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Cholera's Frontiers

Sewage as we know it - the everyday miracle of feces disappearing down the toilet, pushed by a never-ending flow of clean water-is a recent invention. The flush toilet itself has been created, and then forgotten, many times down through the ages. But the grand scheme that we all take for granted—an endless supply of clean water piped in and limitless amounts of dirty water piped out—was thought up by Edwin Chadwick (Fig. 1.1), a British lawyer turned public health crusader, in the 1840s.

Back then the cities of the Old World were awash in human waste. Even the most elegant homes had privies that emptied into cesspits, where decades of accumulated filth sat rotting beneath the parlor floor. The poor lived in tenements where dozens of people might have to share one privy. Chadwick supervised a survey of sanitary conditions in English cities that came up with some amazing statistics. In parts of Manchester there was one privy to every 215 people. Some houses had yards covered six inches deep in "human ordure," which the inhabitants crossed by stepping on bricks.

"Sir Henry De La Beche was obliged at Bristol to stand up at the end of alleys and vomit while Dr. Playfair was investigating overflowing privies," Chadwick wrote of one of his colleagues. "Sir Henry was obliged to give it up."[1]

London had sewers, of a sort: They were open ditches that sloped toward the Thames, and were meant to drain stormwater out of the streets. But by Chadwick's day, the gunk from thousands of overflowing cesspits emptied into these sewers, then oozed its way into the river. Parliament's windows on the riverfront had not been opened in years because of the stench. The Chelsea Water Company, which provided drinking water to many Londoners, still had its intake a few feet from the outfall of the Ranelagh sewer.[2] An editorial in *The Spectator* pointed out that city residents paid the water companies "340,000 pounds per annum for a more or less concentrated solution of native guano."

Chadwick's Sanitary Report of 1842 carefully documented the correlation between bad sanitation and high death rates. Today this idea seems painfully obvious, but in the mid-nineteenth century no one understood why filth could kill.

An eccentric Dutch shopkeeper named Anton van Leeuwenhoek had built the first microscope more than a hundred years earlier, and found that his water

Figure 1.1 Sir Edwin Chadwick. Photo from Wikimedia Commons.

cistern, his skin, and the inside of his mouth were all swarming with live creatures, too tiny to see with the naked eye. Microbes were known to exist, but most scientists remained unimpressed. No one had made the connection between van Leeuwenhoek's discovery and infectious diseases. Despite repeated epidemics of cholera, typhoid, and yellow fever, many prominent doctors did not believe that diseases could be contagious at all.

The medical wisdom of the time held that disease was caused by chemical substances from decaying filth. Breathing in these miasmas could cause deadly illness. "All smell is, if it be intense, immediate acute disease," wrote Chadwick, "and eventually we may say that, by depressing the system and rendering it susceptible to the action of other causes, *all* smell is disease."[3]

Chadwick had a vision of how he would deodorize England's cities. It depended on channeling great volumes of clean water into every neighborhood, then flushing it away once it was dirty. This would mean a restructured water supply system.

No one had indoor plumbing in those days. Instead, people paid water companies for limited access to a well or for delivered water. Chadwick foresaw a newfangled water closet in every household. Complex new sewer projects would have to be built. Instead of the old, rectangular ditches that drained London, he planned to build underground pipes, rounded and tapering at the bottom, so that the sewage would flow fast and carry its smelly load off efficiently—into the nearest river.

He recognized his scheme's drawback: It would pollute rivers all over the country. He hoped to solve this by diverting sewage to farm fields, where it could

be used as liquid manure. But his first priority was to get the waste out of town as soon as possible, no matter where it went. He believed this would save thousands of lives.

Chadwick's "sanitary idea," that water and sewers should be provided by one centralized authority, run by himself, remained a political football for seven years. The companies that had a longstanding monopoly on urban water supplies opposed him. So did local officials who resented Chadwick moving in on their turf.

In 1848 Chadwick landed the position of Sanitary Commissioner of London. As he campaigned to win the appointment, cholera was sweeping through Europe and into England. People who appeared healthy would suddenly collapse, going cold in the limbs and blue in the face. Many died within hours of becoming ill.

The epidemic reached London in February 1849. Fourteen thousand Londoners would die before the outbreak subsided. Chadwick unknowingly helped kill many of them. He ordered the city's antique sewers to be flushed as never before. Better to pollute the river, he believed, than to leave the stuff in the sewers where it would give off "foetid exhalations."[4]

Cholera bacteria are passed in human waste, and heavy loads were washed into the Thames, the only water source for thousands of people. As the epidemic raged in August 1849, 5,773 cubic yards of filth were being flushed from the sewers into the river each week, under Chadwick's enthusiastic direction. The monthly death rate shot up from 246 in June to 1,952 in July and 4,251 in August, peaking at 6,644 in September.[5]

It was the first of many such public health disasters. No one had found a good way to deal with the resulting sewage, but the idea of household taps and the flush toilet gained in popularity. By the 1880s, American cities like Boston and Newark were sewering up, flushing their untreated waste into the nearest river. In towns downstream, death rates from cholera, typhoid, and other waterborne diseases soared (Fig. 1.2).

Chadwick, an arrogant, prickly character, made many political enemies. He might never have achieved enough power and influence to change London's sewer system if cholera had not made people desperate. Cholera gave Chadwick followers, who would transform the urban landscapes of Europe and America forever. Their passion for better sewers would begin to save lives in the largest, most crowded urban centers, while they intensified the fouling of waters downstream.

Cholera and water pollution are bound together in a complex evolutionary knot; each has helped to create the other. The dread disease that has swept every inhabited continent during the past 200 years, and still sickens millions and kills thousands in the developing world, is a new variation on an ancient bacterial theme. And it flourishes in nutrient-rich water, especially when that water is contaminated with human waste.

Robert Koch, one of the founding fathers of microbiology, first isolated the cholera bacterium in Egypt in 1883. Viewed through a microscope, the tiny culprit he'd extracted from the intestines of cholera patients looked like a comma; Koch called it the comma bacillus, and noted that it could also be found clinging to aquatic plants in polluted waters. Later, other scientists would name the germ

Figure 1.2 "Death's dispensary," cartoon published in 1866, illustrating new evidence that water transmitted cholera infection. Public domain.

Vibrio cholerae. The mystery of cholera wasn't solved with the identification of *Vibrio*, however. New questions kept cropping up. One of the most urgent concerned where *V. cholerae* hid out between its intermittent crime sprees.

Cholera is an ancient illness: An outbreak with symptoms typical of cholera is described in 2,500-year-old Sanskrit writings. The disease is endemic in the Ganges River delta and along the coast of the Bay of Bengal, where outbreaks occur predictably every spring and fall. In 1817, the first episode of pandemic cholera spread from the Ganges delta near Calcutta, India, into the Middle East,

Europe, and East Africa, killing hundreds of thousands. The outbreak subsided for a few years, than flared again in 1829. Over the next two decades, epidemic cholera struck around the world, following the routes of human travel.[6] It reached England in 1831, with sailors who came to port in Sunderland. In the late 1840s, while Chadwick was campaigning to flush more sewage into the Thames, *V. cholerae* reached America. The disease arrived at the port of New York and headed west in the distressed innards of ambitious pioneers.

The second pandemic subsided in 1850, but cholera has swept around the globe five more times since then, gradually evolving new variations. The most recent pandemic, which has spread to South America and Haiti, began in 1961 and continues today, having affected more than 7 million people. It involves a new strain of cholera bacteria that was first identified in 1992.

Between outbreaks, cholera may vanish from human populations for several years or decades at a time. Researchers searched for a hidden reservoir of cholera, a sign that people or their animals could carry the infection without showing overt symptoms. Then in the 1980s, a team led by Rita Colwell of the University of Maryland found *V. cholerae* alive and well in the waters of both the Chesapeake Bay and the Bay of Bengal, clinging to the shells of copepods, miniscule crustaceans that drift with the currents.

The cholera bacterium and its close cousins, also members of the genus *Vibrio*, live in estuaries all around the planet. Many types of *Vibrio* survive in even the cleanest of tidewaters—and most have nothing to do with people, growing only among the plankton, clams, and fish.

The hunt for the wild *Vibrio* took so long because in hungry times—when the waters it lives in are not overloaded with nutrients from sewage or stormwater runoff—*V. cholerae* stops reproducing and goes into a dormant form. The bacteria can live for a long time this way, waiting for the opportune moment, the right combination of temperature, salinity, and nutrient load that will signal the time to wake up and procreate. When microbiologists looked for *Vibrios* using the traditional technique of culturing germs from water samples, these dormant *Vibrios* didn't grow, and so they remained invisible.

Colwell and her colleagues uncovered dormant *Vibrios* using a new tool. They exposed mice to *V. cholerae*, so that the mice produced antibodies that would latch onto cholera bacteria and nothing else. Then they attached a fluorescent molecule to the antibodies, turning them into microscopic signal beacons.[7] When these fluorescent antibodies were added to samples of estuary water, they showed that *V. cholerae* were not only present, but abundant. Most of the germs clung to the shells of planktonic creatures, especially the copepods, which look like a miniaturized cross between a lobster and a beetle. In photomicrographs of these water samples, glowing microbes outline the shapes of the copepods, like constellations in a night sky.

Many disease-causing microbes need people to survive, but *Vibrios* do not. They are everyday citizens of normal estuaries, at home attached to plankton and aquatic plants. The bacteria nourish themselves off the chitin in copepod shells—they have a special enzyme designed to digest it. *V. cholerae* is tightly linked to

copepods, so much so that filtering contaminated water through folded sari cloth, which forms a mesh fine enough to capture copepods, removes more than 90 percent of *V. cholerae* cells as well. Five years after Colwell and her colleagues taught this simple technique to women in Matlab, Bangladesh, cholera infection rates there were halved.[8]

When untreated sewage enters the equation, algae, copepods, and *Vibrios* all turn opportunist. Sewage is rich in nutrients, a jolt of liquid fertilizer. Algae absorb it and reproduce like mad. Copepods, which feed on algae, also boom. A polluted estuary is a *Vibrio* paradise, pleasantly brackish and full of abundant food and handy plankton to rest on. When a lot of people are crowded together at the edge of an estuary, without a good sanitation system, their waste fuels an explosion of the *Vibrio* population.

Along the Bengal coast, the disease strikes twice a year, under conditions that can be traced to the abundance of copepods in drinking water. In the spring, low river flows allow plankton-rich bay water to intrude into the ponds used by local people as water sources. In the fall, monsoon rains swell the rivers, flushing nutrients from the land into the delta and bay. Plankton bloom in the fertilized waters, carrying abundant *V. cholerae* across the flooded landscape. Both drought and monsoons are predicted to intensify as the climate continues to warm. Warm-water plankton species are moving toward the poles as ocean temperatures rise. Manmade climate change now threatens to intensify the risk of cholera epidemics.[9]

Yet, of the diverse strains of *V. cholerae* that can be found in the wild, most are not dangerous to humans. To become successful pathogens, strains of *V. cholerae* must acquire a set of genetic traits that allow them to thrive in the human gut, and to spread from one infected victim to another. Among the critical traits are the genes that code for cholera toxin, a protein that wreaks havoc with the salt balance of cells lining the small intestine. The toxin causes cells to pump electrolytes and water into the lumen of the intestine, causing the severe diarrhea and dehydration characteristic of cholera.[10] One result is that the infected person's gut is awash in nutrient-rich, salty fluid, an ideal growth medium for the cholera bacterium.

Pathogenic *V. cholerae* bacteria also produce pili, long filamentous extensions that enable them to attach to the gut lining. The genes that code for pili production act in concert with those that produce cholera toxin. So among cholera researchers, these attachment factors are known as toxin coregulated pili (TCP). The genetic code for cholera toxin comes from a bacteriophage, a virus that infects some strains of *V. cholerae*. TCP act as a receptor for attachment and infection by the bacteriophage. These relationships suggest that the human gut, the only place where pili are expressed, is the site where *V. cholerae* strains acquire their pathogenic traits.

A recent study tracks the evolution of the El Tor strain of *V. cholerae*, the cause of the seventh, ongoing global cholera pandemic. The El Tor strain occupied human guts as early as the 1890s, though at that early stage it did not make people sick. By the 1930s, El Tor was causing isolated outbreaks in which victims suffered symptoms of classic cholera. But the strain was not yet highly contagious,

and the outbreaks subsided. It took decades for this line of *V. cholerae* to pick up the traits that made it into a lethal threat. The first outbreaks of the seventh pandemic occurred in 1961 near the town of Makassar in Sulawesi, Indonesia. The responsible strain had originated decades earlier in the coastal waters of Bengal, and it acquired more and more pathogenic traits as it traveled in human bodies along an ancient migratory pathway that led first to the Middle East and then to Indonesia.[11]

In 2010, the El Tor strain made the leap across oceans to Haiti, where it triggered an intense outbreak of cholera. "The disease struck with explosive force," said reporter Richard Knox. "Within two days of the first cases, a hospital 60 miles away was admitting a new cholera patient every 3-1/2 minutes." Cholera has since killed thousands in Haiti, and is now endemic there as it is in its ancient homeland of Bangladesh.[12] Genomic sequencing of the *V. cholerae* strain involved showed that the disease had traveled to the island in the guts of Nepalese peacekeepers sent by the UN to aid in Haiti's reconstruction following a major earthquake, and had been released into streams and rivers because of improper sewage disposal at the UN camp near the town of Mirebalais.[13]

Throughout its history, cholera has flared up from polluted waters to travel across oceans and continents inside human hosts. In 1867 and again in 1891, cholera struck a large gathering of people who came to the shores of the Bay of Bengal for the Hardwar Fair, and many of the survivors carried the germ back to their hometowns. Several times in the mid-nineteenth century, cholera swept through the thousands of Muslims gathered for the annual pilgrimage to Mecca, and again the people carried pathogenic *Vibrios* back to their homes.

America's pilgrimage in those times was west to the California Gold Rush. People from all over the US dropped everything and followed the immigrant trail. Among them was an opinionated doctor named Israel Shipman Pelton Lord. The journal he wrote during his travels is very much a tale of cholera. Lord lived in Illinois; he'd only gotten as far west as Missouri when, in May 1849, he began to meet victims of the disease.

"We left a dead man by the name of Middleton on the levee at St. Louis, and thought that we had left all the cholera with him," Lord wrote. "We were grievously disappointed, however."[14] Along the Missouri River, he watched some of his fellow steamboat passengers die off, and passed towns that had been emptied by the scourge. Later, as he moved through Kansas and Nebraska, he found cholera victims lying exhausted and alone at the trail's edge.

By September 1850, Lord had tried his hand at gold mining in California and given it up in disgust. He was living in Sacramento, a hectic, filthy boomtown near the spot where gold had first been discovered (Fig. 1.3). The previous spring, the town had been home to 150 people. The Sacramento Lord knew that fall held 6,000, and what primitive sanitation there may have been could not keep pace with the population explosion. When the Sacramento River flooded during the boom years—and it often did—it spread waterborne diseases everywhere. Eventually, the settlers would raise the street level by twelve feet in an effort to escape their own sewage.

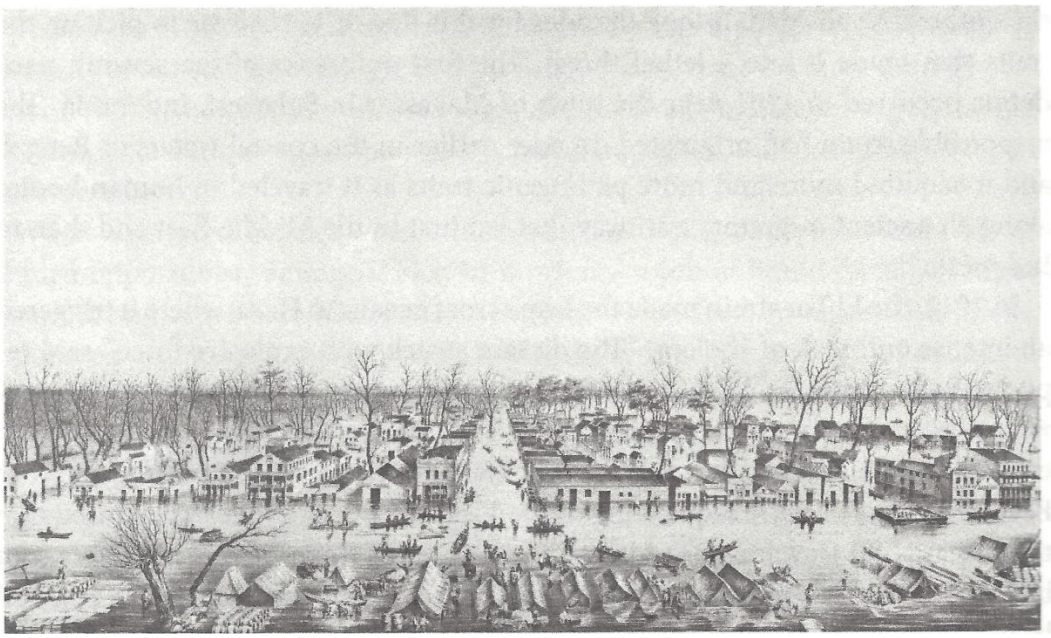

Figure 1.3 View of Sacramento, California during a flood in January 1850. Floods intensified the risk of waterborne disease in Gold Rush boom towns. Drawing by George Casilear and Henry Bainbridge. Courtesy California History Collection, California State Library.

"The cholera is approaching us slowly from both east and west," Lord wrote on September 30, 1849. "It will make a charnel house of Sacramento when it comes." He was soon run ragged trying to attend to cholera victims, and recorded as many as forty deaths in a single day. His diary entries included long, angry harangues against doctors who dosed cholera patients with laudanum, which he believed did more harm than good.

On November 3, his only diary entry was terse: "Sick today. Cholera symptoms. Weather the same." Lord survived. By late November, when the disease had run its course in Sacramento, he estimated that three-fourths of the city's population had died.

In December 1849, Israel Lord suffered through a flood on the polluted Sacramento River. The stink of the sewage-enriched Thames choked London. And Josiah Gregg stood knee-deep in a pristine stream just north of Humboldt Bay. He was cursing like a lunatic. In a few years this river, named the Mad in honor of Gregg's fit of temper, would form Arcata's northern boundary, and farms would cover the lowlands along its banks.

Gregg led a band of eight ragged men who came west from their gold mines on the Trinity River, staggered for weeks over snow-covered mountains and through a maze of giant redwoods, and arrived on the shore of the Pacific just north of Arcata. They were starving, cold, and extremely irritable, and they were about to go down in history as the first white men to discover Humboldt Bay by land.

An adventurer and scholar who had written a popular book about his travels on the Great Plains, Gregg had an obsession for scientific measurement. This, along with the severe trials of the journey, was driving the men with him crazy.

While they were recovering from some nervous encounter with a band of Indians who had never met white people before, or fainting with hunger after two days without food, Gregg would insist on stopping to measure a redwood or to read their latitude.

By the time they reached the Mad River, they had no patience left for Gregg. When he stopped to read the latitude at the mouth of the river, they cursed him soundly—Lewis K. Wood, who survived the expedition to become one of Arcata's founding citizens, remembered that this was not at all unusual—and threatened to launch their canoes without him, leaving Gregg stranded. He had to wade into the water to catch the canoes, and on the other bank he exploded in rage.

Gregg had spent most of his life following the frontier west, beyond the civilized boundaries of the US. "I could never live under my oppression of spirits anywhere in the U.S. where I would be liable to continued annoyance," he once wrote to his brother. But he ended his life by opening up the last untamed corner of California to settlement.

He died trying to make his way back out of the redwood wilderness, and was buried near Clear Lake, about halfway between Humboldt Bay and San Francisco. His companions claimed that starvation killed him, but some historians speculate that they murdered him out of sheer aggravation.

Either way, Wood and the other members of the expedition did make it back to San Francisco, and they brought word of what they'd found: a bay surrounded by fertile lowlands, a nice spot where a man could farm, if he was not too busy getting rich by running supplies to the gold mines on the Klamath and Trinity rivers. Civilization came to Humboldt Bay in a rush.

By 1850, Arcata's town square had sprung up on a small prairie overlooking the bay, where the Gregg expedition had spent Christmas Eve in 1849. Within a few years, stores and saloons lined the edge of the plaza, and more than 500 people lived in town.

The scale of the place was still small enough that people could get along fine with an outhouse in the backyard. Nobody had indoor plumbing. When folks needed water, they carried buckets past the cows grazing in the middle of town and pumped at the well that had been sunk at the center of the plaza.

No one worried about piping in water until 1875, when a fire in Alexander Brizard's store raged out of control and destroyed most of the businesses on the plaza. The town board of trustees decided Arcata needed water mains, the first ingredient for a functioning fire department. After years of dithering, the water system was finally completed in 1884. Pipes, made of hollowed-out redwood logs laid end to end, carried water from holding tanks on the hill above town down to four fire hydrants on the plaza.[15]

The water supply wasn't just used for the fire hydrants, of course. The town's wealthier families were building elegant homes for themselves, and they wanted running water on tap. They also began to order water closets, ornate porcelain fixtures that came up from San Francisco by ship. The flush toilet hit the big time in the 1880s. By the end of the decade, few people would consider building a house without one.

In Arcata, as in cities all over the US, people started to build sewers as an afterthought, when they realized they needed somewhere for the stuff coming out of their toilets to go. The town's first sewer line ran down from the big Victorian houses on the hill, past the newbrick store that was Alexander Brizard's pride. It went down to the edge of the bay, where the raw sewage came gurgling out.

NOTES

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