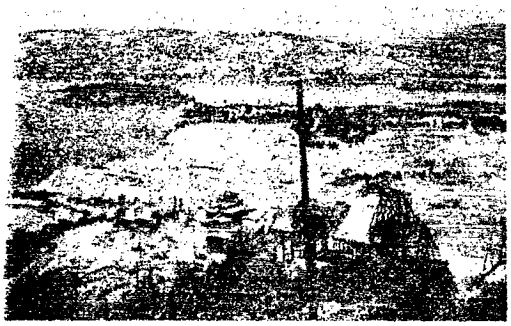
Hundreds of abandoned mercury mines dating back to California's Gold Rush days are contaminating watersheds from the Sierra to the San Francisco Bay. But UC Davis studies at Clear Lake are adding to our understanding of this environmental challenge.

MINING'S TARNISHED LEGACY

BY SUSANNE ROCKWELL



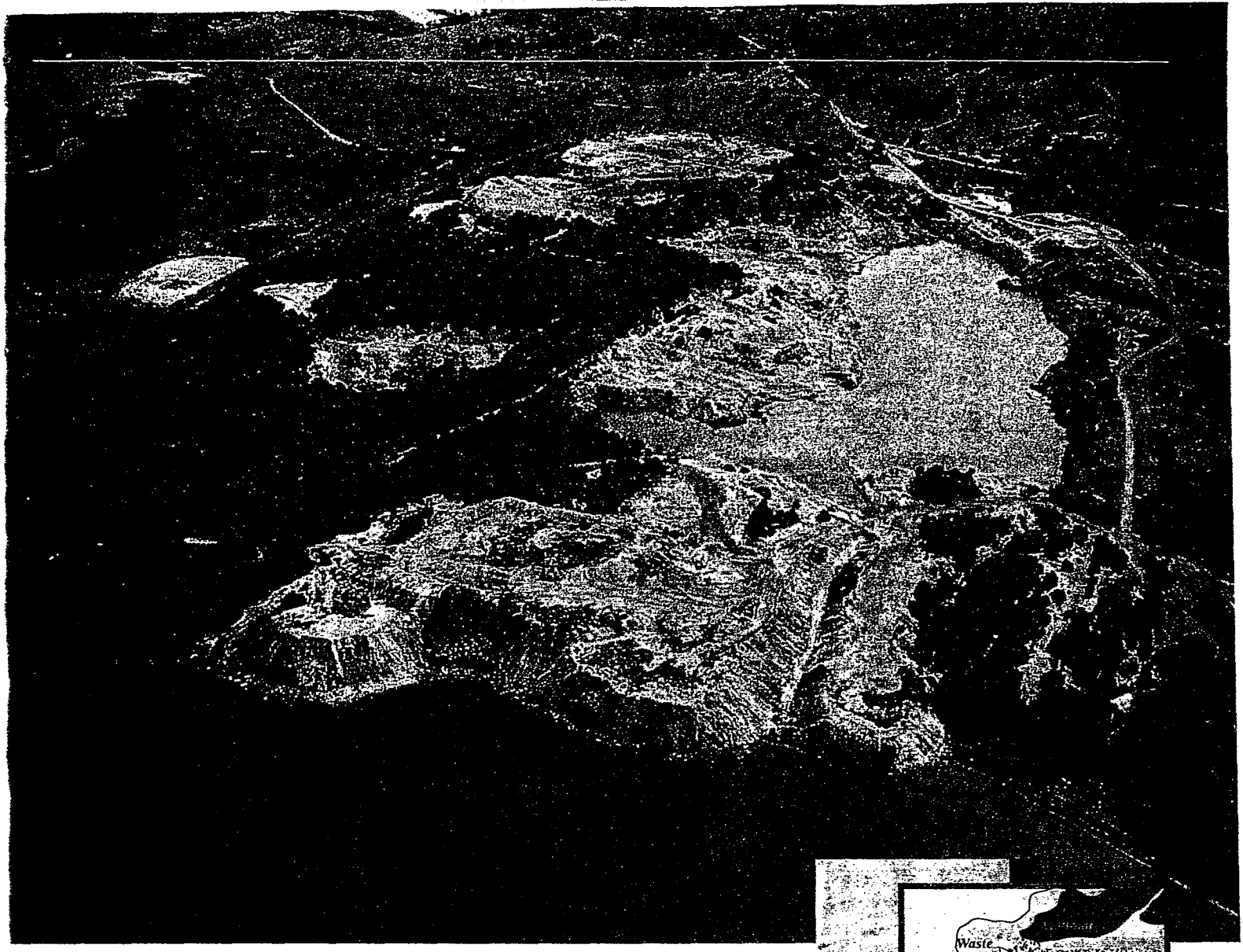
People up in Lake County believe they live in paradise—all because of a big body of shallow water that boasts some of the best fishing, richest bird life and longest geologic lake history in North America. Folks are pretty proud about the fact that Clear Lake, located about 120 miles north of San Francisco in the Central Coast Range, is one of the oldest lakes, if not *the* oldest, in North America and was the home to some of North America's earliest human residents nearly 12,000 years ago. Just how old Clear Lake is remains hard to prove. Scientists have determined, using continuous lake sediment cores, that the lake dates to nearly 500,000 years ago, but it could be even older since some lake presence can be detected in sediments 2 million years old.

Today the lake has 110 miles of often-steep, jutting shoreline, shaped by the contours of volcanic upheavals that have occurred over the past 20 million years. Mt. Konocti, the volcano that first began erupting 350,000 years ago, dominates the lake's south shore. The land under Clear Lake is bubbling with mineral springs from the active crust below. In fact, Lake County is located along the Pacific Ocean volcanic "Ring of Fire."

Much of this is open land populated by native oaks and pines that tenaciously survive the Mediterranean climate of hot summers and rainy winters, rooting on both the steep slopes and in yards along the lake. In the lake's shallow waters are found bass—touted to be some of the biggest in the country—and a complex food chain of perch, hitch, blackfish, trout, bullheads, suckers, plankton and the plant life that sustains them.

Floating near the shore are tule nests created by Western and Clark's grebes, lake-diving birds that have historically chosen Clear Lake as a major breeding ground. The population of ospreys, a fish-eating hawk, has also resurged and taken to nesting in trees in people's yards and in wilderness areas near the lake. And, for the first time in documented history, two pairs of bald eagles chose to breed at Clear Lake.

Ever since bands of Paleo-Indians first settled around the lake some 11,500 years ago, people have lived next to this source of life. Today, more than half of the county population of 56,000 lives either on or within a block of the lake, which is ringed with the products of California's seesaw economic history: fishing cabins and auto courts from the Depression, upscale hillside neighborhoods with gorgeous lake views and modest trailer courts tucked away from sight, bait-and-tackle shops and mini-marts, Indian reservations, and farms with pear and walnut orchards—and vineyards newly planted to take advantage of the boom in wine prices. Since English-speaking settlers arrived 150 years ago, they have reshaped the environment by creating dams, farms from wetlands, mines and lakeshore communities. But Clear Lake's natural beauty and fecundity remain the pride of the county.



The birth of a Superfund site: The history of the Sulphur Bank Mercury Mine stretches back to 1862, when the area was first mined for sulfur for gunpowder and then for mercury, which was used to extract gold from crushed ore. In the early 1920s, mine shafts gave way to open pit mining, as shown in the photograph from the Lake County Public Library archives, far left. Today the pit remains (above), filled with mercury-tainted water that has contaminated the lake.

"We are an economically poor county with a lot of commitment to our environment, and the lake is the key element of that concern," says Lake County Supervisor Karen Mackey, an elected city and county official for the past 22 years. She points out that the county's sources of economic strength—agriculture, tourism, industry, geothermal energy production and gold mining—are all dependent on use of the land, but that Lake County citizens are "very committed to the environment."

And it was this concern for the environment—specifically the health of the fish—that prompted citizens in the late 1980s to ask the federal government to declare one area a Superfund site.

Herman Pit, from a distance a deceptively pretty pond, was once an open-pit mercury mine. The land around the pond is mostly bare, with thin tufts of summer-dried grass growing in patches on mounds and depressions of orange-tinged rubble, composed of iron, aluminum, sulfur, silica and other minerals found in this volcanic region. Various pieces of testing equipment—trays floating in the pond to measure evaporation rates and devices for measuring water levels—stud the site. Large corrugated black pipes connect the pit to the lake to prevent rainy-season overflow from sweeping over the dam of waste rock. On a little test plot, a handful of scrub oaks and native grasses thrive in soil heavily amended with

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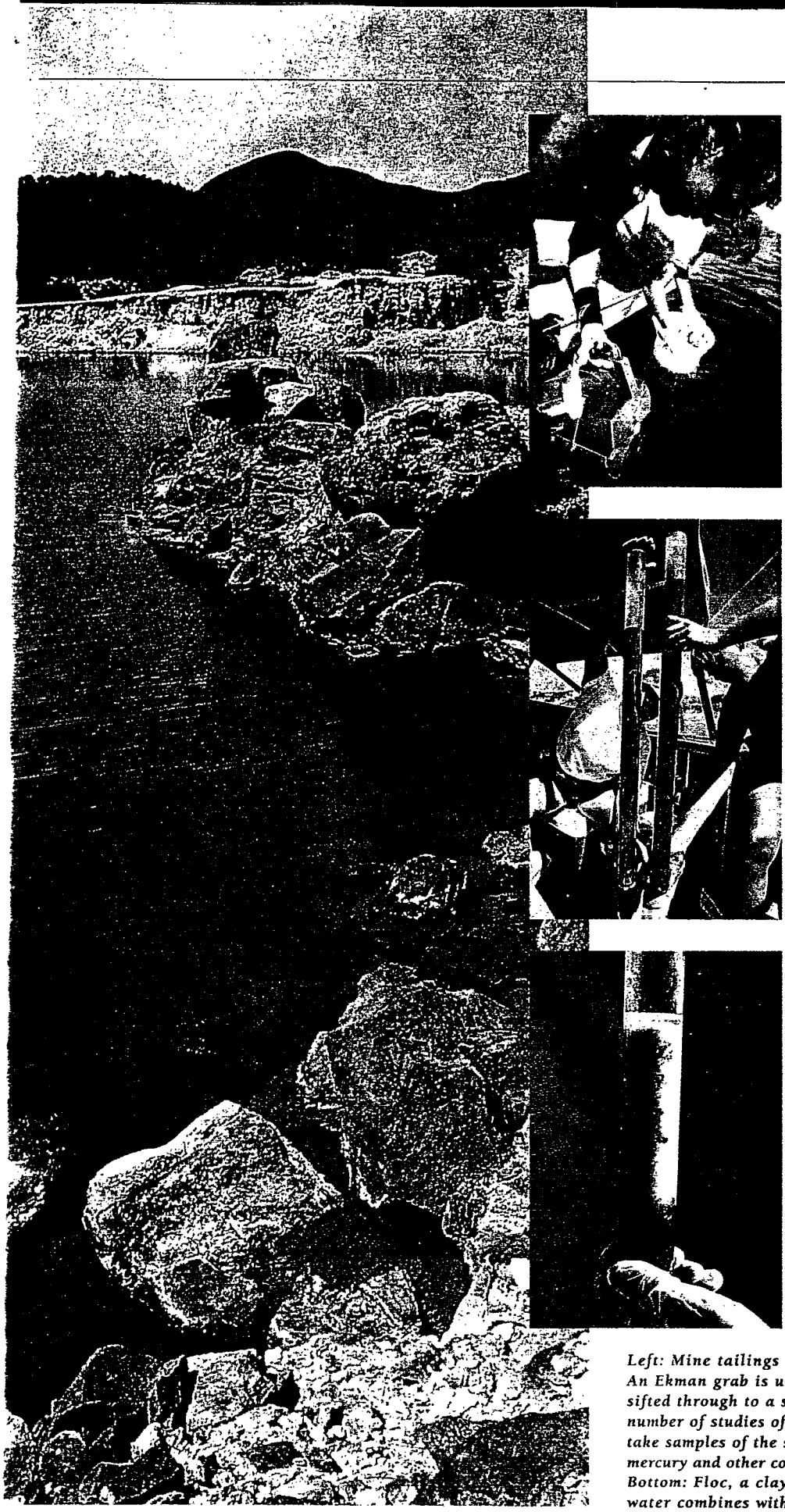


PHOTOS: TOM SUCHANEK

compost from Petaluma and a lime byproduct from a Woodland sugar beet factory. On the whole, the abandoned site looks like a moonscape.

Known as Sulphur Bank Mercury Mine, the property was designated a Superfund site in 1991 and is one of more than 1,200 such hazardous waste areas in the United States that the federal government is currently studying or in the process of cleaning up. For the past seven years, Tom Suchanek, a research scientist with the UC Davis Department of Wildlife, Fish and Conservation Biology and director of the Clear Lake Environmental Research Center, has headed a Superfund team of three dozen scientists and graduate students from campus. Using federal Environmental Protection Agency funding of about $500,000 a year, they have been studying this former open-pit mine and its relationship to the high levels of mercury in certain Clear Lake fish. In the process, Suchanek and his team have conducted what has turned out to be the largest Superfund mercury-mining investigation in the country.

The researchers have had a lot of questions to answer: Where is the mercury coming from: the abandoned mine, geothermal springs in the lake bottom, the Coastal Range watershed? Since mercury in the form of ore is largely inorganic, how are fish absorbing it? Why, with the high amount of mercury "loading," isn't there a greater impact on birds, fish and other organisms in the ecosystem? How, if the source of the mercury is at the west end of the lake, is the toxic mineral getting into fish living in the far east arm of the lake?

Before the mid-'70s, answers to the questions would have been more narrowly focused and supplied by only a few scientists working independently. But the Sulphur Bank Mercury Mine program represents an evolution in environmental science, says limnologist Suchanek.

"You need interdisciplinary studies to find answers," he maintains. For this project, Suchanek gathered ecologists, engineers, microbiologists, wildlife conservationists, chemists, geochemists, soil

Left: Mine tailings create a moonscape around Herman Pit. Top: An Ekman grab is used to dredge a sample of sediment that is then sifted through to a sieve bucket to collect invertebrates in one of a number of studies of the Clear Lake ecosystem. Middle: Researchers take samples of the sediment at the bottom of Clear Lake to test for mercury and other contaminants, including pesticides and phosphorus. Bottom: Floc, a clay precipitate, is produced when the pit's acidic water combines with the lake's alkali water.

scientists and geologists. This kind of research takes not only in-depth expertise but scientists willing to cross disciplines to communicate with others. (Suchanek used a similarly complex approach when leading a research team in the late '80s and early '90s to study the effects of the Exxon Valdez oil spill on shoreline communities in Alaska.)

For the Clear Lake project, Suchanek fostered a process of regular daylong symposiums along with other opportunities for participants to debate interpretations via long—sometime fractious—discussions. According to Suchanek, it's been a process of hashing out opposing hypotheses and connecting the dots between hitherto discrete disciplines to create those exhilarating "ah ha!"s of discovery. From seven years of eliminated hypotheses, serendipitous discoveries, and huge quantities of measurements and statistics leading to stacks of research findings, a whole picture of the mercury contamination has begun to emerge in the past year. That picture confirms the initial suspicion—that the mine site is, indeed, a primary source of mercury for Clear Lake—but also includes a host of surprises.

"This is a monster project that started out as an attempt to solve the problem of acid-mine discharge into the water with a 'we've got to do something about this' approach," explains Jeff Mount, outgoing chair of the geology department at UC Davis. "But it's become a classic example of the future of environmental research."

Researchers are adding to UC Davis' already dominant strength in the state as an environmental campus with a particular expertise in water research.

As the geologists, chemists, engineers, ecotoxicologists, biologists and conservationists make their discoveries at Clear Lake, they are adding to UC Davis' already dominant strength in the state as an environmental campus with a particular expertise in water research. For California, where "save the environment" is often a code phrase for "clean up the water," the Clear Lake studies have the potential to provide a number of answers to questions about how water becomes tainted. That problem certainly has caught the attention of state voters, who in 1996 approved nearly $1 billion in bonds to ensure safe drinking water and increase water supplies, as well as to clean up pollution in rivers, lakes, bays and coastal areas. Since then, Proposition 204 has been funding a number of studies, many involving UC Davis scientists, through a powerful 5-year-old confederation of 11 state and federal agencies called CALFED. Most recently, the confederation has been funding research that focuses on the impact of metal-rich fluids from these old mining sites that, even many decades after the mines have closed, are washing contaminants and mud into the Sierra, Cascade and Coast ranges' watersheds and out into San Francisco Bay.

"There's such a large amount of sediment still moving down," explains Rob Zierenberg, formerly of the U.S. Geological Survey and now a geochemist in the UC Davis Department of Geology. "The Gold Rush permanently changed the whole San Francisco Bay," he said, noting that the San Pablo Bay mud flats were created as a result of the hydraulic mining.

Thanks in part to CALFED grants, numerous studies are being conducted in the north state in response to the concern about mine tailings. Suchanek and others at UC Davis have secured CALFED grants to analyze mercury contamination along Cache Creek in Lake and Yolo counties and conduct a similar study in the San Francisco Bay-Delta.

Sulphur Bank Mercury Mine's operation began promisingly enough. Settlers on the Oaks Arm of the lake in 1862 noticed a sulfur deposit in an area with geothermal springs. They began mining the pale-yellow non-metallic substance for sale to gunpowder makers. Within a few years, the settlers discovered the sulfur was contaminated with cinnabar—an ore that contains mercury, which when extracted into a liquid becomes quicksilver. Mercury, by this time, was essential to efficient gold mining. Miners had discovered that they could extract gold by adding quicksilver to crushed ore to create a gold/mercury alloy. They would then heat the alloy, vaporizing the mercury and leaving the pure gold. Although the mercury was valuable and miners recycled it, much was lost in the environment through inefficient vaporizing/condensation processes.

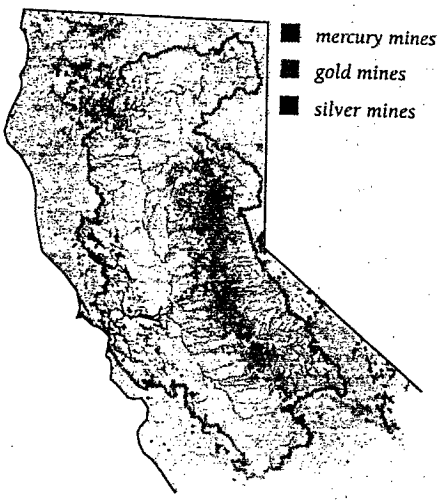
The gold mining demand for mercury during the late 19th century helped spur mercury mine development—more than 300 abandoned mercury mines and prospects can now be found along the California Coast Range. To meet the demand, the Sulphur Bank Mercury Mine owners in 1872 began sending Chinese workers down holes 50 to 60 feet deep to extract cinnabar. The mine owners escalated their excavation in 1882 by constructing mine shafts into the ground 200 feet or more deep. Since the lakeshore area was also a geothermal site, the deeper mines were hot—as high as 120 degrees Fahrenheit at the bottom of the shafts. Laborers could spend only a little time below before being hauled up and cooled down with hoses—and then lowered again to dig more ore. Other mine workers were stationed at sites scattered above the mine, processing mercury from the ore by cooking the rocks in "retorts," or mining ovens. The ovens evaporated the mercury, which then was converted by distilling it back to the more-stable liquid quicksilver. The leftover roasted rocks, or "calcines," were dumped next to the retorts. Trails of calcines and waste rock that contain low levels of mercury still scar the hills above the barbed-wire fence that encloses the Superfund site.

The shafts gave way to an open pit when gas-driven steam shovels, bulldozers and dump trucks were developed in the late 1920s. This method is believed to have caused a major increase in the amount of mercury-contaminated sediment going into Clear Lake beginning in 1927. Suchanek has found sediment cores from the lake bottom show a corresponding increase in mercury. That heightened mercury level continues in the lake today.

By the time the mine was closed in

Tom Suchanek, shown at right taking core samples of sediment from the middle of Clear Lake, heads up the team of three dozen scientists and graduate students working to understand how the abandoned mercury mine is affecting the lake.

Mercury, Gold and Silver Mines



UC DAVIS INFORMATION FOR THE ENVIRONMENT

Top: "Ultra clean" technology is used to prevent contamination of water samples from Clear Lake. Middle: Researchers catch fish to check their mercury levels. Bottom: Mines dotting Northern California's landscape are posing a problem for waterways and coastal areas throughout the state.

1957, more than 4,000 tons of pure mercury had been extracted. What remained was a hole 90 feet deep that began to fill with water from geothermal springs and creeks running through the property. The surrounding environment was left barren except for waste rock—laced with low levels of pyrites and mercury.

The waterhole, now dubbed Herman Pit, is sparkling clear because nothing besides bacteria can live in this highly acidic pool, Suchanek points out. The pit, in fact, measures a quite-acidic pH 3, in contrast to the lake's just slightly alkaline pH 8. According to geochemist Zierenberg, the acidity can be traced to a mineral called pyrite, or iron sulfide, which is common in rocks in the area. Pyrite, when exposed to oxygen—whether in the air or in water—creates sulfuric acid. The sulfuric acid, in turn, dissolves metals in the site's rocky and churned-up ground. These metallic fluids—filled with aluminum, zinc, arsenic, copper and, of course, mercury—make up the acid mine drainage.

That Clear Lake can remain so fecund after enduring its share of human-caused stresses over the years is surprising. During the 1940s and '50s, when the pesticide DDD was used to eliminate a prevalent gnat, populations of grebes and other birds declined because the pesticide poisoned them. The grebe devastation that marked the initial discovery of the impacts of pesticides on bird populations merited a mention in Rachel Carson's 1962 book, *Silent Spring*, which is credited by many as launching the modern environmental movement. In addition, home and commercial development along the lake has contributed to lakeside erosion and eliminated much of the wetlands, further limiting birds and other wildlife and allowing additional nutrients to flow into the lake.

Algae blooms that at times have covered vast areas of the lake have been exacerbated by sediments and nutrients draining off the shore into the lake. And then, in the 1970s, a diligent state Fish and Game senior fisheries biologist named Larry Week discovered that the catfish and bass in Clear Lake had elevated mercury levels.

"Clear Lake was Larry's lake, and he had been reading about mercury poisoning in Japan. He knew about Sulphur Bank Mercury Mine, and he wondered if it was having an impact on fish here," says Terry Knight, a retired engineer and national environmental/outdoors writer living in Lakeport, the county seat of Lake County.

The mercury pronouncement grabbed headlines. Knight says the lake gained its greatest notoriety, when, in 1986, the popular summer tourist destination was one of the first major sports-fishing lakes in the state to be posted with a warning that levels of mercury in the fish were above healthy levels. The state media broadcast Clear Lake's dilemma far and wide, Knight says. Just as the country headed into a recession, the lake's tourist economy took a dive. Knight believes Clear Lake regained its popularity as an outdoor resort only as fish in other Northern California lakes, rivers and even the San Francisco Bay Delta were found to carry similarly high mercury levels.

Today, the state fish and game department warns people not to consume in one month more than a pound of Clear Lake largemouth bass that measure over 15 inches and no more than three pounds of Clear Lake catfish. Women who are pregnant or may soon become pregnant, nursing mothers and children under the age of 6 are told to not eat any fish from Clear Lake—nor those caught in Lake Berryessa at the apex of Solano, Yolo and Napa counties. But the even-higher mercury levels in fish in some Santa Clara County creeks and reservoirs have prompted the state to warn against anyone eating the fish there.

Despite the state's discovery that the fish were tainted, it took a few years for Clear Lake residents to convince the federal government that the contamination might be connected to the old abandoned mine site. "We got copies of studies on the levels of mercury and we got statistics from Fish and Game, but the local citizens gave us the best support because they were also worried about poisoning from the fish. It took us four years to nominate the site for the Superfund, and then we found it was one of the top 10," says Jim Brown, chair of the Elem Indian Tribe, which lives near the mine. Brown's father was one of the last tribal fishermen who worked the shallow waters of the southeast side of the lake in the traditional way, netting fish like blackfish and hitch

that can't be caught with a European-style hook and line.

When UC Davis first became involved with the project, the idea that mercury had been seeping into Clear Lake through the porous dam of crushed waste rock bulldozed between the pit and the lake was not, however, a foregone conclusion, Suchanek says.

"We were hypothesizing that the mercury was coming from the mine, but others said the mercury was coming from natural geothermal springs on the lake bottom. We went out and tested springs all over the lake and found no evidence that the springs were a major source of mercury—but the mine was a significant contributor." Others thought the mercury was washing into the lake through the Coast Range watershed. That idea was also tested and rejected.

The research team's investigations showed that pit water that seeped through the dam into the lake actually increased in acidity, from the pit's pH of 3 to pH levels of 2.6 and 2.8. The change in acidity indicated that the water was picking up minerals along the way, Suchanek says.

The researchers' hypothesis that the piles of exposed waste rock were a major contributing factor was reinforced in 1992 when the Environmental Protection Agency recontoured the dam. The bank, which had been built from mine tailings graded into a 40 percent incline, was given a more moderate slope, covered with topsoil and seeded with grass to stop runoff from the rains. The resulting drop in mercury levels in sediments next to the mine was dramatic, Suchanek says.

But still, the team had no absolute proof that the site was the culprit. The big breakthrough came in 1995, just as Suchanek and his team were about to wrap up their studies and hand over their findings to the EPA Superfund administrator. Heavy flooding that year caused the Herman Pit, which is 13 feet above the elevation of the lake, to overflow its banks and dump quantities of acid pit water into the lake.

"That was when we first observed large clouds of white flocculent material in the lake, right where the pit had overflowed," Suchanek reports. When the pit's acidic water combined with the lake's alkali water, a clay precipitate, composed of aluminum, mercury, silicates and a quantity of iron, eventually created a yogurt-like coagulate several inches thick on the bottom of the lake. The researchers monitored the particles over the summer. What they found proved to be a key to the mercury mystery.

As the sun warmed the shallow lake over the summer, the researchers saw that the conditions in the floc enhanced the concentration of toxic methyl mercury, likely through the activities of microorganisms. The acid mine drainage also contained large amounts of sulfate used by sulfate-reducing bacteria thought by the researchers to be responsible for at least a large part of the methyl mercury production. Through a series of experiments conducted by microbiologist Doug Nelson and his students, the role of the microorganisms and floc in producing methyl mercury became clearer. It appears that they transform the inorganic —and thus non-absorbable—mercury into a highly charged methyl mercury. Methyl mercury is what scientists call bio-available—a form that animals can absorb. This more toxic form also accumulates through the food web so that the biggest animals—the bass and catfish—have the highest concentration, according to Nelson, who is co-director of the Clear Lake Environmental Research Center and co-principal investigator with Suchanek on the mercury studies.

Meanwhile, UC Davis environmental engineer Geoff Schladow charted the lake currents, discovering that prevailing northwest winds created a top current that, when it hit the eastern shore near the mine, turned into a westerly undertow, transporting the methyl mercury-laden floc across the bottom of the lake to the west side's farthest arms.

"The lake is a methyl-mercury generating engine," Suchanek concludes. "The concentration of methyl mercury in the waters flowing out of Clear Lake is five times higher than that entering into the lake from the watershed."

In the past two years, the Superfund team has concentrated on documenting how the entire system functions. Schladow has been tracing the movement of fluids from the pit to the lake. Nelson has been trying to find exactly where the acid mine drainage is entering the lake by looking along the lakeshore for hot spots—areas with high concentrations of sulfates and very low pH levels. He has also been looking at the bacteria that are transforming the inorganic mercury into a bioavailable form. Soil scientist Vic Claussen has been learning how to revegetate the highly acid soil to keep erosion down and minimize the rain percolation.

Geologist Ken Verosub is looking at the magnetic signature in the sediments to see if it correlates to the changing land use. Fish biologist Joe Cech is figuring out how fish take up mercury—past the gills or by ingesting organic materials in the water. Former civil and environmental engineering graduate student Andy Bale put together a model of the accumulation of methyl mercury in the food chain. Meanwhile, bird ecologist and ecotoxicologist Dan Anderson has been studying the osprey and grebes to see if the mercury has had any impacts on the bird life.

"The mercury in the fish doesn't seem to have an effect on these birds," Anderson reports. "Maybe the excess young are filling in the gaps. But we are finding one thing: These birds are depositing a lot of mercury in their feathers, which may be a mechanism to get rid of it as the birds molt."

The UC Davis findings are being handed over to EPA Remedial Project Manager Ellen Manges. Still to be answered is how to fix the problem, Manges says; she will use the UC Davis studies to put together a set of findings that, after public hearings in Lake County, will result in a remediation plan. She expects the process to take at least another year. In the meantime, she's mindful of the lessons the Superfund site may bring to the Bay-Delta water-quality problems.

Addressing the problem of the mercury-laden fish is considered just a small part of a bigger commitment to the Clear Lake environment, say those who live there. Lake County residents have become fierce environmentalists, raising funds so that the Lake County Land Trust can buy private land and rehabilitate wetlands for wildlife.

County Supervisor Mackey expects some additional environmental challenges as the county attracts industries and more people to this land of paradise.

"The key is the people who live here," Mackey says. "They will help drive that positive vision of the lake. People want to be where it is beautiful and where they can be committed to the land, lake, air and mountains." ■