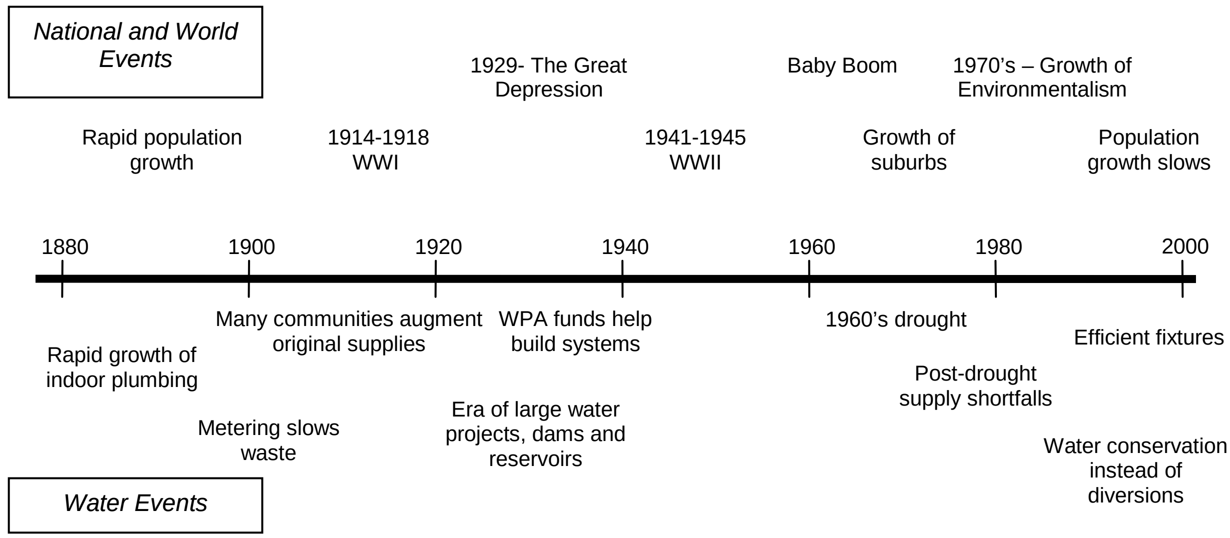
Chapter 2 – The Search for Water – Growth and Water Source Development

Timeline – Water Source Development



Finding the water has always been one of the main tasks for the water supplier, occasionally a thankless task, even a maligned one. Since the growth of environmentalism in the 1970's, many people picture a water engineer in terms of John Huston's shady Noah Cross character from the film "Chinatown". Most books written about New England water supplies tend to focus on the impacts of reservoir construction, prime examples being "*The Day Four Quabbin Towns Died*" about Quabbin Reservoir and "*The Village of the Dammed*" about Saugatuck Reservoir in the Bridgeport system. The loss of one's home for a reservoir that benefits a distant city is almost certain to create a lifetime of resentment.

The fundamental dilemma is that cities exist where they are because of commerce and they drive the economy of the region to everyone's benefit, even the rural areas that are asked to help provide resources like water. But the cities overwhelm water resources where they exist and have to import water from elsewhere. This wasn't a decision to be taken lightly and the state legislatures became the forum to consider the needs of the many against the sacrifice of the few.

From the perspective of the cities, they have historically offered employment and housing for the bulk of the region's population. From the Revolutionary War onward, New England rose to national prominence on the strength of its manufacturing based economy, not on weakening rural agriculture. This manufacturing took place mainly in the cities, driving urban population growth and causing all manner of support services to be developed, including transportation systems, utilities and, of course, adequate water supply. Industry contributed mightily to the tax base and cities enjoyed the most representation in state legislatures. With the United States making its place in the world on the strength of its commerce, it is no wonder that cities had the power to get what they needed. The construction of large water works were themselves often seen as a boon to the regional economy. Concerns over disruption of rural areas and related environmental impacts were clearly a lesser concern before the change in the nation's environmental consciousness, beginning in the early 1970's.

Hundreds of New England communities had to go through difficult choices to assure that enough water would be available to allow the community to function and grow. Failure to address water supply issues in a timely way could be crippling to a local economy and devastating to public health as was the case when many early supplies became too foul for use. It was a balancing act involving water quality, cost, hydrology, ever changing water supply technology, impact on abutters or existing water mill industries and many other factors. The issues were often highly technical but were subject to politics, as was every large financial decision in a community. NEWWA became a forum for communicating experience in such matters.

The past 125 years has seen the growth of water supplies from modest takings from the local pond, up to damming of rivers and diversions across river basin boundaries. This chapter reviews the situation at the several key points:

Existing Conditions - 1882 (Formation of NEWWA)

In most of the pre-1882 water systems, the original choice of a water source was often very limiting. For convenience or economy, many communities chose wells or springs near the service population. Either these original sources became fouled or they were just incapable of sustaining the type of growth that occurred. For example, Boston's Jamaica Pond had less than 2 square miles of watershed and, while this was workable when per capita usage was less than 10 gallons per capita, it was clearly inadequate after about 1820. By 1882, Boston's next sources, Lake Cochituate and the Mystic River, had become dangerously polluted and were once again becoming too small. The larger cities tended to be in southern New England and had the most challenges in finding a nearby source of water especially since the southern New England rivers were flat and tidal near the cities, good for transportation but poor for drinking water. The following table summarizes conditions in the mid-1800's at some of the larger cities:

State	**City**	**Geographical Limitations**	**Early Source**	**1850 Source**
MA	Boston	Coastal peninsula, poor river water quality	1652 Springs	Lake Cochituate
	Cambridge	On Charles River, poor river water quality	1837 Springs	Fresh Pond
	Worcester	On Blackstone River, mills upstream	1798 Springs	Bell Pond
	New Bedford	Coastal city		Acushnet River
	Fall River	Coastal city		Watuppa Lake
	Springfield	On Connecticut River, mills upstream	1843 Reservoir	4 Sm. Reservoirs
RI	Newport	Island, little surface water		Ponds
	Providence	Coastal city, mills upstream	1772 Springs	Springs
CT	Hartford	Adjacent to Connecticut		Connecticut River
	New Haven	Coastal city		Mill River
	Bridgeport	Coastal city	1818 Springs	Springs
NH	Manchester	On Merrimack, mills upstream		Lake Massabesic
	Nashua	On Merrimack, mills upstream		Pennichuck Brk
ME	Portland	Coastal City	1812 Pond	Pond & Springs
VT	Burlington	On large lake		Lake Champlain


1860 Lake Whitney Dam serving New Haven CT

Northern New England cities tended to have more options in that there were larger, unspoiled water bodies available, with the possible exception of some rivers where logging had already begun to foul the source. Southern New England cities had more difficult choices, often needing to go outside their community boundaries to create reservoirs. Topography had a lot to do with these choices, as more elevation drop in upland areas meant better reservoir opportunities. Many communities availed themselves of a large pond or lake, e.g. Burlington VT or Fall River MA. Very few withdrew directly from rivers, partly due to the uncertainty of low flows in smaller rivers and partly due to poor water quality during summer low flows when algae and upstream waste problems were problematic. The few that did so were on large rivers and were forced to go to early and aggressive water treatment to try to cope with the health problems posed by their chosen supplies.

Late 1800's to 1900 – Post NEWWA boom, Finding sources

Population, Per Capita and Growth of Water Use

	Population Growth Factors	Per Capita Growth Factors	Resulting Water Use
Late 1800's	⇧ • Rapid immigration • Slight westward migration • Net change was a rapid rise	⇧ • Absence of meters means waste • Indoor plumbing is a novelty • Per capita saw huge increases	*Very rapid growth*

Influence of Public Health

By 1882, the Public Health community had seen enough evidence linking drinking water to disease outbreaks to conclude that risky supplies were a reason for the high death rates of the period. New bacterial findings were continually coming out of Europe from important biologists like Koch and Pasteur and a new philosophy of sanitary engineering was being put forward to react to these findings. Now that the disease mechanisms were better understood, response strategies could be formulated, including better water treatment, more careful waste disposal, source protection and the choice of appropriate high quality sources. Drinking water adequacy and quality fell within Public Health's purview such that choice of a new supply in the early part of the century would give water quality much more emphasis.

This was the age of the first water quality laboratories and water treatment experimentation such as the work done at Lawrence Experiment Station (LES). Experts came from universities like MIT and from private industry to consult on the problems and assist the Public Health community. Such luminaries as Hiram Mills, Allen Hazen, William Sedgewick, Thomas Drown and others associated with LES published numerous early NEWWA papers on water biology/ chemistry as well as treatment techniques. Given the importance of the subject and the rather large jump that New England had on the rest of the country, it is understandable that these men became the foremost national authorities in the field.

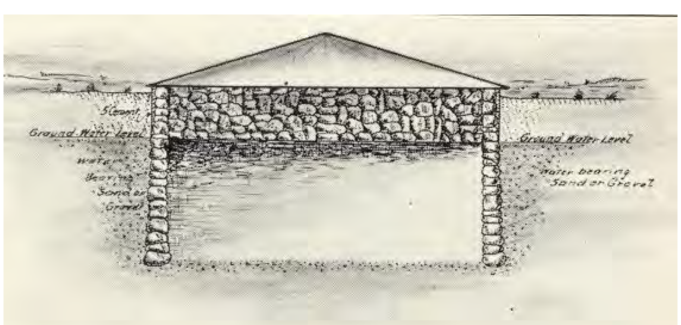
The Massachusetts Board of Health (MBOH), in particular, made clear its intention that water supplies be procured from protected watersheds, as free from wastewater discharges as possible. Its role included studying the adequacy of existing sources and guiding selection of supplies. Their influence was felt well into the 1900's. Not everyone subscribed to this philosophy, as was mentioned previously in reference to Albany's choice during this period to develop the Hudson River for its supply, leading to continued typhoid epidemics into the 1900's, traceable to upstream waste discharges. Hartford CT had made a similar early choice to use the Connecticut River in 1851 but reconsidered in 1867 due to worsening water quality, opting instead to develop a protected gravity flow reservoir system. Bangor ME originally used the Penobscot River in 1875 but eventually developed an upland source for the same water quality reasons. Providence also initially chose, for reasons of proximity, to develop the lower Pawtuxet River, a source whose water quality became progressively poorer until 1922 when the Scituate Reservoir was completed. The 1860 Mystic Water Works serving several communities north of Boston was a similarly poor choice due to the Mystic River watershed having numerous tanneries and other industrial waste discharges, leading to abandonment of the waterworks in the 1890's.

Droughts as triggers

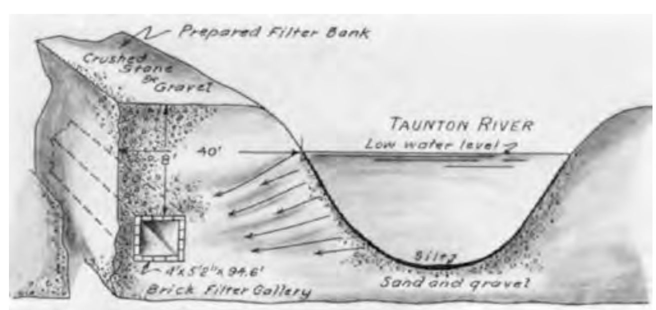
For systems that had already developed supplies, there was a limited amount of experience with runoff through drought periods, leading to occasional overestimation of supply capacity. Severe years or combinations of years were often a revelation in terms of water availability. 1880-1884 happened to be fairly severe drought years in much of New England. The 1890's also had a couple of fairly severe years. As these occurred in the most rapid growth period, the consequences often pushed the community to expand again very soon after completing new works. One of the earliest NEWWA efforts was the publication of hydrologic data and the formation of a committee to study safe yield to assist smaller systems to properly engineer their supplies.

Source development technology

Wells of this age were primarily dug wells or infiltration galleries adjacent to a river. Well drilling was somewhat limited by lack of portable power sources for such machinery. Manually driving relatively shallow well casings into permeable soil was another alternative to groundwater access. Examples of early well users included Taunton, Attleborough, Brookline, Waltham and Newton, all Massachusetts communities that built infiltration galleries adjacent to a river. Most of these supplies needed to build substantial distribution storage to offset mechanical problems with pumps.



Left – Cross-section of typical late 1800's dug well



Example of use of bank filtration to improve water quality –

Inside Attleboro's dug well

Taunton MA

1887 Canton MA pump station adjacent to covered dug well

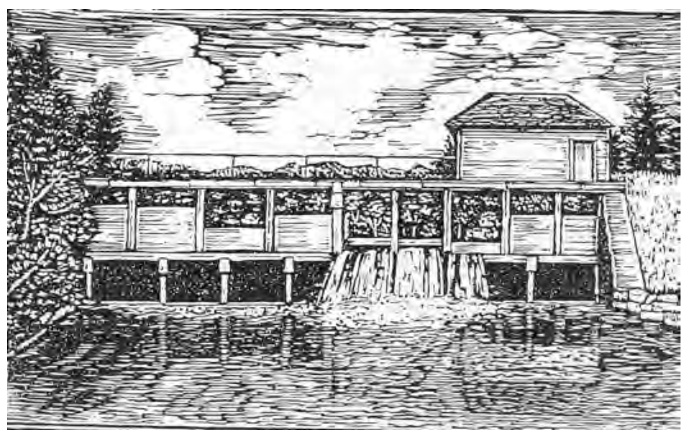
Construction of a dug well has essentially been the same since time immemorial. Towns would find areas with a shallow water table and dig a large infiltration space, then line it with porous rock walls to act as a sump for a pump. Often, such a well would be located adjacent to a pond or river so that water production would be replenished from a consistent water surface. Done properly, this constituted natural filtration and gave reasonably good water quality even under poorer summer conditions. However, many communities using these early dug wells were beginning to find that algae would be a problem in their open distribution reservoirs, which makes some sense given the nutrient loadings in the early urban rivers. The early dug wells also had to be maintained carefully to prevent soil piping and siltation into the well.

Location of potential groundwater was still closer to guesswork than science. Water witching was common but was felt to be hogwash by many. NEWWA discussed the subject, with some knowledgeable water supply men trying their hand at the willow stick and, after some attempts at a controlled experiment, these men found that they could not get any consistent results. This did not stop everyone, some still paid for the service.

Most water supplies in the post 1882 period were surface water supplies. Some communities had a nearby natural lake or pond, so that their technology needs were only for pumping and conveying water. Only a few communities took directly from a river, examples being Saco, ME and Lawrence, MA.


1898 Stripping the bottom of Boston's Sudbury Reservoir with horse drawn scrapers

Many communities opted to build reservoirs, partly to develop storage to increase the sustainable withdrawal, partly to gain water elevation to help with gravity supply and partly to help improve water quality. Even at this early stage, there was a right way and a wrong way to do the job. Early experience with natural ponds and smaller impoundments showed high organic content and poorer water quality. Boston's experiences in developing the Sudbury system in the 1870's – 1880's were presented in early NEWWA papers of this period, documenting the water quality benefits of reservoir detention. The proper preparation of the reservoir inundation area was similarly documented, showing that removal of organic swamp deposits, vegetation and other problem areas would greatly improve future water characteristics. These early papers helped guide many smaller communities in approaching their impoundments properly.


Sketch of early timber Pennichuck Dam, supply for Nashua NH

Another sticky issue of this age was dam construction. Dams had been constructed around New England from the beginning of colonization, the first being a timber mill dam in S. Windham, ME in 1623. Materials had advanced from timber to stone, earth and concrete masonry. Most early dams had been built privately for mills and failure was not an unknown (the first major dam failure in the US was in 1874 in Williamsburg MA, killing 144 people and causing $1 million in damages). Shortly after the 1882 formation of NEWWA, the 1889 Johnstown, PA dam failure took 2,200 lives, still the largest US loss of life due to a dam failure.

There was local cause for concern as well. New England engineers were familiar with the 1842 failure of New York's Croton dam during construction. Within New England itself, there had been several failures of water supply dams including the 1848 failure of Boston's original Lake Cochituate dam during filling, the 1867 failure of Hartford's Dam No. 1 on Trout Brook during a flood event while under construction and the 1876 failure of Worcester’s original Lynde Brook dam.

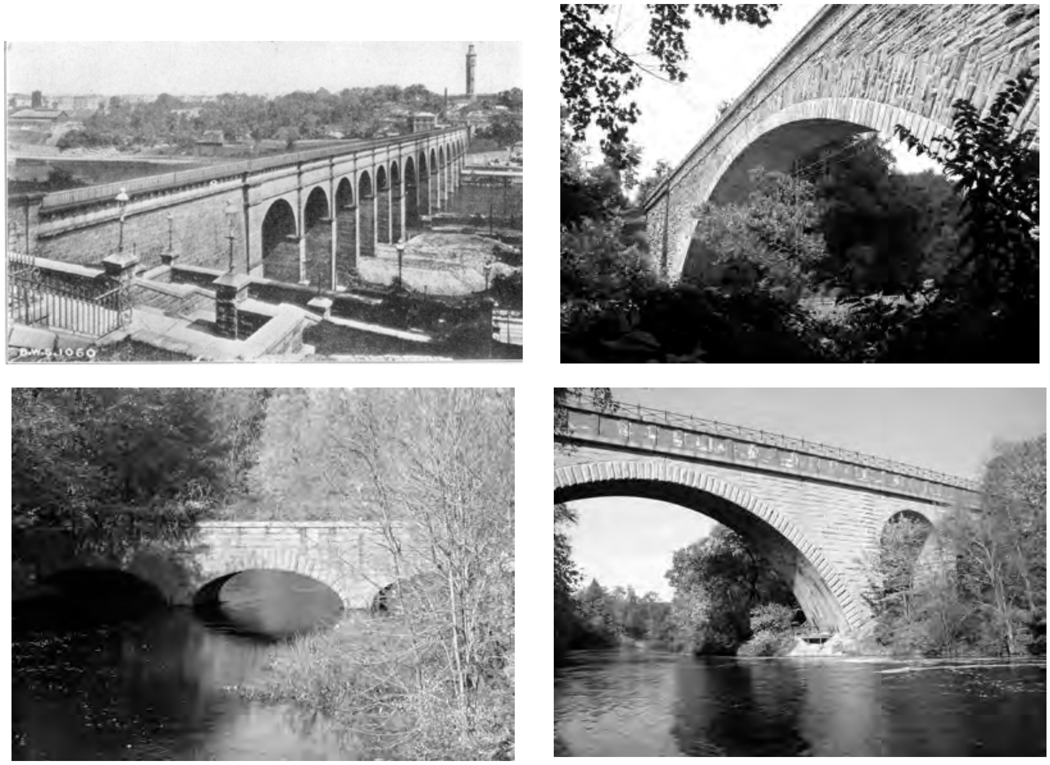
1893 Excavation for Sudbury Reservoir Dam


1893 Temporary housing for Italian masons performing stone work for Sudbury Dam

The mechanisms of failure were varied, including poor understanding of soils engineering in some cases and inadequate spillway capacity leading to overtopping of earth structures in others. Clearly, collaboration among water supply engineers via NEWWA papers and meetings was a positive influence on this field. Such topics as flood flow expectations and proper “puddle” construction for dam cores were covered by early NEWWA papers. The soils engineering aspects of containing water were equally important to those communities building large open distribution reservoirs, which were essentially low dams set on a hilltop.


Roman Aqueduct bridge – the classic solution to moving water long distances across valleys

Another technology associated with early water sources was the use of aqueducts to move water long distances, preferably using gravity. Early examples for such works were taken from Roman aqueducts, lengthy masonry conduits of constant slope with an occasional tunnel through a ridge or the use of grade crossing over a river via an arched aqueduct bridge. Boston made early use of such designs for its Lake Cochituate, Mystic River and Sudbury system sources. The earliest such aqueduct bridge was the 1848 Cochituate Aqueduct crossing of the Charles River, still standing but somewhat hidden off of the side of Rte 95 in Newton, MA. The 1878 Echo Bridge crossing of the Charles River by the Sudbury Aqueduct is a particularly good and accessible example of such a structure and has been designated as an AWWA Historical Landmark on this basis. As with the earlier New York Croton Aqueduct, tunneling was a necessary part of routing these grade aqueducts through high ground. Done with drill and blast methods (black powder since TNT was not yet invented), Boston’s early aqueducts were also the earliest examples of such tunneling in New England.



Examples of old US Aqueduct Bridges:
Top left – 1832 Croton Aqueduct crossing of Bronx River
Top right - 1864 Cabin John Aqueduct Bridge in Washington DC
Lower left - 1848 Cochituate Aqueduct crossing of Charles River in Newton MA
Lower right – 1878 Echo Bridge crossing of the Charles River by the Sudbury Aqueduct in Newton MA

Other water aqueducts in the southern New England lowlands resembled sewer construction in that they were laid on a constant grade and flowed partly full. Portland utilized an oval brick conduit as part of its early Lake Sebago supply and New Bedford used a 7 mile brick conduit for its Acushnet River supply. Manchester, NH utilized an open canal to bring water from its lake source to its pump station. The engineering and materials developed for canal construction in the early 1800's laid an excellent groundwork for these types of aqueducts. Most communities that did not need the large volume required by a community like Boston, opted to use pressure piping for connecting distant sources.

Politics of water transfers and reservoirs

In this early period, most communities looked within their own borders for solutions. The few that did have to go to a neighboring community did so with relatively low impact projects, such as, Boston's development of Lake Cochituate which merely moved back a few homes as the existing natural pond was raised with a new dam.

However, Boston's next step, the Sudbury system, featured construction of 7 water supply reservoirs and 2 compensating reservoirs (reservoirs constructed specifically to provide streamflow for downstream mills), each of which was in a relatively unpopulated area. This marked the beginning of larger scale displacement impacts associated with reservoir construction and property condemnation, otherwise known as "eminent domain". Prime reservoir land in low-lying areas had always attracted farming, homes, roads, all brought there by the presence of the river. As an example, Cambridge, MA developed a reservoir on relatively unpopulated Stony Brook in neighboring Waltham, but it caused the local farmers to vehemently object since they felt they were losing their most fertile lands. Most issues were settled with compensation but surely resentment remained for a long period afterward.

1887 Cambridge's Stony Brook Dam and Gatehouse, Waltham MA

In those days, it was understood that man would manipulate his environment to suit his needs. There was little concern for preservation of the existing environment since the United States was the land of opportunity with its booming economy. Man was in charge and the fish in the river were clearly secondary to the production of the mill. Therefore, the main focus of water diversion issues of the day revolved only around the impact on downstream mill users. Much engineering time and energy was expended to estimate this impact and find solutions. The preferred impact mitigation method of this period was modeled after the English practice of building compensating reservoirs whose sole purpose was to retain flood flows for later release. This would provide the former river base flow during dry periods. In its Sudbury system, Boston needed to compensate mill owners on the lower Sudbury, Concord and Merrimack Rivers so two reservoirs were constructed, one in the Upper Sudbury and one in the Assabet River watersheds. These later became impractical to operate and were eventually transferred to local control.

In 1907, NEWWA assembled an early expert panel on such compensation for loss of water power featuring such engineering luminaries as Charles T. Main, Clemens Herschel and Leonard Metcalf. Part of this effort was the documentation of water power uses throughout New England and quantification of the amount of "work" that was provided by the water wheels. The work done by these early experts helped resolve many compensation cases as more and more water withdrawals were developed.

One of the solutions to getting cooperation from neighboring communities was inclusion in the benefits of the new supply. To some extent, this helped encourage regionalization. Portland, ME provided supply to 5 villages from its facilities bringing water down from Lake Sebago. Providence, RI began supplying Cranston, Johnston and N. Providence from its Pawtuxet River supply. The largest metropolitan district of the period was the 1895 creation of the Metropolitan Water District comprised of Boston and 12 other communities. A ten mile radius of the Boston State House was used to set future eligibility, later to be expanded to 15 miles. The formation of this district was driven primarily by inadequate or unsafe supplies in the abutting communities and was brokered by the MA Board of Health.

1902 Milford MA Masonry Dam

Private water companies faced many of the same problems and managed to get political solutions such as eminent domain when needed for source acquisition. The driving force was the welfare of the overall community and its economic base which was usually adequate to get permission from the state legislature to take lands and water sources as necessary.

Diversion of water from one river basin to another was unusual at this time mainly because the required volumes were satisfied locally more often than not. This doesn't mean that interbasin transfer was frowned upon in this age from any environmental standpoint. The engineers of the day were of a mind to manipulate rivers as a resource for their purposes, most often for some industrial need such as a mill. The earliest major diversion was Mother Brook in Dedham, MA, which was constructed in 1639 to divert about a third of the Charles River flow via a canal to supplement the seasonally low Neponset River and its mills. The development of canals for transportation in the early 1800's also depended entirely on river diversions. When the canal was meant as passage around a river obstacle, diverted water was returned to the source river downstream of the falls or the mill dam. However, some canals, such as the Middlesex Canal in Massachusetts, took water from one basin to another, from the Concord River to the Mystic River in the case of the Middlesex Canal. With all the technological advances in the era, the ability and desire to "improve" on nature had advanced faster than the underlying understanding of river ecology. This was just one aspect of the New England environment that had changed dramatically from the beginning of European settlement. Other major changes had come from the clear-cutting of the New England forests by early farmers and draining of swamps everywhere for development of the land. This was simply consistent with the view of such things at those times.

Protecting or enhancing supplies

Most watershed lands were devoid of trees in the late 1800's, having previously used as farm land. Many of the larger surface water supplies started reforestation programs, partly to help prevent erosion and partly to minimize plant detritus and farm fertilizers from reaching reservoirs and aggravating algae blooms. At this early stage, there wasn't much recreational pressure, nor were there many supplies that developed regulations governing permissible activities on reservoirs.

The period saw the first attempts at source protection. Some communities, like Nashua NH, restricted mill development on its supply tributaries or began considering ways to intercept waste. Boston MA constructed filter beds on Pegan Brook, a tributary of its Lake Cochituate source, to receive the noticeably foul discharge from a local reform school. Fall River MA began a major sewerage diversion program to direct discharges away from its Watuppa Pond source.

Status of Largest Supplies at 1882

State	**City**	**1850 Source**	**1882 Source**
MA	Boston	Lake Cochituate	Added Sudbury System in 1870s, Mystic River in 1860
	Cambridge	Fresh Pond	Added Stony Brook Res. In 1887
	Worcester	Bell Pond	Added Lynde Brook Res. in ?
	New Bedford	Acushnet River	Acushnet River in 1865
	Fall River	Watuppa Lake	Watuppa Lake in 1871
	Springfield	4 Sm. Reservoirs	Added Cherry Valley Res & Ludlow Res. In 1873
RI	Newport	Ponds	Easton's Pond & Paradise Pond in 1876
	Providence	Springs	Directly from Pawtucket River in 1870
CT	Hartford	Connecticut River	Trout Brook Reservoirs in 1865
	New Haven	Mill River	Lake Whitney on Mill River in 1860
	Bridgeport	Springs	Ox & Island Brook, Pequonnock River in 1857
NH	Manchester	Lake Massabesic	Lake Massabesic in 1872
	Nashua	Pennichuck Brk	Pennichuck Brook in 1855
ME	Portland	Springs	Lake Sebago in 1867
VT	Burlington	Lake Champlain	Lake Champlain in 1867

1900 to 1930 – Continued pressure for new sources

In general, water demand in cities continued to grow throughout the period. There were some lags in growth during World War I but immigration was fairly consistent throughout.

Population, Per Capita and Growth of Water Use

	Population Growth Factors	**Per Capita Growth Factors**	**Resulting Water Use**
Early 1900's	↑ • Rapid immigration • Cities become extremely crowded	↓ • Plumbing becomes much more common but more metering cuts waste for a slight reduction	*Rapid growth*

Influence of Public Health

Waterborne disease had declined significantly by 1900, then dwindled down to insignificance by 1930 as water suppliers began to use treatment, especially chlorination, to good effect. The state

Public Health agencies still had a large say in maintaining supply adequacy but advances in treatment technology allowed safe use of virtually any source. Preference was still clearly for starting with the best water quality and most protected supplies possible for reduced risk.

Droughts as triggers

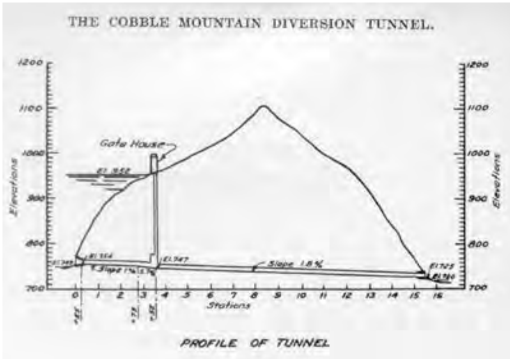
In this period, there was a lengthy period of consistently below average rainfall and runoff from 1910 through to 1920. This didn't necessarily constitute a drought to many systems but it did cause reevaluation of the safe yield of many sources. It also added urgency to the need to augment some larger systems' source capacity.

Wachusett Reservoir drawdown during the 1920's while Quabbin Res. was being debated

Source development technology

Water supply dams got bigger and more complicated. A number of very large water supply dams were constructed in this period including the Providence RI's 1922 Gainer Dam at Scituate Reservoir and the Cobble Mountain Dam by Springfield MA, a hydraulic fill dam of 263' height (tallest in New England and completed in 1932). The Cobble Mountain source was also notable as an early use of deep rock tunneling that was intended to flow full and under pressure, one of the earliest examples of such a design. Large masonry structures or "puddled" earthen dams were no longer the only available methods. The advances in pumping technologies in the early 1900's allowed use of hydraulic fill methods for larger structures, simplifying and improving the placement of a watertight core. Cobble Mountain Dam and Gainer Dam were both done by this method.

1922 Gainer Dam at Scituate Reservoir, Providence RI supply



1932 Springfield MA's Cobble Mountain Tunnel, the first deep rock tunnel made to be pressurized.

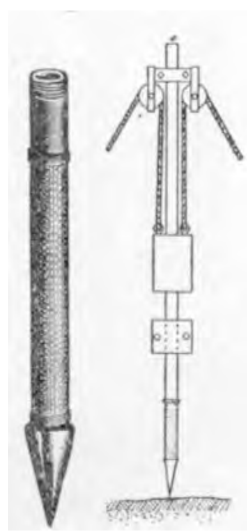
1932 Springfield MA's Cobble Mountain Reservoir

1905 Construction of Gloucester MA dam corewall

1905 Completed Gloucester MA Dam

Many communities opted for the simpler development of well supplies. There was a prevailing sentiment that surface water was more prone to water quality problems and that groundwater, with its natural filtration, was safer and very economical to develop since treatment was usually

1933 Driving a tubular well



Well point

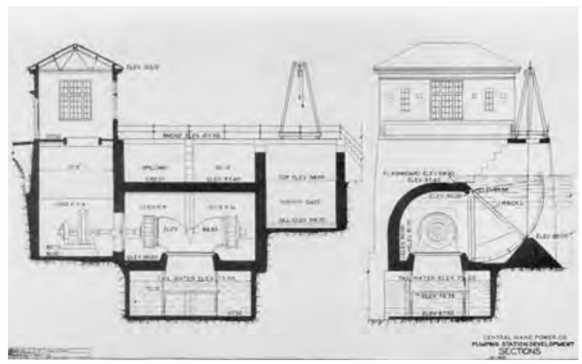
Early artesian well

unnecessary (except for those wells with iron and manganese problems). In the early 1900's, well technology had advanced to the point that construction of very large dug wells and infiltration galleries was no longer necessary. Tubular wells could be drilled into suitable soils having relatively shallow groundwater and connected to pumps to withdraw the necessary volume. It was common to install multiple wells with a common pump, with some supplies installing dozens of wellpoints in a well field. Often these early well fields used suction type pumps which limited the possible depth to relatively shallow water tables. With the development of submersible pumps, wells could be drilled to substantial depths, up to several hundred feet.

Politics of water transfers and reservoirs

Water was being managed and moved around in a big way in the rest of the country. Agencies like the Corps of Engineers had been given a mission to control flooding and navigation of rivers. They approached this with gusto and began building flood control dams and channel improvements across the country.

1925 Waterville ME hydroelectric power station with water supply pumping done by generated power



1925 Waterville ME hydroelectric plant

The western states had federal support for farming and began massive irrigation projects to reclaim desert land. In California, Los Angeles went after the Owens River with its notorious 1913 acquisition of land and water rights from the Owens valley farmers. Boston based engineers, Frederick Stearns and John R. Freeman consulted for Francis Mulholland, the man who led the expansion of the Los Angeles system. Their specialty was to help design and build the system of 226 miles of aqueducts, tunnels and pipeline to carry the Owens River to Los Angeles, an engineering achievement that was viewed by engineers as one of the wonders of the modern world but which went somewhat unheralded by the public due to the controversy surrounding the project. Also in 1913, San Francisco developed the Hetch Hetchy Reservoir in a valley that many thought was the equal of Yosemite, beginning John Muir’s lifelong pursuit of its restoration, planting the seeds of environmentalism that would blossom in the 1970’s. All in all, the country was manipulating its rivers in a big way.

Nearby, the New York water system had expanded from the Croton to the Catskill system and was already eyeing the Delaware. The Catskill system had added 2 more large reservoirs to the 12 smaller Croton system reservoirs and was connected via a new high pressure aqueduct system to the city. Despite these huge increases in capacity, the New York system was again strained by drought. The 1925 proposal to develop reservoirs on the Delaware River watershed brought a law suit that reached the Supreme Court before the 1931 ruling granted New York the development rights.

New Englanders developed many new large sources in this period. The urban areas continued to grow and many southern New England supplies needed source expansion. The new Metropolitan Water District serving the Boston area finished constructing the Wachusett Reservoir in 1905, one of the last big masonry dams. This only brought temporary relief since, by the 1920's, the combination of increasing use and the mild drought years in the 1910's and 1920's brought about the need to go further. For the Boston area, this meant proposing the construction of the Quabbin Reservoir, a straightforward engineering solution, but a difficult political problem. Not only did the reservoir require relocation of several communities but it also began a major interstate water dispute, since removing much of the flow from the 186 square mile Swift River watershed would reduce flow in the Connecticut River. For much of the 1920's, the proposal was studied and restudied. People impacted by the project argued that it was either not needed or that there were local alternatives in eastern Massachusetts that were adequate. One such alternative plan was floated by a group that included Allen Hazen, the hydraulic and water treatment authority. His plan suggested treatment and diversion of just about every eastern Massachusetts river, a complex and risky solution that could have introduced poorer water quality, subjected Boston to more drought risk and depleted river flow in some currently stressed river basins. These discussions didn't end until the Massachusetts legislature adopted the Quabbin plan and the Connecticut lawsuit heard by the Supreme Court was dismissed in 1927. In a sign of the concerns of the times, the lawsuit was mainly about navigation on the lower Connecticut River, not whether there would be an impact on the river environment.

Hartford continued to build its multi-reservoir Nepaug system but its demand also continued to grow, leaving concerns that additional capacity would be needed. The Hartford Metropolitan District Commission was created in 1929, bringing in several towns to the system.

In 1922, Providence moved from its old Pawtuxet River source to Scituate Reservoir. This alleviated their source issues until well into the 1960's. Many other supplies like New Haven CT and Worcester MA added upstream reservoirs on its watersheds to capture more of the available runoff for improved safe yield, with the result that the original streams were impounded into a series of cascading reservoirs.

In each of the larger reservoirs, the issue of moving people out of the way was becoming substantial. Wachusett Reservoir inundated parts of 4 towns and required relocation of 2,000 people. Scituate Reservoir also took parts of 8 villages and relocated 1600 people. The towns that were affected were some distance from the large cities and were typically once vital communities when the local mill was in its heyday, but had actually lost population once the mills closed. The acquisition of property by water supply agencies became a study in real estate wheeling and dealing with some people settling early and many holding out for more money. Some were happy to leave and felt that the real estate payoff was a win for them and some were unhappy to be forced from their homes regardless of the price.

1925 New Bedford deep intake on Quitticas Pond

Boston's 1905 Wachusett Reservoir was also the first major interstate water dispute since the Nashua River was a feeder to the Merrimack River with all of its industrial users, including some from New Hampshire. Impact and compensation discussions drew many of the regions most expert engineers. In the Wachusett case, rights to develop the reservoir required only a fairly small release to the river but compensation was successfully arranged in the form of payments for damages or replacement of some mill turbines with steam power.

Protecting or Enhancing supplies

With the creation of large reservoirs came pressure to use those reservoirs for recreation. As automobiles became more popular, the idea of traveling out to remote water bodies became more possible. People wanted swimming access in some cases, the use of boats for fishing or other recreation. There were documented incidents of contamination from recreational activities from this period. Understanding that the waste from even a small source like a fishing camp had been responsible for many past outbreaks, water suppliers were generally resistant to opening more access, regardless of the public pressure. In this period, NEWWA helped advocate restricting watershed activities and developed committee reports recommending strict regulations for public use of watersheds.

Status of Largest Supplies

State	**City-**	**1882 Source**	**Mid 1900's**
MA	Boston Cambridge Worcester New Bedford Fall River Springfield	Sudbury System in 1870s, Mystic River 1860 Stony Brook Res. In 1887 Lynde Brook Res. Acushnet River in 1865 Watuppa Lake in 1871 Cherry Valley Res & Ludlow Res. In 1873	Wachusett Res in 1898, Quabbin in 1939 Hobbs Brook in 1897 Holden system, Pine Hill Res, Quinapoxet Quitticas Pond in 1899 Same Cobble Mt. In 1932
RI	Newport Providence	Easton's Pond & Paradise Pond in 1876 Directly from Pawtucket River in 1870	Same Scituate Reservoir in 1922
CT	Hartford New Haven Bridgeport	Trout Brook Reservoirs in 1865 Lake Whitney on Mill River in 1860 Ox & Island Brook, Pequonnock River in 1857	Nepaug Supply 1917, Barkhamstead Res in 1940 Added smaller upstream reservoirs Added Saugatuck Res in 1942
NH	Manchester Nashua	Lake Massabesic in 1872 Pennichuck Brook in 1855	Same Added small upstream reservoirs
ME	Portland	Lake Sebago in 1867	Same
VT	Burlington	Lake Champlain in 1867	Same

1930 to 1970 - Source expansion as water use grows

Population, Per Capita and Growth of Water Use

	Population Growth Factors	**Per Capita Growth Factors**	**Resulting Water Use**
Mid 1900's	• WWII slows growth • Population starts shift from cities to suburbs	• Droughts, depression, WWII all inhibit water use	*Slow growth*

This period began with the Great Depression and its major impact on the economy and overall quality of life. Then just as the economy began recovering, along came World War II with its impact on both the population and, once again, the economy. Water use grew slowly through this period but accelerated rapidly after the war as the "Baby Boom" followed. Population began growing rapidly and the desire for single family housing coupled with the affordable automobile and improved highways brought suburban expansion around cities. The period ended with the beginning of a population shift away from the old industrial cities but growth of the surrounding metropolitan areas. This period marked the beginning of a trend of migration out of the region as a whole as the warmer climate and opportunities in California and Florida drew more emigration their way.

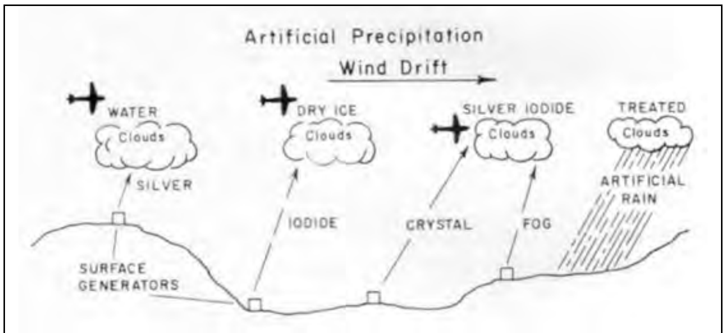
Influence of Public Health

Public Health had a lesser role in this period given that water treatment had essentially eliminated the earlier disease threats. While other threats emerged (discussed in the next chapter), Public Health officials influence over water supply was intended to improve performance than to correct serious deficiencies.

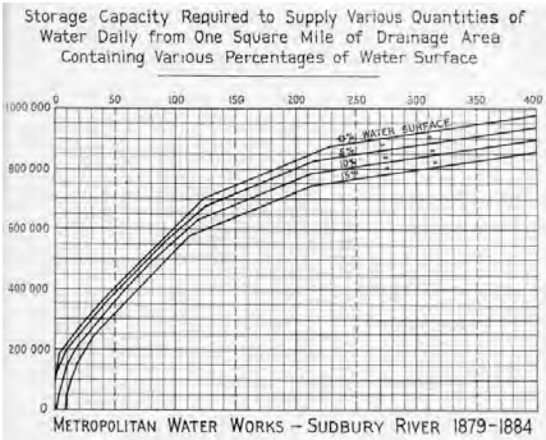
Droughts as triggers

For most of this period, there were only occasional dry years like 1957, but then the 1960's brought the most severe drought ever recorded in New England. Water suppliers had never seen anything like it as river flows and reservoir levels dropped to record lows. Coming as it did on the heels of the Baby Boom growth spurt, it stressed most water supplies to record low levels. The combination of 4 successive years of record low rainfall left even the largest sources depleted and looking at emergency options. Even extreme measures like cloud seeding were considered by desperate communities.

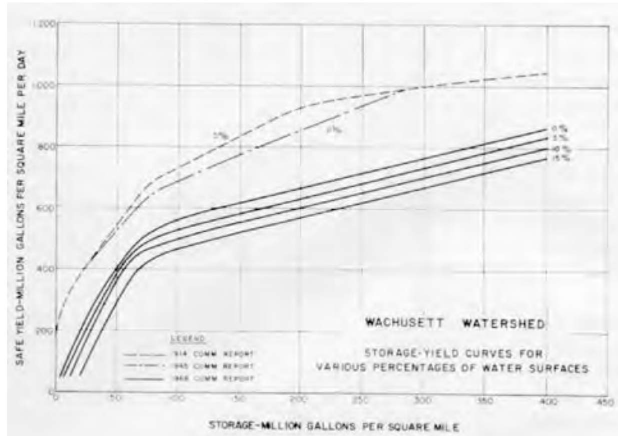
This set the tone for re-evaluation of safe yield for many systems. NEWWA's safe yield committee also reviewed and revised the safe yield estimation curves developed in the early 1900's downward as a result. The other long term effect was to bring about a major review of the adequacy of east coast water supplies by the Corps of Engineers. This included the Boston and Providence metropolitan areas and led to new water supply augmentation proposals in the 1970's.



From a late 1960's paper, cloud seeding was considered by some desperate communities



Example of 1904 NEWWA Safe yield committee curves for estimating safe yield

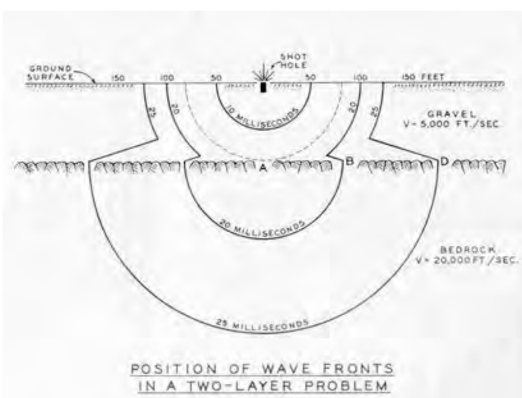


Example of 1968 revised NEWWA Safe yield curves – Note the reduction

Source development technology

Once again, more large reservoirs were built in this period, the largest being Quabbin Reservoir's hydraulic fill dams. Greater use was being made of concrete dams like Bridgeport CT's Saugatuck Reservoir.

During this period, many more communities developed ground water sources. Groundwater location technology using seismic methods was more consistently reliable in predicting production capacity. Deep well drilling methods and pumping equipment improved to the point that groundwater was an easily implemented, economical and reliable source method.



Seismic location of water table

FIG. 1.—RADIOACTIVITY WELL-LOGGING INSTRUMENT TRUCK.

Radioactivity monitoring instruments would be lowered down a well casing to categorize soil layers

Politics of water transfers and reservoirs

During the Great Depression, government spending on big public works projects was accelerated to jump start the economy. Nationally, this meant that water projects were ubiquitous. Large hydroelectric projects like the Hoover Dam in 1935, and the Grand Coulee Dam in 1941 were built in this period. Nationally, Los Angeles diverted flow from the Colorado River to meet its growing needs. New York moved to add the Delaware system to bring its capacity up to present day levels. All of these were controversial projects with interstate law suits.

Construction of hydraulic fill Winsor Dam at Quabbin Reservoir, MA – Note that the Dam is named for Frank Winsor who also built the Gainer Dam for Providence

Quabbin Reservoir, the largest man-made New England supply source, was finally built. Completed in 1939, it took until 1946 to fill completely. Its water quality was everything that engineers predicted it would be and its seemingly limitless volume encouraged Boston's MDC to abandon some of its older sources like Lake Cochituate and some of the Sudbury system reservoirs. Of course, the optimism of the 1940's turned into pessimism in the 1960's as Quabbin was drawn down to 45% full in the drought of the 1960's while demand projections showed even higher water use was ahead.

Hartford CT also built its largest reservoir during this period, the Barkhamstead Reservoir. Similarly, Bridgeport CT also completed its Saugatuck reservoir.

This period is remembered by many for its displacement of communities and residents. Quabbin required relocation of 2,700 people and literally ended the existence of 4 towns. A total of 7,613 graves were moved from 35 cemeteries, buildings were removed and the land stripped of any vegetation to prepare for the reservoir. Barkhamstead and Saguatuck Reservoirs had similar but proportionally smaller impacts. In comparison, New York City had even larger impacts with 26 towns being removed and 6,500 people displaced for its Catskill and Delaware systems.

Again, the communities impacted were old mill towns that had gone from prosperity in the early 1800's to stagnation and population drop in the 1900's. The people were again bargained with for land compensation and the projects were seen as inevitable. It is notable that this was hardly the first or last time that an unfortunate few had to get out of the way of a public works project that was needed for a larger public good. Creation of the interstate highway system in the mid-1950's cut swaths through many populated areas. Urban renewal in older cities condemned property and removed unwilling residents in sweeping projects, an example being the West End reconstruction of Boston. All in all, New England's large reservoirs were built with minimal controversy and few incidents when compared to other major civil works.

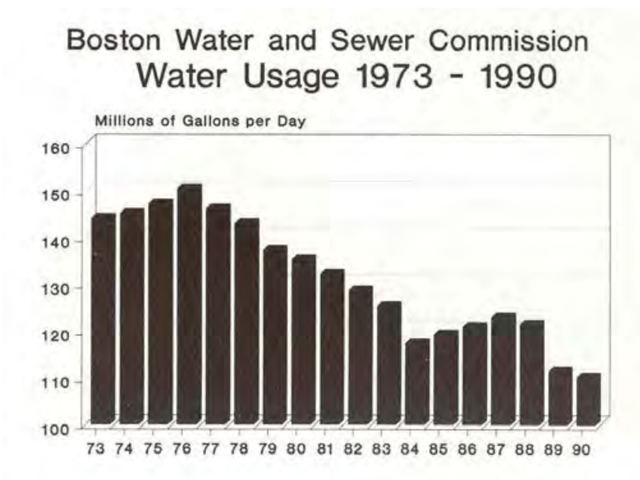
In essence, reservoir construction had become a more difficult siting issue in this period but one that left behind a desirable and scenic resource. It is notable that such projects in the 1930's and 1940's were seen by most people as positive for the economy. WPA financing helped build Quabbin and many other large water facilities, putting many unemployed people to work.

Protecting or Enhancing supplies
With the pressure to do more with less, some water supplies began to look at the state of their watershed forests with a mind to increase runoff by selective cutting. Many NEWWA papers of this period looked at a proper mix of hardwoods and conifers and suggested active forestry programs.

Recreational pressure was still a political problem now that people lived closer to sources. Land acquisition around reservoirs and regulation of allowable activities were given more attention to help control risks.

1970's to the Present Day - Slowing down the growth

Population and water use growth continued through the 1970's. In the 1980's, population stabilized as household size decreased and emigration to other parts of the country continued. Bedroom suburbs of large cities saw the most growth as better transportation systems allowed people to commute from further away. The inner cities themselves lost population through much of the period but many saw some revitalization in the 1990's as real estate booms brought urban renewal, updating the housing stock. Sewer charges began to be billed according to water consumption, which began to have an effect on price elasticity. As water got more expensive and water conservation began to be felt, per capita water use began to drop. Efficient fixtures and appliances became readily available and even required as plumbing codes began to require more efficiency.



Boston had success reducing water use through aggressive leak detection and meter replacement

Population, Per Capita and Growth of Water Use

	Population Growth Factors	Per Capita Growth Factors	Resulting Water Use
Late 1900's	⇧ • Baby boom in late 40s to early 50s • Automobiles/trains allow rapid growth of suburbs • Growth slows in 1980s	⇧ • Water saving devices more common later in period • Plumbing code changes • Per capita stabilizes or goes down slightly	*Rapid growth in 1950's-1960's, slow growth in 1980s*
Now	⇧ • More but smaller households • Slight emigration results in stable population	⇩ • Industrial/commercial users conserve, price effect • Widely available water saving fixtures and appliances	*Stable in region, growth in some areas*

Influence of Public Health

Public health issues associated with drinking water once again became an influence in this period with the discovery that some supplies were being fouled by heretofore undetected contaminants. New technologies like the gas chromatograph/mass spectrometer allowed discovery of volatile organics, pesticides, PCBs, and a variety of chlorinated organics. In 1962, the book Silent Spring identified the consequences of DDT use and generally promoted environmentalism. On a national level, the 1978 investigation of Love Canal demonstrated the severe health effects of pollution leading to a concerted effort to identify hazardous waste sites and clean them via programs like Superfund. Locally, this exposed dozens of hazardous waste sites around New England, many of which had affected water supplies. Throughout the 1970's, researchers actively identified more and more carcinogenic and mutagenic substances and found that many were present in water supplies. All of this contributed to a national push to address the public's growing concern over water quality, resulting in the passage of the 1974 Safe Drinking Water Act which established water quality regulations limiting these contaminants.

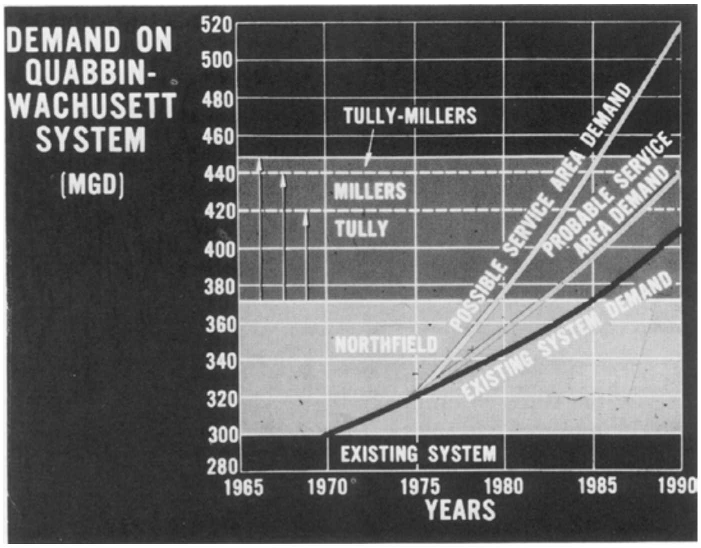
The end result for water suppliers was the finding that some severely polluted industrial sites had indeed caused contamination of water supplies forcing their removal from service. Many systems wrestled with the difficult decision of whether to treat the contamination. In some cases, the technology existed to do the job but the stigma of past health effects, perhaps even involving fatalities, simply made reactivation with treatment unacceptable to the consumers. Thus, some systems found themselves suddenly short of capacity and needing source augmentation once again.

Droughts as triggers

The impact of the 1960's drought was felt through the 1970's in that large scale planning continued into that period. There were occasional dry years thereafter (e.g. 1980) but nothing comparable to the 1960's.

Source development technology

The drought of the 1960's had clearly identified safe yield problems for many New England supplies, some of whom have struggled with capacity shortfalls to this day since new source development began to be much more tightly regulated. The old means and methods of source development were no longer reliable or effective in the face of this pushback.



Corps of Engineers demand projections for Boston MDC

The post-60's drought problems were exemplified by the experiences of two of the larger systems, Boston and Providence. The Corps of Engineers review of eastern water supplies in the 1972 Northeast Water Supply Study (NEWS) had projected the continuing growth of both the Boston and Providence metropolitan areas to the point that supply augmentation appeared necessary well before the year 2000. Both areas had been looking at alternatives, Providence focusing on the Big River proposal and Boston MDC on the use of Connecticut River water. Providence's proposal was creation of another large reservoir (60' tall dam, 27 mgd safe yield), straightforward in an engineering sense but difficult politically in the age of growing environmentalism. MDC proposed to take advantage of their large Quabbin Reservoir storage by flood skimming the Connecticut River in a novel way, using the Northeast Utilities pumped storage facility to take water from the upper reservoir only under high flow conditions through a tunnel to Quabbin. Both projects were met with considerable resistance by the donor areas, i.e. rural Rhode Island and western Massachusetts. The projects were also strongly opposed by downstream interests and environmental groups everywhere.

The other major source issue of this period was the sudden loss of capacity to contamination. Some smaller supplies that had lost sources to contamination were forced to regionalization as a solution, examples being Bedford MA and Woburn MA who turned to the MDC. Others like Dedham MA and Burlington MA developed treatment such as airstripping of problem volatiles. The expense of aggressive treatment technologies and disposal of the removed contaminants became important decision factors.

For groundwater sources, the finding that conservative pollutants could reach the wells was a revelation that countered the popular notion that groundwater was a safer alternative to surface water. Such pollutants as leaking gasoline tanks and improperly disposed industrial wastes were found to have traveled substantial distances to reach drinking water wells. The hazardous material generator that caused the problem may have been financially responsible for damages but getting the problem rectified and collecting damages were not so easy. The period brought new well drilling techniques that would allow deeper wells into fractured bedrock. This allowed more access but, for most groundwater systems, the main focus turned to protection of aquifer recharge areas with better modeling of groundwater movement to understand risk.

One notable area where new technology may be changing source development possibilities is in desalination. As membrane technology improves, the economics of desalination may become more competitive. The first such significant project in New England is a proposal by a private company, Aquaria, to treat the brackish waters of the Taunton River for Brockton and other potential southeastern Massachusetts customers. The project is currently in environmental permitting in 2006 with hopes of proceeding in coming years. A successful demonstration may present an interesting option for coastal areas.

Politics of water supply sources and pollution

The 70's and 80's were the decades of large water project controversies. Even as the memories of the 1960's drought were fading, the 2 largest new supply proposals, Providence's and Boston MDC's were still being debated. The major point of contention was "need", i.e. whether the projects were really necessary. By 1980, a number of water use factors had changed somewhat, population growth didn't follow the projected increases and factors like per capita and non-domestic usage began to show downturns. The water/sewer bill was becoming noticeably high, prompting people to both modify habits and to seek more efficient fixtures. In a parallel to the energy crisis, industry was quick to cut utility costs by simple efficiency measures like eliminating once through cooling. For the first time, the idea that water use would continue to rise indefinitely was questionable and no build alternatives such as leak reduction and water conservation were begun to be seen as effective solutions.

Another significant change in this period was the growth of environmentalism as a political force. After the National Environmental Policy Act of 1969 and other environmentally protective legislation, the impact of projects on the natural environment now had to be fully described and justified. Rare and endangered species presence was now stopping projects, as occurred in 1977 when the snail darter stopped construction of the Tellico Dam in Tennessee. Wetlands were better understood and protected for their beneficial uses. Putting the needs of the ecosystem ahead of man's needs/desires was certainly a different approach than had been tried up to this point, showing a growing public appreciation of nature. Perhaps this was a form of atonement for the centuries of abuses that were heaped on the rivers but it remains troubling that water supply withdrawals have become regarded by some as a negative thing. The balancing of environmental needs versus water supply constraints on a community's growth and prosperity has become and will continue to be a recurring political theme.

The final significant factor in this period was the public reaction to water resources being transferred from one river basin to another, perhaps more importantly from one political area to another, regardless of whether they were in the same state. It clearly rankled the people in western Massachusetts to be proposed as a donor area for Boston's water needs regardless of the small percentage of river water being discussed. It was especially disturbing when water use studies identified a relatively large amount of unaccounted-for water in the MDC service area. The MDC Northfield project never became an interstate controversy because it never got that far, being essentially made a last resort by successive state actions. It did, however, become a lightning rod for setting restrictive controls. In 1978, Massachusetts state water policy emphasized water conservation over augmentation, then the 1984 Interbasin Transfer Act and 1986 Water Management Act were passed to further put in place controls that directed efficiency first, then use of local resources before considering a large new water transfer. Boston MDC's situation was then changed significantly in 1985 with the creation of the Massachusetts Water Resources Authority. Their enabling legislation further reinforced the mission of the new agency to focus on water conservation before consideration of any other supply solution. MWRA then proceeded with a successful water conservation program, bringing water demand to within safe yield by the early 1990's.

In Providence, the Big River proposal began when the Rhode Island Water Resources Board was formed in 1964. The new Board spent $7.5 million on property from 200 landowners in anticipation of building the project. As with the MDC proposal, the project was attacked on the basis of need and consideration of other alternatives. There was also resistance to the project on environmental grounds for the unavoidable physical impact that a large reservoir will have.

In 1990, EPA ruled against funding the project, citing a substantial level of environmental impact, including potential loss of 575 acres of wetlands, 10 ponds, 17 miles of streams and 2500 acres of forest. The project has been in limbo since but has not been entirely abandoned. This falls in place with the national trend in which more dams are coming down than going up. As with the Boston area, water demand has stabilized and life goes on reasonably well, at least until the next major drought.

Elsewhere, the impact of contaminated sources was felt for decades after the first contamination discoveries in the 1970's. Remediation and treatment of the contaminated sources was very costly, but often made necessary by the lack of other options. If the contaminated supply had a very negative connotation, as did Woburn MA's wells G and H that were the presumed cause of leukemia deaths, then public confidence could not be restored and the supply could not be reused. Meanwhile, untapped groundwater resources in stressed basins could not be counted on as a replacement solution due to difficulties in getting development permission. Now that many of the early Superfund issues are essentially cleaned up, there will hopefully be fewer large surprises. Certainly, this isn't the end of problems given the recent emergence of new threats such as MTBE and perchlorate as the latest example of how improved detection technology will continue to influence source use and abandonment. Changes in tolerable contaminant levels, such as the recently more restrictive arsenic standards, may also impact source viability.

One continuing sticky question is when and how to abandon a poor quality source, a problem that will only become more acute in the future as more wells become problematic from such simple issues as elevated iron/manganese, saltwater intrusion or buildup of conservative substances like nitrates or slow degrading organics where subsurface waste disposal takes place. The environmental protections and regulatory hurdles put in place to help rivers and ecosystems make replacement of these sources extremely difficult. This may increase regionalization or much more sophisticated treatment.

Protecting or Enhancing supplies

The important lesson of this period was the definition of contributing areas, be it watersheds or aquifer recharge areas and the reduction of risky contaminant sources. This meant more sewerage works, acquisition of key watershed lands, better sanitary surveys and controls over certain watershed practices.

Are we done yet?

The region's relative population and water use stability is a good thing but complacency should be avoided. Most supply issues get too little attention until an extreme drought forces the issue, often too late to avert a crisis. Hopefully, a fine balance can be achieved in the future where reasonable water use efficiency is required, but water supply augmentation is allowed where needed for relief from chronic shortfalls.

The bottom line is that the age of the large water supply project is probably over in New England, despite the continuing mega-projects in places like China and California.

Public Water Supply Sources in 1985

State	Population served	Ground Water MGD	Surface Water MGD
Connecticut	2,680,000	66	296
Maine	829,000	24	84
Massachusetts	5,330,000	181	586
New Hampshire	637,000	28	61
Rhode Island	884,000	15	101
Vermont	343,000	17	36
Total New England	10,703,000	331	1164