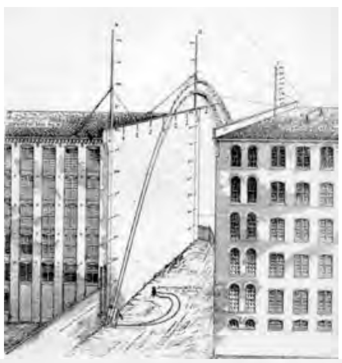
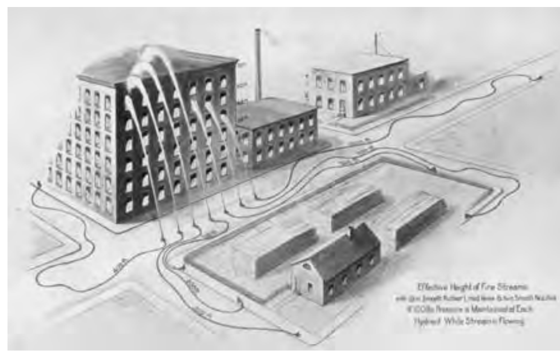
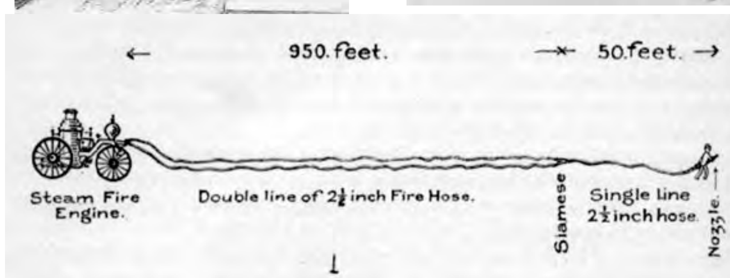
Chapter 4 Water Distribution Systems and Water Efficiency

In the early colonial days, water supply technology wasn't very complex. If you wanted water run to your house, you bored out your own wooden logs. If you wanted water for your town, large scale systems of bored-out logs were needed. Incidentally, pipe laying work was as unpopular back then as it is now because it ruined the roads. Such simple questions as proper depth, means of connecting services and fire taps arose almost immediately. Soon after the initial pipes were laid, the real fun began, as the leaks, outages, water quality complaints and other facts of life for the water supplier became apparent. As with any other emerging technology, the methods and materials weren't always up to the challenge. As systems expanded, NEWWA was to be of enormous help, providing a forum where water suppliers could rub elbows with engineers and equipment manufacturers to learn what the latest developments had to offer.







Examples of test apparatus from early fire flow testing

Distribution System Standards

Design of early distribution systems was driven by two things, first connecting the paying customers and then providing fire protection requirements where necessary, which in turn were driven by the nature and height of buildings. In the early 1800's, most communities had fairly low wood frame housing with unpaved streets and the risk of a conflagration was great. A wooden pipe "fireplug" could at least fill a bucket to be thrown or hand pumped onto a fire. The ability to pump directly from a hydrant on a water main didn't happen until the mid 1800's when fire-fighting technology had evolved to steam powered pumps. The idea of high flow volume being applied directly to fires from a pressurized hydrant was only made possible by the mid 1800's availability of metal pipe and better joint design for high pressure use. If properly designed, such pipes would be capable of pressures needed to direct a nozzle stream up at least six or so stories to protect increasing building heights in urban areas.

The height of buildings also forced improvements with time. In the mid 1800's, cities had mostly timber framed brick faced structures and were usually limited to 4-5 stories because of the timber construction. Early systems had problems delivering water from the street mains to an upper story fire simply because the hydrants and hose nozzles were still non-standard and not well designed to direct a flow in a consistent arc to a great height. By the 1880's, most distribution systems became capable of delivering at least 50-100 PSI pressure to the hydrant. During the early days of NEWWA, much study went into optimum nozzle design to direct an effective fire stream, as well as hydrant spacing to deliver enough fire streams to a large blaze. Minimum pipe sizing was also adopted after considering the results of such major conflagrations as the Great Boston Fire of 1872. Water engineers also began to use distribution storage to supplement flow from sources during peak fire flows.

> ***Odd fire protection strategies***
> In ancient Rome, fire companies were often entrepreneurs that would race to the scene of a fire to negotiate with the owners for a price to either save or purchase the ruins of their structure.
>
> One such story was noted in a late 1800's NEWWA journal which referred to a Canadian community served by a private water company that would not allow the local fire department to use its hydrants unless a hefty fee was paid.

The early 1900's changed urban area fire protection planning again when steel construction allowed taller buildings, culminating in a period of skyscraper construction that was well beyond the ability of normal water supply pressures to protect. This led to tall building designs that incorporated internal pumping and storage and also led to special high pressure fire districts, examples being the Boston and Providence systems which had dedicated fire service mains and fire pumping stations in their downtown areas.

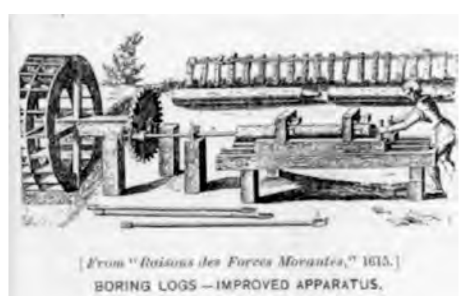
Another major factor in distribution system design was suburbanization as the affordable automobile and better roads resulted in very rapid suburban growth and construction of housing in more remote and higher elevation areas. Extension of the distribution system to serve such area became a greater issue in the second half of the 1900's. The need for new pressure zones, booster pumping, and additional tanks grew steadily with sprawl.

Age and condition of the distribution system infrastructure has also always been an issue beginning in the days of the first wooden pipes. What other expensive asset do you go out and bury in the ground and expect to last over a hundred years? Water engineers have struggled with the inability to find the perfect material for the job even to this day. How best to balance cost, durability, corrosion resistance, installation ease, workability and, most importantly, water quality protection, have occupied the industry since NEWWA began. Every material has its drawbacks and every structure has maintenance needs of some sort.

The following sections examine the evolution of common distribution system components.

History of Pipes

Wood was the available material in New England for any use including pipe manufacturing. Pitch pine was preferred for its resistance to splitting and rot. Joints were usually made by tapering and driving together fitted sections using some pitch for waterproofing. Occasionally, sheets of lead were used as a gasketing between sections or a rolled iron plate tube was inserted to make the joint. Tapping for services and "fireplugs" was done by hand drilling and driving a lead service line or a smaller wood pipe into the hole.



Wood pipe production

Custom fittings could be creatively made by carving larger wood pieces to shape as was done in the piece of the original 1652 Boston "Conduit" that is on display in NEWWA's offices. Other creative solutions include the use of a fork in the tree to make a "Y" or a crooked tree as a bend. Wrought iron bands could be used for reinforcing where needed.

As you can imagine, leaks were common given the poor jointing and splitting of the wood under pressure. Further, even the best wood would have a very short life due to rot, tree root damage and insects.

Wood pipes from 1796 Jamaica Pond Aqueduct

Later wood pipes were manufactured similar to barrels in that staves would be beveled to shape and joined with metal reinforcing bands to allow larger pipe sizes and improved working pressures. This allowed low cost, locally produced pipe that continued to be used in rural systems well into the 1900's.

1916 14" wood stave pipe and valve, Pembroke NH

The next logical advance was metal pipe. Of the available metals of the time, lead was too soft to form a pipe larger than a few inches so it was typically limited to use for service lines. Plate iron was available in the early 1800's and could be heated and rolled into a pipe shape, riveted and joined by using sleeves packed with cement. This was the early wrought iron pipe, sometimes called cement lined pipe or "kalomein" pipe. The metal thickness was not standardized and would be relatively thin for workability. It also had the brittleness of cast iron so it was subject to fracturing under force rather than yielding like later steel pipes. Natural waters in most areas were fairly corrosive and this meant rapid buildup of corrosion deposits unless lined with cement. After some experience in the field, an external cement layer was added for longevity against soil contact corrosion. With the thin metal layer, it was tappable but barely. It was commercially available but some communities developed pipe manufacturing shops and made their own. Even after cast iron pipe was available, the cost of early cast iron pipe production forced such a high price that wrought iron was more often than not chosen by smaller systems as a cost effective substitute. In 1882, when NEWWA was formed, about half the pipe in place was wrought iron. By the late 1800's improved cast iron production methods made the cost more competitive and cast iron became the material of choice for most systems from that point forward.

Catastrophic breaks on wrought iron pipe were common due to the brittleness of the iron. Most of those in the field of water supply were emphatic in their dislike for the material. Towards the end of the first meeting held in 1882 to form NEWWA, the discussion went from organizational matters to technical matters, at which point Mr. Charles K. Walker of Manchester NH let loose a rant on the unsuitableness of that "@&$#*^ cement lined pipe". This was one of the first recorded technical issues among the men, having just met and sizing up their peers for the first time, and the topic broke the ice for spirited future discussions. An interesting counterargument was offered in an 1890 paper which defended wrought iron pipe to the assembled water works men, based on the author's experience. As was the practice at the time, a discussion followed the reading of the paper, apparently going badly for the author. The word "laughter" is recorded in the minutes no less than seven times in the post-discussion and the general consensus was that the author was definitely in the minority.

Example of wrought iron pipe, New Haven CT Water Interpretive Center

The workhorse pipe for the next century was next, that being cast iron. Nationally, Philadelphia installed the first cast iron pipe in 1817. In New England, the first cast iron pipe is believed to be a 1833 North Conway NH cast iron pipe serving its Artist's Brook supply. Peabody MA utilized cast iron pipe as early as 1834 as well. Many more New England communities started using cast iron as their standard from this period forward. NEWWA was a player in this effort in that one of the organization's earliest tasks was to develop standard specifications. The committee for this effort included Dexter Brackett of Boston MA, Freeman C. Coffin (later to start Coffin & Richardson, Inc) and F. F. Forbes of Brookline MA, the most respected distribution system engineers of their age. NEWWA adopted a Cast Iron Pipe Standard in 1902, then AWWA followed suit six years later in 1908 largely based on the NEWWA work.

The early casting of pipes was done by standing a mold on its bell end and casting the pipe vertically. This resulted in considerable non-uniformity of both the thickness (the thickness tended to increase from the weight of the molten iron towards the bell end) and in the variability of wall thicknesses around the circumference if the center mold was a bit off-line. The amount of material used was generous to create conservatively thick walls, helping with longevity of this age of pipe. The fact that pipe was sold by weight probably helped with this conservatism. Before the first American cast iron foundry was started in New Jersey in 1834, cast iron pipe was imported from European foundries. Although some very early versions of cast iron pipe used flanges and lead sheet gasketing for jointing, the mid-1800's version that was adopted by most water supplies was bell and spigot pipe with poured lead joints, a reasonably certain method of leak control for its time. The pipe was very tappable and workable and its only real drawback was the poor internal corrosion protections of the time. Various concoctions of pitch, coal tar, lead paint and other field applied coatings were tried with limited success. Cement lining was developed in the 1920's to resolve this, with the first cement lined cast iron pipe in New England being installed in Dedham MA in 1924. The lengthy roster of Cast Iron Pipe Reasearch Association’s (now DIPRA after ductile iron replaced cast) Century Club demonstrates that those choosing cast iron pipe in the 1800’s were rewarded with a quite reasonable life span, unlike some other materials.

Pit casting continued until 1922, after which, later generations of cast iron were made by centrifugally casting the pipe, thus resolving the uniformity of pipe wall issues. This continued to be the most common material until it was replaced with ductile iron in 1948.

One drawback of cast iron was that larger pipe sizes were difficult to cast and handle. Steel pipe offered a solution when it became commonly available around the early 1900’s. The initial steel pipes were formed similar to wrought iron in that the steel plate was rolled, overlapped, drilled and riveted. Joints were also overlapped and riveted in the early days since field welding methods weren’t available. Corrosion protection was no more effective than on cast iron, consisting mainly of coal tar coatings.

Pipe Oddities - *Don’t like your pipe the way it came? Change it.*

A 1913 NEWWA paper described bending of cast iron in lieu of fittings for gradual curves. The technique required heating the pipe on a bed of coals and applying force.

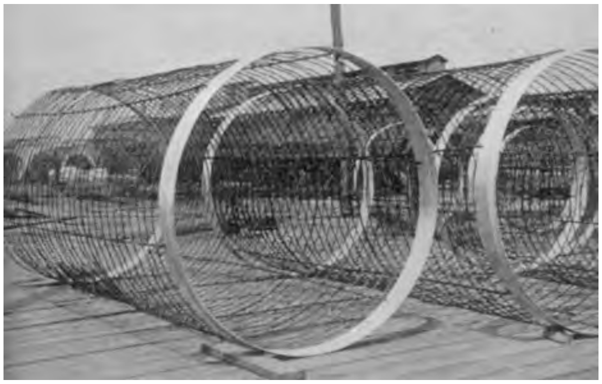
1942 unrolling pipe in Springfield MA – With the steel shortages experienced during WWII, 30” & 26” steel pipe was recycled by unrolling it and welding 2 halves together into a homemade 58” pipe.

One variant on the steel pipe manufacturing was the 1905 Lockbar pipe that had a unique method of joining the rolled plates using an interlocking tongue and groove mechanism. A further improvement was available in the 1930’s when spiral welded pipe was made available. Welding science had at this point made field welding the preferred method of joining pipes. Steel is still commonly used for very large pipe and special transitions.

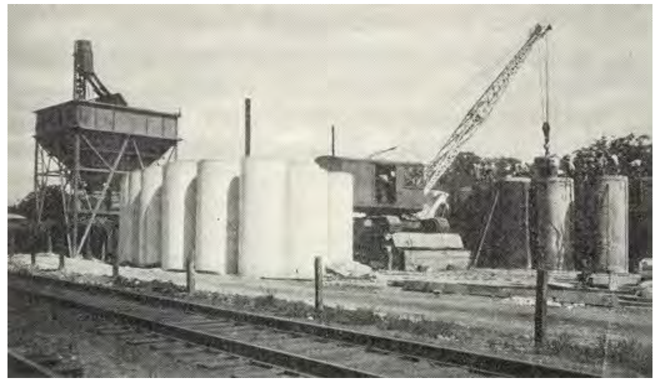
1924 caulking lockbar pipe

1927 welding steel pipe

Reinforced concrete pipe was developed as early as 1842 for use in sewers, performing well in corrosive conditions. It was in 1905 that reinforced concrete was first available for water supply use. It was cast using an internal steel cylinder for watertightness and an external reinforcing



1924 reinforcing cage



1935 Vertical casting in pipe yard

1935 Cage set over cylinder

1946 laying Hultman Aq 138" RCP

cage for structural strength. This method did not have structural uniformity and was not commonly used. In the 1930's, the first prestressed wire wound pipes were developed which greatly increased strength in all directions. The use of steel cylinder prestressed concrete pipe became popular during the 1940's as steel shortages made metal pipes much more scarce. The only blemish on record for this type of pipe was a period of manufacture dating to the 1970's and 1980's during which prestressing wire experimentation led to occasional wire embrittlement and the possible catastrophic loss of pipe wall strength if wires failed. This was since corrected and PCCP continues to be popular for larger transmission mains.

1937 Asbestos cement transite pipe laying, Note ease of handling.

Since smaller rural and suburban systems needed to lay a considerable amount of pipe mileage at low cost, the apparent benefits of asbestos cement (AC) pipe came as a blessing. Although it was only available in smaller diameters, it could be layed simply by hand placement using relatively unskilled crews. It was inexpensive, light, had no internal corrosion issues and featured a fairly simple push-on joint (the first common use of rubber gaskets in pipe joints). It first appeared in the 1930's during the heyday of WPA programs that were intended to put unskilled labor to work. The federal government funded entire distribution systems to be built for needy communities using AC pipe and local labor. It was also a favorite during the metal shortages of World War II.

Asbestos wasn't understood to be a health hazard back in the 1930's so the material was in fairly common household use. The release of fibers to the water was prevented first by a bitumastic coating, then later by an internal vinyl coating which was applied suing a mixture of vinyl with a tetrachloroethylene solvent. Proper installation of this coating was crucial, partly to allow the vinyl to cure to the point that volatile solvent release was stabilized. Pipes installed too rapidly began to have continuing solvent release aesthetic issues. By the 1970's, when organics detection technology made it possible, the release of the tetrachloroethylene was discovered where the internal coating was found to be breaking down in some areas. Further, the asbestos cement pipe itself has been reputed to lose its strength over time under some corrosive soil conditions, making leak repairs a challenge. With these limitations, AC pipe no longer enjoys the popularity it did in the mid-1900's.

Ductile iron came along in 1948 and essentially became the industry standard by 1955, remaining so to this day. It too has changed in the interest of efficiency, with the pipe wall thickness being reduced over the years to the point that it barely resembles its cast iron ancestor.

In looking at all the pipe material choices made by our predecessors to this day, the thing that is clear is that, for the most part, our forefathers did pretty well, with most distribution piping providing a century or more of service. However, not all choices were effective in the long haul, often for reasons unimagined by the designers. New materials become available from time to time, for example, many plastic pipes have been approved for water use by NSF. In addition to plastic service pipes, high density polyethylene has recently become an alternative for some applications, such as sliplining. Other new techniques like pipe bursting have also helped improve the range of options for urban rehabilitation projects. Hopefully, our choices today continue to fare as well as some of our forward thinking predecessors.

Special Pipe Issues – Special Solutions

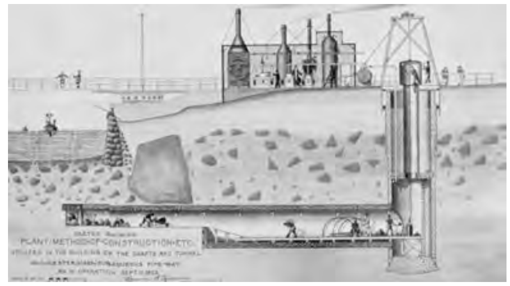
1904 Mobile boiler for pipe thawing, Manchester NH

1920 pipe thawing truck using a portable generator for electric current, Dedham MA

While discussing pipes, certain New England solutions to problems are worth noting. The relatively cold climate is one such problem. As pipe systems grew, freezing of pipes forced some creative solutions. Experience taught that depth of cover in southern New England needed to be at least 3-4 feet and, in northern New England, it needed to be about 5-6 feet. However, when the cold snaps were longer than normal, service pipes or smaller mains occasionally froze. The unfreezing of pipes produced some interesting devices.

The advent of electricity produced electrical pipe thawing using contraptions such as the one shown in the adjacent figure.

1895 Burlington VT diver, placing the intake pipe further in the lake.



1908 Gloucester MA subaqueous pipe tunnel

1923 Portland ME Harbor crossing

1908 Gloucester MA pipe tunnel – men working in pressurized tunnel

In the category of firsts, Boston has the first documented subaqueous river crossing in 1848 using a cast iron pipe. The crossing was one of several built to connect Boston proper to Charlestown, Chelsea, East Boston and South Boston. The pipe trench was dredged and the pipe placed by divers. Other communities faced with river crossings occasionally chose the above water approach. Some tried self supporting arches but not always successfully, as was the case in Nashua N.H. when a local man's design for the initial self-supporting crossing wound up on the bottom of the river (see below right for a successful example, an 84" pipe arch was built by Boston's MDC in its 1903 Weston Aqueduct crossing of the Sudbury River). A truss support bridge was also a common solution or the pipe was often added to the roadway bridge superstructure.

Subaqueous pipelines were also needed for coastal situations to serve islands or portions of the community on the far side of the bay, such as Portland's connections to South Portland and its harbor islands. Many other coastal communities had to develop such mains.

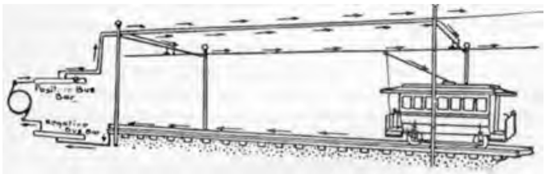
1903 Weston Aqueduct 84" steel self-supporting pipe bridge

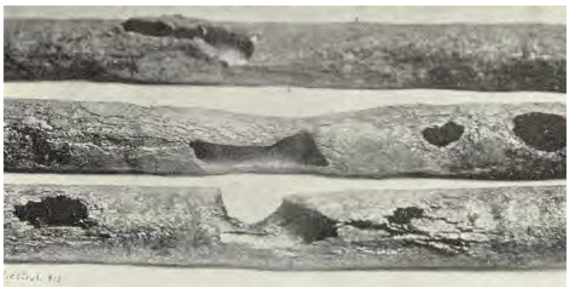
Trolleys came on the scene in the late 1800's bringing a new threat to metal pipes: electrolysis. The direct currents used to power the trolleys became pipe killers, causing extensive pipe pitting to the point of causing holes in inch thick cast iron in a matter of months. This led to new pipe design standards for insulation joints.

In a fairly recent development, pipe bursting and slip lining have become more popular as rehabilitation techniques for old pipes.

Service Pipes

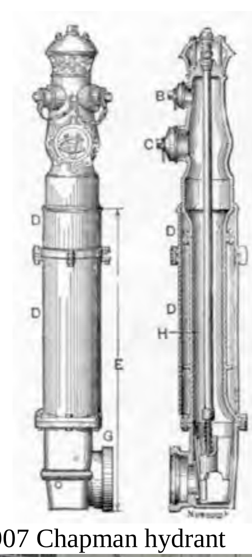
Small pipes sometimes create big problems. As with street mains, experience has taught some hard lessons in the history in making the last connection to the user's tap.



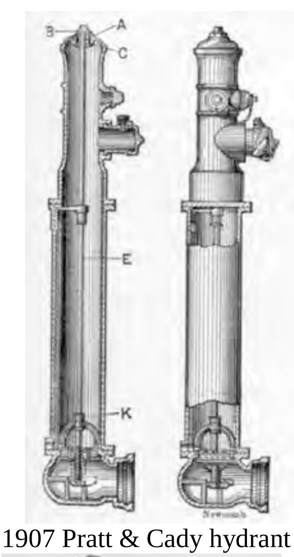


From the beginning of trolleys in the late 1800's, the DC currents associated with the trolley motors would jump off onto pipe surfaces and cause erosion of pipe material. Pipes less than 10 years old needed to be replaced in key locations.

Wood obviously was never going to work as a service line material leaving lead as the most practical early solution. Even the Romans had relied on lead for services some 1,800 years before. The health issues with lead were reasonably well understood but, in the absence of hard science to the contrary, there was a long held belief by many water supply and even public health officials that the internal corrosion layer blocked dissolution of the pipe metal effectively enough to not be a problem. This lasted well into the 1900's and may have been partly a rationalization to defend the use of lead since it was clearly the best material in terms of workability and durability. Even as it was being accepted as a standard by many, empirical evidence of the effects of lead exposure caused many water suppliers to try aggressively to find workable alternatives to lead for services.

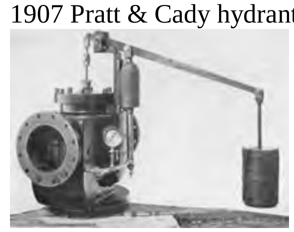


1907 Chapman hydrant



1907 Pratt & Cady hydrant

1936 Dresser coupling



1906 Counterweighted pressure regulating valve

In the late 1800's, wrought iron was tried with the result that internal corrosion in the small diameter service pipes choked off the pipe within a matter of a few years of use. Alternatives were sought, such as dipping in coal tar, coating with zinc or other less reactive metals, and so on. But, even with all these efforts, the best case was extending the useful life of the pipe by a matter of years. Hartford claims the first use of galvanized iron for its services in 1855. Wrought iron also presented a workability issue for use as a house connection so many plumbers used a lead transition piece at the house wall to take up any stress from differential settlement. The use of brass pipe was tried with more or less the same conclusion; the joints were weakened by corrosion and breaks were common. The poor service life of other materials meant a commitment to frequent replacement or a return to the use of lead, with many water systems choosing the latter.

Lead was still heavily used up until it was banned in 1986. By this time, copper pipe had become the preferred solution. Thin wall copper tubing became available in the 1930's and worked well for connecting the service into the house. Within the house, copper tubing soldered with lead was still used up until lead solder was also banned in 1986. As lead testing results so often show, poorly soldered copper pipe can produce problematic lead levels in standing water as well. Nowadays, brass faucets are still a source of lead dissolution to the tap. The use of lead-free solders and plastic service pipes have ameliorated the risk of lead in the water but lead control is far from solved (more on this in the treatment chapter).

History of Pumps and Motors

New England started with only wind and water for its natural energy sources. If pumping was needed, these were the early options but, of course, gravity supply was always the preferred power source for the early water system.

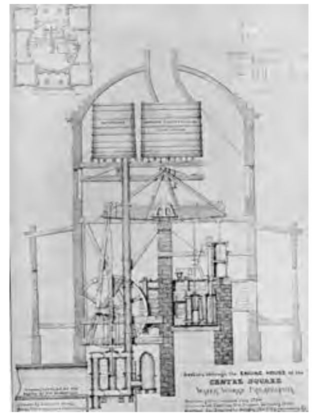
The first pumped municipal water supply in the colonies was in 1755 and was built by a Moravian sect in Bethlehem PA. It featured waterwheel powered pumps to lift water to a 70' tower for distribution to users. The 5" pumps were made of lignum vitae wood and were positive displacement type similar to early hand fire pumps.

Steam engines for water pumping became possible in the early 1700's. Thomas Savery is generally credited with developing the first steam engine in 1698 for mine dewatering. This was followed by Thomas Newcomen's engine in 1712 and James Watt's rotary crank engine in 1769, each step being a huge improvement in practical application or fuel efficiency. Given the wide variety of ways to make steam and use it for force, patenting did not limit the further development of steam engines. The complexity and precision machining necessary to make a successful engine kept the idea from being widely available until well into the 1800's.

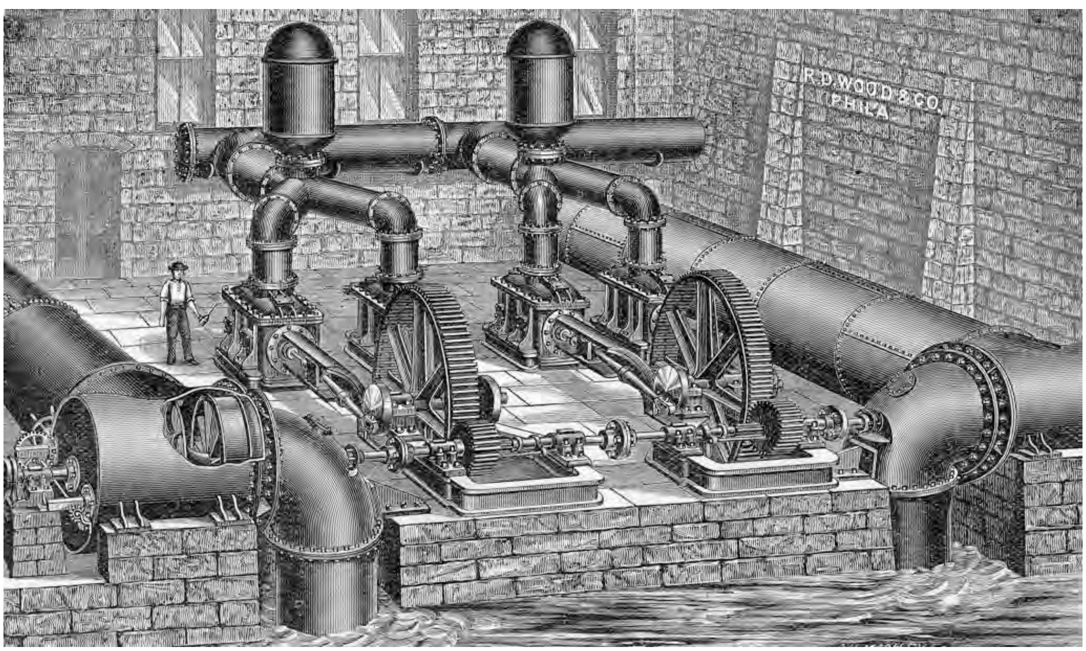
New York actually had the first attempt at steam pumping by an entrepeneur/civil engineer, Cristopher Colles, who was contracted in 1744 to build a steam engine to pump from a well to an above ground tank. After some aborted attempts, the engine was built and appeared to function during trials, at least long enough for the designer to claim his payment. However, the Revolutionary War broke out at that point and the actual use of the engine for water supply never happened.

The first successful use of steam pumping for a municipal system was in Philadelphia in 1815 when Benjamin Latrobe (the noted civil engineer, not the brewer) designed steam pumps to deliver Schuylkill River water to a tank for distribution to a wood and cast iron pipe system. This pump was moderately successful and established a national reputation for the Philadelphia water supply as the finest of its era.

Philadelphia's 1815 Centre Square pump station, the first municipal water supply steam pump in the US



Interestingly, the expense and mechanical problems of the pump (not to mention a fatal boiler explosion) eventually discouraged the city and in 1822, they rebuilt the Schuylkill supply source to be powered by hydraulic pumps.



1885 Hydraulic pumps at Willimantic CT

This same hydraulic pumping approach was successfully used by a number of New England communities such as Nashua NH in 1854, New Haven CT in 1860, Bangor ME in 1875, and Manchester NH in 1872. This required the supply to be on a river of sufficient flow to power the turbines that would then drive the positive displacement pistons to move a portion of the water to a higher elevation.

Most used rotating flywheels to power a piston driven positive displacement pump. Some systems used pump chambers and special valving that would allow water to be pumped on both strokes of the piston. A large surge arresting pressure vessel usually accompanied this pumping to smooth the transition between strokes.

An interesting variant on hydraulic pumping was the use of hydraulic ram pumps. In our time, hydraulic transients are avoided at all costs but these early pumps actually used the water hammer to lift the water. As shown in the accompanying figure, the fast acting valve would be closed to force a pressure build-up in the surge chamber which would then force some water up and out the smaller discharge pipe. This could pump as much as 1 gallon in ten that passed through the hydraulic ram but only to a modest height. These pumps have been around since the early 1800's and were used by some communities adjacent to rivers. They have been more suited to smaller applications like farming given the need for so much flow release, making them impractical for most municipal applications.

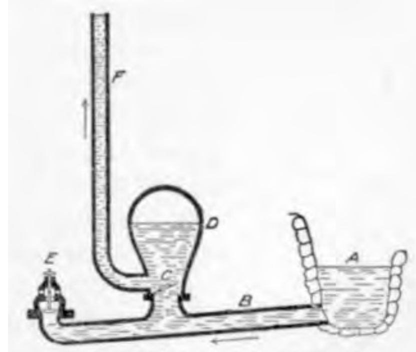


Fig. 64. Illustrating Principles of the Hydraulic Ram.

Hydraulic Ram pump – Valve E is rapidly closed to force water up pipe F

The ability to pump water without fuel was a wonderful thing but the limiting thing for these older supplies was the need for enough water to power the turbine or wheel. Droughts were problematic and growing demands often dictated that the turbine water was needed for supply purposes as well. Old hydraulic pumping stations are notable for their proximity to a dam or channel, their internal hydraulic machinery, and the absence of chimneys.

Unusual Pumping Energy Sources – A One Horse Power Pump?
After its start in 1852, the **Pennichuck Water Co**. which serves Nashua, NH used hydraulic pumping to move its water. This worked well until a combination of water use growth and drought meant that a supplemental solution was necessary. The answer? A horse was harnessed to the wheel to power the hydraulic pumps in slack flow times.

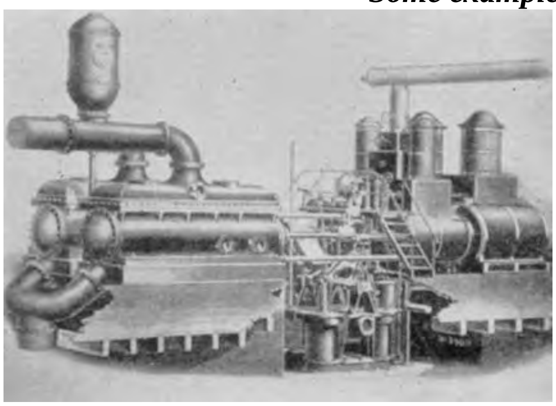
A touch of Yankee ingenuity was added later in the form of a motivational paddle (known as "French's Spanker" after its inventor). It would automatically slap the horse's rear every few revolutions to "urge old Dobbin to greater effort".

By the mid 1800's, practical windmill pumps had been developed for smaller applications like farming. Some New England communities, examples being Sanford ME, Winchester MA and Hyde Park VT, actually applied windmills for pumping to a remote high area. These were unusual and probably fairly unreliable, leading eventually to abandonment in favor of mechanical systems. Wind powered pumps did go on to be hugely successful in other parts of the country, especially for farming applications in the mid-west and plains states, where groundwater was the only water supply option. Daniel Halladay, a Connecticut man, is credited with the 1854 development of the most successful windmill design.

Human powered pumps for firefighting were available well before settlement of New England. These were simple positive displacement type pumps that could at least get a small stream of water up onto a roof. They would be fed from a bucket filled from wherever water was available, often a cistern or rain barrel. Later human powered fire pumpers featured a larger volume stream and better pressure by making the unit bigger, putting wheels on it and adding a rocking arm so both sides could be manned by several firemen. Boston purchased such a "fire engine" in 1654. When steam engines became available, they took the place of the human power. As soon as municipal water systems developed better pressure, all of these became obsolete and the pipe pressure could power a nozzle that could reach most buildings. The use of fire pumping engines to boost the hydrant pressure emerged again as gasoline and diesel engines allowed smaller, more powerful engines.

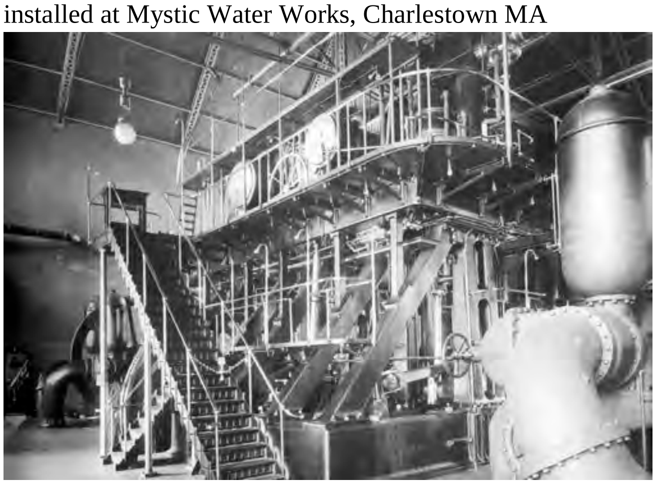
Steam pumps reached their peak in the latter half of the 1800's as a number of designers produced very effective but unique solutions. The principles were roughly the same but some designers began to use multiple expansion chambers and different mechanisms for transferring energy to the flywheel to move the displacement pistons. The engines were often named for their designers and occasionally had names in the same way as car models.

Some examples of early pumps and motors

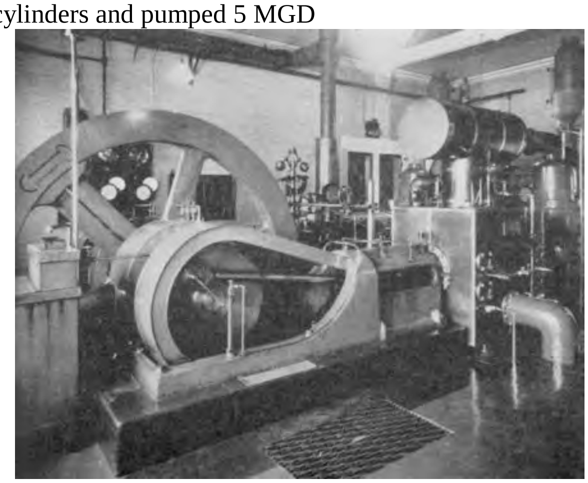


1864 First Worthington Duplex pump in the country installed at Mystic Water Works, Charlestown MA

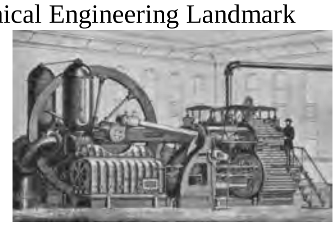
Corliss Spider – Installed in 1873 at Hope Pump Station, Providence RI, it had 5 steam cylinders, 5 pump cylinders and pumped 5 MGD



1894 Leavitt Engine at Boston MA's Chestnut Hill High Service Pump Station– Triple expansion engine, ASME designated it as a Mechanical Engineering Landmark



Later generation of active steam pumps – 1939 engine at Falmouth MA



Holly Quadraplex and Holly Compound – two of many steam models offered in the late 1800's

1920 Early electric pump motor, Putnam CT

1902 Early gasoline engine, Nantucket MA

The first municipal steam water pump in New England was built in Hartford CT in 1851. It took water from the Connecticut River and delivered it to an 8 MG reservoir on Asylum Hill. Designed by Wm. Wright and built by Woodruff & Beach, the steam station operated until 1865 when it became an emergency backup as Hartford brought in a new gravity supply. Cambridge MA and Plymouth MA followed suit in 1855, both using Worthington steam pumps in their stations. The old Mystic Water Works pumping station in Somerville MA had the first Worthington Duplex steam pump in the country installed in 1864. Providence RI began steam pumping in 1870 and became the largest pumped supply in New England by the 1882 start of NEWWA.

At the formation of NEWWA in 1882, the New England leaders of steam pump design were men like Erasmus Leavitt of Massachusetts, George Corliss of Rhode Island and Henry Worthington of New York. Corliss' finest achievement was felt to be the Corliss Spider, installed at Providence's Hope Pumping Station. He had many models and had equipment installed through much of southern New England. Henry Worthington, a designer and fabricator, had probably the most steam engines installed throughout the country in 1882, with 62 of the 182 known steam pumps in New England using Worthington equipment. Erasmus Leavitt was more of a designer, leaving the building of his pumps to contractors. He was known more for larger installations and he designed engines for Boston's Chestnut Hill Pumping Station and several other communities like Cambridge, New Bedford and Lynn MA. The Leavitt Engine at Chestnut Hill Pump Station was designated as an American Mechanical Engineering Landmark. It stands an impressive 2 stories above the operating floor and the flywheels and pistons occupy about the same space in the lower pipe gallery. It took a gang of operators to control the engine while crews of shovelers fed the boiler its ration of the 660 pounds of coal needed per hour to move the 20 mgd. A railroad siding was needed in the back to deliver coal by the train car load.

By 1882, of the 258 works in New England, 130 were supplied by gravity, 50 pumped to an open reservoir, 21 pumped to a tank, 31 used standpipes and 21 pumped directly to service with no storage. This last category required the operators to monitor discharge pressure and constantly throttle the engine.

Steam pumping stations began to pop up in many communities after the 1880's, recognizable by their chimneys and coal rooms. NEWWA began to keep statistics on "duty", the forerunner of modern "wire to water" efficiency, in which the amount of coal needed to do standard units of work was calculated and engines could be compared, often to the great pride of some designers.

The steam age peaked in the late 1800's with most observers noting that the triple expansion engines were the pinnacle of steam powered pumping technology.

Some examples of early pump station architecture


Hope Pump Station, Providence RI


Quitticas Pump Station, New Bedford MA, AWWA Historical Landmark


Branch Street Pump Station, Pawtucket RI, AWWA Historical Landmark


Snow Pump Station, Nashua NH, AWWA Historical Landmark


Manchester NH Low Service Pump Station, AWWA Historical Landmark


Great Sandy Pond Pump Station, Pembroke MA, AWWA Historical Landmark


Stoughton Pump Station, MA


Burlington Pump Station, VT, AWWA Historical Landmark


Chestnut Hill High Service Pump Station, Boston MA


Pawtucket Pump Station, Pawtucket RI


North Easton Pump Station, MA, AWWA Historical Landmark


Oak Bluffs Pump Station, Martha's Vinyard MA

The need for a less complicated and labor intensive method brought the next advance, namely petroleum fuel engines. Up to this point, coal powered virtually everything in New England. In the 1890's, Rudolph Diesel invented his engine, which caught on in water pumping in the early 1900's. In the late 1800's, several inventors developed gasoline engines which were initially of more interest to car developers but which were used in some water works applications. In support of this, the oil industry was just becoming a viable alternative to coal and the refinement of oil to produce the necessary grades of diesel and gasoline made it a commercially available commodity.

This advance in liquid fueled motors allowed the next step to be taken by pump manufacturers. Up until this time, the use of centrifugal pumps was known but low RPM steam pumps required extensive gearing to get the RPMs up to the levels necessary to power a centrifugal pump. Diesel and gasoline motors had the torque to spin a smaller pump shaft and had no problems developing the required RPMs. Many steam pumps were converted to the new power source by simply connecting the old positive displacement setup to the new engine via drive belts. However, in new facilities, centrifugal pumps began to dominate. The other advantage of fuel engines was that they could be throttled similar to the old steam engines so a variable output was possible but with much less labor than a coal fired steam pump.

One footnote to the early 1900's attempts to find better pumping power sources was the use of gas producer plants for pump stations. Up to this point, coal gas had been produced starting in the early 1800's at municipal plants and used for municipal gas lighting systems and industrial uses. Some water supplies tried this technology so that they could still use coal for fuel while powering more modern pumps. In 1908 and 1911 respectively, Hingham and Manchester MA installed gas producer plants and used the coal gas to power a motor that spun its centrifugal pumps. Apparently, such stations were plagued with a smell of gas in the plant and also in the surrounding neighborhood while running. Gas producers and gasoline motors eventually faded out of water supply use because diesel engines were more reliable and economical.

The last truly big step in pumping was the development of the electric motor. While the original idea is credited to Michael Faraday in the 1830's, the development of a practical water pumping motor took until the early 1900's. Obviously, the power developed in such a small footprint was an extraordinary advance. Cleanliness, convenience, controllability and reliability were additional benefits. This did not mean an immediate conversion for all water pumping since the extension of municipal electric power took some time, but, in each successive pump station rehabilitation, electrical pumping was usually the mainstay. Diesel power still had a major role in providing backup for electrical power failure so it continued to be heavily used if this was a main concern. Other types of pumps, e.g. turbines, were developed to handle particular situations but the core concept was still a water power from a spinning shaft of some sort.

Of course, the inconvenience of early electric motors was the single speed nature. This led to interesting decisions in sizing pump stations and much more focus on water storage tanks as a companion to the pumping station. Eventually, around the 1960's, the variable speed motor became commonly available and helped ease some situations that require tight water level control, but the pumping workhorse is still the electric powered pump.

History of Distribution Water Storage

The first distribution water storage was, of course, part of the first water works, that being the 1652 Boston "Conduit". The wooden pipes led to a below grade 12' by 12' chamber from which water buckets could be filled. This mimicked the Roman practice of having terminal reservoirs for their aqueducts. In Boston's later 1796 Jamaica Pond system, there was also a terminal chamber built on Fort Hill to allow for off peak flows to accumulate for later.

The first true municipal systems required distribution storage as a result of uncertainty of flow from the source. When Hartford CT built the first steam pump station, they also built an open earth embankment reservoir on Asylum Hill that could provide water for a matter of days while the pumps were down for repairs. Boston MA built its Brookline Reservoir as part of its 1848 Lake Cochituate supply to allow for daily adjustment of aqueduct flows.

The form of these early reservoirs was usually rectangular, formed by earthen dike walls that used the "puddle" method of construction to get an impervious core. Some had earthen bottoms and had to be relined with concrete at a later date. Covering the reservoir didn't seem to be necessary in the beginning, so virtually all early distribution reservoirs were open. This led to a realization around the turn of the century that such structures were beset by algae growths even in carefully filtered supplies. Much of the early discussion of such structures in the NEWWA journal focuses on this, particularly the findings of Mr. F. Forbes of Brookline MA, who was probably the first to not only study the problem but also correct his system with a cover. So it wasn't birds, regulations or the possibility of intentional contamination that drove many communities to cover their reservoirs, it was algae. Of course, not everyone did so right away, in fact, many larger systems still had uncovered distribution storage well after the Safe Drinking Water Act was passed and states began to regulate open storage out of existence. Of course, this is easier said than done, with cities like New York and Portland OR still utilizing open distribution reservoirs to this day.

Entrance to Boston's Chestnut Hill Reservoir grounds, landscaping designed by F. Olmsted, notable as an example of the ornate style of many early water facilities

Covering the open reservoirs in the early days usually meant columns, a concrete deck and an earthen grassed surface dotted with vents and hatches. In the 1970's, fabric covers became available and became a viable alternative to structural covers. Either way, many systems continue to rely heavily on these larger volume storage reservoirs and have continued to upgrade them to meet today's more rigorous security requirements.

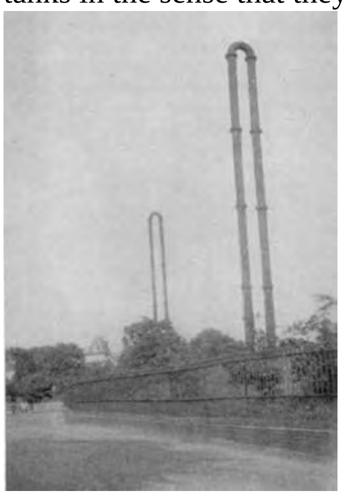

1896 Construction


1927 Relining bottom with gunite


Modern day covered reservoir

The life of an early distribution reservoir: Payson Park, Cambridge MA– Early puddled earth construction lead to concerns over leakage, the bottom is relined, then later columns and a deck are added to cover the water surface.

The original purpose of a standpipe was strictly as a pressure control device. Its English origins intended it to be a vertical pipe that allowed overflow during surges. In 1800's New England, the term standpipe originally referred to fairly narrow tanks that were built close to the pump stations allowing pressure relief as well as water level readings for pump control. These were tanks in the sense that they were above ground, held water, provided fire flows while the pumps were ramping up and generally allowed the pumping to react to demand changes. Notable local examples include Cambridge MA's iron standpipe (now demolished) associated with its 1855 Fresh Pond supply. Cambridge had built an open reservoir at a hilltop location, but also added this standpipe adjacent to the reservoir to supply high areas and act as a pressure relief. The structure had a 5' riveted boiler iron structure surrounded by a granite, brick and wood structure with an internal spiral staircase to a landing on top.


English Standpipe for pressure relief

In 1870, Boston built its Fort Hill tank, which also had a 5' riveted boiler iron tank structure but, in this case was enclosed in a brick structure decorated with an ornate superstructure. This tank served the vicinity of Beacon Hill and the Statehouse for about 15 years before being replaced by another reservoir. In 1872, Fall River also built a standpipe structure housing two 40" pipes in a granite block structure that has the appearance of a lighthouse. In each case, the standpipes served the original steam pump station well but were eventually replaced by other larger, higher storage tanks. Tank placement strategy went on to dictate locations more distant in the distribution system since it wasn't necessary to keep the standpipe close for control purposes. The term "standpipe" went on however to refer to any tank having a uniform diameter from the ground up.

Above ground tanks went on to include elevated tanks (the tank volume being up on legs) and those with non-uniform diameters.

In the world of storage tanks, the earliest material in the late 1800's was iron boiler plate. Plates were rolled to the proper curvature and riveted together on all sides. Roofs were optional for many older tanks. Of course, absence of a roof led to weakness against wind stress leading to an occasional failure. The other major concern of many utilities was freezing of these early tanks which, in a riveted tank, could be hard on the rivet heads as the ice layer rides up and down.

Many utilities chose to enclose their early metal tanks for this reason. An ornamental facade also helped with neighborhood complaints and a viewing platform at the top usually afforded a commanding view of the city for public occasions. Some prime examples of such enclosed tanks are found among the AWWA Historic Landmarks including the Bangor ME Standpipe, the Lawrence MA Tower and the Lawson Tower in Scituate MA. Both the Lawson Tower and the Lawrence Tower were even equipped with bells to allow an occasional concert.


1870 Fort Hill Standpipe, Roxbury MA


1902 Forbes Hill Standpipe, Quincy MA


1897 Thomas Hill Standpipe, Bangor ME, AWWA Hist.Landmark


1855 Cambridge MA standpipe, 1st in NE, demolished in late 1800's


1895 Lawrence Tower, MA, AWWA Historical Landmark


1884 Fall River MA Standpipe, contains two 42" riser pipes


1901 Lawson Tower, Scituate MA, AWWA Historical Landmark


1921 Park Circle Standpipe, Arlington MA


1905 East Providence RI Cast iron tank

After this early period of architecturally interesting structures, tanks became much more utilitarian. When steel became available in the early 1900's, it was riveted in place similar to the old iron plate. Once field welding was possible in the 1930's, the plates were welded to make the smoother looking tank structure that is ubiquitous around New England.

Elevated steel tanks evolved somewhat in shape over the years. Early iron plate tanks features a hemispherical bottom, plate sides and a conical top, occasionally with some ornamentation. As steel tanks came into vogue, the shape flattened a bit in a progression shown in the adjacent figure. Ellipsoids became fashionable in the 1960's. The spheroid tank was developed in the 1930's and became an interesting alternative to the multi-legged versions. Most recently, the pillar shape with either a steel or reinforced concrete base became popular.

The down side of any metal tank, of course, is the need to recoat the tank at regular intervals as protection against corrosion. The glass coated steel tank is an interesting variant that was developed in the past 15 years to avoid this recoating. The sections are shop coated and the rings are bolted to the desired height. This type of tank has become popular in parts of New England.

1881 Oldest steel standpipe, Dedham MA (now demolished)

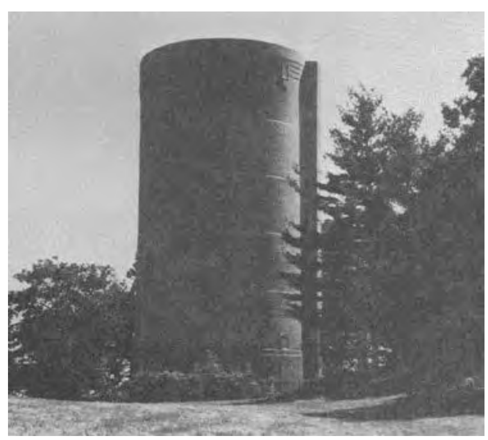
1938 Brookline MA – First spheroid tank in New England, it was chosen to protect against wind damage

The use of concrete for tanks began in 1903 when the first reinforced concrete tank was built for Hull MA. The structure, named for its location in Fort Revere, has been designated an AWWA Historic Landmark and was constructed using forms and reinforcing steel set in 8" lifts until the desired height was reached. It was also enclosed in a brick and concrete structure with a public landing that overlooks Boston Harbor. Other reinforced concrete tanks were built in the early 1900's using similar techniques but the lifespan of these tanks was short. It was difficult to get these early tanks watertight since the water pressure on the structure pushed outward and caused

1963 Stamford CT standpipe featuring pillars

1961 Bellevue Tank, West Roxbury MA featuring ribs for the access ladders

1903 Fort Revere Water Tower, Hull MA, was the first reinforced concrete standpipe in the US, AWWA Historical Landmark



1936 First prestressed concrete tank in NE, New Britain CT, the tank was prestressed by the cable and turnbuckle method cracks, then the resulting spalling of exterior tank walls kept exposing reinforcing and requiring repairs. In the 1930's, the first prestressed concrete tanks were developed. New Britain CT was the site of the earliest prestressed design tank in 1936. In this case, the prestressing was done using cables and turnbuckles that were added after casting the walls in place. The down side of this was that the stresses weren't uniform around the whole tank circumference. While this was better than the earlier designs, it was still lacking. The issue was resolved in the 1960's with the prestressing wire winding techniques that mimicked PCCP manufacturing. In this case, panels could be cast with a watertight layer, then effectively joined in position by using a wire tensioning system that wound continuously around the entire tank circumference. Tank roofs were occasionally domes cast of thin lightweight concrete or, in larger diameters, columns and a cast flat roof were used.

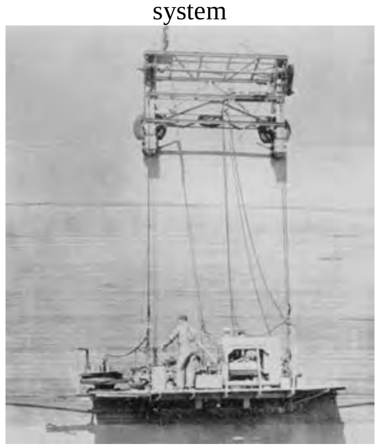

1906 Casting in place in lifts of several feet


1906 Attleboro Standpipe completed


1942 cable winding


1942 turnbuckle prestressing system


1959 Precast wall sections with integral waterproof core


1959 Continuous wire wrapping for uniform stress, gunite coating

These modern prestressed reinforced concrete tanks have been the preferred solution to larger diameter tank construction since the latter part of the 1900's.

Protecting water quality in the distribution system

One topic that started early and continues to this day was the control of cross connections. NEWWA spent considerable time examining the issue of cross connections even in the early days. It was not uncommon to have industrial facilities that had fire protection from non-potable sources or other hazards connected to their plumbing.

There have been numerous cross connection incidents over the years in New England, the most famous of which was in 1969 when 83 members of a local college football team were stricken by infectious hepatitis by drinking water contaminated by a back-siphonage incident involving the irrigation system of its newly fertilized playing field.

Nationally, there have been hundreds of significant cases that have caused illness and even death. Backsiphonage from irrigation systems is a recurring theme and the resulting risk has gone from the usual biological threats to exposure to herbicides and pesticides. Numerous incidents have been found to have exposed customers to such chemicals as Chlordane, DDT, Malathion, Sevin, Diazanon, Heptachlor, Paraquat, and 2,4-D, all associated with irrigation works in an area that was being treated with these substances.

Another fairly frequent offender is a cross-connection with cooling or HVAC systems. Conditioning chemicals like hexavalent chromium have been blamed in many incidents. One of the more ironic events of this type was in 1974 when a chromium compound from chiller water in the air conditioning system was accidentally released through a cross-connection in Boston's Hynes Auditorium which, at the time, was hosting the AWWA conference.

Other more oddball cross-connections recorded in national experience have managed to introduce gasoline, hydraulic oil, propane from tank purging, and caustic soda from an industry (causing customer burns). Odder still was a cross connection with a compressed air system in 1989 that caused 2 dozen toilets and urinals in a Seattle WA courthouse to "explode" when they were flushed. In a 1980 incident in Texas, the municipal water turned blue when a commode tank being flushed reversed flow during a main break.

Who says all backflows are bad?
In 1970, an Ohio wine producer had a backflow when an open valve resulted in a backflow of sparkling Burgundy wine into the city's water main. There was no evidence of consumer complaints.

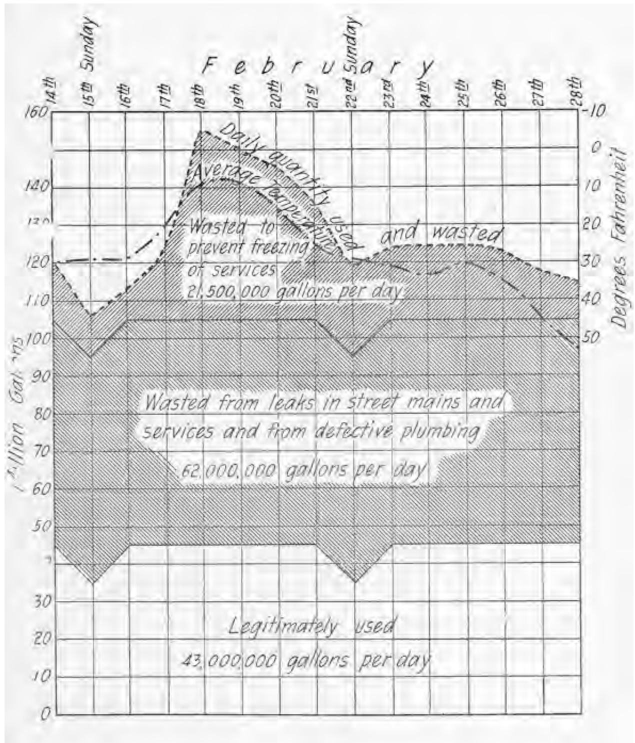
In 2006, a Norwegian pub cross connected its beer tap to its water supply line, sending product to an upstairs apartment. The complaint in this case was that the beer was flat.

The lesson continues to be learned. NEWWA created a committee to adopt standards in 1928. The work of this committee helped with the development of backflow prevention programs within the industry.

The control of red water in the distribution system has also been a long term topic. Sediment accumulation from iron corrosion products, algae or other detritus has always plagued distribution systems, particularly during hydraulic events like breaks and fires. In recent years, more proactive programs like directional flushing have been popularized to help minimize this problem.

Distribution System Waste

One of the earliest and most frequent distribution system topics of the NEWWA Journal was waste. Dexter Brackett of Boston published the earliest and most definitive paper on the subject in 1886. He described the causes and response strategies for all to follow and, to be sure, they did. Today's most effective leak detection and unaccounted for water reduction strategies generally follow his principles. These included the application of metering to identify wasteful users, night flow determination, district measurement to identify high leakage areas, listening for leak sounds at night when it is quiet, and other strategies.



From Dexter Brackett's 1886 Paper on Water Waste; Note the relative amounts of leakage and intentional waste

Top - Late 1800's Deacon Waste meter
Bottom - 1906 Cole pitometer

Prior to universal metering, early estimates of waste were up to 50% of that supplied from the source. This may be partly attributable to the experience with early wood pipe systems that were so unreliable that customers often left the tap on so they wouldn't miss the water while it was available between shutdowns. In the late 1800's, meters were available but were costly. At the 1882 start of NEWWA, there were already many meter manufacturers (the first associate member of the organization was a meter manufacturer). An 1886 survey showed a grand total of 37,913 meters serving 1.7 million people in 286 communities, not a high number. Barrington RI was noted as the only community to have 100% metering but then they only had 30 taps. Woonsocket RI had 88% of its taps metered and Worcester MA had 84% of its 8110 taps metered. Once metering was universally installed, there was an obvious and dramatic reduction in usage.

In the absence of metering, there was no incentive to turn off the tap short of being threatened by water department staff. Water suppliers assigned staff to identify running services by listening at night for just this reason. District measurement was done by using temporary meters. The earliest of these was a Deacon meter, an English invention, which had to be mounted so that pipe flow was physically directed through it. Later in 1903, the Cole pitometer rod was developed to simplify this task by inserting the measuring device into the pipe through a tap. A photo recorder powered by an oil lamp was added in 1908 to provide a means of recording overnight flows. Tracking of unaccounted-for water has remained a significant control measure for determining when to trigger leak surveys.

Leak detection techniques have progressed since NEWWA started. In the early days, field staff would hold a screwdriver to their ear and touch a valve or hydrant to get sound. The use of geophones came in the early 1900's and allowed better detection due to the sensitivity of the resonance chambers. The stereo sensor arrangement allowed the leak detector to get a sense of direction as to which way the leak was located. Geophones gave way to electronic sensors in the 1970s and to leak correlators in the 1980s. Now some water systems are deploying permanent leak sensors with a data collection system that automatically reports developing leakage.

Infrastructure issues at the current time

The looming crisis for many New England water suppliers is the advancing age of facilities.


1912 pipe relocation for Boston subway, the original "Big Dig" for Boston

Since most community systems have now been in existence for well over a hundred years, the original assets like pipes, tanks and dams are now aged beyond reasonable life expectancy and are often in need of renewal or rehabilitation. Many systems have already developed capital expenditure strategies as certain types of pipe required early replacement or hydraulic capacity needed to be restored in pipes choked by internal corrosion. Systemic problems like tuberculation of cast iron pipes or aging equipment have created a significant capital need for the industry as a whole. Many systems with limited resources will have a very difficult time catching up with deferred capital system renewal.