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Irrigated agriculture and freshwater wetlands: A struggle for coexistence in the western United States

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Abstract

This paper is a review of the major environmental problems associated with irrigated agriculture in the western United States. Freshwater wetlands are being contaminated by subsurface agricultural irrigation drainage in many locations. Historic freshwater inflows have been diverted for agricultural use, and remaining freshwater supplies are not sufficient to maintain these important natural areas once they are degraded by irrigation drainage. Migratory birds have been poisoned by drainwater contaminants on at least six national wildlife refuges; waterfowl populations are threatened in the Pacific and Central flyways. Revised water allocation policies and regulatory actions are probably necessary to correct existing damage and prevent future problems. The benefits of maintaining healthy wetlands should be used as a rationale for negotiating increases in freshwater supplies. Cost analyses that show the importance of wetlands in dollar values are critical to the success of these negotiations. The next few years will provide unique opportunities for wetland managers to use cost analyses to make changes in water allocation policies. Federally subsidized water has supported and expanded agriculture at the expense of native wetlands for over 100 years in the western United States. This trend must be reversed if these wetlands and their fish and wildlife populations are to survive.

Introduction

Drainage and salinity problems associated with agricultural irrigation have been occurring in the western United States since the mid-1800's, when the population of many small towns rapidly expanded because of the gold-rush. Early agriculture provided food for the gold seekers and associated businesses, and the techniques used by miners to get water to their claims were adapted to irrigate arid croplands, leading to stable and bountiful yields. However, by 1880 the potential for destruction of agricultural productivity in arid regions due to salinization of the soil was well known (Letley *et al.* 1986).

The standard irrigation strategy that emerged was to apply much more water than was necessary to support crops, thereby flushing away salts that accumulated in crop root zones as evaporation occurred (Moore *et al.* 1990). This practice led to high demand for, and consumption of, irrigation water (Christiansen and Gaines 1981, State of California 1990). In locations with fertile alluvial soils, liberal application of water transformed semi-desert into highly productive agricultural lands. For example, in the San Joaquin Valley, California, more than 200 crops are grown commercially and the Nation's highest production of agricultural commodities occurs in this single basin (Christiansen and Gaines 1981). However, the intensive farming practices necessary to maintain this level of agricultural production led to the demise of over 30% of the Valley's wetlands and deepwater habitats in just 40 years (Frayer *et al.* 1989). Wetlands were lost by draining and direct conversion to agricultural land, or water removal from rivers and streams for use in agricultural irrigation robbed wetlands of their inflow and they simply dried up. This situation was repeated in other western states for the past 90 years (Thompson and Meritt 1988, Preston 1981).

The small proportion of wetlands remaining in arid regions of the U.S. are especially valuable as stop-over and wintering grounds for migrating waterfowl and shorebirds, and as refuges for resident wildlife populations (Frayer *et al.* 1989). Some of these wetlands are classified as hemispheric reserves for shorebirds (Thompson and Meritt 1988). These wetlands also support remnant populations of Federally listed endangered and threatened wildlife, plants, and fishes (Stephens *et al.* 1988, Hoffman *et al.* 1990). In some cases these wetlands are valuable archaeological sites, and have been used to identify and trace Native American occupancy and culture over several thousands of years (Raven and Elston 1988).

Limited availability of water was a major obstacle to settlement of many arid regions in the western states (Reisner 1986). The shortage of water and perceived need to homestead on desert lands led to the establishment of the U.S. Bureau of Reclamation in 1902. The primary mission of this agency was to 'reclaim' unproductive lands by bringing water to arid regions and converting desert into farmland. This reclamation began in earnest with the completion of the Newlands Water Project in Nevada in 1915 and reached a peak with the building of such massive projects as Hoover Dam on the Colorado River, the California Aqueduct across the Mojave Desert, and the Central Valley Irrigation Project in California (Reisner 1986). However, the price for this reclamation and associated increase in agricultural production was a sharp reduction in the amount of water available to native wetlands.

In the early 1980's a new agriculture-related threat to wetlands emerged – subsurface irrigation drainage. This drainage water usually contains elevated concentrations of soil trace elements and other constituents, and poisoned fish and wildlife populations at several locations (Ohlendorf 1989, Presser *et al.* 1994, Lemly *et al.* 1993). These findings raise new questions about the role of agriculture in the health and ultimate fate of remnant native wetlands. The impacts of subsurface agricultural drainage on wetlands are major concerns of wildlife management agencies and private conservation groups (Rude 1989, Sylvester *et al.* 1991). Finding an environmentally acceptable balance between agriculture and wetlands is more complicated, yet more necessary, than ever before (National Research Council 1989, Moore *et al.* 1990, SJVDP 1990). It is essential for policy makers to understand the environmental hazard created by irrigation return flows to achieve this balance.

In this review paper I examine the problem of subsurface agricultural irrigation drainage and diverted freshwater inflows, and discuss implications for managing wetlands in the western United States. I recount relevant historical information as well as recent findings from research studies of drainwater-affected areas. This review brings together a wide range of papers and contributions, many of which are not readily available to those unfamiliar with the topic which continues to expand in both a political and scientific sense.

Sources and characteristics of irrigation drainage

Irrigation practices and drainage

Current agricultural irrigation practices in the western U.S. use water applications that total about 60-80 cm during the growing season (State of California 1990). This is several times the natural precipitation rate. Two types of wastewater are 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 for distribution to fields, or because application rates exceed the soil infiltration rates. This water may contain high concentrations of pesticides and herbicides if aerial spraying is done, or if recent land-based application of these materials has occurred (Neil 1987, Moore *et al.* 1990). Water shortages during the 1985-1992 drought, coupled with increasing demands for water by other economic sectors, led to on-farm conservation measures that curtailed much of the surface runoff, particularly in California (SJVDP 1990).

The other type of irrigation wastewater, subsurface drainage, is produced due to a specific set of soil conditions and cannot be eliminated through water conservation. Shallow subsurface (3-10 m) clay lenses or layers impede the vertical and lateral movement of irrigation water as it percolates downward. This results in waterlogging of the crop root zone and subsequent buildup of salts as excess water evaporates from the soil surface (Moore *et al.* 1990). 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 1800's, including the use of wells and surface canals to forcefully pump and drain the water away. The method of choice became the installation of permeable clay pipe spaced 3-7 m apart and 2-3 m 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 (Letley *et al.* 1986). 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 (Moore *et al.* 1990).

Contaminants in subsurface irrigation drainage

Subsurface irrigation drainage is characterized by alkaline pH, elevated concentrations of salts, trace elements, and nitrogenous compounds, and low concentrations of pesticides (Neil 1987, Fujii 1988). The conspicuous absence of pesticides may appear unusual since 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 (Neil 1987, Nishimura and Baughmann 1988). At the same time, naturally occurring trace elements in the soil, such as selenium and boron, are leached out in drainwater under the alkaline, oxidizing conditions prevalent in arid climates (Presser and Ohlendorf 1987, Deverel and Millard 1988). A variety of serious impacts can occur when subsurface irrigation drainage is discharged into surface waters. The immediate impact is the degradation of surface- 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 have been issued in some drainwater-affected areas to advise against eating contaminated waterfowl tissue (Zahm 1986). Elevated concentrations of trace elements in irrigation drainage can severely impact wetlands and their fish and wildlife populations (Ohlendorf 1989, Lemly *et al.* 1993).

Impacts of subsurface drainage at national wildlife refuges

Kesterson National Wildlife Refuge

Subsurface irrigation drainage was implicated in 1985 as the cause of death and deformities in thousands of waterfowl and shorebirds at Kesterson National Wildlife Refuge (NWR) in California (Ohlendorf *et al.* 1986). Naturally occurring trace elements and salts were leached from soils on the west side of the San Joaquin Valley and carried to the refuge in irrigation return flows used for wetland management (Zahm 1986). One of the trace elements, selenium, bioaccumulated in aquatic food-chains and contaminated 500 ha of shallow marshes. Elevated selenium was found in every animal group contacting these wetlands, including fish, birds, insects, frogs, snakes, and mammals (Saiki and Lowe 1987, Clark 1987, Ohlendorf *et al.* 1988a). Congenital malformations in young waterbirds were severe, and included missing eyes and feet, protruding brains, and grossly deformed beaks, legs, and wings (Ohlendorf *et al.* 1986, 1988b; Hoffman *et al.* 1988). Several species of fish were eliminated, likely due to the combined effects of high salinity, elevated selenium, and other contaminants (Saiki *et al.* 1992), and a high frequency (30%) of stillbirths occurred in the single remaining species (Saiki *et al.* 1991). Laboratory studies conducted by the U.S. Fish and Wildlife Service (USFWS) confirmed the field assessment that irrigation drainage was the cause of the fish and wildlife problem (Lemly *et al.* 1993). The 'poisoned' refuge became highly publicized and sparked a great deal of political and scientific controversy (Marshall 1985, Popkin 1986, Harris 1991).

Other wildlife refuges

The findings at Kesterson NWR led to a new awareness of the dangers posed by agricultural irrigation drainage. In 1986, the U.S. Department of the Interior (USDOI), the Federal steward of more than 400 irrigation-drainage facilities and 200 wildlife refuges in the western states (U.S. Bureau of Reclamation 1981), established a multi-agency program to investigate irrigation-related drainwater problems. This evaluation program is still active and screening-level assessments have been completed at 20 areas in 13 states, including 20 national wildlife refuges (Table 1). The western San Joaquin Valley and Kesterson NWR were used as models for identifying and prioritizing potential study areas based on the occurrence of conditions known to contribute to drainwater problems. Samples of water, sediment, and biota (invertebrates, whole-fish, bird liver, bird eggs) were analyzed for a variety of trace elements, heavy metals, and pes-

Table 1. Study areas and national wildlife refuges investigated in screening-level assessments as part of the U.S. Department of the Interior's Irrigation Drainage Program (Presser *et al.* 1994).

State and Study Area	National Wildlife Refuge(NWR)
Oregon	
Malheur[b]	Malheur NWR[b]
Oregon/California	
Klamath Basin	Lower Klamath NWR
	Tule Lake NWR
California	
Sacramento Complex	Sacramento NWR
	Delevan NWR
	Colusa NWR
	Sutter NWR
Tulare Lake Basin[a]	Kern NWR[b]
	Pixley NWR[b]
Salton Sea[b]	Salton Sea NWR[b]
California/Arizona	
Lower Colorado River	Havasu NWR
	Cibola NWR
	Imperial NWR
Nevada	
Stillwater[a]	Stillwater NWR[b]
Utah	
Middle Green River[a]	Ouray NWR[a]
Montana	
Sun River[a]	Benton Lake NWR[a]
Milk River Basin	---
Colorado	
Gunnison River Basin[b]	---
Pine River	---
Wyoming	
Kendrick Project[a]	Bowdoin NWR[a]
Riverton Project[b]	---
South Dakota	
Belle Fourche Project[b]	---
Angostura Project	---
Kansas	
Middle Arkansas River[b]	---
Texas	
Lower Rio Grande Valley	Laguna Atascosa NWR
New Mexico	
Middle Rio Grande Valley	Bosque del Apache NWR
Idaho	
American Falls Reservoir	Minidoka NWR

[a] Overt symptoms of selenium toxicosis (deformities) were found in young migratory birds.
[b] Toxicity is predicted based on concentrations of selenium found in fish and bird tissues or water and food items.

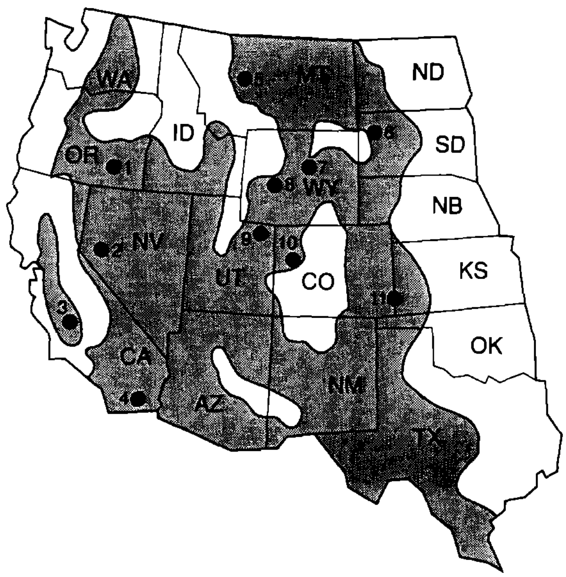

Fig. 1. Arid and semi-arid regions of the western U.S. where irrigation is necessary to support abundant agricultural production (shaded areas). Dots indicate locations where, in addition to Kesterson National Wildlife Refuge (NWR), subsurface drainage from Federal irrigation projects has caused toxicity to fish and wildlife (Presser *et al.* 1994). 1 = Malheur NWR; 2 = Stillwater NWR; 3 = Tulare Lake Basin; 4 = Salton Sea Area; 5 = Benton Lake NWR; 6 = Belle Fourche Reclamation Project; 7 = Bowdoin NWR; 8 = Riverton Reclamation Project; 9 = Ouray NWR; 10 = Gunnison River Basin; 11 = Middle Arkansas River. Deformities associated with selenium bioaccumulation in young birds were found at locations 2, 3, 5, 7, and 9.

ticides, and the results were compared to concentrations known to be toxic to fish and wildlife in experimental studies. Geological and hydrological studies were conducted and, where possible, observations were made to document the occurrence of deformed embryos and hatchlings, which is a biomarker for selenium poisoning in birds (Hoffman and Heinz 1988).

By 1992 it was known that eleven of the sixteen study areas where biological samples had been taken were seriously contaminated by selenium. The concentrations present at these eleven sites exceeded the toxicity thresholds for fish and wildlife (Presser *et al.* 1994). These study areas are spread across nine states (Fig. 1). Overt selenium toxicosis – *i.e.*, deformities in bird embryos and hatchlings – was found in five states; California, Utah, Wyoming, Nevada, and Montana (Fig. 1, Table 1). In some cases, these teratogenic effects occurred even though the waterborne concentrations of selenium were below those established by the U.S. EPA for the protection of aquatic life (Lemly *et al.* 1993).

In 1986-87, at one of the study sites (Stillwater NWR, Nevada), unexplained dieoffs of fish and wildlife occurred following a progressive decline in fish and wildlife populations since the 1960's (Rowe and Hoffman 1987, Thompson and Merritt 1988). Intensive toxicity studies were conducted by the USFWS at this refuge to evaluate the role of irrigation drainage in these problems (Finger *et al.* 1989, Dwyer *et al.* 1992, Ingersoll *et al.* 1992). In contrast to the Kesterson NWR, where selenium was isolated as the primary constituent of concern, selenium concentrations at Stillwater were very low. The investigations determined that high salinity, trace element contaminants (*i.e.*, arsenic, boron, lithium, molybdenum), and atypical ratios of major ions (*i.e.*, sulfate, magnesium, sodium, chloride, calcium) all acted together to cause toxicity; no single contaminant or water-quality variable was responsible. Subsurface irrigation drainage was found to be a complex effluent whose chemical profile and toxic potential varied both spatially and temporally within a given irrigation area. Rapid, direct mortality may occur in some cases while in others, the effects can be more subtle and involve reproductive failure.

The Kesterson effect and migratory birds

The biogeochemical conditions leading to the production of subsurface irrigation drainage, culminating in death and deformities in wildlife, have been termed the 'Kesterson effect' (Presser 1994). The Kesterson effect is prevalent throughout the western United States and includes these conditions: (1) a marine sedimentary basin that contains Cretaceous soils, which usually have relatively high concentrations of selenium; (2) alkaline, oxidized soils that promote the formation of water-soluble forms of selenium and other trace 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)

Fig. 2. Shallow marshes typical of the wetlands impacted by subsurface agricultural irrigation drainage in the western U.S. Diversion of freshwater inflows for agriculture, evaporative losses of water due to the arid climate, and accumulation of irrigation drainwater contaminants all jeopardize the continued existence of these important native wetlands.

subsurface drainage, by natural gradient or buried tile drainage networks, into migratory bird refuges or other wetlands.

The field studies conducted by USDOI indicate that the toxic threat of irrigation drainage to wetlands, fish, and wildlife is not restricted to Kesterson NWR, the San Joaquin Valley, or the State of California. Contamination has proven pervasive throughout the western states (Fig. 1) and threatens waterfowl populations in the Central and Pacific flyways (Presser *et al.* 1994, Skorupa *et al.* in press). In this regard it is a problem with legal implications under the Migratory Bird Treaty Act (Margolin 1979). Conditions that cause poisoning and death of migratory birds are strictly forbidden under the Act, and the ultimate liability for drainage produced from Federal irrigation projects rests with the Secretary of USDOI. Similar environmental liability exists for state fish and game agencies and their commissioners, who are the stewards of migratory birds outside Federal lands. Authorities responsible for managing wetlands in the western U.S. must recognize irrigation drainage as a widespread problem with the potential to affect wildlife populations on an international scale.

Implications for managing wetlands

Reducing environmental risk

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 (Moore *et al.* 1990). Kesterson NWR was developed under this concept as a joint venture between the U.S. Bureau of Reclamation (USBR), who used the refuge as a site for drainwa-

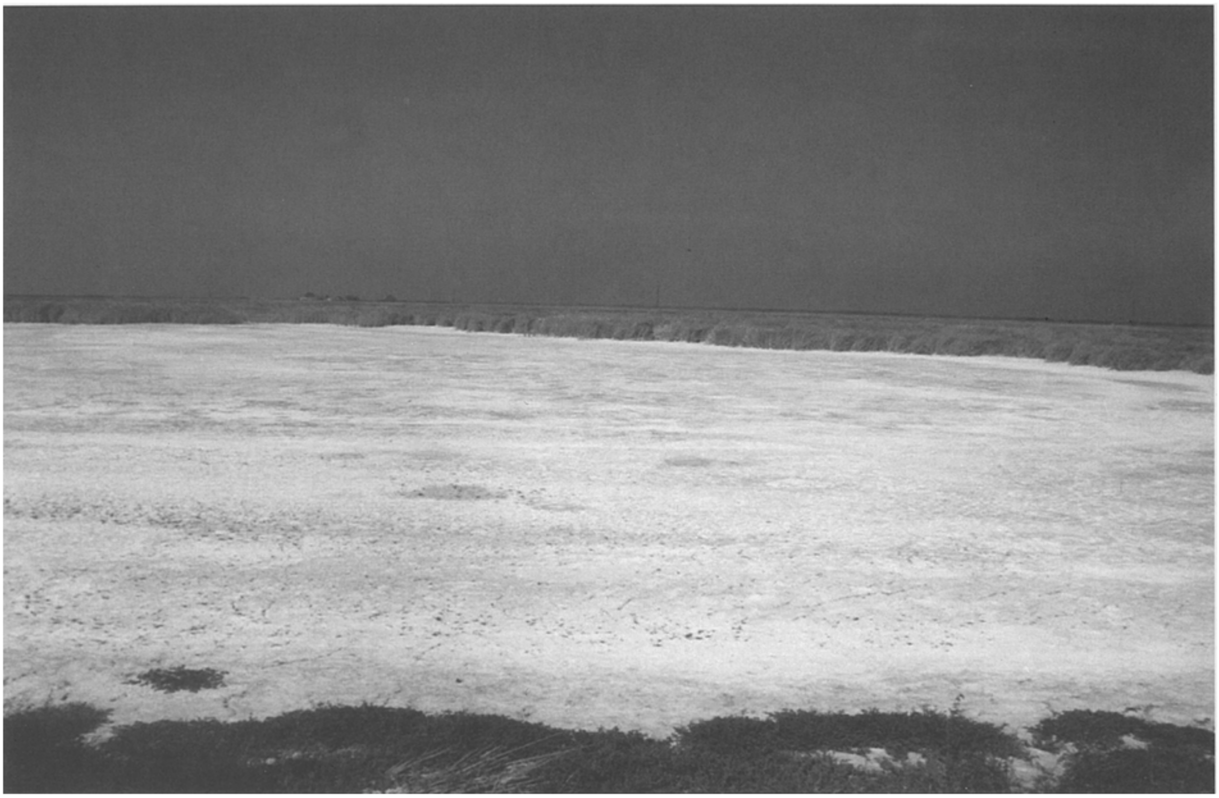

Fig. 3. Management of wetlands in the western U.S. often involves seasonal flooding of shallow marshes. When subsurface irrigation drainage is used as the water supply, salts and contaminants build up and form a white crust during the dry season. Applying water in the fall causes this crust to dissolve, releasing the toxic materials which are then accumulated in aquatic food-chains. Waterfowl and other wildlife that consume these food organisms may be poisoned and experience reproductive failure.

ter disposal, and USFWS, who used the drainage to create shallow marshes for waterfowl (Zahm 1986). This practice carries great environmental risk when considering research findings from the past decade. Evaporative losses result in a salt buildup in seasonal or permanent wetlands supported by irrigation drainage (Figs. 2, 3), thereby changing the species diversity and yield of native marsh plants that are important producers of wildlife food (Fig. 4). Moreover, contaminants in the drainwater can bioaccumulate and cause mortality and reproductive failure in fish and wildlife (Ohlendorf 1989, Lemly *et al.* 1993).

Historically, naturally wide year-to-year fluctuations in rainfall and freshwater inflow to wetlands occurred in the arid western United States. This variation 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. Moreover, 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 a toxicological standpoint it is easy to recommend that irrigation drainage not be used as a source of water for wetlands. Selenium, for example, occurs at concentrations of up to 1,400 μg/l (parts-per-billion) in drainwater, yet the toxicity threshold for fish and wildlife is only 2-3 μg/l (Presser and Ohlendorf 1987, Lemly 1993b). Guidelines based on the occurrence of this single contaminant would be sufficient to halt the use of drainage in most cases. However, the decision to accept or reject drainwater is not that simple. Water diversion has reduced freshwater inflows to the point that wetland managers on national wildlife

Fig. 4. Salts and contaminants in subsurface irrigation drainage reduce the diversity and yield of native wetland plants that are important producers of wildlife food. Bulrush (*Scirpus* spp., shown here) and swamp timothy (*Heleochloa schoenoides*) are two wildlife food plants that can be eliminated by irrigation drainwater.

refuges are sometimes faced with the dilemma of using irrigation drainwater or having no water at all. The situation is critical at several locations in Nevada, California, and Utah, where refusing drainage could possibly mean closing refuges (Stephens *et al.* 1988, Thompson and Merritt 1988, Moore *et al.* 1990).

Water quality and quantity issues

Wetland managers in the western U.S. must sometimes choose the lesser of two evils – accepting irrigation drainage and risking toxic impacts, or rejecting the drainage and having insufficient water to maintain marshes. Making this choice is not easy because both options have serious implications. Moreover, the resource specialist is often placed under intense media and public scrutiny, and openly criticized for whatever decision is made (Harris 1991). Without question, agricultural irrigation drainage has made the job of managing wetlands more complex, frustrating, and stressful than ever before.

From an environmental perspective, one obvious solution to the problem of wetland contamination is to restore freshwater inflows. However, water is a tightly regulated, federally subsidized commodity in the western states and almost all the available supply is controlled by legal 'rights' established during the past 150 years (Reisner 1986). Water rights associated with agriculture, industry, and urban development have clearly been given priority over the water 'needs' of freshwater wetlands and wildlife. Putting water back into wetlands means that less will be going somewhere else; it seems that no one wants to deal with that reality (Moore *et al.* 1990). Thus, more and more water has been squeezed out to meet contract obligations for agriculture and human consumption, and wetland managers have had to get by with less, in terms of both quantity and quality (Thompson and Merritt 1988). The 1985–1992 drought in California underscored the severity of the problem and made it clear that humans have pushed nature's hydrological system to the limit. Resolving the dilemma over water rights of humans and water needs of native wetlands will not be easy. The situation at Kesterson NWR was resolved after several years of scientific and political debate, at a cost of well over 100 million dollars (Harris 1991). Kesterson was declared a toxic waste dump, taken out of the national wildlife refuge system, and partially buried. However, due to monetary, legal, and time constraints this is not a workable alternative for other wetlands already degraded by, or at risk from, irrigation drainage. Decisive actions based on current knowledge of drainwater impacts should be used to correct existing damage and prevent possible future problems. Effectively managing and restoring these wetlands will require creative thinking by wetland managers, cooperation between water authorities and natural resource agencies, and increased conservation by water users.

International implications

The possibility that irrigated agriculture could produce subsurface drainage and wildlife problems in other countries seems very likely. Several of the factors contributing to the formation of toxic drainwater in the western U.S. – *e.g.*, 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 semi-arid regions of the world (Davies 1980, Van Schilfgaarde 1986). It is not clear how widespread the other key element necessary for producing subsurface drainage is, *i.e.*, 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 (Hodge and Duisberg 1963, Van Schilfgaarde 1986), which suggests that the phenomenon may be common. Moreover, elevated concentrations of soil trace elements prone to leaching by irrigation, such as selenium and molybdenum, occur in Canada, Great Britain, and Ireland (Davies 1980). 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 world's fourth largest freshwater lake and it supported vast fish and wildlife populations and extensive delta wetlands. Between 1960 and 1987, its level dropped 13 m, and its area decreased by 40%, primarily because of withdrawals of water for irrigation (Micklin 1988). Severe environmental problems resulted, including salinization, loss of biological productivity, deterioration of deltaic ecosystems, and major changes in native aquatic and wetland communities. Correcting this problem will be very difficult, and may require a change in the lifestyle and water usage of some 40 million people in the region (Micklin 1988). Similarities between the problems in the western United States and Russia are evident. The common denominator is irrigated agriculture and the high demand it carries for water – water that would normally be available for other uses, including the maintenance and management of wetlands.

With human populations and associated water demands continuing to grow in many arid and semi-arid regions of the world, the potential for changes in nature's water balance are 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 occurs. Lessons learned in the western United States can provide valuable information for other countries to use in their water management policies (National Research Council 1989).

Prospects for the future

Economic values – agriculture versus wetlands

Stated optimistically, the prospects for the future are very challenging. The full extent and severity of wetland contamination from subsurface agricultural irrigation drainage are not yet known. Several additional USDOI studies must be completed to make this evaluation for Federal irrigation-drainage projects; few assessments have been initiated for areas that fall outside Federal jurisdiction. It is difficult to develop a comprehensive approach to managing the problem until these studies are completed. Moreover, few people, except a handful of scientists and administrators, are fully aware of the problems associated with selenium and irrigation drainage, or the magnitude and scope of potential wetland and wildlife impacts.

In California, an evaluation of methods for reducing, controlling, and managing irrigation drainage has been completed by the San Joaquin Valley Drainage Program (SJVDP 1990). This program presented options that included taking marginally productive agricultural lands out of cultivation, on-farm water conservation practices, and increased cost to water users to pay for wastewater treatment. It is likely that a combination of several measures will be necessary to improve the drainage situation. However, essentially all the options have the potential to have a negative impact on farm income, and have received considerable opposition from agricultural interests (Harris 1991). Actions by water authorities in California in the late 1980's suggested that they were willing to make tradeoffs in favor of agriculture (CSWRCB 1987). Water quality objectives recommended to protect wetlands were relaxed because of the projected economic impact of more restrictive regulations on farmers. The classic argument over economy versus environment will continue to be a central theme in the irrigation drainage issue, both at a state and Federal level.

The evaluation of potential economic impacts should not be limited to projections of lost agricultural income. This evaluation should be comprehensive and include negative impacts resulting from lost fish and wildlife populations, degradation of wetland habitats, diminished public recreational values, and associated reduction of revenues. The USFWS has a review procedure, known as Natural Resource Damage Assessment (NARDA), that could be used to evaluate irrigation drainwater impacts to wetlands in terms of dollar losses (personal communication with Dr. Peter Escherich, U.S. Fish and Wildlife Service, Division of Environmental Contaminants, Washington, DC). Placing a dollar value on wetland uses would show the economic impacts of the environmental damages caused by agricultural irrigation drainage. Moreover, the projected economic impacts to agriculture could be compared to environmental impacts within the framework of a cost-benefit analysis. Such comparisons are, in general, absent or superficial.

The positive environmental and economic attributes of maintaining healthy wetlands should be used as a rationale for negotiating increases in freshwater supplies. Clear cost-benefit analyses, based on sound scientific data, are needed. Such analyses would make a strong argument in favor of freshwater wetlands. The next few years are critical in determining the fate of these wetlands in the western U.S. because many of the Federal water delivery contracts that have been in place since the 1940's will be reviewed for reauthorization. Wetland managers and natural resource agencies have the opportunity to use damage assessment procedures and cost-analyses to make a difference in water allocation policies. This will require the commitment of time, dollars, and manpower to tasks outside the realm of traditional wetland management. However, this seems to be a necessity to regain freshwater supplies.

New legislation affecting water policy

Recent developments in U.S. Federal law may signal the beginning of a new and more environmentally oriented approach to water allocation and use in California and other western states. Public Law 102-575, Title 34, established the Central Valley Reform Act, which was signed into law by then President Bush in October 1992. This landmark legislation provides for environmental reviews of Federal water contracts being considered for renewal, sets tiered water pricing for different uses, provides wildlife refuges with adequate freshwater supplies, and establishes surcharges on agricultural and industrial contractors with the funds earmarked for wetland restoration. The Act mandates a thorough review of western U.S. water policies. It seeks to restore a measure of equality with respect to all users of water from Federal projects, thereby making fisheries and wildlife an equal participant as new water allocation policies are negotiated.

At the state level, recent legislation in California (SB-1669), provides funds for taking drainage-impacted agricultural lands out of production. This is a positive step that may result in significant reductions in the amount of drainage eventually reaching wetlands. This type of innovative legislation should be promoted as a model for other states to follow to begin addressing impacts that result from drainwater sources other than Federal irrigation-drainage facilities.

A comprehensive approach that combines the strengths of these two new laws is needed. Hopefully, this legislation signals the end of wetland degradation by subsurface irrigation drainage in the western U.S. Cooperation and coordination between state and Federal water authorities will be necessary to implement the legislation and solve this complex problem.

Conclusions

Federally subsidized water has supported and expanded agriculture at the expense of native wetlands for over 100 years in the western states. Subsurface irrigation drainage has replaced freshwater supplies in many locations. This trend must be reversed if these wetlands and their fish and wildlife populations are to survive. Research data from USDOI studies graphically illustrate what the environmental consequences will be if corrective steps are not taken soon.

Several committee and agency reports have reviewed the case history of irrigation in the San Joaquin Valley and recommended alternatives for reducing drainage and salinity problems or impacts to wetlands and wildlife (*e.g.*, National Research Council 1989, Moore *et al.* 1990, SJVDP 1990). It seems that several actions are needed to: (1) reduce the toxic threat of drainage to wildlife, and, (2) provide increased freshwater inflows to wetlands. Specific steps that should be taken are:

1. Review all proposed new irrigation drainage-disposal projects, including on-farm evaporation ponds, to assess environmental hazard and potential wildlife exposure. This review process should fall under the legal authority of the National Fish and Wildlife Coordination Act and the National Environmental Policy Act. Only projects deemed environmentally safe should be approved for construction.
2. Treat subsurface irrigation drainage to remove salts and contaminants, as is done with other municipal and industrial wastes, before it is discharged and contacts wetlands. Subsurface drainage is amenable to this type of treatment (Lemly 1993a).
3. Establish regulatory controls on drainwater discharges based on water quality criteria that protect wetlands and aquatic life. These controls could be implemented and administered under the present Federal-state National Pollutant Discharge Elimination System permit process, with USEPA oversight (Lemly 1993a).
4. Establish additional on-farm water conservation measures to reduce the demand for irrigation water. This should include taking marginally productive fields out of cultivation since the farm income from these lands is offset by the cost of irrigation water.
5. Provide for negotiations between wetland managers and water authorities to secure increased freshwater inflows. These negotiations can be facilitated by using cost analyses or other techniques that clearly point out the economic value of wetlands. Recent precedent-setting legisla-

tion at the state and Federal levels may soon establish a forum for these negotiations.

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