A makeover for Rocky Mountain Arsenal
Transforming a Superfund site into a national wildlife refuge

David Otis emerged from the trailer looking more like an astronaut about to take his first step on the moon than a wildlife biologist conducting a field study. Otis was decked out in a special suit that covered him from head to toe in disposable coveralls, rubber boots and gloves, and a face mask to filter the air he breathed.

Rather than lunar rocks, however, Otis was searching for rodents. Instead of standing on the moon more than 200,000 miles from Earth, the Clemson University professor trod the Colorado prairie just 10 miles or so northeast of downtown Denver. And substituting for the dangers of outer space was one of the most heavily contaminated Superfund sites in the United States.

The site is the Rocky Mountain Arsenal. Here, for more than 40 years, the Army made and stored nerve gases, mustard gas, and other deadly chemical weapons, as well as napalm and hydrazine rocket fuel for the Air Force. Here, too, Shell Oil and other companies made dieldrin, aldrin, and other highly toxic pesticides, mostly for use in agriculture and home gardens.

Now, with military and pesticide production long since shut down, the Rocky Mountain Arsenal is being made over in a 14-year, $2-billion remediation effort launched in 1996. The project, combined with earlier interim efforts, aims to clean the land contaminated by toxic chemicals and turn most of the arsenal’s 17,000 acres into a national wildlife refuge.

As part of the remediation effort, the Army funded studies in the late 1980s and early 1990s designed to better understand the effects on wildlife of pesticides and other toxic chemicals found in the land and ground water at the arsenal. The studies have also provided baseline data that scientists can use for comparison once remediation has been completed.

More immediately, though, the studies helped convince officials that remediation rather than a complete cleanup would be sufficient to protect people and animals. A complete cleanup would have included incinerating some contaminated materials, burying others in off-site landfills, and removing more soil than remediation requires.

Taken together, the studies showed that the effects of dieldrin and other contaminants at the arsenal are less than might have been expected. Although dieldrin soil residues still kill some animals, alter their behavior, and affect species composition, the effects occur mainly in heavily contaminated areas, not in relatively clean ones. The effects seem to strike individual animals exposed to high contaminant levels, rather than affecting entire populations. And relatively few species seem to be seriously affected.

Indeed, despite the presence of contaminants, the arsenal has long been a wildlife haven, probably because only a relatively small area in the middle of the arsenal was used for manufacturing, storage, and disposal of dangerous chemicals. As at many military bases, a much larger, mostly natural safety zone surrounded the active core to protect people outside in case of an accidental spill.

Consequently, mule and whitetail deer, prairie dogs and badgers, bald and golden eagles, great horned and burrowing owls, and ferruginous and Swainson’s hawks abound. Signs proudly proclaim the site to be the Rocky Mountain Arsenal National Wildlife Refuge. A US Fish and Wildlife Service (FWS) visitor’s center offers exhibits, a history of the arsenal, and guided tours of areas that can safely be entered.

For now, though, the Army still owns the arsenal and, along with Shell, is legally and financially responsible for its remediation. Despite the signs, the site does not officially become a national wildlife refuge until the US Environmental Protection Agency (EPA) certifies the remediation as complete. Until then, however, FWS manages most of the area as if it were a refuge.

That anyone would consider turning the Rocky Mountain Arsenal into a wildlife refuge may seem surprising. Residues from more than 600 chemicals have been found there, although only 27 are at levels of concern. Past spills and leaks from various waste basins, landfills, and trenches have contaminated ground water, soil, and buildings at the arsenal and in the 1960s and 1970s killed thousands of migrating waterfowl.

The contaminants of concern at Rocky Mountain Arsenal are mostly dieldrin and other organochlorine pesticides, which persist in soil and ground water for decades. By comparison, most chemical weapons agents break down quickly when exposed to air or sunlight. Nerve gas “is all but gone in 2 or 3 days,” says Michael Hooper, a biochemical toxicologist at Texas Tech University who has studied wildlife at the arsenal. Mustard gas lasts longer, but...
Most badgers at Rocky Mountain Arsenal appear to be unaffected by dieldrin, one of the main chemical contaminants remaining in the soil at the military base. A 14-year, $2-billion remediation effort begun in 1996 will turn most of the arsenal into a national wildlife refuge. Photo: Wendy Shattil and Bob Rozinski, courtesy of US Fish and Wildlife Service.

none was made at Rocky Mountain after 1945, and few traces have been found at the site.

The Army sampled the soil at 15,000 locations throughout the arsenal. Low levels of diisopropyl methyl phosphonate, a nerve gas breakdown product, were found in only about 200 of the locations, Kevin Blose says. Traces of mustard gas were found in only three or four locations. Dieldrin residues, on the other hand, were found in 13,000, adds Blose, a civilian Army engineer and program controller for the Remediation Venture Office, the joint Army, Shell, and FWS agency managing the remediation.

Moreover, only about 15 percent of the soil at the arsenal is heavily contaminated. Most of the contaminated soils are concentrated in the middle of the property, where chemicals were made and wastes dumped. Even the most contaminated locations are often interspersed between less contaminated places, thus reducing the exposure of animals living or feeding in these areas. And most soils are only lightly to moderately contaminated.

Another encouraging note is that much of the cleanup is already completed. Buildings and equipment used to make nerve gas and mustard gas have been chemically cleansed and demolished, and the debris has been buried in off-site landfills. A basin once used to dump chemical wastes has been capped with crushed concrete from runways at Denver's now-decommissioned Stapleton Airport. And all ground water flowing from the arsenal is captured and treated at least three times in a series of five facilities built since 1979.

Moreover, a huge, 1.5-million cubic yard, double-lined landfill at the arsenal was finished earlier this year. It will be filled with contaminated soil and debris from demolished buildings where pesticides were made. The work is expected to take 9 years, Blose says.

A second, 750,000-cubic yard, triple-lined landfill will be built at the arsenal in 2001 to hold material from an excavated 93-acre basin that held nerve gas and pesticide wastes. The basin, which had a state-of-the-art asphalt liner when it was built in 1956, has since leaked, fouling ground water. In an interim remediation, the basin was drained and leftover materials incinerated.

The refuge's genesis

In the 1980s, no one could have predicted that Rocky Mountain Arsenal would have even the possibility of a happy ending. The Army, Shell, and EPA were fighting one another over the extent of remediation required and each party's financial responsibility for cleaning the site. In separate litigation, the state of Colorado was suing the Army and Shell,
the Army was suing Shell, and Shell was suing its insurers. And federal agencies, developers, neighboring communities, and local environmentalists were at odds over what to do with the arsenal once the Army left.

Bald eagles changed all that. Eagles were long known to visit the arsenal during winter, but more than a dozen were found roosting there in 1986. Now, an estimated 100 eagles roost or feed there at least occasionally from November to April. Development elsewhere in Colorado has apparently deprived the eagles of other winter roost sites and prey along the front range of the Rockies, says Jane Greiss, a FWS wildlife biologist who until 1998 oversaw wildlife research and management at the arsenal.

"Oh, my God, we've got an endangered species on a Superfund site," Mike Lockhart recalls thinking when he first arrived at the arsenal shortly after the roosting eagles were discovered. "I thought we would have to chase them away."

Instead, Lockhart, a FWS wildlife biologist now based in Laramie, Wyoming, launched a 3-year study of the arsenal's bald eagles. From 1987 to 1990, Lockhart and his colleagues radio tracked 76 bald eagles who roosted or fed at the arsenal. The researchers sought to learn more about eagle behavior and about the birds' possible exposure to contaminants through their diet.

The scientists found that the normally fish-eating eagles dine mostly on prairie dogs at the arsenal in winter. Interestingly, they also learned that the eagles rarely capture prairie dogs on their own. "We never saw an eagle kill a prairie dog," Lockhart says. Instead, the eagles steal prairie dogs killed by farruginous hawks.

Lockhart and other researchers periodically recaptured the eagles, took blood and tissue samples, and compared the results with data from eagles studied elsewhere in Colorado and Utah. Lockhart found that no bald eagles at the arsenal—and none of the golden eagles or red-tailed hawks—died due to dieldrin or other contaminants. In fact, he found no traces of dieldrin in the eagles and only low levels of other pesticides and heavy metals, which could have come from elsewhere. Lockhart concluded that the arsenal's bald eagles were as clean as and, based on their muscle mass and fat levels, healthier than eagles at other study sites.

The presence of healthy eagles helped change the debate over the arsenal's future, says Kip Cheroutes, a former aide to then-Representative Patricia Schroeder (D-CO). Early suggestions for uses of the land included an industrial park, new homes, and expansion of Stapleton Airport. By the late 1980s, however, some Colorado politicians were talking about preserving the arsenal for wildlife conservation. When the National Wildlife Federation proposed making it a national wildlife refuge in 1989, Schroeder jumped at the suggestion. Her bill passed Congress in 1992, 50 years after the arsenal opened.

Small effects on larger mammals

While the debate over the arsenal's future was proceeding, FWS launched a series of Army-funded studies in the late 1980s and early 1990s on the effects of chemical contaminants on arsenal wildlife. The studies were designed to identify the levels of chemical contaminants in wildlife, their effects, which species were at risk, and what areas were the most dangerous to animals. The investigations yielded some surprising results.

Because organochlorine pesticides such as dieldrin usually accumulate in tissues at higher levels as one moves up the food chain, many scientists had assumed that top-of-the-food-chain predators would be most affected by arsenal contaminants. Like eagles, therefore, badgers seemed highly vulnerable because they not only dig in contaminated soils but also eat prairie dogs and other burrowing rodents that dig in contaminated soils.

Such assumptions were not unwarranted. A FWS biologist found a convulsing badger near a highly contaminated area in 1992. The badger had the highest tissue levels of dieldrin by far of any animal tested at the Rocky Mountain Arsenal. Dieldrin is a neurotoxicant that causes nerve cells to overreact to chemical messages, leading to seizures and respiratory failure. Although designed to kill insects, it kills mammals and birds as well. Animals can pick up dieldrin as a result of eating food contaminated with dieldrin, absorbing it through the skin by burrowing in contaminated soil or licking or cleaning themselves, or inhaling it from the air in their burrows when hot weather volatilizes the compound from the soil.

Beginning in 1993, Hooper, then at Clemson, and graduate student Dale Hoff studied the effect of dieldrin on badgers both in the laboratory and in the field. Hoff, now an ecotoxicologist in EPA's Denver regional office, caught 12 badgers on clean lands in Wyoming in 1993 and brought them to a University of Wyoming laboratory in Laramie. There, the badgers were fed a dieldrin-free diet while baseline physiological data were taken. Some of the animals were then fed a diet low in dieldrin, while others were given an amount equal to levels badgers were exposed to at the arsenal. A third group received even higher levels. None showed any ill effects, Hoff says.

In the next stage of the research, from 1994 to 1996, Hoff caught 30 badgers at the arsenal and took blood and tissue samples. Hoff also surgically implanted radio transmitters to track the animals and correlate their home ranges within the arsenal with known contamination levels in the soil. He regularly recaptured the badgers to test their pesticide levels and collect physiological data.

As with the laboratory badgers, none of the wild badgers showed any ill effects of dieldrin exposure—even the two or three whose home ranges included highly contaminated areas.
US Fish and Wildlife Service biologist Richard Roy found that dieldrin does not appear to affect American kestrels (embryos or hatchlings, such as the 12-day-old chicks shown here, but can kill adult kestrels or alter their behavior so that they abandon their nests. Photo: Richard Roy.

The badgers had large territories that included less contaminated areas, thus diluting their exposure, Hoff says. Apparently, the convulsing badger found in 1992 was an isolated case in an extremely contaminated area.

Another reason for the low dieldrin levels of most badgers and eagles was that FWS managers moved prairie dog towns away from the most heavily contaminated areas, such as the waste basins. Dieldrin has killed ferruginous hawks and would likely kill any bald eagles that eat a prairie dog with high tissue levels of the compound, Lockhart says.

Like badgers, coyotes appear to be unaffected by dieldrin and other pesticides. Eric Hein estimates that 50 coyotes live within or visit the arsenal daily and another 23 go there at least occasionally. Although his study did not look at survival rates, Hein, a FWS wildlife biologist now based in California, says the arsenal's coyotes are the second most dense population of any studied in the West, which suggests that they are not affected by the site's contaminated soils.

Similarly, most deer at the arsenal show few effects of dieldrin and other contaminants. Although a study by Terry Creekmore, a wildlife biologist at the National Wildlife Health Center in Madison, Wisconsin, found that mule and whitetail deer at the arsenal have low tissue levels of dieldrin, as well as of mercury and DDE (a DDT breakdown product), the deer appear to be thriving. FWS managers estimate that more than 600 mule deer and 275 white tails live on the site, Greiss says.

Larger effects on small mammals

Whereas few effects of pesticides have been found in large mammals and bald eagles, the arsenal's small rodents are a different story. Otis, leader of the US Geological Survey's Cooperative Research Unit at Clemson, found that both the numbers of rodents and species diversity depend on the degree of contamination.

In all, Otis and graduate student Danny Allen studied 10 rodent species at the Rocky Mountain Arsenal—deer, harvest, grasshopper, house, silky, plains, and pocket mice; kangaroo rats; thirteen-lined ground squirrels; and prairie voles. Allen set traps in two heavily and two moderately contaminated areas and in two clean ones for 5–7 days straight each season over a 2-year period. All sites were grasslands, the typical habitat at the arsenal.

Not surprisingly, Otis and Allen found that dieldrin levels in deer mice, the most common small rodent at the arsenal, correlated with known soil levels of the compound. Almost two-thirds of the deer mice caught in heavily contaminated areas had detectable dieldrin residues in their tissues. None trapped in clean areas had dieldrin in their tissues or blood.

More important, Otis discovered that deer mice prevail in heavily contaminated sites. Whereas the total rodent biomass remained approximately the same from site to site, species diversity and community structure changed depending on the degree of contamination. Several rodents found in clean areas, such as grasshopper mice, pocket mice, and ground squirrels, were absent from contaminated areas. And the higher the contamination level, the more deer mice dominated the small rodent community. In the most contaminated places, they represented more than 75 percent of all rodents in the area.

Why deer mice are able to tolerate contaminated conditions is unclear. But Otis discovered that deer mice living in highly contaminated areas pay a high price for doing so. He found that 40 percent of deer mice survived from one season to the next on clean sites, compared with 35 percent on moderately contaminated sites and only 25 percent where contamination was heavy. “That’s a fair difference,” he says, although he adds that deer mice may compensate for increased mortality by increased birth rates.

Smaller birds, aquatic insects also suffer

Of all animals at the arsenal, American kestrels may be the most affected by dieldrin. The smallest falcon, American kestrels, or sparrow hawks, have been widely studied both in the laboratory and the field. “They are the white mouse of the raptor world,” says Richard Roy, a FWS wildlife biologist now based at Malheur National Wildlife Refuge in Oregon.

In a 5-year study beginning in 1992, Roy placed 37 nest boxes within the arsenal and an equal number outside. The nest boxes within the arsenal were divided between moderately and heavily contaminated areas. Roy examined one egg from each clutch and took blood and tissue samples from hatchlings. He also radio tagged 30 adult kestrels, corre-
Predators, such as great horned owls, disrupt the birds’ pair bond and affect their ability to successfully raise their young. Kestrels nesting closest to heavily contaminated areas—as indicated by high dieldrin levels in eggs—were the most affected, whereas those nesting farther away showed few effects. Kestrel nest success (i.e., the production of at least one surviving hatchling) dropped 40 percent among nests with more than 50 parts per billion (ppb) of dieldrin in the eggs. At 1 part per million, the success rate fell to 25 percent. Nests with less than 50 ppb dieldrin had a 76 percent nest success rate, about normal for kestrels.

Moreover, Roy found that the dieldrin levels affecting kestrel nest success were lower than had been reported in previous studies of golden eagles, peregrine falcons, and other raptors. Dieldrin does not appear to affect kestrel embryos or hatchlings, Roy says, but it can kill the adults or alter their behavior so they abandon the nest. He believes that the pesticide’s neurological effects disrupt the birds’ pair bond and affect their ability to find food and keep predators, such as great horned owls, away from their nests.

Other birds, too, are adversely affected by dieldrin. Catherine Henry monitored robins, house finches, starlings, and mourning doves living around the arsenal’s buildings. More than 200 birds a year are found dead at the arsenal, most of them killed by dieldrin. Henry, a FWS wildlife biologist now at the Upper Mississippi River National Wildlife and Fish Refuge in McGregor, Iowa, found high and often lethal levels of dieldrin and other contaminants in the dead birds. Birds that nested and fed at the administration building had lower dieldrin levels than those that fed at the former pesticide plants and waste basins.

Henry suspects that robins and starlings pick up chemical residues from insects, worms, and other prey they find in contaminated areas. House finches and mourning doves are probably exposed from the seeds and grit they eat. The birds may also be exposed when they take dust baths and preen themselves.

Dieldrin affects not only land animals but also aquatic ones. William Clements, a Colorado State University wildlife biologist, studied midges and other aquatic insects in three man-made lakes at the arsenal. Clements took insects caught in the lakes and exposed them in the laboratory to dieldrin and other pesticide levels typical of bottom sediments. He found that 60–70 percent of the insects exposed to dieldrin levels typical of heavily contaminated sediments died, compared with only 20 percent of those exposed to levels found in clean sediments.

**Restoring the arsenal’s prairies**

As part of converting the arsenal to a wildlife refuge, Bruce Hastings, a FWS wildlife biologist, is attempting to re-create prairies by restoring native plants lost by decades of farming, chemical production, and remediation efforts. Hastings hopes to eventually restore close to half of the arsenal’s 17,000 acres. He is planting blue grama, buffalo, and western wheat grasses, along with sand sagebrush, blue flax, bluestem, and other annuals. The prairie will not be restored everywhere, however. Some areas will be left alone to retain the more diverse habitats, and thus the diversity of wildlife, created by years of past human disturbance.

Crested wheatgrass, for example, will not be eradicated around prairie dog towns. Prairie dogs avoid this exotic species because, at its typical height of 2–3 feet, the grass is too tall for them to see over. Hastings will keep crested wheatgrass around the former waste basins to discourage prairie dogs from expanding into heavily contaminated areas until remediation is complete.

**The refuge’s future**

In the end, despite remediation, some outside observers question whether the Rocky Mountain Arsenal can ever be made truly clean. “We’re stuck with remediation,” says Sandy Horrocks, of the Sierra Club’s Rocky Mountain chapter. The landfills are not a permanent solution, she says. “The stuff will just be kept there. It won’t deteriorate and some will eventually get out. I wouldn’t take any kids there.”

Others, however, take a more positive view. “It’s not a pure, 100 percent cleanup,” says Tom Dougherty, a National Wildlife Federation senior advisor. “That would have cost billions more. It will be a beautiful place that will be acceptably clean for wildlife and human visitation.”

“We are committed to cleaning it up,” adds Ray Rauch, a FWS project leader for the Rocky Mountain Arsenal National Wildlife Refuge. “It will never be a pristine area, but it’s a great little piece of real estate for wildlife.”

Jeffrey P. Cohn, a Maryland science writer, is a frequent contributor to BioScience.

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