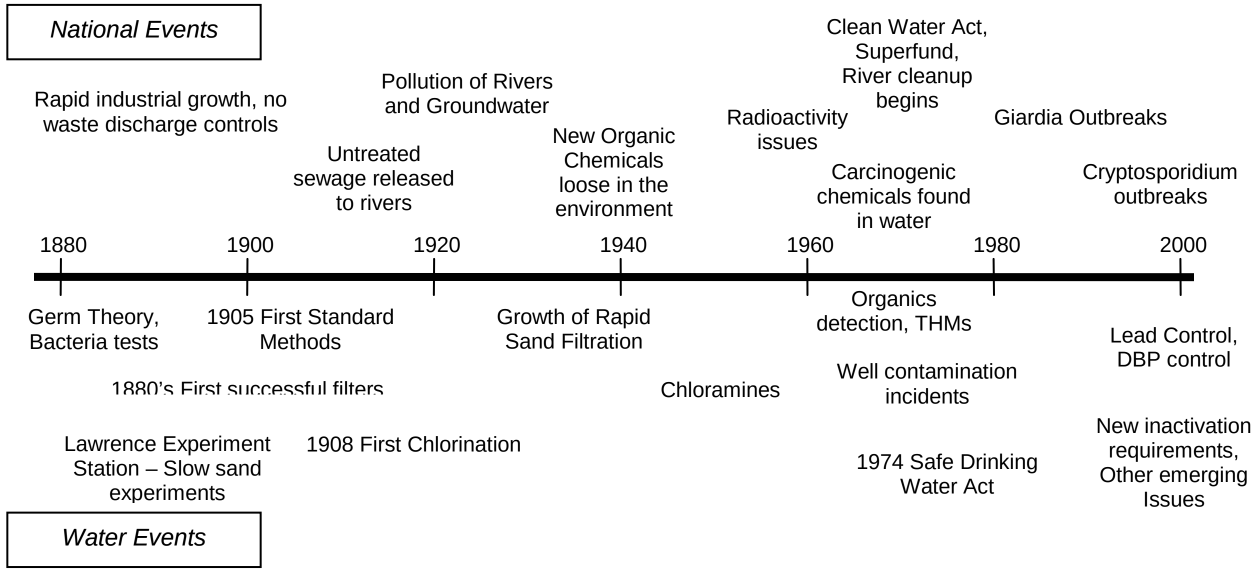
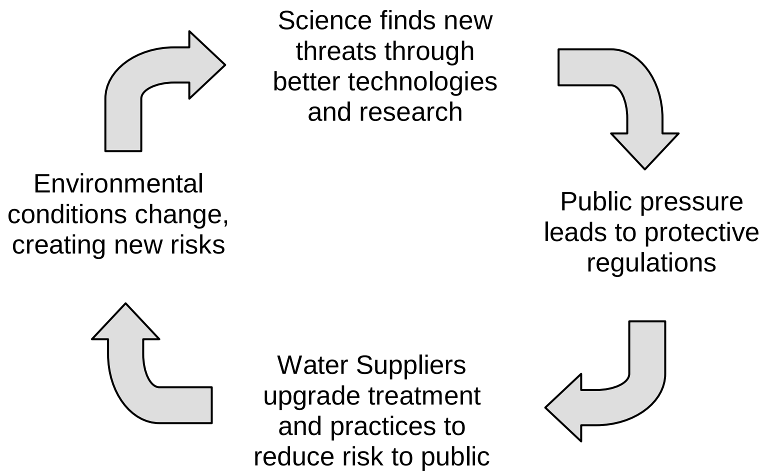
Chapter 3 – Public Health and Water Quality, Water Treatment

Timeline – Public Health, Water Quality, Water Treatment



Much of what we know to be true about water quality and treatment was probably only truly understood in the past century, often only in our own lifetime. This is a bit troubling, considering that sources of pollution are as old as the communities we live in but it is the nature of science and engineering to learn from experience. From the beginning of water supply, we continue to struggle with a cycle in which understanding of health issues is slowly gained as the underlying science is revealed, followed by problem solving and resulting water treatment improvements. The following illustrates the factors in this cycle:



This chapter reviews the emerging threats, the factors that affected treatment strategies and the water supplier's response through NEWWA's history to date. The key periods of interest are discussed in the following:

Late 1800's to 1900 – Post NEWWA boom, solving waterborne disease problems

Public Health/Drinking Water Issues –
The end of the 1800's was still notable for its widespread epidemics. The earlier part of the century had episodes of Asiatic cholera as the disease swept around the world in cycles. Locally, typhoid was omnipresent and flared up in epidemics wherever improper sanitation allowed it to do so. Mortality from bacterial and viral epidemics was so prevalent that life expectancy was still under 50 years on average and lower still among the urban poor. Around the time of NEWWA formation, the Germ Theory of disease became more widely accepted as a potential explanation to many diseases, replacing the miasma theory (foul vapors) and other quasi-religious theories of disease being a form of retribution for sinful ways.

The drinking cup – a common practice in public fountains of the late 1800's and the source of much waterborne disease transmission

1914 Public Fountain

The idea of microscopic germs carrying disease came from Europe, primarily Germany and France, where the foremost scientists were just arriving at their discoveries. Louis Pasteur had been studying microbes since the 1860's and had categorized many functional aspects such as aerobes versus anaerobes but had not yet isolated a disease-causing agent. Pasteur went on to develop many immunization and bactericidal techniques that helped the health community improve early care immeasurably. In 1876, Robert Koch, a German, was recognized as the being the first scientist to isolate a bacterial disease causing agent, in this case, *Bacillus Anthracis*, known commonly as Anthrax. He also went on to isolate *Tuburcule Bacillus*, the cause of tuberculosis, and *Typhus Bacillus*, the cause of most waterborne illnesses at the time. More importantly, his isolation methodology became a widespread success for bacteria testing and his postulates for the process of proving a microbe to be the cause of a disease became the gold standard in the field.

Identification of probably the single most important bacteria for water supply came in 1885 when T. Escherich identified the Bacterium coli, showing it to be responsible for diarrhea and gastroenteritis. Eventually, his name was associated with that nemesis of water suppliers everywhere, the *Escherichia coli*.

Of course, like many other advances in science, there were still many skeptics in this period, including many highly regarded individuals. One such was Max Von Pettenkofer, a respected German man of medicine who felt so strongly that the Germ Theory was just so much humbug that he conducted a public experiment by drinking a vial of live typhoid that was sent to him by Koch. He was fortunate to survive but a couple of his students that joined him in his experiment did get sick. When the City of Hamburg conclusively demonstrated the effectiveness of filtration as a barrier and confirmed that the typhoid bacillus was the cause of an outbreak of disease, Mr. Von Pettenkofer became a reviled figure in his community for having delayed water supply improvement.

Detection Technology

In the 1880's, scientists moved from culturing bacteria in liquid media to agar in 1882 and culture dishes (courtesy of J.R. Petri) in 1887. This allowed easy collection of bacteria samples for enumeration and further microscopic evaluation from the face of the solid media. By 1900, most of the diseases caused by bacteria had been identified, with viral diseases still not being understood. This didn't mean that bacteria testing was, in any way, a routine thing, but the test was at least available as a diagnostic health tool by the end of this period. Many New England state Boards of Health began routinely conducting bacteria tests as a check at about this time.

Ellen Swallow Richards – A woman pioneer in water supply:
Born Ellen Swallow, she graduated MIT in 1873 with a degree in chemistry, marrying Prof. R. H. Richards in 1875. Among her achievements, she worked in the employ of the MA Board of Health with William Ripley Nichols and Thomas Drown, the foremost authorities on water supply chemistry. She oversaw the analysis of over 20,000 water samples and directed the preparation of the "Chlorine Map" of state waters, all while continuing to teach at MIT.

She never joined NEWWA but was a well known water supply figure of her day. She furthered opportunities for women in science and is recognized in a display at the Smithsonian's American History Museum.

Water pollution caused by chemicals was still poorly understood. Only a few water quality tests were available to help characterize waters. In 1867, Sir Edward Frankland had developed the albuminoid ammonia test as measure of pollution and it was adopted by some water supplies as a means to categorize source waters. Another early effort was the use of the so called "chlorine" test to categorize water quality in rivers. This was, in essence, really a chloride test but it was considered indicative of sources of pollution in some inland waters. MA Department of Public Health conducted an early survey of all statewide surface waters and published a "Chlorine Map" around 1890 in what can be considered a first sanitary survey of regional water quality conditions.

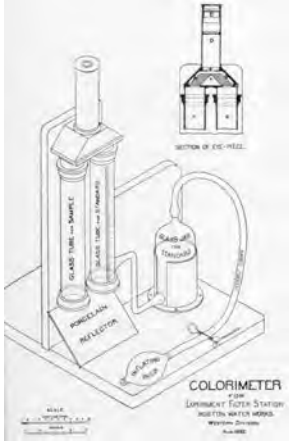
Other tests involved aesthetics like smell and taste. There was also measurement of particulates in water by paper filtering; a further test being to burn the filter and weighing the residue to check the organic portion versus the inorganic portion of the residue.

By the end of the period, turbidity, color, hardness, albuminoid nitrogen, free ammonia, nitrates, nitrites, chlorides, total plate count, and bacteria coli were commonly performed. Remember that you still needed a horse and buggy to collect the samples at this point.

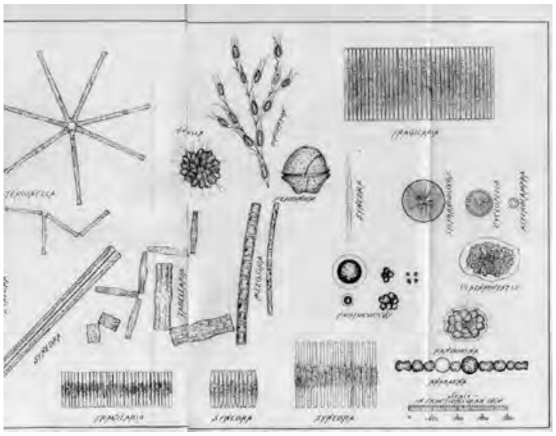

First water supply laboratory in US at Chestnut Hill offices, Boston MA

One notable achievement in this period is the emergence of the water supply laboratory. The first laboratory in the nation operated by a water supplier was created in 1889 by Boston Water at its Chestnut Hill facilities. This laboratory was run by George C. Whipple, an MIT trained biologist, under the direction of Desmond Fitzgerald, an equally important hydrology/water quality expert in early NEWWA. They published a wealth of data on algae and other microscopic analyses and continued to pioneer water quality analyses into the early 1900's when standards became available. Mr. Whipple went on to run the Brooklyn NY system and then joined Hazen, Whipple & Fuller, a significant early water supply consultant, all with ties to MIT and MA BOH. Another pioneering effort was the public health laboratory in Providence RI which was developed to assist statewide water supply analysis as well as clinical analysis of disease.

Regulations



1892 Colorimeter



1889 Algae chart developed by F. Forbes Brookline MA

There simply were no meaningful regulations in place on water suppliers at this time. Public Health Departments had assumed responsibility for inspection of health related problems, including waterborne disease. They strived to understand causes of disease in their communities but there was no easy way to quantify any immediate threats. If a water supply was suspected of contributing to waterborne illness, some sort of corrective action was recommended by the health authorities. This was more likely to be a matter of relocating a water intake or a problematic waste discharge than a change in water treatment.

Nationally, the 1893 Interstate Quarantine Act gave powers to the Surgeon General to make regulations to prevent communicable disease. This is notable since it laid the groundwork for the U.S. Public Health Service's initial attempts in the 1900's at establishing drinking water quality regulations, at least for interstate carriers.

Role of Public Health


Original Lawrence Experiment Station buildings

The single most important event in New England in the late 1800’s was the start up of the Lawrence Experiment Station on the banks of the Merrimack River in Lawrence, MA. Founded in 1887 by the MA Board of Health, the facility was intended to study water and sewerage treatment issues. In 1886, MA BOH’s committee on Water Supply and Sewerage selected its 1st chair to be Hiram Mills, former Chief Engineer of Essex Co., the mill near the Lawrence site. MA BOH also required monthly community testing by 1886 regulations. The facility developed a close link with Massachusetts Institute of Technology and employed many graduates in key roles. In the earliest days, William Sedgewick, the sanitarian/biologist, Thomas Drown, the chemist and Allen Hazen, the hydraulics engineer were the key players.

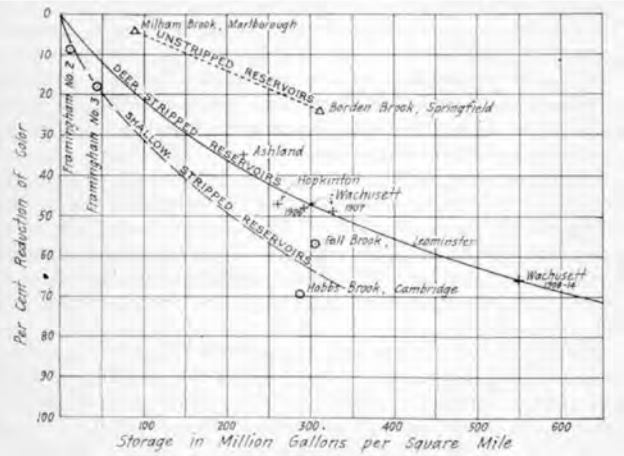
This was the first of 2 nationally important efforts that defined water treatment for the decades to come. Lawrence Experiment Station defined the proper methods of slow sand filtration, not to mention developing a variety of water quality testing and sewerage treatment methods. The Louisville experiments on rapid sand filtration in the 1900’s then built on that work to add rapid sand filtration experiments.

> **Quote from Allen Hazen:**
> *“For every typhoid death, someone should be hanged since it was preventable”*

Role of Water Treatment

With the understanding that bacteria were the cause of many problems, treatment began to take on much more importance in this period since there were certainly many water sources that were vulnerable to bacteria laden discharges.

Several important initiatives are worth noting in this period:

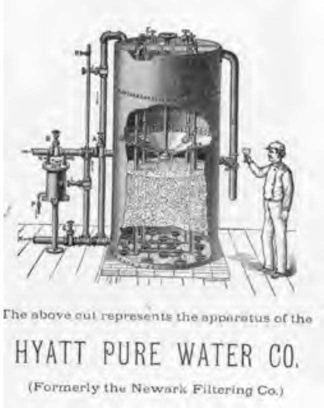


1916 – Color reduction through reservoir bottom preparation

1. Use of reservoirs to improve water quality – The empirical evidence that detention in a reservoir improves source water quality was an early finding, supported by research by key NEWWA members as larger reservoirs began to be built. The other empirical finding that influenced members was the need for surface preparation of the area to be flooded. It was observed that vegetation

and swampy areas tended to impart taste, odor and color for a lengthy period after construction.

2. Filtration – With disinfection still being unknown, the methodology for removal of unwanted contaminants was pretty much limited to filtration. A variety of methods were tried in this period, most notably in trying to use natural methods such as bank filtration or placing a manually cleaned filter bed over a collection gallery. There was little knowledge of the effectiveness of filter media or methods. Municipal size filtration plants were uncommon, with most communities attempting outdoor filters of some sort. Some communities with smaller flow requirements tried the smaller mechanical all-in-one devices.



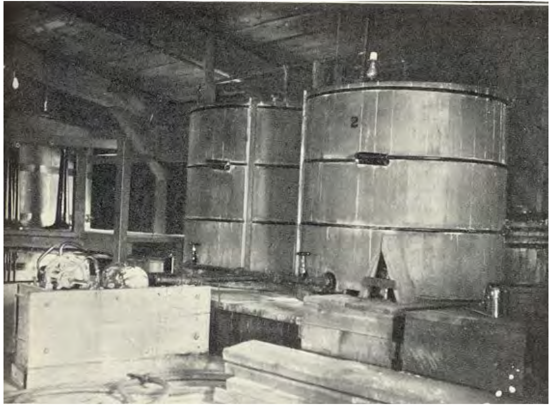
1887 Hyatt Filter

1887 National Filter

Early Continental Filter

Early Jewell Filter

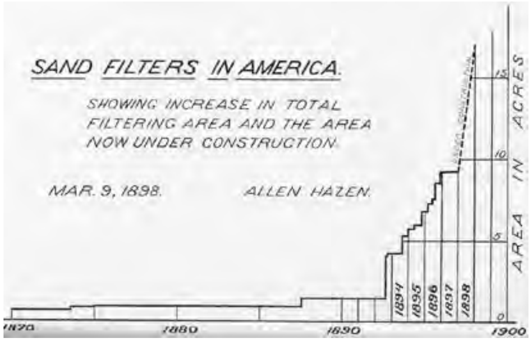
3. The patenting of filtration apparatus – In the late 1800's, inventions were coming fast and furious. Many entrepreneurs were looking to patent a process or a device to make their fortune, filtration being no exception. Many all-in-one devices were developed that featured some unique aspect to allow patenting. These devices usually looked like a large fully enclosed canister housing the filter media and under-drains and were named after their inventors or their companies. Some of these early devices are shown in the illustrations.



1900 Warren Filter

4. Slow sand filtration – This method had been around from earlier European experience but the newly understood need to remove or inactivate bacteria began new interest in adapting the slow sand filter to bacteria removal.

5. Removal of waste streams – Many communities tried to remove as much waste as possible from watersheds by directing waste streams away from intakes and, where the discharge could not be avoided, put open filtration beds to intercept and remove as much offending material as possible.



Trend in filtration up to 1898

1892 Covered filters

Lawrence Filters – Evolution over the years

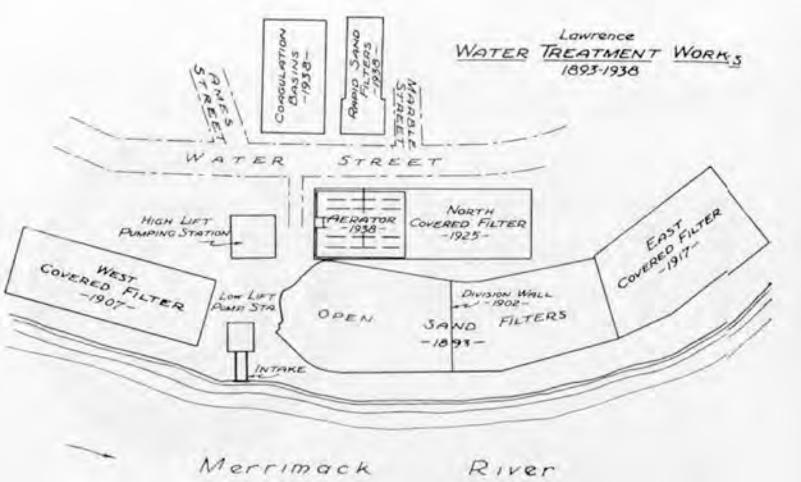
Original 1893 open slow sand filters

HISTORIC
LAWRENCE

FILTRATION
SYSTEM

Completed in 1893.
This was the first municipal filtration system for the elimination of bacteria established in the country.
In 1907 the original filter beds were enlarged and later reconstructed in 1916 to 1918.

1938 Rapid sand plant



Changes to Lawrence MA filter site through 1930's

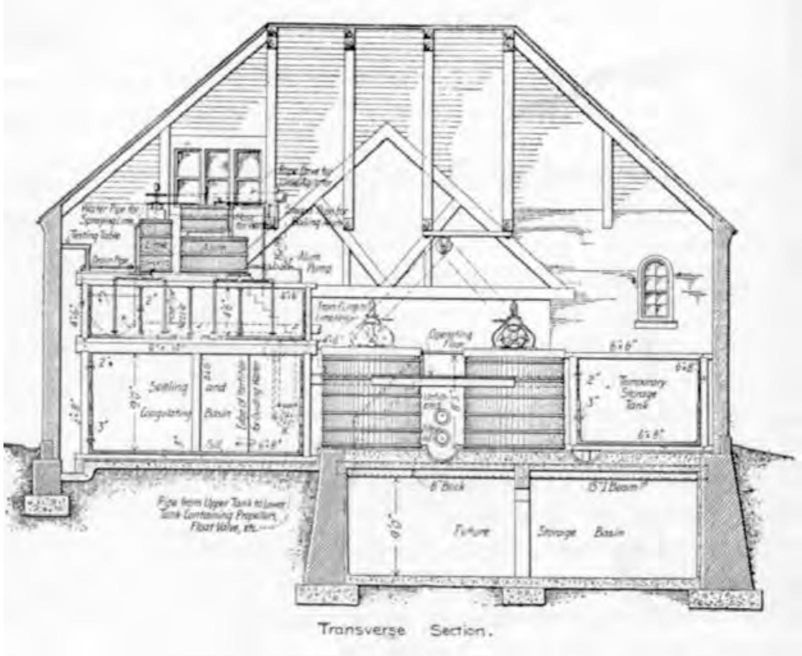
European water treatment experience was studied carefully by key NEWWA members. One important report was Kirkwood's 1869 report on European filters, its page's filled with carefully sketched plans and cross-sections and a wealth of detail on methods of cleaning and operation.

The late 1800's were the beginning of a period of fundamental research that developed effective filtration methods through empirical trials. The important local effort was the Lawrence Experiment Station's (LES) efforts at slow sand filtration. Filter sands and other media were studied, courtesy of Allen Hazen, fresh from his MIT graduation. His reports on effective sand particle sizes were invaluable to proper media designs that followed. The LES pilot testing developed effective flow and loading rates, necessary cleaning methods and all manner of practical guidance to optimize success. The Lawrence Experiment Station's laboratory continued to pioneer bacteria and other water quality testing methods to helped document filtration performance and, in the use of the heavily polluted Merrimack River, they certainly had an appropriate challenge. The end result was their claim that any New England water could be successfully treated, no matter the degree of pollution. Many New England supplies adopted the slow sand filter based on their success.

In 1898, the next major advance began when George W. Fuller, another MIT graduate who trained at Lawrence Experiment Station, began his benchmark work on rapid sand filters at Louisville, KY. He went beyond just the mechanical aspects of filtration to start looking at coagulants to optimize performance. This effort continued well into the 1900's and pretty much defined the principles of "conventional treatment" with coagulation, sedimentation and rapid sand filtration.

Aesthetics

Even with all the concerns over disease, aesthetics were still very much a focal point of the industry. Algae problems were widespread in older reservoirs that hadn't been properly prepared to the point that the customers would lose confidence and clamor for treatment. The use of algaecides was still not widespread.



1896 Reading MA iron removal plant

Presence of iron and manganese was also problematic where it occurred. Without oxidants, the only workable solution for afflicted supplies was to aerate as much as possible and then filter with normal sand and gravel filters.

1900 to 1930 – The beginnings of modern water treatment

This period marked the beginning of water treatment as we currently understand it, with water supply engineers finally beginning to gain ground on biological threats. Not only did disinfection emerge as the single most effective measure against disease causing organisms but rapid sand filtration also emerged as an effective and reliable municipal scale process.

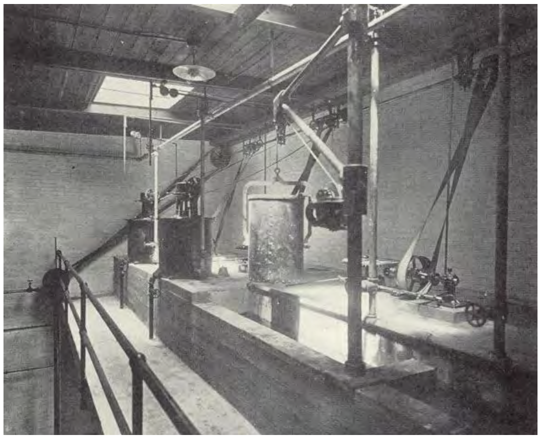
Public Health/Drinking Water Issues

Typhoid deaths per 100,000 population

State	1900	1910	1920	1930
Connecticut	32.0	14.7	4.1	1.0
Maine	28.2	20.3	9.0	3.6
Massachusetts	22.0	12.5	2.5	0.9
New Hampshire	22.1	10.7	6.8	1.9
Rhode Island	28.7	13.6	2.8	1.6
Vermont	33.8	14.0	10.5	1.9
United States	35.8	23.5	7.9	4.8

The epidemics that marked the 1800's were now understood – bacteria and sewage based pathogens were the cause and treatment was the solution. While there wasn't a complete agreement on the most effective form of treatment, disinfection was certainly felt to have promise. The power of chlorine as a disinfectant was demonstrated in experiments well before its first use in a municipal water supply in 1908 in New Jersey. Leading up to that point, there was some understanding that calcium hypochlorite had germicidal properties but the other breakthrough was experimentation with passing electricity through water, also documented to have had a germicidal effect. Lawrence Experiment Station did some early experiments on this before the1908 start of municipal chlorination and concluded that the electricity was really producing hypochlorite ion that was the real germicidal agent. After the experimentation, the electricity process was judged to be potentially useful but less important than other methods.

Around New England, acceptance of chlorination was widespread, especially by those supplies who were the most at risk, while the most vocal dissent was by Massachusetts Board of Health. They were still the biggest proponents of proper source selection, that being protected upland waters free from sewage introduction, and they felt that proper filtration still was the most effective barrier to biological agents. There was also some resistance to adding a chemical of any sort to the water supply, especially one that had some negative aesthetic qualities.



1910 Mixing tank for chloride of lime, first chlorination in New England, Newport RI

1910 Newport RI Water Treatment Plant

At any rate, New England began to practice chlorination well ahead of the rest of the country, with Newport RI being the first to do so in 1910. By the 1930's, most surface water supplies had implemented some form of chlorination and the waterborne disease rate had dropped to be virtually nonexistent. This is not to say that disease epidemics were no longer occurring, non-waterborne diseases like the Spanish Flu of 1918 and the early polio epidemics caused an enormous death toll throughout New England, but at least typhoid dropped off of the leading causes of death list by the end of the period. Many people acknowledge chlorination as one of the biggest health advances of all time.

Detection Technology

In one of the most important advances in water quality testing, the American Public Health Association and the American Water Works Association collaborated in 1905 to define testing methodology in a publication, the first edition of Standard Methods, which could be the agreed upon basis of proper water testing. An effort that was mainly prepared by New England men, this was a necessary precursor to developing water quality regulations since it leveled the playing field for smaller systems that didn't possess much lab expertise and it defined rigorous methods to assure consistent results. The APHA and AWWA also set in motion a process of review and updating that insured that improved methods were being properly peer reviewed and incorporated in subsequent editions. New editions followed in 1912, 1917, 1920, 1923, 1925, 1933 and so forth and featured input from such NEWWA luminaries as Gordon Fair, Abel Wolman and Malcolm Pirnie.

The idea of using coliform as an indicator organism dates back to this period. The coliform test was intended to indicate the presence of fecal contamination, setting in place the biological monitoring strategy that we have followed to this day.

This period also marked the beginning of an understanding of viruses as a cause of disease. After the 1900 discovery that yellow fever was caused by a virus, some of the more problematic diseases, like polio and other potentially waterborne agents, began to be better understood. Virus testing was still in the realm of health laboratories, not water labs.

Detection of chemicals was advancing as well, including tests for many metals such as lead testing in 1906.

Regulations

The first attempt at national regulation came in 1914 with the development of U.S. Public Health Service's Interstate Carrier Standards (a.k.a. the "Treasury" standards), applying only to water served by such carriers as trains with interstate service. No municipal systems were subject to these standards but they did constitute the first attempt to establish defensible maximum contaminant limits. These focused on biological contaminants with a 100/cc limit for total plate count and not more than 1 in 5 samples to have *B coli*. There were no physical or chemical values adopted. States were able to reference these standards for their own purposes as needed and many adopted them as guidelines.

In 1925 USPHS updated these standards to make 1 coliform per 100 ml the standard for post chlorinated water. This update also established standards for lead, copper, zinc, and excessive soluble mineral substances. This update represented the first introduction of the risk concept, i.e. defining the allowable exposure to contaminants based on health studies.

Role of Public Health

George W. Fuller's filter experiments at Louisville began to bring about change within the industry. No longer were the very limited patented systems being used but the prototypical rapid sand filter plant became the most widely used design. The use of coagulants and multi-media filter beds ensured excellent particulate removals followed by disinfection to complete the defense against biological threats.

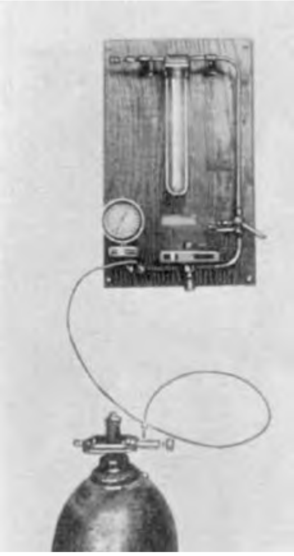
Of course, the world was not standing still and new contaminants were beginning to appear. In the 1920's, leaded gasoline becomes the standard, creating more free lead in the environment. Similarly, industries continued to develop more products involving organic chemicals such as dyes and solvents. Even radioactive materials were being introduced with a poor understanding of their fate in the environment, a famous example being the "radium girls" of the watch industry who were being sickened when they wet their brush points with their lips as they painted clock faces. As the industry was catching up to one threat, more would emerge.

Role of Water Treatment

With the large number of new sources being developed, water suppliers still did their homework and prepared reservoirs for optimum water quality performance, the need for which was made clear in the late 1800's. Watershed management was viewed as a complement to water quality performance with a trend toward avoiding deciduous trees and minimizing overland runoff.

Chlorination went through a cycle where initially most communities had to adopt cumbersome methods, then the chlorine industry stepped up to develop more reliable equipment. While chlorine gas was available in 1908, safe pressurized containers were not, so the first chlorination systems used chloride of lime or calcium hypochlorite as these were the only safe transport methods of the time. This required transporting granular chemicals and mixing them in solution tanks, then using early generation solution feeders, with many problems encountered in mixing and proper pacing. It was a difficult and labor intensive solution.

Wallace & Tiernan, the earliest New England practitioners of chlorine gas feeders, started in 1913, applying chlorine gas directly into the water stream until the 1922 development of the vacuum solution feeder. Chlorine gas compression became workable and common in the 1920's and this was a huge advance in


First Wallace & Tiernen chlorinator


1916 Wakefield MA gas chlorinator – 1st in Massachusetts

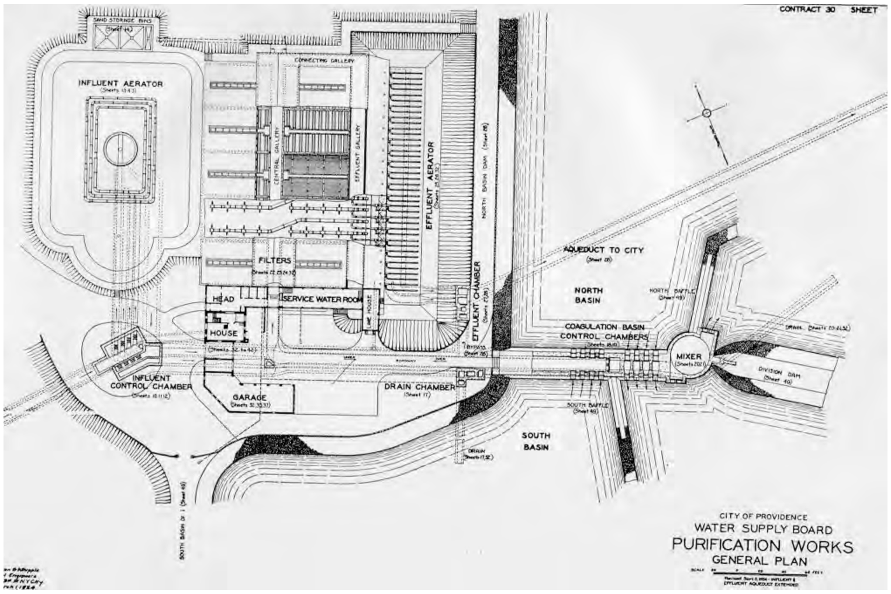
simplicity of delivery. The use of a pressurized gas container to provide the gas feed driving force removed the need for mechanical pumps and even allowed for some rudimentary flow pacing.

The science of chlorination took a bit longer to understand. In 1919, Holman and Enslow defined the concept of chlorine demand, which helped operators understand issues like reactions with other materials, which helped with proper dosing. The verification of residual was done manually by the ortho-tolidine-arsenite (OTA) test which was cumbersome for an operator to perform. Understanding of the relationship of hypochlorite ion formation to pH and breakpoint chlorination came well after this period.

The use of chlorine was also seen as bit of a panacea with the philosophy of “more is better” in play at times. “Double chlorination” became a way of improving source water tastes and odors. Superchlorination was often used to not just destroy tastes and odors, but also with the intent to destroy any and all pollutants in a sort of magic bullet approach. Dechlorination would by necessity have to follow the superchlorination. Obviously, detection of organics, such as disinfection by-products, was not possible at this point in time. Chlorine doses in the range of 10-20 mg/l were not uncommon and doses over 100 mg/l were recorded in some more heavily polluted supplies.

1918 Providence RI slow sand filter interior

1918 Providence RI slow sand filter interior



1926 New rapid sand Providence RI Water Treatment plant

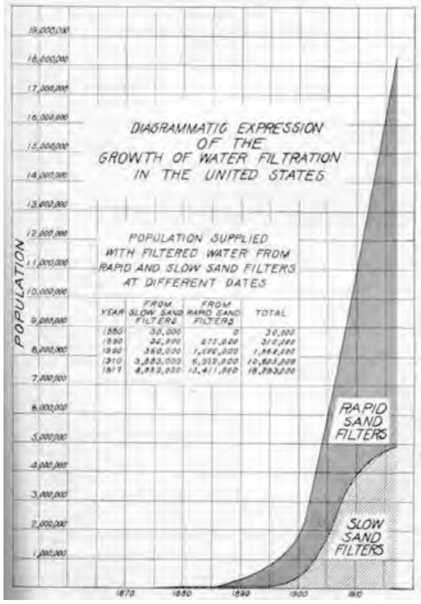
The first chloramination nationally was tried in Greenville, TN in 1926 for taste and odor control, followed shortly in Cleveland, OH in 1929. This was probably a reaction to more than just the free chlorine taste, quite likely it was also due to the presence of industrial pollutants, like phenols, that were producing reactions with chlorine to form unpalatable by-products.

“Conventional treatment” became understood to be coagulation, sedimentation, filtration and disinfection in this period. New filtration plants typically used rapid sand type designs while older slow sand plants saw no reason to change. Allen Hazen, the hydraulics expert, had developed the concept of surface loading rates in 1904 as a means of controlling the sedimentation process. He actually postulated the use of multiple trays but this didn’t get any further attention until much later in the century as most communities were satisfied with conventional contact basins and mechanical sludge collection equipment. The period also saw much work in developing proper coagulation controls as iron and then aluminum salts were tried and effective dosage rates were empirically developed.

In the area of filtration, more work had been done on different medias. The idea of multiple medias had been around since the 1800’s, with everything from sand to sponge being tried. Anthracite coal was discovered to be effective by accident at Harrisburg PA in about the 1920’s, which started its use in dual media given its favorable size to weight relationship to sand, allowing the coarser anthracite particles to be on top in the media bed.

The main focus of the 1920’s and 30’s was on improving filter performance, e.g. better backwash to solve media control issues. Underdrains were improved in the 1920s using tile blocks or better nozzles. The upward expansion of stratified filters was carefully managed to clear solids without loss or disturbance of media.

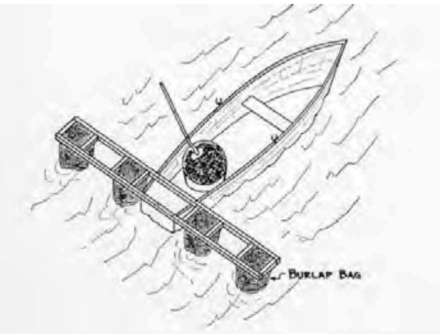
This period also had the first attempt at mass medication via the water supply. Well before fluoridation was ever considered, there were attempts to use water supply to correct iodine deficiency in areas where the absence of iodine in the natural environment was causing incidence of goiter, an endocrine system problem. Iodization was generally not necessary in New England but happened as close as Rochester NY in 1923. The practice was eventually discontinued when a substitute method was developed, i.e. iodization of table salt.



1917 review of filtration showing shift to rapid sand filters after 1900

Aesthetics -
Iron and manganese began to get more attention in the 1900’s as demand for cleaner laundry drove many to treatment for removal of the offending substance. Most often, chlorine use for disinfection was now precipitating the otherwise dissolved Fe/Mn so removal was made more necessary. Removal was done mainly by oxidation followed by lime coagulation/filtration. One other taste and odor tool first appeared in 1929 when powdered activated carbon first became available.

The emergence of copper sulfate as an algaecide was an important development. Its use began locally in Ludlow MA in 1904, once again demonstrating the idea that those in most dire need take the step to advance. The local source was notoriously plagued by nuisance algae and the public demanded a solution. After some experimentation, the application of copper sulfate by boat was declared a success. This brought about widespread interest throughout New England and adoption of copper sulfate as “the” algae solution, which it remains to this day. Application methods were frequently discussed with most developing some means of spreading from a specialized boat. Occasionally, alternatives like chlorine were tried during this period. Chlorine was viewed as such a powerful new tool that its use was tried in any aesthetic situation, even in the source reservoir. Fortunately, this didn’t catch on.



1930 copper sulfate boat

1924 Chlorine gas application to reservoir

1930 to 1970 – Reacting to the new pollutants

Following the post-war period, the general lack of attention to pollution in the environment was catching up to the entire country. Once again, industry was moving into new areas like plastics and pesticides and producing new organic threats. Locally in New England, paper mills, textile mills, metalworking plants and food industries continued to operate unchecked by pollution controls. Greater use of synthetic fertilizers was occurring in farms nationwide. Mercury was used extensively in the 1940’s to 1950’s, while the effects of bioaccumulation were not understood until the 1960’s. As key environmental events exposed vulnerabilities, the public health community was finding that the consequences of pollution were more subtle in both speed and impact than a disease epidemic but extremely hazardous to health nonetheless. The idea of exposure to carcinogens and mutagens was replacing biological risk as the key problem in the minds of many in the drinking water public by the end of this period.

On the environmental awareness front, the 1950’s brought air pollution of many cities to a crisis stage, eventually leading to acid rain issues in New England and other northern states. In 1965, lead in gasoline was exposed as a significant health problem, forcing the industry to shift away from lead additives while again highlighting lead control in the urban setting as an important health issue. In the area of water pollution, the 1969 event where the Cuyahoga River in Ohio caught fire and produced flames over 5 stories tall highlighted the sad lack of controls on industrial discharges to waterways.

The direct detection of many of the associated contaminants in the water supply wouldn't hit until after 1970 as detection technology caught up with the presence of newer, more complex substances.

Public Health/Drinking Water Issues

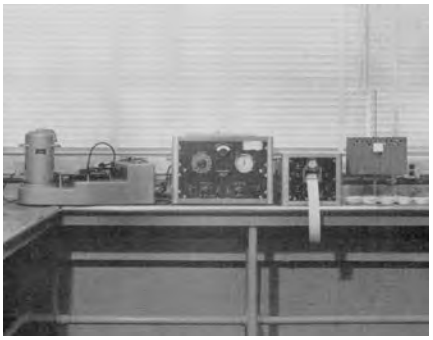
The issues of the day had shifted from biological threats to emerging chemical threats. Pesticides and herbicides became an emerging threat in many watershed areas as farming competition forced many farmers to try chemical control of pests and nuisance plants. Compounds like DDT (created in 1944) were heavily used, becoming environmental hazards and further finding their way into water supplies from agricultural runoff. The DDT story was documented in the 1962 book "Silent Spring" by Rachel Carson which was one of the driving forces in the new environmental consciousness that emerged around 1970 when the first Earth Day was celebrated. Another emerging chemical problem came from the increasing use of polychlorinated biphenyls (PCBs), which, after creation in 1929, had been used extensively starting in the 1940's in electrical equipment and other industrial uses. Conventional treatment struggled with removal of some of the new compounds.

Similarly, in the 1960's, the detergent industry began using alkylbenzenesulfonate with phosphate to improve sudsing. This improved laundry performance but it did so, once again, at the expense of the environment and the drinking water supply as the extra phosphate led to eutrophication of receiving waters and more nuisance algae species. The foaming of some streams was also attributed to this compound, leading to a groundswell to remove the product later in the 1970's.

One minor biological issue of the era was the discovery around 1960, that nematodes (microscopic worms) were abundant in many polluted rivers and, further, that they were making it through surface water treatment in some systems. This made for some interesting microscopic images and news stories but the organism was only marginally a health issue in the sense that the nematodes themselves were not dangerous, they simply may have harbored other pathogenic bacteria. They had some significance to taste and odor issues but faded as a health concern with time and the emergence of other more problematic organisms.

One of the prevailing health issues in this period was notable as being somewhat water related, that being the polio outbreaks of the 1940's and 1950's. As a viral disease, there had been major outbreaks dating back to around the turn of the century. Transmission was concluded to be principally by direct contact via swimming or other bodily contact in a polluted water body. As with every other disease, the waste from an infected population carries large amounts of the causative agent. The polio virus was very well suited for water transmission so the presence of so many untreated or poorly treated sewage discharges was part of the problem. Polio outbreaks have been experienced in past centuries but the incidence increased in the 1900's. This led some health experts to conclude that the improved water treatment following widespread use of chlorine, a proven virus killer, actually may have increased epidemics in the 1900's by removing the public's earlier low level exposure to small amounts of the virus in undisinfected drinking water, thus removing the positive immune system response that was present in the past.

Radiation was also an emerging issue throughout the period. During the Cold War period that followed World War II, the arms race precipitated a significant increase in open air testing of nuclear bombs worldwide, starting in 1951. The ensuing fallout traveled around the globe and contributed measurable amounts of radiation in New England, a fact that was accidentally discovered by scientists in 1953 in Troy, NY. This eventually led to global agreements that curtailed testing as the other nuclear powers agreed that this was a bad idea. The 1979 Three Mile Island nuclear plant near-meltdown disaster was another interesting example of a potential radiation threat. The 1986 Chernobyl incident actually did release radiation but did so far enough away to be a non-issue to the US.

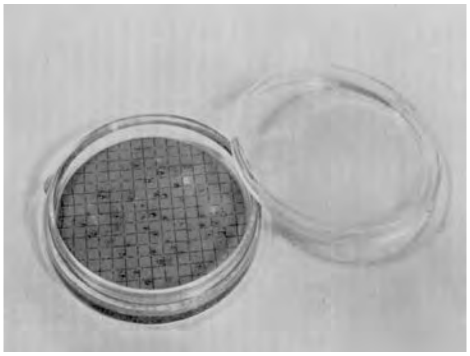

1955 Lawrence Experiment Station radioactivity monitoring

With this new awareness on radioactivity as a health issue, testing began to reveal that some bedrock wells in New England had naturally occurring radioactivity from trace sources like radon and other radionuclides. This again undermined the old belief that groundwater was inherently the lowest risk source.

Detection Technology

In the area of biological threats, the development of the membrane filter test greatly simplified coliform bacteria testing and enumeration of results. The Army chemical corps originally developed the membrane filter as part of its biological warfare agent detection. It declassified the method in 1951, allowing Millipore filter to bring it to market. Standard Methods published the method in its 10th edition, after 1953 lab studies proved the method to be viable. The method continues to be the mainstay of current day Coliform Rule testing.


1955 Membrane filter


1958 Coliform plate

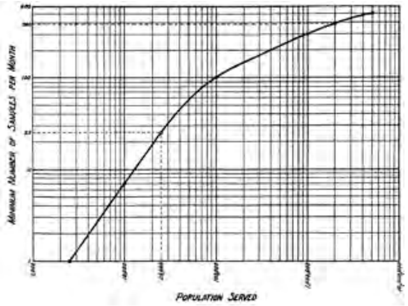
While there were many advances in test methods, especially in chemical detection, the most significant advances were in organics detection. The Carbon Chloroform Extract (CCE) test, developed in 1952, gave a quick reading of organics presence that could be used isolate individual compounds. In the 1960s, the Gas Chromatograph/Mass Spectrometer added a powerful tool for rapid testing with scanning capability and quantification of individual compounds. This new method enabled the alarming discoveries in the 1970's.


1954 New Britain CT Lab

Regulations

In 1942 U.S. Public Health Service updated its "Interstate" standards again, this time using an advisory committee. This update added a minimum number of samples, defined the appropriate points in the distribution system and added the right of state or federal inspection at any time. Chemicals were regulated better with new maximum permissible amounts for lead, fluoride, arsenic, selenium, salts of barium, hexavalent chromium, heavy metals or "other substances having deleterious effects". The update also set maximum concentrations for copper, iron, manganese, magnesium, zinc, chloride, sulfate, phenolic compounds, total solids and alkalinity.

In 1946, a further USPHS update added hexavalent chromium standards. A 1957 amendment authorized use of membrane filter technique.



1944 USPH population based coliform sampling requirement

With the help of a new advisory committee, the USPHS, set forth limits in 1962 for alkyl benzene sulfonates (detergents), barium, cadmium, Carbon Chloroform Extract (CCE, a measure of organic residue), cyanide, nitrate, silver and 28 other existing regulated constituents. These were mandatory limits for health related contaminants and recommended limits for aesthetic concerns like taste and odor, but, once again, these were only legally binding to 700 water systems that supplied interstate carriers (<2%) of the nation's water systems.

In a significant development in 1969, USPHS tested 969 public water systems serving 18.2 million people and found that 41% did not meet the 1962 guidelines, some being potentially dangerous. This was one of the main driving forces for establishing the eventual 1974 Safe Drinking Water Act.

On the environmental side, the 1948 Water Pollution Control Act created the first federal funding for wastewater treatment to start the clean-up of the nation's river. This was followed by the 1956 Federal Water Pollution Control Act (amended again in 1965, 1966, 1970, and 1972). The Water Quality Act of 1965 set stream water quality standards for receiving waters and began establishing a means to require treatment of waste discharges.

Among other environmentally driven regulations, the 1963 Clean Air Act and the 1968 Wild and Scenic Rivers Act began a series of protective legislative requirements that began to improve the quality of source waters.

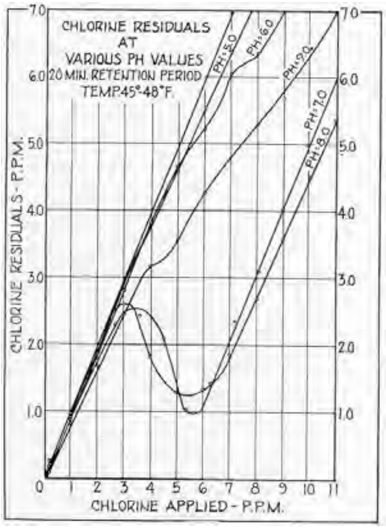
Role of treatment

The period saw the general improvement of all technologies associated with conventional treatment.

In the area of disinfection, chlorine gas was the most used disinfectant, largely due to its simplicity and reliability. There were, of course, much written in the NEWWA Journal of the need for proper safety practices as container sizes grew to ton cylinders for the larger users. On the plus side, Wallace & Tiernan developed better flow pacing in 1950's making the chlorination process even more reliable.

Several other disinfection developments are worth noting in this period. The first is the emergence of chloramination, initially as a solution to the taste and odor associated with free chlorine or as a solution to keeping persistent residuals in systems with very long travel times. Some water supplies began chloraminating in the 1930's but actually had to revert to free chlorine due to ammonia shortages during World War II. By 1948, the relative disinfection strength of chloramines was proven to be considerably less than free chlorine but its effectiveness on control of nuisance organisms and slime growth was found to be a plus. Ratio control was found to be the key to effectiveness.

In the 1930's, the breakpoint reaction became better understood, but it was only in 1943 that the finding that pH affected the hypochlorous/ hypochlorite species and consequently the potency of the residual. The tendency on dosing was still to be fairly generous on dosage with some supplies routinely pushing breakpoint dosages or superchlorination/ dechlorination.



Breakpoint chlorination diagram

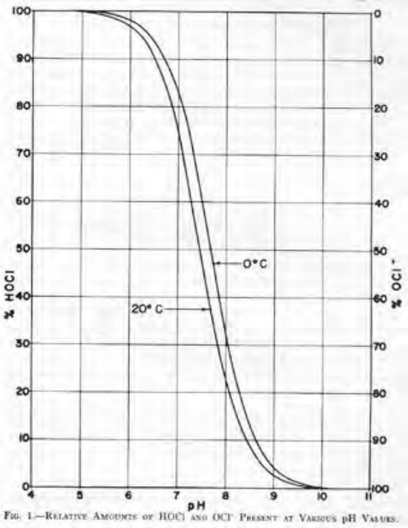
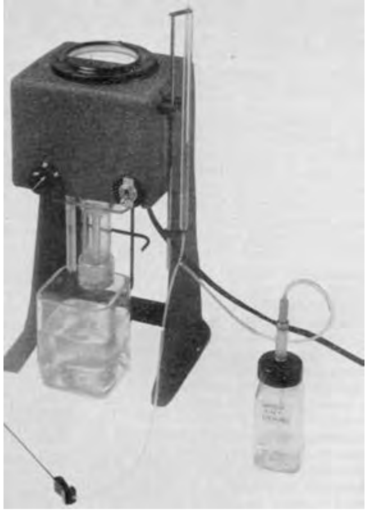


FIG. 1—RELATIVE AMOUNTS OF HOCl AND OCl^- PRESENT AT VARIOUS pH VALUES.

pH relationship on HOCL species graph by Gordon Fair

In other disinfection developments, the calcium hypochlorite product HTH was developed in 1927. Chlorine dioxide was available but infrequently used from a cost standpoint, with a few supplies choosing to use it where there were phenols that were producing undesirable aesthetics during chlorination. From a control standpoint, the ortho-tolidine-arsenite test gave way to amperometric titration in 1942. Procedures for disinfecting mains with chlorine were also adopted in 1947 by AWWA.


Chlorine amperometric titration

In the area of filtration, the 1950's saw more performance improvements, primarily due to better media combinations and the development of polymers. Granular activated carbon (GAC) was developed in 1960s with the initial expectation of use in taste and odor control. Similar to anthracite coal, GAC offered advantageous granular size to weight ratios that allowed good bed stratification in a multi-media filter plus it had notable adsorbtion properties. Polymers were available as a filtering aid as early as 1945, with Nalco, Dow, and Calgon contributing various types of ionic and anionic polymers. Up until this time, all flocculation was done using iron or aluminum salts and the polymers enhanced floc formation considerably. Paddle type flocculators became the most common type, with some plants using static mixers or turbine agitators (first used with Infilco's solids-contact clarifier). In this period, Thomas Camp of MIT became renowned as a flocculation expert, with his 1955 paper, *Flocculation and Flocculation Basins*, being considered a civil engineering classic.

Better methods of collecting filtrate were developed, for example, the 1934 porous plate filter bottoms that were studied by T. Camp at Providence's water treatment plant. Mud ball problems in backwash led to surface washing, use of compressed air, and other media agitation to get better media uniformity and reduce breakthrough. Filter controls also improved using flow metering, pneumatics, and better electronics.


1939 Biddeford ME filter gallery


1923 Putnam CT filter gallery

Jar tests for coagulant dosage control had been used for years but had some difficulty in translating to actual filter conditions. The 1950's development of the zeta meter allowed direct measurement of zeta potential, allowing better adjustment to actual conditions. Some water treatment plants began using pilot filters for actual performance control.

One fairly unconventional method that came in this period was the Diatomaceous Earth filter, first developed for armed forces in WWII. The method offered minimal capital expense but somewhat more difficult and costly operation than conventional treatment. The first DE municipal plant was in Gasport NY in 1949 and was followed by several New England installations.

Much water treatment plant construction occurred in this period with varied architectural styles


1943 Hinsdale NH WTP


1943 Beverly MA WTP


1939 Willimantic CT WTP


1942 Rockport ME WTP


1943 Groton CT WTP


1954 New Britain CT WTP

The following table gives a brief breakdown of water treatment in New England at about the midpoint of the 125 year life of NEWWA:

State	**Communities with slow sand**	**Population served**	**Output MGD**	**Communities with rapid sand**	**Population served**	**Output MGD**
Connecticut	6	285,300	26.62	20	327,800	36.38
Maine	5	20,300	1.73	13	75,300	7.72
Massachusetts	17	378,300	33.20	9	292,700	26.38
New Hampshire	4	21,700	1.67	6	16,200	1.73
Rhode Island	0	0	0	8	567,800	45.14
Vermont	1	6,600	1.50	2	27,300	1.73

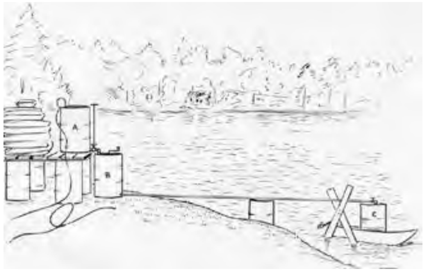
From E. Sherman Chase 1944 paper – "*Water Filtration - Present Practice & Trends*". Approximately 25% of the population of NE is filtered at the time.

As can be seen from the few communities served, there were still many unfiltered supplies at the time.

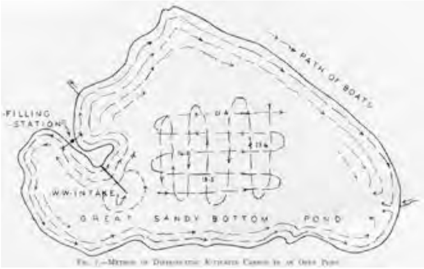
Aesthetics

There were the usual problems just as there are today, i.e. algae and red water. Algae went through a bit of a growth spurt in the 1960's as the detergent industry began to fortify its detergents with phosphates for better sudsing. The result was more nuisance species and increasing eutrophication of surface waters. Copper sulfate treatments were still the preferred solution to algae but other new tools like powdered activated carbon were occasionally tried.

1966 Copper sulfate dosing through ice using a hole and an outboard motor



1947 Powdered activated carbon use at Pembroke MA



1947 PAC application plan Pembroke MA

Iron was beginning to present more problems as the cast iron pipes aged. With the poor coatings on the early generation of cast iron, it wasn't long before the coatings broke down. With the normally corrosive New England waters, rapidly growing pipe scales were causing episodes of discolored water, which, in turn, caused a resulting public push for better iron control to save their laundry. This led to development of phosphate inhibitors in the 1940's with the early preference being sequestration to keep red water down.

In the world of corrosion control, Langelier published his index in 1936, helping many understand the kinetics of metal corrosion. Lead dissolution was not considered a huge problem at this time so pH control strategies were not yet common and most water supplies managed pH only so far as necessary to support other conventional treatment processes. Excessive hardness had never been a big issue in New England so fairly few attempts at lime softening were needed.

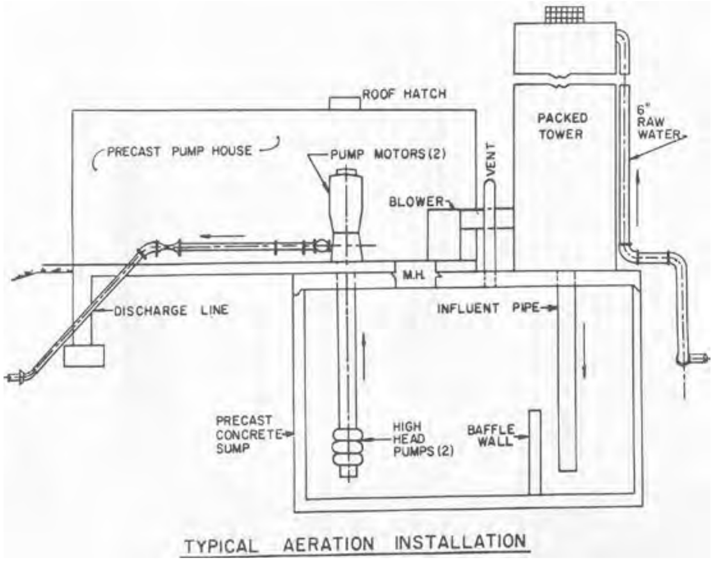
New source water issues emerged in this period such as chlorine reactions with newer chemicals, especially phenolic compounds that produced a particularly noticeable taste and odor, an issue that emerged in 1942. This led to some changes in water treatment, including the use of potassium permanganate for pre-oxidation, a practice that became common in the 1960's. Some systems added aeration to help with volatile organics, more to cure the aesthetics problem than to deal with any health effects. Granular activated carbon became a popular treatment media in the 1960's for the same reasons.

1970 to Now – Emerging threats

Public Health/Drinking Water Issues –

The 1970's was the beginning of the modern era of government regulation. Not only did the causes of pollution get regulated but the 1974 Safe Drinking Water Act began the process of truly ensuring the safety of the nation's water supplies. The late 1960's survey by U.S. Public Health Service of drinking water quality nationwide was eye-opening in that, despite having the means and methods to treat water effectively, a substantial percentage of U.S. water supplies were delivering unsafe water. In this historic first survey looking at organic chemicals, the survey revealed dissolved organics frequently exceeding the 200 microgram/l recommended limit on CCE. There was a public outcry for national regulation as a result.

Water supplies began to benefit from the public push to clean up the environment. After the series of environmental disasters in the 1960's, the government also cracked down on stream pollution from any and all sources while simultaneously funding municipal wastewater treatment. The 1965 Clean Water Act began a series of initiatives that saw discharge limits placed on municipal and industrial discharges in the NPDES program. Pesticides and herbicides were more restricted, especially those that had been found to have serious bioaccumulation consequences like DDT. The point sources of very hazardous materials were regulated under CERCLA and the Superfund was established in 1980 to begin removal of contamination.



1988 aeration for VOCs

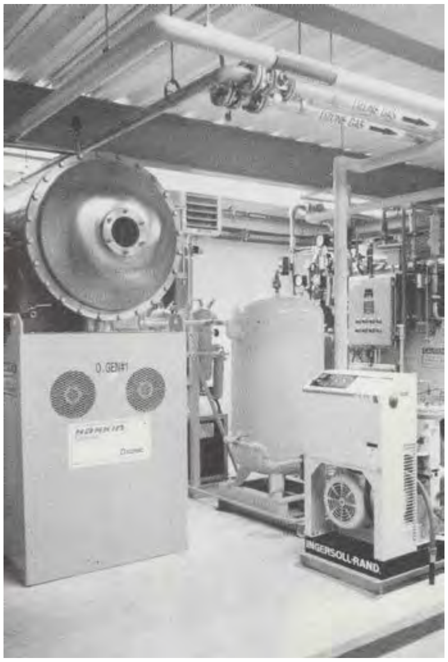
A series of new public health threats emerged in the 1970's, starting with the discovery that disinfection by-products, like tri-halomethanes, were carcinogens. This came after the CCE test allowed organics testing and after a 1974 EPA study in Louisiana detected 66 organic compounds, many being the result of disinfection byproducts. Concurrently, epidemiological studies by Environmental Defense Fund in Louisiana found higher cancer rates in the Mississippi River water users than in local groundwater users, linking the chlorinated organic compounds to cancer. Suddenly, the water supplier's best friend, chlorine, was potentially the cause of significant problems.

This was closely followed by the 1976-77 National Organics Monitoring Survey study of 113 supplies which identified 700 specific organic chemicals but found that tri-halomethanes (THMs) were the most widespread. In 1978, EPA proposed a 2 part strategy, first to control THMs, second to control synthetic organic compounds in sources by use of granular activated carbon (GAC) as a required treatment step. Environmental Defense Fund filed suit to push for organics control, but many opposed the GAC requirement. In 1979 EPA promulgated the THM rule but in 1981 EPA withdrew the GAC requirement after considering arguments by opponents.

A 1977 National Academy of Science study, first in series of nine, put forward a basis for development of regulations that attempted to use health effects to establish maximum contaminant levels. They proposed 5 classes of contaminants: microorganisms, particulate matter, inorganic solutes, organic solutes, and radionuclides. This remains the model for science based development of water quality regulations.

The discovery of other contaminants like organic solvents, PCBs, heavy metals and other industrial wastes coming from point sources, such as the 1970's-1980's Superfund sites, was a huge impact on water supplies in urban industrialized areas. Not only were some surface waters at risk but now even groundwater, long considered the safer of the surface/subsurface source options, was found to be at significant risk.

The response to biological risks in the 1970's began to shift away from considering only bacteria and virus inactivation as the key performance measure of disinfection control. Locally, Berlin NH had a severe Giardia outbreak in 1978. With an increasing number of Giardia incidents nationally, the public health community and regulators realized that there were more disinfection resistant pathogens (Giardia being the foremost) which were causing waterborne illness. This led to the need to update the indicator organism strategies for more thorough disinfection. The research for inactivation of Giardia produced much more strict control of disinfection variables like pH, temperature, dosage and contact time. In the 1990's, cryptosporidium emerged as the next organism to drive risk response when some significant events, like the 1993 Milwaukee incident that infected 400,000 people, demonstrated the potential of this organism to cause significant public health problems. The fact that the cryptosporidium oocyst was extremely resistant to chlorine began to bring about a significant shift in regulatory disinfection control strategies. Water suppliers today are now feeling the impact of this as current cryptosporidium regulatory efforts will soon require substantial and expensive treatment changes.



1997 Package ozone plant

The issue of lead in drinking water also came to a head in this period, the problem being associated with lead service pipes and lead solder, but the regulatory solution being corrosion control treatment requirements on the water supplier. The banning of lead pipes and lead solder in the 1986 SDWA Amendments just stopped the problem from growing and today most water systems are now faced with the threat of replacing any remaining lead services simply because existing lead soldered copper joints and brass fixtures alone could cause non-compliance with the lead standard. This issue has received a great deal of research and much fine tuning of corrosion control strategies.

On the environmental front, the growing awareness of pollution drove the public to demand government regulation of many areas, including air, water, solid waste, endangered species and so on.

The performance of water suppliers and the aging of water treatment plants were also found to be an issue. A 1973 General Accounting Office report on 446 water systems found only 60 in full compliance with bacteria standards and sampling requirements. SDWA oversight was deficient in 5 of 6 states studied. The report noted that many water treatment plants needed expansion due to hydraulic overloading or disrepair.

In 1988, Ralph Nader's study of drinking water, in partnership with the National Wildlife Federation, challenged EPA and Congress that not enough enforcement was being done. The next decade or so was spent with environmental groups pushing for more stringent regulations while water suppliers were trying to cope with all of the new requirements. In 1993 EPA submitted a review of SDWA, finding that the cost of compliance with the regulated 84 contaminants to be $1.4B nationally with a significant shortfall in available funding. The local reaction to this published cost of improvements necessary to get in compliance was that not only was it underestimated but it was also was an unfunded mandate. Unlike the Clean Water Act funding for sewerage works, the huge cost of these required capital improvements had to be borne by the communities and their ratepayers. This continues to be the case as more emerging issues are regulated and costly upgrades are needed. In an effort to support communities, EPA funded and developed the state managed revolving loan program in the late 1990's.

In addition to the emerging environmental threats to water quality, the 9/11/01 attack on the World Trade Towers brought concerns over terrorism. This meant that water supplies needed to consider how to monitor for intentional contamination. This was a significant departure from the use of indicator organisms and sewage contamination since there are literally hundreds of chemicals, biologicals and radiologicals known to be harmful if introduced into the water supply. The other departure is that water quality in the entire distribution system now requires monitoring, not just the sources. While this is not subject to regulation yet, it has raised a new and difficult challenge. The result thus far is that some communities have expanded the use of on-line monitoring or periodic sampling for broad indicators of contamination. More research is underway on better technologies which may make this practical for everyone.

Detection Technology

The CCE test that started the furor over the presence of chlorinated organics was complemented by the gas chromatograph/mass spectrometer (GC/MS). This allowed the rapid and accurate detection of specific organic compounds.

Detection of metals took a major step forward in the 1970's with the development of atomic absorption methods, followed in the 1980's by Inductively Coupled Plasma (ICP) methods.

Biological detection also took some steps forward in this period. Alternative coliform tests were developed, like the enzyme based tests that use presence/absence and dilution schemes to provide a most probable number. As before, the incubation period for enzyme based tests still requires a lengthy turn around for results. Virus, giardia and cryptosporidium testing continues to be a difficult sample collection process and generally requires specialized equipment and procedures. Rapid immunoassay techniques also became available in the 1960's to help with identifying some specific contaminants. Some of these have evolved into the immediate detection kits used by HazMat responders for biological threats.

In the post-2001 world of contamination detection, multi-parameter monitoring stations for simple physical/chemical indicators have been used by some larger systems. These may prove to be helpful to overall operations as they will enhance understanding of dynamic water quality conditions

Regulations

This period reversed the federal government's laissez faire attitude with regard to the environment and pollution. A swarm of regulations of interest to water suppliers followed:

Year	Regulatory Change	Significance
1970	Creation of the Environmental Protection Agency	Established the agency that would become responsible for water and waste risks to public health
1970	Occupational Safety and Health Act	Established all hazard safety standards
1972	Clean Water Act (amended in 1977 & 1987, replaced the older Federal Water Pollution Control Act)	Established goals for river water quality, regulated waste discharges and provided grant funds for upgrading community wastewater plants
1972	Federal Insecticide, Fungicide & Rodenticide Act	Controlled the use of pesticides, banned some like DDT
1973	Endangered Species Act	Established protections that would stop projects like reservoirs that impact critical habitat
1974	Safe Drinking Water Act (amended many times since then)	The first universal national drinking water standards
1976	Resource Conservation and Recovery Act	Required protective changes to dumps and underground storage tanks
1976	Toxic Substances Control Act	Established a cradle to grave system for tracking industrial chemicals
1980	Comprehensive Environmental Response, Compensation & Liability Act, a.k.a. Superfund	Responded to establish a cleanup plan for serious hazardous waste sites
1983	EPA issues first National Priorities List	Established a ranked listing of all significant hazardous waste sites
1986	Emergency Planning and Community Right to Know	Established an emergency response hierarchy for chemical hazards
1999	Section 113 of the Clean Air Act is amended to require risk management plans for hazardous gas release	All large gaseous chlorine or anhydrous ammonia users had to submit RMPs

Many of these had direct effects on water supplies. Most were beneficial in the sense of cleaning the source waters, but some constrained source development since removal of waters from rivers was in conflict with environmental impact considerations.

The evolution of the drinking water regulations themselves is noteworthy. The 1974 Safe Drinking Water Act (SDWA) established the first truly national primary drinking water regulations. The original act was mainly a framework to establish the process of regulation and the roles including the state primacy role with federal oversight. It also set up violation reporting standards and established the schedule for development of the National Interim Primary Drinking Water Regulations (NIPDWRs) using the NAS studies of health effects as the basis. It established 2 steps of regulation setting, the first being Recommended Maximum Contaminant Limits (RCMLs), then Maximum Contaminant Levels (MCLs). It also allowed the option of specifying a treatment technique where necessary if the contaminant was beyond the removal ability of conventional treatment. In 1975, the NIPDWRs were published, creating the first comprehensive limits on drinking water contaminants.

As mentioned previously, EPA promulgated the THM rule in 1979 and withdrew the embedded GAC requirement in 1981.

The 1986 SDWA amendments were a significant step forward. The amendments were a reaction to concern over the slow pace of regulations, with Congress passing PL 99-339 (SDWA 1986) as a mandate to get moving on further regulation. Among other things, it required:

- Mandatory standards for 83 contaminants by 6/89
- Mandatory regulation of 25 new contaminants every 3 years
- National Interim Drinking Water Regulations to be renamed to National Primary Drinking Water Regulations
- Recommended Maximum Contaminant Levels to be replaced with Maximum Contaminant Level Goals
- Required designation of Best Available Technologies for each contaminant
- A specification to be developed for filtration of surface supplies
- Disinfection of all surface supplies (based on Giardia as the most difficult organism to inactivate)
- Monitoring for unregulated contaminants
- A ban on lead solders, pipe and flux
- Wellhead protection and protection of sole source aquifers
- Streamlined and more powerful enforcement

The 1988 Lead Contamination Control Act (PL 100-572) followed with the finding that water coolers released lead. It required testing of water at schools and day care and recalled lead lined coolers. This was followed shortly by the 1991 Lead and Copper Rule. This established the testing protocols and required response actions that we are bound to today.

Amendments to the Clean Air Act also created a significant impact on larger systems when Risk Management Plans were required to be submitted in 1999 for gaseous chlorine and other hazardous gases. The threshold was such that the presence of a ton cylinder triggered the need for a plan and follow-up risk disclosure and emergency response planning needed to be done in affected communities. This created a powerful incentive to switch away from bulk gaseous chlorine.

Other water specific regulations followed, including a significant group in the last decade:

1996 Information Collection Rule
1998 Interim Enhanced Surface Water Treatment Rule
2000 Radionuclides Rule
2000 Public Notification Rule
2001 Filter Backwash Recycling Rule
2001 Arsenic Rule
2002 Unregulated Contaminant Monitoring Regulation
2002 Long Term 1 Enhanced Surface Water Treatment Rule (repl. the 1998 Interim Rule)
2004 Updated Lead and Copper Regulations
2006 Stage 2 Disinfectants and Disinfection By-products Rule
2006 Long Term 2 Enhanced Surface Water Treatment Rule

These updates were intended to bring about solutions to such threats as cryptosporidium, THMs, and lead. The process of finding new contaminant threats continues to the present day so there will certainly be further regulation. Near term possibilities include regulation of perchlorate and the proposed Ground Water Rule, aimed at finding and remediating problem sources.

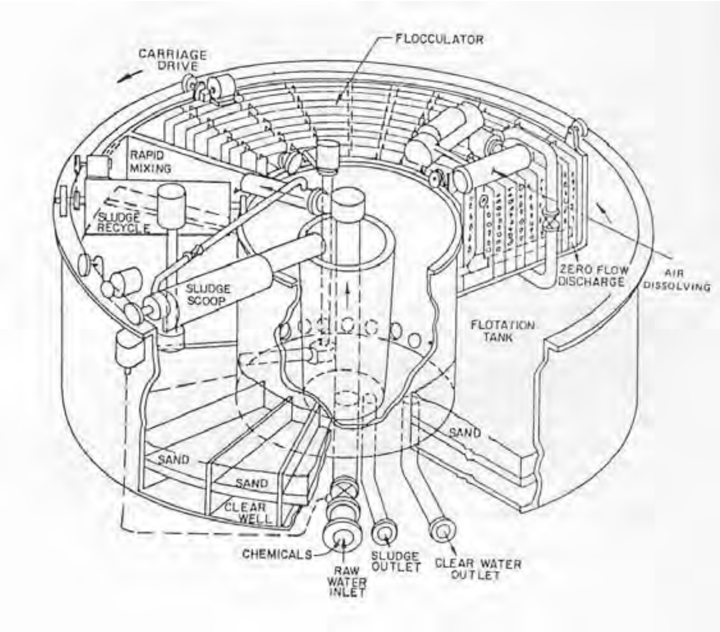
Role of treatment

In the world of disinfection, this period featured the emergence of alternative technologies, namely ozone and ultraviolet light (UV). Ozone had been around since the earlier part of the century but the expense, safety, lack of proven equipment and lack of a stable residual discouraged its use until about the 1970's when European supplies began to use it. Some U.S. supplies began to follow suit in the 1980's. On the plus side, its power as a disinfectant and its benefits on taste and odor issues made it attractive to some water supplies. The recent finding that ozone is effective on cryptosporidium will make it even more attractive to those communities that need to get in compliance on that as well. Ozone is likely to be more widely used by surface water supplies in the future.

This era was also a period where the old methods of conservatively high chlorine dosing needed to change because of the disinfection by-products issues. Many water supplies were caught in a balancing act where more stringent disinfection requirements forced a high dose to be effective while the high dose led to problems with DBP compliance. While some communities switched to chloramine residuals to minimize formation during travel in the distribution system, others tried to remove the precursors or to control dosage more carefully to just meet inactivation requirements without aggravating disinfection by-product formation. This was definitely the end of the more is better philosophy when it came to chlorine dose. The other chlorination trend was concern over gaseous chlorine safety, bringing some supplies to consider conversion to 15% sodium hypochlorite solution. This wasn't a clear cut choice due to the reliability of the gas systems and the significant expense of the conversion, but transporting gas cylinders through sensitive public areas created enough controversy to force some communities to switch.

Pretreatment methods underwent some changes as well. For one thing, hydraulic capacity in many old treatment plants would not allow adequate performance under higher demands. Retrofit solutions tried to make some of these old spaces work. For a time in the 1970's and 1980's, plate settlers and tube settlers were much in demand in these retrofit applications to take advantage of their greater surface loading area for unit volume. Other developments included upflow solids contact flocculators, some of which included an air driven pulse to periodically keep the floc blanket uniform. These pulsator-clarifiers produced better performance in solids removal in the sedimentation step than past conventional sedimentation tanks. The most recent trend in pretreatment is dissolved air flotation which is very effective at treating low turbidity waters like those found in New England. This process uses compressed air to lift particles to a waste weir, somewhat the opposite of sedimentation. All of these processes have reduced loadings carried over to filtration with much improved performance.

In the filtration process, the period saw much more hydraulic performance out of filters. Where conventional treatment had always dictated standard rates of 2 gpm/sf, better pretreatment and multimedia beds began to allow much higher loading rates, as much as 5-10 times greater than before. This had a positive impact on filter construction costs. Another interesting development in rapid sand filtration was the use of biologically active carbon (BAC) media, again an idea that was first successfully used in Europe in the 1960's before appearing in the U.S. This was a variant on GAC media that embraces the idea that some biological activity will occur within the media and uses that activity to further break down source water organics during passage through the filter. In one sense, this is like crossing an old sand filter with a rapid sand filter but the biologically active layer reaches deeper into the bed in the BAC process. Filter controls improved as well with better backwashing and better monitoring of performance from new devices like particle counters.



1985 First dissolved air flotation

With all the available water resources in New England, desalination was only seriously looked at by communities on small coastal islands. However, by the 1990's, membranes for reverse osmosis had progressed to the point that the technology is becoming more cost competitive. The first municipal size project using membranes is expected to begin construction soon in Taunton MA using brackish water from the estuary of the Taunton River.

With the strong SDWA focus on lead control, many more communities began adding phosphate or silicate additives. At this point, the previous iron control methods using hexametaphosphates as sequestering agents had little benefits for lead. Many communities tried orthophosphates to produce the internal pipe coating that would inhibit lead corrosion. This was a successful strategy in many locations but a problem in other communities, especially those with open storage where algae growth was problematic. PH control was actually the most frequently chosen solution, with lime or caustic soda being the most popular chemicals.

1954 Fluoride probe

With the finding that many sources had volatile organic contamination in the 1970's, quite a few groundwater sources had to resort to treatment, most often resorting to aeration and GAC contactors.

Fluoridation also became a widely used process in this period as the Public Health community, especially the American Dental Association, the American Medical Association and the World Health Organization, all endorsed the process. The technique of using the water supply for delivery was first tried in 1945 in a series of pilot communities. Research on the effects was conducted for the next 15 years or so before the public health community concluded that it had positive results and no negative health effects. Widespread implementation didn't take hold in most communities until the 1970's as local Boards of Health would make the decision to introduce fluoride, following which, the water utility would install the equipment and start the feed. To say that this was not without controversy is an understatement but the effort produced a documented decline in tooth decay.

Aesthetics

The same old villains, algae, iron and manganese, were still at work in this period and were still essentially treated the same way. More research on the taste producing compounds within algae was able to identify the mechanisms that cause the problem and how chlorine reactions aggravate some problems but, in the end, copper sulfate still remains the most effective control measure.

Firsts in water treatment

The following is an attempt to collect information on New England systems and the early steps taken by some communities to purify their water:

Treatment	**1st in US**	**1st in NE**	**2nd in NE**	**3rd in NE**
General				
filtration for aesthetics	Richmond 1832			
filtration for bacteria		Lawrence MA 1893		
Early attempts				
Charcoal, sand & gravel		Stockbridge MA 1862		
Sponge, charcoal & sand		South Norwalk CT 1875		
Unsuccesful attempts		Providence RI 1871(infiltration basin)	Springfield MA 1873 (lateral flow)	Brockton MA 1880 (tiles on res bottom)
Succesful Attempts				
Natural Filters (Bank)	Whitinsville MA 1870	Whitinsville MA 1870	Lowell MA 1872	Waltham MA 1872
Slow sand	Poughkeepsie NY 1872	St. Johnsbury VT 1882 (coarse filter in place from 1827), 3rd in US	Nantucket MA 1892 (algae removal)	Lawrence 1893 (6th in US)
Mechanical Filters				
Clark Filter		None		
Hyatt Mechanical Filter (with coag.)	Somerville NJ 1882	Newport RI 1882, 2nd in US	Greenwich CT 1887 (with pre-aeration)	
Warren Filter	Cumberland Mills ME 1884	Cumberland Mills ME 1884	Augusta ME1887, 2nd in US	Brunswick ME 1887, 3rd in US
National Filter	Chattanooga TN 1887	Exeter NH 1887, 3rd in US		
American Filter	Elgin Ill 1888	None		
Blessing Filter	Athol MA 1887	Athol MA 1887		
Jewell Filter	Rock Island IL 1891	None		
Continental Filter	Atlantic Highlands NJ 1893	None		
Filter variations				
Rapid Sand	Louisville KY 1897			
Upward filtration	Richmond VA 1832	New Milford CT , 1874, 2nd in US	St Johnsbury VT 1876	Lewiston ME 1880
Multiple Filtration	Atlantic Highlands NJ 1893	S. Norwalk CT 1908	Lawrence MA 1938	
Coagulation	Somerville NJ 1885			
Other Treatment				
Chlorine (electrolytic hypochlorite)	Jersey City NJ 1908	Newport RI 1910	Stamford CT 1913	
Ozonation	NYC pilot test 1906			
UV	Henderson KY 1916	Taunton MA 2004		
Aeration	Elmira NY 1860	Lawrence MA 1875, 2nd in US	Nantucket MA 1891	Greenwich CT 1887
Iron removal by aeration/filtration	Atlantic Highlands NJ 1893	Reading MA 1896, 3rd in US		
algae/CUSO4	Ludlow 1904	Ludlow 1904		
Softening	Oberlin OH 1903			
Chloramination	Greenville TN 1926			
Activated Carbon	Bay City, Mich 1930			
Iodization	Rochester NY 1923			
Fluoride	Newburgh NY 1945 (pilot)			

Where are we now? - Current Stats on treatment

As a recent snapshot of the current state of water treatment around New England, the following summary was presented by NEWWA's 1993 survey of New England water treatment practices:

Of the 139 Water Treatment Plants surveyed in 1993, the following was found:

Process	No. of WTPs	Details
Aeration	16	
Preoxidation	89	47 use chlorine, 30 use potassium permanganate, 5 use chlorine dioxide, 1 other
Coagulation	120	101 use aluminum sulfate or sodium aluminate, 29 use polymers
Rapid mix	125	63 use mechanical, the rest use static or in line
Flocculation	90	Most use vertical, many horizontal paddles, some baffles
Clarification	107	Most are conventional, some tube settlers, some upflow clarification, a few plate settlers, some dissolved air flotation
Filtration	139	124 rapid filters, 12 slow sand filters, 3 diatomaceous earth, 38 have GAC somewhere, 31 package plants
Disinfection	139	94 use chlorine gas, 45 use hypochlorite, 3 use chlorine dioxide, 1 ozone
Sludge disposal		60 lagoons, 32 sewer discharge
Taste & Odor control		30 use copper sulfate, 40 powdered activated carbon, 25 granular activated carbon
Corrosion Control		116 use pH adjustment, 56 phosphates

Bear in mind that this is surely out of date as the continuing emergence of regulations is causing much updating and reconstruction of treatment plants in the past decade.

The following is a recent snapshot of fluoridation status as a % of population served by public water systems:

State	1992	2000	2002
MA	57%	56%	61%
RI	100%	85%	89%
CT	86%	89%	88%
NH	24%	43%	43%
VT	57%	54%	56%
ME	56%	75%	74%

Are we ever going to get ahead of emerging threats?

The future of water treatment is still going to be dictated by public health risk which is in turn driven by detection technology and new threats being released into the environment. Most water systems take the step necessary to protect against known threats but no more than that. Minimizing impact on the ratepayer makes it necessary to be sure that the next protective step is truly necessary. Chances are that the cycle of learning and improvement will continue.