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

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

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.

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

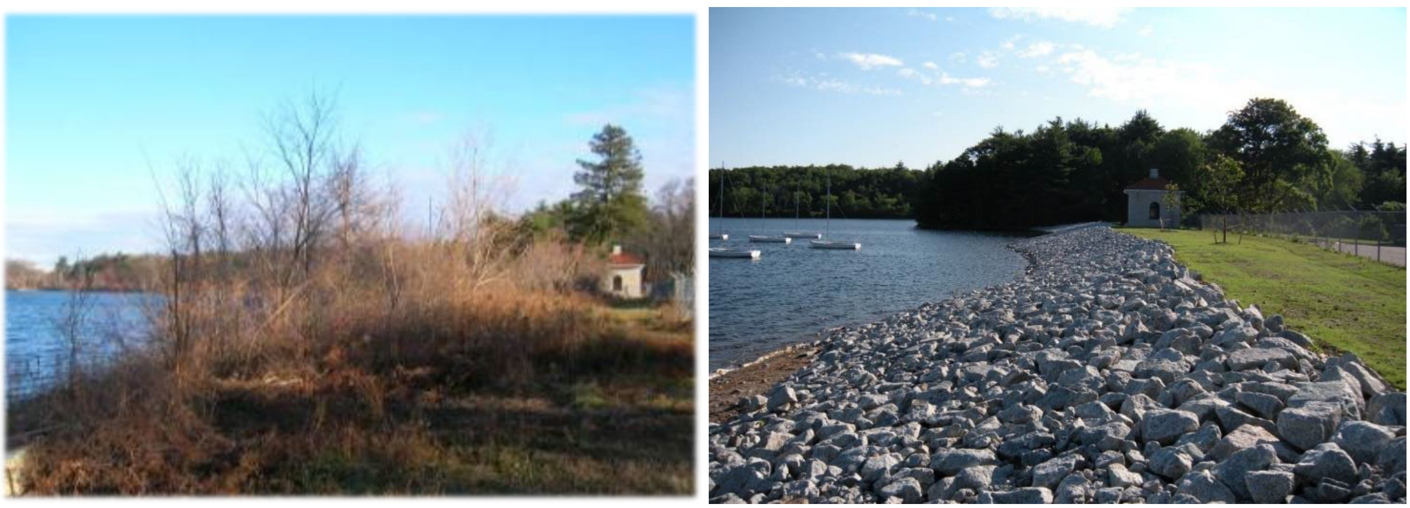

Figure 10. Spot pond dam upstream before tree clearing (L) and after armoring (R)

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

