

lations that were established before federal laws were enacted. Now that the all-pervasive nature of the toxics crisis has been recognized, the limits of traditional regulatory solutions have been reached, prompting a new wave of governmental initiatives to the toxics problem. The following are a few examples of state governments leading the way.

□ *Source Reduction and Recycling:* Some progressive companies are discovering that reducing the use and release of toxic chemicals saves them money. To borrow a corporate slogan, "Pollution Prevention Pays."

North Carolina has begun to institutionalize this approach in its regulatory programs and is considering the creation of a pollution prevention center to assist industry in identifying and implementing pollution control at the source. New York and California have state waste exchange programs to encourage recycling and reuse of toxic wastes. Several states also provide financial incentives or disincentives to promote the use of recycling.

□ *Community Right-to-Know:* The right of workers to know what toxic substances they are being exposed to is basic to protection from toxic chemicals in the workplace. Citizens need the same right to ensure that they are protected from toxic chemicals in their communities. Following the lead of at least eight local governments across the country, Connecticut, Massachusetts, and New Jersey have enacted statewide laws. And in New York, many community right-to-know provisions have been adopted by administrative fiat.

□ *Toxics Victim Compensation:* While workers are now asserting their rights under worker compensation laws to be compensated for occupational diseases caused by toxic chemical exposure, citizens are still forced to resort to the courts when they are injured by toxic chemicals in their air, water, and food. The legal system is still without remedy for the toxics victim who cannot identify the responsible party. The courts have also had difficulty grappling with highly technical problems of cause and effect. At least one state, California, has adopted a compensation plan for victims of toxic chemical exposure, funded by a tax on industries generating toxic wastes.

While the need for state action has increased, states face three major obstacles: shortage of funds; absence of technical and research capabilities; and lack of public trust. The continuous funding problem has been exacerbated by cutbacks in federal funding to the states for participation in federal regulatory programs, even while more responsibility is

being delegated to them. This is part of the "New Federalism," which could also be called the new deregulation of toxic chemicals.

The federal government currently provides nearly half of the funds for state toxics regulatory programs. A recent Natural Resources Defense Council (NRDC) study found that most state environmental agencies predict a decline in their efforts to protect the public from air, water, and toxic pollutant hazards because the federal government is delegating authority to them too fast—with too little assistance. All 44 states NRDC surveyed expected an overall reduction in resources for pollution control programs; 34 said they could not assume additional responsibilities. Insufficient resources have forced some states to return environmental programs to the federal government.

Although there are many progressive solutions to the toxic chemical control problem, they will fail unless states can replace the federal dollars being lost. And taxpayers on the state level are no more willing than federal taxpayers to increase their tax burden.

One way of replacing lost federal dollars is by instituting the "polluter pays" principle. Manufacturing, processing, transporting, using, and disposing of toxic chemicals requires state programs to protect workers and the public from harm. Commercial enterprises that profit from these activities and, in turn, the consumers of their products and services should bear the costs of this regulation, not the taxpayer.

Most states charge fees for permits, but these usually are not sufficient to support regulatory programs. Some states have instituted fee systems for this purpose based on the quantity of toxics released into the environment. For instance, California's hazardous waste program is funded largely by a fee on the land disposal of hazardous wastes. These fees, if set high enough, have the additional benefit of encouraging reductions in toxic discharges.

The problem of insufficient scientific expertise is also linked to the funding problem. States have relied upon research performed at the federal level for standard-setting for toxics, yet federal budget cuts are reducing this basic research. State governments also have difficulty offering competitive salaries to scientists and engineers, thus weakening the technical competence of their regulatory programs. Some states have turned to their state-funded universities for the development of assistance to their regulatory programs.

The root of the states' problem with scientific expertise is that they bear the burden of proof for justifying the control of toxic chemicals. Industries successfully demand a high level of scientific proof

that a chemical needs to be controlled before submitting it to regulation—as if chemicals had constitutional rights. States can avoid massive expenditures for the basic research this burden entails by real-locating some of the burden to the regulated industries. In some cases the regulated industry should have the burden of proving why a chemical or class of chemicals should *not* be controlled.

Finally, state governments face the problem of public distrust of their ability or willingness to solve the toxics crisis. Some of this distrust is well-founded, given the legacies of lax regulation that have allowed contamination of our air and water by toxic chemicals. The only way to rebuild public trust is through extensive public education and participation in the development and implementation of toxics control programs. This level of public participation is most easily handled on the state and local level, where people have a much greater opportunity and reason to participate.

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ECOLOGY

Leaving it to Beaver

Sally L. Duncan

In 1868 Lewis H. Morgan, one of the early experts on the habits of the American beaver, wrote that the animal's behavior "involves as well as proves a series of reasoning processes undistinguishable from similar processes performed by the human mind." By 1904 the prevalent scientific wisdom concern-

ing the beaver was summed up by one scientist as follows: "No animal of the New World has been the subject of so much baseless romancing and color work."² Possibly no other animal is so deeply entrenched in the popular awareness of wildlife.

Although contemporary reports on the beaver in popular literature no longer suggest that it has an almost human intelligence, they do tend to focus on its

The beaver should be seen as a regulator rather than as a passive inhabitant of streams; an innovator and modifier of riparian vegetation rather than a mere consumer.

"picturesque" dams, the "wonders" of its canal building, or its "intriguing" instinct for storing away an underwater cache of winter food in the form of twigs and sticks.

However, much of the more recent attention paid to beavers has emphasized the negative aspects of beaver activity: the dams that must repeatedly be blasted to release water, the culverts that are continually dammed, and the trees that are lost. The beaver has still to be removed from the equally inappropriate realms of the romance and nuisance in popular understanding, and be observed realistically from an ecosystems perspective.

Primal populations of American beaver, *Castor Canadensis*, whose distribution ranged from the Arctic Circle to the deserts of northern Mexico, have been estimated at between 60 and 400 million.³ Assessing that range at 15.5 million square kilometers (km²), this translates to anywhere from 4 to 26 beaver per km². Estimating the total length of stream channels in North America, the number of beavers per kilometer of stream could have ranged from 6 to 38.

It is understood today that consumer populations are capable of closely regulating the physical characteristics, vegetation patterns, and nutrient cycling of ecosystems, and that the pre-historic world was inhabited by many consumer populations of numbers similar to those

estimated for *Castor canadensis*. A mere three centuries has brought on the devastating reductions in population that beaver trapping epitomizes.

The removal of the beaver from the eastern United States began early in the seventeenth century. For example, between 1620 and 1630, over 10,000 were trapped annually in western Connecticut and Massachusetts. On Long Island, the beaver was eliminated by 1630. Beaver

kills of 80,000 annually were recorded in the Hudson River and western New York from 1630 to 1640. In New York annual kills ranged from 40,000 to 66,000 between 1650 and 1675, and even at the end of the seventeenth century exports were still around 15,000 pelts annually.⁴

With the ravaging of eastern populations, beaver trappers moved west, and major explorations were often made solely for the purpose of opening new beaver trapping areas. A trapper needed at least 3,000 pelts per expedition to be counted successful, and the invention of the steel jaw trap around 1825 led to massive harvests in the West. In most of the Rockies and the Southwest, the beaver had been exterminated by 1840. By the time Oregon attained statehood in 1859, its state animal was a rarity.

Over the centuries since the arrival of Europeans in North America, the beaver has changed from an object of trappers' greed to a disappearing species, a hazard to spawning trout, and a cause of debris build-up in streams. More recently, a new perspective based on ecosystem dynamics has begun to develop.

How would today's stream ecosystem studies read if they took into account the numbers of beavers that must once have influenced—and possibly even regulated—much of the structure and function of streams in North America? As will be seen in the following discussion, preliminary studies seeking to answer this question indicate that the beaver is far more than a picturesque architect and laborer that has been much abused by man: beaver have been defined as a keystone species in the structure and dynamics of aquatic ecosystems. In

habitats where they remain, they are important regulators of stream dynamics and morphology, with pervasive effects far beyond their food and space requirements.

It is no longer sufficient simply to admire the industry and skill of the beaver, to tabulate its food preferences, and to observe more carefully its behavior patterns. Instead, it should be seen as a regulator rather than a passive inhabitant of streams, an innovator and modifier of riparian (stream- and pondside) vegetation rather than a mere consumer.

In the awakening recognition of the importance of beaver to their ecosystem, they have occasionally been given employment in erosion control programs. In the 1930s and 1940s beaver populations were increased and used in this way in the Southwest and in some Rocky Mountain areas; Washington and Idaho both successfully augmented low water flow and controlled erosion with the help of beaver activity.⁵

Such a role is in ironic contrast to the previous 150 years, during which approximately 40 to 50 percent of the original wetlands in the United States were "reclaimed" by clearing, draining, and flood control. Crops, pastures, and cities now exist in former primitive marshes, swamps, and seasonally flooded bottomlands.

Perhaps the loudest cries of protest at returning the beaver to its former respected status in the ecosystem can be heard from foresters and ranchers, with whom beaver and their dam-building activities are in direct competition. A 1978 report on beaver damage in Mississippi concludes that

*The timber, row crop, and beef production losses caused by beaver impounding activity are estimated to be \$22,205,285. This figure represents an estimated annual loss of \$2,467,254 from Mississippi's agricultural economy. Since other economically less important beaver damage . . . (e.g., roadbed damage, plugged culverts, stopped-up drainage ditches, and pond levee damage) was not evaluated, . . . loss estimates . . . are considered conservative.*⁶

The report also notes a 300 percent increase in the level of beaver activity over the last decade, along with the absence of natural predators and low economic incentive for trappers.

In July 1982 a report was prepared for the Department of the Interior's Office of Biological Services as well as the Fish and Wildlife Service.⁷ Its summary states, in part, "Significant timber damage occurs when beaver feed upon timber not impounded as a result of beaver activity. . . . The magnitude of damage ranged from a

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low of \$62.22 per acre . . . to a high of \$291.50 per acre."

Another stance is taken in a 1980-81 report titled *Importance of Beaver Management in Grazed Riparian Ecosystems*.⁸ In reaction to the competitive desire of ranchers to remove beavers from their waterways, the report acknowledges the importance of beaver to stream channels and valley bottoms; removal of beaver is seen to immediately reduce wildlife and fish habitats. The report states:

Continued livestock grazing in the absence of beaver often leads to elimination of shrubs, stream channel migration, channel structure changes and a lower water table. . . . Once the channel has degraded and water tables are lowered, livestock forage potential is also reduced, and vegetative type changes are common, resulting in a less diverse wildlife community. Due to lower vegetative productivity and more active stream channels, riparian recovery is seriously inhibited and often necessitates drastic livestock management changes if recovery is a management objective.

Managers can choose among grazing systems that favor shrubs, new shrub plantings, strict regulation of beaver harvest, beaver transplants into favorable habitat, and reduction of riparian grazing where beaver have been eliminated.

A further problem for beaver management is that beaver are commonly vectors of *Giardia*, the scourge of western backpackers. *Giardia* is carried through the digestive tract in cyst form and is usually introduced through infected water. It is the most common pathogenic internal parasite in the United States, and is found in 4 percent of stool samples submitted to state public health laboratories for parasite examination. Symptoms of infection range from mild to explosive and debilitating diarrhea. The bacteria have been found in campers and hikers from nearly every part of the United States and Canada.⁹

There are two distinct species of *Giardia*, of which *Giardia duodenalis* affects man, beaver, coyote, cattle, cats, and dogs. There is a chicken-and-egg kind of debate over the role of beaver and man in introducing an infection to a particular area. A typical conclusion comes from one Rocky Mountain-area study:

*Campers have been infected by drinking untreated mountain stream water in Utah and Colorado and beavers have been implicated as a reservoir. The beavers have probably acquired the infection from man and have served as an amplification reservoir.*¹⁰

Whether the amplification is sufficient to justify punitive action against beavers is a question concerning many microbiologists in the field. What is clear is that beaver are not the sole vectors of the parasite in the wild, nor are they nearly such a significant reservoir of infection as man—although it seems that beaver can maintain *Giardia* independent of human involvement.¹¹

Research today has finally begun to evaluate the role of beaver in whole aquatic ecosystems, from *Giardia*-infected waters to those far downstream of the site of beaver activity. Objectives of recent studies include quantifying the extent to which beaver modify channels, the major influences on nutrient cycling, and on vegetative and invertebrate members of associated ecosystems. Researchers include Dr. Jim Sedell, of the U.S. Forest Service in Corvallis, Oregon, whose interests lie chiefly in the effects of beavers on fisheries; and Dr. Cliff Dahm, of the Oregon State University Department of Fisheries and Wildlife, who is studying their effects on nutrient cycling and microbial activity. Drs. Robert Naiman, of the Woods Hole Oceanographic Institute, and Jerry Melillo, of the Woods Hole Marine Biological Laboratory, are interested in stream ecology and leaf and litter decomposition, respectively.

"There's a huge water rights fight due to start, especially in drier areas," Sedell points out, "between ranchers and people interested in shale oil and synfuels. Beavers have kind of grandfathered their way into that water rights pecking order, so now there's a good legal reason for taking a closer look at their habitat and their ecosystem roles."

Protection of beavers varies from state to state. In Oregon, for example, where the primal population was around one million, a "sustained management" program now aims to hold the beaver population at about 60,000 to 65,000 by controlled trapping. But for many ranchers and foresters the competition for water from even a relatively small number of beaver is unwelcome.

Several years ago, an extensive literature search by Sedell and Dahm revealed only a few studies related to the environmental effects of beaver activity. Nevertheless, Sedell and his colleagues now feel beaver are one of the most significant in situ agents determining the nature of aquatic ecosystems in North America.

For example, the dams built by beavers often persist for centuries and seem to be largely responsible for creating and maintaining wetlands. Extensive and continued flooding raises the water table, wetting forest soils and influencing nutrient cycling and decomposition processes. Not only do dams hold organic materials in the stream for further processing but the added wood provides more stable attachment sites for numerous organisms and affects channel morphology by diverting and redirecting channel currents. Extra wood and leaves provide food to invertebrate consumers, both on site and in downstream communities, making it reasonable to suggest that beavers have a strong indirect effect on the nature of downstream chemistry and productivity.

Just these few examples show the extent of the beaver's role in the ecosystem. The work researchers have completed in four areas of North America—Quebec, Oregon, Mississippi, and Montana—can be expanded, they believe, to most other



areas of the continent where beavers have been or are once again a major consumer population.

Recent studies of beaver in aquatic ecosystems, although preliminary, point to a pivotal role for that rodent in its habitat—no less today than in prehistoric times. Free intelligence or not, beavers do

Beaver dams dissipate the erosional potential of water by their stair-stepped profiles, trapping massive amounts of sediments and changing channel forms from riffles to pools.

choose dam locations that will pond maximum amounts of water. In Oregon, Quebec, and Massachusetts, some 2,000 km of pristine streams have been surveyed, of which 30 to 50 percent are directly affected by beaver.

Beaver dams dissipate the erosional potential of water by their stair-stepped profiles, trapping massive amounts of sediments and changing channel forms from riffles to pools.¹² Associated construction activities have further effects on the geomorphology of stream channels: flow patterns react to the cutting of large trees and bushes, and beaver canals connect streams and lakes intimately with the forest. Slides can develop along river banks where beaver return for concentrated cutting, and the search for roots and rhizomes in winter disturbs bottom sediments.

Specific effects on watershed hydrology include the damping of fluctuations in runoff: it is estimated that up to 30 percent of the water in an Oregon drainage network during dry periods is held in beaver ponds, and the amount may be as high as 60 percent in Colorado.

The raising of the water table not only maintains the integrity of wetlands but also affects nutrient cycling, decomposition and evaporation, plant community structures, available light (by the opening up of the canopy), and the nature of the water leaving the area. A raised water table also favors wet-loving forms such as willow, emergent vegetation, and submerged macrophytes, with dramatic effects on the riparian zone.

Changes in riparian vegetation are among the more obvious effects of the beaver and his works; the extent of the actual riparian zone can be increased several hundredfold by dam building. Previously dry land becomes soggy or inundated; trees die and fall down. Aquatic plants es-

ablish along the edges of dams. In some areas, this so-called muskeg succession tends to be self-perpetuating: it can lead quite rapidly to the development of a large cattail marsh or an open, wet "beaver meadow" of sedge, shrubs, spruce, and tamarack. In other areas, selective cutting of hardwood species may eventually leave only conifer species by the river edge, and by pruning small willow and alder trees

into bushes beaver effectively increase leaf biomass. The cause and effect process continues as such favored species as willow, alder, and macrophytes contribute their readily-assimilated, high nitrogen inputs to the aquatic foodweb.

It is in the quantity of input, however, that the beaver's impact is most impressive. Various recent calculations for Quebec,¹³ for example, conclude that beavers contribute 2.8 kg/square meter of high quality wood annually. This figure assumes only a one-meter-wide stream and does not even include direct leaf fall or lateral movements of litter occurring naturally from the modified riparian zone.

A diet of twigs and branches means beaver can provide "instant sawdust": a beaver might eat 2,500 pounds of hardwood in a year, but only weighs in at 30 to 75 pounds. Their intestinal wastes become sediment, which decomposes into nutrients for microorganisms, which in turn provide food for insects. The insects then become the prey of juvenile fish.

Despite the impressive consumption figures, beaver consume less than one-fourth of the wood they actually cut, which almost entirely explains their dramatic impact on the ecosystem. The remaining wood is left to decompose, with continuing effects on the physical, chemical, and biological nature of its environment.

If exposed to oxygen, cut trees take one to three years to decompose. Any wood incorporated into the largely anaerobic sediments (those where free oxygen is absent), however, will require much longer to decompose. In fact, say researchers, ancient beaver dams with associated organic sediments are common on the floors of western valleys: they can be a few hundred years old in the continental United

States, and even thousands of years old in Alaska.

The term anaerobic attracted bad publicity in the years when the dumping of wastes was believed to transform whole aquatic systems from aerobic (those with free oxygen) to anaerobic, with disastrous results for organisms living in the water. But the current effort to understand the chemical processes of undisturbed ecosystems recognizes zones of anaerobic conditions in the organic-rich sediments as simply a natural part of ecosystem dynamics, rather than as a result to be automatically condemned.

Beaver activity commonly establishes anaerobic conditions within the sediments of their ponds. This is because a beaver dam produces a stillwater zone where organic material can settle out to provide a rich source of sediments. Where water is moving so slowly, the oxygen normally provided by aeration through water turbulence does not match the oxygen demand from decomposing sediments.

The result for the ecosystem is a much slower cycling of nutrients, and for the dam area itself, a less efficient immediate use of the byproducts of decomposition. The nutrients are slowly released to the overlying water by percolation and diffusion in the form of fine particulate or dissolved organic matter, or as elements such as nitrogen and phosphorus. But the build-up of these nutrients has profound effects on downstream reaches.

"The release of these nutrients increases the algal and bacterial productivity of downstream reaches," Dahm explains. "These then become the food resource base for aquatic insects. So both the diversity and the productivity of microorganisms and invertebrate groups will be enhanced by beaver activity. The result is an increased carrying capacity for all these consumers." According to Sedell, this is the first time anyone has studied in detail the chemical link between beaver activity and nutrient cycling.

A better understanding of the beaver's role in aquatic ecosystems is only beginning to be forged. Beyond romanticism and irritation is revealed a rodent whose long-admired magnificence lies more in the complexity of its role in the

NOTE

In Donald L. Dahlsten's article, "Pesticides in an Era of Integrated Pest Management" (*Environment*, December 1983, p. 45), acknowledgment of the contribution of R. Garcia to the article was mistakenly omitted. We regret this error and extend our thanks to Dr. Garcia for his help.

ecosystem than in the immediate wonder of its engineering abilities.

"I don't think any of the data we have gathered will change management approaches any time soon," Sedell says. "Too many people have spent too many years reacting to beaver as nuisances. But when you consider how expensive it is to 'control' them, what cheap laborers they can be for us in the long run."

Indeed, a project near Rock Springs, Wyoming, has included delivering aspen branches and old tires into streams to encourage beaver activity as part of the recovery of riparian willow communities in gully-cut sections. The streams there have lost much of their riparian habitat and channel stability because of erosion problems accelerated by overgrazing.¹⁴

The beaver concerned used the chosen materials without hesitation in their successful rehabilitation work. Clearly, *Castor canadensis* still deserves the attention it attracted three hundred years ago, but for a whole new set of reasons.

"What is new about our approach is we're putting all our findings in an ecosystem perspective," says Sedell. "And in the presentation of those findings we've

tried to emphasize that beaver have, in a sense, an enormous amount to offer the ecosystem."

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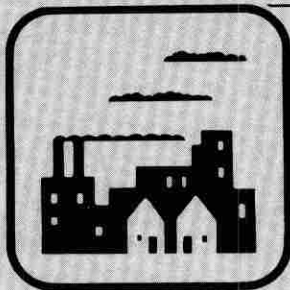
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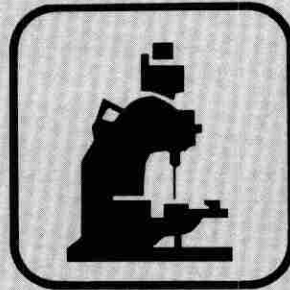
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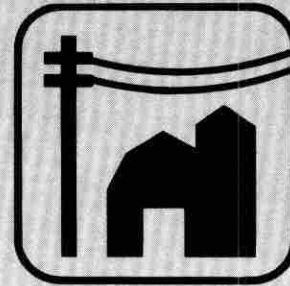
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