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Division of Water Supply Protection
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The Quabbin Interflow

And Other Phenomena of the Reservoir System

Jamie Carr, DCR Aquatic Biologist, and Jim Taylor, DCR Regional Planner

A drop of drinking water faces an arduous journey as it travels from the furthest reaches of the Quabbin Reservoir watershed via the Wachusett Reservoir to eventually quench the thirst of people in the Boston area. The distance from Winsor Dam in Belchertown to Boston Harbor is about 60 miles as the crow flies, but the water's path is much longer.

Starting as precipitation, water trickling through the purifying forested watershed lands collects in meandering streams and rivers that lead to the two reservoirs. The water eventually travels via gravity through underground aqueducts, stopping at the Massachusetts Water Resources Authority's (MWRA) Carroll Water Treatment Plant before completing its passage to millions of taps as safe, clean, award-winning drinking water. There are many marvels on this voyage, including the biophysical phenomenon identified as "The Quabbin Interflow."

Source Water

The Wachusett Reservoir holds 65 billion gallons of water. When it was built at the end of the 19th century it was the largest surface water reservoir constructed in the world. It was not, however, big enough to quench Boston's growing 20th century thirst, so in the 1930s the Quabbin Reservoir and Aqueduct were built. These enhancements have allowed the drinking water system to meet the needs of 40% of Massachusetts' residents well into the 21st century.

Quabbin Reservoir, with a 412 billion gallon capacity, is six times the size of Wachusett and is encompassed by a 120,000 acre watershed. One inch of rain landing in the watershed creates 1.6 billion gallons of water! Nevertheless, this enormous reservoir can still need to be augmented, so the legislation that established Quabbin also allows millions of gallons of water to be diverted from the Ware River, if needed, between October and June each year.

The Quabbin Aqueduct, buried up to 800 feet beneath the ground, is another ingenius part of the water supply system. It can carry water from the Ware River both east to Wachusett and west to Quabbin,

Continued on Page 4

Water destined for people throughout the greater Boston area to drink begins its journey down the Middle Branch of the Swift River on its way to the Quabbin Reservoir.

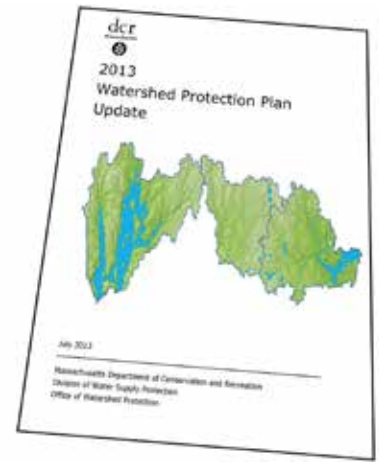
Watershed Protection Plan Update

Less is More

By Joel Zimmerman, DCR/DWSP Regional Planner

In the quest to provide high quality drinking water that requires minimal treatment, DCR's Division of Water Supply Protection (DWSP) develops a Watershed Protection Plan that encompasses all of its efforts that affect both public and private lands in the watershed system. This five year plan takes information from Public Access and Land Management Plans and integrates water monitoring findings with other studies to create an action plan that is the basis for DWSP's annual Work Plan and budget.

The first official Watershed Protection Plans for the active water supplies serving the Massachusetts Water



Resources Authority (MWRA) were developed in 1991. At that time, two separate plans were written, one for Quabbin Reservoir and Ware River, the other for Wachusett Reservoir, as the debate over the necessity of building a filtration plant required looking at these sources separately. Regulatory decisions and court rulings concluded that the watershed management program – with principles detailed in the Watershed Protection Plan – were a critical component of the approved unfiltered drinking water supply system.

The Wachusett plan was first updated in 1998 and then again in 2003; the Quabbin/Ware plan had its first revision in 2000. A Watershed Protection Plan was also developed in 1997 for the emergency supply to this system, the Sudbury and Foss Reservoirs, but it was not quite as thorough as those written for the active water supplies.

Continued on Page 7

In This Issue:

The Quabbin Interflow 1
How water moves through the reservoirs

WPP Update 2
Changes to the Watershed Protection Plan

Res Ops 3
About the Reservoir Operations Committee

Tunnel Boring 6
Making The MetroWest Tunnel

Kids Corner 7
The Water Supply Code

Then and Now 8
Aqueducts Old and New

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Page 1 Clif Read
Page 2 Top - Joel Zimmerman
Bottom - DCR file
Page 3 MWRA
Page 4 Top - Jim Taylor
Graph - Jamie Carr
Page 5 Top - Jamie Carr
Page 6 Top - DCR file
Bottom - MWRA
Page 7 MWRA
Page 8 MWRA

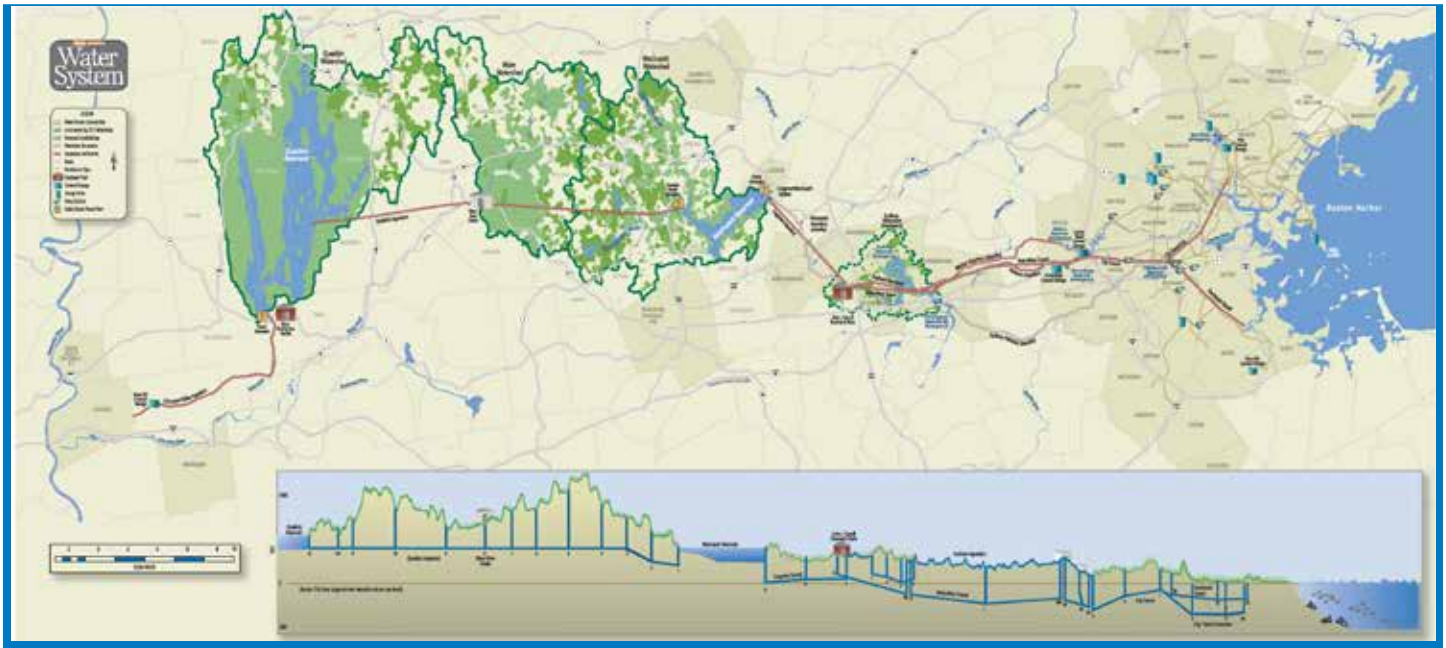
Potential Contaminant Sources	DWSP Watershed Protection Program: Land Procurement	Watershed Preservation Restrictions	Land Management	Wildlife Management	Public Access Management	Watershed Security	Infrastructure	Watershed Protection Act	Interpretive Services	Water Quality/Quantity Monitoring	Watershed Monitoring	Aquatic Invasive Species	Environmental Quality Assessments	Wastewater Management	Stormwater Management	Emergency Response
Wildlife			✓	✓						✓	✓	✓	✓		✓	
Public Access/ Recreation			✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓
Timber Harvesting/ Forestry			✓					✓	✓	✓	✓	✓	✓	✓	✓	✓
Wastewater	✓	✓						✓		✓	✓		✓	✓		
Roadways, Railways and Rights-of-Way										✓	✓	✓	✓	✓		✓
Agriculture	✓	✓						✓		✓	✓		✓	✓	✓	
Construction	✓	✓						✓		✓	✓		✓	✓	✓	
Commercial, Industrial, and Governmental Sites	✓	✓						✓		✓	✓	✓	✓	✓	✓	
Residential Sites	✓	✓								✓	✓	✓	✓	✓	✓	
Future Growth	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓	
Climate Change	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Security Threats					✓	✓	✓			✓	✓		✓			✓

This matrix shows the multiple avenues DCR has for addressing sources of pollution in the watershed system. The overall goal of these control programs is to develop proactive strategies that prevent water quality problems wherever possible and to respond to detected problems quickly to limit their potential impact.

Reservoir Operations Group

Overseeing the Reservoir System

By John Gregoire, MWRA Program Manager



This map shows the DCR/MWRA water supply system. All surface waters and surrounding protected lands within the bounds of the Quabbin, Ware, Wachusett, and Sudbury watersheds, shown in the plan view, are managed by DCR. The MWRA is responsible for treatment and distribution, including the network of tunnels visible in the profile view. The "Res Ops" group is a cooperative team comprised of staff from both agencies that coordinate efforts on the reservoirs' management.

DCR/DWSP and MWRA have collectively managed the water supply system from the watersheds to distribution since 1984. Legislation that year created the MWRA to take over many of the duties of the former Metropolitan District Commission's Water and Sewer Divisions, including drinking water financing, treatment, and distribution, but left the responsibility for land and reservoir management to the newly formed MDC Division of Watershed Management. A Memorandum of Understanding (MOU) was created at that time to define the roles of the two agencies. The Reservoir Operations Group (Res Ops) was established in 1996 to further coordinate water supply protection activities.

The MOU was updated to refine the responsibilities of both parties in 2004 after the newly organized Department of Conservation and Recreation's Division of Water Supply Protection assumed the state's watershed management role. Section 13.4 (d) of the new MOU formalizes Res Ops:

> *The Reservoir Operations Group shall be comprised of designated [DCR] and MWRA personnel and shall meet to coordinate management, policies and activities related to reservoir operations. This working group shall have primary responsibility for the development of all reservoir operations policies and procedures…The group shall meet at least quarterly.*

Res Ops has indeed met for close to twenty years practically every quarter for a summer, fall, winter and spring

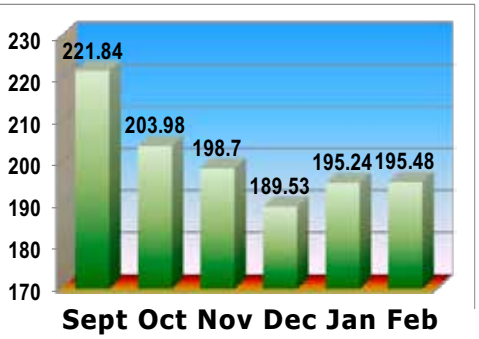
Continued on Page 6

- Reservoir Watch -

Reservoir levels and 6-month precipitation

Reservoir	Quabbin	Wachusett
Minimum	523.42'	388.05'
% Full	87.9%	86.3%
Date(s)	11/26/13 12/22/13	2/24/14
Maximum	526.27'	390.80'
% Full	93.1%	91.6%
Date(s)	9/1-2/13	12/10/13
Precipitation	21.38"	15.98"
Seasonal Avg	23.18"	22.05"

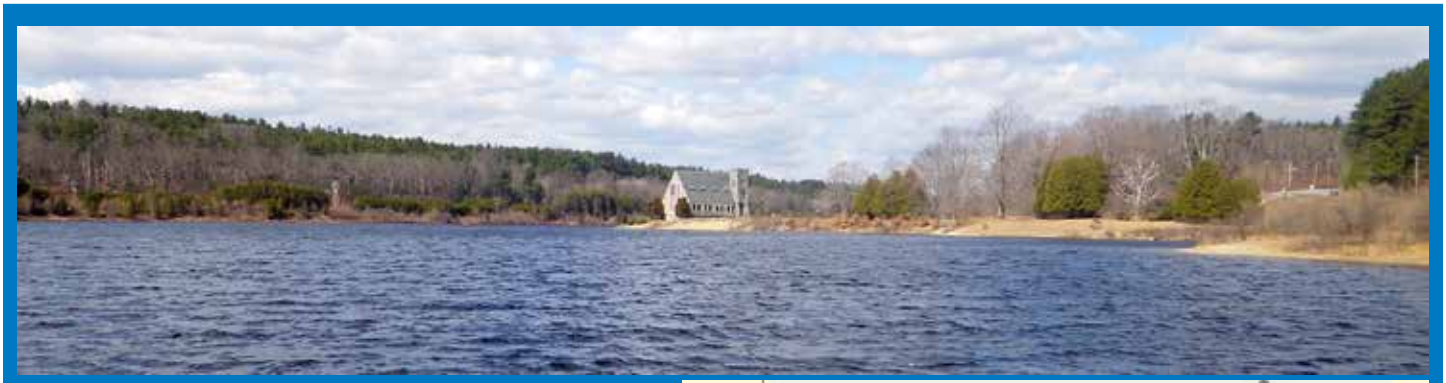
System-wide 6-month Water Usage (in million gallons per day) September 2013 to February 2014



Quabbin Interflow from Page 1

all by gravity. Modern practice is to send Ware water solely to Quabbin Reservoir in order to take advantage of another feat: the immense size of the reservoir combines with the biophysical traits of water to help purify the Ware River water. After entering the Quabbin Reservoir at Shaft 11A, it takes five years for Ware River water to travel around the entire Quabbin Reservoir before re-entering the Quabbin Aqueduct at Shaft 12. This extended residence time allows natural purification processes of light and mixing with the higher quality Quabbin watershed water.

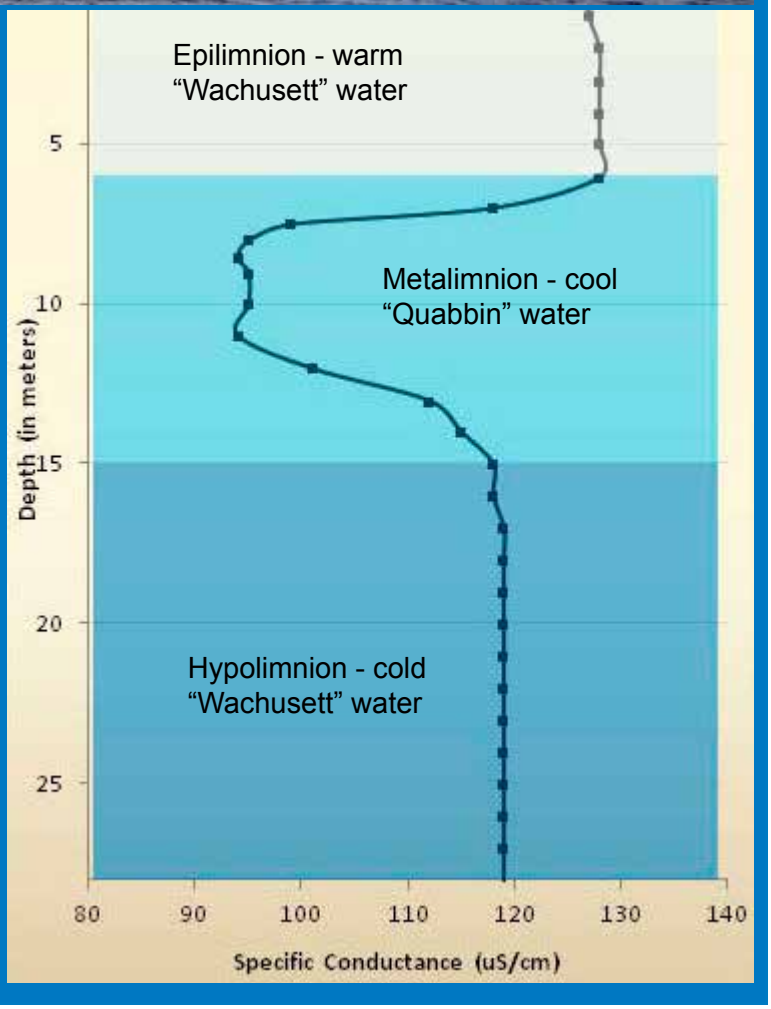
Entrance in the Quabbin Aqueduct at Shaft 12 sends water eastward, by gravity, to the Wachusett Reservoir. Before exiting at Shaft 1 into the Quinapoxet River, the water first generates electricity at the Oakdale Power Plant. This hydro-energy is sold to the West Boylston Municipal Light Plant, earning revenue that off-sets the costs of the DCR Watershed Management Program. In a typical season, the amount of water transferred from Quabbin to Wachusett ranges from 50-100% of the volume of the Wachusett Reservoir. At any time of the year approximately half of the water in the Wachusett Reservoir originated in the



The graph at right is an example of a specific conductivity profile in the Wachusett Reservoir collected by DCR Aquatic Biologists on August 15, 2013.

The top of the graph is the surface of the reservoir. The diagram shows how the first few meters of water, the Wachusett epilimnion, has a specific conductivity of close to 130. However, at a depth of 6 meters the values soon plunge, as there is a layer of water with a specific conductance of only 95, the metalimnion. This is the layer of Quabbin water, and for this sample it is 9 meters (27 feet) thick! As the probe moves deeper, the specific conductance rises again to reveal the ice cold hypolimnion composed solely of Wachusett water.

As water demand increases over the warmer months, greater amounts of water are brought to Wachusett from Quabbin Reservoir and this middle layer of 'lower conductance' Quabbin water –*The Quabbin Interflow* – remains separated while it spreads throughout the Wachusett Reservoir. As the warmer weather subsides and demand drops, this layer disperses and mixes with the resident water of Wachusett.



Quabbin Reservoir. For example, in 2013, 49 billion gallons were delivered to Wachusett via the Quabbin aqueduct. As the Quabbin water enters the Wachusett Reservoir through the Thomas Basin, a fascinating hydrodynamic phenomenon transpires called "The Quabbin Interflow."

The Quabbin Interflow

When warm sun and thoughts of wearing your shorts and flip flops arrive each year, the surface water in the Wachusett Reservoir has begun to warm. This increase in temperature at the surface of the Wachusett Reservoir and other local water bodies starts an annual process called stratification.

Stratification is most pronounced during late summer when biologists on the Wachusett Reservoir use water quality probes deployed from a boat to observe three distinct layers of water: a layer of warm, less dense water occupying the top of the water column, called *the epilimnion*; a cool middle layer where the temperature drops as you go deeper, called *the metalimnion*; and finally the ice cold dense water at the bottom, called *the hypolimnion*. If you can recall swimming in a nice warm pond and catching the piercing sting of ice cold water from a layer below with your toes, then you have firsthand experience of how layers of water separate based on temperature and density.

However, the layering of water in the Wachusett Reservoir is quite different from other local water bodies. This is because an interesting thing happens when the Quabbin water arrives at Wachusett in the summertime. The Quabbin water arriving from the aqueduct is colder and denser than the warmer surface water of the Wachusett epilimnion. However, the trip through the Aqueduct and the mixing with the Quinapoxet River mean that this water is not quite as cold and dense as the ice cold Wachusett hypolimnion.

Dave Worden

Scientist contributed to water quality knowledge

Dave Worden was a dedicated professional who specialized in looking for answers to questions others had not yet even thought to ask. Limnology (the study of inland waters) was Dave's passion. He was the first to describe and understand the Quabbin Interflow, as well as a leader in the identification and control of Aquatic Invasive Species in the DCR/MWRA watershed system. Dave was not only a respected limnologist but also a great friend, colleague, and teacher who taught us about the phytoplankton, water quality, and nutrient dynamics of the Wachusett and Quabbin Reservoirs before his untimely death in the summer of 2013. His knowledge, wisdom, and presence are sorely missed.

The result? The Quabbin water flows in between the Wachusett layers, forming an interflow layer of its own that spreads throughout the Wachusett Reservoir and takes about a month to reach from side to side and end to end and does not mix readily with the other layers. This "Quabbin Interflow" layer has a clear signal of low specific conductivity, which is a measure of how many things that conduct a current are dissolved in the water. Water in the Quabbin Interflow has a direct line of travel to the Cosgrove Intake, traversing the Wachusett Reservoir in just weeks before entering the next step on its journey to Boston via the Hultman Aqueduct.

Just as children are gearing up for trick or treating, the upper layers of water lose enough heat to the cold nights of fall to allow strong winds to mix the layers of water. Soon the entire water column is similar enough in temperature that it becomes mixed and homogenized in an event known as fall turnover.

Understanding the hydrodynamics of the water supply system is a key part of proper management. It is important to monitor the layering of water in the Wachusett Reservoir as each layer can have different levels of nutrients or algae that change as the year goes on. DCR's current level of understanding owes a great deal to the work of limnologist David Worden (see above).

The Final Leg

Once the water enters the Cosgrove Intake in Clinton, it completes the journey east through a series of aqueducts, treatment facilities, and covered storage reservoirs managed by the MWRA, and finally to a tap from a municipal distribution pipe. DCR works cooperatively with MWRA, in concert with the Water Supply Protection Trust, to maintain the high quality water found in the Quabbin and Wachusett Reservoirs so that each of the 2.5 million users can use this precious resource with confidence.

Res Ops - from Page 3

gathering to coordinate and discuss the issues at hand concerning the Quabbin and Wachusett Reservoirs.

Res Ops functions extremely well due to the interdisciplinary nature of its DCR and MWRA staff members. It is comprised of civil and environmental engineers and scientists, aquatic biologists, planners, chemists, and operations and maintenance managers. Many of the members have been involved with the water supply in one form or another since the late 1980s to early 1990s, so the group benefits from a long-range view of the reservoirs' management and history. Representatives of the Water Supply Citizens Advisory Committee have also been longstanding participants. Periodic guests have included the Water Research Foundation as well as professors and researchers from UMass Civil and Environmental Engineering Departments that have performed many years of reservoir modeling.

Thomas Basin at the Wachusett Reservoir.

Res Ops' agendas over the years have reflected the pressing topics of the day. Early on there were bird control and bacteria issues, algae bloom problems, and coordination on spill response activities. Later concerns included the arrival and control of invasive aquatic plants and transitioning over from Cosgrove Intake Disinfection Facility to the new Carroll Water Treatment Plant in Marlborough. Recent issues include security, reservoir modeling, major dam improvements, and infrastructure upgrades such as valve and hydropower turbine improvements. Hazardous releases, improvements to watershed stream gages, snowpack analysis, the removal of direct stormwater discharges, and better understanding of plankton dynamics are other topics that have come to the fore over the course of Res Ops' existence. Through it all, water system yield and demand have remained prominent topics.

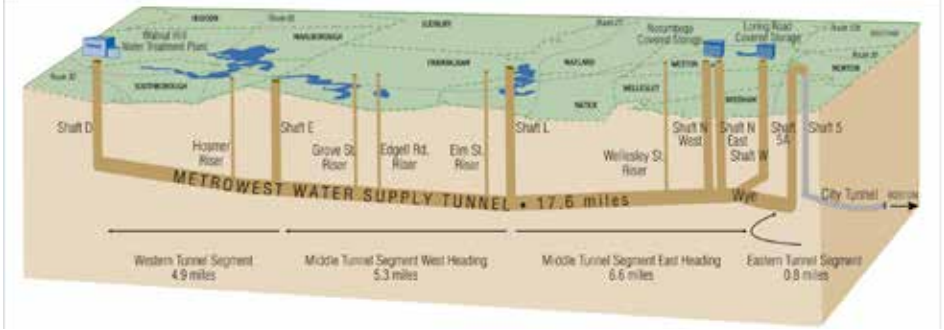
The threat of climate change and sustainability of the reservoirs and watersheds will be major drivers of activities in the future. No matter the concern, the Reservoir Operations Group is well positioned to move ahead as a team.

Tunnel Boring - from Page 8

The MetroWest Water Supply Tunnel is a stellar example of modern aqueduct construction. MWRA opened the tunnel in November 2003, enhancing the security, capacity and reliability of the entire metropolitan Boston water transmission system.

Prior to its construction, MWRA relied on a single 1940s-era surface aqueduct, the Hultman Aqueduct, to serve the region. The Hultman, with its leaks and aging valves, needed to be taken off-line for major repairs. Failure of the Hultman could have caused nearly complete interruption of Boston's water supply. This would have been a disaster for the region's public health, safety and economy.

The MetroWest Water Supply tunnel cost $728 million including design, construction management, and support costs. The 14 foot diameter tunnel spans 17.6 miles, roughly from Rt. 495 to Rt. 128. Mining the tunnel required three Tunnel Boring Machines (TBMs) and three working shafts in Southborough, Framingham and Weston. The TBMs ground their way through over 1 million cubic yards of rock (granite, gneiss, schist, and quartzite). The successful completion of this new aqueduct is part of the $1.7 billion invested by the MWRA in an Integrated Water Supply Improvement Program.



The image above was taken in 2003, just after 'hole through' near the completion of the MetroWest Tunnel. Workers are inspecting the grinding surface of the machine. At left is a diagram of the 17 mile tunnel, 200 - 500 feet below the surface.

Kids Corner

Solve the Water Supply Scramble

At right is a quotation, well known to us here at DCR Division of Water Supply Protection. You will know it too once you find the correct letters that correspond to the substituted letters.

Good luck!

(The answer is at the bottom of the page, but no peeking!)

Here is your clue:

H W E B U K F T X V W E is C O N S E R V A T I O N

"X W Q K W X U H X, Q K U B U K F U T E N U E O T E H U X O U U E F V K W E J U E X W D X O U H W J J W E L U T P X O T E N X W T B B R K U X O U T F T V P T C V P V X G W D Q R K U L T X U K D W K D R X R K U I U E U K T X V W E B."

-N H K / N L B Q J V B B V W E B X T X U J U E X

The WPP - from Page 2

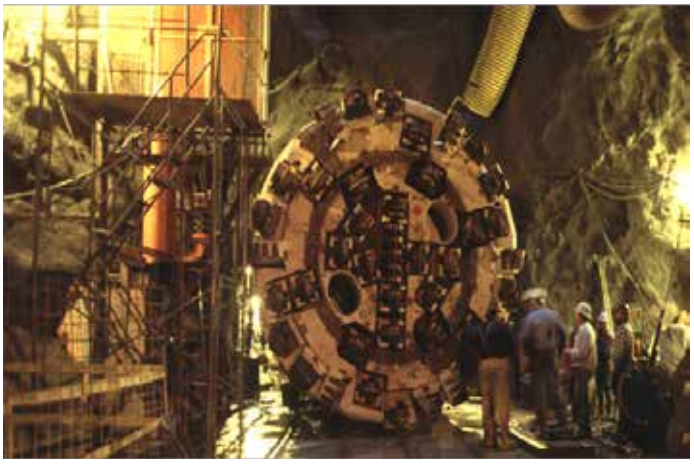
DWSP decided to consolidate all four watersheds into one plan in the 2008 Update, as the filtration issue was now settled and a unified document would help with staff organization. While the 2008 Update successfully gathered information into one place, it was a bit cumbersome, taking up over 500 pages. Staff vowed that the 2013 Update would be leaner and easier to use for both people inside the agency and the general public.

The *2013 Watershed Protection Plan Update* successfully trimmed down all the pertinent information regarding the care and control of the 428 square mile watershed system into 200 pages. The plan assesses changes in watershed threats, develops programs to address the threats, and prioritizes work assignments. It concludes with a five year implementation strategy that summarizes objectives for the Division of Water Supply Protection to achieve for Fiscal Years 2014 to 2019.

The *2013 Watershed Protection Plan Update* continues DCR's successful efforts of managing the source of an unfiltered water supply. The MA Department of Environmental Protection noted that the plan does an "excellent job consolidating the components of the plan into a streamlined document while continuing to provide detailed information about the watershed program for MWRA's drinking water sources." This plan update will help DWSP in meeting its goal of maintaining a drinking water source of exceptionally high quality and enhancing this level of quality for future generations.

And another thing...

by J. Taylor



"Hey Charlie, this work can get really boring!"

Editors Note: In spite of this modest attempt at some 'in-depth' humor, working with a Tunnel Boring Machine (TBM) is anything but mundane. Highly skilled crews carefully navigate the machine through rock and soils as deep as 500 feet below the surface at rate of up to 57 feet per day!

For more information about...

The Quabbin Interflow

2013 DCR Wachusett Water Quality Report

www.mass.gov/eea/docs/dcr/watersupply/watershed/2013wachusettwqreport.pdf (See Section 4.2.3)

Dave Worden's Research

Nutrient and Plankton Dynamics in Wachusett Reservoir

www.mass.gov/eea/agencies/dcr/water-res-protection/watershed-mgmt/nutrient-and-plankton-dynamics-in-wachusett-reservoir.html

Watershed Protection Planning

2013 DCR Watershed Protection Plan Update

www.mass.gov/eea/docs/dcr/watersupply/watershed/2013dcrwatershedprotectionplan.pdf

MWRA

Integrated Water Supply Improvement Program

www.mwra.com/04water/html/iwsip.htm

To protect, preserve and enhance the environment of the Commonwealth and to assure the availability of pure water for future generations
-DCR/DWSP Mission Statement

Then and Now

The Making of an Aqueduct

By John Gregoire, MWRA Program Manager

The two images, top left, show tunneling work in 1897 on the Wachusett Aqueduct. The job of hand-laying brick and installing cribbing was grueling and very dangerous. Tunnel construction has come a long way from over 100 years ago. Pneumatic tools, explosives and manual labor have given way to state-of-the-art underground navigation systems and Tunnel Boring Machines (TBMs).

The images at bottom left show the forms and smooth concrete walls created by today's technology and construction methods used on the MetroWest Water Supply Tunnel.

Continued on Page 7

downstream

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Downstream is produced twice a year by the Massachusetts Department of Conservation and Recreation, Division of Water Supply Protection. It includes articles of interest to the Watershed System communities. Our goal is to inform the public about watershed protection issues and activities, provide a conduit for public input and promote environmentally responsible land management practices.

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DWSP Director: Jonathan L. Yeo
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