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.

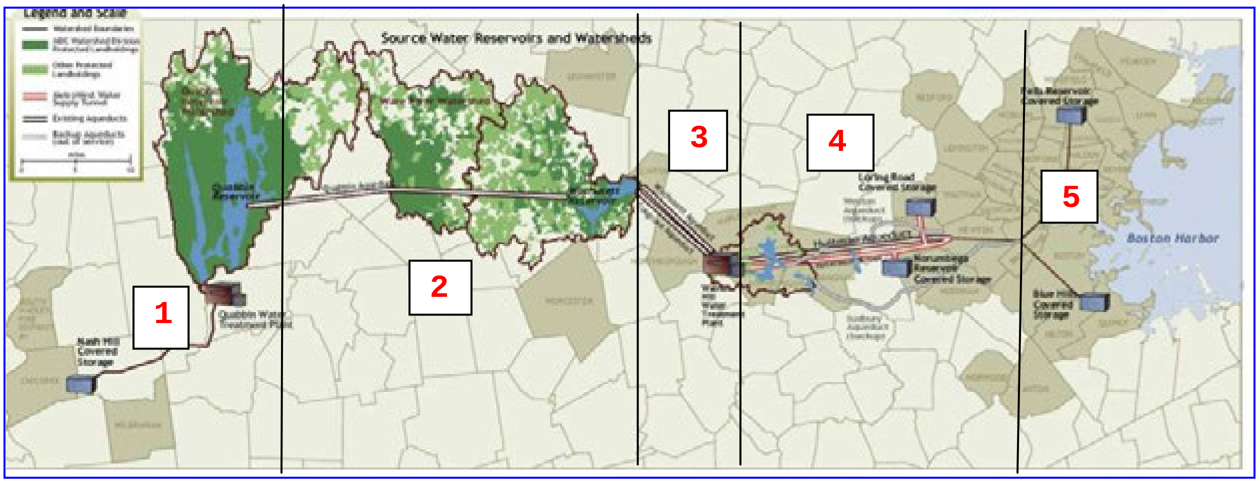


Figure 1 - MWRA Water Transmission System

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.

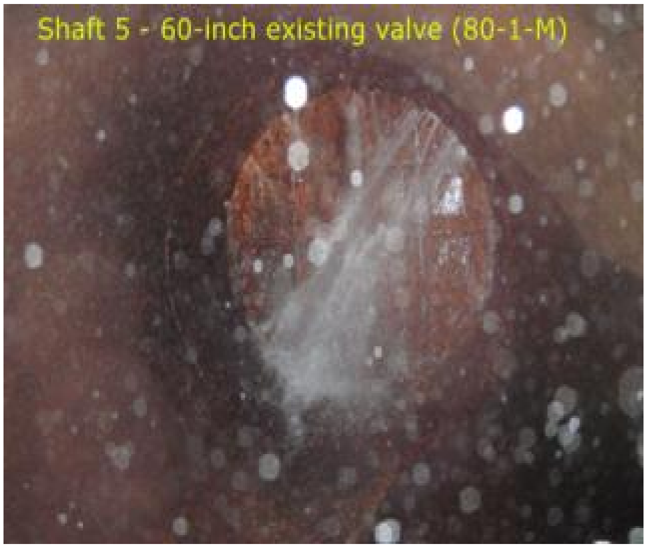
5. Metropolitan Tunnels. The Metropolitan Tunnels include the City Tunnel (1950), the City Tunnel Extension (1963), and the Dorchester Tunnel (1976). These three tunnels come together at Shaft 7 at Chestnut Hill. Together, these tunnels carry approximately 60% of the total system daily demand. The lack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

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.



Leaking Gate Valve at Shaft 5


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

<u>Planned Shutdown</u>

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.

<u>Unplanned Emergency Shutdown</u>

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.

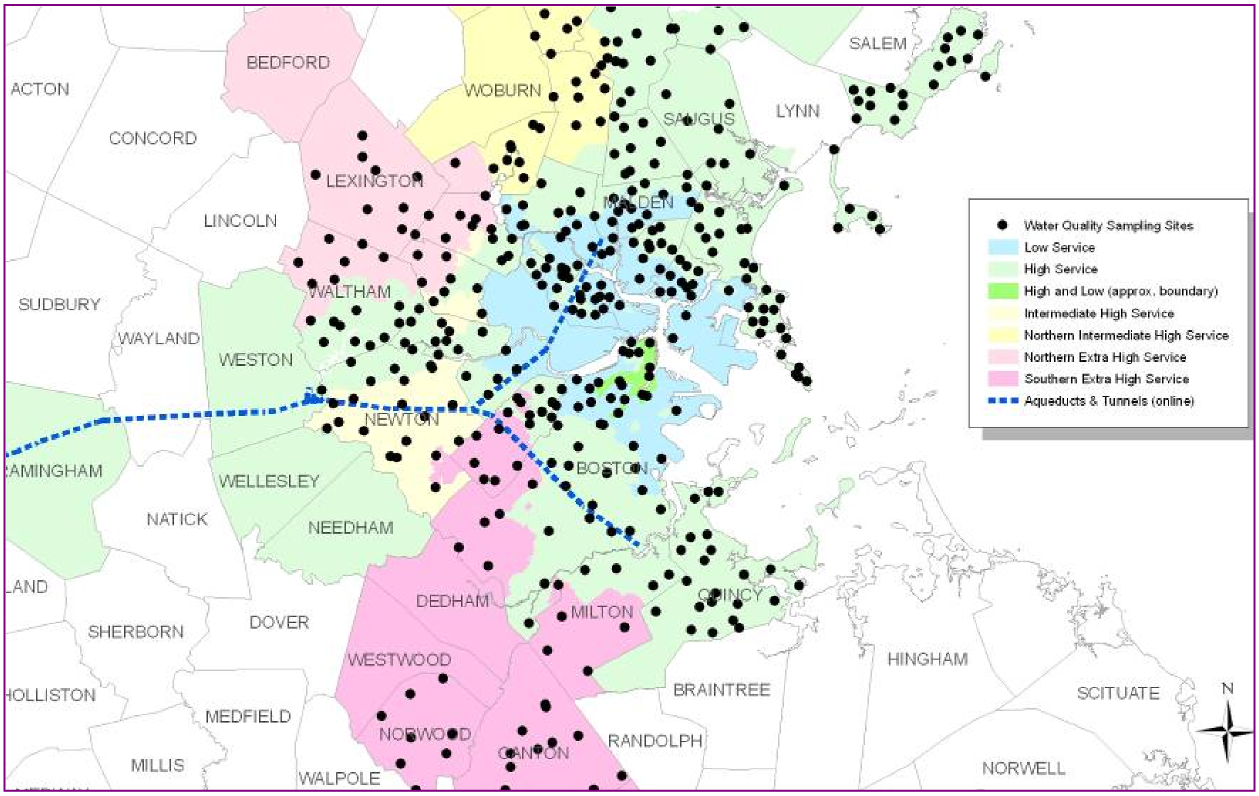


Figure 2 - Water Sample Locations

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.

<u>Analysis of Economic Impact of Failure of Metropolitan Tunnels</u>

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.

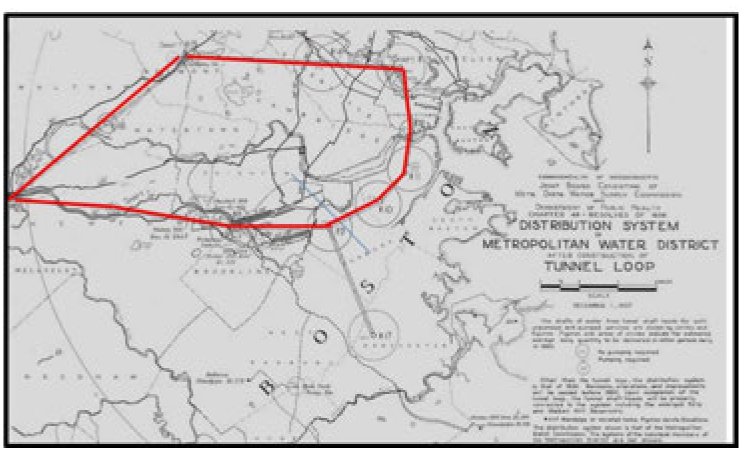


Figure 3 - Original 1936 Tunnel Loop Plan

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.

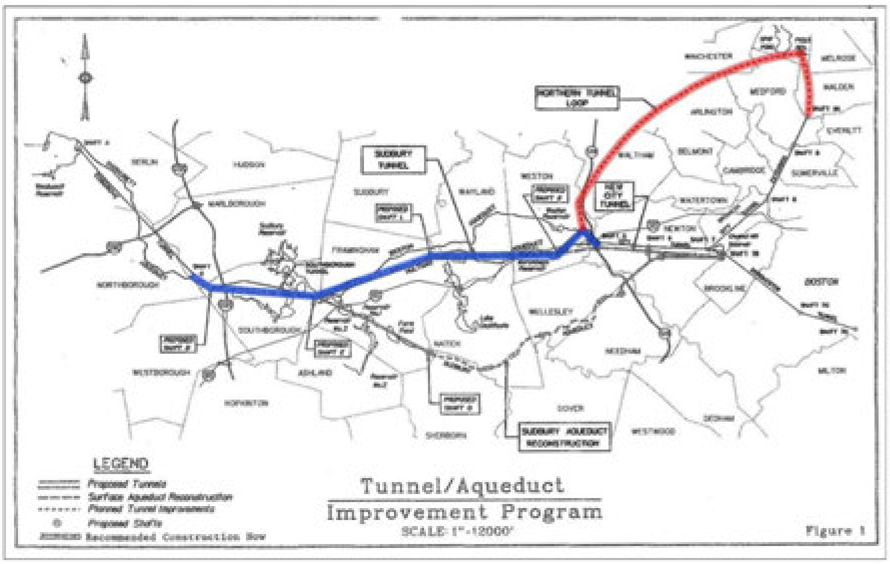


Figure 4 - 1990 Tunnel/Aqueduct Improvement Program

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.

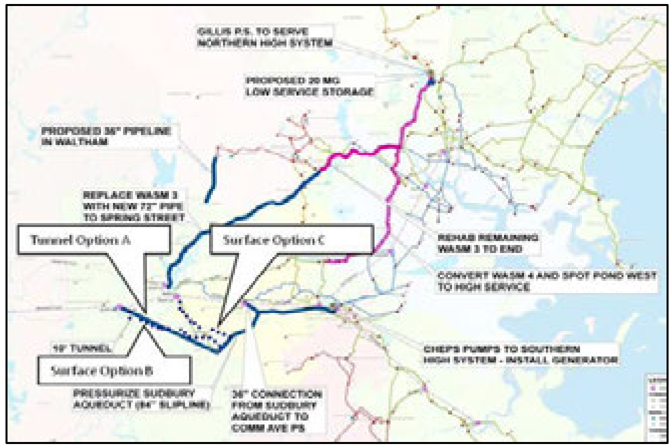


Figure 5 – 2011 Transmission Redundancy Plan

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.

<u>Northern System Alternatives</u>

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. <u>Pushing the System to Its Limit</u>: 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.

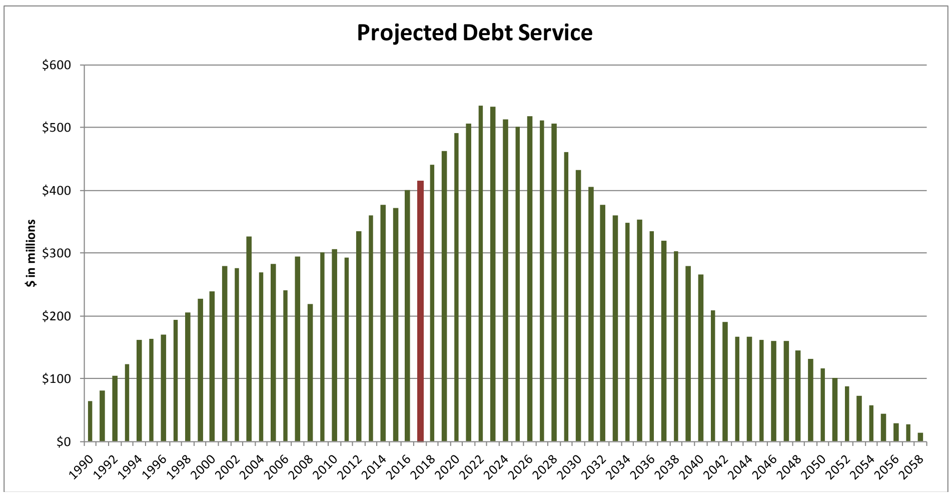
   Staff do not recommend this family of alternatives due to the inability to construct 8 to 10 miles of large diameter surface pipeline in dense urban areas (Needham, Wellesley, Newton, Brookline and Boston) as previously discussed, as well as concerns about the impact of pumping related to surges on the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

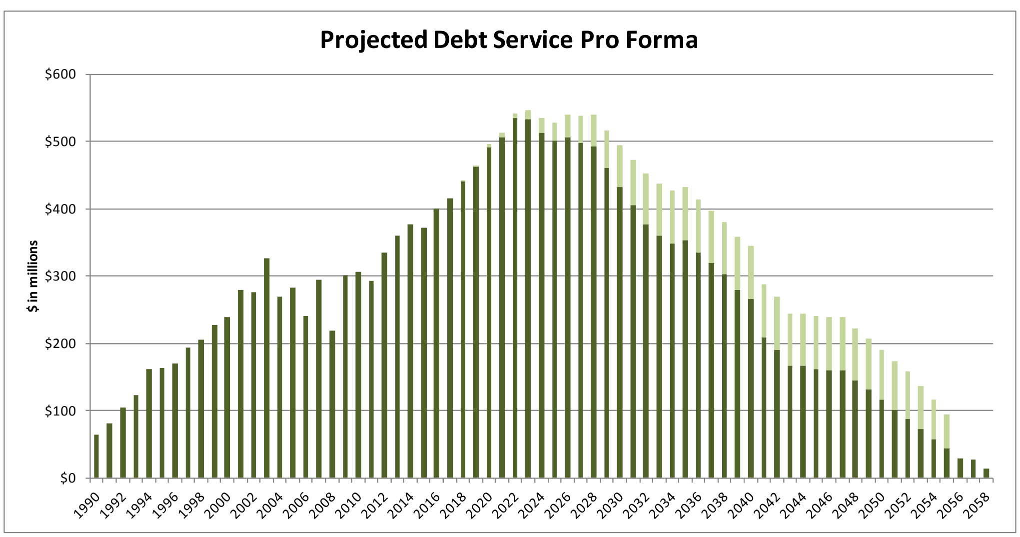
   Staff recommend this family of alternatives. A tunnel would provide the most reliable and seamless operation and would result in less community impact than other alternatives.

FINANCIAL CONSIDERATIONS

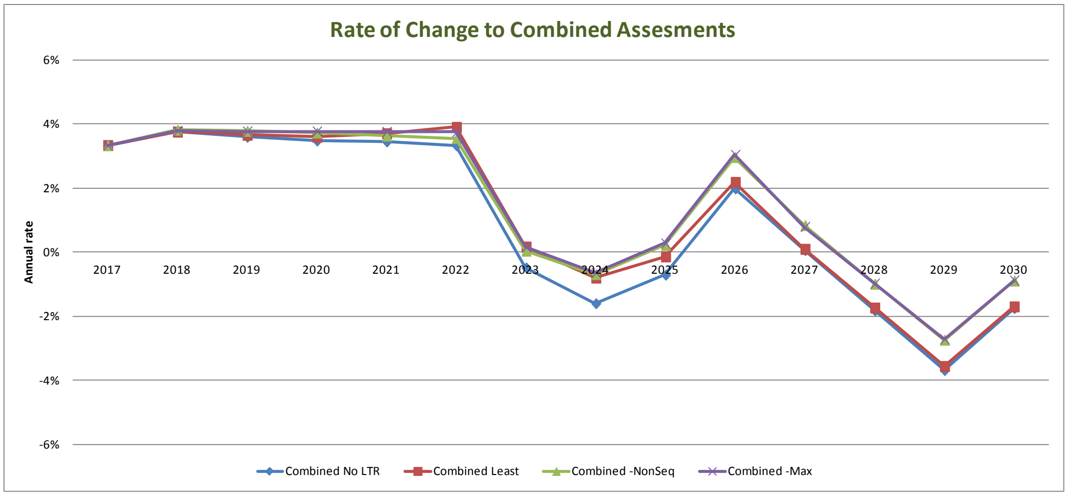
Consistent with MWRA's multi-year rates management strategy to provide sustainable and predictable assessments to our communities, staff evaluated the impact of a variety of options for the redundancy project on the Capital Improvement Program (CIP) and the debt service on the Current Expense Budget (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.

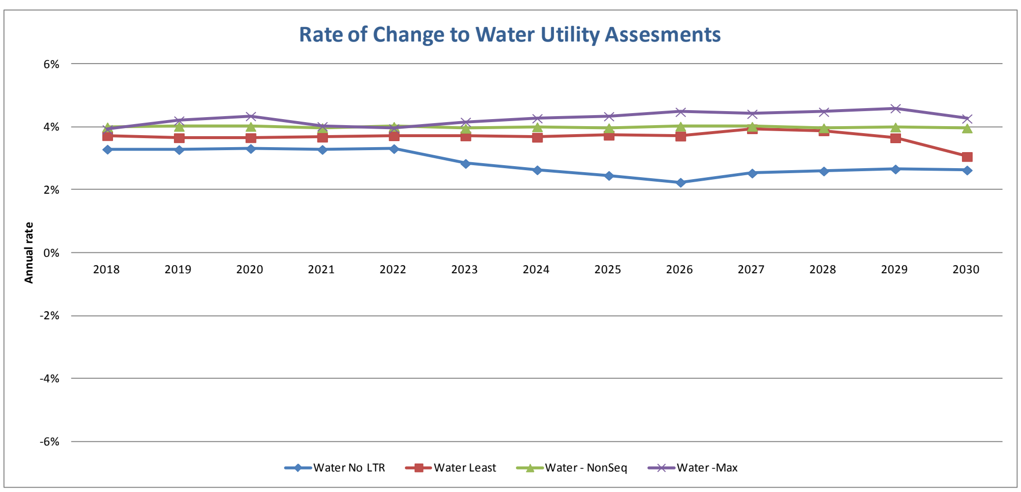


To facilitate discussion staff evaluated the impact of four different redundancy options to provide an estimated range of assessment impacts. The four options are: no long-term redundancy, a least expensive option, a midrange option, and the most expensive option. The total rate revenue requirement represents 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.

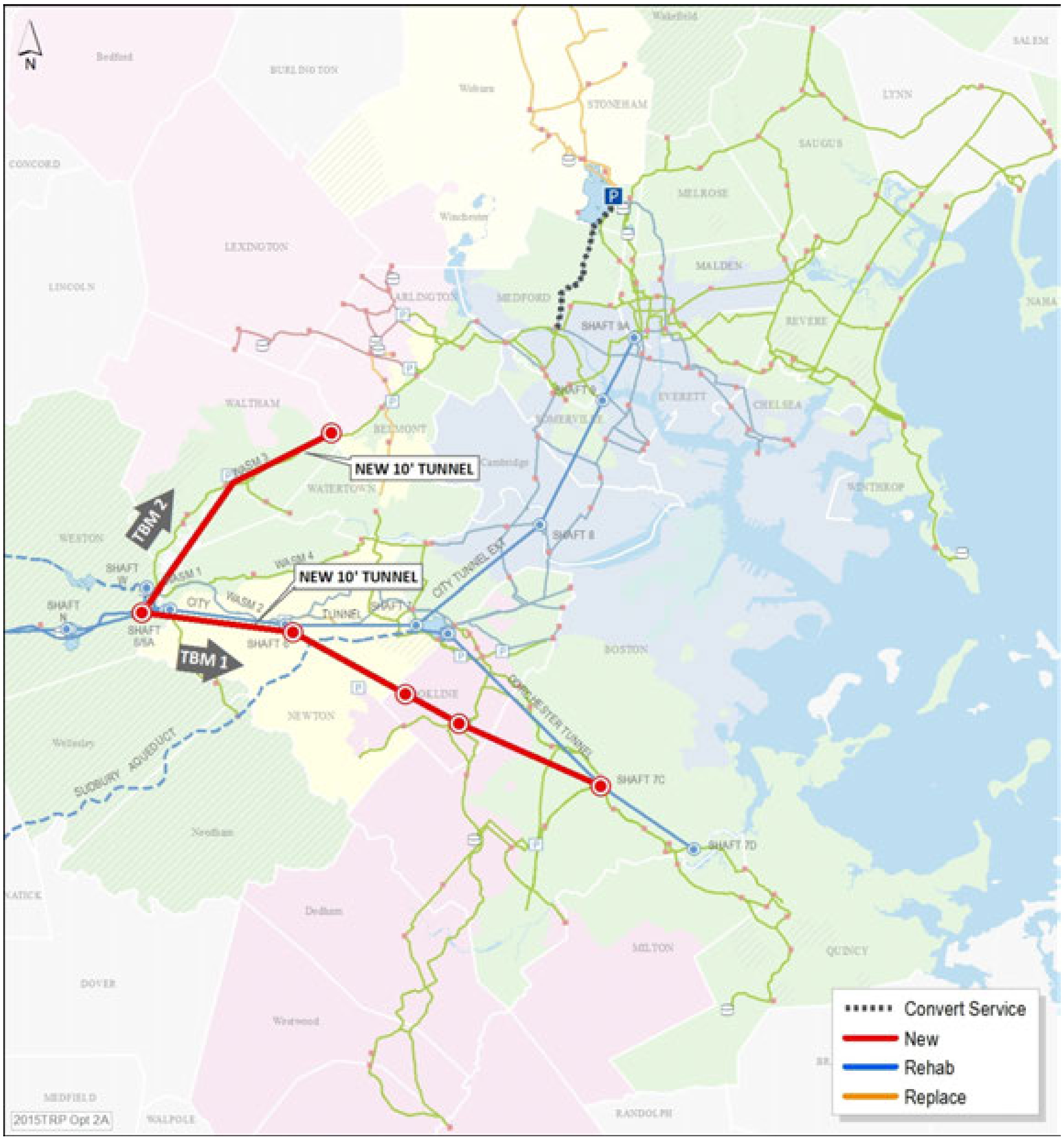


Figure 6 - Staff Preferred Tunnel Alternative

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.