A Tale of **Two Reservoirs**

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Source Water Characterization and Action to Protect Metropolitan Boston

Introduction

Two reservoirs, the Quabbin and the Wachusett, and their associated watersheds provide the majority of drinking water for 47 communities, 2.2 million people and 5,500 industrial users in the metropolitan Boston area. The drinking water system is managed by the Massachusetts Water Research Authority (MWRA) while the source water is managed by their partner agency, the Massachusetts Department of Conservation and Recreation (MA DCR) Division of Water Supply Protection. A schematic of the water system is shown in Figure 1. The Quabbin Reservoir water is transferred to the Wachusett Reservoir through the Quabbin Aqueduct. The Wachusett Reservoir is the terminal supply reservoir via the Cosgrove Intake where the water is carried to the distribution system. The Quabbin Reservoir also serves as the terminal supply reservoir for approximately 95,000 people in three western Massachusetts communities that obtain their water through the Chicopee Valley Aqueduct. The Massachusetts Water Resources Authority (MWRA) is responsible for treatment and distribution of water from these reservoirs.

Source water protection (SWP) for the reservoirs that serve the city of Boston, MA is a priority of the MA DCR since this water supply is currently operating under a filtration waiver as part of the Surface Water Treatment Rule. This means the raw water must meet strict water quality standards prior to disinfection to adequately protect the public health of the user community. The constituent of primary concern to the MA DCR is waterborne pathogens. These are monitored through enumeration of fecal indicator bacteria. The MA DCR manages many activities as part of its SWP program including long-term monitoring of fecal indicator bacteria, current and on-going sanitary surveys, and targeted microbial source tracking studies. The characteristics of the systems' two reservoirs are markedly different and require different SWP strategies. In 2010, the MWRA/MA DCR source water protection program was awarded the American Water Works Association's (AWWA) Exemplary Source Water Protection Award for these efforts.

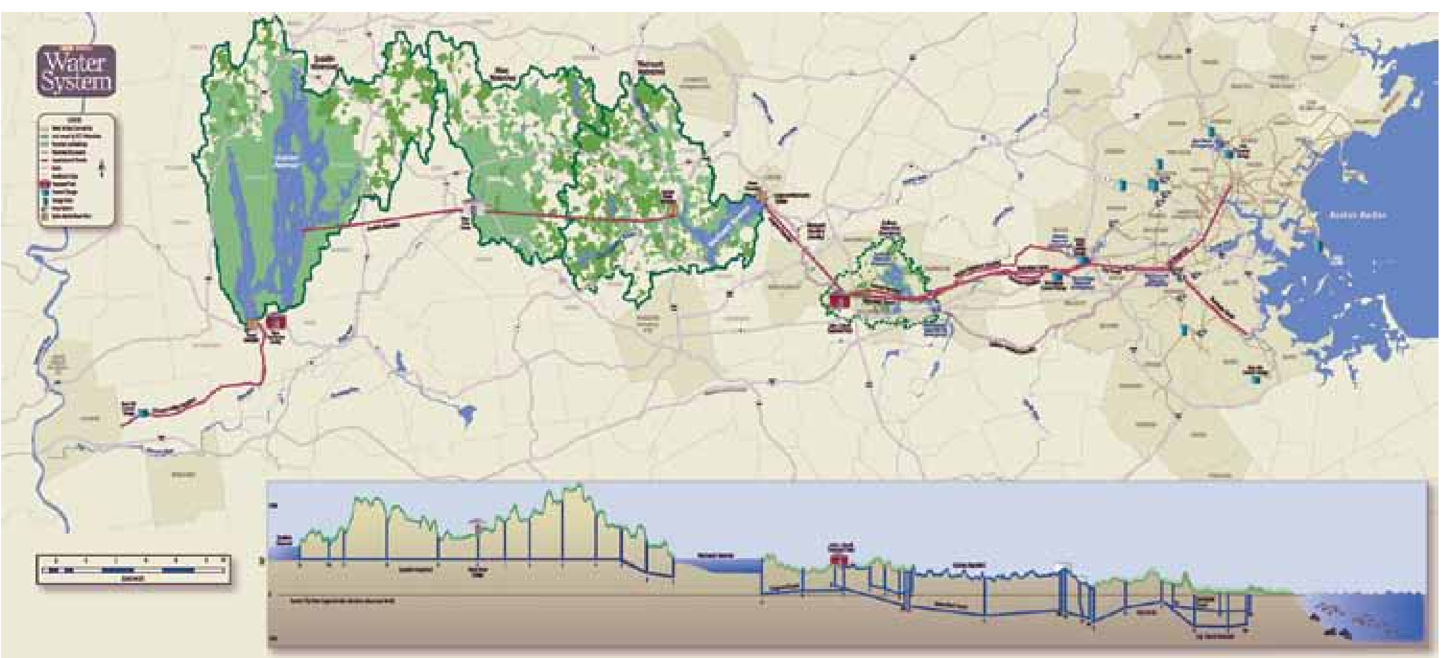

Figure 1. Map of the MWRA Water System (MWRA, 2011).

The Quabbin Reservoir

The Quabbin Reservoir has a 412 billion gallon capacity, a surface area of approximately 40 mi^2 (100 km^2), and 187 mi^2 (485 km^2) of watershed area. Approximately 57 percent of the watershed land is MA DCR-owned and a total of 75 percent of the watershed land is protected between MA DCR ownership and agreements with private owners for limited development and recreational activities. The majority of this land is classified as forest. Full body contact recreation, such as swimming, is prohibited in the Quabbin Reservoir. The water quantity and quality issues for this reservoir revolve around wildlife and forestry management. The MA DCR implements and frequently updates its forest management and land use plan for the Quabbin Reservoir watershed. Long-term monitoring of total coliform and fecal coliform densities from 18 tributaries to the reservoir and the Chicopee Valley Aqueduct provide the MA DCR with a frame of reference for understanding water quality. Changes in microorganism loading to the reservoir are naturally associated with season and precipitation events. Changes in forest cover, composition, and health may also be reflected in water quality variations over time.

In the early 1990s, it was noted that total and fecal coliform densities appeared to be steadily rising, albeit within the same order of magnitude, in samples collected at the Chicopee Valley Aqueduct (CVA). A multiple component study was initiated to determine the potential cause(s) of this trend including forestry and land use evaluations. Among these components, the MA DCR, in collaboration with University of Massachusetts (UMass) researchers, conducted a water quality modeling and watershed management study for the CVA. The contaminants of concern for this study were total coliforms and fecal coliforms. The troublesome source of coliforms near the aqueduct was identified to be gulls roosting on the water overnight.

The UMass study included an analysis of the overall water budget for the reservoir, a field study of currents in the vicinity of the CVA, and a field study of coliform die-off within the reservoir. The water budget for the reservoir included measured inflows, outflows, and net daily reservoir effective yield. These data were used to calibrate a two-dimensional water quality and hydrodynamic model of the reservoir. Evaluation of currents demonstrated that contaminants (coliforms) introduced into the water approximately two miles from the CVA could be transported to the CVA within one to two days. Through the coliform die-off studies, surface decay coefficients of approximately 3.2 to 6.6 per day were calculated, and 0.75 per day at depths of 10 to 20 m.

Prior to this study, gulls were allowed to roost in any location that they chose. This included areas of open water as little as 100 yards from the CVA. Not surprisingly, this location along with wind speed and direction were significant factors in the variability of coliform concentrations reaching the CVA. Therefore, MA DCR established a 5 kilometer (approximately 3.1 mile) gull exclusion zone from the CVA. The gull roosts are pushed to beyond this distance using boats and sirens as part of the MA DCR's gull harassment program.

Because waterfowl populations have proven to be a significant culprit in microbial contamination to the reservoirs, the MA DCR has initiated a water supply gull study. Figure 2 shows MA DCR staff preparing to capture gulls for tagging.

Figure 2. Gull Count Program. Photo: Dan Clark, DCR, Division of Water Supply Protection.

The gulls are then tracked for seasonal movement patterns between feeding and roosting sites, movement between reservoirs, and movement between reservoirs and "alternate roosts."

The Wachusett Reservoir

The Wachusett Reservoir has a 65 billion gallon capacity, a surface area of approximately 6.5 mi^2 (17 km^2), and 108 mi^2 (280 km^2) of watershed area. In contrast to the Quabbin reservoir, approximately 29 percent of the Wachusett Reservoir watershed land is owned by the MA DCR and a total of 53 percent of the watershed land is protected with limited development and recreational activities. The Wachusett Reservoir watershed can be subdivided into 49 subwatersheds based on hydrological features. Routine water quality samples are collected from 34 stations on 22 tributaries and from four stations on the reservoir. All water from the Quabbin Reservoir passes through the Wachusett Reservoir before it enters the Cosgrove Intake where it is then transported to service communities in the eastern part of the state. Source water protection is more complex for the Wachusett Reservoir, which has significantly more development and human activities in the watershed.

The source water protection program for the Wachusett Reservoir includes monitoring of total and fecal coliforms (locations described above), periodic review and revision of sanitary surveys for each subwatershed, and focused source studies using fecal source tracking for coliform "hotspots." Fecal source tracking studies, in collaboration with UMass and Worcester Polytechnic Institute (WPI) researchers, have involved tributaries such as Beaman Pond Brook, French Brook, Malagasco Brook, and West Boylston Brook. For these studies, hydrologically based sampling locations were selected to isolate probable coliform sources determined through sanitary surveys and land use analysis via GIS. These sources included dense residential development served by septic systems, a dairy pasture, a horse stable, and wildlife, among others. Figures 3 and 4 show examples of potential water quality influences in the subwatersheds. The sampling design included all four seasons and both dry and wet weather flow conditions. Water quality monitoring included physical measurements (water temperature, flow, particles), chemical measurements (conductivity, dissolved oxygen, organic carbon), indicator organisms (fecal coliforms, *E. coli,* enterococci), and fecal source tracking targets (sorbitol-fermenting *Bifidobacteria*, *Rhodococcus coprophilus,* coliphages and their genotypes).

For each of the subwatershed studies, the relative contributions of development

Figure 3. Evidence of beaver activity at French Brook. Photo: Larry Pistrang, DCR, Division of Water Supply Protection.

Figure 4. Residential influence in West Boylston Brook. Photo: Larry Pistrang, DCR, Division of Water Supply Protection.

and land use activities were successfully assessed. Statistical analyses demonstrated that one measure each of particulate matter (turbidity, particle counts), organic matter (total and dissolved organic carbon, UV_{254} absorbance), and indicator organisms (fecal coliforms, *E. coli,* or enterococci) were adequate for characterizing water quality. However, in order to fully understand variability in microbial loadings within a watershed, monitoring programs should include schemes to collect and analyze samples each season and under different precipitation conditions. Analysis of fecal source tracking targets from samples over a number of hydrologic and seasonal conditions is suggested for source water protection. Diffuse and transient microbial sources in the study watershed often resulted in non-detects for the source tracking targets. Negative results (i.e., samples that did not contain source tracking microorganisms) for a single sampling time should be viewed as inconclusive; however, repeated negative results over time under different hydrologic conditions can provide evidence that a source is being controlled adequately. In each one of these watershed studies, positive source tracking results provided evidence of the contribution of a specific source. This allowed the MA DCR to enter into negotiations with land owners to apply changes or improvements that would reduce the amount of microbial contaminants entering the reservoir. For example, in the instance of the horse stable, fencing was relocated to keep the animals and manure further from the tributary. The levels of microbial indicators downstream of this site were subsequently significantly reduced.

Source Water Protection as a Tailored Approach

Overall, the site-specific study and management efforts for the Quabbin and Wachusett Reservoirs have resulted in reducing the levels of coliforms in routine monitoring samples. In some instances, these efforts have stabilized or reversed long-term monitoring trends showing increasing coliform microbial loadings to these reservoirs. The award-winning source water protection program for the Quabbin and Wachusett Reservoirs included a number of common but also site-specific components. Focused studies were funded by the MA DCR and conducted by University researchers to identify and define activities within each reservoir watershed that were contributing to microbial loadings. Prior knowledge from sanitary surveys and historic monitoring allowed for the study approach to be tailored to the specific reservoir or watershed location. The collaborative efforts among the utility, management agency, university researchers, and private landowners contributed to the success of the source water protection studies described here.

Further Information

For further information about MA DCR programs and the specific research studies summarized here, the following references may be accessed:

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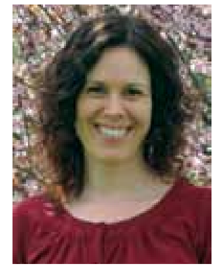

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