Metropolitan Tunnel Redundancy
Off-Site Meeting

History of the Water System

Frederick A. Laskey
Executive Director

October 6, 2016
Early Boston Water System

• Early Bostonians relied on local wells, rain barrels and a spring on Boston Common for their water.

• In 1795 wooden pipes made from tree trunks delivered water from Jamaica Pond to Boston.

• By the 1840s, Jamaica Pond was too small and too polluted to provide water to Boston’s 50,000 residents.

• The pattern of moving continually westward in search of larger water sources began.
The Cochituate System

• After 20 years of study, the Cochituate System was chosen
• In 1845 construction began on a new distribution system
• The Sudbury River was impounded and Lake Cochituate was formed 14.5 miles from Boston
• The Cochituate Aqueduct transported water to the Brookline Reservoir, which supplied smaller reservoirs all over the City
• Lake Cochituate provided 2 billion gallons of storage and 10 million gallons per day
The Cochituate System

- Long Pond was renamed Lake Cochituate Reservoir
- The system flowed by gravity through a series of distribution reservoirs
Cochituate Reservoir and Aqueduct
Water from Lake Cochituate flowed into the Frog Pond on Boston Common in 1848 at a dedication ceremony that drew 100,000
By the early 1890s, Boston’s water supply was deemed unsafe and inadequate.

Governor Russell proposed a water district including the development of a large water supply for a number of communities.

In 1895, the Metropolitan Water Act called for the taking of water from the south branch of the Nashua River, the Boston Waterworks at Chestnut Hill and Spot Pond.

This system would supply water to the cities and towns within 10 miles of the State House that wanted it.
MAP SHOWING WORKS FOR DISTRIBUTING WATER IN THE METROPOLITAN DISTRICT

LOW SERVICE PIPES THUS HIGH — — — — — —
The Sudbury System

- In 1878, the Sudbury River, 18 miles from Boston, was diverted through the Sudbury Aqueduct to the Chestnut Hill Reservoir

- By 1898, the Fayville Dam and the Sudbury Reservoir were completed
A Regional Solution Was Needed

- Boston continued to grow rapidly in the 1880s and 1890s
- And planners had not foreseen the advent of indoor plumbing
- New water sources were considered: the Nashua River, the Merrimack River, Lake Winnipesaukee and Sebago Lake
• Chief Engineer Frederick Stearns planned a water source that would be gravity-operated and not require filtration

• The Nashua River was impounded by the Wachusett Dam, 38 miles from Boston
The Wachusett Reservoir

- At the time it was constructed, the Wachusett Reservoir was the largest man-made water supply reservoir in the world.

- Its 65 billion gallons supplied 118 million gallons per day.
The Wachusett Aqueduct was constructed to bring water from the Wachusett Reservoir to Sudbury Reservoir.
The Quabbin Reservoir
The Quabbin Reservoir

• Construction of the Quabbin required the impoundment of the Swift River and the takings of four towns

• The Quabbin Reservoir, 60 miles from Boston, was another source that could be gravity-operated and not require filtration
The Quabbin Aqueduct

• Construction of the Wachusett-Colebrook Tunnel (now the Quabbin Tunnel) began in 1926, carrying surplus flow from the Ware River to the Wachusett Reservoir.

• In the 1930s, the Tunnel was extended to the Swift River.

• This two-way tunnel carries flows east and west, depending on time of year.

• In 1936, construction of the reservoir began.
The Quabbin Reservoir

- The reservoir was filled with water from the Swift River and the Ware River.
- Filling began in 1939 and was completed in 1946.
- At the time, the 412 billion gallon reservoir was the largest man-made reservoir in the world.

Road still visible beneath surface of water
The Chicopee Valley Aqueduct

- The Chicopee Valley Aqueduct is a 14.8 mile, 4-foot diameter steel and concrete pipeline that supplies Chicopee, South Hadley FD 1 and Wilbraham from the Quabbin Reservoir
In 1936, the Legislature approved the construction of two high-pressure aqueducts to deliver water to the greater Boston area. The two aqueducts would carry water from the Wachusett Reservoir to the new Norumbega Reservoir in Weston.
The Hultman Aqueduct

• One barrel of the aqueduct system - the Hultman Aqueduct - was completed

• But work on the second barrel did not resume after World War II

• Until 2003, 85% of Boston’s water supply was provided without redundancy
By the 1950s, tunnels were used to bring better pressure deeper into the distribution system.
• The City Tunnel is a 12-foot deep rock tunnel that goes from Shaft 5 in Weston to Shaft 7/7B in Brighton

• It was constructed to meet increased demand, followed by the City Tunnel Extension to the north and the Dorchester Tunnel to the south
City Tunnel Extension

• The City Tunnel Extension is a 10-foot diameter deep rock tunnel that goes from Shaft 7 north to Shaft 9A in Malden
• The Cosgrove Tunnel carries water eight miles from the Wachusett Reservoir to the Carroll Treatment Plant

• It is 14 feet in diameter and was constructed to replace the Wachusett Aqueduct with a pressurized tunnel
The Dorchester Tunnel is a 10-foot diameter deep rock tunnel that was needed to serve the Southern High and Southern Extra High zones when the Sudbury Reservoir system no longer met water quality standards.
The MetroWest Water Supply Tunnel - 2003
MetroWest Water Supply Tunnel

- The 17.6 mile, deep rock MetroWest Water Supply Tunnel was brought on-line in November 2003.

- By March 2004, the Tunnel was being fully utilized allowing the shutdown of the Hultman Aqueduct for repair.
Since 2013, for the first time since originally planned in the 1930s, the Metropolitan Water System has redundancy for the Hultman Aqueduct from Marlborough to Weston.
Norumbega Covered Storage Facility

- The tank was completed in May 2004
- It provides 115 million gallons of storage for metropolitan Boston
MWRA Metropolitan Area Storage Capacity Over Time

2.182 million gallons of open distribution storage.

10 Year (2003-2013) Max Day Demand (7/7/2010)
• Will provide redundancy for the Cosgrove Tunnel, from the Wachusett Reservoir to the Carroll Treatment Plant
We’ve Come A Long Way
Special Meeting of the Board of Directors

on

Metropolitan Tunnel Redundancy

October 6, 2016
Status of Existing Transmission System Facilities
1. Chicopee Valley Aqueduct
   - 2007 Improvements

2. Quabbin Aqueduct
   - Inspection planned

3. Cosgrove Tunnel / Wachusett Aqueduct
   - Project underway

4. MetroWest Tunnel / Hultman Aqueduct
   - 2003/2013 Improvements

5. Metropolitan Tunnels
   - Significant Needs
Service Provided to a Large Percentage of MWRA Customers

Approximately 60% of total system flow is carried through the Metropolitan Tunnel System
• Tunnel system:
  – Concrete-lined deep rock tunnels
  – Steel and concrete vertical shafts
  – Surface pipe, valves and appurtenances

• Little maintenance required for tunnels and shafts. **Little risk of failure.**

• Pipe, valves and appurtenances need maintenance, replacement, rehabilitation
Valve Reliability Concern

- Valves that don’t work
- Valves we can’t exercise
Valve Reliability Concern

- Valves that don’t work
- Valves we can’t exercise

60-inch gate valve Shaft 5

Cone Valve at Shaft 7B

Gear box on valve at Shaft 8
Valve Reliability Concern

- Valves that don’t work
- Valves we can’t exercise
Access Can Be Difficult

- High ground water table
- Standing water in some chambers
- Corrosion is a concern
Access Can Be Difficult

- High ground water table
- Standing water in some chambers
- Corrosion is a concern

Shaft 7D located near salt marsh at Neponset River Reservation

Shaft 8 near Storrow Drive and the Charles River

Shaft 7D connecting pipe air valve chamber
Appurtenances Can Be Liabilities

- Small pipe failures can lead to shut downs

Shaft 8 PRVs

Top of Shaft 8
Appurtenances Can Be Liabilities

- Small pipe failures can lead to shut downs

Control piping at Shaft 8  
Air valve at Shaft 9A  
Shaft 8 PRV Chamber
Appurtenances Can Be Liabilities

- Small pipe failures can lead to shut downs

250 MGD flow at Shaft 5 break...

...came from a small gap in the pipe
Shaft Pipeline Improvements to Reduce Risk

- Replace corroded bolts
- Metal thickness evaluation
- Wrap or coat pipe segments
- Replace air valves
- Cathodic protection
- Heat tracing
Location of Concern – Shaft 7

- Six 54-inch hydraulically actuated Dow Disc valves
- Junction point of all three tunnels
- Valve operability uncertain
- Small diameter piping and valves
• Flooding of Boston College
Shaft 7 – Boston College

- Impacts to Chestnut Hill reservoir to Shaft 7B and Cleveland Circle
• Located at tunnel depth for the purpose of dewatering tunnels
• Access extremely difficult
• High pressure bronze pipes connect tunnel to dewatering pumps
• Smaller diameter piping from hydraulic valve actuators to surface
• Shaft 9 also has a hydraulically actuated tunnel isolation valve
• Access shaft and pump chamber have been submerged for decades

Valve control piping still present in both shaft buildings

Shaft 9 access shaft is full of water
Shaft 9 Pump Chamber
Shaft #9 pump chamber - Cylinder at right operates 48" valve to Malden Tunnel - Left cylinder operates 16" dewatering line City Tunnel - Cont. 193 - 4/9/59 - Photo Barbier - 193-257
Location of Concern – Shaft 9A

- Couplings on pipeline located between tunnel shaft and isolation valves
Tunnel System Shut-down Impacts
**Planned Shut Down – Service to the North**

- Partially supplied communities use alternate supplies
- Gillis Pump Station / Spot Pond Pump Station
- Reconfigure Northern High piping
- Pump from Open Spot Pond Reservoir (BOIL ORDER) 1-2 months at average day demand; 1-3 weeks at high day demand
- Replenish from Low Service supply lines (WATER RESTRICTIONS)
Partially supplied communities use alternate supplies

- Chestnut Hill Emergency Pump Station
- Surface Mains to Blue Hills Tanks (PRESSURE SWINGS / BREAKS)
- Pump from Chestnut Hill Reservoir (BOIL ORDER)
- Replenish from Sudbury Aqueduct
Shut Down Sometimes Unplanned

- Flooding/damage/public safety concerns
- May not have time to set up back up systems
• Extent of shut-down depends on failure
• Numerous shaft locations to isolate / multiple valves at some
• Some chambers require pumping
• Valve turn counts / time to close on the order of 45 minutes each
Wide-Spread Impact

- Sudden shut down of Metropolitan Tunnel system
- Loss of supply to high service areas
- Pumped Service Areas lose supply as tanks empty
- Whole system would be on boil order

Highlighted areas of high and pumped service areas that could lose supply
Economic Impact – Total Water Loss

- Daily Business Impact: $208 million
- Daily Residential Impact: $102 million

- Economic Impact for Total Water Loss - One Day:
  - $310 million

- Economic Impact for Total Water Loss - Three Days:
  - $930 million

Analysis based on guidelines in FEMA Benefit-Cost Analysis Version 4 standard
• Activate back-up supplies
• Large areas of MWRA and community systems will need to be refilled SLOWLY to avoid breaking lines
• Flushing to remove air pockets could take days if not weeks
• Water Quality Samples to assure public
Economic Impact – Boil Order

• Daily Business Impact: $195 million
• Daily Residential Impact: $102 million

• Economic Impact for Boil Order – One Week:
  • $2.1 billion

Analysis based on guidelines in FEMA Benefit-Cost Analysis Version 4 standard
Water Quality Sample Locations
Break
Strategic Goals for Redundancy Improvements
• Operating Goals:
  – Protection of Public Health
  – Providing Sanitation
  – Fire Protection

• Average day demand

• High day demand preferred
  – Longer shut downs possible

Water System Operating Goals

Norumbega Daily Flows 2011 to 2015
Strategic Goal for Redundancy Improvements

• Emergency-Only Capability
  – Utilize only if failure occurs
  – Does not allow planned maintenance
  – Decrease in level of service
  – Potential for damage to MWRA and community systems

• Planned Shut-Down Capability Preferred
  – Allows maintenance of system
  – Maintenance reduces risk of failure
  – Meet customer expectations for excellent quality water
  – Minor impact on normal service
National Guidance, Peer Organizations and Redundancy Planning at MWRA
• Recommended Standards for Water Works ("10 States Standards"): 
  
  – “Redundancy...should be incorporated into the design to eliminate single points of failure...”

• EPA Guidance 2011: 
  
  – “Reduce outage risk through system redundancy/resiliency and repair capabilities...”
Example Peer Organization Redundancy Programs: San Francisco

- $4.8 billion Water Supply Improvement Program
- Major Transmission and Storage Projects
- Cross Bay Tunnel
- High Day Design Enables Maintenance of Either New or Old Tunnels
Example Peer Organization Redundancy Programs: Seattle

- Two ways to convey water to all parts of their system
- Two separate supply and transmission systems
- Opposite sides of the city
- Two different feed points
- Two separate tanks
- Loop transmission system
Example Peer Organization Redundancy Programs: New York City

- Tunnel #3 - Designed for Full Redundancy to Tunnels 1 & 2
- Stage 1 and 2 Completed – 27 miles of 24’ tunnel
- $4.7 billion through 2013

- $1 billion of Supply, Treatment, and Transmission projects will enable taking NYC’s largest aqueduct and supply off line for a 2.5 mile Bypass Tunnel and Repairs
• 22 Systems Nationwide representing populations of 100K to 1.8 million

  8 designed for redundant max day /summer demand

  3 designed for most of summer peak

  7 designed for at least winter or average day

  3 systems can only handle less than an average day

  1 system with no redundancy

• MWRA in Lower 25%
Redundancy examples in our water system since 1800s:

- Two basins of Chestnut Hill Reservoir
- East and West Spot Pond Supply Mains
- Hultman Aqueduct planned to have two barrels
Paired Pump Stations Provide Redundancy

Brattle Court Pump Station (1907)

Spring Street Pump Station (1958) redundancy to Brattle Court

Gillis Pump Station (1899)

Spot Pond Pump Station (2015) redundancy to Gillis Station
Other MWRA Redundancy Projects

• CVA pipeline redundancy
• Hultman interconnections / MetroWest tunnel
• Northern Intermediate High Pipe Loop

New valve chamber connecting MWWST and Hultman Aqueduct at Shaft 5 (2013)

Night work on 36-inch NIH pipeline in Woburn (2016)
Other MWRA Redundancy Projects

- Southern Extra High Pipe Loop to provide redundant supply to Boston, Norwood, Canton, Stoughton, and Dedham/Westwood

- Wachusett Aqueduct Pump Station to Provide Redundancy to Cosgrove Tunnel between Wachusett Reservoir and Carroll Treatment Plant
Previous Redundancy Evaluations

Original 1936 Tunnel Loop Plan
Previous Redundancy Evaluations (continued)

- 1990 Plan – MetroWest Tunnel followed by Northern Tunnel Loop
• 2011 Plan – Surface piping with Northern and Southern Components
Difficulties Carrying Out 2011 Plan
• 14 alternatives evaluated

• 2011 Proposed Redundancy Plan included
  – 7 miles of 72-inch pipeline construction to the north
  – 4 miles of 84-inch steel pipe slip-lining Sudbury Aqueduct to Chestnut Hill area
  – 4 miles of tunnel or large diameter surface pipe from Norumbega or Shaft 5 area to the Sudbury Aqueduct
2011 Plan – Surface piping with Northern and Southern Components

- Surface piping with Northern and Southern Components
- 2011 Plan
- 2011 Plan
- Tunnel Option A
- Surface Option C
- Surface Option B
- Replace WASM 3 with new 72" pipe to Spring Street
- Proposed 36" pipeline in Waltham
- Gillis P.S. to serve Northern High System
- Proposed 20 MG low service storage
- Rehab remaining WASM 3 to end
- Convert WASM 4 and Spot Pond west to high service
- CHEPS pumps to Southern High System - install generator
- 10' Tunnel
- Pressurize Sudbury Aqueduct (84" Slipline)
- 36" Connection from Sudbury Aqueduct to Comm Ave PS
Impacts of Surface Pipeline

• Traffic
  – Street Closures & Detours
  – Congested City Streets/Gridlock
• Business Disruption
  – Access Disruption
  – Loss of Business
• Permitting & Approval
  – Multiple Environmental and Agency Permits
  – Street Opening Approvals & Fees
• Community Disruption
  – Noise
  – Dust
  – Detours
  – Long Period of Impacts Over Large Areas
  – Mitigation
Trapelo Road at Pleasant Street - Belmont
Construction of 72-inch Spot Pond Pipeline
Other Utilities Have Constructed Tunnels to Avoid Surface Pipe Construction Impacts

• Washington Suburban Sanitary District
  – 5.3 mile tunnel was constructed in 2015 to avoid construction impacts of a surface pipe

• East Bay Municipal Utility District (MUD)
  – 4 mile tunnel to avoid construction impacts to neighborhoods

• Metropolitan Water District of Southern California
  – 9 mile Tunnel in San Bernardino to avoid construction impacts and seismic concerns
Evaluation of Alternatives
• Due to the major impacts of miles of large pipe construction, additional tunnel alternatives were evaluated

• Previous and new alternatives were evaluated including pipelines, pumping and tunnels
  
  – 13 alternatives to the north
  – 14 alternatives to the south
Six Categories of Alternatives

North

• No new pipes - Push northern system to its limits

• Replace WASM 3 with larger pipe or construct new pipe and/or add pump station

• Construct tunnel to north

South

• New tunnel or pipeline from Norumbega or Shaft 5 area to Chestnut Hill and upgrade Chestnut Hill Emergency Pump Station

• New pipe to southern surface mains with or without new Pump Station

• Tunnel to Dorchester Tunnel Shaft 7C
Baseline Components For 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)
Convert part of WASM 4 and entire West Spot Pond pipeline to high service

- Cost: $10 million (one alternative)
- Cannot supply summer season demands
- Not reliable for planned maintenance shut down of tunnel system
- Could be used as contingency plan for emergency use while long term solution is being implemented
- Potential pipe replacement

Cost is midpoint of construction. Does not include WASM 3 baseline work
Northern Component – Category 2
Increase Capacity to North (Larger Pipe and/or Pump Station)

- Cost: $138 million - $473 million (six alternatives)
- Large diameter pipelines are extremely difficult to construct through congested urban areas
- Pump station could cause potential pressure surges in distribution system

Cost is midpoint of construction. Does not include WASM 3 baseline work.
Northern Component – Category 2
Increase Capacity to North (Larger Pipe or Pump Station)

Alt 2N
Alt 3N
Alt 4N *
Alt 5N
Alt 6N
Alt 7N
Cost: $472 million - $1,292 million (six alternatives)

- Construction impacts would be limited to shaft construction sites and pipe connections
- Would provide redundancy to WASM 3 pipeline
- Meets redundancy goals under all demands
- Allows year round maintenance of tunnel system (in combination with a southern solution)

Cost is midpoint of construction. Does not include WASM 3 baseline work
Northern Component – Category 3
Increase Capacity to North (Tunnel)

Alt 8N *

Alt 9N

Alt 10N

Alt 11N

Alt 12N

Alt 13N
• Cost: $293 million - $629 million (nine alternatives)
• Large diameter pipelines are extremely difficult to construct through congested urban areas
• Pump station would cause higher pressures and potential surges in distribution system

Cost is midpoint of construction. Does not include WASM 3 baseline work
Southern Component – Category 1
Increase Capacity to Chestnut Hill (tunnel or pipeline)

Alt 5S

Alt 6S

Alt 7S

Alt 9S

Alt 11S

Alt 12S
Southern Component – Category 1 (continued)
Increase Capacity to Chestnut Hill (tunnel or pipeline)

Alt 14S

Alt 15S *

Alt 16S
Southern Component – Category 2
Increase Capacity to South (pipeline with or without pump station)

- Cost: $363 million - $390 million (two alternatives)
- Large diameter pipelines are extremely difficult to construct through congested urban areas
- Pump station would cause potential damaging pressure surges in distribution system

Cost is midpoint of construction. Does not include WASM 3 baseline work
Southern Component – Category 2
Increase Capacity to South (pipeline or pump station)

Alt 8S *

Alt 10S
Southern Component – Category 3
Increase Capacity to South (Tunnel)

- Cost: $716 million - $1,034 million (three alternatives)
- Construction impacts would be limited to shaft construction sites and pipe connections
- Meets redundancy goals under all demands
- Allows year round maintenance of tunnel system (in combination with a northern solution)

Cost is midpoint of construction. Does not include WASM 3 baseline work
Southern Component – Category 3
Increase Capacity to South (Tunnel)

Alt 17S
Alt 18S *
Alt 19S
Financial Considerations
Financial Considerations

- Preserve Sustainable and Predictable Rates at Water Utility level
- Ensure Adequate Capital is Available When Necessary
- Minimize Cost of Borrowing
1. CIP without Long –Term Redundancy Project

2. Lowest Cost Alternative - $729M \textit{midpoint of construction}

3. Middle Cost Alternative - $1.47B \textit{midpoint of construction}

4. Highest Cost Alternative - $2.3B \textit{midpoint of construction}
Projected Debt Service Pro Forma
Based on Middle Cost Alternative

$ in millions

$0  $100  $200  $300  $400  $500  $600

Combined Assessments

Combined Rate Revenue Requirement

Amount in $000s


$600,000
$650,000
$700,000
$750,000
$800,000
$850,000
$900,000

Combined No LTR
Combined Least
Combined -Non Phased
Combined -Max
Water Utility Projections

Rate of Change to Water Utility Assessments

Annual rate

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030

Water No LTR  Water Least  Water - Non Phased  Water -Max

-6%  -4%  -2%  0%  2%  4%  6%
Staff Preferred Alternative
Staff Recommendation – Interim Measures

- Take action now to reduce risk of failure/improve ability to respond:
  - Tunnel-shaft pipeline improvements $7.5 million
  - Chestnut Hill Pump Station improvements
    - Emergency power $10.9 million
    - Investigate feasibility of pump output controls $22.5 million
  - WASM 3 rehabilitation $104.6 million
  - Commonwealth Avenue pump station low service suction capability $8.0 million
  - Increase PRV capacity WASM 3 and WASM 4 $8.7 million
  - PRVs for East/West Spot Pond Supply Main community connections $1.3 million

Total $163.5 million
• Emergency and Planned Shut-Down Capability Preferred

  – Allows maintenance of system
  – Maintenance reduces risk of failure
  – Meet customer expectations for excellent quality water
  – Minor impact on normal service
Findings of Alternatives Analysis

• Need additional capacity to supply water to both the north and south

• Chestnut Hill Emergency Pump Station cannot reliably supply enough water to the south with the Dorchester Tunnel shut down

• Long distance large diameter surface pipelines in urban areas present significant implementation challenges
Preferred Alternative for Long-Term Redundancy

- **Two Tunnel Option Preferred**

- **Time to Complete:** 17 - 23 years

- Tunnels begin in the Mass Pike/Route 128 vicinity

- Northern Tunnel 4.5 miles, connects to mid-point of WASM 3 in Waltham/Belmont area.

- Southern Tunnel 9.5 miles, connects to Shaft 7C and southern surface mains
Meets Many Objectives:

- No boil order
- Flow and pressure for normal service and fire protection
- Ability to perform maintenance
- Additional benefit: Ability to meet high day demand. No seasonal restrictions.
Preferred Alternative for Long-Term Redundancy

• Midpoint of Construction Cost: $1,470 - $1,700 million

• Costs include:
  – 30% contingency factor
  – 4% annual escalation

• Cost does not include baseline / interim improvement costs.
• Could be built in phases

• Northern Tunnel
  – Redundancy for City Tunnel Extension
  – Could shut City Tunnel during periods of low demand and still feed south

• Southern Tunnel
  – Redundancy for Dorchester Tunnel
  – Eliminates reliance on the CHEPS
Phased Construction of Preferred Alternative

- If a phased approach is a goal, staff would recommend that the Northern Tunnel be constructed first.

- With Northern Tunnel in place
  - test valves at Shaft 7
  - potentially address Shaft 5, Shaft 9 or Shaft 9A concerns

- Shut down City Tunnel (winter only)
- Supply through new Northern Tunnel & WASM 3
- Supply with Chestnut Hill pump station from Boston Low
- Supplement down City Tunnel Ext to Dorchester Tunnel
Possible Schedule for Preferred Alternative

Concurrent (16.5 years)
- MEPA - EIR
- Design
- Construction - North
- Construction - South

Phased (23 years)
- MEPA - EIR
- Design North
- Construction - North
- Design - South
- Construction - South

Cost to Complete: $1,470 million (escalated to midpoint of Construction)

Cost to Complete: $1,700 million (escalated to midpoint of Construction)
<table>
<thead>
<tr>
<th>Description</th>
<th>Duration</th>
<th>Cost Mid-point of Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non Phased</td>
<td>17yrs</td>
<td>$1.47B</td>
</tr>
<tr>
<td>Phased</td>
<td>23yrs</td>
<td>$1.70B</td>
</tr>
</tbody>
</table>
Cash Flows

Cash Flows Compared

Phased $1.70B MPoC
Non-Phased $1.47B MPoC
Combined Assessments

Combined Rate Revenue Requirement

Amount in $000s


Combined -Non Phased  Combined -Phased
Water Utility Assessments

Water Utility Rate Revenue Requirement

Amount in $000s

Water - Non Phased

Water-Phased
Water Utility Rate Projections

Rate of Change to Water Utility Assessments

Annual rate


Water - Non Phased
Water-Phased
Redundancy for Metropolitan Tunnel system is necessary for maintenance and emergency response.

If we do nothing, failure will eventually occur.

Extensive alternatives were identified and evaluated.

Long distance large diameter pipeline alternatives present significant implementation challenges.

Operational reliability problems were identified with Chestnut Hill Pump Station and other proposed pump stations.

Preferred tunnel alternatives meet service objectives and goals:

- Allows planned maintenance of 60+ year old infrastructure that are beyond their useful life.
- Allows emergency response at normal level of service.
- Constructible.