12

Of Time and the Wetland

At the oldest of Arcata's treatment wetlands, it's now possible to walk on water. Over three decades of filtering sewage, Arcata's wetland cells have developed floating mats of dead cattail stems and leaves underlain by living roots, resilient enough to support a person's weight. The short journey across Treatment Wetland 3 is a strange experience, like walking on a soggy trampoline. Water seeps through the cattail mat and into footprints. On a February day, a dense maze of brown cattail stems stretches twelve feet above the wetland's surface, their shaggy brown seedheads waving in the breeze (Fig. 12.1).

A stroll across the treatment wetland is as close as a modern American can hope to get to the feel of the floating tule islands that William Finley camped on in the upper Klamath Basin in 1905, and that crowded California's unspoiled marshes before the Gold Rush. The floating mats in Arcata were created by accident when the city's treatment plant operators increased the depth of the treatment marshes, part of an effort to improve their declining performance. To their surprise, the dense growth of cattail rose off the bottom and continued to thrive, roots dangling in the water. The wetlands have aged.

"Arcata's is the grandmother municipal treatment wetland," says David Austin, an environmental engineer with CH2M Hill who specializes in treatment wetlands design. Austin remembers studying the Arcata wetlands as a student at University of California at Davis in the 1990s. "It was a pioneering system. Now it's an old design—one that wouldn't be used today."

In 2016, three decades after Bob Gearheart's unconventional marshes began cleaning Arcata's sewage, the city's wastewater plant faced a crisis. During the cold rains of winter, the system often failed to perform to the standards set in its discharge permit. Every part of the plant had aged to the point where its performance is in decline. At the headworks, the two giant Archimedes screws that push raw sewage uphill through a coarse screen had been running for decades; their metal housings were rusting away. The concrete basins of the primary clarifiers—where suspended solids settle out of raw sewage—were cracked, their bottoms eroded by long years of use.

Repairing or replacing these mechanical parts of the system may be costly, but it's a straightforward process. Refurbishing the natural parts of the treatment plant,

Figure 12.1 View from the floating cattail mat on Treatment Wetland 3. Photo by Sharon Levy.

the oxidation ponds and treatment wetlands, is vital, but the path forward is less clear. The bottoms of the treatment wetlands were covered in decades' worth of a nutrient-rich soup of decaying algae and plant parts, which impaired their ability to filter suspended solids and nutrients from wastewater.

All sewage treatment plants age. Mechanical systems, like the activated sludge plants common in big cities, need regular repairs and often require major upgrades after thirty years or so. One of the daunting problems facing Arcata is that nobody knows just how to handle the millions of gallons of organic sludge and the thousands of pounds of overgrown cattail in the treatment wetlands.

The stakes are high. Water quality rules have become more stringent in the decades since the treatment wetlands started up, and every few years Arcata gets a bill from the North Coast Regional Water Quality Control Board for hundreds of thousands of dollars in fines triggered by occasional violations of the city's discharge permit.

"The wastewater treatment plant is our most critical piece of infrastructure," says Mark Andre, Arcata's director of environmental services. The city's future growth depends on the plant working reliably: Every new sewer hookup, or a shift from a single-family home to an apartment building, increases the volume of sewage. Should the city continue to violate its permit, the regional board has the power to impose a building moratorium, as it did during the battle over the regional sewage system in the 1970s.

Rebuilding or refurbishing a sewage plant is one of the biggest investments any US community will make—and forty-five years after the Clean Water Act (CWA) was passed, many cities in California are struggling to find the funds. Rebuilding Arcata's sewage treatment system is expected to cost somewhere in the neighborhood of $30 million to $40 million. In cities that have conventional treatment systems, upgrades are costly but the technical aspects are clear. Arcata's system is unique, and bringing it up to modern standards poses some unprecedented challenges (Fig. 12.2).

In spring and summer the treatment system is at its best. In the oxidation ponds, algae flourish on the rich supply of nutrients. As they photosynthesize, the algae release oxygen into the water, enabling aerobic bacteria to thrive as they break down organic compounds. In engineering lingo, the ponds reduce biochemical oxygen demand (BOD)—the main goal of secondary treatment. When wastewater flows on to the treatment wetlands, dense leaves of cattail shade out the algae, which die and settle to the bottom, dramatically lowering the concentration of suspended solids. In the warm season, when little rain falls, the effluent flowing out of the natural treatment system is often cleaner than is required under the city's discharge permit.

As the days become short and cool, however, algal growth declines and dissolved oxygen levels fall. In the wetlands, the cattails turn brown and stop growing. The rains come, dumping cold water into the system, so that the populations of microbes that do the work of decomposing and transforming pollutants dwindle and their metabolism slows. Growth yields to decay, and the ponds and wetlands begin to release their internal load of nutrients from rotting plant matter.

At the same time, winter rains dramatically increase flows. Many of Arcata's sewer lines are old and cracked, so that rainwater seeps in. A significant number of homes in town have their gutter pipes routed to empty into the sewers. Added to this is the direct loading of rain onto the city's ninety acres of treatment ponds and wetlands. In winter, the plant receives up to 6 million gallons per day of sewage mixed with rain, all of which must be treated—but the treatment wetlands can handle only about 3 million gallons per day.

Most of the permit violations at the Arcata plant result from overloads of rainwater that force operators to bypass the treatment wetlands, releasing effluent that exceeds permitted levels of suspended solids and of BOD. Some of the violations come from the chlorine disinfection system, meant to kill any pathogens that survive passage through the biological sieve of oxidation ponds and treatment wetlands. Gearheart, the wetlands' founding father, has been opposed to chlorination for decades, because in addition to sucking up energy and presenting a hazard to workers, the process produces toxic chlorinated hydrocarbons. Some of the plant's recent violations have been for release of one such poison, dichlorobromomethane.[1]

The extent of the treatment system's troubles became clear as the city worked to move past longstanding conflicts with the regional board. In the days of Arcata's sewage rebellion, the city built its series of three large marshes in defiance of the state water board's directives. Using a grant obtained from the California Coastal Conservancy, Arcata built the wetlands before the board-approved wetlands treatment pilot project had

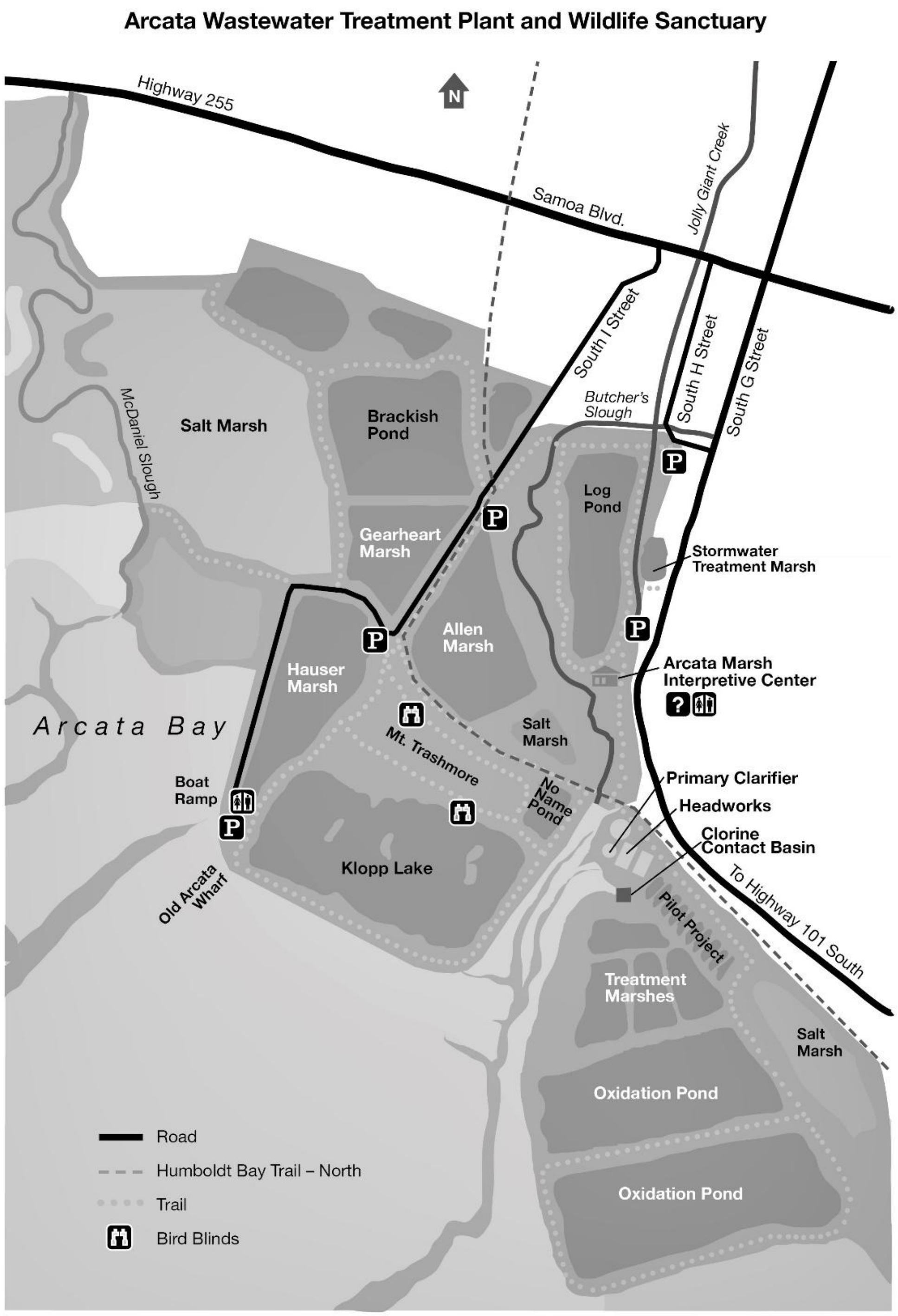

Figure 12.2 Map of Arcata Wastewater Treatment Plant and Wildlife Sanctuary.

been constructed. The marshes, dubbed Allen, Gearheart and Hauser after the major players in Arcata's resistance, were watered for the first few years with flow from a nearby creek because the board had not approved their use to help treat wastewater (Fig. 12.3). In time, the board accepted these three marshes as part of the Arcata treatment system's official "enhancement" of Humboldt Bay's ecology, based on their importance as wildlife habitat and frequent use for environmental education.

Figure 12.3 Allen Marsh, one of the "enhancement" wetlands at the Arcata Marsh and Wildlife Sanctuary. Photo by Maya Scanlon.

Still, the regional board saw these marshes as natural habitats, not as part of the sewage treatment system. Board staff insisted that the city's effluent be treated to discharge standards *before* it flowed through the three enhancement marshes. The result was a complex series of treatment paths in which some effluent flowed to the enhancement marshes and some didn't, and some of the effluent was chlorinated more than once, increasing the risk of toxic byproducts.

In 2012, the city at last negotiated a series of changes that staff had been hoping to achieve for decades. The regional board issued a new permit that specified that Arcata's entire sewage flow should travel a single path, through primary treatment, oxidation ponds, treatment wetlands, and enhancement wetlands, which were at last acknowledged as an integral part of the system. The chlorine contact basin would be retired, and instead effluent would be treated with ultraviolet light as a final disinfection step, before it was released to a brackish marsh created in 2008, where water surges in and out with the bay's tides.

The city hired a consulting firm, Carollo Engineers, to help with the transition to ultraviolet disinfection. The consultants analyzed the capacity of each part of the treatment system to remove BOD. Theydiscovered that the chlorination process had been removing a significant proportion of BOD—in times of heavy loading, as much as 30 percent. Getting rid of the chlorine would mean a significant increase in the need for secondary treatment.

"We always knew that chlorination burns some BOD," explains Brad Finney, an environmental engineering professor at Humboldt State who's been studying the

Arcata treatment system with Gearheart since 1979. “The magnitude of that effect is surprising. It’s not something you ordinarily bother to quantify, because you’re hoping to meet BOD standards without that.”

This new information came as a major setback. In addition to repairing or replacing the headworks and primary clarifier, Arcata had to find some way to significantly increase the plant’s ability to remove BOD. The lion’s share of BOD is taken up in the oxidation ponds—which are at the low point of their efficiency during the winter, when permit violations occur.

In the fall of 2015, Carollo presented its vision of how to bring Arcata’s wastewater system into reliable compliance with discharge standards. Their solution was to build one or more oxidation ditches, a form of activated sludge treatment in which sewage moves through a series of raceways while large paddlewheels churn air into the liquid. Carollo has extensive experience with this technology, and it reliably controls BOD. It’s also a concrete-and-steel, energy-intensive approach, the antithesis of the system Gearheart and his followers have built, studied, and expanded for more than thirty years. Many in Arcata feared the coming of activated sludge would mean the end of the city’s cherished natural treatment system. In Carollo’s preferred design, the oxidation ponds and wetlands would still exist , but would be reduced to a token status. They would continue to serve as wildlife habitat and a recreational site but no longer play a significant role in cleaning the city’s wastewater.

What city staff had thought of as a few minor tweaks to the treatment plant would instead become a complete overhaul of the system. Soon the city was running out of money and time: In December 2016, the deadline for installing UV treatment came and went, while staffers tried to grapple with the unexpected magnitude of the problem. The plant continued to use chlorine for disinfection, while the city searched for a way forward.

Gearheart, now a professor emeritus at Humboldt State, acts as director of the Arcata Marsh Research Institute, headquartered in the old prefab metal building that once housed George Allen’s aquaculture project. He remains actively involved in trying to find a way to keep the natural system going but declined to comment on the current state of affairs.

For Finney, who has worked closely with Gearheart on the marsh treatment system for decades, the Carollo proposal was backwards. “My personal opinion is that you start with fixing the system that you already have to make it run as well as possible,” he says. “We’re not using the existing ponds and wetlands to their full potential, and that can be improved. To instead put an oxidation ditch in as a giant Band-Aid doesn’t make any sense.”

Steve McHaney, now a project manager at the engineering firm GHD in Eureka, is a one-time Humboldt State engineering student who has collaborated with Gearheart on wetland treatment projects in Arizona, Palau, and Saipan. He feels he understands what the Carollo engineers are thinking—he worked for the firm earlier in his career. Wetlands are complex, and many details of their workings remain unknown. Because wetland treatment is unfamiliar to many engineers and remains something of a “black box” even to those who focus on it, it seems like a risky approach.

"It's not unreasonable to see that a more controlled process like activated sludge will make the plant's compliance more reliable," he notes. "But I'd hope that other options are fully explored before Arcata goes that route. Turning to activated sludge means the end of a dream." Gearheart and generations of his students have invested decades of effort to build an understanding of just how the wetlands do the work of treatment using only the energy provided by sun and wind. For them, resorting to conventional treatment would constitute a major defeat.

Greg Gearheart, the kid who grew up watching his father build Arcata's treatment wetlands, became an environmental engineer and has worked in California's water quality regulation system for decades. He's now in charge of data analysis for the State Water Resources Control Board, but he emphasizes that his comments reflect his own opinions, not his employer's.

"It's been an awkward fit from day one," he says, "to take a natural treatment system and make it work in the permit system."

In the early years of the CWA, the standard was that every city or large industry had to use the best available technology to treat its wastewater. In the 1970s, that best technology was assumed to be activated sludge treatment, which cultivates pollutant-digesting microbes from wastewater. Oxygen is pushed into sewage by churning it with high-energy-input agitators, allowing aerobic bacteria to do the work of decomposing organics and oxidizing nitrogen.

Water treatment requirements were eventually expressed in numbers: Dischargers were expected to provide effective secondary sewage treatment, defined as an 85 percent reduction in BOD and a thirty-day average of less than 30 mg per liter BOD and total suspended solids. These numbers are based on the performance of activated sludge systems. Engineers are taught to see activated sludge as the least risky, most reliable way to meet water quality standards.

Arcata's natural system demands far less energy, construction. and maintenance than an activated sludge plant, but its performance changes with the seasons. A few violations of permit standards have always been expected during the winter rains. That understanding was spelled out in the city's general plan, and it was acceptable because back in the 1980s and 1990s, occasional fines did not cost much. But that began to change in the late 1990s. The push for stricter enforcement of water quality laws began in southern California, just as it had a half-century before. The dead, gray waters of Dominguez Channel were again used to illustrate the problem (see Chapter 4). The Equilon oil refinery had routinely violated its National Pollutant Discharge Elimination System permit, releasing oil, grease, chlorine, and sulfides into the Channel. The Los Angeles regional board put off action for years. At last, in September 1999, it announced that Equilon would be fined $700,000, an amount negotiated with the refinery.[2] Environmentalists saw the penalty as too little, too late. The company, they alleged, had saved $2 million or more in treatment costs over the years, and $700,000 amounted to a slap on the wrist.

Statewide, the regional water quality control boards were failing to enforce the CWA. A 1997 study by the California Public Interest Research Group (CalPIRG) found that one in three large dischargers had violated their permits in a four-year period; the average violator stayed out of compliance for two years, often with its board's blessing.[3] Industries and sewage plants self-reported thousands of violations to the regional boards, but only a handful of fines were imposed—and many of these were reduced when dischargers complained. Sediments in the state's urban rivers and bays held dioxins, polychlorinated biphenyls (PCBs), arsenic, chromium, and other potent poisons. Bottom-dwelling fish in southern California bays were too toxic to eat.

"Due to a combination of weak tools, under-staffing and a lax attitude among some officials," concluded a CalPIRG report, "it is evident that enforcement of the Clean Water Act through fines or other penalties has never been a threat for many industries."

In 1999, the state legislature adopted the Clean Water Enforcement and Pollution Prevention Act, sponsored by San Francisco Assemblywoman Carole Migden, which created mandatory minimum penalties for violations of a discharge permit. The idea was based on a similar law enacted in New Jersey in 1990, which was followed by a more than 60 percent decrease in reported violations. The intent of the law was to force regulators to punish serious or chronic polluters. Greg Gearheart worked at the state board as a new bureaucratic machinery was built to enforce mandatory minimum penalties. In his view, the outcome has not been good. "A huge chunk of our resources go into writing and following up on mandatory minimum penalties," he says. "It's a mindless process that distracts the agency from focusing on the violators that are causing real pollution problems." Any violation now must be written up and fined—whether or not it created significant damage.

Gearheart questions whether mandatory penalties are fulfilling their intended mission. The law as it stands may deal a death blow to pond and wetland treatment systems like Arcata's. Traditional engineers have always sought the least risky, most predictable way of meeting discharge standards. Natural systems are dynamic, and seasonal changes can carry them outside the envelope of approved performance for removal of BOD, suspended solids, and ammonia—a form of nitrogen that is toxic to fish and invertebrates in fresh waters, which the North Coast regional board is just beginning to regulate. In the era of mandatory minimum penalties, consulting engineers are more and more averse to the risks that come with natural treatment. Consultants make more money when their clients go with conventional technologies that require construction of cement basins and steel aerators. "A natural system has a snowball's chance in hell of making it through the permitting process these days," says Gearheart, "because of these factors."

A regulatory standard is a blunt instrument, based on a mix of data and bureaucratic pressures. The available scientific literature often measures the toxicity of a particular pollutant in a single aquatic species under a certain set of circumstances, and that information has to be extrapolated to set discharge limits that apply to every treatment plant in a state. In the eyes of some of the people who know Humboldt Bay best, state standards don't make a great deal of sense here.

Chuck Swanson spent more than five years studying Arcata's wetland treatment system as a graduate student at Humboldt State. His thesis project examined nutrient cycles in Arcata Bay, the innermost arm of Humboldt Bay, and compared them to nutrient outflows from Arcata's effluent. His findings show that the contribution from Arcata's plant is dwarfed by the load of nitrogen, phosphorus, and silica carried into the bay from the ocean during spring and summer, when marine currents push nutrient-rich sediments up from the bottom in a process called upwelling. In fall and winter, when the efficiency of the city's natural treatment system declines and more nutrients are released, amounts of nitrogen coming from the wastewater plant are a fraction of those carried in stormwater running off the pastures and creeks around town. Most of the nitrogen in Arcata Bay in winter comes from the ecosystem's own internal load—the decay of eelgrass and phytoplankton that die back in winter in the bay just as cattail dies back in the treatment wetlands.[4]

"We have naturally high nutrient levels in the bay during spring and summer from upwelling in the ocean," says Swanson. "That's when Arcata Marsh is taking all the nutrients out of the water and contributing very little to the bay. In the winter, when the marsh releases more nutrients, Arcata Bay is flushed out because of higher tides and increased freshwater flows. The natural cycles of the wetland treatment system and those of Humboldt Bay are perfectly complementary."

In the end, though, Arcata must find a way to meet state standards year-round—even if those standards are based on much more polluted waters in much more urbanized parts of the state. "There are some who want to argue for exceptions to the discharge limits," says Andre. "That's not where I come from. We want to show strong environmental leadership—so it's awkward to ask for exceptions to the rules everyone has to follow."

Bob Gearheart has found a potential way to clean up and improve the performance of the treatment wetlands: a gizmo invented by a small company called Absolute Aeration, based in Greeley, Colorado. The company's Blue Frog circulator looks like a flying saucer as it floats on the water's surface (Fig. 12.4). Using a small motor and a minimal amount of electricity, the Blue Frogs push still water in a pattern that creates a stratified water column, with an anaerobic bottom layer. A population of anaerobic bacteria thrive in these conditions, digesting the organic gunk that has accumulated on the wetland floor. This approach is unorthodox—conventional systems rely on pushing oxygen into wastewater, an energy-intensive process. Following the discovery of anammox bacteria, which can break down organic compounds and pump nitrogen into the atmosphere in the absence of free oxygen, more engineers have begun to focus on anaerobic treatment systems.

In the spring of 2016, city staff had the dense vegetation cleared from the center of Treatment Wetland 3. Swanson mapped the topography of the sludge bed on the wetland's bottom and found its thickness varied from 1.3 to 2 feet. Two rented Blue Frog units began operating in the wetland in May. Three months later, in August, tests showed that the sludge layer in the wetland had shrunk considerably: About thirty-eight thousand cubic feet of gunk had vanished. The circulators also appeared to improve the wetland's ability to 8 remove suspended solids and BOD,

Figure 12.4 Blue Frog circulators helping to reduce the load of organic sludge in Treatment Wetland 3. Photo by Sharon Levy.

both of which were significantly lower in effluent from Treatment Wetland 3 than in neighboring Treatment Wetland 1, which acted as a control.

The city continues to experiment with the Blue Frog circulators. Over time, they may prove to be an effective, low-cost way of clearing sludge from treatment wetlands, a process essential to restoring their efficient function. This could be an important step toward keeping the natural system going while meeting strict discharge standards.

Cleaned out and buffed up by Blue Frogs, Arcata's treatment wetlands should be able to handle moresewage. City staff also plan to convert the long-dormant aquaculture ponds where George Allen once raised his salmon smolts into an additional wetland cell, increasing the plant's treatment capacity. That would help, but would still fall short of the ability to handle the intense flows of a rainy winter.

For months, Arcatans proud of their treatment wetlands hung in suspense, waiting to see if their pioneering sewage system would endure. "Regulators," notes Scott Wallace, co-author of the 2009 textbook *Treatment Wetlands*, "try to apply a set of steady-state conditions to an ecosystem that's evolving over time." The result is the kind of conundrum facing Arcata.

George Tchobanoglous, an environmental engineer and professor emeritus at the University of California at Davis, reviewed Bob Gearheart's original proposal for a treatment wetland system in the 1970s, when he acted as a consultant for the state water board. Decades later, he's still promoting the radical notion behind

Arcata's wetland system—that wastewater is a valuable source of recyclable water, habitat, and energy.

"The science has advanced dramatically," he says. "You can use intensified wetland technology now and produce the same quality effluent you'd get with activated sludge, using a fraction of the energy."

Researchers have tried a number of ways of intensifying wetland treatment. In tidal flow wetlands, effluent floods the system and then is allowed to drain out. As a result, the wetland shifts between flooded, anaerobic conditions and a drained, aerobic state. This system prevents the buildup of sludge and supports the cycling of nitrogen from the water back to the atmosphere. "To my astonishment," says Austin, "after spending a few years developing the technology, I found that it had been worked out back in the 1890s, by an Ohio inventor named Cleophus Monjou. I've used some of his criteria to design flood and drain systems." The approach works well in many small communities, but likely cannot be scaled up to handle Arcata's peak flow of 6 million gallons per day.

Circulating effluent through a gravel bed that hosts a biofilm of aerobic bacteria can improve the performance of a constructed wetland. There are also a variety of wetland systems that have been given mechanical boosts of one sort or another. Wallace has designed subsurface flow wetlands in which air is pumped into the gravel bed through an irrigation hose, maximizing the action of aerobic bacteria that break down organic compounds. Austin is at work on a system that pumps pure oxygen into wetlands, achieving dissolved oxygen levels so high that the capacity to remove BOD is much increased.

These techniques are still emerging. In 2016, Tchobanoglous suggested that if Arcata was willing to take the kind of risks it did thirty years ago, the city's natural treatment system could survive. "There are real opportunities to intensify the design of the wetlands, and still keep the original function and approach," he said. But Arcata was already well behind schedule on changes the regional board expected, including the installation of UV disinfection as an alternative to chlorine. None of those closest to the problem—the city council, city staff, and Carollo Engineers—were interested in taking a major financial risk on an untried system. In explaining how they decided on recommending activated sludge treatment, Carollo employees wrote that "Any process not yet a proven technology with full scale installation experience was eliminated."[5]

At a public meeting in April 2017, Andre laid out options for upgrading Arcata's sewage plant. A series of aerators could be placed in one of the oxidation ponds, transforming it into a muddy facsimile of an oxidation ditch. This would create more secondary treatment capacity, but not enough to meet permit standards year-round. Carollo's facility plan recommended building two or three oxidation ditches, creating enough secondary treatment capacity to handle Arcata's sewage for the foreseeable future but rendering the treatment wetlands irrelevant.

The energy it takes to run this kind of system could more than triple the treatment plant's annual consumption of electricity. Andre called the energy projections "depressing," and said they represented "a quantum leap in energy consumption."

Susan Ornelas, a member of the city council, was Arcata's mayor until December 2017. She earned an engineering degree at Humboldt State in the 1990s, and studied in Bob Gearheart's classes. So she understands the complex problems facing the city's wastewater treatment system. She's also keenly aware of another coming crisis: Humboldt Bay is experiencing sea level rise at a rate higher than anywhere else in California.[6] Though no one can forecast the timing with precision, in the next few decades the bay is likely to rise up and drown the treatment plant entirely. Andre envisions a ring of fortifications built around the entire wastewater plant, including the treatment wetlands, to keep out the rising bay waters. That's an expensive proposition, which may or may not be approved by the Coastal Commission.

Ornelas had serious doubts. She ran a hand through her thick, graying hair as she explained the dilemma. "I have a deep love for Bob Gearheart," she said. "He wants to keep the wetlands going: they're his baby. We all love the marshes. But how can we invest $40 million in a place that's going to be underwater?"

She looked into the possibility of building any additional secondary treatment facility on an abandoned field inland from the bay's edge, about half a mile from the current oxidation ponds and treatment wetlands. City staff explored the idea, but found it expensive and impractical.

Arcata's wetlands were born out of a rebellion against wasteful conventional technology that would have consumed more energy than any other endeavor in Humboldt County. In the 1970s, when local activists fought the state's proposed regional sewer system, none of them knew about manmade global warming. Thirty-five years later, the evidence for human-induced climate change and rapid sea level rise is overwhelming. But the conventional engineers' response to Arcata's wastewater troubles is an energy-intensive activated sludge system, a choice that will cause the city's carbon footprint to balloon.

Conventional wastewater treatment systems use a lot of energy. A 2013 study found that they consume about 30 billion kilowatt-hours of electricity per year, or about 0.8 percent of the electricity used in the US.[7] Some urban sanitation districts, including the East Bay Municipal Utility District (EBMUD) on San Francisco Bay, have been able to radically reduce their carbon footprint by harvesting biogas energy from decaying restaurant waste and other sources. EBMUD has gone beyond net zero energy consumption and is now selling energy back to the grid. Unfortunately, these biogas systems are not cost-effective in small cities like Arcata.

In the end, city staff worked out a compromise plan. Arcata's sewage treatment plant will be upgraded by investing in and improving elements of the original system—the oxidation ponds and treatment wetlands—as well as building a single oxidation ditch. This hybrid of natural and conventional treatment should keep the effluent within permitted water quality limits even during heavy winter rains.

A single oxidation ditch won't have the capacity to treat all the city's sewage on its own. By deliberate design, the ponds and treatment wetlands will remain an essential part of the system. But space will be left for a second oxidation ditch, which may be needed if rising bay waters drown the ponds and treatment wetlands in the future.

Once an oxidation ditch is running, it must be kept going, or the population of aerobic microbes that do the work will die off. This means the oxidation ditch will have to be powered throughout its life—but operators will be able to turn the aerators down in times of low sewage flow. "We'd be crazy," says Andre, "not to turn it down as far as possible."

Energy consumption at the sewage treatment plant will climb dramatically—and not only because of the power needed to run the oxidation ditch. UV disinfection uses plenty of electricity, and so will the aerators added to the old oxidation pond. As the city staff saw it, the only practical alternative would have been to keep chlorine disinfection, with its toxic hazards, indefinitely. The city council decided against that.

Arcata has begun installing solar panels to transform the sunlight that strikes the open-air treatment system into electricity. The city plans to continue adding panels and selling energy back to the grid. This will put a significant dent in the increased cost of powering the hybrid treatment system planned for the future.

Our compulsive burning of fossil fuels will eventually cause the marshes that inspired this book to vanish under the tides of Humboldt Bay. All of us push the waters higher—when we drive our cars, when we heat our houses, when we flush our toilets. While Arcata's wastewater treatment system is unique, its dilemma is not. Wastewater treatment plants around the world have been built at the edges of estuaries and oceans. Now, many of them have come perilously close to being overwhelmed by rising seas.

The San Francisco Bay area leads the charge in addressing this problem—and a key part of the strategy there is restoration of tidal marshes. Like other wetlands, they provide crucial habitat and filter pollutants out of water. They absorb the shock of powerful waves, buffering the shore from flooding and erosion. They capture and store carbon, helping to offset humankind's fossil fuel addiction. Before we diked and drained and paved them over, tidal wetlands buffered the land from the sea. In the decades to come, they offer the best chance of preserving roads, buildings, airports, and wastewater treatment plants built near shorelines.

NOTES

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