CIVIL ENGINEERING PRACTICE ·

JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS SECTION / ASCE

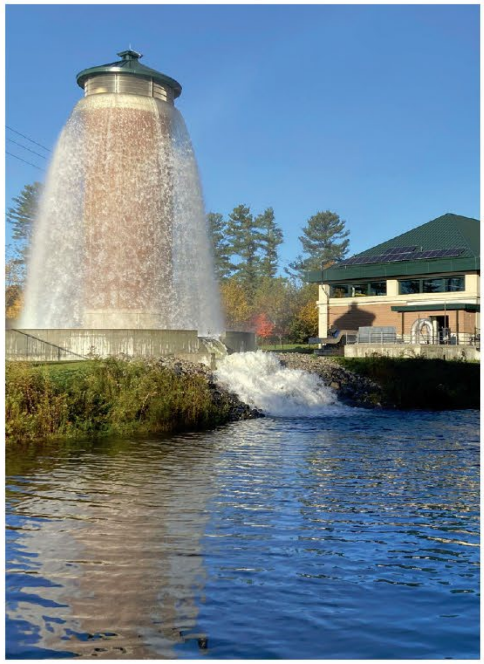
SUMMER/FALL 2023 VOLUME 31, NUMBER 1 ISSN: 0886-9685

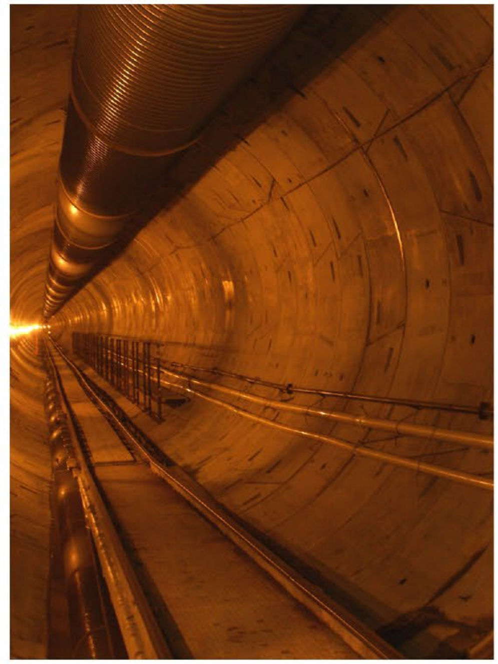
Special Issue: Massachusetts Water Resources Authority

Completing the Great Metropolitan Water System

Modernization of the Metropolitan Sewer System: Deer Island

Energy Matters






Sentinel
Sentinel

Volume 31, Number 1

CIVIL ENGINEERING PRACTICE ·

JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS SECTION / ASCE

CONTENTS

Message from the President	Michael Cunningham	4
Message from the Editor	Gautham Das	5
Forward: MWRA Executive Director's Perspective	Frederick A. Laskey	7
Water Resources for the Commonwealth of Massachusetts	Katherine Ronan Rebecca Weidman	11
Evolution of Water Treatment in the Greater Boston Area	Valerie Moran Betsy Reilley William Sullivan Patricia Mallett	19
Completing the Greater Boston Metropolitan Water System	Kathy Murtaugh David Coppes	27
Responding to Changes in Climate at MWRA	Stephen Estes-Smargiassi Hillary Monahan	35
Protecting our Legacy: MWRA Dam Management	John J. Gregoire	39
Beaches and Rivers: Where the People Meet the Water	Brian Kubaska Betsy Reilley	51
The Modernization of the Metropolitan Sewer System: The Deer Island Treatment Plant	David Duest	61
Energy Matters: MWRA Perspective	Carolyn Fiore Denise Breiteneicher Christian A. Murphy	67

SPONSORS

The following companies, academic institutions and individuals have made generous donations to make this special issue on MWRA a reality. Their contributions are greatly appreciated.

PLATINUM ($2,000)

MWRA, Inc.

GOLD ($1,000)

Wentworth Institute of Technology School of Engineering

Wentworth Institute of Technology School of Management

Silver ($500)

Dr. Ali Touran

CIVIL ENGINEERING PRACTICE JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERING SECTION / ASCE (ISSN 0886-9685) is published by the Boston Society of Civil Engineers Section / ASCE (founded 1848). Editorial, circulation, and advertising activities are located at: Boston Society of Civil Engineers Section / ASCE, The Engineering Center, One Walnut Street, Boston, MA 02108-3616; 617-227-5551. Known as the *Journal of the Boston Society of Civil Engineers Section / ASCE* until 1985, Vol. 71, Nos. 1 & 2.

Civil Engineering Practice seeks to capture the spirit and substance of contemporary civil engineering through articles that emphasize techniques now being applied successfully in the analysis, justification, design, construction, operation and maintenance of civil engineering works. Views and opinions expressed in Civil Engineering Practice do not necessarily represent those of the Society.

Civil Engineering Practice welcomes and invites the submission of unsolicited papers as well as discussion of, and comments on, previously published articles. Please contact our editorial office for a copy of our author guidelines. Please address all correspondence to the attention of the Editor.

Editorial, Circulation & Sales Office:

Civil Engineering Practice
Boston Society of Civil Engineers Section/ASCE
The Engineering Center
One Walnut Street
Boston, MA 02108-3616

617-227-5551

CIVIL ENGINEERING PRACTICE™ · JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS SECTION / ASCE

Message from the BSCES President

Now Hiring

At regular intervals, I dedicate time to browse through my LinkedIn account, seeking updates from my professional network and others within our industry. However, over an extended period, it's become evident that my feed has been overwhelmingly filled with variations of the phrase "Now Hiring," posted by different employers to attract potential candidates. This persistent theme reflects the current labor shortage and the consequent high demand for new hires in our field. In my 25-year tenure as a civil engineering consultant, I've never witnessed such a pronounced scarcity of workers.

Although the Covid-19 pandemic did temporarily disrupt projects for certain individuals, by late 2020, most of us in the industry were already amid a bustling workload and actively seeking additional assistance. This trend has only intensified since the approval of the Bipartisan Infrastructure Law (BIL) by Congress in November 2021—a landmark investment in our nation's infrastructure often characterized as a "once-in-a-generation" endeavor.

Expenditures linked to the BIL were anticipated to commence this year and extend until 2033, with funding reaching its peak around the years 2027 and 2028. An article featured in the May/June 2023 edition of the American Society of Civil Engineers (ASCE) Civil Engineering magazine included the following statement from former ASCE President Dennis Truax, PhD, PE: “The U.S. Bureau of Labor Statistics projects a need for about 25,000 new civil engineers each year throughout this decade. However, this number is based on the need to replace workers; it does little to consider the impact of the (IIJA) and civil engineers’ roles in its implementation.” The term "IIJA" refers to the Infrastructure Investment and Jobs Act, which is an alternate designation for the BIL.

This data prompts me to ponder about how the civil engineering sector will navigate these conditions in the coming decade. The shortage of adequate personnel coupled with the substantial workload has posed significant challenges, inevitably leading to busier and more demanding day-to-day routines. Nonetheless, amidst these challenges, it's easy to overlook the fact that this situation presents a highly advantageous opportunity for our profession—one that is poised to stimulate remarkable progress and innovation.

The *American Society of Civil Engineering* magazine details various reasons why civil engineering and many other professions are facing labor shortages and strategies for employers to attract new hires. However, one important activity we must collectively improve upon over the next decade is our outreach to primary and secondary education students to promote engineering and combat the decline in those pursuing engineering curriculums and careers. The Boston Society of Civil Engineers has a Public Awareness and Outreach Committee that is responsible for planning and implementing educational outreach and our dedicated members consistently organize several great events and competitions each year! We hope to keep this up given its significance these days.

The Most Crucial Natural Resource (Besides Air!)

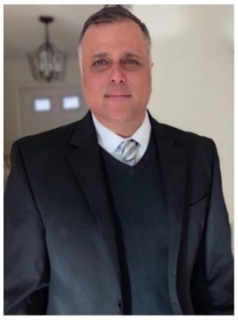
I am particularly enthusiastic about the current edition of the journal, which delves into articles centered around the Massachusetts Water Resources Authority (MWRA). Serving over 3.1 million individuals and more than 5,500 businesses across 61 communities in eastern and central Massachusetts, the MWRA is responsible for providing wholesale water and sewer services. Since its inception in 1985, the MWRA has invested upwards of $6 billion in novel facilities. This commitment has yielded remarkable achievements, including transformative projects like the restoration of Boston Harbor through the construction of the Deer Island Wastewater Treatment Plant, as well as the establishment of the John J. Carroll Water Treatment Plant. The MWRA remains steadfast in its efforts to enhance and maintain the extensive network of water and sewer pipelines, along with numerous other critical facilities that underpin our access to drinking water and the disposal of wastewater.

In my capacity as a consulting project manager, I've had the privilege of collaborating with the MWRA on a range of intricate capital improvement projects. In doing so, I've had the opportunity to witness the unwavering dedication of its staff and the resolute commitment of its leadership to delivering water and sewer services of exceptional quality and reliability to the communities it serves.

Lastly, I extend my heartfelt gratitude to Dr. Gautham Das, the Editor-In-Chief of the Civil Engineering Practice, and the entire Editorial Board for their immense dedication and the countless hours they've dedicated as volunteers to produce this journal issue. It's your steadfast commitment that ensures the continued existence of this invaluable publication.

Michael Cunningham, PE,
BSCES President, 2023-2024

Message from the Editor-in-Chief



It is with immense pride and enthusiasm that we welcome you to this special edition of the Boston Society of Civil Engineering Practice Journal, dedicated to honoring the Massachusetts Water Resources Authority (MWRA) and its profound impact on the field of civil engineering.

For decades, the MWRA has stood as a shining example of innovation, dedication, and excellence in the realm of water resources management, environmental protection, and infrastructure development. As one of the nation's preeminent public agencies, MWRA has been at the forefront of tackling complex challenges related to water supply, wastewater treatment, and sewage disposal in the Greater Boston area. Through its visionary leadership and commitment to sustainability, MWRA has played a pivotal role in shaping the future of civil engineering practice not just in Massachusetts but across the country and beyond.

This journal serves as a tribute to the countless engineers, researchers, and professionals who have been instrumental in the MWRA's remarkable journey. Their unwavering pursuit of cutting-edge technologies, their emphasis on research-driven decision-making, and their passion for transforming theoretical ideas into practical solutions were the driving force behind the agency's achievements.

Within these pages, you will find a rich tapestry of articles and research papers that highlight the transformative projects and groundbreaking initiatives spearheaded by MWRA. From the ambitious construction of the Quabbin Reservoir to the establishment of state-of-the-art water treatment facilities, the MWRA's endeavors have redefined the boundaries of civil engineering practice and set new standards for resilience, sustainability, and public health.

Furthermore, this edition seeks to delve into the collaborative efforts that have fostered a robust relationship between the MWRA and the Boston Society of Civil Engineering Practice. As two entities deeply committed to advancing the science and practice of civil engineering, this partnership has been instrumental in knowledge exchange, professional development, and driving the industry's evolution.

As we celebrate the MWRA's remarkable achievements, it is also a moment to reflect on the challenges that lie ahead. Climate change, population growth, and urbanization are presenting our society with new and complex water management issues. In this context, we must draw inspiration from MWRA's legacy and continue pushing the boundaries of civil engineering practice to create sustainable, adaptive, and resilient solutions.

We extend our heartfelt gratitude to all the contributors, authors, and reviewers who have made this journal a compelling repository of knowledge and expertise. Their commitment to sharing insights and experiences will undoubtedly inspire future generations of civil engineers to rise to the challenges of their time.

A special thanks to Ali Touran, whose personal financial support has helped to make possible the production of a hard copy of this issue of the Civil Engineering Practice Journal. Ali is a good friend of the Journal, having in the past served as the Journal's Chair of the Editorial Board and as President of the Boston Society of Civil Engineers Section.

In conclusion, it is an honor to dedicate this edition of the Boston Society of Civil Engineering Practice Journal to the MWRA—a trailblazer in civil engineering practice. May the MWRA's legacy continue to inspire us all as we forge ahead in pursuit of a better, safer, and more sustainable world.

Gautham P. Das
Editor in Chief
Journal.board@bsces.org

Volume 31, Number 1

Forward: MWRA Executive Director's Perspective

Frederick A. Laskey[1]

[1] MWRA Executive Director, Boston, MA USA

E-mail: fred.laskey@mwra.com

Published August 15, 2023

The Massachusetts Water Resources Authority (MWRA) MWRA is an independent authority that provides wholesale water and sewer services to its customer communities and funds its operations primarily through user assessments and charges. MWRA was created by the legislature in 1984 and inherited operations and facilities beginning in 1985 from the Metropolitan District Commission, a century-old department of state government. Although best known for the successful clean-up of Boston Harbor, MWRA has also modernized the region's drinking water system; curbed daily water demand; invested in on-site, renewable energy sources; has ongoing plans to mitigate the effects of sea level rise; and is committed to developing and retaining a high-performance, diverse workforce that reflects our service area.

In the late 1980s, the Boston area faced the unfortunate reality of having the most polluted harbor in America. Falling into the Charles, Mystic, or Neponset Rivers meant a trip to the hospital for disinfection, while urban beaches remained closed for extended periods due to water pollution. Dry weather sewage overflows further marred the beaches and waterways, leading to a virtually lifeless harbor floor with a thick, black mayonnaise-like substance. The foul smell emanating from the harbor forced waterfront residents to keep their windows closed, becoming a source of national embarrassment for the region.

The situation on the drinking water side was not much better, although it might not have been as visually or odorously apparent. The single-barrel Hultman Aqueduct experienced numerous leaks, and the demand for water consistently exceeded the daily safe yield of the reservoirs. Outdated treatment methods involving gaseous chlorine posed concerns, while storing treated water in open distribution reservoirs left them susceptible to pathogens and pollution.

Fast forward 37 years and the results of our efforts are an indisputable success. Our beaches are now considered the cleanest urban beaches in the country. Boston Harbor has healed itself and is swimmable – even in wet weather. The drinking water is so good that we were named 'Best in the Country' in 2014 and 2021, and this summer when the entire Commonwealth was in a drought, the Quabbin Reservoir never dropped below 90 percent full. So how did we get here and where are we going? The papers in this volume will describe how the work we have done since MWRA took over operations in 1985 have turned the tide.

But we cannot take all the credit. Our predecessors left us with one of the country's greatest water systems. Even through decades of neglect, the water always got to the tap. The engineers who designed each stage – from the Cochituate Reservoir in the 1840s, the Sudbury Reservoir in the 1870s, the Wachusett Reservoir in the 1890s and finally the Quabbin in the 1930s – knew precisely what elevations would get the water east by gravity to provide for an ever-growing population. And all without the aid of computers. Boston also had some of the earliest sewer infrastructure in the country, but it did not take very long before population and progress outpaced the ability to just send it off with the outgoing tide. To make matters worse, this was followed by decades of underfunding and lack of maintenance as it was difficult to convince legislators to fund operations that were out of sight and therefore out of mind.

Enter MWRA. The first order of business for the new authority was the clean-up of Boston Harbor by building a state-of-the-art wastewater treatment plant on Deer Island, with its 9.5-mile deep-rock outfall tunnel. Eleven years and $3.8 billion later, the plant was completed in 2001 and continues to operate better than envisioned. This was followed by a $900 million plan to control combined sewer overflows (CSOs) that discharged raw sewage into Boston Harbor's tributary rivers, the Charles, the Mystic and the Neponset, during heavy rains. In 2015, completed 35 separate projects that included sewer separation, storage, and treatment. To add to the urgency, this work was competed under the oversight of the federal district court.

In 1995, we embarked on a mission to revitalize the drinking water system through the ambitious $1.7 billion Integrated Water Supply Improvement Program. As part of this initiative, we constructed a 17.6-mile-long tunnel to bolster the aging Hultman Aqueduct. In addition, seven covered water storage tanks were built, and a cutting-edge water treatment plant was established, initially utilizing ozone and later adopting ultraviolet light technology. Thanks to these endeavors, our valued customers now enjoy some of the finest water quality in the entire country.

Figure 1: The Deer Island Wastewater Treatment Plant, Boston MA (MWRA, 2023)

It is crucial to acknowledge that the ratepayers within the MWRA service area played a significant role in funding these critical projects. They have shouldered the majority of the $9 billion cost, highlighting their unwavering commitment to safeguarding the water supply and investing in the well-being of the community. Their support and dedication have been instrumental in the success of this extensive modernization effort.

The burden on the residents and businesses we serve is substantial, and MWRA must remain diligent to guarantee that the ratepayers' funds are invested wisely. We are committed to keep up proper maintenance of the systems we have inherited and the projects we have built; to protect those investments and continue reliable service for generations to come.

Figure 2: The Quabbin Reservoir, Belchertown, MA (Mass, 2023)

And what does the future hold? We are in the early design stages of another massive tunnel program to provide redundancy for the metropolitan water tunnels, and we are working on a second phase of the CSO control program to end sewage discharges in the last remaining, and most difficult areas. And challenges are endless: Climate change and PFAS, just to name two. But we will face these future challenges head on, like we have in the past, and hope for the same good results.

Acknowledgements

I extend my heartfelt appreciation to the dedicated women and men of MWRA, who truly embody the spirit of environmentalism. Each day, they labor tirelessly to uphold the safety and security of our water supply, ensuring that Boston Harbor will never again bear the shameful title of "The Dirtiest Harbor in America."

I am also grateful for the unwavering support and invaluable guidance provided by our esteemed Board of Directors. Their commitment has been instrumental in driving our efforts forward. Equally deserving of recognition is the MWRA Advisory Board, who tirelessly advocate on behalf of our ratepayers, ensuring their voices are heard and their interests protected.

A special tribute goes out to the visionary engineers who laid the foundation of our water systems. In their era, individuals like Ellis Chesbrough on the sewer side, and Frederic Stearns and Henry Goodnough on the water side, designed masterful facilities that continue to serve us to this day. We are fortunate to have continued this legacy with exceptional engineers like Dick Fox,

Walter Armstrong, and Charlie Button, who played vital roles in the Boston Harbor Clean-up. Additionally, we owe much gratitude to professionals such as Mike McBride, Frank DePaola, Jae Kim, and John Shawcross, who have contributed significantly to restoring our exceptional water system. Of course, countless others within our organization and partner engineering firms have also played pivotal roles in designing these critical facilities that safeguard public health and protect the environment.

With the dedication and talent exhibited by our current engineers, I am confident that the future holds even greater promise. If our good fortune persists, the great engineers of tomorrow may very well be among us today, continuing the legacy of excellence in service to our community and the environment.

References

MWRA (2023) "MWRA Water Expansion System" Retrieved February 22, 2023, from https://www.mwra.com/02org/html/expansion.html

Massachusetts (2023) "Commonwealth of Massachusetts Quabbin Reservoir". Mass.gov. https://www.mass.gov/locations/quabbin-reservoir

Volume 31, Number 1

Water Resources for the Commonwealth of Massachusetts

Katherine Ronan[1] and Rebecca Weidman[1]

[1]Environmental and Regulatory Affairs, Massachusetts Water Resources Authority

E-mail: Katherine.Ronan@mwra.com and Rebecca.Weidman@mwra.com
Published August 15, 2023

Abstract

MWRA's water sources, the Quabbin and Wachusett Reservoirs, are the largest water bodies in the Commonwealth; together holding over 470 billion gallons of clean drinking water. MWRA currently delivers an average of 200 million gallons per day (mgd) of drinking water to the 54 communities it serves. Over the last 40 years, MWRA and its expanding list of member communities have taken major strides to reduce water consumption, which previously averaged well over the system safe yield of 300 mgd. By successfully shrinking daily demands by over 100 million gallons per day, MWRA has gained capacity to deliver water to additional communities throughout the Commonwealth. These water conservation efforts have also resulted in an even more resilient water supply system, able to withstand drought conditions and recover quickly following a drought. MWRA's high quality source water is a result of our highly protected, forested watersheds. These watersheds act as a buffer against many contaminants, both regulated and unregulated. While many other public water systems across the Commonwealth are detecting harmful per- and poly-fluoroalkyl substances (together known as PFAS) at concerning levels, MWRA has detected no more than trace amounts in its source water. As communities across the Commonwealth continue to contend with water quantity and quality issues, MWRA can be a resource, offering an opportunity to join a regional water supply system. A regional water system provides communities the assurance that a steady supply of clean and safe water will be available to those they serve and limits their responsibility for dealing with the next emerging contaminant. As our climate continues to change and new contaminants are identified and regulated, regional water systems that are well-resourced, such as the MWRA, are best positioned to deal with the uncertainties that public water systems continue to face.

Keywords: Quabbin Reservoir, Wachusett Reservoir, PFAS, regional water system, drinking water

1. Introduction

1.1 Quabbin Reservoir

The Quabbin Reservoir sits prominently in the center of the state and is prominent, even to those unfamiliar with its purpose, on most maps and imagery of Massachusetts. Former hill tops reach up from its vast waters creating islands that are over 150 feet above sea level. Remnants of old roadways mysteriously disappear into the water, a reminder of the four towns of Dana, Enfield, Greenwich and Prescott, whose residents were displaced from their homes and communities when the Swift River valley was flooded to create the reservoir in the 1930s and 40s. Today, the watershed land surrounding the reservoir remains vastly undeveloped and densely forested. The Quabbin Reservoir is a harbor of habitat biodiversity, a vast carbon sink and a resource for the Commonwealth (Figure 1).

1.2 MWRA Water System

MWRA's primary drinking water sources, the Quabbin and Wachusett Reservoirs, together can hold over 470 billion gallons of water. The larger of the two, the Quabbin Reservoir, impounds the Swift River and receives water from the surrounding Chicopee

River Basin. The Wachusett Reservoir impounds the Nashua River and receives water from the surrounding Nashua River Basin. Located 25 miles apart, the two reservoirs are hydraulically connected by a deep rock tunnel used to transfer water between them. The tunnel can also be used to divert water from the Ware River at certain times of year, supplementing flows into the reservoir system and further bolstering capacity. This robust reservoir system ensures an abundant source of drinking water to MWRA member communities that is resilient to dry periods and short- to medium-term droughts, even in the face of climate change.

Drinking water destined to the metropolitan Boston area is transported eight miles from the Wachusett Reservoir through another deep rock tunnel to MWRA's John J. Carroll Water Treatment Plant in Marlborough, Massachusetts. There, water receives ultraviolet and ozone disinfection treatment before continuing its journey east (Figure 2). In addition to the metropolitan system, MWRA also provides water directly from the Quabbin Reservoir to three communities in the Chicopee Valley. Water in the Chicopee Valley system is also treated with ultraviolet light at the Brutsch Water Treatment Facility.

Figure 1. Quabbin Reservoir (MWRA 2021)

2. Well Protected Watersheds

The Quabbin and Wachusett Reservoirs are naturally protected, with more than 85% of their watersheds covered with forests and wetlands. These environmental features filter rainwater and snow entering the reservoirs, both directly and through streams that flow into the reservoirs. As water comes into contact with soil, rock, plants and other material, it is cleaned as it flows on its path. Minimizing impervious area and development surrounding the reservoirs limits the opportunity for contaminated runoff and stormwater to enter the reservoirs directly.

Notably, MWRA is one of only a handful of large public water suppliers (PWSs) in the country that

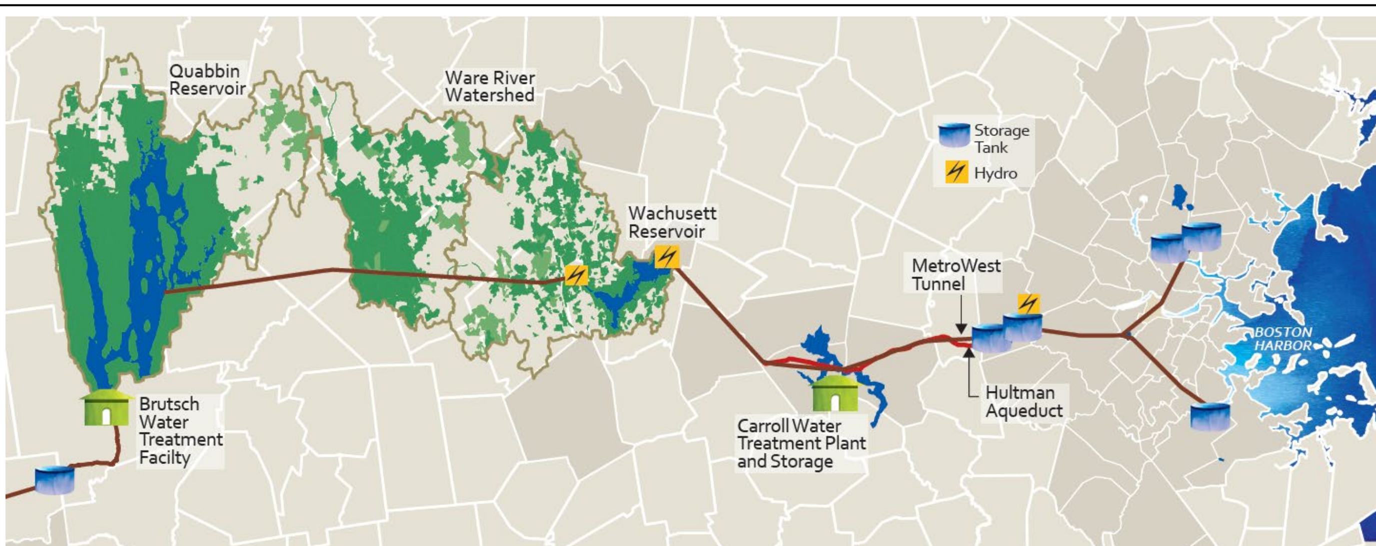


Figure 2. MWRA Water System (MWRA 2021)

does not require filtration treatment. Passed in 1974, the Safe Drinking Water Act (SDWA) is designed to protect public health by regulating the nation's public drinking water supplies. The SDWA also enables EPA to write subsequent rules regulating public drinking water as technology develops or as new threats to public health water supplies emerge. Written in 1989, The Surface Water Treatment Rule (SWTR) is one of these rules and was specifically designed to prevent against the newly identified contaminant threats of *Giardia* and *Cryptosporidium*. This rule requires all public water systems to filter water unless 11 filtration avoidance criteria are met. The criteria are all centered on watershed protection planning, source water quality, and post treatment water quality.

MWRA meets the filtration avoidance criteria largely due to the extensive watershed protection program, administered with our partners at the Massachusetts Department of Conservation and Recreation (DCR) Division of Water Supply Protection (DWSP). This comprehensive program involves a multi-barrier approach comprised of integrated programs that prevent contamination at all points of the water system, from source to tap. DCR's DWSP Rangers provide on the ground support by patrolling and protecting MWRA's watersheds (Figure 3).

Aggressive land acquisition efforts are a key component of DCR's program and involve purchasing property to protect it from development and restore or maintain a stable vegetative cover. Deed restrictions on private properties known as 'Watershed Reservation Restrictions' are another tool which restrict future development and degradation of land surrounding the reservoirs. The watershed protection program involves a host of other efforts including land and wildlife management, invasive species management, water quality and hydraulic monitoring, infrastructure maintenance, watershed security, and public outreach and education.

The highly protected and well managed Quabbin and Wachusett watersheds provide a natural filter resulting in very clean, high quality source water even prior to treatment. In addition to negating the need for filtration, the watersheds act as a buffer against contaminants entering the water supply. The watersheds provide protection against known contaminants, such as pharmaceuticals and per- and poly- fluoroalkyl substances (PFAS), as well as other emerging containments that could be identified in the future.

Figure 3 On-duty DCR DWSP Ranger (DCR, 2023)

3. Declining Demand vs Safe Yield

In the 1980s, MWRA water communities regularly used much more water than could sustainably be supplied from the Quabbin and Wachusett Reservoir system. The system safe yield, or the amount of water that can be withdrawn on a daily basis without negative impacts even during a severe drought, is 300 million gallons per day (mgd). This safe yield is determined by modeling based on the multi-year drought of the 1960s, which is considered to be about a 1 in 400 year occurrence event. This modeling accounts for: system operations during various weather conditions, anticipated increases in use from existing partial MWRA water communities during drought conditions and expected impacts from climate change.

In 1984, the MWRA water system regularly exceeded safe yield, with an average daily demand of 331 mgd. This lead to investigations of ways to increase capacity, including evaluations of diverting water from the Connecticut River, which would have required costly infrastructure and had significant environmental impacts. In an effort to avoid more drastic and highly engineered solutions such as expanding the reservoir system, MWRA ultimately embraced an approach inspired by environmentalism and conservation. Investment in metering and improvements to MWRA's distribution system to detect and eliminate leaks was prioritized. A grant program for MWRA water communities was created to assist and incentivize communities to do the same — meter and detect and eliminated leaks, further reducing water loss. This focus on increasing efficiency and reducing water loss within the water system coincided with a consumer industry shift towards increasingly efficient household appliances and development, new plumbing codes and a transition away from water-intensive manufacturing in the regional economy. Last, but certainly not least, the rising cost of water made customers start to adopt less wasteful habits.

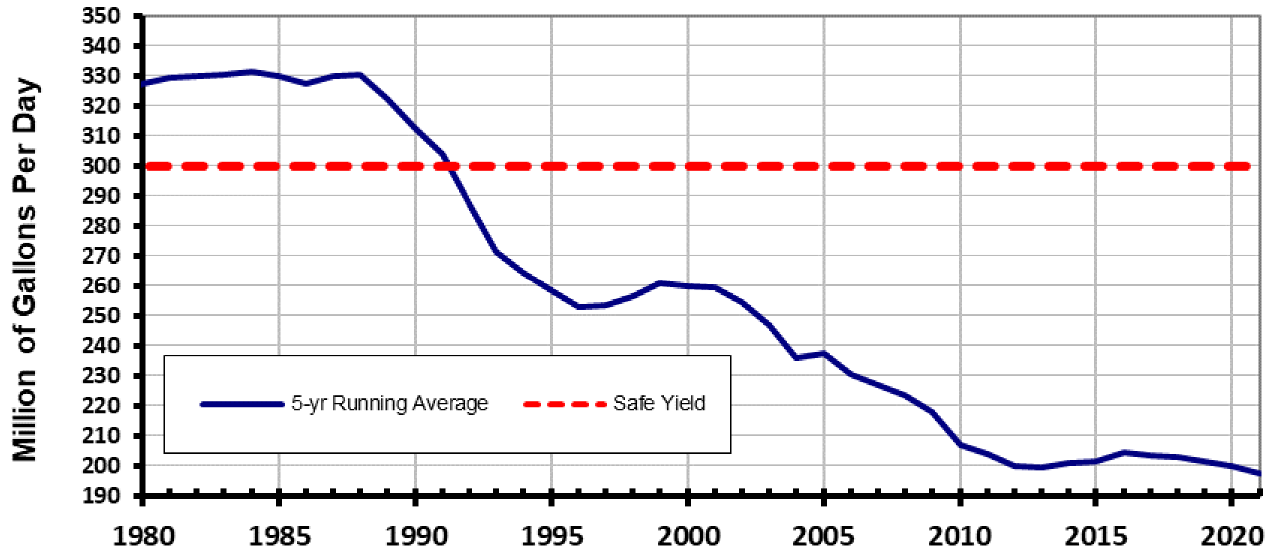


Figure 4 MWRA Average System Demand from 1980 through 2021 (MWRA, 2023)

Together, these factors have resulted in MWRA's average system demand dramatically declining over the past 30 years, despite growth in both the population and geography of MWRA's service area. Between 1980 and 2010, the total population within MWRA's original 1985 service area grew by approximately 163,000. Additionally, six new communities were admitted to the MWRA system with a population totalling approximately 135,000. Since then, two additional communities, Ashland and Burlington have also joined the MWRA water system. MWRA's current average system demand now hovers around approximately 200 mgd, 100 mgd below the system safe yield.

In addition to supplying drinking water to its member communities, MWRA regularly exceeds minimum release requirements to downstream rivers at both reservoirs (Figure 5). These releases ensure that stream flow is maintained in both the Swift and Nashua Rivers, supporting habitat, ecology, recreation and other uses. At the Quabbin Reservoir, discharges must be sufficient to maintain at least 20 mgd in the Swift River at the Village of Bondsville, downstream of the reservoir. Certain stream flow levels must also be met in the Connecticut River at Montague, further governing releases during the summer months. Additionally, MWRA provides six mgd to the Mass Wildlife McLaughlin Fish Hatchery directly from the Quabbin Reservoir. After water is circulated through the trout hatchery, it is discharged into the Swift River and further supplements flows. At Wachusett, at least 12 million gallons per week must be discharged into the South Branch of the Nashua River, downstream of the reservoir. MWRA regularly exceeds these required minimum discharges, helping to maintain downstream aquatic ecosystems.

Figure 5 The Quabbin Reservoir Spillway (Massachusetts 2023)

4. PFAS

PFAS include a suite of more than 9,000 man-made chemicals that have been used globally in a variety of industrial and commercial products since the 1940s (USEPA, 2023). PFAS is used in consumer and industrial products due to its desirable resistance to grease, oil, water and heat. PFAS can be found in stain and water-resistant fabrics and carpets, cleaning products, fabric softeners, polishes, waxes, paints, food packaging, adhesives, personal non-stick cookware, pesticides and herbicides, medical products and fire-fighting foams. Given its prevalence in products used daily, most people have been exposed to PFAS. This is concerning as certain studies have found that PFAS can accumulate and remain in the human body for long periods of time, and that exposure can lead to adverse health outcomes in humans, including cancer and thyroid issues.

PFAS can be found throughout our environment, present in both soil and water. Historically, firefighting foams were a major source of PFAS contamination, entering the ground and water bodies through percolation and runoff. Unfortunately, PFAS has become widespread in our environment, raising concerns for public water suppliers and regulators (MassDEP, 2023).

In 2009, the U.S. Environmental Protection Agency (EPA) issued a provisional health advisory for two common PFAS compounds: perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA). To gather information on PFAS occurrence in drinking water and aid regulatory decisions, large public water suppliers were monitored for six PFAS compounds as part of EPA's Third Unregulated Contaminant Monitoring Rule (UCMR3) between 2013 and 2015. Encouragingly, no PFAS was detected in any fully served MWRA community systems during this period (USEPA, 2023).

In 2016, the EPA replaced the provisional health advisory for PFOA and PFOS with a combined lifetime health advisory of 70 parts per trillion (ppt). Subsequently, in 2019, at the request of MassDEP, MWRA conducted voluntary testing of raw and treated water from the Quabbin and Wachusett Reservoirs. Only trace amounts of a few PFAS compounds were detected, and the levels were too low to be quantified.

In 2020, the Massachusetts Department of Environmental Protection (MassDEP) developed drinking water regulations and promulgated a new PFAS maximum contaminant level (MCL) of 20 ppt for six common PFAS compounds (PFAS6). All PWSs in Massachusetts were required to complete at least one round of testing by the end of 2021. While the results of MWRA's sampling for PFAS6 were 0 ppt, many other PWSs in the Commonwealth have detected PFAS in in excess of the limit. This has left these communities scrambling to implement short term solutions and evaluate long term options for removing PFAS6 from their drinking water supplies (Mass DEP 2023) .

In the short term, some communities detecting PFAS6 in excess of the MCL, have turned off certain water sources (i.e., wells or surface water) with the highest concentrations of PFAS6 and increased reliance on other sources with lower concentrations or no PFAS, blending water to reduce concentrations. This presents challenges related to water quantity and the ability to meet local demand for these communities, a matter complicated further by regular drought conditions across the region. Some communities have installed temporary treatment at local sources to reduce PFAS levels below the MCL. Treatments used to remove PFAS from drinking water, such as granular activated carbon (GAC), are in high demand and in some cases have long lead times. For some communities with limited options, bottled water is provided to vulnerable populations within the communities, such as those who are immunocompromised, pregnant or breast-feeding, while long-term solutions are evaluated and implemented.

In March 2023, EPA issued proposed National Primary Drinking Water Regulations for six PFAS compounds (four of those PFAS compounds are currently regulated by MassDEP). MWRA meets the proposed federal PFAS drinking water regulations, but, if promulgated, these standards will likely result in additional community drinking water sources throughout the Commonwealth requiring treatment for PFAS.

Presently, long-term solutions such as treatment for PFAS include granular activated carbon, ion exchange resins and high pressure membranes. Unfortunately, these treatments are costly and may be difficult to obtain given supply chain issues and high demand. Additionally, there is significant regulatory uncertainty around PFAS given that EPA is in the process of developing a MCL for PFOS and PFOA and recently revised the Health Advisory for PFOS and PFOA to levels below current analytical detection limits. Furthermore, there are challenges and costs associated with disposal of treatment byproducts. For these reasons, it is prudent for communities to evaluate all options for addressing PFAS, including seeking new supplies. For many communities in the Commonwealth, MWRA may be an option.

5. Stressed Basins

In addition to water quality issues, water quantity is a concern for many communities. Communities located in stressed river basins sometimes struggle meeting local demand with their sources, particularly during drought conditions. This may be due to variety of factors including increasing development and density, decreasing impervious area, and limited access to additional sources. Additionally, climate change continues to exacerbate impacts of drought and increase extreme weather conditions. Of particular concern is the Ipswich River Basin, where 14 communities (both within and outside the basin) rely on the Ipswich River as a water source, from PWSs and private ground water wells. The Ipswich River increasingly runs low or dry, even in non-drought years (Figure 6). Concern for maintaining this resource is constant for communities and residents who rely on this river not only for drinking water, but also for fire protection, recreation, tourism, and biodiversity. The river has garnered attention from state leaders and legislators looking for solutions, including obtaining water from sources outside the basin.

Figure 6: The Stressed Ipswich River in August 2016 (IRWA, 2023).

6. MWRA as a Resource to the Commonwealth

After years of relatively limited new drinking water regulations, allowing PWSs throughout the Commonwealth the ability to focus primarily on the operation and maintenance of their infrastructure, several new concerns for community public water suppliers across the Commonwealth are now arising. PFAS is a growing issue for many systems, MassDEP already set an MCL for PFAS6 and EPA recently proposed National Primary Drinking Water Regulations for six PFAS compounds. These emerging contaminants and subsequent regulations have left many communities with difficult and costly decisions to make. Additionally, many communities are facing increasing water quality challenges and difficulty meeting local demand. For many PWSs these impacts will undoubtedly be exacerbated by climate change in the coming years.

Years of strategic planning and the amazing foresight of our predecessors has uniquely positioned the MWRA to be a resource to the Commonwealth and to assist communities at these environmental and regulatory crossroads (Figure 7). MWRA's holistic approach to water system management has successfully maintained very high quality source water and efficiently reduced water use despite its growing service area. Because of this, MWRA has sufficient excess capacity to supply water to additional communities that are not presently part of the MWRA water system, while continuing to reliably supply its existing member communities. As noted, MWRA's average system demand is presently approximately 100 mgd below its system safe yield. This is water that could be utilized by communities struggling with water quality and/or quantity concerns.

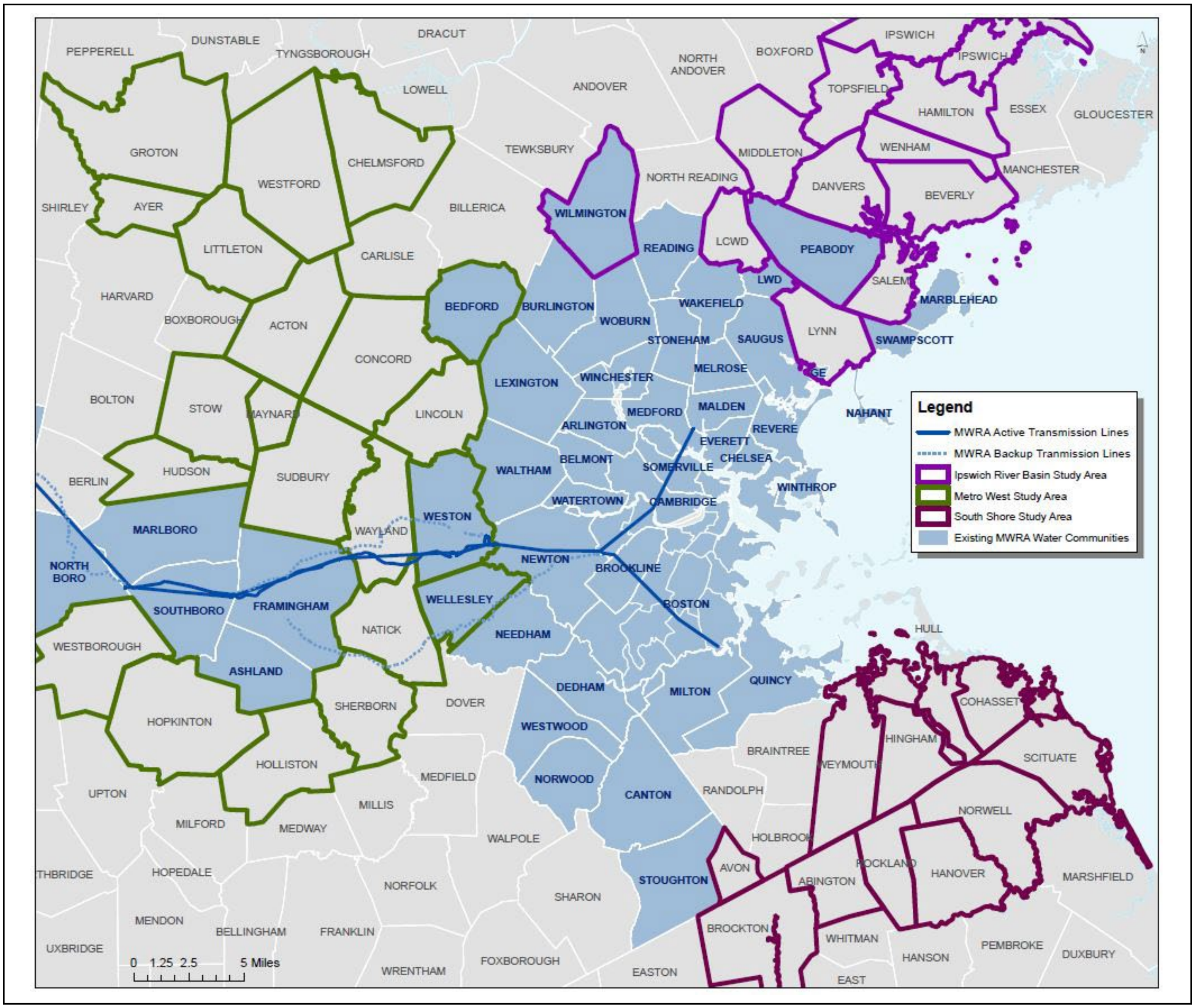
While capacity to supply water to new communities is not a concern, geography and infrastructure are logistical barriers for new communities interested in joining the MWRA water system. MWRA maintains extensive infrastructure; however, it is only feasibly accessible to certain communities based on geographic location and the costs of connection. Typically, communities can receive water from MWRA in one of two ways; directly from a connection to an MWRA pipeline, or indirectly via an existing MWRA water community. For this reason, communities near existing MWRA infrastructure or member communities are typically in a better position to connect with minimal additional infrastructure needed.

All new connections to the MWRA water system require infrastructure and planning to determine if and how much water MWRA could provide to a given community. MWRA is currently undertaking feasibility studies evaluating the potential to provide water to new communities in specific regions (Figure 8). One study focuses on the Ipswich River Basin, including the communities of Beverly, Danvers, Hamilton, Ipswich, Lynn, Lynnfield, Middleton, Peabody, Wenham and Wilmington. Another study focuses on the South Shore including the communities of Abington, Avon, Brockton, Cohasset, Hanover, Hingham, Norwell, Rockland Scituate and Weymouth. MWRA also recently commissioned a third study focusing on the MetroWest region including the communities of Acton, Ayer, Bedford, Chelmsford, Concord, Groton, Holliston, Hopkinton, Hudson, Lincoln, Littleton, Maynard, Natick, Sherborn, Stow, Sudbury, Wayland Wellesley, Westborough, Westford, and Weston. These studies aim to help communities in these regions better understand available water supply options. The studies will evaluate potential connection options to the existing MWRA water system, the cost for communities to connect and other issues that would need to be addressed for a community to be supplied by MWRA.

Figure 7: The Shores of Quabbin Reservoir (Massachusetts 2023)

7. Regional Solutions

Historically, many communities in Massachusetts have preferred to maintain individual, locally owned and operated public water supply systems. While this approach has been cost-effective and provided sufficient water supplies in the past, we are entering a new regulatory and climatic period, where it may be



appropriate for communities to consider other options, particularly evaluating the benefits of being part of a regional system like MWRA. While the logistics of constructing a new connection to the MWRA water system may not be feasible for an individual community due to costs, geography and infrastructure, a collaborative approach may change that outlook. Regional approaches to connecting to the MWRA water system may make the prospect of a large pipeline and construction project possible. Cost sharing of resources related to engineering, environmental permitting and construction, make finances more manageable for individual communities. A regional approach allows for a consolidation of resources to address a common problem.

Public water suppliers throughout the country will continue to face regulatory uncertainty in the years to come. MassDEP and EPA are currently focused on PFAS; there is good reason to believe that additional PFAS compounds will be regulated and that regulatory standards will become even more stringent. In 2023, the fifth Unregulated Contaminant Monitoring Rule (UCMR5) will include sampling for 29 PFAS compounds. Results from UCMR5 may result in additional PFAS compounds begin regulated at the federal and/or state level.

There is significant regulatory uncertainty around PFAS right now. Unfortunately for public water systems, there will always be other emerging contaminants of concern after PFAS to contend with. Connecting to the regional MWRA water system shifts the burden of complying with new regulations from many PWSs to one. In addition, the Commonwealth continues to face unpredictable weather patterns that may further impact communities' ability to provide clean drinking water. Given all of this uncertainty, joining a large, regional system like MWRA may prove to be an efficient and cost-effective decision for public water suppliers and communities throughout the Commonwealth.

8. References

DCR (2023) "DCR Ranger Services" Mass.gov. (n.d.). www.mass.gov. Retrieved June 16, 2023, from https://www.mass.gov/info-details/dcr-ranger-services

Ipswich River Watershed Association (2023). River Conditions. Available at: https://www.ipswichriver.org/river-conditions/ (Accessed: 02 July 2023).

Massachusetts Department of Environmental Protection (2023) " Per- and Polyfluoroalkyl Substances (PFAS)" Available at https://www.mass.gov/info-details/per-and-polyfluoroalkyl-substances-pfas.

MWRA (2021) "The Massachusetts Water Resources Authority (MWRA) Water System". (2021, March 30). Presented to 495/MetroWestPartnership.

MWRA (2023) "MWRA Water Expansion System" Retrieved February 22, 2023, from https://www.mwra.com/02org/html/expansion.html

Massachusetts (2023) "Commonwealth of Massachusetts Quabbin Reservoir". Mass.gov. https://www.mass.gov/locations/quabbin-reservoir

USEPA, 2023. Drinking Water Health Advisories for PFOA and PFOS. https://www.epa.gov/pfas

Evolution of Water Treatment in the Greater Boston Area

Valerie Moran[1], Betsy Reilley[2], William Sullivan[3] and Patricia Mallett[4]

[1] Director of Waterworks, Massachusetts Water Resources Authority, Boston, USA
[2] Director, Environmental Quality, Massachusetts Water Resources Authority, Boston, USA
[3] Senior Program Manager, Engineering & Construction, Massachusetts Water Resources Authority, Boston, USA
[4] Program Manager, Engineering & Construction, Massachusetts Water Resources Authority, Boston, USA

E-mail: Valerie.Moran@mwra.com, Betsy.Reilley@mwra.com, William.Sullivan@mwra.com, Patricia.Mallett@mwra.com

Published August 15, 2023

Abstract

For generations, Massachusetts Water Resources Authority (MWRA) and its predecessor agencies have strived to produce safe and better tasting drinking water. It takes more than a good raw water source to ensure safe and potable drinking water. Water treatment practices are key. This article will discuss what treatment processes MWRA, and its predecessors have used, and currently use, to meet and stay ahead of evolving water treatment requirements and will discuss potential next challenges on the horizon, as science allows us to detect ever smaller quantities of substances in water, and climate change alters natural reservoir and watershed processes.

Keywords: water treatment, drinking water, watershed protection, ozone, ultraviolet, disinfection, chloramination

1. Evolving Water Treatment

From Boston's early beginnings, there was a thirst for water. From the 1600s and into the 1800s, more and more water was needed to support the growing population, and the search for a water source pushed further and further out from the city. With superior foresight and planning, in the late 1800s and through the early 1900s, critical water supplies were developed with the creation of the Wachusett and Quabbin Reservoirs. MWRA's predecessors understood the benefits of establishing water sources upstream and away from the dense urban areas they served, providing protection from industries, large populations, and street runoff. Pristine upstream sources located at higher elevations also allowed the use of gravity to get the water to the coastal metropolitan area. The Wachusett and Quabbin Reservoirs continue to serve the needs of more than a third of the Massachusetts population today, providing clean, plentiful, and safe drinking water.

1.1 Surface Water Treatment Rule and MWRA's Waiver from Filtration

When the U.S. Environmental Protection Agency (EPA) Surface Water Treatment Rule (SWTR) came into effect in 1989, many surface water supply systems were required to provide filtration to address contamination concerns in drinking water. Under a narrow set of criteria, very well-protected sources like MWRA's Wachusett and Quabbin Reservoirs could receive a "waiver" of the filtration requirement. Wachusett Reservoir did not initially meet the filtration avoidance criteria. The MWRA in partnership with the then Metropolitan District Commission (MDC), began developing a Watershed Protection Plan to ensure the high-quality reservoirs would continue to provide clean safe water. While the watershed protection plan was developed, an initial decision was made in 1991 to build a filtration plant. In June 1993, MWRA entered a dual track scheduling Administrative Consent Order with the Massachusetts Department of Environmental Protection (MassDEP). The Consent Order 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.

The Watershed Protection Plan included the establishment of a Watershed Land Acquisition Program. This Program focuses on the protection of source waters by purchase of land or watershed preservation restrictions (WPR) within the Quabbin Reservoir, Wachusett Reservoir, and the Ware River watersheds. Since it was developed, it has protected 28,175 acres of watershed area (Table 1).

As noted, the Wachusett Reservoir did not initially meet the source filtration waiver criterion, specifically for fecal coliform bacteria levels. It was determined that the elevated bacteria levels were primarily due to flocks of gulls roosting on the reservoir. The Watershed Protection Plan included employing various actions to reduce the attractiveness of the region by better management of local landfills, discouraging the gulls roosting on the reservoirs, and incorporating shoreline management practices to minimize nesting and feeding areas. These efforts, including the Watershed Land Acquisition Program, which protected by ownership or easement 29% of the Wachusett Reservoir Watershed, were highly successful in reducing bacteria levels in the source water. By 1993, the Wachusett Reservoir was brought into compliance with the criteria of the filtration wavier (Figure 1). The Watershed Land Acquisition Program continues to be a significant factor in MWRA's ability to maintain our filtration waiver.

1.2. Treatment Decision

After an extensive research and decision-making process, the MWRA Board of Directors voted in October 1998 to request a waiver of the filtration requirements from MassDEP and to build a new water treatment facility using ozone for primary disinfection and chloramines for residual disinfection to treat the water from

Table 1. DCR Watershed Management Land Acquisitions 1985 compared to 2022.

Watershed	Total Watershed Area (Land Acres Only)	Acres Owned 1985	Percent Owned 1985	DWSP Fee 2022*	DWSP WPR 2022*	Total DWSP Controlled 2022*	Percent DWSP Controlled 2022*
Wachusett Reservoir	70,876	5,608	7.9%	17,868	2,716	20,584	29.0%
Ware River	61,671	19,300	31.3%	23,803	1,404	25,207	40.9%
Quabbin Reservoir	95,364	51,792	54.3%	54,280	4,804	59,084	62.0%
TOTAL	**227,911**	**76,700**	**33.7%**	**95,951**	**8,924**	**104,875**	**46.0%**

* Ownership numbers are through FY2022 (6/30/2022)

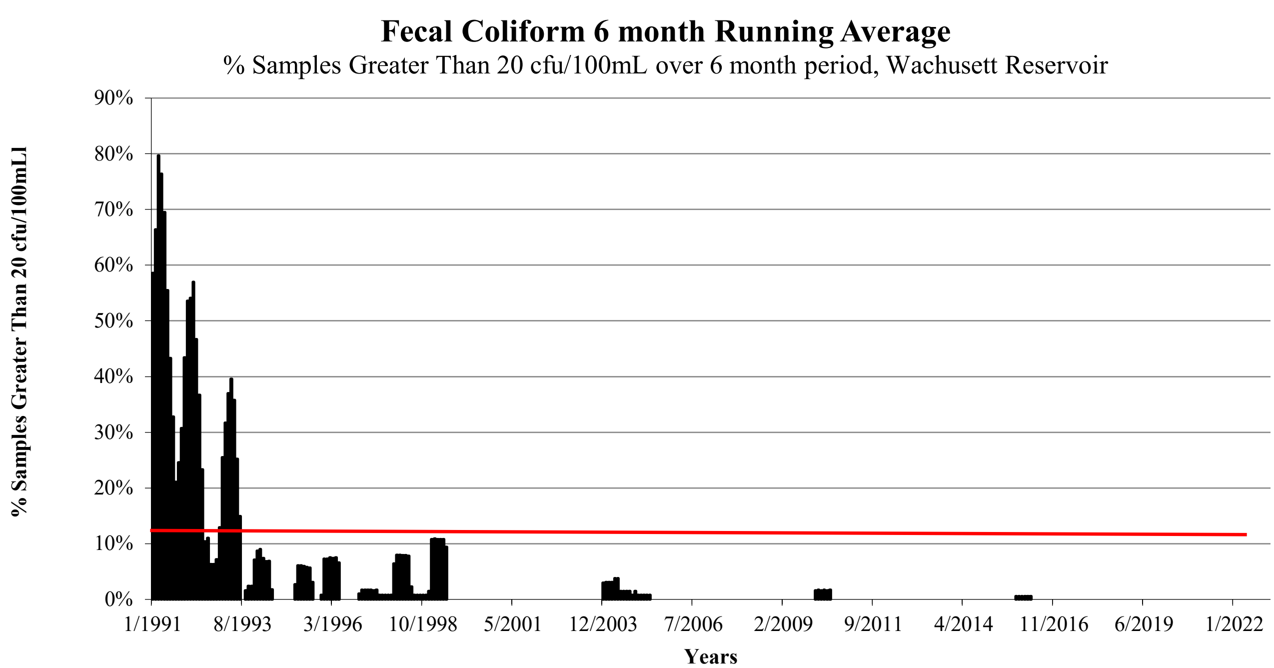


Figure 1. Presents compliance data under the SWTR; No more than 10% of fecal coliform results can exceed a count of 20 CFU/100mL in samples collected at least 5 times per week from the raw water source.

Wachusett Reservoir. To accomplish its overall water quality and water system goals, MWRA established a 10-year, $1.7 billion Integrated Water Supply Improvement Program. The Improvement Program was developed to improve the reliability and quality of the water supply and meet the stringent requirements of the SWTR. Key components of the Improvement Plan included watershed protection, construction of water treatment facilities, construction of a water transmission tunnel, removal the existing open reservoirs from service, construction of covered water storage facilities and distribution pipelines improvements. In December of 1998, MassDEP agreed with the MWRA approach and determined that filtration was not required for the MWRA system. This decision was challenged in court by the EPA, but Federal District Court Richard G. Judge Stearns ultimately found that EPA failed to show that filtration of MWRA water was required either as a matter of cost-benefit or scientific necessity.

1.3 Effective Disinfection

Chlorination of drinking water first began in the United States (US) in the early 1900s and was critical to improving the public safety of water and reducing the transmission of disease. In 1930, the Metropolitan District Commission (MDC), the governing public water supply agency at the time, began using continuous chlorination of all potable water delivered to the water distribution system (DeMarini, 2020). By 1932, the treatment process of water evolved to chloramination. Chloramination is the process of adding chloramine to drinking water to disinfect it and kill germs. It is sometimes used as an alternative to chlorination. Chloramines are a group of chemical compounds that contain chlorine and ammonia (CDC, 2020). MWRA's water distribution system was the first large water distribution system in the US to employ chloramination as its method of disinfection. The combination of effective disinfection practices and the use of pristine water sources are attributed to some of the reasons why the Metropolitan Boston Region experienced lower levels of waterborne disease than the rest of the country, during the 1930s (Kempe, 2006).

The Total Coliform Rule (TCR) was implemented by the EPA in 1989. As data was collected throughout MWRA's and community distribution systems under this new rule; it was apparent that maintaining chlorine residuals through the large distribution system continued to be a challenge. During the 1990s, MWRA member communities experienced elevated total coliform positives and depressed system chlorine residuals within the water. At the time, disinfection with chloramines was performed at the Norumbega Open Reservoir (in addition to chlorination at the other open reservoirs, until they were removed from service) but, there was no free chlorine contact time as chlorine and ammonia were added simultaneously. To better optimize the chlorine to ammonia ratio, MWRA decided to separate the chlorine and ammonia addition points at Norumbega Reservoir, the modification was completed in August of 1997. Following this change, the chlorine to ammonia ratio within the distribution system was adjusted from 11:1 to about 4.5:1 to 5:1. Dramatically improved distribution chlorine residuals were observed after the separation (Figure 3).

1.4 Implementing Corrosion Control

Prior to the promulgation of the EPA's Lead and Copper Rule (LCR) in 1990, lead was regulated at 50 µg/L at a free running tap. The MDC had experimented with full-scale zinc orthophosphate treatment within the distribution system in an effort to reduce lead corrosion in 1976, but discontinued this treatment method when

Figure 2. Map of Key locations at Wachusett Reservoir and Downstream Distribution System.

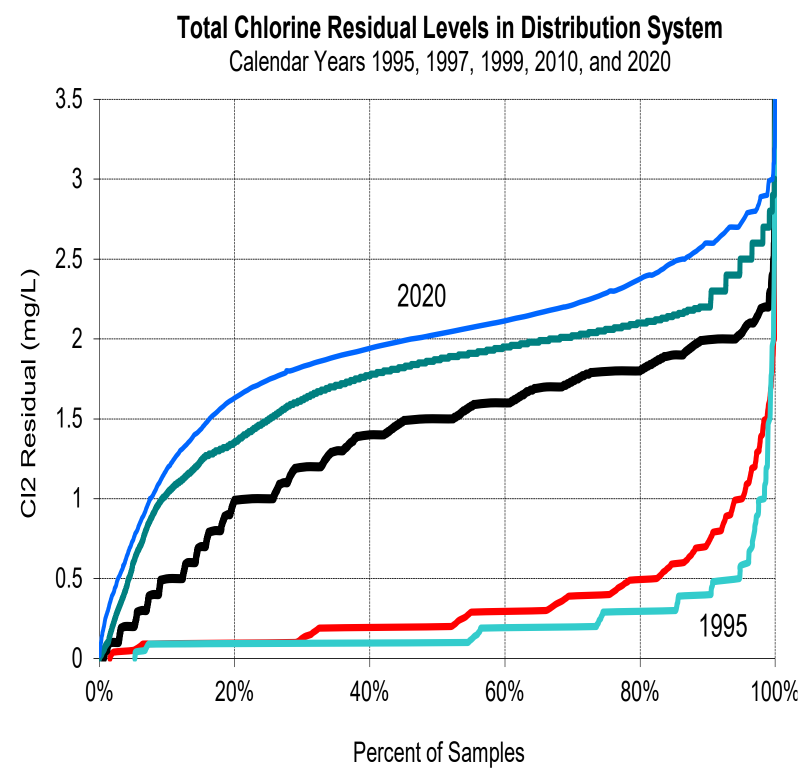


Figure 3. Improved distribution of chlorine residuals recorded following treatment improvements Norumbega Open Reservoir (1997).

lead sampling indicated no improvement and algae blooms occurred in downstream open reservoirs. Starting in 1978 and continuing to 1996, the MDC, and later the MWRA, raised the pH of the water by the addition of sodium hydroxide with a target entering the system of pH around 9 at Shaft 4 (located on Figure 2). However, pH levels varied significantly were frequently in the mid-7 range in the distribution system because Wachusett Reservoir water has little buffering capacity. The LCR established a more stringent Action Level of 15 µg/l in water. To meet the requirements of the new rule, the Interim Corrosion Control Facility (located on Figure 2) was constructed at the beginning of the distribution system, to adjust both pH and alkalinity by feeding soda ash and carbon dioxide into the water. The Interim Corrosion Control Facility was placed on-line in June 1996. Initial targets for water sampling were pH 7.5-7.8 and alkalinity 30 mg/L and were ramped up gradually to avoid scale disruption. In July 1998 the pH was adjusted upward to 9.0, while alkalinity remained at 30 mg/L. In March 2002, alkalinity was adjusted to 35 mg/L. In February 2004 alkalinity was adjusted to 40 mg/L. Current targets are pH 9.3-9.5 and alkalinity 40 mg/L. These small adjustments were made in an effort to reduce lead corrosion and bring water in the overall system into compliance with the lead Action Level. Lead levels have dropped significantly over the period, although individual communities periodically exceed the lead Action Level (Figure 4).

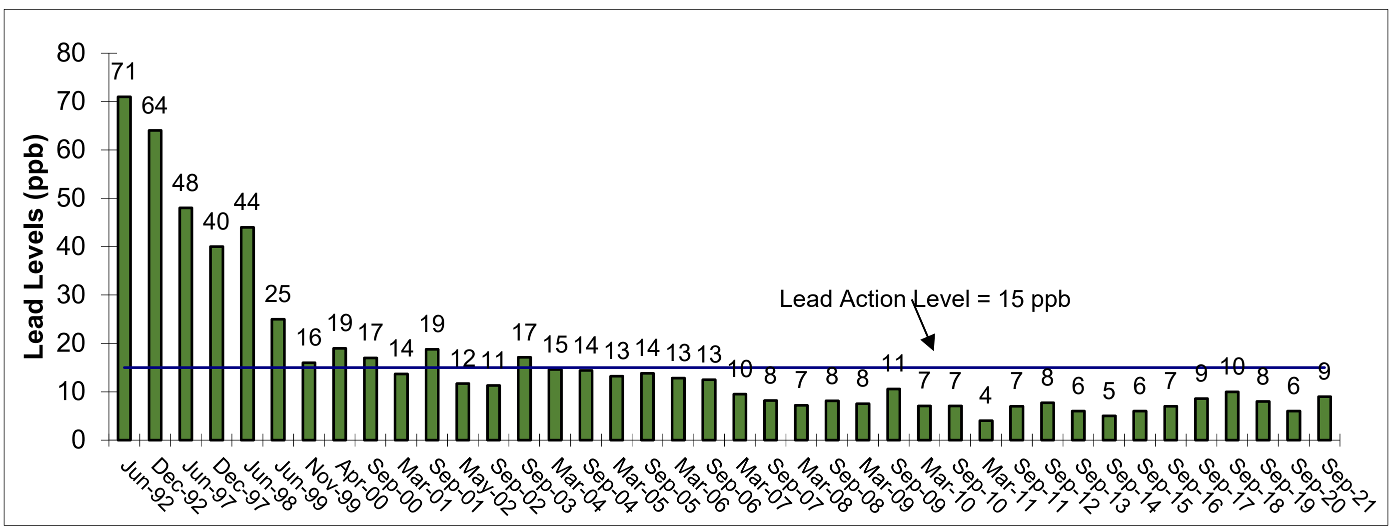


Figure 4. Significant drop in the lead levels after corrosion control processes were established.

1.5 Pivoting from Open Reservoirs to Covered Water Storage

While the Watershed Protection Plan concentrated on source water protection to help meet filtration waiver goals, MWRA formulated a plan to remove its remaining open reservoirs from service. After the Blue Hills Reservoir was removed from service in 1981, MWRA still maintained four open reservoirs in active distribution throughout the 1980s and 1990s. Several of these reservoirs required booster chlorination water downstream, and multiple downstream communities also practiced phosphate addition and additional booster chlorination. Pivoting to covered water storage would lessen the risk of contamination to the potable water and stabilize water quality. Between the years 1995-1998, MWRA retired the Weston, Spot Pond, and Fells Reservoirs, removing them from service. In March 2004, MWRA's 115-million-gallon Norumbega Covered Storage Facility was put on-line and the Norumbega Reservoir, the remaining open reservoir, was removed from service. For the first time, water from the Wachusett Reservoir did not see the light of day from when it left the Reservoir until it reached customers taps.

In subsequent years, two more covered water storage projects were completed replacing two off-line reservoirs; two 10-million-gallon covered storage tanks were completed at Blue Hills Reservoir in 2009, replacing the off-line Blue Hills Reservoir and the Spot Pond Storage Facility completed in 2015 consists of two 10-million-gallon covered storage tanks, replaced the off-line Spot Pond Reservoir

1.6 The John J. Carroll Water Treatment Plant

The Carroll Plant (location shown in Figure 2) was completed in July 2005. This facility allowed for the consolidation of all water treatment − disinfection, and corrosion control − within a single facility, and included water storage at the end of the treatment process, resulting in a more stable treatment process and improved water quality.

Treatment at the Carroll Plant includes ozonation for primary disinfection, chloramines for residual disinfection, fluoridation for dental health, and soda ash and carbon dioxide for corrosion control. The Carroll Plant is designed to treat up to 405 million gallons of water per day.

1.7 Strengthening Primary Disinfection

The SWTR required that distribution water from unfiltered systems achieve 3-log *Giardia* and 4-log virus inactivation. The Carroll Plant uses ozonation (Figure 5) to inactivate *Giardia* and viruses within the water. This process reduces disinfection by-products and enhances taste and odor of the water. The ozonation process at the Carroll Plant was also designed to voluntarily achieve 2-log inactivation of *Cryptosporidium,* even though this was not required by regulation at that time.

When the Long Term 2 Enhanced SWTR was issued in 2006 it required that unfiltered water systems have two primary disinfectants, one of which was required to inactivate *Cryptosporidium.* The Carroll Plant modified their water treatment process to include ultraviolet (UV) disinfection (Figure 6) as a second primary disinfectant to inactivate *Cryptosporidium* in 2014.

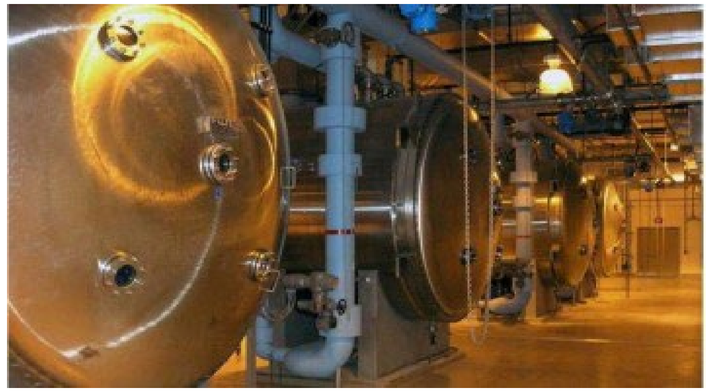


Figure 5. Ozone generators at Carroll Plant.

Figure 6. Ultraviolet disinfection units at Carroll Plant.

Using ozone since 2005 and UV light since 2014, the Carroll Plant has exceeded regulatory requirements for inactivation of 99.9% of Giardia, 99% of *Cryptosporidium* and 99.99% of viruses that may be in our source water. These disinfectants perform without creating the regulated disinfection by-products (total trihalomethanes, and halo acetic acids) that were created by the previous 'chlorine-only' treatment. The levels of disinfection by-products dropped dramatically since the Carroll Plant went on-line (Figure 7). Most noticeably to MWRA customers, ozone reduces apparent water color and neutralizes taste and odor compounds that previously affected the system, particularly during summer when algae grow in Wachusett Reservoir.

Chlorine and ammonia are combined at the Carroll Plant to form monochloramine, a stable and long-lasting residual disinfectant, which carries deep into MWRA's community distribution systems inhibiting microbiological re-growth. Presently, over two thousand bacteriological samples are collected from community distribution systems each month and bacterial counts are continuously very low and chlorine residuals have been very good without a residual chlorine taste and odor complaints.

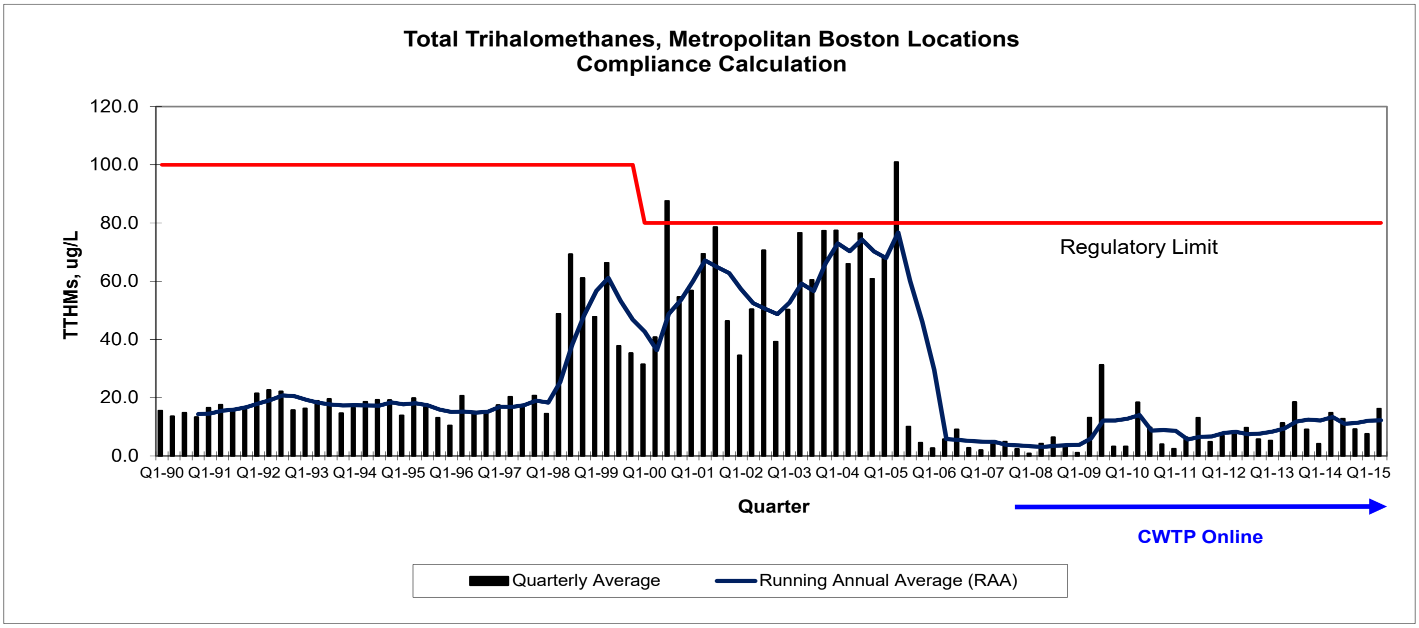


Figure 7. Levels of disinfection by-products dropped dramatically after the Carroll Plant went online.

MWRA's drinking water has achieved several accolades including receiving the New England Waterworks Association (NEWWA) the "Best of New England" taste award multiple times and first and second place ranking in the "Best of the Best" Water Taste Test at the American Waterworks Association's National Conference (AWWA) in 2014 (for Boston and MWRA entries). Most recently, MWRA won first place in AWWA's 16th "Best of the Best" Water Taste Test in 2021. In addition to industry drinking water awards received, the plant water operations and quality assurance staff have also received the MassDEP's Public Water System Award, and the Annual Water Fluoridation Quality Award from both the US Centers for Disease Control (CDC) and Massachusetts Department of Public Health.

2. Future Challenges

2.1 Revisions to the Lead and Copper Rule

To continue to provide excellent drinking water and improve upon the current treatment technology; MWRA will soon initiate a study to evaluate further optimization of corrosion control treatment. This study is in response to the LCR Revisions of 2021. The original LCR, discussed above, included an Action Level of 15 µg/l lead within distribution water. Revisions to the original LCR included a 10 µg/l "Trigger Level" level that will require water systems to provide further water treatment, monitoring and public notification actions when the threshold level is exceeded. When more than 10 percent of samples collected during a monitoring period exceed the action level; the water distribution system must implement additional corrosion control treatment within 48 months of the sampling event. Regional sampling of MWRA distribution system has historically tracked below 10 µg/l. However, since some of MWRA's community member systems water sampling has exceeded 10 µg/l; MWRA has proactively initiated a corrosion control study, in advance of regulatory requirements. As part of the study, MWRA collected excavated lead service lines from community members and assembled six sets of four pipes to support the evaluation of alternative corrosion control strategies (Figure 8). MWRA convened an outside panel of experts in corrosion control treatment to optimize the strategies explored and assist in development of the experimental plan. MWRA plans to commence the study once acclimation is complete in August 2023.

2.2 Emerging Concerns

New challenges are ever present in the drinking water industry. Fortunately, with well-protected water sources and watersheds, MWRA water quality and quantity continues to be excellent. Looking forward, MWRA anticipates experiencing both more intense rain events, and more periods of drought due to changing weather patterns brought on by climate change. The full impacts of the changing weather patterns is not fully understood. MWRA is already observing greater variability in organic levels in samples from source water supply, as measured by UV254. Higher levels of organics have multiple impacts including higher chlorine demand and higher rate of chloramine decay, which makes it harder to maintain chlorine residuals throughout community distribution systems. The changing weather patterns may also favor the growth of cyanobacteria in the water. These developing trends actively threaten water quantity and reliability of other water systems, outside of MWRA's drinking water service area. MWRA's water conservation efforts have resulted in a water

Figure 8. Corrosion control study - lead pipe rigs.

distribution system that has the capacity to aide other communities in the region.

Throughout the Northeastern US, chloride concentrations have been increasing in freshwater bodies, streams, and groundwater. The increased chlorides have been attributed to road salt application and they have the potential to increase the corrosivity in the water distribution system. Increased corrosivity may then have a cascading effect on the water distribution system including, impacting lead levels, and aquatic life in reservoirs. MWRA and DCR staff are monitoring rising chloride levels in the Wachusett and Quabbin Reservoirs. MWRA has funded training for local Department of Public Works (DPW) staff and is funding new de-icing equipment to reduce road salt applications throughout the MWRA – DCR watershed area.

While Per- and polyfluoroalkyl substances (PFAS compounds) − a family of chemicals used since the 1940s to manufacture stain-resistant, water-resistant, and non-stick products − are adversely impacting many water supplies throughout the country, they have only been detected at trace levels in the MWRA system. MWRA continues to routinely tests samples for PFAS compounds as well as for another contaminant of emerging concern, Harmful Algal Blooms (HABs) and cyanotoxins, which have only been detected at very low levels.

MWRA's water distribution system has been instrumental in meeting the water needs of Massachusetts residents and industries. The foresight and dedication of our predecessors have resulted in a remarkable water system that is designed to cater to future generations. MWRA is committed to an ongoing mission of enhancing water quality, striving to deliver reliable, cost-effective, and high-quality water that prioritizes public health, environmental conservation, customer confidence, and a thriving economy. This is achieved through sustained efforts in watershed protection, innovative water treatment methods, and effective communication with member communities.

MWRA remains vigilant in tracking proposed state and federal drinking water regulations to ensure compliance and safety. When appropriate, MWRA provides comments on proposed regulations and collaborates with member communities to discuss their potential impact. This proactive approach helps preserve MWRA's water system for the benefit of future Massachusetts residents, ensuring a sustainable and secure water supply for generations to come.

References

Centers for Disease Control and Prevention. (2020, November 17). Water disinfection with chlorine and chloramine. Centers for Disease Control and Prevention. Retrieved November 19, 2022, from https://www.cdc.gov/healthywater/drinking/public/water_disinfection.html#:~:text=Chloramination%20is%20the%20process%20of,that%20contain%20chlorine%20and%20ammonia.

DeMarini D. M. (2020). A review on the 40th anniversary of the first regulation of drinking water disinfection by-products. Environmental and molecular mutagenesis, 61(6), 588–601. https://doi.org/10.1002/em.22378

Kempe, M. (2006) “New England Water Supplies - A Brief History”, Journal of The New England Water Works Association Volume 120 No. 3, pages 15 and 57.

Morita, S., Namikoshi, A., Hirata, T., Oguma, K., Katayama, H., Ohgaki, S., Motoyama, N., & Fujiwara, M. (2002). Efficacy of UV irradiation in inactivating Cryptosporidium parvum oocysts. Applied and environmental microbiology, 68(11), 5387–5393. https://doi.org/10.1128/AEM.68.11.5387-5393.2002

Volume 31, Number 1

Completing the Greater Boston Metropolitan Water System

Authored by: Kathy Murtagh[1], David Coppes[2]

[1] Director of Tunnel Redundancy, MWRA, Boston, United States of America
[2] Chief Operating Officer, MWRA, Boston, United States of America

E-mail: Kathy.Murtagh@mwra.com and Dave.Coppes@mwra.com

Published August 15, 2023

Abstract

The Massachusetts Water Resources Authority (MWRA) currently provides wholesale water and wastewater services to over 3.1 million customers in 61 communities in eastern and central Massachusetts with most service communities located in the Boston area. The Quabbin Reservoir and Wachusett Reservoirs, which are the main water supply sources, are located 65 and 35 miles west of Boston, respectively. Plans were developed in the 1930's to provide for a redundant water system for the Boston area; however, the outbreak of WWII caused those plans to be postponed. A redundant water transmission system exists for approximately 25 miles from the Wachusett Reservoir to the beginning of existing Metropolitan Tunnel System in Weston with the Boston area remaining without redundancy.

Work today is underway to complete the Great Metropolitan Water System with a combination of pipe, tunnel and storage projects. A number of these projects are complete or currently underway. An integral part of completing the water system is the planned Metropolitan Water Tunnel Program which is proposed to consist of approximately 14.5 miles of 10-ft internal diameter deep rock tunnel at an estimated cost of approximately $1.8 billion.

This paper presents a historical perspective of water supply redundancy for the Boston area including plans originating in the 1930's, redundancy projects completed and currently underway and the Metropolitan Water Tunnel Program.

Keywords: water, redundancy, tunnel, transmission

1. Introduction

Reliable delivery of water is critical to protecting public health, providing sanitation, fire protection and is necessary for a viable economy. Redundancy is important in achieving a high degree of reliability for a water system. One important way that redundancy achieves this is by allowing major equipment, pipelines, and appurtenant structures to be taken offline for regular inspection and rehabilitation. Redundancy is reflected in different ways in different circumstances but generally, it means eliminating or managing 'single points of failure' within a system. Depending on the configuration of a water system, different means of providing redundancy or creating operational flexibility allows a utility to respond to emergencies or unforeseen conditions. For example, for utilities like MWRA, where there is a single water source and treatment facility that feeds the metropolitan Boston area, redundant transmission mains are critically important. Intake and treatment systems are designed following an 'N+1' philosophy to limit the impact of equipment failures on the ability to continue to deliver water. The 'N+1' strategy has a long history in waterworks and is now mandated in Department of Environmental Protection design guidelines. It provides the required number of pieces of equipment (for example chemical feed pumps) to meet the design maximum output of the facility with any (or in case of varying size equipment – the largest) piece of equipment out of service.

1.1 Water System Redundancy Is Not A New Idea

Examples of redundancy principles in our metropolitan water system are sprinkled throughout the history of our great water system. In the late 1800s there were two basins at the Chestnut Hill reservoir (the former Lawrence Basin, now the site of Boston College's Alumni Stadium and Bradley Basin the sole remaining reservoir – see 1949 photograph in Figure 1 showing the two basins with Lawrence Basin in foreground, Shaft 7 construction and the Chestnut Hill pump station in the background); one to settle water from the Cochituate Aqueduct and the other the Sudbury Aqueduct but both somewhat interchangeable. At the outlet of the pump station at Chestnut Hill two (east and west) supply lines carried water to Spot Pond. There were initially two Weston Aqueduct supply lines for the Boston low service system; each taking a different route. The Cordaville pipeline was built in 1928 to bring water in from the south Sudbury (Ashland and Hopkinton) reservoirs while the Quabbin reservoir was being planned and constructed.

The Quabbin intake was constructed with two independent intake lines, one used for releases to the Swift River and the other used decades later for the Chicopee Valley Aqueduct. The Hultman Aqueduct was completed in 1940 with plans and infrastructure left behind for a second barrel. This 1940 photo in Figure 2 shows concrete placement for a future aqueduct connection at Shaft 4 of the Hultman Aqueduct. The onset of World War II prevented completion of the second pipeline. The Chicopee Valley Aqueduct was built on one side of its easement to make room for a second future barrel.

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

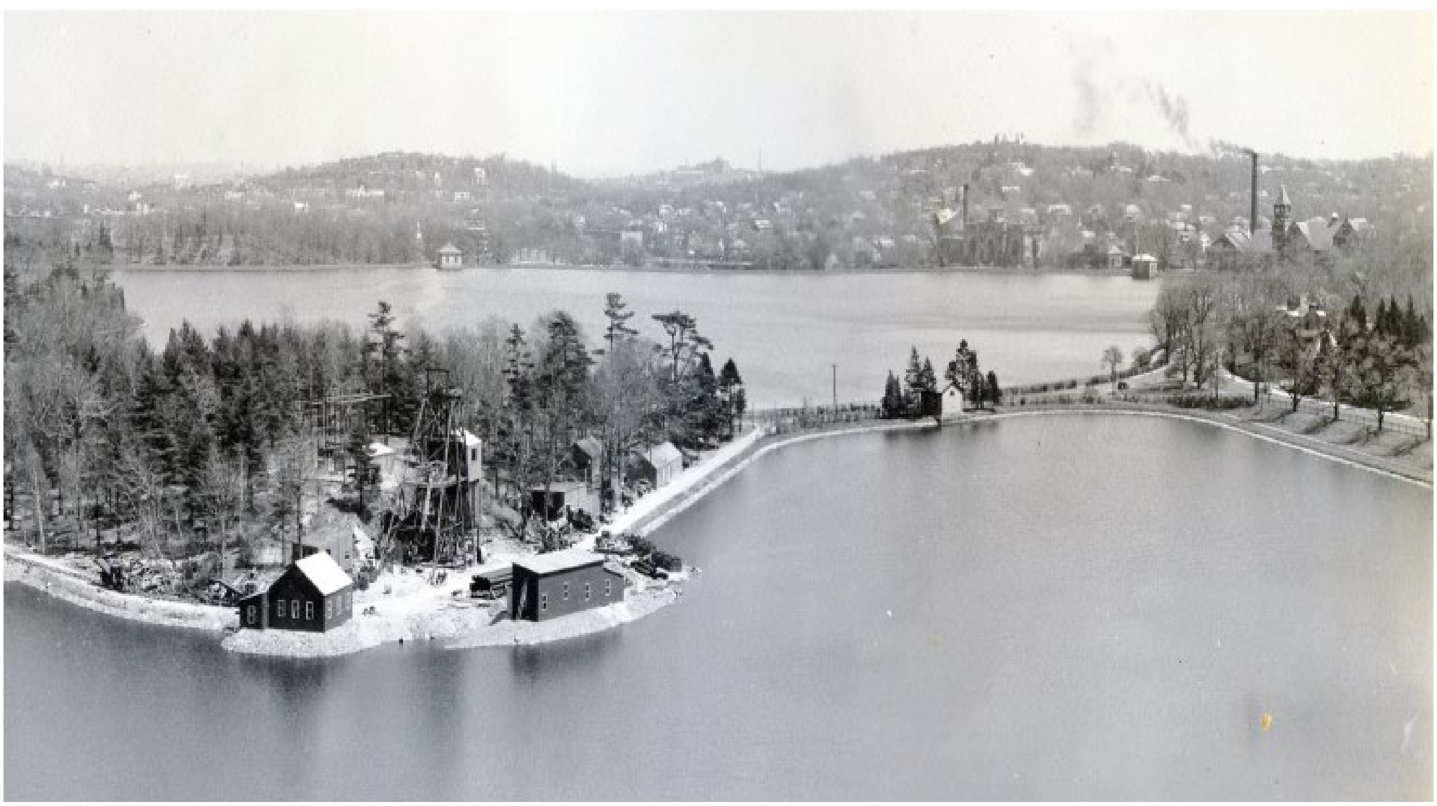


Figure 1. Lawrence and Bradley Basins of the Chestnut Hill Reservoir (MWRA collection)

Figure 2. Future aqueduct connection at Shaft 4 of Hultman Aqueduct (MWRA collection).

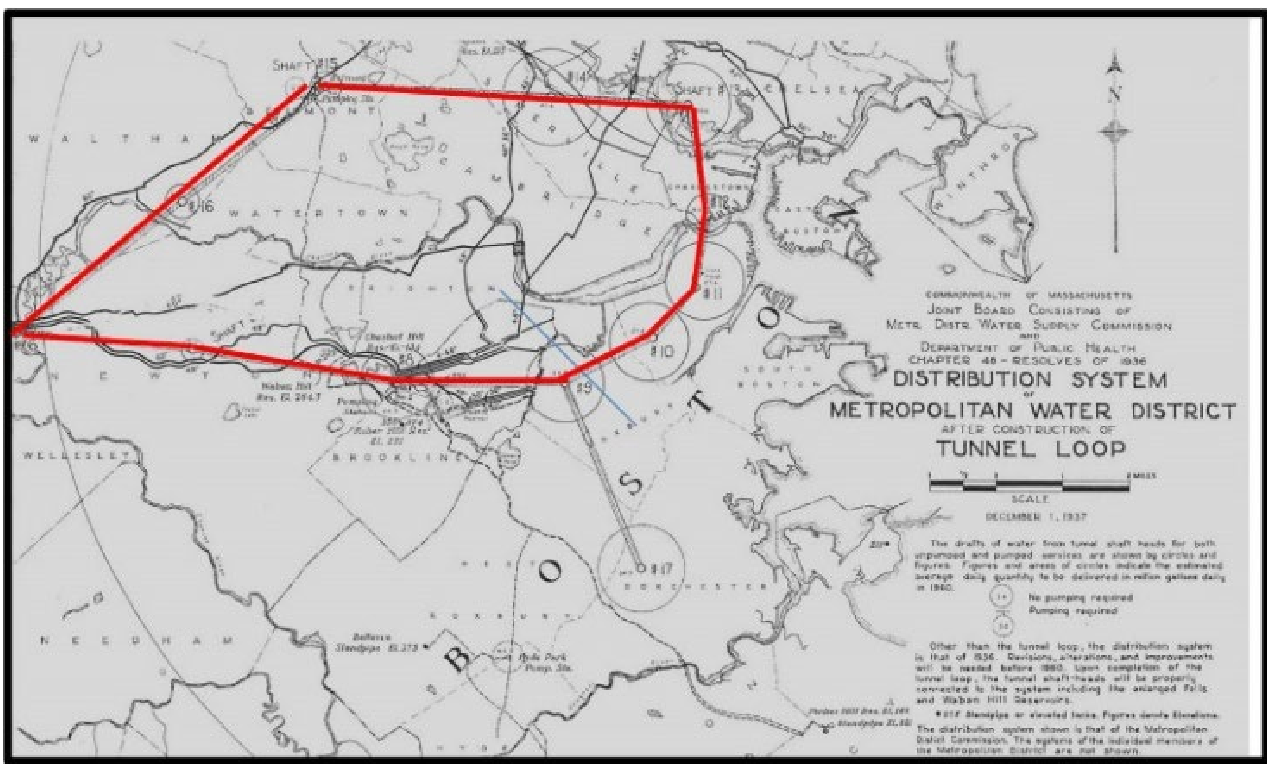


Figure 3. Proposed Metropolitan Water District Tunnel Loop plans, the red line highlights the proposed tunnel loop (MWRA collection).

The original plan for a looped Metropolitan Tunnel system was developed in 1936 as shown in the plan in Figure 3. Some of the spokes of the system were constructed; the City Tunnel (1950), City Tunnel Extension (1963) and the Dorchester Tunnel (1976) which all come together at Chestnut Hill. However, the proposed tunnel loop was never completed.

1.2.1 MWRA Track Record

Since MWRA's inception, there has been an ongoing effort to improve water system operation and reliability through the MWRA capital improvement program and Master Plan process. Many of the projects that have been completed, that are underway, or are proposed provide an improvement in system redundancy in part, if not in total; eliminating single points of failure, preserving the viability of back-up systems, and preventing further loss of redundancy.

Probably the most important accomplishments in terms of elimination of single points of failure of the water transmission system is construction of the MetroWest Water Supply Tunnel, the Hultman Aqueduct interconnections project, and construction of the Wachusett Aqueduct Pump Station. After decades of planning, design and construction the tunnel came on line in November, 2003. It now provides a second means of water conveyance from the John J. Carroll Water Treatment Plant to the Norumbega Covered Storage Facility and ultimately the City Tunnel and Metropolitan Tunnel distribution system.

The MetroWest Tunnel is a 17.6 mile long, 14-foot diameter deep rock tunnel (with a 12-foot diameter connection to the Loring Road Covered Storage Facility) and it was constructed to ensure that there was a redundant means of providing water to the Metropolitan area in the event of a failure along the Hultman Aqueduct. The Hultman Aqueduct was then rehabilitated after 70+ years of continuous service and interconnecting structures created to provide the ability to isolate sections of either transmission main while continuing to provide water service to the Metropolitan area. The final Hultman interconnecting mains project was completed in 2013. This photo in Figure 4 shows the new valve chamber at Shaft 5 which provides an interconnection between the MetroWest Tunnel and the rehabilitated Hultman Aqueduct.

The Cosgrove Tunnel is another critical transmission system component that brings water from Wachusett reservoir to the Carroll Water Treatment Plant. The back-up to this tunnel is the gravity Wachusett Aqueduct which can supply approximately 240 MGD of water to the service area. The aqueduct was rehabilitated in 2002 to allow connection of the treatment plant to the Cosgrove Tunnel. However, it operates at a lower grade line than the treatment plant and therefore could not provide water that meets drinking water standards without boiling and booster chlorination. Construction of a pump station at the end of the Aqueduct was completed in 2018 as the means to protect against a Cosgrove Tunnel failure. The pump station is shown in Figure 5. The facility lifts water to the treatment plant, allowing the Cosgrove Tunnel to come out of service without impacting water quality. The 240 mgd capacity allows for unrestricted supply for at least eight months during the lower demand fall/winter/spring period.

Other completed transmission and distribution redundancy projects include:

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

The Spot Pond Pump Station and Storage Tank project (shown in the photo in Figure 6) provides back-up capabilities to the Gillis pump station, similar to the back-up stations constructed in the 1950's in the Northern Extra High and Southern Extra High service areas. Gillis Pump Station supplies the Northern Intermediate High/Bear Hill service area and the Northern High

Figure 4. Valve chamber at Shaft 5 connecting MetroWest Tunnel and Hultman Aqueduct (MWRA).

Service/Fells service area. The new Spot Pond Pump Station and Storage Tank (completed 2015) provides operational flexibility for supply to the Northern Intermediate High and Fells service areas and 20 million gallons of critical storage for the Northern Low service area in the event of service interruption. The Spot Pond Pump Station is capable of drawing water from either the low service or high service zones and can pump to the high and intermediate high zones providing much needed redundancy to Gillis Pump Station.

Figure 5. Wachusett Aqueduct Pump Station (MWRA 2004-2015)

In addition to the improvements described above to the NIH service area pumping capability, another series of crucial projects is underway to eliminate what is essentially a single pipe system and concern over the potential for a catastrophic failure of a 10,000 foot portion of this pipeline made of Prestressed Concrete Cylinder Pipe that was constructed by a particular manufacturer with a Class IV wire that has been prone to embrittlement and failure elsewhere in the country. A completed redundant pipeline 6 miles long and 36 to 48 inches in diameter now supplies the area and the fifth and final construction contract to replace the pipeline of concern is underway.

Figure 6. Spot Pond Pump Station and Storage Tank project (MWRA 2004-2015)

In the Southern Extra High Service Area, pipeline Sections 77 and 88 were 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. MWRA's Southern Extra High service area provides drinking water to Canton, Dedham, Norwood, Stoughton, Westwood, portions of Brookline and Milton, and the Roslindale and West Roxbury sections of Boston. This project, completed in 2020, provides redundancy for this pressure zone. The photo in Figure 7 shows masked staff turning the valve to activate the new pipeline during the height of the corona virus pandemic. Construction of the 5.4 mile 36-inch diameter water main was broken into three separate construction contracts through Boston, Dedham, and Westwood.

Figure 7. Masked staff activating new pipeline during corona virus pandemic (MWRA)

2. Remaining Transmission System Redundancy Needs / Completing the 1936 Plan:

The completed and ongoing improvements to surface piping, pump stations and storage facilities however, do not replace the need for redundancy for the Metropolitan Tunnel System (i.e., City Tunnel, City Tunnel Extension, and Dorchester Tunnel). The need for this redundancy was highlighted in May 2010 when a coupling joining two segments of 10 foot diameter pipe located between the MetroWest Tunnel and Shaft 5 ruptured resulting in a strain on system supply, the need for a major system reconfiguration and activation of back-up supplies. The incident resulted in a release of approximately 250 mgd over a period of eight hours until the break was isolated. During this time, an emergency water source was activated to maintain water supply prior to shutting down the affected pipe. While the pipe was being repaired over the following two days, the Boston metropolitan area was supplied through alternate lower capacity mains with augmentation from an emergency raw water reservoir with chlorination. The entire metropolitan service area was issued a boil water order during these two days. This boil water order affected approximately 2 million people in 30 serviced communities.

Unfortunately, this water main break occurred while the Hultman Aqueduct was off-line for long needed maintenance and repairs, otherwise a transition of supply from the MetroWest Tunnel to the Hultman would have been implemented with no interruption in service.

In 2017 the MWRA Board of Directors approved a plan to construct 2 new deep rock water tunnels to provide redundancy for the aging Metropolitan Tunnel System which, once constructed, will allow it to be taken out of service and receive much needed inspections, maintenance, and repairs.

Planning and design for the Metropolitan Water Tunnel Program, approximately 14.5 miles of deep rock pressure tunnel located within the greater Boston area, has been underway since 2018. These new tunnels along with rehabilitation of the WASM3 pipeline, will provide the much needed redundancy and complete the 1936 plans for a tunnel loop.

The Tunnel Program will connect to the Hultman Aqueduct in Weston with one tunnel extending ~4.5 miles north to Waltham, near the Belmont line where a connection to MWRA's Weston Aqueduct Supply Main number 3 will be made and a second tunnel extending ~10 miles south/southeast to Mattapan with a connection to surface pipelines near Shaft 7C of the Dorchester Tunnel. Six smaller diameter intermediate shafts will be constructed along the tunnel alignments to allow for connections to be made to MWRA and community pump stations as well as key surface piping. Figure 8 shows the planned shaft locations as well as the Program study area that was initially evaluated.

The Tunnel Program is currently in the preliminary design phase and is targeting the start of tunnel construction in 2027.

Preliminary design involved a significant alternatives evaluation that resulted in the selected shaft sites and a preferred tunnel alignment which is summarized in the recently submitted DEIR and SDEIR for the Program. Geotechnical investigations, survey, permitting, hydraulics analysis, site layout, shaft and tunnel design, and other aspects of preliminary design are underway. An important component of the preliminary design will be the selection of how the various construction elements (shafts, tunnel, surface structures, etc.) will be packaged into construction contracts, the phasing of the construction contracts and an updated cost estimate and construction schedule. MWRA's Capital Improvement Program currently includes $1.8B for the Tunnel Program with overall Program completion on or before 2040.

Once constructed, the Metropolitan Water Tunnel Program will complete the vision of a looped Metropolitan Tunnel system that has been almost a century in the making and at times had few

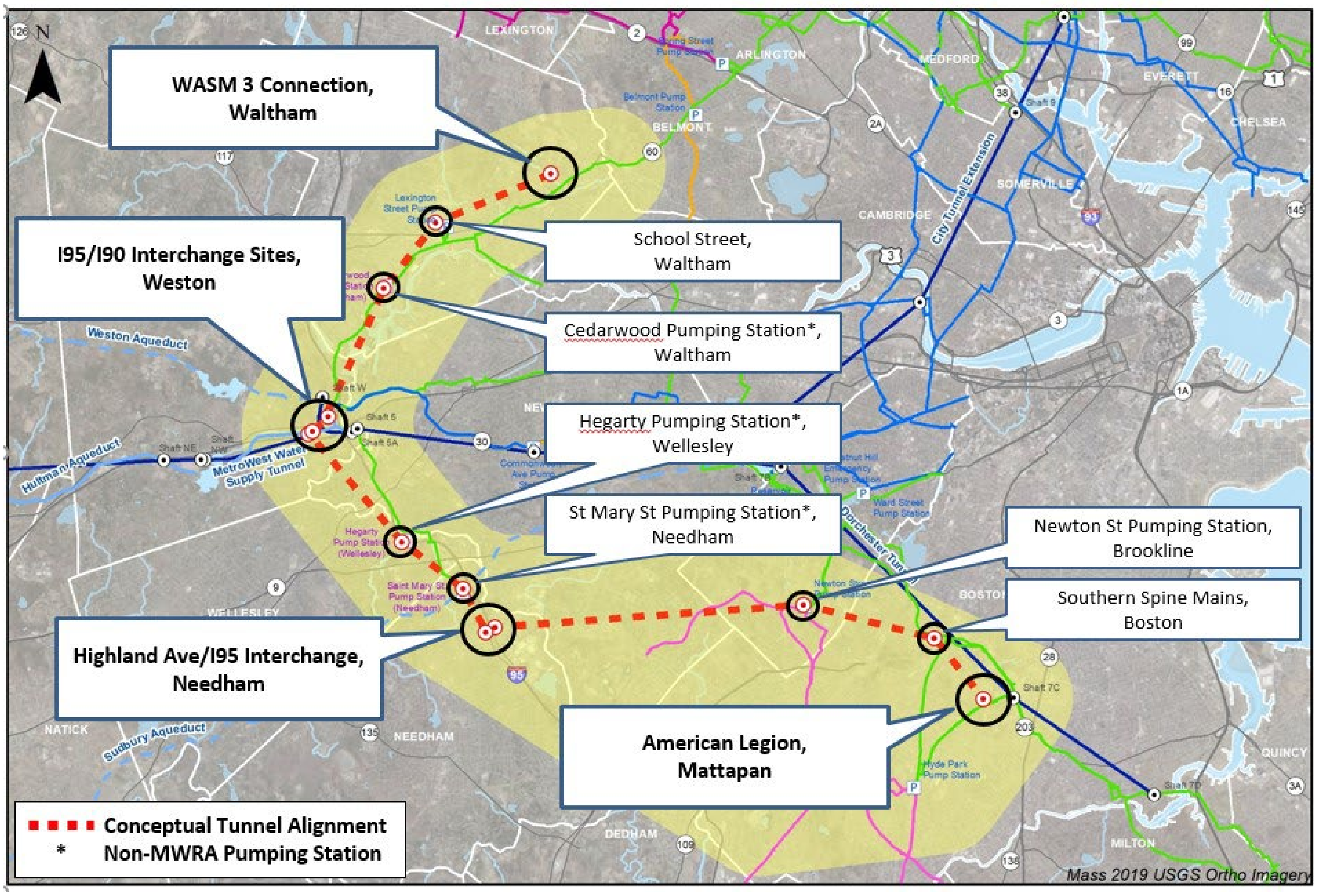


Figure 8. Proposed shaft locations and program study area of initial evaluation (MWRA 2004-2015)

champions and little support. An unfiltered water system, with a pure upland water source, strong watershed protection, gravity feed, and soon with a fully redundant transmission system; the Metropolitan Water System is truly great. In an era of water system vulnerability, the MWRA water supply and distribution system is, and will continue to be for future generations a key element of health, opportunity, and prosperity for the Boston Metropolitan area with the completion of several projects through the MWRA capital improvement program and Tunnel Programs.

Acknowledgements

The Great Metropolitan Water System of the Boston area has been centuries in the making. Significant contributions have been made over time by various organization and individuals, too numerous to list. Their vision and determination cannot be understated. It is the foundation of our current great water system which is now in the capable hands of MWRA leadership and staff along with many consultants, contractors and suppliers. Continuation and completion of that vision is our mission; one that we eagerly pursue.

References

Murtagh, K., F. Brandon. 2019. "MWRA Metropolitan Boston Tunnel Redundancy Program Project Update" In 2019 Proc., Rapid Excavation and Tunnelling Conference, 477-489. Chicago; Society for Mining, Metallurgy & Exploration (SME).

Volume 31, Number 1

Responding to Changes in Climate at MWRA

Stephen Estes-Smargiassi[1] and Hillary Monahan [1]

[1]Massachusetts Water Resources Authority

E-mail: Stephen.Estes-Smargiassi@mwra.com; Hillary.Monahan@mwra.com

Published August 15, 2023

Abstract

As an infrastructure-heavy water and wastewater utility with many of our facilities in coastal areas, Massachusetts Water Resource Authority's (MWRA) operations will be impacted by climate change. While the primary threat is sea level rise and coastal flooding, increased intensity and variability of precipitation and extreme heat will also affect our infrastructure and staff. MWRA's adaptation efforts began with the construction of the Deer Island Wastewater Treatment Plant (DITP). Priority sites for protection were identified based on the Authority's evaluation of coastal facilities' ability to withstand a 100-year storm with 2.5 feet of sea level rise (in line with 2050 conservative projections). To date, flood protection measures have been installed at most of these priority sites, through either short-term measures, including deployable flood barriers in doorways, or by more permanent solutions such as amending designs of facilities undergoing major rehabilitation. MWRA anticipates a modest increase in safe yield due to changes in intensity and frequency of precipitation, however, as locally supplied communities with much smaller water sources, might experience diminished yields, MWRA is anticipating and planning for increased use of the MWRA system by more communities. As part of MWRA's commitment to mitigate the impacts of climate change, the Authority has implemented many energy conservation programs to reduce the energy consumption and carbon emissions required to provide safe drinking water to its member communities. Since 2006, MWRA has reduced annual greenhouse gas emissions by 40% or nearly 58,000 metric tons of CO2 equivalent. This is the result of a multi-pronged approach, including investments in renewable energy, energy efficiency and optimization, and the electrification of both facilities and vehicles.

Keywords: climate change, resiliency, sea level rise

1. Deer Island: Our Resiliency Beginnings

The Deer Island Treatment Plant, which represents MWRA's single largest infrastructure investment, is extremely flood resistant due to its 1986 design that took into consideration sea level rise before it became a mainstay issue. In fact, Deer Island is designed to survive a direct hit from a Category 3 hurricane with minimal damage limited to support systems only with no flooding in the DITP process areas. The plant was designed back in 1998 to withstand a 100-year storm event plus nearly two feet of sea level rise. During design, plant process tanks were raised almost two feet, and the outfall was increased from 24 to 24.5 feet in diameter to accommodate sea level rise without reducing the plant capacity. In addition, the island is surrounded by a seawall that reflects incoming wave energy back to the ocean (see Figure 1).

In planning for the rising tide and storm surge effects on coastal infrastructure, MWRA has closely followed the evolving science of climate change over the past few years with the goal of fully understanding potential impacts to facilities and operations. MWRA has taken a pragmatic approach to climate change adaptation, and efforts have largely focused on the evaluation and implementation of measures to allow MWRA facilities to withstand a significant storm event that could occur in Eastern Massachusetts. Primary concerns for approaching sea level rise include the following:

Figure 1. Deer Island Treatment Plant is protected for 100-year flood, 1.9-foot sea level rise, and a wave run-up of 14 feet on its east side and 2 feet on its west side (MWRA, 2023).

- What are the most vulnerable facilities?
- How vulnerable are they and what are the potential service impacts?
- What can be done in the short-term or long-term to eliminate or mitigate the vulnerability?

Following Super Storm "Sandy" in October 2012, MWRA began an evaluation of coastal facilities to understand each one's ability to withstand such a storm were it to make landfall in the Boston area (MWRA, unpublished internal report, September 2013). The most current information available on climate change scenarios and sea level rise has been and will continue to be incorporated into design and construction contracts to ensure hardening against potential impacts.

MWRA recognizes that mitigation solutions must be approached as an ongoing effort. While there is no singular solution to a constantly changing issue, MWRA has formulated both short- and long-term strategies that address flooding concerns with the overall goal to limit damage, recover fully, and resume activity as quickly and efficiently as possible. Various adaptation strategies have been formulated on the basis of a pragmatic benchmark of 2.5 feet, added to the current 100-year flood elevation as set by the Federal Emergency Management Agency (FEMA) to account for sea level rise and intensified storm surges. This benchmark by no means depicts the "perfect" numerical value in planning for mitigation strategies. It does, however, represent a reasonable estimation of change for staff to utilize in evaluating the potential threat of sea level rise on coastal facilities, and allowed MWRA to move forward even while more detailed modeling of sea level rise was underway by other agencies. As research in climate change continues to advance, MWRA is aware of the potential for new scientific information to warrant re-evaluations of existing benchmarks and plans to act on these analyses accordingly.

While both short- and long-term strategies are imperative in developing emergency preparedness efforts, MWRA has placed particular emphasis on high-priority immediate actions to take in response to a severe weather event. Where major rehabilitation work is not occurring at facility in the short-term, MWRA has identified immediate needs for flood-proofing improvements (such as raising equipment up off floors and installing stop logs at doorways). Mapping out emergency response plans, training, and drilling staff on those actions, and evaluating MWRA's response after each major event have all been crucial initiatives in striving for preparedness.

Long-term initiatives include upgrading facilities on individualized rotation schedules and adding flood mitigation measures. Storm surge, together with anticipated sea level rise resulting from the changing climate, will affect several MWRA and communities' coastal collection systems and wastewater facilities. MWRA's 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. Major 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.

2. Sea Level Rise and Coastal Storm Flood Risk: Evaluating Benchmarks

To determine site vulnerabilities, MWRA evaluated the potential impacts of sea level rise on 30 coastal or near coastal wastewater and administrative/operational facilities – of which 13 were determined to be within the most recent FEMA 100-year flood elevation (or to be conservative, within one foot above the 100-year elevation) (MWRA, unpublished internal report, September 2015). The record drawings for all MWRA coastal facilities were reviewed to identify their lowest flooding elevations. In many cases, this was the first-floor elevation. However, lowest flooding elevations could also include hatches or other access points on the exterior of the facility. Staff performed site-specific inspections of each facility and took note of any major exterior equipment (such as emergency power generators) that might be damaged during a major storm. Using specialized software, staff then performed an inundation analysis that used the three-dimensional elevation data that was recently collected by the Commonwealth through Light Detection and Ranging (LiDAR).

The critical flooding elevations were compared to two benchmarks. The first benchmark is the existing 100-year flooding elevation from the most recent FEMA flood maps. To be conservative, MWRA retrofitted any facilities whose first-floor elevation was within a foot above the 100-year flood.

The second benchmark is the 100-year flooding elevation with an additional 2.5 feet added. Some regional organizations, such as Boston Harbor Now and the NYC Department of Environmental Protection, had adopted this benchmark as a reasonable and conservative estimate of mid-term sea level rise. These benchmarks can be seen on the photo of the Quincy Pump Station below. Climate models have varying estimates for the degree of rise anticipated by 2050 or 2100, and 2.5 feet generally falls in the middle of them. When compared to the recent Boston Research Advisory Group (BRAG) sea level rise projections, 2.5 feet appears to provide protection beyond 2070 - even for the highest C02 emissions scenarios. MWRA is using this benchmark as an appropriately conservative measure of vulnerability, addressing issues of both storm intensity and sea level rise. MWRA will continue to monitor the evolving science and consensus on sea level rise and change benchmarks as appropriate (see Figure 2).

Figure 2. Quincy Pump Station flood line scenarios drawn to represent water levels at two different benchmarks, FEMA 100-year and 100-year +2.5 ft (MWRA, 2016)

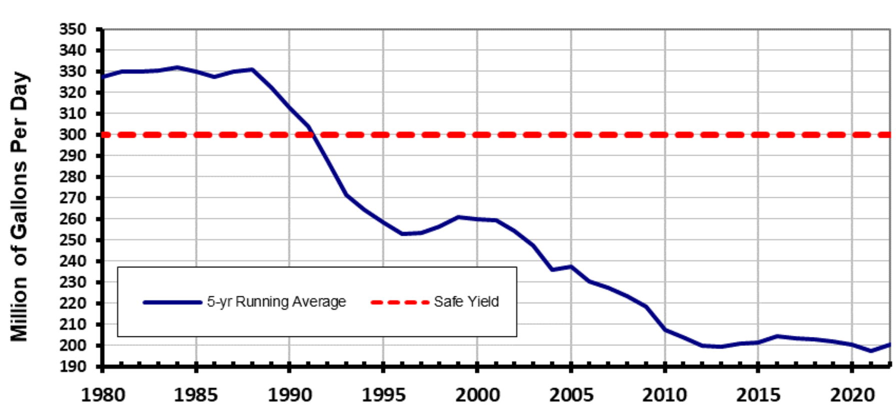


Figure 3. MWRA water demand vs. safe yield, 1980 – 2022 (MWRA, 2022)

3. Safe Yield: A Steady Supply for Future Extremes

MWRA's source reservoirs, the Quabbin and Wachusett, can safely provide around 300 million gallons of water per day - even during periods of extended drought. This number, or the safe yield, is a widely used measure for supply adequacy, and is defined as the quantity of water that can be supplied on a continuous basis during critical drought, without violating a defined operating objective (see Figure 3).

Cooperating with other partners that included the Water Research Foundation, the National Center for Atmospheric Research, the Stockholm Environment Research Institute, Tufts University and UMass, MWRA has evaluated the potential impact of a changing climate on our water system's safe yield. While many locally supplied communities can anticipate diminished yields of their sources, MWRA's system is likely to see a modest increase in its safe yield from the increased but more varied precipitation due to the sheer size of its reservoir storage, thereby setting the stage for MWRA to potentially provide water to these communities during periods of stress or more regularly. During the 2016 drought, for instance, MWRA was able to provide emergency water supply to Worcester, Cambridge, and Burlington (see Figure 4).

4. Next Steps: Energy-Forward Plans of Action

Implementation of initiatives to reduce energy demand and the continued assessment of sustainable cost-saving opportunities are long-standing goals of the MWRA. As part of MWRA's commitment to mitigate the impacts of climate change, the Authority has implemented a wide range of energy conservation programs to reduce the energy consumption and carbon emissions required to provide safe drinking water to its member communities.

Since 2006, MWRA has reduced annual greenhouse gas emissions by 40% or nearly 58,000 metric tons of CO_2 equivalent. This success is the result of a multi-pronged approach, including investments in renewable energy, energy efficiency and optimization, and the electrification of both facilities and vehicles.

5. References

MWRA (Massachusetts Water Resources Authority). 2016. *MWRA Quincy Pump Station flood line scenarios.*

MWRA (Massachusetts Water Resources Authority). 2019. *Deer Island Treatment Plant protected for a 100-year flood.*

MWRA (Massachusetts Water Resources Authority). 2022. *MWRA water demand vs. safe yield, 1980-2022.*

MWRA (Massachusetts Water Resources Authority). 2023. *Stressed basins adjacent to MWRA-served communities.*

Figure 4. Stressed basins adjacent to MWRA-served communities (MWRA, 2023)

Protecting Our Legacy: MWRA Dam Management

John J. Gregoire, Program Manager, Reservoir Operations

E-mail: John.Gregoire@mwra.com

Published August 15, 2023

Abstract

MWRA inherited a neglected and poorly maintained water and sewer system. A key goal of the MWRA is to never allow the system to fall back into disrepair, and MWRA has developed extensive programs of asset assessment, management, and maintenance to ensure that. A key example of those programs is the rehabilitation of our reservoir assets. The history of dams in MWRA's water system follows the westward progression of water supply development. The late 19th century to early 20th was the *Golden Era of Dam Construction.* This was followed by an era of decline and neglect by predecessor agencies. MWRA's dam management and investment in these dams started in 2004 corresponding with new state dam safety regulations. There was much to do on the 28 dams and dikes in MWRA's inventory. Some dams required major capital and maintenance work, some studies and analyses, and all required routine regulatory inspections. Much has been done. To date MWRA has invested over $25 million in its water supply dams, completing major spillway upgrades, clearing forests off dams, seepage control, and earthen and masonry improvements, and planning a dam removal. The work continues at other dams with planned overtopping protection, spillway repointing, and new instrumentation. These investments have added decades of life to these dams and will ensure their service continues well into the future.

Keywords: dam safety, infrastructure management

1. History of the MWRA Reservoir System Dams

The story of Boston's water supply goes as far back as the founding of the City in 1630 from the use of local springs and ponds. The mid 1840's saw development of the first modern water supply system. This was initially from the impoundment of Lake Cochituate in Natick, MA 20 miles west of the City, by small wooden dams (Commonwealth of Massachusetts, 2014). As Boston grew, so did its demand for clean water and improved public health. The westward expansion of water sources continued from 1875 – 1894, made possible by a series of dams constructed on the Sudbury River, notably Framingham Reservoirs #1, #2 and #3 (later renamed for the prominent engineers involved in their development: Stearns, Brackett and Foss, respectively). In 1898, Dam #5 (now known as Sudbury Dam) was completed. Figure 1 contains a photo of the dam taken shortly after construction. Impounded water from the Sudbury System flowed to Boston via the Sudbury Aqueduct. However, by 1898 this system was already insufficient to meets the City's needs. Boston again looked west.

The prominent civil engineer, Frederick P. Stearns (1895) first presented a view of westward water system expansion to the Massachusetts State Board of Health, where he stated:

The very great merit of the plan now submitted is to be found in the fact that this extension of the chain of the metropolitan water supplies to the valley of the Nashua will settle forever the future water policy of the district, ... [then to the] the valley of the Ware River, and beyond the Ware River lies the valley of the Swift…when united of furnishing a supply of the best water for a municipality larger than any now found in the world.

The next great expansion of the water system was to be at the Nashua River in Clinton, MA. As Stearns (1922) reported, "[i]n order to build the reservoir, it is necessary to construct a dam across the [Nashua] river and dikes to the north and south of the main dam, to prevent the water from overflowing from the reservoir…." What he described would ultimately become the Wachusett Reservoir Dam and Dikes system.

Figure 1. Framingham Dam #5, now known as the Sudbury Dam (Massachusetts Metropolitan Water and Sewerage Board, 1910)

Figure 2. Wachusett Dam (Massachusetts Metropolitan Water and Sewerage Board, 1904)

That project began in 1897 with the construction of North and South Dikes which, incidentally, occurred while the finishing touches were still being put on the Sudbury Dam. The main dam (Figure 2) was completed in 1906, impounding the 65-billion gallon reservoir.

However, by 1922 the continued growth of the greater Boston area was again outstripping its water supply. Following the prescience of Frederick Stearns, the State Board of Heath determined that an aqueduct would indeed be required to connect the Ware River to Wachusett Reservoir. This would require yet another dam, this one on the Ware River. The Ware River Diversion Dam and intake works (Figure 3) were designed to allow longstanding downstream uses to remain while intake works skimmed excess water into the Aqueduct, then transferred to the Reservoir. This system was completed in 1931, and not a moment too soon, as Wachusett Reservoir was at record low levels.

By 1932, again following Stearns' plan, the extension of the system began with a western tunnel segment connecting the Ware-Wachusett system to the valley of the Swift River. For that system to come on line, three branches of the Swift River were impounded by two massive earthen dams, later named Winsor Dam and Goodnough Dike, for the original Chief Engineer of the project and his deputy.

By 1941 water from the newly-named Quabbin Reservoir began to flow east through this tunnel system to Wachusett Reservoir, and then on to greater Boston.

With a few exceptions, most of the MWRA water system dams were built during what is generally known in the dam community as the *Golden Age of* Dam *Construction (1895 – 1940)*. Just outside of this period is MWRA's oldest dam, Chestnut Hill Reservoir Dam, built just after the Civil War in the period 1866-1870 (shown in 1893 photo in Figure 4).

Also within this period, a number of smaller but equally critical dams were completed east of the Sudbury System. These dams were built to impound distribution reservoirs designed for daily storage to serve local populations in the wider metropolitan area (Table 1) (MWRA, 2018).

Figure 3. Ware River Diversion Dam today

2. Era of Decline

After that *Golden Era* many dams fell into decline. World War II had an understandable impact in that routine maintenance and upkeep was deferred while former municipal engineers, maintenance workers and contractors were called to military service abroad. Stateside, most resources were directed towards the war effort. While there were exceptions, on many dams vegetation was allowed to spread across earthen embankments leading to tree growth. Spillway mortar deteriorated. Valving wasn't exercised regularly. And seepage went unnoticed for years. Another casualty of this lost half decade was in record keeping. For some limited dam construction, repair and maintenance that did occur, the period 1941 – 1945 reveals gaps in documentation such as record drawings. After the war, while the nation refocused on more promising things, the neglect of aging dams continued. Despite this, these dams continued to quietly serve their purpose – to impound the water supply.

While many factors come into consideration, it is generally accepted in the dam community that the lifespan of earthen and masonry dams ranges from 50 to 100 years. Table 1 reveals that most of MWRA's dams easily fall within this range, with some exceeding it by decades, e.g., Chestnut Hill Dam, which is 153 years old yet still functioning as designed to impound a distribution reservoir. Most also agree that well maintained dams, routinely inspected, can provide many decades more of useful service beyond this range. As a case in point, Chestnut Hill Reservoir was last used during a water emergency in 2010.

Figure 4. Chestnut Hill Reservoir Dam (Butterfield, 1893)

3. Creation of the MWRA Dam Program and Era of Renewal

Regulation of dam safety, in one form or another, has been on the Massachusetts books since at least 1854 (Mass. Gen. Laws Ch. 327 (1854)). While there were additional dam regulations in the intervening years, including some significant additions in the 1970's and 1980's, the *modern era* of Dam Safety Regulations pertaining to MWRA dams was established in 2003 under the Massachusetts General Laws, Ch. 253 (320 CMR 10:00). This provides the current framework and standards for inspections, operations and maintenance, construction, repairs, hydraulics and spillway capacity, embankment stability, and emergency action planning for all jurisdictional dams in Massachusetts, of which twenty-eight are managed by MWRA.

4. The Dams Today

The MWRA water supply system today would not exist without these dams, yet these highly engineered and well-built structures are not as familiar to general public when compared to the scale of the great water bodies they impound. For instance, it seems everyone knows about *Quabbin Reservoir*, but the dams that make this great reservoir possible are often an afterthought.

Today, this system relies mainly on two reservoirs for water supply: Quabbin Reservoir impounded by Winsor Dam (Figure 5), Goodnough Dike and the Quabbin Spillway (itself technically an impounding dam), and Wachusett Reservoir, impounded by Wachusett Dam (Figure 6), North Dike and South Dike. These two sources provide the drinking water for 51 cities and towns and over 3 million people in Massachusetts, mainly in Metro Boston, Metro West, and the Chicopee Valley. The Sudbury Reservoir system remains as an emergency supply consisting of just two of the original reservoirs, Sudbury Reservoir and Foss Reservoir, with their eponymous dams. These were last used briefly during a water emergency in 2010.

MWRA also has several smaller emergency distribution reservoirs, all impounded by dams. They can be found in the MetroWest area to Metro Boston and north. They include Weston Dam, Norumbega Dams, Schencks Dam, Spot Pond Dams, Fells Dams and, of course, the grandfather of them all, the 1870 Chestnut Hill Dam.

Table 1. MWRA Water Supply Dams

Dam Name and Location		Year Completed	Construction / Type	Structural Height (ft)	Hazard Class	Storage (MG)
Quabbin Reservoir, Belchertown and Ware, MA	**Winsor Dam**	1939	Earthen Embankment	170	High	412,000
	Goodnough Dike	1938	Earthen Embankment	135	High	
	Quabbin Spillway	1938	Masonry – Gravity	10	Low	
Ware River, Barre, MA	**Lonergan Intake Dam**	1931	Masonry – Arch	38	Significant	Run of River
Wachusett Reservoir, Clinton and Boylston, MA	**Wachusett Reservoir Dam**	1908	Masonry – Gravity	114	High	65,000
	North Dike	1905	Earthen Embankment	22	High	
	South Dike	1905	Earthen Embankment	45	High	
Wachusett Aqueduct, Southborough and Marlborough, MA	**Open Channel Lower Dam**	1880s	Masonry – Gravity and Earthen Embankment	18.5	Low	8
	Hultman Intake Dam	1940s	Earthen Embankment	12	Low	8
Sudbury Reservoir, Southborough, MA	**Sudbury Dam**	1898	Earthen Embankment	84	High	7,200
Foss Reservoir, Framingham, MA	**Foss Reservoir Dam and Rear Dike**	1890s	Earthen Embankment	29	High	1,500
Norumbega Reservoir, Weston, MA	**Dams 1, 2, 3, 4, and East Dike**	1940s	Earthen Embankment	<42	High	163
Schenk's Pond, Weston, MA	**Schenk's Pond Dam**	1940s	Earthen Embankment	22	High	43
Weston Reservoir, Weston, MA	**Weston Reservoir Dam**	1903	Earthen Embankment	40	High	360
Spot Pond, Stoneham, MA	**Dams 1, 4, and 5**	1899	Earthen Embankment	13	Significant	2,500
Fells Reservoir, Stoneham, MA	**Dams 2 and 3**	1898	Earthen Embankment	12 – 25	Significant	63
	Dams 6 and 8	1940	Earthen Embankment	17 – 48	High	
Chestnut Hill Reservoir, Boston, MA	**Chestnut Hill Dam**	1870	Earthen Embankment	19	High	413

4.1 MWRA Dam Program:

MWRA was created in 1985 when the then Metropolitan District Commission's (MDC's) role in operating and maintaining the water system was assigned to the Authority. However, the legislation kept responsibility for management of the watersheds, which included the reservoirs and most of the dams, with the MDC and their successor, the Department of Conservation and Recreation (DCR).

Later, recognizing the criticality of the reservoirs and dams to the MWRA water supply mission, in 2004 MWRA finalized a Memorandum of Understanding (MOU) with the DCR. Critical in that arrangement was the transfer of responsibility to MWRA for all movement of water between reservoirs and over spillways. Additionally, it assigned to MWRA Capital and major maintenance responsibility for the dams, as well as their routine regulatory inspections and Emergency Action Plans. MWRA's dam management program was born.

First up was a detailed inventory of all of the dams, assembly of extant reports and Phase I Inspections, and the cataloging and prioritizing the Capital, maintenance and regulatory needs at each dam. MWRA established a routine Dam Safety Compliance and Consulting Contract to meet the regulatory inspections required under 302 CMR 10:00. That contractual system allowed MWRA to hire qualified dam safety engineers for inspections, assessments, studies and repair designs, as well as engineering services during construction.

Figure 5. The massive Winsor Dam looking downstream from Quabbin Reservoir

Figure 6. Wachusett Reservoir Dam and Spillway

4.2 Tree growth on dams

One of the first and most obvious challenges for MWRA was to address the literal forests of trees that had been allowed to grow on several earthen dams (Figure 7, South Dike at Wachusett Reservoir). This was imperative to provide the unobstructed view of the embankments necessary for inspection work, identification of deformities, seeps and other potential issues, as required to meet the MA Office of Dam Safety *Policy on Trees on Earthen Dams.* MWRA developed in-house contract specifications for tree and stump removal across several dams. This was followed by restoration of the embankments by loam and seeding to establish a durable and maintainable turf.

4.3 Required Studies and Analyses

Next up was to perform studies such as Hydrologic and Hydraulic (H&H) Analyses as well as Seepage and Stability (S&S) Analyses, both required under the dam safety regulations.

Figure 7. Clearing thick, decades old pine forest from Wachusett Reservoir's South Dike.

The objectives the H&H analysis is to assess the reservoirs storage and discharge capabilities, as well as overtopping potential during extreme events, for the regulatory Spillway Design Flood (SDF). In most cases, the SDF required for existing dams is ½ the Probable Maximum Flood (1/2 PMF), which is based on the dam's size and hazard potential classification[1] as determined by the Dam Safety Regulations (302 CMR 10:00). This analysis is typically performed using updated versions US Army Corps of Engineers Hydrologic Modeling System (HEC-HMS). Out of these H&H studies come recommendations for overtopping protection, armoring and spillway improvements, each of which MWRA has completed at some dams, with more projects in planning and design, as discussed below.

The objectives of the S&S analysis is to assess the stability of the dam against such loading conditions as rapid drawdown, steady state seepage, and seismic activity. Out of this modeling are derived Factors of Safety against these failure mechanisms, to be compared against minimum Slope Stability Factors of Safety defined in the dam safety regulations by dam size and class. Ideally, this modeling is performed with updated geometry and topography of the dam and with inputs such as the geotechnical data on subsurface materials. Where subsurface data are not known or records were lost (such as very old dams), best engineering estimation is applied in the modeling. There are different models used for these analyses, but MWRA has most recently specified the model SEEP/W, a two-dimensional, finite element seepage analysis software. Where deficiencies are noted from model results, repairs or other operational adjustments may be necessary. Most MWRA dams have adequate factors of safety. Where slight FS excursions were noted, it was typically due to lack of actual subsurface data in the model to provide a more accurate output, which MWRA is addressing (as discussed further below under Instrumentation).

5. Capital Projects and Major Maintenance

5.1 Spillway Improvements

With updated H&H studies, MWRA has evaluated spillway adequacy across all its water supply dams. This has resulted in major Capital rehabilitation projects such as *Wachusett Reservoir Spillway Improvements*. For that project, the H&H provided an updated Probable Maximum Precipitation (PMP) analysis to assess rainfall impact from the statistical worst-case storm for the region. This PMP informed the HEC-HMS modeling for the Probable Maximum Flood (PMF). One important difference here is that the design flood used for this analysis was the full PMF (a higher standard compared to the ½ PMF typically employed at existing dams) due to the hydropower generation at the reservoir, and the Federal Energy Regulatory Commission (FERC) guidelines.

The findings of this H&H study determined the design aspects of the project and allow construction of the spillway improvements to pass the design flood (PMF). This included removal of old stop log structures, lowering the existing 100 ft. long lower spillway bay by two feet (Figure 8, left photo), installing a hydraulically-operated stainless steel Crest Gate in that lower bay (Figure 8, right photo), creation of an auxiliary spillway to pass flood water, and creation of a berm adjacent to the spillway to prevent overtopping of the Wachusett Dam's left abutment. This work was completed in 2008. Use of the Crest Gate has become a fairly routine spillway operation at higher reservoir

[1] Most of MWRA's dam are High Hazard Class which is defined as "[d]ams located where failure or misoperation will likely cause loss of life and serious damage to home(s), industrial or commercial facilities, important public utilities, main highways(s) or railroad(s)," 302 CMR 10.06. Significant and Low Hazard Class dams have less critical failure thresholds, although they are still very important.

Figure 8. Lower Wachusett Dam spillway (L) to accept new 100-foot-long Crest Gate (R)

elevations. The improved spillway system stands ready to safely pass the PMF should that occur.

At Weston Dam there is no spillway. In this case the H&H assessed the ability of the reservoir to *store* the ½ PMF. The H&H study found that, while the reservoir could indeed store the PMF, wind generated wave run up on a full reservoir would cause the dam to be overtopped, potentially leading to crest erosion and ultimately dam failure. This finding required an evaluation of alternatives, from which MWRA ultimately selected a wave run up (or parapet) wall (Figure 9). This was completed in 2009.

H&H findings can also result in the need to armor dams to prevent higher reservoir elevation erosion. In this case, based on the elevation of the core wall at Spot Pond Dam #1, the findings recommended a full upstream slope armoring. This was completed as an in-house project in 2014 (Figure 10, right photo).

Masonry mortar degradation is a common spillway issue, particularly if the spillway sees frequent activation. In cases with rare activation, vegetation and weathering also takes a toll on the mortar. MWRA has done a number of repointing projects on spillways as needed, typically resulting from dam safety inspection findings (Figure 11 shows Quabbin Spillway repointing during low reservoir elevation). And more projects are to come.

It's a common adage that all dams leak. It is when the seepage becomes uncontrolled that problems, such as *piping,* can occur. In that case, seepage water carries soil particles along with it which can lead to internal erosion of the dam and, if unchecked, potentially to even greater problems. After clearing trees and heavy growth from the dams, MWRA inspections found some seeps that had been flowing unseen because they were obscured. These were initially monitored to assess changes while corrective designs were developed.

Ultimately, MWRA installed seepage control weirs to collect and filter the seepage locations discovered at Fells Dam #8 (Figure 12), Weston Dam (three weirs) and at Foss Dam. Occasionally seepage may occur due to internal issues such as a high reservoir elevation intersection with a problem stratum in the dam embankment. At Chestnut Hill Dam, MWRA's oldest, such an event occurred in 2019. A prior construction project unknowingly cut into the top of the dam's impervious core material. High water during a wet winter penetrated this breached zone and caused both a seepage boil and a diffuse seep at the dam toe. Initial emergency response actions by MWRA included lowering the reservoir to reduce the seepage pressure. Subsequently, MWRA restored the damaged core zone with impervious fill, installed a seepage filter blanket at the toe, and reduced the reservoir operating band to ensure water will not reach that zone.

Figure 9. Weston Dam Parapet Wall

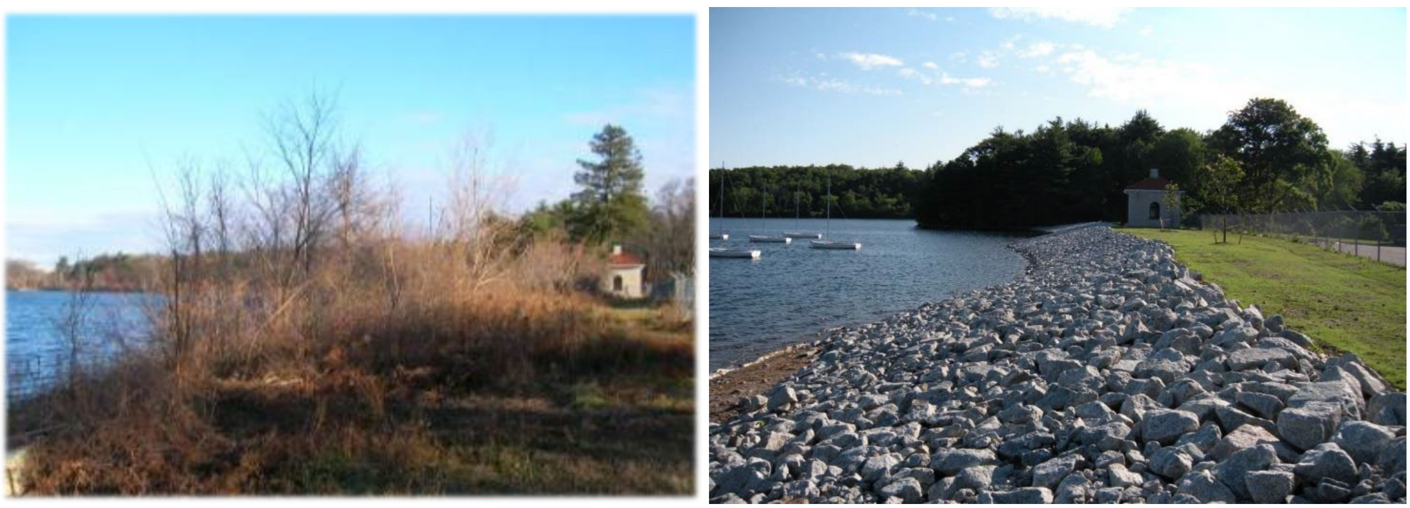


Figure 10. Spot pond dam upstream before tree clearing (L) and after armoring (R)

Figure 11. Quabbin Spillway masonry repairs in 2010

Figure 12. Before: uncontrolled seepage at toe of Fells Dam #8 (L) and new seepage control weir (R)

5.2 Instrumentation

Another Dam Safety regulatory requirement is instrumentation in high hazard class dams to monitor the phreatic surface. This is commonly in the form of piezometers to measure dams internal pore pressures, and by monitoring and/or observation wells. While a number of MWRA dams have such instrumentation, several were found to be deficient. MWRA developed a conceptual design for all dam instrumentation needs on which to prioritize the work. Following that, MWRA established a 5-year Dam *Asset Maintenance Plan* to get the required instrumentation installed.

An additional component of this instrumentation work is the collection of subsurface geotechnical samples from the borings for use in revised Seepage &Stability analyses where that actual data was unknown. The first project was recently completed at the Wachusett North and South Dikes (Figure 13). The next contract at Weston Dam and Chestnut Hill Dam is nearing completion. The required instrumentation at the remaining dams is in planning and design,

6. Looking to the future

A number of other dam improvements are presently under design for MWRA dams. This includes major masonry repairs at Sudbury Dam Spillway (Figure 14), armoring Foss Dam for overtopping protection, a parapet wave wall at Wachusett Reservoir's North Dike where a small area of Dike was removed in the 1960's to build a pump station, and evaluation of new seepage locations.

Lastly, MWRA is also embarking on the physical removal of an obsolete dam. The Quinapoxet Dam on the Quinapoxet River (Figure 15) was originally designed to permit sediment accretion in the downstream over-widened channel before the river entered a series of basins at Wachusett Reservoir. Due to modern reservoir operating regimes, the original function of that dam system is no longer applicable. This project is presently under design for removal of the dam and restoration of the river channel. This will also allow the land-locked salmon in Wachusett Reservoir to migrate back up the Quinapoxet River for spawning.

7. Conclusion

These historic water supply dams have served water consumers since the mid-19th Century, and MWRA's comprehensive maintenance program is a prime example of its ongoing commitment to asset protection. Since assuming their management in 2004, MWRA has invested over $25 million on structural, physical, and operational upgrades, as well as required inspections and studies, to maintain compliance with the MA Dam Safety Regulations. Ongoing work also includes following accepted standards for both routine and extreme weather operation and maintenance, as well as for emergency action planning. MWRA recognizes that the investment in these dams must continue in order extend their service into the next century. The water supply and the people it serves depends on them.

Figure 14. Borings for piezometer installations at North Dike (L), subsurface data collection (R)

Figure 13. Current condition of Sudbury Dam Spillway downstream face (L) and upstream crest (R)

Figure 15. Obsolete Quinapoxet Dam at Wachusett Reservoir slated for removal. (MWRA, 2023)

References

Boston (Mass.) Water Board, and D. W. (David W.) Butterfield. "Distribution Department, Chestnut Hill Reservoir, Effluent Gatehouse and dock along Beacon Street, Brighton, Mass., 1893." Photograph. 1893. *Digital Commonwealth*, https://ark.digitalcommonwealth.org/ark:/50959/4j03d425d (accessed April 03, 2023). https://www.mwra.com/publications/masterplan/2018/mp-water.pdf

Massachusetts. 1895. Report of the Massachusetts State Board of Health Upon a Metropolitan Water Supply. Boston: Wright & Potter Printing.

Massachusetts. 1922. Report of the Joint Board Consisting of the State Dept. of Public Health and the Metropolitan District Commission Relative to Water Supply Needs and Resources of the Commonwealth. Under the Provisions of Chapter 49 of the Resolves of the Year 1919. Boston: Wright & Potter Printing.

Massachusetts Historical Commission. 1990. "Massachusetts Cultural Resource Information System." Historic Dam Detail: FRM.935 Lake Cochituate Dam. Accessed on April 3, 2023. https://mhc-macris.net/details?mhcid=FRM.935.

Massachusetts. Metropolitan Water and Sewerage Board. "Wachusett Dam, from the east, Clinton, Mass., Nov. 1, 1904." Photograph. November 1, 1904. *Digital Commonwealth*, https://ark.digitalcommonwealth.org/ark:/50959/z316q3213 (accessed April 03, 2023).

Massachusetts. Metropolitan Water and Sewerage Board, and Oliver Tryon. "Sudbury Department, Sudbury Dam and Gatehouse, general view, with Meter Chamber and Headhouse, Southborough, Mass., Apr. 28, 1910." Photograph. April 28, 1910. *DigitalCommonwealth*, https://ark.digitalcommonwealth.org/ark:/50959/v692t888d (accessed April 03, 2023).https://ark.digitalcommonwealth.org/ark:/50959/4j03d425d

MWRA (2023) "Update on Quinapoxet Dam Removal, Contract 7347". www.mwra.com. Retrieved August 3, 2023, from https://www.mwra.com/projects/water/7347-quinapoxetdam/7347-update.html

Volume 31, Number 1

Massachusetts Beaches and Rivers: Where the People Meet the Water

Brian Kubaska, P.E, Betsy Reilley, PhD[2]

[1] Assistant Director – Engineering and Construction, MWRA, Boston, United States of America
[2] Director of Environmental Quality, MWRA, Boston, United States of America

E-mail: Brian.Kubaska@mwra.com, Betsy.Reilley@mwra.com

Published August 15, 2023

Abstract

MWRA's innovative, collaborative region-wide Long-Term Control Plan (LTCP) sought to reduce all CSOs within MWRA's tributary system, including those permitted to Boston Water and Sewer Commission and Brookline, Cambridge, Chelsea and Somerville. Through the implementation of 35 major construction projects, 40 of the original 86 CSO outfalls in the MWRA's system have been closed, with 30 of the remaining 46 CSOs meeting LTCP goals. 93% of the remaining combined sewage receives screening and disinfection. Of the remaining 16 outfalls, there are six outfalls that present significant challenges, potentially requiring substantial and costly system modifications to achieve LTCP goals. Even with these remaining challenges, the results of MWRA's and the CSO communities' efforts are an irrefutable success. In 2021, the water quality of the Charles River Lower Basin was rated as "B" and the freshwater reach of the Mystic River was rated "B+". The greater harbor has rejuvenated itself and is swimmable, even during rain events. The Boston area beaches are now considered the cleanest urban beaches in the country. It is truly an environmental success story.

Keywords: Boston Harbor, Charles River, Mystic River, Neponset River, CSO, overflow, sewer separation, water quality

1. Introduction/History

Over the course of the last three decades and beyond, MWRA and its member communities have undertaken various projects aimed at controlling the discharge of combined sewer overflow (CSO). These dedicated efforts have brought about a remarkable transformation in the conditions of Boston Harbor, its tributary rivers, and the beaches in the Boston area. Back in the 1980s and even earlier, combined sewer overflows used to occur regardless of the weather conditions, even during dry spells, leading to significant pollution of the harbor, rivers, and beaches. Figure 1 shows a typical CSO discharge from that time. At that time, Boston Harbor earned the unfortunate reputation of being labeled the "Dirtiest Harbor in the Country." Moreover, the beaches frequently failed to meet bathing standards for more than half of the swimming season. The Charles River's lower basin also received a disappointing Water Quality Report Card Grade of "D" (Levy & Connor, 1992). However, the collective efforts over the years have brought about significant positive changes.

In 1982, the City of Quincy filed a civil lawsuit against the MDC (Massachusetts Department of Conservation and Recreation) and other state agencies, alleging violations of the Mass Clean Water act due to the discharge of untreated and partially treated sewage from Nut and Deer Islands. Following this, in 1983, the Conservation Law Foundation initiated an enforcement case, which was later taken up by the U.S. Environmental Protection Agency (EPA) in 1985. The case involves several parties, including the Commonwealth of Massachusetts, the Boston Water and Sewer Commission, and the Town of Winthrop.

The existing treatment facilities at that time were in a deteriorated and outdated state, leading to unreliable operations and non-compliance with the requirements of the EPA's Clean Water Act. As a consequence of these issues, the Massachusetts Water Resources Authority (MWRA) was established in 1985 (MWRA, 2023).

The Court's Orders outline the prescribed timelines for activities aimed at achieving legal compliance. Since 1985, MWRA has successfully met 420 milestones, including the construction of advanced wastewater treatment facilities at Deer Island. These facilities effectively treat wastewater from 43 communities in the Metropolitan Boston area. The obsolete treatment facility in Quincy has been replaced with a new headworks facility and tunnel system, redirecting wastewater to Deer Island, and managing sludge in Quincy. Additionally, the Orders have directed the planning, refinement, and implementation of 35 CSO construction control projects over the course of several decades.

MWRA's initiative to control CSOs commenced in 1987 as part of the Boston Harbor Case (U.S. v. M.D.C., et al., No. 85-0489 MA). Under the initial CSO stipulation (First CSO Stipulation), MWRA assumed responsibility for devising and executing a comprehensive plan to manage CSOs linked hydraulically to its wastewater system. This encompassed CSO discharges from MWRA's own outfalls as well as those permitted and managed by entities like the Boston Water and Sewer Commission (BWSC) and the cities of Cambridge, Chelsea, and Somerville. MWRA's CSO efforts encompassed projects to eliminate dry weather overflows and the formulation of a recommended CSO control plan, known as the Long-Term Control Plan (LTCP). The Court Order included a total of 184 CSO-related milestones as detailed in the AECOM Task Report 2021 (AECOM, 2021)

Figure 1. Typical sewer overflow discharging to beach in 1980s (MWRA, 2004-2015)

The LTCP included performance goals for CSO activations and volumes, as well as goals for attainment with water quality standards. In 1998, when EPA and DEP issued their initial approvals of MWRA's 1997 recommended CSO plan, DEP also issued water quality standards determinations for some of the CSO affected water segments, and issued CSO variances for others. This brought the plan into compliance with state water quality standards. Table 1 below shows current water quality standards classifications established by DEP for the waters covered by the MWRA's LTCP. As indicated in the table below, the applicable water quality standards for the waters affected by the LTCP include Class B, Class SB, Class B $_{(CSO)}$, Class SB $_{(CSO)}$, and Class B (CSO Variance). Class B and Class SB waters are, respectively, inland and coastal/marine waters designated as a habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation. Water meeting Class B or SB standards indicate that the water is "fishable and swimmable." CSO discharges to Class B and Class SB waters are prohibited primarily to protect beaches and shellfish beds (AECOM, 2021).

DEP did not change the Class B designations for the Charles River and the Alewife Brook/Upper Mystic River at the time determinations were made for other receiving waters, but instead issued water quality standards variances to Class B standards for the impacts from CSO. DEP has since issued a series of multi-year CSO variances that allow MWRA and the CSO communities to continue to discharge CSO to these waters, while CSO control projects were underway through 2015 and continuing while the plan's performance was under evaluation and next steps are being determined. In accordance with agreements MWRA reached with EPA and DEP in 2006 and 2019, DEP reissued, and the EPA approved, the Charles River and Alewife Brook/Upper Mystic River CSO variances through August 2024 (MassDEP, 2019a; MassDEP, 2019b).

The variances apply only to the permitted CSO outfalls to the Alewife, Mystic, and Charles receiving waters and do not otherwise modify Class B water quality standards. The variances authorize limited CSO discharges to these receiving waters subject to conditions in the variances. Each variance extension, including the variances currently in effect, acknowledges that it would not be feasible to fully attain the Class B bacteria criteria and associated recreational uses for these receiving waters within the variance period.

Table 1. Water Quality Standards and Required Levels of CSO Control

Water Quality Standard Classification	Receiving Water Segment	Required Level of CSO Control
Class B	Neponset River	CSO prohibited (25-year storm control for the South Boston beaches in North Dorchester Bay)
Class SB	North Dorchester Bay South Dorchester Bay Constitution Beach	
Class B(CSO)	Back Bay Fens	>95% compliance with Class B or SB ("fishable/swimmable") Must meet level of control for CSO activation frequency and volume in the approved Long-Term Control Plan (LTCP)
Class SB(CSO)	Mystic/Chelsea Rivers Confluence Boston Inner Harbor Fort Point Channel Reserved Channel	
Class B (CSO Variance)	Alewife Brook Upper Mystic River Charles River	Class B standards sustained with temporary authorizations for CSO discharges as the LTCP is implemented and verified. (1998-2024)

Source MA DEP 314 CMR:4.00 & AECOM (2021)

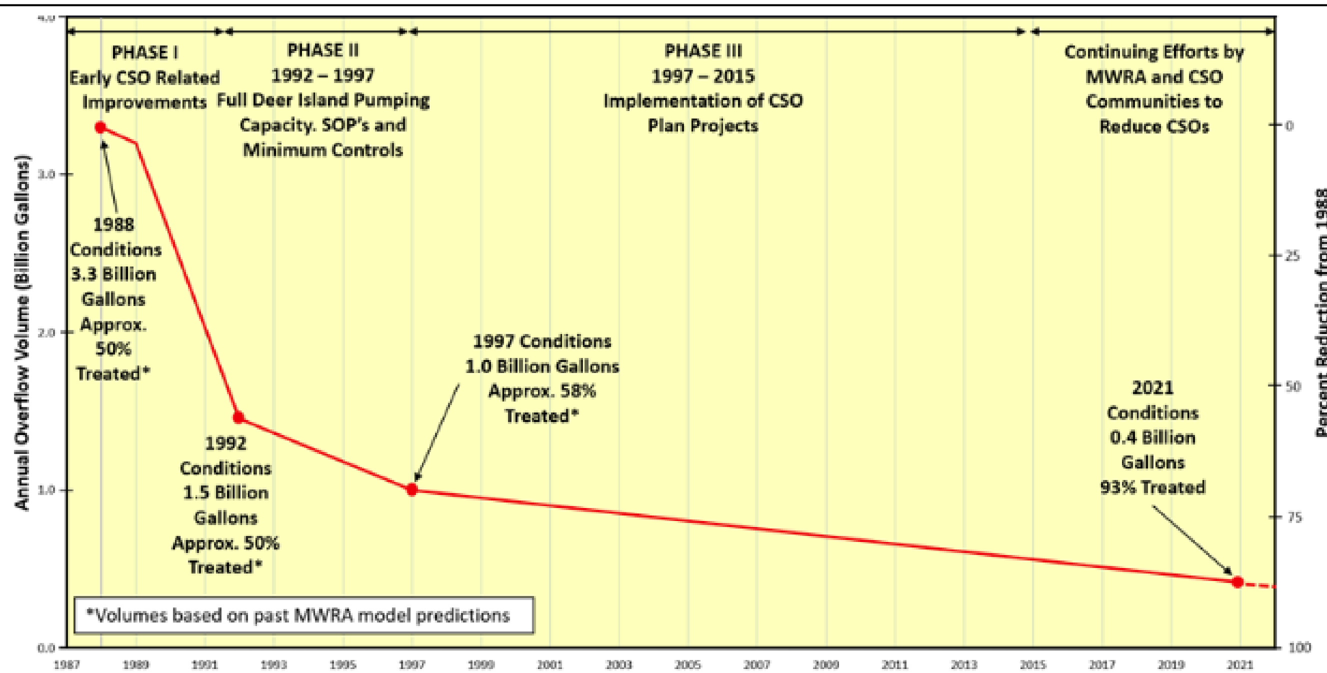


Figure 2. Impact of CSO Control Plan on System Wide CSOs (Somerville, 2023)

2. Accomplishments

2.1 CSO Projects

Since 1987, CSO discharges have been reduced from an estimated annual discharge of 3.3 billion gallons of Combined Sewer Overflows (CSOs) to the harbor and rivers in the late 1980s to 414 million gallons by the end of 2021, an 87% overall reduction with 93% of those remaining discharges treated (Figure 2). Further reductions continue through MWRA and CSO community work, with current CSO discharges estimated at 404 million gallons.

Most of the 35 projects were major undertakings involving the construction of new or improved CSO control and treatment facilities, interceptor relief, or extensive sewer separation, much of which was in historic, densely developed residential and commercial areas. In addition to the design and construction work, the projects also required extensive coordination with landowners, permitting agencies, transportation authorities and neighborhood residents. In some of the project areas, construction impacts were significant and unavoidable, and the collaboration, support and patience of residents and business owners should not be overlooked in understanding the effort borne by many parties to bring these projects to completion and achieve their benefits.

To accomplish the monumental task of designing and constructing 35 diverse projects within less than 20-year period (1996-2015), MWRA required a collaborative approach relying on assistance of its member communities. Memoranda of understanding ("MOUs") and financial assistance agreements totalling $412 million, with BWSC, the Cities of Cambridge, Somerville and Chelsea and Town of Brookline were established, where each municipality agreed to implement the projects within the Long-Term Control Plan involving facilities that would be owned and operated by each community, such as the new storm drain systems that would be constructed in sewer separation projects (Figure 3). MWRA agreed to fund the "eligible" costs, the costs of work to construct the facilities necessary to attain the long-term level of CSO control at each outfall. The MWRA and community CSO control efforts included the management of 125 contracts, including 82 construction contracts, 33 engineering contracts and 10 planning and technical support contracts.

Although meaningful and effective investments were made in CSO reductions throughout MWRA's tributary systems, larger projects were targeted to eliminate CSO discharges and improving water quality where the most recreating and environmental benefit could be realized. The work completed has eliminated CSO discharges to sensitive receiving waters (swimming and shellfishing), including the beaches of South Dorchester Bay and Neponset River (Savin Hill, Malibu and Tenean beaches) and Constitution Beach. For the South Boston beaches (North Dorchester Bay), MWRA's CSO storage tunnel provided a 25-year storm level of CSO control and a 5-year storm level of separate stormwater control. The most expensive project in the LTCP at a total cost of $270 million, the North Dorchester Bay CSO Storage Tunnel/South Boston CSO Storage Tunnel included a 17 MG storage tunnel, odor control facilities, pump station and sewer separation. Figure 4 highlights the CSO construction activities in North Dorchester Bay and South Boston.

For decades, combined sewer overflows discharged about 21 times a year at six outfalls along South Boston beaches. This project eliminated CSOs to these beaches, except in a catastrophic storm event. Stormwater drains also discharged to the South Boston beaches every time it rained - about 95 times a year. No CSO discharges and only 5 stormwater releases have occurred since the facility's commissioning in 2011. Now, these beaches meet water quality standards most days, and are considered some of the cleanest urban beaches in the country. Figure 5 highlights the improvements to water quality at Carson Beach in South Boston.

MWRA, BWSC, the City of Cambridge and the Town of Brookline installed over 100 miles of new storm drain and sewer pipe mostly as part of separating 4,300 acres of combined area, substantially reducing the volume of stormwater requiring collection and treatment. Figure 6 shows a typical sewer separation area for the City of Cambridge.

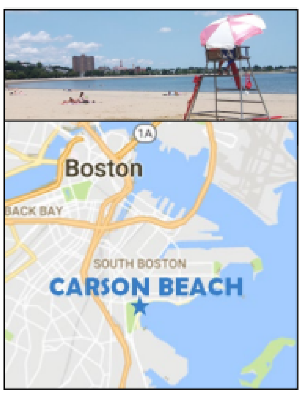
Cambridge undertook the construction of a remarkable storm drain system designed to transport nearly 280 acres of separated stormwater to a newly created 3.4-acre wetland within the Alewife Brook Reservation (Figure 7). This impressive green infrastructure project offers 10.3 acre-feet of storage capacity, effectively mitigating the impact of heightened stormwater flow rates on the Little River and Alewife Brook. The innovative Alewife stormwater wetland project received esteemed recognition, winning the National Recognition Award in the 2014 Engineering Excellence Awards competition organized by the American Council of Engineering Companies.

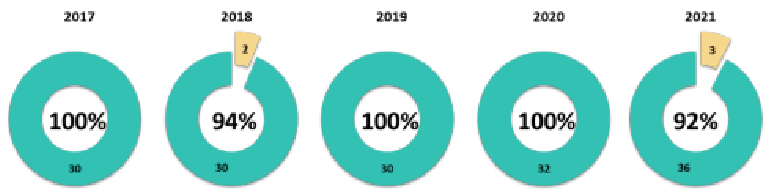
The individual project capital costs, covering both design and construction expenses, varied significantly, ranging from under $100,000 for the Prison Point CSO Facility Optimization to a substantial $228.4 million for the South Boston CSO Storage Tunnel. When considering community costs, the overall expenditure surpassed $1 billion.

Figure 3. Stormwater drain construction to support sewer separation (MWRA 2004-2015)

Figure 4. North Dorchester Bay / South Boston CSO tunnel construction and facilities (MWRA 2004-2015))

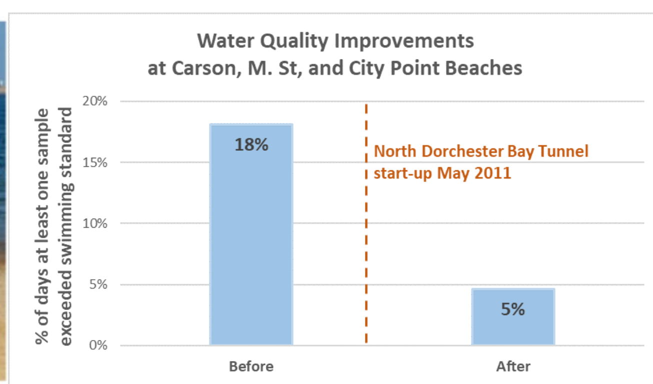
Water quality at South Boston's Carson Beach meets swimming standards nearly all of the time.





In the last five years, 92% to 100% of water samples have met swimming standards at Carson Beach. To meet the standard, a single sample must have *Enterococcus** levels of less than 104 counts in 100 milliliters (mL) of a beach water sample. Water samples are collected at two locations at Carson Beach and analyzed in a laboratory to determine the *Enterococcus* counts. Teal represents the proportion of samples meeting the standard, 104 counts per 100 mL of water or less; yellow represents the proportion with higher than 104 counts per 100 mL of water. Small numbers in the charts represent the number of samples collected each year.

* *Enterococcus* is a bacteria used as an indicator of fecal contamination in water



Results from DCR swimming season sampling at Carson, M. St, and City Point beaches collected 10-years before and after tunnel commissioning. Any day with at least one sample exceeding 104 *Enterococcus*/100mL is counted for the figure.

Figure 5. Beach water quality improvements resulting from tunnel construction (MWRA 2004-2015)

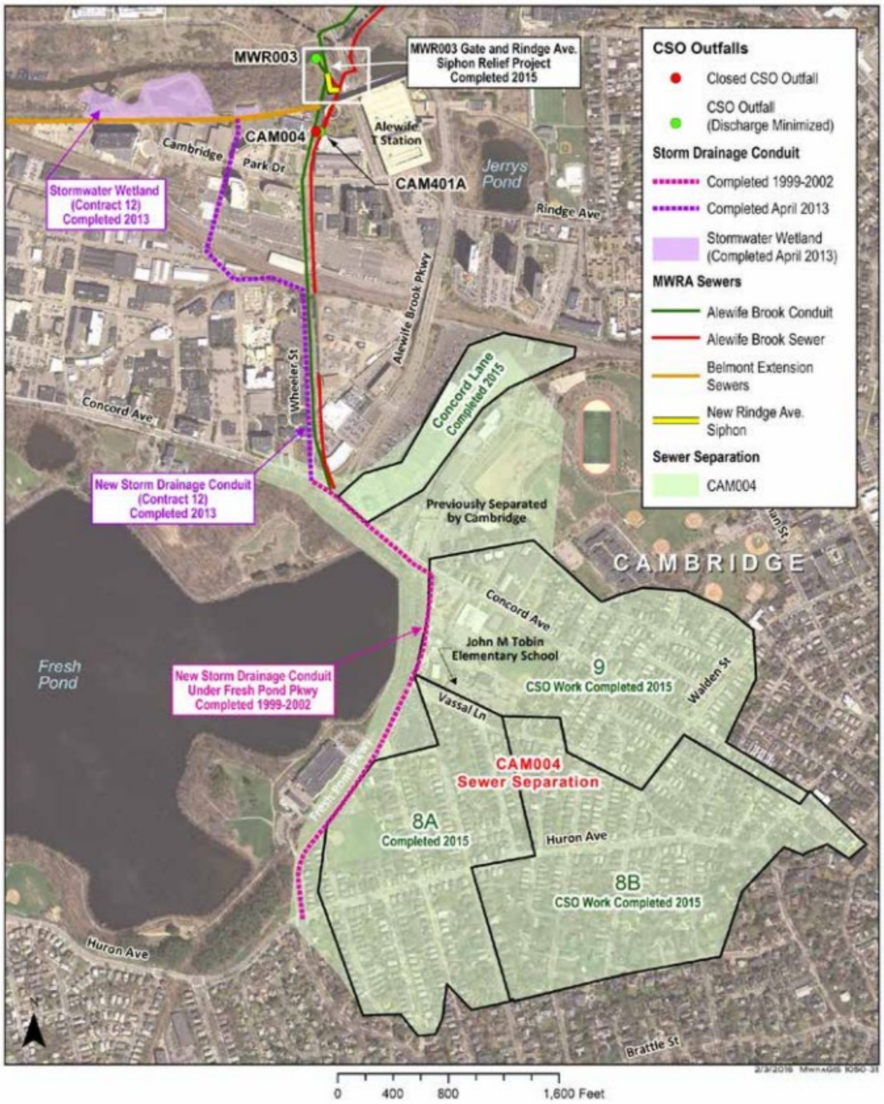


Figure 6. Example Sewer Separation Areas in City of Cambridge (MWRA 2004-2015)

Figure 7. Alewife Brook Reservation constructed wetland (MWRA 2004-2015)

Substantive improvements and upgrades were made to existing CSO treatment facilities that would remain in operation, including improvements to disinfection and dechlorination capabilities.

These 35 projects contributed to the following CSO control accomplishments:

- Permanent closure of 35 of the 86 CSO outfalls that were active in the late 1980s;
- Elimination of CSOs to South Dorchester Bay, the Neponset River, and Constitution Beach through sewer separation;
- Effective elimination (i.e., up to a 25-year storm) of CSOs along the South Boston beaches in North Dorchester Bay and capture of separate stormwater discharges in up to the 5-year storm by the South Boston CSO Storage Tunnel; this project also included re-routing of stormwater outfalls away from Pleasure Bay to the Reserved Channel;
- Decommissioning of three CSO treatment facilities (CSO elimination); treatment and reliability upgrades to three other

CSO facilities; and construction of the Union Park Detention/Treatment Facility;
- A 98% reduction of CSO to the Little Mystic Channel in Charlestown with the BOS019 Storage Conduit;
- A 77% reduction of CSO to Alewife Brook through system optimization and hydraulic relief project, as well as a major sewer separation program that included a constructed wetland for stormwater detention and treatment and habitat restoration;
- Interceptor and hydraulic relief projects that reduced untreated CSOs to the Upper and Lower Inner Harbor by 90% and Mystic/Chelsea Confluence, including Chelsea Creek by 94%;
- A 97% reduction of CSO to the Charles River through separation projects, hydraulic relief and system optimization measures.
- A 99% reduction of CSO to the Reserved Channel through major sewer separation efforts.

2.2 Water Quality Improvements

MWRA's environmental monitoring documents the benefits of these significant achievements in CSO control, and the monitoring along with receiving water quality modeling demonstrates that water quality impacts from CSO discharges are small relative to other sources of pollution (Figure 8).

Improvements in the public perception of regional water quality is evident in the renewed focus on water-centric activities and development along Boston Harbor and its tributary waters. The water quality of Boston Harbor, the Charles, Mystic and Neponset Rivers and Alewife Brook has steadily improved as MWRA and the CSO communities completed the CSO projects and as communities along these waters have implemented programs to control pollutant loadings from storm drains.

Implementation of the LTCP has resulted in the elimination of CSO discharges to sensitive receiving waters, for example,

- For the South Boston beaches, MWRA's South Boston CSO Storage Tunnel provides a 25-year storm level of CSO control and a 5-year storm level of separate stormwater control. As a result, beach closings due to high bacteria are infrequent, allowing for swimming on most summer days at all beaches. The tunnel has captured and therefore prevented more than 2 billion gallons of CSO and stormwater from discharging to the beaches since May 2011. In May 2015, The Boston Globe reported South Boston beaches now "boast some of the cleanest waters of any urban beach in America." (Boston Globe, 2023)
- Improvement in the quality of Boston Inner Harbor waters is also seen in the changes to *Enterococcus* bacteria counts from the time period before improvements (1989-1991) to data collected after most improvements described above were completed.

Today, the results of MWRA's and the CSO communities' efforts are an irrefutable success. In 2021, the water quality of the Charles River Lower Basin was rated as "B" and the freshwater reach of the Mystic River was rated "B+". In fact, swimming races are held in the Charles River and efforts are afoot to reopen a bathing beach. The greater harbor has rejuvenated itself and is swimmable, even during rain events. The Boston area beaches are now considered the cleanest urban beaches in the country. It is truly an environmental success story, and the CSO program has played a critical role.

3. Next Steps

Water quality monitoring data indicates significant improvements in bacteria levels across all weather conditions in the Charles, Alewife, and Mystic Rivers. However, updated receiving water modeling reveals that water quality impacts primarily arise from non-CSO sources, suggesting that CSOs contribute to the E. coli criterion non-attainment less than 0.1% of the time for the Charles River and approximately 2% of the time for the Alewife Brook/Upper Mystic River. These percentages align with the targets set in previous CSO planning efforts.

Considerable progress has been made in reducing CSOs, with 40 out of the initial 86 outfalls being closed or effectively managed. Still, there are 46 active CSO outfalls in the MWRA's system, out of which 30 meet the LTCP goals. The remaining 16 outfalls present challenges and may require substantial and costly modifications to achieve compliance with the LTCP goals.

While significant strides have been taken to comply with the court-ordered requirements established decades ago, work remains to be done. Compliance with the Clean Water Act necessitates variances to the Class B waters of the Charles River, Alewife Brook, and Upper Mystic River, as CSOs are otherwise illegal. Updated CSO Control Plans are being developed by MWRA, Cambridge, and Somerville to explore alternatives and further reduce the 16 remaining CSOs. Creative engineering solutions are being sought to address the infrequent CSOs, as traditional methods may prove expensive with limited water quality benefits.

Receiving water modeling highlights that stormwater is the main challenge to bacterial water quality, and the impact of remaining CSOs is relatively small. Additionally, the changing climate, characterized by more intense rain events, requires innovative solutions for CSO and stormwater control to avoid adverse impacts such as flooding and increased pollutant loads from direct stormwater discharges. Future plans aim to analyze both historical rainfall data and climate models to assess rainfall changes in the coming decades, thereby evaluating alternative approaches in terms of their resilience to such changes.

The "easy" fixes (relatively speaking) have been implemented. The challenges ahead require consideration of:

- Green infrastructure, which presents significant challenges in the highly urbanized communities in and around Boston. The balance between parklands, recreational needs, and green infrastructure may be in conflict.

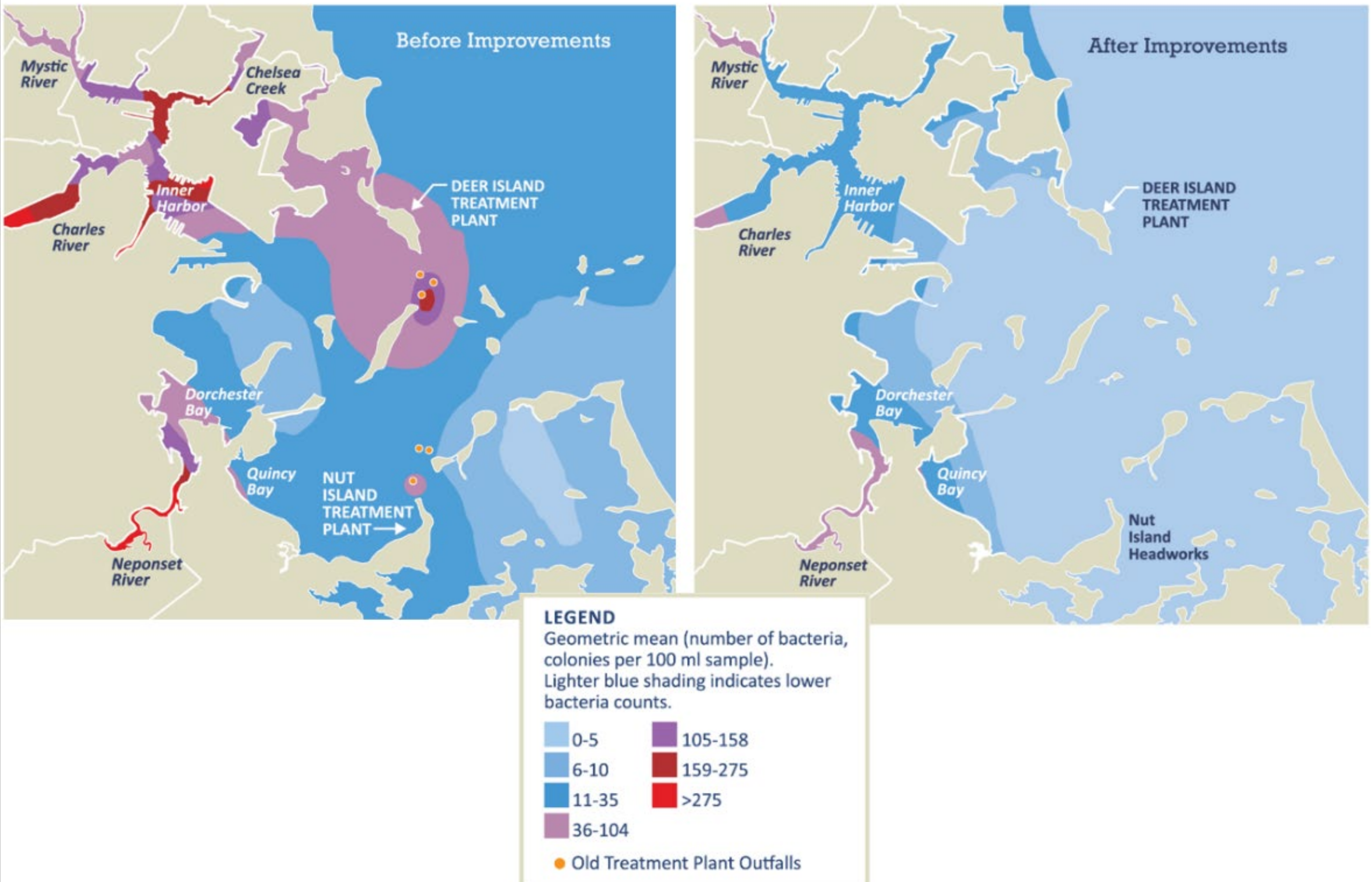


Figure 8. Water quality improvements (MWRA 2004-2015)

- Climate change and infrastructure resiliency adds additional requirements and costs for CSO control projects. Which climate models and how future projections are incorporated into planning will impact design, space needs, and costs.
- Costs and benefits of additional control may be exceeding the "knee of the curve", both in terms of cost, and also environmental benefit. Consideration of the goals of the program are needed to better address those concerns and ensure the best use of limited public funds.
- Call to engineering community for innovative solutions.

MWRA is committed to maintaining the reliability of its collection and treatment systems, allocating approximately $50 million annually to various facility and collection system projects beyond CSO control. Moreover, the four CSO communities continue their efforts to invest in system improvements, contributing to further reductions in CSO discharges in the upcoming years.

Boston Water and Sewer Commission is actively involved in sewer separation work in East and South Boston, while Chelsea continues its sewer separation efforts as part of its master plan. Somerville is engaged in sewer separation and flood control projects, such as the Union Square and Poplar Street Pump Station project, which will decrease flows to MWRA's system. Cambridge is also undertaking sewer separation projects and flood control improvements.

While striving for maximum water quality improvements, the challenges and costs of further CSO reductions, which have minimal water quality benefit, need to be carefully considered. MWRA's ratepayers across the sewer service area have already invested significantly, totalling over $1 billion, to eliminate or control CSO discharges, with the objective of safeguarding the environment and public health.

References

AECOM (2021) Task 6 "Final CSO Post Construction Monitoring Program and Performance Assessment Report" December 30, 2021.

Boston Globe (2023) " Report gives Boston Area Beaches high marks" Available at https://www.bostonglobe.com/metro/2015/05/22/new-report-gives-boston-area-beaches-high-marks/AWIKRsliRr6Wfnpu3obHaJ/story.html.

Levy, Paul F. and Connor, Michael S. (1992) "The Boston Harbor Cleanup," New England Journal of Public Policy: Vol. 8: Issue. 2, Article 7.
MA DEP 314 CMR 4.00: Massachusetts Surface Water Quality Standards.
MassDEP, 2019a. “Final Determination to Adopt a Variance for Combined Sewer Overflow Discharges to Alewife Brook/Upper Mystic River Basin”, Massachusetts Department of Environmental Protection, August 2019.
MassDEP, 2019b. “Final Determination to Adopt a Variance for Combined Sewer Overflow Discharges to Charles River Basin” , Massachusetts Department of Environmental Protection, August 2019.
Massachusetts Water Resource Authority (MWRA) (2023) “Metropolitan Boston's Water System History, available at https://www.mwra.com/04water/html/hist1.htm
Massachusetts Water Resource Authority (MWRA) (2004, 2006, 2011, 2012 & 2015) “Annual Combined Sewer Outflow Reports”.
MWRA 1997 FEIR (Final Environmental Impact Report)
Somerville, 2023. Combined Sewage Overflow Control Planning Program – Joint efforts by Cambridge, MWRA, and Somerville. City of Somerville, https://voice.somervillema.gov/joint-cso-planning, updated June 2023.

Volume 31, Number 1

The Modernization of the Metropolitan Sewer System: The Deer Island Treatment Plant

David Duest[1]

[1]Wastewater Treatment, Massachusetts Water Resources Authority, Boston

E-mail: David.Duest@mwra.com
Published August 15, 2023

Abstract

The Massachusetts Water Resources Authority's (MWRA) inherited two failing treatment plants from its predecessor and was challenged to design, build and commission a new Clean Water Act compliant plant in their place. The Deer Island Treatment Plant was constructed at a cost of $3.8 billion and treats wastewater flows from 2.3 million people from the metropolitan Boston area. The plant is a modern marvel that has unique site constraints and challenges which forced the selection of a number of space saving technologies to meet the end goal: protect public health and the environment. While designing and building the Deer Island Wastewater Treatment Plant, MWRA also began and continues to modernize the collection system, headworks, pumping stations and interceptors feeding the plant.

Wastewater treatment is a critical public service that protects both public health and the environment. Maintaining and upgrading those plants is incredibly important to the health of a region. This is the story of how the Massachusetts Water Resources Authority (MWRA) replaced two severely underfunded treatment plants in the Metropolitan Boston area of Massachusetts with the fully modernized new Deer Island Treatment Plant.

Keywords: wastewater, primary treatment, secondary treatment, disinfection, anaerobic digestion

1. What Did MWRA Inherit?

When MWRA was created in 1984, it inherited two failing primary-only wastewater treatment plants in Boston Harbor – one located on Deer Island and the other on Nut Island – and a poorly maintained combined sewer collection system. Both treatment plants suffered from decades of severe underfunding and lack of maintenance. At Deer Island alone, over one third of the pumps were non-operational when MWRA took ownership. These failures contributed to reduced capacity, poor plant performance and significant environmental impact. While the plants did provide anaerobic digestion and beneficial use of digester gas, the digested sludge was disposed with the out-going tides directly into the harbor along with the poorly treated effluent. Overall, the plants achieved at best 25 to 30 percent solids removal when the Clean Water Act of 1972 mandated 85% removal. It is no wonder Boston Harbor was considered one of the dirtiest harbors in the nation back in the 1980s.

2. How Did This Change?

The MWRA was created to be financially independent from the state with bonding authority to fund its much needed capital improvements to modernize the treatment plants, along with sewer and water infrastructure. MWRA would derive its rate revenue as wholesale suppliers of water services to its water communities and wastewater services to its 43 metropolitan Boston area wastewater communities.

With the MWRA formed, design and construction of one of the most modern and advanced secondary wastewater plants in the county was completed, combining the two obsolete treatment plants into one large facility located on a very constrained Deer Island. The Nut Island Treatment Plant was converted to a Headworks Facility and connected to Deer Island through a deep rock sewer conveyance tunnel.

In addition, MWRA's wastewater collection system is a complex network of conduits and facilities that is strongly influenced by seasonal and wet weather conditions. It 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; 13 pump stations; one screening facility; and four remote headworks facilities. Substantial investment in the rehabilitation and maintenance of these facilities is critical to MWRA's ability to move wastewater from the communities to Deer Island for treatment.

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. To date, a total of $760 million in grant and loan funds have been authorized by the Board and allocated to member sewer communities. 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.

Figure 1. Nut Island sludge disposal to Boston Harbor. (Nut Island, 2023).

Figure 2. Deer Island Treatment Plant (MWRA, 2014).

3. The New Deer Island Treatment Plant

The Deer Island Treatment Plant (Figures 2 and 3) is a modern marvel and cost $3.8 billion US dollars to design, construct and commission. It is the second largest treatment plant in the United States based on maximum capacity. Deer Island treats wastewater from 2.3 million people or 34% of the state's population. It has a design maximum capacity of 1.3 billion gallons per day (4.95 million cubic meters/day) with an average design flow of 361 million gallons per day (mgd) (1.363 million cubic meters/day). The treatment plant is at the edge of its service area and receives wastewater through five deep rock tunnels. Massive pumps in 3 pump stations at the plant lift the sewage between 80 and 150 feet (24 and 46 meters) to bring the untreated sewage to the head of the treatment works.

4. What Treatment Is Used at Deer Island?

Wastewater first travels through grit removal, primary treatment, and then an oxygen activated sludge treatment process before the treated water, now called effluent, is disinfected, dechlorinated and disposed. More than 94% of the solids in Deer Island's incoming wastewater are now removed using Deer Island's modernized treatment processes. Deer Island's new outfall discharges treated effluent over the last

1.25 miles of its 9.5 miles (15.3 km) outfall tunnel, in 110 foot (33.5 meter) deep ocean waters of Massachusetts Bay.

Wastewater solids (sludge and scum), removed from primary and secondary treatment, are thickened: primary sludge by gravity thickening; waste secondary sludge by centrifuges. The thickened sludge is then sent to Deer Island's iconic 12 egg-shaped digesters. These digesters, standing nearly 140 feet (43 meters) tall, hold 3 million gallons of liquid sludge (5.5% solid) for 18 to 22 days. The digesters anaerobically (without free oxygen) break down wastewater solids to a sustainable weak form of natural gas, a valuable fuel for use in Deer Island's energy recovery processes. Any remaining solids are then pumped seven miles to an MWRA-owned pelletizing plant located in Quincy, Massachusetts (Figure 4). The solids are then dewatered and thermally dried into a high quality "Class A" fertilizer, the best EPA rating available for any fertilizer. The fertilizer is sold locally as Bay State Fertilizer and is land applied throughout the eastern half of the continental United States as a great soil enhancer.

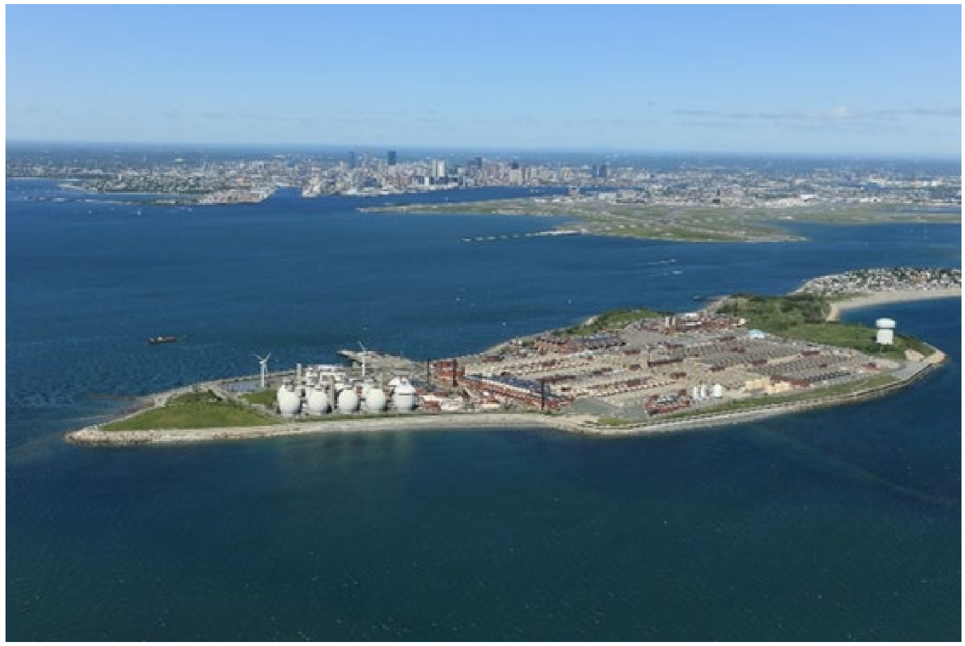


Figure 3. Deer Island Treatment Plant, view from bottom to top, Cryogenic Oxygen Plant, Secondary Reactors and stacked Secondary Clarifiers (open to atmosphere). To the right, disinfection chemical storage (MWRA, 2023).

Figure 4. MWRA Pellet Plant, Quincy, MA (MWRA, 2023).

5. Taking Advantage of the Space It Was Given

Deer Island is a compact 210-acre site, with 150 acres dedicated to the treatment plant. The plant had to be designed to fit into this tight space and the design engineers were not allowed to "grow" the island to build the plant. The plant's design also needed to incorporate future expansion space to ensure the plant would continue to meet future permitting responsibilities should compliance goals change over time. As such, MWRA's design engineers included a number of advanced space-saving treatment technologies on Deer Island: vortex grit chambers; stacked primary and secondary clarifiers; a pure oxygen activated sludge treatment process; egg-shaped digesters and a remote pelletizing operation off-island. While a number of these technologies have been used at other treatment plants, Deer Island was unique in combining them all in one space-limited site to maximize treatment while preserving space for future expansion.

Given that the plant was built on land surrounded by the Atlantic Ocean, protective measures had to be built into the facility to ensure the plant would survive a direct hit from a category 3 hurricane with storm run up. A new energy dispersing seawall was added along the Massachusetts Bay side of the plant to redirect wave run up. The plant was one of the first facilities in the nation to plan and design for sea level rise due to polar ice cap melt. As a result, all Deer Island facilities were built up from the ground while the ground level was raised an appropriate level to ensure the plant would be protected from future weather and climate conditions.

Given its remoteness, the plant was designed with 100% backup power generation capability should the primary electrical connection be compromised. The plant has designed into its systems two, 26-MW combustion turbine generators to fill this role with one unit alone capable of providing enough power to sustain plant operation up to 850 mgd. (Note: 94% of the historical operating time flows are under this level.)

The plant is highly complex and relies on its control system to oversee a majority of its operation, allowing MWRA to maintain a lean operational workforce. With over 30,000 input/output points and over 3,000 control screens within its control system, the control system is one of the largest in the country. It is estimated that over 70% of Deer Island systems are fully automated with 90% of its systems monitored. Maintenance of 70,000 critical pieces of equipment is tracked in a Maximo maintenance management database, dynamically linked to a purchasing and warehousing application for efficient operation.

And if the treatment plant wasn't improvement enough, the land surrounding it is now a public park that features five miles of public walkways and trails for walking, jogging, sightseeing, picnicking, fishing and bicycling. The public access area is open to the public year-round, from sunrise to sunset and includes 60 acres of open space, 10 landscaped overlooks, interpretive signage and dramatic views of the Boston skyline and Harbor Islands.

6. Building For a Sustainable Future

The conversion of wastewater solids to a renewable fuel (a "green" product) is a huge boon to the treatment plant and provides for major operational cost savings to the MWRA. Over 250 dry tons of solids per day ("dtpd" or 226,000 kg) are added to the digesters as a result of Deer Island's wastewater treatment processes. At the end of 18 to 22 days, 100 dtpd remain and this material is then pumped seven miles to MWRA's pelletizing plant where the material is converted to fertilizer. About 150 dtpd of solids are broken down and converted to a weak form of natural gas, roughly 65% methane with a thermal value of roughly 630 BTU per cubic foot ("cuft"). 190,000 cuft per hour (5,380 cm/hr) of digester gas is produced, compressed and sent to Deer Island's thermal plant where the gas is burned in high pressure steam boilers. The resulting steam is sent through a steam topping turbine where electricity is produced and the steam is converted to high temperature water. This high temperature water is circulated around the plant for building and process heating.

In total, digester gas produces more than 95% of the plant's heating needs and 23% of the electricity needs of the plant, an equivalent value of $18 to $26 million US dollars annually. Digester gas is responsible for keeping Deer Island 57 to 65% "off the grid." A future project to revise Deer Island's combined heat and power process could increase, within the next 5 to 10 years, the electrical generation to 52% increasing Deer Island's off-grid percentage up to 80%.[1] Deer Island has an annual budget of slightly over $60 million US dollars. Without digester gas, Deer Island's budget would be over $80 million. In addition to the savings from use of digester gas, MWRA has diversified its green energy portfolio by installing two 1.1-MW hydroelectric generators (in its outfall conveyance tunnel), two

Figure 5. Deer Island view from public access looking south. Egg-shaped digesters (the heart of Deer Island's green energy program), and its two wind turbines (MWRA, 2023).

[1] A more detailed discussion is presented in the "Energy Matters" paper included in this issue.

600-kW wind turbines and 756 kW worth of solar panels. All in all, up to 30% of Deer Island's electricity demand are met by on-site green energy.

7. Motivations for Continuous Improvement

MWRA is an environmental agency that takes its role at protecting the public health and the environment very seriously. Since its inception, it has seen Boston Harbor transformed from the dirtiest harbor in the nation to a harbor with some of the cleanest urban beaches as a result of modernizing its treatment plants and collection system.

MWRA defines itself as an environmental leader and practices what it preaches in all of its daily operations. MWRA derives its funding directly from the local communities it serves. It has always felt a tight connection to its ratepayers and understands it has a fiduciary responsibility to maintain the best operation it can provide for a reasonable cost. Enhanced sustainability practices, reduced operating costs and minimizing its impact on the environment in the pursuit of its mission are key motivations.

In addition to internal motivations, the State of Massachusetts under former Governor Deval Patrick, in 2007, established Executive Order 484. This was further challenged by Massachusetts current Governor Charlie Baker under Executive Order 594, established in 2021. EO 484 and EO 594 set renewable energy and demand reduction goals for all state agencies and awards Massachusetts state agencies that meet these goals. As such, MWRA has been awarded several awards for "Leading by Example" "for outstanding environmental and energy achievement." MWRA has also received USEPA's Green Power Partnership Award as a green power leader. MWRA is also a registered with the Federal Department of Energy under its Better Plants Program which also sets goals to reduce demand and maximize green energy to maintain a sustainable operation. Under this program, MWRA has been awarded a certificate of recognition for "Water Resources Utility of the Future Today". MWRA has been an industry leader. It strives to continue to improve its operation and reduce operating costs all the while protecting public health and the environment.

8. Was It Worth It?

For many decades leading up to the clean-up initiative, Boston had neglected its harbor. A raised highway acted as a barrier, effectively separating the waterfront from the city, and the concept of development in the area was virtually non-existent. Only industrial and maritime industries operated near the water's edge. However, the transformation of Boston Harbor into a pristine environment has proven to be a pivotal force both as an economic driver and a valuable community asset.

Over the past two decades, development along the waterfront has seen remarkable growth, leading to a surge in private investments and economic prosperity, estimated to be worth as much as $80 billion. What were once vacant lots and industrial structures have now been converted into attractive and vibrant neighborhoods. The revival of Boston Harbor has not only created new economic opportunities but has also significantly improved the overall quality of life for residents.

The Boston Harbor Islands, now designated as a National Recreational Area, are teeming with activity. Regular ferry services bring residents and tourists alike to enjoy fishing, camping, and picnicking in these idyllic locations. The harbor itself has become a hub for sailboats and kayaks, while the city's beaches proudly boast the title of the cleanest urban beaches in the country.

In addition to these positive changes, the implementation of the Boston Harborwalk has been a game-changer. This 43-mile linear park gracefully stretches along Boston's shoreline, connecting waterfront neighborhoods to Boston Harbor and, in turn, fostering a stronger sense of community and recreation.

The transformation of Boston Harbor from an overlooked and polluted waterway into a thriving economic, recreational, and community resource stands as a testament to the power of determined efforts to revive and cherish the natural assets of a city.

9. References

Nut Island (2023) "U.S. National Park Service" www.nps.gov. Retrieved https://www.nps.gov/places/nut-island.htm

MWRA (2014) "Struvite: The Deer Island Experience, Presented by Ethan Wenger, Manager, Process Control MWRA Deer Island Treatment Plant"

MWRA (2023) "Deer Island Wastewater Treatment Plant" https://www.mwra.com/03sewer/html/sewditp.htm

Energy Matters: MWRA Perspective

Carolyn Fiore[1], Denise Breiteneicher[2] and Christian A. Murphy[3]

[1] Deputy Chief Operating Officer, Massachusetts Water Resources Authority, Boston, USA
[2] Program Manager, Energy and Environment, Massachusetts Water Resources Authority, Chelsea, USA
[3] Program Manager, Energy Management, Massachusetts Water Resources Authority, Winthrop, USA

E-mail: Carolyn.Fiore@mwra.com, Denise.Breiteneicher@mwra.com, Christian.Murphy@mwra.com

Published August 15, 2023

Abstract

Providing water and wastewater services to 61 cities and towns results in a significant physical footprint with pipelines, pump stations, treatment plants, and buildings for maintenance and administration. Urban water and wastewater transportation and treatment is an energy intensive enterprise, and environmental and public health improvements often require new processes or facilities that consume more energy, but the Massachusetts Water Resources Authority (MWRA) has developed a robust energy management program over the past 20 years to ensure that it is serving its ratepayers and protecting the environment by reducing its purchased energy consumption and carbon footprint.
MWRA energy management projects generally fall into the following categories:

- Energy Consumption Reduction: Energy efficiency projects, water and wastewater process optimization
- Renewable Energy Use: Solar photovoltaics, hydropower turbines, wind turbines, digester gas combustion
- Electrification: Transportation fleet electrification, facility electrification
- Alternative Market Participation: Demand flattening with battery storage, load shedding, renewable energy certificate purchases.

Energy management activities have contributed to a reduction in the MWRA's energy use, expenses and carbon footprint using a range of renewable energy technologies well as efficiency and electrification improvements. This has included the implementation of a policy of including energy efficiency and renewable energy analyses in all facility rehabilitation projects. In addition, projects such as a large, combined heat and power (CHP) replacement at the Deer Island Wastewater Treatment Plant (Deer Island) will further increase the share of energy derived from renewable sources and reduce the plant's dependence on the power grid

Keywords: Renewable energy, Energy management, Combined heat and power, Energy efficiency, Water utility, Wastewater Utility

1. Introduction

For much of its existence, the Massachusetts Water Resources Authority (MWRA) has worked to wisely manage both its energy consumption and where its energy comes from. In recent years, the threats from climate change have become clearer and clearer with the primary driver being the global need for energy. This has added a sense of urgency for MWRA to optimize its energy management program to ensure that both the ratepayers and the environment are served by mitigating purchased electricity costs and reducing greenhouse gas emissions. Where energy comes from and how it is used matters even more now than it has in the past.

This article provides an overview of energy matters at the MWRA. Energy management projects at the MWRA generally fall into the following categories:

- Energy consumption reduction
- Use of renewable energy

- Electrification

The following sections will cover each of these areas individually and discuss the policy of including an energy analysis into all facility rehabilitation projects. It also includes a project currently in the early design phase to replace the existing combined heat and power facility at the Deer Island Treatment Plant.

2. Energy Consumption Reduction

The best way to reduce the environmental and economic impact of energy consumption is to simply consume less of it. As an energy intensive enterprise this is a challenge for the MWRA, but not an insurmountable one.

2.1 Energy Consumption

The total electricity consumption of the MWRA during fiscal year 2021 was approximately 151 gigawatt hours (GWh). The total monthly electricity consumption is shown in Figure 1. (Renewable production is also shown on the bar graph.) Additionally, MWRA used about 1.2 million gallons of fuel oil and 569,000 therms of natural gas in FY21.

Although MWRA owns and operates approximately 50 facilities, one stands out as the primary energy consumer. Deer Island is the regional wastewater treatment plant for 2.3 million people in 43 communities in the metropolitan Boston area with a peak treatment flow capacity of over one billion gallons per day and an average of 345 mgd. In order to treat this volume of wastewater properly, Deer Island consumed a total of 102 GWh of electricity in FY2021. This is about 68% of the electricity consumption of the entire Authority. Deer Island's diesel fuel usage in FY21 was 686,429 gallons or about 58% of the total diesel fuel usage across the MWRA.

For comparison, the average home in New England uses approximately 8,200 kilowatt hours (kWh) of electricity per year, so MWRA's electricity usage is equal to the electricity use of about 18,000 homes.

2.2 Successful Energy Reduction Projects

With over 60 energy audits completed covering MWRA's medium to large facilities, implementation of audit recommendations and other optimization efforts have resulted in an estimated savings of $2 million annually.

To accomplish this, MWRA has worked closely with its electric utilities, signing its first memorandum of understanding (MOU) with Eversource in 2014 with a target of reducing electrical demand by 15% over three years, or approximately 18 GWh. The MOU provided the utility with a partner that is committed to energy use reduction and in turn, MWRA received slightly higher incentives amounts for all kWh reductions as well as specialized technical assistance on complicated projects. MWRA exceeded this target and subsequently signed another MOU with Eversource and National Grid. From 2008 to 2022, MWRA has received over $5 million in incentive payments from the utilities for completion of over 100 separate energy efficiency projects.

Examples of successful process modification efforts implemented to reduce energy consumption include:

- Improvements to the oxygen system at Deer Island, which included the addition of variable frequency drives (VFDs), instrumentation improvements and turning off unneeded equipment, saving 10 GWh per year.

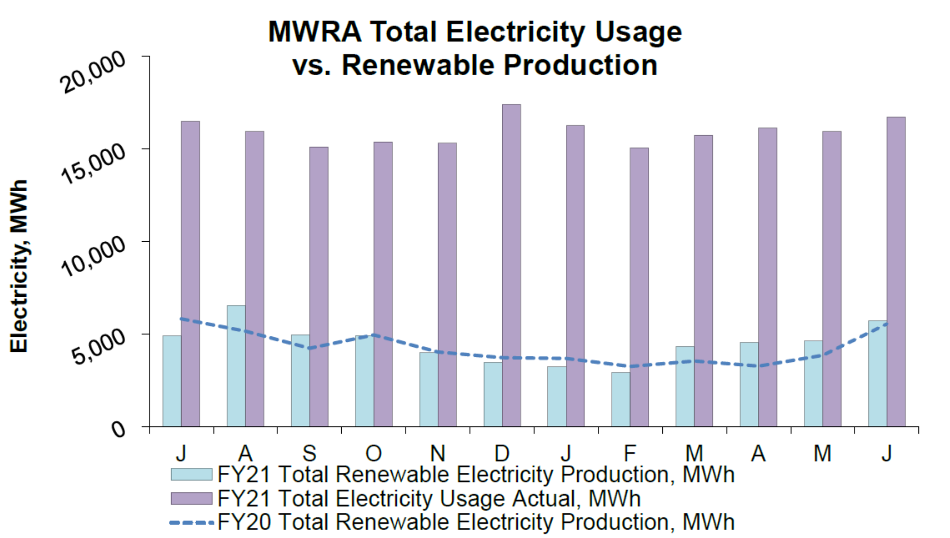


Figure 1. MWRA total monthly electricity consumption for Fiscal Year 2021 (MWRA 2022).

- Adjustment of the pumping shaft wet well level upward at Deer Island, which required the pumps to operate less frequently, saving 4.5 GWh per year.
- Installation of VFDs on a variety of motors for speed modulation to match demand.
- Turning off an unneeded soda ash mixing operation at the Carroll Water Treatment Plant, saving 1.8 GWh per year.

More traditional energy saving measures have also been implemented. For example:

- Replacement of exterior metal halide lights with LED fixtures at a Deer Island administration building reduced fixture energy use by 60%.
- Multi-phase lighting improvements were made across multiple facilities to upgrade to LEDs.
- Installation of an energy management system in an administration building reduced natural gas consumption by 33% in winter.
- Reduction of ventilation rates at a headworks when space is unoccupied reduced fuel usage by 43,000 gallons per year and electricity usage by 66 MWh per year.
- Installation of pump station pipe insulation eliminated dehumidification and reduced maintenance costs from condensation, saving approximately 118 megawatt hours (MWh) per year.

MWRA has implemented several energy consumption reduction projects, and upon reviewing their absolute magnitude of energy savings, it becomes evident that process improvements yield substantially greater energy reductions compared to HVAC modifications. The data indicates that the changes made in the operational processes have a more substantial impact on reducing overall energy consumption than the alterations in HVAC systems. This observation underscores the significance of focusing on process enhancements as an effective strategy for achieving significant energy efficiency gains within MWRA's operations..

3. Renewable Energy Generation

When energy must be consumed, the source of that energy is important to consider. MWRA has long been committed to using renewable energy.

3.1 Total Renewable Electricity Production

Over the years, MWRA has built up a significant portfolio of renewable energy installations. Figure 2 shows the total amount of electricity generated by renewable energy assets as a percentage of the total electricity consumed by the MWRA for FY2021.

The total renewable electricity generated by the MWRA 54,040 MWh, or approximately 28% of the total electricity consumed in FY2021.

An interesting aspect of the renewable electricity generation is that a significant percentage of it is not used on the site where it is generated, but exported to the grid. The exception to this is Deer Island where all the renewable energy is used onsite.

3.2 Wind Turbines

Due to the high population density surrounding many of the MWRA facilities there are limited opportunities for large wind turbine generator installations. There are, however, two installation locations: one 1.5 MW turbine at a wastewater pump station in Charlestown and two 600 kW turbines located at Deer Island. Figure 3 shows the turbines installed at Deer Island.

3.3 Solar Photovoltaics

As a low maintenance energy source, solar photovoltaics are an excellent renewable energy technology. MWRA has two primary installation locations: A ground mounted 496 kW system at the Carroll Water Treatment Plant and four arrays that total 736 kW installed at Deer Island. This includes the 234 kW ground mount system shown in Figure 3. MWRA also has a combined ground/roof mounted system totaling 76 kW at a new backup water pumping station near the Carroll Water Treatment Plant. This facility is also heated by a geothermal heat pump.

Additional sites are currently in the planning stage, including some using parking canopy solar as well as over underground water storage locations.

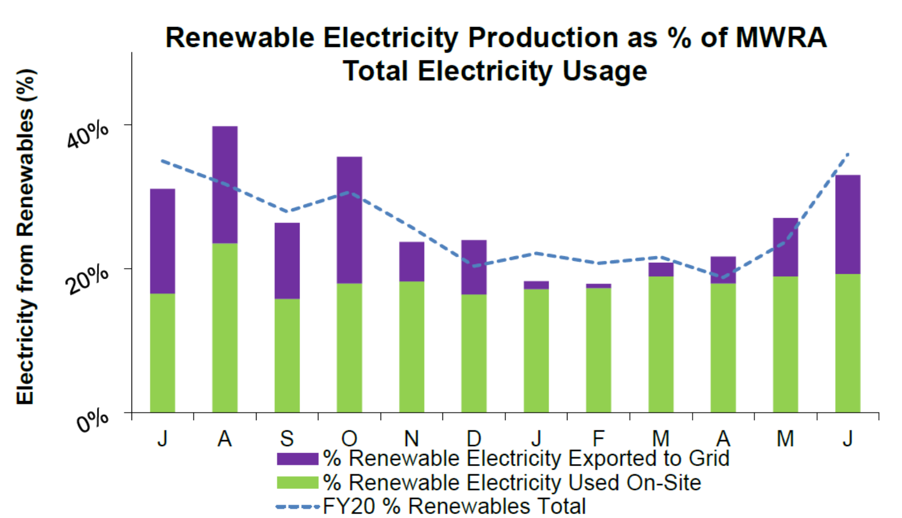


Figure 2. MWRA total monthly renewable electricity production (MWRA 2022).

3.4 Hydro Turbines

As a water utility, there are opportunities for hydro turbine installations that are not inserted into a river flow. In water systems there is often extra water pressure when a reservoir is at a higher elevation than the users of that water. This extra pressure can be used to generate electricity.

The MWRA has four installations in the drinking water system:

- One 3.5 MW hydro turbine at the Oakdale Transfer Station where drinking water is transferred between reservoirs.
- Two 1.7 MW hydro turbines at the Cosgrove Aqueduct where the water from the reservoir drops into the aqueduct.
- One 200 kW in-pipe hydro turbine at Loring Road Covered Storage Facility.
- One 60 kW in-pipe hydro turbine at the William A. Brutsch Water Treatment Facility.

In addition, there are two 1.1 MW hydro turbines at Deer Island, which capture the energy from the treated wastewater as it drops into the outfall at the end of the treatment process.

3.5. Digester Gas

Deer Island's iconic digester "eggs" produce digester gas, rich in methane, through the anaerobic digestion of the solids extracted from wastewater. Figure 4 shows some of the digesters at Deer Island visible from Boston Harbor and planes landing at Logan Airport.

Mimicking the stomach's natural digestion process, microorganisms naturally present in the sludge work to break sludge and scum down into methane gas, carbon dioxide, solid organic byproducts and water. Digestion significantly reduces sludge quantity. The byproduct of the digestion process is 65 percent methane gas, which is captured and piped to boilers that generate enough heat to warm the buildings on the site as well as for the heat-dependent treatment processes.

Deer Island generates an average of 278 GWh per year of digester gas. MWRA also operates a much smaller MWRA wastewater treatment plant in Clinton which generates a much smaller amount of digester gas estimated at 1.5 GWh per year. At the Clinton plant, the digester gas is burned in a boiler to provide heat for the digesters and to heat one of the buildings.

At Deer Island. digester gas is used for heating as well as generating electricity. This is discussed in more detail below.

Figure 3. Wind turbine generators and ground mounted photovoltaic array installed at Deer Island (MWRA 2023).

Figure 4. Two of the twelve digesters at Deer Island (MWRA 2023).

4. Deer Island Combined Heat and Power

As the primary consumer of energy for the MWRA, Deer Island is also one of its primary sources of energy through the generation of digester gas. How this digester gas can be most effectively used is the subject of a current design effort.

4.1 Current Deer Island Use of Digester Gas

The digester gas at Deer Island is currently converted into both heat and electricity using a combined heat and power (CHP) system. A traditional electrical generation system would waste the significant amount of thermal energy generated by burning the source fuel, and a traditional thermal system would generate heat efficiently, but wouldn't generate any electricity.

At Deer Island, the digester gas is to a certain extent a waste product and has to be disposed of shortly after it is generated. As a result, it is a time sensitive fuel source. For much of the year this fuel source's energy content exceeds the thermal energy needs of Deer Island. To make the most of it, it makes sense to generate electricity from it as well as meeting the plant's thermal demand.

Figure 5 shows a high-level schematic of the existing CHP at Deer Island. Digester gas is the primary fuel with some supplementary fuel oil consumption. These are both burned in a boiler that produces high pressure steam. This steam drives two steam turbine generators that generate electricity. The steam exhaust from the steam turbines is then used to meet the thermal demand of the treatment plant.

This system has worked effectively since the construction of Deer Island, meeting the thermal demand at Deer Island as well as being one of the largest sources of renewable electricity in all of the MWRA.

4.2 Proposed CHP at Deer Island

As this facility ages, MWRA has begun the process of replacing it by determining if the onsite energy resources can be used more effectively. A high-level schematic of the proposed design is shown in Figure 6.

In this proposal, digester gas would remain the primary fuel with a reduced amount of supplementary fuel oil. Some of the digester gas and all the fuel would be burned in an array of three boilers. Unlike the existing system, this is a hydronic boiler that generates hot water instead of high pressure steam. A hot water boiler has a few advantages over steam as it is generally more

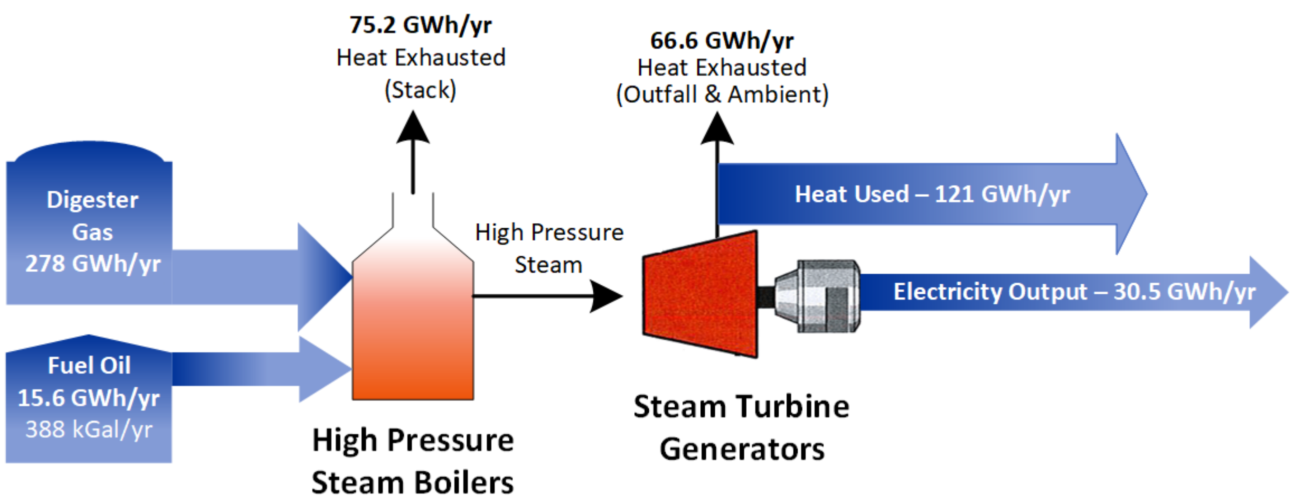
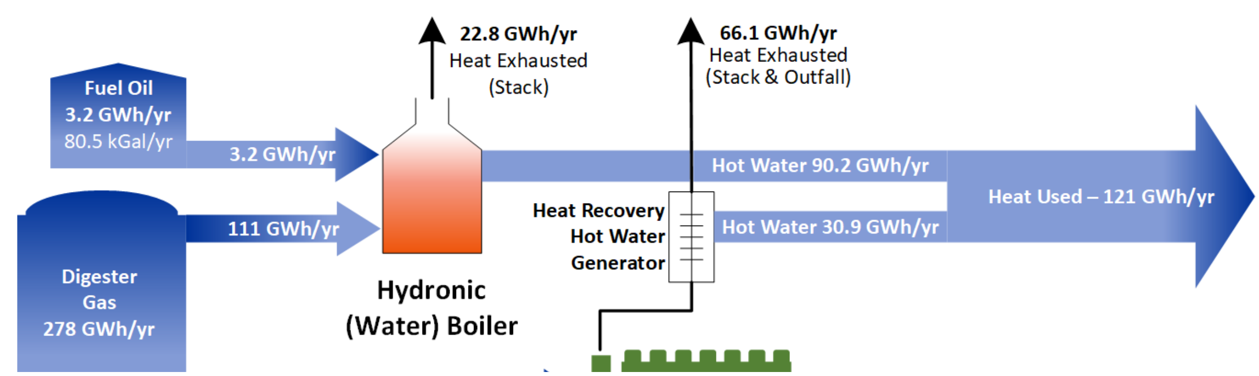


Figure 5. High level schematic of the existing CHP at Deer Island.



efficient, simpler and eliminates the hazards of high-pressure steam. This hydronic boiler would meet about two thirds of the thermal demand of the plant.

The remaining digester gas would be consumed in the CHP engine generators. The current design consists of an array of spark ignited reciprocating engines that are connected to electricity generators. This array is expected to consist of five units with a total electrical output rating of 15 to 17.5 MW. Some of the heat exhausted by these engines would also be captured and used to meet the remaining third of the Deer Island thermal demand.

The performance of this system has been predicted through simulations, one of which was created in Wolfram's Mathematica computational software using hundreds of calculations. Because Deer Island has extensive data collection of various parameters, this simulation was able to use actual resource and demands data from Deer Island in the calculations and pulled in 2.8 million data points. The performance of the new equipment was modelled, and the simulation predicted how it is expected to operate over multiple years when run with the Deer Island data. From this simulation the proposed CHP is expected to generate 69.3 GWh/yr of electricity which is about 2.3 times the electricity generated by the current system.

Table 1 lists three key parameters that are expected to increase with the installation of the new CHP. Currently, the CHP generates 21% of the total electricity consumed at Deer Island. The new CHP is predicted to increase this to 48%. Similarly, the overall yearly average CHP efficiency is expected to increase from 52% to 68%.

Table 1. Expected Increases from New CHP

	Existing CHP	Proposed CHP
Percent electricity from CHP	21%	48%
CHP Efficiency	52%	68%
Percent energy from onsite sources	~60%	~75%

As discussions of net zero energy have become more mainstream, the percentage of energy from onsite sources has become a more important metric. For an energy intensive enterprise like wastewater treatment, approximately 60% of total energy (both thermal and electrical) is generated from onsite sources, which is quite good. It would be very exciting to be able to increase this to approximately three quarters of the total energy consumption coming from onsite sources with the new CHP.

The new CHP is also predicted to have some metrics that will decrease as shown in Table 2. Fuel oil consumption is expected to decrease significantly − by about 300,000 gallons per year. From both the fuel oil consumption reduction as well the reduction of utility electricity consumption, greenhouse gas emissions are expected to decrease by 16,800 metric tons per year. This is the equivalent of about 42 million passenger car miles being driven. (Note, these calculations do not include data from renewable energy certificates and sales.)

Table 2. Expected Decreases from New CHP

	Reductions for new CHP
Fuel Oil Usage	300 kGal/yr
Greenhouse Gas Emissions	16,800 Metric Tons
Construction and 25-year Operating Cost	$43.1M Net Present Value

From a financial perspective, when analyzing the new CHP in comparison to the existing CHP over a 25-year evaluation period, it is projected to result in a significant cost advantage. The anticipated net present value of the new CHP is approximately $43.1 million lower than that of the existing CHP. This evaluation takes into consideration various factors, including the design and construction cost (estimated at $82 million) and the operational expenses of the new CHP. Additionally, it factors in the operating cost and replacement-in-kind cost of the existing CHP at the end of its useful life. The net present value method is utilized to account for the time value of money, facilitating a fair comparison of monetary values over time.

Considering the compelling advantages outlined in Table 1 and Table 2, proceeding with this project appears to be a sensible decision. A preliminary analysis conducted by both a consultant and in-house staff has been completed, and the MWRA (Massachusetts Water Resources Authority) is presently in the process of developing a detailed design contract.

4.3 Where the Energy Comes From

So, how it is possible for this new system to extract more useful energy from less total available energy? It's because the new CHP will convert fuel to electricity more efficiently than the existing system and the thermal demand varies over the course of a year.

In the existing CHP, fuel is converted to steam which then drives steam turbines to generate electricity. This has a fuel to electricity efficiency of about 10% and operates like that year round.

For the proposed CHP, however, when thermal demand is low (in the summer), the digester gas not used by the boiler would be sent to the reciprocating engines. These will convert the digester gas to electricity with an efficiency of around 40%. As a result, significantly more useful energy is extracted from the onsite digester gas resource during those months.

This is shown graphically in Figure 7. The horizontal axis shows months of the year while the vertical axis is the total energy for that month. The top data points in blue represent the total energy that is available or consumed by the existing CHP. The bottom orange data points are the useful energy generated by the existing CHP. The difference between these two curves is the amount of energy that is not used. During the summer months, this difference grows indicating an increase in energy being exhausted.

Similarly for the new CHP, the top green line represents the total energy available while the red data is the energy expected to be generated by the new CHP. As you can see, particularly in the summer months, the new CHP is expected to be able to extract more useful energy than the existing system.

The difference between the orange line for the existing CHP and the red line for the new CHP represents the additional energy that is expected to be extracted from the new system.

5. Electrification

Historically, using electricity for heating did not make a lot of sense from an overall use of source fuel standpoint. This is due to the amount of fuel energy exhausted as heat when generating electricity from fossil fuels. But with the advancement of heat pump technology and the growing percentage of renewable electricity on the grid, electrification appears to be an important step in the long-term lowering of greenhouse gas emissions. As a result, MWRA has begun a program of electrification.

MWRA has a fleet of approximately 400 vehicles ranging from SUVs to light- and medium-duty pickup trucks to large, specialized vehicles such as dump trucks, vactor trucks and backhoes. MWRA began purchasing hybrid SUVs and sedans at least ten years ago and has recently accelerated its purchase of all electric SUVs, buying approximately 5 or 6 per year with the goal of replacing all the SUVs with electric vehicles (EVs) as they age out. Additionally, with the production of electric light-duty pickup trucks beginning in 2023, MWRA will target the replacement of the existing 97 light duty pickup trucks beginning in 2023/2024.

In order to ensure adequate charging for the new EVs and to support electric vehicle purchases among staff for personal vehicles, MWRA is installing banks of primarily Level II smart charging stations along with a few DC Fast chargers at facilities where most of the fleet vehicles are garaged and staff are headquartered. MWRA is taking advantage of utility and state grant programs to help pay for the new electric vehicle charging stations beginning with thirty new ports for charging electric vehicles at its main administration building in 2023.

MWRA is also looking to reduce its dependence on fuel oil for heating its water and wastewater facilities by studying the feasibility of replacing fuel oil heat with either air source or water source heat pumps. MWRA recently completed audits in conjunction with the Industrial Assessment Center at the University of Massachusetts Amherst that looked at the feasibility of using heat pumps to heat two of its medium size pump stations. The audit showed that it would be possible to heat these facilities primarily using heat pumps. As a result of this the MWRA is moving forward with a design for using heat pumps at these

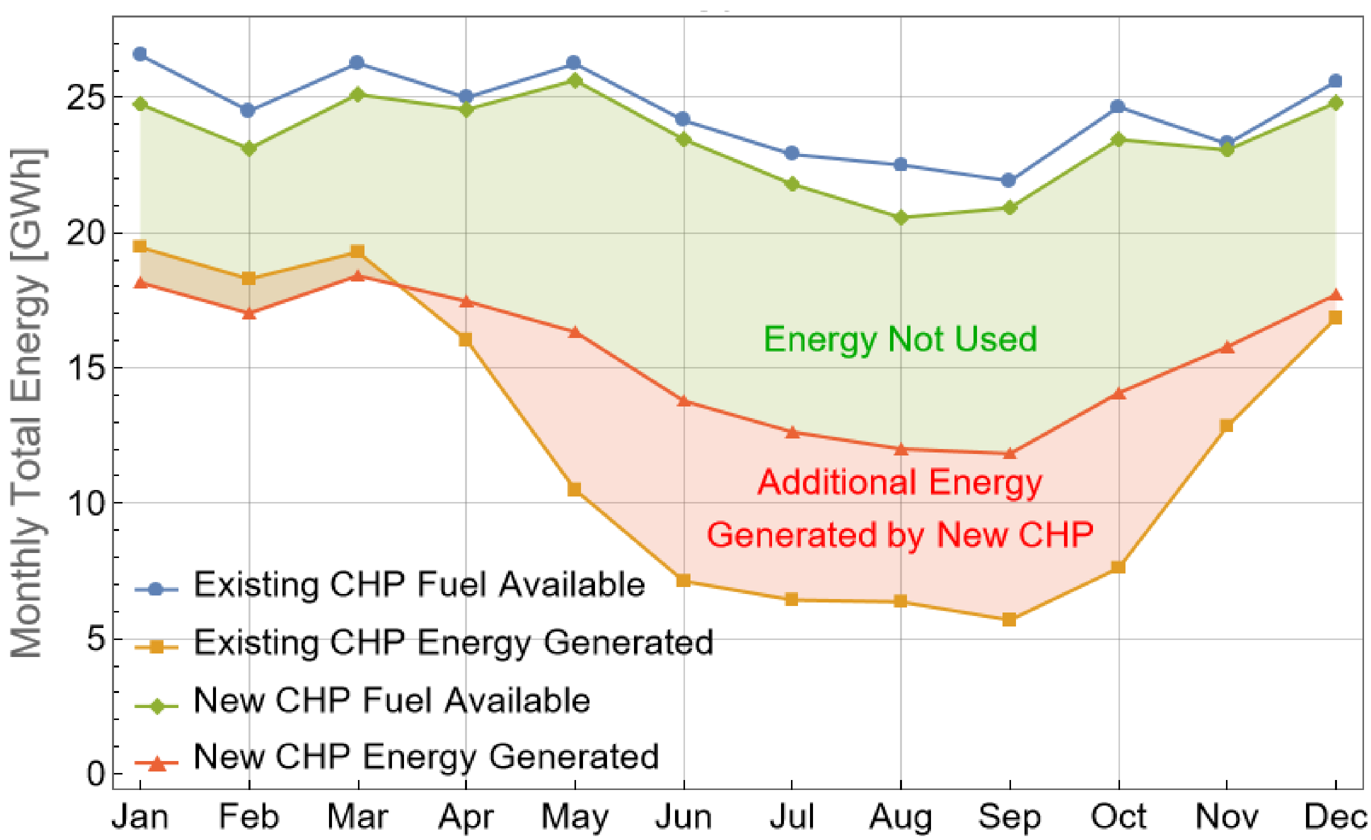


Figure 7. Total monthly energy available and used for the existing and new CHPs.

facilities as a pilot project that can potentially be rolled out to other facilities in the future.

6. Facility Rehabilitation Energy Analysis

MWRA has incorporated the goal of reducing its greenhouse gas emissions and energy costs into all of its planning processes, including its Five-Year Business Plan, master plans and monthly metric reports to management.

As it is easiest and most cost-effective to include energy improvements in significant rehabilitation projects or new construction, the MWRA explicitly includes energy efficiency and renewable energy considerations in its design process.

Engineering staff use previously completed energy audits to identify potential energy saving measures to be included in the design documents at the beginning of a rehabilitation project. MWRA's energy SOPs require an Energy Design Journal (EDJ) be included in the bid for rehabilitation or new construction of facilities. The inclusion of an EDJ, to be completed by the design consultant, ensures that all potential energy savings and reductions are considered in the early stages of the project. It requires that the design consultant look at current energy usage before rehabilitation, and expected future energy use based on the recommended energy efficiency measures so that MWRA staff can make the best decisions to ensure the rehabilitated facility will be as energy efficient as technically and financially feasible.

7. Conclusion

Creating a portfolio of energy practices and sources to meet the challenges of the future is a process the MWRA is actively engaged in. From renewable technologies that have operated for decades, to new installations currently in design, determining how it is possible to maximize the use of renewable energies is continuously investigated. Discovering ways of reducing energy consumption, sometimes with an increase in the service provided - such as additional odor control - is an active area of exploration. MWRA plans to continue maximizing energy value for its ratepayers as well as reducing the climate impacts of its operations.

References

MWRA, 2022. Board of Directors Report on Key Indicators of MWRA Performance, Fourth Quarter FY2021". Boston, MA: Massachusetts Water Resources Authority.

MWRA, 2023. "How the Deer Island Treatment Plant Works" Accessed at www.mwra.com. https://www.mwra.com/03sewer/html/sewditp.htm

Wentworth
School of Management

Master of Science in Construction Management

The Master of Science in Construction Management (MSCM) program is designed for working professionals who wish to advance their career through post-graduate study in construction management principles. This industry focused program is accredited by the American Council for Construction Education (ACCE) and is designed to give students a strong understanding of construction management concepts, from pre-design through closeout. The program combines technical expertise with effective leadership and business management principles to prepare graduates for successful careers in the construction industry.

Master of Science in Construction Management– Fully in person or fully online

Wentworth
School of Engineering

Master of Science in Civil Engineering

Imagine a world of limitless possibilities, where towering skyscrapers scrape the stratosphere, modern transportation networks seamlessly connect cities, and sustainable infrastructure preserves our planet for generations to come. As a civil engineer, you will have the privilege of designing, constructing, and maintaining the critical systems that shape our modern society. As a passionate civil engineer, your role is to blend creativity with precision to solve complex challenges. Together, let's build a brighter tomorrow through the marvels of civil engineering!

Master of Science in Civil Engineering – Fully in person or fully online