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The Prophylactic Landscape: Sand and Typhoid on the Merrimack River

Laila Seewang

Prologue: Sand

“The first municipal water filter of the rapid sand type was built at Somerville, NJ, and thus began its wonderful history.” [1] By 1917 the rapid sand filter was the standard defense against typhoid epidemics in the United States. fig.1 The intrinsic qualities of sand provide a plausible explanation for its success. Sand naturally filters impurities out of polluted water by trapping foreign particles between granules. Sand filters rely on a biofilm that develops on top of the sand to trap inorganic material and adsorb soluble organic particles. The main variable is the size of the grains of sand, which in turn determines the speed of water filtration. The larger the spaces between granules, the faster the water passes through, the result being that more impurities evade adhesion by the biofilm. By 1885, when the Somerville filter began operating, what would soon become known as “slow” sand filters had been operating for over half a century in Europe, as part of the new municipal water and sewage networks constructed to combat cholera. [2] In the United States, patented rapid filters developed to deliver purified water for manufacturing purposes—powering water and steam engines and processes such as dying or bleaching. Using larger sand and processing water up to forty times as fast as a slow filter meant that filter beds could be smaller, reducing the land requirements that made the European systems so costly. [3]

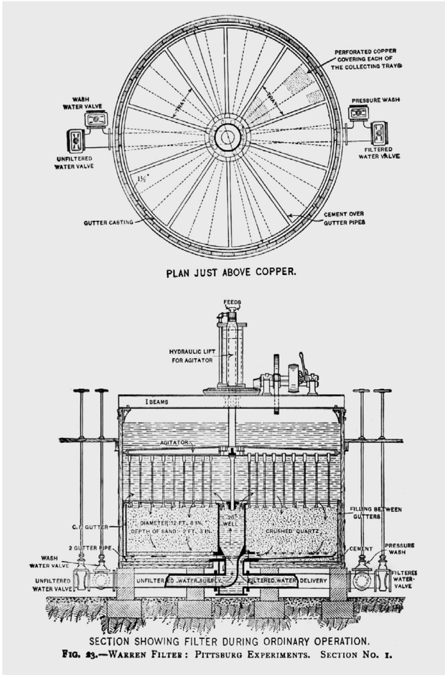

fig.1 The patented Warren rapid sand filter Source: Allen Hazen, *The Filtration of Public Water-Supplies* (New York: Wiley, 1910), 176

In 1917, the rapid sand filter was lauded as an object of technology, ensuring public health in the face of large-scale urban growth—indeed, even making it possible. But it was less clear in 1885 that this would be the case. To understand its significance, it is illuminating to consider the sand filter as the end result of a large design project that assembled a network of public health officers, scientists, mill companies, municipal governments, and typhoid bacteria—to ask how the project was synthesized into this specific form. From this perspective, the development of the rapid sand filter becomes a design process that pitched a clear motivation against an uncoordinated set of methods.

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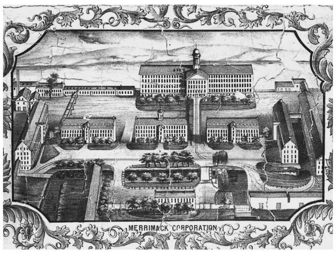
1 George Johnson, “Rapid Sand Filtration,” *Journal of the New England Water Works Association* 31 (1917), 390–473, here 390. Johnson continues, “from its very inception it established its popularity over all other hitherto attempted methods of purifying water, and has steadfastly held that position throughout the thirty-two years which have since elapsed.” He quotes statistics that in 1890, the death rate from typhoid was forty-eight per hundred thousand, and in 1917, thirteen per hundred thousand, and attributes this change almost entirely to water filtration of municipal supplies (391–92).

2 By the turn of the century, Berlin had implemented the largest network of sand filters in the world to process the entire city’s waste and had a municipal water supply system based on the extraction of groundwater passing through the naturally occurring sandy soil. But in 1885, only a handful of US cities had any kind of filtration at all—slow or rapid.

3 Johnson, “Rapid Sand Filtration,” 395.

Inland Waters

As the United States economy transitioned from seafaring mercantilism to inland manufacturing, settlements along rivers increased in both number and density. [4] The mill towns established along Merrimack River in the nineteenth century best exemplify this post-Revolutionary landscape. figs. 2 and 3 In 1828, the Boston Associates, a group of merchants-turned-industrialists, established Lowell, Massachusetts, as an industrial town, scaling up the textile mill technology from Manchester, England, to include both spinning and manufacturing. [5] By the 1850s the Merrimack River,



with its dams and canals, was the pre-coal engine that drove US textile manufacturing. Lawrence, downstream from Lowell, began in 1845 as a speculative follow-up project. The undertaking paired the construction of the United States' largest dam with the leasing of plots to mills driven by mechanical hydraulic power. Almost one hundred thousand people were crammed into the valley, producing a vast array of commodities: not only textiles but also paper, timber, leather, combs, tools, pianos, buttons, cigars, and mattresses. [6]

Lowell and Lawrence were planned as healthy working towns, with attention paid to boarding houses for female workers, churches, and schools. But water was perceived primarily as a source of power for factories, not human consumption, and the

4 Robert Dalzell details this transition from mercantilism to manufacturing in *The Enterprising Elite: The Boston Associates and the World They Made* (Cambridge, MA: Harvard University Press, 1987), 7–12. Sven Beckert describes this moment as a transition from war capitalism to industrial capitalism in *Empire of Cotton: A Global History* (New York: Penguin Vintage, 2015 [2014]), 29–55. The essay at hand is concerned with the geographical and technical changes in urban relationships with water associated with this moment.

fig. 2 The Merrimack Manufacturing Company (also known as Merrimack Mills) in Lowell, Massachusetts, ca. 1850 Photographer: unknown/Source: Lowell Historical Society

5 Lowell was named after Francis Cabot Lowell (1775–1817) of the Boston Associates, who traveled to England and Scotland in 1810 to learn about cotton textile manufacturing, primarily the power loom which, at that point, was heavily guarded technology. While cotton spinning was established in the United States as early as 1790, manufacturing with a power loom was still a British industry. Dalzell, *Enterprising Elite*, 5–6.

6 Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of New England* (Cambridge: Cambridge University Press, 1991), 205.

fig. 3 The Merrimack River at Lowell, Massachusetts, ca. 1900–1910 Photographer: unknown/Source: Library of Congress Prints and Photographs Division Washington, DC, reproduction number LC-D4–34904 towns produced typical environmental problems; unlike cities on the coast that could flush waste out to sea, the waste generated by inland mill cities had nowhere else to go but into the same river from which drinking water was extracted. Lowell and Lawrence were consistently at the top of the list for typhoid-related deaths in Massachusetts. Combined, the towns had a quarter of the population of Boston, yet also a significantly higher mortality rate: "These two cities had sixty-nine more deaths from this disease (in the twelve months) than the city of Boston with four times the population." [7] The mill towns were typhoid ground zero.

Ellen Swallow Richards (1842–1911), a scientist based at the then-newly established Massachusetts Institute of Technology, would become deeply involved in the design project. She was the first woman admitted to the institute and indefatigably championed a vision of environmental and social reform through science. She articulated the need for strategies to protect American society from invisible enemies that drew on the language of the frontier:

"Only through a belief strong enough to ride over unbelief and inertia, a belief in the value of science for personal life strong enough to make a wise choice possible, can the will to obtain a better environment be developed ... Today, belief is much more difficult than ever before because the dangers are unseen and insidious, and our enemies do not generally make an appeal through the senses of sight and hearing. But the dangers to modern life are no less than in the days of the pioneers, when a stockade was built as a defense from the Indians. We have no standards for safety. Our enemies are no longer Indians and wild animals. Those were the days of big things. Today is the day of the infinitely little. To see our cruelest enemies, we must use the microscope. Of all our dangers, that of uncleanness leads—uncleanness of food and water and air." [8]

If public health had been a religious matter governed by charity in the early part of the century, it became an economic strategy during industrialization. [9] The first committee on public health in Massachusetts convened in 1849, and the resulting report was described by their successors, over half a century later, with a touch of the characteristic boosterism of US rhetoric of the time, as "the best public document ever written in Massachusetts, and one of the great documents of the world." [10] The enthusiasm of the language speaks more of the progressive reputation that the Massachusetts Board of Health would later acquire but obscures the slowness of that progress. People—human density, poor living conditions, and individual morality—were seen as the site for intervention, rather than the environment at large.

7 Hiram Mills, "Typhoid Fever in Relation to Water Supplies," *Twenty-Second Annual Report of the State Board of Health of Massachusetts* (Boston, MA: Wright & Potter, 1891), 525–47, here 528.

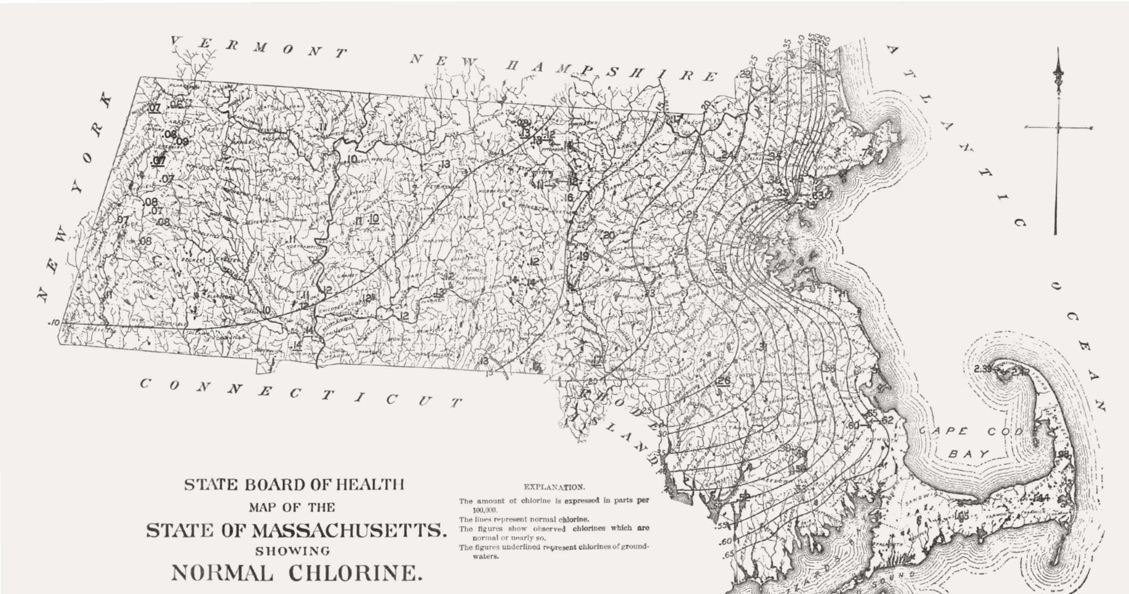
8 Ellen Richards, *Euthenics: The Science of Controllable Environment. A Plea for Better Conditions as a First Step Toward Higher Human Efficiency* (Boston, MA: Whitcomb and Barrows, 1910), 28.

9 Dorothy Porter, *Health, Civilization and the State: A History of Public Health from Ancient to Modern Times* (New York: Routledge, 1999), 46-61, 109, and see 148-155 on the development specific to the United States in this period; Barbara Gutman Rosenkrantz, *Public Health and the State: Changing Views in Massachusetts, 1842–1936* (Cambridge, MA: Harvard University Press, 1972), 113–14.

10 Massachusetts Department of Public Health, *The State Board of Massachusetts: A Brief History of its Organization and Its Work* (Boston, MA: Wright & Potter, 1912), 7. In 1930, Massachusetts's key role in the development of US public health policy was still legendary. One article closes with the statement, "it may truly be said that Massachusetts was the cradle of public-health engineering." Harrison P. Eddy, "Massachusetts: The Cradle of Public-Health Engineering," *Sewage Works Journal* 2, no. 3 (July, 1930), 403.

It was not until 1869 that a Board of Health was established and, reflecting the prevailing conception of health as a moral and philanthropic concern, within the decade it had been merged to become the Department of Health, Lunacy, and Charity. It was not until 1886 that the Massachusetts Board of Health was reorganized as an independent body under the guidance, for the first time, of a physician, signaling "the substitution of scientific for ethical objectives." [11] The new board was charged with advising "towns, corporations and individuals in regard to the most appropriate source of supply for their drinking water and the best method of assuring the purity thereof and disposing of their sewage." [12] In addition, it embarked upon two investigative projects: a map and an experimental station, both closely involving Ellen Swallow Richards.

The board contracted the laboratory for sanitary science at the Massachusetts Institute of Technology, the first in the world, to conduct a two-year sanitary survey of the Commonwealth's waters, performing chemical analysis on each source. Richards was in charge of the work, under the direction of Dr. Thomas Drown, and spent two years supervising the collection and analysis of approximately forty thousand water samples from across the state. [13] The results were compiled as a map, the Normal Chlorine Map, for the state of Massachusetts—a project that would later be replicated by other states. fig. 4 The map was a stock-take of the health of water resources that fell within the state's jurisdiction. The map



interpreted Richards' results as a territory of aqueous risk, with isochlors, or lines of equal chlorine content in water bodies, covering the state. Any water source that contained higher amounts of chlorine than shown on this map indicated human pollution: the extra chlorine came from ingested salts in humans or animals

11 Rosenkrantz, *Public Health and the State*, 178.

12 "1886 Chap. 0274. An Act to Protect the Purity of Inland Waters," Special acts and resolves passed by the General Court of Massachusetts (Boston: Secretary of the Commonwealth, 1886).

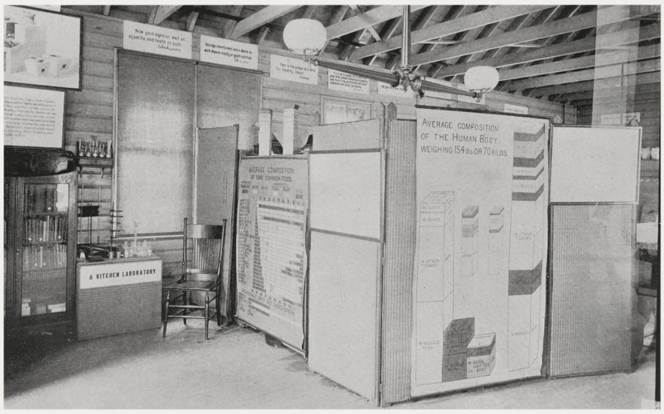
13 The findings were published in the *Twenty-Second Annual Report of the Massachusetts Board of Health* (Boston, MA: Wright & Potter, 1891). The State of Massachusetts is still officially recognized as a commonwealth, but for the sake of clarity, "state" will be used for the remainder of this essay.

fig. 4 The Normal Chlorine Map for Massachusetts
Source: Insert in Ellen Richards and Alpheus Woodman, *Air, Water and Food from a Sanitary Standpoint* (New York: Wiley, 1909), 60–61 [no page or plate number, bound insert]

that had been passed through the body but could not be absorbed into the earth and ended up in waterways. 14 Cut off at the state boundary, the map did not aid an understanding of watershed ecology—although Richard's misgivings about this are hinted at in her tentative continuation of some rivers into the void beyond state lines—but rather devised a new way of seeing the territorial background, establishing baselines that could reveal unusual levels of pollution. The map, simplified as it was, established a general field upon which specific causes could be discerned. Whereas during the heyday of the mill towns, workers—especially immigrant laborers—were blamed for epidemics, increasingly "knowledge of specific agents or conditions became identified as the cause of preventable disease … personal behavior became less important as the determinant of susceptibility." 15 More than a survey, the map offered a conceptual environment that became a precondition for the development of environmental technologies that would intervene in this landscape.


RUMFORD KITCHEN.

Despite her pioneering research, Richards' other scientific endeavors still emphasized the responsibility of individuals to educate themselves about environmental hazards. Her work on what she called the science of Euthenics was represented as part of the World's Columbian Exposition of 1893. While the Board of Health's Hiram Mills (whom we will encounter again) was working furiously on the fair's failing experiment in sewage filtration, Richards and Mrs. John Abel installed the Rumford Kitchen, a model kitchen sponsored by the Bureau of Hygiene and Sanitation that introduced the public to the architecture of the scientific and sanitary kitchen. In her own words, "the intention of the exhibit was to illustrate the present state of knowledge in regard to the composition of materials for human food, the means of making these materials most available for nutrition, and the quantity of each necessary for a working ration." 16 Visitors to the kitchen could purchase, for a small fee, a healthy meal based upon one quarter of a day's



RUMFORD KITCHEN INTERIOR,—A Second View.

14 Folded insert, United States Government Planning Office, *United States Congressional Serial* Set 12 (Washington, DC: Government Printing Office, 1905). Background levels of chlorine steadily drop from a high content (due to salty sea breezes) at the coast to a much lower content inland.

fig. 5 The Rumford Kitchen at the 1893 World's Columbian Exposition, exterior Source: *Report of the Massachusetts Board of World's Fair Managers* (Boston: Wright & Potter, 1894), 40–41 [no page or plate number, bound insert]

15 Rosenkrantz, *Public Health and the State*, 73

fig. 6 The Rumford Kitchen at the 1893 World's Columbian Exposition, interior (partial) Source: *Report of the Massachusetts Board of World's Fair Managers* (Boston: Wright & Potter, 1894), 44–45 [no page or plate number, bound insert]

16 Ellen Richards, letter to the Massachusetts Board of the World's Fair Managers, December 27, 1893. Massachusetts Board of Managers, World's Fair, *Report of the Massachusetts Board of World's Fair Managers* (Boston, MA: Wright & Potter, 1894), 43.

rations. Accompanying the kitchen were also posters, charts, diagrams, books, and menus that educated the public on proper nutrition.

The exterior of the Rumford Kitchen resembled a homestead, but the interior had been transformed into a teaching laboratory that revealed different aspects of food preparation and consumption. One small area resembled a cramped kitchen sink that, instead of a pile of dishes, contained small glass bottles. Test tubes and pipettes lie in place of a drying rack with clean dishes. The nutritional value of different foods, or "materials," could be assessed on a nearby chart. **figs. 5 and 6** There was nothing intuitive about how the space was to be used in the scientific kitchen; it required, as displayed by the books and lessons occupying the interior, a rigorous re-education in home science. Municipalities might protect the drinking water that entered this space, but it was only with the aid "of scientifically trained women ... brought into service to work in harmony with the engineer who has already accomplished so much" that the same vigilance over the food "materials" that entered this space and the ways in which they were handled could be guaranteed. [17]

fig. 7 Cropped image of a map of the Lawrence Experiment Station on the old Essex Company land Source: *Atlas of the City of Lawrence* (Springfield, MA: L.J. Richards, 1896), courtesy of the Lawrence History Center

Richards transferred chemical science from the environment to the domestic realm in characteristically graphic terms:

"Instead of blaming water supplies, dusty streets, or even contagion by the breath, sanitarians are everywhere putting emphasis upon the actual contact of moist mucus with milk and other food, in preparation or in serving. It is not a supercilious notion to examine tumblers for finger marks, or to object to the habit of wetting the finger with saliva in turning leaves of books. These little unclean acts are the unconscious habits that cling to a person in spite of education from reading." [18]

In 1882 she published *The Chemistry of Cooking and Cleaning: A Manual for Housekeepers*, promoting good nutrition, "pure" foods, proper clothing, physical fitness, and especially sanitation, as efficient practices for environmental management. [19] Her work can thus be seen as an educational campaign urging people to protect their bodies in many small ways from latent environmental danger. But it did so when bacteriology in Europe was already leading to the notion that public health protection had to be offered at a larger scale by the state.

Instead of educating people, the board would need to undertake a massive environmental design project. The second project undertaken by the new board would experiment with implementing water infrastructure at the civic scale that had already been established in Europe. It addressed the third of its charges under the Inland Waters Act: "collecting information

17 Richards, *Euthenics*, 138. "The following pages will deal chiefly with such portions of the subject of Sanitary Chemistry as come directly under individual control, or which require the education of individuals in order to make up the mass of public opinion which shall support the city or state in carrying out sanitary measures ... The Federal Department of Labor has studied workingmen's houses, but living in the house has not been worked up. The housewife has no station to which she may carry her trials, like the experiment stations which have been provided for the farmer." Ellen Richards and Alpheus Woodman, *Air, Water and Food: From a Sanitary Standpoint* (New York: Wiley, 1909), 1.

18 Richards, *Euthenics*, 100.

19 Ellen H. Richards, *The Chemistry of Cooking and Cleaning: A Manual for Housekeepers* (Boston, MA: Estes & Lauriat, 1882) in regard to experiments … made upon the purification of sewage." [20] In 1886 it established the Lawrence Experiment Station on Essex Company land, and it is here that Ellen Swallow Richards worked in a collaborative team with not only other chemists but also with a new breed of scientist: bacteriologists. The station was located on a spit of land in the Merrimack River and gradually grew from one shed and a sandpit into a seemingly haphazard collection of uninsulated weatherboard structures surrounding tanks of sand. figs. 7, 8, and 9 If brick was the material that defined the architecture of the industrial town, the laboratory sheds that would shape the future of industry were a kind of exercise in timber vernacular, descendants of the pioneer timber shed, the shack, the lumberman's cottage. If the Normal Chlorine Map had dovetailed with the aesthetics of the frontier landscape, the station appropriated its architecture. But now the architecture housed the most advanced sanitary laboratory in the United States. The interiors were highly organized into clear surfaces and a dizzying array of storage options. The spaces were designed around the use of glass containers: jars, test tubes, pipettes, beakers, glasses supported by smaller timber contraptions. The site at large was landscaped into holding tanks, basins, pipes, embankments, and gullies. The pioneer sheds of the station provided the studios in which the prophylactic landscape was designed.

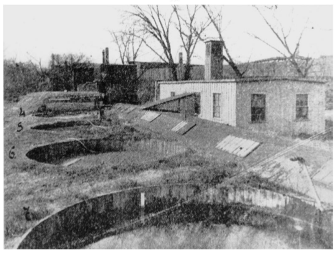


fig. 8 Lawrence Experiment Station, exterior, ca. 1900–1910 Source: courtesy of the Lawrence History Center

fig. 9 Lawrence Experiment Station, interior, ca. 1900–1910, Source: courtesy of the Lawrence History Center

Hiram Mills is the figure who first brought together private industry, public health, and academic science at Lawrence to activate Richard's new chlorinated territory. He had been Chief Engineer at the Essex Company, and later Chairman of the Committee on Water Supply and Sewerage at the Massachusetts Board of Health, and had been set the task of cleaning the water the Essex Company had done so much to pollute. The modest funding Mills acquired was spent on staff: initially, a chemist, a biologist, a bacteriologist, and two assistants, all from the Massachusetts Institute of Technology. By 1886, bacteriology had established itself upon the success of germ theory that was initiated with John Snow's research in London and developed by the work of Louis Pasteur and Robert Koch. [21] Taken together, this work revolutionized how the environment was conceived: environmental threat no longer resided in miasmatic air but in viruses and bacteria that could contaminate water. It was a rapidly advancing science: in 1883 Koch identified the *Vibrio cholerae*, and in 1884 the pathologist Georg Gaffky had

20 „Water Supply and Sewerage", *Nineteenth Annual Report of the State Board of Health of Massachusetts* (Boston, MA: Wright and Potter, 1888), 2–66, here 66.

21 John Snow's work first identified the risk of contaminated water as a potential source of contagious disease. He began publishing on the topic of cholera and its transmission through water in 1849: John Snow, *On the Mode of Communication of Cholera* (London: John Churchill, 1849). By 1854, he had identified contaminated drinking water, namely the Broad Street Pump, located next to an old cesspit, as the source of London's 1854 epidemic. John Snow, "On the Communication of Cholera by Impure Thames Water," *Medical Times and Gazette* 9 (1854), 365–66.

confirmed Karl Eberth's discovery of the typhoid bacteria, the *Salmonella enterica enterica, serovar Typhi*.

The research performed by the team at the station aimed to apply science to engineering technologies, and the primary means for doing so was sand. A variety of pollutants, ranging from blood to soap, sugar, and salt, were added to approximately fourteen tanks of sand to measure nitrification — nitrogenous organic matter being a chemical indicator of the presence of bacteria. The success of sand at filtration depended upon careful preparation and regular maintenance. It was first sifted through a series of increasingly fine sieves, then divided into portions by beaker elutriation, weighed, and its range of granule sizes measured, as much as possible, making irregular grains of material statistically regular. Once in service, it needed to be cleaned and replaced regularly to ensure the biofilm's effectiveness. Each grain of sand was subject to scrutiny. Beyond the size of the grain of sand, which was measured along three axes, the team chemist, Allen Hazen, noted that the "amount of open space depends upon the shape and uniformity … and is independent of their absolute size." [22]

The research was the first of its kind in the United States. But quickly, the research into filtering sewage took a very specific turn. By 1890, new facilities had been built that added a biological laboratory to the existing chemical laboratories. At around the same time, the station turned from studying the chemical components, or molecules, within water as indicators of bacteria to the study of bacteria themselves, as biological species, shaped like "a rod with rounded ends … and fine hair-like appendages." [23] In order to do this, sand, instead of being asked to filter out pollution in general, would now have to filter out specific bacteria. From today's perspective one cannot help but recognize a kind of irony: situated on one of the most foully abused waterways of the nineteenth-century United States, the work nonetheless would unintentionally begin to recast chemical waste, dyes, and industrial pollution as non-threatening in its hunt for the *Salmonella Typhi* bacteria. But first, people had to find where it originated, how it interacted with its environment, and how it was transmitted.

A fortunate, if tragic, opportunity in the quest to separate industrial pollution from malevolent bacteria presented itself in December when station biologist William Sedgwick traveled to Lowell to identify the cause of a new typhoid outbreak. Citizens in Lowell popularly attributed it to the water supply system, but local experts contested this, since Lawrence, nine miles downstream, also drew its water from the Merrimack and was not at

22 Allen Hazen et al., "Experiments on the Purification of Sewage and Water at the Lawrence Experiment Station: November 1, 1889, to December 31, 1891," *Twenty-Third Annual Report of the State Board of Health of Massachusetts* (Boston, MA: Wright & Potter, 1892), 425–601, here 432.

23 Mills, "Typhoid Fever," 525. Mills continues: "it may not be unreasonable to think of the invisible kingdom of bacteria as consisting of as many species as the visible vegetable kingdom and all of them doing as beneficent work, in the economy of nature, as the trees and plants which we see around us; but there is a small fraction, perhaps comparable with the small number of poisonous plants, which are disease producing."

that time experiencing an epidemic. Both towns had municipal water systems that alleviated residents' reliance upon independent wells and potentially polluted groundwater reserves, which since mid-century had been identified as a risk. 24 Given that only Lowell, and not Lawrence, was experiencing the epidemic when Sedgwick was called to investigate, local authorities favored the explanation of contaminated milk. Just as Snow had done before him, Sedgwick designed a survey and went house to house conducting interviews. Plotting personal testimony onto maps, he was able, geographically and chronologically, to trace the epidemic back to a "menacingly-positioned privy" in North Chelmsford. 25 figs. 10 and 11 Beginning with two mild cases in August—teenage girls working in a wool-scouring mill—the pandemic began when Case IV, as Sedgwick described him, contracted typhoid at the iron foundry and then spent a full day in a privy hovering over the Stoney Brook, "a small and often very foul stream emptying into the Merrimack," before dying shortly afterwards. 26 Like a detective, Sedgwick tracked down the bacteria's furtive movements, which revealed a remarkable resilience: the sturdy typhoid bacteria had traveled from Stoney Brook to the Lowell waterworks intake, through Lowell's water system, into its sewer system, nine miles down the river to Lawrence's waterworks intake, and finally made its way to the inhabitants of Lawrence. It was known that Lowell's sewers emptied, unfiltered, into the river only nine miles upstream from Lawrence's waterworks intake, but the delay was what had foiled experts: when Sedgwick arrived in Lowell, the bacteria was still on its way to Lawrence in the icy water and would contaminate that city's water supply only three weeks later.

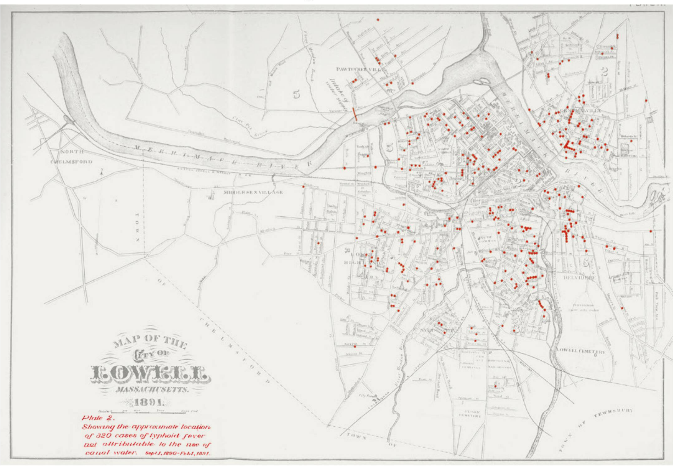


fig. 10 William Sedgwick's survey shows the cases of typhoid not attributed to the suspected canal water
Source: Plate 2 from William Sedgwick, "On Epidemics of Typhoid Fever in the Cities of Lowell and Lawrence," in *Twenty-Fourth Annual Report of the State Board of Health of Massachusetts* (Boston, MA: Wright & Potter, 1893), 667–704

Mills reported in 1891 that the station's main task regarding typhoid was to study "how it can get into the [environmental] system and under what conditions it can live outside of the human body." 27 Between 1890 and 1891, experiments were made by surrounding a bottle of typhoid-laden water with ice to see how long the bacteria, which bred at human body temperature, would survive in freezing temperatures. Other tests included injecting potatoes and milk with the bacteria and numerous sewage filtration experiments with sand aided by a variety of chemicals. By 1893, the station was using more than fifty

24 Mills, "Typhoid Fever," 527, 528. The two towns combined had only a quarter of the population of Boston, yet in 1890 had sixty-nine more deaths from typhoid fever.

25 William Sedgwick, "On Recent Epidemics of Typhoid Fever in the Cities of Lowell and Lawrence due to Infected Water Supply, with Observations on Typhoid Fever in Other Cities," in *Twenty-Fourth Annual Report of the State Board of Health of Massachusetts* (Boston, MA: Wright & Potter, 1893), 667–704, here 681. For a description of Snow's mapping process, see Steven Johnson, *The Ghost Map: The Story of London's Most Terrifying Epidemic—and How it Changed Science, Cities, and the Modern World* (New York: Riverside Books, 2006), 193–213.

26 Sedgwick, "On Recent Epidemics," 679. On January 10, 1891, Mills wrote of the findings to the Mayor of Lawrence, and stated that they should immediately inform residents to boil water before drinking. On April 10, 1891, Sedgwick presented a report to the city's water board, informing them of his findings. William Sedgwick, *A Report upon the Sanitary Condition of the Water Supply of Lowell, Mass.* (Lowell: Vox Populi, 1891).

27 Mills, "Typhoid Fever," 525.

filtration tanks to track the bacteria through sand. They were able to show how sand could function as a suitable filter for sewage before it entered a watercourse by removing at least 99.99 percent of harmful bacteria. [28] In 1892, Hazen, writing on behalf of Mills, summarized the refinement in purpose:

"Our attention has been specially directed toward the bacteria. In sewage purification the removal of the organic matters capable of putrefaction is often of the greatest importance; but in the filtration of sewage-polluted water—water capable of causing disease—the removal of germs of disease is the all-important point." [29]

This impacted the parameters that had been guiding the selectionof sand at the station.

Previously, experiments with sand at the station had been concerned with removing organic matter from sewage. The typhoid

Fig. B. Privy of Foundry, overhanging Stony Brook, North Chelmsford, a Feeder of the Water Supply of Lowell. Point of Infection by T. L., (Case No. IV.)

fig. 11 The site where the 1890–1891 Lowell and Lawrence typhoid epidemic began Source: Figure B from William Sedgwick, "On Epidemics of Typhoid Fever in the Cities of Lowell and Lawrence," in *Twenty-Fourth Annual Report of the State Board of Health of Massachusetts* (Boston, MA: Wright & Potter, 1893), 667–704, plate inserted between 678 and 679

bacteria experiments led scientists at the station now to tailor the porosity of the sand filter specifically to this new biological enemy. It certainly seems as though the changing demands placed on sand paralleled a shift in responsibility from chemists to biologists, specifically bacteriologists. More concretely, the work also began to suggest a different field for prophylaxis than Richard's emphasis on "little unclean acts." [30]

Despite the diagnostic success, there were few instruments available for forcing a reduction in water pollution at its source. All the towns along the Merrimack, after lobbying from the Boston Associates' related companies, had been grandfathered out of compliance with the water pollution laws of 1876, making the laws

28 Hazen et al., "Experiments," 601.

29 Hazen et al., "Experiments" 601.

30 Richards, *Euthenics*, 100.

useless where they were most needed. It is hard to know if legislative roadblocks were the cause, but soon after the epidemic on the Merrimack between 1890 and 1891, the station turned its attention from technology for filtering sewage outflows to filters for drinking water: that is, for filtering inflow. In 1891, the station hired Sedgwick's student, George Fuller, to transfer sand filter technology to drinking water. He had already spent a year in Germany, working with engineers at the Berlin waterworks learning about slow sand filtration for drinking water. In 1893, instead of installing a sand filter for Lowell's sewer system, a slow sand filter was installed for the municipal water supply in Lawrence. City residents were now protected from typhoid, even if the source of their jobs had moved on to other places, and the river remained polluted.

Epilogue: From Filtration to Purification

In 1894, George Fuller was called to Louisville, on the Ohio River, to test seven different mechanical filters for the drinking water supply of the city. There, he turned his attention to the patents of private companies who provided water filtration for industrial, not municipal, purposes: a technology created for factories and mills, not for human consumption. None of the models were suitable. These filters utilized mechanical aids to clean the sand for the filters, eliminating the intensive manual labor of cleaning slow sand filters. But because of the large gaps between sand, many particles evaded capture. The sand for the American filter began to acquire very specific demands. The search for the "right" sand—the right grain size in particular—led to sand being brought from faraway Roslyn and Oyster Bay on Long Island, New York, and Hanover, New Jersey. [31] But despite the years of research that had gone into sand, ultimately what Fuller introduced to the filtration process was coagulation. Coagulation, the grouping together of smaller particles into particles large enough to be caught by the sand filter, was achieved by adding ammonia sulfate to water before it reached the filter. It was considered particularly necessary in Midwestern cities located on heavily sedimented rivers. By increasing the amount of sediment collected in filtration, coagulation increased the amount of potentially dangerous bacteria captured too, but it was largely an aesthetic requirement. Adding chemicals to drinking water meant that Fuller no longer felt he could call the end product filtered water but purified water. Somerville, New Jersey, was listed as the first implementation of a patented Hyatt mechanical filter in 1882, coupled three years later with coagulation—the indirect product of Fuller's research.

31 "It was specified that the filtering sand, which is 30ins. in thickness, should have an effective size within the limits of 0.35 to 0.42 millimeters, with a uniformity coefficient of not more than 1.50. Not more than 1 percent, by weight, of the sand was allowed to be finer than 0.25 millimeters, and not more than 0.2 percent finer than 0.20 millimeters. Considerable difficulty was experienced in getting suitable sand. The two sand dealers with whom the contract was placed by the Filtration Company failed to deliver the material, and the commencement of operations was delayed fully one month, during which time the joint efforts of all concerned were devoted to securing suitable sand from any available source. Part of the sand came from near Oyster Bay and Rosyln on Long Island, New York, and part from Hanover, New Jersey. The difficulty consisted principally in getting sand from which the fine material was properly eliminated … Sand screening at the several places was watched by representatives of the Water Company, and Allen Hazen … in the interests of the Water Company, also advised." George Fuller, "The Filtration Works of the East Jersey Water Company, at Little Falls, New Jersey," *Transactions of the American Society of Civil Engineers* 50 (June 1903), 394–443, here 416.

The first fully operating system to adopt Fuller's recommendations for municipal consumption was installed at Little Falls, New Jersey, in 1902. An area was set aside by the Passaic River for both concrete settling and coagulation tanks where ammonia sulfate from the Pennsylvania Salt Manufacturing Company was added. These tanks could process 1.75 million gallons of raw river water in less than an hour and a half. [32] From here the water passed down to concrete filter tanks containing the sand, which were mechanically agitated using compressed air. Water passed through the sand into a pipe gallery that fed into the city mains.

At this time, the effective benefits of rapid filtration with coagulation were still being debated. John Hill, a hydraulic engineer who built three municipal filters for US cities in this period, presented the sole dissenting voice regarding adding chemicals to water supplies in a testimony to the Washington, DC, Board of Health in 1910, stating that "I think I reflect the sentiment of the people of Cincinnati when I say that they are opposed to the use of chemicals in the water supply. That position has been taken by a number of public bodies." [33] Hill showed that any miscalculation in the amounts of chemical added to the water led to serious stomach ailments, none of which had been systematically studied. But his preference for slow filtration in the service of public health was nonetheless defeated on economic grounds, particularly because of the maintenance required to treat the sand.

Initially, inland waters were still the primary location for the rapid sand filter. In his own testimony at the hearings over Washington, DC's, water, Fuller divided the country into two areas: those whose reasonably clear waterways were based upon glacial drift (such as New England) that could benefit from slow sand filtration without coagulation; and regions, primarily in the South, where clay-based waters in non-glacial geological formations would always contain fine clay particulates requiring chemical treatment. [34] By the time George Johnson wrote his history of the technology in 1917, the United States had committed to it fully. For all the work performed on grains of sand, ammonia turned out to be the catch-all solution for protecting people against infected inland waters. Cincinnati had the largest version, and other major towns to install rapid filters included Columbus, Ohio; Pittsburgh and Harrisburg, Pennsylvania; Little Falls, New Jersey; Washington, DC; and New Orleans, Louisiana. [35] The technology had come to represent the primary method of bacterial defense in urban infrastructure. Instead of eliminating pollution from the environment, then, the rapid sand filter inserted itself as a prophylaxis between the domestic drinking supply and the environment, for which nothing could apparently be done.

32 Fuller, "The Filtration Works," 402.

33 "Statement of John W. Hill," in Charles Moore, ed., *Purification of the Washington Water Supply* (Washington, DC: Government Printing Office, 1903), 72–82, here 77.

34 "Statement of George W. Fuller," in Moore, *Purification*, 40–52, here 41.

35 Johnson, "Rapid Sand Filtration," 401–26. Rapid sand filters based on chemical coagulation were subsequently installed internationally, from Alexandria to Kyoto.

In doing this, it joined the list of inventions that form "the invisible shield, one that has been built, piece by piece, over the last few centuries" resulting in a progress "measured not in events, but nonevents: the smallpox that didn't kill you at age 2; the accidental scrape that didn't give you a lethal bacterial infection; the drinking water that didn't poison you with cholera." [36]

36 Steven Johnson, „How Humanity Gave Itself an Extra Life," New York Times Magazine, April 27, 2021, www.nytimes.com/2021/04/27/magazine/global-life-span.html (accessed May 28, 2021).

As with any design project, there were of course alternative paths not taken. Berlin's municipality purchased huge tracts of land for slow sand filtering of sewage. Although no longer in use, they now form a green periphery of small farms and parks. New York City has the largest filter-free water system in the United States: in 1997, the city embarked upon a major campaign of at-source pollution reduction for the enormous Catskill-Delaware watershed, with farmers and industries working together to combat pollution before it gets into the water supply system. The Hudson landscape today resembles the pastoral landscape paintings of the Hudson River School's paintings even more than it did in the nineteenth century. By contrast, the sites of the rapid sand filter—Little Falls, New Jersey, the Ohio River, the Passaic—present a kind of post-industrial sublime. The Passaic and the Meadowlands are only two of thousands of designated Superfund sites, where governments have spent millions on removing toxicity from the land after industrial profit has moved elsewhere.

Many cities in the nineteenth century were confronted with the same problem—the battle against epidemics in dense industrial settlements. While Germany, England, and France invested their public health institutions with the authority to implement sanitary measures during epidemics, including mandatory surveys, centralized health and mortality statistics, and quarantines, the peculiarity of the American response was that public health research was a state concern notably innovative in research but notoriously lax in implementation. [37] Limitations to enforcement forced adaptation in the American response: from the rapid sand filter, to the Rumford Kitchen, and the Normal Chlorine Map. Resistance to regulation was part of the "freedom" that settlers, and after them, industries, expected of this wilderness. It was politics, rather than geology, that ultimately determined the failure to treat sewerage at its source. The success of the rapid sand filter was that it enabled a detachment between the problems of environmental pollution and safe drinking water. The rapid sand filter's history was "wonderful," precisely because it facilitated massive urban growth in spite of governments impotent to stop waste being dumped into rivers.

37 Federalism meant that States and Commonwealths implemented community health measures independently, but implementation in itself is hardly the correct term. John Duffy, *The Sanitarians: A History of American Public Health* (Urbana: University of Illinois Press, 1990), 138–39, 163.