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The United States of Vanished Wetlands

Before he became a revolutionary general and the nation's first president, George Washington was a destroyer of wetlands. In 1763, he surveyed the edges of a million-acre expanse of wet forest that lay along the Virginia–North Carolina state line. He described the Great Dismal Swamp as a "glorious paradise" full of wildfowl and game.[1] Still, he seemed to have no qualms about dismantling Eden. In 1764 he applied with five partners for a charter to create a business called "Adventurers for draining the great Dismal Swamp."[2] Their goal was to chop down and sell the timber from majestic cypress and cedar trees, then to plow the land for crops.

The brutal work of digging drainage ditches and canals was done by slaves. By the time of the Revolutionary War, the Adventurers Company was producing 8 million shingles a year for sale—valuable slivers of wood cut from the swamp's enormous bald cypress trees.

There was profit in undoing wetlands. Draining a wetland also seemed to make a place healthier. People who colonized swampy land were plagued by a dreadful illness, one that often killed, and left survivors with recurring bouts of a bone-rattling fever. Malaria—the name itself means "bad air"—was believed to be triggered by poisonous vapors rising from still waters.

The drainage and destruction of wetlands was an unwritten founding principle of the US. The pattern began with some of the earliest European settlers. Well before the colonies won their independence, the loss of wetlands had led to pollution that changed the ecology of rivers and bays. Over the centuries, wetlands loss and water pollution have accelerated in tandem, driven by the need for farmland, the urge for profit, and the fear of disease.

The history of these interwoven changes on land and underwater begins in the Chesapeake Bay, the site of the first permanent British colony in America.

In the summer of 1608, Captain John Smith and the colonists of Jamestown were starving. As they sailed into the Chesapeake Bay for the first time, their guts ached and their bones stood out in sharp relief. In the bay they found salvation: a dazzling array of edible creatures. At ebb tide, rich beds of mussels and oysters were uncovered. Blue crab scuttled in the shallows, armed with turquoise claws.

Atlantic sturgeon surged upstream to spawn; an adult could weigh more than eight hundred pounds. The waters were thick with shad and striped bass. A member of the crew wrote that none of them had ever seen such aquatic bounty before.

Captain Smith would not stay long. Injured in a gunpowder explosion, he returned to England for treatment in 1609 and never saw Virginia again. He advertised the wonders of the Chesapeake region, however, helping to recruit new colonists. "Heaven and Earth never agreed better to frame a place for man's habitation," he wrote, "were it fully manured and inhabited by industrious people."

Smith and his men would not recognize today's Chesapeake. On a typical summer's day, 60 percent of the bay's waters are a dead zone, devoid of oxygen, where no fish or crabs can survive. Sturgeon have become a rarity, shad fisheries are closed, striped bass are in decline, oysters have all but vanished. The estuary suffers from an overload of nitrogen, phosphorus, and sediment, generated by the 17 million industrious people who now live in the Chesapeake watershed.

The bay's watery world has been transformed by the axes and plows, and later the bulldozers and cement mixers, of people on land. Paleoecologist Grace Brush has used plant remains preserved in the muddy bottom to read the story of drastic change in the bay's underwater communities. These relics have given her an intimate knowledge of the Chesapeake the first colonists encountered. She has tracked the beginnings of the ecosystem's decline to the early years of European settlement.

When the first colonists arrived, the land surrounding the bay was covered in forest and rich in wildlife. Beaver were abundant. The big rodents cut down trees using their powerful buck teeth, and built dams that formed marshes. Beavers shape the nature of a watershed: Their dams hold not just water, but rich stores of nutrients that would otherwise run off the land. Boggy beaver country made an ideal habitat for the soil microbes that process nitrogen, changing it into forms used by plants and animals, then pulling it out of the realm of living things and back into the air as N_2 gas.

Beaver furs were a prized commodity in Europe. British colonists feared the swamps where beaver lived, so they traded with the Indians for pelts. Beginning in the 1620s, hundreds of thousands of beaver were trapped in Connecticut, Massachusetts, and New York, and on the streams feeding the Chesapeake. In 1638, demand increased when King Charles II made the use of beaver pelts mandatory in hat making.[3] By the mid-1700s, beaver were gone from the Chesapeake watershed.

The beavers' disappearance left a signature in bay sediments: After 1750, levels of nitrogen dropped, possibly due to a sudden absence of beaver poop.[4] Later, after beaver dams slowly rotted away, ponds drained, and areas of wet soil that hosted denitrifying bacteria dwindled. Increasing loads of nitrogen began to run into the bay.

The pulse of added nutrients is recorded in the remains of centuries-old algae. Diatoms are single-celled green algae that form skeletons of silica—each species leaves behind a skeleton with a distinctive shape. Under the microscope, these may resemble a five-pointed star, a pasta shell, a wagon wheel, or a truck tire. In the 1700s, concentrations of nitrogen and sediment climbed, and the diversity of

diatom populations began to dwindle. The *Nereis* worm, a creature that fed on the bay bottom and was a favorite prey of shad and other native fish, had been abundant. After the beaver were hunted out, *Nereis* worms began to die off.

Meanwhile, settlers were chopping down trees and plowing the land to plant wheat and tobacco. The crops exhausted nutrients in the soil, so farmers imported guano from South America as fertilizer. The load of nutrients running off the land increased.

Before European settlement, the Chesapeake's bounty had relied on bottom-dwelling organisms. These included aquatic grasses and diatoms that grew on the sediments or on the leaves of larger plants. As they transformed the sun's energy into green growth, the underwater plants pumped oxygen into the depths.

By the late 1800s, forests and wetlands were gone from the watershed, translated into tidy farm fields or buried under city streets. The release of nutrients from land transformed life in the estuary. The waters were clouded with blooms of floating algae, which blocked light. Aquatic grasses faded, and with them went the benthic diatoms and *Nereis* worms. Oysters vanished, victims of pollution and over-fishing. The bay's bottom turned barren, depleted of oxygen. The entire aquatic ecosystem was turned inside out. Once benthic and diverse, it became planktonic, able to support only a few kinds of plants and animals adapted to live in the upper layer of over-fertilized waters.

Onshore, settlers' traditional fear and loathing of wetlands was reinforced. Many suffered from a disease they knew in awful detail. The illness was called "marsh fever" or "ague," and everyone knew the symptoms: a fever that returned every third or fourth day, bringing on hot sweats followed by cold shakes; a painful swelling of the spleen; weakness; and a yellow complexion.

Malaria was carried to America in the veins of European colonists, and later in those of the slaves they brought from Africa. Many of the early Chesapeake colonists came from the marshy parts of Britain: Kent, Sussex, and the shores of the Thames, where malaria had been endemic since the fifteenth century. People there believed the illness was caused by bad air emanating from wetlands. The impoverished parish of Romney Marsh had one of the highest mortality rates in eighteenth-century England. "The large quantity of stagnating waters engenders such noxious and pestilential vapours as spread sickness and frequent death on the inhabitants," wrote a visitor.[5]

A high proportion of children born in seventeenth- and early eighteenth-century Virginia died between one and four years of age. Babies receive short-term immunity to malaria from their mother's milk, but this ends after the first year, and many young children can't fight the disease off on their own.[6] The colony's death records echo modern mortality statistics from sub-Saharan Africa, where malaria remains endemic and the great majority of malaria deaths strike children under the age of five.

Many of the settlers must have been infected, or malaria would not have taken hold in the New World. The disease involves intricately timed interactions between protozoan parasites, short-lived mosquito hosts, and the humans adult female mosquitoes feed on. Only mosquitoes in the genus *Anopheles* carry malaria, and the species that transmit the human disease are adapted to live among

people, resting on the walls of houses and laying their eggs in a puddle as small as a hoof print. Malaria did not exist in pre-settlement America, but an eligible mosquito species, *Anopheles quadrimaculatus*, was waiting on the Chesapeake shore to receive the parasite.

Malaria persisted. It would travel west with new waves of immigrants, cause great suffering and early death, and add to settlers' intense dislike of wetlands.

A few swathes of wet wilderness were so vast, mucky, and difficult to cross that they foiled the efforts of pioneers to tame them, at least for a time. Among these remarkable places was the Great Black Swamp, an expanse of wet forest and marsh that stretched across a million acres in northwest Ohio and Indiana. The wilderness was home to wolves, deer, elk, black bear, mountain lion, beaver, and river otter. Now it is gone, the land where great beech, elm, and sycamores grew parceled into farm fields.

In 1794 US soldiers under the command of General Anthony Wayne, a Revolutionary War hero called out of retirement by President Washington, marched along the upper Maumee River past a string of Indian villages. Wayne marveled at the "very extensive and highly cultivated fields" that lay along the river's edge. He'd never seen such immense fields of corn, he said, in any part of America, from Canada to Florida. He had his troops set the Indians' homes and impressive crop on fire, then they marched on downriver.

Wayne's troops moved through parts of the Black Swamp and camped in the wetland on August 19. The next day, at the Battle of Fallen Timbers, just south of present-day Toledo, they defeated the Western Confederacy, an alliance of tribes that had joined forces to defend their lands. The soldiers returned upriver to Fort Defiance, where many of the men fell sick with malaria.

Malaria was a deadly threat to Indians, who had no ancestral immunity to the parasite. While bivouacked in the Black Swamp, US Army Major B.F. Stickney daydreamed about using the place as a biological weapon against the Indians. Force the natives to live in the swamp, bring them plenty of good food, keep them there for six weeks, and those who didn't die would be too weak to fight. "All the lives of the troops would be saved, and at least three-fourths of the cash," he wrote. Stickney admitted there might be some "question of morality" in this tactic.[7] Though the army never forced native people into the swamp, many Indians who survived clashes with the army would die of malaria.

After Wayne's victory, the tribes were forced to cede their lands, but settlers were slow in coming. The Swamp was nearly impossible to move through, and the region had a reputation for unhealthiness. At the outbreak of the War of 1812, the only white settlements in northwest Ohio were at the rapids near the mouths of the Maumee River, on the swamp's western edge, and the Sandusky to the east. About four hundred settlers and three thousand Indians lived in the region. When Detroit fell to the British, the settlers fled, and troops were sent under the command of General William Hull to retake the city.

To get to Detroit, Hull's men had to slog through the dark heart of the Black Swamp. It was spring, when the swamp was at its wettest. Soldiers staggered along, thigh-deep in mud, with frequent stops to pry out horses and wagons stuck in the mire.[8] At night they pitched tents, but the mud collected ankle-deep inside.

Journals kept by the men under Hull's command record miserable, wet nights plagued by mosquitoes. Soon after, they suffered the fever and weakness of malaria.[9]

The swamp was "astonishingly fruitful in the production of marsh miasmata," wrote a regimental surgeon.[10] Encamped in the cold waters of the swamp, many of the sick died. One soldier, Elias Darnell, wrote that staying in the swamp killed more of his comrades than an intense battle.

Yet the Black Swamp and Lake Erie's southwestern shore were also bountiful. The Maumee ran clear and was thick with fish: bullhead, bass, sturgeon. On an April morning in 1813, two hungry soldiers stationed at Fort Meigs, near present-day Toledo, walked down to the Maumee River. The clear waters swarmed with perch, muskellunge, sturgeon, and catfish. Plunging spears into the water at random, they caught sixty-seven fish in thirty minutes, often killing two or three with a single stroke.

Every river mouth west of the Sandusky held dense beds of wild rice, where waterfowl settled to feed, then rose in flocks that darkened the sky. The stalks could stand higher than a man's head: To feed, ducks grabbed the stems with their feet and tugged the seedheads down to the water. Waterfowl were so abundant, so fearless and loud, that their constant quacks and honks kept a nervous young army recruit lost in the marsh awake all night.

After the war ended in 1815, white pioneers trickled back to northwest Ohio, settling on the fringes of the Black Swamp, in the same places where Indian villages had stood. Many more emigrants wanted to pass through on their way to Michigan, Indiana, or Illinois, but the swamp remained a formidable barrier.

The first road across the swamp was funded by Congress and completed in 1827 after years of labor (Fig. 7.1). The Black Swamp Road was a thirty-one-mile ribbon of soggy earth, ditched on both sides, cut through forest so dense that travelers never saw the sun. It earned a reputation as the worst route on the continent.[11] The more wagons that sloshed over it, the more impassable it got. Nevertheless, it was used by growing numbers of settlers heading west. In the 1830s, locals earned steady money consoling emigrants and hauling stalled wagon teams out of the worst mud holes. Thirty-one taverns stood along the road between Fremont, on the Sandusky, and Perrysburg, on the Maumee, an average of a tavern for every mile of road.

By 1850, Congress was addressing the widespread urge to do away with all the nation's great wetlands. In a series of new laws collectively known as the Swamp Land Acts, states were granted rights to sell off wetlands within their borders. The idea was that private owners would drain the land, transforming swamps and marshes into productive farms.

In the Black Swamp, the choice farm lands were along streambanks, which formed strips of dry land that could be cleared of trees and farmed without artificial drainage. Inland from the streams, the soil was saturated with water and crops withered. A few German and English farmers settled in the swamp, cleared their plots, and dug ditches to channel excess water off their fields. The advantages of this technique soon became obvious. The land was so flat, however,

Figure 7.1 A crew clearing trees to build a railroad extension across the Great Black Swamp. Photo from Wikimedia.

that workable drainage ditches had to run a long distance, and could not be dug without crossing a neighbor's property.

The local historian Homer Everett, who witnessed the settlement era, wrote that a Yankee would refuse to let a German neighbor dig a ditch through his land, though the drainage would have helped them both. Prejudice and petty disagreements stood in the way of drainage, and therefore of successful farming. "If Mr. Johnson owned a piece of wet land near Mr. Jones, and wanted to get the water off by draining through Jones' land," wrote Everett, "he could not obtain it because, perhaps, Johnson, ten years before, threw a club at Jones' yellow dog to drive him out of the road and keep himself from being bitten."[12]

In 1859 the Ohio General Assembly passed a law authorizing county commissioners to construct drainage ditches. Farmers benefiting from ditch construction shared the cost. The other Midwestern states also enacted laws authorizing drainage districts, enabling the construction of ditch networks that drained great swathes of land—a mission that required investment and coordination, and could not have been accomplished by individual landowners.[13] Through the work of drainage districts, the Corn Belt states of Ohio, Indiana, Illinois, and Iowa would lose more than 95 percent of their native wetlands.

At first, work in the Black Swamp focused on clearing, deepening, and widening natural channels, which were so cluttered with log jams and beaver dams that water barely moved through.[14] Construction of new drainage ditches came later. The most dramatic example is the Jackson Cutoff in Wood County, which is seven miles long and more than twenty feet deep in places. The cutoff was dug in 1879 at a cost of $110,000. First timber crews cleared the trees, saving enough lumber for bridge construction and burning the rest. Work horses pulled plows through the ground, followed by a second crew that dug the channel using horse-drawn scrapers. Men with shovels did the rest of the digging, removing the heavy clay that lay beneath the rich topsoil. The Jackson Cutoff drains thirty thousand acres in Wood County, emptying into Beaver Creek near its confluence with the Maumee—and it is just one ditch among hundreds.

Yet even this proliferation of ditches was not enough to keep farm fields drained and productive. For the first few years after a plot of forest had been

cleared, decaying tree roots underground funneled water out of the topsoil. Once the roots had rotted away, the channels they'd formed collapsed. The soil became waterlogged and depleted of oxygen, and crops failed.

To survive, farms in the region needed underdrainage: a series of channels laid beneath a field that would carry excess water into the nearest ditch. The best way of doing this was with drainage tiles, short pieces of ceramic pipe. Laid end to end in a furrow, then covered over with soil, these tiles could function for many years. The technique had been brought to the US in 1821 by John Johnston, a Scottish immigrant farming in Geneva, New York.[15] Though his neighbors mocked him at first, Johnston's ability to turn unusable, water-soaked land into productive fields soon changed their minds. Influenced by Johnston, a Geneva potter named B.F. Whartenby patented the first tile-making machine in America.

Wood was cheap and abundant in the Black Swamp—there were more than four hundred sawmills operating in the region by the 1870s. The nearest tile factory was far off in central Ohio, so farmers used wooden underdrains, made by nailing planks together in a V-shape. Underdrainage raised crop yields, and the demand for affordable clay tile grew. Some enterprising soul tested the abundant clay that lay a foot or two beneath the surface of the Black Swamp and found that it made excellent tiles. By 1879 there were eleven tile factories in Putnam County alone, producing eighty thousand feet of tile per year.[16] In 1880, more than fifty tile factories operated in northwest Ohio.

The swamp, once a forbidding and near-impassable wilderness, was dismembered and used to feed an accelerating cycle of human industry. The great wetland trees—ash, elm, sycamore—were felled and used to build houses, make furniture, and fuel the railroads that sprouted up across Ohio. In the 1860s Ohio's railways consumed 1 million cords of wood each year as fuel, and an unknown quantity for ties. The process of railroad construction involved building drainage ditches, and showed settlers that the mucky soil could be reclaimed for farming. The discovery of underdrainage created a growing demand for tile. All this drove an orgy of forest-clearing and land-draining, which in the course of five decades (from 1870 to 1920) completely erased the Black Swamp, leaving an orderly landscape of farm fields in its place. A wilderness went up in the smoke from railroad engines, and flowed in drainage ditches down to the Maumee, which began to run murky instead of clear.

The Black Swamp's undoing was speeded by James B. Hill, a native of Fremont, at the eastern edge of the swamp. Born in 1856, when most of the swamp still stood, Hill experienced firsthand the back-breaking labor of digging ditches to place tile. In 1893, he built the first successful steam-driven tractor ditcher while working in a machine shop in Bowling Green, a town set in the heart of the swamp. Hill's invention, known as the Buckeye Traction Ditcher, could set tile faster and more accurately than a crew of experienced men. In 1905, a Buckeye Ditcher raced fifty hand ditchers and laid four hundred feet of perfect trench to the hand crew's three hundred feet.[17] The Buckeye Ditcher would help to place thousands of miles of tile in the Black Swamp, and would be used to drain the Florida Everglades and large stretches of Louisiana wetland.

In 1858, as early settlers struggled in the mud of the Black Swamp, George Waring engineered a network of drainage tiles on a stretch of marshy ground in the heart of Manhattan. Following his plan, workers hand-buried more than sixty miles of clay pipe, draining the land so that Central Park could be created.[18] Waring did such an expert job that more than a century later, some of the original clay tiles were still carrying water and keeping the ground dry.

Waring's work on Central Park was the largest drainage project of its time, and made his reputation. He started out as a farmer and ended up as one of the most respected sanitation experts in the US. He was a drainage fanatic and a staunch believer in the notion that wetlands poisoned human health. "Land which requires draining hangs out a sign of its condition," he wrote. "Sometimes it is the broad banner of standing water, or dark wet streaks in plowed land, when all should be dry and of even color . . . sometimes the quarantine flag of rank growth and dank miasmatic fogs."[19] Waring personified the era's attitudes toward wetlands, farming, and public health (Fig. 7.2). He lived by the notion of killer swamp miasmas—and died by it.

In 1861, when his work on Central Park was almost completed, Waring joined the Union Army as a cavalry officer, and rose to the rank of colonel. After the war he managed a Rhode Island farm and wrote, everything from books on scientific agriculture to popular horse stories and accounts of European travel. He tried, and failed, to market a design for an earth closet, a device that might have limited the gush of water pollution that came with the era of the flush toilet. He wrote a popular and influential book, *Draining for Health and Draining for Profit*, which summed up his view of wetlands as cauldrons of disease, and gave detailed instructions on how to make them disappear.

By the 1870s, Waring had become a sanitary crusader, warning Americans of the danger of sewer gas, the stink that arose from badly plumbed water closets and backed-up sewers.[20] He argued that marsh miasmas and sewer gas were the source of every contagious disease. Waring would carry the banner for miasma even after Pasteur, Lister, and Koch had demonstrated the existence of pathogenic microbes. Many physicians of the time dismissed the newfangled germ theory of disease and agreed with Waring; his 1878 essay on the miasmatic origin of typhoid fever was awarded a prize by the Rhode Island Medical Society.

That year a devastating epidemic of yellow fever struck New Orleans. Half the city's population fled, catching any train they could. These refugees brought the infection to other cities: Mobile, Chattanooga, Memphis.

Yellow fever is a particularly terrifying disease. The first signs of infection are aches and fever, followed by jaundice. The liver breaks down, destroying proteins needed for blood clotting. Victims bleed from their eyes, nose, and mouth. In the final stages, they bleed into their stomachs and vomit up partially digested blood. Death came in a frantic agony, and its source remained mysterious.

Bacteria had been identified as the cause of cholera, but yellow fever is caused by a virus and transmitted by mosquitoes. Viruses were then unknown entities, invisible under nineteenth-century microscopes. The concept of insects as disease vectors was unimaginable.

The 1878 epidemic spread to eleven states, infecting 120,000 people. It ended with the arrival of the first frost in autumn. By then twenty thousand people had died, five thousand of them in Memphis.[21]

Acting as a special commissioner by presidential appointment, Waring went to Memphis to sanitize the city as a protection against future outbreaks. The city had no sewer system. Its streets were full of filth, and Waring saw that filth as the source of the epidemic. He designed and supervised the building of a sewer system that kept human waste and storm runoff separate, an innovation that would be adopted nationwide. Like many of his ideas, the concept of the separated sewer system was adopted from Edwin Chadwick's work in England. Memphis remained free of yellow fever, and Waring's efforts seemed a great success.

Demand for his services grew. Waring acted as a consulting sanitarian for the wealthy landowners of Newport, Rhode Island, and later supervised the cleanup of New York's befouled streets, enlisting local children as his foot soldiers. He became a public health hero, "the apostle of cleanliness, the scourge of dirt."[22]

When the US declared war on Spain in 1898, forty thousand American troops landed on the Spanish colony of Cuba. Yellow fever was endemic on the island. In only three months, the US Army defeated Spain and occupied Cuba. Fewer than four hundred US soldiers died in combat, but more than two thousand were infected with yellow fever.[23]

Waring was asked to chair a commission of experts charged with cleaning up Havana and stamping out contagious disease. He traveled to Havana in October 1898, where he found a city without sewers, where garbage and feces were strewn in the streets. There was a good water supply, but Havana was surrounded by marshes, which he saw as generators of miasmatic illness.

Waring left Havana after three weeks and on his way back to the US wrote up his plan for the city's rescue. He would ban privies, replacing them with flush toilets. He would build a sewer system, pave the streets, drain the marshes. He believed his plan would put an end to yellow fever and other "miasmatic" diseases in Havana, at an estimated cost of $10 million.[24]

Waring fell sick the day after he returned to New York. Four days later, he died of yellow fever. The miasma theory would die with him.

William Gorgas, the US Army doctor in charge of sanitation in Havana, shared Waring's belief that yellow fever was caused by filth, and followed much of Waring's advice. Havana was transformed into one of the cleanest cities in the Americas. Despite all this, the spring of 1899 saw a fresh outbreak of yellow fever: Cleanliness, it seemed, was not enough.

The man who solved the puzzle was a young bacteriologist, Jesse Lazear, who was hired to head the Army's disease lab in Havana. Lazear had been studying malaria and knew that breakthrough research in India had just shown that the disease was transmitted by mosquitoes. Ignoring the skepticism of his colleagues, he consulted with a Cuban doctor, Carlos Finlay, who had painstakingly matched the pattern of yellow fever infection in Cuba to the presence of a single mosquito species, *Aedes aegypti*.

Figure 7.2 George Waring in 1883. Photo from Wikimedia.

Lazear raised *A. aegypti* mosquitoes in his lab, then had adults feed on infected patients in the Army's yellow fever ward. Healthy volunteers agreed to be bitten by the fever-exposed mosquitoes. The experiment took time and repeated trials, because the yellow fever virus must incubate in a mosquito for several days before it becomes contagious. Eventually, the lab-raised mosquitoes did cause yellow fever in volunteers. Several of them died, including Lazear himself.

To prove beyond doubt that yellow fever was transmitted only by mosquitoes, Walter Reed, head of the Army's Yellow Fever Commission, had volunteers sleep in the pajamas and on the sheets used by yellow fever victims, soaked in their vomit and feces. None became ill.

This dramatic evidence convinced Gorgas: He abandoned the miasma theory and made war on mosquitoes. His tactics were efficient but practical only under a state of martial law. He sent sanitation squads into every corner of Havana, coating every puddle of standing water with oil (a thin layer of oil kills mosquito larvae). He prowled the streets, personally checking that all residents oiled or screened every bit of water on their property. *A. aegypti* breeds in the small bodies of water that surround humanity: the water-filled hoof print of a cow, a bucket left standing, a household cistern.

Gorgas would later use similar techniques during construction of the Panama Canal in the early 1900s. Decades earlier, when French colonialists had attempted to build a canal across the isthmus, twenty-two thousand workers died of

mosquito-borne disease, halting construction. If workers dropped at the same rate, America's canal would never be completed.

Gorgas fumigated every building in Panama City and oiled the streets. He had his crews attack all potential mosquito breeding grounds in a long, narrow strip of jungle surrounding the construction zone. They dosed any patch of standing water with a mixture of carbolic acid, resin, and caustic soda. Workers slept under bed nets, and servants patrolled the railcars where workers slept, armed with fly swatters and bottles of chloroform, killing mosquitoes one by one.

These tactics focused on the *A. aegypti* mosquito and, in 1906, succeeded in extirpating yellow fever in Panama.[25] Malaria, however, remained an intense problem, affecting the majority of canal workers. Little was known about the ecology of malarial mosquitoes. That changed when a US Department of Agriculture (USDA) entomologist, August Busck, visited Panama. He collected mosquito larvae from throughout the region and reared them to adulthood. Busck identified more than ninety species, thirty of them unknown to science. His new insights into mosquito ecology made it clear that construction work on the canal was creating habitats for the species most likely to act as malaria vectors: Larvae grew in the puddles between railroad ties, and in ponds formed where excavation spoils were dumped.

The main malaria vector in Panama proved to be *Anopheles albimanus*. Highly susceptible to malaria parasites, *A. albimanus* seeks out humans as a source of blood and breeds in the small puddles that surround human habitation. Joseph LePrince, who worked as Chief Sanitary Inspector on the canal project, came to know the species on intimate terms. He invented a way of tracking mosquito movements by coloring adults with blue aniline dye, a tactic that showed the mosquitoes traveled no more than a mile from their hatching sites.[26] This discovery let public health workers focus on breeding habitats within a mosquito-flight of the work crews building the canal.

LePrince brought the mosquito-fighting strategies developed in Panama back to the US. During World War I he was in charge of mosquito control at military bases in the South, where malaria remained a serious problem, and succeeded in dramatically lowering infection rates. He identified *Anopheles quadrimaculatus*, later known as the quad mosquito, as the vector of malaria in North America. After the war he continued to battle mosquitoes as an officer of the US Public Health Service (USPHS), using strategies that included draining marshes, stocking ponds with minnows that devour mosquito larvae, supplying low-cost screens for rural households, and spraying the shallow waters of lakes with Paris green, a highly toxic compound of copper and arsenic.[27]

The new insight into the link between mosquitoes and disease triggered a flurry of wetland drainage. In the 1910s, the New York City Health Department hired hundreds of workers each summer to dig drainage ditches and build tidal gates in coastal marshes. New Jersey followed, requiring local governments to create their own "county mosquito extermination commissions."[28] In the South, the USPHS took charge of drainage campaigns against mosquitoes.

Ditching of salt marshes was meant to increase tidal flow and prevent the pooling of stagnant water that mosquitoes need for breeding. The work was done

at random, however, without testing for the presence of quad mosquitoes. Poorly done drainage efforts often created new puddles of standing water where mosquitoes could breed. There's no clear evidence that the mass drainage efforts of the early twentieth century helped to control malaria. A more certain result of ditching was the loss of native salt marsh plants, the lowering of the water table, and the destruction of habitat for birds and fish.[29]

Epidemic malaria had slowed the settlement of southern Illinois and Missouri and plagued settlers throughout the Midwest, but it was gone from the region by 1890. People assumed this was a happy effect of wetland drainage.Yet the disappearance of malaria in the Midwest cannot be traced to a single cause. Drainage of wetlands for agriculture was not the most significant factor—it could not have been, because malaria began to dwindle years before the establishment of organized drainage districts.[30]

In American history, malaria was very much a disease of pioneers. As masses of people moved west, they carried their malaria parasites with them, just as early Chesapeake colonists brought their parasites from England. The log cabins of early settlers were crowded with a dangerous combination of immune malaria carriers, non-immune people vulnerable to infection, and hungry mosquitoes. Quad mosquitoes found plenty of shelter in the dark crevices of log cabin walls. As human populations stabilized in the late nineteenth century, people stopped moving and started living in better housing, and infection rates went down.

Other changes helped too. Railroad construction carried people inland, allowing them to settle away from mosquito-infested bottomlands. The rise of dairy cattle in Iowa, Wisconsin, and Minnesota gave quad mosquitoes an alternate source of blood meals, decreasing human infection rates.

In the colder parts of the country, where temperatures were less favorable to malaria parasites and mosquitoes could be active only a few months of the year, the disease faded as settlements became more established. In New England and New York, malaria was first reported in the 1670s and was gone by 1750. The disease remained endemic in the American South, where warmer temperatures favored the persistence of malaria parasites and mosquito vectors remained active most of the year. It would migrate North again during and after the Civil War, when thousands of soldiers infected in boggy Southern battlefields returned, carrying malaria home with them.

In the summer of 1905, a young ornithologist and wildlife photographer named William Finley ventured into the wet wilderness of the Klamath Basin on the Oregon–California border. In Lower Klamath Lake, he and his partner Herman Bohlman found thousands of water birds nesting on floating islands of tule, or hard-stem bulrush (Fig. 7.3). The ten-foot-tall, tubular leaves of tule had formed flexible mats over centuries of growth, the green shoots of each spring weaving up through the dead stalks of previous years.[31] Finley and Bohlman lived among the birds on these precarious tule mats for two weeks. At times the surface of the floating islands gave way without warning, dumping the men into the lake. They laid their sleeping bags out on piles of tule straw three feet deep, slept through the night, and awoke floating just at the water's surface.[32]

Surging beneath them was an astonishing wealth of lake trout and suckers. At one fishing spot where the rocky bottom forced migrating suckers to swim to the surface, Klamath and Modoc Indians had caught more than fifty tons of suckers each year until 1900. Tule Lake, just east of Lower Klamath, hosted one of the largest breeding colonies of osprey (fish-eating hawks) in North America.[33]

Finley and Bohlman captured a series of intimate portraits of breeding pelicans, avocets, western grebes, terns, and ducks. Finley published a written and photographic portrait of bird life in the tule jungles of the Klamath Basin. He brought his photos to the White House, inspiring President Theodore Roosevelt to issue an executive order in 1908 setting aside all of Lower Klamath Lake—eighty-one thousand acres of lake, islands, and marsh—as a wildlife refuge. It was the first such refuge in the West created with the goal of protecting waterfowl.

The birds were in dire need of protection. Plume hunters sought out adult egrets, terns, gulls, grebes, herons, and pelicans on their nesting grounds and killed them by the thousands. In a single summer, hunters shipped thirty thousand grebe skins to San Francisco from Klamath Lake. Hunters also shot thousands of ducks: In 1903, more than 120 tons of ducks were shipped to San Francisco meat markets from the Klamath Basin. Plume hunters had already devastated the once-abundant bird populations of the Florida Everglades.

The Oregon Audubon Society lobbied the state legislature to pass a law against killing "inedible" birds, like herons and pelicans. The National Audubon Society paid the wages of two state game wardens to enforce the new law on Lower

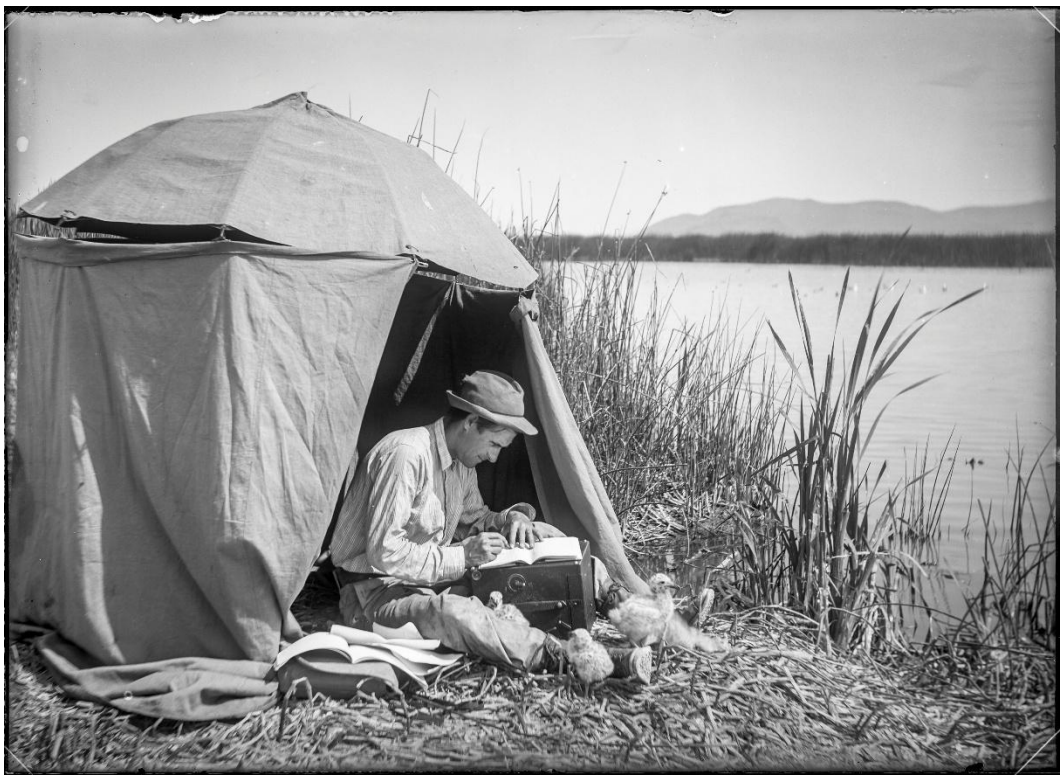

Figure 7.3 William Finley sitting at an umbrella blind, taking notes, during his 1905 Klamath expedition. Several gull chicks are perched around his legs. Photo Oregon Historical Society, Org Lot 369, Finley A1600.

Klamath and Tule lakes. Yet the federal government would prove a deadlier enemy of wildlife than the most unscrupulous hunters: At great expense, federal engineers would drain Lower Klamath Lake dry.

The story of the Klamath Refuge illustrates the long conflict between conservationists and the US Reclamation Service, which drained wetlands and diverted rivers throughout the arid West. Created with the support of President Roosevelt under the Reclamation Act of 1902, the Service's mission was to turn unproductive land into small, irrigated family farms. Roosevelt had declared the Lower Klamath Lake Refuge on a rich wetland already slated for destruction.

The Reclamation Service proposed to build two dams, which would cut off the flow of water to Lower Klamath and neighboring Tule Lake, exposing their beds for farming. During the summer dry season, irrigation water would be released from the dams. The arrival of Reclamation Service engineers in 1904 set off a land rush, in which speculators snatched up large plots of still-wet lakebed and marsh at low prices, intending to resell at a profit after the reclamation project was complete. By 1908, when Roosevelt declared Lower Klamath Lake a wildlife refuge, one-third of its acreage was already in private ownership. Over time, more and more of Lower Klamath and Tule Lake were transferred into the hands of homesteaders and speculators.

Under the law, federal reclamation was meant to provide affordable land for family farmers. Frederick Newell, head of the Reclamation Service, insisted that the government would not invest a single dollar in the Klamath Basin until lands there were sold off in small units of 160 acres or less. While land speculators complained bitterly that this deprived them of their private property rights and refused to sell, Reclamation Service engineers went ahead with design and construction of the dams. The way events played out in the Klamath Basin was typical. Despite the letter of the Reclamation Act, on the ground federal engineers acted to enrich speculators, not to provide affordable new farms for impoverished families. The Act's acreage-limitation rule went routinely unenforced; a 1916 review board concluded that the government's management "closely verges on fraud."[34]

Reclamation Service engineers saw it as their mission to re-plumb the West in the interests of agriculture. Their indifference to the details of the law that had created their agency was fueled in part by self-interest: Under contracts with landowners' associations, reclamation projects brought in large amounts of money to the Reclamation Fund that paid their salaries. The Reclamation Service would grow to become the largest bureaucracy in the history of irrigation and worked at cross-purposes with the underfunded US Biological Survey. The Biological Survey had no money to pay game wardens, so the Audubon Society and the State of Oregon came up with the cash. In a pattern that would be repeated in other federal refuges, the first Klamath Refuge wardens were defied by the local district attorney, who announced that the feds had no jurisdiction and he'd continue to hunt as much as he wanted.

Construction on the Klamath Project began before any data had been collected on conditions in the basin. The lakes and marshes were watered by melting snow that ran off the surrounding mountains, giving the region a deceptively lush

appearance. Eventually federal officials noticed that the basin made a poor place to farm—chilly, with little rainfall and a short growing season. A 1909 test by the USDA found that crops would not grow in a drained section of Lower Klamath marsh because the soil was full of alkaline salt, but by then it was too late to stop the project's momentum.

On November 30, 1917, a group of private landowners who had organized as the Klamath Drainage District signed a contract with the Reclamation Service. That day the headgates of the Klamath Dam closed, cutting off the flow of water to Lower Klamath Lake. By 1919, the lake had been reduced to a wide, shallow puddle. It still attracted birds, but they died in large numbers of alkali poisoning. A few years later, all that remained of the bountiful wildlife habitat Finley had once explored was a 365-acre sump at the southern end of the lake bed.

Finley, who by the time the headgates closed had been appointed State Biologist for Oregon, loudly protested the destruction of the Lower Klamath refuge. Two years later, he was fired without notice by the Oregon Fish and Game Commission. Several of the commissioners were boosters of the Klamath reclamation project and were fed up with Finley's passionate campaign to reflood the refuge.

Soon after, cattle ranchers on the south end of the old lake bed complained that the water table had sunk, drying out their pastures. The vanished marshes had left behind a thick layer of peat, which dried out in the sun and caught fire. In the mid-1920s, Finley described the desolate landscape:

> Today, Lower Klamath Lake is but a memory. It is a great desert waste of dry peat and alkali. Over large stretches fire has burned the peat to a depth of from one to three feet, leaving a layer of white loose ashes into which one sinks above his knees. One of the most unique features in North America is gone. It is a crime against our children.[35]

Among those who joined Finley in demanding Lower Klamath Lake's revival were duck hunters, naturalists, and residents of nearby Merrill, Oregon, who suffered from repeated dust and ash storms blowing off the dry lakebed. In the fall of 1922, schools in Merrill and Klamath Falls were closed when a thick cloud of ash enveloped both towns. It was a small-scale foreshadowing of a wider disaster.

In the 1930s, a series of intense droughts struck the Plains states. Windstorms sucked great clouds of dry topsoil into the air and carried them away. This catastrophe, called the Dust Bowl, drove thousands of farm families off their land. Decades of drainage and wetland destruction had lowered water tables in the region by as much as fifty-nine feet, putting groundwater out of reach as an alternative supply.

The ecologist William Vogt wrote that wetland drainage plagued North America like a disease. In a 1938 booklet published by the Audubon Society, he laid out the multiple arguments for wetland conservation.[36] Wetlands capture rainwater, allowing it to percolate underground instead of rushing off the land carrying topsoil away with it. They nurture fish and wildlife, absorb excess water in times of flood, and act as reservoirs in time of drought.

Vogt's impassioned argument came in the midst of President Franklin Roosevelt's New Deal. To address mass unemployment and the farm crisis in the Plains, Roosevelt's administration created new federal agencies, among them the Soil Conservation Service and the Civilian Conservation Corps (CCC). The mission of the Soil Conservation Service was to encourage practices that would keep soil on the land. The agency promoted planting trees around fields as shelter belts, retiring marginal crop land, and planting legume cover crops in winter. It also became increasingly involved in the drainage business, seen as an essential part of good farming.

The CCC put thousands of young men to work—and much of the time, they worked on drainage. In 1939, the CCC redrained more than 1.5 million acres where ditches or tiles had grown clogged from neglect.[37] CCC workers also dug and repaired mosquito ditches on the Atlantic Coast and in Michigan, draining millions of acres by 1940.

During FDR's second term, the Works Progress Administration (WPA) continued large-scale drainage work, transforming thousands of acres of Louisiana wetland to farms and repairing and building more than twenty thousand miles of mosquito ditches. WPA workers built California's Shasta Dam, a project that contributed to drastic loss of marshes. By 1939, 85 percent of the Central Valley's wetlands were gone.

Meanwhile, the surviving wetlands of the Prairie Pothole region, in the northern Midwest, shriveled in the drought. Potholes are shallow marshes that were formed during the retreat of the glaciers at the end of the Ice Age. More than half of North America's waterfowl traditionally bred there. In 1934, the continent's waterfowl population reached a historic low of 27 million birds. Some species were in serious danger of extinction: Only fourteen whooping cranes survived.

Roosevelt instituted a President's Committee on Wildlife Restoration, charging its members to create a plan that would restore waterfowl habitat while helping to resolve the farm crisis.[38] On the committee were Thomas Beck, a leader of the duck hunter's group that would evolve to become Ducks Unlimited; the pioneering wildlife biologist Aldo Leopold, who'd witnessed firsthand the mass loss of pothole wetlands to drainage; and Jay "Ding" Darling, an editorial cartoonist who'd won two Pulitzer Prizes for his conservation-oriented drawings. The committee proposed that the government buy 4 million acres of marginal farmland to be restored as waterfowl nesting and breeding grounds, and more than 12 million acres total for wildlife of all kinds.

Soon after, Darling was appointed chief of the US Biological Survey. He enlisted CCC and WPA crews to build dikes to impound water for birds, reversing farm drainage systems to restore wetlands. Darling oversaw the purchase and re-engineering of drained land for refuges around the country. He protected the Aransas Refuge on the Texas coast, the last place where whooping cranes wintered in the US. Working with Finley, he raised funds to buy the rights to return water to the Malheur Refuge in eastern Oregon, which had been reduced to a dry alkali flat by water diversions.

While Darling and other conservationists struggled to protect and restore wetlands, other federal agencies continued to destroy them. The US Army Corps

of Engineers was busily building flood control levees, wiping out wetlands in the process. The USDA subsidized farm drainage with millions of federal dollars.

In Darling's eyes, the USPHS was the worst offender. USPHS drained marshes nationwide in the name of malaria control. In 1936, the agency requested $74.5 million to drain coastal wetlands in Maine, New York, and other northern states that were malaria-free. The USPHS had refused to consult with Darling's Biological Survey on its drainage plans. Survey biologists reported cases of wetlands being destroyed under the guise of "malaria control" when the only benefit was to private landowners seeking more tillable acres on their property—in fact, the finished work left behind more mosquito breeding habitat than had been there before.[39] "The conclusion is inescapable," wrote Darling, "that the US Public Health Service under its existing administration is a pernicious racket."[40]

Between World War I and beginning of the New Deal, drainage work was seen as too expensive to be used to rid the South of malaria. Starting in 1935, the WPA provided labor for drainage projects on a massive scale: 544,414 acres of mosquito breeding sites drained through construction of 33,655 miles of ditches by 1942.[41] Soon after, malaria was gone from the American South.

It's difficult to pin down just how this happened. A growing contingent of biologists and conservationists were appalled by the WPA drainage program, which was carried out without regard to the biological intricacies of mosquitoes or malaria. Wetlands were drained without first testing for the presence of quad mosquito larvae. Melvin Goodwin, an ecologist studying mosquitoes in Georgia, often found quad larvae in malaria control ditches in greater abundance than in natural wetlands.[42] While some historians believe drainage played a pivotal role in extirpating malaria from the South,[43] others argue that the movement of impoverished tenant farmers out of the countryside and away from wet bottomlands during the Great Depression was key.[44]

In any case, malaria, along with the most deadly infectious diseases of the nineteenth century (cholera, tuberculosis, diphtheria, typhus, yellow fever), had been extirpated or brought under control in the US. Then, on December 7, 1941, the Japanese attacked Pearl Harbor, and the nation was drawn into World War II. Soldiers would be sent to Europe, Africa, and the South Pacific—places where the insect-borne diseases of malaria and typhus (a parasitic infection transmitted by body lice) were either endemic or exploding under the unsanitary conditions of battle. In the long history of war, these diseases had decided many military campaigns. US public health officials set out to make sure that insect-borne disease would not defeat the Allies.

To accomplish this, they focused on killing off the insect vectors. The weapon of choice had been pyrethrum, a compound derived from chrysanthemum petals, which had been used to fight body lice during the Napoleonic wars and was a popular insecticide in the US. Japan produced more than 90 percent of the chrysanthemums used to manufacture pyrethrum, however, and with the start of the war the supply of blossoms was cut off.

In the urgent search for a replacement insecticide, US researchers studied a new chemical being marketed by the Swiss manufacturer Geigy. In 1939, a Geigy scientist named Paul Muller had been assigned to find a chemical that would

control invasive Colorado potato beetles. Muller dug up a formula first created in 1874, which synthesized dichloro-diphenyl-trichloroethane, soon to become known as DDT. The stuff made potato beetles vanish as if by magic. It was long-lasting too: In Muller's lab, a tube treated with DDT only once continued to kill flies for many weeks.

US researchers confirmed Geigy's claims: DDT powder dusted on humans did away with body lice. DDT sprayed from planes killed off mosquitoes (as well as many other insects). Some people exposed to the chemical got rashes, but there was no acute toxicity. Military researchers knew that DDT acted as a nerve toxin, and that heavy doses caused convulsions or death in lab animals.[45] In time of war, however, the short-term ability to fend off insect disease vectors outweighed any subtle questions of risk.[46]

In the fall of 1943, US forces pushed German occupiers out of Naples, Italy. The city had been torn apart by months of fighting and had no running water, gas, or electricity. In the first few months of American occupation, a growing number of typhus infections were recorded. By late December, the disease had become epidemic, and official reports estimated that more than 90 percent of the civilian population carried lice.

With the assistance of the Rockefeller Foundation, the US military began dusting every civilian with DDT powder. By March 1944, 1.3 million people had been dusted with DDT, and typhus had been vanquished in Naples. Though civilians had been given little choice in the matter, they were happy to be louse-free. "Neapolitans are now throwing DDT at brides instead of rice," claimed the *New York Times*.[47]

Through the rest of the war, the pesticide was widely used by the US military. A petroleum–DDT mixture was sprayed from planes to clear mosquitoes from beachheads before Allied invasions. An epidemic of dengue fever that broke out after the invasion of Saipan was quashed with a massive aerial spraying campaign. World War II became the first major war in which more soldiers died of combat than disease.[48] DDT was seen as a miraculous chemical that had been integral to the Allied victory.

Some of the largest chemical companies in the US mass-produced DDT for the war effort, and were soon marketing it to the public as a safe way to get rid of any and all insects. It was widely used against crop pests. In the postwar years, pesticide trucks rolled down suburban streets, emitting a fog of DDT spray that enveloped children playing outside.

There were some early warnings of the chemical's dangers. In August 1945, aerial spraying of DDT was tested on the New Jersey shore. Army officials reported that mosquitoes vanished, allowing troops to do their outdoor calisthenics unmolested. A representative of the State Agricultural Experiment Station in New Brunswick pointed out a downside: An experimental spraying on nine miles of beach caused a mass fish kill.[49] Researchers at the Patuxent Wildlife Refuge tested the effects of DDT on wildlife and began to find serious impacts on wild birds.[50] Biologist and science writer Rachel Carson tried to pitch an article on the dangers of DDT to *Reader's Digest* in 1945, but the editors weren't interested.

Agricultural pesticide use in the US skyrocketed after the war, climbing from 125 million pounds per year in 1945 to more than 600 million in 1955.[51] Industry developed new kinds of organochlorine pesticides. They were sprayed on the farms of the Midwestern corn belt and California's Central Valley. DDT and other organochlorines accumulated in the fatty tissue of exposed animals, becoming more concentrated as they moved up the food chain. The whole class of pesticides would prove especially deadly to predatory birds.

Malaria was gone from the US, aside from a few remnant pockets of infection in the South. Public health agencies continued to battle an already vanquished enemy on the theory that malaria would rise again if the fight was stopped. DDT spray campaigns replaced the ditching projects of the prewar era. The military agency Malaria Control in War Areas morphed into the Communicable Disease Center and continued pumping DDT into the environment. The agency used DDT sprayed on the inside walls of houses in the South, in addition to aerial spraying on wetlands. The modern incarnation of the Communicable Disease Center, the Centers for Disease Control and Prevention, still claims credit for knocking malaria out of the American South with DDT.[52]hat notion is questionable. The single controlled study of the Communicable Disease Center's postwar spraying program found that the malaria parasite vanished from an untreated pond just as it did in a comparable pond sprayed with DDT.[53] Today the quad mosquito remains common in much of the US, though the malaria parasite is vanishingly rare.

In 1955, the World Health Organization established a program designed to rid the Earth of malaria using the sole tactic of killing mosquitoes with DDT. By 1969, anopheline mosquitoes had evolved resistance to the pesticide, and the effort was suspended.[54] More recent campaigns to control the disease in sub-Saharan Africa, where malaria remains endemic and up until a few years ago was killing millions of young children, have used pyrethrum sprayed on walls and insecticide-treated bed nets, with remarkable success. Cutting-edge research on malaria control now focuses on a range of creative tactics, from luring mosquitoes into traps using a chemical mix that mimics the smell of human sweat and breath, to bioengineering malaria-resistant mosquitoes.[55]

In 1957, a mosquito control plane flew over Duxbury, Massachusetts. It returned to spray repeatedly over the marshy property of Olga Owens Huckins, a friend of Rachel Carson's. The next day Huckins found several songbirds lying dead on the ground. "They were birds that had lived close to us, trusted us, and built their nests in our trees year after year," she wrote. "All of them died horribly. Their bills were gaping open, and their splayed claws were drawn up to their breasts in agony."

Huckins' outrage would inspire Carson to write her influential book, *Silent Spring*, in which she meticulously documented the ecological damage caused by organochlorine pesticides. Among the many examples Carson cited were a mass fish kill that followed the 1955 spraying of two thousand acres of Florida salt marsh with dieldrin, an organochlorine forty times more toxic than DDT. Crabs fed upon the many fish carcasses and the next day were dead themselves.[56]

Wild birds were also dying of pesticide poisoning at the Klamath Wildlife Refuge. Water was finally returned to the Lower Klamath refuge in 1942—not to recreate lost wildlife habitat, but because farmers in the dried-out bed of neighboring Tule Lake were being swamped in their own runoff. Irrigation water ran off cropland into the Tule sump, a remnant of the original lake. As the number of homesteaders grew, so did the volume of runoff and the water level in the sump. In 1928, the Tule sump was declared a bird refuge. Later, at William Finley's urging, President Franklin Roosevelt would triple the refuge's size to 37,000 acres. Waterfowl flocked there.

Eventually, the Tule sump would threaten to flood nearby farms. Meanwhile, peat fires and dust storms continued to plague the desiccated bed of Lower Klamath Lake. A solution was created by a Reclamation Service engineer, J.R. Iakisch. He envisioned a six-thousand-foot tunnel dug through the ridge separating the two lake beds so that excess water from the Tule sump could be pumped to the dry bed of the Lower Klamath.[57] In 1940, the Klamath Drainage District, representing private landowners, signed a cooperative agreement with the US Biological Survey. The government agreed to build the drainage tunnel and to build a dike across the southern edge of Lower Klamath Lake to prevent flooding of neighboring farms. The long-lost wetlands of the Lower Klamath were resurrected, at least in part. They were fed with agricultural runoff, and the fate of the farms created by the Reclamation Service dams was forever tied to that of the area's wildlife refuges.

From a bird's point of view, the Klamath Basin refuges were irresistible—even if the waters were tainted with alkali, fertilizer, and pesticides. At the peak of fall migration, 7 to 8 million ducks, geese, and swans gathered there. "There is probably no more important waterfowl area in the country," Interior Secretary Stewart Udall told a Congressional hearing in 1962. The Klamath refuges, he said, act like the waist of an hourglass, through which all the birds of the Pacific Flyway funnel on their annual migrations.[58]

Irrigation water flowing to Klamath Basin farms was recycled seven times before it ran to the wildlife refuges. By then it was tainted with the chemical residues of postwar agriculture. Between 1960 and 1964, hundreds of white pelicans, egrets, and western grebes died at the Klamath Basin refuges. A few birds were seen to drop from a flock in flight, dead before they hit the water. Adults and chicks in breeding colonies suffered tremors and convulsions as they died. The affected species were all fish-eating birds, vulnerable to the impacts of organochlorine pesticides because the chemicals concentrate in their prey. A 1966 study found that birds from the Tule Lake and Lower Klamath refuges carried high concentrations of DDT and the organochlorines toxaphene and endrin in their tissues.[59] Previous studies had shown that small concentrations of organochlorines in water could translate into deadly doses for fish-eating birds.

There were also subtler effects. DDT poisoning caused female birds to produce thin-shelled eggs that broke before the embryo inside could mature. The syndrome was observed in many species of North American birds after 1946 when widespread DDT use began.[60] Eggshell thinning contributed to major declines in the populations of pelicans, bald eagles, and peregrine falcons.

Agricultural use of endrin was banned in 1964. In 1972, after a long battle by conservationists, DDT was banned in the US. Because organochlorines persist in the environment, white pelicans breeding at the Klamath refuges were producing abnormally thin-shelled eggs as late as the 1980s.[61]

In the midst of the mass drainage and poisoning of the mid-twentieth century, a new generation of wetland defenders emerged. In the 1950s, pioneering work by ecologist Eugene Odum at Sapelo Island, Georgia, showed that salt marshes are among the most biologically productive ecosystems on the planet, and provide nutrients vital to the growth of fish and shellfish in nearby marine waters. Representative Henry Reuss of Wisconsin successfully sponsored a 1962 law that forbade the USDA from helping farmers in the Prairie Pothole region to drain marshes if wildlife was at risk. Activists fought to stop the US Army Corps of Engineers from destroying the last remnants of Pennsylvania's Tinicum Marsh.[62]

When Arcata's sewage rebels stumbled onto the idea of a treatment marsh, the idea of wetland restoration was still a low murmur in the ambient roar of destruction. Building the town's marsh would take not just bold scientific invention but political cunning as well.

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