958) to serve it. Similarly, the Southern Extra High has Hyde Park (1912) and Newton Street (1954) pump stations. The practice of having parallel pump stations operating in each service area allows facilities to be taken off line for maintenance and rehabilitation and also allows service to continue in the event of a more significant equipment failure. In 1994, a catastrophic pipeline failure shut down the Spring Street Pump Station and the system was able to shift to use of the Brattle Court Pump Station, avoiding major system disruptions to Arlington, Bedford, Belmont, Lexington, Waltham and Winchester. All of the metropolitan pump stations were designed with N+1 pumps and each has emergency backup power supply or redundant hydraulic supply (pressure reducing valves from a higher service area) to supply water in the event of a power loss.

MWRA's approach is not unique and is reflected in key national guidance documents.
The Recommended Standards for Water Works (the "10 States Standards" which was the basis for development of the Massachusetts Department of Environmental Protection's Guidelines for Public Water Systems) says that designs should "*...identify and evaluate single points of failure that could render a system unable to meet its design basis. Redundancy (geographically separated) and enhanced security features should be incorporated into the design to eliminate single points of failure when possible, or to protect them when they cannot be eliminated.*"

The Environmental Protection Agency's Vulnerability Assessment Guidance recommends redundancy development as a strategy to decrease the criticality of specific facilities, processes and assets. "In assessing those assets that are critical, consider...single points of failure (e.g. critical aqueducts, transmission systems, aquifers, etc.)..."

Other major utilities across the United States have taken varied approaches to this guidance. One example is San Francisco where the focus has been on being able to maintain and/or quickly recover service in the event of an earthquake. This has meant the need to develop redundant tunnels in parts of their system. The San Francisco Public Utilities Commission (SFPUC) recently completed the last of three new tunnels, creating a water lifeline able to withstand earthquakes on three different faults (Hayward, Calaveras, and San Andreas). The project was part of the agency's \$4.8 billion Water System Improvement Program (WSIP) which has completed all but one its 83 total projects. The New Irvington Tunnel measures 8.5 feet in diameter and was constructed parallel to the existing Irvington Tunnel completed in 1932, with a goal of restoring water deliveries within 24 hours after a major earthquake in the Bay Area. This placement allows the SFPUC to take either tunnel out of service for maintenance and inspections. For more information on San Francisco redundancy projects, see Attachment 2.

New York City essentially operates three separate supply and aqueduct systems which gives the City great flexibility if one needs to be shut down for any reason. Most recently, the focus has been on improving interconnections between the Catskill and Delaware aqueducts and on maximizing capacity to deliver water from the Catskill/Delaware system. In 2013, DEP broke ground on the Shaft 4 connection of the Delaware and Catskill Aqueducts and expects to complete construction in 2016. Activation of the Manhattan Section of City Water Tunnel No.3 took place in October 2013, providing redundancy for the older Water Tunnel No.1 in Manhattan. The construction of Water Tunnel No.3 is intended to provide the City with a critical third connection to its Upstate New York water supply system, allowing for the repair of tunnels No.1 and No.2 for the first time in their history. Construction on Tunnel No.3 began in 1970, and its first phase is now completed. The tunnel will eventually measure more than 60 miles long, though completion of all phases is not expected until at least 2020.

MWRA Track Record

Since MWRA's inception, there has been an ongoing effort to improve water system operation and reliability through the MWRA capital improvement program and Master Plan process. Many of the projects that have been completed, that are underway, or are proposed provide an improvement in system redundancy in part, if not in total. Clearly, any project whose sole purpose was elimination of a single point of failure could be considered a redundancy project. It is also useful to think about projects that address redundancy in other ways, so staff have sorted completed projects that have a redundancy component into the following three categories.

A. Elimination of Single Points of Failure. Projects constructed specifically to allow continuation of service in the event of a failure of an asset (pipeline, tunnel, storage tank, pump station, etc). Equally important, these projects may allow other assets, that otherwise could not, be taken out of service for inspection, maintenance, rehabilitation, or replacement. Types of projects in category A and representative examples include:

    - System improvements necessary to allow construction of redundancy projects (example: The Dorchester Corridor Valve Installation project allowed isolation of key sections of pipelines so that the Southern Spine projects, including construction of Section 107 to back up Section 22, could be completed.
    - New storage where pipeline redundancy is limited or that greatly increases operational flexibility (Blue Hills, Spot Pond)
    - Improvements in pump station suction and discharge piping (Section 99-Redundant suction line to Gillis PS; Section 96-redundant discharge line from Newton Street PS)
    - Redundant transmission system projects (MetroWest Tunnel and Hultman Interconnections, Chicopee Valley Aqueduct redundancy project)
    - Redundant distribution system pipelines (Section 91, 91B and 92 in the Northern High system)

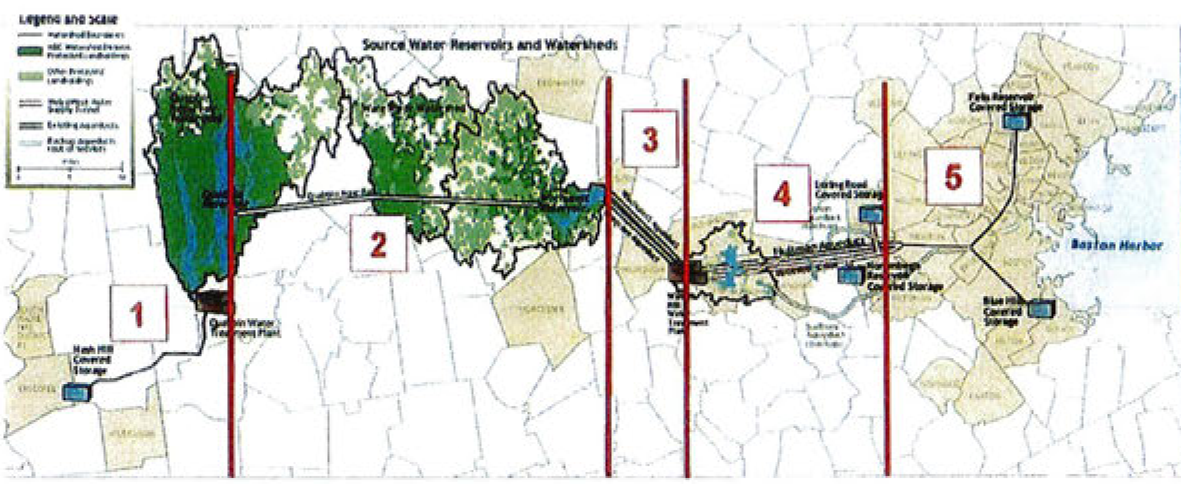
B. Preserving viability of existing back-up systems. Projects that are necessary to maintain an existing back-up system and ensure its availability. Most of these projects involve rehabilitation of existing transmission system assets or condition assessments designed to monitor the asset on an ongoing basis. This would include projects such as the lining of Wachusett Aqueduct and the tunnel inspections recommended for the Cosgrove Tunnel and the Quabbin Tunnel. However, this category also includes those projects done to increase operational flexibility in an emergency. For example, Safe Drinking Water Act requirements mandated the removal of open distribution storage reservoirs and, in order to comply, MWRA took such reservoirs off-line throughout the system. New covered storage at Fells Reservoir, Loring Road, Norumbega and Spot Pond have been constructed with the ability to bring those off-line reservoirs back into service in the event of a major system failure. This photo shows the new valve chamber constructed at Norumbega Reservoir which would allow the Reservoir to be re-connected to the system in the event of an emergency.

C. Preventing loss of redundancy. Projects to rehabilitate or replace assets that provide an existing level of redundancy in order to avoid unintended single points of failure through assets failing. Many of MWRA's capital projects identified and completed in the past 30 years fall into this category given the age and deteriorated condition of much of the infrastructure inherited by MWRA. These vary from small projects such as repairs to the Beacon Street Line in the Boston Low Service area to major rehabilitation projects spanning many communities such as the East-West Spot Pond Mains project which restored major pipelines and connecting "ladder rungs" in the Low Service pressure zone. This photo shows the location of the replacement turbine by-pass valve at the Oakdale Power Station which preserves the ability for Quabbin to Wachusett water transfers in the event of a hydro turbine failure. The previous valve had failed repeatedly, creating damaging water hammer that had threatened the station piping system.

Examples of Completed Projects that Eliminated Single Points of Failure:

MetroWest/Hultman Aqueduct Interconnections: Probably the most important accomplishment in terms of elimination of single points of failure of the water transmission system is construction of the MetroWest Water Supply Tunnel and the Hultman Aqueduct interconnections projects. After decades of planning, design and construction the tunnel came on line in November, 2003 to provide a second means of water conveyance from the John J. Carroll Water Treatment Plant to the Norumbega Covered Storage Facility and ultimately the City Tunnel and Metropolitan distribution system at Shaft 5. The tunnel is a 17.6 mile long, 14-foot diameter deep rock tunnel (with a 14-foot diameter connection to the Loring Road Covered Storage Facility) and it was constructed to ensure that there was a redundant means of providing water to the metropolitan area in the event of a failure along the Hultman Aqueduct. The Hultman Aqueduct was then rehabilitated after 70+ years of continuous service and interconnecting structures created to provide the ability to isolate sections of either transmission main while continuing to provide water service to the Metropolitan area. The final Hultman interconnecting mains project was completed in 2013. This photo shows the new valve chamber at Shaft 5 which provides an interconnection between the MetroWest Tunnel and the rehabilitated Hultman Aqueduct.

Chicopee Valley Aqueduct: Also in the transmission system, in 2007, MWRA completed construction of a 30-inch diameter 8,100 foot long second barrel of the CVA from Nash Hill Covered Storage to the City of Chicopee; 3,100 feet of 16-inch redundant pipeline between Nash Hill Covered Storage and the take-off point for South Hadley; and 2,400 feet of 20-inch redundant pipeline between the Route 21 valve chamber and the Wilbraham takeoff. These pipelines provide redundant supply for critical sections of the 14.8 mile long aqueduct. With these new pipelines in place, the communities will be connected to Quabbin Reservoir, Nash Hill Covered Storage or both in the event of a failure along the Aqueduct. In addition, emergency connection points to the Springfield water system were created to allow connection of MWRA's mobile pumping unit to supplement supply in the event of a prolonged interruption.



These 2 projects address single points of failure in segments 1 and 4 of the 5 MWRA water transmission system segments shown in the figure above. Segment 2 shows the Quabbin Aqueduct between Quabbin and Wachusett Reservoirs. Although the assumption is that tunnels have a useful life of 100 years, risk of failure considers both major subsurface issues, such as structural vulnerabilities due to earthquake or faults and the potential for failure due to pipe failures at the surface connections. The Quabbin Aqueduct has not been recently inspected and the CIP includes development of an inspection plan for this tunnel. Because the system can rely on the Wachusett Reservoir during winter/spring months in years with normal precipitation if necessary, staff believes that this tunnel can be inspected with minimal risk or disruption. The remaining two segments are described here but further information is provided below. Segment 3, from Wachusett Reservoir to the John J Carroll Water Treatment Plant will be strengthened with the upcoming Wachusett Aqueduct Pump Station project. Segment 5, the City Tunnel, Dorchester Tunnel and City Tunnel Extension will be addressed in a series of staff summaries in 2016.

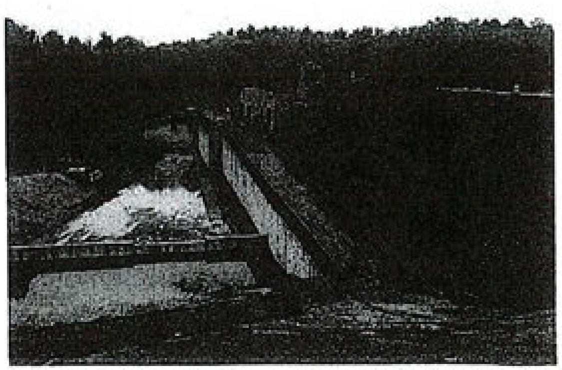
Other completed transmission and distribution projects include the following:

The Chestnut Hill Emergency Pump Station was constructed in 2001 to supply the Southern High and Southern Extra High in an emergency by taking water from the Sudbury Aqueduct via the Chestnut Hill Reservoir or by taking water from the Low Pressure system. The 90 mgd capacity reflects the station taking non-potable water from the Chestnut Hill Reservoir. This station was instrumental to the success of MWRA's response to the break at Shaft 5 in 2010.

Section 97A was completed in 2009. This project installed approximately 2,000 feet of 20-inch water main, a rehabilitated metering station and a new PRV. This project also addressed existing pressure deficiencies in the Orient Heights area. The PRV allows the line to serve critical parts of the Boston Low (Logan airport) in emergencies. The completion of 97A improves the MWRA's operational flexibility for moving ahead with Section 8 work in the Northern Low system.

For Lynnfield, the new Lynnfield Pipeline was completed in 2013. This addressed the insufficient capacity of the existing 8-inch MWRA line feeding the District. The project connects Lynnfield's Meter 169 to Section 70 in Saugus and includes 4,700 linear feet of new 24-inch main and 1,800 linear feet of 36" main.

The recently completed Spot Pond Pump Station and Storage Tank project (shown in this photo) provides back-up capabilities to the Gillis pump station, similar to the back-up stations constructed in the 1950's in the Northern Extra High and Southern Extra High service areas. Gillis Pump Station currently supplies the Northern Intermediate High/Bear Hill (NIH) service area and the Northern High Service/Fells (NHS/Fells) service area. The new Spot Pond Pump Station and Storage Tank provides terminal low service storage which provides operational flexibility for supply to the NIH and Fells service areas and critical storage for the Northern Low (NL) service area in the event of service interruption. The Spot Pond Pump Station is capable of drawing water from either the low service or high service zones and will pump to the high and intermediate high zones providing much needed redundancy to Gillis Pump Station.



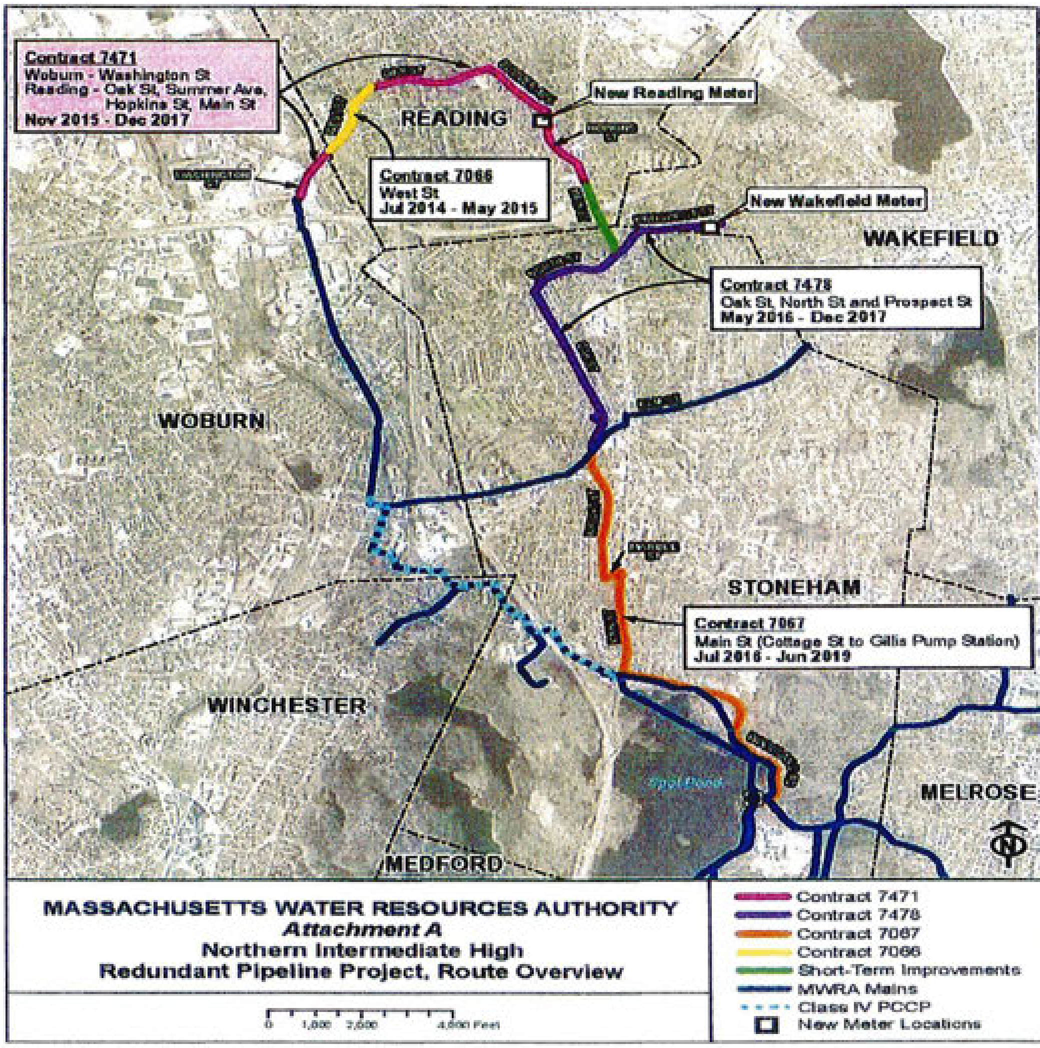
Important Projects to Eliminate Single Points of Failure are Underway:

There are several critically important projects that are in design, about to be bid, and under construction which will dramatically improve either transmission or distribution system redundancy and eliminate serious single points of failure.

The Cosgrove Tunnel is a critical transmission system component that brings water from Wachusett reservoir to the Carroll Water Treatment Plant. The back-up to the tunnel is the gravity Wachusett Aqueduct which can supply approximately 240 MGD of water to the service area. The aqueduct was rehabilitated in 2002 to allow connection of the CWTP to the Cosgrove Tunnel. However, it operates at a lower gradeline then the treatment plant and therefore could not provide water that meets drinking water standards without boiling and booster chlorination. Design and construction of a pump station at the end of the Aqueduct was selected as the means to protect against a Cosgrove Tunnel failure. The graphic above shows the planned pump station. This pump station will lift water to the treatment plant allowing the Cosgrove Tunnel to come out of service without impacting water quality. The 240 mgd capacity would allow for unrestricted supply for at least eight months during the lower demand fall/winter/spring period. The construction contract was awarded in 2015.

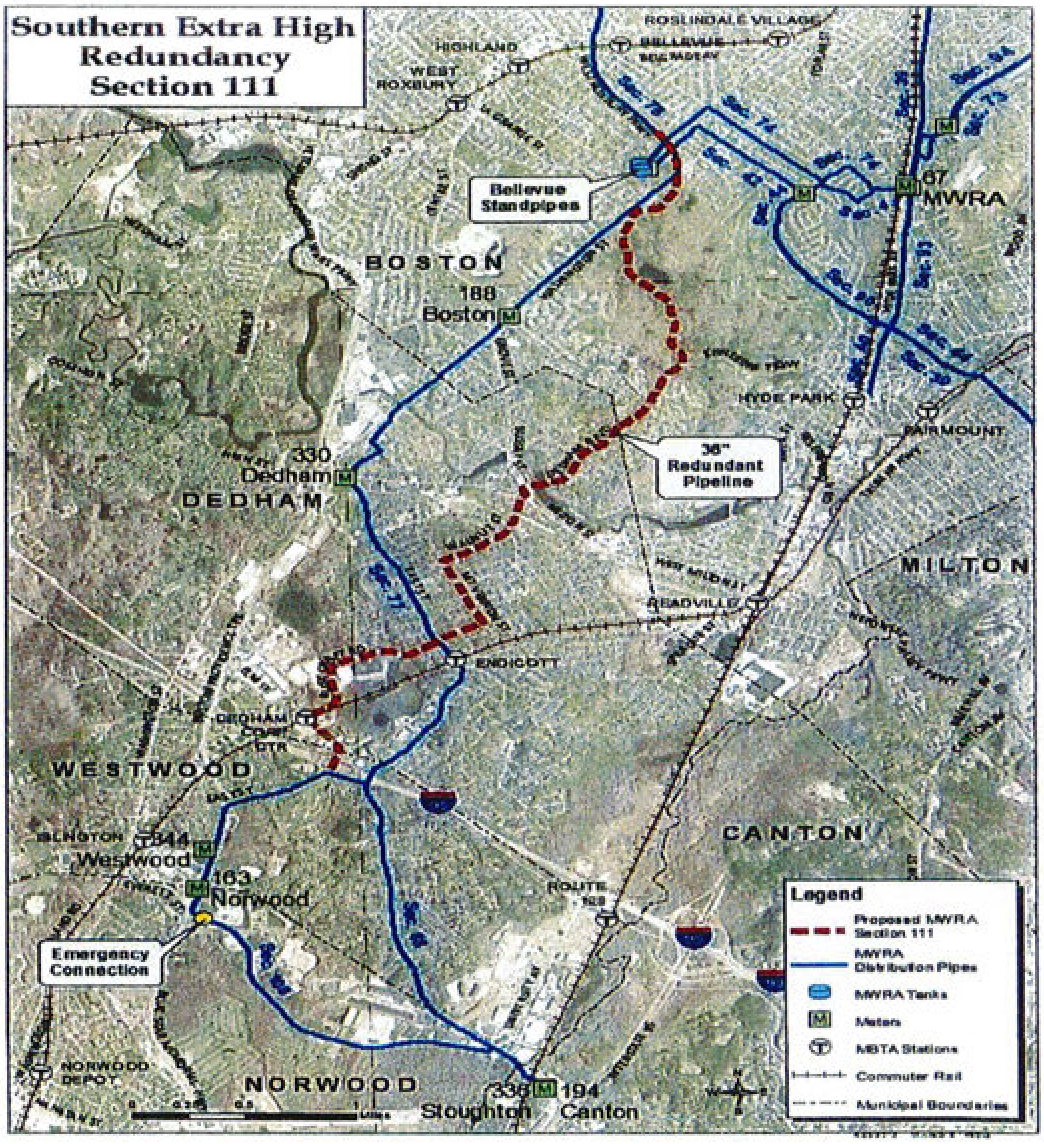
In addition to the improvements described above to the NIH service area pumping capability, the 2006 Master Plan identified the single tank and pipe system in the NIH distribution service area as lacking redundancy. Concern over the potential for a catastrophic failure of the main Section 89 pipeline increased when in-house research showed that a 10,000 foot portion of this pipeline is Prestressed Concrete Cylinder Pipe (PCCP) that was constructed by a particular manufacturer with a Class IV wire that has been prone to embrittlement and failure elsewhere in the country.

The map illustrates the various contracts that will help to provide looped service for this pressure zone. Short term improvements to interconnect Stoneham and Reading along Rt. 28 are complete as is work along West St. in Reading. Contract 7471 was also awarded in 2015 and work will begin this year. Overall, the project is expected to be completed in 2019 at an estimated cost of approximately $81 million (Final FY16 CIP-excludes rehab cost of existing sections 29 and 89).



In the Southern Extra High Service Area, Sections 77 and 88 are single spine mains serving Canton, Norwood, the Dedham-Westwood Water District and Stoughton. Although four of these communities are partially supplied and may be able, in part, to provide some level of service in the event of a pipeline leak, break or other failure, Norwood is fully supplied by MWRA.

The University Avenue Connection (Section 108) at the lower portion of the map was constructed separately to provide partial redundancy. Construction on the first contract is expected to begin in 2016. Total estimated cost for the complete project is approximately $86.6 million (Final FY16 CIP excluding University Ave and costs of rehab for Sections 77 and 88 but including long term new storage).



Remaining Transmission System Redundancy Needs:

Metropolitan Tunnels: Segment 5 as shown on the overall transmission system map (page 5) includes the tunnel system to the east of Shaft 5 and encompasses the City Tunnel, the City Tunnel Extension, and, to the south, the Dorchester Tunnel. These three tunnels come together at Shaft 7. Of particular concern is the area around and underneath the Chestnut Hill Reservoir that is critical to MWRA's ability to deliver water to the greater Boston area. On average, over 60 percent of the water delivered by MWRA flows through the Metropolitan tunnels, supply mains, pipes and valve chambers in and around the Chestnut Hill Reservoir footprint. Shaft 7 is the end of the City Tunnel and provides connection to supply the City Tunnel Extension to the north and the Dorchester Tunnel to the south. As noted above, tunnels are generally assumed to have a 100-year useful life and these tunnels were constructed in 1950, 1963 and 1976, respectively. The major concern with tunnels is the potential for a failure at the surface connections at the top of the tunnel shafts. A rupture of piping at surface connection points on any of the metropolitan area tunnel shafts would cause an immediate loss of pressure throughout the entire High Service area and would require difficult emergency valve closures and lengthy repairs.

Ideally, in the event of an emergency with either a tunnel or surface connection, the best resolution would be to have a transition to a backup system that is unnoticeable by the end consumer. However, MWRA's system is not yet at that point and, depending upon the location of a failure, service could be significantly disrupted.

With the current system configuration, in the event of a failure of the City Tunnel or the interconnections with the City Tunnel Extension or the Dorchester Tunnel, a limited amount of water could be transferred through the 60-inch WASM 3 line and the recently rehabilitated WASM 4. The Sudbury Aqueduct would need to be brought on line and extensive use of the Sudbury Aqueduct/Chestnut Hill Emergency Pump Station and open distribution storage at Spot Pond and Chestnut Hill would be required. Supply would be limited and a "boil water" order would be put in place. Failure of the City Tunnel Extension would be similar with reliance on WASM 3 and open storage at Spot Pond. In the above scenario, the ability to put the Sudbury Aqueduct quickly into service would be critical.

This potential situation has elicited careful study on the part of MWRA to determine the best course of action. The CIP has several projects that have been contemplated to increase operational response capabilities to these failure scenarios. Staff plan a series of future briefings for the Board of Directors to specifically address this part of the water transmission system and discuss the merits of the various approaches to fulfilling elimination of these single points of failure. This white paper was intended to provide additional context for the initial staff summary which will look at why redundancy for the metro tunnels is essential, including the condition of the system, potential failure scenarios, the difficulty of recovering from any failure and restoring service, and the inability to shut down the system for either inspection or maintenance. The second will review work done over the past several years examining a wide range of alternatives to provide full or partial redundancy, including their costs, reliability of operation, constructability issues and environmental impacts. The third staff summary will examine whether and how the costs can be accommodated within the framework of predictable and sustainable rates.

ATTACHMENT 1
LIST OF PROJECTS

Category A-New Infrastructure to Specifically Address SPF

Already Constructed:

MetroWest Tunnel/Hultman Interconnections
Chicopee Valley Aqueduct
Section 99-Redundant suction to Gillis
Lynnfield Pipeline-Section 109
Section 91/91B/92
Section 97A/97/98
Section 101-part of Section 83 redundancy
W10B/W10C-Suction to Lexington St. PS
Sections 105/106-part of Chestnut Hill Connecting Mains project
Section 94-reinforced Hyde Park suction-allowed rehab of Sec 73
Section 107 (replaced 21/43)
Sections 95/100-redundancy to Dudley Rd. PS
Section 96-redundancy to Section 76-discharge from Newton St PS
Section 108-University Ave-part of SEH short-term solution
Chestnut Hill Emergency Pump Station
Dorchester Corridor Valve Installation
Fire Chief's Study-other targeted interconnections
Deer Island Storage Tank
Blue Hills Storage
Spot Pond Storage and Pump Station

In Progress:

NIH-Section 89
SEH-Section 77
Wachusett Aqueduct Pump Station

Future:

Section 75

ATTACHMENT 2

WATER SYSTEM REDUNDANCY – UTILITY EXAMPLES & POLICY GUIDANCE

UPDATED FROM DECEMBER 2007

Depending upon the configuration of a water system, different means of providing redundancy or creating operational flexibility allow the utility to respond to emergencies and/or unforeseen conditions. In December 2007, staff compiled a list of reviews regarding water system redundancy structures from a variety of cities across the U.S. Utility examples and corresponding policies were examined to provide guidance and further understanding of the work carried out by water systems on a national level. The following document provides an update of the utilities reviewed in 2007, outlining progress made on initiatives and goals that have been accomplished.

San Francisco, California

The San Francisco Public Utilities Commission (SFPUC) has accomplished an extensive amount of utility upgrades since last review in December 2007. SFPUC customers are currently served by 280 miles of pipelines, 60 miles of tunnels, 11 reservoirs, five pump stations and two treatment plants that bring snowmelt from the Sierra Nevada Mountains to the cities surrounding the San Francisco Bay. San Francisco's principle failure scenario remains an earthquake, as pipelines and tunnels from the Hetch Hetchy Reservoir cross three major earthquake faults that could interrupt water service for days and weeks after a significant event. The following updates represent the most recent findings on redundancy/operational flexibility projects that were originally examined in our 2007 report:

On March 3, 2015, the San Francisco Public Utilities Commission (SFPUC) announced that after more than four years of construction, a new 3.5-mile-long, seismically improved tunnel is now delivering water to 2.6 million people in the San Francisco Bay Area.[2] The New Irvington Tunnel Project completes the last of three new tunnels, creating a water lifeline able to withstand earthquakes on three different faults (Hayward, Calaveras, and San Andreas). The project is located between the Sunol Valley and Fremont, and is part of the agency's $4.8 billion Water System Improvement Program (WSIP) which has only one remaining project (of 83) to complete. The New Irvington Tunnel measures 8.5 feet in diameter and was constructed parallel to the existing Irvington Tunnel completed in 1932, with a goal of restoring water deliveries within 24 hours after a major earthquake in the Bay Area. This placement allows the SFPUC to take either tunnel out of service for maintenance and inspections, improving redundancy and securing access to the water from Hetch Hetchy, San Antonio, and Calaveras Reservoirs. In the coming weeks, crews will take the existing tunnel out of service for inspection while the project team will work to restore above ground facilities around the new tunnel. This above ground work is expected to last through fall of 2015.

2 http://sfwater.org/modules/showdocument.aspx?documentid=6846

On April 13, 2015, SFPUC announced the completion of a $278-million project to improve the seismic and operational reliability of the Harry Tracy Water Treatment Plant located in the city of San Bruno.[3] The largest part of the construction was a new 11-million-gallon treated water reservoir. During the design, the discovery of the Serra Fault trace directly beneath crucial portions of the plant prompted a significant redesign of the project to relocate and completely rebuild the reservoir in its current location. The plant upgrade has been seismically designed and reinforced to withstand a magnitude 7.9 earthquake on the San Andreas Fault, with the goal of providing 140 million gallons of water per day, for 60 days, within 24 hours of a major earthquake. In September, 2015, the San Andreas Pipeline No. 3 (a 1,000-foot segment of 66-inch pipeline) that runs through San Bruno was completed and this pipeline can now also withstand a 7.9-magnitude earthquake.

The New Crystal Springs Bypass Tunnel was completed ahead of schedule, measuring 4,200 feet long at depths of up to 160 feet underground.[4] Tunnel excavation was completed on March 24, 2010, and pipeline installation was completed on May 26, 2010. The goal of the project was to provide redundancy to the existing Crystal Springs Bypass Pipeline built in 1969 and to ensure water delivery after a major earthquake. The old pipeline will remain in service to provide redundancy for inspection and maintenance of the new tunnel.

The San Antonio Backup Pipeline began construction in April of 2013 and was expected to reach completion in March 2015. Once completed, the Backup Pipeline will enable the SFPUC to discharge Hetch Hetchy water to a nearby quarry pit during emergency events while transporting San Antonio Reservoir water to the Treatment Plant at the same time. The goal is to add operational flexibility to the system and minimize the risk of service disruption to 2.6 million customers, as the existing San Antonio Pipeline has limited conveyance capacity and a history of failure due to wire corrosion and breakage in the Pre-stressed Concrete Cylinder Pipe.

As the SFPUC's Quarterly Report for FY14-15 states, The East-West Transmission Main project has successfully been completed with the installation of approximately 4.5 miles of 36-inch and 42-inch welded steel pipes, allowing the SFPUC to move water from the east side of the city into the Sunset system in the event of a peninsula pipeline failure or emergency.[5] Prior to this project, there was no transmission main dedicated to supply emergency water from the eastern part of the city to the west.

The objective of the San Joaquin Pipeline System project was to construct a 78-inch-diameter pipeline totaling approximately 11 miles at the Western portion of the SJPL System to ensure adequate flow at that end. As of June 2013, the eastern segment of the system was completed, which was the last of five projects constructed in that region.

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3 http://www.waterworld.com/articles/2015/04/sfpuc-completes-new-seismic-upgrades-to-drinking-water-treatment-plant.html

4 http://www.tunneltalk.com/SFPUC-Mar10-Crystal-Springs-bypass-tunnel-complete.php

5 http://www.sfwater.org/Modules/ShowDocument.aspx?documentID=6341 . pg. 17

New York City[6]

New York City released its PlaNYC Progress Report in 2014, providing an update of any progress made in areas of sustainability and resiliency since the previous year. The City's initiative to repair the leak in the Delaware Aqueduct is still in progress, and is expected to reach completion in 2017. The first half of the bypass tunnel project (focusing on construction of access shafts) commenced on schedule in March 2013, and the second half of the project (which includes the construction of the 2.5 mile long bypass tunnel) recently reached the 60% design milestone. The project is currently on schedule to commence work in 2015.

The initiative to improve interconnection between the Catskill and Delaware aqueducts and maximize capacity to deliver water from the Catskill/Delaware system remains in progress. In 2013, DEP broke ground on the Shaft 4 connection of the Delaware and Catskill Aqueducts and expects to complete construction in 2016. Activation of the Manhattan Section of City Water Tunnel No.3 took place in October 2013, providing redundancy for the older Water Tunnel No.1 in Manhattan.[7] The construction of Water Tunnel No.3 is intended to provide the City with a critical third connection to its Upstate New York water supply system, allowing for the repair of tunnels No.1 and No.2 for the first time in their history. Construction on Tunnel No.3 began in 1970, and its first phase is now completed. The tunnel will eventually measure more than 60 miles long, though completion of all phases is not expected until at least 2020.

Seattle, Washington[8]

Seattle Public Utilities has recently embarked on a seismic vulnerability study (project scope released in March 2015) to assess facility risk involved with 100-year and 500-year return interval earthquake ground motions.[9] Since SPU's last comprehensive evaluation in 1990, understanding of the seismicity of crustal faults in the Puget Sound area has changed dramatically. Lessons have been learned on water system performance from recent earthquakes, thereby causing seismic codes and standards to evolve. The purpose of this project will be to develop mitigation alternatives that avoid single points of failure and to develop seismic design standards for the new SPU water transmission/distribution facilities with an emphasis on pipeline reliability.

Seattle has continued to make investments in its drinking water system since last review in 2007. SPU released its *2013 Water System Plan* in July 2012, which focuses primarily on the 2013-2018 time scale and identifies infrastructure improvement needs for the water supply system that include Morse Lake Pump Plant, Overflow Dike Replacement, and Landsburg Dam Flood Passage Improvement projects. SPU also plans to complete investigations that support water resources operations including refill of Chester Morse Lake to elevation 1566 feet, potential impact on water quality that could be caused by failure of Lake Youngs Cascades Dam, and potential additional drawdown of South Fork Tolt Reservoir.

6 http://www.nyc.gov/html/planyc2030/downloads/pdf/140422_PlaNYCP-Report_FINAL_Web.pdf, pg. 101
7 http://www.nyc.gov/html/nycwaterboard/pdf/blue_book/bluebook_2015.pdf, pg. 6
8 http://www.seattle.gov/util/cs/groups/public/@spu/@water/documents/webcontent/04_007871.pdf
9 http://www.seattle.gov/util/cs/groups/public/@spu/@engineering/documents/webcontent/1_036077.pdf

SPU plans to mitigate the risk of pipe failure in the slide area between the Regulating Basin and Tolt Water Treatment Facility through continued slope monitoring, additional geotechnical data collection, periodic internal inspections, and biannual leak testing. Acquiring ownership of the land in the slide area and implementing pipeline stress relief measures when necessary will also aid to mitigate the risk of pipe failure. Cost-effective cathodic protection projects will be implemented as needed for the concrete cylinder and steel transmission pipelines to protect these from corrosion and extend their service lives.

Washington, DC – DC WASA[10]

In the coming years, DC Water will be performing rehabilitation of large water mains throughout the city involving the joint seal of large transmission mains to help improve water quality and system reliability, increase water pressure in some areas, and maintain adequate flows throughout the system. The City has embarked on a ten-year $3.8 billion Capital Improvement Program (CIP) that, when completed, will significantly enhance DC WASA's water and sewer facilities infrastructure. The following project examples represent small-scale reliability efforts within the CIP:

The 17th NE/SE Project, as part of DC Water's CIP, will result in the installation of a new 20-inch water main and replace the existing 8-inch main within that location. The 20-inch water main acts in a dual capacity of alleviating low flow and pressure in the community near Kenilworth NE while serving as a redundant water main for the RFK Stadium area in case of emergency or water outages. These efforts will improve water quality and system reliability, increase water pressure, and maintain adequate flows throughout the system. Construction is scheduled to span from March 2015 to April 2016.

The 16th & Alaska Pumping Station Rehabilitation Project will allow DC Water to perform improvements for its pumping station located at 16th Street NW and Alaska Ave NW, as no major construction or design improvements have been conducted to the station in almost twenty years. The work being proposed under this project will improve overall reliability of the facility and provide operational flexibility. Construction is scheduled to span from June 2014 to May 2015, and involves the installation of a generator (operating as a backup electrical source to the pumping station), an upgrade of the security system, and an upgrade of all pump controls/control system as needed.

Portland, Maine[11]

Portland Water District's website remains unchanged since last review in 2007, stating that "having more than one transmission main is not a coincidence," and "as with the whole distribution system, redundancy is maintained to ensure minimum interruptions in water service." Portland's Water Main Replacement Program has a goal of providing a reliable distribution system designed and maintained to enhance public health and safety. In the coming 2015 season, water main replacement will involve replacing existing water mains with new ones

10 http://www.dcwater.com/about/cip/default.cfm

11 https://www.pwd.org/water-distribution

to improve water flow characteristics and to improve service to customers. There are various projects scheduled between April 1 and mid-November of 2015 to begin construction, including an array of water main replacements around Portland and a CSO project scheduled for May 2015.

Portland, Oregon

The Portland Water Bureau released its Annual Watershed Control Program Report for Water Year 2014 in December 2014, detailing the "several layers of redundancy" in its chlorination system. Chlorine is injected via the carrier-water line into each conduit from two primary and secondary chlorination systems at the Bureau's Headworks. Although each system is capable of delivering a sufficient dose of chlorine, both normally operate, adding just over one-half of the applied dose each. If one were to fail, CT's would sufficiently be met with just one of the two systems operating. One-ton chlorine cylinders are used, and 12 are ready at any given time with 12 one-ton cylinders typically in stand-by with automatic switch-over. In addition, there is a spare chlorinator in the primary system that can be used to back up any of the chlorinators in the primary system. There are multiple low level alarms and low vacuum alarms, along with extra chlorination systems and carrier-water lines that are used regardless of which intake is in use. The valves for switching from one carrier-water line to the other are manual, but normally both are used simultaneously. Chlorination can continue in the event of a power failure since the carrier water supply is gravity-fed.

Board of Director's Briefings Regarding Redundancy Projects

November 28, 1990	Board approval to proceed with design of the MetroWest Water Supply Tunnel. Staff recommended that a future tunnel extend north from Weston to Shaft 9A.
September 13, 1995	Informational briefing at a special Board meeting regarding the planning and interrelationships of the proposed MetroWest Water Supply Tunnel, Norumbega and other covered storage projects, and the Carroll Water Treatment Plant
September 20, 1995	Board approval to award the Spot Pond Pipeline (Section 99) construction contract to provide a redundant supply to the Gillis pump station. Completed September 30, 1999.
May 22, 1996	Board approval to award the first construction contract for the MetroWest Water Supply Tunnel. Construction of the tunnel was completed on April 3, 2003.
August 7, 1997	Board approval to award the Loring Road Covered Storage construction contract. Completed November 30, 2000.
February 11, 1998	Board approval to award the Nash Hill Covered Storage construction contract. Completed February 17, 2000.
February 10, 1999	Board approval to award the Chestnut Hill Replacement Pumping Station to provide redundancy to the Southern High and Southern Extra High service areas. Completed March 30, 2001.
September 29, 1999	Board approval to award the Norumbega Covered Storage design build contract. Completed June 30, 2005.
October 12, 2005	Board approval to award the Chicopee Valley Aqueduct Redundancy construction contract. Completed April 21, 2008.
November 15, 2006	Board approval to award the Blue Hills Covered Storage design build contract. Completed April 1, 2010.
January 10, 2007	Informational staff summary on construction progress of the Chicopee Valley Aqueduct Redundancy construction project.
June 27, 2007	Informational staff summary on the benefits and proposed schedule for the Hultman Aqueduct Rehabilitation and Interconnections to the MetroWest Tunnel project.

December 12, 2007	Informational Staff Summary describing the level of redundancy throughout the water transmission and distribution systems and the status of ongoing or proposed projects and studies.
March 12, 2008	Board approval to award the University Ave Water Main construction contract to provide a pipeline loop supplying Norwood. Completed November 7, 2008.
September 17, 2008	Board approval to award a contract (Transmission Redundancy Plan) to evaluate alternatives and develop conceptual design for redundancy for the metropolitan tunnel system and the Cosgrove Tunnel.
July 15, 2009	Board approval to award the Hultman Aqueduct Rehabilitation and Interconnections construction contract (CP-6A). Completed May 31, 2013.
December 16, 2009	Board approval to award the Southern Spine Distribution Mains Section 107 construction contract to provide a redundant supply to Milton and Quincy. Completed January 17, 2012.
May 6, 2010	White paper on Water System Redundancy Planning and Construction. The white paper described completed, ongoing and planned redundancy projects throughout the water system. The white paper identified the need for redundancy for the metropolitan water system and noted that the findings of the Transmission Redundancy Plan would be presented soon.
June 30, 2010	Informational Staff Summary presenting the findings and recommendations of the Transmission Redundancy Plan. The recommended alternative included the construction of seven miles of large diameter surface pipes, Slip lining the Sudbury Aqueduct with a seven foot diameter pipe, rehabilitation of the Chestnut Hill Emergency Pump Station and a four mile tunnel from Norumbega Reservoir to the Sudbury Aqueduct.
December 22, 2010	Board approval to award the Lynnfield/Saugus Pipeline construction contract to provide redundancy to the Lynnfield Water District. Completed December 10, 2012.
October 12, 2011	Board approval to award the Spot Pond Water Storage Facility and Pump Station design build contract. Put into service in December 2015.

January 18, 2012	Informational staff summary on construction progress of the Hultman Aqueduct Rehabilitation and Interconnections to the MetroWest Water supply Tunnel
March 14, 2012	Board approval to award the Hultman Aqueduct Interconnections construction contract (CP-6B). Completed June 23, 2013.
May 15, 2013	Informational Staff Summary on the completion of the Hultman Aqueduct Rehabilitation and Interconnections with the MetroWest Water Supply Tunnel. For the first time since the Hultman Aqueduct was planned in the 1930s, the transmission system has full redundancy from Marlborough to Weston.
November 18, 2015	Board approval to award the Wachusett Aqueduct Pump Station construction contract to provide redundancy to the Cosgrove Aqueduct

STAFF SUMMARY

TO: Board of Directors
FROM: Frederick A. Laskey, Executive Director
DATE: July 13, 2016
SUBJECT: Weston Aqueduct Supply Main 3
Project Update

COMMITTEE: Water Policy & Oversight

X INFORMATION
___ VOTE

A. Navanandan, P.E., Chief Engineer
David Coppes, P.E., Director, Waterworks
Frederick Brandon, P.E., Assistant Director, Engineering
Preparer/Title

Michael J. Hornbrook
Chief Operating Officer

On June 26, 2013 the Board approved the award of Contract 6539, Weston Aqueduct Supply Main 3 (WASM 3): Design, Construction Administration and Resident Engineering Services, to Stantec, Inc. (formerly Fay Spofford and Thorndike, LLC). WASM 3 is a critical pipeline in the MWRA distribution system and has experienced an increased number of leaks in its eighty-year life. WASM 3 serves over 250,000 customers and it has no existing redundancy. It is one of MWRA's largest potential single source of failure. It is a necessary component of all the proposed various metropolitan redundancy alternatives to be presented at an upcoming off-site Board meeting in September. The only variable for the WASM 3 in the long-term metropolitan redundancy alternatives is the selection of rehabilitation of the line or its replacement with a larger sized pipe.

RECOMMENDATION:

For information only.

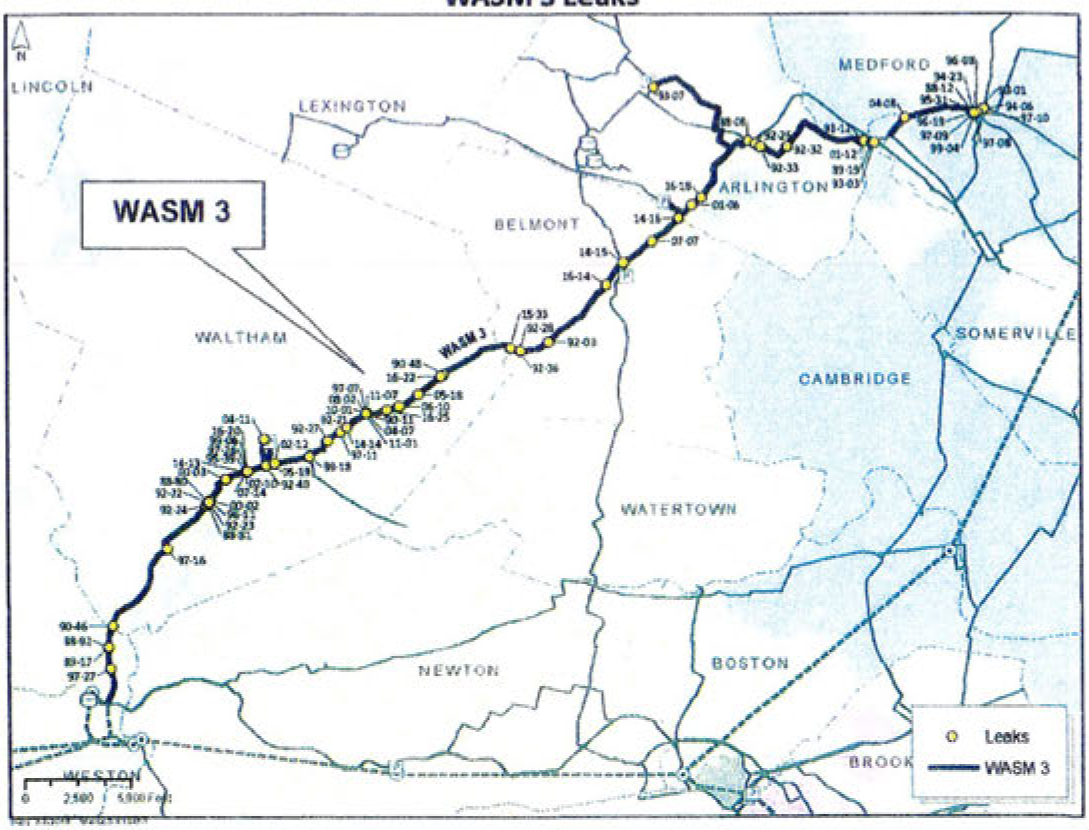
DISCUSSION:

The Weston Aqueduct Supply Main 3 (WASM 3) is a ten mile long 56-inch and 60-inch diameter steel pipeline that supplies the communities of Waltham, Watertown, Belmont, Arlington, Lexington, Bedford and Winchester (see Attachment 1). The pipe, which was built in the 1920s, requires frequent leak repairs and rehabilitation is critical. WASM 3 carries high service water from the 7-foot diameter branch of the Hultman Aqueduct to community connections and MWRA pumping stations serving the Intermediate High, the Northern High and the Northern Extra High pressure zones. It extends from the Hultman Branch in Weston to the Shaft 9 connection pipe in Medford and supplies approximately 250,000 customers over all. There is currently no back-up for this pipeline and it has been identified as a key element for providing long-term redundancy to a large portion of the metropolitan area. WASM 3 is one of the most critical single points of failure in the water distribution system after the metropolitan tunnel system.

3: Design, Construction Administration and Resident Engineering Services, to Stantec, Inc. (formerly Fay Spofford and Thorndike, LLC). The scope of this contract includes engineering services for rehabilitation/replacement of the WASM 3 pipeline. The project as originally envisioned included the replacement of 7.3 miles of existing pipe trough Weston, Waltham and Belmont with a new 72-inch diameter pipeline and rehabilitation of the remaining 2.7 miles of existing pipe through Arlington, Somerville and Medford. The design and construction services span a total duration of 13 years.

The pipe has had seventy two leaks since 1987. Figure 1 below shows the locations of repaired leaks along the pipeline. In recent years, two to three leaks have been repaired per year. There are certain locations with high ground water areas where corrosion leaks have occurred repeatedly.

WASM 3 Leaks



A large portion (7.3 miles) of WASM 3 was originally proposed to be replaced with a larger diameter 72-inch pipe in order to provide greater capacity to the north and provide redundancy for the City Tunnel system. Staff's initial recommnedatoin was that a new larger sized WASM3 and the pressuration of the Subury Aqueduct to the south would be sufficient to provide necessary redundanacy to the exisitng City Tunnel, City Tunnel Extension and Dorchester Tunnel.

WASM 3 Leak

Leak Repair

Plugged Leak Prior to Cap Weld

Cap Welded Over Plug

The Preliminary Design for replacement of WASM3 with a larger diameter surface pipeline was initiated on July 2013 and continued for about twelve months when it became apparent that surface construction of the large diameter pipeline through downtown congested areas and heavily traveled streets would be extremely difficult to execute and may be infeasible to build.

At that point, staff began the process of evaluating various tunnel alternatives and combination of tunnels and surface pipelines for WASM 3 to provide redundancy for the water transmission system within the metropolitan area.

Regardless of the long term redundancy alternative chosen (tunnels, surface pipeline or combination) a functional and reliable WASM 3 is necessary to provide a supply of water to twenty-six MWRA water meters or pump stations serving seven communities. It is a necessary component of all redundancy alternatives and all alternatives include the rehabilitation of WASM 3, but some alternatives require the replacement of WASM 3 with a new 72-inch diameter pipeline or potentially, a deep rock tunnel, depending on the level of redundancy to be provided. If a tunnel were to be provided for redundancy to the north, the WASM 3 pipeline could be rehabilitated over its entire length, thereby minimizing community impacts associated with replacing it with a 72-inch diameter pipeline.

Given the uncertainty of whether the redundancy program will require the replacement of WASM 3 with a larger pipe, the WASM 3 design work was put on hold pending a final decision on the selected redundancy alternative for the metropolitan area. To date, approximately three percent of the engineering budget has been expended.

While the evaluation of alternatives for providing water transmission system redundancy within the metropolitan area proceeds, staff propose to move forward with the field work necessary to evaluate and document the current condition of the WASM 3. Based on the results of field work, a program will be designed to excavate the existing pipe at various critical locations to determine the exact nature of the existing leaks, quantify the amount of corrosion at those locations, and to measure the remaining local pipe wall thickness. The information gathered from these field studies will be analyzed and used to inform the decision whether to replace the corroded sections of WASM 3 and to rehabilitate the sections that are determined to be structurally sound.

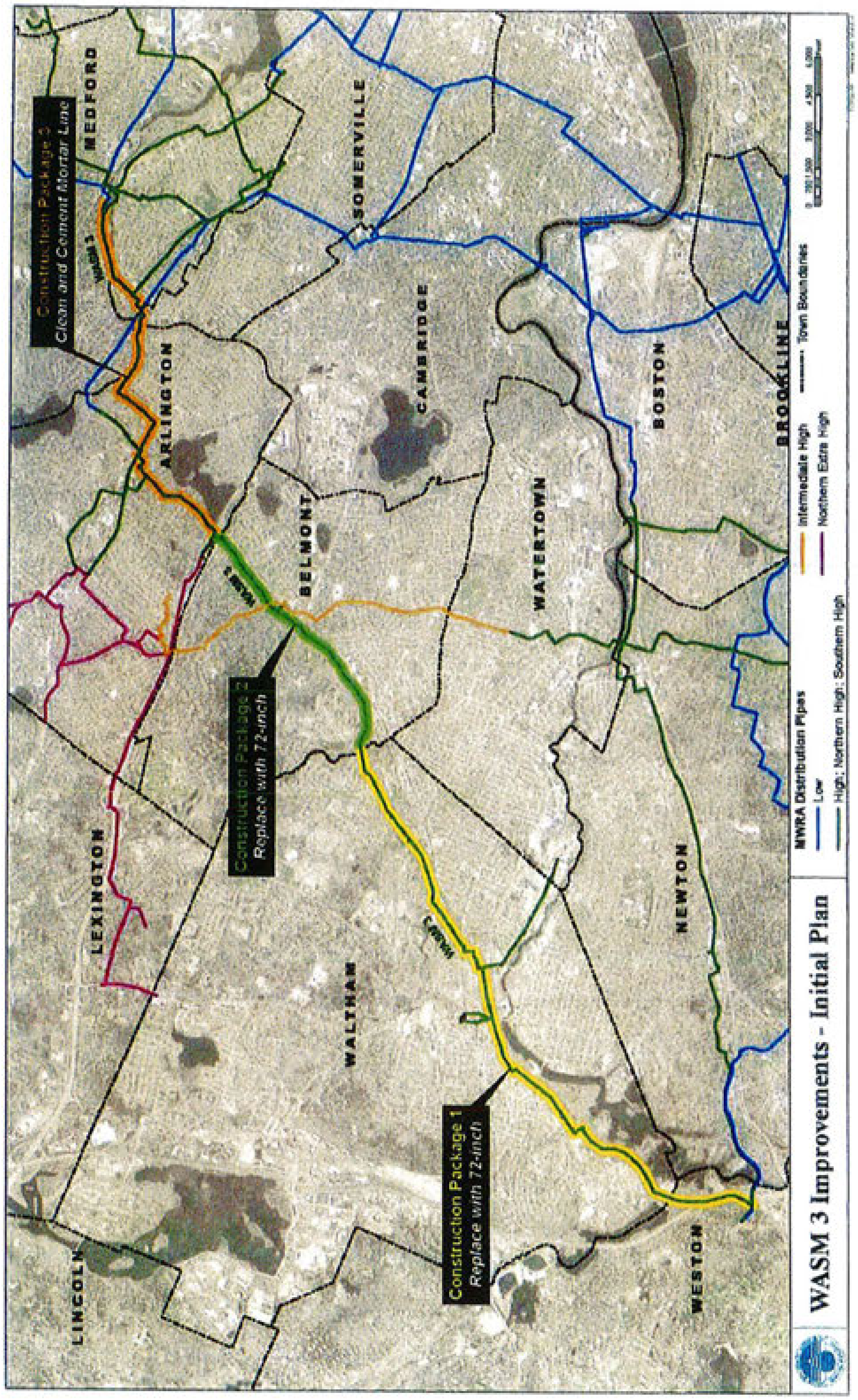
BUDGET/FISCAL IMPACT:

The FY17 CIP includes a budget of $130 million for the WASM 3 rehabilitation project.

ATTACHMENT:

Attachment 1. WASM 3 Improvements – Initial Plan

Attachment 1
WASM 3 Improvements – Initial Plan



W A.3
9/14/16

STAFF SUMMARY

TO: Board of Directors
FROM: Frederick A. Laskey, Executive Director
DATE: September 14, 2016
SUBJECT: Chestnut Hill Emergency Pump Station
Southern High Service Area Redundancy

COMMITTEE: Water Policy & Oversight

X INFORMATION
___ VOTE

Stephen Estes-Smargiassi, Director, Planning & Sustainability
David Coppes, P.E., Director, Waterworks
Preparer/Title

Michael J. Hornbrook
Chief Operating Officer

As part of a series of briefings on Metropolitan Tunnel system redundancy evaluation, this staff summary addresses use of the underground Chestnut Hill Emergency Pump Station for emergency supply to the Southern High and Southern Extra High service areas. Construction of the station was completed in 2001 to provide supply from the Sudbury Aqueduct and the open Chestnut Hill Reservoir in the event of a Hultman Aqueduct or City Tunnel failure. The station was utilized in 2010 to assist with water delivery during peak demand after the Shaft 5A pipeline failure forced closure of an important large capacity water pipe in Weston. The station works well at meeting the system needs of the Southern High and Southern Extra High service areas provided that the Dorchester Tunnel remains in service. However, recent Metropolitan Tunnel redundancy analysis identified capacity and pressure concerns in the surface piping that could affect operation in the event that the Dorchester Tunnel is not in service.

RECOMMENDATION:

For information only.

DISCUSSION:

Background

In the 1880's and 1890's two pump stations were constructed at Chestnut Hill to serve the low service system via the Spot Pond Supply lines and the High Service system to the south via Fisher Hill reservoir (elevation 251 BCB) in Brookline and the Forbes Hill Reservoir in Quincy. These coal-fired steam driven pump stations supplied water for decades and were ultimately retired in the 1970's as metropolitan pipe networks expanded. The High Service station now serves as site of the Metropolitan Waterworks Museum.

Figure 1: A plume of smoke from the coal-fired High Service Pump Station in 1898.

Construction of the City Tunnel in 1950 provided high service water directly to the southern surface mains via Shaft 7B, reducing pumping from Chestnut Hill. The Blue Hills open reservoir was later constructed (1954) at the far end of the Southern High Service distribution system at an elevation of 260 BCB but increasing demands and pipeline friction losses made it increasingly difficult to maintain adequate water in the reservoir. A section of the High Service system was supplied via the Waban Hill Reservoir in Newton, elevation 264 BCB, from either the tunnel or the pump station through a manually throttled valve in front of the original Chestnut Hill Pump Station.

In the early 1970's, the connection to the south from Shaft 7B of the City Tunnel, located adjacent to Chestnut Hill Reservoir and the Low Service Pump Station, had to be shut down to allow for construction of the Dorchester Tunnel. The pumps at Chestnut Hill once again provided supply from Sudbury Aqueduct to the Southern High Service area.

Upon completion of the Dorchester Tunnel in 1974, the level of water in Blue Hills open reservoir was finally able to be adequately maintained, but shortly after the tunnel went on line it was determined that the section between Shafts 7C and 7D was leaking. Gas turbine pumps were installed in the basement of the pump stations, since the historic steam turbine pumps had begun to be dismantled. In 1980, after repairs to the Dorchester Tunnel were completed, the gas-fired pumps were shut down and maintained for emergency back-up. Blue Hills open reservoir was taken out of service in 1981 due to concerns about deteriorating water quality.

Figure 2: Chestnut Hill Emergency Pump Station provides back-up supply to Southern High and Extra High Service areas

Chestnut Hill Emergency Pump Station

The Chestnut Hill Emergency Pump Station was constructed as part of a larger effort by MWRA to divest itself from the crumbling maintenance-intensive pump station buildings. The design intent was to quickly construct a station to replace the function of the old back-up gas fired turbine pumps. Design was awarded in May of 1998 and construction bid documents were advertised in September of the same year. The construction contract was awarded the following February and construction was completed in 2001.

Figure 3: Four 1,000 HP electric pumps in an underground chamber.

The underground pump station sits adjacent to Shaft 7B, surrounded by condominiums. It has 4 constant speed pumps sized to pump raw untreated water out of Chestnut Hill Reservoir. The pumps are manually stopped and started. There are two alternate feeds for electricity to the station but no emergency back-up power. It was built to pump to the Waban Hill Reservoir grade line with a nominal capacity of 90 million gallons per day (MGD) and slightly less capacity (and higher head required) to pump to Blue Hills. The station also has the capability to draw approximately 35 MGD of treated water from the Boston Low service area in lieu of pumping out of Chestnut Hill reservoir. Discharge from the station connects to the surface piping on either side of Shaft 7B so that water can be pumped into the Dorchester Tunnel and/or to the Fisher Hill lines and Section 106 to the Southern High Service area.

To operate the station, vent hatches need to be manually opened in gardens located above the station. There is a driveway adjacent to the station to park a trailer of sodium hypochlorite and adequate piping connections for injection for emergency disinfection of the Chestnut Hill open reservoir supply. Use of the open reservoir would not be in compliance with current water supply regulations and would require a boil order. The equipment is tightly placed within the footprint of the below grade concrete enclosure with little room for modification or expansion.

Figure 4: The top of the Emergency Pump Station with the low service condominiums in the background

Figure 5: Last used to supplement peak hour demand during Shaft 5A emergency in 2010

To comply with current federal and state drinking water requirements, MWRA discontinued use of all open distribution reservoirs from the water system, except for several reservoirs that have been kept for emergency use only when boil orders would be required. Blue Hills Covered Storage tanks replaced the off-line Blue Hills open reservoir and Waban Hill Reservoir was declared surplus in 2013. To utilize the station now requires pumping directly to Blue Hills at the far end of the distribution system. The station was used in 2010 to pump water from Sudbury Aqueduct to the Dorchester Tunnel and southern surface mains as part of the Shaft 5A transmission line failure. The station supplemented supply during peak hours of water use. It was the use of the Sudbury Aqueduct and the open

Chestnut Hill Reservoir that prompted the need for a boil order during that emergency. The water was chlorinated by addition of sodium hypochlorite.

Operational Challenges and the Role of the Pump Station in Future Redundancy Initiatives

During the Metropolitan Tunnel redundancy evaluation, staff identified limitations in operation of the Chestnut Hill Emergency Pump Station *with the Dorchester Tunnel out of service*. In order to maintain water level in the Blue Hills tanks, the grade line at the discharge of the station would need to be raised significantly above the existing grade line because of the smaller surface transmission pipelines and higher pressure loss. This higher grade line would increase the chance of lines breaking in the MWRA or local community distribution systems. The concern level is higher for pipelines closer to the station. The higher grade line is required to overcome the poor carrying capacity of the Southern High surface mains compared to the Dorchester Tunnel and to maintain the level of service that communities close to Blue Hills have come to depend on in the decades since the Dorchester Tunnel went in to service. If the Chestnut Hill emergency pumps are shut down due to power failure or as a result of the Blue Hills tanks being full, the head loss from water flowing back from Blue Hills is so high that pressure would be inadequate in the Fisher Hill/Chestnut Hill area.

Controlling the current Chestnut Hill emergency pumps without the Dorchester Tunnel is problematic and may not be reliable. Starting and stopping the constant speed pumps, (i.e. going from two pumps to three), greatly changes the discharge head by producing more or less water than the system requires. There is no means of controlling flow between discrete steps of the constant speed pumps. In addition, starting and stopping MWRA's downstream pump stations to the Southern Extra High service area (Newton Street and Hyde Park stations) would change the flow pattern in the system causing dramatic increase or decrease in discharge pressure at the Chestnut Hill Pump Station. These changes result in the need to quickly add or drop pumps at Chestnut Hill Pump Station as a result of inadequate or excessive pressures. Proposed long term redundancy improvements include emergency diesel generators to power the station. Other improvements could include replacement of pumps, installation of variable frequency drives, automatic pressure regulating or re-circulating valves. These changes (if space could be identified) would improve operation of the station but could not overcome the deficiencies in the carrying capacity of the southern surface mains.

With the Dorchester Tunnel in service the pump station can maintain the level in the Blue Hills tanks without excessive discharge pressure as was demonstrated in 2010 when the station was used effectively to alleviate supply concerns. This still required a boil order.

In addition to the operating concerns, the location of the station makes it potentially inaccessible and possibly flooded in the event of a large rupture of piping at Shaft 7.

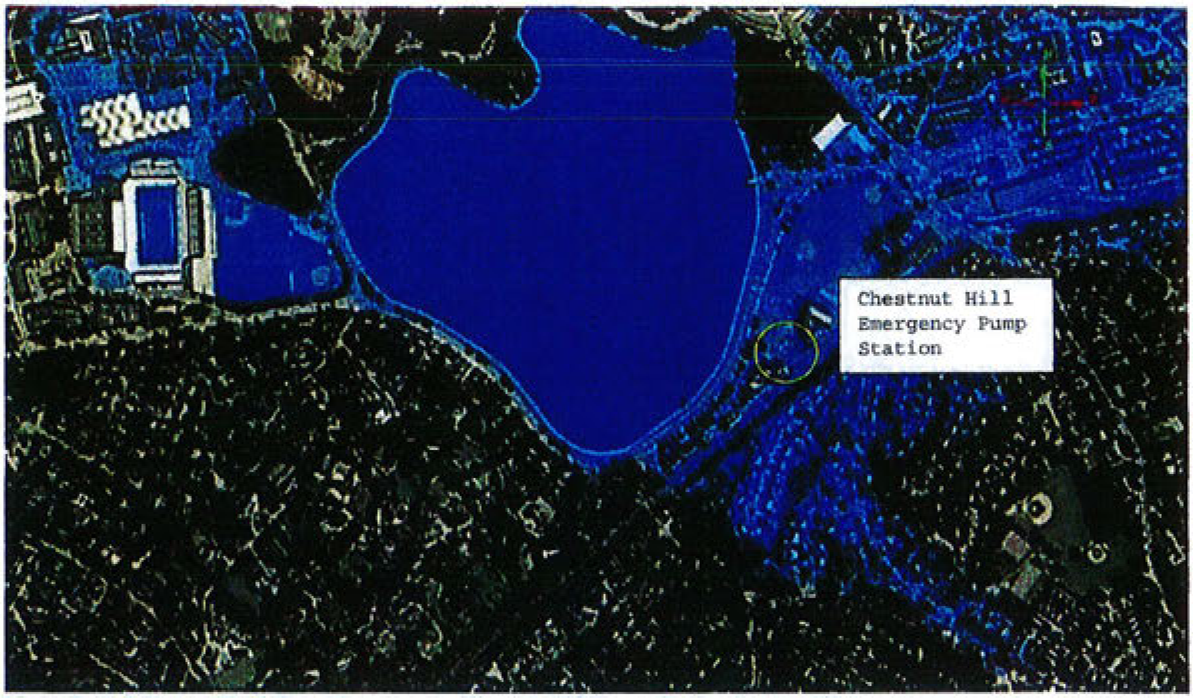


Figure 6 - A failure at Shaft 7 could render the Chestnut Hill Pump Station inaccessible.

<u>Summary</u>

Modeling of the water system with the Dorchester Tunnel out of service pushes the accuracy of our model beyond the limits of its calibration[1]. It is difficult to predict exactly how the system will operate in this emergency case, but looking at the way the system operated in the past when the Blue Hills open reservoir had to be taken off line, it is clear that the southern surface mains have limited capacity and a high amount of head loss. To overcome this head loss with the Pump Station requires forcing water into the system at higher pressures and/or results in lower pressures at the opposite end. The operational challenges to keep pace with the existing pumps, maintain adequate pressures without breaking mains with no speed control, no means of pressure relief, and without back-up power strongly influences the strategic decisions about how to provide redundant supply to the Southern High and Southern Extra High service areas. Modifying the station with variable frequency drives and other improvements (if space could be identified) could reduce some these problems, but would not completely overcome the lack of capacity in the surface pipelines with the Dorchester Tunnel out of service.

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[1] Models are calibrated using flow and pressure data collected during operation of the pipe network. If flows and pressures in a simulation are substantially different than could be observed during calibration, the model may not be able to accurately simulate friction losses and pressure changes. The Dorchester tunnel represents 70% of the carrying capacity of the Southern High piping network. Removing the tunnel represents a major change to the model.

Economic Impact of Metropolitan Tunnel Failure

MEMORANDUM

To: Thomas Durkin, Finance Director
Kathy Soni, Budget Director
From: Louise Miller, Budget Manager
Matthew Horan, Treasurer
Cc: Frederick Laskey, Executive Director
Stephen Estes-Smargiassi, Director, Planning and Sustainability
Date: September 30, 2016
Re: Economic Impact Analysis of Water Service Loss in the Metropolitan Tunnels Area

In conjunction with the evaluation of the water supply redundancy project(s) for the Metropolitan Tunnels area, the Finance Staff was asked to complete an updated economic impact analysis of a water distribution failure in that area. The first section of this analysis is a summary of the document explaining broadly the assumptions and methodology used and the results of the analysis. The second part details the methodology, explains the calculations, and includes tables that reference the economic impact for the area on a municipal level.

Summary

This analysis quantifies the economic impact, both business and residential, of a water system failure in the Metropolitan Tunnels. The models used in this analysis are based primarily on one academic study of economic loss based on water supply interruption following catastrophic events and on FEMA's analysis for standard economic benefit-cost values of disaster events. The models are internationally recognized and have been used both in California and in Europe to determine the economic cost- benefit of water infrastructure projects.

Under this analysis, a number of scenarios have been considered with water system failures in the City Tunnel, City Tunnel Extension, the Dorchester Tunnel, and all three tunnels. The duration and severity of the system failures was provided by the Engineering Department. Each scenario assumes that, in the event of a failure in the Metropolitan Tunnels, there would be a period of total water loss followed by a "boil order" during a repair period prior to restoration of normal water service. Other scenarios can be run for water system failures if it is desired. It should be noted that water service interruption could result in more than just monetary loss, possibly requiring a complete shut- down of certain business and municipal activities and the displacement of residents.

Attachment 1 sets forth the business and residential economic loss by community in the Metropolitan Tunnels area under different scenarios for a water system failure.

Description of Economic Loss to Businesses

Economic loss to business from water service interruption varies by business sector. The economic output for the State by business sector is published by the US Department of

Commerce, Bureau of Economic Analysis. The economic output for each municipality was calculated by taking the fraction of the business sector's employment as reported by the Massachusetts Executive Office of Labor and Workforce Development. FEMA has synthesized empirical studies and produced a table of "factors" by business sector which represent the fraction of the business output that is lost depending on disaster type. The economic loss for each business sector is quantified by applying the water factor to the economic output for that business sector in each of the community served by the Metropolitan Tunnels.

Description of Economic Loss to Residents

FEMA adopts the academic study approach to determine residential economic loss, since residents have no economic output. The approach is based on a constant elasticity demand function to calculate the loss of welfare from water service loss based on the average cost of water for MWRA communities and the average water use in Massachusetts, to which is added the out-of- pocket expense equal to the actual cost of replacement of water for residents from a water service interruption event. We assume that governments or residents will provide or buy water from alternate sources to replace the minimum daily requirements for humans for drinking and cooking and basic sanitation. An average local cost for bottled water is used as the replacement cost of water in the residential loss.

Methodology and Calculations of Economic Impact of Water Service Loss in the Metropolitan Tunnels Area

Because the calculations for business and residential loss differ, the economic impact of water service loss in the Metropolitan Tunnels area is divided into two separate components: the business loss and the residential loss. Tables summarizing both the business and residential economic loss for each city and town affected by water service interruption in the Metropolitan Tunnels Area are attached and referenced in the sections below.

Economic Impact on Businesses

Economic impact of water supply interruption to business users is determined based on the reliance of the particular business on water for its operations. Business resilience in the context of loss of use of water is defined as the proportion of normal production that would occur in the event of a water supply interruption. Studies have quantified business resilience due to loss of use of water by economic sector on a scale of 0 to 1, with 0 meaning that a business is unable to operate without water and 1 meaning that a business is independent of water use. In addition, economic impact models use a sliding scale based upon the level and nature of the water service interruption. While water supply interruption is characterized by the level of the interruption, for purposes of this analysis, we only assume two levels: complete water outage for and a "boil order" water supply. Since a complete water outage would result in loss of wastewater systems as well as loss of water systems, a wastewater loss resilience factor is more appropriate for a complete water outage and the water loss resilience factor for a "boil order" water supply. For this analysis, a linear relationship is assumed between business activity and monetary gain/loss.

The aggregate loss by economic sector for the cities and towns served by the Metropolitan Tunnels is calculated as follows:

$$\sum_{\text{sectors}} LL_{\text{sector}} = \left(\frac{GSP_{\text{sector}}}{365}\right)\left(\frac{E_{LGP}}{E_{GSP}}\right)(1\text{-}r_{\text{sector}})$$

Where:

$\sum_{\text{sectors}}$ =the sum of the individual business sectors

LL_{sector}=the local economic loss by aggregate industry sector economic loss

GSP_{sector} = annual Gross State Product for the business sector

E_{LGP}=the local employment for the business sector

E_{GSP}=the total state employment for the business sector

r_{sector}= resilience factor for the business sector

The Gross Domestic Product for Massachusetts (Gross State Product), broken down by business sector, is used as the measure of economic output for that business sector, as published for 2015, the last year of data available, by the US Department of Commerce, Bureau of Economic Analysis. The total employment in Massachusetts for each business sector of the Gross State Product was obtained from the Massachusetts Executive Office of Labor and Workforce Development. The Massachusetts Executive Office of Labor and Workforce Development also maintains data for the total annual employment and wages by municipality within the State. In order to determine an accurate allocation by municipality of each business sector, the employment for that municipality's business sector as reported in business wage reports was divided by the total state employment by business sector. The resulting local employment by business sector allocation is then multiplied by the Gross State Product for the business sector. This yields an annual business sector economic output for each municipality which is divided by 365 to yield a daily economic output. The last term of the equation is the complement of the resilience factor for the business sector for water or wastewater. The FEMA factors for water and sewer in the FEMA Benefit-Cost Analysis standards are applied to the municipal economic output for each business sector, yielding a daily economic output loss by business sector for each municipality.

In this analysis, such factors as whether certain businesses would be allowed to operate if fire sprinkling systems could not be used or whether systems such as rooftop chillers, closed cooling system loops or other water cooled equipment would need to be shut down, causing the shut-down of buildings, are not considered. Also not considered were public services costs such as police, fire, public safety, and public health, and governmental losses such as lost taxes. All of these factors would add to the economic loss and could be significant. The Production Recapture Factor for businesses by industry sector, which measure the ability to recapture some economic loss suffered during a water supply interruption was also not calculated because it varies greatly based upon the length and severity of the interruption in service.

Attachment 2 shows the Gross State Product by business sector and the annual economic loss for water and wastewater events using FEMA water and sewer factors.

Attachment 3 shows the total annual and daily economic output loss by municipality for water and sewer factors.

Economic Impact on Residential Users

Economic impact to residential users is determined on a per capita basis. The business loss analysis does not apply in the residential context because residential users do not have measurable economic output. Instead, residential impact is measured by the loss of welfare to individuals from lack of water and out-of-pocket costs to replace the water. The loss of welfare to individuals is calculated by measuring the willingness of the users to pay more for water in order to avoid water supply interruption. To the loss of welfare calculation is added the cost of purchasing water for basic human needs. Empirical studies conclude that residential demand for water is mostly price inelastic by region, and residential users are more willing to pay higher amounts to avoid large, infrequent water supply losses rather than smaller and more frequent losses. It is important to note that the price elasticity can vary significantly. FEMA summarizes the various empirical studies and arrives at a value for the price elasticity of demand of -.41. Since no empirical data for the price elasticity of water in the Metropolitan area is available, we use the FEMA value. The formula for calculating the cost of loss of welfare is as follows:

$$W=\frac{\eta}{1+\eta}P_{baseline}Q_{baseline}\left[1-\left[\frac{BWR}{Q_{baseline}}\right]^{\frac{1+\eta}{\eta}}\right]$$

Where:

W=economic impact per capita per day

$P_{baseline}$=the average water price when there are no water service interruptions

$Q_{baseline}$= the average amount of water consumed where there are no water interruptions

BWR= Basic Water Requirement, which is the minimum amount of water per capita per day required for drinking and basic sanitation

η=the price elasticity of water demand.

This analysis uses the average cost of water for 170 hundred cubic feet for MWRA's communities as $642.00. The average water usage is based on 50 gallons per day, the average consumption per day in Massachusetts. The Basic Water Requirement is calculated using the United Nations definitions for minimum amount of water needed for drinking and basic sanitation of 6.6 gallons per day and another 6.6 gallons per day for cooking and some bathing. Under this calculation, the daily loss of welfare to residents is $.2344.

In addition a cost factor for potable water to residential users based on the average cost of bottled water. We assume that either residents themselves or the government will provide some amount of bottled drinkable water to users for which we use a figure of $4.24 per gallon as an estimate based on the numbers reported by numbeo.com for the month of September 2016.

We did not consider other costs such as displacement of residents or property damage from water interruption, which would be added to the residential economic loss.

Calculations and Conclusions for Assumed Water Supply Failure Scenario

Scenario 1: water supply failure in the entire Metropolitan Tunnels area of 3 days of total water shutdown followed by 4 weeks of water supply subject to a "boil order."

Because a total water shutdown affects both the use of water and the ability to move wastewater through the system, the FEMA sewer factor was used to calculate economic loss in the first 3 days and the FEMA water factor was used to calculate economic loss for the following 4 weeks. The economic impact models yields a total business economic loss of $6.1 billion for the assumed water supply failure and a total residential economic loss of $3.2 billion totaling approximately $9.3 billion.

If scenario 1 affects the City Tunnel and City Tunnel Extension (North), then the total business economic loss is $3.3 billion and the total residential loss is $1.95 billion totaling $5.25 billion.

If scenario 1 affects only the Dorchester Tunnel (South), then the total business economic loss is $2.8 billion and the total residential loss is $1.25 billion totaling $4.05 billion.

Scenario 2: water supply failure in the Metropolitan Tunnels of 1 day of total water shutdown followed by 2 weeks of water supply subject to a "boil order."

Again, because a total water shutdown affects both the use of water and the ability to move wastewater through the system, the FEMA sewer factor was used to calculate economic loss in the first day and the FEMA water factor was used to calculate economic loss for the following 2 weeks. The economic impact models yields a total business economic loss of $2.9 billion for the assumed water supply failure and a total residential economic loss of $1.5 billion totaling $4.5 billion.

If scenario 2 affects the City Tunnel and City Tunnel Extension, then the total business economic loss is $1.6 billion and the total residential loss is 0.95 billion totaling $2.55 billion.

If scenario 2 affects only the Dorchester Tunnel, then the total business economic loss is $1.35 billion and the total residential loss is $0.6 billion totaling $1.95 billion.

Scenario 3: water supply failure in the Metropolitan Tunnels of 1 day of total water shutdown followed by 1 week of water supply subject to a “boil order”.

Again, because a total water shutdown affects both the use of water and the ability to move wastewater through the system, the FEMA sewer factor was used to calculate economic loss in the first day and the FEMA water factor was used to calculate economic loss for the following one week. The economic impact models yields a total business economic loss of $1.6 billion for the assumed water supply failure and a total residential economic loss of $0.8 billion totaling $2.4 billion.

If scenario 3 affects the City Tunnel and City Tunnel Extension, then the total business economic loss is $0.9 billion and the total residential loss is $0.5 billion totaling $1.4 billion.

If scenario 3 affects only the Dorchester Tunnel, then the total business economic loss is $0.7 billion and the total residential loss is $0.3 billion totaling $1 billion.

Sources:

This economic analysis of the impact of total water service loss in the Metropolitan Tunnels Area is based primarily upon the guidelines provided in the FEMA Benefit-Cost Analysis Version 4 standard default values for quantifying economic loss following disasters and two academic studies modeling economic loss from water supply interruption to business and residential users. The two studies are based on actual water supply interruption events in California following catastrophic earthquakes. The models developed in the academic studies have been widely cited and have been used in California and in Europe to determine the cost benefit of water infrastructure project alternatives. Two examples of the use of the models in infrastructure projects decision-making are included, one from California and one from Italy.

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Massachusetts Water Resources Authority
Scenario 1: No Water for Three Days and Four Week Boil Order
(in millions)

Community	Business Impact North	Business Impact South	Business Impact Total	Residential Impact North	Residential Impact South	Residential Impact Total
Arlington	$ 34.48	$ -	$ 34.48	$ 74.65	$ -	$ 74.65
Bedford	$ 107.82	$ -	$ 107.82	$ 23.21	$ -	$ 23.21
Belmont	$ 25.17	$ -	$ 25.17	$ 43.08	$ -	$ 43.08
Boston	$ 1,623.51	$ 1,623.51	$ 3,247.01	$ 538.01	$ 538.01	$ 1,076.02
Brookline	$ -	$ 74.37	$ 74.37	$ -	$ 102.33	$ 102.33
Canton	$ -	$ 121.90	$ 121.90	$ -	$ 37.57	$ 37.57
Chelsea	$ 117.45	$ 117.45	$ 234.90	$ 30.64	$ 30.64	$ 61.29
Dedham	$ -	$ 65.55	$ 65.55	$ -	$ 43.08	$ 43.08
Everett	$ 50.98	$ -	$ 50.98	$ 72.60	$ -	$ 72.60
Lexington	$ 83.11	$ -	$ 83.11	$ 54.70	$ -	$ 54.70
Lynnfield	$ 19.84	$ -	$ 19.84	$ 20.20	$ -	$ 20.20
Malden	$ 64.89	$ -	$ 64.89	$ 103.58	$ -	$ 103.58
Marblehead	$ 26.74	$ -	$ 26.74	$ 34.51	$ -	$ 34.51
Medford	$ 71.84	$ -	$ 71.84	$ 97.87	$ -	$ 97.87
Melrose	$ 19.29	$ -	$ 19.29	$ 48.75	$ -	$ 48.75
Milton	$ -	$ 24.78	$ 24.78	$ -	$ 47.05	$ 47.05
Nahant	$ 0.95	$ -	$ 0.95	$ 5.94	$ -	$ 5.94
Newton	$ -	$ 231.95	$ 231.95	$ -	$ 148.35	$ 148.35
Norwood	$ -	$ 121.34	$ 121.34	$ -	$ 49.83	$ 49.83
Peabody	$ 106.55	$ -	$ 106.55	$ 89.29	$ -	$ 89.29
Quincy	$ -	$ 245.26	$ 245.26	$ -	$ 160.76	$ 160.76
Reading	$ 22.35	$ -	$ 22.35	$ 43.12	$ -	$ 43.12
Revere	$ 29.59	$ -	$ 29.59	$ 90.17	$ -	$ 90.17
Saugus	$ 35.12	$ -	$ 35.12	$ 46.39	$ -	$ 46.39
Somerville	$ 89.30	$ -	$ 89.30	$ 131.98	$ -	$ 131.98
Stoneham	$ 30.62	$ -	$ 30.62	$ 37.35	$ -	$ 37.35
Swampscott	$ 9.35	$ -	$ 9.35	$ 24.02	$ -	$ 24.02
Wakefield	$ 55.18	$ -	$ 55.18	$ 43.44	$ -	$ 43.44
Waltham	$ 319.64	$ -	$ 319.64	$ 105.64	$ -	$ 105.64
Watertown	$ -	$ 91.27	$ 91.27	$ -	$ 55.60	$ 55.60
Westwood	$ -	$ 48.67	$ 48.67	$ -	$ 25.47	$ 25.47
Wilmington	$ 107.52	$ -	$ 107.52	$ 38.90	$ -	$ 38.90
Winchester	$ 30.30	$ -	$ 30.30	$ 37.24	$ -	$ 37.24
Winthrop	$ 7.17	$ -	$ 7.17	$ 30.48	$ -	$ 30.48
Woburn	$ 226.13	$ -	$ 226.13	$ 66.42	$ -	$ 66.42
Total	**$ 3,314.87**	**$ 2,766.05**	**$ 6,080.92**	**$ 1,932.18**	**$ 1,238.69**	**$ 3,170.87**

Total Business and Residential Impact $ 9,251.79

Massachusetts Water Resources Authority
Scenario 2: No Water for One Day and Two Week Boil Order
(in millions)

Community	Business Impact			Residential Impact		
	North	South	Total	North	South	Total
Arlington	$ 16.66	$ -	$ 16.66	$ 36.12	$ -	$ 36.12
Bedford	$ 52.08	$ -	$ 52.08	$ 11.23	$ -	$ 11.23
Belmont	$ 12.11	$ -	$ 12.11	$ 20.85	$ -	$ 20.85
Boston	$ 783.43	$ 783.43	$ 1,566.87	$ 260.33	$ 260.33	$ 520.65
Brookline	$ -	$ 35.77	$ 35.77	$ -	$ 49.51	$ 49.51
Canton	$ -	$ 59.14	$ 59.14	$ -	$ 18.18	$ 18.18
Chelsea	$ 56.80	$ 56.80	$ 113.60	$ 14.83	$ 14.83	$ 29.66
Dedham	$ -	$ 31.66	$ 31.66	$ -	$ 20.85	$ 20.85
Everett	$ 24.72	$ -	$ 24.72	$ 35.13	$ -	$ 35.13
Lexington	$ 40.06	$ -	$ 40.06	$ 26.47	$ -	$ 26.47
Lynnfield	$ 9.61	$ -	$ 9.61	$ 9.78	$ -	$ 9.78
Malden	$ 31.36	$ -	$ 31.36	$ 50.12	$ -	$ 50.12
Marblehead	$ 12.94	$ -	$ 12.94	$ 16.70	$ -	$ 16.70
Medford	$ 34.67	$ -	$ 34.67	$ 47.36	$ -	$ 47.36
Melrose	$ 9.33	$ -	$ 9.33	$ 23.59	$ -	$ 23.59
Milton	$ -	$ 11.91	$ 11.91	$ -	$ 22.76	$ 22.76
Nahant	$ 0.46	$ -	$ 0.46	$ 2.87	$ -	$ 2.87
Newton	$ -	$ 111.75	$ 111.75	$ -	$ 71.78	$ 71.78
Norwood	$ -	$ 58.66	$ 58.66	$ -	$ 24.11	$ 24.11
Peabody	$ 51.48	$ -	$ 51.48	$ 43.21	$ -	$ 43.21
Quincy	$ -	$ 118.57	$ 118.57	$ -	$ 77.79	$ 77.79
Reading	$ 10.80	$ -	$ 10.80	$ 20.86	$ -	$ 20.86
Revere	$ 14.30	$ -	$ 14.30	$ 43.63	$ -	$ 43.63
Saugus	$ 17.00	$ -	$ 17.00	$ 22.45	$ -	$ 22.45
Somerville	$ 43.15	$ -	$ 43.15	$ 63.86	$ -	$ 63.86
Stoneham	$ 14.80	$ -	$ 14.80	$ 18.07	$ -	$ 18.07
Swampscott	$ 4.52	$ -	$ 4.52	$ 11.62	$ -	$ 11.62
Wakefield	$ 26.66	$ -	$ 26.66	$ 21.02	$ -	$ 21.02
Waltham	$ 154.48	$ -	$ 154.48	$ 51.11	$ -	$ 51.11
Watertown	$ -	$ 44.13	$ 44.13	$ -	$ 26.91	$ 26.91
Westwood	$ -	$ 23.54	$ 23.54	$ -	$ 12.32	$ 12.32
Wilmington	$ 52.13	$ -	$ 52.13	$ 18.82	$ -	$ 18.82
Winchester	$ 14.61	$ -	$ 14.61	$ 18.02	$ -	$ 18.02
Winthrop	$ 3.47	$ -	$ 3.47	$ 14.75	$ -	$ 14.75
Woburn	$ 109.54	$ -	$ 109.54	$ 32.14	$ -	$ 32.14
Total	**$ 1,601.18**	**$ 1,335.37**	**$ 2,936.55**	**$ 934.93**	**$ 599.37**	**$ 1,534.29**

Total Business and Residential Impact $ 4,470.85

Massachusetts Water Resources Authority
Scenario3: No Water for One Day and One Week Boil Order
(in millions)

Community	Business Impact North	Business Impact South	Business Impact Total	Residential Impact North	Residential Impact South	Residential Impact Total
Arlington	$ 2.30	$ -	$ 2.30	$ 19.26	$ -	$ 19.26
Bedford	$ 27.87	$ -	$ 27.87	$ 5.99	$ -	$ 5.99
Belmont	$ 6.53	$ -	$ 6.53	$ 11.12	$ -	$ 11.12
Boston	$ 420.04	$ 420.04	$ 840.07	$ 138.84	$ 138.84	$ 277.68
Brookline	$ -	$ 19.30	$ 19.30	$ -	$ 26.41	$ 26.41
Canton	$ -	$ 31.38	$ 31.38	$ -	$ 9.69	$ 9.69
Chelsea	$ 30.32	$ 30.32	$ 60.65	$ 7.91	$ 7.91	$ 15.82
Dedham	$ -	$ 16.94	$ 16.94	$ -	$ 11.12	$ 11.12
Everett	$ 13.13	$ -	$ 13.13	$ 18.73	$ -	$ 18.73
Lexington	$ 21.52	$ -	$ 21.52	$ 14.12	$ -	$ 14.12
Lynnfield	$ 5.12	$ -	$ 5.12	$ 5.21	$ -	$ 5.21
Malden	$ 16.76	$ -	$ 16.76	$ 26.73	$ -	$ 26.73
Marblehead	$ 6.90	$ -	$ 6.90	$ 8.91	$ -	$ 8.91
Medford	$ 18.58	$ -	$ 18.58	$ 25.26	$ -	$ 25.26
Melrose	$ 4.98	$ -	$ 4.98	$ 12.58	$ -	$ 12.58
Milton	$ -	$ 6.43	$ 6.43	$ -	$ 12.14	$ 12.14
Nahant	$ 0.24	$ -	$ 0.24	$ 1.53	$ -	$ 1.53
Newton	$ -	$ 60.10	$ 60.10	$ -	$ 38.28	$ 38.28
Norwood	$ -	$ 31.34	$ 31.34	$ -	$ 12.86	$ 12.86
Peabody	$ 27.54	$ -	$ 27.54	$ 23.04	$ -	$ 23.04
Quincy	$ -	$ 63.34	$ 63.34	$ -	$ 41.49	$ 41.49
Reading	$ 5.77	$ -	$ 5.77	$ 11.13	$ -	$ 11.13
Revere	$ 7.64	$ -	$ 7.64	$ 23.27	$ -	$ 23.27
Saugus	$ 9.06	$ -	$ 9.06	$ 11.97	$ -	$ 11.97
Somerville	$ 23.08	$ -	$ 23.08	$ 34.06	$ -	$ 34.06
Stoneham	$ 7.91	$ -	$ 7.91	$ 9.64	$ -	$ 9.64
Swampscott	$ 2.42	$ -	$ 2.42	$ 6.20	$ -	$ 6.20
Wakefield	$ 14.26	$ -	$ 14.26	$ 11.21	$ -	$ 11.21
Waltham	$ 82.58	$ -	$ 82.58	$ 27.26	$ -	$ 27.26
Watertown	$ -	$ 23.57	$ 23.57	$ -	$ 14.35	$ 14.35
Westwood	$ -	$ 12.57	$ 12.57	$ -	$ 6.57	$ 6.57
Wilmington	$ 27.70	$ -	$ 27.70	$ 10.04	$ -	$ 10.04
Winchester	$ 7.85	$ -	$ 7.85	$ 9.61	$ -	$ 9.61
Winthrop	$ 1.85	$ -	$ 1.85	$ 7.87	$ -	$ 7.87
Woburn	$ 58.30	$ -	$ 58.30	$ 17.14	$ -	$ 17.14
Total	**$ 850.23**	**$ 715.34**	**$ 1,565.57**	**$ 498.63**	**$ 319.66**	**$ 818.29**

Total Business and Residential Impact $ 2,383.86

ATTACHMENT 2

Gross domestic product (GDP) by state (millions of current dollars)

Bureau of Economic Analysis

Area	IndCode	Industry	2015	FEMA Water Factor	Water Factor GDP	FEMA Sewer Factor	Sewer Factor GDP
Massachusetts	1	All industry total	476,743				
Massachusetts	2	Private industries	425,009				
Massachusetts	3	Agriculture, forestry, fishing, and hunting	695				
Massachusetts	4	Farms	(NA)				
Massachusetts	5	Forestry, fishing, and related activities	(NA)				
Massachusetts	6	Mining	206				
Massachusetts	7	Oil and gas extraction	(NA)				
Massachusetts	8	Mining, except oil and gas	(NA)				
Massachusetts	9	Support activities for mining	(NA)				
Massachusetts	10	Utilities	5,635	0.4	2,254	0.2	1,352
Massachusetts	11	Construction	18,225	0.5	9,113	0.2	3,645
Massachusetts	13	Durable goods manufacturing	31,137	0.8	24,910	0.9	26,466
Massachusetts	25	Nondurable goods manufacturing	16,856	0.7	11,799	0.7	11,799
Massachusetts	34	Wholesale trade	24,007	0.2	4,801	0.1	2,401
Massachusetts	35	Retail trade	20,269	0.2	4,054	0.2	4,054
Massachusetts	36	Transportation and warehousing	7,666	0.2	1,533	0.1	767
Massachusetts	45	Information	25,782	0.2	5,156	0.2	5,156
Massachusetts	50	Finance, insurance, real estate, rental, and leasing	108,870	0.2	21,774	0.2	21,774
Massachusetts	56	Real estate and rental and leasing	66,777	0.2	13,355	0.2	13,355
Massachusetts	59	Professional and business services	80,844	0.2	16,169	0.2	16,169
Massachusetts	68	Educational services, health care, and social assistance	57,879	0.4	23,152	0.8	46,303
Massachusetts	74	Arts, entertainment, recreation, accommodation, and food servic	17,839	0.8	14,271	0.8	14,271
Massachusetts	78	Accommodation and food services	13,322	0.8	10,658	0.8	10,658
Massachusetts	81	Other services, except government	9,100	0.2	1,820	0.2	1,820
Massachusetts	82	Government	51,734	0.25	12,934	0.2	10,347
Massachusetts	86	Natural resources and mining	901				
Massachusetts	87	Trade	44,276				
Massachusetts	88	Transportation and utilities	13,301				
Massachusetts	89	Private goods-producing industries	67,119				
Massachusetts	90	Private services-providing industries	357,890				

Legend / Footnotes:

Note-- NAICS Industry detail is based on the 2007 North American Industry Classification System (NAICS).

(NA) Not available.

Note-- Per capita real GDP statistics for 1997-2015 reflect Census Bureau midyear population estimates for 1997-

Last updated: June 14, 2016 -- revised statistics for 2008-2014 (estimates in current dollars), 1997-2014 (estimates in chained [2009] dollars); new advance statistics for 2015.

ATTACHMENT 3

amounts are in millions	Year		Day	
	Local Business Water Factor	**Local Business Sewer Factor**	**Local Business Water Factor**	**Local Business Sewer Factor**
Arlington	404.55	418.94	1.11	1.15
Bedford	1,262.73	1,332.84	3.46	3.65
Belmont	291.12	344.95	0.80	0.95
Boston	37,897.15	41,346.72	103.83	113.28
Brookline	858.76	1,033.80	2.35	2.83
Canton	1,447.36	1,322.00	3.97	3.62
Chelsea	2,761.22	2,808.24	7.56	7.69
Dedham	767.54	811.53	2.10	2.22
Everett	604.72	558.09	1.66	1.53
Lexington	966.62	1,089.38	2.65	2.98
Lynnfield	234.24	227.44	0.64	0.62
Malden	761.13	790.85	2.09	2.17
Marblehead	314.62	317.10	0.86	0.87
Medford	839.00	910.10	2.30	2.49
Melrose	227.07	269.92	0.62	0.74
Milton	285.82	347.50	0.78	0.95
Nahant	11.41	9.24	0.03	0.03
Newton	2,692.82	3,087.76	7.38	8.46
Norwood	1,424.53	1,467.13	3.90	4.02
Peabody	1,248.53	1,311.26	3.42	3.59
Quincy	2,879.74	2,962.38	7.89	8.12
Reading	262.21	272.15	0.72	0.75
Revere	347.04	360.77	0.95	0.99
Saugus	414.41	404.90	1.14	1.11
Somerville	1,046.60	1,096.57	2.87	3.00
Stoneham	359.17	373.22	0.98	1.02
Swampscott	109.62	114.60	0.30	0.31
Wakefield	646.42	680.28	1.77	1.86
Waltham	3,749.00	3,898.40	10.27	10.68
Watertown	1,072.50	1,094.11	2.94	3.00
Westwood	572.18	581.57	1.57	1.59
Wilmington	1,273.76	1,193.31	3.49	3.27
Winchester	352.37	397.92	0.97	1.09
Winthrop	84.37	84.40	0.23	0.23
Woburn	2,671.92	2,574.73	7.32	7.05
Total	**71,142.23**	**75,894.09**	**194.91**	**207.93**

amounts are in millions	Population	Year Residential	Day Residential
Arlington	42,844	878.90	2.41
Bedford	13,320	273.24	0.75
Belmont	24,729	507.29	1.39
Boston	617,594	12,669.25	34.71
Brookline	58,732	1,204.82	3.30
Canton	21,561	442.30	1.21
Chelsea	35,177	721.62	1.98
Dedham	24,729	507.29	1.39
Everett	41,667	854.75	2.34
Lexington	31,394	644.01	1.76
Lynnfield	11,596	237.88	0.65
Malden	59,450	1,219.55	3.34
Marblehead	19,808	406.34	1.11
Medford	56,173	1,152.33	3.16
Melrose	27,983	574.04	1.57
Milton	27,003	553.94	1.52
Nahant	3,410	69.95	0.19
Newton	85,146	1,746.67	4.79
Norwood	28,602	586.74	1.61
Peabody	51,251	1,051.36	2.88
Quincy	92,271	1,892.84	5.19
Reading	24,747	507.66	1.39
Revere	51,755	1,061.70	2.91
Saugus	26,628	546.24	1.50
Somerville	75,754	1,554.01	4.26
Stoneham	21,437	439.76	1.20
Swampscott	13,787	282.82	0.77
Wakefield	24,932	511.45	1.40
Waltham	60,632	1,243.80	3.41
Watertown	31,915	654.70	1.79
Westwood	14,618	299.87	0.82
Wilmington	22,325	457.97	1.25
Winchester	21,374	438.46	1.20
Winthrop	17,497	358.93	0.98
Woburn	38,120	781.99	2.14
Total	**1,819,961**	**37,334.45**	**102.29**

Potential Short Term Measures - Top of Shafts

Potential Short Term Measures - Top of Shafts

	Pipe assessment / Metal thickness, etc.	Recoat or wrap as applicable	Exercise downstream valves	Replace corroded nuts	Inspect/replace air valve	Install new valve	Install heat tracing, insulation	Replace dewatering pump	Assess condition of removable planks	Cathodic protection as applicable
Shaft 5	X	X								
Shaft 6	X	X	X							
Shaft 7	X	X		X	X					
Shaft 8	X	X		X	X	X				
Shaft 9	X	X		X	X	X	X	X		
Shaft 9A	X	X		X	X					
Shaft 7B	X	X				X			X	
Shaft 7C	X	X		X	X					
Shaft 7D	X	X		X						X

North and South Alternatives

Baseline Construction
Common to all Alternatives

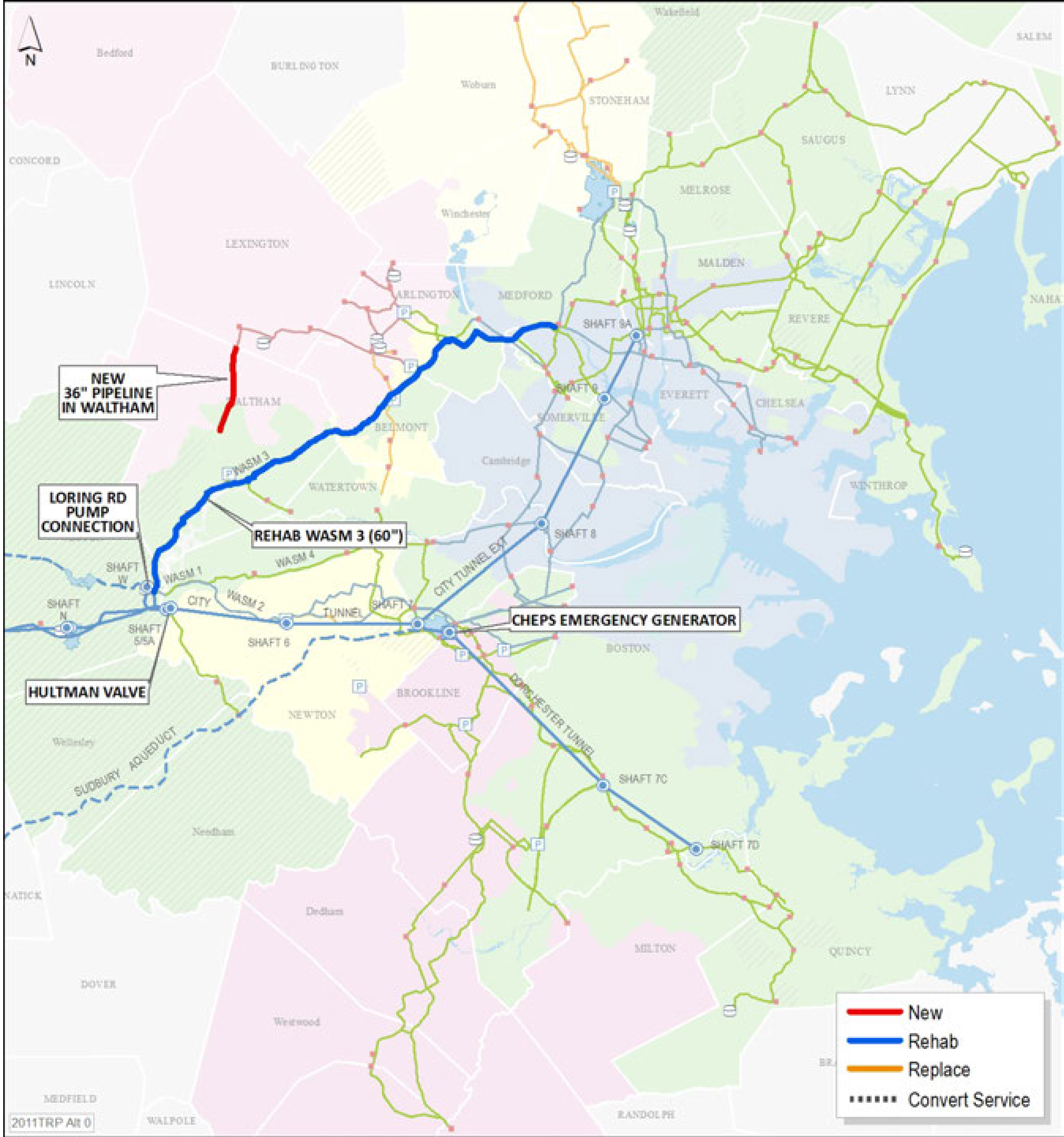
Baseline Construction:

- Rehabilitate WASM 3
- CHEPS Emergency Generator
- New Loring Road pump connection
- New Hultman valve
- New 36” Waltham pipeline

Cost to Complete:

$145M

(Midpoint of Construction)



North Alternatives

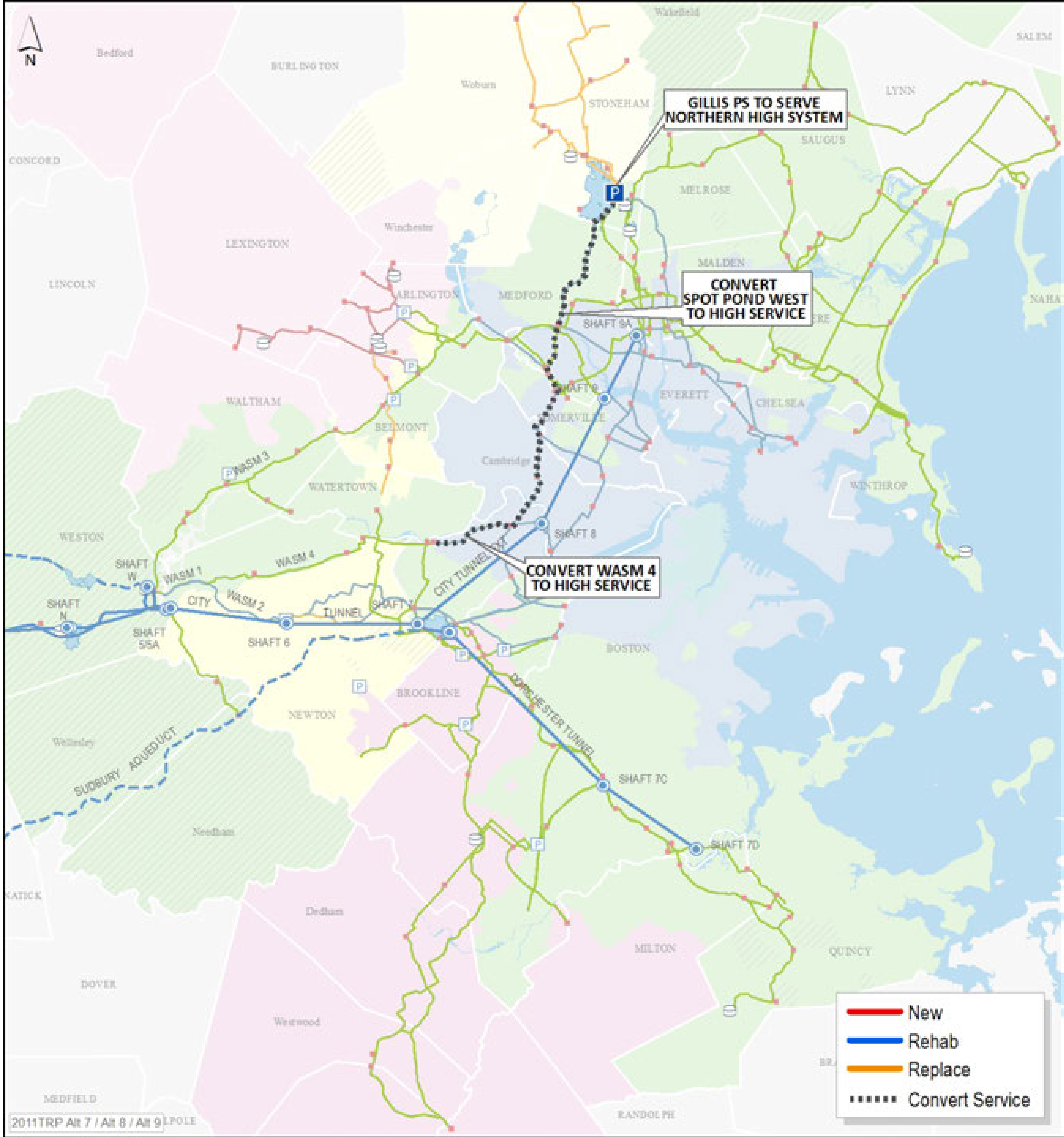
Alternative Number (Low Cost to High Cost)	Midpoint of Construction Dollars less baseline costs of $119M	Midpoint of Construction Year	Surface or Tunnel	Level of Redundancy	Construction Impacts	Allows maintenance to be perfomend at top of tunnel shafts	Comments
NORTH ALTERNATIVES							
Category 1 - No new Pipes - Push existing system to its limit							
1N	$10	2024	Surface	-	+	-	Not feasible for long term solution; Cannot supply summer demands; Not reliable for planned maintenance; Requires all assets to be in service; Could be used for contingency planning in near term
Category 2 - Replace WASM 3 with larger pipeline and/or add pump station							
2N	$138	2024	Surface	-	-	-	Not reliable for planned maintenance; Excessive pressure surges and swings increase risk of pipe failures; Construction deemed infeasible due to miles of street closures and disruptions
3N	$147	2024	Surface	-	-	-	Not reliable for planned maintenance; Excessive pressure surges and swings increase risk of pipe failures; Construction deemed infeasible due to miles of street closures and disruptions
4N	$188	2024	Surface	+	-	+	Construction deemed infeasible due to miles of street closures and disruptions; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a southern solution)
5N	$275	2024	Surface	+	-	+	Construction deemed infeasible due to miles of street closures and disruptions; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a southern solution)
6N	$326	2024	Surface	+	-	+	Construction deemed infeasible due to miles of street closures and disruptions; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a southern solution)
7N	$473	2024	Surface	+	-	+	Construction deemed infeasible due to miles of street closures and disruptions; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a southern solution)
Category 3 - Tunnel to north							
8N	$472/$487	2024	Tunnel	+	+	+	Less Construction impacts than pipeline; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a southern solution)
9N	$782	2024	Tunnel	+	+	+	Less Construction impacts than pipeline; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a southern solution)
10N	$1,085	2024	Tunnel	+	+	+	Less Construction impacts than pipeline; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a southern solution)
11N	$1,150	2024	Tunnel	+	+	+	Less Construction impacts than pipeline; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a southern solution)
12N	$1,209	2024	Tunnel	+	+	+	Less Construction impacts than pipeline; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a southern solution)
13N	$1,292	2024	Tunnel	+	+	+	Less Construction impacts than pipeline; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a southern solution)

Category 1

No New Pipes
Push Existing System to its Limit

Alternative 1N:

• Convert part of WASM 4 and entire West Spot Pond pipeline to high service



Cost to Complete:

$10M

(Midpoint of Construction)
(less baseline costs)

Category 2

Replace WASM 3 with Larger Pipeline and/or Add Pump Station

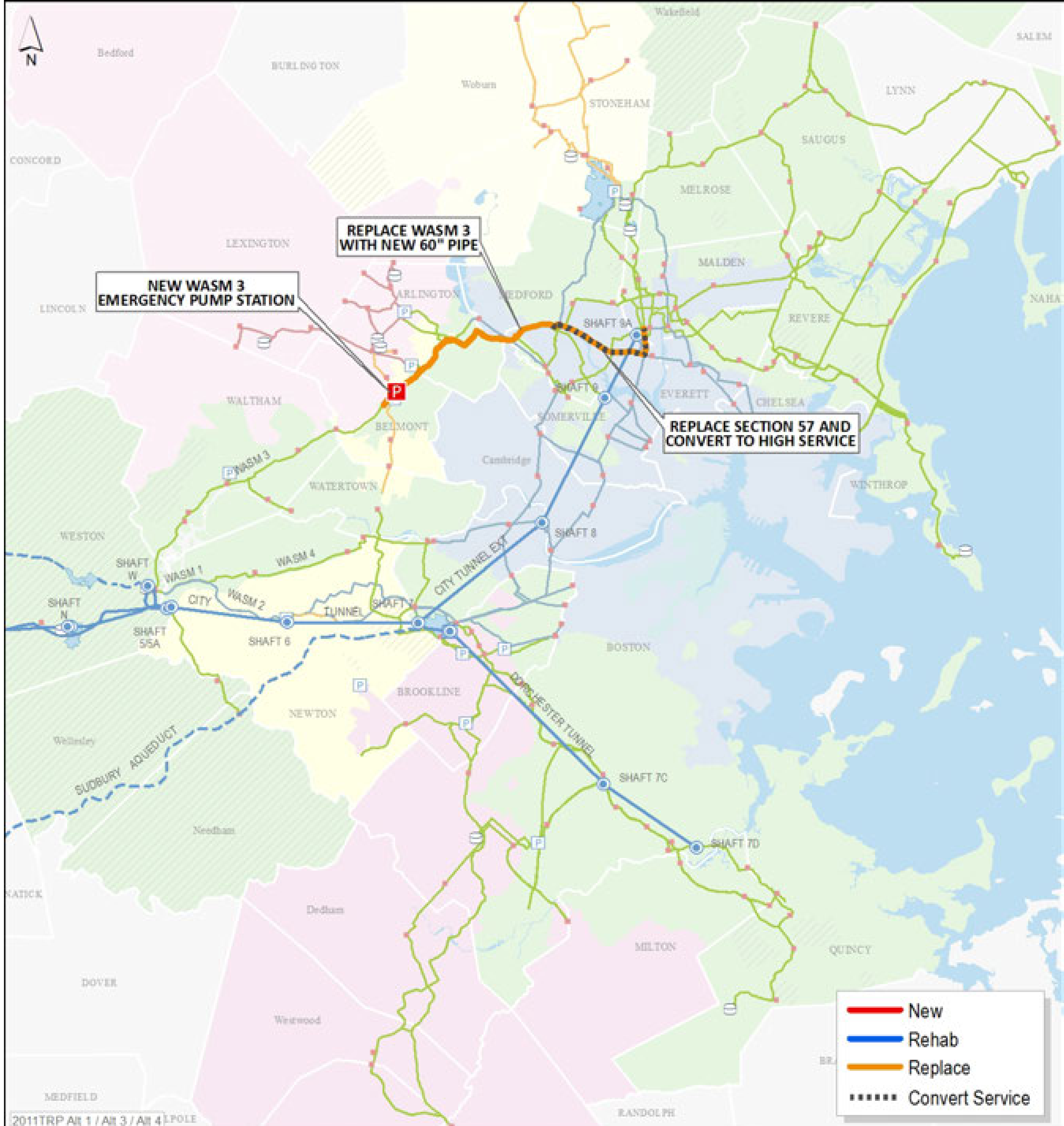
Alternative 2N:

- New WASM 3 emergency pump station with
- New 60” WASM 3 discharge line
- Convert Section 57 to high service

Cost to Complete:

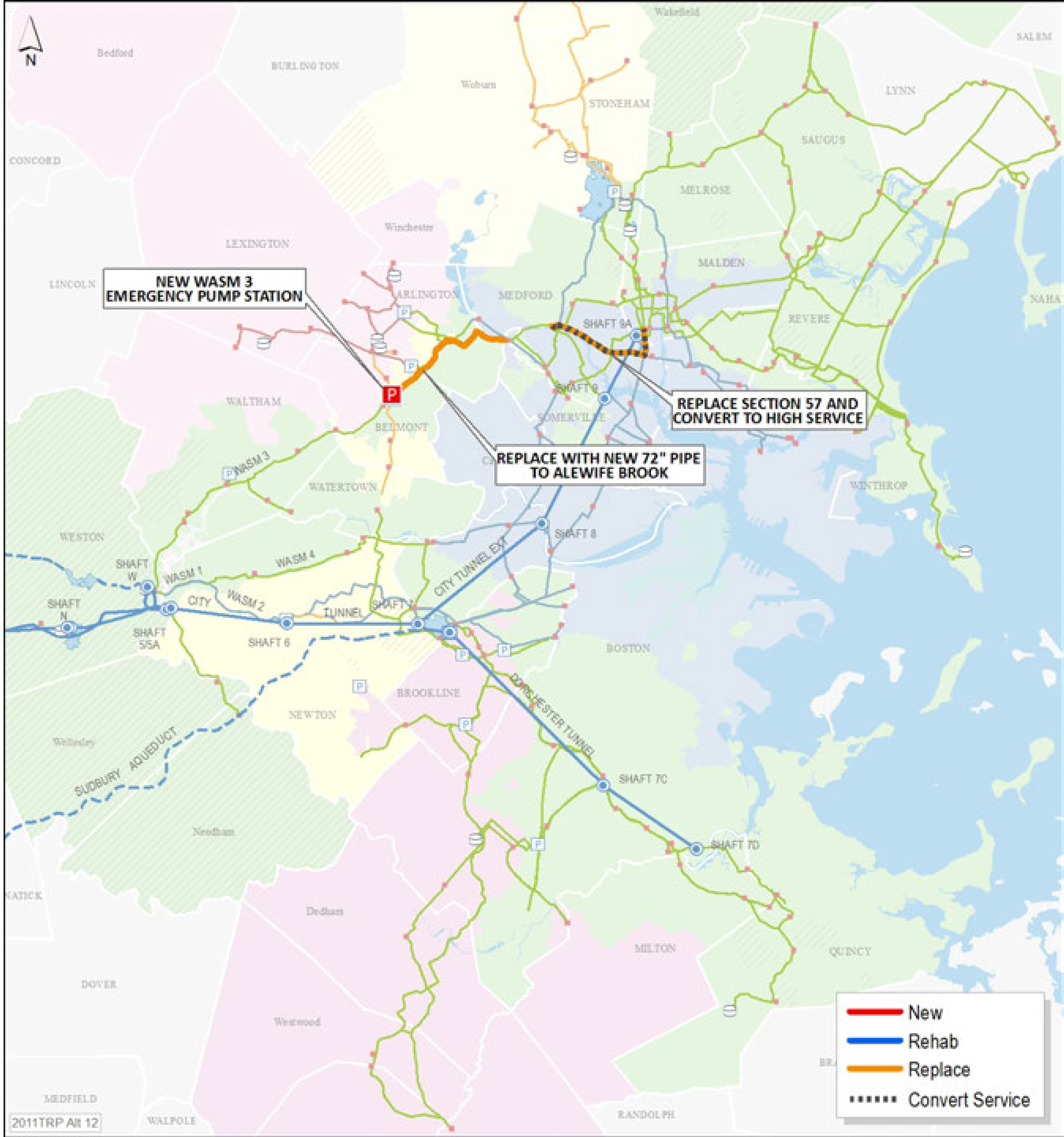
$138M

(Midpoint of Construction)
(less baseline costs)



Alternative 3N:

- New WASM 3 emergency pump station
- New 72” WASM 3 discharge line
- Convert Section 57 to high service



Cost to Complete:

$147M

(Midpoint of Construction)
(less baseline costs)

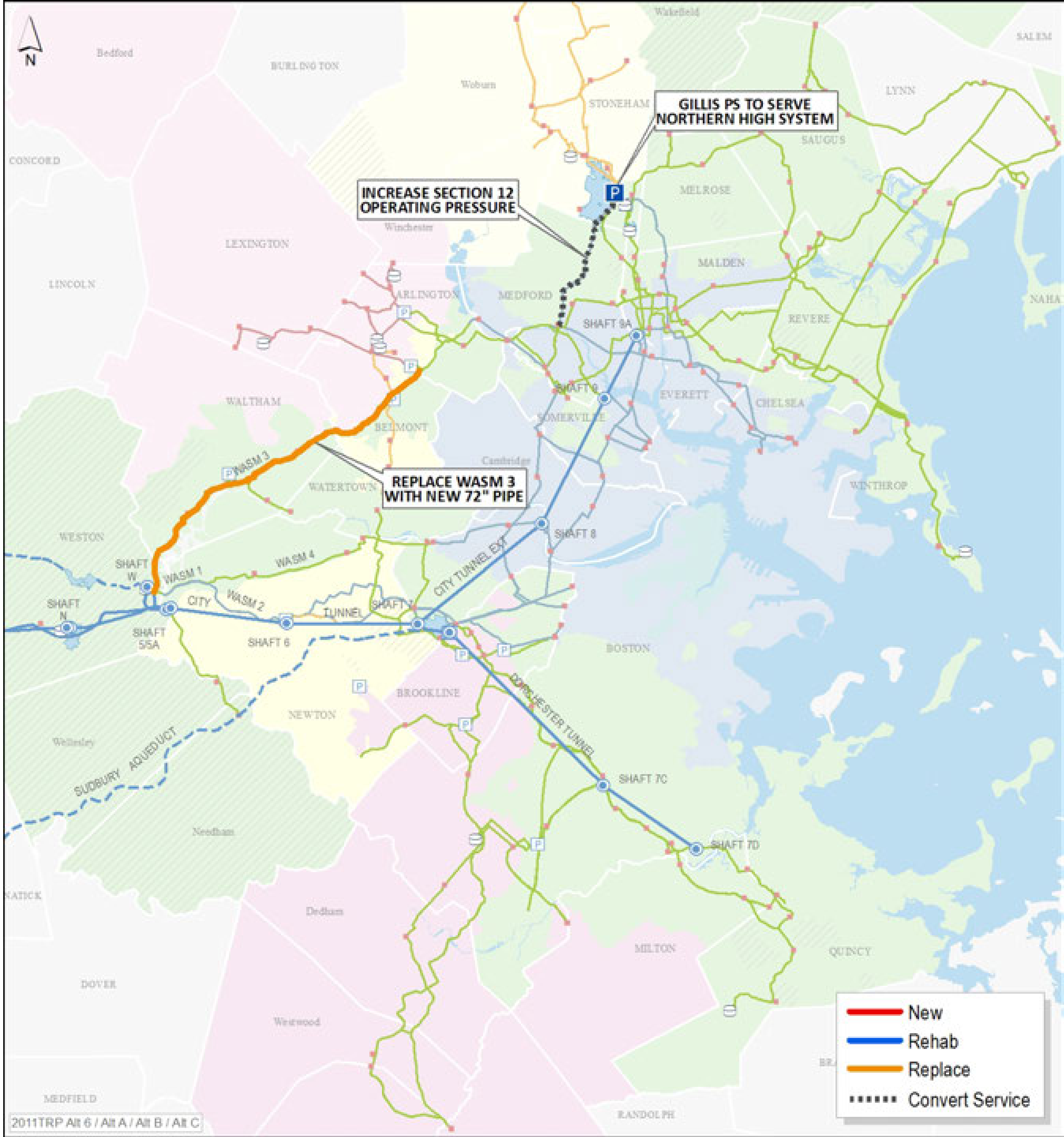
Alternative 4N:

- New 72" WASM 3 to Spring Street Pump Station
- Convert Section 12 to high service

Cost to Complete:

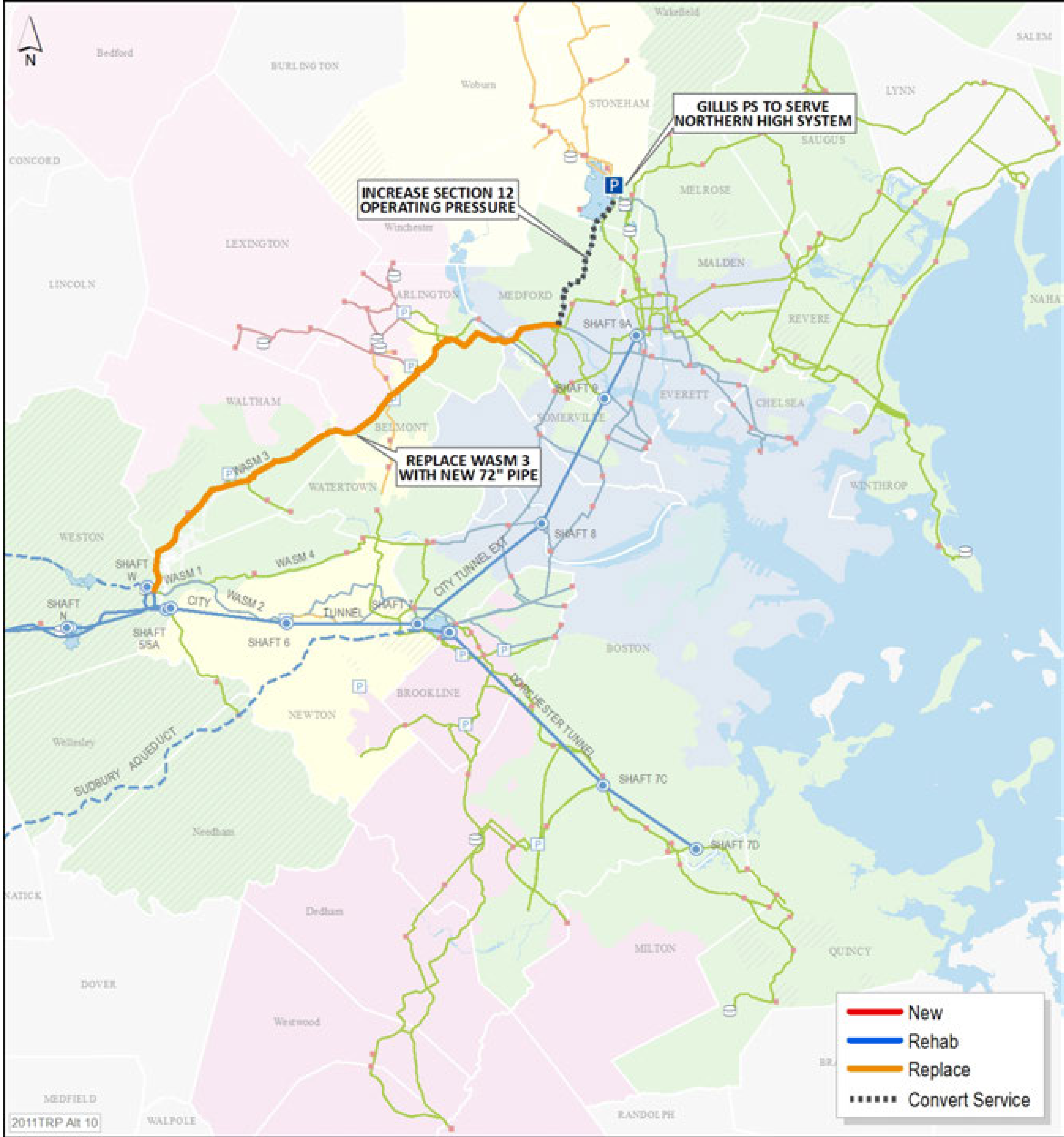
$188M

(Midpoint of Construction)
(less baseline costs)



Alternative 5N:

- New 72"WASM 3
- Convert Section 12 to high service



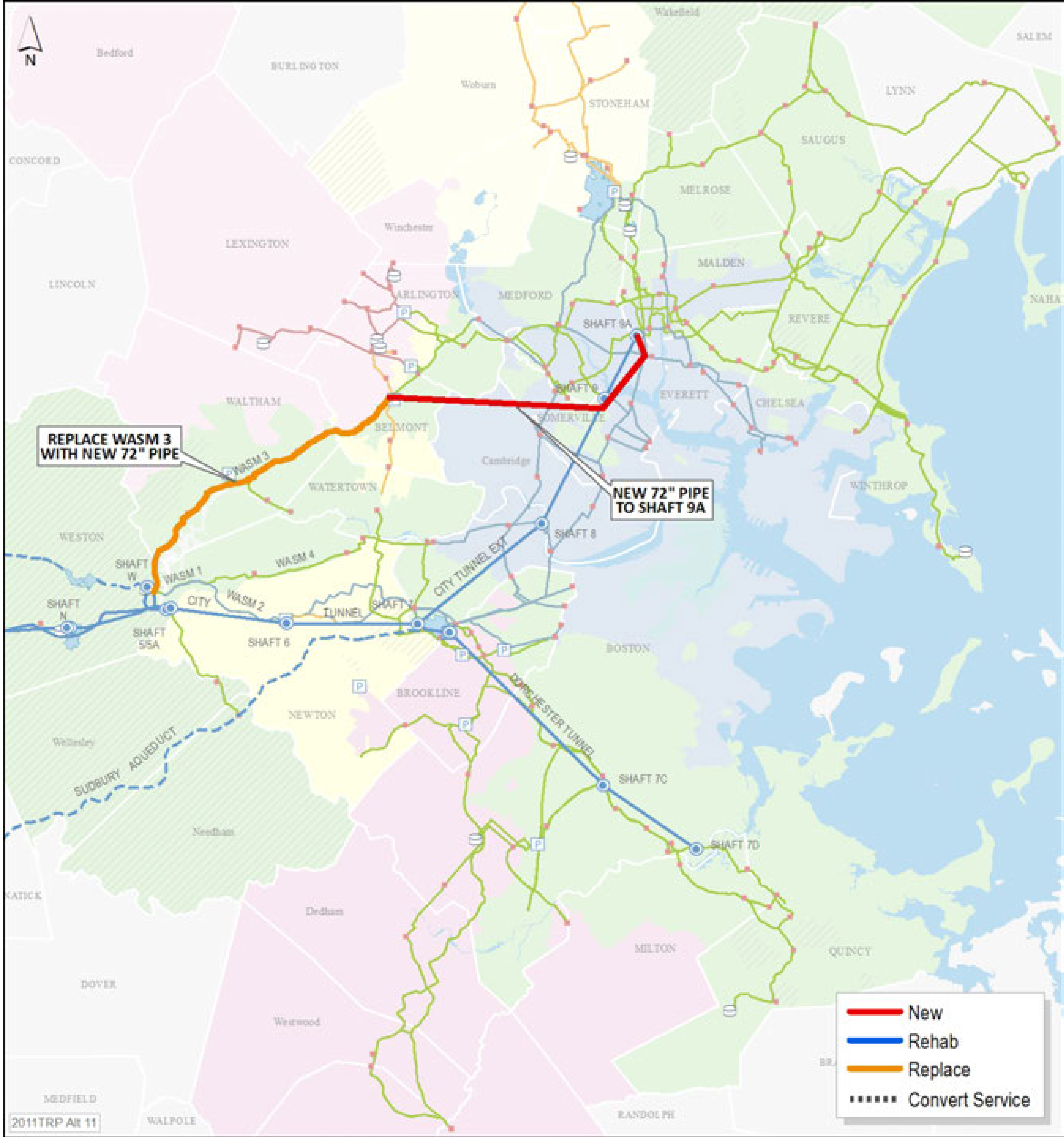
Cost to Complete:

$275M

(Midpoint of Construction)
(less baseline costs)

Alternative 6N:

- New 72” WASM 3
- New 72” to Shaft 9A



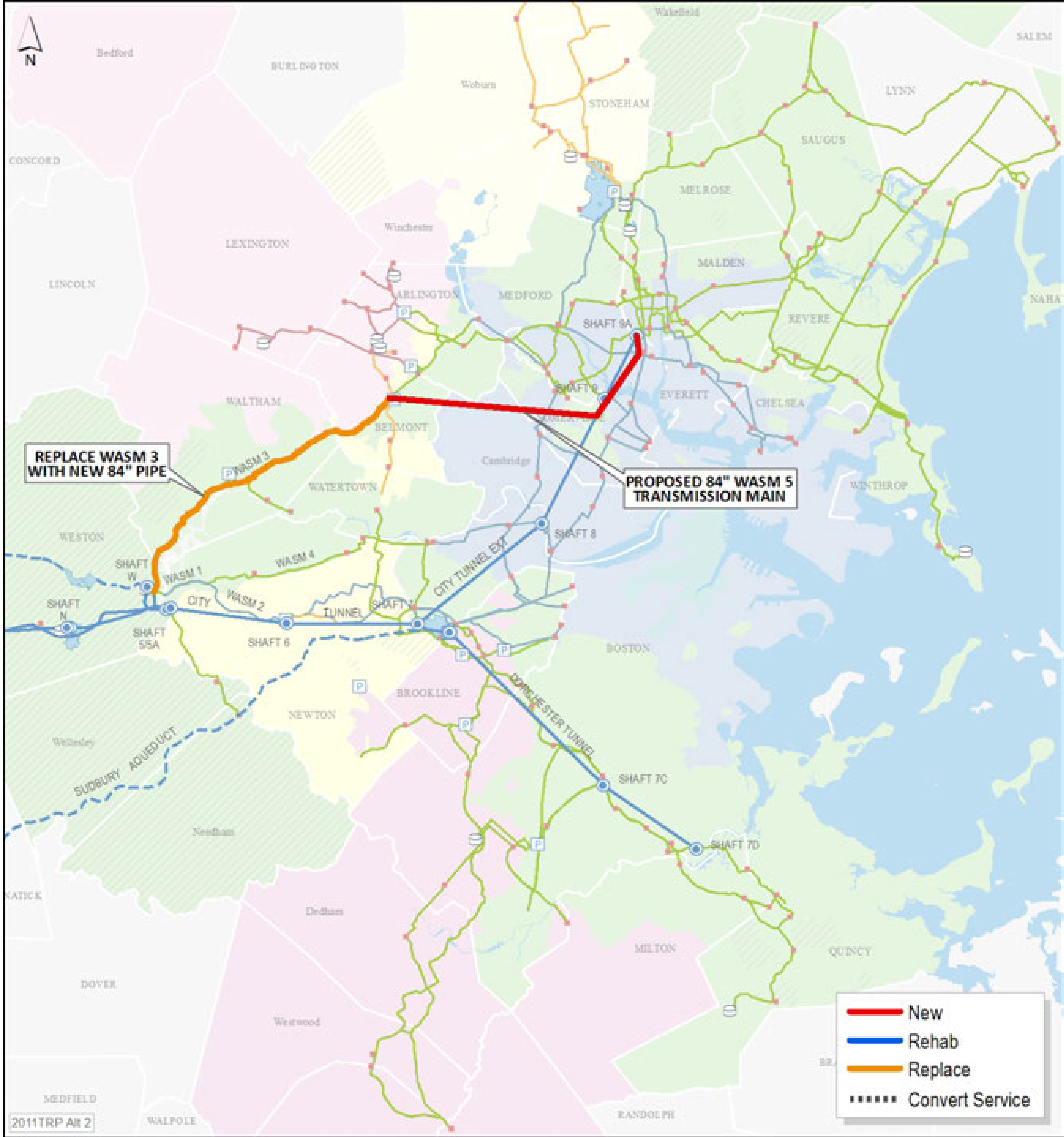
Cost to Complete:

$326M

(Midpoint of Construction)
(less baseline costs)

Alternative 7N:

- New 84” WASM 3
- New 84” to Shaft 9A



Cost to Complete:

$473M

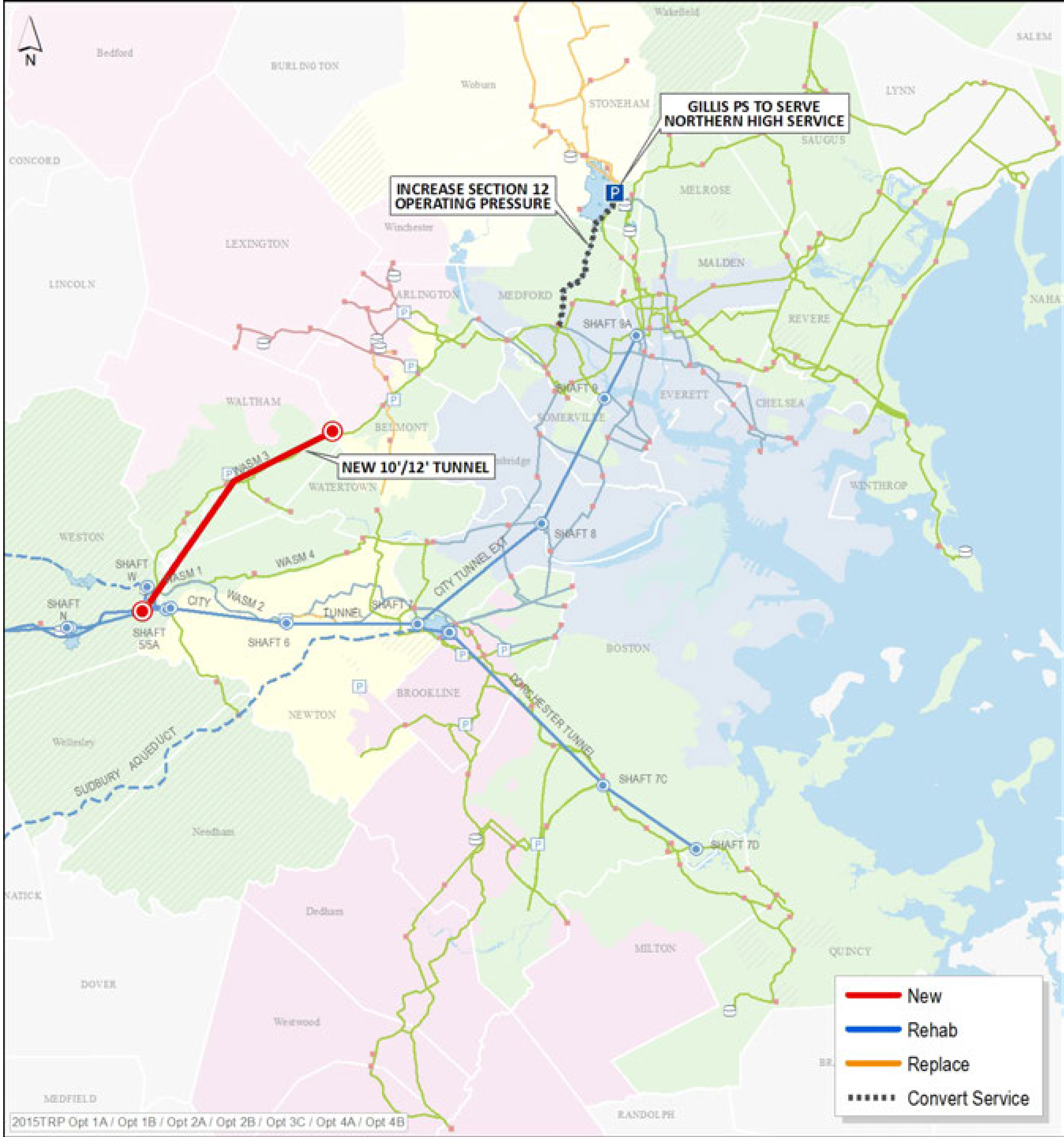
(Midpoint of Construction)
(less baseline costs)

Category 3

Tunnel to North

Alternative 8N:

- New 10’/12’ tunnel



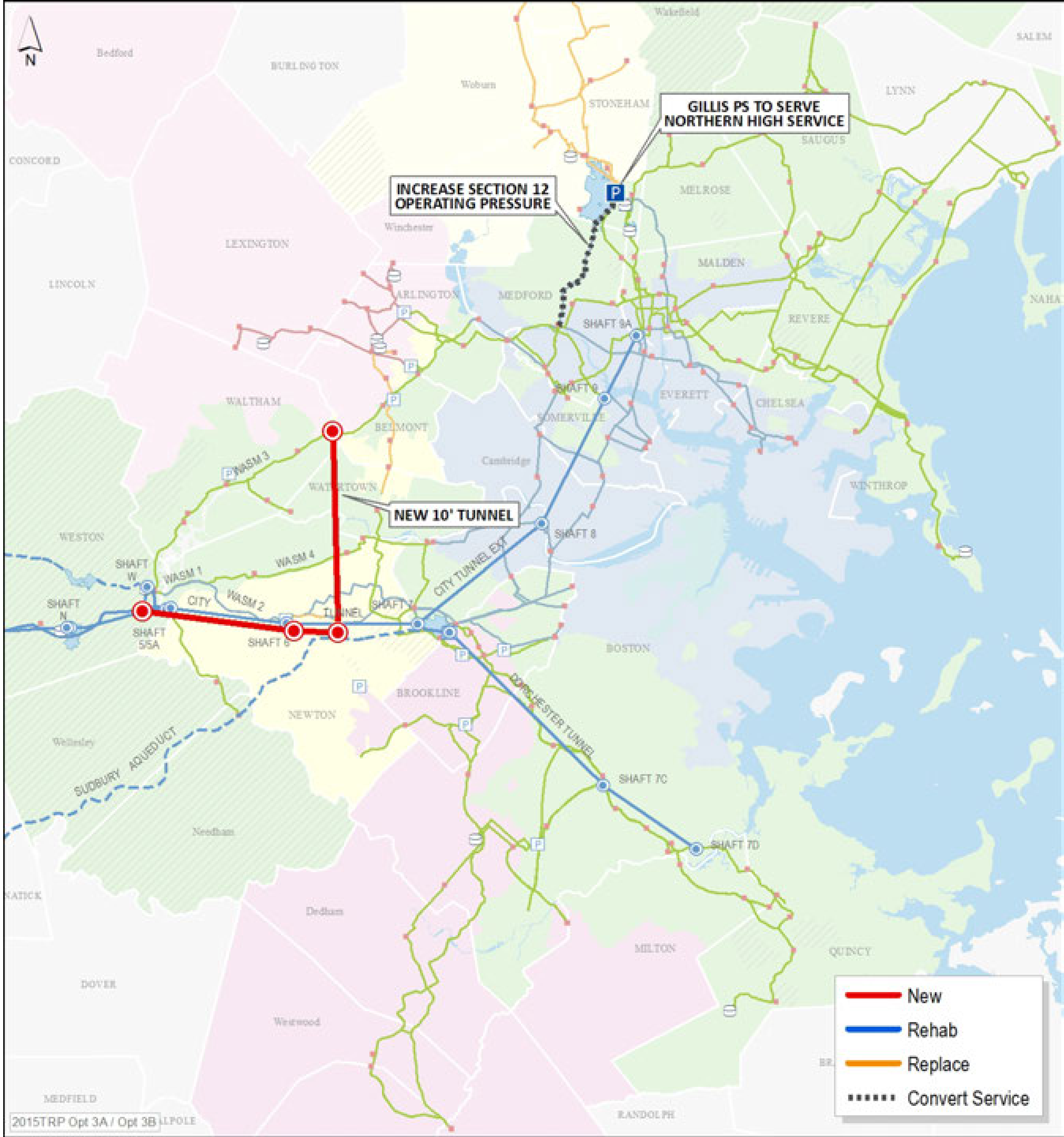
Cost to Complete:

$472M @ 10’ Dia.
$487M @ 12’ Dia.

(Midpoint of Construction)
(less baseline costs)

Alternative 9N:

- New tunnel from Bifurcation to Fernald School via Shaft 6



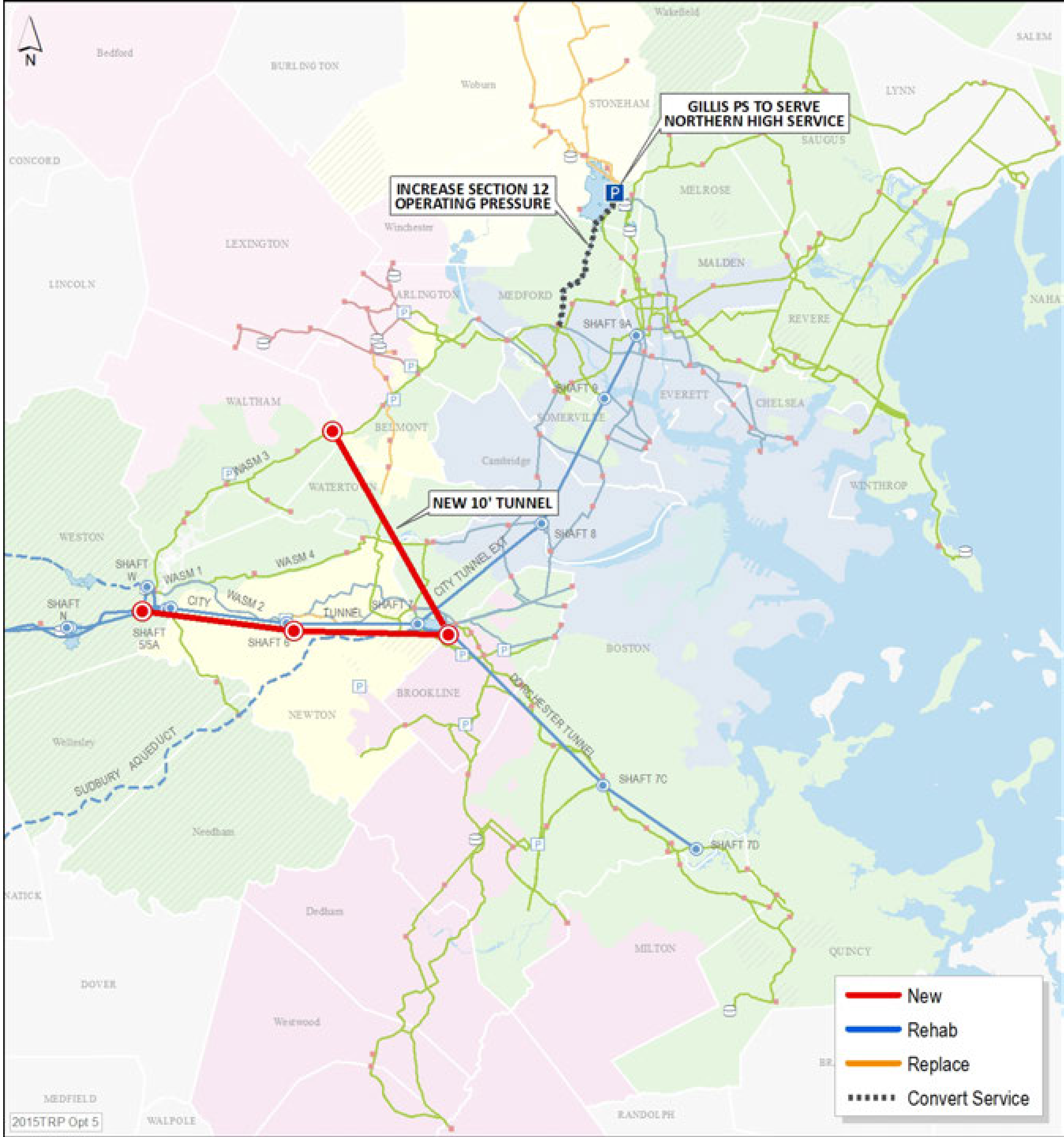
Cost to Complete:

$782M

(Midpoint of Construction)
(less baseline costs)

Alternative 10N:

• New tunnel from Bifurcation to Chestnut Hill and Fernald School



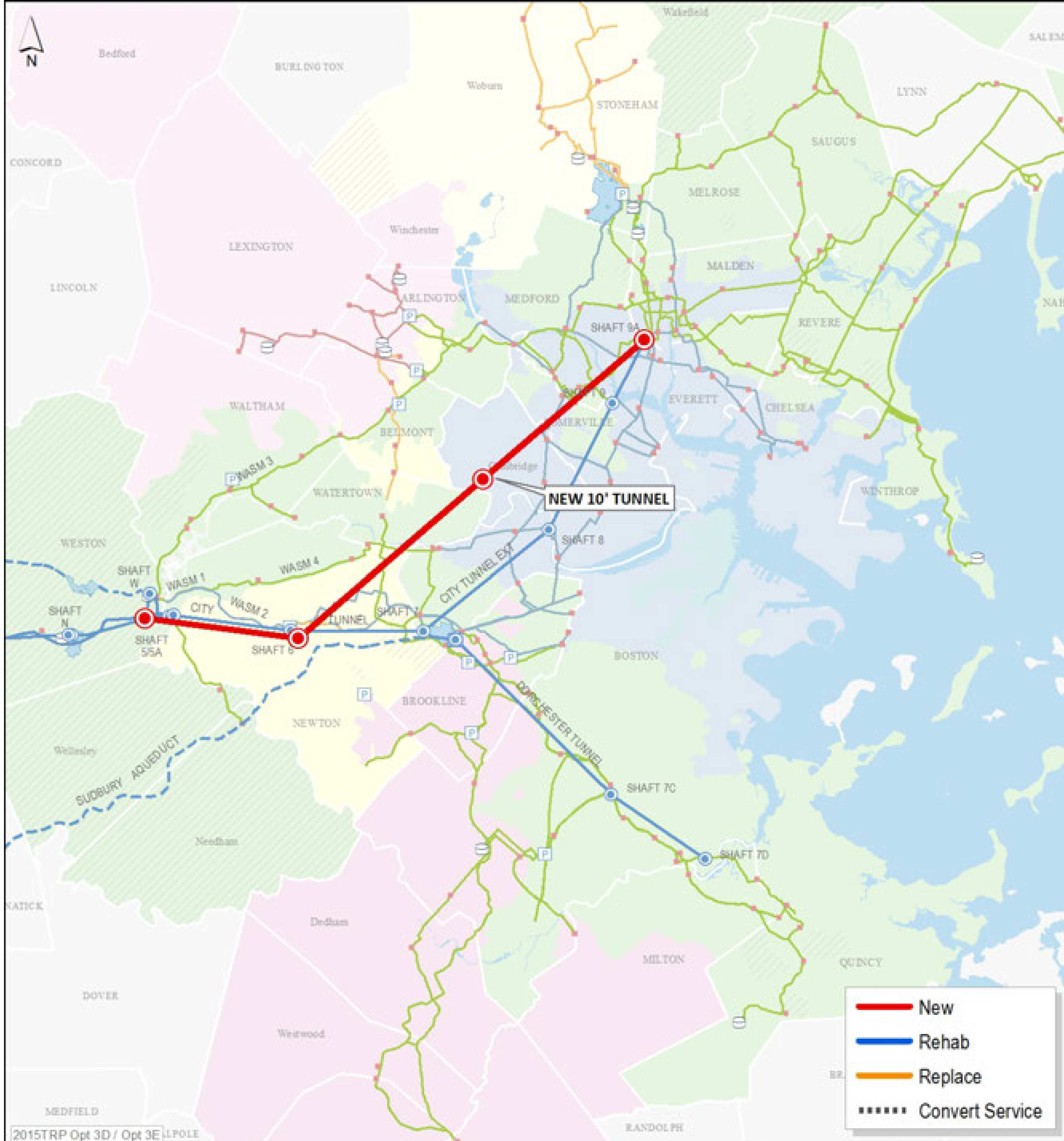
Cost to Complete:

$1,085M

(Midpoint of Construction)
(less baseline costs)

Alternative 11N:

- New tunnel from Bifurcation to Shaft 9A via Shaft 6



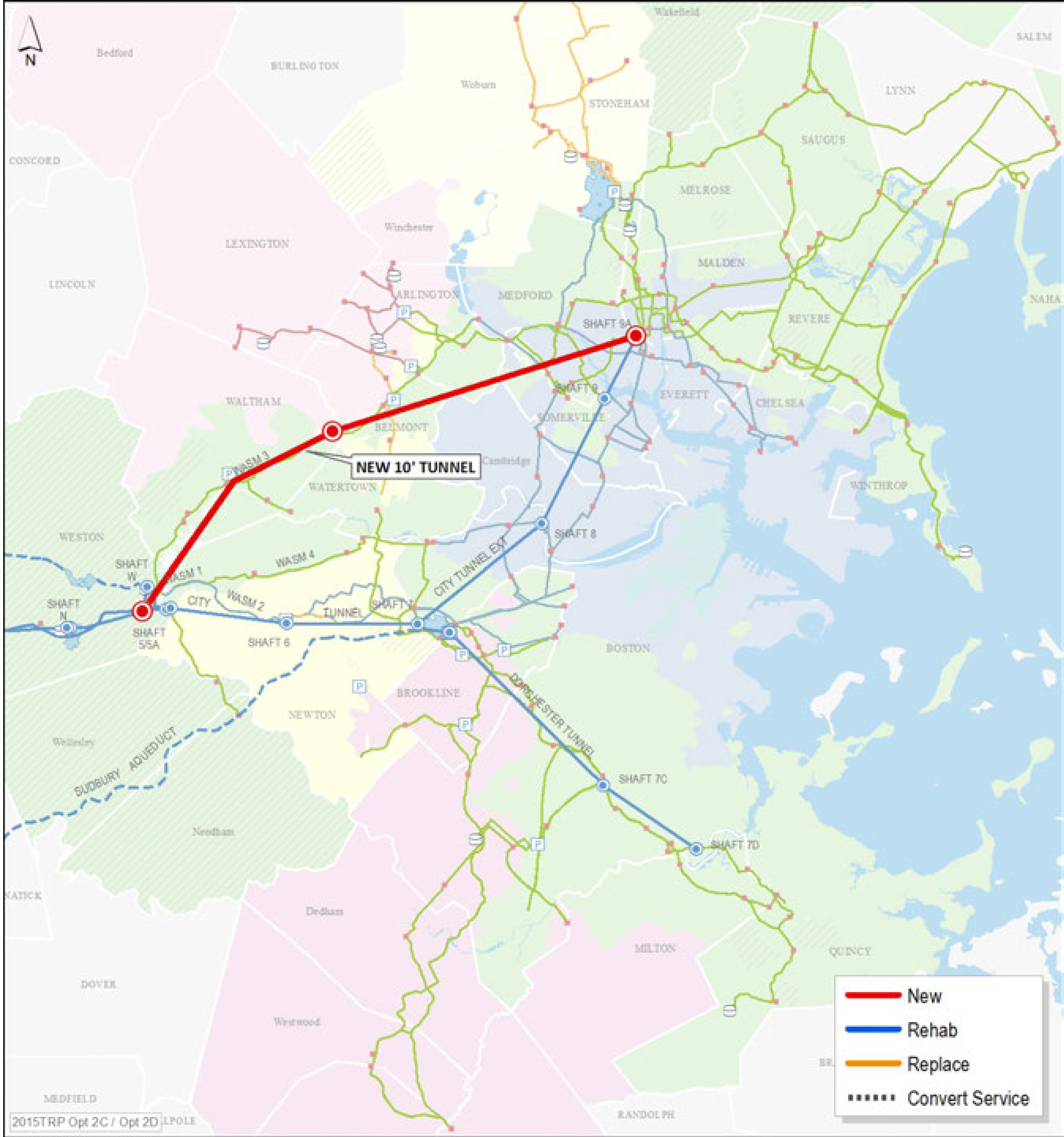
Cost to Complete:

$1,150M

(Midpoint of Construction)
(less baseline costs)

Alternative 12N:

• New Tunnel from Bifurcation to Shaft 9A



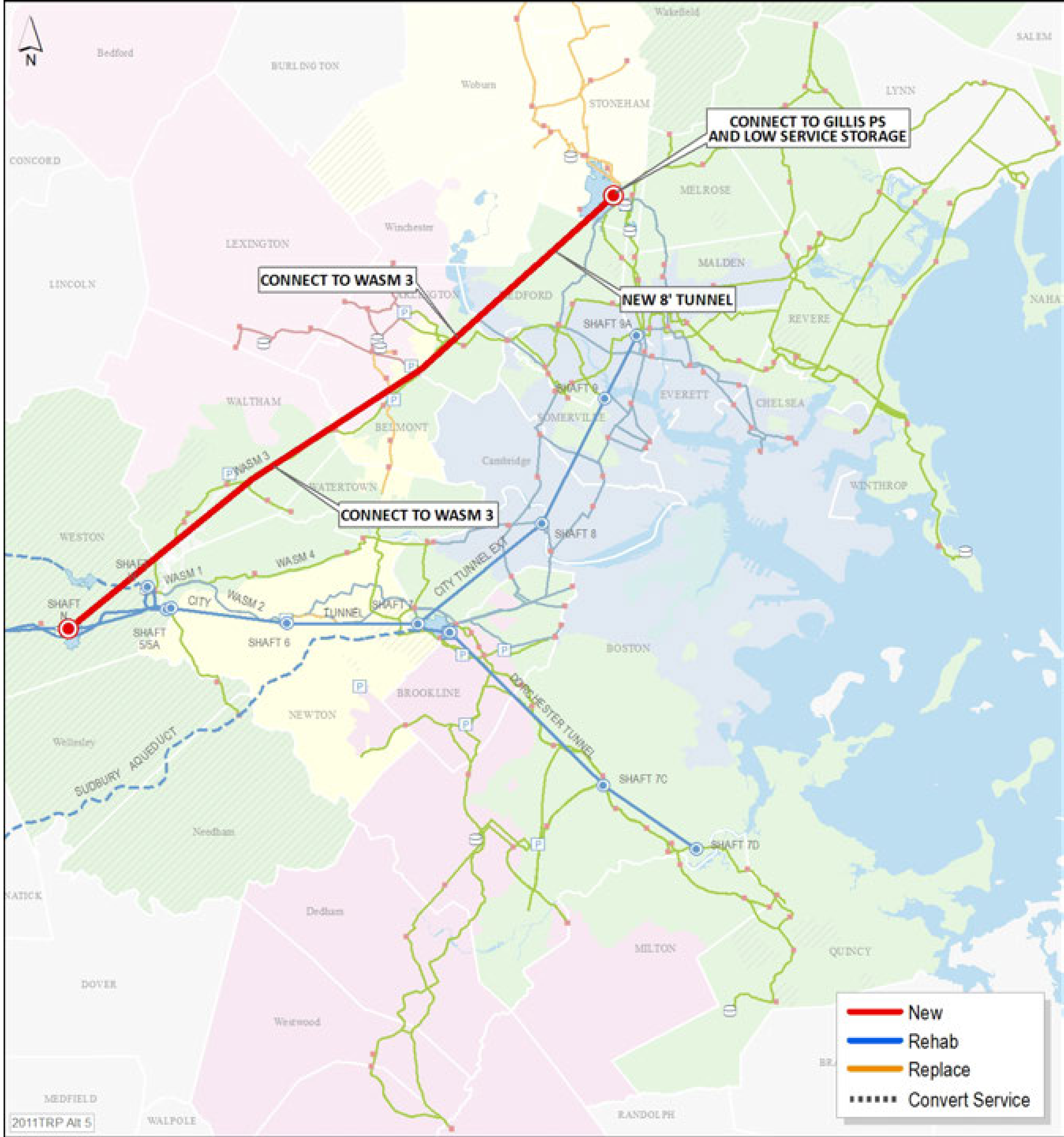
Cost to Complete:

$1,209M

(Midpoint of Construction)
(less baseline costs)

Alternative 13N:

- New tunnel from Shaft N to Gillis pump station



Cost to Complete:

$1,292M

(Midpoint of Construction)
(less baseline costs)

South Alternatives

Alternative Number (Low Cost to High Cost)	Midpoint of Construction Dollars less baseline costs of $119M	Midpoint of Construction Year	Surface or Tunnel	Level of Redundancy	Construction Impacts	Allows maintenance to be perfomend at top of tunnel shafts	Comments / Potential Tunnel Extension
SOUTH ALTERNATIVES							
Category 1 - Pipeline to Sudbury Aqueduct/Slipline Sudbury Aqueduct or Tunnel to Chestnut Hill Emergency Pump Station							
5S	$293	2026	Surface	-	-	-	Insufficient capacity in southern surface mains; excessive discharge pressures pressures at Chestnut Hill Emergency Pump Station increase risk of pipe failure; major construction impacts with sliplining Sudbury Aqueduct; Construction of pipeline deemed infeasible due to miles of street closures and disruptions
6S	$300	2025	Surface	-	-	-	Insufficient capacity in southern surface mains; excessive discharge pressures pressures at Chestnut Hill Emergency Pump Station increase risk of pipe failure; major construction impacts with sliplining Sudbury Aqueduct; Construction of pipeline deemed infeasible due to miles of street closures and disruptions
7S	$306	2025	Surface	-	-	-	Insufficient capacity in southern surface mains; excessive discharge pressures pressures at Chestnut Hill Emergency Pump Station increase risk of pipe failure; major construction impacts with sliplining Sudbury Aqueduct; Construction of pipeline deemed infeasible due to miles of street closures and disruptions
9S	$390	2025	Surface	-	-	-	Insufficient capacity in southern surface mains; excessive discharge pressures pressures at Chestnut Hill Emergency Pump Station increase risk of pipe failure; major construction impacts with sliplining Sudbury Aqueduct; Construction of pipeline deemed infeasible due to miles of street closures and disruptions
11S	$465	2026	Tunnel/ Surface	-	-	-	Insufficient capacity in southern surface mains; excessive discharge pressures pressures at Chestnut Hill Emergency Pump Station increase risk of pipe failure; major construction impacts with sliplining Sudbury Aqueduct; Tunnel portion has less construction impacts than new pipeline
12S	$467	2026	Tunnel/ Surface	-	-	-	Insufficient capacity in southern surface mains; excessive discharge pressures pressures at Chestnut Hill Emergency Pump Station increase risk of pipe failure; major construction impacts with sliplining Sudbury Aqueduct; Tunnel portion has less construction impacts than new pipeline
14S	$521	2027	Tunnel	-	+	-	Insufficient capacity in southern surface mains; excessive discharge pressures pressures at Chestnut Hill Emergency Pump Station increase risk of pipe failure; Tunnel portion has less construction impacts than new pipeline
15S	$551	2026	Tunnel/ Surface	-	-	-	Insufficient capacity in southern surface mains; excessive discharge pressures pressures at Chestnut Hill Emergency Pump Station increase risk of pipe failure; major construction impacts with sliplining Sudbury Aqueduct; Tunnel portion has less construction impacts than new pipeline
16S	$482/$629	2027	Tunnel	-	+	-	Insufficient capacity in southern surface mains; excessive discharge pressures pressures at Chestnut Hill Emergency Pump Station increase risk of pipe failure; Tunnel portion has less construction impacts than new pipeline
Category 2 - Pipeline to Southern Surface Mains with or without new pump station							
8S	$330	2027	Surface	-	-	-	Surge pressures at new Pump Station increase risk of pipe failure; Construction of pipeline deemed infeasible due to miles of street closures and disruptions
10S	$390	2025	Surface	-	-	-	Surge pressures at Chestnut Hill Emergency Pump Station increase risk of pipe failure; Construction of pipeline deemed infeasible due to miles of street closures and disruptions
Category 3 - Tunnel to Shaft 7C of Dorchester Tunnel							
17S	$716	2026	Tunnel	+	+	+	Less Construction impacts than pipeline; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a northern solution)
18S	$1,003	2027	Tunnel	+	+	+	Less Construction impacts than pipeline; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a northern solution)
19S	$1,034	2026	Tunnel	+	+	+	Less Construction impacts than pipeline; Meets redundancy goals under all demands; allows year round maintenance of tunnel system (in combination with a northern solution)

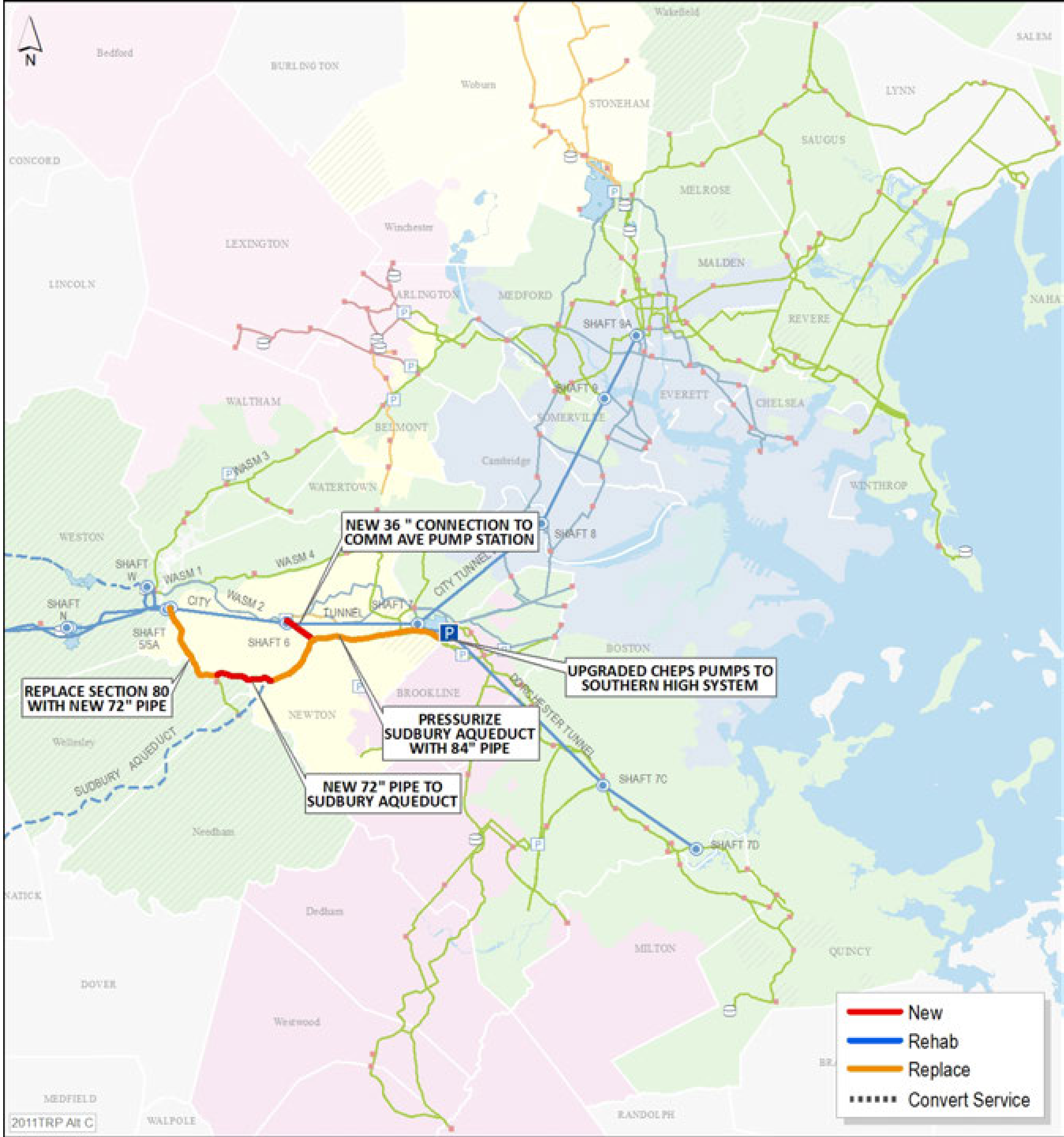
Category 1

New Pipeline or Tunnel to Chestnut Hill Emergency P.S.

Pump to Southern Surface Mains

Alternative 5S:

- New 72" Section 80
- New 72" pressurized Sudbury Aqueduct
- New 36" connection to Commonwealth Ave. pump station



Cost to Complete:

$293M

(Midpoint of Construction)
(less baseline costs)

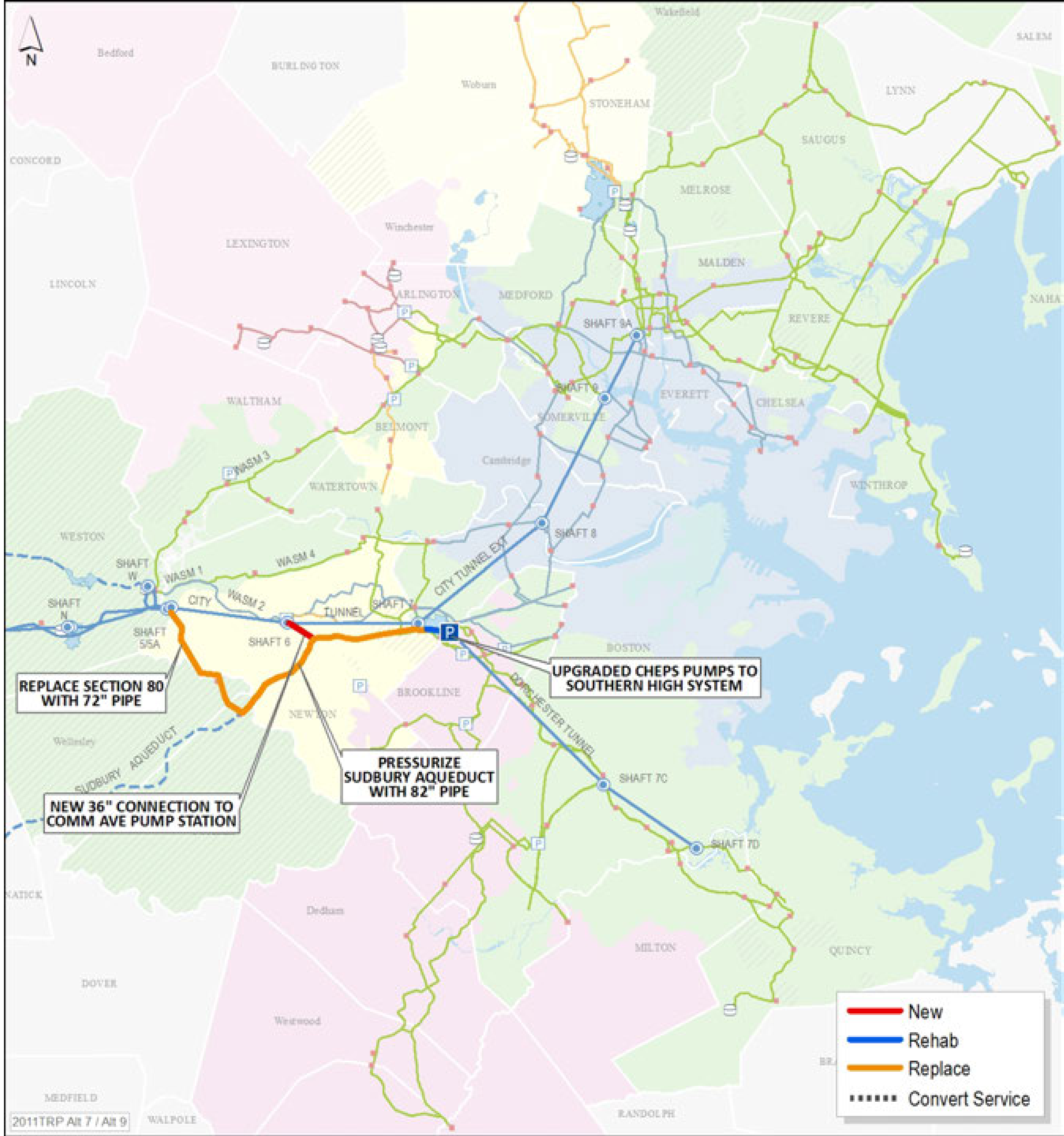
Alternative 6S:

- New 72” Section 80
- New 82”pressurized Sudbury Aqueduct
- New 36”connection to Commonwealth Ave. pump station

Cost to Complete:

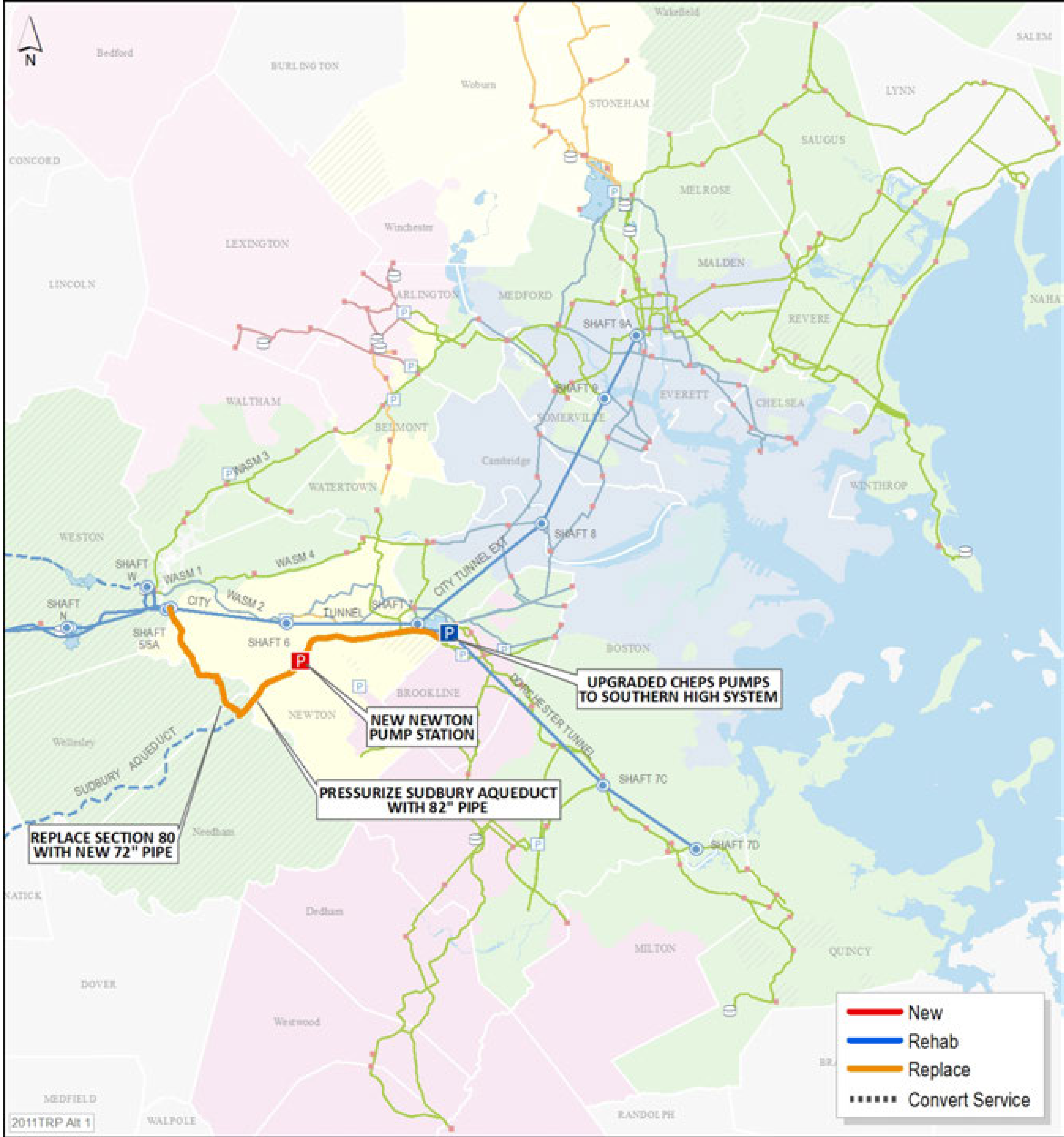
$300M

(Midpoint of Construction)
(less baseline costs)



Alternative 7S:

- New 72" Section 80
- New 82"pressurized Sudbury Aqueduct
- New Newton pump station



Cost to Complete:

$306M

(Midpoint of Construction)
(less baseline costs)

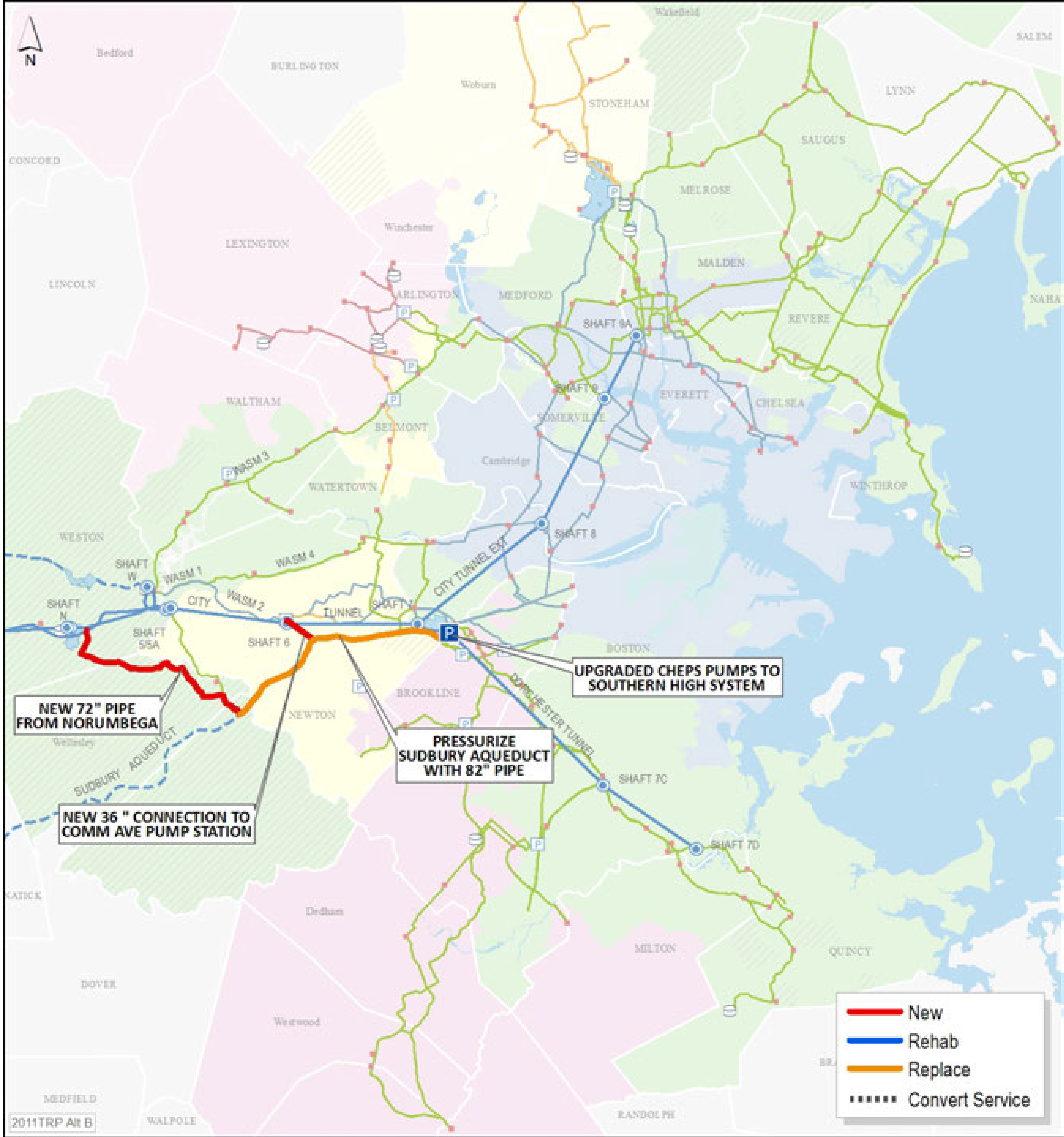
Alternative 9S:

- New 72" pipeline from Shaft N
- New 82" pressurized Sudbury Aqueduct
- New 36" connection to Commonwealth Ave. pump station

Cost to Complete:

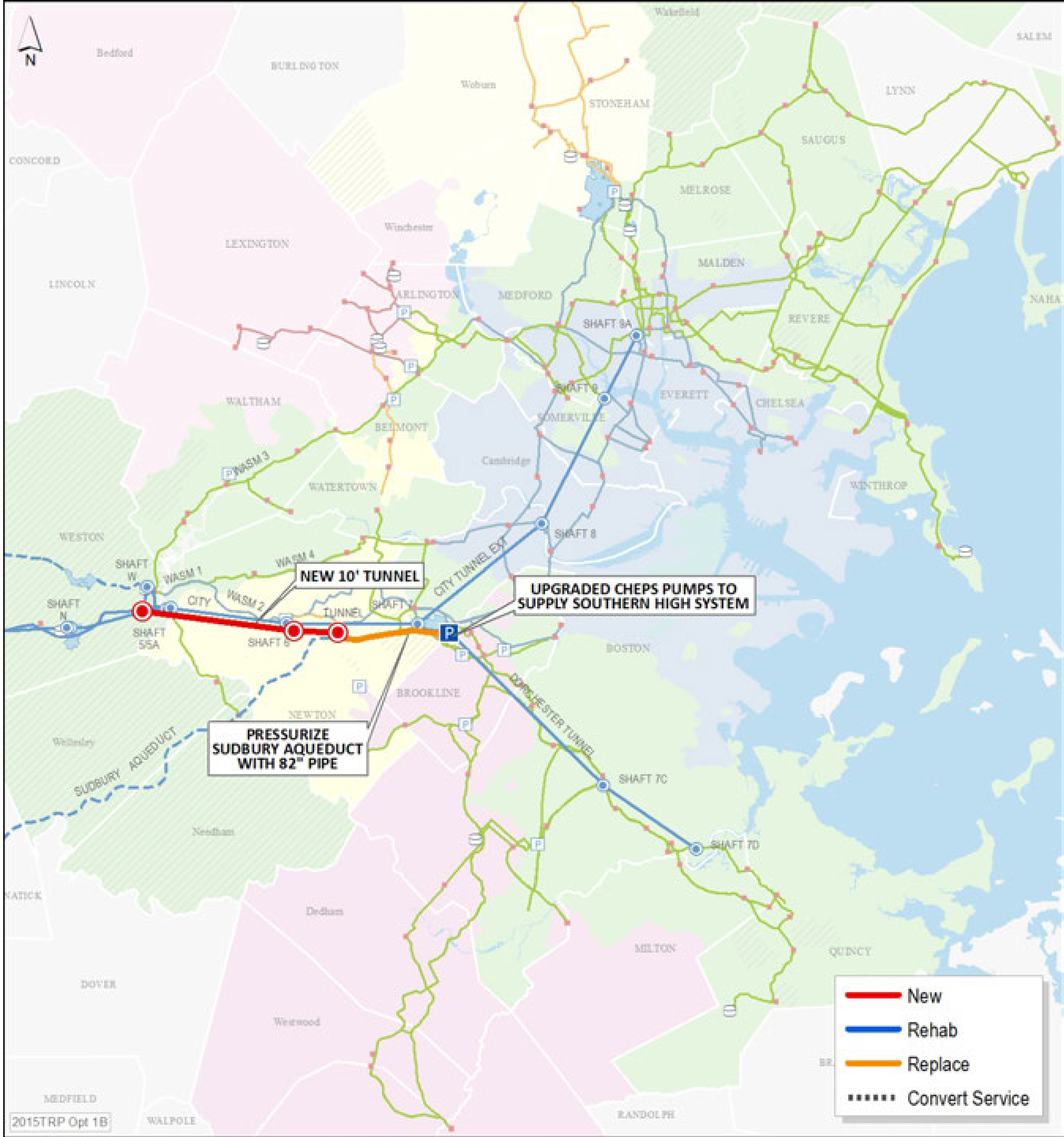
$390M

(Midpoint of Construction)
(less baseline costs)



Alternative 11S:

• New tunnel from Bifurcation to Sudbury Aqueduct
• New 82" pressurized Sudbury Aqueduct



Cost to Complete:

$465M

(Midpoint of Construction)
(less baseline costs)

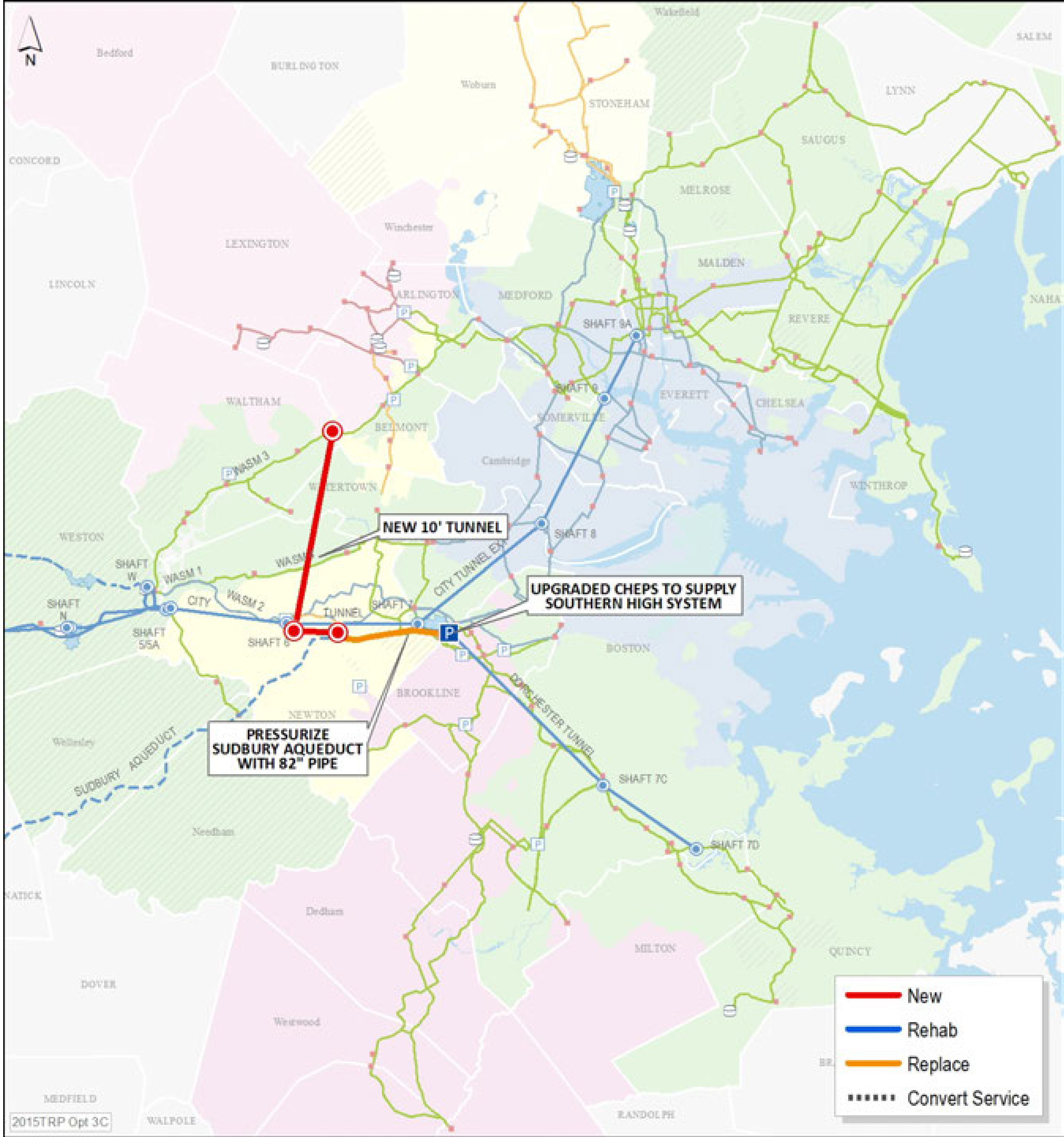
Alternative 12S:

- New tunnel from Fernald School to Sudbury Aqueduct
- New 82" pressurized Sudbury Aqueduct

Cost to Complete:

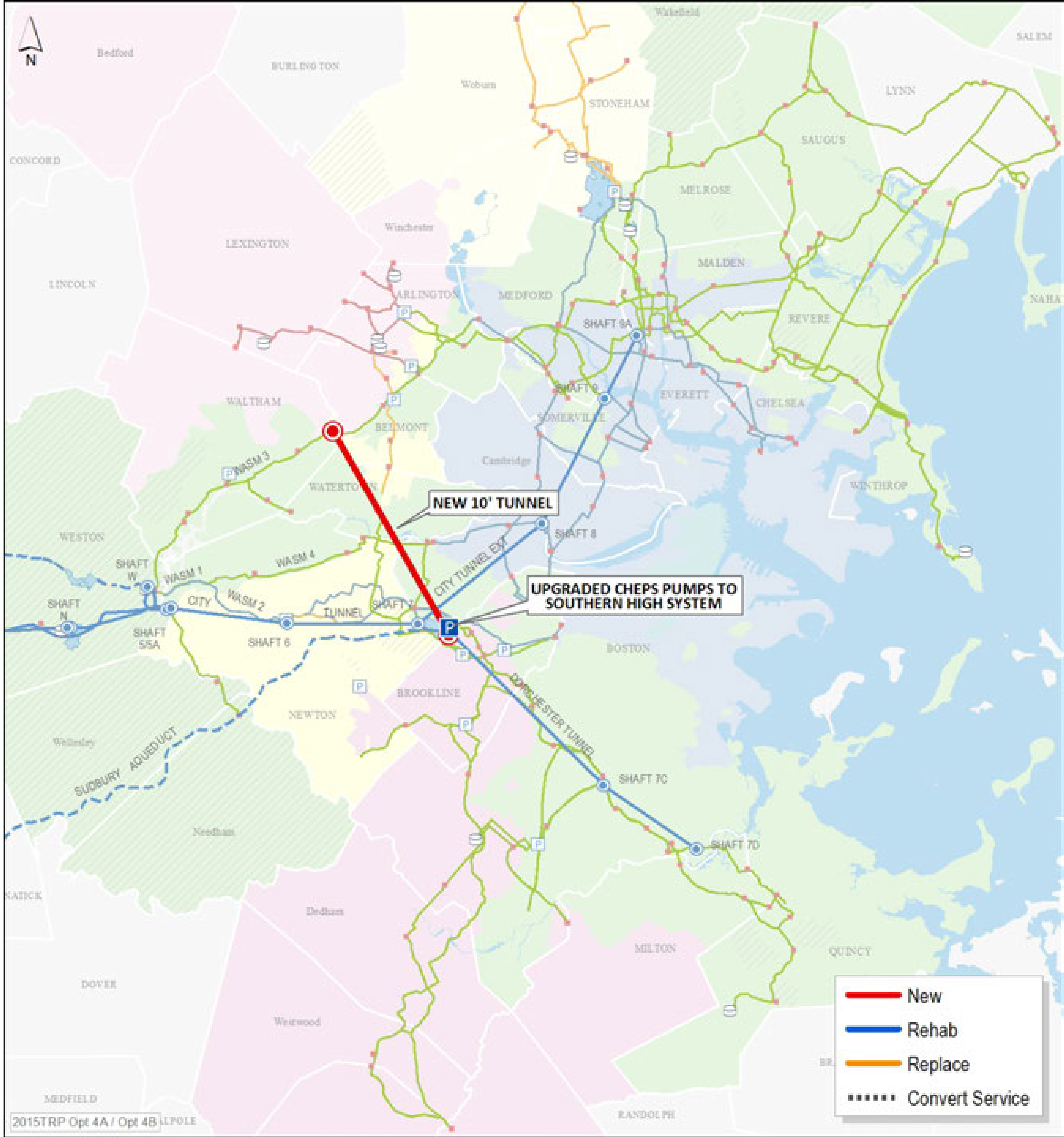
$467M

(Midpoint of Construction)
(less baseline costs)



Alternative 14S:

- New tunnel from Fernald School to Chestnut Hill



Cost to Complete:

$521M

(Midpoint of Construction)
(less baseline costs)

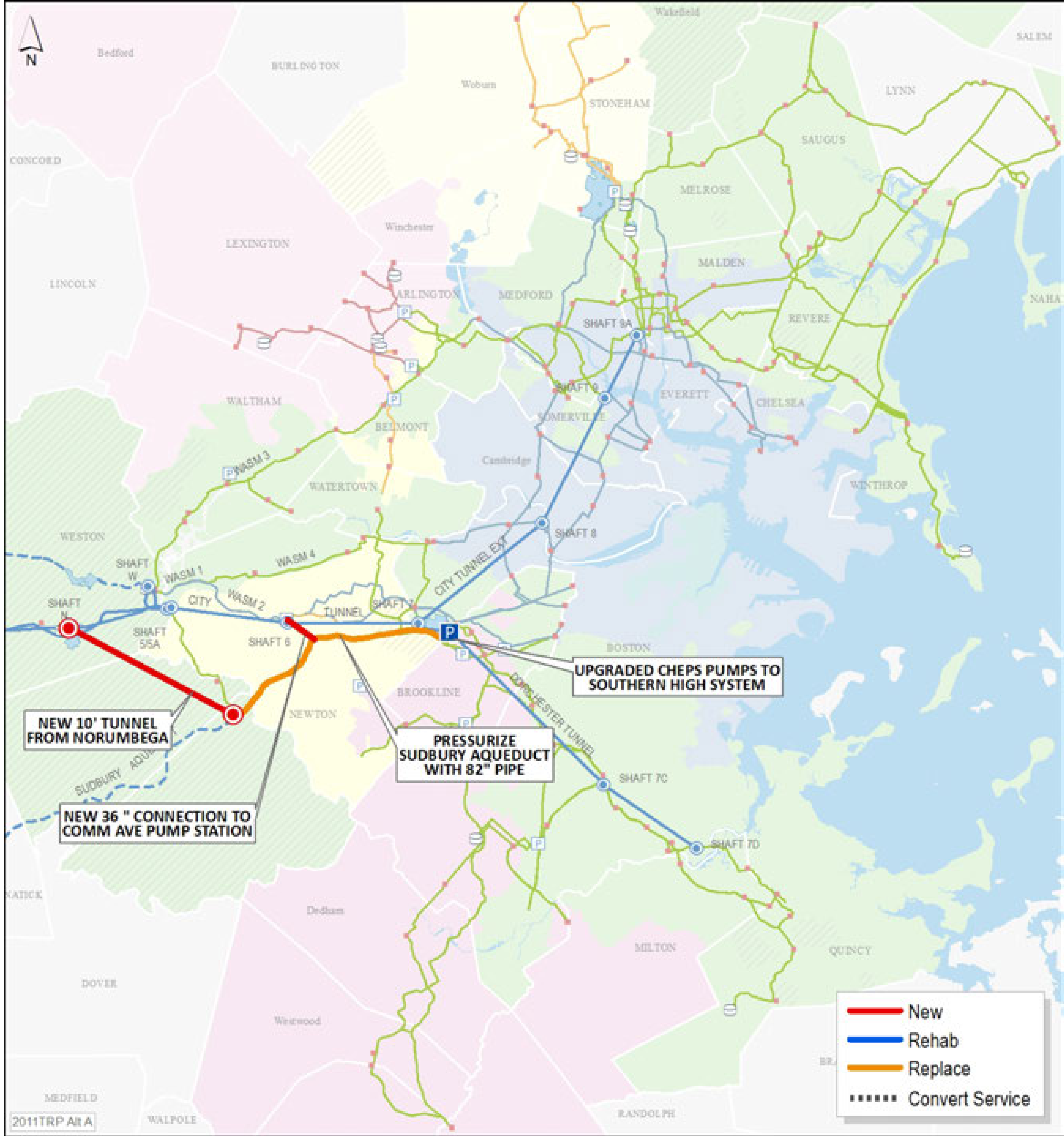
Alternative 15S:

- New tunnel from Shaft N to Sudbury Aqueduct
- New 82” pressurized Sudbury Aqueduct
- New 36” connection to Commonwealth Ave. pump station

Cost to Complete:

$551M

(Midpoint of Construction)
(less baseline costs)



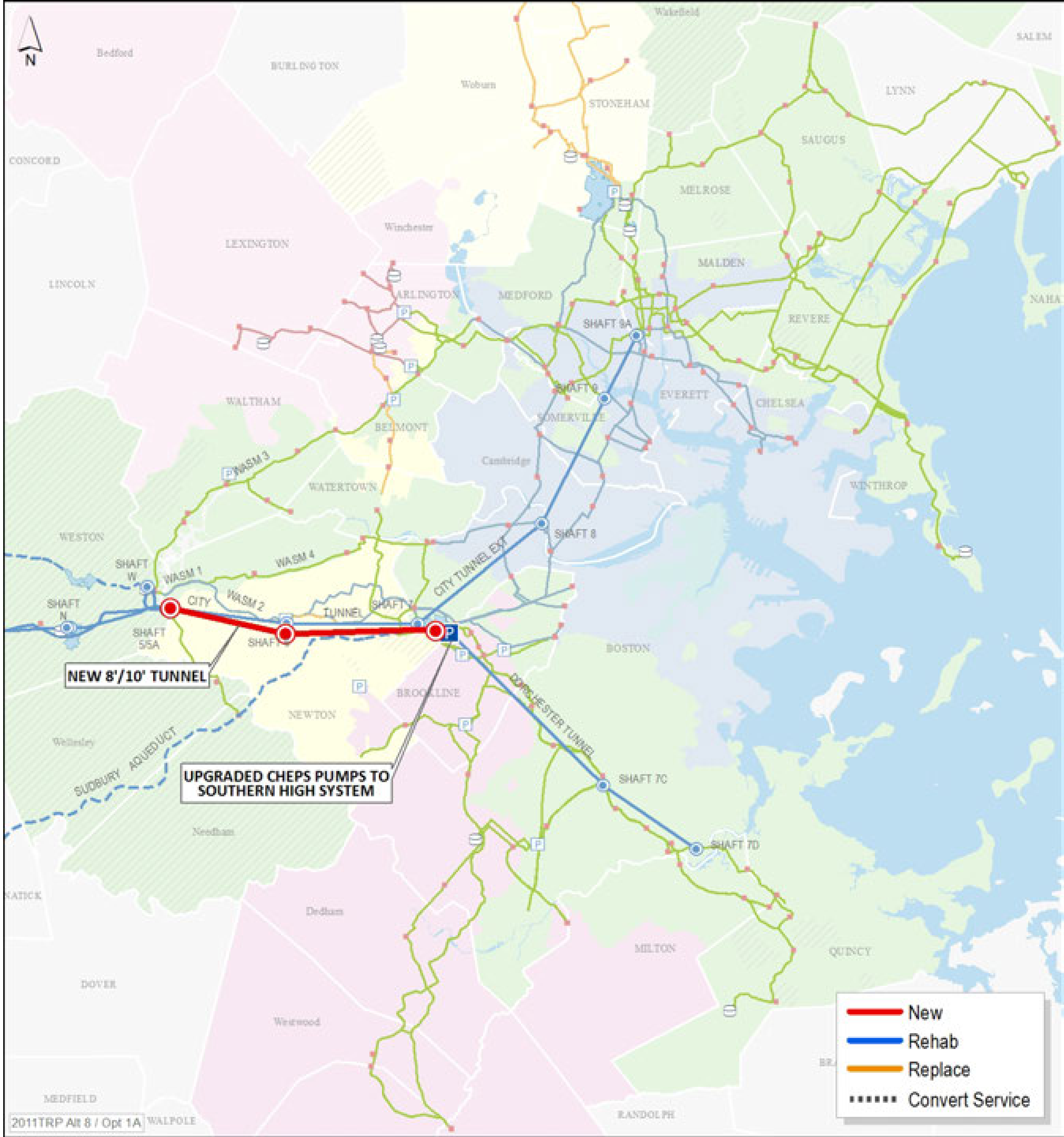
Alternative 16S:

• New 8'/10' diameter tunnel to Chestnut Hill

Cost to Complete:

$482M @ 8' Dia.
$629M @ 10' Dia.

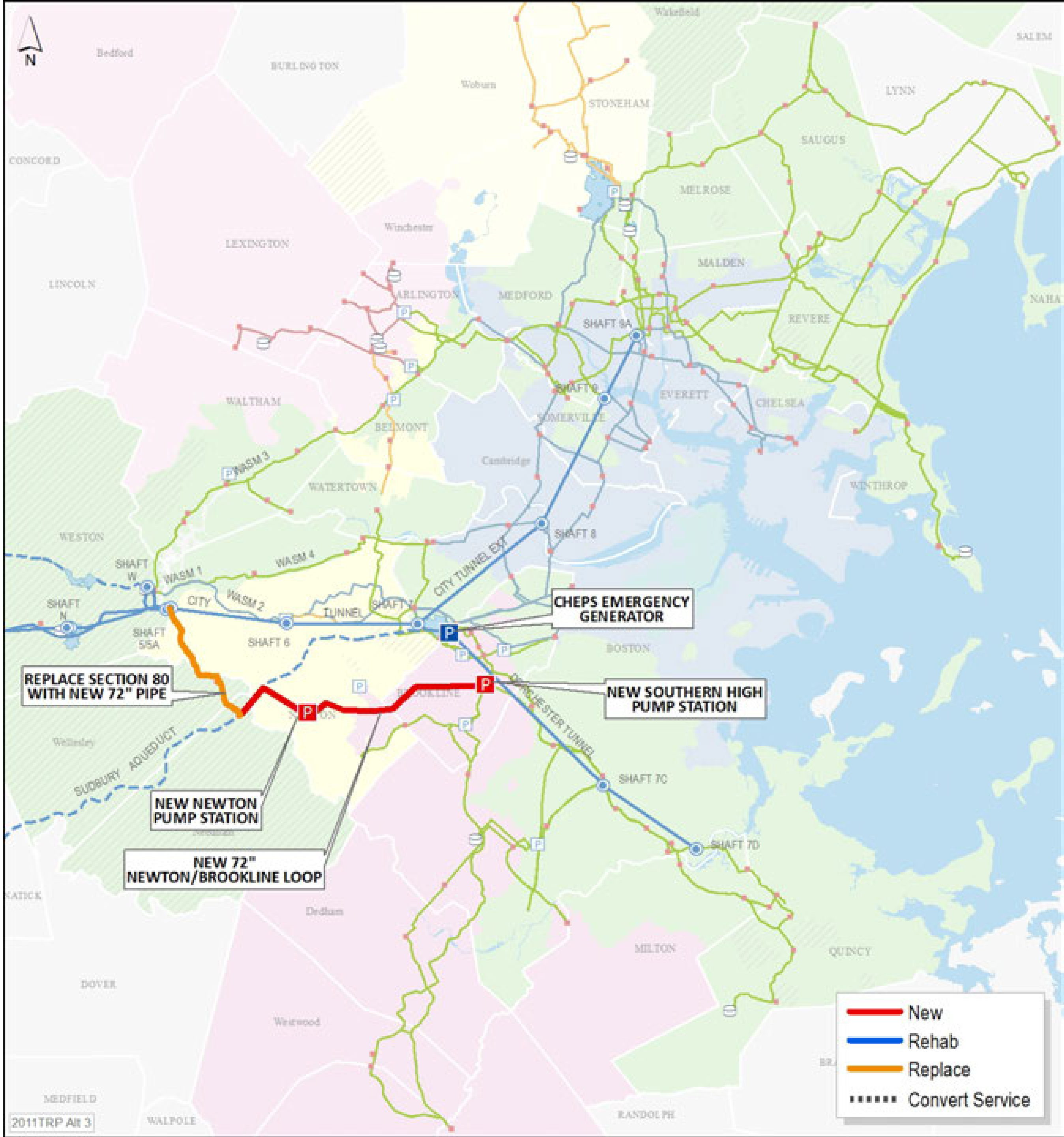
(Midpoint of Construction)
(less baseline costs)



Category 2
New Pipe to Southern Surface Mains
with or without Pump Station

Alternative 8S:

- New 72" Section 80
- New 72" loop to Brookline
- New Newton pump station
- New Southern High pump station



Cost to Complete:

$330M

(Midpoint of Construction)
(less baseline costs)

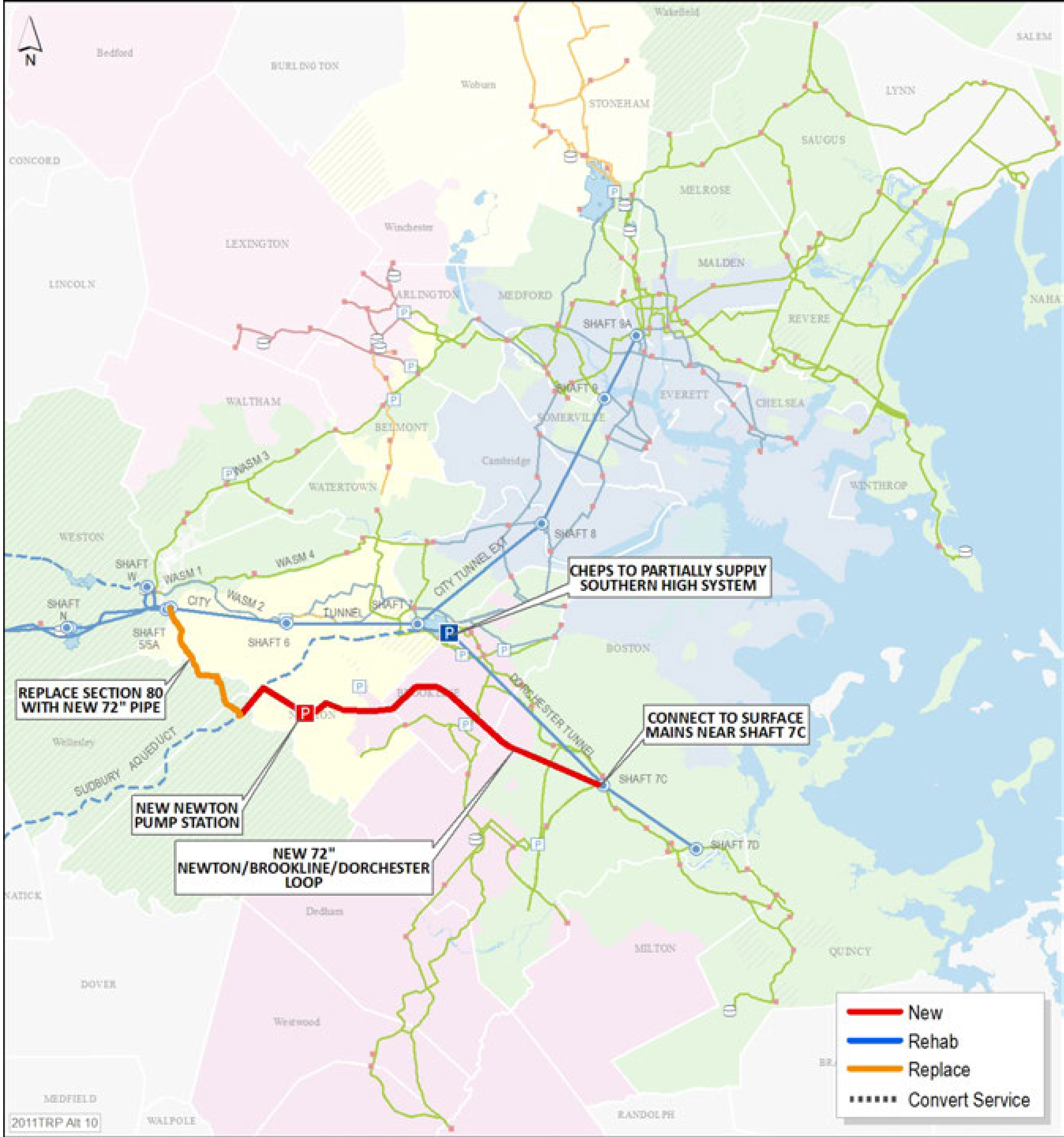
Alternative 10S:

- New 72” Section 80
- New 72” loop to Shaft 7C
- New Newton pump station

Cost to Complete:

$390M

(Midpoint of Construction)
(less baseline costs)



Category 3

Tunnel to Dorchester Tunnel

Shaft 7C

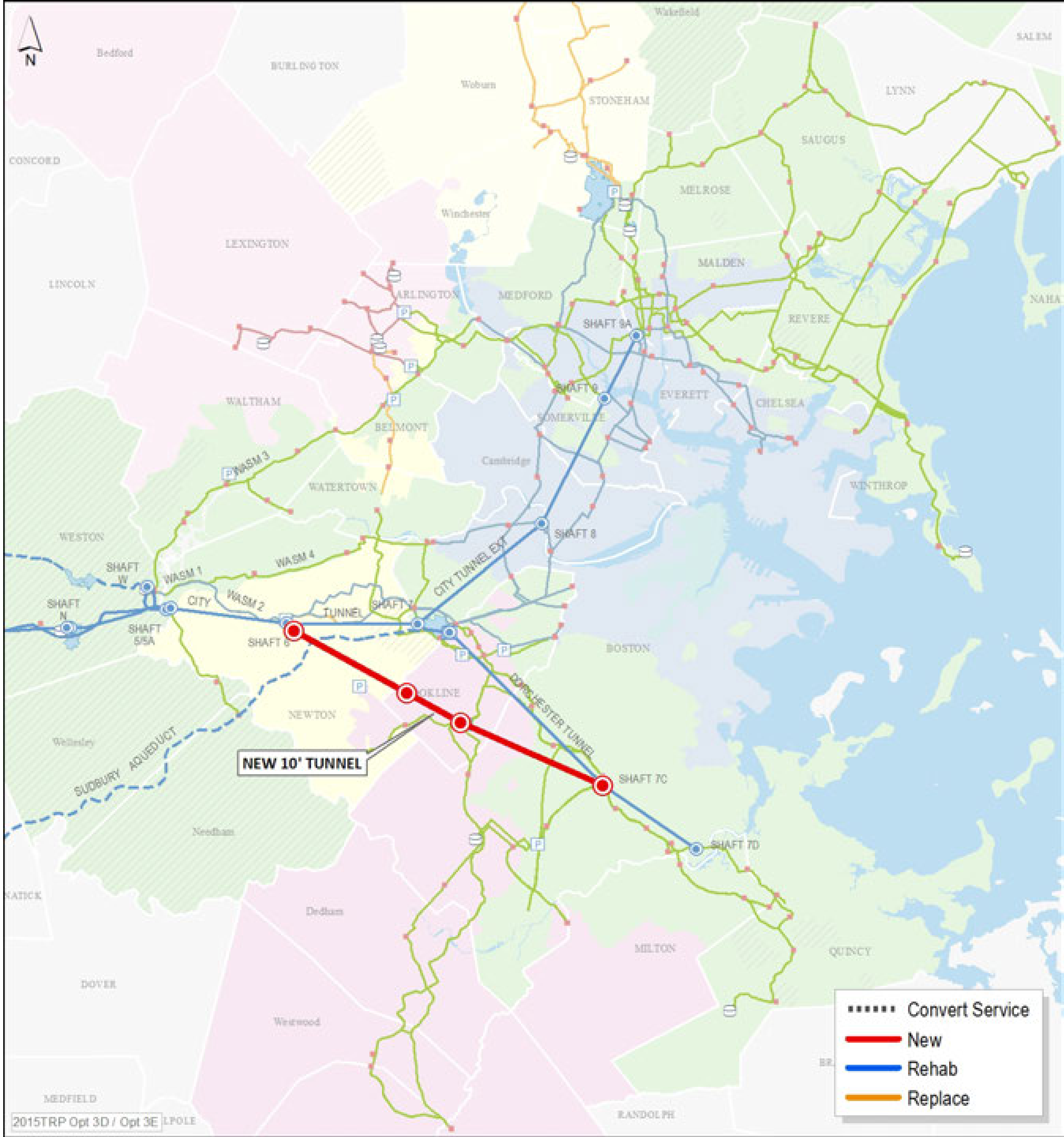
Alternative 17S:

- New tunnel from Shaft 6 to Shaft 7C *(common tunnel from Bifurcation to Shaft 6)*

Cost to Complete:

$716M

(Midpoint of Construction)
(less baseline costs)



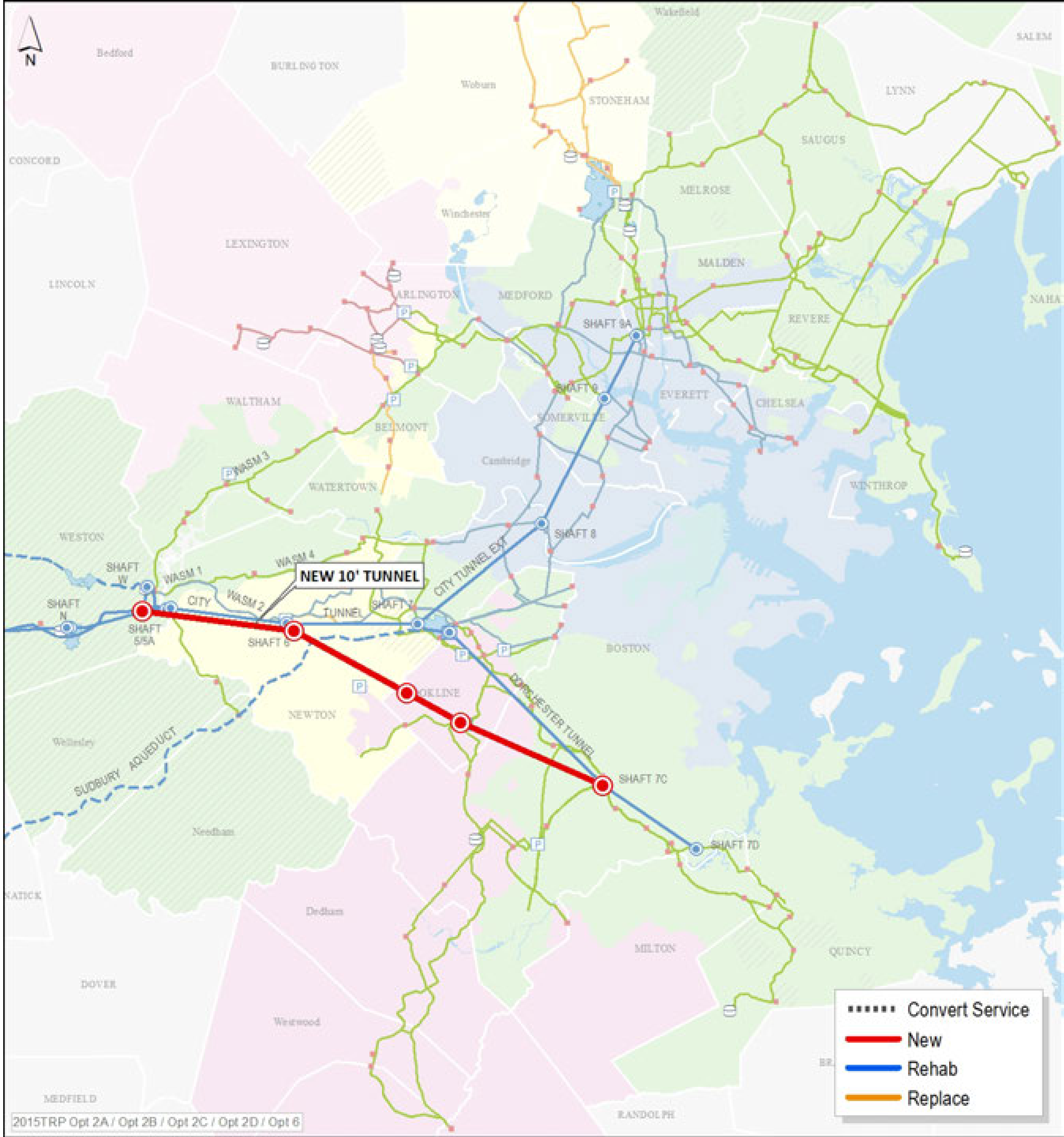
Alternative 18S:

• New tunnel from Bifurcation to Shaft 7C via Shaft 6

Cost to Complete:

$1,003M

(Midpoint of Construction)
(less baseline costs)



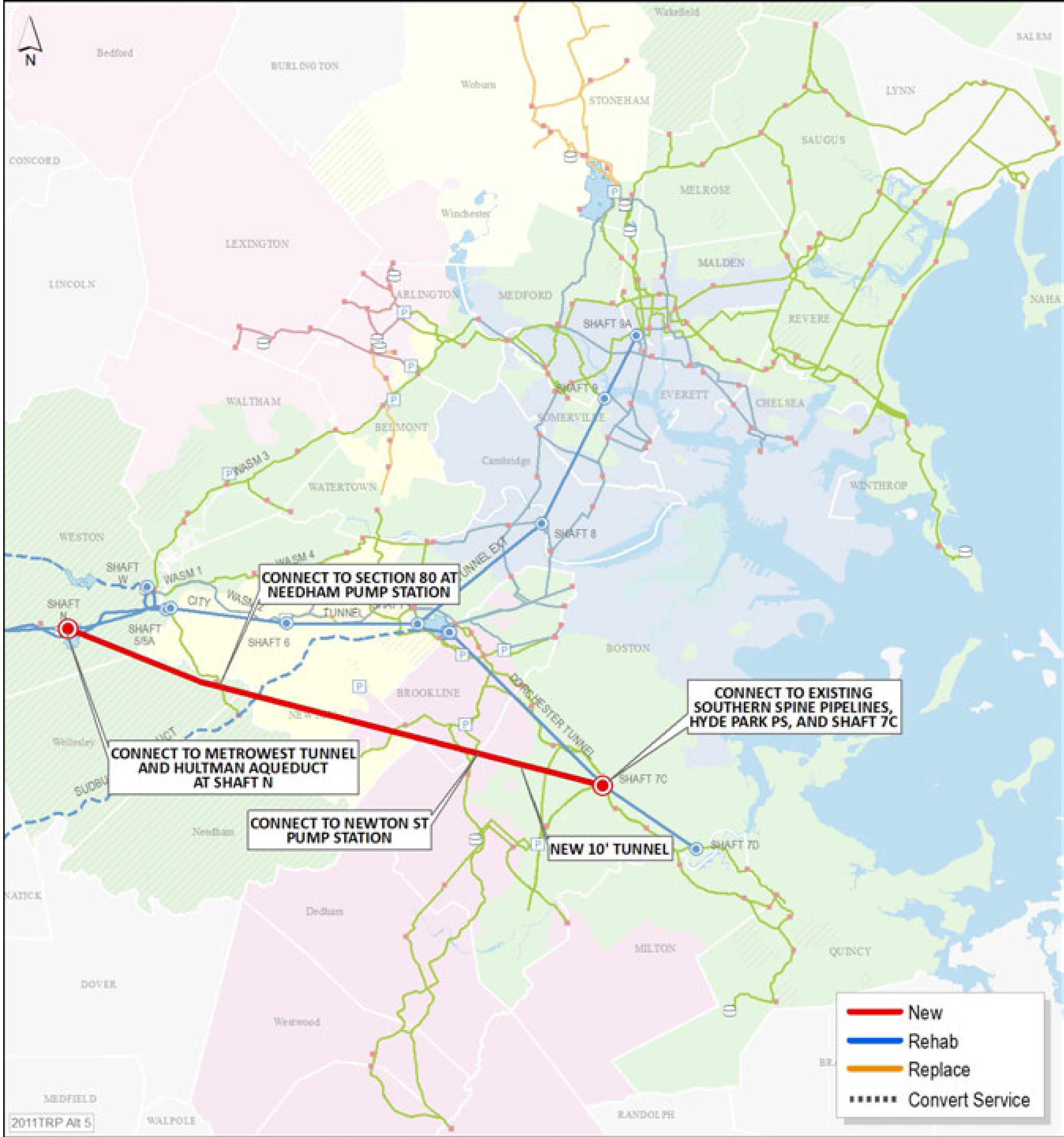
Alternative 19S:

• New Tunnel from Shaft N to Shaft 7C

Cost to Complete:

$1,034M

(Midpoint of Construction)
(less baseline costs)



Rate Analysis

Projected Assessment Changes Based on Long-Term Redundancy Options

	Option	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Average
Combined Assessments	No Long-term Redundancy	$ 694,879	$ 720,957	$ 746,863	$ 772,831	$ 799,479	$ 826,076	$ 822,083	$ 808,925	$ 803,187	$ 819,107	$ 819,572	$ 804,616	$ 774,949	$ 761,385	$ 790,772
		3.34%	3.75%	3.59%	3.48%	3.45%	3.33%	-0.48%	-1.60%	-0.71%	1.98%	0.06%	-1.82%	-3.69%	-1.75%	0.74%
	Least Expensive Option	$ 694,879	$ 720,976	$ 747,343	$ 774,232	$ 802,925	$ 834,277	$ 835,690	$ 828,999	$ 827,846	$ 845,946	$ 846,775	$ 832,083	$ 802,472	$ 788,837	$ 806,800
		3.34%	3.76%	3.66%	3.60%	3.71%	3.90%	0.17%	-0.80%	-0.14%	2.19%	0.10%	-1.74%	-3.56%	-1.70%	1.01%
	Mid-range Option	$ 694,879	$ 721,378	$ 748,649	$ 776,534	$ 804,723	$ 833,349	$ 833,692	$ 827,938	$ 829,750	$ 854,337	$ 861,506	$ 852,963	$ 829,598	$ 822,192	$ 815,124
		3.34%	3.81%	3.78%	3.72%	3.63%	3.56%	0.04%	-0.69%	0.22%	2.96%	0.84%	-0.99%	-2.74%	-0.89%	1.33%
	Most Expensive Option	$ 694,879	$ 721,192	$ 748,409	$ 776,656	$ 805,868	$ 836,118	$ 837,443	$ 832,068	$ 834,379	$ 859,760	$ 866,601	$ 858,158	$ 834,898	$ 827,589	$ 818,395
		3.34%	3.79%	3.77%	3.77%	3.76%	3.75%	0.16%	-0.64%	0.28%	3.04%	0.80%	-0.97%	-2.71%	-0.88%	1.38%
Water Assessment	No Long-term Redundancy	$ 234,263	$ 241,986	$ 249,931	$ 258,225	$ 266,717	$ 275,559	$ 283,392	$ 290,873	$ 298,035	$ 304,723	$ 312,453	$ 320,586	$ 329,133	$ 337,801	$ 289,955
		3.49%	3.30%	3.28%	3.32%	3.29%	3.32%	2.84%	2.64%	2.46%	2.24%	2.54%	2.60%	2.67%	2.63%	2.86%
	Least Expensive Option	$ 234,263	$ 242,997	$ 251,896	$ 261,125	$ 270,734	$ 280,815	$ 291,259	$ 301,970	$ 313,270	$ 324,905	$ 337,727	$ 350,835	$ 363,671	$ 374,813	$ 305,078
		3.49%	3.73%	3.66%	3.66%	3.68%	3.72%	3.72%	3.68%	3.74%	3.71%	3.95%	3.88%	3.66%	3.06%	3.68%
	Mid-range Option	$ 234,263	$ 243,647	$ 253,447	$ 263,641	$ 274,135	$ 285,160	$ 296,460	$ 308,346	$ 320,614	$ 333,532	$ 346,953	$ 360,747	$ 375,187	$ 390,090	$ 311,689
		3.49%	4.01%	4.02%	4.02%	3.98%	4.02%	3.96%	4.01%	3.98%	4.03%	4.02%	3.98%	4.00%	3.97%	4.00%
	Most Expensive Option	$ 234,263	$ 243,461	$ 253,705	$ 264,741	$ 275,401	$ 286,304	$ 298,230	$ 310,995	$ 324,507	$ 339,058	$ 354,049	$ 369,933	$ 386,946	$ 403,475	$ 316,216
		3.49%	3.93%	4.21%	4.35%	4.03%	3.96%	4.17%	4.28%	4.34%	4.48%	4.42%	4.49%	4.60%	4.27%	4.27%

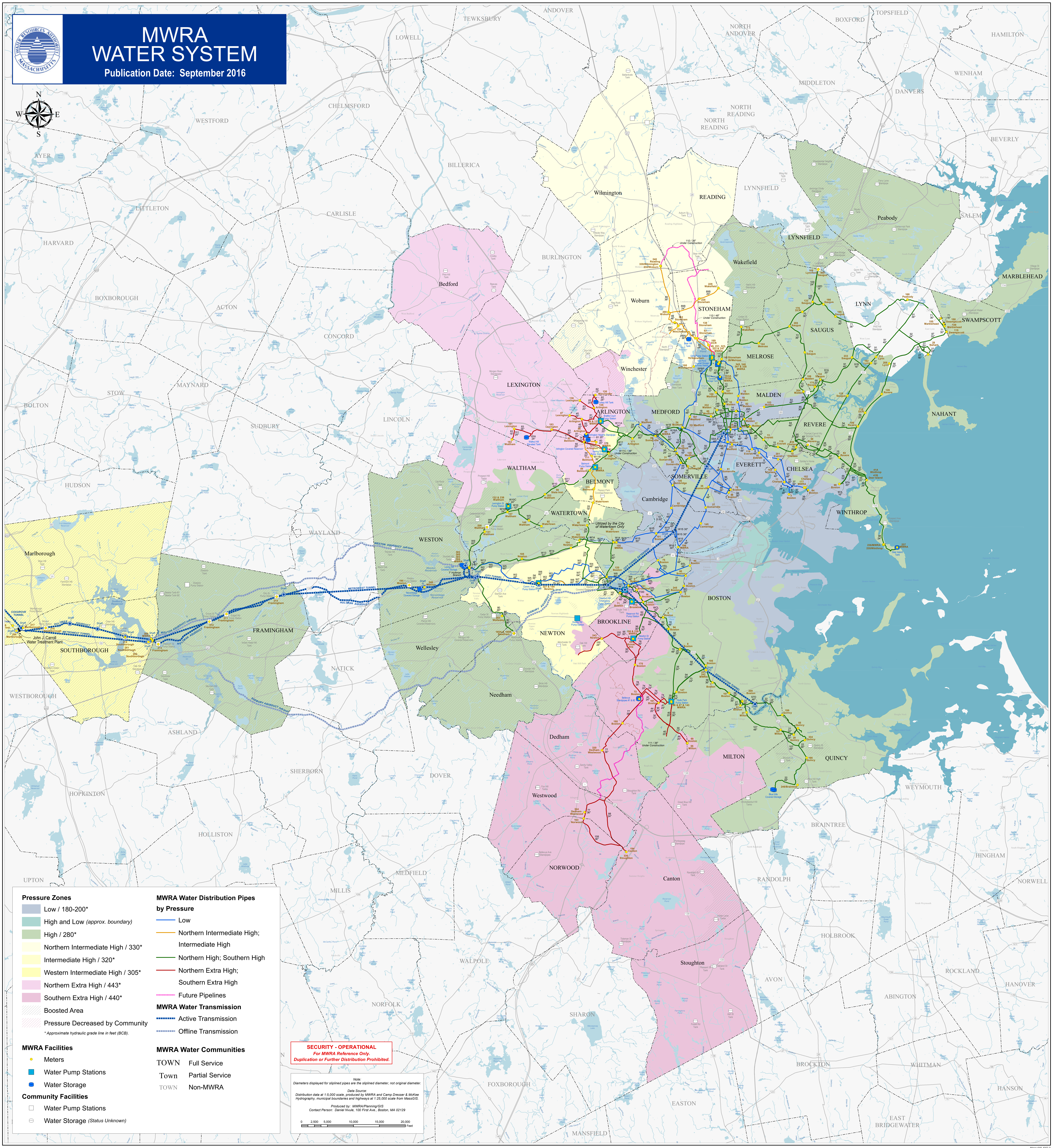
Comparison of Rate Impact of Options to the No Redundancy

	Option	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Average
Combined Assessments Difference between No Redundancy and other Options	Least Expensive vs. No Long-term Redundancy	$ -	$ 19	$ 480	$ 1,400	$ 3,446	$ 8,201	$ 13,607	$ 20,075	$ 24,659	$ 26,839	$ 27,203	$ 27,467	$ 27,523	$ 27,452	$ 16,028
		0.0%	0.00%	0.06%	0.12%	0.26%	0.58%	0.65%	0.80%	0.57%	0.20%	0.04%	0.09%	0.13%	0.05%	0.27%
	Mid- Range vs. No Long-term Redundancy	$ -	$ 420	$ 1,786	$ 3,703	$ 5,244	$ 7,272	$ 11,609	$ 19,013	$ 26,562	$ 35,230	$ 41,934	$ 48,348	$ 54,649	$ 60,807	$ 24,352
		0.0%	0.06%	0.19%	0.25%	0.18%	0.23%	0.52%	0.91%	0.93%	0.98%	0.78%	0.83%	0.95%	0.86%	0.59%
	Most Expensive vs. No Long-term Redundancy	$ -	$ 235	$ 1,546	$ 3,825	$ 6,389	$ 10,041	$ 15,360	$ 23,143	$ 31,191	$ 40,653	$ 47,029	$ 53,543	$ 59,949	$ 66,204	$ 27,624
		0.0%	0.03%	0.18%	0.30%	0.31%	0.43%	0.64%	0.96%	0.99%	1.06%	0.74%	0.85%	0.98%	0.87%	0.64%
Water Assessment Difference between No Redundancy and other Options	Least Expensive vs. No Long-term Redundancy	$ -	$ 1,011	$ 1,965	$ 2,900	$ 4,017	$ 5,257	$ 7,867	$ 11,097	$ 15,235	$ 20,182	$ 25,274	$ 30,249	$ 34,538	$ 37,012	$ 15,123
		0.0%	0.43%	0.38%	0.35%	0.39%	0.41%	0.88%	1.04%	1.28%	1.47%	1.41%	1.28%	0.99%	0.43%	0.83%
	Mid- Range vs. No Long-term Redundancy	$ -	$ 1,661	$ 3,516	$ 5,416	$ 7,419	$ 9,601	$ 13,067	$ 17,473	$ 22,579	$ 28,809	$ 34,500	$ 40,161	$ 46,054	$ 52,289	$ 21,734
		0.0%	0.71%	0.74%	0.70%	0.69%	0.71%	1.12%	1.37%	1.52%	1.79%	1.49%	1.37%	1.34%	1.34%	1.14%
	Most Expensive vs. No Long-term Redundancy	$ -	$ 1,475	$ 3,774	$ 6,516	$ 8,685	$ 10,746	$ 14,837	$ 20,122	$ 26,473	$ 34,335	$ 41,596	$ 49,347	$ 57,813	$ 65,674	$ 26,261
		0.0%	0.63%	0.92%	1.03%	0.74%	0.64%	1.32%	1.64%	1.88%	2.24%	1.88%	1.88%	1.93%	1.64%	1.41%

Preferred Option - Phased and Un-Phased Rates Impact

	Option	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Combined Assessment	Mid-range Phased	$ 694,879	$ 720,981	$ 747,388	$ 774,181	$ 801,387	$ 828,796	$ 827,344	$ 819,009	$ 818,690	$ 840,802	$ 846,258	$ 834,626	$ 807,578	$ 797,745
		3.3%	3.8%	3.7%	3.6%	3.5%	3.4%	-0.2%	-1.0%	0.0%	2.7%	0.6%	-1.4%	-3.2%	-1.2%
	Mid-range Un-Phased	$ 694,879	$ 721,378	$ 748,649	$ 776,534	$ 804,723	$ 833,349	$ 833,692	$ 827,938	$ 829,750	$ 854,337	$ 861,506	$ 852,963	$ 829,598	$ 822,192
		3.3%	3.8%	3.8%	3.7%	3.6%	3.6%	0.0%	-0.7%	0.2%	3.0%	0.8%	-1.0%	-2.7%	-0.9%
Water Assessment	Mid-range Phased	$ 234,263	$ 243,002	$ 251,942	$ 261,320	$ 271,068	$ 281,065	$ 291,366	$ 302,163	$ 313,295	$ 325,013	$ 337,194	$ 349,611	$ 360,846	$ 369,744
		3.5%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.2%	2.5%
	Mid-range Un-Phased	$ 234,263	$ 243,647	$ 253,447	$ 263,641	$ 274,135	$ 285,160	$ 296,460	$ 308,346	$ 320,614	$ 333,532	$ 346,953	$ 360,747	$ 375,187	$ 390,090
		3.5%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
Difference Un-Phased vs. Phased	Combined	$ -	$ (396)	$ (1,261)	$ (2,354)	$ (3,336)	$ (4,552)	$ (6,348)	$ (8,930)	$ (11,060)	$ (13,535)	$ (15,248)	$ (18,338)	$ (22,020)	$ (24,447)
		0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.2%	-0.3%	-0.3%	-0.3%	-0.2%	-0.4%	-0.5%	-0.3%
	Water	$ -	$ (645)	$ (1,506)	$ (2,321)	$ (3,067)	$ (4,095)	$ (5,094)	$ (6,183)	$ (7,319)	$ (8,519)	$ (9,759)	$ (11,136)	$ (14,340)	$ (20,346)
		0.0%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.8%	-1.5%

Metropolitan Water System Map


MWRA
WATER SYSTEM
Publication Date: September 2016
Pressure Zones
Low / 180-200*
High and Low (approx. boundary)
High / 280*
Northern Intermediate High / 330*
Intermediate High / 320*
Western Intermediate High / 305*
Northern Extra High / 443*
Southern Extra High / 440*
Boosted Area
Pressure Decreased by Community
* Approximate hydraulic grade line in feet (BCB).
MWRA Water Distribution Pipes by Pressure
Low
Northern Intermediate High; Intermediate High
Northern High; Southern High
Northern Extra High; Southern Extra High
Future Pipelines
MWRA Water Transmission
Active Transmission
Offline Transmission
MWRA Facilities
Meters
Water Pump Stations
Water Storage
Community Facilities
Water Pump Stations
Water Storage (Status Unknown)
MWRA Water Communities
TOWN Full Service
Town Partial Service
TOWN Non-MWRA
SECURITY - OPERATIONAL
For MWRA Reference Only.
Duplication or Further Distribution Prohibited.
Note:
Diameters displayed for sliplined pipes are the sliplined diameter, not original diameter.
Data Source:
Distribution data at 1:5,000 scale, produced by MWRA and Camp Dresser & McKee.
Hydrography, municipal boundaries and highways at 1:25,000 scale from MassGIS.
Produced by: MWRA/Planning/GIS
Contact Person: Daniel Nvule, 100 First Ave., Boston, MA 02129
0 2,500 5,000 10,000 15,000 20,000 Feet
N
S
E
W
ANDOVER
TEWKSBURY
LOWELL
NORTH ANDOVER
BOXFORD
TOPSFIELD
HAMILTON
WENHAM
MIDDLETON
DANVERS
BEVERLY
CHELMSFORD
WESTFORD
NORTH READING
AYER
BILLERICA
Wilmington
READING
LYNNFIELD
Peabody
SALEM
LITTLETON
CARLISLE
LYNNFIELD
MARBLEHEAD
HARVARD
BURLINGTON
Wakefield
Bedford
Woburn
STONEHAM
LYNN
SWAMPSCOTT
BOXBOROUGH
ACTON
SAUGUS
CONCORD
MELROSE
Winchester
NAHANT
STOW
MAYNARD
LEXINGTON
MALDEN
BOLTON
ARLINGTON
MEDFORD
REVERE
LINCOLN
SUDBURY
EVERETT
CHELSEA
SOMERVILLE
WALTHAM
BELMONT
HUDSON
Cambridge
WINTHROP
WATERTOWN
WAYLAND
WESTON
Marlborough
BOSTON
BROOKLINE
FRAMINGHAM
NEWTON
SOUTHBOROUGH
Wellesley
NATICK
WESTBOROUGH
Needham
ASHLAND
Dedham
MILTON
QUINCY
SHERBORN
DOVER
WEYMOUTH
HOPKINTON
Westwood
HOLLISTON
BRAINTREE
HINGHAM
NORWOOD
UPTON
MEDFIELD
Canton
RANDOLPH
NORWELL
MILLIS
HOLBROOK
WALPOLE
Stoughton
ROCKLAND
AVON
HANOVER
ABINGTON
NORFOLK
SHARON
BROCKTON
WHITMAN
FOXBOROUGH
HANSON
EASTON
EAST BRIDGEWATER
MANSFIELD
John J. Carroll Water Treatment Plant
METROWEST TUNNEL
WESTON AQUEDUCT
SUDBURY AQUEDUCT
Utilized by the City of Watertown Only