

## The Microbe Solution

In the hot, dry summer of 1858, the Thames was a stew of sewage that festered in the sun, giving off an unbearable stench. “We believe this to be the uncleanest, foulest river in the known world,” wrote a London pundit in July. “There you shall see in the brief space of half an hour and two or three miles, a hundred sewers disgoring solid filth, a hundred broad acres of unnatural, slimy chymical compost . . . The water—the liquid rather—is inky black.”<sup>1</sup>

Dockworkers suffered nausea, headache, sore throats, temporary blindness—some of them fainted from breathing in the river’s aroma.<sup>2</sup> In the newly rebuilt Houses of Parliament, on the riverbank, legislators choked on what the press labeled “the Great Stink.” The Thames had been badly polluted for decades, but the heat and low water that summer brought the situation to a crisis. Benjamin Disraeli, leader of the House, held a handkerchief over his nose as he fled from the Chamber, complaining that the Thames had become a “Stygian Pool.”<sup>3</sup> In July 1858, he introduced a law that authorized the construction of a costly new sewer system, designed by engineer Joseph Bazalgette, that would carry London’s waste downstream of the city.

Britain’s rivers were overwhelmed with sewage, its cities bursting at the seams. Between 1801 and 1841 London’s population had grown from 958,000 to 1,948,000. Numbers of people living in smaller cities like Leeds, Bradford, and Huddersfield doubled or tripled in the same span of time. While the same pattern held in other European and American cities, geography made the problem more intense in Britain, where the rivers were too small to carry off the wastes of the towns that sprouted on their banks. In 1885, engineer James Gordon estimated that dumping the raw sewage of the major towns along the Rhine would give that river a concentration of only one part sewage per 2,345 parts water. The lower Lea, a tributary of the Thames whose upstream flows had been diverted to provide drinking water for London, was by contrast composed of two-thirds sewage.<sup>4</sup>

The extreme pollution took a heavy toll on aquatic life. An overload of nutrients in raw sewage fueled algal blooms that created oxygen-depleted dead zones, suffocating fish. The last Thames salmon was caught in 1833. By 1890, nine thousand river basins in England and Wales were devoid of fish. The River Almond in Scotland was inundated with waste from shale oil works, and flames thirty feet



**Figure 3.1** Monster Soup: A woman drops her teacup in horror after viewing the microscopic beasts in a drop of polluted Thames River Water. Drawing by William Heath, 1828. Courtesy of Wellcome Library.

high were reported rising from its waters—a phenomenon that would be echoed decades later on the burning surface of the Cuyahoga River in Ohio.

Sewage was a pressing problem in nineteenth-century Britain, at a time when the idea that microbes could both cause disease and digest sewage was not understood. Politics dominated science, a pattern that has been repeated during struggles to protect water quality ever since. Experts were recruited to argue for interested parties in court cases and at government hearings, often shading their testimony to fit the cause of their clients. Progress toward solutions to the crisis was also impaired by widespread beliefs that now seem quaint but at the time inspired intense argument over matters that truly meant life or death for both rivers and the people who lived along them.

One such idea was the theory of zymotic disease, which held that decay was catching. In dead matter, some experts argued, contact with oxygen or anything already rotting caused complex organic molecules to begin to shake themselves apart. Putrefaction could cause disease if the vital force in a living creature was weaker than the disturbance caused by contact with rot. “The essence of the concept of zymotic disease,” notes the historian Christopher Hamlin, “was that disease was a spreading internal rot, that it came from an external rot, and that it could be transferred to others.”<sup>5</sup>

The influential chemist Justus von Liebig was a strong advocate of the zymotic disease theory, but he also understood that decay was an inevitable part of natural cycles. Plants needed nutrients from rotted organic matter to grow—he was

among the first to understand that crops require minimum amounts of specific elements, including phosphorus and potassium.

Edwin Chadwick, the famous cheerleader for water closets and modernized sewers, believed that decay was an evil that should be kept away from humanity at all costs. The only place for sewage or anything else liable to rot was in the soil; there human waste could feed crops, but only if it reached the farm in a fresh condition. In Chadwick's view, sewage needed to flow quickly away from houses and towns. Disease arose from the smelly gases generated by organic matter putrefying in stagnant sewers. At an 1870 meeting of the Institution of Civil Engineers, Chadwick described, in approving tones, the sight of fresh feces and toilet paper flowing into the Thames from newly built, self-cleansing tubular sewers at Croydon. In his eyes this was a vast improvement on the homogenized brown muck that oozed from the antique sewers in London, where waste sat in stagnant pools until a rainstorm washed it down to the river. Chadwick was certain that Croydon's unrotted waste would fertilize the river, just as it could fertilize farmland if it were piped there. "Whilst old sewage that was putrid killed fish, sewage that was fresh fed them," he declared. At Carlisle, after new tubular sewers were installed, Chadwick claimed that "the fish were not only increased in quantity by greatly improved in quality. Anglers now found their best sport at the mouths of the tubular outfalls discharging sewage fresh."<sup>6</sup>

The notion that decay was an inevitable part of nature's cycles disturbed many who believed in natural theology, which held that a benevolent Creator had designed the world for humanity's use. This philosophy led its adherents to tie themselves in some intriguing intellectual knots.<sup>7</sup>

In the midst of London's Great Stink, William Odling, a chemist and health officer to the Vestry of St. Mary, Lambeth, argued that the expense of the new London sewer system proposed by engineer Joseph Bazalgette was not needed, because microscopic animalcules in the water would devour the organic matter in sewage, rendering the Thames clean. These tiny creatures would magically prevent the gunk fouling the river from putrefying, and cause it to vanish.<sup>8</sup>

Like other believers in natural theology, Odling refused to let the foul reality of the Thames change his conviction. It would take the combined impact of the two major advances in biological science of the late nineteenth century—Darwin's theory of natural selection, along with the discovery that microbes could cause disease—to loosen the chokehold of natural theology on many Victorian minds. (As a young man, Darwin himself had accepted that all things in Nature were designed by a benevolent Creator.)<sup>9</sup>

Because decay seemed contrary to this divine order, British sewage experts would long strive to prevent the decomposition of sewage—a hopeless ambition that prevailed in the years before the basic ecology of bacteria was understood. When oxygen is abundant, aerobic bacteria decompose organic matter into harmless, odorless components: carbon dioxide, nitrates, and water. This is the process at work in every modern sewage treatment plant, as it is in every healthy river, bay, or wetland. In the absence of oxygen, anaerobic bacteria dominate—and while they too break down organic matter, they do so through a different

chemical process that releases the nasty-smelling gas hydrogen sulfide, the source of the rotten-egg stink of polluted waters. The Victorians called this odiferous process “putrefaction.” They were both surrounded and horrified by it.

Parliament approved Bazalgette’s plan, and construction of his sewers was completed in 1860. The new system was an impressive feat of engineering that relocated London’s sewage downstream to the Thames estuary.<sup>10</sup> The Thames also continued to receive sewage from towns upstream of London. Throughout Britain, downstream cities took to suing their upstream neighbors over the fouling of water supplies. London’s Metropolitan Board of Works, dumper of the city’s sewage, collected evidence of pollution by others in the Thames estuary, in case of a lawsuit.<sup>11</sup> Eventually, “Bazalgettianism” became an insult applied to those who advocated dumping sewage without treating or recycling it.<sup>12</sup>

Chadwick, the original advocate for more efficient sewers in London, had always envisioned city sewage being used to irrigate and fertilize farmland. The idea made intuitive sense; before the coming of the water closet, London had a longstanding tradition of scavengers who made their living by carrying night soil to surrounding farms to be used as manure. The same was true of many cities in India, China, and parts of Europe.<sup>13</sup> Dumping sewage into rivers or the sea meant an irretrievable loss of valuable fertilizer.

Liebig, the chemist, was also a determined advocate of using sewage as manure on croplands. In the introduction to his book, *Agricultural Chemistry*, Liebig wrote that the rise of water closets in England led to the annual loss of nutrients capable of producing food for 3.5 million people, while the expensive guano farmers imported from South America as fertilizer ran off the fields and into rivers, adding to the pollution problem. In his eyes, the flush toilet had created a parasitic nation. “England,” he wrote, “like a vampire it hangs upon the breast of Europe, and even the world; sucking its life-blood.”<sup>14</sup>

Enthusiasts like Chadwick and Liebig believed that sewage was such a valuable fertilizer that it could be sold for great amounts of cash—enough to pay the enormous expense of sewer construction. Chadwick tried to prove the worth of the idea in 1849, when he formed the Metropolitan Sewage Manure Company, which planned to use some of London’s sewage for irrigation. The company never turned a profit and folded a few years later, having lost £50,000 in capital.<sup>15</sup>

Filtering sewage through the soil did a fair job of cleaning it up, but it was a nuisance for farmers. The sewage came day after day, an unending flow of tainted water, whose volume increased during wet winters when it was least needed on the land. In many cases an excess of sewage flooded the fields, cutting off the supply of oxygen to bacteria in the soil and creating a stinking landscape of anaerobic decay. Even when they worked, sewage farms required vast expanses of suburban land. Experts advised at least one acre of farmland per 100 people in the city generating the sewage. Under this formula, 1850s London would have needed 40,000 acres of sewage farm adjacent to the city, where real estate was at a premium. (Some cities did have successful sewage farms, most notably Berlin, Germany, where farmworkers drank effluent flowing off the fields. Such farms functioned as treatment systems first and croplands second. Proof of the Berlin

farm's effectiveness as a treatment system came during a typhoid epidemic: While the waterborne disease ravaged the city, workers on the sewage farm stayed healthy.)<sup>16</sup>

Fed up with the failure of many sewage farms to prevent water pollution, Britons turned to a different set of experts who claimed they could use chemistry to spin a profit from wastewater. The idea was that the right chemical recipe would cause organic matter to settle out of sewage, producing a convenient, dry fertilizer while leaving a clean effluent that would flow to rivers without causing a nuisance. Four hundred eighty patents for processes related to extracting nutrients from town sewage were taken out in Britain from 1850 to 1890.<sup>17</sup> Most used substances such as lime, charcoal, phosphate rock, clay, and alum to precipitate organic matter.

These processes failed. Heavy loads of organic pollutants remained dissolved in the effluent. Worse, the strong chemicals used killed the aerobic bacteria that decompose organic matter. Victorian chemists who believed that decay was evil may have been pleased with this state of affairs, but it was only temporary. Once the precipitated sewage flowed into a river, the harsh chemicals were diluted and the process of decay kicked in again. Much of the organic matter in the sewage remained, fertilizing blooms of algae. Soon the waters were drained of oxygen, so that anaerobic bacteria took on the work of decomposition, emitting the stink of putrefaction.

Bazalgette's sewers carried waste out of London and released it, untreated, at two outfalls on opposite banks of the Thames, at Barking and Crossness. The sewage flowed up and downstream with the tides. At low ebb, banks of stinking black mud emerged from the water. People who lived and worked along the lower Thames complained often of the stench and the dead state of the river, but nothing changed. In 1878, the *Princess Alice*, a cruise ship, sank near the outfalls. Locals claimed that the lost passengers died not of drowning, but of immersion in a river composed mostly of sewage.<sup>18</sup>

The *Princess Alice* disaster, along with a petition signed by 13,000 lower Thames residents, triggered a series of hearings held by the Royal Commission on Metropolitan Sewage Discharge, created to consider the impacts of dumping London's raw sewage into the Thames estuary. In May 1882, as the Metropolitan Board of Works was bracing to defend itself at the upcoming hearings, a young chemist named William Dibdin was appointed to head the Board's chemistry department. As an argument for continued sewage discharge, Dibdin resurrected the old notion that minute creatures in the river would get rid of the pollution. At first this was a political dodge to evade the great expense of intensive chemical treatment, or of creating a large sewage farm on the lower Thames. After the Royal Commission issued its verdict, finding that London's sewage was indeed fouling the estuary and would have to be cleaned up, Dibdin scrambled to find an affordable solution. In the process, his understanding of microbes and water pollution evolved.

His work was inspired by two witnesses who testified before the Royal Commission. Henry Clifton Sorby, an amateur microscopist, had studied tiny

crustaceans, called entomostraceae, and used their numbers as an index of pollution in the Thames.<sup>19</sup> Sorby found that fecal particles from entomostraceae were abundant in polluted stretches of the river, and deduced that the creatures fed on human waste. He proved this point by experimentation, keeping entomostraceae in a tank with human excrement as the only food source. “I have kept a number of them for six weeks,” he told the Royal Commission, “and you could see that they are healthy and happy and in good spirits; you could see them eating human excrement all the time.”<sup>20</sup> Sorby believed this was strong evidence that the creatures helped to remove sewage pollution. (Fig. 3.1)

The respected chemist August Dupre, testifying as a consultant to the Metropolitan Board of Works, suggested that pollutants in the Thames would be removed through the action of even smaller life forms: aerobic bacteria. Dupre was among the first to achieve this insight, and later collaborated with Dibdin in creating England’s first biological sewage treatment filters.

In the years following the Commission hearings, Dibdin studied oxygen concentrations and the corresponding presence or absence of sewage and of fish at different points along the Thames. He experimented with sewage treatment at the Barking outfall, and discovered that filtering sewage through heaps of piled rock removed most of the pollutants. Dibdin created a one-acre bed of coke breeze that, if managed well, could successfully treat 4.5 million gallons of sewage per week. (Coke breeze—chunks of partially burned coal—happened to be abundant and cheap; coarse gravel would have worked just as well. The filter served as a habitat for aerobic bacteria, which formed films on the surfaces of the coke and did the work of decomposing the waste dissolved in sewage.) By 1892, Dibdin had come to understand the microbes in sewage, or in the river, as a living community with distinct needs for nutrients and oxygen:

By reason of the multitude of organisms to be dealt with, a filter may be fittingly compared to a great animal. If you overfeed it, the result will be disastrous. If you overfeed the river with effluent, then you put more organic matter into the river than the aquatic life is capable of dealing with. The food on which the aquatic life lives, if in excess becomes corrupt . . .<sup>21</sup>

These ideas, which remain the basis of modern sewage treatment, were established only after great political and intellectual struggle. As early as 1860, Louis Pasteur had shown that microbes are responsible for fermentation, the spoiling of broth or milk. Nobody generalized this concept to infer the role of bacteria in breaking down organic matter in soil and water until 1877, when two French chemists, Theophile Schloesing and Achille Muntz, proved that nitrification—the oxidation of organic matter to carbon dioxide, water, and nitrates—was a transformation performed by microbes.<sup>22</sup>

Schloesing had studied sewage farms outside Paris, and wondered what mysterious property of soil purified the water. He and Muntz designed a simple experiment. They filtered sewage through a glass container filled with sterile sand and limestone. Nitrates appeared in effluent from the container only after twenty days.

Sterilization of the sand with chloroform vapors halted the nitrification, which started up again only after the sand was inoculated with washings from fresh soil. The researchers concluded that nitrification was performed by microbes; the twenty-day delay occurred because it took that long for a thriving population of bacteria to become established.

Nitrification, which takes place only in aerobic conditions, had been regarded as the ultimate process of purification since the 1840s. The findings by Schloesing and Muntz, which were soon repeated by British researchers, seemed to some to vindicate the belief that nature was designed for the convenience of humanity. The Earth would be cluttered with corpses, fallen leaves, and kitchen scraps, in addition to an infinite amount of undecomposed excrement, had the Creator not had the foresight to stock the planet with these benevolent microbes.

Still, at the moment in history when the germ theory of disease was becoming widely understood, the notion of bacteria cleansing sewage did not reassure everyone. Some feared that nitrifying bacteria might also be pathogens, while others felt sure these useful microbes must also devour disease-causing germs at the same time they broke down waste. In an 1893 editorial, *The Lancet* opined that the right kinds of bacteria would power the sewage treatment plants of the future; still, for the present, it was best to try to obliterate them all.<sup>23</sup>

Dibdin predicted that bacteria would be harnessed to treat sewage in industrialized systems.<sup>24</sup> In a paper he read to the Institution of Civil Engineering in January 1887, he wrote, “when this subject is better understood, in all probability the true way of purifying sewage . . . will be to turn into the effluent a charge of the proper organism, whatever that may be, specially cultivated for the purpose . . .” Some attendees of the meeting laughed out loud, and Dibdin was thoroughly mocked for his statement. If he was wrong about some details, he proved right about the gist: Modern sewage treatment plants are carefully managed habitats for aerobic bacteria.

Dibdin’s research at the Barking outfall was a painful process of trial, error, and argument. At one point, a colleague assigned to run the one-acre filter bed overloaded it with sewage, causing the whole system to clog and putrefy. Dibdin and his assistant, George Thudichum, let the bed rest for three months, then slowly filtered increasing volumes of sewage through it, allowing time for a thriving population of bacteria to become established on the surfaces of the chunks of coke. They monitored levels of oxygen in the effluent to make sure they didn’t load too much sewage too fast. They achieved a filtration rate of more than 1 million gallons of sewage per day through the one-acre bed, with 80 percent of the pollutants removed.<sup>25</sup> “The whole mass of the filter remains perfectly sweet and free from putrescent organic matter,” reported Thudichum. “The life of the filter appears to be without limit, provided always that the balance between aeration and food supply to the organisms is preserved.”

The same principles were worked out across the Atlantic, at the Lawrence Experiment Station, established in 1886 by the Massachusetts State Board of Health. The Station’s mission was to find the best way to treat sewage in order to rescue the state’s increasingly foul waters. Boston Harbor had received the

city's raw sewage for decades, and was far too contaminated to swim in. Similar conditions prevailed in many of the older cities in the US. A newspaper editor described the odor of Baltimore's inner harbor in the hot summer of 1897: "It is a 2000-horse-power smell that lays limburger cheese in the shade."<sup>26</sup>

London chemists and sanitarians were limited by politics and a chronic lack of funding for research. At Lawrence, scientists and sanitarians had the freedom to take a more systematic approach, testing the effects of different types of filtration media from sand to coarse gravel, comparing bacteria found in their sewage filters to those found in nature, and studying the environmental conditions that favored bacterial growth.

William Sedgewick, a professor at the Massachusetts Institute of Technology, and his former student Edwin Jordan led the biological studies.<sup>27</sup> Both were Darwinists, and applied the concept of natural selection to the ecosystems in their sewage filters. The microbes living in filters came from water and soil in the surrounding environment, but Jordan expected that not all species found in nature would thrive there:

The sewage itself—a nutritive medium of varying composition and richness—will contain only those species capable of living and holding their own in the continual struggle for existence. . . The chemical composition of the sewage undoubtedly debars some species from taking part in the contest.<sup>28</sup>

Jordan knew the germs that inhabited the sewage filters at Lawrence in intimate detail. It was his job to coax them into visibility. He did this by mixing a sample of sewage effluent with nutrient gelatin, pouring the mixture onto a sterile glass plate, and waiting for bacterial colonies to grow. Each colony represented the offspring of a single parent germ. Under a microscope, he could see the shape of individual cells. Cocci were spherical, bacilli rod-shaped, spiral bacteria twisted. The color of the colony offered a clue to the nature of the bacterium—*Bacillus coli communis*, one of the most common microbes in sewage, made red colonies. (Now known as *Escherichia coli*, this bacterium was known to be a normal resident of the human colon, as well as the guts of other animals, and is still used as an indicator of sewage contamination.) Jordan took small samples from a single colony and studied a microbe's response to different growth media: milk, potato, agar. Could the microbe grow without air? Did cells sprout flagellae and swim? What temperatures could it tolerate? All of these factors had to be worked out before he could label the bacterium as a member of a particular species.

In the early 1890s, Jordan took a position as an instructor at the University of Chicago. By the time he was named Professor of Bacteriology in 1907, he'd spent years immersed in the city's complex sewage problems.

Chicago's population had mushroomed from about 350 in 1833 to over 1 million in 1890.<sup>29</sup> Raw sewage generated by the growing population, along with the blood and guts discarded by the city's stockyards, ran into the two branches of the Chicago River, which emptied into the lake. A branch of the river's South

Fork, downstream of the meatpacking district, was known to locals as Bubbly Creek. Upton Sinclair described it:

One long arm of the river is blind, and the filth stays there forever and a day. The grease and chemicals that are poured into it undergo all sorts of strange transformations, which are the cause of its name; it is constantly in motion, as if huge fish were feeding in it, or great leviathans disporting themselves in its depths. Bubbles of carbonic acid gas will rise to the surface and burst, and make rings two or three feet wide. Here and there the grease and filth have caked solid, and the creek looks like a bed of lava; chickens walk about on it, feeding, and many times an unwary stranger has started to stroll across, and vanished temporarily.<sup>30</sup>

The city had been built on flat marshland, and the river's flow was so sluggish that winds off the lake sometimes pushed the polluted water back upstream into town. This changed during times of heavy rain, however, when pollution from the river flowed into Lake Michigan, the source of drinking water. "In the great rain of August 2, 1885," noted a report on Chicago's sewage, "the contents of both branches of the Chicago River, with the sewage accumulation of many weeks . . . were, in a few hours, belched incontinently into the lake."<sup>31</sup>

The city's water department had built a tunnel that extended two miles into Lake Michigan, designed to pull clean drinking water back to shore. Pollution from the river often spread far into the lake, however—far enough to contaminate water drawn into the offshore tunnel.

Chicago had high numbers of typhoid fever deaths compared to other major cities in the US and Europe. Typhoid fever is caused by the bacterium *Salmonella typhi*, which, like the cholera germ, thrives in sewage-contaminated water. Typhoid attacks the gut, causing vomiting, diarrhea, dehydration, and high fevers. In severe cases, the disease can cause coma and death.<sup>32</sup> In 1891, Chicago lost 1,997 citizens to the disease, and about 20,000 people suffered infection—a situation experts described as "an epidemic of really alarming proportions."<sup>33</sup>

Chicago had just been chosen to host the Columbian Exposition, an event expected to draw hundreds of thousands of visitors. Jordan's mentor William Sedgewick, along with Allen Hazen, a young chemist trained at the Lawrence Experiment Station, studied the history and causes of typhoid epidemics in the city, pointing out the danger of disaster if visitors were exposed to Chicago's tainted drinking water. They cited evidence that the city's makeshift sewage system failed on a regular basis. Chicago used pumps, located at Bridgeport, to lift the sewage-laden waters of the Chicago River into the Illinois & Michigan Canal, built in the 1820s to allow shipping between the Great Lakes and the Mississippi. This strategy had been discovered by accident, when workers pumping water out of the river to raise the level of the canal noticed they'd reversed the river's flow. The pumps pushed Chicago's filth over the natural divide between watersheds, sending it into the Des Plaines River, which flowed into the Illinois, which emptied into the Mississippi.

“The cause of the enormous excess of typhoid in May 1891,” wrote Sedgewick and Hazen, “was the total stoppage of the Bridgeport pumps . . . allowing sewage to flow directly into Lake Michigan.”

Forewarned of the risks of drinking Chicago tap water, the organizers of the Columbian Exposition built their own water purification plant, as well as importing clean water from a famous spa in Waukesha, Wisconsin. In an inspired public relations move, they hired Hazen to set up a lab that tested the quality of the Exposition’s drinking water daily. Hazen’s data showed the Exposition’s water was much safer than the city’s. In May 1893, for example, city tap water contained 630 bacteria per cubic centimeter, while Waukesha water had only 204, and the figures for filtered water were even lower.<sup>34</sup>

A few years later, city officials decided to permanently reverse the Chicago River’s flow by cutting a new canal that would carry its foul waters into the Illinois Valley. The channel would be large enough to accommodate shipping traffic, replacing the old Illinois & Michigan Canal. Its construction involved a mammoth excavation. One booster described it as “a mighty channel which will rank with the most stupendous works of modern times.”<sup>35</sup>

The city of St. Louis, Missouri, which lies just below the junction of the Illinois and Mississippi rivers, had also been suffering typhoid epidemics. In an effort to stop Chicago from flushing its sewage into the watershed that provided drinking water for St. Louis and other cities on the Mississippi, the state of Missouri filed suit in what became the first pollution case decided by the US Supreme Court.<sup>36</sup> In classic Chicago style, the Sanitary and Shipping Canal was opened by stealthy crews of men armed with shovels, who broke down the dams holding back their city’s filthy waters before dawn on January 17, 1900, the day St. Louis’ attorneys were to file for a court injunction to stop them. The Chicago River began to flow backward into the Des Plaines, diluted by relatively clean water from Lake Michigan. A *New York Times* report on the events bore the headline, “The Water in the Chicago River Now Resembles Liquid.”<sup>37</sup>

Jordan, who’d begun his career by studying the workings of biological treatment in intricate detail, testified in support of Chicago’s right to re-engineer its river and let its raw sewage flow down to the Mississippi. He took samples from points scattered along the hundreds of miles of river between Chicago and St. Louis. The typhoid germ was difficult to isolate and identify, so Jordan used the number of *E. coli* colonies cultured from each sample as an indicator of sewage pollution, and as a stand-in for the typhoid bacterium.<sup>38</sup> “The best index for gauging the continued vitality of the typhoid bacillus in running water is information from the fate of the colon bacillus,” he explained.

Jordan (Fig. 3.2) found abundant *E. coli* in the Sanitary Canal at Chicago, and as far downstream as the town of Morris on the Illinois River. The water also held high concentrations of organic matter in the early stages of decomposition—the stuff that fed the booming population of *E. coli*. It carried high concentrations of ammonia, a volatile form of nitrogen typical of heavily polluted waters. But at Ottawa, twenty-four miles downstream of Morris, the *E. coli* had almost vanished. Through the action of aerobic bacteria, the ammonia had been transformed into

nitrate.<sup>39</sup> This improvement was due in part to dilution from the Kankakee River, which joined the Illinois just above Morris, and partly to the river's natural ability to cleanse itself through the action of aerobic bacteria.

By the time the Illinois flowed past the town of Averyville, signs of the intense pollution from Chicago had disappeared. The water quality was comparable to that of relatively pristine tributary streams, like the Kankakee, Fox, Vermilion, and Sangamon rivers. The Illinois suffered another dose of filth when it passed through the city of Peoria, with its stockyards and distilleries. Yet by the time it joined the Mississippi, at the site of the town of Grafton, the river had shrugged off the new load of pollution and had lower bacterial counts than the main stem of the Mississippi. The self-purification of rivers, Jordan testified, "is not an interesting biological myth, but an actual and definite occurrence."

The great majority of bacteria in the Sanitary Canal at Chicago did not survive long enough to reach Ottawa. Based on Jordan's findings, it was a fair assumption that any increase in typhoid bacteria that occurred in the Mississippi upstream of St. Louis was far more likely to be caused by pollution from Peoria. What counted in dealing with sewage pollution, Jordan said, was the destruction of pathogenic bacteria, not levels of organic matter or chemicals in the water. By this standard, the Illinois River had shown a remarkable ability to cleanse itself.



Figure 3.2 Edwin O. Jordan, the pioneering bacteriologist who studied the ability of rivers to cleanse themselves of bacteria from sewage. Photo from Wikipedia.

In 1906, Justice Oliver Wendell Holmes wrote the Supreme Court decision in the case of *State of Missouri v. State of Illinois and the Sanitary District of Chicago*. The question at hand, Holmes said, was “whether the destiny of the great rivers is to be the sewers of the cities along their banks.”<sup>40</sup> The court’s answer to this question was a resounding “yes.” Chicago had the right to pollute the Illinois River, even though the city had dug an artificial canal to bring its sewage into the watershed. American cities spewed raw sewage into rivers throughout the nation. The burden of proof rested not with Chicago, the polluter, but with St. Louis, the plaintiff. In a long battle of experts, St. Louis had failed to prove that Chicago’s waste caused significant harm to people drinking tap water drawn from the Mississippi.

In the aftermath of the court decision, St. Louis built a water purification plant, using a design developed at the Lawrence Experiment Station. Mississippi River water passed through beds of sand that filtered out bacteria, providing safe tap water. The right to pollute rivers became the legal and political norm in the US; if a city wanted safe drinking water, it would have to build itself a filtration plant as St. Louis had done.

There were objectors. In 1910, the Pennsylvania State Board of Health required Pittsburgh to build new sewers that would separate household wastewater from street runoff, along with a treatment plant. The city hired Allen Hazen and another well-known sanitary expert, George Whipple, to make a plan of action. Hazen and Whipple’s influential report concluded that replacing Pittsburgh’s sewers and building a treatment plant would cost at least \$46 million. The twenty-six towns downstream from Pittsburgh on the Ohio River could provide filtered water for their residents for much less. “No radical change in the method of sewerage or of sewage disposal as now practiced by the City of Pittsburgh is now necessary or desirable,” they wrote.<sup>41</sup> The Board of Health backed down, and the status quo of raw sewage discharge continued. Communities that did bother with sewage treatment went only as far as primary treatment: building simple tanks where the solids would settle out of standing sewage. Few imitated the efficient sewage filtration beds that had been created at Barking and Lawrence.

Chicago’s population quickly ballooned into the millions, and the impact of the increasing sewage load could be seen and smelled on the Illinois River. In the summer of 1911, two biologists from the Illinois Natural History Survey observed “septic conditions for twenty-six miles of the course of the Illinois from its origin . . . the water was grayish and sloppy, with foul privy odors distinguishable in hot weather. Putrescent masses of soft, grayish or blackish slimy matter, loosely held together by threads of fungi, were floating down the stream.”<sup>42</sup> They might have been describing many other rivers and estuaries downstream of major cities in the US.

The same year, officials in New York were scrambling to remedy intense pollution in the city’s harbor. They invited Gilbert Fowler, a chemist and bacteriologist from Manchester University in England, to consult on the problem. Fowler had been studying a curious microbe his colleague Ernest Mumford had discovered in polluted Manchester canals. Given air, iron, and a source of nitrogen, the bacterium, dubbed M7, broke down proteins and created deposits of

iron compounds. Fowler and Mumford had hopes that M7 could be harnessed to treat sewage.

After his visit to New York, Fowler traveled to Lawrence, which he described as the Mecca for sewage researchers. Harry Clark, the chief chemist at Lawrence, had been trying to determine how much sewage fish could tolerate and still survive. His team had found that as they increased pollution levels, fish would die unless increasing amounts of air were bubbled into the aquaria.<sup>43</sup> That observation had led them to abandon their studies of fish and move to studies of the effect of aeration on sewage itself. By bubbling air into bottles of raw sewage, they could purify it in only twenty-four hours.

Back in Manchester, Fowler asked his assistants, Edward Arden and William Lockett, to repeat the sewage experiments he'd seen in Massachusetts. Arden and Lockett put raw sewage in a bottle and bubbled air into it until all the nitrogen had been converted to nitrate, the stable form that was the mark of an effluent that would not putrefy when released into a river. The process took six weeks, far too long to be useful in treating city sewage. But Arden and Lockett went a step farther: They poured off the purified sewage, saving the sludge that had accumulated on the bottom of the bottle. Then they added a new batch of raw sewage, bubbled air into it, and poured off the purified liquid again, saving the gunk at the bottom. After repeating this process several times, they'd created a powerful brew that, in the presence of plenty of oxygen, could purify raw sewage in about six hours. The process needed no contact beds, which require substantial space—a problem in cities where every scrap of land is valuable.

Arden and Lockett had created a living stew of aerobic microbes capable of rapidly breaking down organic matter and oxidizing nitrogen; they called it “activated sludge.” The power of the sludge was in the organisms it contained. The researchers proved this by showing that sterilized batches had no ability to cleanse sewage. When Arden presented their findings at a 1914 meeting of the Society of Chemical Industry, his colleagues saw it as an “epoch-making” advance in sewage treatment.<sup>44</sup>

Soon after, Robbins Russel of the University of Illinois isolated the nitrifying bacteria in activated sludge. They proved to be familiar organisms, first identified in 1890 by the great Russian microbiologist Sergei Winogradsky. Winogradsky had shown that the decomposition of organic matter in soil involves a chain of bacteria, each performing a different chemical reaction. Among them were microbes that gathered their life force not from harvesting the energy of sunlight, as green plants do, nor from feeding on organic matter, as every creature from protozoans to people do. These bacteria harvested energy from the chemical reactions of inorganic substances, in a process called chemosynthesis. The first such group of microbes he isolated were what Winogradsky called his “beautiful oval bacteria.”<sup>45</sup> They were *Nitrosomonas*, the genus that metabolizes ammonia into nitrite in soils, and in sewage, around the world. Later he isolated *Nitrobacter*, the germ that oxidizes nitrite into stable nitrate.

Nitrogen, like carbon, oxygen, phosphorus, and sulfur, is essential to life. It is everywhere—more than 70 percent of Earth's atmosphere is composed of

molecular nitrogen gas,  $N_2$ . Yet nitrogen is among the least available of the primary nutrients. In the elemental gas, two nitrogen atoms are connected with powerful chemical bonds, which can be broken only by a bolt of lightning—or by a few kinds of nitrogen-fixing microbes. These bacteria convert  $N_2$  gas to ammonia,  $NH_3$ , a form that can be absorbed by plants. Once this happens, nitrogen enters the realm of living things, where a single N atom may cycle over and over through many different forms. It may be oxidized into nitrate ( $NO_3$ ) by nitrifying bacteria, absorbed through roots and incorporated into the DNA or protein of a plant, eaten and pissed away by a cow or a human, broken back down to ammonia, oxidized into nitrate, built into a protein again. Sewage is loaded with biologically available nitrogen, which helped to fuel blooms of algae that plagued rivers like the Thames, the Hudson, and the Illinois.

In the early twentieth century, the activated sludge process, with its groomed populations of nitrifying bacteria, was a major improvement on existing ways of treating urban sewage. It was fast, and it didn't take up lots of space, as large contact filter beds did. Pumping air into the system used energy, but nobody was concerned about that at the time. Within a year of Arden's presentation at the Society of Chemical Industry, fifteen cities around the world had begun testing the process and building sewage plants designed to put it into action.<sup>46</sup> By the early 1920s, activated sludge treatment plants were up and running in cities scattered across Britain and the US.<sup>47</sup>

The rapid rise of activated sludge was halted by a dispute over patents. Gilbert Fowler had quietly sold rights in the activated sludge concept, developed by his underlings Arden and Lockett while all three were employed by the City of Manchester, to Walter Jones, an entrepreneur and ironworker. Jones had been among the first to work out ways to scale up the activated sludge process from laboratory bottles to industrial-sized tanks that could handle city sewage. His firm, Jones & Attwood Ltd., took out British patents in 1914, laying claim to both the idea and the hardware involved in activated sludge treatment. "The Sewage Work of the World is a big thing," wrote J.A. Coombs, Jones & Attwood's chief sewage engineer, "and the firm are by no means selfish in trying to corner it."<sup>48</sup> Jones & Attwood warned American engineers against infringing on the firm's activated sludge patents. The American Society of Civil Engineers organized to prevent the grant of a patent in the US, but their appeal failed.

Meanwhile, more US cities began to test and build activated sludge systems. As Chicago's population boomed, the limitations of its existing system of routing raw sewage into the Illinois Valley became obvious. Chicago pumped increasing amounts of water from Lake Michigan to dilute the waste in the Sanitary and Shipping Canal. Neighboring cities on the shores of Lake Michigan sued to protect their share of the lake's waters. The case moved through the legal system all the way to the US Supreme Court, which issued a ruling limiting the amount of water Chicago could take from the lake.<sup>49</sup> The need for sewage treatment then became urgent. The city began building and testing activated sludge plants in the early 1920s.

In 1924, Activated Sludge Inc. (ASI), the US representative of Jones & Attwood, filed suit against the city for patent infringement. Chicago forged ahead. The lawsuit languished in the legal system for years before any real action was taken. In 1927, Chicago put its North Side Treatment plant, the first full-scale activated sludge system in the city, into operation. The plant, designed to treat 175 million gallons of sewage per day, is still in use nine decades later.

ASI next went after the city of Milwaukee, Wisconsin, farther north on the shore of Lake Michigan. Both cities drew their drinking water from the lake and had a long history of dumping raw sewage into it, with serious consequences for public health. Milwaukee's Jones Island activated sludge plant started up in 1925, and the same year ASI filed suit for patent infringement.

The Milwaukee case went to trial in June 1928. Fowler and Ardern testified before Judge Ferdinand Geiger that the concept of activated sludge treatment had been developed in the City of Manchester's laboratory, under Fowler's supervision. Yet Judge Geiger bought into the fiction, supplied by ASI's attorney, that both the scientific experiments and the equipment needed to expand the concept to an industrial scale had leapt from Walter Jones's mind.<sup>50</sup> Jones could not comment: He had died the year before.

In 1933, Geiger found the city of Milwaukee liable for hundreds of thousands of dollars in damages to ASI. He also issued an injunction that would have forced the city to shut down its treatment plant, causing the release of raw sewage to Lake Michigan. On appeal, Geiger's decision was upheld except for the injunction against operation of the Jones Island plant. In the view of the appeals court, the threat to public health outweighed the infringement of ASI's patents. In the fall of 1934, after the Supreme Court had declined to hear an appeal of Milwaukee's case, the judge in the Chicago lawsuit issued his decision. He seemed skeptical that Walter Jones had been the sole inventor of the activated sludge process, but he found the patents to be valid nonetheless. In the end, after more than two decades of litigation, Chicago was forced to pay ASI \$950,000. Milwaukee paid \$880,000.

At the time of the appeals court decision, in 1937, *Time* magazine reported that several other US cities had paid lump-sum license fees to ASI to avoid the long, expensive process of a court case. The fees ranged from \$85,000 for Cleveland and \$75,000 for Houston to \$23,000 for Peoria, Illinois. ASI had lawsuits pending against New York and more than one hundred other cities in the US.<sup>51</sup> Most had refused to pay, arguing that they'd designed their own systems based on original experiments.

The outcomes of the Chicago and Milwaukee cases affected plans for treatment plants throughout the country. Several existing plants, including one in San Marcos, Texas, which in 1916 had become the first operating activated sludge system in the US, closed down to avoid fines. Others paid royalty fees to ASI in order to keep their plants running. A large number of communities that had plans to build new activated sludge plants used an alternative—usually a trickling filter system like the one Dibdin had built at Barking—or just sat back and waited.

Los Angeles, which had been the target of an ASI lawsuit for patent infringement, gave up on the idea of an activated sludge treatment plant and did not go

beyond installing filters to catch the larger solid chunks before raw sewage was discharged to the Pacific. By the 1940s, acres of sewage could be seen floating offshore. Clots of dung and debris settled on the beaches. In the summer of 1943, the State Board of Health quarantined Los Angeles' beaches because of extremely high levels of *E. coli* in the water.<sup>52</sup> When people kept coming, Dr. Elmer Belt of the Board of Health advocated arresting bathers and beachcombers for their own protection. The city's first activated sludge plant was not built until 1950, and within a few years it had failed to keep up with the ever-growing population and volume of sewage.

A young man came of age in those years. He grew up not far from Los Angeles Harbor, where the water was so drained of oxygen that only a single hardy species of marine worm could survive. His name was David Joseph, and he would use the weapons of science to wage war on "pollution as usual" in California. In time he would clash, long and hard, with Arcata's sewage rebels.

## NOTES

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<sup>3</sup> Halliday, S. (1999). "The Great Stink of London: Sir Joseph Bazalgette and the cleansing of the Victorian metropolis," p. ix.

<sup>4</sup> Hamlin, C. (1987). "What becomes of pollution? Adversary science and the controversy on the self-purification of rivers in Britain, 1850–1900."

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<sup>8</sup> *Ibid.*, p. 173.

<sup>9</sup> Darwin, C. "Autobiography of Charles Darwin, 1809–1882," as quoted in C. Hitchens, "The portable atheist," p. 94.

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<sup>14</sup> Halliday, S. (1999). "The Great Stink of London: Sir Joseph Bazalgette and the cleansing of the Victorian metropolis," p. 109.

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<sup>16</sup> Hamlin, C. (1980). "Sewage: waste or resource?" *Environment* **22**(8): 16–42.

<sup>17</sup> *Ibid.*

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