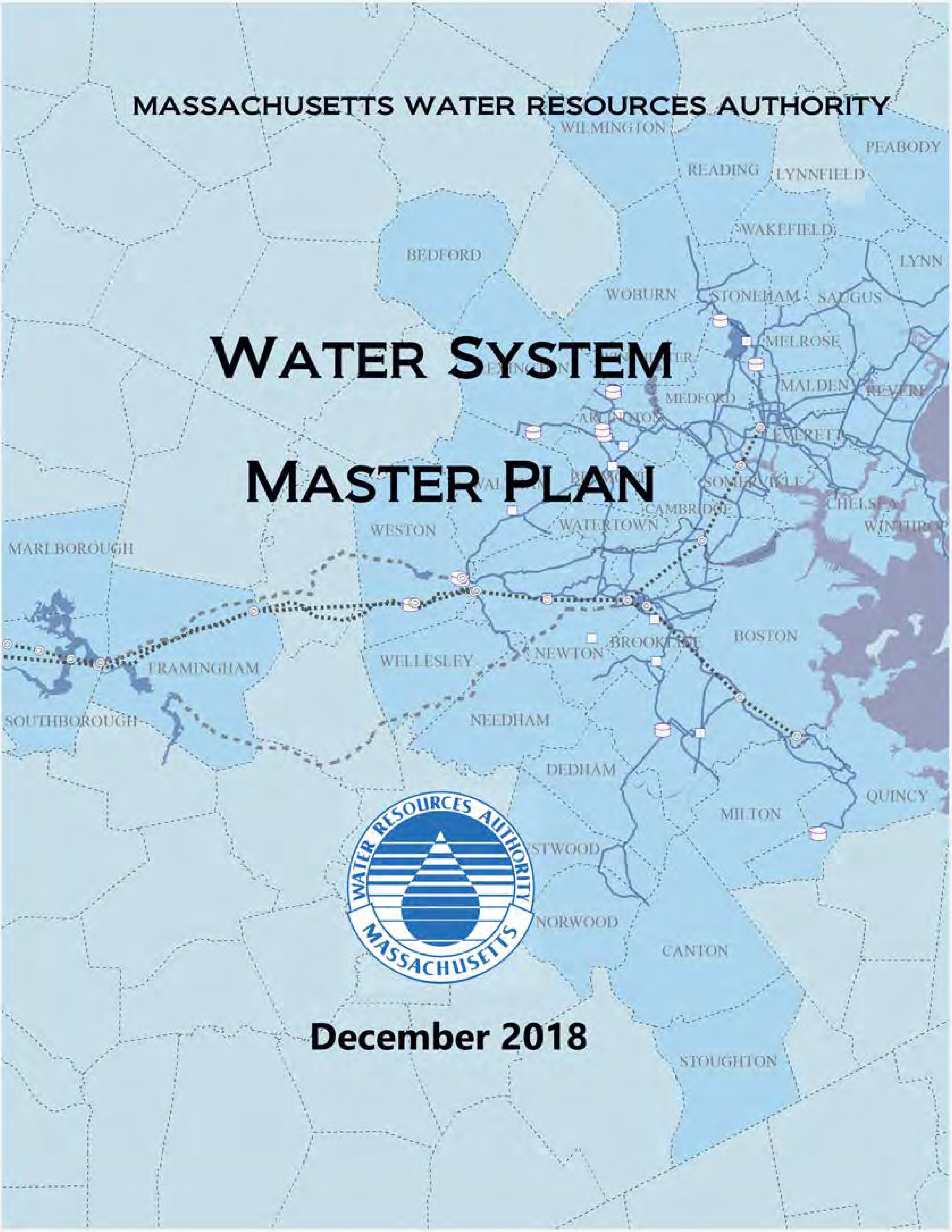
MASSACHUSETTS WATER RESOURCES AUTHORITY

WATER SYSTEM MASTER PLAN



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2018 MWRA Water System Master Plan

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2018 MWRA Water and Wastewater Master Plan - Executive Summary

OVERVIEW

Since its inception, MWRA has expended $8.3 billion on capital initiatives (FY86 through FY18). The 2018 Master Plan documents the investment needs of MWRA's regional water and wastewater systems over the next 40 years (FY19-58) through the identification of 344 prioritized projects estimated at $5.75 billion in 2018 dollars. All projects are either already programmed in the FY19 Capital Improvement Program (CIP) (total of $3.76 billion) or are recommended for consideration in future CIPs (total of $1.99 billion). Development of the Master Plan is a collaborative process involving MWRA's Planning, Operations, Engineering, and Finance staff. The 2018 Master Plan is a comprehensive update of the 2013 Master Plan.

The Master Plan is an important tool for annual capital planning and budgeting and its spending recommendations have been incorporated in MWRA's multi-year financial planning estimates. The draft 2018 Master Plan was used as a reference to help guide development of the CIP spending cap for FY19-23. The final 2018 Master Plan has been updated to be consistent with the final FY19 CIP budget and is intended to be a companion document to facilitate staff and Advisory Board recommendations and allow for comparison of future investment needs between different parts of the water and wastewater systems. The Master Plan provides information on water and wastewater system facilities and operations at a level of detail to provide the reader the context to understand recommended future capital spending. The 2018 Master Plan lists both projects programmed in the CIP and projects recommended for future consideration during the 40-year planning period. The focus is on projects proposed to require capital spending during the next two 5-year CIP cap cycles, FY19-23 and FY24-28. Following these two 5-year periods, potential capital needs during additional 10-year (FY29-38) and 20-year (FY39-58) planning periods are projected. Estimates of project costs and schedules over the shorter term are expected to be more reliable than out-year estimates. The Master Plan is a key reference document that will be updated every five years to reflect changing water and wastewater system needs, updated asset conditions, evolving regulatory requirements, revised priorities identified through new studies, and other appropriate considerations.

The MWRA Master Plan has two volumes, one detailing water system needs and the second detailing wastewater system needs. This comprehensive Executive Summary covers both volumes and summarizes overall costs. The Water System Master Plan includes major chapters on treatment, the transmission system, and the metropolitan system. The Wastewater System Master Plan includes distinct chapters for major facilities (e.g., Deer Island Treatment Plant, Residuals Pellet Plant, remote headworks, sewers, pump stations, etc.). Chapters include project recommendations to address the issues and needs identified during the planning process. Both Water and Wastewater Plans also provide related background information including system goals and objectives, history of the system, and the assumptions which provide the context for master planning, including: regulatory framework, future population estimates, water demand and quality, wastewater flow and quality, residuals volumes, etc. Information on MWRA's Energy Management strategies and programs is also included in both documents.

In June 2018, the Board of Directors set the FY19-23 5-year CIP spending cap at $984.8 million, an increase of $193.1 million over the FY14-18 cap, but less than the FY04-08 and FY09-13 caps which both exceeded $1.1 billion. The CIP spending cap excludes the Infiltration/Inflow Local Financial Assistance and Local Water System Assistance Programs which are driven by member community requests for funding assistance. Staff expect the Board will continue to establish CIP spending caps for future 5-year periods (FY24-28 and beyond) as part of future CIP process discussions. Total Master Plan water and wastewater needs identified for FY19-23 are approximately $1,002 million, including $984 million in projects currently programmed in the CIP and $18 million in new projects recommended for consideration in future CIPs. Total water and wastewater needs identified for FY24-28 are approximately $2,073 million, including $1,756 million in projects currently programmed in the CIP and $317 million in new projects recommended for consideration in future CIPs. MWRA's estimated water and wastewater reinvestment needs for the 40 year planning period are presented in Table 1 and also displayed graphically in Figures 1 and 2. All wastewater and water project costs recommended in the Master Plan are summarized by chapter in Attachments A and B.

Since five year updates for the Water and Wastewater System Master Plans were initiated in 2006, it is clear that master planning efforts have been valuable to MWRA and certain key themes have emerged. On the water side, the 2006 Plan reflected the completion of the MetroWest Tunnel and the Carroll Water Treatment Plant; then began the look ahead towards the future design and construction of UV treatment and the remaining system redundancy. In 2018, distribution system redundancy projects moved closer to completion and a more developed plan for Metropolitan Tunnels redundancy has replaced placeholder values. UV treatment is now in place at both the Carroll and Brutsch water treatment plants. The plan's focus has moved towards continued asset protection for pipelines and facilities.

On the wastewater side, the 2006 Plan identified the increasing needs of Deer Island's asset protection that now represents over half of all wastewater project costs programmed in the CIP. The 2006 Plan identified the need to develop rehabilitation plans for residuals facilities and the headworks. Project schedules and costs have now been programmed in the CIP and headworks upgrades are underway. In 2006, only 15 of 35 CSO Control Plan projects were complete; with an additional $460 million in future spending programmed in the CIP. Today, the last element of the $900 million CSO Control Plan, the $2.5 million 3-year CSO Control Performance Assessment, is underway and will be completed in 2020. The initial interceptor renewal methodology that prioritized future projects based on risk and consequence of failure was developed as part of the 2006 Master Plan. Scheduling of interceptor renewal projects was stretched out to allow other critical expenditures to move forward while constructability and permitting issues are assessed. Major investment in interceptor renewal is now recommended over the next 25 years. For long-term regulatory changes, MWRA continues the initial 2006 theme of monitoring emerging contaminants and environmental issues with no significant near-term spending anticipated.

Efforts to protect coastal facilities from sea level rise moved from planning into construction, and continuing improvements in green energy production and energy efficiency have reduced MWRA's greenhouse gas footprint by 32% between 2006-2016. During the plan period, these efforts will continue; most notably with the combined heat and power project on Deer Island improving MWRA's use of digester gas to produce additional green power.

TABLE 1 - 2018 MWRA MASTER PLAN PROJECT COST SUMMARY ($ in thousands)

Asset	FY19-23	FY24-28	FY29-38	FY39-58	SUBTOTAL FY19-58
Water Treatment and Land Acquisition Programmed in FY19 CIP	13,016	18,204	28,500	0	59,720
Future Recommended - Water Treatment and Land Acquisition	0	3,596	15,000	45,000	63,596
Transmission System and Dams Programmed in FY19 CIP	96,455	576,243	826,278	52,862	1,551,838
Future Recommended - Transmission System and Dams	4,050	7,600	10,850	70,500	93,000
Metropolitan System, Lab, SCADA, Metering, Energy and Info Management Programmed in FY19 CIP	230,769	321,531	60,454	0	612,754
Future Recommended - Metropolitan System, Lab, SCADA, Metering, Energy and Info Management	3,575	7,600	33,700	150,400	195,275
SUBTOTAL - Water Projects Programmed in FY19 CIP	340,240	915,978	915,232	52,862	2,224,312
SUBTOTAL - Future Recommended Water Projects	7,625	18,796	59,550	265,900	351,871
TOTAL WATER PROJECTS	**347,865**	**934,774**	**974,782**	**318,762**	**2,576,183**
Wastewater Treatment and Residuals Programmed in FY19 CIP	324,596	423,977	68,801	0	817,374
Future Recommended - Wastewater Treatment and Residuals	7,400	49,000	140,750	596,000	793,150
Headworks, Tunnels, Pump Stations, CSO Facilities, Sewers, SCADA and Metering Programmed in FY19 CIP	196,396	287,545	35,215	0	519,156
Future Recommended - Headworks, Tunnels, Pump Stations, CSO Facilities, Sewers, SCADA and Metering	3,000	142,900	204,000	342,400	692,300
Community Financial Assistance Programmed in FY19 CIP	123,200	129,100	-40,600	-13,300	198,400
Future Recommended - Community Financial Assistance	0	106,100	48,000	-4,100	150,000
SUBTOTAL - Wastewater Projects Programmed in FY19 CIP	644,192	840,622	63,416	-13,300	1,534,930
SUBTOTAL - Future Recommended Wastewater Projects	10,400	298,000	392,750	934,300	1,635,450
TOTAL WASTEWATER PROJECTS	**654,592**	**1,138,622**	**456,166**	**921,000**	**3,170,380**
TOTAL - Projects Programmed in FY19 CIP	984,432	1,756,600	978,648	39,562	3,759,242
TOTAL - Future Recommended Projects	18,025	316,796	452,300	1,200,200	1,987,321
TOTAL PROJECTS	**1,002,457**	**2,073,396**	**1,430,948**	**1,239,762**	**5,746,563**

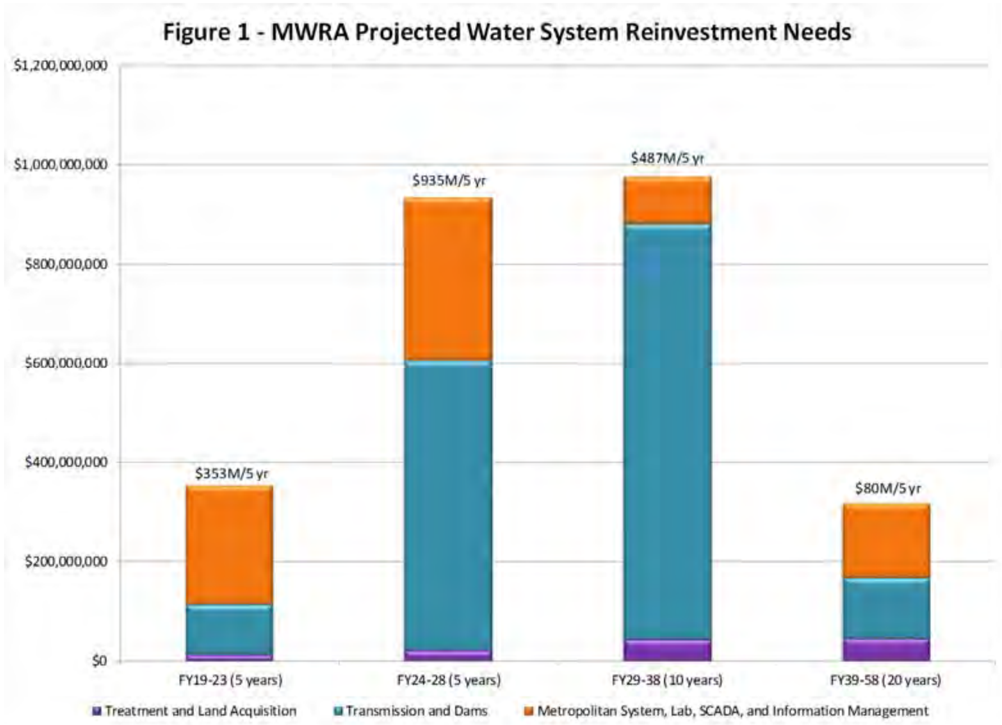
Figure 1 - MWRA Projected Water System Reinvestment Needs
$1,200,000,000
$1,000,000,000
$800,000,000
$600,000,000
$400,000,000
$200,000,000
$0
$353M/5 yr
$935M/5 yr
$487M/5 yr
$80M/5 yr
FY19-23 (5 years)
FY24-28 (5 years)
FY29-38 (10 years)
FY39-58 (20 years)
Treatment and Land Acquisition
Transmission and Dams
Metropolitan System, Lab, SCADA, and Information Management

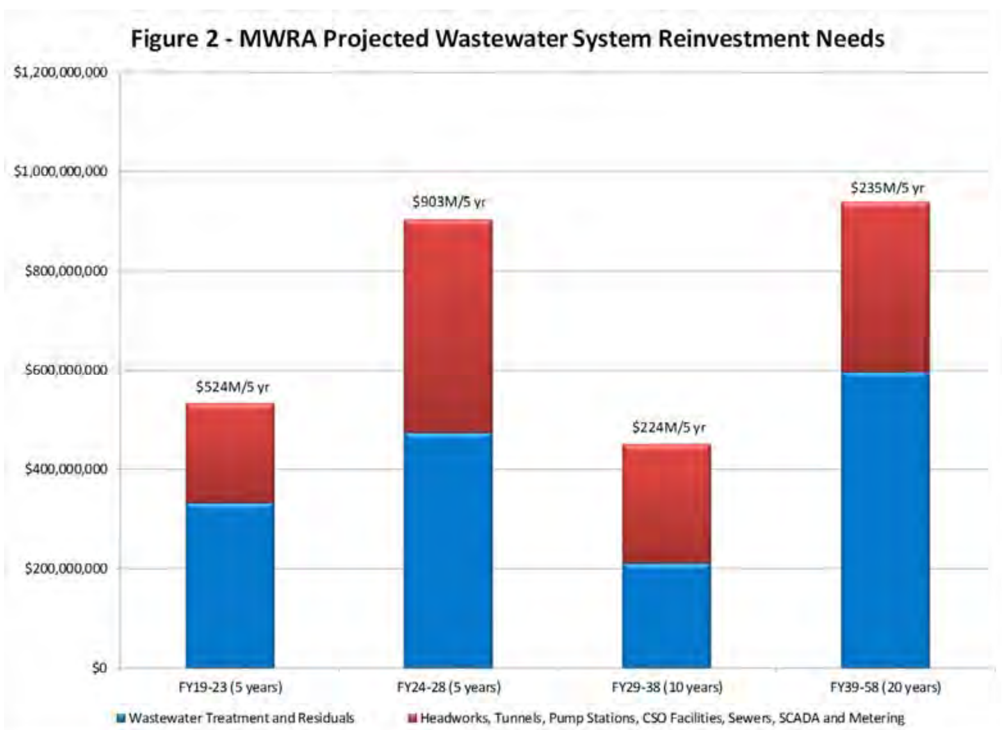
Figure 2 - MWRA Projected Wastewater System Reinvestment Needs
$1,200,000,000
$1,000,000,000
$800,000,000
$600,000,000
$400,000,000
$200,000,000
$0
$524M/5 yr
$903M/5 yr
$224M/5 yr
$235M/5 yr
FY19-23 (5 years)
FY24-28 (5 years)
FY29-38 (10 years)
FY39-58 (20 years)
Wastewater Treatment and Residuals
Headworks, Tunnels, Pump Stations, CSO Facilities, Sewers, SCADA and Metering

All Master Plan projects have been prioritized on a scale from 1 to 5, as follows: 1 – critical; 2 – essential; 3 – necessary, 4 – important, and 5 – desirable. Highest priority projects will resolve critical threats to public health and prevent imminent system failure resulting in significant service loss. High priority projects will improve system reliability and maintain effluent/residuals quality. Lower priority projects will optimize system performance, assure future capacity, and provide more efficient operation. Project ratings were assigned by MWRA senior managers in concert with Operations, Engineering, and Planning staff. Project priority is reviewed during the annual CIP development process.

SUMMARY OF THE 2018 WATER SYSTEM MASTER PLAN

MWRA's water system includes its source reservoirs, treatment facilities, transmission lines, and distribution system facilities and pipelines; the system (excluding the source reservoirs) has an estimated replacement asset value of approximately $6.7 billion. Total water system needs identified for the FY19-58 Master Plan timeframe are approximately $2.6 billion (in current dollars), including all projects currently in the CIP and those recommended for consideration in future CIPs. Approximately 69% of the total water system need addresses major remaining system redundancy costs including interim and long-term Metropolitan Tunnel Redundancy costs, WASM 3 work and remaining water distribution system storage and pipeline redundancy projects. The remaining 31% includes ongoing asset protection projects for valves, pipelines, pump stations, storage facilities, dams, and treatment facilities. Also included are costs for continuing watershed land acquisition, and replacement and optimization of other smaller yet critical assets such as radio and SCADA equipment, lab equipment and facilities, and metering equipment. Table 2 shows the breakdown of project CIP and Master Plan costs by planning period.

TABLE 2 - 2018 Water System Master Plan Cost Summary

	FY19-23	FY24-28	FY29-38	FY39-58	Total Cost ($1000)
Projects Programmed in the FY19 CIP	340,240	915,978	915,232	52,862	2,224,312
Projects Recommended for Future CIPs	7,625	18,796	59,550	265,900	351,871
Total	347,865	934,774	974,782	318,762	2,576,183

The water system needs assessment is based on the following major assumptions and findings:

- The 300-mgd safe yield of MWRA's water system is sufficient to meet future demand for water both within the service area and additional demand outside the service area.
- Modeling efforts indicate that climate change is not expected to have significant impacts on reservoir yield; in fact, safe yield may increase slightly. Changes in climate may encourage surrounding communities to turn to MWRA for portions of their supply as droughts become more frequent or severe.
- No design and construction funds are included to address the impacts on MWRA's water system of potential changes in federal or state regulations. Staff continue to track potential changes to the Federal Lead and Copper Rule which may cause MWRA to reevaluate corrosion control.

- Water supply redundancy and new storage projects provide for system reliability, operational flexibility, and enhanced security. Planning for redundancy for key elements of both the transmission and distribution systems was a focus of both the 2006 and 2013 Water System Master Plans and continues to be a point of emphasis. Projects to address Metropolitan Tunnel Redundancy have now been incorporated into the CIP as have interim projects to address immediate risk reduction needs in the existing tunnel system prior to the implementation of tunnel redundancy. As a placeholder, the Master Plan includes $65 million in future funding for repair or rehabilitation needs for the existing Metropolitan Tunnels once the new tunnels are in service. This value will be refined as the redundancy work is completed and a full inspection and assessment can be done. The Master Plan programs these costs in the FY39-58 planning period. Work on redundancy for the Northern Intermediate High and Southern Extra High service areas has progressed significantly during the past five years as well. Approximately $15 million in new project costs are recommended to enhance redundancy in the Northern Extra High system moving forward.

- Master Plan recommendations include inspections of the Cosgrove Tunnel periodically over the 40-year Master Plan period. The inspection of the Quabbin Tunnel is in the FY19 CIP and is scheduled to begin in FY24. At this time, no funds are included for rehabilitation or repair of those tunnels. However, if inspections of any of the tunnels were to indicate more significant problems, future costs would need to be added.

- The Master Plan again emphasizes the need to continue the systematic cleaning and lining of remaining MWRA-owned, older unlined cast-iron mains to address potential water quality degradation concerns and related health risks. This effort addresses MWRA customer expectations and EPA’s anticipated direction for distribution system regulation and reduces pipeline corrosion and leakage. Metropolitan system pipeline expenditures identified in the CIP or recommended in the Master Plan are approximately $321 million (excludes WASM 3 pipe costs). Additionally, the current CIP includes approximately $56 million for an expanded cathodic protection program for the metropolitan system.

- The Master Plan recommends a pipeline study in FY25 to help MWRA assess the ongoing need for rehabilitation beyond currently planned work. The study will look at any pipe remaining to be rehabilitated (mostly constructed since 1950), expected replacement cycles for lined pipes, and assess information on corrosion and other factors.

- The Master Plan recommends continuing to systematically address the long-term need to protect and eventually replace other water system assets, including equipment, valves, pump stations, storage facilities, treatment and transmission system buildings and equipment (not including tunnels or piping), dams, and support systems. Including what is already in the CIP as well as recommended asset protection projects, the overall water system master plan total for this category is approximately $361 million between FY19-58.

- Financial assistance to support member community water system rehabilitation projects to help maintain high quality water is recommended to continue but must be evaluated against competing MWRA CIP needs. Even with the substantial progress made over the last 20 years via MWRA’s community water loans, approximately 1,800 miles (27%) of community-owned water mains remain unlined. The Master Plan recommends two additional water loan program phases FY29-48 (each at $250 million in loans over 10 years) to extend the current program approved through FY30. Since there is no grant component to water financial assistance; the impact to MWRA’s CIP is minor compared to the sewer grant/loan program.

The Transmission System – Tunnels and Aqueducts, Facilities, and Dams

MWRA's water transmission system consists of over 100 miles of tunnels and aqueducts in daily use which transport water by gravity from the supply reservoirs to points of distribution within the service area. The basic layout of the system as designed is fundamentally sound. System improvements over time have allowed for older facilities, no longer in daily use, to remain as critical emergency standby facilities as long as maintained and linked to new facilities where necessary. The performance standards for a major transmission system are: ability to transport sufficient water to meet the maximum daily demands of the service area, and reliability in that there must be sufficient redundant components to ensure a continued supply of water system if any one "leg" of the system were to fail. MWRA's transmission system ably meets system demands and much of the system has redundant components that may be brought on line.

However, as noted in the previous Master Plans and discussed in this plan, shortfalls in redundancy remain although significant improvements have been completed since the 2013 Master Plan. The Wachusett Aqueduct Pump Station which will provided needed redundancy for the Cosgrove Tunnel is undergoing final testing and is anticipated to be operation soon. Major work has been underway since 2013 to address redundancy for the Metropolitan Tunnels: City Tunnel, City Tunnel Extension and Dorchester Tunnel. As outlined in greater detail in Chapter 7 of this Plan, staff undertook a major review of potential alternatives that would achieve the redundancy goals. Failure of the existing deep rock tunnels is not the major concern; potential failure of surface connections, valves and piping which could require isolation of the tunnel system is of prime concern. However, without redundant facilities, the tunnels cannot be taken off line for inspection, maintenance and needed repairs. In 2017, staff presented a conceptual plan to construct both North and South tunnels to the Board of Directors for their consideration and was given authorization to move forward. A Tunnel Redundancy Department has been formed, initial work is underway and a future contract for preliminary design and MEPA review is expected to be procured in FY20.

In addition, a number of interim improvements have been identified that will further reduce risk prior to new tunnels being constructed. These include improvements at the top of shaft locations; improvements at the Chestnut Hill Emergency Pump Station; Low Service PRV improvements and improvements to the Commonwealth Avenue Pump Station. It is also apparent that rehabilitation of WASM 3 must proceed as soon as possible. Work is underway on all of these projects. Inspection of the Quabbin Aqueduct is included in the FY19 CIP. The 2018 Master Plan also recommends period inspections of the Cosgrove Tunnel and sets aside a placeholder value for longer-term future inspection and rehabilitation of the Metropolitan Tunnels once redundancy is in place.

MWRA, under its 2004 Memorandum of Agreement with the Department of Conservation and Recreation (DCR), is responsible for water supply dams, with a couple of exceptions. MWRA previously paid DCR Division of Watershed Management to perform capital improvements for these dams. Significant work to meet regulatory requirements, ensure dam safety and provide operational flexibility where possible has been completed. Continued long term asset protection of dams remains a critical effort going forward. Additional improvements to allow for increased operational range and flexibility at the Quabbin spillway have been identified as a future project. Overall, between those projects included in the FY19 CIP and recommended work, the Master Plan identifies approximately $1.65 billion in future transmission system spending.

Treatment Plants

Since the 2013 Master Plan, UV disinfection has been completed and operational at both the Carroll Water Treatment Plant (CWTP) and the Brutsch Water Treatment Plant. Although the CWTP has been more recently constructed, there are substantial electrical and mechanical systems which require ongoing replacements and upgrades approximately every ten years. Approximately $41 million of such costs are included in the FY19 CIP and the Master Plan recommends an additional $30 million in the FY 29-58 time period.

The Metropolitan System

The Metropolitan System consists of approximately 284 miles of distribution pipeline east of Shaft 5, twelve storage tanks, twelve pump stations, nine tunnel shafts, and over 4800 valves. The system is divided into 7 pressure zones.

Since the 2013 Master Plan, MWRA has moved towards completion of the two most significant pipeline redundancy projects within the distribution system. For the Northern Intermediate High service area, three contracts are completed and a fourth is expected to be completed in 2020. Total cost for these projects is approximately $55.7 million. For the Southern Extra High service area, one contract is substantially complete and all three contracts are expected to be completed by the end of 2020 at a total estimated cost of approximately $49.4 million. Work has also been completed for the Spot Pond Covered Storage Facility which provides an additional 20 MG of Low Service storage in the northern part of the system. As part of the same project, a pump station which provides redundancy to Gillis Pump Station has also been constructed. These projects significantly improve operational flexibility. Long term, the NIH and SEH also have shortfalls in storage as does the Northern Extra High Service area and these projects are either in the FY19 CIP or recommended in the Master Plan.

Continuing to systematically line remaining older unlined cast iron mains to address water quality degradation concerns remains a goal of pipeline rehabilitation and replacement. Additional funds are also allocated to improved cathodic protection going forward. Overall, Metropolitan system pipeline expenditures identified in the FY19 CIP or the Master Plan are approximately $321 million in the FY19-58 time period. This excludes WASM 3 which is approximately $102 million. The Master Plan recommends a pipeline study in 2025 to help MWRA assess the ongoing need for rehabilitation beyond the above work. The study will look at the expected replacement cycles for lined pipes and assess information on corrosion and other factors.

The 2018 Master Plan also reaffirms the need to systematically protect and replace other MWRA water system assets. The FY19 CIP and the Master Plan allocate $361 million for equipment, valves, pump stations, storage facilities, treatment and transmission buildings and equipment, dams and ancillary support systems between FY19-58.

Land Acquisition

The FY19 CIP includes approximately$6.4 million to enable DCR to acquire parcels of, or interests in, real estate critical to protection of the watershed and source water quality. The Master Plan recommends an ongoing program of approximately $1 million per year through the FY19-58 planning horizon for total of $40 million.

Community Financial Assistance – Local Water System Assistance Program

Even with the substantial progress made over the last 20 years, MWRA estimates that approximately 1800 miles of community water main remain unlined, representing a future community water main replacement/rehabilitation cost of $1.5 billion. For master planning purposes, staff recommend future fourth and fifth phases of the Local Water System Assistance Program be considered for funding in future CIPs. Each new phase is recommended to provide $250 million in interest-free loans (with 10-year loan repayments) during the FY29-38 and FY39-48 time periods. MWRA staff will continue to work cooperatively with the Advisory Board to identify potential program improvements which may be recommended to the Board for approval.

SUMMARY OF THE 2018 WASTEWATER SYSTEM MASTER PLAN

MWRA's wastewater system is a complex network of conduits and facilities receiving flow from 43-member sewer communities covering an area of about 500 square miles. The regional system serves approximately 2.2 million people, including the City of Boston and surrounding metropolitan area. The Deer Island Treatment Plant (DITP) receives an average daily flow of 353 mgd and has a peak wet weather capacity of 1,270 mgd, with additional system capacity available at combined sewer overflow (CSO) outfalls. Residuals from DITP are processed into pellets for beneficial reuse at MWRA's sludge-to-fertilizer plant in Quincy. The MWRA collection system includes four remote headworks facilities, a network of 274 miles of sewer pipelines and cross-harbor tunnels, 13 pump stations, one screening facility, and six CSO treatment/storage facilities. MWRA also operates the Clinton Advanced Wastewater Treatment Plant (AWWTP) providing sewage treatment services to the Town of Clinton and the Lancaster Sewer District. MWRA's goal is to operate and maintain these facilities to provide uninterrupted wastewater collection and treatment service in a safe, cost-effective, and environmentally sound manner.

The scale and scope of MWRA's wastewater system operation – encompassing collections, pumping, CSO, treatment, effluent discharge, and beneficial reuse of residuals – presents challenges in maintenance, rehabilitation, and replacement. MWRA's wastewater infrastructure has an estimated replacement value of approximately $6.8 billion. Deer Island alone has approximately 70,000 pieces of equipment and instrumentation components. Regular maintenance and replacement cycles have become standard plant operating practice, but will become increasingly costly as the plant ages. Capital projects across the system will be implemented while facilities are on-line, posing operational challenges, and project staffing considerations will also need to be weighed. Finally, all system spending is against the backdrop of rates management.

Total wastewater needs identified for the FY19-58 Master Plan timeframe are $3.17 billion (in current dollars), including $1.53 billion already programmed in the FY19 CIP and $1.64 billion recommended for consideration in future CIPs. More than 94 percent, $2.99 billion of the $3.17 billion needs estimate for all wastewater projects are rehabilitation or replacement of existing infrastructure assets at end of their useful life. The remaining $180 million in needs are for projects to optimize existing systems or add capacity, technology upgrades and new equipment to support automated facility operation, condition assessments, and wastewater modeling.

The wastewater system needs assessment is based on the following major assumptions and findings:

- No new communities are expected to join the wastewater system. Future population and employment growth in the service area is projected to modestly increase. These population and growth increases could result in a projected increase of up to 27 mgd of sanitary wastewater flow through 2040. This potential increase represents a 10% increase over the current 270 mgd average dry day flow (last 20 years). MWRA's continued commitment to invest in community infiltration, inflow, and combined stormwater reductions is expected to offset the increase in new sanitary flows.

- Wastewater quality parameters are not projected to change significantly. The need for capital projects to address wastewater quality will most likely be based on revised NPDES permit limits.

- No significant design and construction funds are included for potential long-term regulatory changes that may impact MWRA based on current Deer Island NPDES permit discussions and the 2017 Clinton permit. Future regulatory issues that may have cost implications for MWRA include more stringent limits on nutrients, conventional pollutants, or emerging contaminants; more stringent biosolids reuse criteria; rapid public notification of CSO discharges (location and volume); a higher level of CSO control; more stringent focus on reduction or elimination of sanitary sewer overflows (SSOs); and expansion of MWRA's role in local stormwater permitting and initiatives for promoting green infrastructure.

- Storm surge, together with anticipated sea level rise resulting from the changing climate, will affect a number of MWRA and communities' coastal collection systems and wastewater facilities. Sea level rise was accounted for during the design and construction of the Deer Island Wastewater Treatment Plant. As climate change projections evolve, projected infrastructure impacts, and identification of appropriate projects to counter negative impacts will become a more critical theme of future MWRA Master Plans. The 2018 Master Plan assumes any significant flood mitigation efforts will be undertaken as each MWRA facility is rehabilitated or upgraded, and that simpler measures will be implemented as maintenance efforts. Rehabilitation projects at the Alewife Brook Pumping Station and the Chelsea Creek Headworks have already incorporated anticipated changes in sea level into the design criteria, and other coastal facilities have had flood mitigation measures implemented. Future coastal projects may need to be targeted so that increases in tidal and storm surge inflow do not impact MWRA's ability to provide reliable wastewater collection and treatment.

- Significant asset protection investment at Deer Island will continue, as well as green energy production and energy optimization, with $660 million programmed in the FY19 CIP over the next 10 years. Three of the most expensive Deer Island projects include:
    - The combined heat and power project to optimize use of methane gas and overall energy efficiency ($90 million);
    - Rehabilitation of primary and secondary clarifiers ($134 million); and,
    - A series of odor control and HVAC equipment replacement projects ($85 million).

- The Pelletizing Plant in Quincy will require large-scale equipment replacement which is included in the FY19 CIP at $100 million over the next 15 years.

- The cross-harbor tunnels are assumed to be in good condition. A $1.3 million cross-harbor tunnel shaft study and follow-up $9.7 million shaft rehabilitation project are programmed in the FY19 CIP during FY19-27. A $5 million tunnel inspection and condition assessment project is also programmed in the CIP during FY24-28. The condition of the cross-harbor tunnels and potential need for future investment is a significant unknown for MWRA until the inspection/condition assessment project is complete. Included as a Master Plan recommendation is a $50 million placeholder for future inspection/cleaning/repair of the tunnels in the out years of the planning period (FY46-50).

- Headworks facilities require significant reinvestment that is programmed in the CIP (estimated at over $240 million over the next 10 years). The Chelsea Creek Headworks Upgrade is well into construction and will be followed by the Columbus Park and Ward Street Headworks Upgrades. Improvements programmed in the CIP for the Nut Island Headworks include odor control, HVAC, mechanical, and electrical system upgrades. Upgrade projects at the headworks must be implemented while systems remain on-line, posing operational challenges.

- MWRA's 20 pump stations and CSO facilities, while generally in good condition, are aging and some are in need of rehabilitation or upgrade. The Master Plan reinvestment strategy for these facilities estimates a $163 million need over the next 10 years, only 45% of which is currently programmed in the FY19 CIP.

- No significant additional CSO capital costs are included (other than maintenance of existing facilities) beyond the $2.5 million (through FY21) to complete the 3-year CSO Control Performance Assessment. If regulatory action were to mandate a higher level of CSO control, additional capital needs would be required.

- The average age of MWRA's 226-mile sewer system is approximately 70 years old, with approximately 39% of the sewers more than 100 years old. Overall, the collection system is in reasonably good condition, given its age. MWRA's interceptor renewal program targets the approximate 13 miles (6% of gravity sewers) that have significant physical defects. The sections requiring repair are prioritized based on risk and consequence of failure and are regularly monitored through internal TV inspection. In addition to the gravity sewers and structures, MWRA also maintains 29 miles of force mains, siphons, and CSO/emergency outfalls. The Master Plan reinvestment strategy for all sewer pipelines estimates a $168 million need over the next 10 years, of which 70% is currently programmed in the FY19 CIP.

- Wastewater metering and supervisory control and data acquisition (SCADA) systems will continue to require upgrades based on assumed useful life/obsolescence of the electronic equipment. Much of this equipment is expected to require replacement every 10 to 20 years (programmed in the FY19 CIP at $22 million for the next 10 years).

- Financial assistance to support member community projects for sewer system rehabilitation and infiltration/inflow reduction is planned to continue but must be evaluated against competing MWRA CIP needs. Continued investment in rehabilitation of member community sewer systems is key in minimizing the potential for regional wastewater flow increases, which could require additional future transmission and treatment capacity. The Master Plan carries recommended funds for additional community financial assistance beginning in FY24. Staff will continue to work cooperatively with the Advisory Board to identify potential improvements for community financial assistance programs.

The 2018 Master Plan lists programmed and recommended projects with CIP spending in FY19-58 and focuses on projects proposed to require capital spending during the next two 5-year CIP cap cycles: FY19-23 and FY 24-28. Following these two five year periods, potential capital needs during additional 10-year (FY29-38) and 20-year (FY39-58) planning periods are identified. Wastewater System Master Plan project costs for these planning periods are presented in Table 3, below.

TABLE 3 - 2018 Wastewater Water System Master Plan Cost Summary

	FY19-23	FY24-28	FY29-38	FY39-58	Total Cost ($1000)
Projects Programmed in the FY19 CIP	644,292	840,622	63,416	-13,300	1,534,930
Projects Recommended for Future CIPs	10,400	298,000	392,750	934,300	1,635,450
Total	654,692	1,138,622	456,166	921,000	3,170,380

Wastewater System Master Plan projects during the FY19-23 and FY24-28 timeframes are summarized below under five major headings: (1) Wastewater Treatment - Deer Island and Clinton Plants; (2) Residuals Processing (off-island) at the Pellet Plant, (3) Wastewater Headworks and Cross-Harbor Tunnels, (4) Wastewater Pump Stations, CSO Facilities, and CSO Control Plan, (5) Collection System Sewers, SCADA, Metering, and Community Financial Assistance.

Wastewater Treatment - Deer Island and Clinton Plants, FY19-23 and FY24-28

MWRA's Deer Island Treatment Plant (DITP) is the centerpiece of MWRA's $3.8 billion construction program to alleviate pollution in Boston Harbor. The plant provides primary and secondary treatment of wastewater collected from approximately 2.2 million people in 43 greater Boston communities. Treated wastewater effluent is carried by a 9.4-mile, 24-foot diameter outfall tunnel and discharged into the 100-foot deep waters of Massachusetts Bay. DITP is designed to process a maximum of 1.27 billion gallons per day and components include: influent pumps, primary treatment, secondary treatment, disinfection, dechlorination, the outfall tunnel, sludge digesters, odor control, and on-site power generation.

The Deer Island Treatment Plant is the second largest plant in the country in terms of maximum daily capacity. Its multiple treatment processes, high level of automation, and its uniquely-constructed technical and engineering systems present challenges to operating, maintaining, and replacing the plant’s equipment, structures, and related support systems. Components of DITP came on-line sequentially beginning in January 1995 with construction completed in 2001. Most plant equipment and structures are up to twenty years old and in good condition. The Wastewater System Master Plan identifies $310 million in DITP project needs for the FY19-23 timeframe, $305 million programmed in the FY19 CIP and $5 million recommended for consideration in future CIPs. For the FY24-28 timeframe, the Master Plan identifies $392 million in DITP project needs, $354 million programmed in the FY19 CIP and $38 million recommended for consideration in future CIPs. Some major DITP projects during FY19-28 include: pump variable frequency drive replacements, primary and secondary clarifier rehabilitation (phase 2), sludge digester and storage tank rehabilitation, combined heat and power project, continued electrical equipment upgrades (phase 5), switchgear replacement (phase 2), HVAC equipment replacement, fire alarm system replacement, and as-needed design.

The Clinton Advanced Wastewater Treatment Plant (AWWTP) provides advanced sewage treatment services to the Town of Clinton and the Lancaster Sewer District. MWRA upgraded the treatment plant and sludge landfill in 1992 at a cost of $37 million. The plant provides secondary treatment using an activated sludge process in combination with advanced nutrient removal and dechlorination. Effluent is discharged into the South Branch of the Nashua River. The Clinton AWWTP is 25 years old and in generally good condition. Some equipment rehabilitation and replacement projects are recommended; however, significant reinvestment is not required in the short-term. The Master Plan identifies $8.4 million in project needs for the Clinton Plant for the FY19-23 timeframe, $7.8 million programmed in the FY19 CIP and $0.6 million recommended for consideration in future CIPs. For the FY24-28 timeframe, $4.1 million is programmed in the CIP and $9.5 million is recommended for consideration in future CIPs.

Residuals Processing (off-island) at the Pellet Plant, FY19-23 and FY24-28

Digested sludge is pumped from DITP through two 14-inch, seven-mile-long force mains that are embedded in concrete within the 11-foot diameter Inter-Island Tunnel and connect to the Residuals Pellet Plant in Quincy. The Pellet Plant was built in 1991 and expanded in 2001 to handle sludge production from DITP secondary treatment facilities. The Residuals Pellet Plant is designed to handle up to 180 dry tons per day of residuals with four of the six operational trains running. Current production is 100 dry tons per day (annual average) or 140 dry tons per day on a 5-day operational week. Pellets are distributed for beneficial reuse. The Pellet Plant is operated and maintained under a long-term contract (March 2001 through December 2020, as amended) with a private firm, the New England Fertilizer Company (NEFCo). The annual operating cost is $14 to $16 million per year. Since NEFCo is responsible for all operation, maintenance, and capital improvements for the term of the contract, MWRA has not incurred additional major expenditure at the facility.

In 2018, the facility equipment is 17 to 27 years old. In January 2014, MWRA completed an assessment of long-term technology options for residuals processing and disposal. The study identified a few technology efficiency improvements for the Pellet Plant that will be evaluated in the long-term. Significant reinvestment is anticipated for residuals processing and disposal during the next 10 years.

The Wastewater System Master Plan identifies $13.8 million in Residuals Pellet Plant project needs for the FY19-23 timeframe, $11.5 million programmed in the FY19 CIP and $2.3 million recommended for consideration in future CIPs. For the FY24-28 timeframe, the Master Plan identifies $67 million in Residuals Pellet Plant facilities upgrade design and construction needs, all of which $66 million is programmed in the FY19 CIP.

Wastewater Remote Headworks and Cross-Harbor Tunnels, FY19-23 and FY24-28

MWRA's four remote headworks (Chelsea Creek, Columbus Park, Ward Street, and Nut Island) and 19 miles of cross-harbor tunnels are critical facilities because almost all flow to DITP passes through them. The primary function of the remote headworks is to remove grit and screen out debris from wastewater flow to minimize solids accumulation in the cross-harbor tunnels and protect downstream pump facilities at the DITP. The cross-harbor tunnels (North Metropolitan Relief Tunnel, Boston Main Drainage Tunnel, Inter-Island Tunnel, and Braintree-Weymouth

Tunnel) transport wastewater from the remote headworks to Deer Island. The Wastewater System Master Plan identifies $103 million for FY19-23 and $165 million for FY24-28 in remote headworks and cross-harbor tunnel project needs, almost all of which is programmed in the FY19 CIP.

The Chelsea Creek, Columbus Park, and Ward Street Headworks were all built in 1967 and are over 50 years old. Equipment at the headworks was upgraded by MWRA in 1987 and is over 30 years old. These three older facilities remain operational, but, largely due to age and equipment obsolescence, are in only fair condition and need significant reinvestment. A Headworks Condition Assessment/Concept Design project was completed in FY10 and Preliminary Design was completed in FY12. These projects reviewed the adequacy of existing headworks components and processes and provided replacement/upgrade recommendations based upon current technology. MWRA has developed a prioritized design/construction schedule through FY28 at a cost of approximately $190 million to rehabilitate the three older remote headworks. Design of upgrades for the Chelsea Creek Headworks began in FY11 and construction is scheduled to run through FY21. The second phase of the project will be to design and construct upgrades for both Columbus Park and Ward Street Headworks during FY17-28. The newer Nut Island Headworks, built in 1998, is in good condition. Significant projects to provide mechanical, electrical, odor control, and HVAC upgrades are programmed for the Nut Island Headworks during FY17-29 at an overall cost of $67 million.

The North Metropolitan Relief Tunnel and Boston Main Drainage Tunnel were built in 1953 and are 65 years old. The Inter-Island Tunnel (1996) and Braintree-Weymouth Tunnel (2005) are relatively new. Based on the industry benchmark of 100+ years for useful life for tunnels, it is assumed that the older cross-harbor tunnels are still in good condition. However, the existing condition of the tunnels is unknown; therefore, there is uncertainty associated with the potential for future repair/rehabilitation and risk of a very large future cost. Some deterioration of concrete in the tunnel shafts has been documented and attributed to hydrogen sulfide corrosion. Since the cross-harbor tunnels and shafts are critical facilities, a study/rehabilitation of the effluent shafts, as well as a tunnel inspection are high priorities. These projects are programmed in the FY19 CIP at $15 million during FY19-27.

Wastewater Pump Stations, CSO Facilities, and CSO Control Plan, FY19-23 and FY24-28

The MWRA collection system includes 13 pump stations, one screening facility, and six CSO treatment/storage facilities. The primary function of a pump station is to lift wastewater from an upstream sewer (at a lower elevation) to a downstream interceptor (at a higher elevation) so the wastewater can continue to flow by gravity to MWRA headworks facilities. Most pump stations operate continuously; however, two MWRA pump stations (Framingham and New Neponset Valley Sewer Pump Stations) are designed to operate during peak flows (wet weather) only. The primary function of a combined sewer overflow (CSO) facility is to store and/or treat combined (sanitary and stormwater) flow that exceeds the capacity of the combined sewer system in large rainfall events.

The average age of MWRA’s 20 collection system facilities is 27 years. Six of the 20 facilities are more than 30 years old. The oldest pump station, Alewife Brook in Somerville, is 67 years old and is undergoing a major rehabilitation scheduled for completion in FY20. Two of MWRA’s CSO facilities are 47 years old: the Cottage Farm Pumped CSO Facility and the Somerville Marginal

Gravity CSO Facility. Overall, the 20 collection system facilities are in good condition. Significant automation upgrades were implemented under MWRA's Wastewater Central Monitoring/SCADA Implementation Project during 2007-2009. The CSO facilities have undergone upgrades under the CSO Control Plan. The highest priority immediate needs for wastewater pump stations and CSO facilities are rehabilitation/replacement projects being implemented at the 10 older facilities.

For wastewater pump stations and CSO facilities, the Wastewater System Master Plan identifies \$51 million in project needs for the FY19-23 timeframe, \$49 million programmed in the FY19 CIP and \$2 million recommended for consideration in future CIPs. For the FY24-28 timeframe, the Master Plan identifies \$113 million in wastewater pump station and CSO facility needs, \$24 million of which has been programmed in the FY19 CIP. Some major projects during FY19-28 include: a condition assessment for the 10 oldest wastewater facilities; and follow-up design and construction of upgrades at the oldest stations (Alewife Brook, Caruso, Chelsea Screen House, DeLauri, Hayes, Hingham, Prison Point, Wiggins - Castle Island Terminal, Cottage Farm, and Somerville Marginal).

MWRA's Long-Term CSO Control Plan, as mandated by the Federal Court, is comprised of 35 wastewater system improvement projects that address 84 CSO outfalls. All 35 of these projects have been completed. The Federal Court schedule required MWRA to commence a 3-year performance assessment in January 2018 and submit a report assessing attainment of the long-term levels of control by December 2020. The Master Plan includes details on project engineering and construction requirements, schedules, long-term levels of CSO control, benefits achieved to date, and future activities. The total cost of the CSO Control Plan (including both previous and future expenditures) is \$910 million, of which \$902.3 million (99 percent) was expended through FY18. The FY19 CIP includes \$7.7 million in spending during FY19-21 to complete the 3-year CSO control performance assessment, additional inflow removal in the Dorchester interceptor, and cured-in-place-pipe lining of the Somerville Marginal pipeline to facilitate in-system storage. There are no future MWRA or community-managed CSO Control Plan projects recommended for consideration in future CIPs. Funds to replace equipment at CSO facilities are included in collections system facilities costs.

Collection System Sewers, SCADA, Metering, and Community Financial Assistance. FY19-23 and FY24-28

The primary function of the collection system is to transport wastewater received from the 43 member sewer communities (through over 1,800 community connections) to the MWRA headworks facilities. Collection system operations are intended to optimize system performance and minimize potential CSOs and SSOs, particularly before and during storm events that stress the system's hydraulic capacity. The collection system includes a network of 274 miles of sewer pipelines - 19 miles of cross-harbor tunnels, 226 miles of gravity sewers, 18 miles of force mains, 7 miles of siphons, 4 miles of CSO and emergency outfalls, and 4,000 manholes and other structures. Internal inspection information (physical, television, and sonar) is used to develop maintenance schedules, identify structural problems, and help define rehabilitation projects.

For collection system sewers, supervisory control and data acquisition (SCADA) systems, wastewater metering, and community financial assistance, the Wastewater System Master Plan identifies \$161 million in project needs for the FY19-23 timeframe; \$159 million programmed in the FY19 CIP and \$2 million recommended for consideration in future CIPs. For the FY24-28 timeframe, the Master Plan identifies $388 million in collection system needs, $233 million programmed in the FY19 CIP and $155 million recommended for consideration in future CIPs. Some major projects during FY19-28 include: a series of prioritized interceptor renewal/asset protection projects ($120 million); sewer siphon structure, manhole, and force main rehabilitation ($18 million); SCADA and wastewater metering ($22 million); and member community financial assistance ($358 million).

The average age of the sewer system is about 70 years old. Approximately 39 percent of sewers are over 100 years old; however, the collection system is in reasonably good condition given its average age. Based on internal TV inspection ratings for gravity sewer pipe, approximately 74 miles (33 percent) are in very good condition (A-rated), 139 miles (61 percent) are in fair to good condition with some defects (B-rated), and 13 miles (6 percent) of interceptors are severely damaged and/or have defects requiring repair (C-rated). The most critical need for the sewer system is rehabilitation construction that will address long-term sewer asset protection for C-rated pipelines. To meet this need, MWRA developed a series of prioritized interceptor renewal/asset protection projects. The gravity sewer inspection ratings have not been used for force mains, siphons, or outfalls; however, based on available data, these also appear to be in reasonably good condition. MWRA continues to monitor hydrogen sulfide corrosion and odor issues in the collection system to prioritize inspections for affected sewers. TRAC staff oversee the pre-treatment work of municipalities and industries. The Wastewater System Master Plan does not include recommendations for future large scale capital projects to target capacity/optimization projects. Collection system operations, particularly in preparation for and during large storm events, are intended to optimize system performance and minimize potential CSOs and SSOs.

The SCADA systems provide a means of monitoring and controlling facilities and equipment from a remote centralized location, as well as providing a continuous record of facility operations. MWRA's Wastewater SCADA system went through a major upgrade from 2007 through 2009 as part of the Wastewater Central Monitoring/SCADA Implementation Project. This project created a unified SCADA system covering all significant wastewater facilities. New facilities have been incorporated into the system. All wastewater facilities can be monitored and controlled at the Chelsea Operations Control Center using the SCADA system. MWRA's wastewater metering system provides rate-basis data on community flows, as well as additional operational support data for hydraulic modeling, capacity analyses, engineering studies, and community flow component (sanitary/infiltration/inflow) estimates. Upgrades to the SCADA and wastewater metering systems are scheduled to continue throughout the 40-year Master Plan schedule.

Since 1993, MWRA has made a commitment to assist member sewer communities to finance infiltration and inflow (I/I) reduction and sewer system rehabilitation projects within their locally-owned collection systems. Funding of community projects through MWRA's I/I Local Financial Assistance Program is provided most recently as 75 percent grants and 25 percent interest-free ten year loans. The program goal is to assist member communities in improving local sewer system conditions to reduce I/I and ensure ongoing repair/replacement of the collection system. It is a critical component of MWRA's Regional I/I Reduction Plan. The FY19 CIP includes a net cost of $198 million (including loan repayments) for approved local distribution through FY30 and loan repayments through FY40. The Master Plan includes placeholders for two additional rounds ($100 million in grant/loans in each round) of CIP funding beginning in FY24 at a net cost of $75 million each. For the FY19-58 timeframe, a total of $348 million is identified for community financial assistance.

Green Power Production and Energy Efficiency

MWRA is an energy intensive organization due primarily to the power needed to transport and treat wastewater, and to a lesser extent, treat and distribute drinking water. MWRA has seen a net reduction of 19.5 percent (about 38 million KWh) in electricity purchases between 2006 and 2017, partly due to increases in renewable electricity production and energy efficiency improvements made throughout the MWRA system. To further reduce greenhouse gas emissions and increase energy efficiency, MWRA will continue to implement cost effective alternative energy projects and continue to incorporate energy efficiency into rehabilitation of facilities, new construction projects and equipment replacement. During FY18, green electric power from MWRA's solar, hydro, wind and digester gas powered generators produced and used on site, or produced and sold to the grid represented about 28 percent of electric power use by all MWRA facilities. At Deer Island, 26 percent of all electric use was generated on site by green power, and if the heat value of the digester gases is included, 62 percent of all power needs were met from green sources. It is anticipated that once the upgraded combined heat and power project is implemented, 65 to 70 percent of electricity needs and up to 90 percent of total power needs at Deer Island will be met by green energy. Chapter 10 of the Water System Master Plan and Chapter 13 of the Wastewater System Master Plan more thoroughly discuss MWRA Energy Management efforts and programs.

Attachment A
2018 Water System Master Plan - Summary of Existing and Recommended Projects

Last revision 4/22/19

Project	Cost ($1000)	FY19-23	FY24-28	FY29-38	FY39-58	Total Cost ($1000)
SUBTOTAL - Existing Projects - Water Treatment and Land Acquisition	59,720	13,016	18,204	28,500	0	59,720
SUBTOTAL - Future Recommended - Water Treatment and Land Acquisition	63,596	0	3,596	15,000	45,000	63,596
SUBTOTAL - Existing Projects - Transmission and Dams	1,551,838	96,455	576,243	826,278	52,862	1,551,838
SUBTOTAL - Future Recommended - Transmission and Dams	93,000	4,050	7,600	10,850	70,500	93,000
SUBTOTAL - Existing Projects - Metropolitan System	592,987	212,743	319,987	60,257	0	592,987
SUBTOTAL - Future Recommended - Metropolitan System	137,500	0	3,000	17,500	117,000	137,500
SUBTOTAL - Existing Projects - Lab Services, SCADA, Metering, Information Management and Security	19,767	18,026	1,544	197	0	19,767
SUBTOTAL - Future Recommended - Lab Services, SCADA, Metering, Information Management and Security	57,775	3,575	4,600	16,200	33,400	57,775
SUBTOTAL - Existing Projects - Energy Management	0	0	0	0	0	0
SUBTOTAL - Future Recommended - Energy Management	0	0	0	0	0	0
SUBTOTAL - Existing Projects - Community Financial Assistance	(141,500)	(8,300)	3,100	(17,900)	(9,500)	(141,500)
SUBTOTAL - Future Recommended - Community Financial Assistance	0	0	0	137,500	(137,500)	0
SUBTOTAL - Existing - ALL (including Community Financial Assistance)	2,082,812	331,940	919,078	897,332	43,362	2,082,812
SUBTOTAL - Future Recommended - ALL (including Community Financial Assistance)	351,871	7,625	18,796	197,050	128,400	351,871
SUBTOTAL - Existing - ALL (without Community Financial Assistance)	2,224,312	340,240	915,978	915,232	52,862	2,224,312
SUBTOTAL - Future Recommended - ALL (without Community Financial Assistance)	351,871	7,625	18,796	59,550	265,900	351,871
TOTAL (including Community Financial Assistance)	2,434,683	339,565	937,874	1,094,382	171,762	2,434,683
TOTAL (without Community Financial Assistance)	2,576,183	347,865	934,774	974,782	318,762	2,576,183

Attachment B

2018 Wastewater System Master Plan - Summary of Existing and Recommended Projects by Chapter

Last revision 4/22/19

Project	Cost ($1000)	FY19-23	FY24-28	FY29-38	FY39-58	Total Cost ($1000)
		5 years	5 years	10 years	20 years	
SUBTOTAL - Existing Projects - Deer Island - Chapter 6	703,127	305,344	353,982	43,801	0	703,127
SUBTOTAL - Recommended - Deer Island - Chapter 6	681,750	4,500	38,500	135,750	503,000	681,750
SUBTOTAL - Existing - Residuals - Chapter 7	102,432	11,488	65,944	25,000	0	102,432
SUBTOTAL - Recommended - Residuals - Chapter 7	82,000	2,300	1,000	0	81,000	84,300
SUBTOTAL - Existing - Headworks and Tunnels - Chapter 8	262,650	103,118	159,532	0	0	262,650
SUBTOTAL - Recommended - Headworks and Tunnels - Chpater 8	115,500	0	5,500	40,000	70,000	115,500
SUBTOTAL - Existing - Sewers - Chapter 9	145,065	20,296	98,496	26,273	0	145,065
SUBTOTAL - Recommended - Sewers - Chapter 9	295,500	1,500	48,000	124,000	122,000	295,500
SUBTOTAL - Existing - Pump Stations and CSO Facilities - Chapter 10	73,407	49,390	24,017	0	0	73,407
SUBTOTAL - Recommended - Pump Stations and CSO Facilities - Chapter 10	250,500	1,500	89,000	40,000	120,000	250,500
SUBTOTAL - Existing - CSO Control Plan (MWRA and Community Managed) - Chapter 11	7,713	7,713	0	0	0	7,713
SUBTOTAL - Recommended - CSO Control Plan (MWRA and Community Managed) - Chapter 11	0	0	0	0	0	0
SUBTOTAL - Existing - SCADA and Metering - Chapter 12	30,321	15,879	5,500	8,942	0	30,321
SUBTOTAL - Recommended - SCADA and Metering - Chapter 12	30,800	0	400	0	30,400	30,800
SUBTOTAL - Existing - Clinton - Chapter 14	11,815	7,764	4,051	0	0	11,815
SUBTOTAL - Recommended - Clinton - Chapter 14	27,100	600	9,500	5,000	12,000	27,100
SUBTOTAL - Existing - Community Support - Chapter 15	198,400	123,200	129,100	-40,600	-13,300	198,400
SUBTOTAL - Recommended - Community Support - Chapter 15	150,000	0	106,100	48,000	-4,100	150,000
SUBTOTAL - Existing - ALL	1,534,930	644,192	840,622	63,416	-13,300	1,534,930
SUBTOTAL - Recommended - ALL	1,633,150	10,400	298,000	392,750	934,300	1,635,450
TOTAL	3,168,080	654,592	1,138,622	456,166	921,000	3,170,380

1 Introduction

1.1 Overview of MWRA

The Massachusetts Water Resources Authority (MWRA) was established by the Massachusetts Water Resources Authority Act, Chapter 372 of the Acts of 1984 of the Commonwealth of Massachusetts. In 1985, responsibility for water distribution for 46 municipalities (currently 51 communities are served fully or in part by MWRA), and sewage collection and treatment for 43 municipalities was transferred from the Metropolitan District Commission (MDC) to the MWRA. MWRA's facilities span from the Quabbin Reservoir in central Massachusetts to the Deer Island Treatment Plant in Boston. Approximately 2.5 million people, about 37% of the total population of Massachusetts, live in the communities served in whole or in part by the MWRA.

MWRA is an independent public agency with the ability to raise its revenues from customer communities, bond sales and grants. In addition to its operating responsibility, the MWRA was created to modernize the area's water and sewer systems and clean up Boston Harbor. MWRA's long-term business plan emphasizes improvements in service and systems and includes performance targets for operating the water and wastewater systems and maintaining new and existing facilities. Parallel to MWRA's goal of carrying out its capital projects and operating programs is its goal of limiting rate increases to its customer communities. The need to achieve and maintain a balance between these two goals is a critical issue in the development of both the Water System and Wastewater Master Plans. MWRA maintains an extensive website at **www.mwra.com** that provides information on the development and organizational structure of MWRA, the water and sewer systems, agency budgets and finance information, customer communities, updates on major capital projects and many other items.

1.2 Purpose of the Water System Master Plan

MWRA's Water System Master Plan presents a long-term vision of the capital development needs of the water system and the actions planned for the next forty years to meet those needs. The primary purpose of this Plan is to ensure that key staff from across the Authority engage in proactive planning to enhance system performance while minimizing long-term costs to MWRA ratepayers. The treatment and delivery of water to a major region of the state (over 2 million customers) represents an essential public service. It is the MWRA's responsibility to protect public health, promote environmental quality improvements, support a prosperous economy, maintain customer confidence, and minimize water charges. To fulfill this responsibility, significant expenditures for system rehabilitation and improvements will continue. This Water System Master Plan identifies system/facility conditions, operational risks and capital project needs. The Master Plan accounts for all projects included in the FY19 CIP, and newly-identified projects. Budgets and schedules for those projects have been updated to reflect the approved FY19 CIP. Projects have been prioritized (see Section 1.7) and a recommended implementation timetable developed that corresponds with MWRA's annual CIP development cycle.

Concurrent with this update to the Water System Master Plan, the MWRA is also updating the Wastewater System Master Plan. The preparation of updated Master Plans was recommended by the MWRA Advisory Board in order to provide a more thorough context for developing, analyzing, and evaluating the annual Capital Improvement Program (CIP). These updated plans are intended to serve as an important tool for future planning, budgeting and rate setting decisions. Every five years, MWRA sets a five-year spending cap for the capital budget. This cap was intended to set a not-to-exceed amount for spending over the five year period. The goal is to control spending while ensuring that MWRA's operational needs are met. The Water and Wastewater System Master Plans are updated on a five-year schedule concurrent with the setting of the next five year cap (FY 19-23). This allows the agency to have the most recent information on project needs when setting the next spending cap.

1.3 Planning Approach, Assumptions and Time Frame

In its three-decade existence, MWRA has constructed billions of dollars of facilities to repair, replace, and modernize aging infrastructure. The $1.7 billion Integrated Water Supply Improvement Program greatly improved the quality and reliability of MWRA's water treatment and transmission system consistent with federal and state Safe Drinking Water Act requirements. The estimated replacement value of MWRA's water system assets is over $6 billion. MWRA is now moving forward with construction of key water distribution system redundancy projects and is beginning planning and design activities for addressing redundancy for the Metropolitan Tunnels (see Chapter 7). As reflected in the FY19 CIP, these projects will clearly be a major focus of engineering efforts and spending over the next two decades and will be followed by the need to inspect, evaluate and rehabilitate the existing Metropolitan Tunnel system. However, MWRA cannot lose focus on the need to continue rehabilitation and replacement of other water system assets. The Master Plan functions as a key opportunity to ensure such projects are identified and considered for implementation.

For the 2018 Master Plan, MWRA has selected a 40-year planning period through FY58. The Master Plan focuses on projects included in the FY18 CIP and newly recommended projects that are proposed to generate capital spending during the next two 5-year CIP cap cycles FY19-23 and FY24-28. Estimates of project costs and schedules over this shorter term are expected to be more reliable than looking ahead to the out-years. Following these two 5-year periods, additional 10-year (FY29-38) and 20-year (FY39-58) planning periods are utilized.

As will be explained in the specific chapters, a number of assumptions were made based on the information gathered for this plan and these assumptions explain why certain financial needs are not identified. The analyses summarized in Chapter 4 indicate that source capacity (the 300 MGD safe yield of the MWRA system) is sufficient to meet future demand for water both within the service area and additional demand outside of the existing service area as may be approved and thus, raw water reservoirs are expected to be sufficient. Finally, at this time, no design and construction funds are included to address the impacts on MWRA's water system of potential changes in federal or state regulations.

All projects have been prioritized on a scale from 1 to 5, with 1 being projects considered critical and 5 considered desirable (see Section 1.7). Priorities for the water projects reflect the water system goals and objectives found in Chapter 2 of this plan. Highest priority projects will resolve critical threats to public health and prevent imminent system failure resulting in significant service loss. High priority projects will improve system reliability including the elimination of "single points of failure". Projects that will provide critical condition assessment information were also considered high priority. Lower priority projects will monitor long-term system needs and provide more efficient operation. Project ratings were assigned by MWRA senior managers in concert with Planning and Sustainability Department staff. All MWRA capital projects will be further reviewed and priorities will be reconsidered during the development process for future CIPs.

1.4 Organization of the Master Plan

The 2018 Water System Master Plan is organized into chapters for distinct topics and/or separate asset classes (such as the Transmission System, Treatment, and the Metropolitan System etc.). Each chapter that recommends capital projects includes a summary section that provides an overview of major findings, recommendations, costs, and project schedules. The 2018 Wastewater System Master Plan has been compiled in a separate volume. The Master Plan Executive Summary presents the combined existing and recommended capital projects for both water and wastewater. Key information sources for the development of the Master Plan are identified in the Appendices.

1.5 Periodic Updates

The Water System Master Plan is intended to represent an ongoing process; it is not intended to be a static document. The Plan presents a broad range of recommended projects, some critical (to be completed in the short-term) and some lower priority (to be completed in the long-term). Changes in scope, details and scheduling of certain projects may be required over time to respond to emergencies, new regulations, emerging technologies, etc. Although this Plan will map out major expenditures for the water system for many years, conditions change and flexibility is important. The Plan is intended to be reviewed annually as an integral component of MWRA's Capital Improvement Program development and will be revised periodically to reflect new initiatives and/or major changes in priorities. A complete Master Plan review/update is recommended to be performed no less than every five years.

1.6 MWRA Business Plan

Separate and distinct from the Master Plan, MWRA maintains and periodically updates its Business Plan. The MWRA Business Plan is a strategic roadmap that presents specific steps that the agency will undertake to continue to provide excellent quality drinking water; meet high environmental standards for wastewater effluent discharge; expand use of renewable energy in its facilities, as well as implement other sustainability practices; improve the capacity, performance, and reliability of its water and wastewater systems; promote investor and ratepayer confidence in Authority financial management; and manage its staff and support systems resources effectively. Many themes overlap between the Master Plan and the Business Plan, however, the intended uses and target audience are quite different. The Master Plan is a very detailed listing, explanation, and prioritization of both short and long-term projects that will impact MWRA's capital development needs. Alternatively, the Business Plan is a concise listing of MWRA goals over a relatively short, generally five year, timeframe. It includes a bullet list of core and special initiatives to achieve each stated goal. The concise nature of the Business Plan makes it effective as both a communications document and a management tool.

1.7 Project Prioritization

As noted in Section 1.2, all projects in the Water System Master Plan have been prioritized on a scale of 1 to 5. A detailed list of priority ratings is presented below. This same prioritization system is also used for new projects proposed in the annual CIP process via the Project Prioritization Assessment Worksheet, whether or not the new project was previously recommended in the Master Plan.

2018 Water

Priority One **Critical/Emergency** Risk moderate to high/Consequence very high
Projects which:

Resolve emergencies or critical threats to public health or worker health and safety

Prevent imminent failure of the system and significant loss of service

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Priority Two **Essential Projects** Risk variable/Consequences high
Projects which are essential to:

Critical facility assessment

Fix existing reliability problems related to “single points of failure”

Upgrade or maintain emergency back-up facilities in operational condition

Address facilities in poor condition where the ability to provide uninterrupted service, sanitary protections or adequate flow is compromised.

Meet minimum hydraulic performance requirements and service needs including adequate distribution storage in areas with a critical shortfall of storage

To comply with mandated legal, regulatory or statutory requirements

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Priority Three **Necessary Projects** Risk moderate to high/Consequences moderate to low
Projects which are necessary to:

Improve public health and worker safety

Restore the system’s infrastructure where it is seriously deteriorated

Significantly improve the effectiveness, efficiency, or reliability of system operations and service delivery including where appropriate, the ability to monitor the system

Preserve water quality during distribution

Maintain consumer confidence

To comply with other legal, regulatory or statutory requirements

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Priority Four **Important Projects** Risk moderate/Consequence low
Projects which are important to:

Maintain the integrity of the system’s infrastructure

Improve hydraulic performance or add distribution storage

Produce significant cost savings or revenue gains for MWRA

Monitor system needs and plan appropriate longer-term responses

Provide acceptable working conditions at field sites and at maintenance support facilities

Maintain efforts to manage system demands

Provide broader environmental benefits

Priority Five **Desirable Projects** Risk/Consequence both low
Projects which are desirable because they would:

Yield worthwhile cost savings, revenue gains, or efficiency improvements for MWRA

Protect the long term value and usefulness of system assets

Solve future problems and conditions which are expected to arise in the latter half of the planning period

Be beneficial towards the improved operation of a local system

2 Water System Goals and Objectives

2.1 Planning Goals and Objectives Defining MWRA's Water System Mission

MWRA's mission is to provide reliable, cost-effective, high-quality water and sewer services that protect public health, promote environmental stewardship, maintain customer confidence, and support a prosperous economy.

MWRA's fundamental mission regarding water service delivery is established in the Enabling Act: to reliably and efficiently deliver an adequate quantity of high quality water to the customer communities, and to properly manage, repair, rehabilitate, and improve the waterworks system so that its service requirements can be met. For the purposes of setting priorities among needs and guiding the planning process, this basic mission is articulated in four distinct principles:

- Provide reliable water delivery.
- Deliver high quality water.
- Assure an adequate supply of water.
- Manage the system efficiently and effectively.

Since these principles represent basic goals and ideals for operating and caring for the water system, further definition of objectives is necessary to establish how MWRA intends to satisfy these goals.

OBJECTIVES

Guidance on the application of each principle is provided by a set of objectives. The objectives express the philosophy and emphasis for program planning and project implementation and identify where efforts should be focused and what approaches should be followed in assessing conditions and developing solutions. These objectives reflect both MWRA's current understanding of the needs and priorities of the system but also the need to be cognizant of potential future changes. These changes may be internal to MWRA or they may be driven by external events, such as regulatory changes or changes in member community priorities.

Individual projects identified during the master planning process will be evaluated at a threshold level in the context of how they meet the stated objectives. However, once projects have been identified and determined to meet specific objectives, their relative prioritization for inclusion in the capital budget will be the result of a more targeted analysis.

2.2 Provide Reliable Water Delivery

Dependable and continuous water delivery at adequate pressures and flow rates is an essential public service integral to the public health, safety, and economic well-being of the region's population. It is MWRA's goal to secure, operate and maintain the water system as needed so that the potential for supply interruption within the service area is kept to an absolute minimum. Disruptions will inevitably occur but fundamental water supply principles prescribe that the consequences of such disruptions be managed and that secondary modes of delivery be available in the event that primary modes are taken off-line for servicing or due to breakdown. Distribution storage sufficient to prevent or minimize significant supply disruptions must also be developed in order to reduce risk. MWRA also recognizes its role to provide wholesale water service in a manner that supports the communities' abilities to meet local requirements for pressure and fire flows. In general, water pressures at community meters should be within an appropriate range at all times and flow rates should be capable of satisfying maximum rates of demand.

Objectives

1) Fix existing reliability problems related to "single points of failure": MWRA has developed information through emergency planning and vulnerability assessments on those points within the transmission and distribution systems where a component failure or shut-down could lead to a disruption in service. The next step is to develop remedies that provide secondary modes of delivery at these locations or develop appropriate emergency response plans. MWRA should continue to move forward with construction of redundant pipelines in the NIH and SEH service areas and with other identified redundancy projects in the distribution system (see Shaft 9 and 9A projects, Section 75, Sections 53 and 99 and others) as they are identified. In the transmission system, the Wachusett Aqueduct Pump Station construction is underway and in early 2017, MWRA's Board of Directors approved moving forward with new tunnels to provide redundancy to the existing Metropolitan Tunnels. That project will address a significant lack of redundancy in the Transmission system. Longer term, the Wachusett Bypass Tunnel should be further considered.

2) Fix facilities in poor condition: MWRA has made significant progress in the identification and rehabilitation of operating and emergency facilities where mechanical or other systems were in poor condition. These facilities will need to be continually evaluated and renewed at regular intervals. Pipeline rehabilitation and replacement must continue in order to address key assets that are in poor condition or are hydraulically deficient and are thereby compromising the system's ability to provide uninterrupted service or adequate flow, or that may potentially contribute to poor water quality. Ongoing leak detection results and potential patterns in water pipeline breaks should be evaluated to determine potential rehabilitation needs as should failures of mechanical systems or other appurtenances. In addition, work to identify and implement dam maintenance and rehabilitation needs should continue during this next five-year Master Planning period.

3) Increase and maintain distribution storage: Continue to implement the recommendations of the 1993 "Water Distribution System Storage Study", and the 1993 and 2006 Water System Master Plans relative to the development of additional distribution storage. Although the volume of system-wide storage has increased, specific areas of the distribution system do not have

sufficient localized distribution storage. Long term CIP projects assume that there will be additional storage developed in both the NIH and SEH pressure zones. Storage requirements should also be considered when addressing potential system expansion requests.

4) Use effective planning and preventive maintenance to minimize risks: In order to reduce the risk of failure, implement systems and preventive maintenance practices to identify, monitor, maintain and replace key equipment in an orderly way to reduce the risk of service disruptions. Continue successful programmatic maintenance that reduce risks such as valve exercising, valve rehabilitation and replacement, and leak detection efforts. Follow through with additional efforts to improve cathodic protection in those areas with stray current or problematic soil conditions to reduce the likelihood of pipeline corrosion.

5) Support work force safety: Provide adequate workplace and field site conditions, and equip crews with the tools, materials and information necessary to carry out operational and maintenance duties safely. Consider staff safety when making decisions about maintenance activities and process technologies.

6) Monitor the system: Continue to implement and enhance measures that allow 24/7 monitoring of key system components. Track upgrades to existing technologies and follow emerging technologies for applicability to the MWRA system.

2.3 Deliver High Quality Water

Since its inception, MWRA has invested significant funds into water quality/treatment improvements to ensure that the customer communities receive water that meets all governmental standards. Provision of high quality water involves four key elements: source water protection, effective and reliable treatment, prevention of water quality degradation in the distribution system and monitoring. In addition, because it is critical that consumers maintain confidence in the quality of their tap water, MWRA should continue to provide a water product which has a consistent and appealing character, and does not arouse doubts about its quality and healthfulness.

Objectives

1) Protect public health: Deliver water that meets, or is better than, the quality standards set by federal and state regulations. Since regulatory standards lag scientific knowledge, monitor emerging trends in public health protection.

2) Preserve water quality within the distribution system: Maintain treatment process equipment to minimize risk of treatment disruptions. Continue to aggressively rehabilitate or replace remaining MWRA unlined pipe that tends to be in poor condition and that degrades water quality. Size, maintain and optimize the operation of storage facilities to ensure protection from potential pollutants and to avoid nitrification.

3) Financial support and technical assistance: Continue to provide financial support and technical assistance as requested to assist the communities in maintaining high water quality to the customer's tap through MWRA's Community Assistance Programs and other efforts.

4) Track and Participate in the development of federal and state drinking water legislation, regulations and guidance materials: Closely follow the development of and any modifications to drinking water legislation, regulations and guidance materials, and look for opportunities to represent MWRA's interests in order to maximize our options and to ensure that resulting water quality requirements are reasonable and appropriate for our situation. Where appropriate, pursue flexible planning strategies that maximize opportunities for selecting treatment methods that are cost effective, meet regulatory requirements and that provide the most value and return in terms of public health benefits and water quality enhancement.

5) Continue to work with the Department of Conservation and Recreation (DCR) in order to maintain excellent source water quality: Develop budget and project priorities to ensure the prevention of contamination, and to provide strong support for DCR watershed protection measures and watershed monitoring efforts. Continue to review and implement appropriate measures to address security concerns relative to water quality.

6) Ensure customer confidence: Recognize the importance of ensuring consumer confidence in the quality of water at the tap, and promote greater awareness of what can be done to prevent water quality deterioration within community and household pipes. Continue systems to ensure responsiveness to customer complaints. Develop clear, understandable information and educational materials for consumers.

2.4 Assure an Adequate Supply of Water

As a regional water supply utility, the Authority maintains a fundamental goal of ensuring that enough water is available to reliably meet water needs within the areas served. Under normal circumstances, this means that water needs should not exceed the safe yield of existing supplies. MWRA's source reservoirs, the Quabbin and Wachusett, can be counted on to safely provide about 300 million gallons per day (mgd) of water. For a 20-year period from 1969 to 1988, the customers of MWRA (and its predecessor MDC) routinely drew more than the safe yield. To address this problem, MWRA launched an aggressive water conservation program in 1986. By 1989, withdrawals were below the safe yield, where they have remained and have continued to drop over time. Water system demand now averages approximately 203 mgd (five-year average 2013-2017).

Objectives

1) Periodically review water needs: Base water needs assessments on demand forecasts that incorporate realistic assumptions about service area population, usage factors, and local source availability including consideration of how those local sources may be impacted by climate change.

2) Maintain demand management efforts: Continue to provide educational materials to communities and to individuals. Maintain management controls to monitor community and system use in order to identify and investigate any unanticipated increases in water use. Continue to support leak detection efforts for both the MWRA system and the community systems.

3) Review Opportunities for System Expansion: Look for opportunities to use excess MWRA capacity to provide environmental benefits, particularly in the headwaters of stressed river basins and within MWRA's watersheds. Consider current and anticipated system demands and the requirements of MWRA's Enabling Act and MWRA policies.

4) Encourage the protection of local sources: Encourage continued local source protection efforts by local communities.

5) Monitor supply conditions and manage drought conditions responsibly: Use a planning approach which monitors key data, preserves options and allows for timely decisions and actions as needed to effectively respond to changing conditions. In the event of actual or impending drought conditions, follow the actions and responses in the Drought Management Plan and seek full cooperation from customer communities. Assess the potential impacts of climate change on smaller local sources, both within the partially supplied communities and in nearby non-MWRA communities to address opportunities to provide short-term assistance as needed. Continue to maintain a high degree of supply reliability so that drought restrictions are not imposed on the public too frequently or for long periods of time.

2.5 Manage the System Efficiently and Effectively

The Authority recognizes its responsibility as a public entity to manage the water system efficiently and effectively. This means that operations are to be conducted safely and appropriately, and that careful attention will be given to efficiency, sustainability of resources and cost-effectiveness in order to provide the greatest value to ratepayers while meeting our standards for service.

Objectives

1) Minimize water losses and waste: Seek to continually improve water distribution efficiency by minimizing water losses, waste, and in-system consumption.

2) Implement sustainable and energy efficient practices: Continue to consider opportunities to reduce the energy used to operate the MWRA water system; purchase renewable power where appropriate; and, continue to develop solar, wind and hydroelectric facilities at locations within the water system as are determined to be feasible.

3) Maintain and enhance measurement and monitoring technologies: Continue to support measurement and monitoring technologies, including SCADA, to facilitate the accurate measurement and monitoring of flow conditions for the purposes of water accountability, determining community consumption levels, monitoring system status, flood control and developing data for analysis and planning. Review new technologies and implement system upgrades as appropriates for improved monitoring and/or control of certain water system facilities that will yield benefits in terms of operational efficiency and flow control precision.

4) Identify and evaluate new pipeline materials or other technologies: Staff should follow industry research and practical experience of peer utilities with new pipe materials, coatings, linings,

wraps, leak detection technologies and/or other innovations and evaluate whether there are applications that should be considered within the MWRA water system.

5) Support work force productivity: Support the productivity of the work force by providing adequate workplace and field site conditions, and equipping crews with all necessary tools, materials and training necessary to carry out operational, maintenance, and repair duties cost-effectively and efficiently. Move forward with MWRA succession planning efforts to ensure a continuity of operations.

6) Update and refine mapping and modeling tools as appropriate: Use up-to-date modeling and mapping tools to facilitate system analyses and decision making. Support records management activities that promote the documentation of accurate, comprehensive and up to date information on the MWRA system, including development of record drawings for those assets where no record drawings currently exist. Compile and organize the data and provide access to appropriate staff.

7) Optimize system operations: In designing long-term improvements, look for opportunities to optimize the operation of the system. Thoroughly review proposed engineering solutions to ensure that proposed projects will not negatively affect hydraulic performance. Aim to satisfy service area pressure requirements more efficiently by taking advantage of available hydraulic gradients within the transmission system.

3 Water System History, Organization and Key Infrastructure

3.1 The Beginning - The Water System

Boston's water supply system has had a remarkable progression dating back as far 1630 when the City was first settled and relied on water from cisterns and wells. As the City grew, so did its need to provide sufficient clean sources of water for a growing population. The pattern of looking west beyond the city for larger and cleaner water supplies repeated itself over and over again. Beginning as early as 1795**,** Jamaica Pond was tapped to provide adequate water sources for metropolitan Boston, followed by Lake Cochituate in Wayland in 1846, then, the Mystic Lakes in 1870, and subsequently, the Sudbury River (shown below) in 1872 (See Figure 3-1 for chronology). At the same time, in order to ensure that there were adequate conveyance systems in place to transport the water resources, significant construction projects including the Cochituate, Mystic, and Sudbury aqueducts were completed. Boston began development of its distribution system in 1848 with the introduction of Lake Cochituate water via a system of cast iron pipes, open distribution reservoirs and, eventually, pumping stations. Other metropolitan area communities installed water works in the late 1800's such that there were already thousands of miles of smaller pipes and a variety of local sources in place by the end of the century. Poor water quality and limited yield of some of these sources, like the heavily polluted Mystic Lakes, became an issue.

Figure 3-1 Development of the Metropolitan Water System

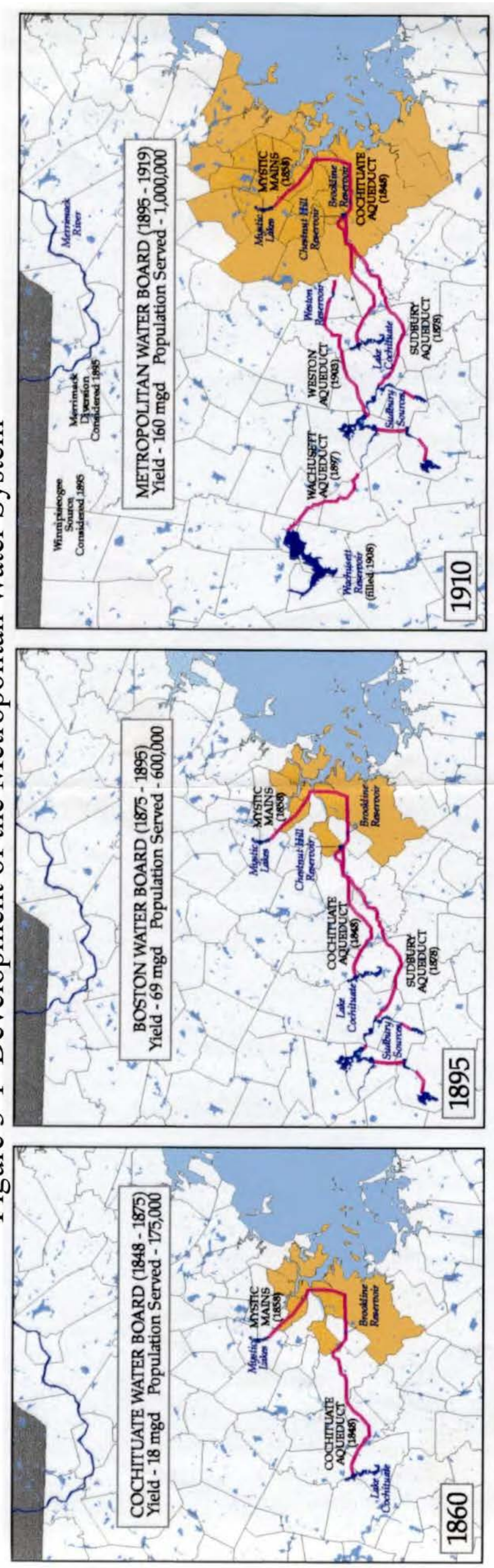
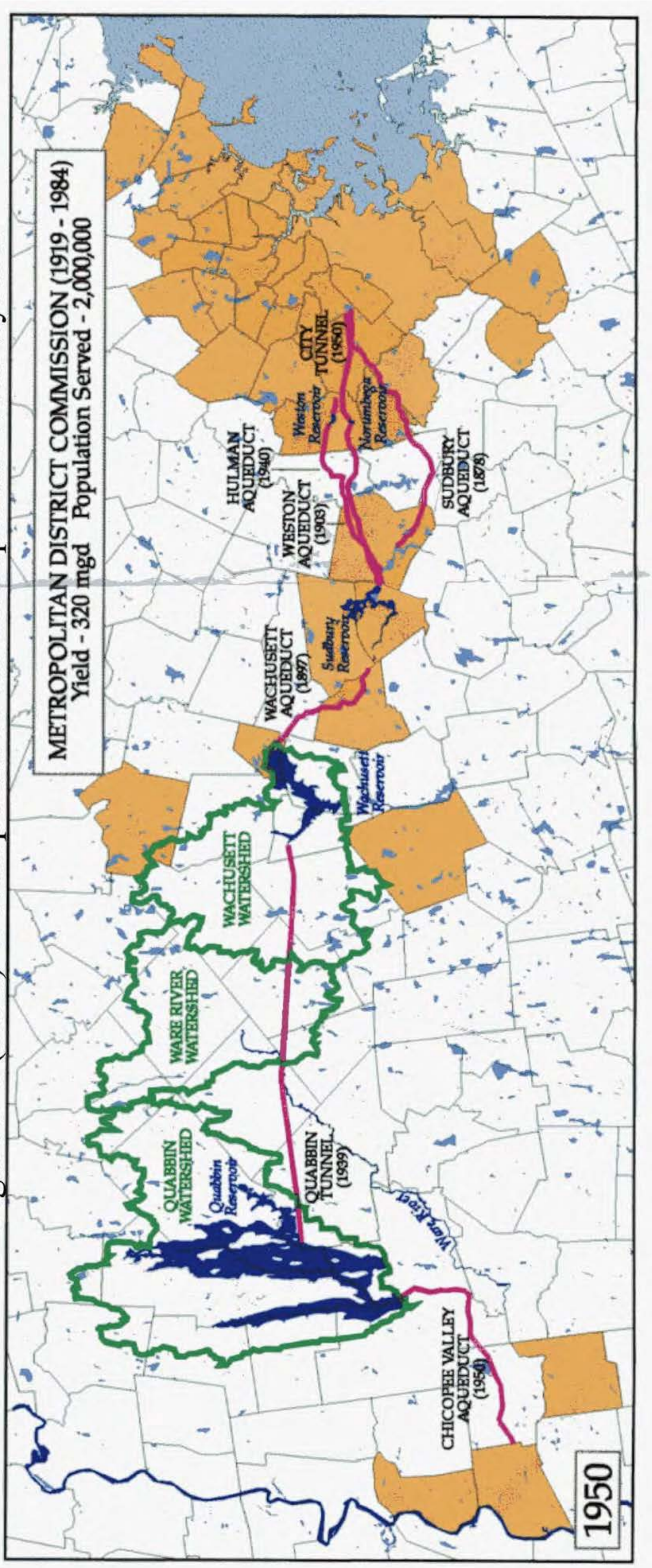


Figure 3-1 (cont.) Development of the Metropolitan Water System



By 1895, in response to continuing growing needs spurred by population growth, the industrial revolution, and increased fire protection needs, Boston's expanding water supply system became one of the first in the nation to be integrated into a multi-municipality Metropolitan water district governed by the newly created Metropolitan Water District and Metropolitan Water Board. These two entities later became the Metropolitan Water and Sewerage Board in 1901. Understanding the need for future planning and the need for additional water supply sources, the Board directed the construction of the Wachusett Reservoir (65 billion gallons) in 1907 which served as the principal water supply for metropolitan Boston. After World War I, it became apparent that Wachusett Reservoir would be insufficient to meet water supply needs and the State Legislature commissioned a major study in 1919 to examine other water supply sources. Later that same year, the Legislature also felt the need to create a new agency, the Metropolitan District Commission (MDC) which consolidated responsibility for metropolitan water, sewage, and parks into one agency in 1926.


WACHUSETT DAM FROM THE EAST. NOV.1-04. 5743.

The Quabbin Tunnel, a 24-mile-long deep rock tunnel, was completed in 1939 to eventually transport water from the Quabbin Reservoir to the Wachusett Reservoir. The tunnel is also used to divert water west from the Ware River into the Quabbin when such diversions are permitted. In 1944, the MDC completed the construction of the 17.8 mile Hultman aqueduct to augment the old brick aqueduct system. The Hultman was built to deliver clean water directly from the Wachusett Reservoir to the Boston area. It was under the direction of the MDC and their visionary engineers that the last major expansion to the water supply system was finished in 1946, with the filling of the 412 billion gallon Quabbin Reservoir (Figure 3-2). While the creation of the Reservoir brought many benefits to watershed protection and water supply for metropolitan Boston, it was not without loss. The Quabbin Reservoir was created by flooding the Swift River Valley eliminating the towns of Dana, North Dana, Greenwich, Enfield, and Prescott, Massachusetts and is one of the largest manmade reservoirs in the country accommodating over two million people in 51 cities and towns daily.

It would be another 66 years until another agency would be created to succeed the MDC in overseeing the metropolitan Boston's water and sewer system needs when in 1984 the Massachusetts Water Resources Authority (MWRA) was created.

3.2 MWRA Water System Today

Created by the State Legislature in 1984 as an independent public authority, MWRA assumed responsibility for the delivery and distribution of water to 46 communities (now 51 after recent additions). What made MWRA different from its' predecessor, the MDC, was the fact that MWRA had the ability to sell bonds and raise revenues to hire essential staff, undertake major capital projects like the Boston Harbor Project and MetroWest Tunnel, as well as handle essential day-to-day routine operation and maintenance.

MWRA is governed by an 11-member Board of Directors who are appointed by the Governor or directly or indirectly by elected officials in MWRA customer communities. Eight of the 11 members of MWRA's Board of Directors are directly or indirectly appointed by the 61 customer communities. Three members are appointed by the Governor.

Today, the water system is managed as a partnership with the Department of Conservation and Recreation (DCR) (formerly MDC), which still maintains responsibility for managing the reservoirs and watersheds. At MWRA, much of the work described in the Water System Master Plan is carried out by the Operations Division under a variety of interrelated departments including: Water and Wastewater Operations and Maintenance, Water Distribution and Pumping, Water Treatment and Transmission, Operations Support, Engineering and Construction and Planning, Figure 3.3 provides an overview of the water system. MWRA's system, in turn, feeds another 6,400 miles of locally owned water distribution pipes. Additional information on MWRA's structure, administration and staffing can be found on the MWRA web site: **www.mwra.com**.

Since 1984, issues at the forefront of MWRA's concern have changed over time:

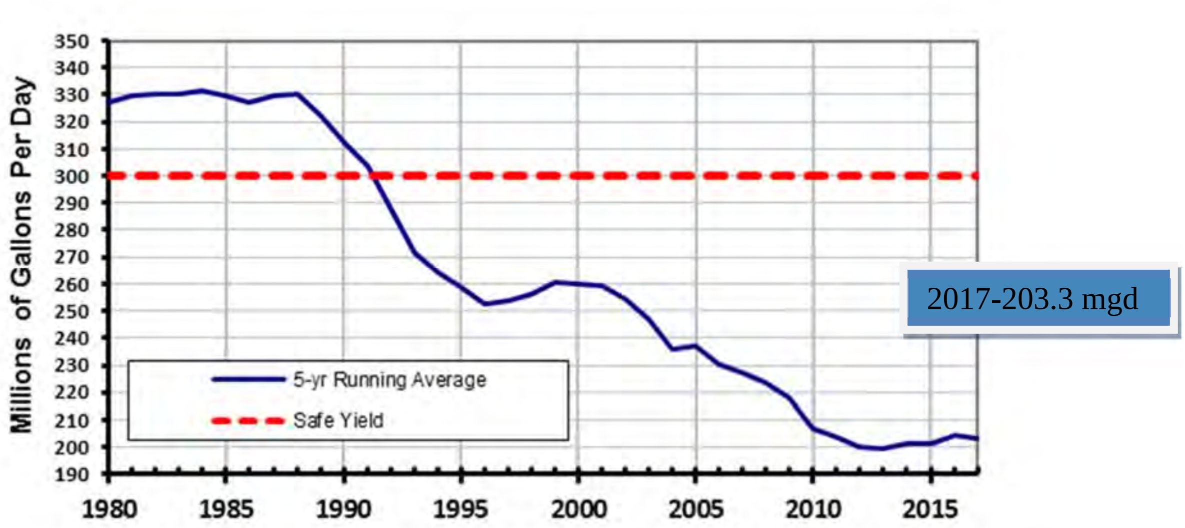
Supply

Following the construction of Quabbin Reservoir in the 30's, there was a continued expansion of the MWRA system driven both by the availability of the new supply and, in some cases, failure or inadequacy of local sources of water in some communities. Along with the growth in demand, the physical expansion of the system also continued and the 1970's saw the completion of the "Y"-shaped Metropolitan tunnel system (the City Tunnel, City Tunnel Extension to the north and the Dorchester Tunnel to the south). Demand had continued upward to a peak average daily demand of 342 mgd in 1980; beyond the safe yield of the sources. The drought of the 1960's had shown the potential vulnerability of the system as the level of water in Quabbin dropped to 45% full in 1967. Thus, the high demand and potential need for additional supply sources was one of the over-arching water supply issues as MWRA was created in 1984.

Demand

As a result of these demand pressures, MWRA launched its Long-Range Water Supply Program in 1987 with 30 different recommendations and programs and an investment of tens of millions of dollars. These initiatives were designed to reduce water use and water losses throughout the MWRA service area and to prevent additional demands due to loss of local sources to contamination. Due to the significant drought conditions experienced by many communities across Massachusetts in 2016, calendar year 2016 water consumption by MWRA communities was 200.7 mgd which was about 4.2 mgd (2.1%) greater than in 2015. These totals were impacted by partially supplied communities, including the larger communities of Cambridge and Worcester, taking additional water. Cambridge and Worcester who do not take water from MWRA under normal conditions took a combined 4.6 mgd. Demand by all communities when Cambridge and Worcester were excluded decreased by 0.4 mgd. Reservoir withdrawals are the metric used to compare to the 300 mgd safe yield of the watershed/reservoir system. Withdrawals include water sold to MWRA communities, as well as other uses in the watershed and MWRA system. Total MWRA water withdrawals increased by 1.1 percent in 2016 from 206.74 mgd in 2015 to 208.94 mgd in 2016. MWRA water withdrawals now average approximately 203 mgd (5-year average 2013-2017), a decline of approximately 128 mgd from the 1984 peak of 331 mgd. Figure 3-2 below shows the five year averages for total reservoir withdrawals from 1980-2017. Using the five-year averages reduces the effects of year to year variability due to weather and provides a good indication of longer term trends. Chapter 4 contains additional information on historical, current and future demand trends.

Figure 3-2: Total Reservoir Withdrawals -- Five Year Running Average 1980 to 2017



Water Quality

The focus then turned to the continued long-term protection of the sources and the modernization of the water supply system in compliance with new federal laws. In the early 1990's, MWRA established a 10 year $1.7 billion Integrated Water Supply Improvement Program. This program was designed to improve the reliability and quality of MWRA water and to meet the stringent requirements of the federal safe Drinking Water Act[1]. The Program included watershed protection, construction of new water treatment facilities, a new water transmission tunnel, covered storage facilities and distribution pipelines improvements. The capstone project, completed in 2005, was the John J. Carroll Water Treatment Plant that treats drinking water for the majority of MWRA customers, residents and businesses in Metro West and Metro Boston communities. The Plant uses ozone as a primary disinfectant and chloramines for residual disinfection, allowing MWRA to meet current and tougher future state and federal water quality standards. Due to additional EPA regulations in 2006 to address microbial protection (Long Term 2 Enhanced Surface Water Treatment Rule or LT2ESWTR), MWRA was required to add a second primary disinfectant and ensure somewhat more stringent inactivation of cryptosporidium than the plant's initial design. Ultraviolet light disinfection treatment was added to the plant to meet these requirements. The UV system went into service in February 2014.

For the three communities served directly off of the Quabbin Reservoir, primary disinfection went on-line in 2000. To meet the requirements of the LT2ESWTR, ultraviolet technology was deemed to be the most efficient and cost effective system upgrade and the UV system in the Brutsch Water Treatment Facility came on line September 2014.

In addition, as an unfiltered supply, source water quality and watershed protection are key factors to maintaining that status. DCR (formerly MDC) has implemented aggressive efforts to "control the watershed" through use of the State's Watershed Protection Act but also through the identification of critical lands and by taking action to prevent adverse development of those lands by use of fee simple purchases when necessary, or more commonly through purchase of conservation restrictions. These protections help retain MWRA's "unfiltered" status but also provide protection against many potential "emerging" contaminants which mostly impact water systems with significant upstream pollutant sources. Chapter 5 contains additional source water quality information and Chapters 6, 7 and 8 provide information on Water Treatment and Facilities, and the Transmission and Metropolitan Distribution systems.

Efficiency

As new facilities have come on line, MWRA has also made significant efficiency improvements in day to day operations. The fact that water flows to the east by gravity is of course a major advantage over many large systems. MWRA has continued many of the hydropower facilities put in place in earlier decades and has continued to look for opportunities to increase the use of hydropower and other renewable sources at new locations (See Chapter 10). With new facilities there has also been an increase in automation. New control and operating systems have allowed MWRA flexibility in staffing to meet CEB goals and have improved operational response times to emergency or anomalous system conditions.

[1] The Safe Drinking Water Act (SDWA) was originally passed by Congress in 1974 to protect public health by regulating the nation's public drinking water supply. The law was amended in 1986 and 1996 and requires many actions to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and ground water wells. (SDWA does not regulate private wells which serve fewer than 25 individuals.)

Security and Redundancy

Since the events of September 11, 2001, MWRA, as all utilities, has returned to a focus on security and redundancy. As Chapters 7 and 8 explain, identification and elimination of “single points of failure” was a major topic in both the 2006 and 2013 Water System Master Plans and work has been completed or is ongoing for the major distribution system redundancy projects called out in those documents. For MWRA’s water transmission system, the coupling failure in May 2010 emphasized the need to continue to move forward with redundancy improvements and the need for continued maintenance of stand-by facilities to ensure a seamless transition to alternative or back-up systems as necessary. Planning work to identify options for Metropolitan Tunnels redundancy was underway during the last master planning cycle and the Board of Directors has now directed staff to proceed with the plan as proposed to them in the special Board of Directors meeting in October 2016 (see Chapter 7 for further information). Vulnerability assessments of the system have been conducted and physical “hardening” of facilities continues. Much of this work has been accomplished in incremental phases as projects are designed and constructed. Cyber security to protect all of MWRA’s systems also remains a major focus of ongoing efforts (see Chapter 9 for further information).

3.3 Water Infrastructure Replacement Asset Value

MWRA water infrastructure is a network of reservoirs, facilities, structures, tunnels, and pipelines. In preparation of the 2006 Master Plan, staff developed a replacement asset value (cost valuation) of MWRA’s infrastructure using MWRA-specific appraisal data and actual MWRA project cost information. For the 2013 and 2018 updates of the Water System Master Plan, the 2006 replacement asset value analysis was reused (in 2006 dollars) with only minor revisions for new facilities added between 2007 and June 2018. In 2006 staff estimated MWRA’s water infrastructure had a replacement asset value of approximately $6.3 billion and this increased to approximately $6.5 billion by 2013 due to continued work to replace, rehabilitate and build new pipelines and the construction of the Blue Hills Covered Storage Facility. For this 2018 plan additional system work including UV treatment, continued pipeline work and the Spot Pond Covered Storage Facility and Pump Station have come on line in addition to other projects. Finance staff have reviewed the more recently completed work as well as the data used in 2006 and 2013 and both Table 3-1 and Figure 3-4 reflect the updated analyses. These values were used where appropriate to provide additional context for reinvestment needs.

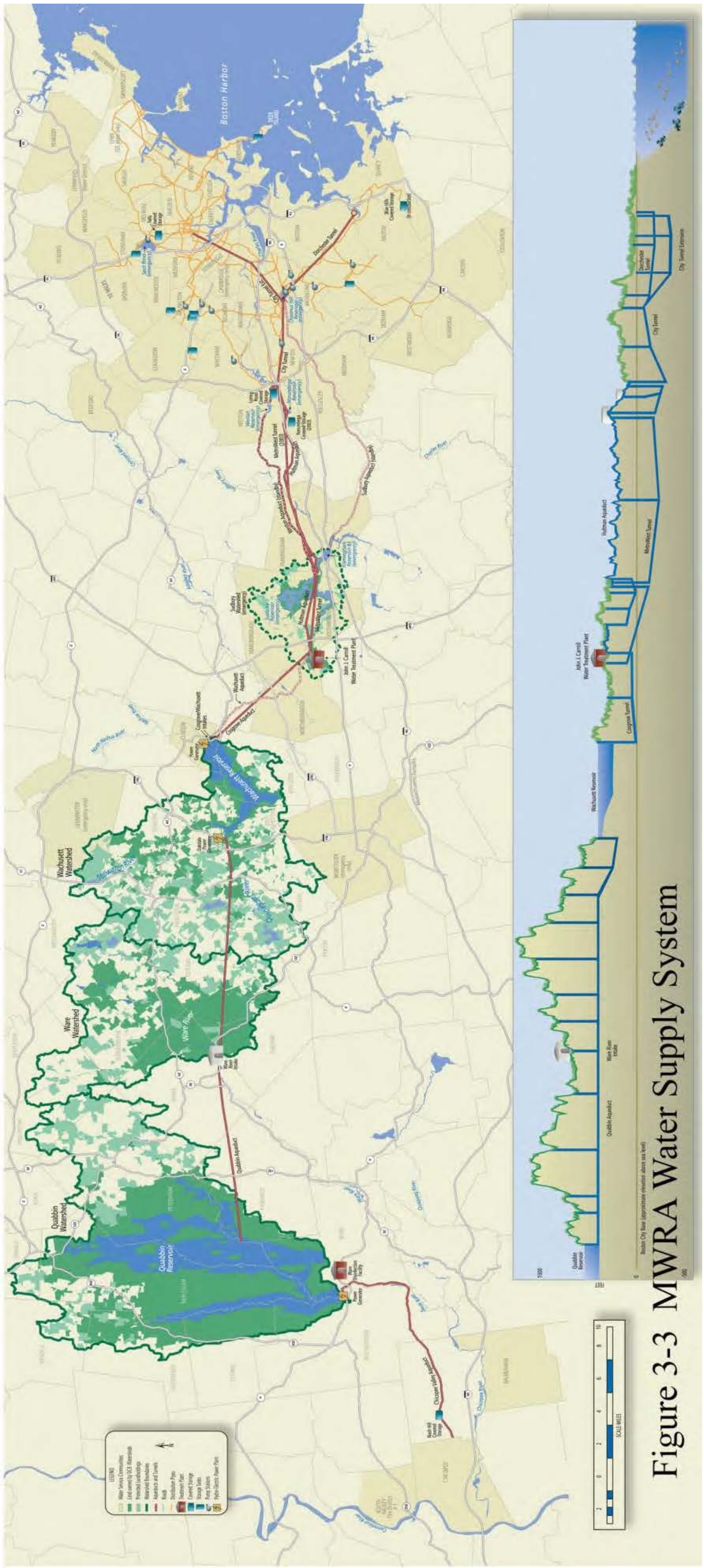


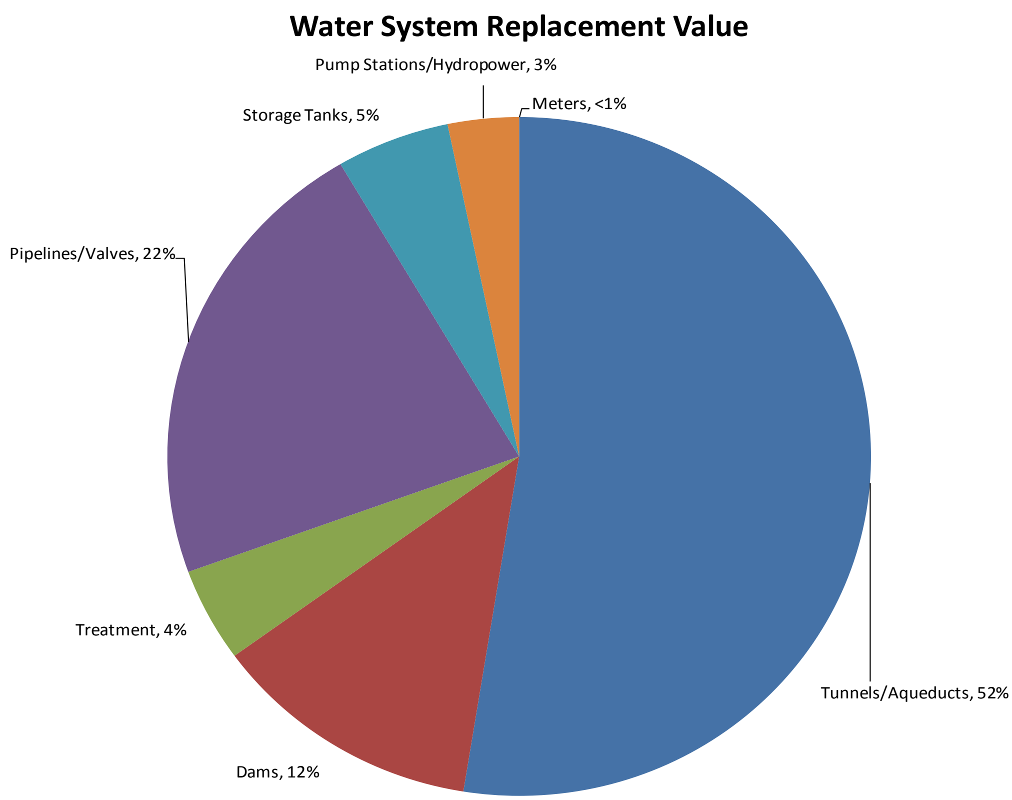
Figure 3-3 MWRA Water Supply System

Table 3-1

Water Infrastructure Replacement Value

Asset Class	Replacement Asset Value	% of Total
Tunnels/Aqueducts	$3,492 million	52%
Dams	$829 million	12%
Treatment	$297 million	4%
Pipelines/Valves	$1,465 million	22%
Storage Tanks	$347 million	5%
Pump Stations/Hydropower	$217 million	3%
Meters	$25 million	<1%

Figure 3-4



3.4 The Future Years

Completing major redundancy work will remain an agency priority for a number of years given the complexity of design, engineering and community issues to be resolved. And, as key redundant assets come on-line, it will be important to plan ahead for their use. While they will be available for day to day or emergency use, depending upon the asset, they will likely be primary water system facilities while other assets (tunnels, valves, pipelines etc.) are taken out of use, inspected and rehabilitated as necessary. It is important that planning for such transitions and the need to potentially access or replace valves in order to transition to new redundant facilities be addressed.

In addition, MWRA will also continue to monitor the physical condition of all water supply infrastructure from tunnels, dams, pump stations, storage facilities to valves, meters and other mechanical and electrical equipment to ensure that assets are rehabilitated or replaced in a timely manner.

Climate change will play a role in MWRA water system planning far into the future. As Chapter 4 discusses, there is currently an expectation that there may be an increased frequency of intense storms with the possibility of more frequent periods of drought. This suggests that MWRA's large reservoirs will be well-suited to assist local communities whose reservoirs may be subject to more significant fluctuations and who may require additional water from MWRA. However, long term, MWRA will also need to review whether temperature and rainfall changes are impacting vegetation and land cover in the watersheds and what, if any, the effects might be on water quality. Although MWRA believes that flood elevations used to design dam spillways and other structures are appropriate for now; this information will continue to be periodically reviewed.

Continued tracking of federal and state regulatory issues and requirements will also allow MWRA to be appropriately positioned to address new requirements or to take advantage of opportunities. This may include opportunities for further system expansion as environmental concerns are raised relative to local source withdrawals in the headwaters of area streams and rivers. The decreases that have occurred in MWRA water demand may allow additional communities to join the water system over the next decades. It will be important to continue to consider such possibilities as new infrastructure is planned, designed and built.

Ensuring the continued security of the water system will remain a critical task. New technologies and monitoring equipment may play a role in this and cyber-security will continue to grow in importance.

MWRA must proceed with these improvements while balancing the parallel goal of limiting rate increases to the customer communities to the extent feasible. The need to achieve and maintain a balance between these two goals is a critical issue facing MWRA today and into the future. In addition, MWRA must, like utilities across the country, deal with an aging workforce and the need to ensure knowledge transfer throughout the agency. MWRA remains optimistic that through smart planning, continued maintenance and upgrades of its facilities, controlling costs, and working as a partner to our service area constituencies that the Authority will successfully face and meet the challenges over the next 40 years to 2058.

4 Supply and Demand

Supply and demand characteristics of the MWRA system are documented in a series of annual staff summaries (most recently January 2018) and two major reports presented to the Board, *MWRA Water System Supply and Demand* (May 2002) and *Long Range Water Supply Planning Topics for Consideration II* (May 2006).

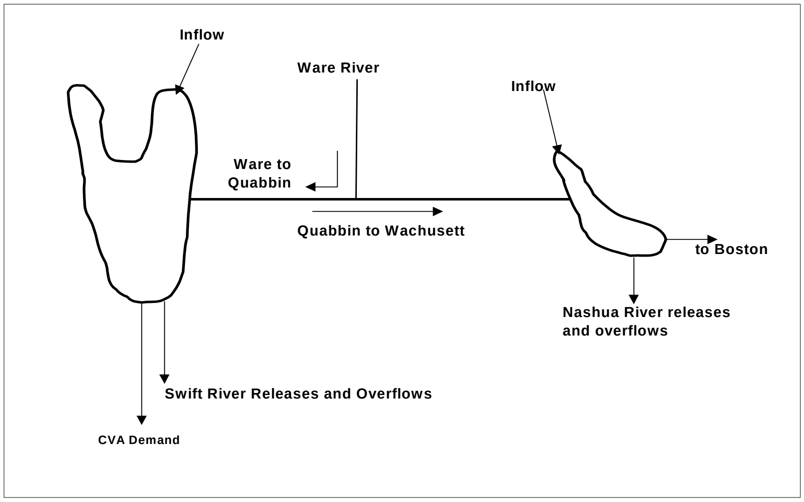
Average annual MWRA reservoir withdrawals have dropped from a peak of approximately 340 million gallons per day (mgd) in 1980, to approximately 196 mgd in 2017 compared to a safe yield of 300 mgd. Sales to communities, within the same period, have dropped from 304 mgd to 183 mgd. Despite increases in population and employment within the service area, and the addition of six communities since 1993, both base demand (primarily indoor demand) and seasonal demand continue to decrease, although at a slower rate more recently. A summary of key findings follows a brief introduction to the MWRA system to put the supply and capacity discussion in context.

4.1 Overview of the Water Supply System

The principal components of the MWRA system consist of Quabbin and Wachusett Reservoirs, the Ware River intake, the deep rock tunnels which deliver water by gravity eastwards and about 284 miles of pipe that distribute water to MWRA communities. The Quabbin Reservoir contributes about 53% of the total system safe yield, the Wachusett about 34%, and the Ware, 13% of total system safe yield, although with lower water demand, less Ware River water is typically diverted. The MWRA reservoir system is operated with the primary objectives of ensuring high quality and adequate water supply and maintaining required minimum releases to the Swift, Nashua and Ware Rivers. Another operational objective includes maintaining an adequate flood protection buffer particularly during the spring melt and hurricane seasons. A third objective is to generate hydropower, which is currently generated at two locations within the source reservoir system (Oakdale at the outlet of the Quabbin Aqueduct, and the Cosgrove Intake) and a third location within the distribution system (Loring Road Covered Storage Facility).

Water can flow into each reservoir from inflows or transfers (Figure 4-1). Flow out of the reservoirs is made up of withdrawals for water supply, required or other planned releases, and overflows when the reservoir is full. Releases are mostly controlled (i.e. result of human decision) but they can also be uncontrolled (i.e. when the reservoir fills and overflows).

Figure 4 -1 Supply System Schematic



Quabbin Reservoir

Water is transferred from the Quabbin Reservoir through the Quabbin Aqueduct where it ultimately discharges into the Wachusett Reservoir, after first passing through a hydropower turbine at Oakdale Station. Quabbin transfers can constitute more than half of the average annual inflow to Wachusett Reservoir. Withdrawals from Quabbin also occur through the Chicopee Valley Aqueduct to supply water to three communities west of Quabbin.

Additional outflow from Quabbin includes releases to the Swift River at the Winsor Dam, pursuant to Chapter 321 of the 1927 Acts of Massachusetts and the 1929 War Department Requirement. The 1927 Acts of Massachusetts requires that sufficient water must be released from Quabbin Reservoir to provide at least 20 mgd in the Swift River at Bondsville located 5 miles downstream of Winsor Dam. No matter how low precipitation levels are, MWRA provides at least 20 mgd in the Swift. The 1929 War Department Requirement also requires additional releases. From June 1 to November 30, streamflows on the Connecticut River at Montague govern the required releases to the Swift River. When the daily average flows in the Connecticut River at Montague are less than the 4900 cfs and 4650 cfs, the releases from Quabbin must equal 45 mgd and 70 mgd, respectively. Thus during dryer periods, the required releases actually increase. Between December-May, and when flows in the Connecticut River at Montague are above 4900 cfs, the minimum flow release of 20 mgd at Bondsville governs.

Work was more recently completed on the approximately 5,000 linear feet of new pipeline which conveys up to 6 mgd of cold, well oxygenated, hypolimnetic water from the Chicopee Valley Aqueduct to the downstream McLaughlin State Trout Hatchery. This provides a consistent and reliable source of high quality water to the hatchery as well as supplementing flows to the Swift River. For 2017, the average flow to the Hatchery was 5.49 mgd. The project also includes a hydro-electric turbine that captures some of the hydraulic energy contained in the pipeline as the water is conveyed to the hatchery. The power generated is sold to the grid. The hydro portion of this work is funded under the Alternative Energy Initiatives project and the Massachusetts Leading by Example Program. The new pipeline also allows the hatchery to eliminate pumping, reducing their costs and greenhouse gas emissions.

Wachusett Reservoir

Wachusett Reservoir is operated to meet three primary objectives.

The first objective is to maintain Wachusett's elevation in a narrow operating band. The range of elevations was established because it provides adequate supply to meet customer demands, minimizes shoreline erosion, provides adequate free board to minimize spillway activations (and the possibility of downstream flooding), and improves water quality by submerging gull roosting areas near the intake.

The second objective is to maintain acceptable water quality at the intake. MWRA has historically maintained water quality by mixing Wachusett water with higher quality Quabbin water, which is transferred through the Quabbin Aqueduct. Transfers from Quabbin to Wachusett are beneficial any time of the year since they lower, by dilution, the concentration of reactive organic matter considered a precursor to disinfection byproducts. Through reservoir modeling and testing, MWRA has also observed the benefit of transferring water between reservoirs particularly between May and October. During this time of the year the reservoir stratifies and its thermocline has developed which allows the colder water transferred from Quabbin to move as an *interflow* from the aqueduct's point of discharge to the Cosgrove Intake, providing a more rapid and stronger effect. Having the higher quality water at the intake is particularly important during this period due to the relationship between warmer temperatures and disinfection processes. Testing shows that sustained flow rates of 250 to 300 mgd appear to be necessary to create this desired interflow regime. When Wachusett watershed yields are sufficient to maintain reservoir elevations within the normal operating range, and transfers of additional water for water quality purposes are made, higher levels of releases from valves at the Wachusett Dam may and do occur. With decreased demands for water supply in the MetroBoston and MetroWest region, it has become increasing necessary to release more flows to the Nashua River (and occasionally to the Sudbury Reservoir and Sudbury River) to allow for sufficient transfers of Quabbin water to ensure a high quality water supply, especially in wetter years with higher inflows from the Wachusett watershed. In prior years, higher demand for water supply meant higher quantities of Quabbin transfers were needed to simply keep up with the demand.

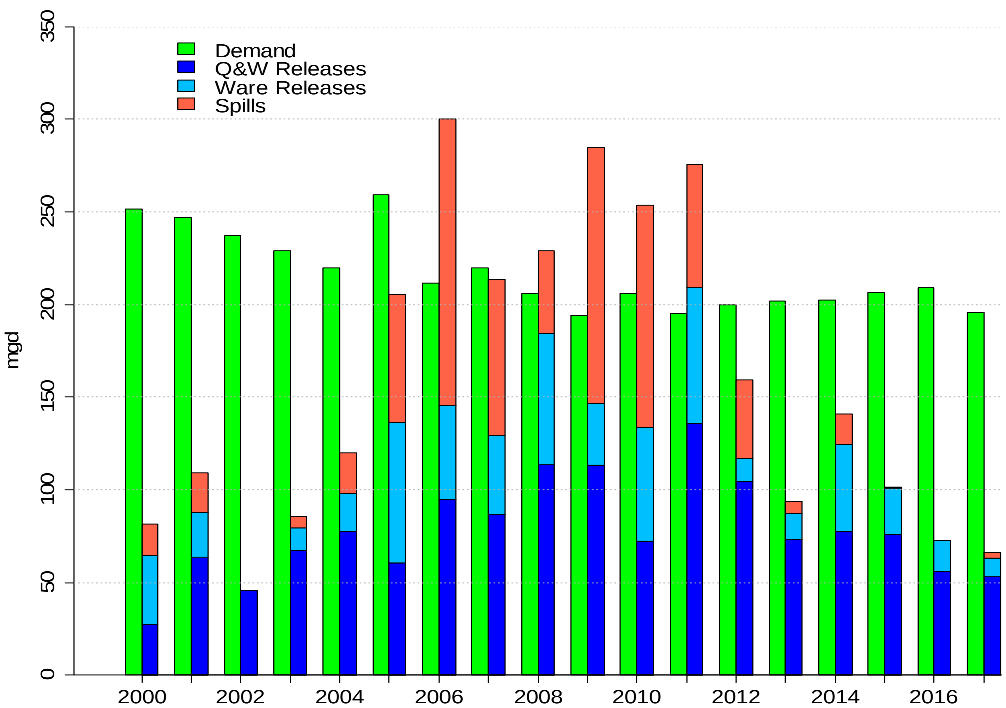
The third objective is to meet the minimum release requirement. The MWRA releases water to the Nashua River consistent with *Chapter 488 of the Acts of 1895*, which requires that not less than 12 million gallons per week must be released into the South Branch of the Nashua River. Typical releases are higher than required.

Ware River

The MWRA can increase system safe yield through diversions from the Ware River watershed to Quabbin Reservoir. Ware River diversions are limited to a period when river flows exceed 85 mgd and are subject to the following conditions: no diversion of Ware River flows are allowed from June 15 to October 15. Diversions from June 1 to June 15 and from October 15 to November 30 must have prior permission from the DEP Division of Water Supply. Typical operations limit diversions to Quabbin Reservoir during periods when the Quabbin is in Normal Operating range, and consider the potential for transferring invasive organisms.

Figure 4-2, below compares the amount of water withdrawn to supply customer demand to the total amount of water spilled and released to the Swift River from Quabbin Reservoir, water spilled or released to the Nashua River from Wachusett Reservoir, water released from Wachusett Reservoir to the Sudbury River through the Wachusett Aqueduct, and Ware River water, which could have been diverted to Quabbin but was not due to lowered demands. With reduced demands, MWRA's annual average releases and spills from the reservoir system have exceeded the amount of water withdrawn for water supply purposes five times in the last 17 years: 2006, 2008, 2009, 2010, and 2011.

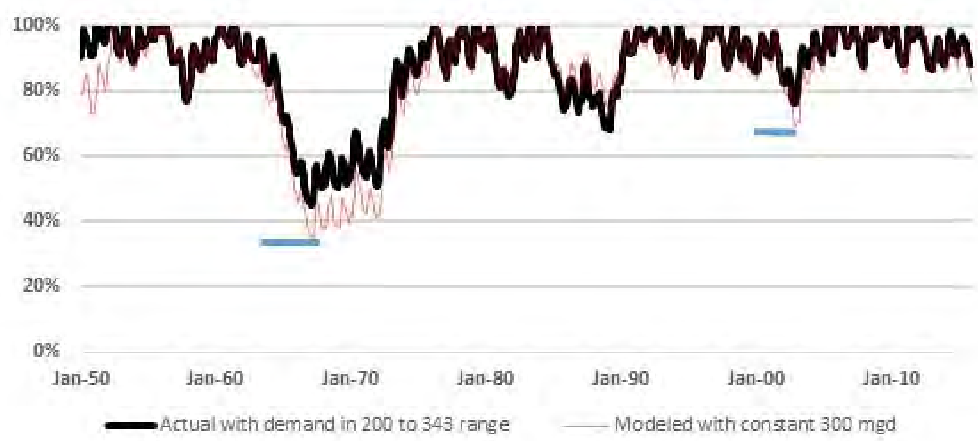
Figure 4-2 Spills, Releases and Demands



4.2 System Capacity

The safe yield is the quantity of water that can be reliably supplied over a period that includes a critical drought. The safe yield of the Wachusett-Ware-Quabbin system has been described as around 300 million gallons per day since the design of the Wachusett Aqueduct in 1895. Since then, many studies have been completed – in 1922, 1950 and several during the 1980's and 1990's – which validate that 300 mgd is a conservative estimate of safe yield. Figure 4-3, below shows the modeled performance of the system during a drought as severe as the 1960s and the 1989 drought, with modeled demands of 300 mgd as well as actual historical demand. Even in a drought as severe as the multi-year drought of the 1960's, Quabbin storage levels would only drop to around 40 percent with demands as high as 300 mgd.

Figure 4-3 Quabbin Reservoir Levels Showing Performance During Drought



During 2016, Quabbin Reservoir dipped to Below Normal status for the first time since 2002. Following the dry year of 2015, the Quabbin watershed yield of 94.4 for the calendar year of 2016 was the second lowest on record with only 1965 being lower at 72.8 mgd. In the summer months of June, July and August 2016, the combined month precipitation at Logan Airport was a mere 3.92 inches making it the driest summer on record.

Calendar Year 2017 saw an end to severe drought conditions in the region and in the MWRA service area. However, due to the multi-year storage volume of the Quabbin Reservoir and the continued weather pattern of many significant rain storms bypassing the watersheds, the improvement in the service area was not matched by a comparable improvement in Quabbin Reservoir levels. Although the Reservoir spent much of the year in "Normal" range, the Quabbin both started and ended 2017 in "Below Normal" status. However, the Reservoir ended 2017 with 24 billion more gallons of water in storage than in the start of the year.

During Calendar Year 2018, Quabbin steadily gained ground peaking to 96% full in mid-May. By the end of June, storage was well above normal at 94.5% full.

As demonstrated during 2015 and 2016 and discussed elsewhere in this Chapter, adequate supply exists in Quabbin and Wachusett Reservoirs to meet the needs of MWRA's fully and partially supplied water communities, and as needed, to augment supplies of adjacent stressed communities.
The amount of water a system can supply can be enhanced if a drought management plan is used to curtail demand. MWRA developed a Drought Management Plan in 1989 that has since been incorporated into the Commonwealth's drought plan. The objective of the plan is to conserve water through implementing demand reduction measures during dry periods, allowing the system to withstand a more severe drought without jeopardizing reliability. Drought response actions are triggered by seasonal levels of Quabbin Reservoir. Table 4-1 presents the stages of this plan.

Table 4-1 MWRA Drought Management Stages		
Stage	**Trigger** Range (Quabbin % Full)	**Target Water Use Reduction**
Normal Operation	80-100	0
Below Normal	65-90	Previous year's use (Voluntary)
Drought Warning	50-75	5% (Voluntary)
Drought Emergency		(Mandatory Restrictions)
Stage 1	38-60	10%
Stage 2	25-38	15%
Stage 3	Below 25%	30%

4.3 Potential Impacts of Climate Change on Supply

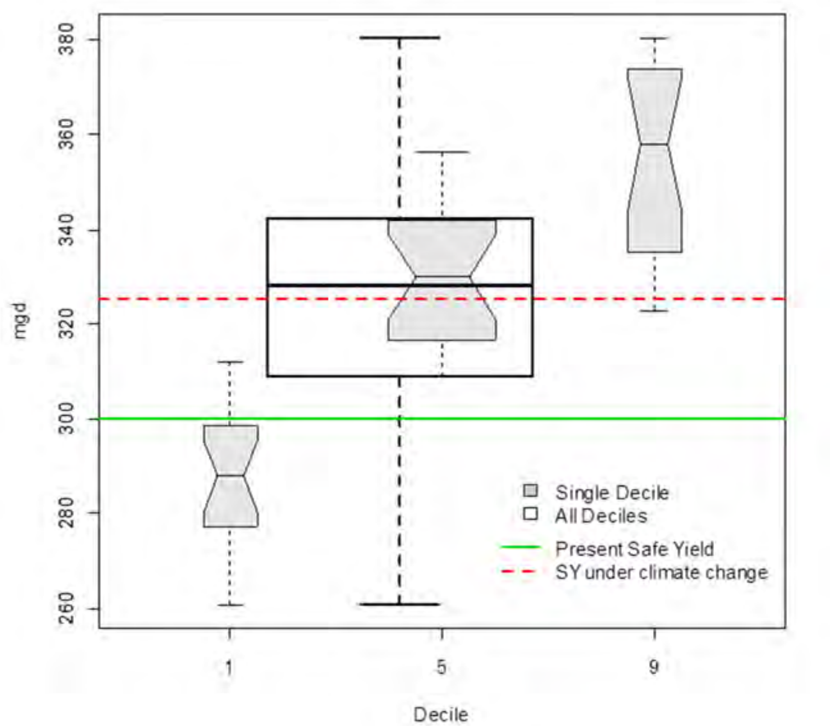
MWRA staff have undertaken a series of efforts to evaluate the potential impacts of climate change on the MWRA water system, working with researchers for several universities and research institutions, including several studies funded by the Water Research Foundation. These cooperative efforts have leveraged MWRA staff knowledge of our system and our sophisticated reservoir modeling tools to allow MWRA to actively participate in these regional and national studies.

In the New England region, most climate change models and scenarios show both an anticipated increase in temperature and an increase in precipitation. Many of the models also show changes in the patterns of precipitation, in particular, periods of both dryer and wetter conditions, and potentially more extreme conditions. (Referred to in the popular literature as "wetter wets and dryer drys" and more intense storms.)

Working with climate specialists from the National Center for Atmospheric Research (NCAR) a probabilistic estimate of the impact of climate change on Safe Yield was done. This work is described in detail in a 2011 Water Research Foundation Report authored by David Yates and Kathleen Miller titled *Climate Change in Water Utility Planning: Decision Analytic Approaches*. At the heart of the probabilistic approach is the strategy of using all the results of available General Circulation Models (GCMs) to derive regional probability distributions of the likely increases in temperature and precipitation. Climate ensembles are then derived using statistical techniques at the 10th percentile, median, and 90th percentile (1st, 5th and 9th deciles) of these distributions, which are in turn used to estimate Safe Yield. This contrasts with earlier efforts which looked at only a single point estimate of a single climate model and greenhouse gas scenario. Along with the probabilistic modeling, more geographically detailed rainfall projections were used, based on actual rainfall data adjusted for the climate projections. In previous modeling, only generalized regional rainfall data was available, and at only monthly time steps. The most recent work included localized rainfall and weekly time steps. The current approach provides more robust and descriptive results, but these are generally in line with the several previous modeling studies, which indicated an expected increase in Safe Yield.

Figure 4-4, below summarizes the outcome of this study, and it shows an expected overall estimate of 324 mgd, representing a modest increase of 8% over current yield under the modest emissions scenario that was considered in the study. In well over 90 percent of the simulations, yields were up, in some cases substantially. In a small number of cases, simulations indicated that yields could decrease. These results have recently been duplicated over a wider range of climate change scenarios in on-going work by a research team at U-Mass Amherst.

Figure 4-4: Potential Increase in Safe Yield with Climate Change



The potential increase in Safe Yield is largely due the large over-year storage of Quabbin Reservoir. The large storage volume of Quabbin allows it to capture the increased precipitation, and more inflow from more intense storms, making it available for use during dry periods. In other parts of the country, and elsewhere in Massachusetts, systems without very large reservoirs will find that their reservoirs overfill (and overflow) during wet periods, and do not have enough storage to get through dry periods, reducing their safe yields. The partially-supplied and self-supplied communities on the periphery of our service area that do not have over-year storage will be vulnerable and are likely to turn to the MWRA for emergency supplies. Some of the redundancy planning projects described in the master plan can therefore be thought to have dual uses. In addition to providing redundancy, they also increase transmission capacity which may be needed to supply neighboring communities as their supplies become less reliable.

Potential impacts of climate change on water demand are described below in Section 4-4, and those of the potential impacts of sea level rise are described in other sections of the Master Plan.

4.4 Current System Demand

System water demand on the MDC system increased steadily during the 60's, 70's and 80's. In 1986, rather than pursue options for increasing supply, MWRA's Board of Directors opted to pursue a range of demand management strategies. Following this commitment, MWRA launched its Long-Range Water Supply Program in 1987 with 30 different recommendations and programs requiring an investment of tens of millions of dollars over the next decade. The demand management and supply protection programs were designed to reduce water use and water losses throughout the MWRA service area and prevent new demands due to local source contamination.

MWRA system demand now averages approximately 203 mgd (5-year average 2013-2017), a decline of approximately 128 mgd from the 1984 peak of 331 mgd. Between 1980 and 2010, the population within the original MWRA service area grew by about 163,000, and six new communities were added to the service area with a population of 135,000. Within the same time period (1980 to 2010), total reservoir withdrawals decreased by approximately 139 million gallons per day. Figure 4-6, on the next page, shows the corresponding downward trend in MWRA sales to communities which were down by 120 mgd in 2017 from a peak of 304 in 1980. MWRA's aggressive water conservation efforts, including local leak detection and repair programs, yielded significant gains early on, with a 20 percent drop in five years. The new plumbing code, more efficient appliances, the shift in the commercial base from water-intensive manufacturing to less intensive users, good system management, and improved metering all likely contributed to lower demand. Significant water and sewer rate increases also played a part in focusing attention on water use efficiency and thus reducing water use in member communities. The 2008 economic recession likely accelerated water use reductions, with some slowing of the rate of decrease as the economy recovered over the next decade. While not as dramatic as the reduction in water demand in the MWRA service area, decreased residential water demand is also occurring in many utilities across the country, due to many of the same factors.

Over time, reductions have come in both base use, defined as water use from November to March, and outdoor use (or seasonal use), defined as the increase over the base demand (the light solid line on Figure 4-8) during the irrigation season of May to September. Indoor water use has dropped substantially over the past several decades. Decreases from 2001 to 2010 ranged from around one to two percent per year. Post-recession, decreases appear to be much slower. This is likely due to the improvements in the efficiency of water use in homes and businesses as water-saving technologies continue to increase market share and consumers react to price increases (as well as reduced pipeline leaks), being counterbalanced by increased use due to the improving regional economy and population growth.

Figure 4-5 Total Reservoir Withdrawals-Five Year Running Average (1980-2017)

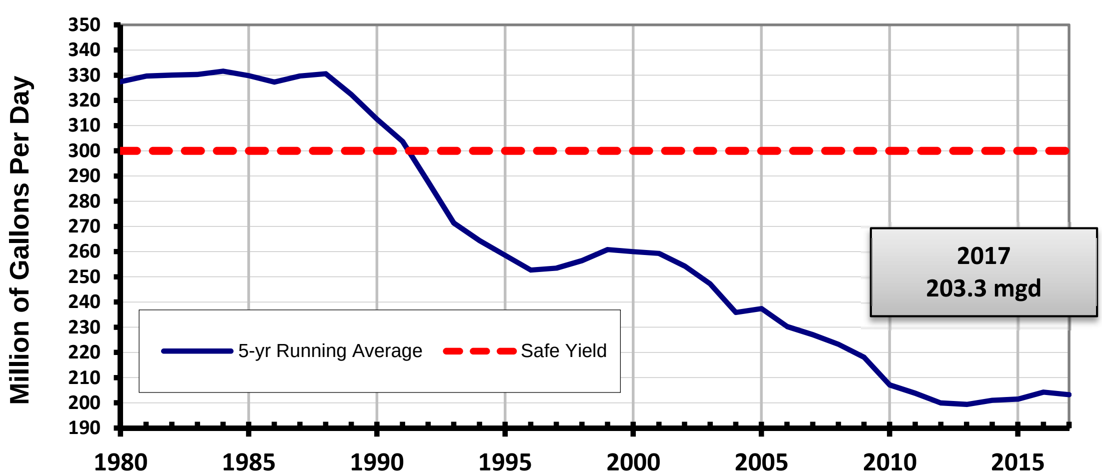
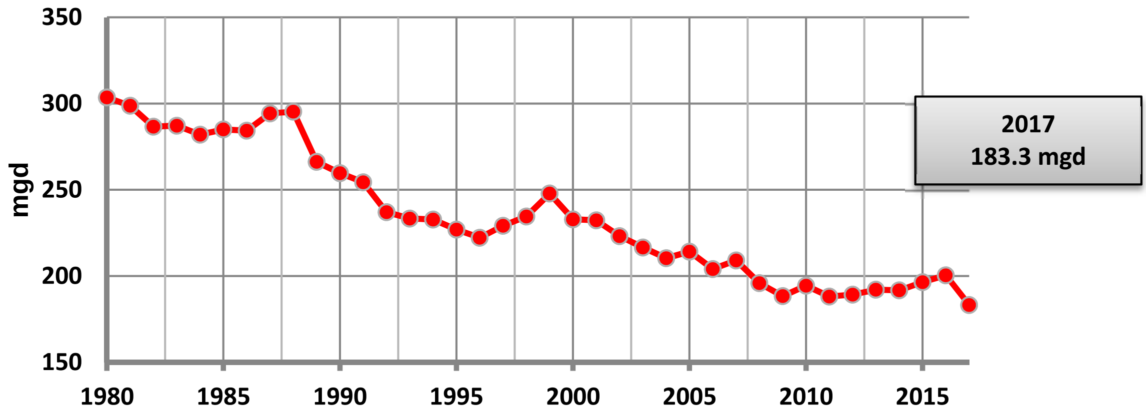


Figure 4-6 Total Consumption by MWRA Communities (1980 to 2017)



As can be seen in Figure 4-7, demand from MWRA's largest customer, the Boston Water and Sewer Commission, was 63 mgd in 2017, which was lower than the previous year by about 2.5 mgd (3.8 percent). Current Boston demand continues to be lower than demand before 1900.

Figure 4-7: Boston Water Use (1900-2017)

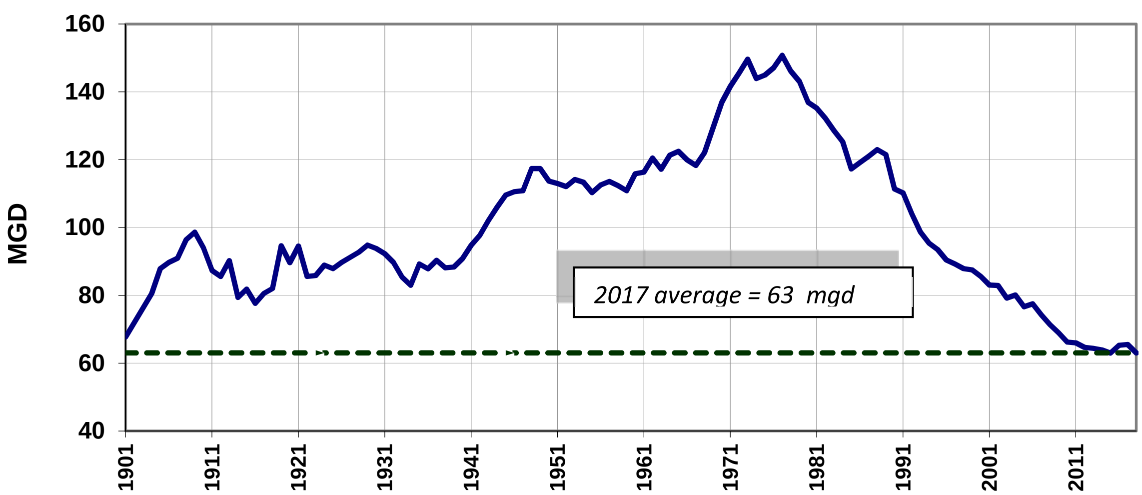
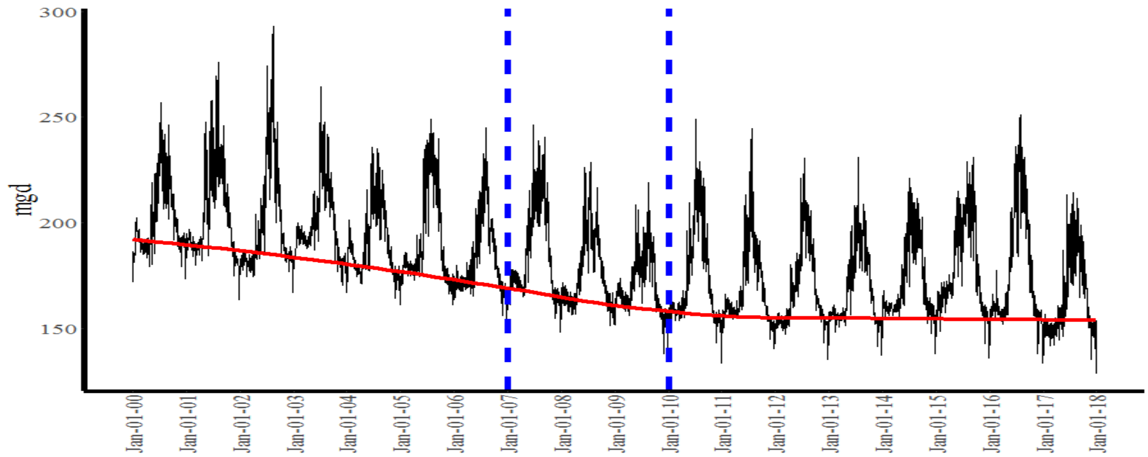
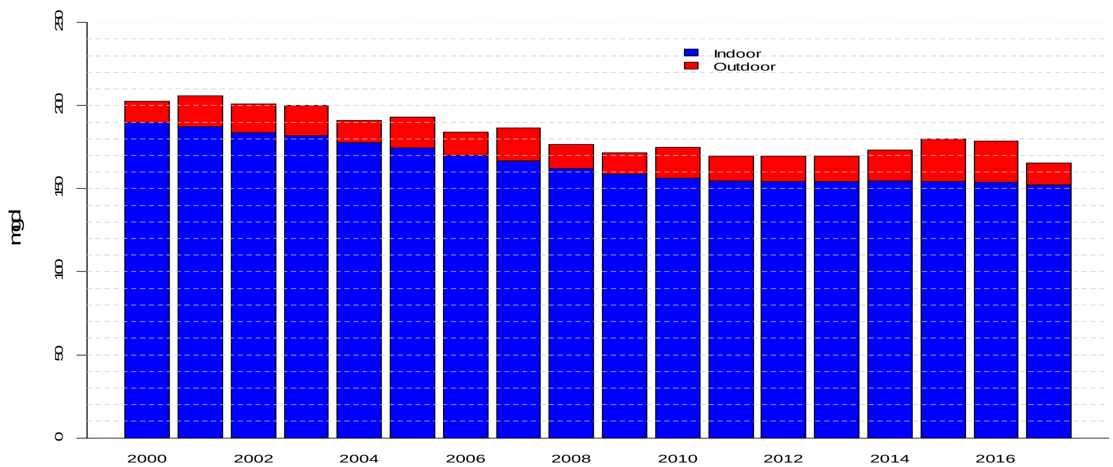


Figure 4-8: Fully-Supplied Communities Demand 1999-2017



Seasonal water use (labeled as outdoor on Figure 4-9, next page) is more variable and driven in large part by weather during the irrigation season. Factors influencing seasonal use include the total irrigation season precipitation, the number of dry days between rainfall events, temperature, and the total amount of sunshine. Over time, water price also influences seasonal use. During the past 18 years, seasonal use in the fully-supplied communities has varied from a low of 13 mgd (7.4% of total use) in 2009 to 26 mgd (14.3%) in 2015, with an average of approximately 17 mgd (9.3%).

Figure 4-9: Fully-Supplied Communities' Annual Base and Seasonal Demand



Annually, public water suppliers across Massachusetts file Annual Statistical Reports (ASRs) with DEP. The reports provide data on the components of water demand in the MWRA service area. As seen in Table 4-2, residential water use represents almost fifty-five percent of total water use in the service area. Based on the reported data in the ASRs, the residential gallons per capita per day (RGPCD) in the MWRA water service area communities in 2017 was 53 compared to 56 in 2010. The state performance standard for residential consumption is 65 RGPCD.

Table 4-2 Community Water Use in the MWRA Service Area Communities (2017)	
Type of Use	Percent of Total (available for distribution)
Residential	54.7%
Commercial	16.5%
Industrial	4.1%
Municipal	8.6%
Agricultural	0.1%
Other	1.5%
Unaccounted for Water[1]	14.5%

In examining demand, it is helpful to look separately at different classes of customers. MWRA serves several categories of communities: fully supplied communities which take all of their water from MWRA; partially supplied communities which normally supply a portion of their demand with locally owned and operated surface and groundwater sources; emergency-only communities, and certain miscellaneous users.

Fully Supplied Communities

There are 22 core MWRA water and sewer communities that are fully supplied users that take all of their water from MWRA. Fully supplied communities also include the three Chicopee Valley Aqueduct (CVA) communities, and seven communities in the metropolitan area that are part of the MWRA water system, but not the sewer system. Average annual water demand of fully supplied communities in 2017 was 165.5 mgd.

Partially Supplied Communities

There are fourteen communities served by MWRA that typically use a combination of local sources and MWRA water to meet their demand. In 2017, 20.1 mgd of demand in the partially supplied MWRA communities was met by MWRA, whereas 66.9 mgd was met by local sources (Table 4-3). However, due to the regional drought conditions in 2017, these numbers reflect use by both Worcester and Cambridge. The communities of Leominster, Worcester and Cambridge are eligible to receive MWRA water as Emergency communities meaning that they use MWRA as an emergency back up and do not routinely purchase MWRA water. Those communities continued to use local water during periods it was available but took extensive MWRA water during parts of the year. If those two communities are removed from the above calculation, MWRA met 16.5 mgd of demand from partially supplied communities and the communities themselves supplied 29.5 mgd. MWRA's obligations to its partially supplied communities are to provide the communities with additional water if local sources are not sufficient. Many of the local supplies are small and thus are subject to more significant variations in available water. Shorter-term periods of dry weather that would not have significant adverse effects on the Quabbin/Wachusett/Ware system may reduce available supply at the local level resulting in water use restrictions or the need to supplement local supplies with additional water from the MWRA. MWRA's drought plan assumes increased use by partially

[1] Unaccounted for water includes losses due to leaks, but also unmetered uses and under registration of use from older meters.

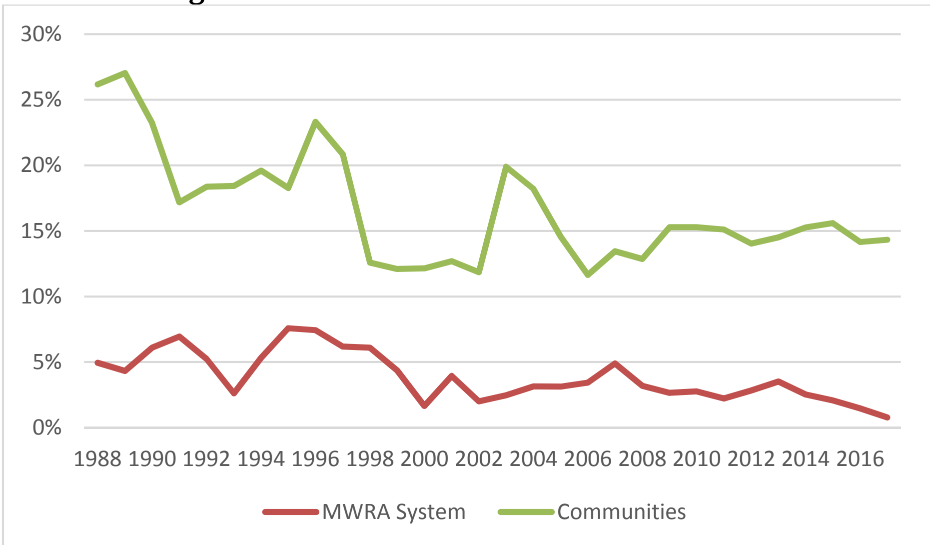
supplied communities during a drought including the above Emergency communities. With climate change, it is anticipated that drought-related increases in demand will grow.

Table 4-3: 2017 Water Use by Partially Supplied Communities

Community	Local Sources (mgd)	MWRA (mgd)
Cambridge	16.5	0.1
Canton	1.2	1.3
DWWD	3.7	0.1
Lynn	9.7	0.2
Marlborough	0.0	4.0
Needham	2.6	0.6
Northborough	0.0	0.9
Peabody	2.7	2.9
Stoughton	1.7	0.1
Wakefield	0.4	1.5
Wellesley	2.1	1.0
Wilmington	1.7	0.3
Winchester	0.9	1.3
Woburn	2.9	2.2
Worcester	20.9	3.5
Total	**66.9**	**20.1**

Over the last 30 years as communities repaired leaks and improved metering, unaccounted for water has trended downward as shown in Figure 4-10, below. Community unaccounted for water use dropped from 84 mgd to 34 mgd, and MWRA unaccounted for water use (also referred to as MWRA system use) dropped from 16 mgd to 2 mgd.

Figure 4-10: Unaccounted for water use trend



Miscellaneous Uses and Obligations

Worcester's Pine Hill Reservoir is in the Quinepoxet sub-basin of the Wachusett watershed. Pursuant to Chapter 699 of the Acts of 1949, Worcester has first rights to the flows in the Quinepoxet. Therefore, Worcester's water supply indirectly exerts a demand on the MWRA/MDC reservoir system and affects system yield[2]. (Essentially what they do not take from their Quinepoxet Reservoir source, runs down into the Wachusett Reservoir.) Clinton is also allowed to withdraw up to 800 million gallons per year of raw water from the Wachusett Reservoir from its own intake at Wachusett Reservoir at no charge. Clinton's current demand is approximately 2 mgd. MWRA also supplies several facilities including the Lynn General Electric Plant[3] and the Westborough State Hospital[4].

Emergency Demands from Neighboring Communities

MWRA policies allow for supplying water to non-member communities under emergency conditions. These could be a loss of supply due to contamination or facility failure, major main breaks, or reduction in supply due to drought or overuse due to growth. MWRA plans assume some small amount of emergency demand, but our policies encourage communities to resolve local supply problems or move toward joining the MWRA system long term if local supplies are inadequate.

Table 4-4 shows the emergency supply that was provided during the drought of 2016.

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[2] As part of the agreement that allows Worcester access to a portion of the Wachusett watershed, Worcester contributes approximately 7.9% of the direct expenses for the Clinton Wastewater Treatment Plant.

[3] Lynn is a member of the MWRA water district, but their contract currently only provides for service to the area of the GE plant with a dedicated meter.

[4] Westborough State Hospital is in the process of being decommissioned and surplused, and it is anticipated that the area will be serviced by the Town of Westborough water department.

Table 4-4: Community Emergency Supply for 2016

Community	Supply (MG)
Worcester	847.3
Cambridge	515.2
Burlington	7.9
Ashland	3.2

4.5 Projected System Demand in 2040

Projecting the demand on the MWRA system into the future must acknowledge two competing trends: continuing increases in efficiency in the home and workplace and an increase in population and employment within the service area. Any projections must also include assumptions about the potential for partially supplied customers to turn toward the MWRA for an increased portion of their supply periodically or long term, and the assumptions about the potential for new communities to join the MWRA system. How all the assumptions are worked together can provide varying degrees of conservatism in the planning projections. The master plan projections are conservative and thus protective of existing customers:

- They assume current levels of conservation and efficiency among existing users, that is, no increases in efficiency;
- They assume new residential use will be less efficient than the current average use; and
- They provide for an assumed level of increased use by partial users.

Because the projections are conservative, plans for system expansion can be evaluated without jeopardizing the reliable supply of current and future users within the service area.

Existing Service Area

Population projections prepared by planning agencies, primarily the Office of Transportation Planning in the Massachusetts Department of Transportation (MassDOT) and the Population Estimates Program of the Donahue Institute at the University of Massachusetts Amherst (pep.donahue-institute.org), were used as the starting point for the following future water demand projections.

Population growth between 2010 and 2040 for water communities typically served by MWRA (which does not include emergency only communities of Worcester, Leominster, and Cambridge) is projected by MassDOT to increase by approximately 362,000, or 16.3%, as shown in Attachment 1.

Assuming a residential consumption rate of 65 gallons per capita per day (the state performance standard), the total increase in residential water demand throughout the MWRA service system would be approximately 23.6 mgd if it is assumed that new population growth in MWRA's communities, both partially and fully served, would be met by MWRA, not local sources. An assumption of 65 RGPCD is consistent with the Massachusetts Water Resources Commission water needs forecasting methodology. Since the projection assumes an RGPCD of 65, rather than the actual 2017 RGPCD of 53 for the MWRA service area in 2017, the 2040 projection of an additional 23.6 mgd in residential demand is considered conservative.

MassDOT also developed employment projections which were similarly reviewed by the MAPC and PVRPC; based on employment data for 2010, along with MDOT and MAPC adopted employment forecasts through 2040, the MWRA water service area is projected to add 130,993 new jobs by 2040, a 9.8 percent increase, as shown in Attachment 2. To project water use associated with increased employment, the Water Resources Commission Water Needs Forecast methodology was used. This methodology multiplies the baseline non-residential average daily demand (ADD) by the percent change in employment to derive the new water demand due to employment growth. For the MWRA fully and partially supplied communities, the nonresidential demand is 57.4 mgd. Based on MassDOT employment projections adopted by the Regional Planning agencies, 9.8% employment growth between 2010 and 2040 is projected, resulting in an increase of 5.9 mgd in non-residential demand, or 45 gallons per each new employee. The WRC's methodology is arguably conservative, as the nonresidential demand includes not only commercial, industrial, agricultural and other uses, but also includes all municipal water uses, and assumes no improvements in efficiency for new users.

Table 4-5 presents residential growth projections and employment projections by community, and by MWRA water pressure zone/service area.

Projected new demand in each service area is summarized in Table 4-5. The greatest growth, approximately 16.6 mgd, is projected in the Low Service Area; baseline plus projected demand in this service area is well below the historical demand.

Table 4-5
Existing MWRA Service Area
Projected Increase in Water Demand Due to Population and Employment Growth
2010-2040

PRESSURE ZONE	New Water Demand Residential (mgd)	New Water Demand Employment (mgd)	Total New Demand (mgd)
Intermediate High	0.54	0.01	0.55
Low Service	12.71	3.88	16.59
Northern High	3.34	0.22	3.56
Northern Intermediate High	0.69	0.03	0.72
Northern Extra High	1.18	0.56	1.74
Southern High –Norumbega	0.52	0.11	0.63
Southern High - off Dorchester Tunnel	2.13	0.28	2.41
Southern Extra High	0.74	0.24	0.98
MetroWest	1.29	0.48	1.77
CVA	0.42	0.08	0.50
TOTAL	**23.56**	**5.89**	**29.45**

In terms of total system demand, this conservative projection of future water demand growth is projected to be very modest – a total of approximately 29 mgd. Adding 29 mgd to the average annual demand of the MWRA water service area for the five preceding years results in a demand estimate of 232 mgd in 2040, if it is assumed that use of local sources remains roughly the same.

A factor in the overall demand on the MWRA system is the potential for changes in the use of local sources through either restrictions on use of local sources (e.g., communities in the Ipswich River Basin), decrease or loss of local sources, or potential development of new local sources (e.g. Framingham). While it is might be reasonable to assume that that there will be no substantial change in local sources, as the various increases and decreases balance out, a more conservative assumption is to provide cushion for partially supplied and emergency supplied communities to require additional water from MWRA.

MWRA staff continue to examine the potential effects of both an increased environmental awareness in how local sources are operated (perhaps in the short term), and the possibility that climate change may decrease the reliable yield of some local sources as discussed above (over the longer term). While conceptually both result in a long term increase in demand on the MWRA system, no numerical analysis is possible at this point in time. Assuming approximately 25% of the demand in both the partially supplied and emergency-only communities now met by local sources were to be met by MWRA, this would equate to approximately 17 mgd.

Summary of Projections

Combining the existing five-year average reservoir withdrawals (2013-2017) of approximately 203 mgd with the 29 mgd growth from increased population and employment, and the conservative assumption of 17 mgd additional demand from partial and emergency users results in a total projected demand on the MWRA system of approximately 249 mgd. The safe yield of the MWRA supply system is approximately 300 mgd currently, and potentially increasing with climate change induced increases in average precipitation. This would still leave a comfortable margin of over 50 mgd between demand from the existing service area and safe yield. Table 4-6, presents the projected summary.

Table 4-6
Summary of Conservative Demand Projections

Current demand within the service area (5-year average)	203mgd
Potential growth due to increased population and employment	29 mgd
Contingency for potential increase in demand from partial user communities	17 mgd
TOTAL PROJECTED DEMAND IN 2040	**249 mgd**
MWRA Supply System Safe Yield	300 mgd
AVAILABLE MARGIN	**51 mgd**

Potential Effects of Climate Change on Demand

There is limited information on the potential effects of climate change on demand in a climatic region such as MWRA's; most existing work has been done in more arid regions. However, MWRA staff have examined some of the factors which currently drive seasonal demand (primarily outdoor uses) on the assumption that these will be the uses most affected. Seasonal demand represents only a small portion of MWRA demand – averaging about 8 percent. Warmer temperatures during the growing season tend to raise seasonal demand, particularly periods of consecutive days above 85°. Precipitation during the growing season depresses demand, while periods of consecutive days without rain increase it. While climate models can provide average changes in rainfall and temperature on a monthly or weekly time step, this is not sufficient for a robust evaluation of seasonal demand changes. Overall, based on what information is available, it seems likely that the impact on demand is likely to be relatively small, on the order of a several percent increase. Given that base demand has been dropping by one to two percent per year, these current demand projections do not include an allowance for climate change. MWRA staff will continue to review this factor as better information on potential changes in climate become available.

Potential Service Area Expansion

Since 2013, a number of communities not currently served by the MWRA water system have approached MWRA about purchasing MWRA water to supplement their local sources. At this time, although several communities have taken initial steps to evaluate the feasibility of joining the MWRA system, there are no active applications under MWRA's #OP.10, Admission of a New Community to MWRA Water System policy although the Town of Ashland has taken preliminary steps towards potential MWRA admission. During 2017 and 2018, several communities and other entities in addition to Ashland have inquired about the possibility and feasibility of connecting to the MWRA or expanding existing service contract volumes. Some of these include Lynnfield Center Water District, the Town of Burlington, and Union Point (a mixed use development at the site of the former Weymouth Naval Air Station).

There are additional communities at MWRA's periphery that derive their local sources in river basins where there is extensive flow alteration. Local water supply withdrawals are one factor that contributes to extensive flow alteration. The flow policy and regulatory changes that emerged from a Sustainable Water Management Initiative (SWMI) led by the Executive Office of Energy and Environmental Affairs may result in restrictions on expansion of water supply during basin permitting. In the long run, to accommodate growth, there may be more reliance on a regional water management approach that capitalizes on the ample capacity of MWRA's large storage reservoirs.

This is an area of evolving information and policy, and will continue to be evaluated by staff. It seems likely that some new communities will join the MWRA system, but the review of likely cases indicates that the demand will be small compared to the available margin between projected demand and supply.

ATTACHMENT 1

MWRA Service Area Population Projections and Additional Water Demand					
Service Area	**Community**	**2010 Census**	**2040**	**2010-2040 Increase**	**Add. Water (gpd)**
Intermediate High					
	Belmont	24,729	27,977		
	Watertown	31,915	36,901		
	TOTAL	**56,644**	**64,878**	**8,234**	**535,210**
Low Service					
	Boston	617,594	743,967		
	Cambridge	105,162	123,808		
	Chelsea	35,177	42,054		
	Everett	41,667	60,434		
	Malden	59,450	76,825		
	Somerville	75,754	101,971		
	TOTAL w/ Cam.	**934,804**	**1,149,059**		
	TOTAL w/o Cam.	**829,642**	**1,025,251**	**195,609**	**12,714,585**
Northern High					
	Lynn	90,329	100,819		
	Lynnfield	11,596	11,520		
	Marblehead	19,808	20,515		
	Medford	56,173	64,380		
	Melrose	26,983	27,487		
	Nahant	3,410	3,113		
	Peabody	51,251	58,884		
	Revere	51,755	73,696		
	Saugus	26,628	28,740		
	Swampscott	13,787	14,193		
	Winthrop	17,497	17,311		
	TOTAL	**369,217**	**420,658**	**51,441**	**3,343,665**
Northern Intermediate High					
	Reading	24,747	27,975		
	Wakefield	24,932	26,075		
	Wilmington	22,325	23,836		
	Woburn	38,120	42,679		
	Stoneham	21,437	21,543		
	TOTAL	**131,561**	**142,108**	**10,547**	**685,555**

ATTACHMENT 1 (continued)

MWRA Service Area Population Projections and Additional Water Demand

Service Area	Community	2010 Census	2040	2010-2040 Increase	Add. Water (gpd)
Northern Extra High					
	Arlington	42,844	45,159		
	Bedford	13,320	16,093		
	Lexington	31,394	34,717		
	Winchester	21,374	21,733		
	Waltham	60,632	70,009		
	TOTAL	**169,564**	**187,711**	**18,147**	**1,179,555**
Southern High off of Norumbega Supply Lines					
	Newton	85,146	90,182		
	Needham	28,886	31,623		
	Weston	11,261	12,053		
	Wellesley	27,982	27,403		
	TOTAL	**153,275**	**161,261**	**7,986**	**519,090**
Southern High off of Dorchester Tunnel					
	Brookline	58,732	72,613		
	Quincy	92,271	111,114		
	TOTAL	**151,003**	**183,727**	**32,724**	**2,127,060**
Southern Extra High					
	Canton	21,561	24,190		
	Dedham	24,729	28,539		
	Norwood	28,602	30,771		
	Milton	27,003	28,917		
	Stoughton	26,962	27,209		
	Westwood	14,618	15,253		
	TOTAL	**143,475**	**154,879**	**11,404**	**741,260**
MetroWest					
	Framingham	68,318	75,997		
	Marlborough	38,499	45,653		
	Northborough	14,155	17,836		
	Southborough	9,767	11,082		
	TOTAL	**130,739**	**150,568**	**19,829**	**1,288,885**
CVA					
	Chicopee**	55,298	59,445		
	South Hadley**	17,514	18,074		
	Wilbraham**	14,219	15,925		
	TOTAL**	**87,031**	**93,444**	**6,413**	**416,845**
	TOTAL	**2,222,151**	**2,584,485**	**362,334**	**23,551,710**

ATTACHMENT 2

MWRA Service Area Employment Projections and Additional Water Demand					
		DET 2010	2040	2010-2040	Increase Water
Service Area	**Community**	**Total Employed**	**Total Employed**	**Delta**	**(gpd/cap) - 45**
Intermediate High					
	Belmont	7,299	7,306		
	Watertown	18,214	18,438		
	TOTAL	**25,513**	**25,744**	**231**	**10,395**
Low Service					
	Boston	573,584	646,947		
	Chelsea	16,682	17,138		
	Everett	13,417	17,043		
	Malden	14,634	14,984		
	Somerville	24,368	32,839		
	TOTAL	**642,685**	**728,951**	**86,266**	**3,881,970**
Northern High					
	Lynn	27,074	28,816		
	Lynnfield	3,699	4,879		
	Marblehead	6,140	6,140		
	Medford	18,893	19,255		
	Melrose	7,063	7,345		
	Nahant	510	510		
	Peabody	27,360	27,741		
	Revere	7,980	8,878		
	Saugus	11,308	11,270		
	Swampscott	4,061	4,083		
	Winthrop	4,146	4,184		
	TOTAL	**118,234**	**123,101**	**4,867**	**219,015**
Northern Intermediate High					
	Reading*	6,061	6,112		
	Wakefield	14,236	14,238		
	Wilmington*	19,965	20,353		
	Woburn	34,323	34,601		
	Stoneham	7,798	7,823		
	TOTAL	**82,383**	**83,127**	**744**	**33,480**
Northern Extra High					
	Arlington	8,796	8,790		
	Bedford	15,510	16,566		
	Lexington	18,592	22,506		
	Winchester	8,576	8,571		
	Waltham	51,816	59,403		
	TOTAL	**103,290**	**115,836**	**12,546**	**564,570**

ATTACHMENT 2 (continued)

MWRA Service Area Employment Projections and Additional Water Demand

		DET 2010	2040	2010-2040	Increase Water
Service Area	**Community**	**Total Employed**	**Total Employed**	**Delta**	**(gpd/cap) - 45**
Southern High off of Norumbega Supply Lines					
	Newton	47,269	49,185		
	Needham	18,060	18,442		
	Weston	6,669	6,666		
	Wellesley	21,859	21,960		
	TOTAL	**93,857**	**96,253**	**2,396**	**107,820**
Southern High off of Dorchester Tunnel					
	Brookline	20,015	20,740		
	Quincy	36,351	41,944		
	TOTAL	**56,366**	**62,684**	**6,318**	**284,310**
Southern Extra High					
	Canton	28,179	28,446		
	Dedham*	14,658	15,164		
	Norwood	23,823	24,437		
	Milton	7,459	7,464		
	Stoughton*	13,777	15,512		
	Westwood*	10,265	12,375		
	TOTAL	**98,161**	**103,398**	**5,237**	**235,665**
MetroWest					
	Framingham	49,164	55,002		
	Marlborough	25,260	27,147		
	Northborough	6,014	7,158		
	Southborough	6,400	8,175		
	TOTAL	**86,838**	**97,482**	**10,644**	**478,980**
CVA					
	Chicopee	19,003	20,428		
	South Hadley	4,441	4,486		
	Wilbraham	4,510	4,784		
	TOTAL	**27,954**	**29,698**	**1,744**	**78,480**
	TOTAL	**1,335,281**		**130,993**	**5,894,685**

* Dedham, Westwood, Reading, Stoughton, and Wilmington were not members of the MWRA water system in 2000.

DET = Department of Employment & Training

5 Water Quality - Regulatory Context & Requirements

5.1 Chapter Summary

MWRA decisions about water quality and treatment are made in the context of both existing and anticipated EPA and DEP regulations. More importantly, they are also guided by the expectations of our customers about the taste, odor, appearance and safety of the water, as well as an understanding of all known potential risks of both the water itself and the treatment processes.

With news coverage of the lead crisis in Flint and firefighting foam contamination elsewhere in New England, and the advent of heavily marketed bottled waters and home filtration devices, customer expectations and misinformation about tap water have become more important drivers. MWRA staff stays abreast of current health research regarding drinking water, regularly reviewing current studies and participating in professional association's expert panels, both to influence the direction of future regulations and to anticipate and prepare for water quality concerns.

Regulations, both existing and anticipated, as well as changing customer expectations, affect our partially supplied communities, on the periphery of the MWRA service area, driving short and long term local treatment investment decisions. These communities face the long term choice of either investing in local supplies or relying more heavily on the MWRA. For example, the town of Reading's decision to join the MWRA system was in part driven by a cost/benefit analysis of complying with current and future treatment regulations.

This chapter provides the regulatory context and requirements which drive decision making about water quality from the sources through treatment, transmission, distribution, and to the customers' taps.

The next chapter describes the existing treatment facilities put in place to meet those regulatory requirements, and customer expectations, and outlines what will be required to maintain those facilities over time. It also discusses what new facilities and modifications may be needed to meet new and expected regulations.

MWRA staff will continue to carefully track new state and federal drinking water regulations and work with customer communities to influence the rules as they develop. MWRA will continue to provide technical, and in some cases financial, assistance to communities in compliance planning.

The Master Plan recommends that:

- Recognizing the importance of local pipeline condition in preserving water quality all the way to consumers' taps, MWRA should continue to provide incentive loans totaling $292 million through the revised Local Water System Assistance Program (LWSAP) through its 2030 end date, and consider extending the program beyond that date with additional funds given the magnitude of community needs, allocating loan repayments to extend the program similar to a revolving loan fund (see Chapter 8). The recently created $100 million lead service line replacement loan program should continue until every community has been able to fully remove all lead service lines.

- Recognizing that a continued appropriately targeted program of watershed land acquisition is necessary to avoid longer term degradation of reservoir source water quality and to preserve the flexibility of MWRA remaining an unfiltered system, that $1million be allocated annually after FY2024 for the purchase of the most critical lands which are in danger of detrimental development. These expenditures should be primarily focused on conservation restrictions, and they may not be spread uniformly year to year as the DCR takes advantage of opportunities as they arise to prevent degradation of water quality over the medium term (10-20 years).

5.2 Existing and New Regulatory Context & Requirements

MWRA is subject to a number of issued rules by the Environmental Protection Agency (EPA) under the federal Safe Drinking Water Act (SDWA)[1]. These rules, some in place for almost 30 years, others issued in 2013, include the protection of source water, treatment processes, allowable limits on contaminants entering the distribution system, and other requirements on water all the way though the MWRA and community distribution systems to the customer's tap. The SDWA also requires that EPA review each rule every six years, resulting in a continuing series of changed requirements. Table 5-1 summarizes the applicable current and expected future rules.

Table 5-1

Promulgated Rules – Already Effective

Trihalomenthane (THM) Rule (1979)	This rule established the first limits (maximum contaminant level or MCL) for the byproducts of chlorine disinfection. The limit for the group of THM disinfection byproducts (DBPs) was set at 100 ug/l as an annual average. Two new sets of rules have since modified it.
Surface Water Treatment Rule (1989)	This rule affects all systems using surface waters (or ground waters under the influence of surface water). It required filtration unless certain criteria on source water quality, watershed protection and disinfection effectiveness could be met. Several rounds of additional rules have added requirements to the SWTR.
Total Coliform Rule (1989)	This rule requires regular and frequent monitoring of water quality within the MWRA and community distribution systems for indicator bacteria and chlorine residual. If more than 5% of the samples in a given month are positive for total coliform bacteria, a violation occurs and the public must be notified. Modified in 2013.
Lead and Copper Rule (1991)	This rule sets "action levels" for lead and copper levels in worst case samples at selected customer's taps. It requires corrosion control, and mandates education and lead service line replacement if more than 10%

1 EPA issues rules under the SDWA. Generally, state environmental or health agencies in each state accept primacy under the SDWA, and issue their own rules to implement the EPA rules. Massachusetts Department of Environmental Protection (DEP) has primacy for almost all drinking water rules, and thus MWRA is usually regulated directly by the DEP, although EPA is an active participant in most decisions. Certain aspects of current rules require formal EPA concurrence, and generally it takes about 2 to 3 years for DEP to accept primacy for new rules.

	of tested homes are above the "action levels." Revisions are anticipated in draft form in 2019.
Information Collection Rule (1996) Unregulated Contaminants Monitoring Rules (1995, 2005, 2012 and 2016)	These rules are part of EPA's process for collecting the necessary information on the nation-wide occurrence of contaminants in order to determine if they ought to be regulated and what the benefits and costs of that regulation will be. The ICR collected information on *Cryptosporidium* and DBPs. The UCMR establishes a new list of microbial and chemical contaminants to be tested for every several years.
Interim Enhanced Surface Water Treatment Rule (1998)	This rule added more stringent requirements on filtration processes for those large systems which filter, and a maximum contaminant level goal and watershed protection requirements for *Cryptosporidium.*
Stage 1 Disinfection/Disinfection Byproducts Rule (1998)	This rule tightened the THM limits from 100 to 80 ug/l and added annual average limits on haloacetic acids (HAAs) at 60 ug/l and bromate at 10 ug/l. It became effective in January 2002.
Long Term 1 Enhanced Surface Water Treatment Rule (2000)	Established standards similar to those of the IESWTR for smaller systems.
Inorganic Compounds Volatile Organic Compounds Synthetic Organic Compounds	This series of rules set MCLs for specific contaminants. Periodically updated with additional contaminants.
Consumer Confidence Rule (1998)	While not strictly a water quality rule, the CCR rule requires that systems publish an annual water quality report describing the water source, how it is treated, and what contaminants are detected. Guidance to allow publishing flexibility issued in 2013, and Federal legislation in 2018 will require twice annual delivery by 2020 and formalized allowability of electronic publication (EPA must issue implementing regualtions)
Long Term 2 Enhanced Surface Water Treatment Rule (2006)	This rule requires that systems using surface water test for *Cryptosporidium* and add additional treatment based on the levels. Unfiltered systems must achieve at least 99% *Cryptosporidium* inactivation, and must use two separate primary disinfection systems. Compliance was required by 2014.
Stage 2 Disinfectants/ Disinfection Byproducts Rule (2006)	This rule further tightened standards for DBPs by requiring sampling in locations expected to be high, and by changing the averaging method. Compliance was required by 2014.
Groundwater Rule (2006)	This rule requires a tiered monitoring, protection and treatment protocol for groundwater to identify and remediate the systems with the highest risk to public health. May require disinfection of many currently untreated groundwater sources, and upgrading of treatment in others.
Perchlorate Rule (2006)	Massachusetts became one of only two states to issue a maximum contaminant level for perchlorate, setting its standard at 2 ppb, lower than California's limit of 6 ppb. EPA is likely to issue a draft perchlorate rule in 2019.
Short-Term Regulatory Revisions and Clarifications to the Lead and Copper Rule (2007)	These changes and clarifications to the LCR included a revamped more flexible, public education requirement, better clarity on sampling and reporting schedules, and additional requirements for the review of treatment changes to attempt to identify situations where lead levels may be increased by other actions.
Revised Total Coliform Rule (2013)	This rule revised the Total Coliform Rule, eliminating the MCL for total coliform, and focusing on "find and fix" response actions if a 5% "action level" threshold is exceeded, through completion of an assessment. The MCL for *E. coli*, was retained and confirmed *E. coli* are still an acute violation and typically require a boil order.
Proposed and Anticipated Rules	
Long Term Revisions to the Lead and Copper Rule (Draft expected mid 2019)	This revised rule may make substantial changes to the required "worst case" sampling requirements as well as possibly requiring complete inventories of lead service lines and their complete removal on some

	timetable. Changes in required corrosion control treatment and public education and outreach may also be included. It may also require additional sampling and education focused on higher copper levels. EPA has issued several rounds of additional guidance to states and water suppliers during rule development and in reaction to public events such as Flint.
Distribution System Rule	Because EPA chose to undertake a more narrowly focused revision to the TCR, it may later issue a broader distribution system rule, focusing intensively on management and control of the distribution system, including additional or better focused monitoring. It may include provisions related to unlined cast iron pipe, older poor condition pipe, and storage tank management.
Additional Chemical Rules	EPA has indicated that it is likely to move toward regulating perchlorate, hexavalent chromium, strontium, NDMA, perflourinated substances, and possibly chlorate. EPA has issued already health guidance advisories for algal produced cyanotoxins and certain perflourinated substances.
Additional State Chemical Rules	DEP has issued Office of Research and Standards Guidance values for NDMA, manganese, and five of the perflorinated substances: these have most of the force of maximum contaminant levels.

5.3 Treatment and Source Water Related Rules

The series of rules related to the Surface Water Treatment Rule, most recently culminating in the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR or LT2), mandates treatment of surface water (and groundwater under the influence of surface water). Generally, filtration is required, but under a narrow set of criteria very well-protected sources like MWRA's Quabbin and Wachusett Reservoirs may receive a "waiver" of the filtration requirement[2]. Until the LT2, the SWTR was essentially a "one-size-fits-all" rule, with every system being required to remove or inactivate 99.9 percent of *Giardia*[3] regardless of source water quality. Finally, under the LT2, source water quality is considered in determining the level of treatment required, with poorer quality sources (those with higher levels of *Cryptosporidium)* requiring more treatment or other protective actions.

The filtration avoidance requirements include 11 criteria, all of which must be continuously met to maintain the waiver. These criteria have not changed substantively with the recent rules.

- Low levels of source water fecal bacteria
- Low levels of source water turbidity
- Adequate watershed protection and control

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2 Only a few large surface water systems have qualified for the filtration avoidance determination, and over the past several years, some have moved towards filtration. Large systems currently unfiltered systems include New York City's Catskill and Delaware sources (supplying about 90 percent of their use – their Croton system is now filtered), San Francisco's Hetch Hetchy source with its watershed in Yosemite National Park, Seattle's Cedar River source (their Tolt source is now filtered) and Portland Oregon's Bull Run source (although they have recently decided to filter it and are moving ahead with design). Tacoma choose to filter its well-protected Green River source to increase capacity and resilience. Other smaller unfiltered systems include Holyoke, Portland and Bangor, Maine, Walla Walla, Washington and Syracuse, New York.

3 *Giardia* and *Cryptosporidium* are two protozoan pathogens which can cause gastro-intestinal illness. Both are excreted with the feces of certain warm-blooded animals, and exist in the environment in a protective cyst which protects them from certain kinds and levels of disinfection. Because they are hard to disinfect, they are used as the target organism in various rules.

- Adequate inactivation of *Giardia, Cryptosporidium,* and viruses
- Redundant disinfection equipment to ensure reliability
- Adequate and consistent disinfectant residual levels at the entry point
- Adequate disinfection residual levels within the distribution system
- Compliance with the disinfection byproducts rules
- Low levels of total coliform bacteria within the distribution system
- No evidence of waterborne disease outbreaks
- Adequate performance on annual on-site inspections

MWRA Compliance History with Surface Water Treatment Rule

When the SWTR came into effect, the Wachusett Reservoir did not initially meet the avoidance criteria, as source water fecal bacteria levels were substantially over the allowable limit. As a result, while a watershed protection plan was developed, an initial decision was made in 1991 to build a filtration plant. Subsequent implementation of the watershed plan by the MDC (now DCR[4]) Watershed Division demonstrated that the high bacteria levels were due primary to flocks of gulls roosting on the reservoir. Employing various actions to reduce the attractiveness of the region to gulls by better management of local landfills, and harassing the gulls at dusk reduced the number of roosting gulls and bacteria levels dropped dramatically, bringing the reservoir into compliance with this source water criterion by 1993. MWRA then entered into a dual track Administrative Consent Order with DEP: the ACO required the siting and design of a filtration plant, but allowed MWRA and DCR until 1998 to demonstrate compliance with all criteria and request a waiver of filtration just prior to construction. This section provides a very brief overview of MWRA's compliance history as it is germane to the decision process on treatment going forward[5]. The watershed protection plan and related activities are discussed later.

As the decision point in 1998 approached, MWRA staff provided a wide ranging series of briefing documents to the Board of Directors on treatment, and in October 1998 the Board decided to request from DEP a waiver of the filtration requirement. As part of this, MWRA would continue as an unfiltered water system and implement an integrated water supply improvement program from the source reservoirs to the consumers' taps. The $1.7 billion 10-year program would include improvements to watershed protection, completion of the Metro-West tunnel, building an ozone disinfection facility capable of inactivating *Cryptosporidium*, replacing all MWRA open distribution reservoirs with covered storage, implementing a $250 million zero-interest loan program for communities to replace old unlined cast iron water mains[6], and a commitment to monitoring water quality and health outcomes and re-evaluating the decision once the plant was on-line.

DEP approved MWRA's decision, but the US Environmental Protection Agency disagreed with MWRA's approach and sued in federal court. After an extended legal process, MWRA's decision

4 Hereinafter, all references to the Watershed Protection Agency, whether to the MDC or later to the DCR, will simply be made to DCR.

5 A longer more detailed version was presented in an attachment to the 2006 Master Plan providing more background on the treatment technology decision process, and is available online.

6 The Local Pipeline Assistance Program made available approximately $370.5 million through February 2018, and was extended and modified as the Local Water System Assistance Program.

was upheld, and the ozone plant, dedicated as the John J. Carroll Water Treatment Plant, was constructed and placed into operation in July 2005. The plant generally performed as expected. Inactivation was greatly increased, reaching the site-specific inactivation targets of 99 percent inactivation of *Cryptosporidium*, as well as greatly increasing the inactivation of viruses and *Giardia* beyond those required by regulation. Disinfection byproduct levels were reduced even more dramatically than anticipated. While a higher chloramine dose than originally anticipated was required, once adjusted, disinfection residuals throughout the distribution system were generally as good as or better than before.

The Quabbin Reservoir had a much less significant issue with roosting gulls, and met the source water quality criteria. MWRA and DCR implemented the watershed protection plan, built interim disinfection facilities by reusing an existing chlorine injection system, and then proceeded to design and build a modern chlorine disinfection facility in Ware (2001) and replace the open distribution reservoir at Nash Hill with two covered storage tanks (1999).

Changes to Treatment Rules Following Construction

All the while MWRA was working towards the construction and operation of new facilities to comply with the SWTR, EPA was developing new rules as described in Table 5-1. While several new rules relating to surface water treatment and disinfection byproducts were promulgated during this period, none had a substantive impact on the decisions made and the processes being built. The CWTP came on line, and complied with all current regulations in July 2005.

In January 2006, EPA issued their long anticipated new microbial and disinfection products rules[7]. These two rules required upgrades to both the CVA and MetroBoston treatment systems, and mandated changes in monitoring programs.

The pair of rules, the Long Term 2 Enhanced Surface Water Treatment Rule (LT2, for short) and the Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 D/DBP or Stage 2), focused on the control of *Cryptosporidium* and on further reducing the amounts of chlorine disinfection byproducts to which consumers are exposed. The two rules were developed in tandem because of the recognition that there is a strong potential for what is called a risk-risk trade-off: improvements to inactivate more pathogens may cause utilities to take actions that increase disinfection byproducts or improvements to reduce disinfection byproducts may actually reduce the effectiveness of treatment against pathogens[8].

7 The rules were developed using a regulatory negotiation process under the Federal Advisory Committee Act which allows the creation of stakeholder committees (called FACAs) to agree upon and recommend approaches to complex regulatory issues. The unfiltered water systems had a specific representative on the panel, and MWRA was an active caucus member and commented throughout the process. The FACA process culminated in September 2000 with an Agreement in Principle (AIP) which represented the compromise position of all the stakeholders. As reported to the Board at that time, notable in the agreement was the “deal” that there would remain an unfiltered option, but that unfiltered systems would use two primary disinfectants as a “multiple barrier” and provide at least 99% *Cryptosporidium* inactivation. Over the next 5 years, EPA developed the draft and final rules based on the compromises reached in the AIP. Staff provided a series of updates to the Board on the evolving regulations.

8 It has also become increasing clear that this issue of “simultaneous compliance” affects all attempts to improve treatment and water quality. Corrosion control efforts can affect disinfection effectiveness, and changes in disinfection or filtration chemicals can affect corrosion control and cause lead levels to increase.

The focus of the pathogen rules since 1993 had been on understanding and controlling the potential risk due to *Cryptosporidium*. In March 1993, over 400,000 thousand people became sick and as many as 100 died in Milwaukee due to an outbreak of *Cryptosporidiosis* caused by inadequate treatment of polluted source water. *Cryptosporidium* can be very infectious, with as few as one oocyst needed to infect an individual, many source waters contain the organism, and some infectious oocysts can and do breach even well-run conventional filtration plants. It was clear that nationwide some systems were at risk. MWRA conducts very sensitive tests for *Cryptosporidium* and occasionally finds evidence of its presence, at very low levels, but generally only empty oocysts regarded as unlikely to be infectious.[9] No firm conclusion about health risk can be drawn given the inadequacies of current testing methods, but MWRA levels would be considered very low even based on levels leaving conventional filtration plants, and MWRA's current treatment with ozone and UV provides at least 99% inactivation of any oocysts that are potentially infectious.

Concurrent with the attention on *Cryptosporidium*, EPA was under increasing pressure to recognize that the format of its earlier rules presented essentially a "one-size-fits-all"[10]. The LT2 called for treatment tailored to the degree of risk by both filtered and unfiltered water systems based on testing of *Cryptosporidium* levels in source water; retained an option for unfiltered systems; and mandated covering of existing uncovered distribution storage reservoirs. The retention of the unfiltered option was a significant victory, as the additional requirements for remaining unfiltered – 99% *Cryptosporidium* inactivation and use of a second primary disinfectant – were reasonably achievable and significantly less costly than filtration.

For the MWRA system, the most important impacts of these new regulations were:

- required inactivation of *Cryptosporidium;*
- required second means of primary disinfection: and
- higher than anticipated "CT" requirements for *Cryptosporidium* that would have translated into higher ozone doses.

Combined, these standards required the addition of a second disinfection process capable of meeting the *Cryptosporidium* inactivation requirements at both the John J. Carroll and Ware Water Treatment Plants by 2014. MWRA met the requirements by adding ultraviolet light (UV) disinfection at both plants.

New research on disinfection byproducts continues to raise the possibility that in addition to risks for certain cancers, high levels of DBPs may affect the developing fetus, possibly resulting in lower birth weight, developmental problems or birth defects, and miscarriages. While the science continues to be uncertain on this issue, the level of concern was such that the consensus of those

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9 The current EPA approved testing protocol for *Cryptosporidium* calls for filtration and examination of 10 liters of water. The test has relatively low recovery efficiency (approximately 40%) and cannot actually distinguish whether the oocysts are live and potentially infectious. MWRA tests raw water weekly at the CWTP and every other week at Quabbin, and filters and examines 50 liters. MWRA also conducted a multi-year research study using weekly 1000 liter samples collected at Shaft 9A.

10 EPA's own research agenda clearly pointed out the fallacy of that approach, showing that some locations had too little protection, while others may have been forced into over-investing on unneeded protection. Draft Report on Research to Support New Rules, EPA, November 12, 1997

working on the new regulations thought that it was prudent to call for reductions[12]. The new rule shifted the focus from a long term average exposure across the entire region, to shorter term exposures in specific locations.

Essentially the new Stage 2 D/DBP rule required that water systems look for chlorinated DBPs where they are most likely to be high, and then adjusted the compliance calculation to focus on an annual average at each of these locations. If any single location is above the MCL, then the system is in violation of the rule. Previously, all locations, both high and low, were averaged together. This new locational running annual average (LRAA) has the effect of reducing the chance of higher exposures. There are also provisions responding to individual high results even when a system remains in compliance and on preventing treatment changes intended to reduce DBPs from degrading pathogen inactivation. The rule made no change in the standard of 10 ug/l for bromate, a byproduct of ozonation of water with elevated levels of bromide.

For the MWRA system, there was no impact beyond the requirement the DBP sampling program be expanded from 15 to 32 sites each quarter. Bromate levels continued to not be a problem, and the dramatic reductions in THMs and HAAs brought about by the switch from free chlorine to ozone for primary disinfection meant that no fully supplied community had any risk of exceeding the new standard[13].

5.4 Lead and Copper Rule

This rule is designed to reduce the risks of lead or copper being leached out of consumers' home plumbing and service lines by corrosive water. It is different than almost any other drinking water rule in that the water system does not control a large portion of the relevant physical assets. The rule requires that water systems sample for lead in certain homes, and depending on the results, provide corrosion control treatment to reduce the leaching of lead from home plumbing. In addition, if levels are above the Action Level, water systems may be required to undertake education efforts to inform their

Lead Tragedy in Flint Michigan: Any current discussion of lead in drinking water, must include a discussion of the events in Flint Michigan as they have substantially influenced public awareness of the issue, have increased current regulatory scrutiny and will influence revisions to the Lead and Copper Rule. In 2014, in a money saving effort, Flint switched from the Detroit water system to the Flint River, and did not include corrosion control treatment in its treatment plant. The lack of corrosion control, combined with an estimated 50 percent of homes having lead service lines, resulted in highly elevated lead levels in the drinking water and subsequent increases in blood lead levels in children. The resulting national outcry spawned civil and criminal lawsuits against responsible officials, forced the community to return to the Detroit system and to begin work to remove its lead services. National attention, including numerous congressional hearings, have resulted increased regulatory scrutiny by both EPA and DEP and further attention to EPA's anticipated revision to the LCR.

12 There have been two research papers published on MWRA water (prior to the start-up of the Carroll Water Treatment Plant) suggesting a potential effect on birth weight, but each has had methodological issues weakening the power of the conclusions. In any case, the level of disinfection byproducts has been dramatically reduced by the switch from free chlorine to ozone for primary disinfection.

13 In addition, the low levels allowed MWRA and the communities fully supplied by the CWTP to avoid an initial extensive sampling program, for a one-time savings of about $500,000.

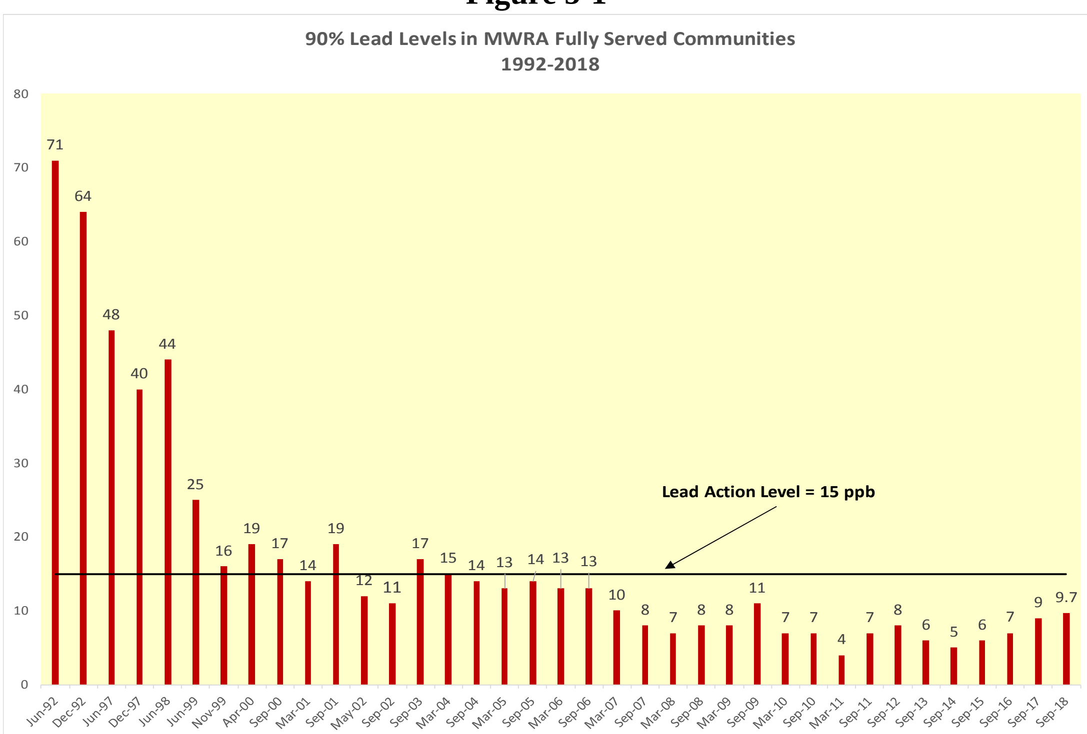
customers about lead, and to remove any lead service lines which may still exist.

The samples are not the usual samples that water systems are required to take of source water or of water as it leaves the treatment plant, but of stagnant water in individual homes. And not just any random homes or homes which are representative of average conditions within the service area, but homes which were judged by EPA to be of higher risk of having lead containing plumbing within the house, or in the service line under their front yards.

When testing began for this rule in 1992, the MWRA system had levels substantially above the action level of 15 ug/l. MWRA immediately began an aggressive education program and fast track design and construction of corrosion control. The selected technology was to adjust the pH and alkalinity of the source water to reduce corrosively, using sodium carbonate and carbon dioxide. The plant went on-line in 1996 and treatment was fully ramped up by 1998. Incremental changes were made to water chemistry over time, and in 2005 DEP indicated that MWRA had optimized corrosion control and approved MWRA’s “Optimum Water Quality Parameters”. The Carroll Water Treatment Plant contains the same corrosion control processes. Lead levels have declined by about 80% as can be seen in the chart below.

System-wide lead results have been below the Action Level in each of the past twenty-three sampling rounds. However, while results have dropped there is still the possibility that a relatively small number of samples with slightly higher results could result in the system exceeding the Action Level. There continues to be variability in the individual community results based on the small number of sampled sites and changes in individual volunteer sampling homes. Due to the small number of homes which continue to be above the Action Level, a number of communities have been required to do mandatory lead service replacement programs and mandatory lead education.

Figure 5-1



Recent results have seemed to indicate an upward trend on lead levels (at least as indicated by the 90th percentile statistic), which has caused staff to initiate a number of reviews to determine the potential causes. Potential contributing factors include inter-annual variability in certain source water parameters including UV absorbance (also called UV254), chloride and sulfate, due to wetter or dryer years and varying amounts of Quabbin vs. Wachusett Reservoir water. Another key factor is likely to be the mix sample sites in each community's DEP approved sampling plan. In response to the Flint publicity, DEP has required communities to update their sampling plans, resulting in many cases in the addition of more homes with lead service lines. The sampling data indicates that homes with lead service lines are more likely to have elevated lead levels that homes with copper pipe and lead solder.

After the Flint incident, MWRA conducted a review of its corrosion control practices and data using a recently released EPA guidance manual, concluding that MWRA water quality is chemically stable and that the corrosion control strategy employed by MWRA (pH/ alkalinity/DIC control) is appropriate. MWRA has committed to continue to review and evaluate corrosion control treatment as new information becomes available.

In 2016, the MWRA Board of Directors approved the creation of a $100 million program to provide zero-interest loans to MWRA communities for the full removal of all lead services. As of 2018, MWRA communities indicate that there are about 18,000 lead service lines, and 22,000 lead goosenecks still in service. The LCR requires that any system which is above the Action Level for lead and still has lead services undertake a mandatory program of removing those services at a rate of at least 7 percent per year. The expectation was that removing the lead service would reduce lead exposure from the drinking water, even if only the portion owned by the water system was replaced, leaving the portion on the homeowners' property untouched. Recent studies do not support that expectation, finding that in the short term lead levels will rise after a replacement and that in the case of partial replacements, the levels often do not drop below the original level even after months. As replacing only part of the lead service line can actually cause increases in lead levels, the new program requires full replacement of all lead from the main up to the building. As of the end of 2018, over $10 million to nine communities has been distributed.

MWRA's goal is to continue to reduce the lead levels until no community has results above the action level. Reaching that goal would be difficult with corrosion control as MWRA's corrosion control treatment is very close to optimum according to our outside experts. Replacing lead service lines combined with continued effective corrosion control should provide an effective path to reduced lead levels.

At this point, no additional capital expenditures are recommended.

As a number of studies have indicated that some portions of EPA's Lead and Copper Rule actions may not be providing the expected public health benefits, and in response to instances of increased lead levels in a number of cities, most notably Flint, EPA has been in a substantial and lengthy process to make revisions to the LCR. EPA has indicated that they expect to revise the lead service line replacement requirement, but the specifics and how ownership concerns and the need to do repairs or replacements during ordinary maintenance or other utility work in the street will be addressed are unknown. It is almost certain that EPA will require that water systems develop and make available inventories of all lead service lines, and make data on lead test results more publicly available. EPA is also considering changes to the sampling protocols which may have the effect of increasing the lead levels in sample results, such as requiring that all samples be at homes with lead services and that the samples be of water which has sat stagnant within the lead service itself. This may have the impact of increasing the risk of exceeding the action level.

If as a result of these changes, the MWRA system is above the lead action level, a comprehensive review of corrosion control treatment will be required, and potentially different treatment chemistry would be required by both MWRA and perhaps the partial user communities. MWRA already provides transparent access to all lead data, and several communities have publicly available lead service line inventories. Changes in lead service line replacement requirements could require all communities move more quickly to develop comprehensive inventories of all lead service lines, and to implement replacement programs.

MWRA staff continue to be actively involved in research and with EPA regulatory development processes.

5.5 Distribution System Rules

The principle current rule related to water quality within the distribution system is the Total Coliform Rule, promulgated in 1989 and substantially revised in 2013. The revisions to the Total Coliform Rule included:

- Eliminating the maximum contaminant level (MCL) for total coliform, and
- Replacing it with an action level of 5%;
- Replacing the required (and confusing) public notice with a series of required investigations designed to understand distribution system problems resulting in total coliform positives;
- Defining a rule violation as failing to conduct the investigations following an exceedance of the 5% action level or failing to follow up on recommendations; and
- Retaining the *E. coli* MCL and required actions for exceeding it.

The rule requires an extensive monitoring program at locations within the distribution system which are representative of system wide water quality. Each community and MWRA have their individual monitoring program. Across the MWRA/community system, about 2,200 samples are collected each month at over 600 locations. Larger communities collect samples weekly; smaller ones less frequently; and MWRA collects samples at key locations daily. Each sample includes a total coliform result, a chloramine residual measurement, temperature and heterotrophic plate count (HPC) bacteria results if the chloramine residual is very low.

The total coliform test is an *indicator* of overall water quality – not a direct test for pathogens. Total coliform bacteria can come from the intestines of warm-blooded animals, or it can be found in soil, plants, or other places. Most of the time, these bacteria are not harmful. However, their presence could signal that harmful bacteria from fecal waste may be present as well. The TCR requires that no more than 5 percent of the samples in a given month may be positive for total coliform. If a water sample tests positive for total coliform, more specific tests for E. coli are conducted. *E. coli* is a specific coliform species that is almost always present in fecal material and whose presence indicates likely bacterial contamination of fecal origin. If *E. coli* are detected in a drinking water sample, this is considered evidence of a critical public health concern. Additional testing is conducted immediately and joint corrective action by DEP, MWRA, and the community is undertaken.

If more than 5% of all samples are total coliform positive in a month (or more than one sample when less than 40 samples are collected each month), under the revised Total Coliform Rule, the community must conduct an assessment to try to determine the cause, and resolve an identified problems. This “find and fix” approach is different than the old TCR, which considered it a violation if more than 5 percent of samples were total coliform positive, and required public notification usually via advertisement in the local paper. The change is a recognition that total coliform are not a health risk, and focuses on identifying and resolving problems within the distribution system.

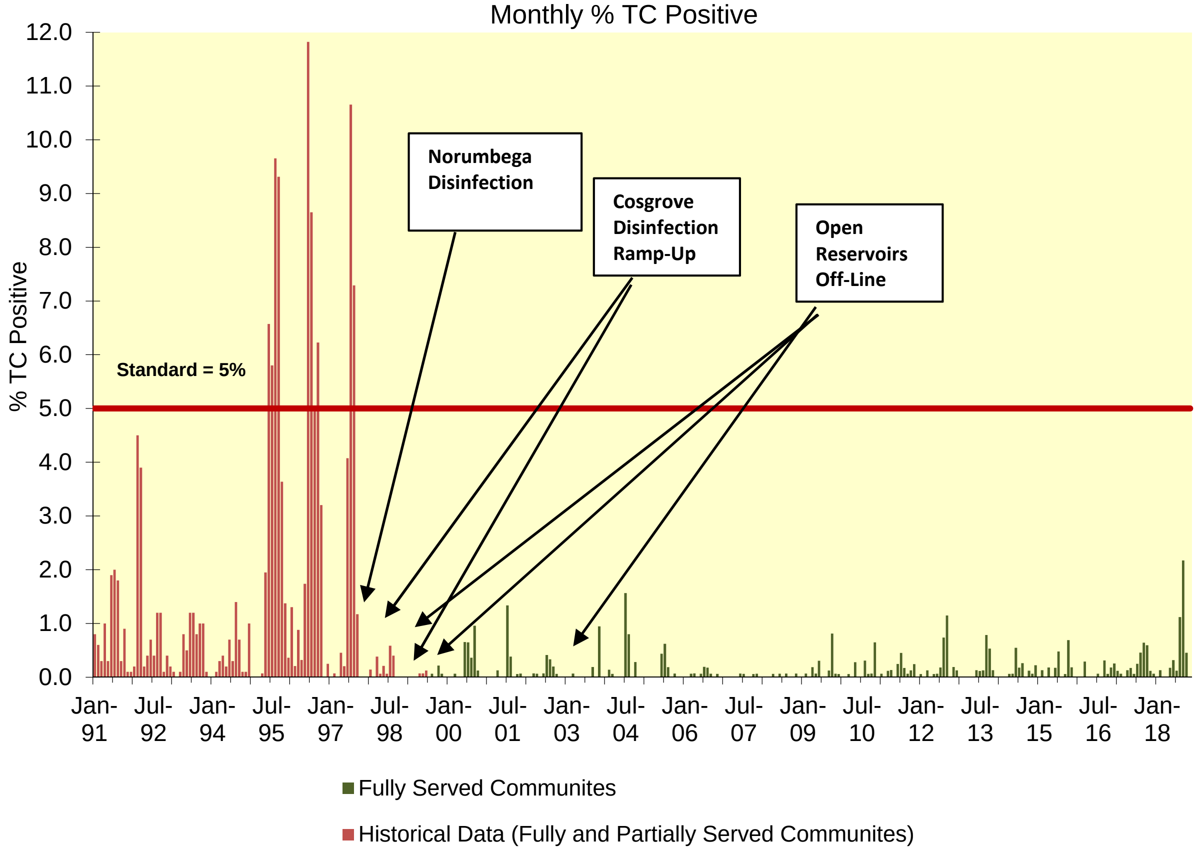
No changes were made to the requirements for *E. coli*. Public notification is still required if follow-up tests confirm the presence of *E. coli* and a boil order is typically required by DEP.

The total coliform rule monitoring program is jointly conducted by MWRA and the communities. Communities conduct the actual field sampling, and MWRA’s laboratories do the analysis and reporting. In addition, a portion of MWRA’s TCR monitoring program includes the results from the community sampling location nearest the MWRA connection.

The total coliform sampling results are also used in the aggregate as one of the criteria for maintenance of the filtration waiver. No more than 5 percent of all samples from fully supplied communities system-wide in any month can be positive

With improvements to treatment and the removal of the open distribution reservoirs, the system wide total coliform positives have been reduced substantially since the mid 1990’s.

Figure 5-2
Community Total Coliform Rule (TCR) Result
Monthly % TC Positive



While the aggregate results are much lower, there are still occasional total coliform positives both within the MWRA system and in some community systems. Often there is a single positive sample, and none of the repeat samples are positive. These are difficult to categorize and assess. Other community positives are related to local distribution issues, especially storage tanks and low chlorine residuals. When these occur, communities can take local action to improve the residuals by flushing or tank draining, and the situation corrects itself. Less frequently, communities will have actual contamination within a tank, and the tank must be drained and cleaned. Partial users which mix MWRA water with their local source water can present more complicated investigations when there are distribution system issues.

One area of potential concern has to do with “nitrification” within community systems. MWRA tracks chloramine residuals in pipes and tanks, not just because it is needed as a distribution system disinfectant, but because when the residual is reduced, it frees up ammonia. Chloramine is made up of chlorine and ammonia – combined they produce chloramine which is a very mild and long lasting disinfectant, ideally suited to a system like the MWRA/community system with over 5000 miles of local pipes. However, when chloramine breaks down and ammonia is released, a type of bacteria called ammonia oxidizing bacteria (AOB) can consume the ammonia, creating nitrite and then nitrate which further reduces the chloramine residual in a positive feedback situation. If not controlled, this type of situation can get out of control, potentially resulting in no disinfectant residual at all. Water systems must maintain an adequate chloramine residual throughout their pipe network by managing water age, allowing tanks to cycle in two to five days and improving the condition of pipelines. MWRA staff provide technical assistance to communities as needed, and the Local Water System Assistance Program now grants funds for storage tank improvements, distribution system master planning, and the elimination of old unlined cast iron pipelines.[14] If a partially supplied community uses free chlorine as its residual disinfectant, rather than chloramine, the mixing of the two waters can result in chlorine residual loss, and potential for nitrification.

In addition to a concern about low chloramine residuals, there is an upper regulatory limit on the annual average of these samples of 4.0 mg/l, but as levels at the entrance to the distribution system are typically 2.5 to 3, it is unlikely that the MWRA or community systems would exceed the limit. More important is the reduction of chlorine residuals across the distribution system, and what the lowest levels are. As with total coliform results, treatment changes over the past decade have resulted in substantial improvements as shown in Table 5-3.

MWRA considers a disinfectant residual of 0.2 mg/L a minimum target level at all points in the distribution system. Many of the community systems currently have at least one location which does not meet the MWRA goal. Generally, this is due to the condition of community pipes, and to prolonged detention with pipes and tanks in the community system. In addition to its current *goal* of no locations below 0.2 mg/l, MWRA routinely reviews the chlorine dose based on a number of factors including reservoir water quality trends, bacteria positives within community systems and the percentage of samples below 0.1 mg/l, 0.2 mg/l and 0.5 mg/l. As would be expected, there is substantial winter/summer variability, with lower residuals in the summer due to the warmer water temperatures causing faster chlorine decay, and lowest residuals often in last summer or early fall, as shown in Table 5-2.

Table 5-2

Fully Supplied and MWRA TCR Sample Residuals

	2017						2018					
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
% <0.1	0.2	0.9	1.0	0.7	0.7	0.5	0.2	0.1	0.1	0.0	0.2	0.0
% <0.2	0.7	2.7	2.6	2.4	2.5	1.1	0.5	0.2	0.2	0.3	0.2	0.4
% <0.5	3.2	5.7	6.2	5.6	5.7	3.1	1.4	0.5	0.8	0.7	0.4	0.7
% <1.0	6.7	12.3	10.5	9.4	9.6	6.0	3.2	2.2	1.4	1.5	1.3	1.6
% ≥1.0	93.3	87.7	89.5	90.6	90.4	94.0	96.8	97.9	98.6	98.5	98.7	98.4

There has been a gradual state by state movement toward requiring minimum disinfectant residuals within the distribution system, and EPA has indicated some interest in a similar approach. A typical requirement is that no more than five percent of all samples with a system be below 0.5 mg/l. If such a standard were adopted in Massachusetts, MWRA would likely require some adjustment to seasonal chlorine targets leaving the plant to meet the target on a regional basis, but some communities with large percentage of unlined cast iron mains and internal longer travel times would likely have difficulty meeting it without substantial distribution system improvements.

14 At least one community has experienced substantial nitrification in recent summers, possibly due to distribution system issues, excessive water age in local tanks, and the use of free chlorine at its local source. MWRA staff have provided substantial technical and logistical support over a number of years, but the problem is not yet completely resolved.

Table 5-3 - Improvements to Distribution System Chlorine		
	Chlorine Residual Below 0.2 mg/l	Chlorine Residual Above 1.0 mg/l
1995	57%	2%
1996	47%	1%
1997	33%	5%
1998	8%	51%
1999	3%	74%
2000	5%	76%
2001	4%	75%
2002	5%	70%
2003	4%	63%
2004	5%	69%
2005	5%	71%
2006	5%	75%
2007	2%	90%
2008	2%	94%
2009	3%	90%
2010	2%	91%
2011	2%	92%
2012	4%	88%
2013	3%	89%
2014	2%	92%
2015	1%	94%
2016	0.7%	96%
2017	1%	94%
2018	0.7%	94%

MWRA has had a long standing program of monitoring water quality in storage tanks on a weekly basis. A chloramine trigger of 1.0 mg/l is set: immediate action is taken to improve the residuals of a weekly sample is less than that. With the recent addition of the on-line contaminant monitoring system, tanks are monitored continuously, for more parameters, and action can be taken more quickly if chloramine residuals appear to be dropping or nitrification appears to be increasing. Typically, response actions are to cycle the tank more rapidly and more deeply, "freshening up" the water and improving residuals. If that is insufficient, the tank may be drained and refilled or drained, disinfected and then refilled. As MWRA storage tanks have been rehabilitated, consideration has been given to adding in tank mixers to reduce stratification.[16]

16 MWRA has added mixers to Turkey Hill Tank. Communities have begun to add mixers and/or booster disinfection equipment to tanks which experience below residuals, stratification or nitrification: these are eligible expenses under MWRA's Local Water System Assistance Program.

5.6 New Distribution System Requirements

The Microbial and Disinfection Byproducts (M/DBP) Federal Advisory Committee (FACA) which negotiated the LT2 and Stage 2 rules, also agreed in principle that valid health concerns from distribution systems existed, and that EPA should review available data and research on distribution system risks and work further with stakeholders. These efforts were expected to result in the review and possible revision of the TCR, as well as the potential for requirements to address finished water quality in the distribution system.

As EPA began to consider what might need to be changed in the Total Coliform Rule in 2002, and solicit input from utilities and others, it became clear that simply updating the TCR might not be sufficient. Therefore EPA began an effort to potentially replace the TCR with an entirely new Distribution System Rule. EPA, in association with distribution system experts, compiled existing information regarding potential health risks that may be associated with distribution systems in "white papers" on nine distribution system issues to inform EPA and stakeholders of areas of potential TCR revisions and distribution system requirements:

- Intrusion
- Cross-Connection Control
- Aging Infrastructure and Corrosion
- Permeation and Leaching
- Nitrification
- Biofilms/Growth
- Covered Storage
- Decay in Water Quality over Time
- New and Repaired Mains

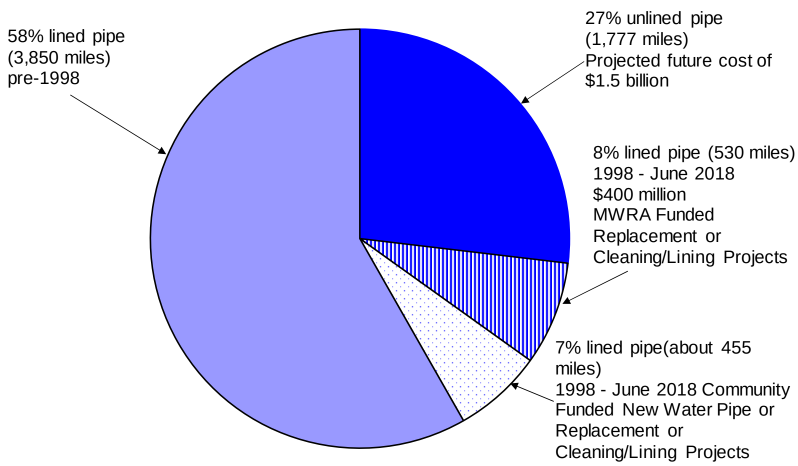
MWRA staff tracked and participated extensively in the research and rule development process. Ultimately, EPA chose to revise the TCR, and to continue research and information collection on distribution system issues in anticipation of further regulatory action at a later time.

It is clear that as treatment has improved nationwide, there are still potentially important risks to water quality and public health after the water leaves the treatment plant. MWRA’s approach to investment mirrors that understanding, focusing on water quality all the way to the tap with substantial investments in MWRA distribution system storage and MWRA and community pipeline rehabilitation. Looking at the range of issues in the EPA white papers, it is clear EPA will likely continue to take a more careful look at storage tank maintenance and operation, internal condition of pipes, the possibility of contamination getting in through small holes in pipes and aging infrastructure and corrosion. The degradation of water quality which occurs as the water “ages” in pipes and tanks, and the potential of pathogen growth (or at least increased biological activity) within the pipes may also be important.

MWRA already has adopted many of the best practices for operations and maintenance being discussed, so the impact on the MWRA system operations may be limited. Some community systems may be less prepared to comply with any new requirements.

It is also clear that many of the potential distribution system health risks (or at least opportunities for degradation in water quality) are related to the age and condition of the buried infrastructure. There is a substantial potential for increased attention and investments by communities in their own distribution systems. The recommended remedial action for many of the identified problems is essentially rehabilitation of old unlined cast iron pipelines, and replacement of pipe which is in poor condition. MWRA created a pilot grant/loan program that distributed $30 million to member water communities in FY98-99 substantially for pipeline improvement projects. Based on the initial success of the pilot financial assistance program, MWRA created the Local Pipeline Assistance (interest-free loan) Program as part of the 1998 Board Decision on Treatment Technology recognizing that regardless of the level of treatment provided by MWRA, the water must pass through the local community pipe network before reaching customers. The Local Pipeline Assistance Program distributed $222 million in zero interest, 10-year loans for the rehabilitation or replacement of member community unlined cast iron pipe from FY00-13. Prior to the beginning of the program in 1998, about 42 percent of the 6,612 miles of water pipe in community systems was unlined. Since then (through February 2018), 527 miles of local pipe rehabilitation or replacement has been financed through MWRA loans, and another 455 miles have been funded by local funds, resulting in a current estimate of approximately 27 percent unlined pipe in community systems.

Regional Water System Lined and Unlined Pipe
6,612 Miles of Community Water Mains
Updated as of July 2018



As recommended in the 2013 Master Plan, in FY18 MWRA launched the Phase 3 Local Water System Assistance Program (LWSAP) to continue providing zero interest, 10-year loans for member water community projects. The Phase 3 program is budgeted at $292 million for FY18-30. The revised program expanded the eligible activities to include system master planning efforts, storage tank rehabilitation and efforts to improve water accountability such as improved metering. Even with this additional funding, there is still a long way to go before all the old unlined tuberculated pipe is removed from local distribution systems. MWRA estimates, at current rehabilitation/replacement rates, it will take another 40 to 50 years and a regional investment of at least $1.5 billion before the last of the community unlined water pipe is removed.

<u>Recommendation-Distribution System</u>

- *Recognizing the importance of local pipeline condition in preserving water quality all the way to consumers' taps, MWRA should continue to provide incentive loans totaling through the revised Local Water System Assistance Program (LWSAP) through its 2030 end date, and consider extending the program beyond that date given the magnitude of community needs, allocating loan repayments to extend the program similar to a revolving loan fund (see Chapter 8).*
- *Recognizing the critical need to reduce lead exposure through the replacement of lead service lines, continue to offer zero-interest loans for the removal of lead service lines and lead goosenecks, and periodically evaluate the adequacy of funding to complete their full removal in every MWRA community.*
- *MWRA will also need to find additional ways to encourage a continued long term program of local distribution system rehabilitation and lead service line replacement.*

While MWRA cannot directly affect the rate of community efforts to deal with poor quality pipelines, and as MWRA pipeline rehabilitation will also take decades to complete, source water quality, treatment and potential distribution system impacts of treatment are within MWRA's more immediate control.

5.7 Interaction between Treatment and the Distribution System

Once water leaves the treatment plant, it continues to change as it travels through the distribution system. The type of treatment, the characteristics of the source and finished water, the condition of local infrastructure (pipes and tanks) and the total travel time all affect how stable the water quality is as it travels to the ultimate customer. Ozone breaks down complex naturally occurring organic carbon compounds into smaller compounds. There is concern that increased levels of these smaller compounds, referred to as biologically degradable organic carbon (BDOC) or assailable organic carbon (AOC) could lead to the proliferation of biological activity within the distribution system. Frequently, biologically active carbon filters are added after ozone to capture the BDOC by allowing bacteria to grow and feed upon the organic material in the water. During the treatment technology decision process, extensive research on this topic was undertaken to determine if filtration would be required after ozonation in the MWRA system, using both laboratory bench scale and pilot testing using actual old tuberculated cast iron water mains. Based on the results of the research, MWRA and its research team drew the conclusion that proper corrosion control and the maintenance of an adequate chloramine residual throughout the system were more important than the level of BDOC in preventing issues within the distribution system. Based in part on those research conclusions, MWRA decided that treatment with ozone alone was feasible.

There have not been indications of widespread distribution system problems since the ozone plant went on-line in 2005. The initial dose of chloramine was raised somewhat, and with the higher initial dose, residual levels throughout the system were able to be maintained at least as high as prior to startup. As discussed above, there have been some indications of increased nitrification in areas with very high water age, particularly in certain community or MWRA tanks, but there does not appear to be any system-wide change at this point. Of particular concern are community storage tanks which stratify during warm weather, allowing a portion of the water to remain in the tank for extended periods. Some communities have found that in addition to increasing the tank turnover by monitoring and adjusting the operating band, in some cases tank mixers can eliminate stratification and prevent extended water age problems. These are eligible for funding under MWRA's Local Water System Assistance Program. Given the potential for degradation of disinfectant residuals with nitrification, MWRA staff will continue to closely monitor this, and work with communities to control it.

If it is determined that the nitrification presents a problem which cannot be resolved by changes in how the plant and system are operated, it is possible that additional remedial actions will be required including community flushing programs, higher chloramine levels, and more aggressive targeted pipeline rehabilitation efforts[17]*. *

Of emerging national interest, are issues associated with "premise plumbing", the interior plumbing within a building or complex outside the control of the water system. The Lead and Copper Rule discussed above has already moved some aspects of water system responsibility into the arena of how interior plumbing affects and can degrade water quality. Nationwide, an increasing number of cases (or at least an increasing number of reported cases) of legionella disease associated with water quality within buildings or building complexes has raised awareness of very low levels of the pathogens in system water, which may be able to proliferate within building plumbing systems under the right conditions. *MWRA staff monitor the research on premise plumbing issues, provide technical assistance and information to communities or building owners as needed, and are tracking plumbing association and EPA efforts to grapple with this issue.*

5.8 Organic and Inorganic Contaminant Rules

MWRA is required to test for and meet maximum contaminant level (MCL) standards for over 100 specific chemicals. Generally, only a few are found and at levels well below the MCL. Results are required to be included in MWRA's annual water quality report each year and generate a few questions from consumers. MWRA has never failed an MCL for any of these regulated contaminants.

The SDWA requires that EPA engage in a periodic process to determine whether additional contaminants should be regulated, and Massachusetts has a parallel independent process as well. The process generally includes research into chemicals which may potentially have negative health effects, and which may be present in drinking water. Once these candidates are identified, EPA or the state will require that systems conduct "occurrence" sampling to estimate the prevalence and levels of the chemical. (This is done five years under the Unregulated Contaminants Monitoring Rule (UCMR).) If the toxicological and epidemiological research indicates there is a potential health effect, AND the chemical is present AND EPA determines that there is a meaningful way to effect a health risk reduction, then it will issue a standard. This lengthy process can result in an interim situation where the public receive information about the potential presence of a potentially

17 In addition to conducting twice annual training sessions which typically include at least one session on distribution system management issues, MWRA staff have been conducting one-on-one meetings with communities to review water quality data, distribution system best practices and offering technical assistance.

harmful chemical long before a consensus (or perhaps even evidence) of what constitutes a safe level is available[18].

For well protected sources such as MWRA's, this process generally (but not always) results in our being able to simply say we didn't find the chemical. Less well protected sources will find trace levels more frequently.

<u>Lower detection levels/ more chemicals detected</u> - An area which may have profound effects on how water systems operate in the future is the continued trend toward lower detection levels for all sorts of natural and human-made environmental contaminants. While a few years ago water suppliers were mostly concerned about chemicals measured in part per million (milligrams/liter), detections have since moved to parts per billion (micrograms/liter) and more recently to parts per trillion (nanograms/liter) and parts per quadrillion(picograms/liter)[19]. Concurrent with the increased ability to find ever smaller amounts of chemicals in water is the science of evaluating their health effects. While the science of detection is always necessarily ahead of the science of understanding the health implications, researchers now regularly publish epidemiological or toxicological findings which cast doubt on the safety of chemicals which may be found in water. These may or may not eventually be determined to be of sufficient concern to be regulated, but their presence does raise concerns among consumers.

This is one area where MWRA's well protected and undeveloped watersheds are an important asset. While most water systems using surface water across the country rely on water which has passed over developed areas and includes often substantial amounts of treated wastewater, MWRA's sources are much closer to pristine. An area receiving increasing public and scientific interest is trace amounts of pharmaceutical and personal care products (often referred to as PPCP). Wastewater generally contains some amount of these chemicals, and studies by the USGS have detected them in most surface waters. At this point, relatively little is known about the effects of very low amounts of these chemicals on human health, but there are concerns that they may disrupt important hormonal processes, especially in growing fetuses and children. (More likely is that there could be ecological impacts on fish and amphibians at levels well below human health concern.) MWRA would not expect to find PPCP in its source waters, and tests conducted in 2008 of a representative selection of 31 pharmaceuticals, hormones and potential endocrine disrupting compounds detected none in source or finished water.

MWRA must regularly respond to customer concerns about chemicals or health risks reported in the media. Most frequently, we can report that we have tested for the chemical and that it is not present in the water we deliver. However, as detection limits decrease, it becomes increasingly likely that we may find some very small levels of chemicals and have to report on or otherwise disclose that information. Because it is almost always the case that the reports of possible health effects and detection in the environment or in drinking water will be years prior to a definitive assessment of safe levels, there is little that can be done to reassure consumers. Our goals for

18 Even though there is no regulatory benchmark to help consumers understand the significance of the results, all substances detected during required UCMR testing must be provided to the public as part of the annual Consumer Confidence Report. MWRA links to a comprehensive report on the results on MWRA.com.

19 In each case a thousand fold less of the chemical of concern. A practical comparison is that a part per million represents about one drop in a 55 gallon drum, a part per trillion is less than one drop in an Olympic sized swimming pool, a part per trillion would be less than one drop in a thousand swimming pools, and a part per quadrillion would be one drop in a million swimming pools.

source water protection and treatment are designed to reduce the potential for harmful levels of environmental, human-caused, or treatment-related contaminants, but as knowledge evolves, we may find unexpected issues.

Increasingly, attention has been focused on trace levels of regulated contaminants in the treatment chemicals used by water suppliers. Perchlorate can be constituent of the sodium hypochlorite used for disinfection. It has been regulated in Massachusetts since 2006 with an MCL of 2 parts per billion (ppb), and EPA is working towards issuing a draft rule in 2019. While MWRA does detect trace amounts of perchlorate in finished water due to the very sensitive testing methods used, the amounts are well below the state standard. EPA is also considering regulating chlorate, which is a breakdown byproduct of sodium hypochlorite. Initial testing under the UCMR3 program indicated levels which were above the preliminary health reference level (a context setting level published along with the requirement to conduct the testing with no regulatory force). Chlorate production is influence by the quality of the sodium hypochlorite, its strength, its age, storage temperature and exposure to sunlight. Staff reviewed and modified how the chemical storage tanks were used to reduce chemical age, and were able to substantially reduce chlorate levels. If EPA chooses to regulate chlorate, depending on the MCL issued, MWRA may need to make additional changes, perhaps including air conditioning the chemical storage building or adding cooling for the storage tanks themselves.

MWRA specifies strict limits on the allowable limits of any expected trace contaminants in our chemical procurements, does regular testing, and periodically reviews the specifications to avoid (if possible) adding detectable amounts of reportable chemicals to the water. Chemical storage conditions will also continue to be evaluated.

A series of numbers accompanies each drinking water regulation: the MDL, the PQL, the MRL, the MCLG, the MCL and sometimes an AL.

Each regulation specifies a laboratory technique(s) to be used in detecting and quantifying the contaminant. The method detection level (MDL) is the lowest level at which the laboratory can assure the chemical is present, but it cannot be reliably quantified. The practical quantification level (PQL) specifies the lowest level at which the laboratory can say that the chemical is present and tell what the amount is. The method reporting level (MRL) is the level above which a water system must report that it has detected a chemical. It is typically set near or at the PQL. Typically, if a chemical is detected below the MRL it does not need to be reported to the regulatory agency, but does still provide useful information to the water system.

The MCLG or maximum contaminant level goal is a non-enforceable goal. It is set by EPA and is the level of contaminant in drinking water below which there is no known or expected risk to health. MCLGs are required to allow for a margin of safety. The Maximum Contaminant Level (MCL) is the enforceable standard, and is the highest level of a contaminant allowed in water. MCLs are required to be set as close to the MCLGs as feasible using the best available technology. Both the MCL and MCLG must be reported to the public, which occasionally can cause confusion about whether a contaminant detected above the MCLG is still “safe”. There is no good answer to the question.

In some cases, EPA will set an action level which is essentially a trigger for certain actions, such as corrosion control or mandatory education. EPA can also set a treatment technique if a contaminant is not easily measured, but can be controlled by a specified level of treatment such as disinfection or filtration. In addition, both EPA and DEP may sometimes set a health advisory level which may require action or notification to consumers.

5.9 Potential for Regulation of Additional Ozone, Chloramine or UV DBPs

Researchers continue to identify additional compounds created when disinfectants react with natural and man-made substances in the source water. EPA continues to review the toxicological and epidemiological data associated with any potential health risk associated with these disinfection byproducts. In the past several years, their attention has moved beyond just the byproducts of chlorine to those of other disinfectants. Some of the byproducts of chloramine are already regulated, as is one ozone byproduct. To date no potential byproducts of UV have been identified.

The Unregulated Contaminants Monitoring Rule requires that water systems provide data to EPA on certain unregulated contaminants so that EPA can determine how widespread their occurrence is. Results are available from UCMR2 and UCMR3 and testing will occur between 2018 and 2020 under the UCMR4. Of the many dozens of chemicals that have been or will be looked at nationwide, only a couple are likely to be of concern to MWRA: nitrosamines (specifically NDMA) and chlorate.

Chloramination has the advantage of producing very little of the two primary regulated DBPs – HAAs and THMs, but at least one class of byproducts of potential health concern – nitrosamines - can be produced by chloramination[20]. None of the nitrosamines are regulated by EPA at this time, but advisory or guidance levels have been set by Massachusetts and California at 10 parts per trillion (nanograms per liter) for one of them, N-Nitrosodimethylamine (NDMA). EPA has listed NDMA on its Contaminant Candidate List; it was detected in about one quarter of systems tested; and a decision on whether it will be regulated by EPA is still uncertain. As more water systems adopt chloramination to comply with the new DBP rules, it is likely that additional byproducts of concern will be identified, and possibly regulated. Complicating regulation of NDMA is that it is also produced within the human digestive system as well, making specific risk allocation to levels in water very difficult, and reducing the relative benefit of any reduction in water levels.

MWRA and our fully and partially supplied communities could all be affected by new chloramine byproduct regulations. In seven rounds of testing of MWRA water, no NDMA was found in raw water, water right after treatment, or in water at an average detention time site. Detections were limited to the site selected as typical of the longest detention time. At that location, levels generally ranged from 2 to 5 ppt, about one half the DEP guidance limit.

As discussed above, chlorate is a degradation byproduct of the sodium hypochlorite was to add chlorine to the water for disinfection. *MWRA successfully reduced levels by adjusting operating procedures, but depending on the ultimate regulatory level set if EPA chooses to regulate it, may need to take additional steps such as providing cooling for the chemical storage area.*

Ozone is a powerful oxidant and can transform many of the naturally occurring compounds in water. To date, only one ozone DBP is regulated – bromate - at an annual average MCL of 10 ppb. Generally, bromate is produced when water containing bromide is ozonated.

20 NDMA can also be a direct source water contaminant from certain industrial processes, and a byproduct of certain water filtration processes using polymer coagulants.

MWRA's source water has relatively low levels of bromide, and it appears that levels of bromate will remain well below the MCL[21].

5.10 Uncertainty, Margin of Safety, and Perceived Risk

An area receiving increased attention on the national stage is how to set regulations and make public resource allocation decisions in the face of scientific uncertainty about the effects of various chemical or biological contaminants. The scientific community recognizes that how risks are understood and described can and will affect the policy debate over a particular contaminant, but there is not a consensus about how to best deal with uncertainty in risk estimates. Some believe that any risk is unacceptable, and that if the degree of the risk (or perhaps even the existence of an actual risk to health) is unknown or uncertain that a precautionary approach should be taken. In practice for water suppliers this might mean that any potential contaminant which has been described as a risk in any single animal toxicological study or preliminary epidemiological study should be regulated and removed from the water. Others believe that a weight of evidence approach is appropriate, and that action should wait until there is some reasonable certainty that an actual effect may happen at doses likely to be experienced by consumers. In practice for water suppliers this might mean that a potential risk would exist and be publicly discussed for many years before action is required. Neither approach seems particularly satisfying. MWRA's approach to date has been to stay abreast of health and contaminant research and the regulatory process, and armed with that information, examine the potential risks in the MWRA system. *If a risk seems plausible, MWRA undertakes specific investigations on whether the contaminant occurs or is likely to occur in our water. In some cases, such as with Cryptosporidium, MWRA began taking action immediately after the issue was raised nationally by the Milwaukee outbreak, and treatment decisions were made prior to the issuance of any EPA rule.*

A related question is how especially sensitive populations should be protected. The effects on any given contaminant will vary by individual and by their health circumstances. Those with weakened immune systems due to cancer therapy, transplants or disease may be at a higher risk of infection from a given level of a pathogen than the general population. Lead exposure is of more critical importance for pregnant women and small children than others. Growing evidence links the risk of certain cancers to certain genetic factors. The setting of a safe threshold in a regulation or treatment decision must account for the variability of the population risk by establishing some margin of safety or other actions may be appropriate. The recent scientific debate over an appropriate maximum contaminant level for perchlorate focused extensively on what the targeted at-risk population should be. The policy conclusion by Massachusetts DEP was that the regulation should be protective of the most vulnerable. By contrast, EPA's regulations for the annual Consumer Confidence Report require the publication of specific language about the health risks of *Cryptosporidium* for those with compromised immune systems. Here the conclusion is that no water system could be expected to provide the extreme degree of protection that some might require, and that those individuals might have to take additional individual actions.

21 Bromate is also an identified trace contaminant in the sodium hypochlorite, which MWRA uses to produce chloramines. Two monthly samples have had detectable levels of bromate since the CWTP was brought on line. It appears that the bromate was not produced by ozonation, but was most likely from the sodium hypochlorite. MWRA's purchase specifications should prevent this from happening, and there have been no additional detections since this issue was brought to the attention of the chemical vender.

A recent example of perceptions creating consumer concerns has arisen recently in a number of communities converted to chloramines. MWRA has been using chloramines since the 1930's originally because it was an effective long lasting disinfectant for a large regional system, but more recently, many other systems have been switching from free chlorine to chloramine to reduce their disinfection byproducts. In many of those communities, citizens groups have sprung up concerned that the switch will cause a variety of health problems. While the science clearly seems to point to the switch <u>reducing</u> health risks, perception and the spread of rumor and supposition via the internet can provide a powerful counter narrative for citizens. Some MWRA customers contact the agency concerned that we might switch to chloramines, but generally are surprised to find that they have been drinking and bathing with chloraminated water for decades.

All of this relates to what our consumers expect of the water delivered to their taps. If asked, consumers will indicate that they want the water to be "safe". Unfortunately, there is no simple straightforward way of measuring "safety". As with all things in life, water cannot be delivered free of any risk to any individual. National policy decisions (as well as any local decisions) balance the degree of risk with the allocation of funds. Measured simply on the reduction of the risk from water, if disinfection is good, more disinfection is better, and more powerful disinfection and filtration is better still. Even better yet, two or three steps of filtration. Taken to the absurd, it is clear that there is some point where additional resources spent provide diminishing benefits, and that allocating those resources elsewhere make common sense.

MWRA's Integrated Water Supply Improvement Program and the treatment technology decision process balanced the investments in (and benefits derived from) treatment with additional resources allocated to community distribution systems, successfully arguing that a balanced investment profile yielded the largest benefits to consumers.

5.11 Simultaneous Compliance

An emerging issue of concern is the interaction of various rules. The interaction of disinfection to kill germs and the creation of undesirable byproducts of disinfection has been recognized for some time, but more recently it has become clear that almost all stages of treatment can potentially affect other compliance goals. The lead in drinking water debacle in Washington DC in early 2004 now seems to have been definitely related to inadequately considered changes in disinfection practice which dramatically and unexpectedly increased lead levels. Similar lead corrosion problems have been identified as potentially related to changes in coagulation chemicals in filtration plants, and one cause of the cryptosporidiosis outbreak in Milwaukee may have been a change in the type of coagulant to improve filter performance. EPA and treatment researchers are now looking carefully at a wide range of chances for improvements in one aspect of treatment or system operation to adversely affect other important goals.

In addition, subtle seasonal or longer term changes in source water quality may have unexpected effects on treatment effectiveness. For example, in the MWRA system, levels of certain more reactive natural organic matter (as measured by UV 254 absorbance) appear to affect the amount of lead leaching from home plumbing or decreases in chloramine residuals with community systems, even if all other aspects of treatment are unchanged. These changes can occur, not because of changes in watershed activities, but due to the relative contribution of "younger" Wachusett or "older" and better Quabbin reservoir water being delivered in wetter or dryer years.

It is not yet clear if there are simple changes in treatment which could be used to adjust for these types of source water quality.

A related issue is the mixing of waters from different sources either routinely or during emergencies. Each system may be properly treated for its source water quality, but the areas where the two water mix may not be optimally treated. Examples include where disinfectant residuals may be lower due to breakpoint chlorination water with a chlorine residual mixes with water with a chloraminated residual or where lead levels may increase due to the use of water with a different type of corrosion control allowing the dissolution of previously formed protective scales.
Additional analyses of water quality interactions are now routinely requested by DEP and undertaken by communities with MWRA technical support when water quality changes are anticipated.

5.12 Source Water Quality and Watershed Protection

As indicated above, source water quality and watershed protection are key factors in maintaining MWRA's unfiltered status. Both are the responsibility of MWRA's partner agency the DCR. With the exception of land acquisition, almost all DCR's water quality related activities are essentially maintenance type activities and are accounted for within DCR's annual current expense budget.

For the purposes of treatment and regulatory compliance planning, this plan assumes that DCR will be able to continue its successful watershed protection efforts, that source water quality will be maintained within the filtration waiver criteria, and that both the CVA and MetroBoston systems will remain unfiltered[22].

The key issues in remaining unfiltered are likely to continue to:

- "Control of the Watershed"
- Source water quality (bacteria and turbidity) and
- Management of organics (UV254) as related to treatment.

Only one aspect of watershed protection falls within the capital budget framework: land acquisition[23]. Under the new institutional arrangements created with the Watershed Trust, MWRA directly funds any DCR land purchases through the MWRA CIP. Protection of the watershed and source water quality through the control of the land within the watershed is one of EPA's yardsticks for measuring the effectiveness of a watershed protection plan. Over the past decade, many of the unfiltered systems have added filtration to their systems. As one of a shrinking group, it can be assumed that MWRA's watershed programs will continue to be under careful EPA scrutiny.

The SWTR includes the requirement that an unfiltered system "Gain ownership or control of the land within the watershed…for the purpose of controlling activities which will adversely affect the

22 The capital cost of adding the filtration components to the CWTP is roughly estimated to be $250 to $300 million, with annual operating costs of about $4 million per year, and of course, additional energy use, greenhouse gas production, and asset protection costs for all the additional process equipment and facilities.
23 While not currently anticipated to require capital expenditures, and not strictly related to the filtration avoidance criteria, MWRA and DCR are closely monitoring long term trends in nutrients, sodium and chloride to understand changes and to moderate or mitigate any effects of the increases.

microbial quality of the water." As originally conceived by EPA in its guidance documents, a well-protected watershed was one which was entirely owned and controlled by the water system.

Many of the west coast unfiltered systems achieve this standard or come close. Seattle owns 100% of its Cedar River watershed. . Portland Oregon's Bull Run watershed is 95 percent owned by the US Forest Service, 4 percent by the city and 1 percent by the US Bureau of Land Management, with legislative and written agreements providing that it be managed for water supply protection. No public access is allowed in either the Seattle or Portland watersheds. San Francisco's watershed is owned by the National Park Service, and while there is public access, it is managed for protection of the supply. The eastern unfiltered systems generally have more fragmented ownership within their watersheds, and own less of the land. Even with over 20 years of aggressive land acquisition, New York City still only owns only about than 16.7 percent of their 1,970 square mile watershed (with other state and local protected lands, the total is still only 38 percent). Portland Maine only owns about 2 percent. The Quabbin, Ware and Wachusett watersheds have a combined DCR ownership of 47.3 percent. If lands protected by other local, state and non-profit groups are included, approximately 67 percent is protected. (If the areas where development is regulated by the Watershed Protection Act are included, the total rises to over 75 percent.) While it began with a standard of requiring 100 percent ownership or control, EPA does recognize the value of on-going efforts to protect undeveloped land over time and the benefits of protecting higher value lands rather than simply owning more land.

In the protection plans approved by DEP to maintain MWRA's waiver of filtration, a continuing program of land acquisition is assumed without specifics on pace and scope. The MWRA/DCR approach has been to identify highest "value" critical lands and intercept them before adverse development occurs. The pace and scale of the program are linked to the ability to "stay ahead" of development which might adversely affect water quality. DCR's land acquisition plans (along with on-going regulatory activity under the Watershed Protection Act) focus on the need for an on-going commitment to preventing adverse development on critical lands through:

- Support of good local community planning;
- Use of Watershed Protection Act (Cohen Bill);
- Purchase of conservation restrictions (CRs); and
- The purchase of land in "fee simple" with the associated long term commitment to payments in lieu of taxes, only if necessary.

Purchases are expected to focus primarily on lands and activities likely to result in microbial contamination of the source water, with more limited focus on ease of management (reduction of fragmentation and boundary issues) and protection of continuous corridors. A critical issue for MWRA over the longer term will continue to be the payment-in-lieu of taxes (PILOT) on land that the DCR owns. Purchases of development rights or conservation restrictions do not create an obligation for PILOT payments and achieve substantially the same long term protection. Therefore there is a strong MWRA preference for having future land acquisition activities largely limited to conservation restrictions.

Figure 5-3

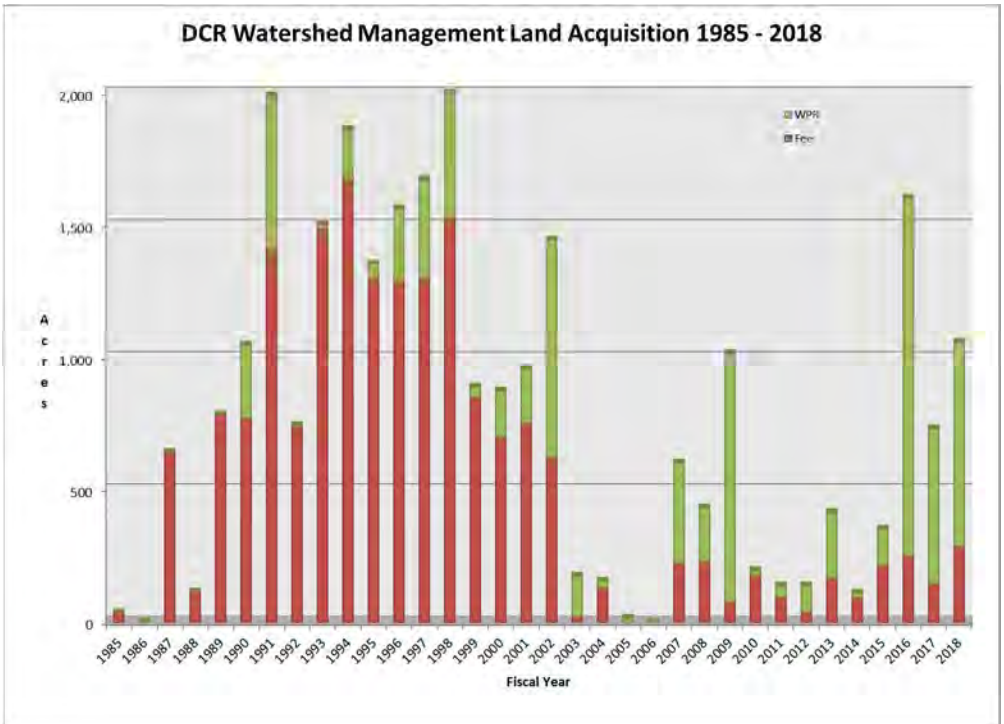


Table 5-4

Watershed	Total Watershed Area	Acres Owned 1985	Percent Owned 1985	Acres Owned 2018	Percent Owned 2018
Wachusett	70, 678 acres	5, 608	7.9	20,743	29.3
Ware River	61,737 acres	19,300	31.3	25,486	41.3
Quabbin	95, 466 acres	51, 792	54.3	61,540	64.5
TOTAL	**227,881 acres**	**76,700**	**33.7**	**107,769**	**47.3**

Opportunities to protect land typically come when the current owners desire to sell the land to retire or relocate. If the development rights or land are not purchased at the point in time, they will usually pass to a developer, and future protection opportunities will be more costly. Timing and the ability to respond to a particular owner's circumstances will continue to be critical to cost effective protection.

Recommendation - Land Acquisition:

- The FY19 CIP contains $1 million per year through FY2023

- *It is recommended that that an average of $1 million continue be allocated annually between FY2024 and FY2033 for the purchase of the most critical lands which are in danger of adverse development.* It is anticipated that these expenditures may not be uniform over time as the DCR takes advantage of opportunities as they arise to prevent degradation of water quality over the medium term (10-20 years). No recommendation is made for activities beyond that period.

In addition to a continuing program of land acquisition, and not strictly related to the filtration avoidance criteria, MWRA and DCR continue to take action to prevent, as well as be better prepared for accidental releases within the watershed. Both roadway and rail traffic present the possibility for an accident to introduce chemicals within the watershed or into the Wachusett Reservoir. DCR has worked with the Massachusetts Highway Department to eliminate direct discharges of road related storm water into the Wachusett Reservoir by rerouting flows out of the watershed and building detention basins. MWRA continues to evaluate ways to better manage the risks of rail transportation through the watershed, beyond the current activities of tracking cargoes and conducting joint spill response exercises with local fire departments and the railroad. *Continue to work with the railroad seeking opportunities to improve track safety within the watershed and along the over-reservoir causeways.*

Table 5-5

Water Master Plan - Watershed Land Acquisition

Existing and Recommended Projects

Last revision 12/28/18

Prioritization

1 Critical
2 Essential
3 Necessary
4 Important
5 Desirable

Project Types

NF	New Facility/System
RF/IC	Replacement Facility/Increase Capacity
Opti	Optimization
AP	Asset Protection
Plan	Planning/Study

Line No	Priority	Project	Project Type	FY18 CIP Project No.	FY18 CIP Contract No.	Project Duration	Total Project Cost ($1000)	FY19-58 Planning Period Cost	Schedule	FY19-23	FY24-28	FY29-38	FY39-58	FY19-58 Planning Period Cost
										5 years	5 years	10 years	20 years	
		LAND ACQUISITION												
5.01		Watershed Land Acquisition	AP	621	60081_7069	7 years	6,404	6,404	FY19-25	5,000	1,404			6,404
		SUBTOTAL - Existing - Land Acquisition					**6,404**	**6,404**		**5,000**	**1,404**	**0**	**0**	**6,404**
5.02		Watershed Land Acquisition	AP	new		as needed	33,596	33,596	FY25-58		3,596	10,000	20,000	33,596
		SUBTOTAL - Recommended - Land Acquisition					**33,596**	**33,596**		**0**	**3,596**	**10,000**	**20,000**	**33,596**
		SUBTOTAL - Existing and Recommended - Land Acquisition					**40,000**			**5,000**	**5,000**	**10,000**	**20,000**	**40,000**

6 Water Treatment and Facilities

6.1 Chapter Summary

This chapter describes the existing treatment facilities put in place to meet regulatory requirements and customer expectations, and outlines what will be required to maintain those facilities over time. The chapter deals first with the John J Carroll Water Treatment Plant (CWTP) serving metropolitan Boston and then with the William A Brutsch Water Treatment Facility (BWTF) serving the three CVA communities.

The Master Plan recommends that:

The existing Carroll Water Treatment Plant requires certain ancillary modifications to optimize its performance and incorporate improvements from lessons learned over the first years of operation. These modifications and improvements have been ongoing and are expected to cost approximately $ 1.7 million in additional funds over the period FY19-20. Investments should be made to convert obsolete facilities at the CWTP and at Cosgrove Intake to provide expanded maintenance and storage space and permanent work space for the SCADA technicians.

Both the CWTP and the BWTF will require regular investments in asset protection to maintain them in proper working order. Approximately $40 million is specific asset protection projects have been identified and are included in the FY19 CIP. Based on the mix of long lived concrete facilities and shorter lived electrical and moving components, it is also prudent to step back and look in greater detail at the anticipated costs and schedule for other asset protection measures. The FY19 CIP contains $465,000 for a study to examine this issue. Work would be done in FY21-22. However, the Master Plan recommends a placeholder value of $30 million for asset protection measures in the FY29-58 time period.

6.2 Current Treatment for Metropolitan Boston

The John J. Carroll Water Treatment Plant was the center piece of the Integrated Water Supply Improvement Program. When it went on-line in July 2005, it consolidated all treatment steps for the metropolitan area into one site at the junction of Marlborough, Southborough and Northborough, essentially at the western edge of the service area. The ozonation system at the plant was initially designed and operated to achieve site-specific

99 percent inactivation of *Cryptosporidium*[1], at least 99.9 percent inactivation of *Giardia*, and at least 99.99 percent inactivation of viruses through ozone contact in primary and extended contactors. Ozone operation was modified in April 2013 to comply with the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) as discussed in Chapter 5. The ozone system is now operated solely in the primary contactors to achieve the required *Giardia* and virus inactivation requirements. The plant was also modified in April 2014 to include ultraviolet (UV) disinfection in place of the former extended ozone contractors to meet the LT2ESWTR requirement for a second primary disinfectant and is operated to achieve the required *Cryptosporidium* inactivation requirement. At the same time, a new chlorine contact channel was constructed downstream of UV to control total coliform regrowth and to provide a redundant virus inactivation capability.

The plant has a maximum day capacity of 405 million gallons per day. Water flows into the plant from the Cosgrove Aqueduct by gravity. Upon completion of the Wachusett Aqueduct pump station in 2019, operators will have the option of pumping water to the plant from the Wachusett Aqueduct, allowing the Cosgrove Tunnel and Cosgrove Intake to be taken out of service for maintenance. Water passes through the plant to the MetroWest Tunnel and Hultman Aqueduct without pumping. The plant is designed and operated as two parallel plants allowing for half plant operations during low flow months for system maintenance and upgrades. The 45 million gallon storage tank is also able to be isolated in two parts for cleaning or maintenance. Pumping is provided at the CWTP for internal plant use and for Northborough and Westborough State Hospital.

The plant generates ozone on-site for primary disinfection of *Giardia* and viruses using purchased liquid oxygen (LOX) and four 3,380 pounds per day ozone generators. The generators can be used in various combinations to feed ozone into four ozone contact chambers. These concrete "under and over" baffled chambers allow the water to be ozonated in several locations, and for measurements of the residual ozone to be made at several points.

The ozone generators are power intensive, and require high quality power. Interruptions, even for less than a second, can cause the ozone generators to shut down. The plant has been modified to stay in operation for very brief periods of ozone generator shut down, but if the outage extends beyond five minutes the plant shuts down and must be restarted. Ozone gas is extremely hazardous and the plant provides negative pressure in the contactors through ozone destruct units. If ozone gas is detected above safe levels in the area above the contactors, the ozone generators automatically shut down which will cause the plant to shut down. Pressure fluctuations within the Cosgrove tunnel caused by any sudden change in flow through the Cosgrove Intake and Power Station can cause vacuum changes and thus cause the ozone units to shut down. With operators trained in procedures for restarting the plant, and the onsite storage in the 45 million gallon clear well and at the

1 The 99 percent or 2-log inactivation was a voluntary operating target for plant operations. It was based on site specific testing infectivity studies of ozone disinfected water. The methodology for demonstrating *Cryptosporidium* was later promulgated in the LT2ESWTR, as this rule was issued after the design was completed.

115 million gallon Norumbega Covered Storage Tank, no service disruptions have resulted due to plant interruptions and shut downs.

The plant has full back-up power capability with four 2,000 KW diesel generators. These are used when line power is down and to avoid a plant shutdown if a power interruption seems likely, and can be used to reduce demand charges and as part of utility demand response programs reducing the cost of electricity.

Once the water is ozonated, it passes through medium pressure UV treatment units to achieve 99 percent inactivation of *Cryptosporidium*. UV disinfection uses intense light energy to disrupt or alter the DNA of microorganisms rendering them incapable of reproducing and thus causing illness. UV disinfection has no known disinfection by-products and is not known to increase the risk of re-growth in the distribution system.

The UV treatment units were installed within the extended ozone contactors adjacent to the post treatment building. This location was chosen because it:

- Would not preclude later addition of filtration;
- Minimized the value of facilities that would be rendered obsolete if filtration were later added;
- Took advantage of the fact that UV disinfection is more effective after ozonation then before;
- Minimized the reduction in storage within the storage tank.

Water then flows into a chlorine contact channel where hypochlorite and fluoride are added to the water. The water enters the post treatment building where it receives corrosion control, and ammonia to form monochloramine for residual disinfection. Corrosion control involves raising the alkalinity with sodium carbonate (soda ash), and adjusting the pH with carbon dioxide.

CWTP is the Operations Control Center (OCC) for the entire treatment and transmission system. The treatment and transmission operators on duty are responsible for operations from Shaft 5 of the City tunnel in Weston all the way to the CVA system treatment and storage facilities in Ware and Ludlow. The plant control room is connected via SCADA to all Western Operations facilities.

The CWTP OCC also includes duplicate equipment to serve as a back-up for the metropolitan operations control center for both water and sewer functions if the Chelsea OCC is unavailable. An emergency operations center (EOC) in the training room of the CWTP operations building serves as a back up to the Chelsea EOC as well. Critical MIS functions will also have back up capability at the CWTP to ensure continued operations if the Chelsea MIS center is inoperable.

The plant is normally operated by a minimum of 3 operators per shift. During the day shift, additional operators and management staff are present, as well as maintenance staff.

During off shifts, the operators also manage the BWTF in Ware, and if available, one of the operators may perform off-site monitoring rounds.

The plant is extensively automated for both operations and regulatory compliance. Monitoring of raw water quality occurs both at the Cosgrove Intake at Wachusett Reservoir several hours upstream of the plant, and at the plant inlet. Treatment parameters are tracked throughout the process for calculating regulatory compliance and for process control feedback.

Monitoring instrumentation requires regular maintenance and calibration if it is to be relied on for process control and compliance. Instrumentation and electronic control equipment must also be supported by the manufacturer, and may become obsolete if the manufacturer no longer supports it with maintenance, updates and spare parts. The SCADA system hardware and software at CWTP is scheduled to be replaced in the short-term.

Table 6-1 JJCWTP Treatment Process Control Instrumentation

Parameter	Purpose	Number of Instruments
Temperature	Compliance and Process Control	37
pH	Compliance and Process Control	9
Turbidity	Compliance	2
UV 254 Absorbance	Process Control and Source Monitoring	2
Ozone Residual	Compliance and Process Control	20
Ozone Ambient Air	Worker Safety	20
Sulfur Dioxide Ambient Air	Worker Safety	2
Oxygen Ambient Air	Worker Safety	4
Chlorine Ambient Air	Worker Safety	2
Ammonia Ambient Air	Worker Safety	2
Carbon Dioxide Ambient Air	Worker Safety	4
Pressure	Process Control	42
Level	Process Control	56
Free Chlorine	Process Control	4
Total Chlorine	Process Control and Compliance	4
Conductivity	Process Control	1
Oxidization Reduction Potential	Process Control	4
Fluoride	Compliance and Process Control	2
Particle Count	Source Monitoring	2
Flow Metering	Process Control and Compliance	82
Flue Gas NOx	Process Control and Compliance	4
Dewpoint	Process Control	4
Oxygen Percent	Process Control	4
Ozone Gas Concentration	Process Control	10
Contaminant Monitoring System	Security	2
UVT	Process Control	4

6.3 Asset Management and Ancillary Modifications to the Existing CWTP

As major facilities age and as operating conditions and technologies change opportunities present themselves to make “ancillary modifications” to the plant to optimize operations, facilitate maintenance, and achieve efficiencies in operating.

A series of plant improvements and evaluations have been undertaken.

1. Liquid oxygen is stored in three separate storage tanks. The liquid is converted to gas in the vaporizers and then piped to the Ozone Building through two separate 4-inch diameter stainless steel pipes. The two pipes were combined into a single pipe in the Ozone Building. This single pipe carried all the oxygen to the ozone generators. Failure of this pipe would have disrupted plant operation. A second oxygen feed pipe was constructed to provide redundancy in oxygen supply piping.

2. Vacuum relief valves were installed over the effluent channel in the Ozone Building to address high vacuum conditions that can occur during rapid flow changes. Positive pressurization also occurred during certain flow conditions. As discussed above, both conditions can result in plant shutdowns. Positive pressurization results in ozone release inside the work space of the plant which has worker safety implications. The larger the release, the longer it takes to clear the area and allow restart of the plant. Modifications to the pressure relief valves and piping were constructed to allow positive pressure to be released outside the building, thereby limiting worker exposure to ozone, and allowing for quicker plant restart.

3. The Wachusett Aqueduct is the emergency water supply conduit to the metropolitan Boston area in the event that the Cosgrove Intake or Tunnel is damaged or taken out of service. In order to meet sanitary conditions, the Wachusett Aqueduct cannot be connected “live” to the plant; some type of physical separation is required during normal operations to prevent a possible cross connection. This was initially achieved by the removal of a six-foot long piece of 120-inch diameter pipe and capping the pipe ends. Reactivation of the Wachusett Aqueduct would require the removal of the two 120-inch diameter flange caps and the insertion of a 6-foot long spool piece, taking approximately two days. Recently completed construction of valves to be installed on this pipe will allow for a rapid transition to the Wachusett Aqueduct, while still achieving an acceptable sanitary air gap between raw water supply piping and the plant during normal operations.

   It is important to note that, as discussed in the Chapter 7, the flow from the Wachusett Aqueduct is only able to meet winter time demands; and that it currently would require chlorine treatment at the reservoir because the flow passes below the CWTP process elevations and cannot be ozonated. Construction of the Wachusett Aqueduct Pump Station will allow the full capacity of the Aqueduct to be treated at the CWTP. This will provide the ability to supply approximately 230 million gallons per day and allow the potential for shut down of the Cosgrove Aqueduct or Intake during the lower demand portions of the year.

4. The plant receives frequent (8 to 9 per week) deliveries of commercially produced liquid oxygen, and a delay in deliveries could interrupt treatment. A study has recommended providing additional liquid oxygen storage and more flexible supply piping as a way to achieve additional reliability. Adding one or two additional liquid oxygen storage tanks would provide 3 or 6 days of additional storage at a cost of $1 to 1.5 million dollars.

5. The ozone generators were initially cooled with raw water. An open-loop system was selected during design as it has a lower operating cost than a closed-loop system. Premature fouling of the generator sleeves and subsequent corrosion of the stainless steel sleeves and plate were discovered due to biological growth in the generators. A closed-loop cooling system was designed and installed to circulate cooling water through heat exchangers. This has provided for more certain control of cooling water quality.

6. Concrete condition monitoring in all chambers has indicated incipient failure of expansion joints in the ozone contact chambers due to harsh conditions. Repair work will likely be done in stages over several years as part of annual winter maintenance while half the plant can be removed from service, and thus will likely be funded out of the CEB.

7. Security to the entrance of CWTP has been improved to prevent access to the plant by unauthorized vehicles and also to document the number of people at the facility, including cameras to document activity at the entrance. Additional security measures, partly funded by a federal grant, and a covered entrance to help concentrate lighting and provide weather protection for security staff is under design.

It is expected that additional potential modifications will be identified over the next several years of operations and maintenance and these will be incorporated into later ancillary modifications to the plant. Approximately $1.7 million remains to be spent during FY19-20.

All facilities require regular investments over the long term to maintain them in good working order. While the concrete and major piping of the CWTP should provide good service for 50-100 years, much of the operating equipment can be expected to need replacement or refurbishment after providing service on the order of 10 to 20 years. The plant has substantial electrical and mechanical systems which will likely require replacements/upgrades starting at a 10-year life. It is anticipated that the SCADA software and hardware will need to be replaced within the next 5 to 10 years.

Certain equipment is operated on a continuous basis and experiences severe duty, such as the sluice gates and valves that provide continuous hydraulic control for the plant and which control application of chemicals for treatment processes. Replacement of these types of equipment is difficult as plant by-pass or complete shut downs may be required. Based on condition inspections, it is anticipated that the sluice gates within the post treatment building which have experienced accelerated aging due to ozone exposure may have a useful life of only 10 to 20 years rather than the more typical 50. Replacement cost is estimated to be approximately $1 million.

Other equipment, such as chemical storage tanks, ozone generators, and the plant water system, were installed and the building construction was completed around them. This sets up the potential for difficult future replacement projects toward the end of the equipment life. The ozone generators are expected to have a useful life of about 20 additional years, assuming a “rebuild” every ten years at a cost of $1 million. An evaluation of whether it is possible and advisable to “derate” the ozone generators after the UV disinfection is operational is recommended. Lowering the capacity of some of the generators would allow improved operational flexibility, and potentially reduce ozone operating costs during low flow periods without sacrificing reliability.

The soil on the top of the covered storage tank has been found to be less permeable than required, causing ponding of water above the water storage facility, and hindering drainage of rainwater. This is an unacceptable condition, as it increases the risk for leakage of stormwater into the finished water tank, potentially compromising its sanitary protection. In addition, MWRA has improved its design approach to the waterproofing and drainage system on subsequent covered storage tanks, reducing the risk of water intrusion. The soil must be removed and replaced with suitable material, and the waterproofing replaced. An initial portion of the work is being done on the roof over the UV area. A project to design and construct a long-term solution to this problem is scheduled in the FY24-27 frame at a cost of approximately $7 million.

It is impossible to predict which specific systems, non-equipment assets, and equipment will need replacing at any point in the future. However, it is prudent to expect that a percentage of the assets will need replacing, and that significant efforts will be required to replace some of them after 20 years of service. Good planning for such replacements should include a regular process for project identification and prioritization along the lines of the model being developed by the MWRA’s asset replacement task team. By the end of this Master Plan’s planning horizon, portions of the CWTP will be almost 50 years old, and even the new UV equipment will have been in service for 40 years.

For this reason, staff have identified a number of specific asset replacement projects in the shorter term while simultaneously recommending a study of future asset protection needs. The study is schedule for FY21-22 with an estimated cost of $465,000. Other projects listed in the FY19 CIP include:

- A Control Room Fire Suppression System for FY20 at a cost of approximately $325,000. This project will replace the existing wet fire sprinkler system in the CWTP control room, communications room, electrical room and emergency operations center with a clean agent type system that does not use water to suppress fire.

- LOX Yard Redundancy is scheduled in the FY21-22 period at an approximate cost of $670,000. This project will provide new piping, valves, vaporizer and/or additional liquid oxygen storage to eliminate single points of failure in the CWTP Liquid Oxygen Yard.

- Water Pumps Variable Frequency Drive Replacements. This project is scheduled for FY21-22 at an estimated cost of $181,000. The variable frequency drives in the CWTP Water System are 13 years old and should be replaced in the near future. The normal life of VFDs is shorter than the pumps they control. It is unlikely that the existing VFDs will be operable until 2030 when the plan water pumps are scheduled to be replaced.

- Re-Build of the Ozone Generators is expected to be required in the FY22-23 period at an approximate cost of $930,000. To maintain proper operation, it is necessary to re-build the ozone generators including cleaning and gasket replacement on a periodic basis.

- Soda Ash Equipment Replacement is scheduled for the FY 23-24 period at an approximate cost of $415,000 in order to maintain operability.

- Chemical System Pipe Pumps and Tank Replacement is scheduled for the FY28-29 period at an estimated cost of $4 million. The condition of the plant chemical system components varies. There have been leaks in the hypochlorite pipes and tanks. The ammonia, bisulfite and fluoride feed systems are aging. This project will rehabilitate these systems as needed.

- HVAC Equipment Replacement is scheduled in the FY20-22 period at an approximate cost of $1.75 million. The HVAC equipment at CWTP is over 10 years old. The refrigerant used in this equipment (R-22) is being phased out. The existing equipment will not function with the new refrigerant. Replacement of this equipment will be necessary.

- Water Pump Replacement is scheduled in the FY28-31 period at an approximate cost of $2 million. The plant water pumps will need to be replaced in the future as they approach the end of their useful life.

- Ozone Generator Replacement is scheduled in the FY28-31 period at an estimated cost of approximately $20 million. The generators are scheduled to be rebuilt in 2022. Eventually spare parts will no longer be available so it is expected that the generators will need to be fully replaced.

- Ultra Violet Reactor Replacement is scheduled for FY33-35 at an estimated cost of approximately $10 million. It is anticipated that by 2034, spare parts will no longer be available for the existing reactors necessitating total replacement.

Although the projects noted above have already been identified, the Master Plan recommends a placeholder value of an additional $30 million in the FY29-58 time period to address costs identified in the future asset protection study.

6.4 Current Treatment for the Chicopee Valley Aqueduct System

The William A Brutsch Water Treatment Facility (BWTF) provides primary and residual disinfection for the Chicopee Valley Aqueduct (CVA) system serving the three communities of Wilbraham, Chicopee and South Hadley Fire District No. 1. The facility, placed into service in 2000 and modified in 2014, is located adjacent to the CVA and the Swift River just north of Route 9 in Ware. The facility replaced interim disinfection facilities and allowed Wilbraham and South Hadley Fire District #1 to discontinue their chlorination facilities (although South Hadley employs booster chlorination seasonally deep within their distribution system). Due to its location downstream of the Nash Hill Tanks, and larger distribution system, Chicopee still needs to provide booster disinfection at their entry point to maintain adequate chlorine residual to the ends of their system. Each community also provides their own corrosion control treatment.

The facility has a maximum day capacity of 16 million gallons per day and provides multiple primary disinfection steps to meet the requirements of the LT2ESWTR. Treatment consists of medium pressure UV treatment units, chemical injection equipment to inject sodium hypochlorite (chlorine) into the CVA and process monitoring equipment. The UV system achieves 99 percent inactivation of *Cryptosporidium*. The travel time between the addition of chlorine and a monitoring location in Ludlow ("the Ludlow Monitoring Station" or LMS) provides the necessary contact time to meet the required CT values for 99.9 percent *Giardia* inactivation and 99.99 percent virus inactivation, meeting current Surface Water Treatment Rule requirements. Process monitoring includes monitoring for pH, temperature, turbidity, UV absorbance, and chlorine residual.

The facility is highly automated and can be monitored and controlled remotely via SCADA. The BWTF is staffed a single shift each day, and monitored and controlled remotely from the CWTP during off shifts. Day shift is two operators.

Table 6-2 BWTF Treatment Process Control Instrumentation

Parameter	Purpose	Number of Instruments
Temperature	Compliance and Process Control	4
pH	Compliance and Process Control	3
Turbidity	Compliance	1
UV 254 Absorbance	Process Control and Source Monitoring	1
Pressure	Process Control	2
Level	Process Control	4
Free Chlorine	Process Control and Compliance	3
Conductivity	Process Control	1
Flow Metering	Process Control and Compliance	5
Contaminant Monitoring System	Security	1

6.5 Asset Management for the Existing BWTF

The assumptions which lead to planning for periodic asset replacement at CWTP are similar for BWTF. Most of the equipment is not subject to the kind of physical or operating constraints as equipment at CWTP and subsequently a smaller percentage of total replacement cost funding can be assumed. It is anticipated that the asset protection study being done for the CWTP will inform decision making for an asset protection schedule and cost estimate for the BWTP.

6.6 Recommended Actions and Future Capital Improvements

- It is expected that additional potential modifications will be identified over the next several years of operations and maintenance and these will be incorporated into later ancillary modifications to the plant. Approximately $1.7 million remains to be spent during FY19-20.

- A project to design and construct a long-term solution to issues associated with roof drainage is scheduled in the FY24-27 frame at a cost of approximately $7 million.

- One project not noted within the discussion on asset replacement has been identified and is in the CIP for the FY25-28 period at an estimated cost of $2.25 million. This is Wachusett Algae project which would entail the construction of an automated chemical dispersing system for algae control. Staff closely monitors algae in the Reservoir and to date, other management mechanisms have been successful. However, long-term implementation of an automated system may be necessary.

- A Control Room Fire Suppression System for FY20 at a cost of approximately $325,000. This project will replace the existing wet fire sprinkler system in the CWTP control room, communications room, electrical room and emergency operations center with a clean agent type system that does not use water to suppress fire.

- LOX Yard Redundancy is scheduled in the FY21-22 period at an approximate cost of $670,000. This project will provide new piping, valves, vaporizer and/or additional liquid oxygen storage to eliminate single points of failure in the CWTP Liquid Oxygen Yard.

- Water Pumps Variable Frequency Drive Replacements. This project is scheduled for FY21-22 at an estimated cost of $181,000. The variable frequency drives in the CWTP Water System are 13 years old and should be replaced in the near future. The normal life of VFDs is shorter than the pumps they control. It is unlikely that the existing VFDs will be operable until 2030 when the plan water pumps are scheduled to be replaced.

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- Soda Ash Equipment Replacement is scheduled for the FY 23-24 period at an approximate cost of $415,000 in order to maintain operability.

- Chemical System Pipe Pumps and Tank Replacement is scheduled for the FY28-29 period at an estimated cost of $4 million. The condition of the plant chemical system components varies. There have been leaks in the hypochlorite pipes and tanks. The ammonia, bisulfite and fluoride feed systems are aging. This project will rehabilitate these systems as needed.

- HVAC Equipment Replacement is scheduled in the FY20-22 period at an approximate cost of $1.75 million. The HVAC equipment at CWTP is over 10 years old. The refrigerant used in this equipment (R-22) is being phased out. The existing equipment will not function with the new refrigerant. Replacement of this equipment will be necessary.

- Water Pump Replacement is scheduled in the FY28-31 period at an approximate cost of $2 million. The plant water pumps will need to be replaced in the future as they approach the end of their useful life.

- Ozone Generator Replacement is scheduled in the FY28-31 period at an estimated cost of approximately $20 million. The generators are scheduled to be rebuilt in 2022. Eventually spare parts will no longer be available so it is expected that the generators will need to be fully replaced.

- Ultra Violet Reactor Replacement is scheduled for FY33-35 at an estimated cost of approximately $10 million. It is anticipated that by 2034, spare parts will no longer be available for the existing reactors necessitating total replacement.

- Both the CWTP and the BWTF will require regular investments in asset protection to maintain them in proper working order. Based on the mix of long lived concrete facilities and shorter lived electrical and moving components, approximately $465,000 is recommended in the FY21-22 period for a consultant study to identify asset protection needs at the CWTP. Asset protection needs at the BWTP are also expected to be identified in this time period and the next Master Plan will reflect projects required for the BWTP. The Master Plan recommends that $30 million in placeholder funds be added to the CIP to address additional asset protection needs at the CWTP in the FY 29-58 period.

Table 6-3
Water Master Plan - Water Treatment and Facilities
Recommended Projects

Last revision 12/28/18

Prioritization	Project Types	
1 Critical	NF	New Facility/System
2 Essential	RF/IC	Replacement Facility/Increase Capacity
3 Necessary	Opti	Optimization
4 Important	AP	Asset Protection
5 Desirable	Plan	Planning/Study

Line No	Priority	Project	Project Type	FY18 CIP Project No.	FY18 CIP Contract No.	Project Duration	Total Project Cost ($1000)	FY19-58 Planning Period Cost	Schedule	FY19-23	FY24-28	FY29-38	FY39-58	FY19-58 Planning Period Cost
										5 years	5 years	10 years	20 years	
		WATER TREATMENT AND FACILITIES												
6.01	2	Existing Facility Modifications CP7	Opti	542	53426_6650	1 year	810	810	FY19-20	810				810
6.02	2	Ancillary Modifications - Construction 2	Opti	542	53457_7085	1 year	902	902	FY19-20	902				902
6.03	2	Technical Assistance 8, 9, 10	Opti	542	75531_7407 75601_7543 75602_7544	1 year	1,563	1,563	FY19-20	1,563				1,563
6.04	2	CWTP Storage Tank Roof Drainage	Opti	542	73470_7376	3 years	7,000	7,000	FY24-27		7,000			7,000
6.05	4	Wachusett Algae - Design and Construction	Opti	542	53428_6671 53448_6889	4 years	2,250	2,250	FY25-28		2,250			2,250
6.06	3	CWTP Control Room Fire Suppression	AP	555	54000_7592	1 year	325	325	FY20	325				325
6.07	3	CWTP AP Study	AP	555	54001_7594	1 year	465	465	FY21-22	465				465
6.08	3	Lox Yard Redundancy	AP	555	54002_7594	1 year	670	670	FY21-22	670				670
6.09	3	CWTP Water Pump VFD Replacement	AP	555	54003_7595	1 year	186	186	FY21-22	186				186
6.10	3	Ozone Generator Re-Build	AP	555	54004_7596	2 years	930	930	FY22-23	930				930
6.11	3	Chemical Pipe System Replacement	AP	555	54005_7597	2 years	4,000	4,000	FY28-29		2,000	2,000		4,000
6.12	3	Post Treatment Building Soda Ash Equipment Replacement	AP	555	54006_7598	2 years	465	465	FY23-24	415	50			465
6.13	3	HVAC Equipment Replacement	AP	555	54007_7605	3 years	1,750	1,750	FY20-22	1,750				1,750
6.14	3	Water Pump Replacement	AP	555	54008_7606	3 years	2,000	2,000	FY28-31		500	1,500		2,000
6.15	3	Ozone Generator Replacement	AP	555	54009_7607	3 years	20,000	20,000	FY28-31		5,000	15,000		20,000
6.16	3	Ultra Violet Reactor Replacement	AP	555	54010_7608	2 years	10,000	10,000	FY33-35			10,000		10,000
		SUBTOTAL - Existing - Water Treatment and Facilities					**53,316**	**53,316**		**8,016**	**16,800**	**28,500**	**0**	**53,316**
6.17		CWTP Asset Protection	AP			30 years	30,000	30,000	FY29-58			5,000	25,000	30,000
		SUBTOTAL - Recommended - Water Treatment and Facilities					**30,000**	**30,000**		**0**	**0**	**5,000**	**25,000**	**30,000**
		SUBTOTAL - Existing and Recommended - Water Treatment and Facilities					**83,316**			**8,016**	**16,800**	**33,500**	**25,000**	**83,316**

7 The Transmission System

7.1 Chapter Summary

The transmission system consists of over 100 miles of tunnels and aqueducts in daily use which transport water by gravity from the supply reservoirs to points of distribution within the MWRA service area as well as back-up facilities for use in emergencies. The transmission system has evolved over time in response to increased population, expansion of the service area and the need to go farther from developed areas for adequate and high quality sources of water. This system was designed in such a way that the basic layout remains fundamentally sound and useable. The performance standards required to be met by a major transmission system are twofold. The system must be able to transport sufficient water to meet the maximum daily demands of the service area. Secondly, the system must be reliable in that it must have sufficient redundant components to ensure a continued supply of water if any single "leg" of the system were to fail or needed to be taken off-line for maintenance or rehabilitation.

The previous Water System Master Plans contained a number of recommendations for transmission system improvements. The major recommendations addressed the need to continue to develop solutions to identified short-falls in system redundancy. The 2006 plan noted that, in the interim, system improvements over time have allowed for older facilities, no longer in daily use, to remain as critical emergency standby facilities as long as maintained and linked to new facilities where necessary. The importance of this was demonstrated in May 2010 (May 1-4, 2010) when a coupling gave way on a 120-inch diameter connecting pipe adjacent to Shaft 5A where the MetroWest Water Supply Tunnel meets the City Tunnel. This catastrophic leak resulted in an immediate need to shut-down and re-direct flow to the Metropolitan area. Adequate flow and pressure for all uses was maintained throughout the incident. A precautionary boil order was put in place as the Sudbury Reservoir system, the Sudbury Aqueduct, the Chestnut Hill Reservoir and the Chestnut Hill Emergency Pump Station were all activated. Preparations were also made to activate the Spot Pond Reservoir if necessary. The initial break took place on May 1st and on May 3rd, the repairs were completed and the line pressurized and put back into service. Extensive coliform testing within the communities allowed the lifting of the boil order on May 4th. MWRA worked extensively with the Governor's office, DEP and many other agencies through the Massachusetts Emergency Management Agency to mitigate the effect of the break.

The ability to maintain flow and pressure for fire protection, sanitation and, with the precaution of the boil order, all other household uses demonstrated the value of redundancy. The implementation of the emergency measures and the cost of the boil order demonstrated the need for redundancy that allows fully potable water to be delivered. This "lesson" has been a factor in long-term redundancy planning subsequent to this event and will be fully discussed later in this chapter.

The events of May 2010 confirmed the need to move expeditiously forward with redundancy planning, design and construction. But, it also underscored the fact that while failures of the actual tunnels may be of relatively less concern, failures of connecting pipes, valves or other appurtenant structures of the tunnel system could have the same system impact. Clearly, the goal of the redundancy planning is to allow the seamless transfer to the redundant systems without a disruption in the supply of potable water. However, maintaining the older stand-by facilities for emergency use if needed will continue to be a component in MWRA's ability to respond to a range of operational or emergency disruptions.

At the time of the break, rehabilitation of the Hultman Aqueduct was underway, including additional interconnections between the Aqueduct and the MetroWest Water Supply Tunnel (MWWST). This project ultimately has allowed the seamless transfer of water between those two facilities increasing the water system redundancy and operational flexibility. In addition, in 2008, MWRA initiated Concept Planning to address redundancy shortfalls for the Cosgrove Tunnel and for the Metropolitan Tunnel System including the City Tunnel, City Tunnel Extension and the Dorchester Tunnel. This chapter will provide an update on redundancy work undertaken to date and identify the remaining goals to be accomplished.

The organization of this chapter is generally focused on the assessment of the transmission system in terms of both its physical condition and an assessment of how well it meets the goals for reliability, including redundancy. The components of the system that operate under normal conditions are discussed first, organized for discussion geographically, beginning at the Quabbin Reservoir and moving through facilities and structures to the eastern part of the system. Following the discussion of active facilities, the portions of the system that are not in daily use and that are maintained for emergency use, are discussed. Dams are discussed separately in Section 7.6 followed by a Summary of Recommended Improvements in Section 7.7.

Summary of Chapter Recommendations

The Master Plan identifies approximately $1.645 billion in transmission system project needs for the FY19-58 timeframe, including all projects currently in the FY19 CIP as well as recommended projects. Projects specific to water treatment facilities and anticipated needs to ensure continued production of high quality drinking water are discussed in Chapters 5 and 6.

It is worth noting (and as more thoroughly explained elsewhere in this chapter) that the list of redundancy related projects in the CIP has greatly expanded since the 2013 Master Plan. This is due to the extensive work done to both identify projects that are critical to short term risk reduction while Metropolitan Redundancy planning and design proceeds but also the development of a specific framework for implementation of that redundancy. Some of the projects listed below are included here rather than only within the Metropolitan System Chapter because these projects (WASM 3 rehabilitation, Section 101) are necessary to fully implement the long term redundancy plan for the Metropolitan tunnels.

Transmission System Projects already in the FY19 CIP

The FY19 CIP includes most notably the following transmission system projects:

- Tops of Shafts Interim Improvements Design and Construction

- Chestnut Hill Emergency Pump Station Improvements Design and Construction
- Chestnut Hill Emergency Pump Station Emergency Generator Design and Construction
- WASM 3 Rehabilitation-MEPA, Design and Construction
- WASM/Spot Pond Supply Mains West PRV Design and Construction
- Shafts 5 and 9 Building Improvements Design and Construction
- Section 101/Waltham Section Design and Construction
- Commonwealth Avenue Pump Station Improvements Design
- Metropolitan Tunnel Redundancy Conceptual Design and EIR
- Metropolitan Tunnel Redundancy Construction Management
- Metropolitan Tunnel Final Design and Engineering Services
- Tunnel Construction
- Tops of Shafts Connecting Mains Surface Construction
- Tops of Shafts Rehabilitation Design and Construction
- Shaft 7 Buildings Design and Construction
- Cosgrove Tunnel Redundancy
- Winsor Power Station Upgrades and Quabbin Buildings Rehabilitation Design and Construction
- Shaft 12 Isolation gate Construction
- Quabbin Aqueduct Inspection
- Ware River Intake Valve Replacement Design and Construction
- Rehabilitation of Oakdale Turbine Design and Construction
- Rehabilitation of Wachusett Gatehouse/Bastion and Lower Gatehouse
- Oakdale High Line Replacement

- Valve Chamber and Storage Tank Access Improvements Design and Construction
- Evaluation of Farm Pond Buildings and Waban Arches
- Waban Arches Rehabilitation Design and Construction
- Farm Pond Inlet and Chamber and Gatehouse Design and Construction
- Sudbury/Foss Dam Improvements/Wachusett North Dike Overtopping Protection Design and Construction
- Quinapoxet Dam Removal Design and Construction
- Short term repairs to the Sudbury Aqueduct-Phases 1 and 2
- The Ash Street Sluice gates replacement
- Cosgrove Valve Replacement Design and Construction
- Cosgrove Flat Roof Replacement
- Electrical Distribution Upgrades at Southborough
- Cathodic Protection-Shafts E, L and W16
- Cathodic Protection Western System

Projects Recommended in the Master Plan

- Metropolitan Tunnel Rehabilitation
- Cosgrove Tunnel Inspections
- Covered Storage Asset Protection-Nash Hill
- Covered Storage Asset Protection-Norumbega
- Covered Storage Asset Protection-Loring Road
- Covered Storage Asset Protection-Blue Hills
- Dams Asset Maintenance
- Quabbin Spillway Improvements

7.2 Existing System Overview

As noted above, the system was built over time while maintaining the geographical advantage inherent to the Boston location. That is, while much of the service area is relatively low in elevation, supply sources are located at higher elevations allowing much of the system to be served by gravity. As the metropolitan areas in eastern Massachusetts grew, the service area expanded to include services areas served through the use of pump stations. However, approximately 80% of the water delivered by MWRA remains served by gravity flow. About one quarter of the MWRA communities pump some or all of the water delivered by MWRA to reach higher local service zones. Figure 7-1 shows the full system, including transmission and supply facilities currently held in reserve for emergency use. Table 7-1 provides overview information on each of the active and stand-by aqueducts and tunnels.

The principal structural components of the MWRA system consist of Quabbin and Wachusett Reservoirs, the Ware River intake and the deep rock tunnels and surface aqueducts that deliver water by gravity eastwards to the approximately 280 miles of pipe that distribute water to 44 metropolitan area communities. In addition, Clinton, Leominster and Worcester take directly from Wachusett Reservoir or the Quabbin Aqueduct and the Chicopee Valley Aqueduct (CVA) system delivers water to three communities to the southwest of Quabbin Reservoir, (i.e. Chicopee, Wilbraham and South Hadley Fire District No. 1).

Quabbin Reservoir has a maximum storage capacity of 412 billion gallons, equivalent to nearly six years of supply at current demands. It is fed by a well-protected watershed of 186 square miles. Quabbin Reservoir can also receive water from the Ware River watershed through the Shaft 8 intake structure, which diverts water to the Quabbin. Wachusett Reservoir has a maximum capacity of 65 billion gallons and is fed by a slightly more developed watershed that is 107 square miles. More information on these sources and operating considerations is contained in Chapters 4 and 5.

Figure 7-2 shows system inflows and outflows. Runoff from the Wachusett Reservoir watershed is normally enough to support all metropolitan area demands in the spring but it needs supplemental supply from Quabbin in the drier months to maintain water elevation. The transfer of water from Quabbin is also essential to maintain high water quality in the Wachusett Reservoir. Ware River water is normally diverted to Quabbin in high runoff months to take advantage of Quabbin’s long detention times to improve water quality. Flow out of the reservoirs is made up of withdrawals for water supply, required releases, and overflows when the reservoirs are full.

Water is discharged from the Quabbin Reservoir primarily from the Quabbin Tunnel, which has a flow capacity of 610 MGD. However, flow is restricted by the Oakdale Turbine and bypass valve capacity to approximately 300 MGD. The water enters the aqueduct at Quabbin Tunnel Intake, Shaft 12, and travels over 24 miles to Wachusett Reservoir. Releases from Quabbin also occur through the Chicopee Valley Aqueduct, which supplies an average of 8 MGD to three communities west of the Quabbin, and to the Swift River.

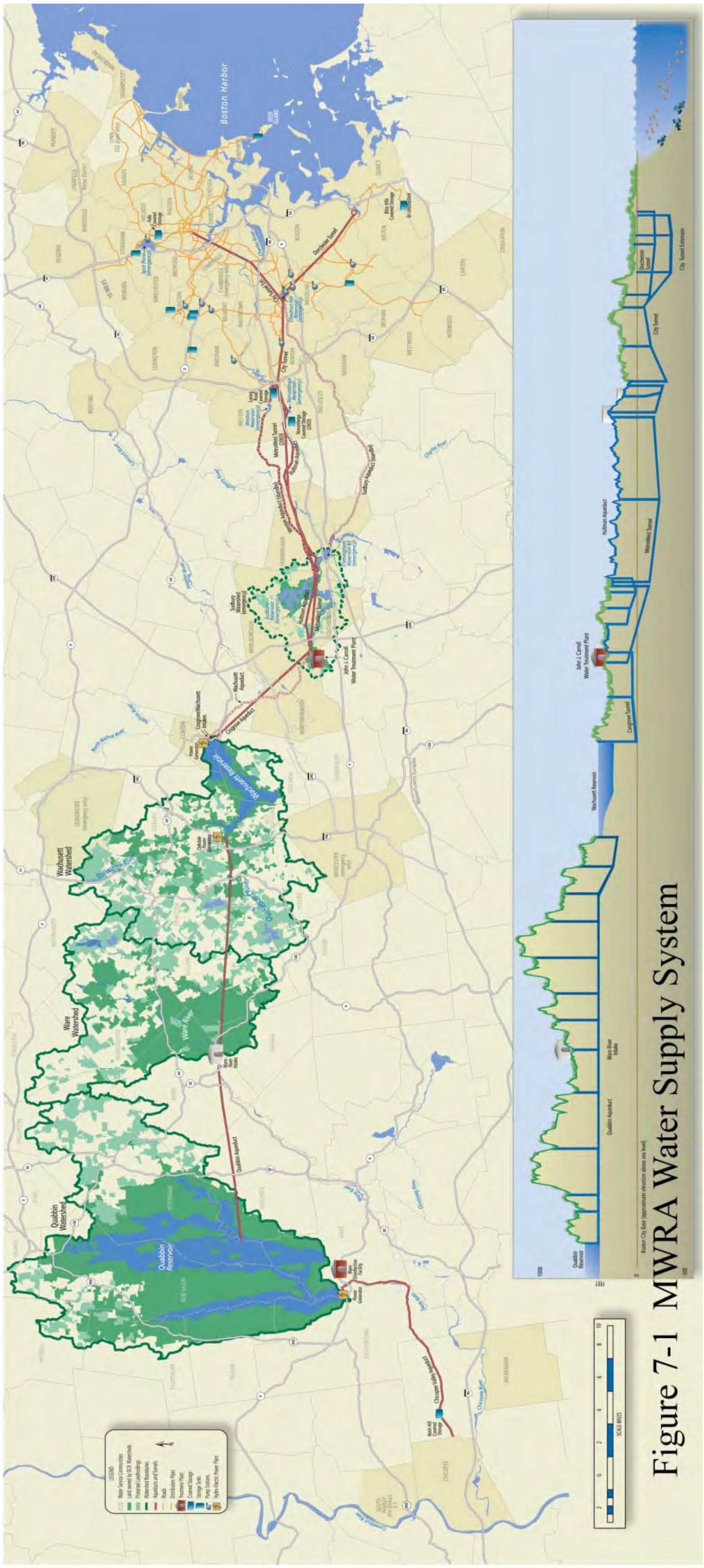


Figure 7-1 MWRA Water Supply System

Table 7-1
Overview Information on Aqueducts and Tunnels

Aqueduct/Tunnel	Year Built	Capacity (mgd)	Diameter (ft)	Length (miles)	Types of Construction	Status
Chicopee Valley Aqueduct	1949 [1]	24	3-4	14.8	steel reinforced concrete	Active
Quabbin Tunnel	1939	610	13	24.6	concrete lined rock	Active
Cosgrove Tunnel	1967	600	14	8	concrete lined rock	Active
Wachusett Aqueduct	1897 [2]	320	10-12	12	brick, concrete, open channel, gravity	Stand-by
MWWST	2003	450	14	17.6	concrete lined rock	Active
Southborough Tunnel [3]	1940	600	14	3	concrete lined rock	Active
Hultman Aqueduct	1940 [4]	325	11-12	15	concrete; steel	Active
Weston Aqueduct	1903	250	10-12	13.5	brick, concrete, gravity	Stand-by
City Tunnel	1950	300	12	5.4	concrete lined rock	Active
City Tunnel Extension	1963	200	10	7	concrete lined rock	Active
Dorchester Tunnel	1976	200	10	6.4	concrete lined rock	Active
Sudbury Aqueduct	1878	90	7-9	17.4	brick, gravity	Stand-by

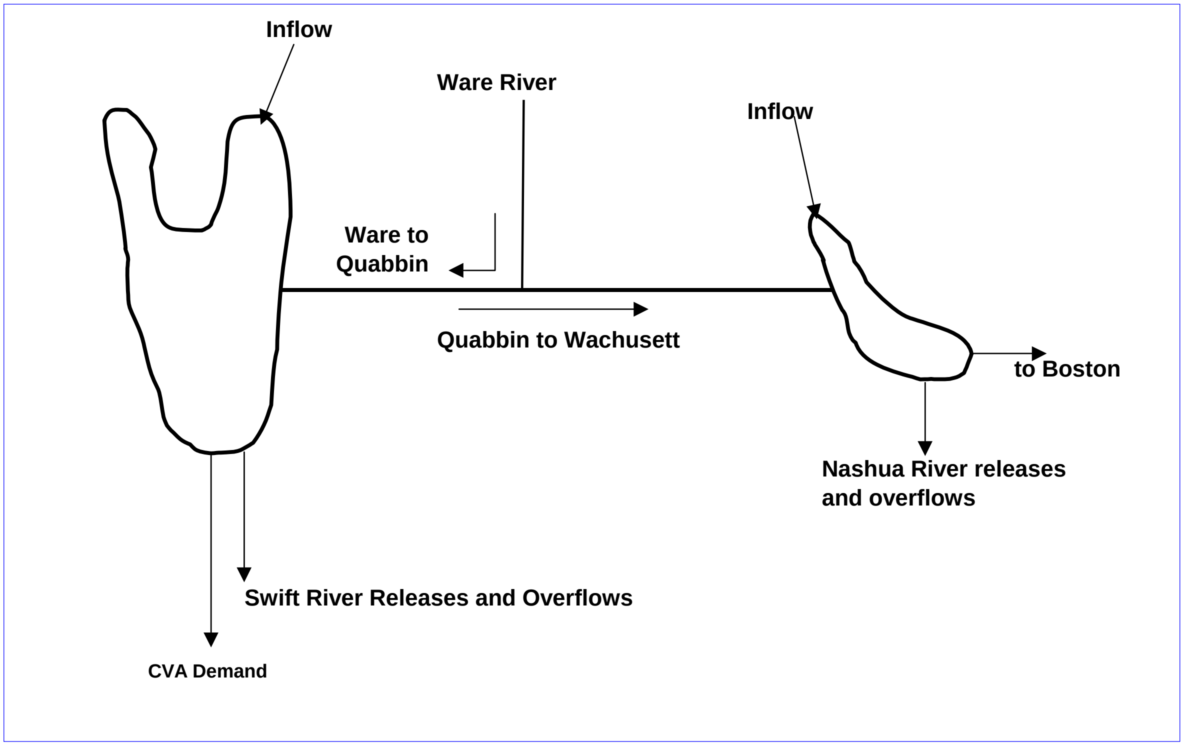
[1] Redundant sections completed in 2007

[2] Rehabilitation completed in 2002

[3] Part of Hultman system

[4] Rehabilitation completed in 2013

Figure 7-2 System Inflows and Outflows



When Ware River flow is diverted westward to Quabbin Reservoir, shuttered stop logs close at the Shaft 12 intake and force the water to discharge into the Quabbin Reservoir at Shaft 11A. This prevents the lower quality Ware River flow from accumulating around the Shaft 12 intake. Baffle dams direct the Ware diversion water northward into the reservoir and force the water to flow many miles to reach the Quabbin Tunnel intake structure at Shaft 12. As referenced in Chapter 4, Ware River transfers are limited to the portion of river flows above 85 mgd and are subject to the following conditions: no diversion of Ware River flows allowed from June 15 to October 15. Diversion from June 1 to June 15 and from October 15 to November 30 must have prior permission from the DEP Division of Water Supply.

Under normal operating conditions, the Cosgrove Intake and Tunnel carry 100 percent of the flow from the Wachusett Reservoir to the newly constructed John J. Carroll Water Treatment Plant ("CWTP"). This tunnel is backed up by the old Wachusett Dam Intake and the rehabilitated Wachusett Aqueduct, both of which were used in the winter of 2004/2005 while new connections to the CWTP were constructed. However, the Wachusett Aqueduct is limited in its flow capacity of 240-250 MGD which does not allow it to consistently meet summer demands. Also, since the aqueduct delivers water at a low elevation, it cannot supply flow into the ozone contactors at the CWTP and would require that temporary chlorination facilities be activated for treatment. It would also take at least a day to activate the Wachusett Aqueduct to deliver flow into the MetroWest Water Supply Tunnel (MWWST) for use in the metropolitan Boston area in the same manner that was done for the CWTP start-up. Since the CWTP plant flow system would not be supplied, the current supply to Northborough, Marlborough, Southborough and the Westborough State Hospital would require special temporary pumping as was done temporarily during CWTP start-up but which was disassembled afterward. Please see the discussion of redundancy for the Cosgrove Tunnel beginning on page 7-13.

From the plant, flow can continue east from through the new MWWST or through the Hultman Aqueduct. The MWWST was constructed to remedy the significant lack of transmission system redundancy when the decision was made to not build the second barrel of the Hultman Aqueduct following WWII. Construction of the tunnel has eliminated a major weakness in the transmission system and has allowed MWRA to proceed with the necessary repairs to the Hultman Aqueduct. The MWWST tunnel also provided some hydraulic benefits and, given the depth of the tunnel (200-600 feet below the surface), provides additional security for the water transmission system. The role of additional stand-by facilities that can be used in the event of a catastrophic emergency is discussed on pages 7-35 through 7-44.

The Hultman Aqueduct is a 1940's vintage reinforced concrete pipeline for most of its length, the upper section being 12.5' diameter and the lower section being 11.5' diameter. A portion of the Hultman Aqueduct consists of the three-mile long tunnel section, known as the "Southborough Tunnel", which travels beneath the Sudbury Reservoir. The Hultman Aqueduct historically was connected to the Norumbega open storage reservoir, but is now connected to the CWTP and the MWWST and to the new Norumbega Covered Storage Facility. With rehabilitation work on the Hultman complete, either the MWWST or Hultman Aqueduct can be isolated for emergencies with no loss of service to metropolitan Boston or the MetroWest communities.

East of the Norumbega facility, the MWWST or Hultman Aqueduct flow can be directed to the 20 MG storage tank at Loring Road to supply the Boston Low service area. The facility can also be configured to supply the Northern Low Service area and the City Tunnel which feeds both the City Tunnel Extension to the north and the Dorchester Tunnel to the south. The City Tunnel, constructed in 1950, is a 12' diameter deep rock tunnel that extends five miles to Shafts 7 and 7B in Brighton. The City Tunnel Extension was constructed in 1963 and is a 10' diameter deep rock tunnel that goes from Shaft 7 north to Shaft 9A in Malden. The Dorchester Tunnel is a 10' diameter tunnel that extends southward from Shaft 7B to Shaft 7D in Dorchester. The Dorchester Tunnel was constructed in 1976. Shafts along each of these tunnel sections bring water up riser pipes that feed the distribution system.

7.3 Hydraulic Capacity Issues

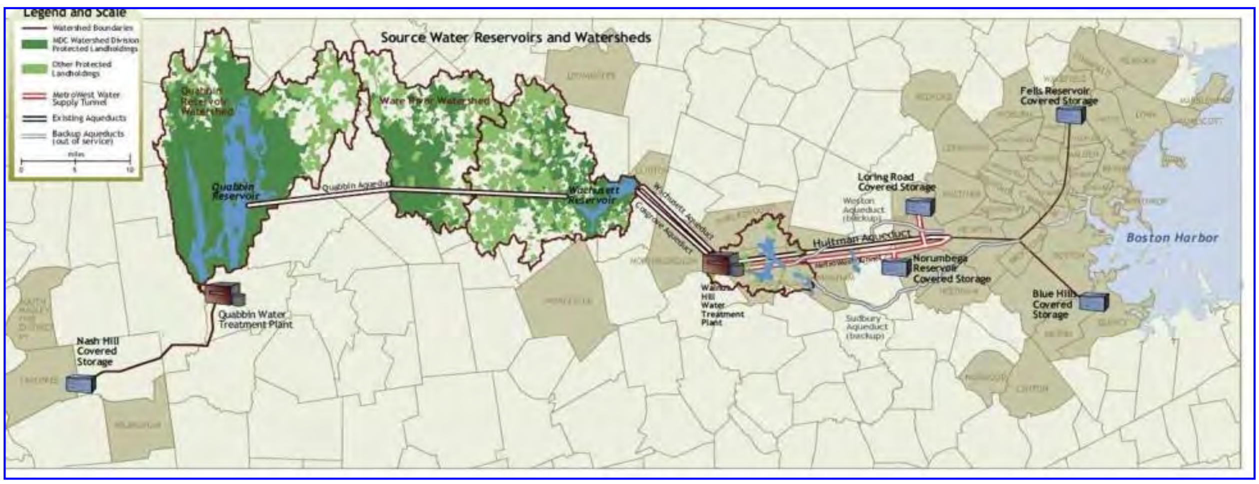
As noted earlier, one of the prime functions of the transmission system is to ensure the capacity to supply maximum day demands for the foreseeable future. It should be noted that during the peak water use years in the 1980's, water demands had reached as high as 340 mgd with maximum days of well over 400 mgd. During these earlier periods, maximum day flow required the use of the older aqueducts, (e.g. Weston Aqueduct supply to Boston Low and Sudbury Aqueduct use with Chestnut Hill pumping). It also required the use of the large open distribution reservoirs like Spot Pond, Fells, Blue Hills, Chestnut Hill and Weston. These large reservoirs allowed the old Cosgrove/Hultman backbone to function, albeit with some bottlenecks and weaker max day hydraulic gradients to the distribution system. Addition of the MWWST has significantly improved hydraulic capacity but the replacement of older open distribution storage with smaller tanks has placed more of a peak hour burden on the tunnel backbone. The trend towards removal from service of local community tanks has also increased peak flows.

The net effect of these changes is that the current system with CWTP and the MWWST/Hultman backbone is adequate to meet projected maximum day demands but it should be noted that the goal of maintaining one day of distribution storage continues to be an important one to maintain transmission system adequacy.

7.4 Transmission System Redundancy and Reliability

The following section focuses on those parts of the Transmission system that are in active use under normal operating conditions for the system. Summary information is provided on redundancy shortfalls in the MWRA system and an overview of condition assessment information for the Transmission system is provided. Following that, each facility is discussed in greater detail and for each asset or facility notes what is known of the condition and what level of redundancy exists for that facility. Any current work in progress or identified for funding in the current CIP is identified and any future recommended projects are also discussed.

Figure 7-3



<u>Reliability and Redundancy</u>

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.

To evaluate the ability of the Transmission system to meet the performance standard for reliability, one must consider both the risk of failure for any part of that system but also the consequence of a failure. To do this, information on the condition of the asset is critical to determining risk. The consequence of any particular failure can vary from insignificant to catastrophic. Redundancy in a water transmission system serves to reduce the consequence of failure because emergency back-up or stand-by facilities can be brought on-line. This means that the condition of these back-up facilities must also be ascertained and evaluated.

Redundancy Shortfalls

Table 7-2 provides an overview of the risk and consequence of failure for those tunnels and aqueducts (including surface pipe and other appurtenant facilities) that are used during normal operations. It must be noted that a number of the tunnels have not been able to be inspected since they cannot be removed from service. The Southborough Tunnel component of the Hultman Aqueduct was inspected as part of the early Hultman rehabilitation work and was determined to be in good condition. Since the previous Master Plan was completed in 2006, approximately $2.8 million has been added to the CIP for an inspection of the Quabbin Aqueduct. At this time there is still no means to inspect the City Tunnel, City Tunnel Extension or Dorchester Tunnel until redundancy plans have been designed and constructed and can be put into use.

Table 7-2 Risk and Consequence of Tunnel/Aqueduct Failure			
Aqueduct/Tunnel	**Age (yrs)**	**Risk of Failure**	**Consequence of Failure**
Quabbin Tunnel	79	Tunnel - Low Surface pipe - Moderate	Low
Chicopee Valley Aqueduct	69	Moderate	Moderate
Cosgrove Tunnel	51	Tunnel - Low Surface pipe - Moderate	Moderate [1]
MetroWestTunnel	15	Tunnel - Low Surface pipe - Moderate	Low
Southborough Tunnel	78	Tunnel - Low Surface pipe - Moderate	Low
Hultman Aqueduct	78	Moderate	Low
City Tunnel	68	Tunnel - Low Surface pipe - Moderate	High
City Tunnel Extension	55	Tunnel - Low Surface pipe - Moderate	High
Dorchester Tunnel	42	Tunnel - Low Surface pipe - Moderate	High

[1] Pump Station which will allow the Wachusett Aqueduct to provide redundancy for the Cosgrove Tunnel has been constructed and is currently in testing.

Completion of the MWWST has made the system significantly more robust and has alleviated much concern over a single-spine surface conduit as the major supply line to the metropolitan area. That said, there remain areas of concern where additional transmission improvements could increase operational flexibility both in the event of an emergency and would also allow regular inspection and rehabilitation of the system. Ideally, in the event of an emergency, the best resolution is to have a transition to a backup system that is unnoticeable by the end consumer. MWRA's system is not at that point and depending upon the location of a failure, service could be significantly disrupted. Moving from west to east, redundancy considerations are as follows:

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.

Quabbin Aqueduct

The FY19 CIP includes development of an inspection plan for this tunnel (July 2023) and an isolation gate for the Quabbin end of the tunnel. With the exception of the Oakdale power station, which has undergone 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.

Cosgrove Tunnel/Wachusett Aqueduct

For the Cosgrove Tunnel, in 2003, an inspection of the tunnel noted the need for some repairs. Any repair project could require an extended shutdown of the Cosgrove Tunnel. The tunnel provides the primary raw water supply to the CWTP and is backed up by the stand-by, non-pressurized grade line, Wachusett Aqueduct. Although the Wachusett Aqueduct was rehabilitated in 2003 to allow its use during a short duration winter period in order to allow the Cosgrove Tunnel to be connected to the CWTP, it is limited in both its flow capacity and by its inability to meet the grade line requirements of the CWTP. Flow from the Wachusett Aqueduct cannot supply water to the ozone contactors at the CWTP without pumping; use of the Aqueduct would require that the CWTP be turned off and temporary chlorination facilities be installed at the Wachusett Reservoir end of the Aqueduct to be used for treatment. This would also disrupt service to Northborough, Southborough, Marlborough, and to Westborough State Hospital.

The 2006 Master Plan recommended inclusion of $100 million as a placeholder for the provision of redundancy for the Cosgrove Tunnel. As part of the broader 2008 Concept Plan for Transmission system redundancy, the consultant considered two main alternatives: 1) Use the existing gravity Wachusett Aqueduct and construct a new emergency pump station at the CWTP site to boost the raw water in the Aqueduct to meet the required hydraulic grade line for the CWTP; and, 2) Pressurize the Wachusett Aqueduct through installation of a pipe within the existing structure with various pipe diameters considered. In January, 2012, the Board of Directors approved the award of a design contract for the pump station.

Wachusett Aqueduct Pump Station

The Wachusett Aqueduct Pump Station is currently in the testing phase and is expected to be available for use in 2019.

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. This section is now capable of seamless transfer of flow delivery, i.e. no significant service impacts, if either MWWST or Hultman requires an emergency shutdown.

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. These tunnels cannot be shut down for inspection or repairs.

Condition and Reliability of Metropolitan Tunnels

The tunnels in the Metropolitan Boston area, (i.e. the City Tunnel, City Tunnel Extension and Dorchester Tunnel) remain a weak link. The need for Metropolitan system redundancy is driven by two compelling interests. First, MWRA must be able to respond quickly to a disruption in service. While the integrity of the underground tunnel sections is believed to be good based on very low unaccounted for water levels in the MWRA transmission system, there is still risk of failure, possibly due to major subsurface issues such as earthquakes but more likely due to pipe failures at the surface connections to the distribution system or at connecting valves (as seen in May 2010). Depending upon the location of such an event, this scenario could cause an immediate loss of pressure throughout the High Service area and may require isolation of the entire tunnel system (with extensive, difficult emergency valve closures), fabrication of specialized repair pieces and could take weeks or months to repair. Secondly, equally important to being able to address emergency scenarios, is the need to be able to take key parts of the tunnel system out of service periodically for inspection, maintenance and rehabilitation.

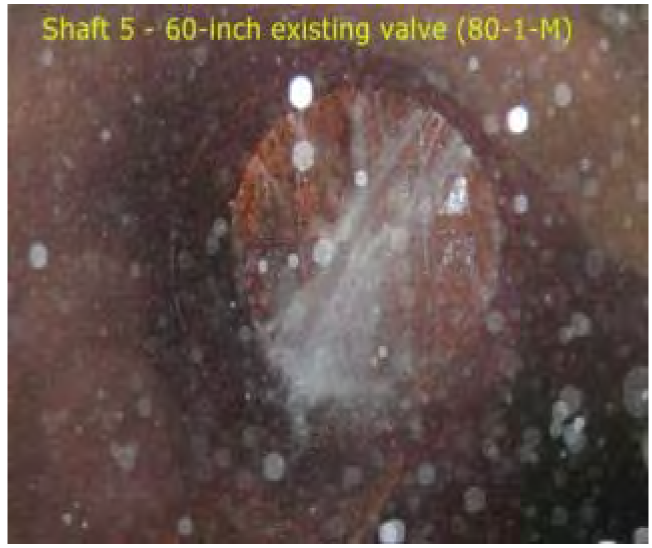
Although the assumption is that tunnels have a useful life of 100 years, due to the need to keep these lines in service, these subsurface structures have not been inspected and their actual condition is unknown. The three Metropolitan tunnels range in age from 42-68 years old. Failures of deep rock tunnels are considered unlikely; however, appurtenant structures including valves and surface piping are far more likely to fail. Many of these tunnel components cannot be inspected or repaired with the tunnels in service.

In the event of a failure of the City Tunnel, a limited amount of water could be transferred through the WASM 3 line (scheduled for major rehabilitation) and WASM 4 and the Sudbury Aqueduct would need to be brought on line. 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 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.

If the Dorchester Tunnel were to experience a problem, flow could be routed to the south through surface mains. However, this relies on the construction of additional surface pipelines at the Chestnut Hill Reservoir area.

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.



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 has developed an Interim Improvements list of projects to be implemented (discussed below) in order 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.

<u>Interim Improvement Contracts</u>

Tops of Shafts Interim Improvements Design/CA/RI (7560) and Construction (7562) This project will provide strengthening of pipe directly connected to the tunnel system, if it is found to be deteriorated; cathodic protection for pipe connections to prevent further corrosion; replacement of faulty air valves directly on the shafts and piping; replacement of nuts on valve connections if found to be at risk; improvements in dewatering systems inside shafts; and installation of additional valves to allow isolation of the tunnel without operating old valves that are directly connected to the tunnel.

Chestnut Hill Emergency Pump Station Improvements Design/CA/RI (7574) and Construction (7562) The Chestnut Hill Emergency Pump Station is in need of improvement to piping and pumping systems to reduce surge loads on the suction and discharge piping during emergency operation when the Dorchester Tunnel is out of service. Discharge pressures from the pump station would exceed normal pressures in community pipelines increasing risk of failure during emergency operation. Also, coordination of pump station operation between Chestnut Hill and Newton Street and Hyde Park pump stations is of concern. With CHEPS not operating, grade lines in the Southern High system fall below acceptable levels at high points in the system and Blue Hills tank is unable to be filled. Improvements under this contract include potential pump and motor replacement, pipe reconfiguration, surge controls, and possibly installation of variable frequency drives on motors to regulate discharge pressures.

Chestnut Hill Emergency Pump Station Emergency Generator Construction (7566) Construction for the Chestnut Hill Emergency Pump Station Emergency Generator and electrical connections.

WASM 3 Rehabilitation MEPA/Design CA/RI (6539) and WASM 3 Rehab CP- 1(6544), CP-2 (6543) and CP-3 (6545) MEPA/Design CA/RI and construction of the WASM 3 rehabilitation from the Hultman Aqueduct Branch in Weston to the existing PRV chamber near Section 12 at Medford Square. Construction will include cleaning and cement mortar lining, some sliplining and some pipe replacement.

WASM/Spot Pond Supply Mains West PRV Design CA/RI (7575) and Construction Improvements (7563) This project was developed as a phase of contingency planning until the new tunnel system is in place. The project will allow the Low Service system to be utilized to increase the supply to the Gillis Pump Station in Stoneham to avoid the need to pump out of the Spot Pond Reservoir in an emergency. The Low Service pipelines would be operated at grade lines consistent with WASM

3 grade line to push additional flow to the Gillis Pump Station in an emergency. Low Service revenue meters would require pressure reducing valves to lower pressures to communities along the way. In addition, PRV's on WASM 3/4 would also require replacement to maximize the supply to the north.
Shafts 5 and 9 Building Improvements Design/CA/RI and Construction (7599/7600)
Electrical and architectural improvements at Shafts 5 & 9 buildings in Weston and Somerville.

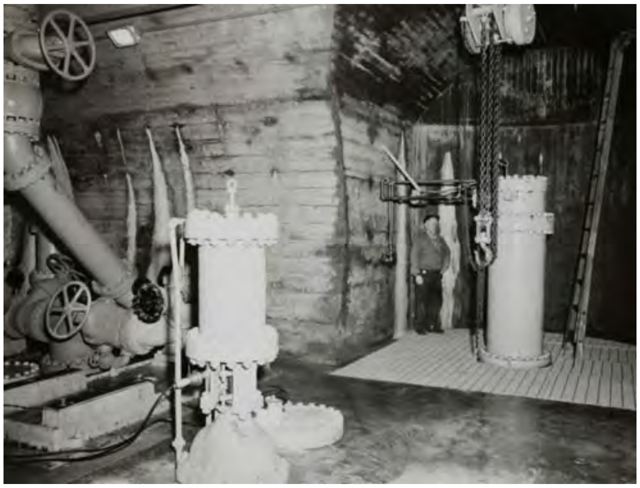
Section 101/Waltham Section Design CA/RI and Construction (7547/7457) Design Construction Administration/Resident Inspection and Construction of 8,800 linear feet of a new connection to Waltham from the Northern Extra High Service Area.

Commonwealth Avenue Pump Station Improvements Design CA/RI (7523) and Construction (7524) Design, engineering services during construction, resident engineering/inspection services and construction to provide improvements to the Commonwealth Avenue Pump Station. The project includes new pipe connections to the Low Service Pipes and two new pumps (one replacement and one additional) for redundancy. Also, includes Supervisory Control and Data Acquisition (SCADA) controls, new electric switchgear, electric transformers, and heating, ventilation and air conditioning equipment to replace older equipment.

Even when all of these interim 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 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. See picture below.

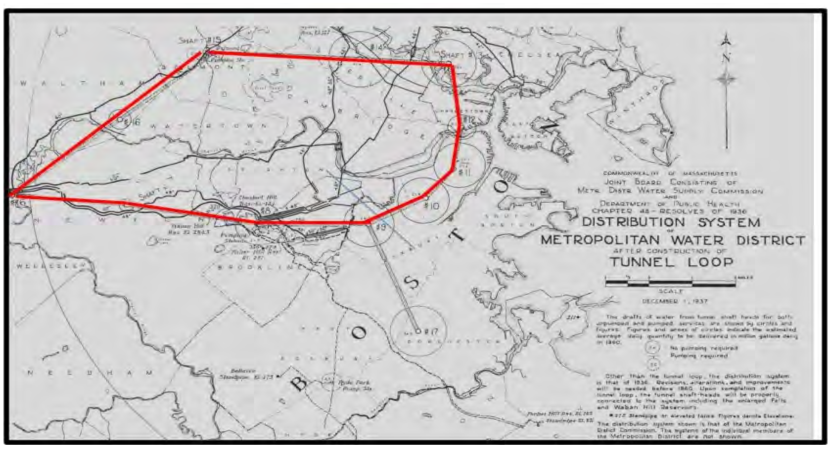


At the end of the City Tunnel Extension at Shaft 9A there is a pair of pipe couplings between the tunnel isolation valves and the top of the shaft. These couplings are indicated on record drawings as being 56-inch (a non-standard size). Staff are searching for shop drawing information on these couplings 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.

Metropolitan Tunnels Redundancy

MWRA's predecessor agencies began considering redundancy for the tunnel system as early as the 1930's when a preliminary plan to construct a Northern Tunnel Loop (See Figure 7-4) was identified. The proposed loop began in Weston and ended north of the Mystic River in Everett.

Figure 7-4

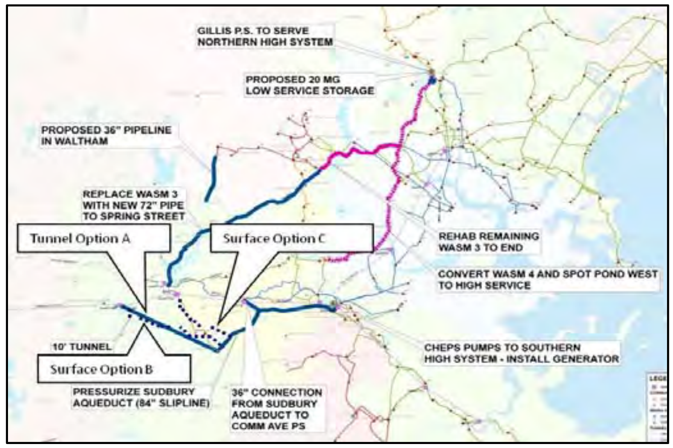


The 2006 Master Plan recommended that a CIP placeholder value of $100 million be included to support redundancy planning for the Metropolitan system.

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 7-5



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 7-5). 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.

<u>Challenges Implementing the 2011 Plan</u>

On June 26, 2013 the Board approved a contract award to provide 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. 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.

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). For this reason, staff recommended 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.

- Electrical and architectural improvements at Shaft 5 and 9 Building Improvements

- Design and Construction of a new Section 101 to serve Waltham from the Northern High Service Area.

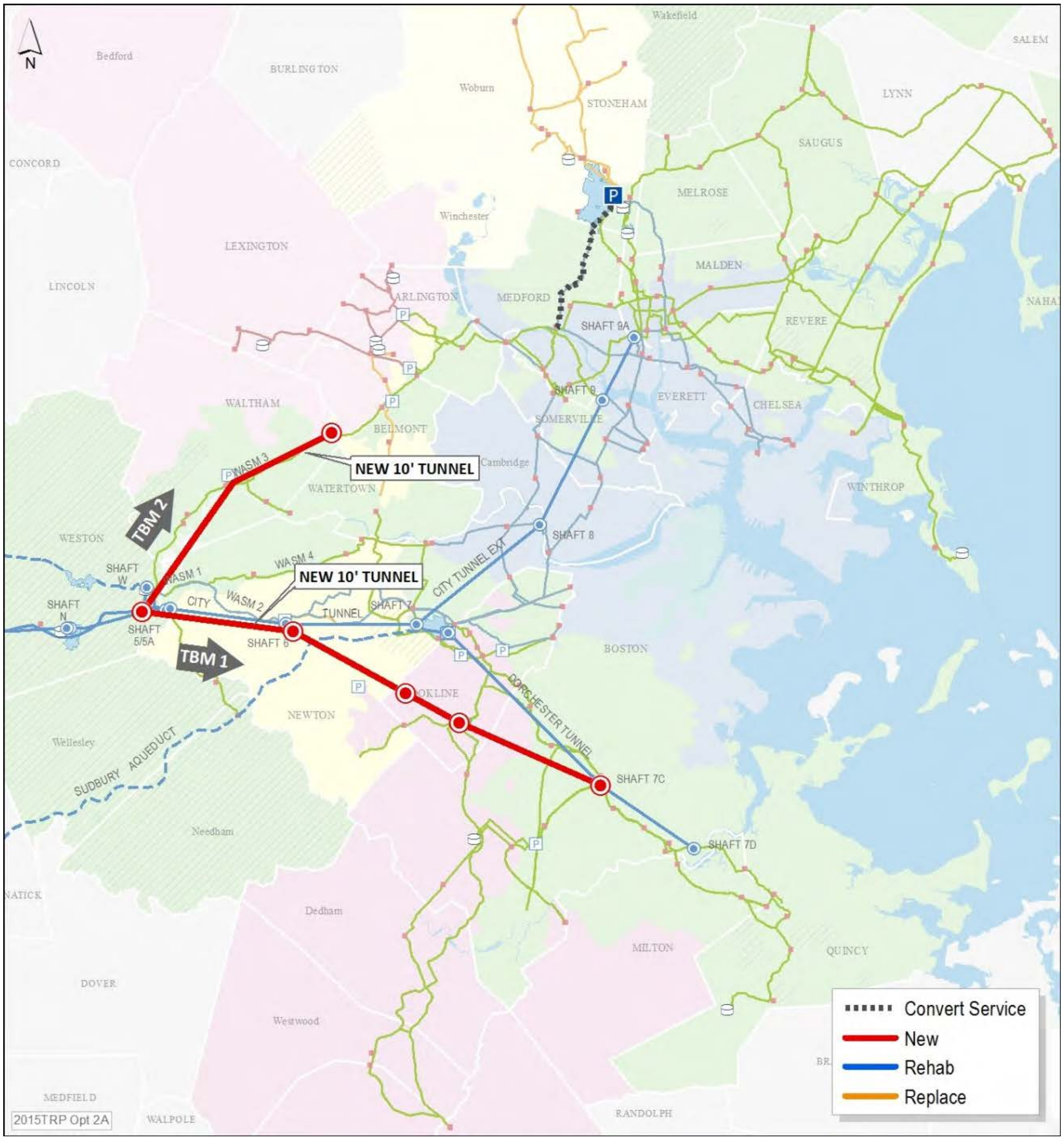
- Evaluation and potential installation should be undertaken of new pressure reducing valves on WASM 3 and 4 and the West Spot Pond Line capable of supplying flow adequate to serve the Boston Low, Northern Low and Northern High Service Areas and evaluate the ability to operate the West Spot Pond Supply 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 Figure 7-6 below.

Figure 7-6



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.

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.

The Board of Directors authorized staff to proceed with the tunnels as recommended in the 2016 special board meeting. Since that time, further conceptual work has been completed to refine these projects. A Tunnel Redundancy Department has been formed and staffed. A Program Support Services contract is expected to be procured in early 2019 and procurement of consultant services for preliminary design and MEPA review is anticipated for FY20.

Recommended Redundancy Projects in FY19 CIP (excludes Interim Projects discussed above):

- Conceptual Design and Environmental Review will be done in the FY20-23 period and is estimated to cost approximately $9 million.

- Final Design and Engineering Services for the tunnels and connecting mains. This work is expected to begin in FY23 with an estimated cost of $87.4 million.

- Construction Management including constructability reviews, construction inspection and all ancillary services. This work is expected to extend from FY23-37 at an estimated cost of $114 million.

- Public Relations and Legal Services will provide support for community agreements, land takings and Owner-Controlled Insurance at an estimated cost of $164 million.

- Top of Shafts Rehabilitation Design and Construction will be focused on the Shafts of the existing tunnel system. This work is scheduled for FY38-43 at an estimated cost of $6.4 million.

- Construction of Connecting Mains at Tops of Shafts will make connections between the new tunnel system and existing facilities and piping. This work is scheduled for FY40-42 at an estimated cost of $40.5 million.

- Shaft 7 Buildings Design and Construction project will construct a new building over the Shaft 7 top of shaft structure including all new electrical, HVAC, piping corrosion protection, PRV replacement, flow meters and other building improvements at an estimated cost of $6.4 million.

- Tunnel Construction is scheduled to occur between FY25 and 38 at an estimated cost of $957.2 million.

- An inspection of the Quabbin Aqueduct is proposed to begin in FY24 at an approximate cost of $3.2 million.

Recommended Redundancy Projects-Master Plan

- Metropolitan Tunnel Rehabilitation: Staff have proposed that a $65 million placeholder amount be considered to anticipated needed inspections and rehabilitation of the existing Metropolitan Tunnel system following completion of the new tunnels. This work is estimated to occur in FY39-58.

- Staff recommend that regular inspections be done of the Cosgrove Tunnel at 15 year intervals at a cost of $5000,000 per inspection. There would be three inspections in the planning horizon of this Master Plan.

7.5 Transmission System and Facilities -Active Components

The following section focuses on those parts of the Transmission system that are in active use under normal operating conditions for the system. Each facility is discussed in greater detail and for each asset or facility notes what is known of the condition and what level of redundancy exists for that facility. Any current work in progress or identified for funding in the current CIP is identified and any future recommended projects are also noted.

In 2006, a consultant study, called the *Transmission Facilities Engineering Assessment* was completed. This project included inspections of key transmission facilities and top of shaft structures. Reports on condition assessment, recommendations and costs were developed. The recommendations were tiered and considered both the minimum level of work necessary to operate or stabilize the asset and also potential additional measures that might enhance the operation of the facility or bring the facility fully up to its original condition. Given the historic status and architectural style of many of the facilities, the latter level of rehabilitation may not be financially feasible at this time. Thus, improvements to halt any ongoing deterioration and ensure safe and secure facility operation may be the short-term course of action with the study serving as the blueprint for the requirements to fully bring the asset up to its original condition, if desired, over a longer time frame. Many of these projects have been completed; several remain and are included in the FY19 CIP.

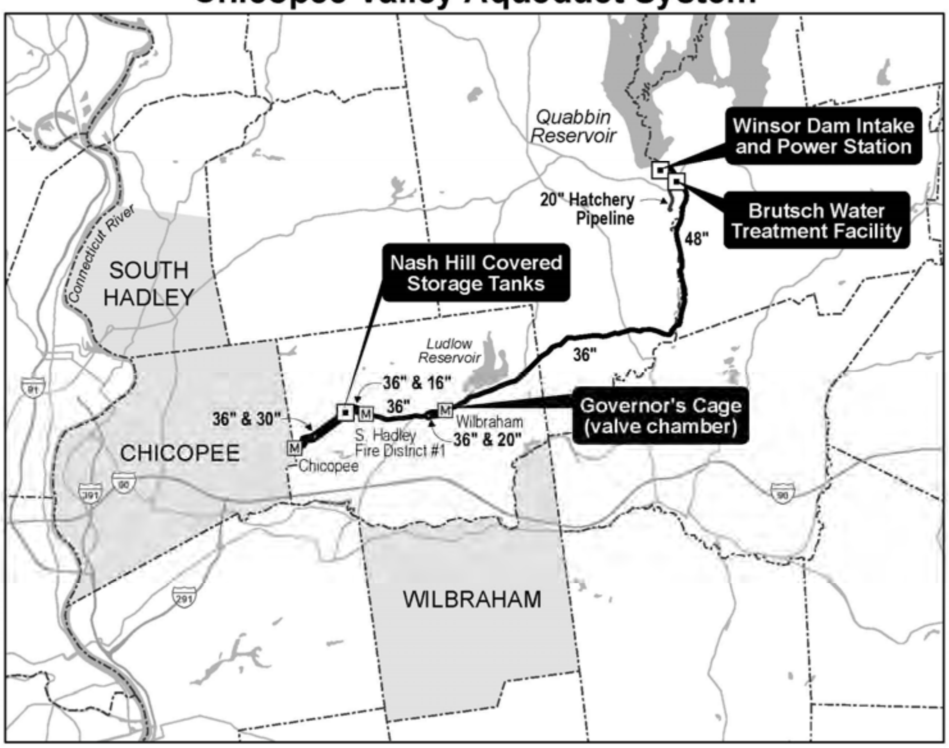
<u>Chicopee Valley System</u> (shown in Figure 7-7 below)

<u>Chicopee Valley Aqueduct</u>

The Chicopee Valley Aqueduct was initially constructed in 1949 to serve the communities of Chicopee, Wilbraham and South Hadley Fire District #1. The Aqueduct extends approximately 15 miles in length and is reinforced concrete pipe with an embedded steel cylinder. The pipe varies from 36”-48” in diameter. The pipe has a capacity of 23 MGD which is sufficient to meet peak summer demands.

Figure 7-7

Chicopee Valley Aqueduct 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.

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.

Associated CVA Structures and Facilities

CVA Intake Facility

The CVA Intake structure controls water flow from the Quabbin Reservoir into the Chicopee Valley Aqueduct. It also conveys water to be released to the Swift River. It is located on the Winsor Dam and is partially located in the Reservoir itself. It houses two bays with rotating screens to prevent debris from entering the aqueduct. The rotating screens and spray water pump system are nearing the end of their useful life and will need replacement. In addition, the isolation valves are old and will need replacement sometime in the future.

Winsor Power Station

The Winsor Power Station was constructed below the Winsor Dam to house the valving and hydropower generation equipment associated with supplying the CVA and releasing water to the Swift River. The facility had actively generated power on the flow being released to the Swift River until an electrical system fire in 1991. In addition to damage from the fire, the overall facility is now over 65 years old and the pipes and valving need replacement based on recent condition assessments and leakage problems. A new head dissipating valve was installed to allow for safer releases to the Swift River as part of a first phase of rehabilitation of the facility. Restoration of hydrogenation capability at this station raises significant technical and permitting issues, including issues relative to release requirements, which MWRA has elected to not address at this time.

However, since the 2013 Master Plan, MWRA has completed the design and construction of 5,000 feet of pipeline to convey 6 MGD of water from the CVA to the downstream trout hatchery. This will provide a consistent and reliable source of high quality cold water to the hatchery as well as supplementing Swift River flows. A small hydro turbine is included in this project and this is further discussed in Chapter 10.

Ongoing Work

- The FY19 CIP includes the future design and construction work to upgrade the Winsor Power Station including upgrading of the large diameter piping and associated valving as well as rehabilitation of the building and electrical system. This CIP project also includes improvements to the CVA intake structure and repairs to Shaft 2.

- The FY19 CIP also includes funding for the construction of Shaft 12 Isolation Gates. This entails the replacement of the antiquated shutter system that was the sole means of controlling flow in the Quabbin Aqueduct with a new gate (See *Quabbin Intake Structure at Shaft 12* below). Design has been completed.

Brutsch Water Treatment Facility

The William A Brutsch Water Treatment Facility (BWTF) provides primary and residual disinfection for the Chicopee Valley Aqueduct (CVA) system serving the three communities of Wilbraham, Chicopee and South Hadley Fire District No. 1. The facility, placed into service in 2000 and modified in 2014, is located adjacent to the CVA and the Swift River just north of Route 9 in Ware. The facility replaced interim disinfection facilities and allowed Wilbraham and South Hadley Fire District #1 to discontinue their chlorination facilities (although South Hadley employs booster chlorination seasonally deep within their distribution system). Due to its location downstream of the Nash Hill Tanks, and larger distribution system, Chicopee still needs to provide booster disinfection at their entry point to maintain adequate chlorine residual to the ends of their system. Each community also provides their own corrosion control treatment. The facility also provides flow regulation via SCADA controlled throttling valves to supply CVA demands in response to Nash Hill Tank variations. Please see Chapter 6 for further information on water treatment at this facility.

Ludlow Monitoring Station

Ludlow Monitoring Station is located approximately 12 hours (on average) of flow travel time downstream of the Brutsch Water Treatment Facility and above the first CVA user (the Wilbraham meter). The facility consists of a small building that encloses sampling and SCADA equipment. The facility monitors chlorine residual for determination of disinfection effectiveness.

Nash Hill Tanks

The Nash Hill Tanks are two 12.5 MG above ground pre-stressed concrete storage tanks which were constructed in 1998 to replace an existing open water surface reservoir. The open reservoir was disconnected and serves only as a detention basin for any overflows.

Recommended Project

- $1.1 million is recommended in FY24-25 for rehabilitation of the Nash Hill tanks.

Nash Hill Service Building

The Nash Hill Service Building is a one story garage type building that is near the entrance of the Nash Hill Tank site. Its purpose is for storage of maintenance equipment associated with buildings and grounds maintenance of the CVA.

Quabbin Reservoir to Wachusett Reservoir

Quabbin Aqueduct

The Quabbin Aqueduct was constructed in the early 1930's and was initially brought on line for the diversion of Ware River water to the Wachusett Reservoir during that time prior to the completion of Quabbin Reservoir. In addition to access, many of the shaft locations have specific functions as outlined below. At these locations, there are some above-ground facilities. Although there is no redundancy to the Quabbin Aqueduct, water could be provided from Wachusett Reservoir for a duration of six months or more during which repairs could be made to the tunnel.

Planned Work

- The FY19 CIP includes approximately $3.2 million for an inspection of the Quabbin Aqueduct.

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Quabbin Aqueduct Structures and Facilities

Quabbin Intake Structure at Shaft 12

This is the location where flow enters the tunnel for transport to the Wachusett Reservoir. Reservoir water enters the building's intakes, passes through shuttered stop logs and screens and enters the tunnel which is 125' deep at this point. It is a 40' x 30' granite block structure with a concrete substructure and pitched slate roof. Power for this building and the Shaft 12 service building is provided by a manually operated propane generator. A permanent power supply is needed for desired security system upgrades.

Projects in the FY19 CIP

- If the water piping in the Oakdale Power Station were to fail, there is currently no way to stop the flow of water. The Shaft 12 structure has stop log bays but it is an intensive process to remove the stop logs to set the shutter valves in the opposite direction and this cannot be done on an emergency basis while flow is moving. The FY19 CIP also includes funding for the construction of Shaft 12 Isolation Gates. This entails the replacement of the antiquated shutter system that was the sole means of controlling flow in the Quabbin Aqueduct with a new gate (See *Quabbin Intake Structure at Shaft 12* below). Design has been completed.

Shaft 12 Service Building

This building is located about 240' away from the intake building and is of similar size and construction. The building houses two garage bays, a bathroom and two additional rooms. No major facility work is required.

Shaft 11A Ware River Diversion Discharge

This shaft is used to discharge flow into the Quabbin Reservoir through shuttered stop logs when the Ware River is being diverted towards Quabbin via the Quabbin Tunnel. During normal operation, this shaft acts as a vent and access point for the aqueduct.

Miscellaneous Shaft Structures with No Buildings

At a number of the shaft locations without larger, ancillary facilities, relatively minor improvements in physical hardening are recommended.

Quabbin Aqueduct Shaft 9

The headhouse at this location provides access and pressure relief for the Quabbin Tunnel. Pressure relief is particular important when Shaft 8 is being used for diversion of water from the Ware River. It is a granite block structure approximately 29’ x 21’ with a concrete substructure and a pitched slate roof. Minor building improvements appear to be required to maintain the integrity of the structure.

Shaft 4

This tunnel shaft serves as an access point and air relief structure for the Tunnel. There is no electrical service or heat in the structure which is approximately 30’ x 19’ in size. It is a granite block structure with a pitched slate roof. Minor building improvements appear to be required to maintain the integrity of the structure.

Shaft 3

This is the location where the City of Worcester Interconnection Building is located. This allows the City to take water from the Quabbin Aqueduct on an emergency basis with prior notification to MWRA. This facility is the responsibility of Worcester and is in poor condition.

Shaft 2

This shaft provides pressure relief for the Quabbin Aqueduct by allowing overflows and venting air both in and out of the tunnel. Typical operations avoid overflows at this location but they can occur during high volume transfers from the Ware River to either Quabbin or Wachusett Reservoirs. It is an above ground concrete structure and is in poor structural condition. Upgrades to this structure are included in the same contract as the improvements to the Winsor Power Station.

Oakdale Power Station

The Oakdale Power Station is at Shaft 1 of the Quabbin Tunnel and is the terminus of the tunnel where it flows through a 3.4 MW turbine and combines with the Quinapoxet River to flow into the Wachusett Reservoir. Within the structure, water flows up Shaft 1 and is split between a generator penstock inlet pipe and a bypass pipeline. A brand new 84-inch butterfly valve provides isolation for the generator. Flow through the bypass is controlled by a new 72-inch butterfly valve and fixed orifice sleeve valve. The structure dates from the construction of the Quabbin Aqueduct and the generator was added around 1950 with limited electrical upgrades done around 1991. Piping and valve rehabilitation was completed in 2006. Since the 2013 Master Plan, work was completed to upgrade the electrical control system and switchyard as well as other building improvements. These facilities both operate the turbine and connect the facility to the grid.

Projects in FY19 CIP

- The Oakdale Turbine was last rehabilitated in 1986. A future project to rehabilitate the Oakdale turbine has been added to the CIP for FY25-29 at an estimated cost of $1.2 million. Although the turbine is currently operating, it has an expected useful life of 30 years.

- Oakdale High Line Replacement: This project includes the replacement of a 70 year old 69kv overhead transmission line and ground operated switch that supplies power and delivers power from the Oakdale Power Station. This work is scheduled for FY20 at a cost of $465,000.

Ware River Facilities

Lonergan Intake and Service Building

Shaft 8 (elevation 656') on the Quabbin Tunnel, also known as the Lonergan Intake, is the location where water is withdrawn from the Ware River (seasonally and flow restricted as noted in Chapter 4) and dropped into the Quabbin Tunnel. This facility was constructed in 1931 and was used at that time to supplement the volume of water available from Wachusett prior to the completion of construction at Quabbin. Although flow in the tunnel can be directed in either direction, for water quality reasons, Ware River flows are normally directed to Quabbin (elevation 530') rather than to Wachusett Reservoir (elevation 395). A dam across the Ware River extends from the intake building and the bypass flow to the downstream reach of the river is controlled by the intake building. Flow into Shaft 8 passes through a system of siphons which is primed by the bypass water flow. The facility has an automated control system using floats, pneumatics for siphon priming and hydraulically controlled valves to control the diversion rate but the equipment is old and not normally operated in automatic mode. The building is a granite block superstructure, with a pitched slate roof set on a concrete plant structural steel support system and a reinforced concrete substructure. The building size is approximately 78' x 65' x 29' high at the eave. Although this ingeniously designed system works, in the long term, it is desirable to simplify facility start-up and SCADA controls are planned to allow unstaffed operation and remote monitoring of the facility and replacement of the siphon system. Valves are currently hydraulically actuated using an oil system which should be corrected thus valve and/or actuator replacements may be necessary.

There is no redundancy to these facilities, however, given the seasonal restrictions on taking Ware River water, it is expected that any necessary repairs could be made without impacting the ability to provide water from Quabbin or Wachusett Reservoirs.

The Shaft 8 Service Building is a single story structure containing three garage bays, a maintenance room, an office and bathrooms. The building is approximately 59' x 37' and is a granite block structure with a pitched slate roof atop a concrete slab. No major improvements appear to be necessary.

Projects in FY19 CIP

- A project that addresses the above issues by replacing the underwater, inaccessible, oil-actuated valves with electric actuated valves. In addition, the siphons will be replaced with hard piped intakes and equipment will be automated with remote control capabilities. This project is scheduled to start in FY21 at an estimated cost of $1.2 million.

Barre Lower Garage

The Barre Lower Garage is a former textile mill building. It is a large single story structure with brick exterior walls wooden flooring, interior walls and roof system. It was built prior to the 1930's water supply development of the site. The first floor is supported by a stone and concrete foundation walls and wooden beams and columns resting on concrete piers in the basement. Besides storage, the first floor houses an office, bathroom and lunchroom. A mechanical room in the basement houses the furnace, well water tank and hot water heater. The building is approximately 50' x 133' in size. Minor building improvements appear to be required to maintain the integrity of the structure.

Wachusett Reservoir Facilities

Cosgrove Intake

The Cosgrove intake building was constructed in 1967 and is the sole active intake from the Wachusett Reservoir. Water passing through the facility enters the Cosgrove Tunnel at Shaft A located near the intake building. Water flows through the intake screens into intermediate wells. It is then controlled through bypass sleeve valves or through one of two 1.7 MW hydroelectric turbines. The water passes into a stilling basin and then through a horizontal tunnel to Shaft A of the Cosgrove Tunnel. The building is approximately 116' wide x 147' long but the substructure depth ranges from 70-100' below the first floor.

In the mid-1990's this building experienced cracking of wall tiles which may have been associated with some slight movement of the building. Minor water damage due to leakage has also been noted in the structure. In-house and outside experts evaluated these areas and monitoring of these areas was initiated on a regular basis. There does not appear to have been any subsequent movement and the building has been deemed to be fundamentally structurally sound during the inspections.

Algae Control Chemical Feed System

Management of algae at Wachusett Reservoir has always been done manually using application of copper sulfate distributed by boat. This has been very effective for algae species that bloom on the reservoir surface but is less effective when the algae is dispersed in the water column. There have also been infrequent nuisance algae below the surface during winter months when there is an ice cover that doesn't allow copper sulfate dosing. Following studies and piloting, the Master Plan recommended implementation of an algae dosing system which would consist of piping placed in the reservoir to supply copper sulfate solution to an anchored underwater mixer to dose the area of concern in front of the intake. However, since 2006, significant algae concerns have been infrequent and are addressed to the extent feasible through reservoir operations. In addition, ozone treatment appears to address taste and odor issues associated with some species of algae. For these reasons, the project has been left in the CIP but implementation has been moved out in time. This project is in the FY19 CIP at an estimated design and construction cost of $2.25 million and is scheduled for design in FY25 (See Chapter 6).

Wachusett Reservoir to Shaft 5

Cosgrove Tunnel

The Cosgrove Tunnel was completed in 1967 and is a concrete lined, deep rock tunnel approximately 8 miles in length that extends from the Power Station and Intake to Shaft C in Marlborough. This 14’ diameter tunnel is designed to operate under pressure and has a potential capacity of 615 MGD. However, with hydraulic restrictions at Shaft B and the elevation of the CWTP inlet, this capacity cannot be met. At its deepest point, it is over 500 feet below grade. There are three shafts along the alignment with Shaft A at the intake, Shaft B at the midpoint (a hydraulic relief structure to prevent over-pressurization which was raised and rehabilitated in 2003) and Shaft C which is the outlet at the Carroll Treatment Plant site. The tunnel was taken off-line during the winter of 2003 in order to make connections between the tunnel and the new treatment plant. This allowed the tunnel to be inspected using submersible technology in December of 2003.

A Remotely Operated Vehicle (ROV) performed the tunnel inspection using sonar technology to capture detailed information using Shaft B as the point of access in order to be able to go both directions from that location. Results of the inspection indicated circumferential, longitudinal and multiple cracks (a combination of circumferential and longitudinal cracks) were observed throughout the tunnel length. The consultant report prepared in 2004 concluded that the tunnel was not in imminent danger of collapse, but recommended that structural repairs to the tunnel liner be completed and that a more detailed risk assessment be conducted to focus on tunnel liner stability and to identify potential failure scenarios and the probability of the tunnel lining failing under those scenarios. A subsequent review of the available information in 2012 resulted in the recommendation that the tunnel continue to be inspected at 15 year intervals with the initial inspection in the FY20 time period.

As noted previously, there has not been full redundancy for the Cosgrove Tunnel. The gravity flow Wachusett Aqueduct can provide up to approximately 240 MGD. The delivery gradient at the terminus of the Wachusett Aqueduct is only approximately 280’ which is inadequate to supply water through the CWTP ozone contactors and to directly supply some of the MetroWest communities. Therefore, use of the Wachusett Aqueduct as it exists today would require temporary chlorine disinfection in place of ozonation and temporary pumping to some MetroWest communities as was done during the Cosgrove Tunnel shutdown preceding CWTP start-up. The 2006 Master Plan recommended that either pressurization of the Wachusett Aqueduct or construction of a pump station be further studied in order to allow the Cosgrove Tunnel to be taken off-line for further inspection or repairs.

As a result, MWRA proceeded with design and construction of the Wachusett Aqueduct Pump Station which has been completed and is currently undergoing tests. This emergency pump station will pump water from the Wachusett Aqueduct to the Carroll Water Treatment Plant and will provide redundancy in the event of a failure at the Cosgrove Tunnel or Intake and for the inspection/rehabilitation of the Cosgrove Tunnel. During a planned or emergency shutdown of the Cosgrove Tunnel, the existing gravity Wachusett Aqueduct with the proposed emergency pump station could deliver approximately 240 million gallons per day (mgd) of raw water to the CWTP for full treatment. The 240-mgd capacity would allow for unrestricted supply for at least eight months during the lower-demand fall/winter/spring period. This project, along with the completed Hultman Aqueduct rehabilitation and interconnections project, will provide fully treated water transmission redundancy from the Wachusett Reservoir to the beginning of the metropolitan distribution system in Weston. The completed pump station has been in testing and will be available for use in 2019.

<u>Recommended Projects</u>

- Program inspections of the Cosgrove Tunnel every 15 years at $0.5 million per inspection. Inspections will need to be seasonally scheduled to allow demand to be met by the Wachusett Aqueduct Pump Station (currently in design).The first of these recurring expenses would be scheduled for FY20. No repair or rehabilitation work is proposed at this time; however, this will be reevaluated following each inspection. Subsequent inspections within the time period of this Master Plan would be done in FY35 and FY50.

<u>MetroWest Water Supply Tunnel</u>

The MetroWest Water Supply Tunnel came on line in November, 2003 as the major transmission facility from the CWTP to the Norumbega Covered Storage Facility and on to the City Tunnel connection 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 tunnel works in parallel with the Hultman Aqueduct and the interconnections allow both improved ability to respond to service disruptions or concerns on either the tunnel or the Hultman and allow for either facility to be taken out of service for inspection and maintenance. MetroWest communities previously connected either to the Wachusett Aqueduct (Town of Northborough, Westborough State Hospital) or only to the Hultman Aqueduct (City of Marlborough, Towns of Southborough, Framingham, Weston, Wellesley and Needham) now have either direct connections to the MWWST or indirect connections via new interconnections between the Hultman Aqueduct and the MWWST.

<u>Projects in FY19 CIP</u>

- Valve Chamber and Storage Tank Access Improvements Design and Construction in order to provide better and safer access to valve chambers for Water Quality and Maintenance personnel. The project will also provide secure hatches at Loring Road Tanks. This work is scheduled for FY25-27 at an estimated cost of $2.4 million.

Hultman Aqueduct

The Hultman Aqueduct, a surface aqueduct, was constructed in 1940 and is a pressurized concrete pipeline 18 miles in length extending from the CWTP in Marlborough to Shaft 5 in Weston. Flow could also be diverted to the Norumbega Open Reservoir (now off-line). The Hultman initially was designed to take water from the Wachusett Aqueduct's open channel. The system was modified in the 1960's when the Cosgrove Tunnel was constructed and was modified again in 2005 with connection to the CWTP. The Hultman was also designed to be able to deliver water to the Low system through the Weston Aqueduct (now on emergency stand-by status) and by using the 7' Branch to supply Loring Road Tanks[1]. The initial Hultman plans called for the construction of a second barrel of the Aqueduct in the same right-of-way for redundancy and operational flexibility. This second barrel was delayed and, ultimately, the MWWST was built to provide that redundancy. The Hultman ranges between 11.5 and 12.5 in diameter but the Southborough Tunnel which is the 3 mile section of the Hultman that transverses under Sudbury Reservoir is a 14 foot diameter deep rock tunnel. The major work to rehabilitate the Hultman was completed in 2012; remaining work on the Upper Hultman was completed in 2013.

Southborough Tunnel

The Southborough Tunnel section of the Hultman Aqueduct was inspected in as part of the early Hultman Aqueduct rehabilitation work and was found to be in good condition. No deficiencies were noted. This tunnel should be re-inspected in 25 years.

Recommended Projects

- Develop a plan and schedule for inspections of the Southborough Tunnel.

Southborough Facilities

Most administrative and maintenance activities for Western Operations are centered at the MWRA's Southborough facilities at the Sudbury Dam site. The administrative offices and maintenance shops were constructed in 1996. Roof and other improvements to the water quality lab have been completed under the contract to modify existing facilities.

Shaft 5 to the East

City Tunnel

The City Tunnel, constructed in 1950, is a 12' diameter deep rock tunnel that extends five miles to Shafts 7 and 7B in Brighton. Shaft 5 is the location where flow enters the City Tunnel from either the MWWST and/or the Hultman Aqueduct. Shaft 5 has experienced significant building and electrical/mechanical deterioration as a result of condensation within the building when the tunnel is venting. In addition, due to the alternating wet and dry conditions at this location, it may be

[1] The Hultman Aqueduct 7-foot branch provides a connection from the Hultman Aqueduct immediately upstream of Shaft 5 to the Weston Aqueduct Supply Main at River Road in Weston and ultimately to the Loring Road Storage Facility.

necessary to overhaul electrical equipment and to replace motors in order to ensure that valves can be operated. This work is discussed under the Interim Improvements section of Metropolitan Tunnel Redundancy. Some physical hardening and improvements to facility access are recommended at the remaining City Tunnel shaft locations.

City Tunnel Extension

The City Tunnel Extension was constructed in 1963 and is a 10’ diameter deep rock tunnel that goes from Shaft 7 north to Shaft 9A in Malden. Shafts 8, 9 and 9A each have pressure regulated connections to the Northern Low. Shafts 9 and 9A supply water to the Northern High. As with the City Tunnel, the shaft structures along the City Tunnel Extension are in need of more physical hardening and improved facility access for maintenance. The Shaft 9 building, in particular, is in poor condition both internally and externally, and site security improvements should be made to prevent further vandalism at the site. Electrical and architectural improvements at the Shaft 9 site are bundled with the proposed improvements at Shaft 5 discussed above. These projects are included under the Interim Improvements work on Metropolitan Tunnel Redundancy.

The building at Shaft 9A was previously used to boost chlorine residual through the addition of gaseous chlorine. Due to system improvements, this is no longer necessary and equipment has been removed. This building, located in Malden, is still used for crews to take regular water quality samples. As a part of the review of existing information on shaft locations, record drawings for this site indicated pipe couplings in a non-standard size. Although excavation at this site without tunnel redundancy in place is not recommended, staff is looking at opportunities to minimize risk at this location. Fabrication of replacement couplings which could be stockpiled is under consideration. Other needed improvements at this site are expected to be minimal. Shaft 8 structures are below ground and improvements are expected to be minimal.

Dorchester Tunnel

The Dorchester Tunnel is a 10’ diameter tunnel that extends southward from Shaft 7B to Shaft 7D in Dorchester. The Dorchester Tunnel was constructed in 1976. Redundancy for the Dorchester Tunnel still requires use of emergency backups like the Chestnut Hill Reservoir and Emergency Pump Station which are expected to require a boil water order if use is required. Work to provide redundancy to the Dorchester Tunnel is part of what will be done under both the Interim Improvements and the Metropolitan Tunnel Redundancy Program.

7.6 Standby Aqueducts and Facilities

The following section discusses those parts of the system not currently in active use and potentially available for emergency operations.

General Information: Public Access

In March 2012, the MWRA Board of Directors approved the *Policy and Guidelines for Authorized Public Access to Water Supply Lands Under the Care and Control of the MWRA.* This policy allows MWRA to enter into revocable agreements with local communities, public agencies and/or nonprofits to allow certain limited public access on specific MWRA controlled water supply lands. The policy specifically addresses the aqueduct alignments for the Cochituate, Sudbury, Wachusett and Weston Aqueducts and the lands around Weston and Norumbega Reservoirs. MWRA continues to use the 8(m) permitting process as the vehicle to authorize public access along the Aqueducts. Each location has unique characteristics and customized 8(m) permits allow the flexibility to address those characteristics within the framework of the broader policy.

Since implementation of the Program, MWRA has partnered with the Towns of Weston, Wayland, Wellesley, Needham, Natick, Southborough and Northborough and the City of Framingham to authorize public access along the emergency back-up aqueducts in their respective communities. The Aqueduct Trails Program has opened up new recreational opportunities in many communities across Metro West through the issuance of 8(m) permits authorizing over 25 miles of new open space and trails never officially open to the public. To date, in late 2017, approximately 17.5 miles are currently open to the public while the remaining miles will eventually be opened when the local communities have the resources to do so. Lastly, MWRA is currently working with the cities and towns on the installation of interpretive signage and wayfinding trail markers along the open trail segments of the Aqueducts.

MWRA will continue to address unauthorized uses as necessary. However, authorized use of lands which are not part of the active water supply system allows MWRA to focus staff resources on the active system and enhances system security and safety through the development of partnerships with the communities.

Wachusett Aqueduct

As part of the preparation for construction of the MetroWest Water Supply Tunnel, rehabilitation of the Wachusett Aqueduct was completed in 2002. The intent was to ensure that the Aqueduct could be the single transmission facility during the winter of 2003-04 when the Cosgrove Tunnel was taken out of service for connection to the CWTP. In addition to structural rehabilitation of portions of the aqueduct, a pressure reducing structure was constructed at elevation 281.5 BCB to prevent over pressurization of the aqueduct during operation and a shotcrete liner was applied to the inside to reduce head loss as much as possible and maximize flows through the aqueduct. The rehabilitated aqueduct was found to be capable of approximately 240 MGD but cannot operate with any internal pressure which limits the delivery water gradient to elevation 281 BCB.

Subsequent inspection of the Cosgrove Tunnel identified a need for future repair of the Tunnel and the long-term need to have the Wachusett Aqueduct available for use during those times when the Cosgrove Tunnel would not be available. The 2006 Master Plan recommended inclusion of $100 million as a placeholder for the provision of redundancy for the Cosgrove Tunnel. As part of the broader Concept Plan for Transmission system redundancy, the consultant considered two main alternatives: 1) Use the existing gravity Wachusett Aqueduct and construct a new emergency pump station at the CWTP site to boost the raw water in the Aqueduct to meet the required hydraulic grade line for the CWTP; and, 2) Pressurize the Wachusett Aqueduct through installation of a pipe within the existing structure with various pipe diameters considered.

As a result, MWRA proceeded with design and construction of the Wachusett Aqueduct Pump Station which has been completed and is currently undergoing tests. This emergency pump station will pump water from the Wachusett Aqueduct to the Carroll Water Treatment Plant and will provide redundancy in the event of a failure at the Cosgrove Tunnel or Intake and for the inspection/rehabilitation of the Cosgrove Tunnel. During a planned or emergency shutdown of the Cosgrove Tunnel, the existing gravity Wachusett Aqueduct with the proposed emergency pump station could deliver approximately 240 million gallons per day (mgd) of raw water to the CWTP for full treatment. The 240-mgd capacity would allow for unrestricted supply for at least eight months during the lower-demand fall/winter/spring period. This project, along with the completed Hultman Aqueduct rehabilitation and interconnections project, will provide fully treated water transmission redundancy from the Wachusett Reservoir to the beginning of the metropolitan distribution system in Weston.

Open Channel (see discussion of bridges and roads)

Wachusett Aqueduct Structures and Facilities

Wachusett Dam Upper Gatehouse

This structure is part of the dam structure and is the intake for the former Wachusett Power Station (Lower Gatehouse). The building houses operators for valves at three reservoir intake levels as well as screens and stop logs. The upper two intakes discharge to four vertical wells which are connected to 48" discharge pipes running horizontally 113' below the floor. These pipes flow directly to the lower gate house for discharge to the Wachusett Aqueduct or to the Nashua River. Some level of repairs to reduce long-term building deterioration will ultimately be required.

The Wachusett Power Station and Lower Gatehouse

This facility is located at the base of the Wachusett Reservoir Dam. This is the intake and gate house for the Wachusett Aqueduct and the bypass to the Nashua River. It is a granite superstructure and a concrete substructure with a copper sheet roof. The substructure is separated into 4 main chambers of which 2 feed the Wachusett Aqueduct. The building footprint (105' x 74') includes a three story office area and a large open room with four generators. The heating system is adequate for the abandoned offices but not capable of maintaining heat in the main turbine floor area. The brick work in the turbine room is exhibiting deterioration. This facility was retired from active service in the 1960's. Repairs will be necessary to prevent further building deterioration. The river valves and cross-over piping were not replaced in 2003 when mechanical rehabilitation was completed. These pipes and valves are deteriorated and should be replaced or rehabilitated.

Projects in the FY19 CIP

- A project to rehabilitate Wachusett Gatehouse/Bastion & implement Lower Gatehouse geo-thermal heating for the structure. This includes rehabilitation of the piping and valves in the Lower Gatehouse and a determination of whether the layout of the valving can be simplified. Existing piping and valves are of poor quality. Other piping and valves of the same age in this facility have already been replaced. Building repairs including the replacement of the leaking roof, gutters, and addressing degraded masonry, doors and windows. Sealing of the building will allow more efficient heating of building space to prevent further deterioration. The plan is to convert from propane fueled boilers to geo-thermal heating utilizing the internal water in the piping located in the building. The existing heating isn't sufficient to keep building warm enough and therefore remaining moisture contributes to accelerated deterioration.

Assabet River Bridge and Siphon

The original Wachusett Aqueduct crossing of the Assabet River was done by use of an aqueduct bridge similar in style to the Echo Bridge on the Sudbury Aqueduct crossing of the Charles River. Due to deteriorated condition and leakage, a siphon was added under the Assabet River and all flow now passes through the siphon. The aqueduct bridge structure remains and will require masonry rehabilitation and other remedial work as it ages.

Other Roads and Bridges

The portion of the Wachusett Aqueduct along the open channel includes a number of roads and bridges that were initially constructed by predecessor agencies (see Table 7-3). Besides Wachusett Aqueduct, additional bridges cross within the Sudbury Reservoir system and at the Weston Reservoir. The list of roads/bridges identified by Western Operations is included in Table 7-4 below. MWRA has performed maintenance on some of these structures but ownership and maintenance responsibilities need to be better delineated. To date, costs have generally been absorbed within the CEB expenditures but more significant costs could be incurred over time as the structures age.

Table 7-3

Bridge Location	Associated With
Bridge Near Hultman Intake Dam	Wachusett Aqueduct Open Channel
Carroll Water Treatment Plant	Wachusett Aqueduct Open Channel
Ward Road	Wachusett Aqueduct Open Channel
Route 495	Wachusett Aqueduct Open Channel
Johnson Road	Wachusett Aqueduct Open Channel
Northborough Road	Wachusett Aqueduct Open Channel
Route 30	Wachusett Aqueduct Open Channel
Lynbrook Road	Wachusett Aqueduct Open Channel
Deerfoot Road	Wachusett Aqueduct Open Channel
Parkerville Road	Wachusett Aqueduct Open Channel
Middle Road	Wachusett Aqueduct Open Channel
Stonybrook	Sudbury Reservoir
Route 30	Sudbury Reservoir
Route 9	Foss Reservoir (Framingham #3)
Salem End Road	Foss Reservoir (Framingham #3)
Fountain Street	Brackett Reservoir (Framingham #2)
Winter Street	Stearns Reservoir (Framingham #1)
Ash Street	Weston Reservoir (Open Channel)

Recommendation

- Recommend that staff request clarification from the Law Division on the ownership and maintenance responsibilities for bridges and roads across the Open Channel and at other locations as determined by Western Operations.

Additional structures along the Wachusett Aqueduct include the circular Rattlesnake Hill Access Shaft and the Linden Street Gatehouse. Rattlesnake Hill may have been used for personnel access to the aqueduct. The shaft is offset to the side of the aqueduct, which lies approximately 25-30 feet below the building's first floor. The building has deteriorated significantly over time and is currently blocked off for safety reasons.

Weston Aqueduct

The Weston Aqueduct was completed in 1903 and begins at the Sudbury Dam near Shaft 4 and continues from there to the west side of the Charles River in Weston near the intersection of I-128 and the Massachusetts Turnpike. The aqueduct is approximately 12 miles in length and was constructed of concrete and brick masonry. It varies between 9 and 12 feet in height and 10-13 feet in width. The Weston Aqueduct was originally designed to bring water from the Sudbury Reservoir but due to deteriorating water quality conditions in the Sudbury in the 1960's was last operated by a pressure reduced feed from the Hultman or through the hydropower turbine at Shaft 4. The use of the open Weston Reservoir was eliminated in the early 1990's by replacing its flow from pressure reduced connections from the High Service.

The Weston Aqueduct has two main sections, the first intended to get water from the Shaft 4 area to Weston Reservoir and the second being to bring water from the reservoir to the Weston Terminal Chamber where low service distribution begins via the Weston Aqueduct Supply Mains (WASM) lines. In between the two aqueduct sections, the flow has to pass through the open Weston Reservoir. This aqueduct still provides emergency redundancy in a failure scenario which interrupts flow of both MetroWest and Hultman facilities since it can convey water from the Sudbury Dam vicinity all the way to supply the Low Service tanks at Loring Road if necessary. Temporary disinfection and a boil water order would be required in such a scenario

Weston Aqueduct Structures and Facilities

Also located at Shaft 4 is the Aqueduct transfer power station and connecting piping. The original building was constructed around 1899 and the Weston Aqueduct was fed by three 60-inch diameter pipes from the Sudbury Dam Gatehouse. Around 1985, the facility was modified for hydropower generation. Given that the Weston Aqueduct is no longer in routine operation, this facility is inactive.

In 2004 repair work was undertaken on the Ash Street Bridge in response to a routine inspection conducted by DCR. Repairs included replacement of deteriorated concrete on the underside of the bridge arch, repointing of the stone masonry mortar on one side, and sealing capstone joints under the bridge rail. In addition, a raised bituminous asphalt sidewalk was constructed over the bridge to provide safer access and crossing by pedestrians in the Weston Reservoir area.

Four siphon structures (#1, #2, #3, #4) exist along the Weston Aqueduct. These buildings are all approximately 21' x 21' and have no electricity, heating or plumbing. At one of the siphon locations, i.e. the Sudbury River crossing, the aqueduct crosses the river with two barrels, one piped under the river and one which is an 84-inch free standing pipe bridge over the river. These facilities are currently in good condition but may require rehabilitation in the future.

The Weston Reservoir Terminal Chamber is located at the terminus of the Weston Aqueduct where it becomes a section of open channel upstream of the open reservoir. The west wall of the building sets on the Aqueduct arch. Stoplogs can be set in place along the outlet wall to allow maintenance within the part of the aqueduct affected by reservoir backwater.

The Weston Aqueduct Screen Chamber is located on the Weston Reservoir Dam at the beginning of the lower aqueduct section and provides screening of the flow from the Weston Reservoir to the Weston Aqueduct. This is an older facility with some deterioration. The Weston Reservoir Headquarters and Chlorine Building formerly provided chlorine and ammonia storage and delivery equipment for the Weston Aqueduct.

The Weston Aqueduct currently ends at the west side of the Loring Road tanks and is connected via an air gap to the Loring Road piping. This allows use of the aqueduct if necessary to feed the tanks or Low Service pipes in an emergency.

The Weston Aqueduct lower terminal chamber lies at the former discharge end of the Weston Aqueduct just east of the Loring Road tanks. When in operation, the building substructure was normally flooded with water entering from the aqueduct termination point on the west wall of the facility. This facility was disconnected from the active water system when the Loring Road tanks were completed in 2002. The building currently provides storage for site maintenance.

Projects in the FY19 CIP

- Ash Street Sluice gate design and construction. This project will provide a means to isolate the Weston Reservoir from a break west of Ash Street. The work also includes an investigation of the Ash Street and Happy Hollow Siphon. Existing gates in the siphon are in need of repair. This work is scheduled for FY19-20 at an estimated cost of approximately $1.1 million.

Sudbury Aqueduct and Associated Structures and Facilities

The Sudbury Aqueduct was completed in 1878 and extends from Framingham Reservoir #1 to the Chestnut Hill area in Boston. It is a somewhat smaller diameter concrete and brick masonry gravity aqueduct (with a typical cross section of 7'8" high by 9' wide). It was primarily constructed using cut and cover methods but has several tunnel segments, two aqueduct bridges and a siphon interspersed to address localized conditions. Surface pipelines connect it to the Chestnut Hill Pump Station and the Chestnut Hill Reservoir. It was designed to carry 90 MGD and was originally used to convey water from Framingham Reservoirs 1, 2, and 3 and indirectly from the Sudbury Reservoir or the Hultman Aqueduct via Reservoir No. 3. Reservoirs 1 and 2 were bypassed in the 1920's for water quality reasons by connecting the Reservoir 3 gatehouse to the aqueduct via two 48-inch pipes. The Sudbury Aqueduct and ancillary facilities are important legacy facilities both because they provide critical back-up but also because the system provides key right-of-way for potentially addressing future system needs. The proposed pressurization of a portion of the Aqueduct as part of redundancy planning options illustrates this well.

The Sudbury Aqueduct was an essential element of serving the Southern High and Southern Extra High prior to completion of the Dorchester Tunnel in 1974. The water quality of the Sudbury system no longer met standards so routine use was discontinued as soon as the new Dorchester Tunnel allowed, relegating the Sudbury Aqueduct to emergency back-up status. However, it is a particularly significant asset in that regard since it goes all the way into the Chestnut Hill area. In May, 2010 the Aqueduct was brought on line to supply water to the Chestnut Hill reservoir.

MWRA staff most recently investigated the Aqueduct thoroughly in 2002 to determine its physical condition and to determine the location, extent and characterization of sediment in the Aqueduct. (Sudbury Aqueduct Condition Assessment with Interior Rehabilitation Recommendations, June, 2004). In 2005-2006, consultant staff undertook follow-up investigations for the MWRA of the aqueduct condition with particular effort on the known hazardous waste sites, the clogged Rosemary Brook siphon and the areas where previous examinations had noted structural problems.

External investigations included a walk-over of the entire Aqueduct length and inspection of critical structures including approximately 46 culverts; approximately 45 manholes, two 500-foot bridge structures, one 1,800-foot siphon including two chambers and siphon blow-off valves, four waste weir culverts and all areas identified as having internal defects. Internal inspections focused on those areas identified as having invert heaving and possible undermining and areas identified as having a large aperture crown crack (a particular soft ground tunnel segment).

Crack in Rosemary Brook Siphon

The Rosemary Brook siphon crosses a wide low area by use of pressurized 48-inch pipes. The East and West Rosemary Brook Siphon Chambers are twin facilities that transition Sudbury Aqueduct flow from a normal aqueduct cross section conduit to two pipelines and then back into a normal aqueduct structure. These structures were cleaned by MWRA staff to ensure availability during an emergency occurrence. The siphon chamber facilities are constructed in a similar fashion with the exception being a circular tower within the west Chamber. These structures were inspected and fencing was used to provide protection from deteriorated structures until options were evaluated and a plan for stabilization was implemented.

As a result of work done to evaluate options for stabilizing the buildings and other site structures and, in line with MA Historical Commission interests in the site, some site facilities were stabilized and other above grade facilities demolished. The siphon chamber stabilization efforts are illustrated by this photo of the completed work at the west chamber.

West Siphon Chamber

The Sudbury Aqueduct has four waste weirs located along its length (A, B, C, D). All of these structures serve as overflow release points for the aqueduct when it is in service and they allow small streams or brooks to transverse the aqueduct. Structures at all four locations are single story granite and brick structures approximately 15' x 20' in size with slate roofs. None of the structures have electricity, heat or plumbing. Waste Weir A is where Course Brook transverses the aqueduct; Bacon's Brook Waste Weir B allows Davis Brook to transverse the aqueduct; Waste Weir C is where Fuller's Brook transverses the Aqueduct and Waste Weir D allows an unnamed drainage way to pass underneath the Aqueduct. When inspected during 1995-96, significant deficiencies were identified including the need for significant structural and safety improvements. Many of these deficiencies were fixed as part of more recent sluice gate rehabilitation.

MWRA has care and control of the Echo Bridge (1878) which spans the Charles River from Newton Upper Falls to Needham. The structure contains a water conduit and essentially functions as a pipe bridge over the river. The surface has a heavily used pedestrian bridge and is located in Hemlock Gorge, a DCR owned park. Echo Bridge was included on the National Register of Historic Places in 1980, prior to the rest of the Waterworks system. MWRA has repointed the brick surfaces of the structure in the late 1980's and the masonry is currently in good condition. The handrails along the top of the 500' pedestrian bridge are original, made of cast iron and have been determined to be in poor condition. In 2006, the MWRA installed interim safety fencing in front of the hand railings on both sides of the bridge as a protective measure. Since the hand rails are historic and must be repaired or replaced, MWRA has offered to work with elected officials and other interested parties to identify potential sources of outside funding.

Since the 2013 Master Plan, MWRA has undertaken an evaluation of the Waban Arches Bridge and the Farm Pond Inlet Chamber and Farm Pond Gatehouse. The intent of this work was similar to the work undertaken at Rosemary Brook to assess options to evaluate the conditions and to safety address any deteriorated structural conditions. The Farm Pond Gatehouse and Inlet Chamber are located in Framingham and historically, provided access to the Aqueduct. In addition, the Inlet Chamber provided a connection to Farm Pond (stop-logs) and the Gatehouse provided flow control through 4' x 4' sluice gates and screening. These facilities are in seriously deteriorated condition, in danger of collapse and can longer be accessed in any fashion due to safety considerations. Given the poor condition of these structures, a decision should be made whether the sluice gates are necessary at this location and whether access to the aqueduct could be maintained in another manner. The 1995 condition assessment recommended that access to the aqueduct be capped at this location.

The Waban Arches Bridge is similar to Echo Bridge and also has cast iron railings that have deteriorated with broken anchor rods and safety fencing has been installed at this location as well.

The bridge is a multi-span concrete-lined stone arch bridge extends over Waban Brook in Wellesley. It is a nine span masonry arch structure 540 linear feet long and 21 feet wide rising 48 feet above Waban Brook. Other than the railings, the bridge is in generally satisfactory condition with minor cracks, water stains, efflorescence and some deteriorated mortar. As all of the Sudbury Aqueduct facilities, these two structures are on the National Register, coordination should occur with appropriate staff to determine if these facilities can be fully documented and taken down or whether some level of stabilization is feasible and cost effective. MWRA received the consultant report in December, 2017

Projects in the FY19 CIP

- Phase 1 and Phase 2 (combined estimated cost of approximately $2.6 million) of Short-Term Repairs are scheduled to begin in FY24 in order to better prepare the Aqueduct for emergency activation if necessary.

- 7473-Evaluation of Farm Pond Buildings and Waban Arches-Assessment of historic structures to assess needs to repair and stabilize. This phase includes MA Historic Commission review of the recommended alternatives.

- Waban Arches Rehabilitation Design and Construction: Once specific measures have been identified and reviewed and accepted by all parties, work on the recommended alternative is expected to proceed in FY24 at an estimated cost of approximately 1.5 million.
- Farm Pond Inlet Chamber & Gatehouse Design: Once specific measures have been identified and reviewed and accepted by all parties, work on the recommended alternative is expected to proceed in FY25 at an estimated cost of approximately $2.4 million.

Southern Sudbury Transfer System

In the 1930's, MDC constructed a temporary water transfer piping system to act as a drought supplement to the existing Sudbury system reservoirs while Quabbin was being constructed. The transfer piping included an open channel and 24" pipe to transfer water from Whitehall Reservoir to Hopkinton Reservoir, a 30" pipe from Hopkinton Reservoir to Sudbury Reservoir, a transfer pumping station for the 30" pipe in Cordaville and a 24" pipe from Ashland Reservoir to Reservoir 1. This system was only needed until Quabbin was completed and was never utilized again. The pump station was demolished and all of the southern Sudbury system reservoirs were transferred to DEM (now DCR). The remaining issue is that the pipelines still exist and may become an issue if there is a collapse in the public way or if the pipeline causes property damage due to inadvertent leakage. MWRA has no plans for reuse but there may be a cost of stabilization (e.g. filling the pipes to prevent collapse) prior to disposition as surplus.

Norumbega Facilities

The Norumbega Open Reservoir and associated back-up facilities remains as part of the emergency back-up system. However, structures that were in daily use prior to the construction of the Norumbega Covered Storage Facility coming on line are no longer used or will be phased out as the final interconnections are made between the Hultman and new facilities.. These include the

Norumbega Reservoir Gatehouse and Screen Chamber through which the Hultman Aqueduct passes. Ongoing and future work will disconnect this portion of the Hultman and redirect flows around the Gatehouse. It will be possible to reconnect the Hultman to the Open Reservoir in the event of an emergency. In the event chlorination is required during an emergency; temporary equipment will be brought to the site. No major expenditures are anticipated at this location.

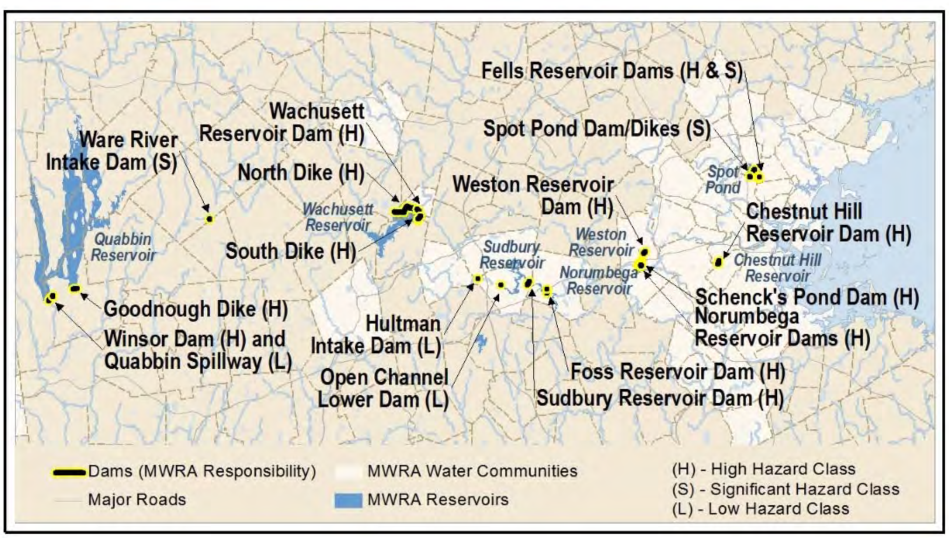
7.7 Dams

Overview and Responsible Parties

There are 28 water supply dams and dikes across the MWRA water system (Figure 7-8). These dams are technically owned by the Commonwealth of Massachusetts and the Department of Conservation and Recreation-Division of Water Supply Protection (DCR-DWSP) with MWRA sharing routine maintenance and inspection activities. Since the 2004 Memorandum of understanding with the DCR, MWRA has responsibility for Capital and major maintenance for the reservoir dams and has taken the lead in assuring regulatory compliance. MWRA also has responsibility for the emergency reservoir dams as they were part of the water transmission system. DCR continues to be responsible for tributary dams and inactive source dams such as Reservoirs 1 and 2 in the Sudbury system. The Commonwealth of Massachusetts retains ownership of all the dams. These dams are presented geographically in the following map.

Some reservoirs are impounded by one dam (e.g., Weston Reservoir) and others are impounded by several dams and dikes (e.g., Norumbega Reservoir, Table 7-4). Of these structures, 17 are classified as High Hazard potential and seven are classified as Significant Hazard potential with the remaining three classified as Low Hazard. The hazard class is a regulatory definition that refers to the potential life and/or property damage that could result from dam failure. Design, maintenance and inspection parameters are based on the class of the dam. All MWRA water supply dams are well maintained, regularly inspected and undergoing regulatory evaluations in compliance with the Massachusetts Office of Dam Safety Regulations.

Figure 7-8 Geographic Location of MWRA Dams



Dams of the MWRA Water System

As shown in Table 7-4, the majority of MWRA source and emergency reservoir dams are earthen embankment dams. There are also four masonry gravity dams, one of which is the large Wachusett Dam. These dams range in age from 148 years old (Chestnut Hill Reservoir Dam) to about 80 years old (Norumbega and Weston Dams). Some reservoirs have several dams and dikes creating the named impoundment (e.g. Norumbega Reservoir has Dams 1, 2, 3, 4 and East Dike). All of these are jurisdictional under the Office of Dam Safety regulations 302 CMR 10:00.

The lifespan of a dam is strongly dependent on when and to what standards it was built. The dam safety industry generally states that the typical lifespan of an earthen impoundment dam ranges from 50 years to 100 years, with the lifespan dependent upon on the level of maintenance performed and its structural safety. The average age of an impoundment dam in the U.S. is 56 years old (ASCE[2]). The average age of dams in the MWRA's fleet is 105 years old, with the youngest at 78 years and the oldest at 148 years. MWRA seeks to maintain and extend the life of these water supply dams through good dam safety practices, routine inspections, and performing required maintenance and improvements.

Table 7-4

Dams by location and type

Dam Name and Location		Year Completed	Construction/Type	Storage (MG)
Quabbin Reservoir	Winsor Dam, Belchertown	1939	Earthen Embankment	412,000
	Goodnough Dike, Ware	1938	Earthen Embankment	
	Quabbin Spillway	1938	Masonry - Gravity	
Ware River	Lonergan Intake Dam, Barre	1931	Masonry - Arch	Run of River
Wachusett Reservoir	Wachusett Reservoir Dam, Clinton	1905	Masonry - Gravity	65,000
	North Dike, Clinton	1905	Earthen Embankment	
	South Dike, Clinton	1905	Earthen Embankment	
Wachusett Aqueduct	Open Channel Lower Dam, Southborough	1880s	Masonry – Gravity & Earthen Embankment	8
Wachusett Aqueduct	Hultman Intake Dam, Marlborough	1940s	Earthen Embankment	8
Sudbury Reservoir	Sudbury Dam, Southborough	1898	Earthen Embankment	7,200
Foss Reservoir	Foss Reservoir Dam, Framingham	1890s	Earthen Embankment	1500
Norumbega Reservoir	Dams 1, 2, 3, 4 and East Dike, Weston	1940s	Earthen Embankment	163
Schenck's Pond	Schenck's Pond Dam, Weston	1940s	Earthen Embankment	43
Weston Reservoir	Weston Reservoir Dam, Weston	1903	Earthen Embankment	360
Spot Pond	Dams 1, 4 and 5, Stoneham	1899	Earthen Embankment	2,500
Fells Reservoir	Dams 2, 3, 6, 7, and 8, Stoneham	1898	Earthen Embankment	63
Chestnut Hill Reservoir	Chestnut Hill Dam, Boston	1870	Earthen Embankment	413

[2] Infrastructure Report Card – Dams, American Society of Civil Engineers,2017

Major Investments in Dams

MWRA began conducting Phase I dam safety regulatory inspections under 302 CMR 10:00 in 2005 and continues to conduct biennial inspections at High Hazard Class dams, 5-year inspections at Significant Hazard class dams, and 10-year inspections at Low Hazard class dams. These inspections identified a number of necessary improvements and needed analyses for these dams. Early in the dam safety compliance program development, staff created a prioritization of needs, with a plan and timeline for repairs, evaluations, and upgrades. Table X shows the same list of dams with an updated status on repairs made and remaining work underway at each location.

To date, MWRA has invested over $22 million in capital upgrades and major maintenance projects, required studies and assessments, and routine regulatory compliance work. This work includes dam safety engineering studies to understand Hydraulics and Hydrology Analyses for extreme precipitation events[3] and spillway adequacy, major spillway improvements such as the upgrade of Wachusett Dam's spillway and Winsor Dam's toe drain system, earthen dam maintenance such as major tree removal at many dams, major masonry improvements to spillways and structures, and installation of seepage weirs.

Long term dam maintenance activities are largely determined by the type of dam structure. Tree removal and brush control is a factor on all dams but the earthen dams are more likely to require greater attention to vegetation maintenance and close monitoring of surficial issues such as animal burrows, erosion and drainage (e.g., toe drain conditions). The masonry dams will need repointing at approximately twenty-year intervals. Some minor seepage and leakage is to be expected at all dams and this must also be monitored for changes in rate and water quality (e.g., sediment in seepage could mean internal erosion). Over time settlement occurs and all dams may need periodic resetting of riprap as well.

Dams' Conditions and Safety

By making improvements to MWRA dams and keeping current with regulatory requirements, the condition of these dams has improved, all dams are in compliance, and have been certified by the Massachusetts Office of Dam Safety to have adequate spillway capacity to meet the regulatory Spillway Design Floods (or SDF).[4] Where spillways do not exist at reservoirs (such as at the Fells and Weston distribution reservoirs), they have adequate freeboard (capacity) to store this design flood. At Weston Dam, MWRA completed a parapet wall (or wave wall) to prevent this stored design flood from eroding the dam crest (Figure 7-9).

[3] Recent updates to regional climate and precipitation studies have shown that weather patterns are changing resulting in more frequent and intense wet weather events.

[4] Existing dams must meet a SDF of ½ the Probable maximum Flood (1/2 PMF) which is based on regional extreme precipitation events.

Figure 7-9

Table 7-5 List of Water Supply Dams

Dam Name and Location	Year Completed	Construction	Capital and Major Maintenance/Recent Improvements/Completed and Future Needs
Winsor Dam, Belchertown, MA	1939	Earthen	Toe and surface drains rehab completed at Winsor Dam. Quabbin Spillway injection grouting and repointing completed. Spillway fence rehab completed. Power lines rehab completed. Quabbin Spillway needs improved operations ability such as an automated gate for elevation control options. Spillway training/retaining wall requires vegetation maintenance and limited repointing. Goodnough Dike needs further evaluation of blanket drain outlet structure and tail water conditions.
Goodnough Dike, Ware, MA	1938	Earthen	
Quabbin Spillway	1938	Masonry	
Ware River Diversion Dam, Barre, MA	1931	Masonry	Major spillway repointing completed. Needs: minimal. Local drainage improvements are needed to correct a deficiency where a local runoff discharge occurs on the toe of dam.
Wachusett Reservoir Dam, Clinton, MA	1905	Masonry	Spillway rehab and crest gate installation completed. East berm construction completed. Auxiliary spillway channel completed. Dam face masonry and top-of-dam Promenade rehab completed. Needs: Upper masonry spillway repointing, Bastion Structure rehab is needed to improve that appurtenant structure to the dam
Wachusett Reservoir North Dike, Clinton, MA	1905	Earthen	Major tree clearing and slope restoration completed. Needs: installation of dam monitoring instrumentation (concept design completed 2017). Evaluation of Factors of Safety and potential repairs to (underway 2017); reconnection on earthen North Dike around Leominster Pump Station to protect against wave runup overtopping at this location (design contract underway 2017/18). Piezometers are required at this dam (design underway in 2018).
Wachusett Reservoir South Dike, Boylston, MA	1905	Earthen	Major tree clearing and slope restoration completed. Needs: installation of dam monitoring instrumentation (concept design completed 2017). Evaluation of Factors of Safety and potential repairs (underway 2017). Piezometers are required at this dam (design underway in 2018)
Open Channel Lower Dam, Southborough, MA	1880s	Masonry	Masonry cosmetic repointing completed in 2012. Needs: Limited capstone resetting and dowling and additional upstream and downstream face grouting and masonry reporting repair
Sudbury Dam, Southborough, MA	1898	Earthen	Major tree clearing completed. Riprap and training wall repairs completed. Spillway crest grouted and repointed. 5-year weep hole maintenance completed. Needs: spillway face repointing and upstream underwater conditions inspection (design underway 2018). Requires upstream underwater inspection and conditions assessment (design underway 2018), Requires spillway outlet venting repairs (design underway 2018)
Framingham Reservoir #3 Dam, Framingham, MA	1890s	Earthen	Major tree clearing of dam and dike completed. Spillway Design Flood (SDF) determination completed. Construction of seepage control and monitoring weir completed 2016. Needs: installation of dam monitoring instrumentation (concept design completed 2017). Armoring of right side of dam and turf enhancement to withstand overtopping under SDF (design underway 2017/18). Evaluation of Factors of Safety and potential repairs (underway 2017). Piezometers are required at this dam (design in planning)
Norumbega Reservoir Dam #1, Weston, MA	1940s	Earthen	Needs: Evaluation of Factors of Safety and potential repairs (underway 2017); installation of dam monitoring instrumentation (concept design completed 2017final design in planning)
Norumbega Reservoir Dam #2, 3 and 4, and East Dike, Weston, MA	1940s	Earthen	Major tree clearing and grading completed. Needs: installation of dam monitoring instrumentation (concept design completed 2017 Final design in planning)
Schencks Pond Dam, Weston, MA	1940s	Earthen	Major tree clearing and grading completed. Evaluation of Factors of Safety and potential repairs (underway 2016/17) installation of dam monitoring instrumentation (concept design completed 2017 Final design in planning)
Weston Reservoir Dam, Weston, MA	1903	Earthen	Major tree clearing and grading completed. Installation of parapet (wave) wall completed. Installation of seepage weir structures completed. Needs: Evaluation of Factors of Safety and potential repairs (underway 2016/17) installation of dam monitoring instrumentation (concept design completed 2017 Final design in planning)
Spot Pond Dam #1, 4 and 5, Stoneham, MA	1899	Earthen	Major tree clearing and grading completed. Armoring of Dam #1 completed. Needs: clearing downstream emergency spillway channel and Woodland Road underdrain repaired (coordination/responsibility needs to be determined on Woodland Rd./ underdrain w/ DCR)
Fells Reservoir Dam #2 and 3, Stoneham, MA	1898	Earthen	Major tree clearing and grading completed. Needs: installation of dam monitoring instrumentation (concept design completed 2017 Final design in planning)
Fells Reservoir Dam #6,7 and 8, Stoneham, MA	1898	Earthen	Major tree clearing and grading completed. Needs: Installation of seepage weir monitoring structure at Dam #8 (2018), installation of dam monitoring instrumentation (concept design completed 2017 Final design in planning)
Chestnut Hill Dam, Boston/Newton, MA	1860s	Earthen	Riprap and Gatehouse #2 roof leader repairs completed. Downstream toe grading and surface drain work completed. Gatehouse #1 internal stability repairs) completed in 2018. Evaluation of Factors of Safety and potential repairs (underway 2017). Exterior building repointing planned for future contract, installation of dam monitoring instrumentation (concept design completed 2017 Final design in planning)
Hultman Intake Dam	1940s	Masonry	Needs: Minimal tree clearing and repointing

Dam Condition Assessments

Table 7-6 Current Status of MWRA's Dam Inspection Program

MWRA
Dams Conditions Summary Report, 2017

Table 1. MWRA Water Supply Dam Safety Inspection Program under 302 CMR 10:00 **Status: In Compliance w/ 302 CMR 10:00**

Dam Name and Location	Note	Construction type	Year Completed	Structural Height (ft)	Storage (MG)	Storage (Ac. ft.)	Hazard Class.	Recent Phase I Inspection	Condition	Insp. Cycle (yrs)	Next Phase I Inspection
Winsor Dam, Belchertown, MA	1	Earthen	1939	170	412,000	1,264,382	High	8/4/2016	Good	2	8/4/2018
Goodnough Dike, Ware, MA	1	Earthen	1938	135			High		Good		
Quabbin Spillway	1	Masonry		10			Low		Good		
Ware River Diversion Dam, Barre, MA	2	Masonry	1931	38	Run of River		Significant	9/18/2014	Satisfactory	5	9/18/2019
Wachusett Reservoir Dam, Clinton, MA	1	Masonry	1905	114	65,000	199,478	High	7/27/2016	Satisfactory	2	7/27/2018
Wachusett Reservoir North Dike, Clinton, MA	1	Earthen		22			High		Satisfactory		
Wachusett Reservoir South Dike, Boylston, MA	1	Earthen		45			High		Satisfactory		
Open Channel Lower Dam, Southborough, MA	2	Masonry	1880s	18.5	8	25	Low	4/18/2008	Satisfactory	10	4/18/2018
Sudbury Dam, Southborough, MA	1	Earthen	1898	84	7,200	22,096	High	8/5/2016	Satisfactory	2	8/5/2018
Framingham Reservoir #3 Dam, Framingham, MA	1	Earthen	1890s	29	1,500	4,603	High	8/5/2016	Satisfactory	2	8/5/2018
Norumbega Reservoir Dam #1, Weston, MA	2	Earthen	1940s	42	163	500	High	9/9/2016	Fair **	2	9/12/2018
Norumbega Res. Dams #2, 3, 4 and East Dike, Weston	2	Earthen	1940s	<42	163	500	High	9/12/2016	Satisfactory	2	9/12/2018
Schencks Pond Dam, Weston, MA	2	Earthen	1940s	22	43	132	High	9/9/2016	Satisfactory	2	9/12/2018
Weston Reservoir Dam, Weston, MA	2	Earthen	1903	40	360	1,105	High	8/19/2016	Fair **	2	8/19/2018
Spot Pond Dam 1, 4 and 5 , Stoneham, MA	1*	Earthen	1899	13	2,500	7,672	Significant	5/22/2013	Satisfactory	5	5/22/2018
Fells Reservoir Dam 2 and 3 Stoneham, MA	1	Earthen	1898	#2=12, #3=25	63	193	Significant or High	9/23/2016	Satisfactory	2	9/23/2018
Fells Reservoir Dam 6,7 and 8, Stoneham, MA		Earthen		#6=17,#7=4, #8=48					Satisfactory	2	
Chestnut Hill Dam, Boston/Newton, MA	1*	Earthen	1860s	19	413	1,267	High	8/19/2016	Satisfactory	2	8/19/2018
Hultman Intake Dam	2	Masonry	1940s	12	8	25	Low	9/12/2014	Satisfactory	10	9/12/2024

All 2016 Dam Safety Inspection Reports submitted to MA Office of Dam Safety per 302 CMR 10:00.

Notes:
1. Indicates MWRA/DCR shared Capital/operational responsibility with DCR-DWSP. * indicates shared operational/grounds responsibility with DCR-State Parks.
2. Indicates sole MWRA Capital/operational responsibility

** 2014 and 2016 Dam condition reported similar to previous 2012 inspection which had a rating of Satisfactory. However, change in rating was due to a ***calculated*** factor of safety (FS) value where actual subsurface soils data was not available for engineering review. MWRA performing a re-evaluation of FS conditions in 2017/18 including sensitivity analysis in the modeling to assess improvements if needed.

Quabbin Reservoir (Winsor Dam, Goodnough Dike, Quabbin Spillway)

At the Quabbin Reservoir, the major impounding dam structures are Winsor Dam, Goodnough Dike and Quabbin Spillway, all of which are over 70 years old

At Quabbin Reservoir, the Winsor Dam internal toe drainage system and piezometers were upgraded in 2007. The masonry Quabbin Spillway (technically a gravity dam itself) was structurally improved through injection grouting and repointing on its upstream and downstream faces and crest in 2010.

Pieszometer Installation at Winsor Dam

Quabbin Spillway crest stone repairs before (L) and after (R)

Quabbin Spillway upstream repairs before (L) and after (R)

MWRA performed an evaluation study in FY 13 to regarding drainage of the Goodnough Dike blanket/toe drain relative to downstream elevations.

The findings of that study showed the existing drainage system at the dam appears to be functioning as designed. Based on the relative elevation survey completed, the observed conditions and finding of this evaluation, and the existing drawings for the dike, it appears that the drainage system will continue to flow unobstructed from tail water conditions when the tailwater is below elevation 416.0 feet. At elevations above 416.0 feet, water will start to back charge piping from MH-3 to MH-2 and may impact the functionality and capacity of the toe drain system. Therefore, the study identified elevation 415.5 feet as the critical tail water elevation at which mitigative measures would be required.

The existing spillway discharge channel is cut from bedrock and capable of withstanding substantial discharges from the regulatory design flood (1/2 the Probable Maximum Flood or PMF) without engaging the Auxiliary Spillway, which is 1,500 feet away from the dam. A 2012 Hydraulics and Hydrologic study of the system showed that the Quabbin Spillway can also accommodate the full PMF (twice the regulatory level) with the Auxiliary Spillway having a discharge of only 0.7 ft of water over its crest.

Quabbin Spillway

Reduced consumer demand, water saving measures, and above average precipitation over the last decade has resulted in high Quabbin elevations for several years running. However, from 2015 to 2017 a regional drought brought Quabbin elevation to the “Below Normal” status for the first time in 14 years. Even at the nominal Below Normal level, Quabbin volume is sufficient to supply the service area for nearly five years. Quabbin levels recovered later in 2017 and have remained above the long-term average throughout 2018.

Operationally, MWRA has no ability to lower Quabbin Reservoir in the event of an emergency. The incident at Oroville Dam in California in 2017 highlights the need for greater operational control of elevation to created freeboard (storage) in advance of a major meteorological event.

Quabbin Spillway

For example, during hurricane season or spring runoff conditions, a full-to-the-brim reservoir is not operationally desired and could result in greater downstream flooding problems due to uncontrolled spilling. Likewise, in a condition such as in Fall 2018 where the reservoir is full, a large snowpack over the winter could result in extensive spilling during the spring.

Since there is no structural means for MWRA to remove[5] excess water from Quabbin Reservoir, a preliminary analysis and design study was performed to assess options allow greater operational seasonal elevation control. This 2013 report analyzed three different drawdown scenarios with conceptual design options to install a new spillway configuration and hydraulically-operated crest gate (similar to the Wachusett Spillway type described later):

1. 2 ft. drawdown over 4 weeks
2. 2 ft. drawdown over 1 week
3. 2 ft. drawdown over 3 days

Under scenario 1. The current width of the lower spillway (the center section in the photo above) would remain the same and the invert of the spillway lowered by 3 ft. to elevation 525 ft. BCB with a crest gate installed to elevation 530 ft. BCB. Under scenario 2. The spillway width would remain the same but the invert lowered to 518.7 ft. BCB and a new sill placed on bedrock, and a crest gate installed to elevation 530 ft. BCB. Option 3, is a much greater change and would require the lower spillway and approximately 60 feet of the main spillway lowered to 522 ft. BCB with two crest gates installed to elevation 530 ft. BCB. The concept level costs are $1.4 M for Option 1, $2.3 M for Option 2, and $3.5 M for Option 3. Option 2 is currently preferred and is included under Recommended Projects.

Wachusett Reservoir (Wachusett Dam, North Dike, South Dike)

At both Quabbin and Wachusett Reservoirs, dam spillway systems exceed the minimum regulatory SDF requirement. At Wachusett Reservoir, the spillway can provide for the full PMF.[6] To achieve this, improvements were made from 2008 – 2009 that included lowering the existing spillway by 2 feet and installation of a 100 foot long by 5 foot high stainless steel automated Crest Gate. This

[5] Seasonal Quabbin Transfer (Shaft 12), CVA demand and WPS releases to the Swift River amount to relatively insignificant releases considering the massive volume of Quabbin. An additional structural means to move water is desired.

[6] The regulatory requirement for existing dams is to design for the ½ PMF (28 inches of rain in 72 hours).

system provides MWRA with greater operational flexibility to control reservoir elevations, such as lowering the reservoir in advance of a hurricane or major storms. This project also included creation of an auxiliary spillway carved in bedrock and lined with stone gabion armoring to pass the design flood. A riprap berm was created on the spillway side of the dam to protect from overtopping erosion.

Wachusett Spillway Crest Gate

Construction of Auxiliary Spillway (L) and after completion (R)

East Berm created along left abutment

East Berm armored

During the spillway project, spoils from the excavation were used to structurally reinforce the North Dike at a historically weakened area where static liquefaction had occurred in 1907 when the reservoir first filled. This area was stripped back, benched and backstopped with rock spoil. The area was re-graded to original slope conditions.

North Dike structural improvements

Also in 2007 it was discovered that PCB caulking used in the Promenade walkway joints in the mid 1960's had leached into concrete and was carried by runoff down the face of Wachusett Dam where it penetrated efflorescence and mortar. Under US EPA remediation guidance, the Promenade walkway was demolished with the PCB concrete wastes sent to special landfills. A new walkway with improved drainage was constructed. Total investment was $2.22 M.

Promenade with PCB contaminated areas marked in red.

Rebuilt Promenade

In 2009-2010, the next major remediation project was completed to remove the PCB contamination from efflorescence and mortar on the face of Wachusett Dam, followed by repointing and high-pressure power washing of the dam face. Additionally, this project also included the installation of eight new piezometers to replace failed and unserviceable ones. The total investment in this project was $2.441 M.

PCB-contaminated efflorescence and mortar

Previous Phase I Dam Safety Inspections have noted that widespread tree growth on several MWRA dams was a regulatory deficiency under the 302 CMR 10.00 and the MA Office of Dam Safety's "Policy on Trees on Earthen Dams," which prohibits this condition.

Tree growth on earthen dams can allow reservoir water penetration of decayed root pathways leading to "piping" – a phenomena which can cause internal erosion and ultimately failure of the dam. Uprooted trees can also create dam safety problems, and widespread tree and vegetation growth and forest litter on a dam slope prevents optimal inspection for early signs of problems such as slumps and seeps. Trees must be cut and have the stumps pulled to remove the bulk of root matter. The stump voids are then backfilled and compacted, covered and seeded for uniform grass cover. From 2005 through 2013, MWRA performed massive tree and stump clearing from all water supply dams including Wachusett North and South Dikes, Sudbury Dam, Foss Dam and Rear Dike, Fells Dams, Norumbega and Schencks Dams, Spot Pond Dams, and Weston Dam.

Stump removal from dam

Stump void fill and compaction, prior to final loaming and seeding

Dam Improvement and Maintenance Projects

MWRA continues to address other identified dam improvement and repair needs which are either in progress now or in planning for the near future. Projects may be identified for implementation using Current Expense Budget Funds or larger projects may be identified for inclusion in MWRA's Capital Budget. As noted below, staff believe that it is critical to have funding in place for longer term maintenance needs for both the earthen and masonry dams maintained by MWRA. A number of tasks fall logically under such a long term program as identified below.

Dam Projects Included in the FY19 CIP

- Sudbury Spillway Masonry Repair. This is presently under procurement. An added task is the Sudbury Spillway outlet vent pipe which failed in 2018 and needs to be repaired.

- Foss Dam Improvements for overtopping protection, which resulted from the reclassification of the spillway from the ½ Probable Maximum Flood (PMF) to the 500-year flood. This dam requires armoring and turf enhancements.

- Wachusett North Dike earthen berm reconnection around Leominster Pump Station to prevent overtopping at this low spot. This project meets regulatory requirements and includes reconnection of a 150-foot long by 5 foot high gap in the Wachusett North Dike created in the mid-1960s to accommodate the Leominster raw water pump station; Design is anticipated to begin in FY19. Costs are estimated to be approximately $1.6 million for these three efforts.

- Piezometer design and installation at Wachusett Reservoir's North Dike and South Dike.

- Quinapoxet Dam Removal: A project to provide final design, ESDC/RI and construction for the removal of the Oakdale Dam adjacent to the Oakdale Pump Station is included in the FY19 CIP. The removal of the dam will help landlocked fish in the Wachusett Reservoir reach spawning grounds in the Quinapoxet River. The project cost is $801,000 plus permitting costs with initial permitting anticipated to begin in FY19 and design to commence in FY21 followed by construction.

<u>Recommended Projects</u>

- Dams Asset Maintenance Program: As dams continue to age, constant maintenance work will be necessary for shorter lifespan components directly exposed to weathering and climate such as soils and turf on earthen dams, and concrete and masonry components. Mechanical components such as gates and valves must also be inspected and maintained more frequently to ensure their long-term operability. A new Dams Asset Maintenance Program has been developed to address these and other items to better plan for and budget dam maintenance projects. This program will look at a 5-year timeline for needed work that can be considered more maintenance level type projects such as the sequential installation and maintenance of instrumentation, masonry and repointing needs, dams turf improvements and vegetation needs, and correction of erosion areas. The goal of this program is to provide consistent budgeting. The Master Plan recommends the addition of $10 million within the 40 year planning horizon. Examples of these projects may include:
    - Installation of dam monitoring instrumentation such as piezometers to assess internal pore pressure and slope stability conditions (Wachusett underway FY19), Sudbury, Weston, Foss, Chestnut Hill, Norumbega, Schenck's Pond, and Fells);
    - Seismic safety factor evaluations for Norumbega, Foss and Wachusett dikes. This work could be substantially aided by the addition of the monitoring equipment identified above.
    - The drought of 2016/17 had adversely affected turf conditions at several dams leading to both erosion and invasive plants. A more detailed assessment of local conditions at each dam (soils, ground cover, orientation, slope, etc.) is needed to repair and restore failed ground cover with the most suitable cover for the local conditions. Underway FY 19.
- Quabbin Lower Spillway Improvements: This project would make modifications to the Quabbin Spillway in order to allow greater operational seasonal elevation control. The recommended alternative would lower the spillway invert, place a new sill on bedrock and install a new hydraulically operated crest gate. The estimated cost of this work is $2.3 million.

Additionally, in terms of agency priorities, MWRA has continued to invest in developing and updating Emergency Action Plans (EAPs) for all High and Significant Hazard Class dams to address recent changes in Federal dam safety guidelines (FEMA-64) which includes approaches and practices that are consistent with the National Response Framework and with emergency action planning. These EAPs updates will also have improved inundation zone mapping to identify critical facilities and transportation nodes to assist downstream emergency managers for evacuation plans.

Looking to the future, MWRA must remain vigilant to changing climate conditions that will likely result in longer drought periods but interspersed with extreme wet weather events.

7.8 Summary of Recommended Transmission System Improvements

Staff recommends consideration for the FY19-58 timeframe of the following projects:

- Metropolitan Tunnel Rehabilitation: Staff have proposed that a $65 million placeholder amount be considered to anticipated needed inspections and rehabilitation of the existing Metropolitan Tunnel system following completion of the new tunnels. This work is estimated to occur in FY39-58.

- Staff recommend that regular inspections be done of the Cosgrove Tunnel at 15 year intervals at a cost of $5000,000 per inspection. There would be three inspections in the planning horizon of this Master Plan.

- Nash Hill: $1.1 million is recommended in FY24-25 for rehabilitation of the Nash Hill tanks.

- Norumbega: $8.1 million is recommended in FY24-32 for rehabilitation of Norumbega Covered Storage.

- Loring Road: $2.5 million is recommended in FY27-32 for rehabilitation of Loring Road Covered Storage.

- Blue Hills: $2.5 million is recommended in FY30-35 for rehabilitation of Blue Hills Covered Storage.

- Dams Asset Maintenance Program: As dams continue to age, constant maintenance work will be necessary for shorter lifespan components directly exposed to weathering and climate such as soils and turf on earthen dams, and concrete and masonry components. Mechanical components such as gates and valves must also be inspected and maintained more frequently to ensure their long-term operability. A new Dams Asset Maintenance Program has been developed to address these and other items to better plan for and budget dam maintenance projects. This program will look at a 5-year timeline for needed work that can be considered more maintenance level type projects such as the sequential installation and maintenance of instrumentation, masonry and repointing needs, dams turf improvements and vegetation needs, and correction of erosion areas. The goal of this program is to provide consistent budgeting. The Master Plan recommends the addition of $10 million within the 40 year planning horizon.

- Quabbin Lower Spillway Improvements: This project would make modifications to the Quabbin Spillway in order to allow greater operational seasonal elevation control. The recommended alternative would lower the spillway invert, place a new sill on bedrock and install a new hydraulically operated crest gate. The estimated cost of this work is $2.3 million.

- Staff recommend that an inspection plan be developed for the Southborough Tunnel.
- Staff recommends that Western Operations request clarification from the Law Division on the ownership and maintenance responsibilities for bridges and roads across the Open Channel and at other locations as determined by Western Operations.

Table 7-7
Water Master Plan - Transmission System and Dams
Recommended Projects

Last revision 1/2/19

Prioritization

1 Critical or Under Construction
2 Essential
3 Necessary
4 Important
5 Desirable

Project Types

NF	New Facility/System
RF/IC	Replacement Facility/Increase Capacity
Opti	Optimization
AP	Asset Protection
Plan	Planning/Study

Line No	Priority	Project	Project Type	FY19 CIP Project No.	FY19 CIP Contract No.	Project Duration	Total Project Cost ($1000)	FY19-58 Planning Period Cost	Schedule	FY19-23	FY24-28	FY29-38	FY39-58	FY19-58 Planning Period Cost
										5 years	5 years	10 years	20 years	
		TRANSMISSION SYSTEM AND DAMS												
7.01	1	Metro Redundancy Interim Design	AP/Opti	628	60200_7560	5 years	2,200	2,200	FY19-23	2,200				2,200
7.02	1	Top of Shafts Int Improvements Construction	AP/Opti	628	60202_7561	2 years	6,197	6,197	FY20-22	6,197				6,197
7.03	1	Chestnut Hill emergency Pump Station - Design & Construction	AP/Opti	628	60207_7574 60203_7562	7 years	25,292	25,292	FY19-26	7,985	17,307			25,292
7.04	1	Chestnut Hill Emergency Pump Station Generator	New	628	60205_7566	1 year	9,007	9,007	FY22-23	4,507	4,500			9,007
7.05	1	WASM/SPSM West PRV - Design & Construction	New	628	60208_7575 60204_7563	6 years	16,182	16,182	FY19-24	16,182				16,182
7.06	1	Shafts 5 & 9 Building Improvements - Design & Construction	AP/Opti	628	60209_7599 60210_7600	3 years	3,750	3,750	FY19-22	3,750				3,750
7.07	1	Section 101 Waltham - Design & Construction	New	628	68334_7547 68333_7547	5 years	16,287	16,287	FY20-25	10,919	5,368			16,287
7.08	1	Comm Ave Pump Station Improvements - Design & Construction	Opti	628	75580_7523 75581_7524	3 years	8,977	8,977	FY19-22	8,977				8,977
7.09	1	Metro Redundancy Concept Design - EIR	New	625	60092_7159	3 years	9,022	9,022	FY20-23	9,022				9,022
7.10	1	Metro Redundancy Construction Management	New	625	60126_7356	14 years	113,965	113,965	FY23-37	1,000	40,000	72,965		113,965
7.11	1	Metro Redundancy PR/Legal Administration	New	625	60170_7516	15 years	163,673	163,673	FY23-38	3,673	80,000	80,000		163,673
7.12	1	Metro Redundancy Final Design	New	625	60174_7556	16 years	87,373	87,373	FY22-38	5,461	70,000	11,912		87,373
7.13	2	Top of Shafts Rehab - Design & Construction	AP/Opti	625	60172_7521 60173_7522	5 years	6,369	6,369	FY38-43			369	6,000	6,369
7.14	2	Top of Shafts Connecting Mains - Construction	New	625	60127_7357	2 years	40,452	40,452	FY40-42				40,452	40,452
7.15	2	Shaft 7 Buildings - Design & Construction	New	625	60176_7558 60177_7559	5 years	6,410	6,410	FY38-43				6,410	6,410
7.16	1	Tunnel Construction	New	625	60107_7291	13 years	957,191	957,191	FY25-38		300,000	657,191		957,191
7.17	3	Quabbin Aqueduct TV Inspection	Plan	597	60033_6277	1 year	3,170	3,170	FY24-25		3,170			3,170

Table 7-7
Water Master Plan - Transmission System and Dams
Recommended Projects

Last revision 1/2/19

Prioritization

1 Critical or Under Construction
2 Essential
3 Necessary
4 Important
5 Desirable

Project Types

NF	New Facility/System
RF/IC	Replacement Facility/Increase Capacity
Opti	Optimization
AP	Asset Protection
Plan	Planning/Study

Line No	Priority	Project	Project Type	FY19 CIP Project No.	FY19 CIP Contract No.	Project Duration	Total Project Cost ($1000)	FY19-58 Planning Period Cost	Schedule	FY19-23	FY24-28	FY29-38	FY39-58	FY19-58 Planning Period Cost
										5 years	5 years	10 years	20 years	
		TRANSMISSION SYSTEM AND DAMS												
7.18	2	Winsor Power Station Rehab - Design & Construction	AP	597	60140_7460 60088_7115	5 years	23,241	23,241	FY24-29		20,000	3,241		23,241
7.19	2	Shaft 12 Isolation Gates - Design & Construction	New	597	60141_7509 60095_7197	3 years	16,314	16,314	FY19-26	134	16,180			16,314
7.20	2	Valve Chamber/Storage Tank Access Improvements	AP/Opti	604	60160_7476	2 years	2,400	2,400	FY25-27		2,400			2,400
7.21	3	Oakdale High Line Replacement - Construction	AP	616	60068_6940	1 year	465	465	FY20	465				465
7.22	3	Ware River Intake Valve Replacement - Design & Construction	Opti/New	616	60108_7282 60138_7487	5 yeasr	1,200	1,200	FY21-26	300	900			1,200
7.23	3	Oakdale Turbine Rehab - Design & Construction	AP	616	60201_7545 60135_7378	4 years	1,200	1,200	FY25-29		1,000	200		1,200
7.24	3	Wachusett Gatehouse Rehab - Design & Construction	AP/Opti	616	60113_7333 60137_7380	5 years	5,588	5,588	FY20-24	1,100	4,488			5,588
7.25	2	Ash Street Sluice Gates - Construction	AP	617	60130_7369	1 year	1,070	1,070	FY19-20	1,070				1,070
7.26	2	Sudbury Short Term Repairs	AP	617	60076_7016	1 year	477	477	FY24		477			477
7.27	3	Sudbury Short Term Repairs - Phase 2	AP	617	60110_7317	1 year	2,098	2,098	FY24		2,098			2,098
7.28	3	Evaluation of Farm Pond Buildings/Waban Arches	Plan	617	60151_7473	1 year	15	15	FY19	15				15
7.29	3	Waban Arches Rehab - Design & Construction	AP	617	60153_7616 60154_7617	4 years	1,500	1,500	FY24-28		1,500			1,500
7.30	3	Farm Pond Inlet Chamber & Gate House Repair - Design & Construction	AP	617	60155_7618 60156_7619	4 years	2,400	2,400	FY25-29		2,000	400		2,400
7.31	1	WAPS - Design & Construction	New	622	60090_7156 60091_7157	1 year	5,566	5,566	FY19-20	5,566				5,566
7.32	2	Design and Construction - Sudbury/Foss Dam Improvements and Wachusett North Dike Overtopping	Opti	623	60190_7614 60191_7615	2 years	1,810	1,810	FY19-21	1,810				1,810
7.33	4	Quinapoxett Dam Removal Permits/Design & Construction	Opti	623	60119_7347 60120_7348	6 years	801	800	FY17-24	582	218			800
7.34	3	Cosgrove Valve Replacement - Design & Construction	AP	766	75510_7565 75509_7564	2 years	2,198	2,198	FY25-26		2,198			2,198
7.35	3	Electrical Distribution Upgrades at Southborough	AP/Opti	766	75535_7425	1 year	1,200	1,200	FY20-21	1,200				1,200

Table 7-7
Water Master Plan - Transmission System and Dams
Recommended Projects

Last revision 1/2/19

Prioritization	Project Types	
1 Critical or Under Construction	NF	New Facility/System
2 Essential	RF/IC	Replacement Facility/Increase Capacity
3 Necessary	Opti	Optimization
4 Important	AP	Asset Protection
5 Desirable	Plan	Planning/Study

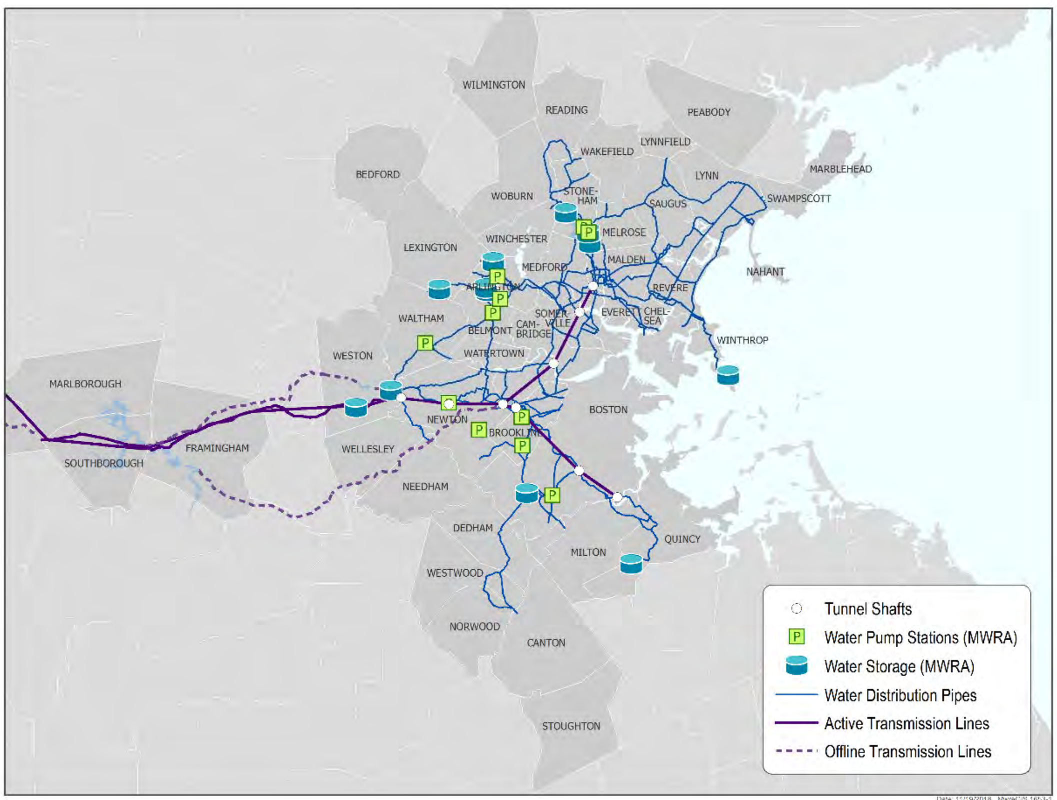
Line No	Priority	Project	Project Type	FY19 CIP Project No.	FY19 CIP Contract No.	Project Duration	Total Project Cost ($1000)	FY19-58 Planning Period Cost	Schedule	FY19-23	FY24-28	FY29-38	FY39-58	FY19-58 Planning Period Cost
										5 years	5 years	10 years	20 years	
		TRANSMISSION SYSTEM AND DAMS												
7.36	3	Cosgrove Flat Roof Replacement	AP	766	75505_7022	1 year	640	640	FY19	640				640
7.37	3	Cathodic Protection Shafts E and L+ W16 Construction	AP	712	68131_6440	1 year	909	909	FY19-20	909				909
7.38	3	Cathodic Protection Western System - Design & Construction	AP	712	68380_7609 68381_7610	5 years	5,230	5,230	FY20-25	2,791	2,439			5,230
		SUBTOTAL - Existing - Transmission System and Dams					**1,551,839**	**1,551,838**		**96,455**	**576,243**	**826,278**	**52,862**	**1,551,838**
7.39	2	Metro Tunnel Rehabilitation	AP	new		As Needed	65,000	65,000	FY39-58				65,000	65,000
7.40	2	Cosgrove Tunnel Inspections	AP	new		As Needed	1,500	1,500	FY20, 35, 50	500		500	500	1,500
7.41	3	Covered Storage - Nash Hill	AP	new		1 year	1,100	1,100	FY24-25		1,100			1,100
7.42	3	Covered Storage - Norumbega	AP	new		8 years	8,100	8,100	FY24-32		4,000	4,100		8,100
7.43	3	Covered Storage - Loring Road	AP	new		5 years	2,500	2,500	FY27-32		1,250	1,250		2,500
7.44	3	Covered Storage - Blue Hills	AP	new		5 years	2,500	2,500	FY30-35			2,500		2,500
7.45	3	Dams Asset Maintenance	AP	new		As Needed	10,000	10,000	FY19-58	1,250	1,250	2,500	5,000	10,000
7.46	2	Quabbin Spillway Improvements	Opti	new		3 Years	2,300	2,300	FY24-28	2,300				2,300
		SUBTOTAL - Recommended - Transmission System and Dams					**93,000**	**93,000**		**4,050**	**7,600**	**10,850**	**70,500**	**93,000**
		SUBTOTAL - Existing and Recommended - Transmission System and Dams					**1,644,839**	**1,644,838**		**100,505**	**583,843**	**837,128**	**123,362**	**1,644,838**

8 The Metropolitan System

8.1 Chapter Summary

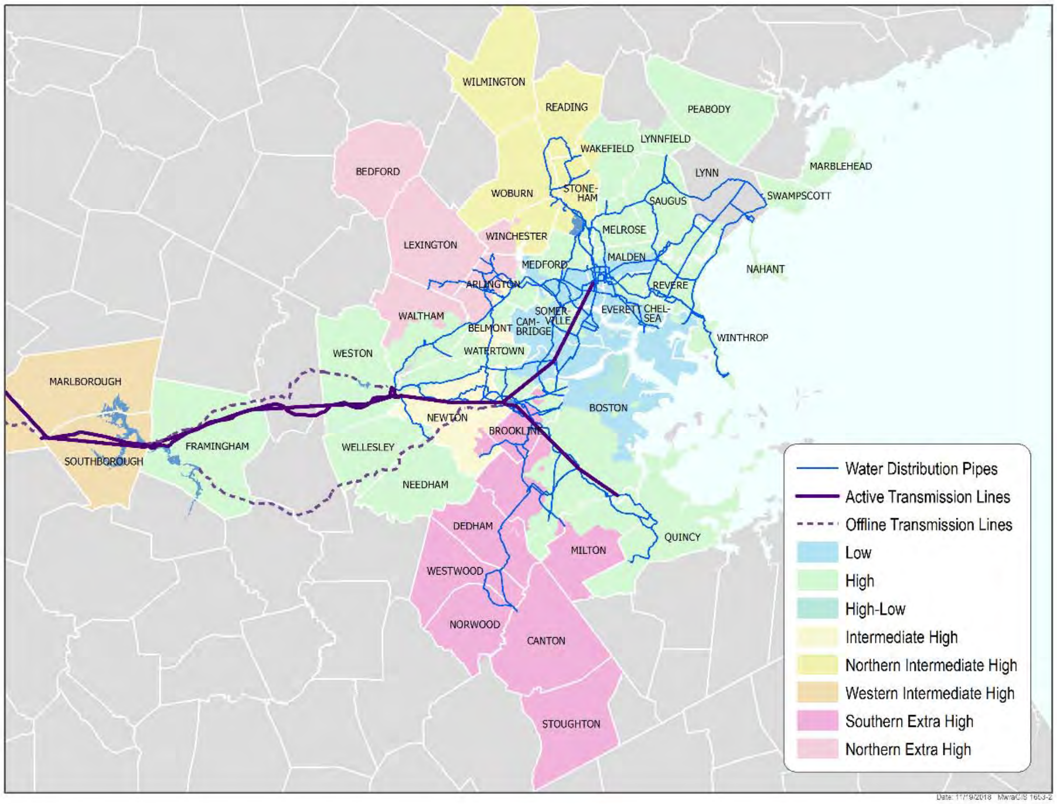
The Metropolitan Water System (also known as the Distribution system) consists of the various components shown in Figure 8-1 below:

Figure 8-1
Metropolitan System Overview



The Metropolitan Water System serves 40 communities and meets an average day demand of approximately 205 MGD in 2011. This does not include the communities of Weston and Framingham and the Western Intermediate High (Grade Line 305' BCB) of Northborough, Southborough and Marlborough. The remaining system is divided into seven (7) "pressure zone" service areas (shown in Figure 8-2) based upon the ground elevation of each zone.

Figure 8-2
Pressure Zones



The following are the service areas, and the elevations at which water is generally delivered. All elevations given are in feet, Boston City Base (BCB). The High Service as shown on the map includes both the Northern High and the Southern High pressure zones which are distinguished geographically; however, both are at an elevation of 280’ BCB. For some analyses, the High System is sometimes further sub-divided to consider areas served off of Fells Covered Storage and those communities served off of the Weston Aqueduct Supply Mains (WASM).

Low Service Area (including Northern Low) (LS)	184’-200’ BCB
Northern High Service Area (NHS)	280’ BCB
Intermediate High Service Area (IH)	320’ BCB
Northern Intermediate High Service Area (NIH)	330’ BCB
Northern Extra High Service Area (NEH) –	443’ BCB
Southern High Service Area (SHS) –	280’ BCB
Southern Extra High Service Area (SEH) –	400’ BCB

The sources of water for the service areas are the tunnel shafts as shown on Figure 8-1. The tunnel shafts are supplied by the Norumbega Covered Storage Facility, which sets the hydraulic grade line for the Metropolitan system. Water from the shafts feed the surface piping system that supplies each of the pressure zones. The NLS, NHS, and SHS all flow by gravity (no pumping required). The IH, NIH, NEH, and SEH all require pumping and storage to provide service.

The “hub” of the Metropolitan Water System is the Operations Control Center (OCC), located within the Chelsea Facility. The OCC operates and monitors the entire Metropolitan system remotely. This includes hydraulic grade line (pressure) at many tunnel shafts; suction and discharge pressure, flow, and basic operation of all of the water pump stations; operating elevation and volume of the water storage tanks; pressure and flow of the supply to the customer communities; and operation of some of the key valves in the MWRA system.

From planning and design through construction and operation and maintenance of the water system, MWRA makes use of standards and manuals developed by organizations such as the American Waterworks Association (AWWA) and the AWWA Research Foundation (AwwaRF). [1]

Chapter Organization

This chapter begins with an overview of the major elements (pipelines, valves, pump stations and storage) to provide an overview of MWRA’s assets including operational philosophy, condition assessment practices, maintenance practices and performance standards and goals for those assets. This information provides a framework for the individual pressure zone sections that follow. The pressure zone sections allow for an integrated discussion of all of the distribution system assets within a pressure zone since operational flexibility may depend upon the interrelationship between these assets. A “breakdown” in any individual asset may be more or less of a problem depending upon the other assets within that pressure zone (i.e. storage may mitigate the effects of a pipeline break). Each pressure zone section identifies ongoing work within that service area and recommendations for future projects.

Summary of Chapter Recommendations

Projects already in the FY19 CIP**:** (cost numbers have been rounded)

- WASM 3 rehabilitation design and construction at an estimated cost of approximately $102 million between FY19-28.
- Phases 8 and 9 of valve replacement design and construction at an estimated combined cost of approximately $9.4 million between FY24 and 30.

[1] Two documents that provide a good summary of critical requirements for the effective operation and management of drinking water distribution systems are:

- Distribution Systems Operation and Management (AWWA Standard G200-04), and
- Development of Distribution System Water Quality Optimization Plans (AwwaRF Report 91069)

These documents provide the elements for a water utility to develop and summarize Best Management Plans (BMPs) for water system management. The G200-04 standard describes the critical requirements for the effective operation and management of drinking water distribution systems. The AwwaRF report provides the processes that water utilities can use to improve distribution system operations above and beyond regulatory requirements to improve water quality and to reduce the potential for contamination.

- Pump Station evaluation and rehabilitation design and construction. The evaluation is scheduled to begin in FY20 with construction to be completed in FY28. The estimated total cost is $20.2 million.

- Northern High Service-Section 27 rehabilitation scheduled for FTFY19-26 at an estimated cost of $1.2 million.

- Northern High Service-Revere/Malden Section 53. Work is expected to be done between FY24-25 at an estimated cost of $11.5 million.

- Northern High Service-Section 99 Connection. This work is scheduled for FY23-25 at an estimated cost of $7.9 million.

- Northern High Service-Section 56 demolition, design and construction is scheduled for FY19-25 at an estimated cost of $13.3 million.

- Northern High Service-Section 53 and 99 Design. This is scheduled for FY19-25 at an estimated cost of $4.8 million.

- Northern High Service-Sections 13 and 48 design and construction. This is scheduled for FY25-30 at an estimated cost of $12.9 million.

- Connecting Mains-Sections 23, 24 and 47. This work is scheduled to occur from FY 19 to 22 at an estimated cost of $16.3 million.

- Connecting Mains-Cleaning and lining of Sections 59-60. This work is scheduled for FY19-26 at an estimated cost of $8.7 million.

- Intermediate High-Design of Sections 25, 75 and 59/60 replacement. This work is scheduled for FY19-26 at an estimated cost of $2.7 million.

- Intermediate High-Section 25 Replacement construction. This work is scheduled for FY24-25 at an estimated cost of $$3.8 million.

- Intermediate High-Section 75 Extension construction. This work is scheduled forFY22-24 at an estimated cost of $4.2 million.

- Northern Extra High Sections 34 and 45 design and construction. Work is scheduled for FY22-28 at an estimated cost of $7 million.

- Metropolitan System Cathodic Protection design and construction. This work is scheduled for21-27 at an estimated cost of $56.3 million.

- Chestnut Hill Final Connection design and construction. This work is scheduled for FY24-29 at an estimated cost of $15.1 million.

- Southern Spines-Sections 20 and 58 design and construction. This work is scheduled between FY22-28 at an estimated cost of $18.7 million.

- Southern High-Section 22 FP/EIR, design and construction. This work is scheduled between FY19-27 at an estimated cost of $22.1 million.

- Northern Intermediate High-Sections 89/29 Redundancy-all phases. This work is continuing through FY21 at an estimated remaining cost of $27.2 million

- Northern Intermediate High-Section 89/29 Rehabilitation design and construction. This work is scheduled between FY19-23 at an estimated cost of $19.9 million.

- Northern Intermediate High Storage design and construction. Contingent on siting, this work is scheduled between FY24-29 at an estimated cost of $4.5 million.

- Northern Low Service-Section 8 construction. This work is scheduled for FY27-29 at an estimated cost of $24.6 million.

- Northern Low-Sections37/46 design and construction is scheduled for FY24-28 at an estimated cost of $4 million.

- Northern Low-Section 57 Water and Sections 21/20/19 Sewer design and construction. This work is scheduled between FY19-24 with an estimated cost of $25.6 million.

- Southern Extra High Redundancy Sections 77/88-all phases. This ongoing work is expected to continue through FY22 at a remaining estimated cost of $35.7 million.

- Southern Extra High-Sections 77/88 Rehabilitation. This work is scheduled for FY21-26 at an estimated cost of $7.3 million.

- Southern Extra High New Storage-All phases. This work is scheduled between FY28-36 at an estimated cost of $51 million.

- Southern High-Section 80 Rehabilitation design and construction. This work is scheduled between FY22-27 at an estimated cost of $10.5 million.

- Various Storage Tank Improvement and Rehabilitation Projects. This includes work at Walnut Hill, Turkey Hill and Bellevue 2 and Deer Island as well as overall Steel Tank Improvement Projects. These contracts will extend between FY19-24 at a total estimated cost of $24.6 million.

- Covered Storage Tank Rehabilitation design and construction. This work is scheduled between FY23-27 at an estimated cost of $5 million.

- Various roof replacement projects including work at Gillis PS, Cottage Farm CSO Facility and various other water pump stations. This work is scheduled between FY19-27 at a total estimated cost of $950,000.

Recommended Projects-Master Plan

The following projects are recommended for consideration to be included in the CIP for implementation in the FY19-58 time period:

- Valve Replacement Phases 10 and 11. This work is schedule from FY30-58 at an estimated cost of $10 million.

- Pump Station Rehabilitation-Phase 2. This work is proposed for the FY43-58 period at an estimated cost of $25 million.

- Pipeline Study to assess long-term pipeline renewal needs based on MWRA specific information. The Master Plan proposes that this work be done in FY25 at an estimated cost of $500,000.

- Old Mystic Main-Section 66 rehabilitation design and construction beginning in FY45 at an estimated cost of $8.5 million.

- Northern High Service-Coastal Pipelines Rehabilitation. This work is recommended for the FY28-33 period at an estimated cost of $16.3 million.

- Northern High Service-Sections 33, 49, 49A and 50 Rehabilitation design and construction. This work is recommended for the FY40-45 period at an estimated cost of $10 million.

- Northern High Service –Sections 70, 71 and 79 Rehabilitation design and construction. This work is recommended for the FY39-47 period at an estimated cost of $35.7 million.

- Fisher Hill Pipeline Rehabilitation design and construction. This work is recommended for the FY40-44 period at an estimated cost of $3 million.

- Southern Extra High-Section 19 Rehabilitation design and construction. This work is recommended for the FY40-44 period at an estimated cost of $8.5 million.

- Parallel Main to serve Meters 55/68 design and construction. This work is recommended between FY35-39 at an estimated cost of $5 million.

- Northern Extra High Redundancy Loop. This work is recommended in the FY26-32 period at an estimated cost of $10 million.

- Northern Extra High Storage Project design and construction. This work is recommended for the FY 42-48 period at an estimated cost of $8.5 million.

Community Financial Assistance

MWRA began financial assistance to member water communities during FY98 and FY99 with the two-year, $30 million "pilot" program that provided grants and loans for local water distribution system rehabilitation projects. The rationale for the initial program was that funds spent on improving local water distribution systems provide greater regional water quality benefits than spending those same funds for water treatment filtration.

Building on the success of the pilot water financial assistance program, the Phase 1 - Local Pipeline Assistance Program (LPAP) was approved in FY01 to provide 10-year interest-free loans to water system communities primarily for water main replacement or cleaning and lining projects. Under the Phase 1 - LPAP, $222 million in loans for local water projects were distributed from FY01 through FY13. MWRA established the Phase 2 - Local Water System Assistance Program (LWSAP) in FY11 to extend the local water loan program through FY23. This expansion of the water loan program added $210 million in interest-free loans for member water communities (including a $10 million allocation specifically for the three Chicopee Valley Aqueduct communities). MWRA established the Phase 3 - Local Water System Assistance Program (LWSAP) in FY18 to extend the local water loan program through FY30. This expansion of the water loan program added $292 million in interest-free loans for member water communities (including a $14 million allocation specifically for the three Chicopee Valley Aqueduct communities).

Financial assistance to support member community water system rehabilitation projects to help maintain high quality water is recommended to continue but must be evaluated against competing MWRA CIP needs. Even with the substantial progress made over the last 20 years via MWRA's community water loans, approximately 1,800 miles (27%) of community-owned water mains remain unlined. The Master Plan recommends two additional water loan program phases FY29-48 (each at $250 million in loans over 10 years) to extend the current program approved through FY30. Since there is no grant component to water financial assistance; the impact to MWRA's CIP is minor compared to the sewer grant/loan program.

8.2 Pipelines

Since the 1993 Water Plan, MWRA has made extensive improvements in the distribution network. The 1993 Plan cited excessive leakage, hydraulic deficiencies at meters and the lack of redundancy within the distribution system as key issues. Recommendations for pipeline improvements accounted for approximately 46 of 100 projects identified in that plan. Since 1993, MWRA has constructed new pipelines where needed and has completed rehabilitation of over 100 miles of pipe.

The pipes identified in this Master Plan for future inclusion in the CIP generally reflect the continued need to clean and line older cast iron mains for the purpose of maintaining hydraulic capacity and to ensure that distribution system water quality is maintained at a high level. The major exception to this is the network of larger diameter steel mains that serve the Northern High system where it is recommended that rehabilitation be staged (planning work is in the existing CIP) and scheduled in an orderly fashion over time prior to the maintenance needs significantly increasing.

The pipes not selected for rehabilitation at this time are primarily pipes constructed in the 1950-2000 time frame and reflect a range of pipe materials. They are also pipes without a pattern of maintenance requirements or leaks to date.

As was done in 2006, as part of this master planning process staff reviewed both the industry literature on pipeline rehabilitation and replacement and at the specific experience with the MWRA system in order to determine how to assess the remaining useful life and the relative need for rehabilitation or replacement between the various pipe segments. This analysis focused on the following questions:

1. Which pipelines, if they should fail, have no redundancy to supply customers?
2. Which pipelines have exhibited the most leaks?
3. Which pipelines are located in areas which accelerate pipe deterioration?
4. Which pipelines currently have or have had material problems?
5. How can we best prioritize, using the information we have, pipeline replacement?

Redundancy

The goal of system redundancy has been a significant factor in water supply planning nationwide and at MWRA. Since 9/11/2001, the work completed to assess water system vulnerability has stressed the need for water suppliers to eliminate the "single points of failure" where severe loss of service could occur during a break or other emergency. This is a key element in MWRA's own goals and objectives. Pipelines without redundancy or with less than adequate redundancy were categorized based on whether the lack of redundancy presents a minor, moderate or major problem. These categories considered such factors as available storage and availability of local water supplies. Of the three areas identified in 2006 as "major problem" areas, the Lynnfield Pipeline is completed and redundant pipelines for both the Northern Intermediate High and the Southern Extra High pressure zones are expected to be completed in 2020. Two new pipeline projects providing addition redundancy are noted in this plan. These include a redundant loop for the Northern Extra High System and a parallel pipeline to serve Meters 55 and 68. This Master Plan also recommends construction of additional storage in the Northern Extra High service area. More details on proposed projects are discussed in those sections of this plan.

Pipe Structural Considerations

The questions of leaks, pipe materials and site conditions are all related. The number of recorded breaks and leaks is a factor used by many utilities as a basis for pipeline rehabilitation and replacement decisions. Leak and break data is most predictive in those large retail systems with many miles of small diameter pipe of various materials where statistical information can appropriately be generated to predict the likelihood of leaks and breaks by pipe material or age. MWRA maintains leak information in our GIS database and this information was analyzed. For the MWRA system, such data is not as good a factor to base rehabilitation decisions on except in very limited circumstances (see steel pipe discussion below). MWRA's relatively smaller number of pipe miles (at 284), means that there may only be a few miles of pipe at most in any single age and material category which makes it harder to draw broad based conclusions about the effects of those pipeline characteristics.

In the 30-year period prior to 1993 there were 17 pipeline sections that had between 10 and > 20 leaks in that timeframe. These pipelines were prioritized for replacement and as a result, overall leak numbers have decreased in the MWRA system and that trend has continued as MWRA has also continued aggressive leak detection. The annual goal is for staff to perform leak detection surveys of the entire MWRA system every year, and to survey the steel mains in the system twice each year. MWRA staff also assist our customer communities with special leak investigations when requested.

It is worth noting that these leaks in steel mains, while requiring repair, are usually not catastrophic failures and are often repaired while the pipes remain in service. Cast iron mains tend to have more significant circumferential or longitudinal cracking and thus are more likely to fail catastrophically.

The current literature and MWRA experience suggests that pipe age and pipe material have to be examined together to make decisions about rehabilitation or replacement. The historic rule of thumb used in the MWRA system has been that a pipe has an average useful life of 100 years with older cast iron mains lasting even longer due to their thicker pipe walls. Some literature suggests that pipes installed post WWII have an average useful life of 75 years. There can be general deterioration associated with aging pipes and many pipes are subjected to far greater surface loads and stresses than were present when the pipes were installed. However, depending upon location, soil condition and durability of construction, pipes may be quite long-lived.

MWRA experience with pipe materials since 1993 has shown that certain steel pipe sections have continued to be significant maintenance problems due to leaks associated with corrosion. Although use of appropriate pipe coatings and pipe bedding materials can mitigate the impact of the soil corrosion, these have not always been installed historically and this information is inconsistently noted in MWRA's records, limiting the predictability of such leaks. When these pipelines are located in areas of wet soils, particularly in former and present salt marsh areas, riverbanks, wetlands and floodplains, leaks appear to be more common and appear to recur more frequently once corrosion has begun to affect the pipe. There are some pipelines in areas associated with salt storage facilities that also tend to show recurring leaks. Areas with significant stray current from transportation facilities or other utilities can also be a catalyst for pipe corrosion. The FY19 contains $56.3 million for a Metropolitan System Cathodic Protection Program to address these issues in areas where needed and where previously installed systems have failed.

Interior Pipe Condition: Hydraulics and Water Quality Considerations

In addition to the exterior condition of a pipe, another issue related to pipe materials is whether a pipe is lined or unlined. Unlined pipes (primarily older cast iron or steel) are far more susceptible to tuberculation, corrosion and pitting than more recent materials. This can impede water flow and impair water quality. Since the 1940's, pipe materials have primarily included lined steel pipes, lined ductile iron and reinforced concrete cylinder pipe. In 1993, approximately 80% of MWRA's pipe network was unlined cast iron or steel. That percentage has dropped to approximately 44% and will continue to drop as projects identified in the current CIP move forward.

Hydraulic deficiencies caused by tuberculated pipes might also be a reason to prioritize a pipe for replacement. The measure of a pipe's carrying capacity is determined by the pipe's diameter and resistance to flow, otherwise known as the pipe's "C" value.[2] C-values for new pipe are typically in the 130-140 range; C-values between 70 and 100 are indicative of pipe in poor condition and C-values below 70 are generally associated with pipes in bad condition. A C-value of 70 can deliver only about 50 percent of the amount of water that it was designed to carry. MWRA has determined C-values for all of its pipe segments and this information was also factored into the renewal analysis. In MWRA's experience, a poor C-value is not necessarily a good predictor of potential pipe failures but it is an indicator of hydraulic inefficiencies which may impact the level of service at specific locations. MWRA modeling can identify potential areas within the communities where the target hydraulic gradeline may not be met under max day conditions. Many of these locations reflect development on hills at a grade higher than that served by the MWRA's pressure zone so the most common means of addressing such deficiencies is community construction of local booster pumping stations.

Besides being hydraulically inefficient, tuberculated cast iron pipe may be a source of water quality problems. The accumulation of metallic salts and rust (tubercules) on interior pipe surfaces can lead to water quality complaints related to discolored water which, in some instances, can result in staining of fixtures or laundry items. In addition, the presence of tubercules may also lead to opportunities for bacterial growth along the pipe walls. Industry practices suggest that it is preferable to replace such pipe from the inner core of the system outward. Most water quality complaints relative to "colored" water are related to work in community systems where flow is disrupted or changes direction. This tends to break off or scour rust from the pipe interior and transport to the service lines. However, concerns about potential bacterial growth are very relevant to both the MWRA and community systems and as noted in Chapter 5, future regulatory actions will likely address the need to maintain water quality within the distribution system.

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[2] The friction coefficient of a pipe is used as the measure of flow resistance. Standard waterworks design uses the "C" value in the Hazen-Williams pipe flow formula as the parameter of resistance. Higher "C" values correlate with better conditions and lower flow resistance.

Methods of Pipeline Rehabilitation

Pipelines can be renewed, rehabilitated or replaced depending upon the location and circumstances. Each of the strategies below yields different benefits in terms of extending the life of the asset.

Cleaning & Lining This is a process which cleans and resurfaces the interior of an old pipe to make it comparable to a new pipe's interior. The old pipe must be structurally sound and expected to remain intact for another 50 years for a pipe to be a candidate for this technology. The pipes are cleaned, lined with cement mortar and valves or other appurtenant structures are replaced. This can be approximately 40% less expensive than the cost of pipeline replacement and based, on industry literature can extend the life of the old pipe by up to fifty years or longer. Water quality benefits may also be gained by the cleaning and lining of cast iron pipe.

"Sliplining" This technology involves inserting a smaller diameter pipe within the existing pipe and either expanding the insert or filling the annular space with grout. There is an associated loss of hydraulic capacity which must be closely reviewed to determine if such loss is acceptable. This is less expensive than conventional replacement due to the use of smaller pie. It is most often considered when the loss of capacity is not problematic and where conventional construction methodologies are extremely difficult due to access or construction impacts.

Replacement This technology entails the removal of the pipe segment and the replacement of it with a new pipe segment generally of the same size (depending upon capacity needs). Typically, this is used where a pipe is structurally in poorer condition and ongoing maintenance of the existing pipe would not be cost-effective or would pose risks to service.

Parallel Piping This methodology entails the installation of a new pipeline in parallel with the existing pipeline. The old pipe may not remain in service depending upon the specific conditions and needs in that service area. This approach can be preferred where additional service objectives must be met by the project, where pipe replacement is excessively costly or disruptive or where additional capacity or redundancy may be needed.

MWRA has used all of these technologies over time depending upon the site specific circumstances. Based on work done to date, staff generally assumes for the purposes of preliminary cost estimates that two-thirds of the pipeline length can be rehabilitated through cleaning and lining and that one-third of the pipeline will require replacement. Actual determinations are made during design for most projects. Sliplining may also be evaluated as an alternative during the design process depending upon site specific conditions. However, for some projects, initial recommendations specifically call for parallel piping. This is generally because the pressure zone evaluations have identified a need for pipeline redundancy or for additional capacity to serve a specific area. Selection of pipe materials is also dependent upon review of the project by engineering, operations and construction staff and includes consideration of soils, location and specific pipe design characteristics (for example, long straight sections versus many bends and turns). In addition, for those areas where record drawings are not available or are inaccurate, there may be a need to change or fabricate piping connections in the field, resulting in materials such as steel, which are more suitable for such modifications. Consultation with local officials provides an opportunity for their input into project design.

Pipeline Prioritization

A number of factors have been used be MWRA to make the recommendations contained in the Master Plan. In recent years, redundancy projects, particularly for the NIH and SEH systems ranked very highly towards maintaining reliable service within the Metropolitan system. Additional projects that remedy other system vulnerabilities and/or increase operational flexibility during emergencies are also highly ranked.

The continued systematic removal or lining of unlined cast iron and steel mains is also recommended. Remaining unlined cast iron, although it may have the greatest longevity of pipe materials, can create hydraulic inefficiencies and water quality problems. It is expected that future distribution system regulatory requirements will also focus on the need to remove unlined pipes. In addition, when cast iron pipes fail, they often fail catastrophically, resulting in damage to homes, businesses and roadways. For steel pipes, recent literature suggests a life expectancy of approximately 75 years and MWRA experience suggests that once corrosion begins, steel pipes begin to experience leaks and leak frequency begins to accelerate over time. Although these can often be fixed “live”, (with the line in service), depending upon their location, these lines create a greater and greater drain on maintenance staffs.

Recommended Actions and Capital Improvements-Pipelines

The pressure zone sections of this plan identify the specific pipe sections recommended for rehabilitation and the proposed cost and schedule. These projects reflect a continued need to replace unlined cast iron main and to systematically rehabilitate steel mains. They also reflect the need to continue to enhance system redundancy and operational flexibility. The Master Plan also proposes that a Pipeline Study be done in FY25. This study would look at remaining pipeline projects to aid in prioritization. MWRA has completed many miles of cleaning and lining projects throughout the system and assuming an average useful remaining life of 50 years for all of these projects may not be the best available information. Information from other utilities may be useful in this regard as will information learned through implementation of the new Metropolitan System Cathodic Protection Program.

8.3 Valves

There are over 5500 valves in the MWRA Metropolitan water system. Valves provide the means to control the flow of water in the pipes, and their operability is critical. Valves provide the means to isolate leaking or broken water mains, control the flow of water in redundant piping systems, reduce pressure depending upon service area needs, and to allow pipes to be shut down (isolated) and drained so that new or rehabilitated water mains can be connected to the existing water system.

Types of Valves

The following are the types and numbers of each of the valves that are currently in the Metropolitan water system.

Table 8-1
As of 10/2018

Valve Type	#	*What it does*
Main Line	1210	Control water flow in the distribution pipelines and isolate flow in and around pump stations, tanks and reservoirs.
Meter	609	Control water flow to the community meters.
Cross Over	131	Control water flow in the distribution system between pipelines of similar pressure (within pressure zones).
Division Gate	33	Control water flow in the distribution system between pipelines of different pressure (normally closed).
Emergency Connection	126	Allow water to flow from the MWRA system to the community system without metering (normally closed).
Control-Check Valves	145	Allow flow in only one direction and are normally installed immediately up or downstream of a community meter. Contains water in the community system in event of a major MWRA break.
Control-Pressure Reducing	50	Reduce the Norumbega gradient (270’ BCB) to the Northern Low gradient (185’) to prevent over pressurization.
Blow Off	1551	Allow water to be released from the distribution pipelines to drain lines, provide for flushing or for disinfection preparation.
Air Release	1447	Allow air to enter or leave distribution pipelines during filling or draining of lines.
Bypass	203	Small diameter gate valves installed on piping around newer, large diameter butterfly valves

Valves of particular importance include the pressure reducing valves (PRV) that reduce the hydraulic grade line from Norumbega Covered Storage Tank (NCST) to the Northern Low Service (NLS) pressure zone. PRV are located at most of the tunnel shafts, and at many meter connections to customer communities. The OCC monitors the performance of the PRV to confirm that they are operating within the required parameters. Blow off valves are notable in that they are used to dewater the MWRA pipelines for a variety of reasons and were originally designed to flow into drainage lines, sewer lines, or direct discharges to surface water bodies (primarily small streams). The Massachusetts Department of Environmental Protection (DEP) determined that the direct connections constituted a cross connection condition, and need to be severed in order to eliminate the potential health hazard. In addition, discussions are ongoing with DEP relative to whether air release valves may pose a potential possibility of cross connection and the appropriate means to address such hazards. It is likely that some portion of future valve replacement funds will be necessary to address this issue.

Valve Database and Performance Standards for Valves

All maintenance done at the MWRA is managed through the use of a computerized maintenance management system (CMMS). The specific software package used is MAXIMO and all water system maintenance work is captured on work orders within MAXIMO. This database allows for reports to be run on demand to determine the current valve operability for any of the valve types in our system. The database contains all of the pertinent valve information, such as age, material, manufacturer, number of turns to open or close, and maintenance history. Valve operability is reported on a monthly basis, as a part of our overall maintenance management reporting.

The MWRA has established criteria with associated codes to define the operability of the valves in our system. The following are the codes and their definitions as used to define valve operability.

Code	Definition	Meaning
OE	Operable/excellent	Full number of turns achieved
OA	Operable/adequate	Enough turns achievable for an adequate shut down in an emergency
PI to	Partially Operable	Partial closure achievable but inadequate shut down in an emergency
FO	Frozen open	
FC	Frozen closed	
FU	Frozen in unknown position	
AB	Abandoned	
BA	Broken Air Valve	Air valve inoperable, do not operate
RE	Removed	Valve removed from the system
SP	Special Status	Position and operability never checked "Do Not Touch"
UN	Unknown position	Presently unknown, due to inaccessibility & operability
Not Visit	Not yet visited	Valve has not been visited by crew

The MWRA considers the valves in the OE and OA categories as those that are operable. All others are considered inoperable, except for those that are abandoned or removed.

The physical condition of most of the valves in the MWRA system is good to excellent which is a significant improvement over the situation in 1993 where the Plan said "Operational experience with mainline valves indicate that many valves are inoperable or only partially operable due to a general lack of maintenance for many decades" . It is difficult to make a gross assessment of valve condition, however, and individual reporting, using valve operability statistics provides a much better method of valve conditions. Capital construction projects, in-house valve replacement, and valve maintenance programs (discussed below) have made a great improvement in the overall condition of the valves.

Table 8-2
Valve Operability-2018

Valve Type	Total	Operability
Main Line	1210	96.4%
Air Release	1447	94.9%
Blow Off	1551	98.3%
Control-PRV	50	87.0%
Total All Others	1339	N/A

Valve Maintenance Program

Pipeline and Valve crews are dedicated to water system maintenance. Pipeline crews replace broken or inoperable valves, repair leaks, retrofit blow off valves, and perform a variety of other tasks. The valve maintenance program includes the goal setting and tracking stressed in the standards set by the AWWA.[3] The goal is to exercise all main line valves once every two years. However, some valves cannot be exercised as it would cause a loss of supply in the system. This is the case when a redundant line is out of service due to a construction project, leak repair, or some other maintenance activity. Closing of the

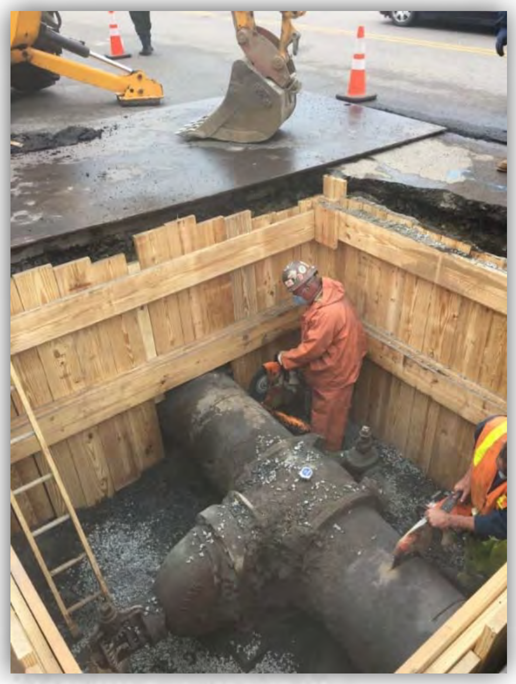
[3] Valve exercise program. The utility shall have a valve exercising program. This program shall include at least the elements:

a. A goal for the number of transmission valves to be exercised annually based upon the percentage of the total valves in the system.
b. A goal for the number of distribution valves to be exercised annually.
c. Measures to verify that the goals are met and written procedures for action if the goals are not attained.
d. Critical valves in the distribution system shall be identified for exercising on a regular basis. Potential quality and isolation concerns shall be recognized. The program shall track the annual results and set goals to reduce the percent of inoperable valves.

The AWWA also publishes a series of Manual of Water Supply Practices. One of these manuals is M44, Distribution Valves: Selection, Installation, Field Testing, and Maintenance. This manual provides the following for guidance in the planning of a maintenance schedule for valve exercising:

- Inspections should be made of each valve on a regularly scheduled basis (annually if possible) and at more frequent intervals for valves with a 16” diameter and larger.
- All gate valves should be cycled from full open to full close and back to open at least once every two years.

valves on the active line would cause a disruption in service. Valve exercising can drop to as low as 10% of the work load in the summer months, as the majority of the time is spent on construction support and the other activities.



Valve Replacement Section 65

There have been dramatic improvements in system performance in the last 15 to 20 years, due to the success of the combined program. Since the completion of the 2006 Master Plan, Phases 6 and 7 of the ongoing Valve program have been completed at a construction cost of approximately $4.4 million. Phase 6 included 4 blow-off valve retrofits, 8 main line valve replacements and 9 globe valves for tank isolation. one check valve and rehabilitation of one meter. Phases 8 and 9 of the valve program are now in the CIP with additional work continuing in FY24-30 at a remaining estimated cost of %9.4 million.

<u>Recommended Actions and Capital Improvements-Valves</u>

- Two additional phases of valve replacement (Phases 10 and 11) are recommended at a total cost of $10 million with a start date of FY30. In order to continue to increase the percentage of operable valves and to address valves that fail during the next 40 year period, work will need to continue using both the current CIP project and in-house design services. In addition, it is expected to take additional time to complete the blow off valve retrofit program. The mix of in-house and CIP work on all phases of the MWRA valves has been the key to operational success of the system.

- Staff should also continue to monitor the maintenance needs for the butterfly valves that have replaced gate valves in various parts of the system. Gate valves have routinely had an expected life in the MWRA system of 50-75 years and there is some concern that the butterfly valves may not be as resilient and more prone to breakage and misalignment. For the next master plan update, review this information and complete a revised life cycle cost analysis if appropriate.

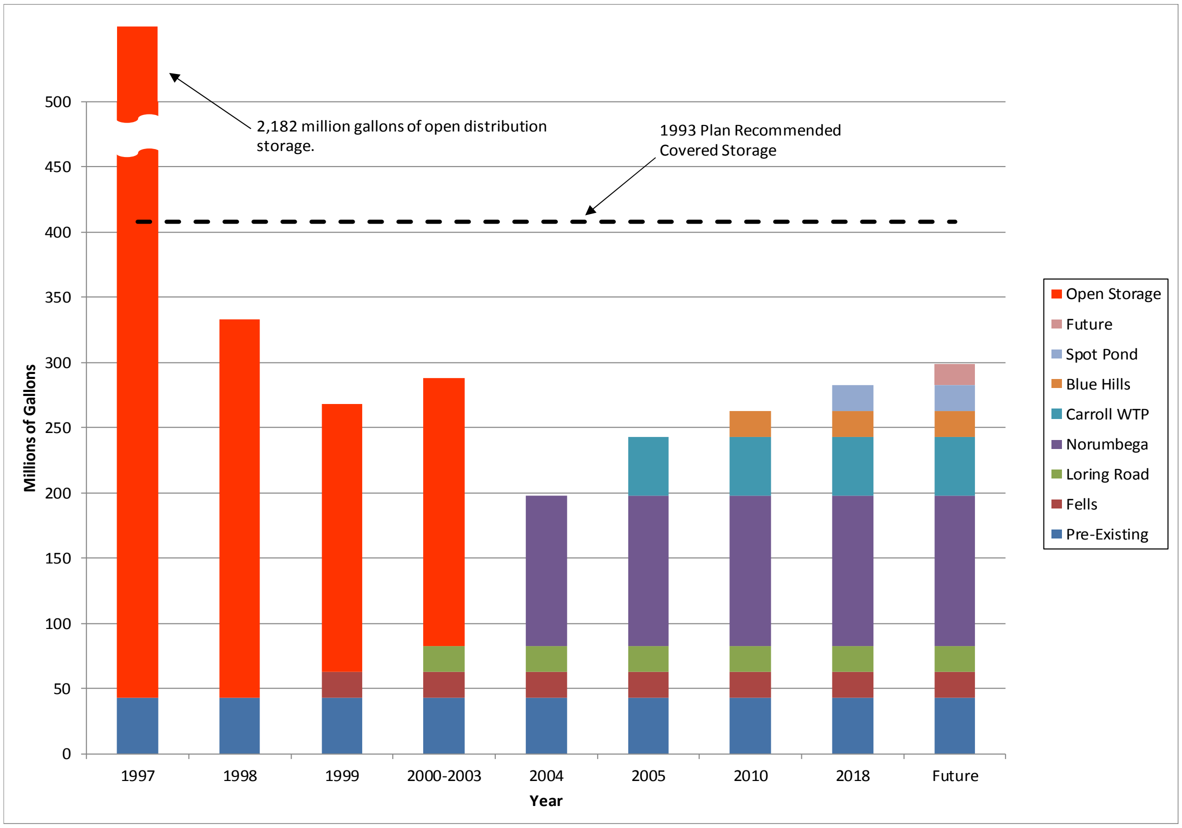
8.4 Storage

Meadow above Spot Pond Covered Storage

The majority of the water (81%) delivered in the Metropolitan area is done by means of gravity. The remaining 19% is delivered through the use of pumping stations and the 12 water storage tanks. In 1993, MWRA had approximately 2,182 MG of open distribution storage in Eastern Massachusetts. MWRA had initiated efforts to comply with the regulatory requirements to eliminate uncovered storage. Although work was in the early stages, MWRA accepted that the requirement would greatly reduce the storage volume available. Based on generally accepted standards, MWRA's planning assumptions were based on the need to provide a storage quantity equal to a max day demand for the system. The 1993 Master Plan enumerated the projects identified by the 1993 *Water Distribution System Storage Study* and noted that by 2017 covered storage within the distribution system should approach 345 MG (including Nash Hill in the Chicopee Valley Aqueduct (CVA) system but not including planned storage of 50 to 100 MG at the proposed water treatment plant). This would get MWRA close to the 1993 conservatively projected goal of having storage for a max day demand of 460 MG.

As shown in Figure 8-3, since 1993 major uncovered reservoirs at Norumbega, Weston, and Spot Pond have been disconnected from the system. However, significant covered storage has become operational as Fells, Loring Road, Norumbega, the Carroll Water Treatment Plant, Blue Hills and now, twenty million gallons of storage for the Low system (Spot Pond Covered Storage Facility) is now operational. Additional storage has not been constructed for the Northern Intermediate High service area and the Southern Extra High service area. MWRA now has 283 MG of available storage in the Metropolitan system (excludes Nash Hill in the CVA system). MWRA also anticipates the future addition of approximately 12 MG of storage within the Northern Intermediate High and Southern Extra High systems for a longer-term total of 295 million gallons and the Master Plan recommends an additional 6 MG of storage also be constructed in the Northern Extra High System.

Figure 8-3



Recommendations for Additional Storage

The FY19 CIP contains funding for additional storage needs as proposed in both the Northern Intermediate High and Southern Extra High service areas. These projects should proceed as agreements relative to storage tank siting can be resolved. This Master Plan recommends that additional storage also be constructed in the Northern Extra High System. Current storage including Park Circle is about 6 MG but average day demand is approximately 11 MGD. The Master Plan proposes this work beginning in FY42 at an estimated cost of $5 million.

Purpose of Storage

Distribution storage tanks serve two important functions in a water system: they provide equalization flows to dampen the effects of daily flow variations and they provide emergency storage in the event of a short-term supply disruption[4]. Thus, it is necessary for

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[4] **Equalization storage** is the amount of water necessary to supply peak water usage at times when the demand exceeds the system's delivery capacity. The availability of sufficient equalization storage keeps the elevation of stored water within an acceptable range, thereby preventing excessive reductions in pressure. During times of maximum demand, water flows from the distribution storage facility to the consumers. When demand drops off, the flow refills the reservoir. The volume of equalization storage

a distribution storage tank to have an elevation high enough to provide adequate pressure throughout the system served.

However, the MWRA system may present some flexibility in terms of emergency storage. Although, ideally, most system emergencies should be handled transparently to the communities and end consumers with system operations automatically or unobtrusively shifting to the use of emergency storage, MWRA has not lost the ability to use the large uncovered reservoirs in the event of a significant system problem. This type of shift would not be transparent and would be accompanied by water restrictions, boil orders etc. but a level of service could be maintained. The ability to use the uncovered reservoirs in an extreme emergency can be considered in determining the right amount of new covered storage for the MWRA system.

Locating Storage

The ideal location for distribution storage is affected by many factors but should reflect where demands are located within the pressure zone. This set-up results in minimal head losses and pressure fluctuations, since, on average, the water travels the shortest distance from its storage location to the consumer. Distribution storage should be relatively proportional to water demand in each of the service areas. The original open reservoirs at Norumbega, Fells Reservoir and Blue Hill Reservoirs were laid out in such a way to meet this objective and these locations are now the site of the key covered storage reservoirs (including the future Blue Hills Covered Storage facility). The remaining smaller covered storage, which receive pumped water from the MWRA system, are located on hilltops in the areas served.

Storage Facility Condition Assessment

The active storage and stand-by facilities in the Metropolitan system range in actual age from 3 to 97 years old (excluding Norumbega which is west of the Metropolitan system). Generally, prestressed storage structures have expected lives of 50 years while cast-in-place concrete structures have expected lives of approximately 100 years. For the purpose

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required for an area is a function of the magnitude and variability of water usage and the capacity of the water delivery system.

Emergency storage is the quantity of storage required to maintain water service in the event of an interruption in supply due to circumstances such as a pipeline break or a mechanical malfunction. The amount of emergency storage required depends upon the magnitude of water usage and the anticipated response times for emergency repair operations. It is common practice to design water systems to have enough overall distribution storage to meet at least one day’s maximum demand. To appropriately serve a large region with variable land elevations, individual distribution storage facilities must be appropriately sized and located relative to the needs of each service area.

The sum of equalization and emergency storage volumes equals the total useable storage. A relatively small volume of water is also necessary to provide a buffer depth at the bottom of a storage facility to maintain the water quality of the water leaving the tank. This amount is called reserve volume.

of the asset value analyses done in 2004, MWRA assumed that overall, MWRA's storage facilities had an average useful life of 80 years. Internal piping and appurtenant structures are expected to last approximately 50 years. In addition, for those facilities significantly rehabbed, the 2004 analyses reset the clock at 80 years of useful life. The age, material and operating condition of each of MWRA's storage facilities is found on the table below.

Table 8-3

Storage Facility	Year Built	Year Rehabbed	Years to Next Rehab*
Arlington Covered Reservoir (active)	1937		Rehab Required
Arlington Heights Standpipe (active) aka Park Circle Tank	1922	1999	61
Bear Hill Tank (active)	1986		48
Bellevue Standpipe #1 (standby)	1915	1999	61
Bellevue Standpipe #2 (active)	1955	2000	62
Deer Island Tank (active)	1994		56
Turkey Hill Tank (active)	1945	2000	62
Walnut Hill Tank (active)	1961	1999	61
Fells Covered Storage (active)	1999		61
Loring Road Covered Storage (active)	2000		62
Blue Hills Covered Storage (active)	2010		72
Spot Pond Covered Storage	2015		77

*Years to Next Rehab-Remaining Useful Life from MWRA asset replacement analysis; however, interim asset protection measures will be required.

Routine maintenance practices do need to be applied to storage facilities to ensure that structural features are secure. Catastrophic failure is not generally a concern but gradual problems can include cracks in side walls, internal and/or external ice damage, loose or fractured welds, broken control valves or other appurtenant piping, damaged overflow weirs and malfunctioning instrumentation. However, the "failure mechanism" would likely be rusting, followed by weeping, followed by leaking.

AWWA recommends that finished water storage facilities undergo an in-depth inspection every 3 to 5 years. The MWRA started an inspection program in 1999.

The FY19 CIP includes several projects to rehabilitate storage facilities. These include work to repaint, replace cathodic protection and other improvements for the Walnut Hill, Turkey Hill and Bellevue 2 tanks; repainting of the Deer Island tank and future tank rehab work at Fells and Loring Rd Covered Storage Facilities.

Recommended Storage Projects:

- In addition to construction of new storage in the NEH system (as discussed above); the Master Plan recommends Covered Storage rehab projects for Nash Hill, Norumbega, Loring Road and Blue Hills within the Master Plan planning period.

Water Storage Tank Operation and Maintenance

The operation and maintenance of water storage tanks requires that attention be paid to tank level monitoring, operating ranges, turnover rates, mixing process, and water quality. Maintenance has to consider activities required on a routine, annual, and detailed inspections basis. Security issues, including fencing, inspection frequency, and access have become a significant issue for both MWRA and for the community-owned storage facilities.

The OCC monitors the water storage tanks, pump stations, pressure reducing valves, community meters, and tunnel shafts. The individual water storage tanks are controlled using programmable logic controllers (PLCs) at the pump station that is the tank's source of water. Normal operation is managed by the OCC remotely. In the event of a loss of communications from the OCC, the PLC is capable of operating the pumps and the tank levels on a local/remote basis. All of the tanks have high and low level alarms to alert the operator at the OCC if there is a problem.

Maintaining Water Quality

Maintaining the best quality of water possible is accomplished by monitoring the turnover rates, mixing process, and water quality of each of the water storage tanks. This provides for the lowest water age, and in turn, the highest water quality.[5] The turnover rates calculated for the MWRA tanks were determined to be between 1.3 and 2.4 days (which equate to daily rates of 40% to 77%). Another element to promote the optimum water quality in storage tanks is through the mixing process. This can also help to minimize water age, and to minimize stagnant zones in the tank. The mixing of the water in the tank is encouraged by a more aggressive or turbulent flow into the tank. Confirmation of water age and water quality is through weekly water quality samples taken at each water storage tank. MWRA samples each tank every week to confirm water quality[6]. If water quality

[5] The AWWA Research Foundation (AwwaRF) published a report titled "Maintaining Water Quality in Finished Water Storage Facilities" (AwwaRF report 90763, 1999), The study recommends water in storage tanks should be turned over an average of every 2.5 days to minimize water age and maximize water quality. A 2.5 day turnover rate translates to a 40% daily turnover in tank volume.

[6] Field Operations coordinates with the OCC staff so that the tanks are at the appropriate elevations to allow for a sample to be taken. Crews radio the OCC while driving to each tank, to confirm that water is leaving the tank. This way the sample is sure to be from the tank, and not inbound system water. If the tank is filling, the OCC notifies the crew to wait anywhere from 15 to 30 minutes to make sure that the pumps are disabled, and water is flowing out of the tanks. The crew performs a field chlorine residual test, and radios the results to the OCC. Sample bottles are taken to the lab for bacteria testing. Results are published in the weekly and monthly operations reports. The sample results are plotted and are monitored

sampling and testing continue to show a drop in chlorine residual, despite operational changes, then more drastic measures, such as draining the tank, may be required.

8.5 Pump Stations

Since 1993, the initial work to rehabilitate the Spot Pond (now the James L. Gillis P.S.), Commonwealth Avenue, Lexington Street and Newton Street pump stations has been completed, as well as work to construct the Chestnut Hill emergency pump station. A fast track contract completed in 2001, installed SCADA systems at each station and all stations are now remotely operated. Since the 2006 Master Plan, the remaining five pump stations at Brattle Court, Reservoir Road, Hyde Park, Belmont and Spring Street were

Table 8-4
Pump Station Overview

Pumping Station	MWRA Pressure Zone	Peak Flow[1] [MGD]	Pumps	Year Built	Year Rehabbed
Gillis, Stoneham	Northern High - Fells	20	3	1900	1998
Gillis, Stoneham	Northern Intermediate High	30	5	1900	1998
Brattle Court, Arlington	Northern Extra High	14	3	1907	2010
Spring Street, Arlington	Northern Extra High	17	4	1958	2010
Lexington Street, Waltham	Northern Extra High	8.2	3	1949	1998
Belmont, Arlington	Intermediate High	5.78	3	1937	2010
Commonwealth Ave., Newton	Southern Extra High	26	4 now and 5 Future	1952	1999 (In Design)
Dudley Road, Newton	Southern Extra High	0.6	2	1954	2004
Reservoir Road, Brookline	Southern Extra High	4.68	2	1936	2010
Newton Street, Brookline	Southern Extra High	20	4	1954	1996
Hyde Park Ave., Hyde Park	Southern Extra High	16	3	1912	2010
Chestnut Hill Emergency	Southern High	90	4	2001	2023
Spot Pond, Stoneham	Northern Intermediate High	17	3	2015	2015
Spot Pond, Stoneham	Northern High	25	3	2015	2015

[1] Maximum flow based on peak hourly demand and typical operating rules

also rehabilitated in 2010. Work included installation of new mechanical, electrical, instrumentation and security systems with building and site refurbishment. The Dudley Road Pump Station in Newton was rehabilitated in 2006 by in-house staff. The FY19 CIP proposes $500,000 for an evaluation in FY20-21 for the pump stations first rehabbed in the 90's to assess the needs for a second round of pump station rehabs. The FY19 also contains $19.7 million for design and construction in FY22-28. The Master Plan recommends that

by Metropolitan Operations staff, and Quality Assurance staff. A threshold level of 1.0 mg/l is used to review water quality, and determine if operational changes should be made, such as increasing the operating range to move more water in the tank. The specifics of each tank is considered, such as the existence of separate inlet and outlet piping, configuration, and volume and the disinfection methods used must also be considered. The use of chloramines suggests that testing for ammonia and nitrification needs to be done in the warmer months.

funds be added in the FY43-58 period to ensure continued systematic condition assessment and rehabilitation. Please also see Pressure Zone discussion.

Broken down by component, pump stations have an average useful life of 10-50 years. Computer control systems, generally used as a part of the Supervisory Control and Data Acquisition (SCADA) systems have a useful life of between 10 and 15 years. This is due to the nature of the computer industry, and the pace at which technology changes. Routine condition assessment of pump station equipment has been initiated in order to identify any equipment or instrumentation issues.

Please see Table 9-1 in Chapter 9 for recommended SCADA equipment replacements and upgrades.

Maintenance Practices

There are a variety of maintenance activities that are performed at the pump stations. Theses preventative maintenance (PM) tasks are performed on a monthly, quarterly, semi-annual, and annual schedule, depending upon the type of equipment. The following are examples of the equipment that are maintained at the pump stations:

- Emergency Generators
- Motors
- Pumps
- Motor Control Centers
- Surge Control Valves

Although recent and ongoing rehabilitation projects have addressed the major capital needs of these facilities, the useful life of certain components including equipment such as pumps and instrumentation are generally within the 20-25 year time range and equipment replacement is expected to be necessary within the Master Planning period. In addition, Field Operations continually evaluates opportunities for facility optimization. As part of this, VFDs have been installed in a number of pump stations and this will continue as part of the remaining rehabilitation work. VFDs were also installed in Gillis Pump Station as part of NIH short-term improvements.

The next phase of rehabilitation will include Gillis, Newton Street and Lexington St. pump stations. Rehabilitation of the Commonwealth Avenue Pump Station is included in the Metropolitan Redundancy Interim Improvements project. The FY19 CIP includes a contract to evaluate the pump stations for condition and necessary work as well as design and construction contracts. This work is recommended in the FY20-28 at an estimated cost of $20.2 million.

Recommended Projects-Master Plan

- In order to ensure that facilities rehabilitated in the past project grouping be reevaluated and rehabilitated on an ongoing schedule, staff recommend an additional $25 million be provided in the FY43-58 time period for future pump station rehabilitation.

8.6 Local Pipeline and Water System Assistance Program

MWRA's goal in providing financial assistance to member communities is to improve local water systems to help maintain high quality water as it passes from MWRA's facilities through local pipelines to customers' taps. Continued improvement of local water systems is a critical element of MWRA's Integrated Water Supply Improvement Program and was a component of the Board's October 1998 treatment technology decision for the John J. Carroll Water Treatment Plant. Older water mains, particularly those constructed of unlined cast-iron pipe, need to be replaced or cleaned and lined to prevent tuberculation (rust build-up), loss of disinfectant residual, and potential bacteria growth.

Unlined tuberculated water mains

At the beginning of FY19 (July 2018), approximately 27 percent of locally-owned distribution systems remain unlined, representing a regional need of approximately $1.5 billion for future water main rehabilitation, as depicted in the pie chart below.

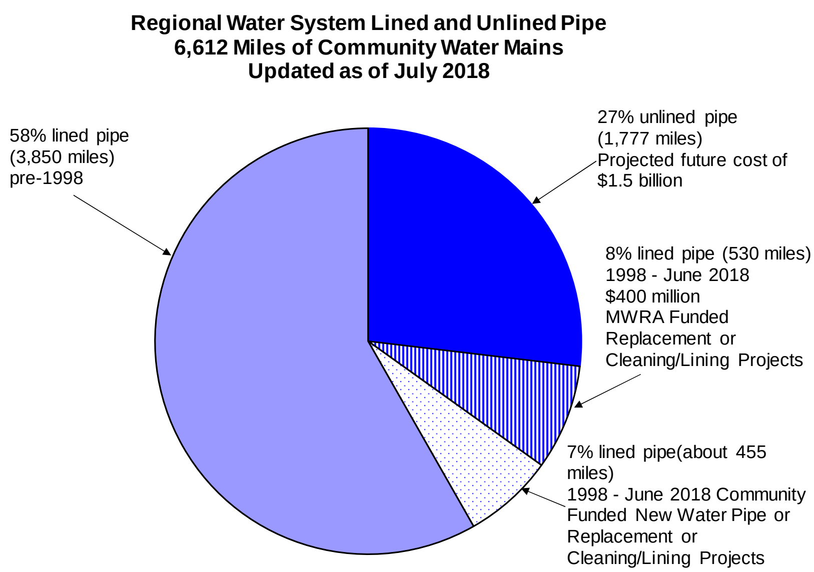
MWRA began financial assistance to member water communities during FY98 and FY99 with the two-year, $30 million "pilot" program that provided grants and loans for local water distribution system rehabilitation projects. The rationale for the initial program was that funds spent on improving local water distribution systems provide greater regional water quality benefits than spending those same funds for water treatment filtration.

Building on the success of the pilot water financial assistance program, the Phase 1 - Local Pipeline Assistance Program (LPAP) was approved in FY01 to provide 10-year interest-free loans to water system communities primarily for water main replacement or cleaning and lining projects. Under the Phase 1 - LPAP, $222 million in loans for local water projects were distributed from FY01 through FY13. MWRA established the Phase 2 - Local Water System Assistance Program (LWSAP) in FY11 to extend the local water loan program through FY23. This expansion of the water loan program added $210 million in interest-free loans for member water communities (including a $10 million allocation specifically for the three Chicopee Valley Aqueduct communities). MWRA established the

Phase 3 - Local Water System Assistance Program (LWSAP) in FY18 to extend the local water loan program through FY30. This expansion of the water loan program added $292 million in interest-free loans for member water communities (including a $14 million allocation specifically for the three Chicopee Valley Aqueduct communities).

New cement mortar lined mains

Since FY98, a total of 530 miles of community water mains have been replaced or rehabilitated via MWRA financial assistance projects. Forty-two of MWRA's 45[7] eligible member water communities have participated in the water system loan programs with $406 million invested to fund local water projects that will help maintain high water quality in



[7] MWRA has a total of 50 water communities (with Dedham/Westwood Water District counted as one), of which 45 are allocated loan funds under the Local Water System Assistance Program. The five ineligible water communities have special case considerations; these include: Clinton, Leominster (emergency only), and Worcester (emergency only), that receive untreated water from the Wachusett Reservoir; Cambridge, that receives water on an emergency-only basis; and Lynn, that receives water for the GE plant only. Under the initial Local Pipeline Assistance Program, the three Chicopee Valley Aqueduct (CVA) communities (Chicopee, South Hadley FD#1, and Wilbraham) were not allocated loan funds.

local distribution systems. The allocation and funds utilized by each eligible community under the Phase 1 – LPAP, Phase 2 – LWSAP, and Phase 3 - LWSAP are listed on Tables 8-5 and 8-6. MWRA's partially supplied water communities received pro-rated shares of loan fund distributions based on their percentage use of MWRA water. Table 8-7 provides individual statistics for the total miles of lined and unlined water main in each member water community.

Table 8-5

MWRA LOCAL PIPELINE ASSISTANCE PROGRAM ALLOCATION AND FUND UTILIZATION BY COMMUNITY THROUGH JUNE 2013

Community	Community Total Allocation	Funds Distributed Thru Jun 13	Percent Distributed	Unutilized Funds
Arlington	$9,723,620	$6,099,000	63%	$3,624,620
Bedford*	$1,018,610	$1,018,610	100%	$0
Belmont	$4,213,570	$4,213,570	100%	$0
Boston	$61,571,330	$61,571,330	100%	$0
Brookline	$625,090	$0	0%	$625,090
Canton*	$2,080,380	$0	0%	$2,080,380
Chelsea	$5,023,870	$4,825,468	96%	$198,403
Dedham/Westwood* ##	$7,500	$7,500	100%	$0
Everett	$5,429,020	$5,429,020	100%	$0
Framingham	$8,681,800	$8,681,800	100%	$0
Lexington	$1,539,570	$1,539,570	100%	$0
Lynnfield WD	$320,000	$320,000	100%	$0
Malden	$10,244,520	$10,244,520	100%	$0
Marblehead	$6,320,350	$0	0%	$6,320,350
Marlborough*	$1,166,200	$1,166,200	100%	$0
Medford	$9,723,620	$7,212,923	74%	$2,510,697
Melrose	$6,586,590	$6,586,590	100%	$0
Milton	$6,771,800	$6,771,800	100%	$0
Nahant	$1,331,210	$1,111,242	83%	$219,968
Needham*	$1,286,520	$257,304	20%	$1,029,216
Newton	$25,860,190	$25,860,190	100%	$0
Northborough*	$97,180	$0	0%	$97,180
Norwood	$5,139,630	$5,139,630	100%	$0
Peabody*	$838,030	$838,030	100%	$0
Quincy	$15,835,600	$15,835,600	100%	$0
Reading ###	$1,916,000	$1,916,000	100%	$0
Revere	$5,371,140	$3,500,000	65%	$1,871,140
Saugus	$9,029,070	$9,029,070	100%	$0
Somerville	$9,480,530	$9,480,530	100%	$0
Southborough	$81,030	$0	0%	$81,030
Stoneham	$1,736,360	$1,736,360	100%	$0
Stoughton* #	$4,480,000	$4,480,000	100%	$0
Swampscott	$5,602,660	$5,602,660	100%	$0
Wakefield*	$2,524,950	$0	0%	$2,524,950
Waltham	$13,636,210	$2,552,968	19%	$11,083,242
Watertown	$1,736,360	$1,736,360	100%	$0
Wellesley*	$1,279,280	$1,279,280	100%	$0
Weston	$127,330	$127,330	100%	$0
Wilmington* ####	$73,000	$0	0%	$73,000
Winchester*	$665,190	$665,190	100%	$0
Winthrop	$4,167,260	$2,027,600	49%	$2,139,660
Woburn*	$3,454,330	$3,454,330	100%	$0
TOTAL	**$256,796,500**	**$222,317,575**	**87%**	**$34,478,926**

*** Partially Served Communities**

 # Stoughton's total allocation is for eight years; the Town was not an MWRA member water community for the first two years of the Program.

Dedham/Westwood's total allocation is for five years; the Town was not an MWRA member water community for the first five years of the Program.

Reading's total allocation is for five years; FY06 and FY07 as a partially supplied MWRA water community at $142,000/year and FY08, FY09, and FY10 as a fully supplied MWRA water community at $544,000/year.

Wilmington's total allocation is for one year - FY10.

Table 8-6

MWRA LOCAL WATER SYSTEM ASSISTANCE PROGRAM
ALLOCATION AND FUND UTILIZATION BY COMMUNITY
AS OF JULY 2018

Community	Community Total Phase 2 Allocation	Phase 2 Funds Distributed Thru Sep 18	Total Remaining Phase 2 Funds	Community Total Phase 3 Allocation	Community Phase 3 Annual Allocation	Phase 3 Allocation To Date (Year 2)	Phase 3 Funds Distributed Thru Sep 18	Phase 3 Funds Currently Available	Total Phase 2 and 3 Funds Available
Arlington	$6,225,000	$4,400,000	$1,825,000	$8,687,000	$868,700	$1,737,400	$0	$1,737,400	$3,562,400
Bedford *	$2,418,000	$2,418,000	$0	$3,649,000	$500,000	$1,000,000	$0	$1,000,000	$1,000,000
Belmont	$3,477,000	$3,477,000	$0	$3,852,000	$500,000	$1,000,000	$0	$1,000,000	$1,000,000
Boston	$38,754,000	$35,870,928	$2,883,072	$52,787,000	$5,278,700	$10,557,400	$0	$10,557,400	$13,440,472
Brookline	$3,426,000	$660,000	$2,766,000	$4,585,000	$500,000	$1,000,000	$0	$1,000,000	$3,766,000
Canton *	$3,216,000	$2,000,000	$1,216,000	$2,971,000	$500,000	$1,000,000	$0	$1,000,000	$2,216,000
Chelsea	$3,814,000	$3,011,200	$802,800	$5,039,000	$503,900	$1,007,800	$0	$1,007,800	$1,810,600
Dedham/Westwood *	$503,000	$503,000	$0	$849,000	$500,000	$849,000	$0	$849,000	$849,000
Everett	$4,672,000	$4,441,000	$231,000	$6,298,000	$629,800	$1,259,600	$0	$1,259,600	$1,490,600
Framingham	$7,357,000	$5,149,900	$2,207,100	$9,003,000	$900,300	$1,800,600	$0	$1,800,600	$4,007,700
Lexington	$3,024,000	$1,145,015	$1,878,985	$3,777,000	$500,000	$1,000,000	$0	$1,000,000	$2,878,985
Lynnfield Water Dist.	$1,396,000	$650,000	$746,000	$1,678,000	$500,000	$1,000,000	$0	$1,000,000	$1,746,000
Malden	$7,272,000	$1,774,000	$5,498,000	$10,605,000	$1,060,500	$2,121,000	$0	$2,121,000	$7,619,000
Marblehead	$4,237,000	$0	$4,237,000	$5,112,000	$511,200	$1,022,400	$0	$1,022,400	$5,259,400
Marlborough *	$1,917,000	$1,283,800	$633,200	$3,512,000	$500,000	$1,000,000	$0	$1,000,000	$1,633,200
Medford	$6,959,000	$2,075,000	$4,884,000	$10,800,000	$1,080,000	$2,160,000	$0	$2,160,000	$7,044,000
Melrose	$3,988,000	$3,394,000	$594,000	$6,865,000	$686,500	$1,373,000	$0	$1,373,000	$1,967,000
Milton	$4,123,000	$2,000,000	$2,123,000	$5,967,000	$596,700	$1,193,400	$0	$1,193,400	$3,316,400
Nahant	$1,490,000	$1,142,100	$347,900	$1,835,000	$500,000	$1,000,000	$0	$1,000,000	$1,347,900
Needham *	$794,000	$794,000	$0	$1,894,000	$500,000	$1,000,000	$337,265	$662,735	$662,735
Newton	$13,602,000	$9,521,400	$4,080,600	$20,837,000	$2,083,700	$4,167,400	$0	$4,167,400	$8,248,000
Northborough *	$1,048,000	$986,053	$61,947	$1,450,000	$500,000	$1,000,000	$0	$1,000,000	$1,061,947
Norwood	$4,395,000	$4,000,000	$395,000	$6,296,000	$629,600	$1,259,200	$0	$1,259,200	$1,654,200
Peabody *	$1,089,000	$1,089,000	$0	$2,756,000	N/A +	$2,756,000	$2,756,000	$0	$0
Quincy	$10,505,000	$9,679,459	$825,541	$14,252,000	$1,425,200	$2,850,400	$0	$2,850,400	$3,675,941
Reading	$4,146,000	$4,146,000	$0	$5,073,000	$507,300	$1,014,600	$0	$1,014,600	$1,014,600
Revere	$5,034,000	$1,850,000	$3,184,000	$5,315,000	$531,500	$1,063,000	$0	$1,063,000	$4,247,000
Saugus	$6,621,000	$4,012,054	$2,608,946	$9,688,000	$968,800	$1,937,600	$0	$1,937,600	$4,546,546
Somerville	$7,419,000	$3,355,234	$4,063,766	$10,791,000	$1,079,100	$2,158,200	$0	$2,158,200	$6,221,966
Southborough	$1,512,000	$0	$1,512,000	$1,920,000	$500,000	$1,000,000	$0	$1,000,000	$2,512,000
Stoneham	$2,339,000	$2,339,000	$0	$2,742,000	$500,000	$1,000,000	$0	$1,000,000	$1,000,000
Stoughton*	$2,506,000	$2,506,000	$0	$3,547,000	$500,000	$1,000,000	$0	$1,000,000	$1,000,000
Swampscott	$3,755,000	$2,849,468	$905,532	$5,276,000	$527,600	$1,055,200	$0	$1,055,200	$1,960,732
Wakefield *	$2,325,000	$1,776,250	$548,750	$3,356,000	$500,000	$1,000,000	$0	$1,000,000	$1,548,750
Waltham	$10,293,000	$4,318,370	$5,974,630	$14,904,000	$1,490,400	$2,980,800	$0	$2,980,800	$8,955,430
Watertown	$2,978,000	$2,978,000	$0	$3,745,000	$500,000	$1,000,000	$0	$1,000,000	$1,000,000
Wellesley *	$2,350,000	$241,569	$2,108,431	$3,268,000	$500,000	$1,000,000	$0	$1,000,000	$3,108,431
Weston	$1,625,000	$1,005,000	$620,000	$2,295,000	$500,000	$1,000,000	$0	$1,000,000	$1,620,000
Wilmington *	$611,000	$611,000	$0	$1,306,000	$500,000	$1,000,000	$0	$1,000,000	$1,000,000
Winchester *	$882,000	$775,000	$107,000	$1,394,000	$500,000	$1,000,000	$0	$1,000,000	$1,107,000
Winthrop	$3,312,000	$3,312,000	$0	$4,119,000	N/A +	$4,119,000	$4,119,000	$0	$0
Woburn *	$2,591,000	$2,591,000	$0	$3,905,000	$500,000	$1,000,000	$0	$1,000,000	$1,000,000
SUBTOTAL	**$200,000,000**	**$140,130,800**	**$59,869,200**	**$278,000,000**	**$31,859,500**	**$70,443,000**	**$7,212,265**	**$63,230,735**	**$123,099,935**
Chicopee	$7,153,000	$4,035,000	$3,118,000	$9,774,000	$977,400	$1,954,800	$0	$1,954,800	$5,072,800
South Hadley F.D. 1	$1,538,000	$1,538,000	$0	$2,026,000	$500,000	$1,000,000	$500,000	$500,000	$500,000
Wilbraham	$1,309,000	$0	$1,309,000	$2,200,000	$500,000	$1,000,000	$0	$1,000,000	$2,309,000
SUBTOTAL	**$10,000,000**	**$5,573,000**	**$4,427,000**	**$14,000,000**	**$1,977,400**	**$3,954,800**	**$500,000**	**$3,454,800**	**$7,881,800**
TOTAL	**$210,000,000**	**$145,703,800**	**$64,296,200**	**$292,000,000**	**$33,836,900**	**$74,397,800**	**$7,712,265**	**$66,685,535**	**$130,981,735**

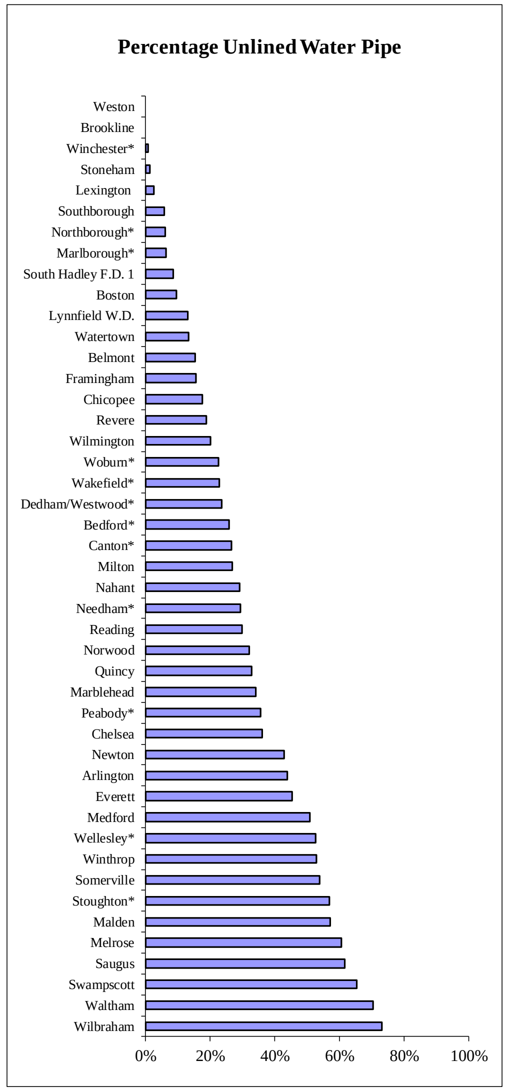
* Partially Served Communities
+ Exempt per Board Approval

Table 8-7

MWRA LOCAL WATER SYSTEM ASSISTANCE PROGRAM
LINED AND UNLINED PIPE BY COMMUNITY
AS OF JULY 2018

Community	Total Miles of Pipe	Miles of Lined Pipe	Miles of Unlined Pipe	Percent Unlined
Arlington	132	74	58	44%
Bedford*	85	63	22	26%
Belmont	93	79	14	15%
Boston	1011	914	97	10%
Brookline	140	140	0	0%
Canton*	128	94	34	27%
Chelsea	59	38	21	36%
Chicopee	269	221	48	18%
Dedham/Westwood*	203	155	48	24%
Everett	68	37	31	45%
Framingham	276	233	43	16%
Lexington	165	161	4	2%
Lynnfield W.D.	29	25	4	13%
Malden	121	52	69	57%
Marblehead	97	64	33	34%
Marlborough*	180	169	11	6%
Medford	144	71	73	51%
Melrose	82	32	50	60%
Milton	138	101	37	27%
Nahant	23	16	7	29%
Needham*	135	95	40	29%
Newton	319	182	137	43%
Northborough*	65	61	4	6%
Norwood	119	81	38	32%
Peabody*	208	134	74	36%
Quincy	240	161	79	33%
Reading	114	80	34	30%
Revere	107	87	20	19%
Saugus	125	48	77	62%
Somerville	125	58	67	54%
South Hadley F.D. 1	83	76	7	9%
Southborough	87	82	5	6%
Stoneham	80	79	1	1%
Stoughton*	151	65	86	57%
Swampscott	58	20	38	65%
Wakefield*	114	88	26	23%
Waltham	150	45	105	70%
Watertown	82	71	11	13%
Wellesley*	150	71	79	53%
Weston	111	111	0	0%
Wilbraham	74	20	54	73%
Wilmington	126	101	25	20%
Winchester*	112	111	1	1%
Winthrop	45	21	24	53%
Woburn*	190	147	43	22%
TOTAL	**6,612**	**4,835**	**1,777**	**27%**

*** Partially Served Communities**



Details on the application process, the Program Guidelines, and the Financial Assistance Application are provided on the MWRA Community Support Program web page: http://www.mwra.com/comsupport/communitysupportmain.html. Eligible projects focus on elimination of unlined water mains. For Phase 2 and Phase 3 – LWSAP, eligible projects were expanded, particularly for those communities that have demonstrated a commitment to water pipeline improvements. Local projects that rehabilitate water distribution systems, improve water quality, and/or enhance system efficiency are eligible for MWRA financial assistance, as noted below:

- Water main cleaning and lining of unlined water mains;
- Replacement, sliplining, or abandonment of unlined water mains;
- Replacement or abandonment of asbestos cement pipe or other water pipeline work performed for water quality purposes;
- Identification and replacement of water service connections constructed of lead or other water services in poor condition;
- Looping of dead-end water mains;
- Water valve and hydrant installation or replacement;
- Water storage tank installation, rehabilitation, or replacement; and,
- Engineering planning, design and construction services associated with the above items.

To provide communities some flexibility with regard to water system rehabilitation needs, additional community projects (Tier Two Projects) that target water system efficiency are also eligible for Phase 2 and Phase 3 - LWSAP loan funding. To emphasize the Program's goal of improving water quality, the amount of LWSAP funds that may be used for Tier Two Projects is restricted to the community's percent of lined water main miles times the community's total LWSAP allocation. Tier Two eligible projects include:

- Water meter purchase and installation;
- Water meter reading system purchase and installation;
- Water booster pump station installation and/or upgrades;
- GIS mapping and system modeling; and,
- Engineering planning, design and construction services associated with the above items.

Commitments to provide interest-free loans for local water projects are issued by the MWRA in the form of a financial assistance and loan agreement subject to the availability of Program funds. Financial assistance is distributed quarterly, on or about: February 15, May 15, August 15, and November 15. Complete community applications are due to MWRA one month prior to the proposed loan distribution date. The financial assistance award is electronically transferred into a Massachusetts Municipal Depository Trust (MMDT) account established by the community. All financial assistance funds, together with the earned interest from the MMDT account, are required to be expended on approved community water system rehabilitation projects. Both the community and the MWRA receive monthly MMDT account statements to track account expenditures.
Even with the substantial progress made over the last 20 years, MWRA estimates that over

1700 miles of community water main remain unlined, representing a future community water main replacement/rehabilitation cost of $1.5 billion. For master planning purposes, staff recommend future fourth and fifth phases of the Local Water System Assistance Program be considered for funding in future CIPs. Each new phase is recommended to provide $250 million in interest-free loans (with 10-year loan repayments) during the FY29-38 and FY39-48 time periods. MWRA staff will continue to work cooperatively with the Advisory Board to identify potential program improvements which may be recommended to the Board for approval.

On recommendation from the MWRA Advisory Board, the MWRA Board of Directors approved an enhancement to the Local Water System Assistance Program to provide up to $100 million in 10-year zero-interest loans to communities solely for efforts to fully replace lead service lines. This program began in FY17 and is titled the Lead Service Line Replacement Loan Program or Lead Loan Program. Each community can develop its own program, tailored to their local circumstances. The presence of a lead service line connecting a home to the main in the street can lead to elevated lead levels in tap water, especially if that water sits stagnant for an extended period. MWRA's stable water quality and effective corrosion control treatment reduce the risk that a lead service line will cause elevated lead levels, and measured lead levels in high risk homes have decreased by 90 percent since corrosion control was brought on-line in 1996. However, the risk of elevated levels remains as long as lead service lines are in use.

Table 8-8 lists the net costs of the Local Pipeline and Water System Assistance Program (Phases 1, 2, 3, and Lead Loans) that are programmed in the FY19 CIP, as well as, the net costs of additional Phases 4 and 5 that are recommended for consideration in future CIPs.

Table 8-8

Water System Master Plan - Community-Owned Systems/Community Support

Existing and Recommended Projects

Last revision 12/28/18

Prioritization		**Project Types**	
1	Critical or Under Construction	NF	New Facility/System
2	Essential	RF/IC	Replacement Facility/Increase Capacity
3	Necessary	Opti	Optimization
4	Important	AP	Asset Protection
5	Desirable	Plan	Planning/Study

Line No	Priority	Project	Project Type	FY19 CIP Project No.	FY19 CIP Contract No.	Project Duration	Total Project Cost ($1000)	FY19-58 Planning Period Cost	Schedule	FY19-23	FY24-28	FY29-38	FY39-58	FY19-58 Planning Period Cost
										5 years	5 years	10 years	20 years	
		COMMUNITY-OWNED SYSTEMS/COMMUNITY SUPPORT - WATER												
8.01	3	Phase 1 - Local Pipeline Assistance Program (Net Cost-Repayments Only)	AP	765	multi	23 years	0	(22,200)	FY01-23	(22,200)	0	0	0	(22,200)
8.02	3	Phase 2 - Local Water System Assistance Program (Net Cost-Loans and Repayments)	AP	765	multi	23 years	0	(99,900)	FY11-33	(19,800)	(64,000)	(16,100)	0	(99,900)
8.03	3	Phase 3 - Local Water System Assistance Program (Net Cost-Loans and Repayments)	AP	765	multi	23 years	0	(9,000)	FY18-40	60,500	83,700	(146,000)	(7,200)	(9,000)
8.04	3	Lead Service Line Replacement Loan Program (Net Cost - Loans and Repayments)	AP	765	multi	24 years	0	(10,400)	FY17-40	13,900	3,100	(17,900)	(9,500)	(10,400)
		SUBTOTAL - Existing - Community Support					**0**	**(141,500)**		**32,400**	**22,800**	**(180,000)**	**(16,700)**	**(141,500)**
8.03	3	Phase 4 - Local Water System Assistance Program ($250 million interest-free loans)	AP	new		20 years	0		FY29-48			137,500	(137,500)	0
8.04	3	Phase 5 - Local Water System Assistance Program ($250 million interest-free loans)	AP	new		20 years	0		FY39-58				0	0
		SUBTOTAL - Recommended - Community Support					**0**			**0**	**0**	**137,500**	**(137,500)**	**0**
		SUBTOTAL - Existing and Recommended - Community Support					**0**	**(141,500)**		**32,400**	**22,800**	**(42,500)**	**(154,200)**	**(141,500)**

Projects in the FY19 CIP:

- Phase 1 - Local Pipeline Assistance Program is programmed in the FY19 CIP at net revenue of $22.2 million in the FY19-23 timeframe. The net revenue of the Phase 1 - LPAP includes only loan repayments since Phase 1 loan distributions were completed in FY13.

- Phase 2 - Local Water System Assistance Program is programmed in the FY19 CIP at net revenue of $99.9 million in the FY19-33 timeframe. The net revenue of the Phase 2 - LWSAP includes $66.3 million in additional 10-year interest-free loans through FY23 and $166.2 million in offsetting community loan repayments through FY33.

- Phase 3 - Local Water System Assistance Program is programmed in the FY19 CIP at a net revenue of $9.0 million in the FY18-40 timeframe. The net revenue of the Phase 3 - LWSAP includes $283.0 million in additional 10-year interest-free loans through FY30 and $292.0 million in offsetting community loan repayments through FY40.

- Lead Service Line Replacement Loan Program is programmed in the FY19 CIP at a net revenue of $10.4 million in the FY17-40 timeframe. The net cost of the Lead Service Line Replacement Loan Program includes $89.0 million in additional 10-year interest-free loans through FY30 and $99.40 million in offsetting community loan repayments through FY40.

Projects Recommended for Consideration in future CIPs:

- Given the $1.5 billion anticipated need for future community water main replacement/rehabilitation cost, staff recommend continued systematic investment in local water system infrastructure through MWRA financial assistance. For master planning purposes, staff recommend future fourth and fifth phases of the Local Water System Assistance Program be considered for funding in future CIPs. Each new phase is recommended to provide $250 million in interest-free loans (with 10-year loan repayments). Future Phase 4 financial assistance distributions are projected during the FY29-38 timeframe with loan repayments extending through FY48. Future Phase 5 financial assistance distributions are projected during the FY39-48 timeframe with loan repayments extending through FY58. Because loan distributions are offset by community repayments over time, the net CIP budget of each recommended future loan phase is zero. Prior to expansion of the current program, coordination with the MWRA Advisory Board is required to develop a recommendation for Board of Directors consideration.

8.7 Community Training and Assistance

The MWRA is actively engaged in providing training, technical guidance, field assistance, and incident response to our customer communities, and also to communities outside of the district if called for.

Annual Emergency Response Plan Training

Mass DEP requires that water distribution system operations staff attend 10 hours of emergency response plan training annually. Since 2011, MWRA staff has prepared and presented the 10 hours of training each year to our own and community staff. Community staff has participated as trainers during several annual sessions. Topics have included water storage tank operation and maintenance, valve exercising, preparing for emergency response and incidents, contagious disease response training, incident command system training, water quality complaint tracking and analysis, Revised Total Coliform Rule (RTCR) training, and many other topics. MWRA and community staff attends the training sessions.

Water Quality Sampler Training

Every other year, Quality Assurance staff have presented water sampler training. This provides hands on training for MWRA and community staff in the proper techniques and protocols for collecting water quality samples.

Technical Assistance

MWRA staff provides technical assistance to the communities regarding water storage tank operation and maintenance, pressure reducing valve (PRV) operation and maintenance, large diameter valve operation and maintenance, and pipeline disinfection and dechlorination.

Field Assistance and Emergency Response

MWRA staff has assisted many of the customer communities with a variety of assistance in the field, and during emergency/incident response. Leak detection staff (working Sunday thru Thursday evenings, 11pm thru 7am) has assisted many of the communities with pinpointing leaks in the local distribution systems. The communities do perform leak detection via the contracting system provided by the MWRA, but our staff will assist when the communities do not have an active leak detection contract, or if there is a stubborn or difficult leak to pinpoint. MWRA staff has located leaks totaling many hundreds of thousands of gallons of leaks for the communities.

MWRA staff has assisted the communities with the operation of hard to operate valves in the local systems, and have assisted with the isolation of leaks and breaks if requested. The photo to the right shows a local leak that was isolated by our staff at the request of the community.

MWRA staff have also assisted communities by providing repair parts and in some cases participating directly in assisting with leak repair. Four 30” mechanical couplings were driven to Washington DC by one of our staff in response to a catastrophic water main break in the DC system. Staff have also assisted many local communities with break repair assistance. At the request of MEMA, MWRA staff assisted Brockton by providing 24” repair parts and assisting with the repair of the city's raw water intake main break in May, 2016. A photo of the repair is shown below.

Staff has provided training in the field with basic preventative maintenance (PM) task of PRV with many of the customer communities, and has assisted with PRV adjustments when requested.

Deployment of Mobile Emergency Response Equipment

Staff has deployed mobile disinfection unit (MDU) equipment to several of the communities when requested. In all cases, the deployment has been coordinated with the appropriate regional DEP staff. The equipment is also used for routine disinfection of MWRA water pipelines so that staff maintain working knowledge of the equipment. Mobile pump units (MPU) are also available for use in the community or MWRA water systems. The MPU have been used on scheduled maintenance projects, and in emergency response when needed. Below are photos of the MDU and MPU.

Emergency Water Supply and Drought Management Planning

Water has been provided to several communities as a result of the drought in the summer of 2016, and for other unusual situations. MWRA staff participated in drought response planning with several communities to plan for water supply contingencies. One community experienced a fire in one of their water treatment plants, and as a result, had to purchase more water than usual from the MWRA. Staff worked with the community and DEP on the emergency plan to maximize water supply to the community.

Pressure Zone Issues and Recommendations

8.8 Boston Low and Northern Low Service Areas

The Low Service area accounts for approximately 23% of MWRA use and provides water to low lying areas of Boston (Boston Low) and five suburban communities to the north (Northern Low). The Low system is the oldest part of the metropolitan system. As such, it has been the focus of much pipeline renewal work, particularly in the vicinity of Chestnut Hill.

The Boston portion of the service area is normally supplied from Loring Road Covered Storage (elev.200') by two of the large diameter Weston Aqueduct Supply Mains (WASM 1 & 2). In addition, Operations can feed one of the Boston meters from the Spot Pond Supply Mains from the Shaft 8 PRV.

The Northern Low Service (NLS) area is supplied by high service tunnel water which is reduced in pressure and distributed through the Spot Pond Supply Mains extending north from Chestnut Hill to meters in the northern part of the Low system. Shafts 7, 7B, 8, 9, and 9A all have pressure reducing valves (PRVs) which provide for the noted pressure reduction. The NLS PRV provide for great redundancy due to the number of pressure reducing valves, and their location throughout the service area. Because the Low service area includes those areas at the lowest elevations, hydraulic deficiencies in this area are rare. The Nonantum Road PRV also allows the Northern Low to also be fed from WASM 4.

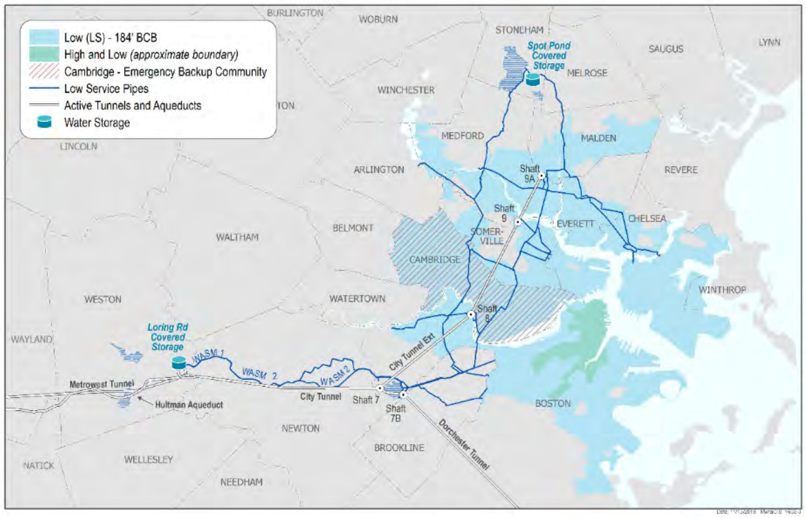
The Spot Pond Covered Storage project in Stoneham, MA was completed in late 2015. This storage facility was identified as part of the original *Water Distribution System Storage Study* and replaces 20 MG of the storage previously available from the Spot Pond Reservoir. The tanks will be filled at night via the Nonantum Road PRV and can be used in conjunction with Loring Road to meet peak demands for the Low Service system.

Figure 8-4 shows the communities and key infrastructure of the Low System including the Spot Pond Covered Storage Facility and Pump Station in Stoneham, MA. MWRA serves as an emergency back-up for the City of Cambridge. This section of Winchester also can be partially supplied through a metered connection from Spot Pond to their local water treatment plant.

Delivery System Condition and Ongoing Work:

The pipes in this service area include the oldest sections owned by the Authority including some pipes that date to the 1840's. Much of the pipe rehabilitated to date has been is old unlined cast iron and some sections that have deteriorated to the point of removal from service due to the risk of breaks are scheduled for replacement or

Figure 8-4



abandonment. Substantial work has been completed since MWRA's inception to rehabilitate WASM 1 and WASM 2 primarily using cleaning and lining techniques. The Low Service supply to the downtown Boston area has no significant pressure problems when fully in service.

The rehabilitation of the 100 year old East and West Spot Pond Supply Mains was completed in 2008. These mains serve as distribution mains to the eight communities in the Northern Low system and can provide emergency back-up to the Gillis Pump Station. The East Spot Pond Supply Main is 61,000 linear feet of mostly 48" diameter pipe and the West Spot Pond Supply Main is approximately 53,000 linear feet of 48-inch and 60-inch pipe.

In September 2006, the Shaft 9A PRV in Malden malfunctioned to allow the discharge hydraulic gradient in the Northern Low to rise from a normal of about 180 feet to a brief spike reaching over 220 feet. This pressure spike and additional ones that followed caused over forty breaks in the five communities of Chelsea, East Boston, Medford, Malden and Everett. A second PRV at Shaft 9A was brought on line and experienced similar fluctuations. An alternate PRV was brought on line at Shaft 9 and has performed well. This illustrates the value of the operational flexibility provided by the redundant PRVs at the tunnel shafts.

Another older pipeline in this pressure zone requiring a mix of replacement and cleaning and lining work is Section 8 in Malden and Everett. Section 8, a 48" cast iron main, was installed between 1897 and 1915 and is in excess of 100 years old. In 2002 a 22 ½ degree bend failed along its length, causing extensive damage to the street. Service to the NLS was temporarily affected until the break was isolated. As part of the existing CIP, the pipeline will be cleaned and lined and all defective or inoperable valves replaced in the 7,500 feet of 48-inch pipe and new 36-inch ductile iron main will replace 9,722 feet of the 42-inch deteriorated cast iron main in Everett to the Mystic River Bridge in Chelsea. Construction is expected to begin in FY27.

Design will commence in FY24 to rehabilitate and strengthen Sections 37 (3,550 linear feet of 36-inch cast iron main) and 46 (2,500 linear feet of 36-inch cast iron main) which provide service to East Boston with construction scheduled to be completed in 2028. Section 38, the 36-inch ductile iron pipeline under Chelsea Creek is assumed to not require rehabilitation.

The Northern High line (97A) was completed to improve service to Orient Heights, however, a new PRV will allow this line to provide redundant service to East Boston including Logan Airport.

Design and Construction for the rehabilitation of the remaining portion of Section 57 in Riverside Avenue (approximately 8,000 linear feet) in Medford along with rehabilitation of approximately 11,000 feet of Section 20 of the Metropolitan Sewer which is in the immediate proximity is ongoing This work should be complete in FY24.

Recommended Projects: Low Service

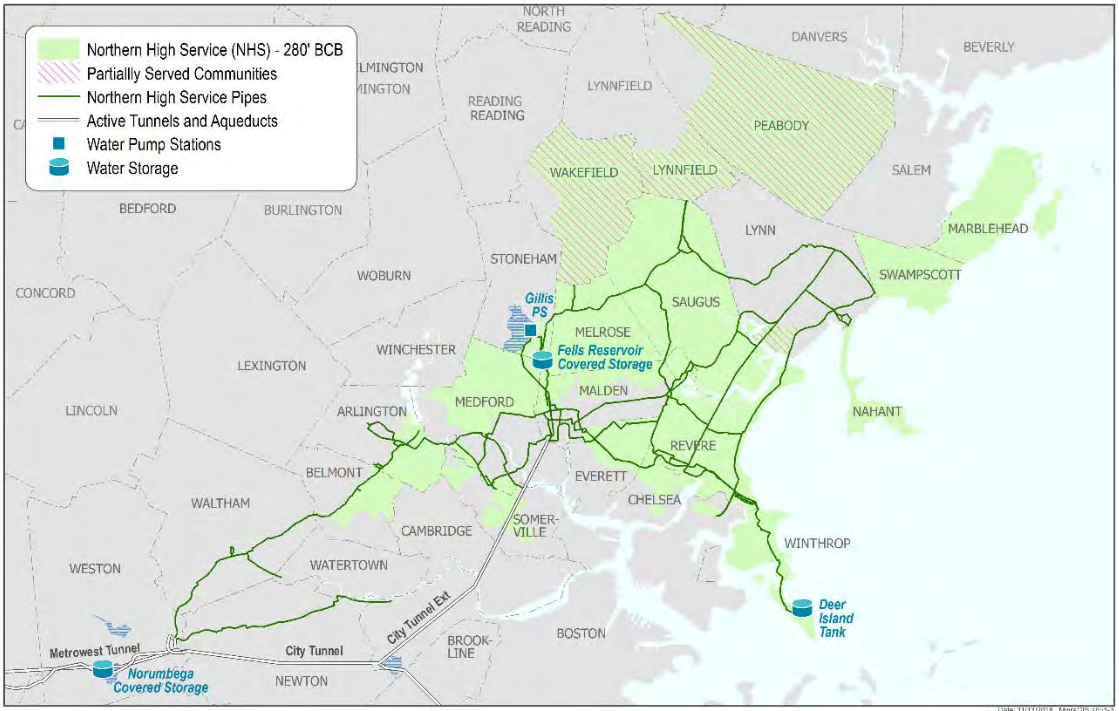
The existing CIP project to rehabilitate Section 8 must be completed prior to these two projects being done.

- Design and Construction for replacement and rehabilitation of 5,000 linear feet of 36-inch pipe on Section 66 and replacement and rehabilitation of 5,000 linear feet of 30-inch pipe with 36-inch pipe on Old Mystic Main. Abandonment of 14,000 linear feet of 150 year old 24-inch cast iron main. This work was previously in the CIP as part of the Spot Pond Supply Mains project. The estimated cost is approximately $8.5 million and, in conjunction with the project below, should be scheduled in the FY45-49 period.

8.9 Northern High Service

The Northern High Service zone is the largest geographical service zone and is located north of Boston. Water is supplied from Norumbega Covered Storage Facility (elev. 282') via the City Tunnel and City Tunnel Extension and distributed to 20 communities by gravity flow. The remaining three communities, Melrose and portions of Stoneham and Saugus, are supplied from the Gillis Pumping Station by pumping to the Fells Reservoir Covered Storage (elev. 270’). The Northern High system also provides service to MWRA facilities on Deer Island.

Figure 8-5



Delivery System Condition and Ongoing Work

Since this service is so large and distant from Norumbega reservoir, it had historically experienced the widest pressure fluctuations during summer peak flows. This has improved with the increased grade line of Norumbega Covered Storage. The northeastern corner of the service area, which feeds Marblehead, Swampscott and Nahant, was significantly strengthened by the completion of Section 91 through Lynn. The southern part of the Northern High, including Chelsea, Everett, Orient Heights and Winthrop, has already been improved by the addition of reinforcing pipelines including 97A in 2009. Previously marginal areas are no longer a factor. The Deer Island tank came on line in 1995 and has improved the reliability of service to Winthrop and on Deer Island.

Fells Gravity Operation

Normal operation of the Fells system is through the use of the Gillis pump station and the Fells Covered Storage Facility (FCSF). Water is normally pumped using one of three pumps at Gillis dedicated to the service area. Communities served by the Fells service area include Melrose, Saugus, Stoneham, and Wakefield. The hydraulic grade line of the city tunnel system varies seasonally, due to overall system demand. During the summer peaks, the grade line can drop below 260’ BCB during peak daytime periods; during the winter season, the grade line can remain significantly higher. Use of the Fells service area maintains the hydraulic grade line between 262’ BCB and 270’ BCB thru the use of the pumps at Gillis and the covered storage facility. Activation of the Norumbega Covered Storage facility has provided for a much more stable hydraulic grade line in the tunnel and surface piping systems. There are approximately 10 months during the year that the FCSF can be filled via gravity from the tunnel system. The summer peaks still create too much of a drop in the hydraulic grade line to enable gravity supply 12 months a year. For those 10 months or so when the hydraulic grade line is high enough, a SCADA controlled valve will be used to control the elevation of the FCSF. The valve is programmed to open and close on water elevation in the FCSF. The operation of the valve replicates the filling of the FCSF identical to the use of the pumps at the Gillis pump station. A successful trial operation was conducted in the spring and early summer of 2012, using manual control of the valve. A new actuator has been installed on the valve, and new programming applied to the valve operator such that it will be used to fill the FCSF. The programming is designed to monitor the water elevation at Fells, such that if the elevation drops a foot below the normal valve opening position, the valve will close, and one of the Fells pumps at Gillis will activate.

For Lynnfield, the new Lynnfield pipeline was completed in 2013. This addressed the insufficient capacity of the 8-inch MWRA line previously used to feed 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. In addition, 6.000 linear feet of 12-inch water main was constructed for the Town of Saugus under a cost sharing arrangement.

Gillis Pumping Station is one of the oldest stations in the system but it was substantially overhauled and upgraded in the 1990’s. In addition a new suction pipeline to the Station from the City Tunnel shaft in Malden was installed which provides water at a higher head than was provided by Spot Pond (which now serves only as an emergency back-up). These improvements have facilitated the ability to transfer water between the low and high service systems and allow the full use of the 20 MG Fells Reservoir Covered Storage facility which came on line in Fall, 1999. As recommended in the 2008 *NIH Assessment and Concept Plan on Short-Term Risk Reduction Strategies*, variable frequency drives (VFDs) were installed at the pump station. This allows the pumps to operate over a much larger flow and head range further increasing the operational flexibility of the Gillis Station.

Spot Pond Pump Station

As part of the new Spot Pond Storage Project for the Low system, a pump station was also built to provide redundancy to the Gillis Station. Gillis currently supplies two service areas from the one station – five pumps are dedicated to the Northern Intermediate High (NIH) service area, and three pumps are dedicated to the Northern High Service/Fells (NHS/Fells) service area. The Bear Hill tank and the Fells Covered Storage Facility (FCSF) are the tanks in the two respective service area. Normal suction to the pump station is from Section 99, which is part of the NHS area. Gillis can also pump from the Northern Low Service (NLS) piping, which is connected to the station from the Spot Pond Bypass line, and Sections 7 and 12. Gillis can also be used to pump water from Spot Pond on an emergency basis, and serve the entire NHS area. The new Spot Pond pump station will also be capable of the same operation, and will have the benefit of the immediately adjacent 20 million gallon Spot Pond storage tank. The operation of the new station will be integrated into the day to day operation of Gillis to the NIH service area, similar to the operation of Hyde Park and Newton Street pump stations in the Southern Extra High (SEH) service area, and Brattle Court and Spring Street pump stations in the Northern Extra High (NEH) service area. The NIH pumps at Spot Pond and Gillis will be programmed to run in a lead/lag fashion to provide redundancy that has been lacking to the NIH service area.

<u>Pipelines</u>

The Northern High Service has a wide range of pipe ages and materials. Of particular concern are the remaining unlined cast iron mains and the larger diameter steel mains which serve as major transmission mains for this service area. The Northern High system contains a significant amount of the remaining unlined cast iron pipe and these mostly small diameter unlined cast iron pipe can be a contributor both to water quality problems as well as pressure problems. MWRA's initial capital budget focused on rehabilitation of larger pipes and on resolving immediate, known piping problems. More recently, focus has also turned to projects to address redundancy shortfalls in the distribution system. However, it is critical that MWRA continue to address the remaining older cast iron pipe in the system. Recommendations in this section and other service areas identify remaining projects that should be gradually moved into the CIP. Many of these projects had been removed from previous CIPs due to budgetary concerns; however, systematic replacement is still critical. Future potential changes in water quality regulations (see Chapter 5) will likely focus on the distribution system and this unlined, highly tuberculated pipe needs to be systematically replaced.

The Northern High also contains some of the remaining steel pipe constructed approximately 80 years ago which has tended to corrode and leak frequently. Although some sections, as mentioned above, have been replaced in this service area, Sections 70 and 71, and 79 remain to be addressed. These sections are predominantly steel but are comprised of many different sections of pipe materials. This Master Plan recommends the rehabilitation of these pipelines beginning in FY39. Initial work to determine the appropriate way to stage such a significant project may be done in-house.

Work completed to date to address older pipelines includes Revere and Malden pipeline improvements such as the significantly corroded 18,900 linear feet of steel pipeline (Section 53) in Malden and Revere which was completed in 2009. The Shaft 9A-D Extension will provide a more reliable connector to the Section 99 pipeline that serves as the suction line to the Gillis Pump Station. Design is ongoing and construction is scheduled to begin in FY23. Additional Section 53 work is scheduled to be constructed in FY24-25.

Section 27 is a 12-20-inch cast iron main (approximately 120 years old) that serves the communities north of Lynn. In-house design work was previously completed and significant rehabilitation and pipe replacement has also been completed in-house. Remaining work on this project is expected to begin in FY19.

Section 97A was completed in 2009. The completion of 97A improves the MWRA's operational flexibility for moving ahead with the Section 8 work in the Northern Low system.

Another project recently completed under the Connecting Mains Project is the rehabilitation of Sections 18, 50 and 51. These mains provide high service water to Medford and a majority of the high service area of Somerville. These pipes include approximately three miles of cast iron water main with an age range of 80-100 years old. Prior to rehabilitation, carrying capacity is these mains had been reduced to approximately 50 percent of the original design capacity due to tuberculation. However, the existing pipes were structurally sound allowing these pipes to be rehabilitated by cleaning and cement mortar lining. Additionally, many of the valves were undersized or inoperable, both causing flow restrictions and limiting MWRA's ability to isolate portions of these mains in the event of a break, leak or for maintenance. The project replaced 12 mainline valves, retrofitted blow-off valves to eliminate cross connections and replaced Meter 32 serving Somerville. This project is a key element in allowing the future shut-down of WASM 3 during the pending replacement and rehabilitation of that pipe.

The design for the rehabilitation of Section 56 which is currently isolated at the General Edwards Bridge due to excessive leaks is ongoing. This is a 30-inch unlined steel pipe approximately 80 years old. This project is important particularly due to Section 26 being out of service for an extended period of time due to bridge replacement work by DOT to ensure a level of continued redundancy to the North Shore communities if there are failures in any of Sections 91, 87 or 72. Directional drilling is the likely construction method although start and end points are yet to be determined. In addition, it may be advisable to evaluate whether a 36-inch pipe would make sense in order to provide additional operational flexibility.

Pipeline rehabilitation of NHS Sections 13 and 48-unlined cast iron (except Section 48 which is unlined steel) with identified hydraulic restrictions. These pipelines connect Malden meters 16 and 187 and Medford meters 65 and 159 to the distribution system. Section 48 is 30-38-inch diameter steel pipe constructed in 1930 with C-values of approximately 75. The estimated cost for design and construction is $18.4 million. This work is currently scheduled for the FY25-30 time period at an estimated cost of $12.9 million.

Recommended Projects: Northern High Service

The recommendations for the Northern High system address an immediate need for pipe rehabilitation to preserve redundancy; the need to continue the systematic cleaning and lining of old cast iron mains; and the rehabilitation of steel pipe nearing the end of its expected life. The following projects were all identified in earlier MWRA CIP's but were eliminated for budgetary reasons. The projects are configured geographically as previously identified. However, as in the past with NHS improvements, project groupings and/or schedules can be modified to address local community issues or paving concerns. It is expected that Water Engineering will review these project groupings prior to initiating design work on any of these projects and regroup them as necessary to reflect other project schedules. The key, however, is the continued progress to eliminated older unlined mains.

- Pipeline rehabilitation of the small diameter unlined cast iron along the coastline from East Boston north to Lynn. This includes Sections 54, 55, and 69. Although these cast iron pipes are not as old as some of the other pipes in this service area (1932 and 1951 for Section 69), the C-values associated with these pipelines are estimated to range from 67-73 indicating that the 20-24-inch mains are severely corroded. The cost of this work is estimated to be \$16.3 million. This is recommended for the FY28-33 period.

- Pipeline rehabilitation of NHS Sections 33, 49, 49A, 50 in Revere and Malden at a cost of approximately \$10 million. These are smaller diameter unlined cast iron mains ranging in age from 85 to over 100 years old in age and with C-values in the 60-70 range. Based on historical leak information and C-value, portions of Section 33 ranked in the top ten worst pipe segments in the analyses completed. This work is recommended for FY40-45.

- Rehabilitation of the major unlined steel mains that serve the Northern High. This includes NHS Sections 70 and 71 and 79 which consists of more than 10 miles of corroded pipeline in Stoneham, Saugus, Melrose and Lynn. Design and construction for rehabilitation of these mains could extend over a 10-20 year period and will need to be carefully phased. Moving forward with rehabilitation is expected to extend the life of the pipe and postpone need for more costly pipe replacement. The estimated design and construction costs for the rehabilitation work is \$35.7 million and should be initiated in the FY39-47 period.

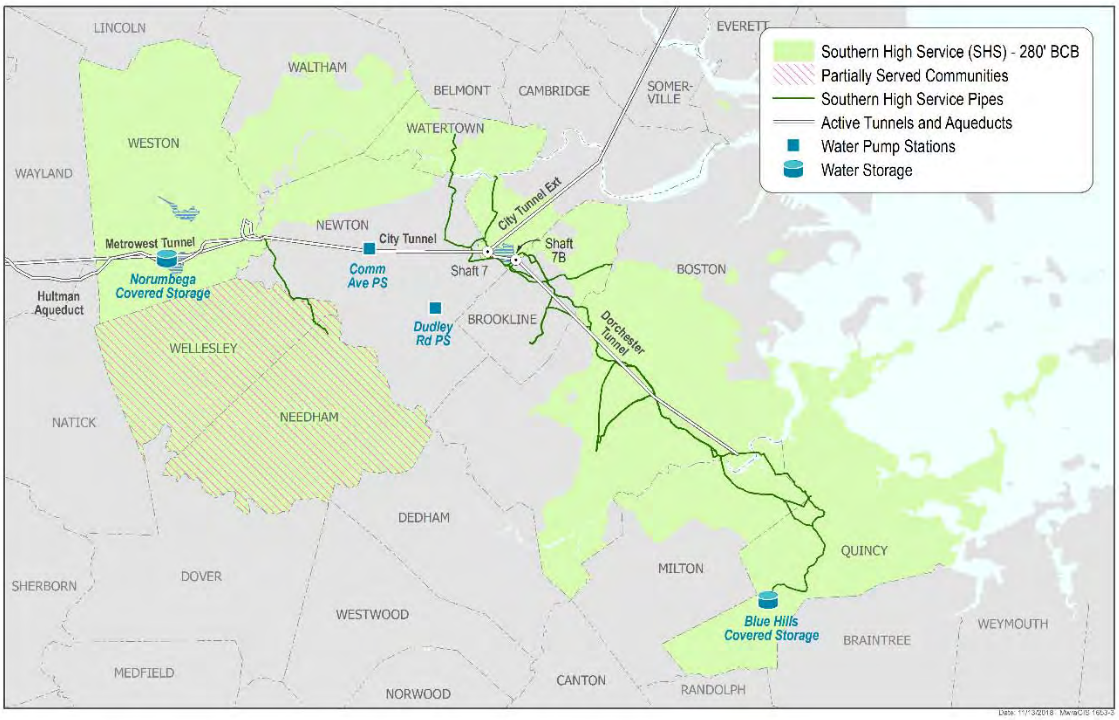
8.10 Southern High Service

The Southern High Service Area has the greatest average daily water demand at 51.1 MGD. Due to its configuration, the Southern High can be characterized in three sub-areas. A small sub-area includes two communities (Needham, Wellesley) supplied by Section 80 which is directly off of the Hultman/MWWST system. A second sub-area is served off of the Norumbega Supply lines (WASMs 3 and 4). This includes Arlington, Belmont, Newton, Waltham and Watertown. In total, during 2011, these communities had a 7.1 MGD average daily use from the WASM lines (in addition to the 51.1 MGD noted above). Weston is served at the same grade line but it is not considered part of the Metropolitan system and is not included in the 51.1 MGD total above.

The third sub-area includes that area served off of the Dorchester Tunnel. This includes parts of Boston (Brighton, downtown Boston, Dorchester and Roxbury), Brookline, Milton and all of Quincy. The older pipes in this system were constructed to work with the earlier aqueduct systems, the Cochituate and Sudbury, and thus, piping in the Chestnut Hill Vicinity is both complicated and, given its age, in need of extensive rehabilitation. The 2011 average day demand for this area was approximately 48 MGD of the above total. This second area of the Southern High system can only be served off of Shaft 7B on the

Dorchester Tunnel. If the Dorchester Tunnel were to go out of service, it would be necessary to activate the Sudbury Reservoir system, transport water via the Sudbury Aqueduct to the Chestnut Hill Reservoir and use the new emergency pump station at Chestnut Hill to pump non-potable water to the Southern High system.

Figure 8-6



<u>Delivery System Condition and Ongoing Work</u>

One ongoing concern is that Section 80, which supplies Needham and Wellesley, was constructed with a tar epoxy lining. Since the communities it serves primarily rely on local supplies, the line is not in regular use. Flushing of the line by the local communities prior to its activation is necessary to reduce the potential for customer complaints. This main has also experienced several leaks. The FY19 CIP contains approximately $10.5 million for the design and construction to clean and line 16,200 linear feet of pipeline through Newton, Wellesley and Needham along Route 128/95 to remove tar epoxy lining. This lining will reduce the level of phenols and mitigate public health concerns and maintain consumer confidence. A temporary transmission main would need to be provided during construction because Section 80 would need to be taken off line for the duration of the construction phase. Design and construction is a five-year duration and staff recommend that it is currently scheduled to begin in 2022. However, the timing and scope of this rehabilitation is potentially impacted by the outcome for the southern part of the metropolitan system redundancy work that is ongoing. As recommended alternatives for that project are developed, refinements or significant changes may be required to the Section 80 rehabilitation project.

For the communities served off of the Norumbega Supply Lines, specifically WASM 3, the eleven mile long, steel WASM 3 pipeline remains a significant concern due to corrosion. The pipe, which was built in the 1920's, requires frequent repairs and rehabilitation is critical. This supply line 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 to Shaft 9 in Medford and supplies approximately 230,000 customers over all. There is no back-up for WASM 3, which is the sole source of supply for the higher elevations of Waltham, Belmont, Arlington, Lexington, Bedford and Winchester. A new Waltham connection to the Northern Extra High system is required to allow WASM 3 to be shut down for rehabilitation.

Results of the conceptual planning process for the Metropolitan Tunnels Redundancy Program grew, in part, out of the difficulty of implementation of the previous WASM 3 plan. The planning work begun in 2008 was to re-examine redundancy options. The Consultant was also asked to review the existing system and current and proposed CIP projects to see whether there were ways to use existing or modify proposed facilities to develop redundancy alternatives that would optimize use of the existing system. The initial recommendations for the northern portion of the work entailed replacement of the 60-inch diameter sections of WASM 3 with 72-inch diameter pipe north to Spring Street; rehabilitation of the remainder of WASM 3 and, construction of a 36-inch pipeline to Waltham. Design began in 2013 and it became clear that implementation for areas requiring a 72-inch replacement pipe would be infeasible given space constraints, traffic and neighborhood concerns. The current proposed tunnel plan requires that WASM 3 be rehabilitated at the same size but work must be done as one of the Interim Improvement Projects discussed in Chapter 7. The FY19 CIP allocates approximately $102 million for WASM 3 work.

For the area of the Southern High served off of the Dorchester Tunnel, pressures generally have not been a problem since the completion of the tunnel in the 1970's. Additionally, the former pressure complaints and peak hourly pressure problems at higher elevations experienced in the City of Quincy (Hospital Hill, Penns Hill and the vicinity of Nut Island) have been alleviated by the completion in 2009 of the 20 million gallons of storage at Blue Hills. This project has increased pressures during peak flows and provided stored treated water closer to the demand.

The Southern Spines Distribution Mains project includes both the rehabilitation of existing pipe and construction of new pipeline segments. Section 22, a steel pipeline, goes from Boston through Milton and into Quincy and has been a significant maintenance concern over time, due to leaks. This is exacerbated by those parts of the pipeline that travel through saltmarsh. The southern portion of Section 22 was rehabilitated in 2005 and the northern section is proposed to be rehabilitated with a planning/EIR phase beginning in 2016. Section 22 North is expected to include rehabilitation of 17,300 linear feet of 48-inch main.

The Southern Spines project also included construction of 4,400 linear feet of new 48-inch main from East Milton Square to Furnace Brook Parkway in Milton and Quincy and replacement of Sections 21 and 43 with 9,200 linear feet of new 48-inch water main from Dorchester Lower Mills in Boston to East Milton Square (Section 107). The activation of Section 107 provides critical redundancy with a pipe loop to the Blue Hills Covered Storage Tanks from the tunnel system. This project has provides sufficient capacity, improved water quality (maintaining chlorine residual in the system) and provides a new level of redundancy for the Southern High Service communities. The hydraulic grade line to Milton and Quincy also improved slightly. In addition, as part of this project, 1,500 linear feet of existing mains were cleaned and lined and three new community revenue meters and additional valves were installed. Sections 20 and 58 are also scheduled for rehabilitation in the FY19 CIP. Design is expected to begin in FY22 at an estimated cost of $18.7 million.

The Chestnut Hill area is in many ways the nexus of the water system. The City Tunnel divides into two branches: the City Tunnel Extension going north to supply the Northern High System, Northern Intermediate High System and the Northern Extra High System and the Dorchester Tunnel, which goes south to feed the Southern High System and the Southern Extra High System. Shaft 7 on the City Tunnel is located in this area and Shaft 7B on the Dorchester Tunnel is also located in this area. At each of these shafts, newer pipes extend to connect with the older pipelines of the Boston Low Service System, the Northern Low System and the Southern High Service System.

The older pipes in the area were originally designed to be supplied from the Cochituate and Sudbury Aqueducts, the Chestnut Hill Reservoir, or the Chestnut Hill High Service and Low Service Pump Stations. None of these facilities are presently in normal use and a new underground pump station, completed in 2001, has replaced the Chestnut Hill Stations. The pipe network in this area is both old and complex and was not designed to take water from the two tunnel shafts that are the present sources of potable supply. Since MWRA's inception, changes to better connect these tunnel shafts with the surface pipe network have involved construction of new pipes and abandonment of some old pipe sections. The Chestnut Hill Final Connections Project is scheduled for FY24-29 at an estimated cost of $1.1 million. Additional projects related to making the best use of the Chestnut Hill Pump Station under both emergency conditions and work that must be done prior to implementation of the Metropolitan Tunnels Redundancy Project is discussed in Chapter 7 under Interim Improvements.

Commonwealth Avenue Pump Station was upgraded as part of the initial series of improvements during the 1990's and the current CIP includes funding for pump station rehabilitation and design work, including redundancy to increase the operational flexibility of the pump station is underway. The Dudley Road Pump Station has been rehabilitated by in-house staff. Dudley Road is used when the PRV that functions as the control valve to Newton's Oak Hill tank is unavailable.

Recommended Projects: Southern High Service

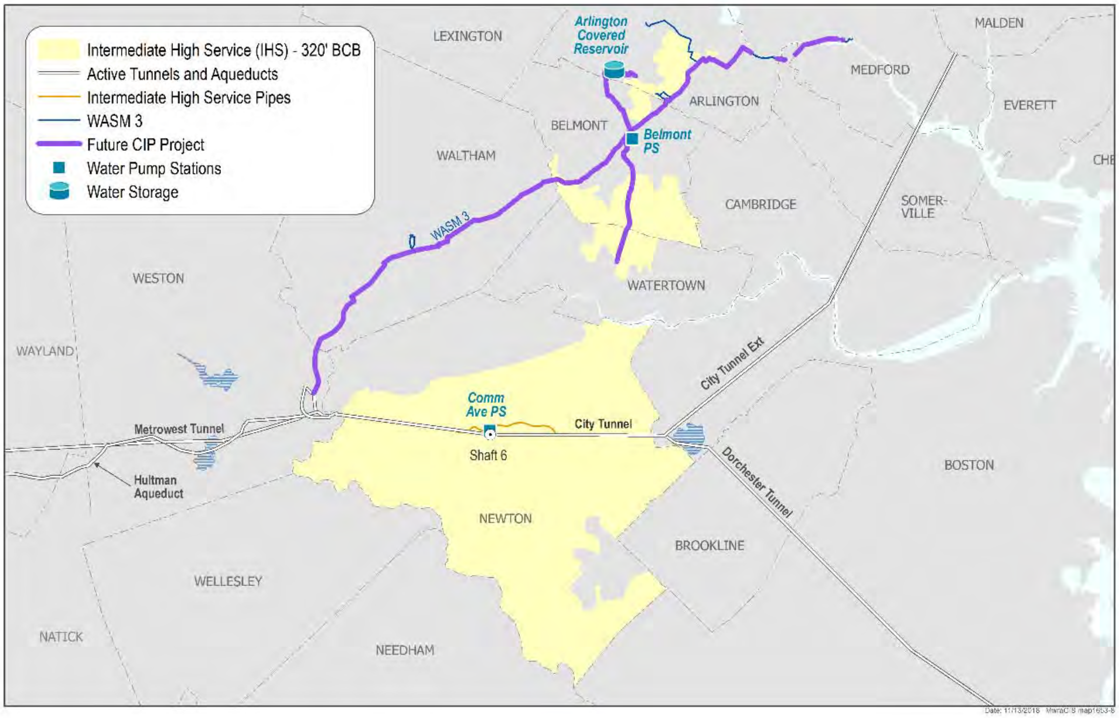
- The Fisher Hill Pipeline was initially proposed to be rehabilitated with the Walnut Street Pipeline but was removed from the CIP. This project involves the design and rehabilitation of approximately 3,200 linear feet of 36-inch pipe; 3570 linear feet of 30-inch pipe; and 1,190 linear feet of 42-inch cast iron mains. These mains are all in excess of 100 years old and have limited carrying capacity due to tuberculation with C-values in the 58-60 range. The estimated cost for construction of this project is $3 million and this work is proposed for FY40.

- Southern Spines Distribution Mains-Rehabilitation of Section 19. This project would include the design and construction of 13,000 linear feet of 48-inch main. Rehabilitation is expected to be cleaning lining and replacement of main line valves, blow-off valves and appurtenances. This project was previously dropped from the CIP due to budgetary concerns. However, Section 19 was constructed in the 1890's and has C-values in the 60's. The estimated cost for design and construction is approximately $8.5 million. This project is proposed to be started in FY40.

8.11 Intermediate High Service

The Intermediate High Service zone consists of two geographically distinct and hydraulically unconnected areas served at similar grade lines (elev. 320') approximately 50 feet higher than high service. The southern area is a portion of Newton lying south of the Massachusetts Turnpike supplied by the Commonwealth Ave. pumping station which takes suction from Shaft 6 of the City Tunnel and pumps to the City owned Newton Covered Storage Reservoir on Waban Hill. The second area is further north and consists of portions of three communities served by water from Norumbega Covered Storage Facility which is transported via WASM 3 and then pumped from the Belmont Pump Station to the Arlington Covered Reservoir (elev. 320').

Figure 8-7



Delivery System Condition and Ongoing Work

The northern part of this area is served by a small diameter, single north/south pipe (Section 59) which is in poor condition with low C-values. From a redundancy standpoint, this system is vulnerable. MWRA staff installed a PRV in the vicinity of the Arlington Covered Reservoir which can provide Northern Extra High water if the Belmont Pumping Station fails or needs to be taken out of service. The major vulnerability is the single pipeline service, and the fact that the covered storage is not at an optimal location. Section 75 serves the southern part of this zone. This is a concrete pipe approximately 65 years old.

The pipes in the Intermediate High system are generally unlined cast iron with C-values in the 70's. The FY19 includes a number of projects for this service area.

Cleaning and lining of Sections 59 and 60 is scheduled for FY19-26 at an estimated cost of $8.7 million. The length of pipeline involved is 16,400 linear feet of 20-inch diameter pipe.

Cleaning and lining of 21,950 linear feet of 20-inch diameter pipe (sections 24 and 47) and 5,800 linear feet of 36-inch pipe (section 23) is scheduled to begin in FY19 at an estimated cost of $16.3 million.

Replacement of Section 25 is scheduled for FY24-25 at an estimated cost of $3.8 million. This project will replace approximately 4,800 linear feet of 16-inch pipe with a new pipeline.

The Belmont pump station was part of the $29 million project to upgrade the five remaining older pump stations in the system. The Belmont station was built in 1937 and has occasionally been out of service for extended periods due to fire damage or the need to replace equipment. This rehabilitation included installation of new mechanical, electrical, instrumentation and security systems and also included building and site renewal.

An additional project recommended in the 2006 Water System Master Plan has been added to the CIP. This is the Section 75 Extension. Section 75 delivers water to the Newton Covered Reservoir (owned and operated by Newton) from the Commonwealth Ave. P.S. but Section 75 does not extend the full distance to the Reservoir with the last 6,000 feet being Newton pipe. A new 30-inch diameter pipe would permit Sections 23, 24 and 47 to be operated at the head of the Intermediate High system. In conjunction with the Section 25 replacement (noted above) it would permit the two geographically distinct areas to be connected and operated as one system. This project would also allow Section 59 to be taken out of service for rehabilitation. This eliminates the need to build a replacement pipeline for Section 59 which had been estimated to cost $10 million. This proposed project would have the additional benefit of increasing pressure to Boston Meter 120 (Notting Hill area). This project has an estimated construction cost of $4 million. Design for this project has been bundled with design of Section 25 Replacement and Sections 59/50.

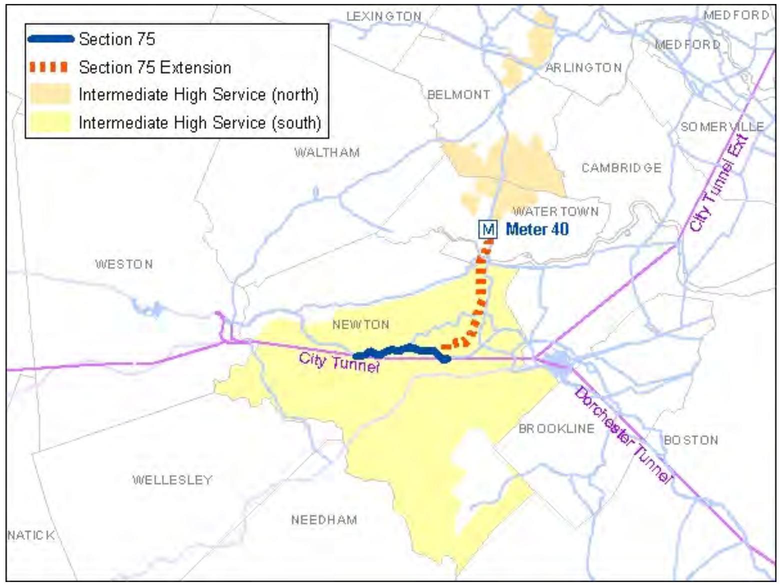


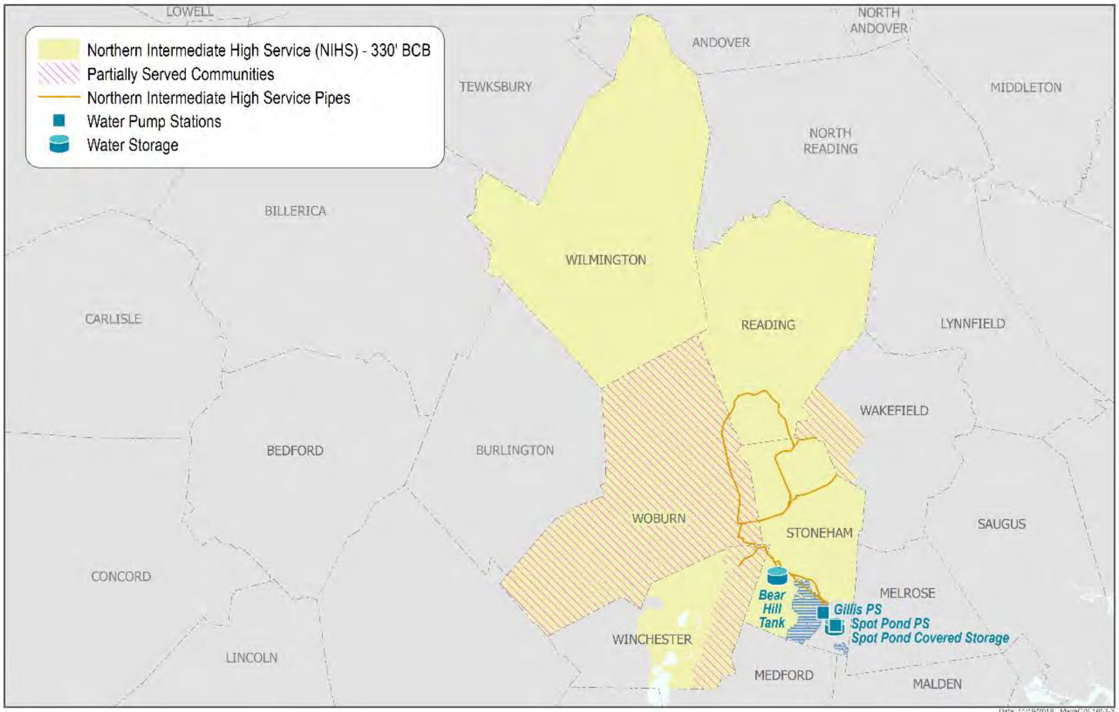
Figure 8-8

No projects beyond those identified in the FY19 CIP are recommended at this time.

8.12 Northern Intermediate High Service

The Northern Intermediate High Service zone is one of the smaller pressure zones and was once considered part of the Northern High Service area. It is supplied by water pumped from the Gillis Pump Station to the Bear Hill Tank (elev. 330'). The Gillis Pump Station draws its supply from the Northern High via the 72-inch diameter Section 99. Water is distributed to 6 fully or partially supplied communities north of Spot Pond.

Figure 8-9



Delivery System Condition and Ongoing Work

From a redundancy standpoint, the NIH service area was identified in the 2006 Master Plan as an area lacking redundancy-the service area has a single supply point and a single tank which limits repair or maintenance opportunities as well as increasing the impact if a failure were to occur. Stoneham, in particular, has no local storage or other connections to rely on during a system problem. Concern over the potential for a catastrophic failure of Section 89 increased when in-house research showed that a 10,000 foot portion of this pipeline was a 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. Because of this, the NIH Assessment and Concept Plan was initiated to assess short-term risk reduction measures that might be undertaken to limit the effects of a pipe failure and develop conceptual level plans for the provision of a redundant pipe, a redundant pump station and additional storage. Concept Planning work was completed and a series of projects, both short and long-term have been added to the subsequent CIPs to reflect the Concept Plan's recommendations.


Example of a brittle wire failure

Pipelines The one section of Section 89 that has redundancy is a small part underneath Spot Pond which is backed up by Section 29 north of the Pond. However, Section 29 is an old, unlined cast iron main which is severely corroded and has limited carrying capacity. Emergency repair parts for Section 89 have been purchased, and are kept at the Chelsea facility if needed.

Design of a redundant pipeline approximately seven miles in length, is now nearing completion with a total estimated construction cost of $55.7 million.

When work is complete, rehabilitation work on the existing Section 89 can begin. This work is scheduled for FY19 at an estimated cost of $19.9 million.

Pump Stations Historically, this service area has been entirely dependent on the Gillis Pumping Station. The rehabilitation of this pumping station substantially improved the reliability of providing flow from the station to Bear Hill, however, the Concept Plan also recommended a redundant pump station to improve the flexibility and reliability of operations. The new Spot Pond Pump Station has similar operational capabilities as does Gillis pump station. Gillis currently supplies two service areas from the one station – five pumps are dedicated to the Northern Intermediate High (NIH) service area, and three pumps are dedicated to the Northern High Service/Fells (NHS/Fells) service area. The operation of the new station will be integrated into the day to day operation of Gillis to the NIH service area, similar to the operation of Hyde Park and Newton Street pump stations in the Southern Extra High (SEH) service area, and Brattle Court and Spring Street pump stations in the Northern Extra High (NEH) service area. The NIH pumps at Spot Pond and Gillis will be programmed to run in a lead/lag fashion to provide redundancy to the NIH that has been lacking.

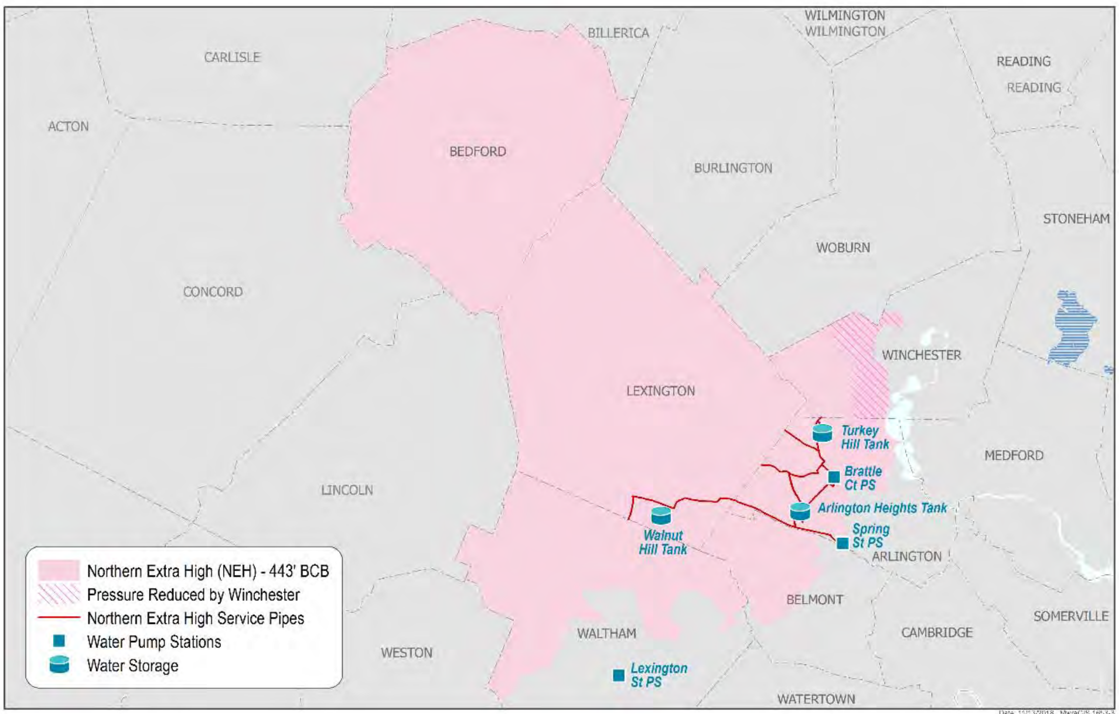
Storage The single storage facility, Bear Hill Tank, has a capacity of 6 MG and is located near Gillis Station. The Bear Hill tank was built in the 1980's and is in good physical condition but it is not able to be taken off-line for cleaning. Mechanical cleaning while the tank is in operation has been used but major rehabilitation work, if necessary, is not currently possible.

The 1993 *Water Distribution System Storage* study recommended placement of additional storage at the Bear Hill site. Given the shift in demand to the north, the Bear Hill site was no longer considered a preferable location compared to potential sites further to the north in the service area. The additional storage required continues to be estimated at 6 MG. Although the Concept Plan identified potential storage locations, MWRA has been unable to come to a final agreement on siting of storage. Discussions are ongoing and the FY14 CIP contains approximately $4.5 million for design beginning in FY24.

8.13 Northern Extra High Service

The Northern Extra High zone provides water to the highest gradelines in the system. Six suburban communities in the hilly region northwest of the Boston are supplied by water from the Norumbega Reservoir via WASM 3 which is pumped to three MWRA owned tanks and one community owned tank. The elevations of the MWRA tanks range from 442' to 445'. The Brattle Court and Spring Street Pumping Stations discharge directly into the Northern Extra High while the Lexington Street Pumping Station discharges directly into Waltham's Prospect Hill service area.

Figure 8-10



Delivery System Condition and Ongoing Work

Sections 34, 36, 45, 63 and 83 provide service to the NEH communities of Waltham, Lexington, Bedford, Belmont, Winchester and Arlington. In addition, Burlington has begun discussions with MWRA to become a water supply community and the Town would also be supplied by the NEH system. As was noted in 1993, the original pipelines were not large enough to meet maximum day demands plus fire flow service goals. To address this issue, Section 45, a 16-inch diameter pipe installed in 1920 was partially rehabilitated but 2,600 linear feet remain to be done. Approximately 3,400 linear feet of Section 63 was rehabilitated and Section 83 was reinforced with a parallel main.

Section 34 is an undersized 1,532 linear foot 12-inch diameter cast iron main installed in 1911 and is a potential source of localized water quality issues. The pipe is a key component of the NEH service area and provides service between Brattle Court Pump

Station and the community distribution systems. The remaining portion of Section 45 is a 16-inch diameter cast iron main 3,374 linear feet long installed in 1920. The project to rehabilitate these two pipeline sections is scheduled to begin in FY22 at an estimated cost of $7 million.

The Lexington Street Pumping Station was rehabilitated in the 1990's and the Brattle Court Pumping Station and Spring Street Pumping Stations were rehabilitated in 2010. This work includes new mechanical, electrical, instrumentation and security systems as well as building and site renewal. SCADA installation at all stations was completed under a fast track contract in 2001.

The storage tanks in the service area vary from the old Arlington Heights Standpipe to the more recently constructed Walnut Hill and Turkey Hill tanks. Tank location also prevents good circulation of water in Arlington Heights. Current inspection and maintenance programs are meeting needs in this area and no major expenditures are anticipated.

The 2006 Water System Master Plan recommended rehabilitation of the Section 83 dropholes. Although it does not affect capacity, Section 83 was constructed to specification that required an additional metal fitting inserted into the top of the pipe (dropholes) along the 4-5 mile length. These have a tendency to fail and result in leakage and require frequent maintenance. A design and construction contract to eliminate these dropholes (using vacuum excavations to locate them) was recommended in 2006. However, since 2006, there have not been any recurring issues. It is now recommended that this situation continue to be monitored and if maintenance needs increase, consideration again be given to developing and implementing a project to address this pipe.

Recommended Projects: Northern Extra High

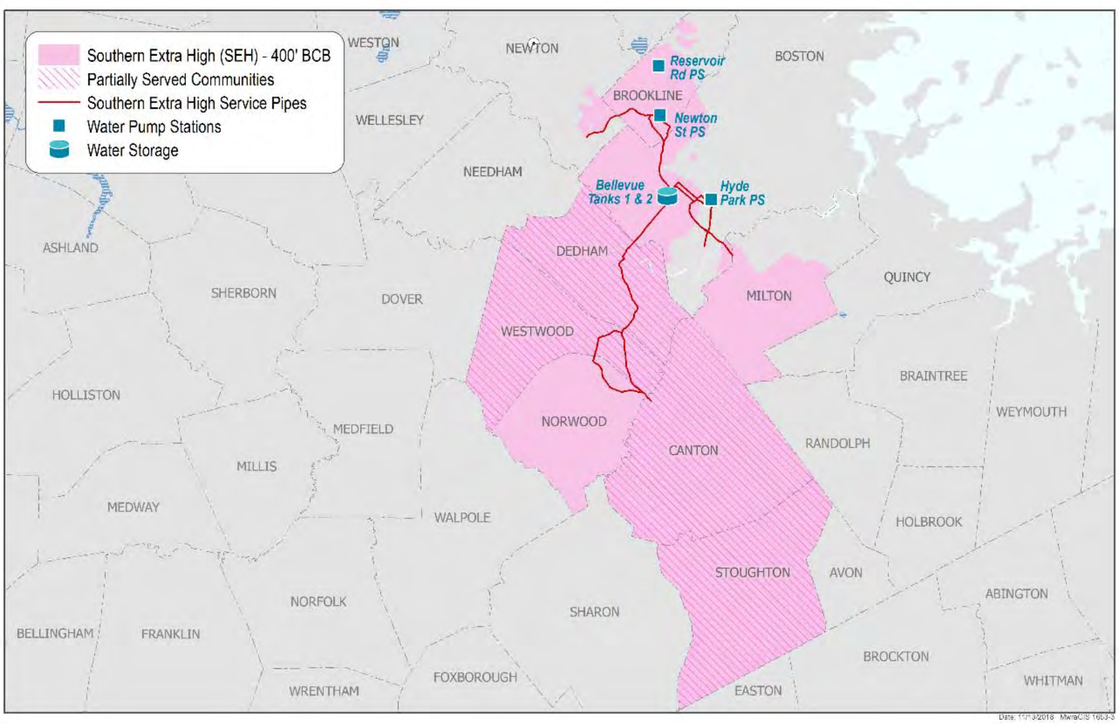
- NEH average daily demand is just shy of 11 mgd. If we include Park Circle, we have a total of 6 mg of storage in the service area. The Master Plan recommends up to 6 MG of additional storage be constructed in the FY42-48 period at an estimated cost of $5 million.

- Sections 83, 45, and 63 (south to north) are three single, dead end lines that currently supply Lexington (and Waltham and Arlington). The Master Plan recommends that a loop connect the ends of the three lines so that they are then looped, and to extend a main from the end of Section 63, in Lexington, to Burlington. The Master Plan recommends that this be done in the FY26-32 period at an estimated cost of $10 million.

8.14 Southern Extra High Service

The Southern Extra High zone includes the Roslindale and West Roxbury sections of Boston, a portion of Brookline and six suburban communities to the south of Boston. This zone is supplied by water from Norumbega Covered Storage to the Southern High Mains via the City Tunnel and the Dorchester Tunnel. The Southern High Mains provide the suction for three pumping stations: Hyde Park, Newton Street and Reservoir Road. Hyde Park and Newton Street Pump Stations pump to the Bellevue standpipe No. 2 while Reservoir Road Pump Station pumps to the Singletree Tank owned by the Town of Brookline. In the event of a power failure or some other service disruption that takes Reservoir Road out of service, there is a PRV that opens automatically at the Newton St. Pump Station to supply the Singletree service area. The SEH service area has grown in the past several years with the addition of the partially supplied Town of Stoughton and the Dedham-Westwood Water District. As discussed below, this further exacerbates concerns about the lack of redundancy and limited storage in this pressure zone.

Figure 8-11



<u>Delivery System Condition and Ongoing Work</u>

Lack of redundancy has been the major issue within the SEH system. 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 Bellevue tanks consist of a newer 3.7 million gallon tank having a 400' elevation and an older 2.5 million gallon tank having a 375' elevation. The older tank stagnates since it cannot contribute unless there is a 25 foot drawdown on the higher tank. It has been valved off due to concerns that the stagnant water may accidentally be drawn back into service. There is a plan to use a recirculation unit to better maintain water quality within the older tank.

The volume of storage in the SEH is small in proportion to demand such that there is little storage dampening on a summer day. In past summers, there have been 35' fluctuations in tank levels over the course of a peak day. In addition, like the NIH system, the SEH service area has geographically expanded and the growth has been concentrated to the south meaning that the existing Bellevue tanks are at the upper periphery of the service area. Additional storage to the south (closer to the center of demand) would be of great benefit.


FIGURE 1
Southern Extra High Redundancy Section 111

At the November 2006 Board of Directors meeting, the Board approved inclusion of $900,000 in the CIP for development of a Concept Plan for the Southern Extra High service area. This study was completed and projects added to MWRA's capital budget to address the service area deficiencies. Prior to the completion of the Concept Plan, a short term measure to link Sections 77 and 88 together along University Avenue in Norwood was completed in 2008 as an immediate way to reduce the level of risk in the service area. As a result of Concept Planning, a new plan for redundancy was developed and designed and construction is expected to be complete in 2020. This provides an alternative to flow coming through Section 77. Future project phases will extend through 2037 and will address the continued need for storage in the SEH service. The funds for these future stages have been incorporated into MWRA's CIP. In addition, rehabilitation of the existing Sections 77 and 88 are included in the CIP to be done in the FY21-26 period at an estimated design and construction cost of approximately $7.3 million.

Pipe Installation

Other pipes in the service area are typically smaller diameter and not as old as in some other parts of the system. Sections 41 and 42 are unlined cast iron 20-inch pipe built in 1914 and Section 74 was built in 1951 of PCCP. These mains connect the Hyde Park Pump Station and the Newton Street Pump Station discharge pipeline (Section 77) to Bellevue Tanks 1 and 2. These pipes were initially installed prior to the construction of Bellevue 2 which is 25 feet higher than Bellevue 1. Thus, these pipes were not designed to withstand the higher pressures associated with the use of Tank 2 and the result was that the Pump Station could not be operated at full capacity without limiting the volume of water in Tank 2 which subsequently led to problems in meeting peak demands. To fix this, construction was completed in 2003 to replace Sections 41 and 42 with 8,000 feet of new 24-inch diameter pipe and to a portion of Section 74 with about 2,700 feet of new 24-inch diameter pipe. An additional 6,400 feet of Section 74 was rehabilitated.

The remaining small diameter unlined cast iron mains (Sections 30, 40, 44 and 39) range in age from 97 to 104 years old (with a small part of Section 44 only 49 years old). Sections 30 and 44 serve Boston and Milton. Section 39 provides suction to the Hyde Park Pump Station. These lines are tuberculated and have low C-values. Meters 55 and 68 are served by a single line and all of Milton cannot be fed off of Meter 55 due to tuberculation. Milton is installing a PRV to allow the Town's low service system to be fed off of the high system in the event that it is necessary. A parallel main would improve service to the meters.

Newton Street was one of the pumping stations included in the initial round of upgrades in the 1990's. Reservoir Road and Hyde Park Pumping Stations (built in 1936 and 1912 respectively) were included in the upgrade project completed since 2006. All major building systems were replaced and building and site refurbishment was done.

Recommended Projects: Southern Extra High

- A parallel line to serve meters 55 and 68 in Milton should be considered. The estimated cost is $5 million in the FY35-39 period.

8.15 Summary of Recommended Metropolitan System Improvements

- Two additional phases of valve replacement (Phases 10 and 11) are recommended at a cost of $10 million with a start date of FY30. In order to continue to increase the percentage of operable valves and to address valves that fail during the next 40 year period, work will need to continue using both the current CIP project and in-house design services. In addition, it is expected to take additional time to complete the blow off valve retrofit program. The mix of in-house and CIP work on all phases of the MWRA valves has been the key to operational success of the system.

- Staff should also continue to monitor the maintenance needs for the butterfly valves that have replaced gate valves in various parts of the system. Gate valves have routinely had an expected life in the MWRA system of 50-75 years and there is some concern that the butterfly valves may not be as resilient and more prone to breakage and misalignment. For the next master plan update, review this information and complete a revised life cycle cost analysis if appropriate.

- Staff recommends that an additional $25 million be added to the CIP in the FY43-58 period for the next cycle of pump station rehabilitation for those stations completed in 2010. This would include replacement of instrumentation, electrical and mechanical systems at the pump stations.

- Staff recommends that a pipeline study be done at a cost of up to $500,000 to assess long-term pipeline renewal needs based on MWRA specific information. The Master Plan proposes that this work be done in FY25.

- Given the $1.5 billion anticipated need for future community water main replacement/rehabilitation cost, staff recommend continued systematic investment in local water system infrastructure through MWRA financial assistance. For master planning purposes, staff recommend future fourth and fifth phases of the Local Water System Assistance Program be considered for funding in future CIPs. Each new phase is recommended to provide $250 million in interest-free loans (with 10-year loan repayments). Future Phase 4 financial assistance distributions are projected during the FY29-38 timeframe with loan repayments extending through FY48. Future Phase 5 financial assistance distributions are projected during the FY39-48 timeframe with loan repayments extending through FY58. Because loan distributions are offset by community repayments over time, the net CIP budget of each recommended future loan phase is zero. Prior to expansion of the current program, coordination with the MWRA Advisory Board is required to develop a recommendation for Board of Directors consideration.

- Design and Construction for replacement and rehabilitation of 5,000 linear feet of 36-inch pipe on Section 66 and replacement and rehabilitation of 5,000 linear feet of 30-inch pipe with 36-inch pipe on Old Mystic Main. Abandonment of 14,000 linear feet of 150 year old 24-inch cast iron main. This work was previously in the CIP as part of the Spot Pond Supply Mains project. The estimated cost is approximately $8.5 million and, in conjunction with the project below, should be scheduled in the FY45-49 period.

- Pipeline rehabilitation of the small diameter unlined cast iron along the coastline from East Boston north to Lynn. This includes Sections 54, 55, and 69. Although these cast iron pipes are not as old as some of the other pipes in this service area (1932 and 1951 for Section 69), the C-values associated with these pipelines are estimated to range from 67-73 indicating that the 20-24-inch mains are severely corroded. The cost of this work is estimated to be $16.3 million. This is recommended for the FY28-33 period.

- Pipeline rehabilitation of NHS Sections 33, 49, 49A, 50 in Revere and Malden at a cost of approximately $10 million. These are smaller diameter unlined cast iron mains ranging in age from 90 to over 100 years old in age and with C-values in the 60-70 range. Based on historical leak information and C-value, portions of Section 33 ranked in the top ten worst pipe segments in the analyses completed. This work is recommended for the FY 40-45 period.

- Rehabilitation of the major unlined steel mains that serve the Northern High. This includes NHS Sections 70 and 71 and 79 which consists of more than 10 miles of corroded pipeline in Stoneham, Saugus, Melrose and Lynn. Design and construction for rehabilitation of these mains could extend over a 10-20 year period and will need to be carefully phased. Moving forward with rehabilitation is expected to extend the life of the pipe and postpone need for more costly pipe replacement. The CIP currently contains a planning study at a cost of $1 million to evaluate the appropriate sequencing of work prior to proceeding with rehabilitation. It is possible that such a study could be completed in-house if staff resources are available. The estimated design and construction costs for the rehabilitation work is $35.7 million and should be initiated in the FY39-47 period.

- The Fisher Hill Pipeline was initially proposed to be rehabilitated with the Walnut Street Pipeline but was removed from the CIP. This project involves the design and rehabilitation of approximately 3,200 linear feet of 36-inch pipe; 3570 linear feet of 30-inch pipe; and 1,190 linear feet of 42-inch cast iron mains. These mains are all in excess of 100 years old and have limited carrying capacity due to tuberculation with C-values in the 58-60 range. The estimated cost for construction of this project is $3 million and this work is proposed for the FY40-44 period.

- Southern Spines Distribution Mains-Rehabilitation of Section 19. This project would include the design and construction of 13,000 linear feet of 48-inch main. Rehabilitation is expected to be cleaning lining and replacement of main line valves, blow-off valves and appurtenances. This project was previously dropped from the CIP due to budgetary concerns. However, Section 19 was constructed in the 1890's and has C-values in the 60's. The estimated cost for design and construction is approximately $8.5 million. This project is proposed to be started in FY40.

- A parallel line to serve meters 55 and 68 in Milton should be considered in conjunction with the above project. The estimated cost is $5 million in the FY35-39 period.

- NEH average daily demand is just shy of 11 mgd. If we include Park Circle, we have a total of 6 mg of storage in the service area. The Master Plan recommends up to 6 MG of additional storage be constructed in the FY42-48 period at an estimated cost of $5 million.

- Sections 83, 45, and 63 (south to north) are three single, dead end lines that currently supply Lexington (and Waltham and Arlington). The Master Plan recommends that a loop connect the ends of the three lines so that they are then looped, and to extend a main from the end of Section 63, in Lexington, to Burlington. The Master Plan recommends that this be done in the FY26-32 period at an estimated cost of $10 million.

Table 8-9
Water Master Plan - Metropolitan System
Recommended Projects

Last revision 12/28/18

Prioritization		Project Types	
1	Critical	NF	New Facility/System
2	Essential	RF/IC	Replacement Facility/Increase Capacity
3	Necessary	Opti	Optimization
4	Important	AP	Asset Protection
5	Desirable	Plan	Planning/Study

Line No	Priority	Project	Project Type	FY18 CIP Project No.	FY18 CIP Contract No.	Project Duration	Total Project Cost ($1000)	FY19-58 Planning Period Cost	Schedule	FY19-23	FY24-28	FY29-38	FY39-58	FY19-58 Planning Period Cost
										5 years	5 years	10 years	20 years	
		METROPOLITAN SYSTEM												
8.01	1	WASM 3 MEPA/Design/CA/RI	AP	628	68166_6539	11 years	13,740	13,740	FY19-29	6,528	6,212	1,000		13,740
8.02	1	WASM 3 Sliplining	AP	628	68170_6543	2 years	26,889	26,889	FY22-24	6,805	20,084			26,889
8.03	1	WASM 3 Rehab	AP	628	68171_6544	2 years	19,832	19,832	FY20-22	19,832				19,832
8.04	1	WASM 3 Rehab CP-3	AP	628	68172_6545	4 years	41,480	41,480	FY24-28		41,480			41,480
8.05	3	Phase 8 Valve Replacement - Design & Construction	AP	677	68330_7417 68300_7195	6 years	4,693	4,693	FY24-30		3,000	1,693		4,693
8.06	3	Phase 9 Valve Replacement - Design & Construction	AP	677	68331_7418 68307_7236	5 years	4,693	4,693	FY25-30		2,500	2,193		4,693
8.07	3	Pump Station Rehab Evaluation	Plan	704	75582_7525	2 yaers	500	500	FY20-21	500				500
8.08	3	Pump Station Rehab - Design & Construction	AP	704	75583_7526 75584_7527	6 years	19,700	19,700	FY22-28	821	18,879			19,700
8.09	3	Peabody Pipeline - Design & Construction	NF	618	60061_6893 60063_6895	3 years	17,497	17,497	FY19-22	17,497				17,497
8.10	3	NHS - Section 27 - All Costs - TA Easement/Survey/Construction	AP	692	68229_6809 68211_6712 68192_6589 67769_6333	7 years	1,170	1,170	FY19-26	27	1,143			1,170
8.11	3	NHS - Revere/Malden Section 53	AP	693	67790_6335	2 years	11,547	11,547	FY24-26		11,547			11,547
8.12	3	NHS - Section 99 Connection Construction - Easements/Permits	Opti	693	68258_6958	2 years	7,914	7,914	FY23-25	31	7,883			7,914
8.13	3	NHS - Section 56 Demo/Design & Construction	AP/Opti	693	75570_7536 75545_7454 75549_7486	5 years	13,253	13,253	FY19-25	3,503	9,750			13,253
8.14	3	Sections 53 and 99 - Design	AP/Opti	693	75548_7485	5 years	4,843	4,843	FY19-25	3,851	992			4,843
8.15	2	NHS - Sections 13 and 48 - Design & Construction	AP	693	75571_7602 75572_7603	5 years	12,900	12,900	CY25-30		10,000	2,900		12,900
8.16	3	New Connecting Mains CP3-Section 23 Design & Construction/Easements/Section 24, 47	AP	702	68115_6388 68112_6385 68119_6392	3 years	16,302	16,302	FY19-22	16,302				16,302

Table 8-9
Water Master Plan - Metropolitan System
Recommended Projects

Last revision 12/28/18

Prioritization

1 Critical
2 Essential
3 Necessary
4 Important
5 Desirable

Project Types

NF New Facility/System
RF/IC Replacement Facility/Increase Capacity
Opti Optimization
AP Asset Protection
Plan Planning/Study

Line No	Priority	Project	Project Type	FY18 CIP Project No.	FY18 CIP Contract No.	Project Duration	Total Project Cost ($1000)	FY19-58 Planning Period Cost	Schedule	FY19-23	FY24-28	FY29-38	FY39-58	FY19-58 Planning Period Cost
										5 years	5 years	10 years	20 years	
8.17	3	New Connecting Mains - Clean/Line Sections 59-60 - Construction/Easements	AP	702	68175_6547 68174_6548	6 years	8,691	8,691	FY19-26	25	8,666			8,691
8.18	2	Sections 25, 75, 59/60 Replacement - Design	AP/NF	702	68255_6955	6 years	2,697	2,697	FY19-26	2,055	642			2,697
8.19	2	Section 25 Replacement - Construction	AP	702	68256_6956	2 years	3,802	3,802	FY24-25		3,802			3,802
8.20	2	Section 75 Extension - Construction	NF	702	68350_7484	2 years	4,185	4,185	FY22-24	2,325	1,860			4,185
8.21	3	NEH Sections 34 and 45 - Design & Construction	AP	708	75528_7404 68162_6522	6 years	7,028	7,028	FY22-28	390	6,638			7,028
8.22	2	Cathodic Protection Metro System - Design & Construction	AP	712	68382_7611 68381_7610	7 years	56,307	56,307	FY21-27	7,831	48,476			56,307
8.23	3	Walnut Street Bridge - Construction	AP	713	60145_7483	2 years	800	800	FY22-23	800				800
8.24	3	Chestnut Hill Final Connection - Design & Construction	AP	719	68268_6995 68267_6982	6 years	15,133	15,133	FY24-29		14,133	1,000		15,133
8.25	3	Southern Spines - Sections 20 and 58 - Design/Construction/Easements	AP	721	68091_6297 68089_6296 68091_6298	6 years	18,650	18,650	FY22-28	14	18,636			18,650
8.26	2	Section 22 North - FP/EIR	Plan	721	68299_7155	2 years	1,000	1,000	FY19-21	1,000				1,000
8.27	2	Section 22 North - Design & Construction	AP	721	68298_7120 68235_6844	5 years	21,063	21,063	FY22-27	874	20,189			21,063
8.28	1	Sections 89/29 Redundancy - Design	NF	722	68252_6906	2 years	1,136	1,136	FY19-21	1,136				1,136
8.29	1	Sections 89/29 Redundancy Construction - Phase 2	NF	722	68283_7067	2 years	19,246	19,246	FY19-20	19,246				19,246
8.30	1	Sections 89/29 Redundancy Construction - Phase 1C	NF	722	68318_7478	1 year	1,806	1,806	FY19	1,806				1,806
8.31	2	Section 89/29 Rehab - Design & Construction	AP	722	68294_7116 68295_7117	4 years	19,874	19,874	FY19-23	19,874				19,874
8.32	2	NIH Storage - Design	NF	722	68316_7311	5 years	4,472	4,472	FY24-29		4,000	472		4,472
8.33	3	Section 8 Northern Low - Construction	AP	723	68095_6322	2 years	24,616	24,616	FY27-29		24,000	616		24,616

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Water Master Plan - Metropolitan System
Recommended Projects

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Prioritization	Project Types	
1 Critical	NF	New Facility/System
2 Essential	RF/IC	Replacement Facility/Increase Capacity
3 Necessary	Opti	Optimization
4 Important	AP	Asset Protection
5 Desirable	Plan	Planning/Study

Line No	Priority	Project	Project Type	FY18 CIP Project No.	FY18 CIP Contract No.	Project Duration	Total Project Cost ($1000)	FY19-58 Planning Period Cost	Schedule	FY19-23	FY24-28	FY29-38	FY39-58	FY19-58 Planning Period Cost
										5 years	5 years	10 years	20 years	
8.34	3	Northern Low Easements	NF	723	68094_6321	9 years	73	73	FY19-28	47	26			73
8.35	3	Section 37/46 Rehab - Design & Construction	AP	723	75529_7405 68262_6962	4 years	4,031	4,031	FY24-28		4,031			4,031
8.36	2	Section 57 Water & 21/20/19 Sewer - Design & Construction	AP	723	75610_7540 75611_7541	5 years	25,558	25,558	FY19-24	18,213	7,345			25,558
8.37	1	SEH Redundancy Phase 1 - Design	NF	727	53398_6453	4 years	3,115	3,115	FY19-22	3,115				3,115
8.38	1	SEH Redundancy Section 111 Phase 2 - Construction	NF	727	68555_7504	2 years	13,578	13,578	FY19-20	13,578				13,578
8.39	1	SEH Redundancy Section 111 Phase 3 - Construction	NF	727	68556_7505	2 years	19,000	19,000	FY19-21	19,000				19,000
8.40	2	SEH Sections 77/88 Rehab - Design & Construction	AP	727	68292_7112 68293_7113	5 years	7,280	7,280	FY21-26	690	6,590			7,280
8.41	2	SEH Redundancy Storage - Phase 2 Construction	NF	727	68308_7245	3 years	35,883	35,883	FY28-31		500	35,383		35,883
8.42	3	SEH Redundancy Phase 3 - Second Tank Design & Construction	NF	727	68312_7263 68311_7262	8 years	15,164	15,164	FY28-36		164	15,000		15,164
8.43	2	Section 80 Rehab - Design & Construction	AP	735	68250_6892 68249_6891	5 years	10,484	10,484	FY22-27	681	9,803			10,484
8.44	3	Walnut Hill Tank Rehab - Elevated Tank Repainting - Design	AP	766	75497_6832	5 years	3,348	3,348	FY19-24	3,348				3,348
8.45	2	Gillis PS and Cottage Farm Roof Replacement	AP	766	75500_6888	2 years	350	350	FY19-20	350				350
8.46	3	Generator Docking Station	AP	766	75508_7025	2 years	820	820	FY19-21	820				820
8.47	3	Covered Storage Tank Rehab - Design & Construction	AP	766	75524_7385 75553_7482	5 years	5,000	5,000	FY23-27	184	4,816			5,000
8.48	3	Di Tank Repainting	AP	766	75555_7601	1 year	3,871	3,871	FY19-20	3,871				3,871
8.49	3	Water PS Roof - Design & Consturction	AP	766	75558_7628 75556_7626	3 years	600	600	FY25-27		600			600
8.50	3	Bellevue 2 and Turkey Hill	AP	766	75559_7634	1 year	5,693	5,693	FY19-20	5,693				5,693

Table 8-9
Water Master Plan - Metropolitan System
Recommended Projects

Last revision 12/28/18

Prioritization

1 Critical
2 Essential
3 Necessary
4 Important
5 Desirable

Project Types

NF	New Facility/System
RF/IC	Replacement Facility/Increase Capacity
Opti	Optimization
AP	Asset Protection
Plan	Planning/Study

Line No	Priority	Project	Project Type	FY18 CIP Project No.	FY18 CIP Contract No.	Project Duration	Total Project Cost ($1000)	FY19-58 Planning Period Cost	Schedule	FY19-23	FY24-28	FY29-38	FY39-58	FY19-58 Planning Period Cost
										5 years	5 years	10 years	20 years	
8.51	3	Steel Tank Improvements - Construction	AP	766	77552)_7493	2 years	11,680	11,680	FY22-23	10,080	1,600			11,680
		SUBTOTAL - Existing - Metropolitan System					**592,987**	**592,987**		**212,743**	**319,987**	**60,257**	**0**	**592,987**
8.52	3	Valve Replacement Phases 10 and 11	AP	new		As Needed	10,000	10,000	FY30-58			2,500	7,500	10,000
8.53	3	Pump Station Rehab - Phase 2	A{	new			25,000	25,000	FY43-58				25,000	25,000
8.54	2	Pipeline Study	AP/Plan	new		1 year	500	500	FY25		500			500
8.55	3	Coastal Pipelines Rehab	AP/Plan	new		5 years	16,300	16,300	FY28-33			5,000	11,300	16,300
8.56	3	NHS - Sections 33, 49, 49A, 50	AP/Plan	new		5 years	10,000	10,000	FY40-45				10,000	10,000
8.57	3	NHS - Sections 70, 71, 79	AP/Plan	new		8 years	35,700	35,700	FY39-47				35,700	35,700
8.58	3	Fisher Hill Pipeline	AP	new		4 years	3,000	3,000	FY40-44				3,000	3,000
8.59	3	SEH Section 19	AP	new		5 years	8,500	8,500	F40-44				8,500	8,500
8.60	2	Parallel Line to Meters 55/68	NF	new		5 years	5,000	5,000	FY35-39			2,500	2,500	5,000
8.61	3	NEH Loop	NF	new		7 years	10,000	10,000	FY26-32		2,500	7,500		10,000
8.62	3	NEH Storage	NF	new		6 years	5,000	5,000	FY42-48				5,000	5,000
8.63	3	Section 66 - Old Mystic Mains	AP	new		5 years	8,500	8,500	FY45-49				8,500	8,500
		SUBTOTAL - Recommended - Metropolitan System					**137,500**	**137,500**		**0**	**3,000**	**17,500**	**117,000**	**137,500**
		SUBTOTAL - Existing and Recommended - Metropolitan System					**730,487**	**730,487**		**212,743**	**322,987**	**77,757**	**117,000**	**730,487**

9 Ancillary Services

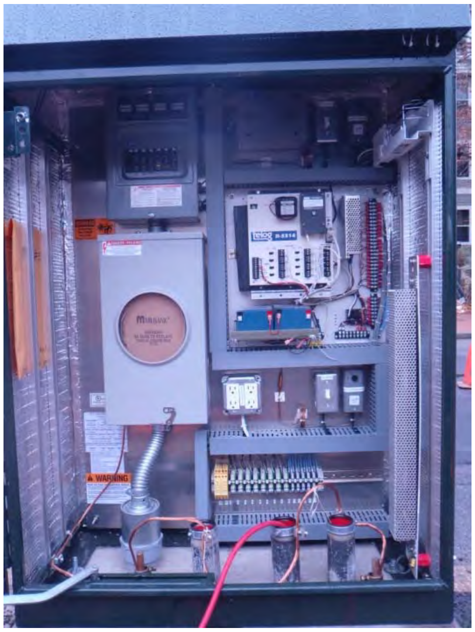
9.1 Chapter Summary

The operation and maintenance of the water supply and wastewater systems are supported by an array of processes, systems, and equipment. As an example these include metering equipment for flow measurement, telecommunications to monitor remote facilities, informational maps and records for locating existing underground mains and documenting changes to the system, laboratories for performing water quality tests and upgrades to equipment and facilities to address security needs. This chapter includes five specific support areas 1) Metering; 2) SCADA; 3) Laboratory Services; 4) Information Management; and, 5) Security. The first two areas (Metering and SCADA) are specific to the MWRA's water system. The latter three support functions apply to both the water and the wastewater systems and the discussions and recommendations for these functions (Laboratory Services, Information Management and Security) are also included in the 2018 Wastewater System Master Plan (see Chapter 13). The current conditions and needs of each functional group are discussed below along with corresponding recommendations for each group. Detail on wastewater SCADA and the wastewater metering system are provided in Chapter 12 of the Wastewater Master Plan.

9.2 Metering

There are essentially two kinds of meters, master meters and revenue meters. The approximately 68 master meters measure flow at key locations within the water transmission and distribution systems. Approximately 1/3 of these meters are tested every year with the entire system being tested within three years to ensure they are working properly. Water revenue meters measure delivered flow to the communities. There are approximately 172 water revenue meters. Each meter is comprised of a primary and secondary system. The primary flow device is the venturi tube. The secondary devices are the transmitters, above ground cabinet, data loggers and communications. As a general rule of thumb, the venturi tube should last at least 50- 100 years. During the meter modernization of the early 1990s, plastic insert venturi tubes were utilized at some 90 sites. Using this installation allows for cost effective replacement of these tubes in the future should a replacement become necessary. We continue to replace older venturi tubes, some as old as 100 years, with these newer insert venturis as pipeline and other major rehabilitation projects take place. If a new community comes on-line, staff will put together an in-house design and construction project to install a new meter.

The secondary equipment, noted above and pictured below, does require upgrade and replacement every 10-15 years. All meter sites feature the latest d/p transmitter with a much improved accuracy over previous models. The communication equipment is currently cellular utilizing 1XRTT communication protocol. Once 4G equipment becomes available, staff will consider a replacement program throughout the system. The data loggers also need periodic replacement at an expected cost of approximately $750,000 – $1,000,000. The Master Plan costs include three cycles of replacement at $1,000,000 each during the FY28-58 period.



A key theme for metering is the need for periodic replacement of the meters to ensure the most accurate information is being transmitted back to the Authority. The role of new technology is a critical element in how the meters are managed and when they are replaced. The Authority strives to stay on top of new metering technology and anticipate new technology changes.

While electronic components are expected to last a minimum of ten years, Venturi tubes are expected to last at least fifty years. The tubes only become a problem when the inside becomes tuberculated, changing the calibration relationship. Significant meter rehabilitation work was done at the largest community meters by the MDC in the mid-1980’s but this work primarily involved the replacement of secondary equipment (new transmitters and steel chambers). In the early 1990’s, MWRA replaced the remaining 90 or so smaller community meters and for these, the Venturi tubes were also replaced leaving approximately 53 meters that were pre-1992. However, a number of Venturi tubes installed in 1903 remain in operation and the size and condition of these tubes is in question. Although 15 of the pre-1992 meters are included in other scheduled scopes of work, it may now be appropriate to initiate new contracts to replace the remaining meter equipment and Venturi tubes independent of other ongoing work. Replacing the remaining Venturi tubes will cost about $10 million. No funds are proposed at this time on the assumption that any necessary replacements would be completed as part of larger capital projects in those areas.

<u>Recommended Projects-Metering</u>

- Continuously review metering technology to stay abreast of changes to the technology.
- Proceed with meter and Venturi tube replacement already included within the scope of current pipeline and/or valve projects.
- Develop an asset protection program for water meter components for the duration of the planning period at an estimated cost of $8 million.
- Replace data loggers on an as needed basis through the FY28-58 planning period at a total estimated cost of $3 million.

Please refer to Chapter 12 of the 2018 Wastewater System Master Plan for a discussion of wastewater metering recommendations.

9.3 SCADA (Supervisory Control and Data Acquisition)

The SCADA system is a powerful process control technology used to monitor and control facilities and equipment locally and from a remote central location. It also provides a continuous record of facility operations. The SCADA system consists of four main components along with their software configurations and programs: 1) field instruments and equipment, 2) field programmable controllers, 3) communication and network devices and media, and 4) computer hardware and software. The Water SCADA System is maintained by MWRA staff.

The SCADA system has its genesis in the completion by staff in 1995 of a pilot project to automate the Reservoir Road Pumping Station. Now there are 61 water facilities on the SCADA system that are monitored and/or controlled. They include the Carroll Water Treatment Plant, the Ware Disinfection Facility, all the pump stations and their associate tanks, control valve chambers, reservoirs, and power generation facilities. The SCADA system makes extensive use of data radio and microwave radio communications to provide redundancy for critical signals and to provide long haul connections. The microwave system includes 8 high ground sites, such as MDC Hill in Southborough, that are not associated with water facilities but are used as relay points.

New water projects that will expand the SCADA system include the Wachusett Aqueduct Pump Station, Section 57 Control Valve, and to a lesser extent, the Brutsch Hydroturbine Project. Some of these projects will be installed and programmed by MWRA staff and others by contractors.

Over time, the SCADA system needs hardware and software upgrades. There has been a continual process of system upgrades and improvements through in-house and external projects using CIP and CEB funds. One example currently in progress is the in-house upgrade of the Brutsch Water Treatment Facility Main PLC including system programming and Human Machine Interface (HMI) Screen development. A recent upgrade lead by a contractor was the work under a task order to upgrade the field programmable controller at the Commonwealth Ave. East Pump Station. Another upgrade is a transition to a new Verizon communications technology that when coupled with in-house network and microwave modifications will provide more reliable communications for pump stations and critical valves to an enhanced backup Operations Control Center. Upgrades at the CWTP are also scheduled in the FY19 CIP for FY19-23 at a cost of approximately $9 million.

Recommended Projects-SCADA

- Evaluate the need for and timing of microwave radio replacement. This involves a mix of strategies including appropriate levels of spare parts, incremental upgrades, and larger contracted replacements. Examples of this approach include a recent staff installed microwave hop that replaced three other hops with older equipment that can now be retired, and a short term plan to replace the oldest microwave hardware at two western locations with CIP funds.

- Microwave towers should last approximately 75 years. The oldest towers in the SCADA system are on the Wastewater side and are scheduled to be replaced under the Headworks upgrade contracts. The Ward St tower is being retired and replaced with access to the top of the new Mass College of Art building. Continue to review and evaluate opportunities to replace towers or modify equipment locations as existing facilities age.

- Replace radio feed line and antennae by FY20 at an approximate cost of $1 million. Some of this work will be done incrementally.

- Replace radio equipment periodically on an as-needed basis. The Master Plan allocates $375,000 for this purpose in the FY19-58 period.

- Replace or upgrade Waterworks PLCs every 15-20 years or when a significant enhancement in security architecture is released. Replacement or upgrade costs will depend on the level of reconfiguration and reprogramming required. For planning purposes, an equipment upgrade cost of $18 million during the FY29-58 timeframe has been assumed. Some of this work may be done incrementally by in-house staff.

- Replace communications and network equipment on an ongoing basis as needed over the planning period (FY19-58) at an estimated cost of $400K.

- Integrate the use of wireless cellular communications for additional redundancy and low bandwidth applications.

- Regularly review available communications technology and update and replace equipment as new features are determined to be beneficial to MWRA operations or as existing equipment becomes obsolete or where vendor support is no longer available. An example of this would be to replace the existing serial communication protocol data radio with Ethernet communication protocol data radios.

- Constantly review our security stance and pursue required upgrades to achieve the designed protection.

Please refer to Chapter 12 of the 2018 Wastewater System Master Plan for a discussion of wastewater SCADA recommendations.

9.4 Laboratory Services

The Laboratory Services Section presented here is also presented in Chapter 13 of the Wastewater System Master Plan. All laboratory services costs programmed in the FY19 CIP and recommended for consideration in future CIPs are included only in the Water System Master Plan and not in the Wastewater System Master Plan so that there would be no double counting of overall costs.

MWRA’s laboratory services are client based. Clients include Deer Island, ENQUAL, TRAC Drinking Water Programs (including MWRA communities) and the Department of Conservation and Recreation (DCR). To accommodate the range of program needs, the geographic range of the MWRA system, and the types of samples to be analyzed requires MWRA’s Department of Laboratory Services to operate multiple laboratory facilities in Chelsea, Clinton, Quabbin, Southborough, and the Central Laboratory located on Deer Island.

Samples are generally taken by staff within various programs and submitted to the appropriate laboratory location for analyses in compliance with a range of regulatory requirements, though Laboratory Services collects regulatory samples at the Clinton and Deer Island Treatment Plants. For example, TRAC staff sample industrial discharges for permit compliance and ENQUAL Quality Assurance staff obtain samples from the Carroll Water Treatment Plant to ensure proper plant performance and compliance with federal and state drinking water regulations. To provide a sense of the magnitude of work, Laboratory Services analyzes more than 250,000 tests per year for MWRA programs and 43 MWRA member communities. The work for the communities allows MWRA to both ensure sampling consistency and to quickly recognize patterns of bacterial contamination that could potentially occur in the system. MWRA also analyzes all DCR’s reservoir and tributary samples in accordance with the MOU between MWRA and DCR.

Given the magnitude of the work effort, Laboratory Services continues to be proactive in identifying current and emerging issues. Staff safety while handling and analyzing samples must be protected through training and use of well-maintained laboratory equipment and facilities. Staff resources must be efficiently allocated to ongoing work while thinking ahead to potential regulatory changes that may occur, particularly the identification of emerging contaminants. The laboratory must work closely with other MWRA departments to try to anticipate which contaminants might actually become a problem in order to focus limited resources on the relevant contaminants. Key questions to be answered when considering which contaminants to gear up for include: (1) how probable is it that a particular contaminant will become a problem, (2) will the concern be short-lived or a long-term problem, and (3) how much training and equipment are involved? A second issue relative to staff resources is the need to staff laboratories seven days a week in order to accommodate various sampling needs and requirements. This is a particular issue at those laboratory sites with limited staff overall. Finally, data management tools must keep pace with both the laboratory work load and significant advances in technology. Projects identified for Laboratory Services address these challenges.

For example, in FY16-17 and continuing into FY19, MWRA has offered to test school lead samples for its member communities. This work was coordinated with a similar effort by MassDEP for non-MWRA communities. So far over 18,000 lead samples have been tested.

Facility needs generally include periodic reconfiguration of space for work efficiency or to adapt to new test and/or equipment requirements. This is of particular importance at the Central Laboratory where this issue is addressed jointly by Laboratory Services, Deer Island managers, Operations, and Finance. In addition, periodic replacement of analytical or safety equipment is necessary. Ventilation equipment is particularly critical in this regard. Fume hoods at the Central Laboratory are now recommended for replacement along with the rest of the HVAC system both to address worker safety and to preserve sensitive analytical equipment. The fume hoods in the metals preparation laboratory were replaced in FY12 because they had corroded due to acid used in metals tests. This is a recurring expense approximately every 15-20 years and would likely be folded into periodic lab renovation contracts.

Data management was addressed in 2009-2010 through the replacement of the 17-year old Laboratory Information Management System (LIMS). The benefits of a new LIMS are more automation, consolidation of data, and the ability to electronically report drinking water results to MassDEP. Any additional data management tools necessary to more fully utilize and interface with the updated LIMS system are identified and coordinated between MIS and laboratory staff.

Summary of Existing and Recommended Laboratory Services Projects

- Fume Hoods and HVAC Systems - In 2010, Laboratory Services and Deer Island Engineering staff concluded that the replacement of the Central Laboratory fume hoods and the Administration/Laboratory Building's HVAC system should be combined into the same design and construction contracts. DITP HVAC equipment replacement design, engineering services during construction, and construction to replace odor control and air handler equipment (including DITP laboratory fume hoods) is programmed in the FY19 CIP at a cost of $44.19 million during FY14-23. This project is carried as a DITP project in Chapter 6 of the Wastewater System Master Plan. This project is likely to present severe logistical issues for the Central Laboratory, though the design contractor has sequenced the laboratory portion of the work into 10 phases of a laboratory section at a time to avoiding the need to shut down large portions of the laboratory for extended periods of time. This will be supported by the use of two laboratory trailers to meet MassDEP laboratory certification requirements and operational needs. These contingencies were addressed during the design contract. The NTP is expected in FY19 and the construction is expected to take 3.5 years.

- Major Laboratory Instrumentation **-** For decades the trend in environmental laboratory testing has been to detect lower and lower concentrations of contaminants in small quantities of complex samples. Over the past 20 years, decisions have been made as new contaminants have emerged into prominence whether MWRA should perform this testing in-house or contract the work out. These decisions have been weighted by whether the contaminant is likely to be important in MWRA drinking water or wastewater, how many samples are likely to need to be tested, and how expensive or complex the laboratory instruments will be. For example, when MassDEP began regulating perchlorate in drinking water, MWRA decided to contract out the few required samples a year since perchlorate was unlikely to be detected in MWRA drinking water. As MassDEP and EPA continue to regulate more contaminants in drinking water and wastewater, it is likely that eventually MWRA will choose to purchase complex, and therefore expensive, laboratory instruments when the number or tests is likely to be large or the consequences of the testing critical to MWRA's mission. The CIP should continue to carry funding for major laboratory instrumentation, such as ICP-MS (inductively coupled plasma mass spectrometry for metals and high resolution GC-MS (gas chromatography-mass spectrometry) or LC-MS (liquid chromatography-mass spectrometry) for organics. For these types of major laboratory instrumentation, $1.0 million is programmed in the FY19 CIP and spending is projected in FY19-23. Through October 2018, $424,000 of this budget had been expended on major laboratory instrumentation. A budget should be continued for this at $1.0 million for each five years.

- Laboratory Facilities Renovations - Department of Laboratory Services staff, together with other MWRA Operations staff, should develop a system to efficiently and quickly reconfigure laboratory space to accommodate new sampling requirements or new equipment. This will allow the Laboratory to maintain high levels of efficiency with minimum disruptions to ongoing work. Laboratory Services staff should identify any technological changes or equipment that will assist in improving staff efficiency. The Central, Chelsea, and Southborough Laboratories are fairly new, while the Clinton and, in particular, Quabbin Laboratories are showing signs of age. A renovation of the Quabbin Administration Building, which houses the laboratory, is under discussion. A future project to facilitate renovations at all five laboratory facilities is recommended for consideration in future CIPs (planning, design, and construction) at an estimated total cost of $20.0 million over the 40-year planning period FY19-58 (this represents an average annual investment in the five laboratories of $500,000 per year).

- Laboratory Information Management System (LIMS), including Instrument Data Management and Electronic Laboratory Notebooks (ELN) – LIMS is vital to the laboratory operation to keep track of sampling schedules, quality control, and sample custody. MWRA began with LabWare LIMS version 5 and migrated to version 6 several years later. Eventually MWRA will need to adopt version 7, which will be a significant effort to demonstrate that all programs function correctly. This is funded though the MIS CIP budget. Advances in wireless tablet and handheld devices are becoming suitable for use in laboratories. Samples progress from the field to sample receiving, preparation, analysis, data processing, final reporting, and disposal. In the future, each staff in the laboratory is likely to have their own mobile device that is used for all tasks involving samples, instruments, and instrumentation which will increase productivity and reduce the need for paper records. In the mean-time, staff have begun an ELN project at the three Water Quality laboratories which should be completed in FY18. Then staff will pursue ELN opportunities at the remaining two laboratories. MassDEP certification and Massachusetts records retention laws requires that raw data from instruments be retained and accessible for up to 15 years. While the final results and a limited amount of raw data are transferred from the instruments' data systems to LIMS, the bulk of the raw data are retained and archived outside of LIMS. The current approach is labor-intensive, thus a more user-friendly, automated approach is needed. Laboratory Services has identified a need for this type of system as part of the MIS CIP budget.

9.5 Information Management

The Information Management Section presented here is also presented in Chapter 13 of the Wastewater System Master Plan. All information management services costs programmed in the FY19 CIP and recommended for consideration in future CIPs are included only in the MIS Five Year Strategic Plan (MIS Plan) and not in the Water System or Wastewater System Master Plans. However, water mapping and an update to MWRA's hydraulic model of the distribution system are also further discussed in the Water System Master Plan.

MWRA owns and operates many dozens of facilities, miles of tunnels, interceptors and pipelines, dams, treatment facilities and thousands of ancillary structures (manholes, valves, meters etc.). This results in an extensive number and range of documents and records to be maintained and continually updated. Tools for organizing and accessing this information are critical to allow information to be accessed both quickly in emergency situations and in an organized manner to facilitate long-term rehabilitation and replacement of MWRA assets and to design new system components. Information must also be available to document permit or regulatory compliance, protect MWRA assets from damage by outside contractors or utilities, and for responding to litigation, if necessary. Given decreased staffing levels, it is important that procedures and tools for information management be developed and used to facilitate access to the most accurate information in the most efficient manner. This includes the need to ensure that "baseline" information systems at MWRA are brought up to date and include all of the agency's current information and, equally important, that subsequent updates can be systematically added both to the baseline and to all of the other MWRA databases that rely on that baseline information.

In March 2012, MWRA completed a MIS Five Year Strategic Plan ("MIS Plan"). This MIS Plan was a result of conducting a baseline analysis of IT best practices compared with actual MWRA IT operating conditions, identifying the future needs of the business and developing a target state for technologies, and developing a set of programs and plans to meet those needs. Program initiatives were identified within four areas: 1) Technology Infrastructure Program; 2) Application Improvement Program; 3) Information Security Program; and, 4) IT Management Program. The analysis of current water and wastewater information management issues and recommendation are made within the context of the MIS strategic planning efforts. From the four areas identified in the MIS Plan, of greatest relevance to water and wastewater system master planning are those identified under Application Improvement Programs.

An important recommendation from the MIS Plan was that the Authority implement an Enterprise Content Management (ECM) program which would "address the organization's dependence upon paper records, support records management activities, improve access to information, streamline work flows, and replace several existing departmental-level solutions." ECM is an umbrella term which among other things includes document management, records management and work-flow management activities. These endeavors are particularly relevant to MWRA's water and wastewater record drawings, mapping and modeling, and work order management using Maximo. These information management areas are detailed in the subsections below.

Record Drawing Management

Record drawings are a major category of information maintained by MWRA and provide the basis for MWRA's GIS-based mapping and modeling systems. Authority record drawings exist on hardcopy and film, and are located in the Records Center, as well as at a number of MWRA and DCR facilities. A survey of these locations estimates the total number of drawings referencing MWRA infrastructure at 75,000. A subset of 60,000 of those drawings has been electronically scanned to the network. Record drawings at these locations vary from complete sets on MWRA managed contracts, to incomplete sets on pre-MWRA contracts, and partial sets for others. Design Information Systems Center (DISC) staff from the Engineering Department are involved in a review of these drawings in order to secure the latest revision for MWRA use. Drawings secured by DISC are chronicled in a number of pre-MWRA logbooks, recent departmental databases, and/or the Authority-wide document control system.

Organized drawing collections include the Records Center drawing archive, Chelsea water and sewerage microfilm archive, Deer Island (the Technical Information Center–TIC), the Western Operations files, Metro Operations files, and the Wastewater Engineering Unit compilation of recent construction projects, along with other miscellaneous collections. When a request for record drawings is made by staff or by outside consultants or contractors, staff search these sources first. InfoStar, acquired through the Boston Harbor Project, is used as the indexing tool. InfoStar requires replacement since the product is obsolete and there is no vendor support. Newer technology would provide improved efficiency and management control. Extensive documentation of current practices and procedures for processing record drawings, shop drawings, specifications, field sketches, etc. must be completed to ensure that any new system will thoroughly meet Authority needs.

In addition to proper management of records previously developed, there remains concern about missing or inaccurate records and the continued maintenance of multiple databases. As ECM programs are put in place, it will be critical to simultaneously begin to determine what records are missing or inadequate and institute projects to obtain the best available information. As an example, a preliminary review of water system GIS information indicates that approximately 120 record drawings and approximately 250 detail records are missing, incomplete or require updating. In addition, as an ECM approach is developed, historical issues such as non-standardized nomenclatures or lower/upper case differences, different data formats (Access v. Excel as an example) and variability in data collected for projects should be addressed. Mechanisms to efficiently update information so that the updated information is simultaneously available to all users should also be addressed. A broad based group of Authority staff familiar with the Authority's business practices and with both the current uses of these sources of information should be convened by MIS staff to ensure that these issues are addressed. Consultant assistance may be required in the development of missing information.

Current Projects-Records Management

- The Document Control System Software Replacement project has been folded into the Enterprise Content Management CIP project for consistency with the MIS Strategic Plan. Work is scheduled for FY19-20.

Mapping and Modeling

MWRA sewer and water infrastructure data is created from Record Drawings and Detail Records and stored in GIS. GIS is then used to update the hydraulic model. A change in the field brought about by a capital improvement or an in-house project causes a chain reaction of updates: record drawings and detail records need to be updated and finalized, then submitted to GIS so the GIS and the hydraulic model can be updated. An up-to-date GIS and hydraulic model facilitate flow of accurate information during emergencies, future project planning, and even master planning efforts. Thus, many of the recommendations for ensuring updated mapping and modeling data are the same as for ensuring that accurate record drawing information is available.

Program initiatives under the MIS Plan's Application Improvement Program address GIS Applications and Integration. GIS use at the MWRA has increased exponentially over the years for water and wastewater site and routing studies, environmental analyses, hazard mitigation analyses, real property applications and litigation, and many other scientific, environmental and engineering uses. It also has the potential to "spatially enable" other Authority applications including programs such as sewer inspections, PIMS, expanded Maximo functionality and others. The MIS Plan recommends that an agency-wide GIS strategic plan be developed which would identify organizational roles and responsibilities, project priorities and processes for updating the GIS and keeping the data current. Programmed in the FY19 CIP is $350,000 for this project with work scheduled in FY20 to complete the project with expenditure of the remaining $328,000.

Although it is not solely related to mapping and modeling, the MIS Plan also identifies Mobile Integrations as another initiative. The relationship to MWRA's GIS system and to mapping and modeling efforts is that immediate data entry at the source will help to update system information in the timeliest fashion so that subsequent use of that information is accurate. In addition, it can be noted when previously mapped information is determined in the field to be inaccurate.

MWRA's Planning Department within the Operations Division manages the use of the water and wastewater hydraulic models. The water system model is schedule to be updated. Changes in model capability since the initial model was developed are significant and MWRA has much better information on the system and these factors will improve MWRA's ability to model a range of scenarios for various projects.

Current Projects: Mapping and Modeling.

- The Distribution Systems Facility Mapping Records Development project is currently in the CIP and work is projected to start in FY20. This project is designed to develop or update record drawings and detail records for critical areas within the water distribution system where accurate records do not currently exist. It is anticipated that the initial contract will help to establish parameters for record drawing recording and updating. This would be followed by another contract to target selected areas of the water system where as built information has not been developed. The cost of these two contracts combined is approximately $1.263 million during FY20-23.

- A contract to update and calibrate the hydraulic model is scheduled to commence in FY20 with an anticipated budget of $500,000.

Work Order Management-Maximo

Maximo is currently used as a work order maintenance system and it is designed to provide the planning function for the Maintenance Group. The Work Coordination staff use MAXIMO for planning and scheduling work and reporting on labor utilizations hours and percentage of work orders completed. MWRA staff also use MAXIMO to manage asset repair costs and to evaluate that cost in the determination of further equipment repair or replacement. The data are also used for specialized analyses.

Use of Maximo is always being reviewed and refined. The MIS Plan recommended the migration to Maximo Version 7.5, acquisition of additional modules and richer integrations, reconfiguration, improvements to work flow and reporting and business process improvements to exploit the added functionality. Maximo upgrades are scheduled to be completed in FY19. The upgrade to Version 7.5 will eliminate the need for some in-house developed applications, will provide users a more fully integrated solution, and redundant entries will be eliminated. The added functionality of the updated version will also allow for future integrations, particularly with GIS.

Pretreatment Information Management System

Another application improvement program identified in the MIS Plan with relevance to wastewater operations is the proposed enhancement to the existing Pretreatment Management System (PIMS). This package is used by TRAC to monitor industrial pretreatment permits, inspections, sampling, and enforcement activities for MWRA’s 195 Significant Industrial Users and 1,250 permitted facilities. PIMS integrates with MWRA’s Laboratory Information Management System which provides the results of samples. According to the MIS Plan, this enhancement program will assess the current state of PIMS implementation with the intent of developing a plan to address both existing functional issues and also to comply with new regulatory requirements. This project is programmed in the FY19 CIP at $3.550 million.

9.6 Security

The Security Section presented here is also presented in Chapter 13 of the Wastewater System Master Plan. All security costs programmed in the FY19 CIP and recommended for consideration in future CIPs are included only in the Water System Master Plan and not in the Wastewater System Master Plan so that there would be no double counting of overall costs. In addition, costs embedded in the MIS budget are not included.

MWRA’s investment in security for water and wastewater pipelines and facilities, as well as, the Authority’s information systems, has increased significantly over the past seventeen years. Since

2001, MWRA has invested approximately $9.0 million in security related upgrades specific to security equipment and installation projects. Additional funds have also been expended that were included within individual capital projects for new or rehabilitated facilities. A detailed description of MWRA security measures is not included in the Master Plan due to the sensitive nature of the topic. In general, MWRA has been evaluating and ranking facilities and locations with respect to the critical nature of service delivery for each site. As appropriate, effective security improvements are planned, scheduled, and constructed. In general, MWRA's security improvements include:

- Gate and signage upgrades to limit access in specific areas and to denote areas where the public is welcome;
- Access card readers at facilities to monitor entry;
- Continuous intrusion alarm monitoring;
- Video camera monitoring of key locations;
- Central monitoring of data and alarms for all facilities;
- Automated water quality monitoring;
- Planning and coordination with state and local police, FBI and DHS;
- Planning and drills for incident response; and,
- Contaminant monitoring within the water system.

While much of the obvious security work has focused on MWRA's physical assets and the ability to monitor access and potential physical intrusions; as these measures have been implemented, the focus has shifted towards other types of intrusions. Cyber security has continued to grow in importance and MWRA's ability to effectively monitor and combat attempts to access MWRA systems is a significant priority of both MWRA's MIS staff responsible for the business network and Operations staff responsible for SCADA and PICS. Many of these costs are embedded in the Operations and MIS capital and CEB budgets. Recognizing the important role that employees play in cyber security, there is ongoing annual awareness training for all staff and advanced training for technical staff.

<u>Current Projects-Security</u>

- Additional expenditures under the Security Equipment and Installation project are included in the FY19 CIP at $1.963 million during FY19-23. This project will continue to upgrade security measures for water and wastewater facilities.

- Information systems security is an integral part of the MIS Strategic Plan. MIS security related projects including Information Security Protection Infrastructure Upgrades and Electronic Security Plan Implementation are combined under the Information Security Program and are budgeted in the FY19 CIP at $2.045 million and scheduled during FY19-23.

Table 9-1
Water Master Plan - Ancillary Services
Recommended Projects

Last revision 12/28/18

Prioritization		Project Types	
1	Critical	NF	New Facility/System
2	Essential	RF/IC	Replacement Facility/Increase Capacity
3	Necessary	Opti	Optimization
4	Important	AP	Asset Protection
5	Desirable	Plan	Planning/Study

Line No	Priority	Project	Project Type	FY18 CIP Project No.	FY18 CIP Contract No.	Project Duration	Total Project Cost ($1000)	FY19-58 Planning Period Cost	Schedule	FY19-23	FY24-28	FY29-38	FY39-58	FY19-58 Planning Period Cost
										5 years	5 years	10 years	20 years	
		ANCILLARY SERVICES												
9.01	2	Meter Vault Manhole Retrofits - Design and Construction	AP	766	75490_6689 75550_7479	4 years	1,844	1,844	FY20-23	1,836	8			1,844
9.02	3	Water Meter Upgrades - Replacement	AP/Opti	766	75554_7542 75536_7453	6 years	1,200	1,200	FY19-24	1,164	36			1,200
9.03	3	Waterworks SCADA/PLC Upgrades	AP/Opti	753	75310_5218	13 years	2,997	2,997	FY19-31	1,400	1,400	197		2,997
9.04	2	CWTP SCADA Upgrades - Design and Construction	AP/Opti	753	75630_7581 75631_7582	4 years	9,000	9,000	FY19-23	9,000				9,000
9.05	2	Major Lab Instrumentation	AP	881	95795_7632	5 years	1,000	1,000	F19-23	1,000				1,000
9.06	3	Records Development	Opti	763	75484_6525	3 yaers	763	763	FY21-24	663	100			763
9.07	3	Update Record Drawings	Opti	763	75600_7489	1 year	500	500	FY20	500				500
9.08	2	Update Water Hydraulic Model	Opti	763	75650_7613	1 year	500	500	FY20	500				500
9.09	2	Security Equipment and Installation	Opti	881	92374_6760	5 years	1,963	1,963	FY19-23	1,963				1,963
		SUBTOTAL - Existing - Ancillary Services					**19,767**	**19,767**		**18,026**	**1,544**	**197**	**0**	**19,767**
9.10	3	Water Meter Asset Protection	AP	new		AS Needed	8,000	8,000	FY24-58		500	2,500	5,000	8,000
9.11	3	Data Loggers	AP/Opti	new		As Needed	3,000	3,000	FY19-58		500	500	2,000	3,000
9.12	3	Waterworks SCADA/PLC Upgrades	AP/Opti	new		Ongoing	18,000	18,000	FY29-58			6,000	12,000	18,000
9.13	2	SCADA Radio Feed Line and Antenna	AP/Opti	new		1 year	1,000	1,000	FY20	1,000				1,000
9.14	3	Radio Equipment	AP	new		As Needed	375	375	FY19-58	25	50	100	200	375
9.15	3	Networking Communications Equipment	AP	new		As Needed	400	400	FY19-58	50	50	100	200	400
9.16	2	Major Lab Instrumentation	AP	new		35 years	7,000	7,000	FY24-58		1,000	2,000	4,000	7,000
9.17	3	Laboratory Renovations	AP	new		40 years	20,000	20,000	FY19-58	2,500	2,500	5,000	10,000	20,000
		SUBTOTAL - Recommended - Ancillary Services					**57,775**	**57,775**		**3,575**	**4,600**	**16,200**	**33,400**	**57,775**
		SUBTOTAL - Existing and Recommended - Ancillary Services					**77,542**			**21,601**	**6,144**	**16,397**	**33,400**	**77,542**

10 Energy Management

10.1 Chapter Summary

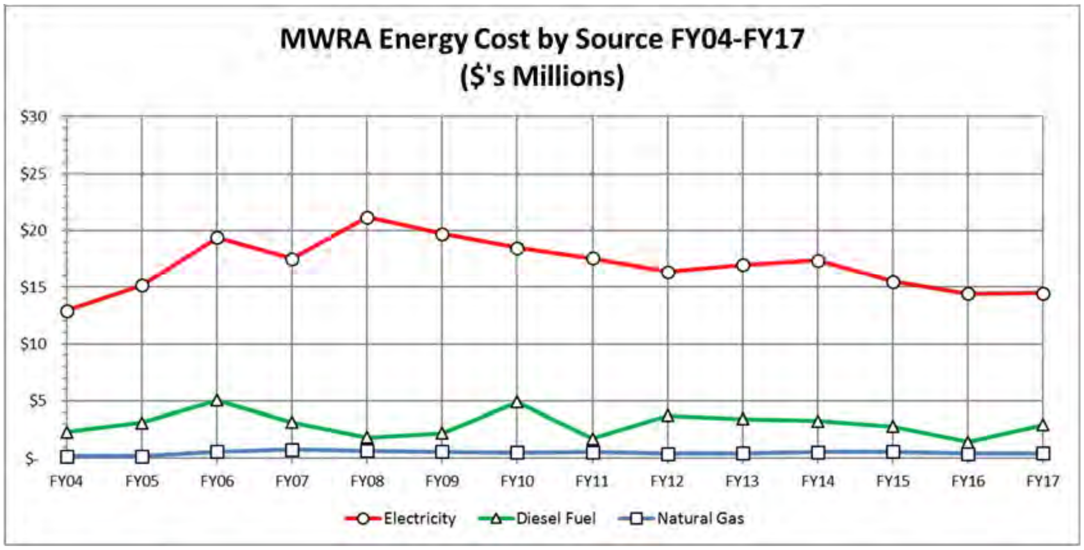
The operation and maintenance of MWRA's water supply and wastewater systems are supported by an array of processes, systems, and equipment. In this chapter, energy management at MWRA is discussed. The discussion and recommendations have been included in both this chapter of the 2018 Water System Master Plan and also as a part of Chapter 13 of the 2018 Wastewater System Master Plan. This chapter discusses overall energy use and management at MWRA; production and use of renewable energy; demand and supply-side initiatives; other sustainability efforts; greenhouse gas inventory work and recommendations for future efforts.

10.2 Energy Management

The Energy Management Section presented here is also presented as Chapter 13 of the 2018 Wastewater System Master Plan. Any energy management costs programmed in the FY19 CIP and recommended for consideration in future CIPs are included only in the Water System Master Plan and not in the Wastewater System Master Plan so that there would be no double counting of overall costs.

The MWRA's Deer Island Treatment Plant (DITP) is one of the largest wastewater treatment plants in the world. Along with DITP, MWRA also operates large potable water distribution and sewer collection systems; altogether making MWRA a large energy user in Massachusetts. The cost of powering multiple facilities makes up a significant portion of MWRA's direct expenses. MWRA's total electricity usage[1] in FY17 (for both water and wastewater systems) of 188,300,000 kWh (electricity only) is equivalent to approximately 17,000 homes[2]. MWRA also used 514,580 therms of natural gas in FY17. Energy costs ranged from \$15.4 million (8.9% of total direct expenses) in FY04 to \$17.9 million (7.9% of budget) in FY17 (due in part to the addition of major new facilities including the Carroll Water Treatment Plant and to the varying price of energy). Spending temporarily escalated to \$26 million (13.8% of directs) in FY06 due to the spike in energy costs subsequent to Hurricane Katrina, highlighting the volatility of energy prices. MWRA is also impacted on the wastewater side by weather patterns with major rain events driving energy consumption higher. For these reasons, the MWRA has reinforced efforts to aggressively manage energy usage and costs as an important part of MWRA's overall rates management strategy.

1 Demand vs usage – Demand is the total power needed to run MWRA's facilities. "Purchased" or "procured" energy is that energy not produced on site. Demand (-) purchased = on site generation.
2 In 2016, the average annual electricity consumption for a U.S. residential utility customer was 10,766 kWh. https://www.eia.gov/tools/faqs/faq.php?id=97&t=3



Notes:

- Significant increases in diesel fuel and electricity prices in FY06 to FY07 due to Hurricane Katrina.
- Significant increases in electricity prices again in FY08-FY10 due to market volatility was offset by declining purchases due to self-generation and energy-efficiency projects.
- Diesel fuel purchases increased in FY10 due to extensive CTG use during spring storms.

While MWRA's energy initiatives have focused on all energy sources, the major emphasis has been on reducing costs for electricity since it accounts for over 80% (in FY17) of the energy spending.

Strategies are generally broken into demand-side strategies and supply-side strategies. Demand-side strategies focus on opportunities to implement additional energy conservation measures and maximize the use of existing and potential new base-load self-generation assets to reduce or offset MWRA's need for purchased energy. Supply-side strategies include efforts to focus on reducing energy costs through the optimization of competitive energy supply contracts while maintaining a balanced energy portfolio. Other supply-side initiatives include continued evaluation of the operational and economic feasibility of enrolling back-up generation assets in load reduction programs and evaluating opportunities to shave peak demand, thereby reducing electricity demand charges.

In September 2016, Governor Baker issued *Executive Order 569 – Establishing an Integrated Climate Change Strategy for the Commonwealth*, an order that lays out a comprehensive approach to further reduce greenhouse gas emissions, build a more resilient Commonwealth for future generations, and safeguard residents, municipalities and businesses from the impacts of climate change.

Massachusetts has also incorporated Clean Energy Standards ("CES"), effective calendar year 2017. The CES works in tandem with the Renewable Portfolio, with the intention of increasing the percentage of procured energy to include renewable power. Additionally, Massachusetts promulgated the Clean Peak Standards ("CPS") in July 2018, which further adds the clean energy requirement to procured load, but focuses on peak demand hour consumption.

The new Order ensures that Massachusetts will continue to lead by example and collaborate across state government to reduce greenhouse gas emissions while building resiliency within government operations. The Order also directs the Executive Offices of Energy and Environmental Affairs and Public Safety and Security to lead the development and implementation of a statewide comprehensive climate adaptation plan that will provide a blueprint for protecting the built and natural environment of the Commonwealth, using the best available data on existing and projected climate change impacts.

Governor Baker's Executive Order 569 mirrors the earlier 2007 Executive Order, *Executive Order 484 – Leading by Example – Clean Energy*, which directed state agencies to make strides in energy conservation, develop and use power from renewable sources, and reduce greenhouse gases. Progress was to be tracked and specific targets were set.

The sections below discuss MWRA's work to implement: (1) renewable energy projects, (2) demand-side management programs, (3) supply-side management programs, (4) other sustainability initiatives, (5) Greenhouse Gas Inventory, and (6) recommendations for future work.

10.3 Renewable Energy

Consistent with 2007 Executive Order 484, MWRA has made a priority of siting new renewable energy projects at as many facilities as economically feasible and continues to aggressively seek out any available grant and loan funds to improve project paybacks. Each renewable project is reviewed on a case-by-case basis to evaluate the reasonableness of payback periods (including the impact of grants and rebates).

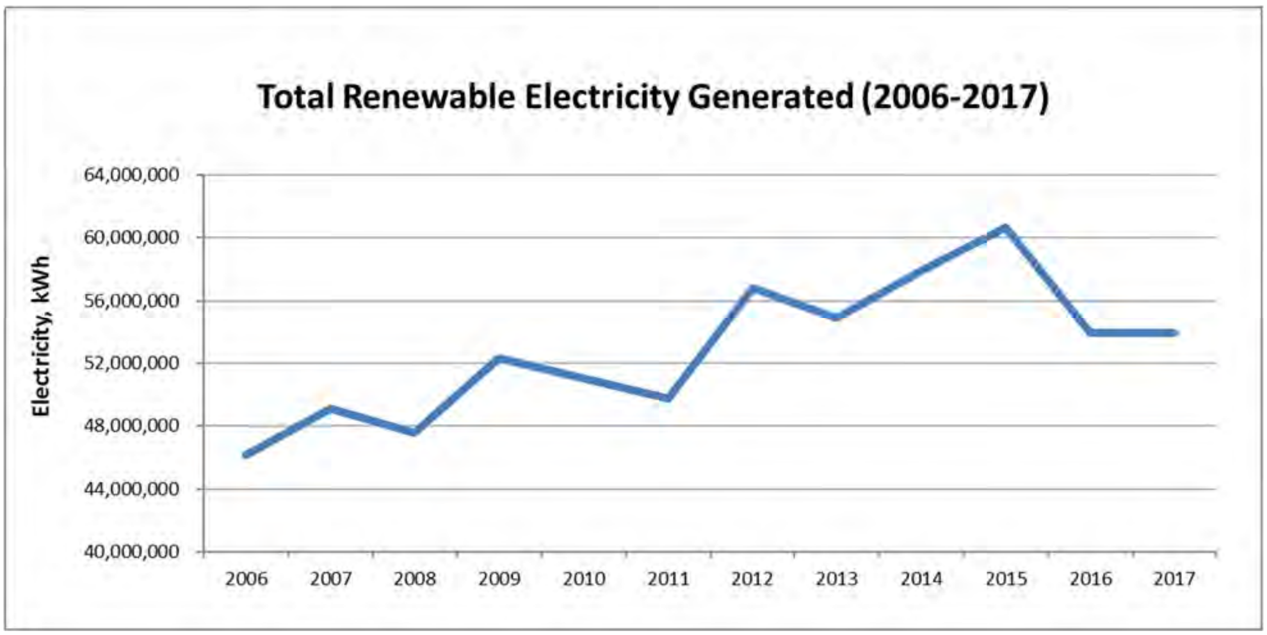
The Quabbin Reservoir supplies water to the metro Boston region from a high elevation (approximately 526 feet). The MWRA is able to capture energy at two hydroelectric facilities, Oakdale and Cosgrove, as the water travels downhill from western Massachusetts to the Metro Boston area. Hydropower is also generated at the Loring Road Covered Storage Facility as water is directed from a higher grade-line into the storage tanks which establish the grade-line of MWRA's Low Service Area. This serves as a more efficient way to dissipate energy and provide a steady flow rate to the tanks. Hydropower generation was also incorporated into the design of facilities at Deer Island to capture energy as flows drop into the outfall shaft and into the outfall tunnel following treatment.

MWRA has also recently finished the Hatchery Pipeline and Hydroelectric project that consists of a water pipeline which taps raw water off of MWRA's Chicopee Valley Aqueduct (CVA) just prior to the Brutsch Hydropower Facility and conveys six million gallons per day of cooler water from deep in the Quabbin Reservoir through a hydropower turbine/generator on the grounds of the Brutsch Hydropower Facility, downstream 4,400 feet to the State's McLaughlin Fish Hatchery. The project has multiple environmental benefits besides operational advantages to the Hatchery. It is an important green energy initiative, since not only does MWRA generate hydropower, the

Hatchery's electrical demand associated with pumping water from the Swift River has been eliminated under typical conditions.

Wind energy is captured with turbines at Deer Island and the Charlestown Pump Station. Solar electric panels have been installed at several locations on Deer Island and at the Carroll Water Treatment Plant.
The majority of renewable energy generation comes from methane gas captured from sludge digestion at DITP. The methane generated from the sludge digestion process is collected and used in Deer Island's on-site power plant to create steam that supplies hot water and heat for the facility. This results in the avoided purchase of over 5 million gallons of diesel fuel each year (to heat the facility). The steam is also run through a steam turbine generator that produces electricity, approximately 30 million kWh a year. This system alone generates over 20% of the electricity needed at the Deer Island Treatment Plant.

Agency-wide green power production has increased from 46.1 million kWh in calendar year 2006 to 53.9 million kWh in 2017, an increase of 16.8 percent as shown in the graph below. MWRA's renewable energy generation of 53.9 million kWh (not including the thermal value of digester gas on Deer Island) is equivalent to about 5,000 homes[3]. This is similar to MWRA service area towns the size of Wilmington, Ashland, Bedford, and Swampscott. MWRA continues to look for additional opportunities for renewable energy within the water and wastewater systems.



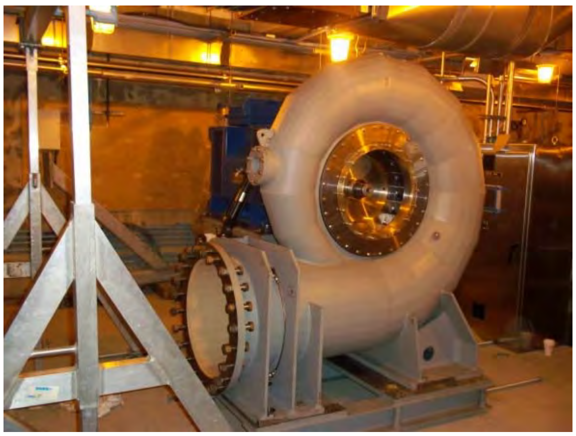
3 In 2016, the average annual electricity consumption for a U.S. residential utility customer was 10,766 kWh. https://www.eia.gov/tools/faqs/faq.php?id=97&t=3

Wind – MWRA has three operating wind turbines: two 600kW at DITP, and one 1.5 MW at Charlestown Pump Station. These three turbines generate approximately 3.5 million kWh per year and provide an average annual savings and revenue of about $530,000 (The savings and revenue value does not include RPS REC revenue).

Solar – Solar photovoltaic systems are currently installed at Deer Island on the roofs of the Residuals/Odor Control, Maintenance/Warehouse, and Grit Buildings (on the ground in the south parking lot). A system is also located on the grounds at the Carroll Water Treatment Plant. The solar photovoltaic systems represent over 1.2 MW of capacity and produces approximately 1.4 million kWh per year of electricity, providing average annual savings and revenue of $166,000 (the savings and revenue value does not include RPS REC revenue). Future solar projects are being considered with the start of the new SMART program in 2018.

Wachusett Aqueduct Pumping Station solar will be a roof and ground mounted array of 93kW capacity (photo at left in October 2018).

Hydroelectric - MWRA has a long history of using hydroelectric energy and continues to look for opportunities to capture the energy of water as it moves from higher to lower elevations. Hydroelectric facilities are currently located at Deer Island, Loring Road, Oakdale, Cosgrove, and Brutsch Hydropower Facility. These facilities represent over 8 MW of capacity and will produce about 23 million kWh of electricity per year with projected annual savings and revenues of over $1,800,000.



Recent Progress in Hydropower - Construction on the Hatchery Pipeline and Hydroelectric Project, a 20-inch water pipeline running from the MWRA's Brutsch Hydropower Facility in Ware to the McLaughlin Fish Hatchery in Belchertown was completed in 2017. The project includes a 65 kW hydropower facility to capture excess energy as water is conveyed from the higher reservoir elevation to the pipeline take-off at the Chicopee Valley Aqueduct. The water in the pipeline replaces the use of river water and flows by gravity, thereby eliminating the energy used to pump water from the river. This reduces the hatchery's electrical demand by an estimated 588,000 kWh annually. Ultimately, after circulating through the hatchery's raceways and treatment, the roughly six million gallons of water each day is discharged into the Swift River. Because of the multiple environmental and operational benefits of this project, the Massachusetts Division of Fisheries and Wildlife and the Massachusetts Department of Fish and Game have joined the MWRA in sponsoring this project. The hydropower component, which is projected to export 440,000 kWh to the grid, attracted two separate grants – one from the Massachusetts Clean Energy Center, and the other from the Massachusetts Executive Office of Energy and Environmental Affairs.

Methane - The capture of methane from the digesters was included in the original design contract of the Deer Island Treatment Plant. Co-generation at the Deer Island Thermal Power Plant (capacity of over 6 MW) using methane saves MWRA approximately 5 million gallons per year in annual fuel oil purchases (to heat the digesters and Deer Island buildings). The Power Plant Steam Turbine Generator at Deer Island allows MWRA to use steam from the methane powered boilers to produce electricity (valued at about $2.5 million in FY17). In addition, methane is a potent greenhouse gas; therefore, its capture and use significantly reduces MWRA's carbon footprint. If fuel oil had been used for heating instead of digester gas for the period of 2006-2016, there would have been a net additional 591,645 metric tons of CO_2e emissions. This is equivalent to 1.45 billion miles driven by an average passenger vehicle, or the carbon sequestered by over 696,000 acres of U.S. forests in one year - a land mass about twelve times that of the Boston area.[4] An engineering study is planned to start in FY18 to optimize the use of methane gas production and overall CHP efficiency (see Deer Island section for more details).

List of all MWRA Renewable Electricity Generation Facilities and Rated Capacities

Facility	**Rated Capactiy**
Methane	
Deer Island Steam Turbine Generator	18 MW
Deer Island Backpressure Steam Turbine Generator	1 MW
Hydro	
Cosgrove Hydro	2 @ 1.7 MW
Deer Island Hydro	2 @ 1 MW
Loring Rd Hydro	200 kW
Oakdale Hydro	3.5 MW
Brutsch Facility Hydro	65 kW
Solar	
Carroll Water Treatment Plant Ground Mounted Solar	496 kW
Deer Island Maintenance/Warehouse Roof Mounted Solar	180 kW
Deer Island Grit Roof Mounted Solar	222 kW
Deer Island Parking Lot Ground Mounted Solar	234 kW
Deer Island Residuals Odor Control Roof Mounted Solar	100 kW
Wachusett Aqueduct Pumping Station Solar	93 kW
Wind	
Charlestown Wind Turbine	1.5 MW
Deer Island Wind Turbine 1	600 kW
Deer Island Wind Turbine 2	600 kW

4 http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results

Energy Optimization Measures – Wachusett Aqueduct Pumping Station

The Wachusett Aqueduct Pumping Station (WAPS) is under construction with a completion date of February 2019 and is currently in testing. This facility will provide a redundant raw water supply from the Wachusett Reservoir to the Carroll Water Treatment Plant via the Wachusett Aqueduct. This facility will be used either during emergency or planned shutdown of the Cosgrove Tunnel. The project includes the construction of a 240 MGD pumping station. A number of green energy attributes including photovoltaic panels and an open-loop geothermal system will be installed to reduce the reliance on fossil fuels and electricity for heating and cooling of the station. The geothermal system will take advantage of the constant supply of water in the Forebay. An outline of green energy attributes for the Wachusett Aqueduct Pumping Station is presented below.

Photovoltaic System

- Photovoltaic system on the roof of the pumping station and on the ground;
- Will generate the equivalent of the electrical power used on average throughout the year while in stand-by mode (not including power for pumping).

Zero Net Energy Improvements

- Cold roof design (double roof with air gap) will be implemented to reduce heating and cooling requirements;
- Insulation values for the roof, walls and basements will be greater than code requirements;
- Air and vapor barrier will be continuous from the foundation through the roof;
- A hard ceiling will be installed in the pump room to minimize the volume of air to be heated and cooled;
- Process pumps will be specified with the minimum pump efficiency of 87% and motor efficiency of 93%;
- Energy Performance will be exceeded with:
  - LED light fixtures on the exterior and interior;
  - Light control system using motion and daylight sensors;
  - Premium efficiency motors and variable frequency drives on all HVAC equipment;
  - Automatic Temperature Control system with set points at 55°F for Heating & 85°F for cooling;
  - Low water temperature heating system will be utilized;
  - Heat Energy Recovery System on the air handling system; and,
  - Geothermal Heating & Cooling for the building and process.

LEED Plus Items

- Porous Pavements will be used in all new parking and storage areas;
- Roof with a Solar Reflective Index greater than 34;
- “Water Sense” ultra-low flow plumbing fixtures;
- No irrigation system will be included, use of native drought resistant plantings;
- Refrigerants used will not contain CFCs;
- Regional materials will be specified where appropriate;
- Ventilation rates above code requirements will be used at 0.2 air changes per hour (ACH) unoccupied and 1 ACH in the occupied mode; and,
- Low VOC emitting materials will be specified.

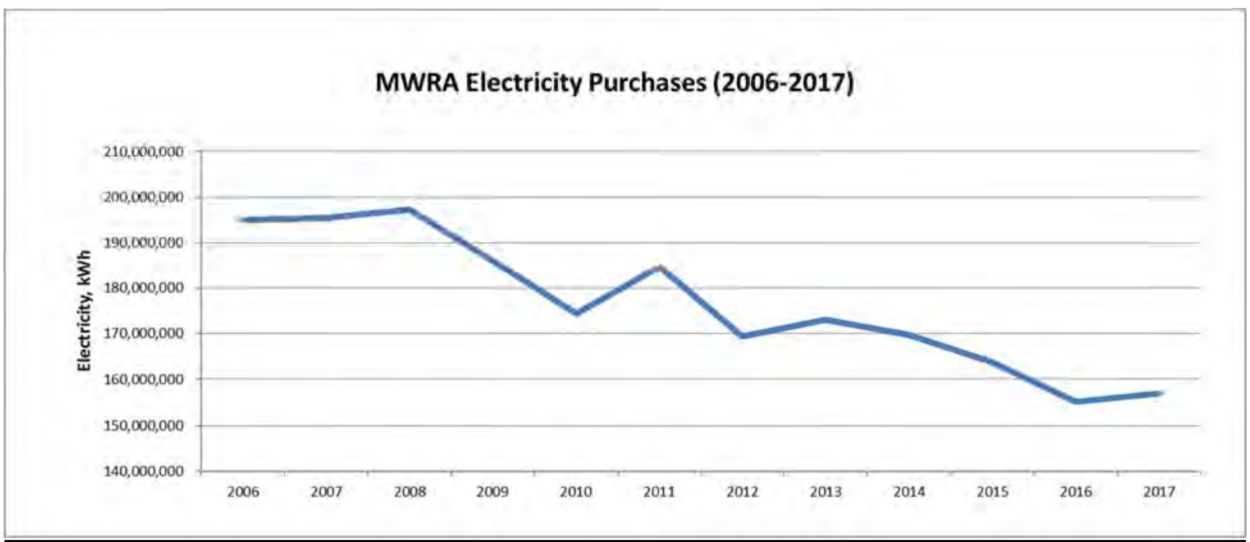
Massachusetts Renewable Energy Portfolio Standard (RPS) – Retail electricity suppliers are required by Massachusetts regulation to provide a portion of their power from renewable energy sources. Renewable energy generators (like MWRA) can sell credits to electricity suppliers to help them meet the regulatory requirements. Since December 2002, MWRA has been selling its renewable energy credits through a competitive bid process. MWRA RPS eligible facilities have increased in recent years due to both new facilities being brought on line, as well as the Green Communities Act regulations that made hydropower eligible in 2009. MWRA receives an average of $1 Million in RPS revenue annually.

10.4 Demand-Side Management

MWRA demand side management efforts include:

- Improving equipment energy efficiencies at operating facilities (lighting, variable frequency drives, HVAC system updates, treatment process modifications, etc.);
- Establishing operating protocols to reduce monthly and annual peak energy demand charges; and,
- Enrolling in demand response programs offered by regional grid operators.

Overall, MWRA has seen a net reduction of 19.5 percent (about 38 million KWh) in electricity purchases between 2006 and 2017, partly due to increases in renewable electricity production as discussed above and energy efficiency improvements made throughout the MWRA system. This is offset by increases in energy use at facilities which have seen functional upgrades requiring new energy demands, such as improved CSO capture and the addition of UV disinfection to the Carroll Water Treatment Plant and the Brutsch Hydropower Facility. The graph below shows the electricity purchase trend during this time.



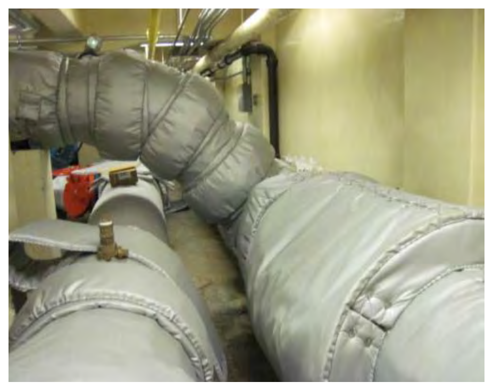
Using both MWRA resources and free or reduced cost assistance from power suppliers whenever available, MWRA has conducted energy audits at almost every MWRA facility - in some cases, returning several years later as improved technologies offered new opportunities for savings.

Some examples of actions undertaken by MWRA to improve efficiency include:

- Installation of new Dissolved Oxygen probes and control panels in 2011 at Deer Island's secondary treatment train enabled 9.2 million kWh annual savings in electricity and $830,000 dollars annually with no impact to effluent quality or secondary capacity.

- Installation of Energy Management Systems in the Chelsea Administration and Maintenance Buildings, Southborough Administration Building, Charlestown Navy Yard Offices, and the Brutsch Hydropower Facility allows MWRA to centralize control of each building's HVAC system components (including thermostats, heat pumps, cooling tower, boilers, and domestic hot water heaters) to allow temperature setback at night and on weekends and holidays, outdoor air reset control, etc. The total energy reduction from all four projects is approximately 1,086,331 kWh and 21,600 therms annually, resulting in a reduction in GHG emissions of 878 metric tons of CO_2e[5] and annual savings of $238,800.

- Insulation of Water Piping at Reservoir Road, Spring Street and Brattle Court Water Pump Stations**.** Custom insulation was installed around the incoming water pipes to eliminate condensation, thereby significantly reducing the need for dehumidification at three facilities, as well as improving safety and reducing maintenance needs. The total energy reduction from these three projects is about 164,800 kWh annually, resulting in a reduction in GHG emissions of 116 metric tons of CO_2e and annual savings of $25,000.



Insulation of Water Piping

- Installation of Energy Efficient Lighting at MWRA Facilities**.** Interior and exterior lighting has been installed at over 40 MWRA facilities, including the Deer Island and Clinton Wastewater Treatment Plants, the Carroll Water Treatment Plant, and Administration Building, most of the water and wastewater pump stations, headworks facilities, CSO treatment facilities, and underground chambers. The energy-efficient lighting has been installed in both offices and process areas, and includes low wattage fluorescent as well as LEDs. In many cases, the installation of LEDs has cut the energy use at a facility by 50-60 percent, while improving working conditions. The annual energy savings from 21 lighting replacement projects over the last 3 years totals 2.3 million kWh, resulting in a reduction of GHG emissions by 1,616 metric tons of CO_2e and annual savings of $254,105.

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5 CO_2e is carbon dioxide equivalent, which is a measure that allows the comparison of the emissions of other greenhouse gases relative to one unit of CO_2.

Energy-efficient lighting at Nut Island Headworks – Explosion-proof LED lighting is being installed at MWRA facilities to reduce energy usage. In most installations, energy usage is being reduced by about 75 percent, while providing a brighter light output and a safer work environment.

- Installation of Variable Frequency Drives on motors at MWRA facilities reduces the amount of energy used when the need is less than full power. For example, VFDs were installed at Gillis Water Pump Station, potentially reducing energy usage by approximately 927,000 kWh annually, resulting in a reduction of GHG emissions by 651 metric tons of CO_2e and annual savings of $137,600.

Through the optimization and modification of processes to increase energy efficiency**,** capital investments have been made in lighting, VFDs, HVAC, and other equipment to reduce energy usage and GHG emissions. MWRA is reviewing its operational procedures to identify areas where it can change how it operates to reduce energy usage while still maintaining optimal service. Additional efforts include eliminating the use of chemical mixers at the Carroll Water Treatment Plant and reducing channel blower run time at Deer Island. These changes in operational procedures have resulted in a reduction of about 520,600 kWh and 366 metric tons of CO2e of GHG emissions.

<u>Demand Response Programs</u> - The Carroll Water Treatment Plant (CWTP) and Deer Island Wastewater Treatment Plant participate in a demand response program run by ISO-New England that pays these facilities a monthly “capacity fee” for being available to go on back-up generation during periods of extremely high New England grid electricity demands. Deer Island began participating in 2001 and Carroll in 2008. In FY17, the total revenue received under this program for Deer Island was just under $1 Million and approximately $34k for CWTP.

10.5 Supply-Side Management

Due to its large power purchasing, MWRA was an early entrant to the competitive electricity marketplace in 2001. The process has evolved into the creation of three distinct electricity supply contracts:

- Deer Island Wastewater Treatment Plant;
- Larger operations facilities including the Carroll Water Treatment Plant, Nut Island Headworks, Clinton Treatment Plant, and 22 other facilities; and,
- Smaller accounts including some of the pump stations and CSO facilities.

MWRA maintains a balanced electricity portfolio by contracting for a base block of power at a fixed-price and purchasing the balance of the load on the open market at real-time clearing prices.

10.6 Other Sustainability Initiatives

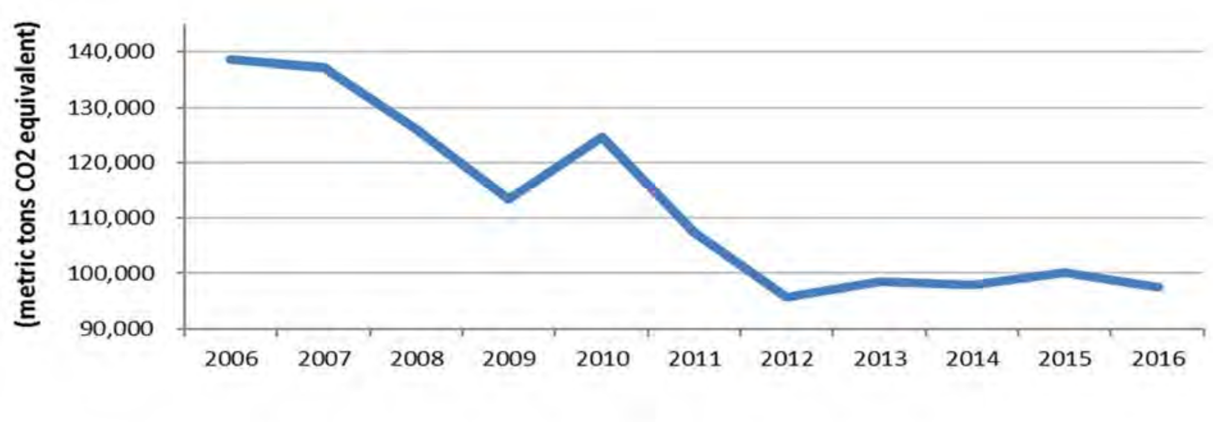
In addition to all the efforts discussed above in support of MWRA and Commonwealth shared goals to increase renewable energy purchases and reduce greenhouse gas emissions at state facilities, MWRA has undertaken additional efforts to directly use more green power by maximizing the use of alternative fuel vehicles (Electric, biodiesel, hybrid, propane, and flex-fuel) representing about 70% of the fleet.

MWRA has recently installed charging stations at its Chelsea facility for a new all-electric vehicle and a hybrid electric vehicle. They are the beginning of an electric vehicle initiative that will help reduce vehicle emissions at MWRA.

10.7 Greenhouse Gas Inventory

Over the last eleven years, MWRA has reduced its GHG emissions by 32.1 percent (between 2006 and 2016) as shown in the chart below. The reductions result from a combination of improved efficiency efforts resulting in the reduction of energy needed to run MWRA facilities; increases in MWRA's production of green power; and the gradual greening of the region's electrical power production. The bump-up in emissions during 2010 was due to the spring severe weather that required the Deer Island Plant to use its diesel powered backup generator for an extended period to provide reliable service during the high flow conditions. By continuing to measure and analyze GHG emissions, MWRA is able to quantify its emissions and track the progress it is making from on-going energy conservation efforts, as well as target areas for future reductions.

MWRA GHG Emissions (from 2006 – 2016)



In 2016 the major sources of GHG emissions in the MWRA's operations (as a percent of total emissions) include:

- 46% of MWRA's total emissions is electricity use - 17% from natural gas; 15% from diesel; 22% from a combination of other sources, such as fleet vehicle emissions, fugitive emissions, and process methane emissions.

- 11% of MWRA's GHG emissions are from transporting and treating drinking water, while 89% are from the transport and treatment of wastewater (water distribution primarily uses gravity while wastewater has a higher energy demand for pumping and treatment).

10.8 Summary of Existing and Recommended Energy Initiatives

All Master Plan projects related to energy management are summarized below. Generally speaking, the Authority has done a commendable job in optimizing grants and incentives for past alternative energy projects and energy projects, in general. Going forward, energy projects will continue to be an integral part of the MWRA's philosophy, and future projects will require more attention simply due to the fact that many of the more obvious sites have been claimed. While maintaining an eye toward renewables, a big part of the focus going forward will be on energy efficiency at the equipment level.

Energy Efficiency – The MWRA is an energy intensive organization due primarily to the power needed to transport and treat wastewater, and, to a lesser extent, treat and distribute drinking water. Pumps and other equipment that utilize most of this energy become less efficient over time and require upgrades. The MWRA will be using grants and funding, as available, to address the upkeep and maintenance of this equipment and increase energy efficiency. Working closely with engineering, operations and management will be an important part of this effort as the Authority gravitates from some of the more visible and cost effective projects (i.e., alternative energy projects) toward more equipment intensive assessments. This will include incorporating energy efficiency into new construction/rehabilitation projects, equipment replacements, continuing to conduct energy audits at all facilities and establishing regular audit schedules.

Metering and Real Time Energy Monitoring – The success of a deeper energy efficiency program will be largely dependent on the ability to monitor energy use at the facility and equipment level. Going forward, the Authority will be evaluating monitoring tools at a more granular level to both assess baseline and establish metering techniques to verify savings.

Energy Benchmarking – Over the next two to five years, the MWRA will evaluate its internal progress by benchmarking certain processes and evaluating trends. Benchmarking will also be useful in evaluating the MWRA's performance relative to the rest of the water and wastewater industry. The metering and real time energy monitoring will be instrumental in supporting the benchmarking.

Alternative Energy – Over the next two to five years, the MWRA will evaluate its internal:

- Hydropower – The fish hatchery hydro turbine at the Brutsch Facility is complete as of FY17. Staff will continue to explore alternative locations in the water transmission system which may provide hydropower development potential. Currently, the general consensus is that hydropower facilities going forward will likely require more marginal resources than past due to limited opportunities.

- Solar - Staff are currently working to conduct a comprehensive study for MWRA sites to assess the solar capability and technical/economic feasibility under the Massachusetts “SMART” solar program, effective November 2018. The program is designed to facilitate more stability in the solar subsidy market than the conventional “REC” approach, by guaranteeing a steady tariff rate for twenty years after installation of the project.

- Wind – The MWRA will continue to maintain its current turbines at the Deer Island and Chelsea locations. Staff will continue to evaluate opportunities for wind where economically and technically feasible.

<u>Demand Response</u> – Often associated as being a revenue-only program, demand response contributes to energy optimization at the grid scale. As ISO-NE focuses more and more on peak energy use, demand response programs offer financial incentives to decrease this use. Natural gas is becoming the fuel of choice in the New England region, driving generation pricing for older and dirtier fossil fuel facilities up, which results in these plants being turned on last during high demand. By decreasing peak demand, the MWRA is doing its part in optimizing energy use and quality at the grid level.

<u>Supply-Side Management</u> - Staff will continue supply-side energy management initiatives, maintaining a balanced electricity portfolio using both fixed price contracts and open market prices to minimize energy costs.

<u>Other Sustainability Initiatives</u> – MWRA recently received an electric vehicle charging station from PowerOptions in 2018. Staff will continue to pursue grants and funds for electric vehicles and equipment.

<u>Battery Storage</u> – Energy storage will be an important component to any energy portfolio in the coming years. The MWRA will pursue cost effective approaches toward incorporating energy storage in to its operations, thereby decreasing energy use and reducing retail demand and wholesale capacity costs.

<u>Utility MOUs</u> – The MWRA coordinates with Eversource and National Grid in updating Memorandums of Understanding. The MOUs are intended to further incentivize energy efficiency measures by increasing the reimbursement rate for energy savings.