IRRIGATION DRAINAGE

Process of applying water to crops, usually through a system of aqueducts, such as canals, that move the water from its source to the point at which it will be used; also the process of dealing with problems that develop when water is applied to croplands. Irrigation is essential to support agricultural production in most arid regions of the world. Intensive irrigation places high demands on available water supplies and may lead to the production of drainage water that is toxic to fish and wildlife. The lifeline of scarce but important wetlands present in arid regions is cut when ground and surface water is removed for agricultural use. In the western United States major losses of native wetlands have occurred due to agricultural irrigation.

Agricultural irrigation practices commonly use water applications that total about 60-80 centimeters during the growing season. This is several times greater than the natural precipitation, and two types of wastewater can be produced in the process: surface runoff and subsurface drainage. Surface runoff, also known as irrigation tailwater, occurs because of operational spillage as water is pumped into canals or pipelines for distribution to fields, or because application rates exceed infiltration rates of the soil. This water can contain high concentrations of pesticides and herbicides if aerial spraying is being done, or if recent land-based applications of these materials have occurred. Shortages of water during the 1985-1992 drought in the United States, coupled with increasing demands for water by other economic sectors, led to on-farm conservation measures that curtailed much of the surface runoff in the western United States, particularly in California.

The other type of irrigation wastewater, subsurface drainage, results from a specific set of soil conditions and cannot be eliminated through water conservation. Shallow (3-10 meters) subsurface clay lenses, or layers, impede the vertical and lateral movement of irrigation water as it percolates downward. This causes waterlogging of the crop root zone and subsequent buildup of salts as excess water evaporates from the soil surface. The accumulated subsurface water must be removed in order for crop production to continue.

Several methods of removing excess shallow groundwater were attempted in the mid- to late 1800s, including the use of wells and surface canals to pump and drain the water away. The method of choice became the installation of permeable clay pipes spaced three to seven meters apart and two to three meters below the surface. Once these drains were in place, irrigation water could be applied liberally, thus satisfying the needs of crops and also flushing away excess salts. More recently perforated plastic pipe has replaced earthen clay tile as the conduit in agricultural drainage collector systems. The resultant subsurface wastewater is pumped or allowed to drain into surface canals and ditches and is eventually discharged into ponds for evaporative disposal, or into creeks and sloughs that are tributaries to major streams and rivers.

Subsurface irrigation drainage is characterized by alkaline pH, elevated concentrations of salts, trace elements, nitrogenous compounds, and low concentrations of pesticides. The conspicuous absence of pesticides may seem to be unusual as surface runoff can contain high concentrations of these chemicals. However, the conditions responsible for producing subsurface drainwater also result in the removal of these potentially toxic compounds. The natural biological and chemical filter provided by the soil effectively degrades and removes pesticides as irrigation water percolates downward to form subsurface drainage. At the same time naturally occurring trace elements in the soil, such as selenium and boron, are leached out under the alkaline, oxidizing conditions prevalent in arid climates and are carried in solution in the drainwater.

When subsurface irrigation drainage is discharged into surface waters, a variety of serious impacts can occur. The immediate impact is degradation of surface water and groundwater quality through salinization and contamination with toxic or potentially toxic trace elements (e.g., arsenic, boron, chromium, molybdenum, selenium). This water quality degradation can in turn affect irrigation, livestock watering, industrial processing, recreational use, and drinking water supplies. Human health warnings not to eat contaminated waterfowl and fish have been issued in some drainwater-affected areas.

Elevated concentrations of trace elements in irrigation drainage can severely affect wetlands and their fish and wildlife populations. Many of these wetlands are closed aquatic systems with no outflow, formed at the terminus of the drainage. Such closed-basin systems are particularly susceptible to water quality degradation. With no outlet, incoming contaminants are effectively trapped and accumulated; the exposure of fish and wildlife is thereby maximized. The arid climate also contributes to water quality problems. Contaminants and salts can become concentrated as large quantities of water evaporate. Thus inflows carrying low concentrations of contaminants may become toxic as evaporative losses occur.

In 1985 subsurface irrigation drainage was implicated as the cause of death and deformities in thousands of waterfowl and shorebirds at Kesterson National Wildlife Refuge in California. Naturally occurring trace elements and salts were leached from soils on the west side of the San Joaquin Valley and carried to the wildlife refuge in irrigation return flows that were used for wetland management. One of the trace elements, selenium, bioaccumulated in aquatic food chains and contaminated 500 hectares of shallow marshes. Elevated selenium was found in every animal group coming into contact with these wetlands—from fish and birds to insects, frogs, snakes, and mammals. Selenium caused reproductive failure and congenital malformations in young waterbirds and fish. Some of these deformities were severe, for example, missing eyes and feet, protruding brains, and grossly deformed spines, beaks, legs, and wings. Several species of fish were eliminated due to the combined effects of high salinity, elevated selenium, and other contaminants; a high frequency (30 percent) of stillbirths occurred in those species that survived. Studies conducted by the U.S. Fish and Wildlife Service confirmed that irrigation drainage was the cause of the fish and wildlife problem.

The findings at Kesterson National Wildlife Refuge led to a new awareness of the dangers posed by agricultural irrigation drainage. In 1986 the U.S. Department of the Interior established a multiagency program to investigate irrigation-related drainwater problems. Eleven study areas in nine states were found to be seriously contaminated by selenium. The concentrations present at these eleven sites exceeded toxicity thresholds for fish and wildlife. Selenium-induced deformities in bird embryos and hatchlings were found in five states: California, Utah, Wyoming, Nevada, and Montana.

The biogeochemical conditions leading to the production of subsurface irrigation drainage, culminating in death and deformities in wildlife, have been termed the “Kesterson Effect.” The Kesterson Effect is prevalent throughout the western United States and is caused by these conditions: (1) a marine sedimentary basin that contains Cretaceous soils that have high concentrations (several parts per million) of selenium, boron, or other elements; (2) alkaline, oxidized soils that promote the formation of water-soluble forms of these elements; (3) a dry climate in which evaporation greatly exceeds precipitation, leading to salt buildup in soils; (4) subsurface layers of clay that impede downward movement of irrigation water and cause waterlogging of the crop root zone; and (5) subsurface drainage, by natural gradient or buried tile drainage networks, into migratory bird refuges or other wetlands.

Before the discovery of problems at Kesterson National Wildlife Refuge, irrigation drainage was viewed as being acceptable for wetland management. It was thought that agricultural wastewater could be recycled and used to supplement freshwater supplies. Kesterson National Wildlife Refuge was developed under this concept as a joint venture between the U.S. Bureau of Reclamation, which used the refuge as a site for drainwater disposal, and the U.S. Fish and Wildlife Service, which used the drainage to create shallow marshes for waterfowl. Viewed in light of the research findings of the past decade, this practice carries great environmental risk. Seasonal or permanent wetlands supported by irrigation drainage experience salt buildup as evaporative losses of water occur, thereby changing the species diversity and yield of native marsh plants that are important producers of wildlife food. Moreover, contaminants in the drainwater can bioaccumulate and cause mortality and reproductive failure in fish and wildlife.

Historically wide year-to-year fluctuations in rainfall and freshwater inflow to wetlands occurred as a consequence of natural hydrological cycles in the arid western United States. This resulted in varying salinities and produced a mixture of fresh and brackish wetlands. Irrigated agriculture has changed the natural hydrologic regime and greatly accelerated the rate of salt deposition in wetlands. Diversion of water for use by agriculture has meant that freshwater inflows to wetlands are inadequate to flush away excess salts, as would periodically occur under natural conditions.

From an environmental perspective, one obvious solution to the problem of wetland contamination is restoration of freshwater inflows. However, putting water back into wetlands means that less water will be going somewhere else, and there seems to be too little to satisfy all demands.

Resolving the dilemma over water rights of humans and water needs of native wetlands will not be easy. The situation at Kesterson National Wildlife Refuge was resolved after several years of scientific and political debate, at a cost of well over $100 million. Kesterson was declared a toxic waste dump, taken out of the national wildlife refuge system, and partially buried. Effectively managing and restoring wetlands will require creative thinking by wetlands managers, cooperation between water authorities and natural resource agencies, and increased conservation by water users.

The possibility that irrigated agriculture could produce subsurface drainage and wildlife problems in other countries is very likely. Several of the factors contributing to the formation of toxic drainwater in the western United States—a marine sedimentary basin containing soils with elevated concentrations of trace elements, alkaline conditions that favor the formation of water-soluble forms of trace elements, soil salinization problems that require the use of irrigation to flush away excess salts—occur in many other arid and semiarid regions of the world. It is not clear how widespread the other key element necessary for producing subsurface drainage is, that is, the presence of layers of clay or other impermeable soil materials that impede downward movement of irrigation water. However, drainage or salinity problems have been reported from virtually every arid region where intensive irrigation occurs, which suggests that the phenomenon may be common. Moreover, soils with elevated concentrations of trace elements prone to leaching by irrigation, such as selenium and molybdenum, are known to occur in many countries.

Heavy use of freshwater for agricultural irrigation has led to water shortages and associated wildlife problems in many locations around the world. For example, the Aral Sea, located in the driest part of Russia, was once the worlds fourth-largest freshwater lake and supported vast fish and wildlife populations and extensive delta wetlands. It is now disappearing. From 1960 to 1987 its level dropped 13 meters and its area decreased by 40 percent, primarily because of withdrawals of water for irrigation. Severe environmental problems have occurred, including salinization, loss of biological productivity, deterioration of deltaic ecosystems, and major changes in native aquatic and wetland communities. The large area of exposed former sea bottom along the eastern shore is a source for major dust and salt storms that are causing significant ecological and agricultural damage for hundreds of kilometers inland. The former major shipping ports of Aral’sk and Muynak are now tens of kilometers from the sea. Correcting this problem will be very difficult and expensive, necessitating a change in the lifestyle and water usage of some 40 million people in the region. Preservation of the Aral will likely require implementation of a major, and controversial, project to divert water from western Siberia into the Aral Sea basin, a distance of more than 1,000 kilometers. The possible economic gains related to this project are brought into serious question by the huge environmental and economic losses already suffered.

With human populations and associated water demands continuing to grow in many arid and semiarid regions of the world, the potential for changes in nature’s water balance is increasing. These hydrological changes can cause a variety of unforeseen negative environmental and economic impacts. In some cases the effects may occur suddenly and with little warning. In others the effects may be quite subtle, resulting in a gradual degradation of water quality and wetland ecosystems over several years or even decades. It is important for resource managers and water authorities to recognize the high potential for negative impacts and take steps to prevent them from occurring. Prevention is likely to be much easier than trying to find and choose among difficult and perhaps unpopular alternatives once environmental damage has occurred. Lessons learned in the western United States can provide valuable information for other countries to use in their water management policies.—A. Dennis Lemly

See also **AGRICULTURE IN DESERTS; COLORADO RIVER; CONTAMINATION; DAM; DESERTIFICATION; DURICRUSTS; GROUNDWATER; HYDROLOGICAL CYCLE; HYDROLOGY; INSECTICIDES; MIDDLE EAST, DESERTS OF; PLAYA; POLLUTION; RIVERS; SALINITY; SALT; SALT CRUST; SALT DESERT; SALT PAN; SOILS, DESERT; SOILS, DESERT, CLAY; WATER**

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