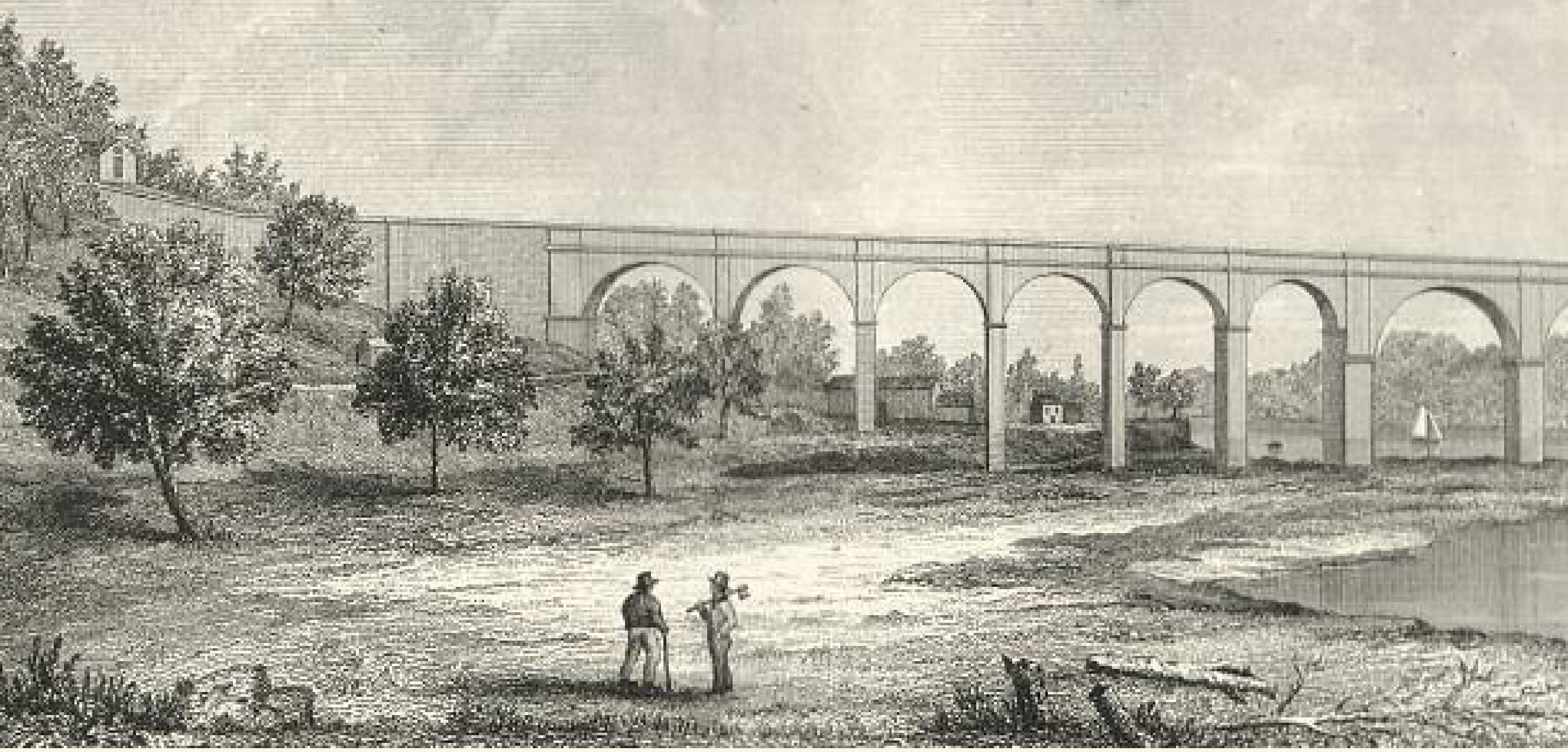
A Century of Water

By **Edward H. Winant**, Ph.D., PE, NESC Engineering Scientist



Mention Scotland, and images of castles, moors, or craggy coastlines spring to mind. The country's reputation tends more toward the romantic than scientific. But the period from 1740 to around 1800 marked the Scottish Enlightenment, a time of intense philosophical and economic debate. Substantial scientific, intellectual, and aesthetic achievements continued into the next century. Amongst these contributions was the development of public water treatment practices.

In Paisley, Scotland, the first municipal water treatment plant was constructed in 1804. Treatment there consisted of concentric sand and gravel filters, and distribution was by horse cart. Nearly a century later, in Middlekerke, Belgium, the first permanent chlorination treatment was used to disinfect drinking water.

The changes made during the 19th century—from Paisley to Middlekerke—were revolutionary. Medical and scientific advances led to alterations in engineering design and construction and changed public opinion relating to public water supply.

Aesthetics Prompted Treatment

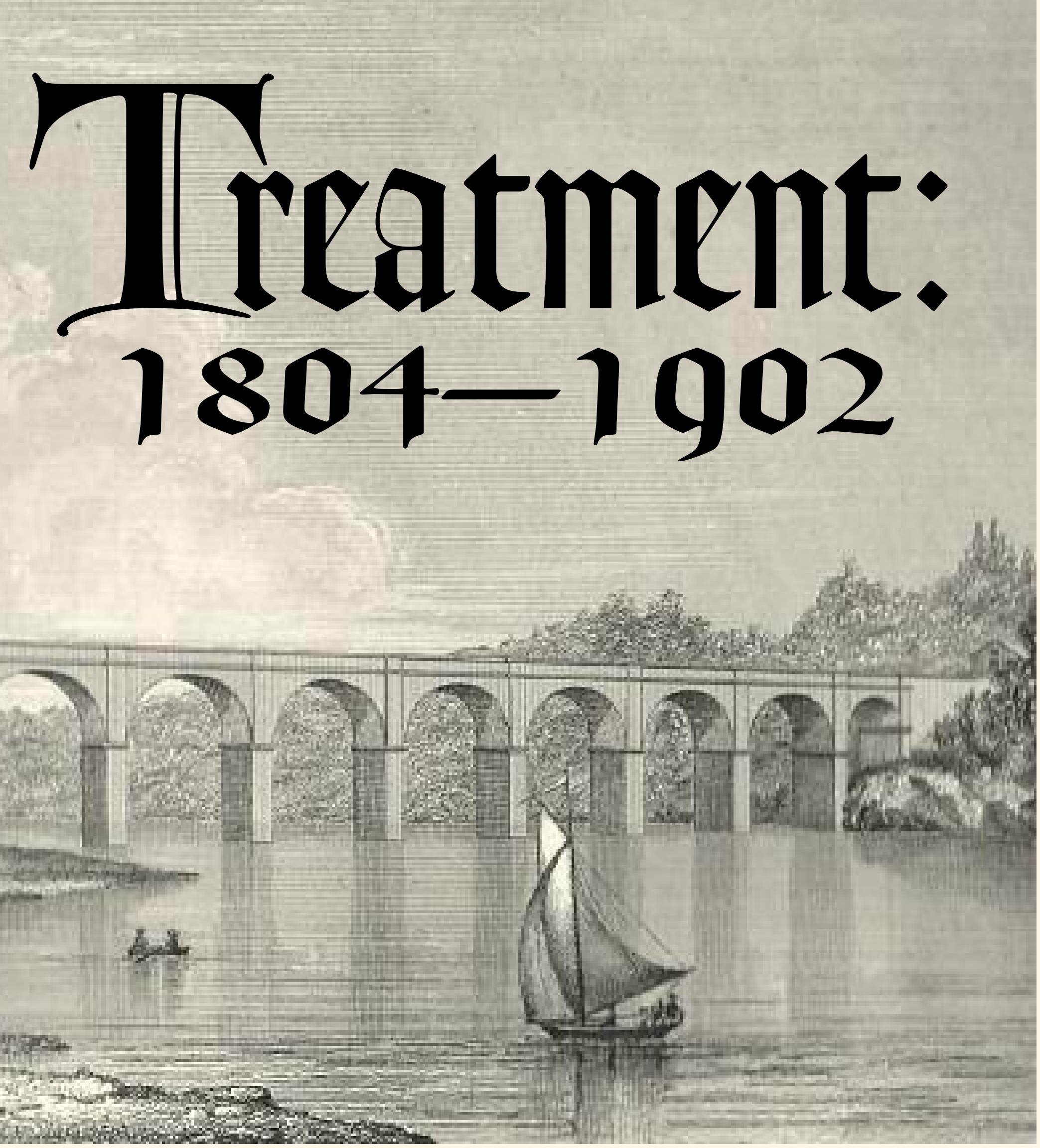
Paisley's water treatment was initiated to clarify the River Cart, which contained a great deal of municipal waste and was unsuitable for bleaching operations of the local textile industry. The river water was treated by passing it through concentric rings: the outermost being a settling basin, then through a gravel filter, and finally a sand filter, before being stored in the central pool. An interesting note is that the Paisley filter may be described as vertical, because the water passed horizontally through the upright filter media. Subsequent slow sand filters were constructed of horizontal media beds with the water draining vertically through them.

Most of the treatment plants in the early 19th century were constructed to remove sediment or to improve taste and odor. No one was yet aware of the disease-carrying capabilities of water. Prevailing medical views had descended from Hippocrates and the primary view was that atmospheric conditions, foul odors, or noxious gasses escaping from marshy land caused epidemic diseases.

Discussing Water Quality Theories

There were some tests of water quality, even at this early stage. Dr. Joseph Brown of New York stated that clear water with a good flavor, able to boil legumes tender, and dissolve soap was good water. Softness was an important aspect, as a New York

Treatment: 1804—1902



scientific report from 1831 stated that the contamination of water supplies with high concentrations of minerals by runoff from graveyards and privies was counteracted by the presence of urine, which acted as a water softener. According to Nelson Blake in the book *Water for Cities*, the report went so far as to claim that:

> This liquid, [urine] when stale or putrid, has the remarkable property of precipitating the earthy salts from their solution, or in other words, it makes hard waters soft. Although the fastidious may revolt from the use of water thus sweetened to our palate, it is perhaps fortunate that this mixture is daily taking place, for otherwise the water of this city would become, in a much shorter space of time than it actually does, utterly unfit for domestic consumption.

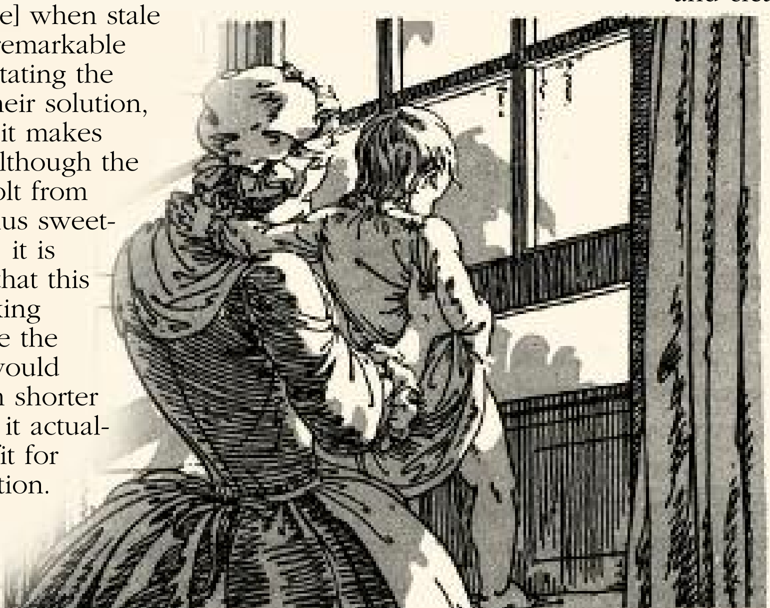
In keeping with the perceived need to remove only sediment from the water, treatment plants in the early 1800s consisted of various reservoirs used as settling basins with sand and gravel filters in between. In times of normal river flows, this type of treatment worked satisfactorily, but flood waters with increased sediment loads were little affected by filtration. One other method was the filtration gallery, which made use of natural filtration in drawing water from a river through existing soils into a storage gallery.

In Boston, circa 1834, the debate on water quality centered around the observance of minute organisms in the water, some visible with the naked eye but some seen only with the aid of a microscope. These "animalcules" as they were called, were noted to abound in Long Pond, a source water supply for the city. According to *Water for Cities*, John Wilkins advised drawing water from the Charles River because, "animalcules are much less likely to be found in running, or river water, than in pond water." There was some debate over this point. Certain experts postulated that the presence of animalcules was evidence of the purity of the water since these delicate creatures could not be expected to live in polluted water.

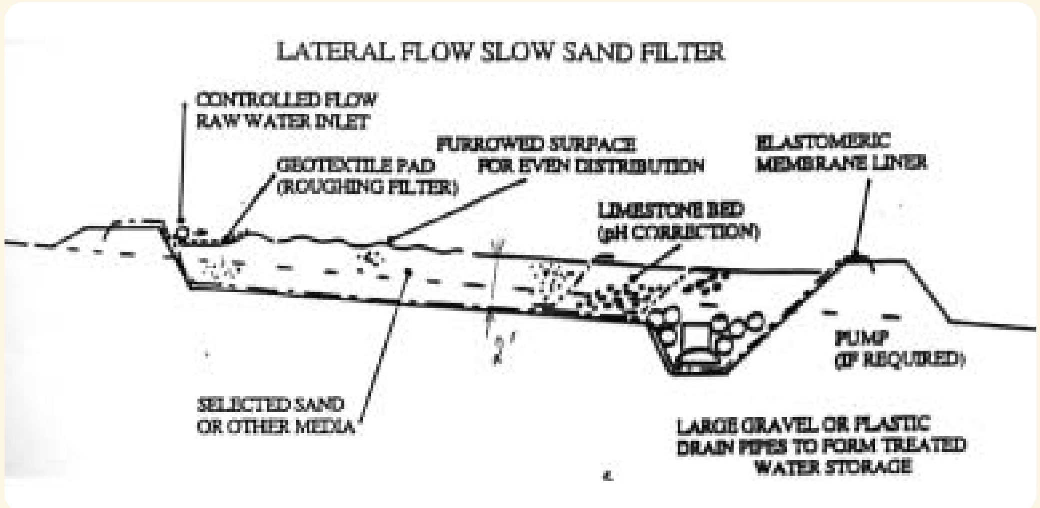
Lead piping, used for service connections between houses and main water lines, was another concern, as the lead would dissolve in certain waters. Lead had long been known to be poisonous but was still used for house connections because it was highly malleable and easily jointed.

Filtration Begins

The slow sand filter continued to be the mainstay of water treatment for most of the 19th century, although it had its drawbacks. The sand beds, two to four feet thick, covered acres of ground, and cleaning was only accomplished by shoveling off the dirty sand and replacing it with clean sand. The large area was needed because the dosing rate of water through sand was approximately three gallons per square foot per hour.



As an example, the combined water companies of London treated 44.4 million gallons per day (mgd) in 1849. This volume would have required treatment beds



covering 12 acres. While 12 acres may not sound like much, the rapid increase in city size during this century placed land at a premium, and the expanding population would need even more water. As the population grew, so did the daily demand for water per person. The increased need for supply water soared. By 1901, London's water requirements had grown to 215 mgd, an increase of 380 percent. Clearly the land requirements of slow sand filters could not keep pace with the growing need for clean water.

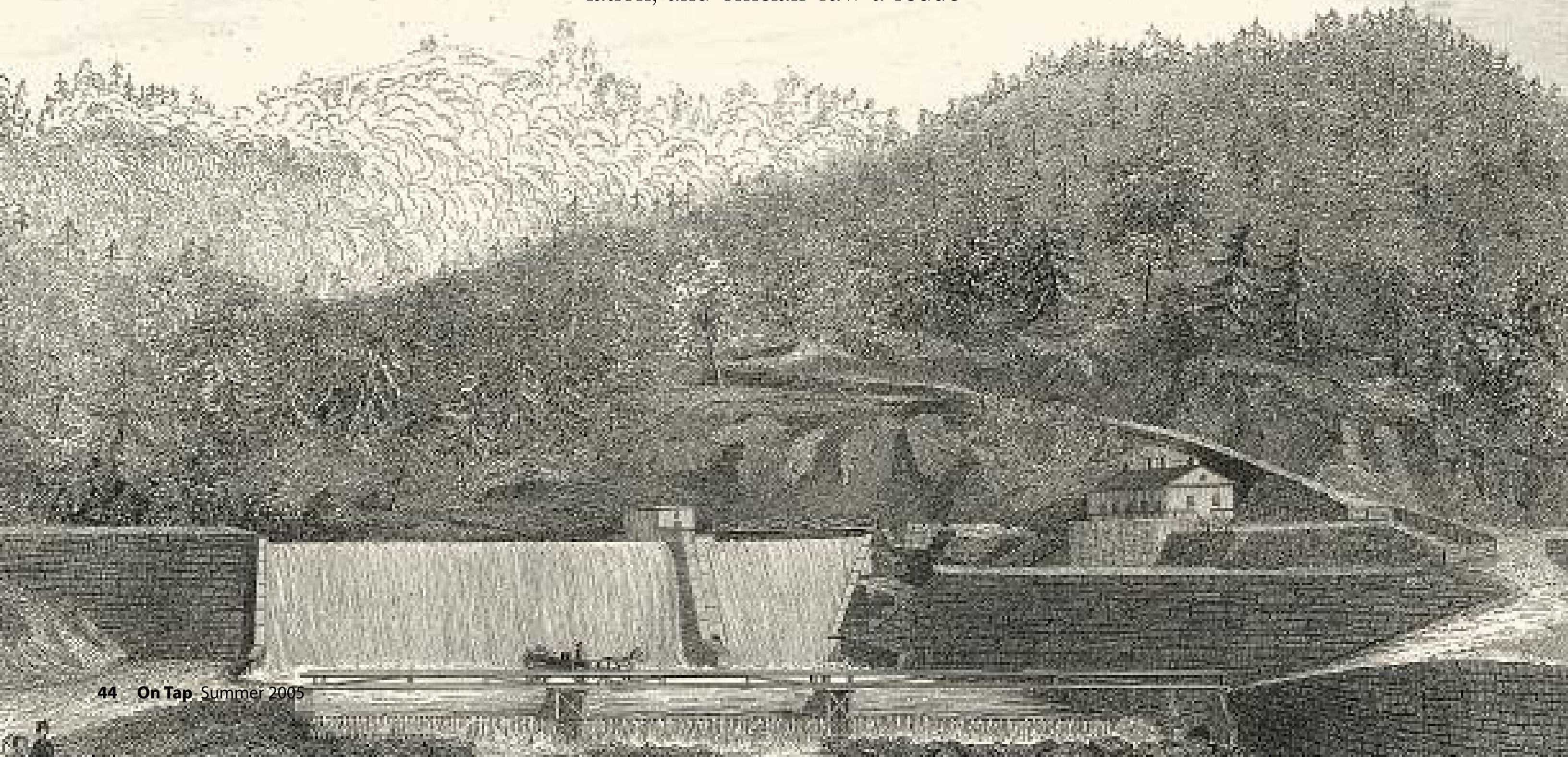
To fill this need, the rapid sand filter was developed, oddly enough, in America where land was more plentiful. Rapid or mechanical filters used backwash to automatically clean the filter media and mechanical agitators to loosen it. The rapid filter greatly increased treatment capacity, thus reducing size requirements. However, the new procedure depended on pretreatments, such as coagulation and settling, to reduce the sediment load to the filter.

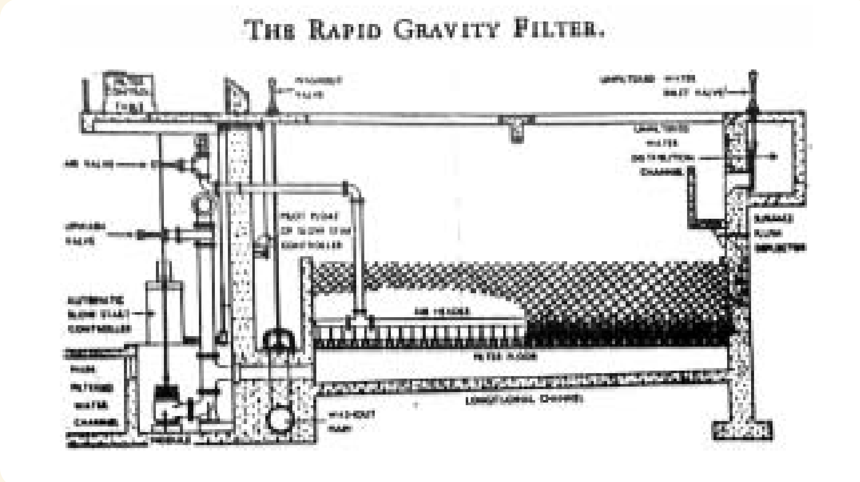
Treatment to improve taste and odor was achieved by using charcoal filtration. This practice, like many early treatment procedures, evolved from long-used water treatment methods for personal supplies. The practice of charcoal filtration was not widespread, though, as it was judged unfeasible for large supplies and was generally restricted to treating water for shipboard use. Where it was used, the common practice was to install the charcoal filter between two gravel filters.

Linking Water Quality and Public Health

The first ties of water quality to public health were noted in London around the mid-19th century. London had slow sand filters for at least part of the population, and officials saw a reduction in cholera victims in areas thus served in the epidemics of 1849 and 1853. Even more convincing was John Snow's tracing of multiple cholera deaths to a single pump in Soho where the sump was contaminated by leakage from a nearby sewer. Ironically, many of the users of the Broad Street well water came from other sections of town and used this water because they preferred the taste. This is a most telling indictment against the use of subjective standards of water quality like taste or clarity.

Following the epidemics and taking note of Snow's study, Parliament passed the Metropolitan Water Act of 1852 requiring filtration of all water supplied to London. In addition, the act required that water sup-





plies be drawn from cleaner, nontidal reaches of the River Thames. This act was one of the first instances of governmental regulation of public water supply.

This legislation leads to the question of locating the water supply, as raw water quality greatly affects the treatment needed. Cities located along rivers for transportation purposes had a ready supply, but these sources could be easily contaminated by industry, upstream cities, or the tides. Further, as noted earlier in the Boston water debate, was the question of preferring running water to standing water. Since antiquity, water authorities had observed that standing water was more prone to putrification than running water.

On the other hand, reservoirs provide a more certain supply of water, especially for river-less cities. However, reservoirs require a good deal of land and must often be located some distance from the cities they serve.

For example, Manchester, England, drew water from a reservoir 96 miles away, and Liverpool required a 77-mile-long aqueduct for their supply. New York City, in a quest to find pure source water rather than providing treatment, located their reservoir 40 miles from the city.

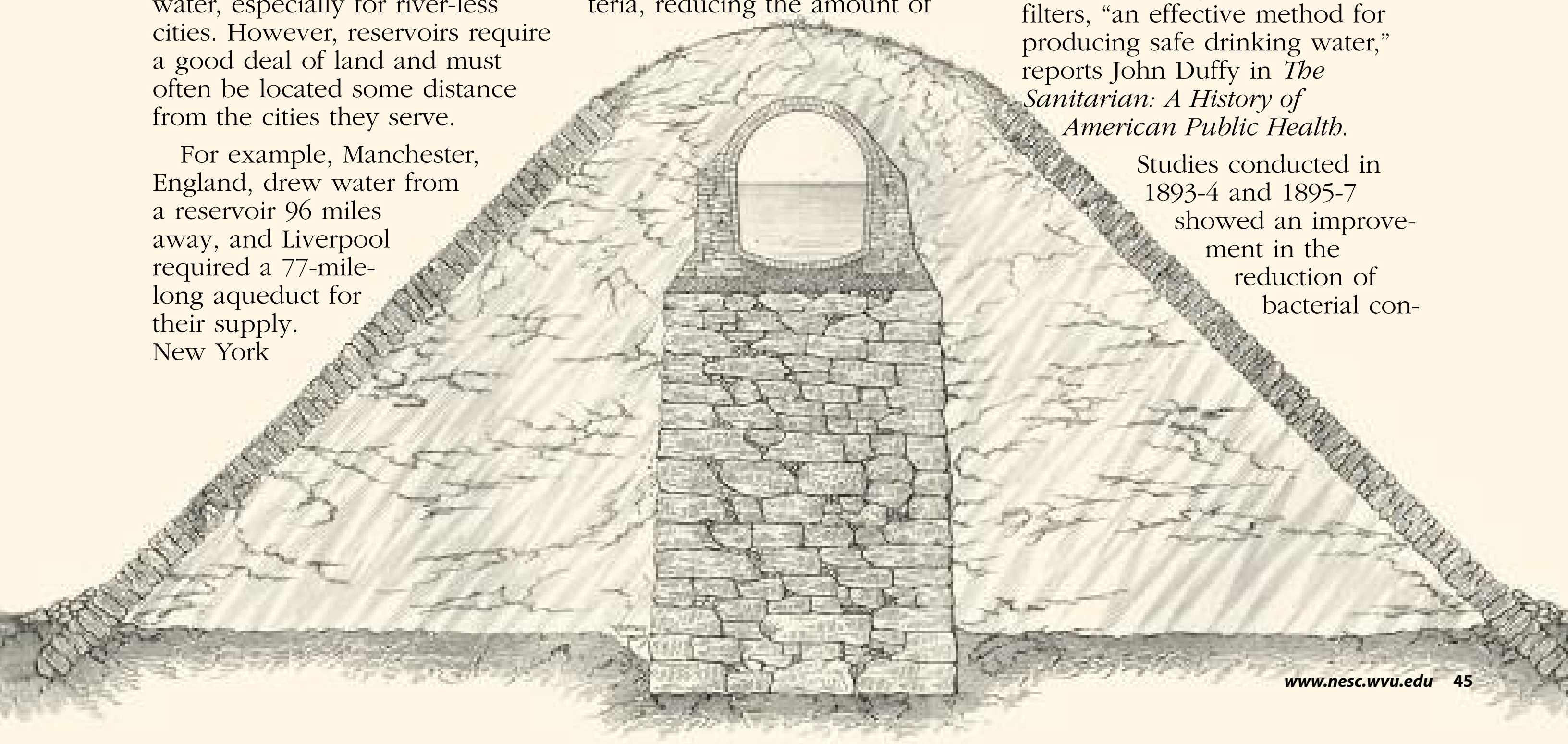
Reservoirs and aqueducts were constructed both to ensure a steady supply of water and to obtain a better quality from the source. Locating reservoirs further from the city usually led to higher quality sources because they were separated from population centers. Quality issues also affected the design of aqueducts, since covered channels or pipes provided more protection than open channels. The extra expense was offset by the fact that the water would be kept pure.

One of the great miracles of modern water engineering is that suspended solids removed from the water and trapped in the sand filters support cleaning bacteria, reducing the amount of *E. coli* in the water by up to 98 percent. Further, while engineers noticed these bacterial growths, the law requiring filtration predated germ theory development and the isolation of bacteria as disease culprits by about a decade. *E. coli* was tested for after the development of germ theory instead of more virulent strains of bacteria, because testing for *E. coli* is easier, and there is a linkage between the presence of this pathogen and the contamination of a water source with sewage. Thus, *E. coli* is known as marker bacteria for testing purposes.

Standards for water quality became more objective in the later part of the 19th century. Instead of relying on subjective matters, such as clarity or taste, a chemical standard was developed. This standard stated that water was pure if the nitrogen was in an oxidized form, but it ignored the presence of organic material in water as a test of purity.

The drawback to chemical standards was that treating for mineral salts did nothing to help prevent epidemics. It was not until the work of Louis Pasteur and Robert Koch in the 1860s that the role of bacteria in disease was determined. Furthermore it was not until 1880 that the typhus bacillus was isolated. As late as 1890, disinfection as a component of water treatment was empirically based and mostly occurred through the use of sand filters, "an effective method for producing safe drinking water," reports John Duffy in *The Sanitarian: A History of American Public Health.*

Studies conducted in 1893-4 and 1895-7 showed an improvement in the reduction of bacterial con-



The photo above shows decaying 20th century-water supply pipe. To the left, a water sump for a 19th century wind-powered system is shown.

centrations with coagulation. Coagulants had been used for personal water treatment since 2000 B.C.E. and were first used in municipal treatment in 1881 in Bolton, England, as a pretreatment for rapid sand filtration.

Earlier in the century, many prominent authorities, including Francois Arago, director of the Paris Observatory, and the Massachusetts Board of Health, protested the use of coagulants in water treatment. These authorities objected to the unknown effects caused by adding a chemical to drinking water. Their fears were somewhat alleviated by two studies performed in France (in 1838 and 1865) on aluminum sulphate, commonly known as alum, which is still the most widely used coagulant.

The Science of Treatment

It was not until chlorination became an accepted practice, though, that water treatment reached its scientific peak. Empirical engineering practice predates scientific discovery even here. As early as 1850, bleach solutions were used to treat well water under the assumption that diseases were transmitted by odor. Chlorination had been an accepted practice in sewage treatment since 1830. In 1896, chlorine was first used to disinfect water at the Louisville, Kentucky, experiment station and also used to combat a typhoid epidemic around the Adriatic Sea. These were temporary measures, and the first permanent use of chlorine occurred in 1903 in Belgium when Dr. Maurice Duyk added it before the filtration process.

Thus, during one century of development, water treatment progressed from a crude craft to a scientifically based discipline of engineering. Throughout these years, treatment methods improved from simple sand filters to an integrated, multi-step process. The philosophy behind water treatment evolved from providing the textile industry with clear water to a societal duty of protecting public health. Water quality standards improved from subjective methods to objectively determining concentrations of suspended solids and organics and keeping these concentrations below accepted allowable levels.

Interestingly, many of these advances in water treatment occurred as attempts at progress with scientific justification coming later. Indeed, some engineering advances were based on prevailing medical opinions that were flat-out wrong and yet yielded viable treatment procedures. Even more miraculous is the fact that most of the empirical attempts were evaluated on the basis of their ability to clarify water and not on potentially harmful side effects. In spite of this, the treatment methods chosen were benign and even healthful.

References

American Water Works Association. 1971. *Water Quality and Treatment: A Handbook of Public Water Supply.* Denver.

Baker, M.N. 1981. *The Quest for Pure Water.* Vol. 1. Denver: American Water Works Association.

Baylis, J.R. 1935. *Elimination of Taste and Odor in Wastewater.* New York: McGraw Hill.

Blake, Nelson M. 1956. *Water for the Cities.* Syracuse, NY: Syracuse University Press.

Bruce, F.E. 1958. "Sanitary Engineering." Chapter 14 in *History of Technology.* Vol. 5. Oxford: Oxford University Press.

Duffy, John. 1990. The *Sanitarian: A History of American Public Health.* Urbana, IL: University of Illinois Press.

Ed Winant, a member of the National Environmental Services Center technical staff, has a Ph.D. in the history of technology. This paper was originally written for work he did as a graduate student.