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Subsurface Agricultural Irrigation Drainage: The Need for Regulation[1]

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Subsurface drainage resulting from irrigated agriculture is a toxic threat to fish and wildlife resources throughout the western United States. Studies by the U.S. Department of the Interior show that migratory waterfowl have been poisoned by drainwater contaminants on at least six national wildlife refuges. Allowing this poisoning to continue is a violation of the Migratory Bird Treaty Act under U.S. Federal law. Critical wetlands and waterfowl populations are threatened in both the Pacific and Central flyways. The public is also at risk and health warnings have been issued in some locations. Subsurface irrigation drainage is a complex effluent containing toxic concentrations of trace elements, salts, and nitrogenous compounds. Some of the contaminants are classified by the U.S. Environmental Protection Agency (EPA) as priority pollutants and they can be present in concentrations that exceed EPA's criteria for toxic waste. The on-farm drainage systems used to collect and transport this wastewater provide point-source identification as well as a mechanism for toxics control through the National Pollutant Discharge Elimination System (NPDES) permit process. A four-step approach is presented for dealing with irrigation drainage in an environmentally sound manner. This regulatory strategy is very similar to those commonly used for industrial discharges and includes site evaluation, contaminant reduction through NPDES, and compliance monitoring. The EPA must recognize subsurface irrigation drainage as a specific class of pollution subject to regulation under the NPDES process. Active involvement by EPA is necessary to ensure that adequate controls on this wastewater are implemented.

INTRODUCTION

Drainage and salinity problems associated with agricultural irrigation have been occurring in the western United States since the mid-1800s, when the population of many arid regions exploded as a consequence of the gold rush. Early agriculture provided food for the gold seekers and associated business folk, and the techniques used by miners to get water to their claims (pumps and canals) were applied 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 the buildup of salts in the soil was well known (1).

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The scenario leading to reduced crop production is quite simple. Arid climates necessitate irrigation, which is normally applied at two to six times the natural precipitation. Subsurface (3-10 m) clay lenses or layers impede the vertical and lateral movement of irrigation water percolating downward, resulting in waterlogging of the root zone and subsequent buildup of salts as excess water evaporates from the soil surface (2). Two options are then available-abandon the "alkali" land or provide a means of drainage. Pioneer farmers frequently chose to abandon the land and move on since homesteading programs with land giveaways were plentiful in the west. However, early agricultural researchers recognized that salinity problems would have to be dealt with in ways other than land abandonment (1).

Several methods of removing excess shallow groundwater were attempted in the mid- to late 1800s, including the use of wells and surface canals. The method of choice became the installation of permeable tile (clay pipe) drains 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 flexible plastic pipe has replaced earthen tile as the conduit in agricultural drainage collector systems (1, 2). The resultant subsurface wastewater is pumped or allowed to drain into surface canals or ditches and is eventually discharged into ponds for evaporative disposal, or into creeks and sloughs that are tributaries to major streams and rivers (1, 2).

Subsurface irrigation drainage is characterized by alkaline pH, elevated concentrations of salts, trace elements, nitrogen compounds, and low concentrations of pesticides (3, 4). The conspicuous absence of pesticides may appear somewhat surprising because farmers in irrigated regions use many kinds of agricultural chemicals (2). However, the conditions responsible for producing subsurface drainwater also result in the removal of these potentially toxic compounds. Irrigation tailwater (surface ponded water and runoff) can contain high concentrations of pesticides and herbicides (2, 5), but the natural biological and chemical filter provided by the soil effectively degrades and removes these materials as irrigation water percolates downward to form subsurface drainage (3, 4, 6). 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 (7, 8).

When irrigation drainage is discharged into surface waters a variety of serious impacts can occur. The immediate impact is degradation of surface- and groundwater quality through salinization and contamination with toxic or potentially toxic trace elements (e.g., arsenic, boron, chromium, molybdenum, and selenium). This water quality degradation can, in turn, affect irrigation, stock watering, industrial processing, recreational use, and drinking water supplies. Trace elements in irrigation drainage can bioaccumulate in aquatic food chains and severely impact fish and wildlife populations. In California, contaminated drainwater poisoned thousands of waterfowl and forced the closure of an entire wildlife refuge (2, 9). Human health warnings have also been issued in drainwater-affected areas (9).

Despite the host of water quality problems associated with subsurface irrigation drainage, it is not recognized by the U.S. Environmental Protection Agency (EPA) as a known class of pollution. It therefore continues to go unregulated at the Federal level. Moreover, only one state (California) is developing a plan for dealing with irrigation drainage and this comes after nearly two decades of serious environmental damage. Unfortunately, agricultural interests in the state are seeking modifications that would severely reduce the ability of this proposed legislation to protect against environmental toxicity.

This paper examines the problem of agricultural irrigation drainage in a regulatory context, giving particular emphasis to its effects on fish and wildlife resources. Examples are given to illustrate how irrigation drainage impacts fish and wildlife populations, and the geographical extent of this toxic threat in the western United States. The perceived need and role of EPA in regulating irrigation drainage is discussed along with a proposed strategy for implementing regulations and compliance monitoring.

A CASE HISTORY OF CONTAMINATION: KESTERSON NATIONAL WILDLIFE REFUGE

Water Development and Irrigation Drainage

In response to concerns about reliability of water supplies, a major Federal water delivery and irrigation project was proposed for California's Central Valley in the mid-1930s (2). This proposal, known as the Central Valley Project (CVP), was developed for a variety of purposes including navigation, flood control, land reclamation, water storage and delivery, and public recreation. Today, about 85% of the total consumptive use of water from the Central Valley Project is for irrigation of agricultural crops (10). Although remarkable in its ability to stimulate agricultural production, intensive irrigation of this arid valley has claimed a toll on the land for many years. By 1940, substantial San Joaquin Valley (Valley) farm acreage was abandoned due to salt buildup and poor drainage (11).

In 1949 the U.S. Bureau of Reclamation (USBR) submitted a status report to the U.S. Congress recommending additional water development in the Valley, but also noted that because subsurface soils on the west side of the Valley consisted of impervious clay that prevented deep infiltration of water, continued intensive irrigation of the area would eventually demand that drainage systems be installed to collect and convey return flows to the lower Valley and the ocean (2). This drainage water was viewed by project planners as an unfortunate waste that could be handled through downstream transport to the Sacramento-San Joaquin River Delta (Delta); from there it would simply be flushed into San Francisco Bay and the sea. The first subsurface drainage systems were installed in the area in the 1960s, concurrent with the construction of the San Luis Unit of the CVP (12). Irrigation drainwater was dealt with on a piecemeal basis until the late 1970s, when the San Joaquin Valley Interagency Drainage Program was formed to review drainage needs for the Valley. The final report of that program recommended construction and operation of a valley-wide master drain complete with a series of flow-regulating reservoirs to be operated as wetlands for wildlife (13).

The master drain, known as the San Luis Drain (Drain), was originally designed to be operated in conjunction with adjacent regulating reservoirs and to seasonally discharge subsurface irrigation wastewater into the Delta during periods of high outflow, thereby ensuring drainage water dilution. Kesterson Reservoir, the first regulating reservoir to be built, was also to be used as a management area for waterfowl (2). In 1970, the U.S. Fish-and Wildlife Service (then named the Bureau of Sport Fisheries and Wildlife) and the USBR signed a cooperative agreement for management of Kesterson Reservoir and associated wetlands. That agreement formally established the

5900-acre wetlands as Kesterson National Wildlife Refuge and specified that the Fish and Wildlife Service manage the area for wildlife and associated recreational values, but retained the right for USBR to use the reservoir for management of irrigation drainwater (9). By 1972, only 82 of the intended 188 miles of the concrete-lined Drain was finished, and project funds were depleted. The 1283-acre Kesterson Reservoir became the terminus of the Drain and its 12 shallow ponds functioned as an evaporation and seepage basin (2, 9).

Through the mid-l 970s the Drain conveyed a mixture of operational spill from the Valley water projects, agricultural tailwater (surface runoff), and subsurface drainage. In 1978 the proportion of subsurface drainwater increased and by 198 1 almost all of the flows discharged into Kesterson Reservoir were composed of subsurface drainage generated by 8000 acres of irrigated agricultural lands in the Westlands Water District of the San Luis Unit (9). In 1980– 198 1, samples of water from the Drain and Kesterson Reservoir were found to contain high salinity and elevated concentrations of selenium, other trace elements, and metals (14). In 1982-1983, greatly elevated concentrations of selenium were detected in aquatic food-chain organisms, fish, and wildlife using Kesterson Reservoir (15, 16). By 1985, death and deformities had affected thousands of aquatic birds, and the "poisoned" refuge became highly publicized (17, 18). Although irrigation drainwater was strongly implicated as the cause of the problem, research data available at the time were not sufficient to positively link contaminants in the drainwater to observed toxic effects. In 1986, the U.S. Fish and Wildlife Service (Service) and the USBR entered into an intraagency agreement for the purpose of funding studies on the effects of agricultural irrigation drainwater on fish and wildlife populations. This agreement initiated a multiyear research effort conducted by Service research centers in support of the San Joaquin Valley Drainage Program (a different program than the SJVIDP mentioned earlier), which had been established in 1984 to investigate problems associated with the drainage of irrigated agricultural lands in the Valley (2). The principal findings and implications of this toxicological research are summarized in the following sections.

Field Studies of Wetland Contamination and Toxicity

Beginning in 1982, some 4 years before the formal Service-USBR research agreement was signed, biological surveys were conducted by Service scientists to determine the extent and severity of contamination in aquatic food chains at Kesterson Reservoir, and to identify the primary contaminants of concern for further study (14, 15). Extensive chemical analyses (12 trace elements, 23 pesticides, nutrients, ionic composition) revealed that selenium was greatly elevated in the water, detritus, and organisms present in the reservoir, and was likely the most important constituent for detailed toxicological study. Some of the highest concentrations of selenium ever reported for fish tissues (370 μg/g) were found in these early studies. Aquatic food-chain organisms contained from 1000 to 5000 times the concentrations of selenium present in the water, which clearly illustrated the tendency of this trace element to bioaccumulate. Later surveys confirmed these high selenium concentrations and also identified boron as another constituent of concern, particularly in regard to avian reproduction (19-22). Elevated selenium was found in every animal group coming in contact with Kesterson Reservoir-from fish and birds to insects, frogs, snakes, and small mammals

(14, 23, 24). The finding of high selenium in food organisms of predatory birds and endangered species such as the San Joaquin kit fox (*Vulpes macrotis mutica*) was particularly alarming and placed additional emphasis on rapid, accurate assessment of the toxic threat of irrigation drainage.

The concentrations of selenium identified in the biological samples were of great concern because field studies indicated a high frequency (up to 65%) of developmental deformities-a known symptom of selenium toxicity-in the embryos and hatchlings of waterfowl and other aquatic birds nesting at Kesterson Reservoir (25-27). Congenital malformations were often multiple and included missing eyes and feet, protruding brains, and grossly deformed beaks, legs, and wings (28-30). All of the birds examined (four ducks, coot, avocet, grebe, stilt) were affected. The types of deformities observed in these wild birds closely matched those seen in experimental studies of selenium toxicity in domestic chickens (30). Moreover, the amount of selenium in food organisms eaten by aquatic birds at Kesterson equalled or exceeded concentrations known to cause mortality and deformities in chicken embryos (20, 30). Several pathological and biochemical indicators of selenium toxicosis were also found in the adults of the wild birds (29). Other field studies documented a massive fish kill at Kesterson Reservoir in 1983 (14), followed by a high frequency (30%) of stillbirths in mosquitofish (*Gambusia affinis*), the only fish species remaining in the reservoir (3 1). Tissue concentrations of selenium in these mosquitofish were greater than those associated with reproductive failure in fish populations of reservoirs impacted by selenium from coal-fired power plants in the eastern United States (32). Collectively, the field evidence strongly implicated selenium as the cause of mortality and reproductive failure in fish and wildlife populations at Kesterson Reservoir. However, detailed laboratory studies were also conducted to identify specific cause-effect relationships and establish toxicity thresholds for selenium and other trace elements of concern.

Laboratory Evaluation of Drainwater Contaminants

Numerous studies were conducted to determine the direct toxicity (effects on growth, survival, and behavior) of dietary and waterborne selenium to fish, waterfowl, and their food organisms (Table 1). The effect of dietary selenium on reproductive success was also examined (Table 1). A synthesis of this toxicity information indicates the following: (A) organic selenium is generally much more toxic than inorganic selenium to fish and wildlife, both in waterborne and dietary exposures (relative toxicity: selenomethionine, 100–1000; selenite, 10; selenate, 1); (B) reproductive effects were induced to a much greater extent by organic selenium (selenomethionine) than inorganic forms (selenate, selenite), and teratogenic effects such as those observed in the field at Kesterson Reservoir were only induced by organic selenium; (C) significant sublethal effects (physiological, biochemical, behavioral) were found which add to the overall toxic threat of selenium: (D) selenomethionine is a good experimental model for the form(s) of organic selenium occurring naturally in food-chain organisms in the field; (E) the most sensitive indicator of selenium toxicity in fish and waterfowl is reproductive failure; (F) reproductive effects normally occur with no mortality or visible toxic symptoms in the adults; (G) selenium is biochemically transferred from parents to offspring in the eggs, where it exerts toxic effects (teratogenesis and mortality) as the yolk is absorbed during early development and hatching; (H) selenium has the ability

TABLE I

TOXICITY OF SELENIUM TO FISH, WILDLIFE, AND INVERTEBRATES IN STUDIES CONDUCTED AS PART OF THE U.S. DEPARTMENT OF THE INTERIOR'S KESTERSON RESERVOIR IRRIGATION DRAINWATER INVESTIGATIONS

Species and life stage	Exposure and duration	Toxic effect	Reference
Cladoceran	**Waterborne—48-hr acute**		
(Daphnia magna)	Selenate	LC_{50} = 2.56 mg/liter	*45*
neonates"	Selenite	LC_{50} = 0.70 mg/liter[b]	*45*
	6:1 Selenate/selenite mixture.	LC ≈ 1.79 mg/liter	*45*
	Seleno-L-methionine	50–70% mortality at 4-8 μg/liter	*45*
	Waterborne-2 l-day life cycle		
	6:1 Selenate/selenite mixture	Reproduction impaired at 348 μg/liter[b]	*45*
Midge *(Chironomus*	**Waterborne—48-hr** acute		
riparius)	Selenate	LC_{50} = 10.5 mg/liter	*45*
neonates[a]	Seienite	LC_{50} = 14.6 mg/liter	*45*
	6:1 Selenate/selenite mixture	LC_{50} = 14.3 mg/liter	*45*
	Seleno-L-methionine	LC_{50} = 6.88 mg/liter	*45*
	Waterborne-30day life cycle		
	6:1 Selenate/selenite mixture	Reproduction impaired at 6.05 mg/liter	*45*
Rainbow trout	Waterborne-90day chronic		
(Oncorhynchus	Selenite	35–70% mortality at 47-100 μg/liter[b]	*46*
mykiss) sac fry			
Chinook salmon	Waterborne-96-h acute		
(Oncorhynchus	Selenate	LC_{50} = 115 mg/liter	*35*
tshawytscha) fry	Selenite	LC_{50} = 13.8 mg/liter	*35*
	6:1 Selenate/selenite mixture	LC_{50} = 50.9 mg/liter	*35*
	Seleno-D,L-methionine	No effect to 2 1.6 mg/liter[c]	*35*
	Waterborne- 120-day chronic		
	Selenate	No effect to 139 &liter	*54*
	Selenite	No effect to 139 &liter	*54*
	6:1 Selenate/selenite mixture	No effect to 130 μg/liter	*54*
Chinook salmon	**Dietary—60–120** day chronic		
fingerlings	Natural selenium[d]	30–50% mortality at 26 mg/kg[e]	*47*
	Natural selenium[d]	Reduced growth at 6.5 mg/kg[b]	*47*
	Natural selenium[d]	Impared behavior at 6.5 mg/kg	*47*
	Natural selenium[d]	Reduced smolting at 6.5 mg/kg	*47*
	Natural selenium[d]	35–50% mortality at 9-35 mg/kg[b]	*48*
	Natural selenium[d]	Reduced growth at 5.3 mg/kg	*48*
	Seleno-D,L-methionine	35–50% mortality at 9.5-35 mg/kg[b]	*48*
	Seleno-D,L-methionine	Impaired behavior at 18.2 mg/kg	*48*
	Seleno-D,L-methionine	Seawater mortality at 35.4 mg/kg	*48*

TABLE 1—*Continued*

Species and life stage	Exposure and duration	Toxic effect	Reference
Coho salmon (*Oncorhynchus kisutch*) fry	Waterborne-96-hr acute		
	Selenate	LC_{50} = 32.5 mg/liter	48
	Selenite	LC_{50} = 7.80 mg/liter	48
	6:1 Selenate/selenite mixture	LC_{50} = 24.5 mg/liter	48
Striped bass (*Morone saxatilis*) fingerlings	Waterborne-96-hr acute		
	Selenate	LC_{50} = 39.0 mg/liter	54
	Selenite	LC_{50} = 1.0 mg/liter[b]	54
	6:1 Selenate/selenite mixture	LC_{50} = 15.0 mg/liter	54
	Seleno-L-methionine	LC_{50} = 4 μg/liter	54
	Waterborne—90-day chronic		
	Selenate	No effect to 3.0 mg/liter	54
	Selenite	No effect to 3.0 mg/liter	54
	6:1 Selenate/selenite mixture	No effect to 3.0 mg/liter	54
Bluegill (*Lepomis macrochirus*) juveniles'	Waterborne-96-h acute		
	Selenate	LC_{50} = 98.0 mg/liter	54
	Selenite	LC_{50} = 7.8-13.0 mg/liter	54
	6:1 Selenate/selenite mixture	Mortality at > 13.0 mg/liter	54
	Seleno-L-methionine	LC_{50} = 13 μg/liter	54
	Seleno-D,L-methionine	LC_{50} = 13 μg/liter	54
	Waterborne—30-60-day chronic		
	6:1 Selenate/selenite mixture	50-97% mortality at 1.4-5.3 mg/liter	54
		Abnormal behavior at 1.4 mg/liter	54
Bluegill juveniles	Dietary-90day chronic		
	Seleno-L-methionine	Reduced growth at 16.7 mg/kg	54
	Seleno-L-methionine	No mortality to 33.3 mg/kg	54
Bluegill adults	Waterborne- 140-day chronic		
	6:1 Selenate/selenite mixture	No effect to 8 &liter	49
	Dietary- 140day chronic		
	Seleno-L-methionine	No direct effect[g] to 33.3 mg/kg	49
		Impaired reproduction at 33.3 mg/kg[b]	49
		Toxic threshold for reproductive effects = 16-33 mg/kg[b]	49
Mallard (*Anas platyrhynchos*) ducklings	Dietary—42-day chronic		
	Selenite	25-97% mortality at 40-80 mg/kg[b]	50
		Reduced growth at 20 mg/kg	50
	Selenomethionine	12.5-100% mortality at 40-80 mg/kg[b]	50
		Reduced growth at 20 mg/kg	
	Dietary-28day chronic		
	Seleno-D,L-methionine	100% mortality at 60 mg/kg[b]	37
		Reduced growth at 15 mg/kg	37
		Physiological effects at 15 mg/kg	37

TABLE 1—*Continued*

Species and life stage	Exposure and duration	Toxic effect	Reference
Mallard adults	Dietary- I ?O-day chronic		
	Selenite	No direct effect[g] to 10 mg/kg	51
		95% mortality at 100 mg/kg	51
		Impaired reproduction at 25 mg/kg[b]	51
	Seleno-D,L-methionine	No direct effect/at 10 mg/kg	51
		Impaired reproduction at 10 mg/kg[b]	51
		Teratogenesis in young at 10 mg/kg[b]	51
Mallard adults	Dietary- 120-day chronic		
	Selenite	No direct effect[g] to 25 mg/kg	52
		Impaired reproduction at 25 mg/kg	52
	Seleno-D,L-methionine	No direct effect[g] to 16 mg/kg	52
		Impaired reproduction at 8 mg/kg[b]	52
		Teratogenesis in young at 8 mg/kg[b]	52
Mallard adults	Dietary- 120-day chronic		
,	Seleno-D,L-cystine	No direct effect[g] at 16 mg/kg	53
		No reproductive effect at I6 mg/kg	53
	Seleno-D,L-methionine	No direct effect[8] to 16 mg/kg	53
		Impaired reproduction at 8 mg/kg[b]	53
		Teratogenesis in young at 8 mg/kg[b]	53
		Toxic threshold for reproductive effects = 4-8 mg/kg[b]	53

[a] All individuals were less than 24 hr old at the initiation of tests.

[b] For comparison, subsurface irrigation drainage contains as much as 1400 μg/liter (1.4 mg/liter) selenium and can result in fish and wildlife dietary intake of over 200 mg/kg selenium.

[c] The notation "no effect to" indicates no effect through the concentration indicated, which was the maximum of a range of concentrations tested in the study.

[d] The source of selenium was selenium-contaminated fish collected from the field.

[e] Dietary selenium concentrations are given on a dry weight basis.

'Individuals were 5 months old at the initiation of tests.

[g] Effects on growth, condition factor, gonadosomatic index, survival, physiology, and apparent health of adults.

to bioaccumulate in aquatic food chains and, thereby, contaminates the diet and induces reproductive effects in fish and waterfowl even though total waterborne concentrations are far below levels of concern for direct toxicity; (I) concentrations of selenium in subsurface irrigation drainage typically range from 7.5 to 1400 &liter (4, 7, 33), yet concentrations of only l-3 μg/liter may be sufficient to load aquatic food chains with residues that reduce the reproductive success of fish and wildlife; (J) once in an aquatic system, selenium is biologically accumulated, transformed, and cycled such that the ultimate toxic threat to fish and wildlife is similar regardless of whether the chemical form coming into the system is predominantly selenate or selenite: and (K) the concentrations of selenium present at Kesterson Reservoir were 10–500 times greater than the toxic effects thresholds for fish and wildlife.

Other laboratory studies examined the toxicity of boron (34–37), which is also commonly found at greatly elevated concentrations in drainwater environments. The findings indicated that boron could be toxic to fish and wildlife at concentrations similar to those occurring at Kesterson Reservoir, both from the standpoint of direct toxicity and reproductive effects (no teratogenesis). Moreover, the results showed that the combined toxicity of boron-selenium mixtures to ducklings was approximately additive, particularly when the nutritional status of birds was compromised (37). Studies of whole and diluted irrigation drainwater indicated that direct waterborne toxicity to fish was caused by atypical ratios of major ions (calcium, chloride, magnesium, sodium) and sulfate, in addition to trace elements such as selenium and boron (38). Collectively, these findings indicated that the overall toxicity observed in fish and wildlife at Kesterson Reservoir was not caused exclusively by selenium-several other factors affecting water and food quality also played a part.

Cleanup Costs and Implications for Managing Wetlands

Soon after the toxic threat of contaminants in irrigation drainage was verified (1984-1985), the Secretary of the Interior, citing concerns over possible violation of the Federal Migratory Bird Treaty Act, officially closed Kesterson National Wildlife Refuge to the public, began a hazing program to scare waterfowl and other wildlife away from the refuge, and issued an order for the San Luis Drain to be plugged (39). By June 1986, all irrigation drainage flows into Kesterson ponds had stopped. In 1987 a plan was implemented by the Department's Bureau of Reclamation for cleaning up the contaminated refuge. This plan called for drainage of the contaminated wetlands, excavation and on-site disposal of contaminated soil and plant material in a lined and capped containment area, and long-term site monitoring to detect possible seepage of contaminated water (39). The cost associated with these cleanup efforts was approximately 50 million dollars (5 million for environmental impact statement and preliminary feasability studies, 45 million for actual cleanup (39, 40)). The lands comprising Kesterson Reservoir were removed from the National Refuge System and placed under the jurisdiction of the Bureau of Reclamation for management as a contaminated landfill. To offset this loss of wetlands, some 23,500 acres of private lands adjoining the refuge were purchased and developed into waterfowl and upland wildlife habitat at a cost of approximately 10 million dollars (39, 4 1). Thus, the total cost of mitigating selenium contamination at Kesterson was about 60 million dollars: not including ongoing costs for long-term site monitoring.

The episode of contamination at Kesterson Refuge is a classic example of what can happen if irrigation drainwater is used to support wetlands in an arid environment. Selenium that had been present in San Joaquin Valley soils for millions of years was mobilized by what was thought to be the answer to some of the Valley's most important problems-water. Yet, a new and even bigger concern over water management emerged. The set of conditions present in the Valley-geological sources of selenium, mobilization and transport mechanisms, concentrating mechanisms, sites for bioaccumulation-set the stage for a trace element problem unlike any other seen before in the United States (7). This biogeochemical pathway for selenium, culminating in death and deformities in fish and wildlife, has been termed the "Kesterson effect." and it is present throughout the western United States (42).

The case history of Kesterson Refuge illustrated valuable principles of how ***not*** to manage wetlands in the western United States. Agricultural irrigation drainwater is a toxic waste that can severely impact fish and wildlife populations. It should not be used to create or maintain wetlands even if it is only a supplemental source of water. Strict environmental regulations are needed to prevent other "Kestersons" from becoming a reality wherever irrigation drainage is disposed. Moreover, once the aquatic environment is contaminated, cleanup can be extremely expensive-prevention is the key, not cleanup.

The clear message sent from Kesterson to wetland managers throughout the West was to identify and evaluate water sources and biota that could be contaminated by irrigation drainage. This message was particularly important for public lands because some 200 wildlife refuges and management areas in the western United States receive water from more than 400 U.S. Department of the Interior (USDOI) water projects, the majority of which consist of agricultural irrigation-drainage facilities constructed by the Bureau of Reclamation (43). Concerns voiced by the news media, environmentalists, politicians, and scientists about the health and well-being of other wildlife refuges and arid wetlands became more and more persistent following Kesterson (44). In 1986 the USDOI established a Federal multiagency program headed by the U.S. Geological Survey to investigate irrigation-related drainwater problems throughout the western United States.

A WIDESPREAD PROBLEM

U.S. Department of the Interior Reconnaissance Studies

This evaluation program is still active and screening-level assessments have been completed at 20 areas in 13 states, which include a total of 20 national wildlife refuges (Table 2). The western San Joaquin Valley and Kesterson National Wildlife Refuge were used as models for identifying and prioritizing conditions known to contribute to drainwater problems. In general, reconnaissance areas were selected for study if six factors were present: (A) a marine sedimentary basin that includes soils derived from Cretaceous deposits (Cretaceous soils contain relatively high concentrations of selenium); (B) alkaline, oxidized soils that promote the formation of water-soluble forms of selenium; (C) a dry climate in which evaporation greatly exceeds precipitation, leading to salt buildup in soils; (D) agriculture served by USDOI irrigation-drainage facilities to provide water and leach salts; (E) subsurface layers of clay that impede downward movement of irrigation water and cause waterlogging of the crop root zone; and (F) drainage by natural gradient or through buried tile drainage networks to USDOI-managed migratory bird refuges or other areas receiving USDOI waters (55). Samples of water, sediment, and biota (whole fish, bird liver, bird eggs) were analyzed for a variety of trace elements, heavy metals, and pesticides, and the results were compared to concentrations known to be toxic to fish and wildlife in experimental studies. Where possible, observations were made to document the occurrence of deformed bird embryos and hatchlings, which is a known marker for selenium poisoning in waterfowl (30, 52).

TABLE

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 (55)

State and study area	National Wildlife Refuge (NWR)
Oregon	
Malheur[b]	Malheur NWR
Oregon/California	
Klamath Basin	Lower Klamath NWR
California	
Sacramento Complex	Sacramento NWR
	Delevan NWR
	Colusa NWR
	Sutter NWR
Tulare Lake Bed”	Kern NWR
	Pixley NWR
	Tule Lake NWR
Salton Se3	Salton Sea NWR
California/Arizona	
Lower Colorado River	Havasu NWR
	Cibola NWR
	Imperial NWR
Nevada	
Stillwatef	Stillwater NWR
Utah	
Middle Green River[a]	Ouray NWR
Montana	
Sun Rivef	Benton Lake NWR
Milk River Basin	—
Colorado	
Gunnison River Basin[b]	—
Pine River	—
Wyoming	
Kendrick Project’	Bowdoin NWR
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	Minidaka NWR

[a] Study areas where overt symptoms of selenium toxicosis (deformities) were found in young migratory birds.

[b] Study areas where toxicity is predicted based on concentrations of selenium found in fish and bird tissues.

Eleven of the 16 study areas at which biota were sampled proved to be contaminated with selenium at concentrations that exceed toxicity thresholds for fish and wildlife (55). These study areas are spread across nine states from California to Montana and

Kansas (Fig. 1). Overt selenium toxicosis—i.e., deformities in bird embryos and hatchlings-were found at locations in five states: California, Utah, Wyoming, Nevada, and Montana (Fig. 1, Table 2). In three locations (Stillwater Wildlife Management Area in Nevada, Sun River Basin in Montana, and Rivet-ton Reclamation Project in Wyoming), concentrations of selenium in bird livers and fish exceeded toxicity thresholds even though waterborne selenium was less than 3.0 μg/liter, which is considerably lower than the current EPA national water quality criterion of 5.0 μg/liter (56, Fig. 1). Deformities were found in young birds at two of these three locations (Stillwater Wildlife Management Area and Sun River Basin). This finding emphasizes the importance of measuring selenium in biota because concentrations in water do not always provide a good indication of the degree of bioaccumulation. For irrigation drainage areas, selenium contamination must be assessed on an ecosystem level (55).

Stillwater Refuge Toxicity Studies

Information from reconnaissance investigations suggested that irrigation drainage was responsible for death and deformity in fish and wildlife at Stillwater National Wildlife Refuge (NWR) in Nevada. To further characterize the toxic threat and identify cause-effect relationships, intensive studies were undertaken in 1988 by the U.S. Fish and Wildlife Service (57). In field studies, the toxicity of drainage from seven locations was evaluated in a series of on-site tests conducted over a 1 O-day period with a variety of fish (bluegill, *Lepomis macrochirus;* fathead minnows, *Pimephales promelas;*

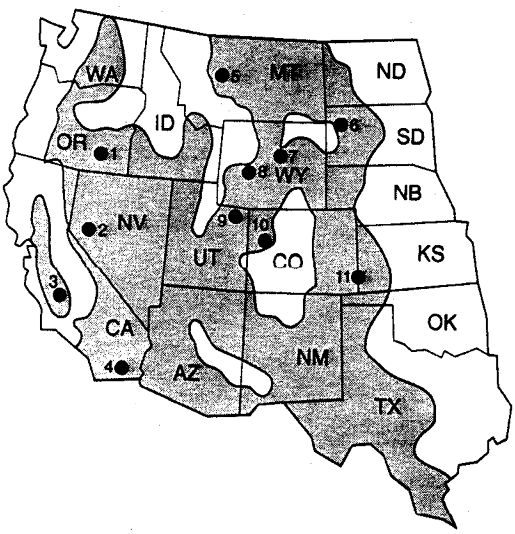

FIG. I. Arid and semiarid regions of the western United States where irrigation is necessary to support abundant agricultural production (shaded areas). Dots indicate locations where, in addition to Kesterson National Wildlife Refuge (NWR), subsurface drainage from Federal irrigation projects has caused toxicity to fish and wildlife, as determined in studies by the U.S. Department of the Interior (Table 1, 55). I. Malheur National Wildlife Refuge; 2, Stillwater NWR, 3, Tulare Lake Bed Area; 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; I 1, Middle Arkansas River. Deformities associated with selenium bioaccumulation in young aquatic birds have been found at locations 2, 3, 5, 7, and 9.

sheepshead minnows, ***Cyprinodon variegatus***) and invertebrates (cladocerans, ***Daphnia magna:*** mysids, *Neomysis* sp.). Contaminant levels, salinity, and conductivity exhibited wide spatial and temporal fluctuations over the IO-day testing period and the toxicity of drainwater differed between locations. Some samples caused no effects, while others caused 100% mortality even after being diluted by 50% with clean water (57). Toxicity occurred in some drainwater that had been diluted by almost 90%.

In addition to irrigation drainage, surface water on the refuge was found to be contaminated. Samples of lake water used by migratory waterfowl and other aquatic birds caused 60–80% mortality of aquatic organisms within 10 days (57). No individual contaminant was detected at toxic concentrations but the combined presence of four metalloid trace elements-arsenic, boron, lithium, and molybdenum-was strongly related to the observed pattern of toxicity (57). Selenium was present at low concentrations ($<4.0\ \mu g$/liter), confirming findings from the reconnaissance studies which indicated that selenium bioaccumulated in birds and caused reproductive effects even though waterborne concentrations were below the EPA national criterion (55).

Laboratory studies were conducted using euryhaline species (striped bass, ***Morone saxatilis;*** amphipod, *Hyalella azteca*) and freshwater species (fathead minnows and ***D. magna)*** to separate the effects of high salinity in the drainwater from toxicity due to trace element contaminants. These organisms were exposed in effluent toxicity tests (58) to drainage collected from five sites at Stillwater NWR. The drainage was highly toxic, causing mortality within 96 hr (59). Reconstituted water formulated to resemble surface water from Stillwater NWR, but without the complement of trace element contaminants (e.g., As, B, Cu, Li, Mo, Sr), was toxic to salt-tolerant organisms (60). However, the level of toxicity increased in samples that also included trace elements at concentrations normally found in the drainage. The results indicated that salinity, contaminants, and atypical ratios of major ions (e.g., sulfate, magnesium, chloride, sodium, etc.) all acted together to cause the observed toxicity; no single contaminant or water-quality variable was responsible (59, 60).

The field and laboratory studies at Stillwater NWR showed what has now become a classic pattern of toxicity associated with subsurface irrigation drainage. Raw drainwater is a complex effluent whose chemical profile and toxic potential varies both spatially and temporally within a given irrigation area. The water quality of lakes, streams, and marshes can be severely degraded. Acute poisoning of freshwater organisms is possible as well as chronic toxicity and reproductive impairment in fish and wildlife due to bioaccumulation of individual trace elements such as selenium. The biogeochemical conditions leading to the production of toxic irrigation drainage are consistent throughout the western U.S. (42). The toxic effects are also consistent, and are caused by a mixture of several contaminants, high salinity, and atypical ion ratios. Reduced freshwater inflows to wetlands, usually due to diversion of surface water for agricultural use, also substantially increases the potential for a toxic scenario to develop in the arid climates where irrigated agriculture predominates (6 1).

Liability and Implications for Irrigated Agriculture

The findings of the USDOI studies indicate that the toxic threat of irrigation drainage to fish and wildlife is not restricted to Kesterson National Wildlife Refuge, the San Joaquin Valley, or the state of California. Contamination has proven to be prevalent throughout the western United States (Fig. 1) and threatens waterfowl populations in the Central and Pacific flyways (55). In this regard it is an international problem which carries clear penalties under the Federal Migratory Bird Treaty Act (62). Knowingly creating or maintaining conditions that cause poisoning and death of migratory birds is strictly forbidden under the Act, and the ultimate liability for drainage produced from Federal irrigation projects rests with the Secretary of the USDOI. Similar environmental liability exists for state fish and game management agencies and their commissioners, which are the stewards of migratory birds outside Federal lands.

Because of the Kesterson episode, the biogeochemical conditions leading to the formation of contaminated subsurface irrigation drainage, and its toxic threat to migratory birds, is now well established. To allow development of new irrigation-drainage projects in locations conducive to problems would be irresponsible and in clear violation of the basic tenet of the Migratory Bird Treaty Act. Restrictions on new projects should also include proposed on-farm evaporation ponds, which is a method of drainage management, if they are accessible to migratory birds or discharge into surface waters. The immediate question is what to do about irrigation-drainage projects and disposal sites that are currently on-line and causing environmental damage. Several options are being considered in California, including taking agricultural lands out of production and increasing water costs to farmers to pay for drainwater treatment (63). The classic arguments over economic impacts versus environmental protection have raged since the discovery of Kesterson's problems in the early 1980s, and tradeoffs are likely to be made in favor of agriculture (64). It is clear that if irrigated lands are to remain in production, the subsurface drainage they produce must be rendered environmentally safe before it is discharged and comes into contact with fish and wildlife resources. An aggressive regulatory program must be implemented throughout the western states to provide the necessary level of environmental protection.

REGULATORY IMPLICATIONS

Subsurface Irrigation Drainage as a Point-Source Hazardous Waste Discharge

Regardless of whether biological or chemical criteria are used, subsurface irrigation drainage must be considered a toxic waste. Findings from USDOI studies indicate that when the full complement of biological effects are considered-i.e., direct water-borne toxicity, food-chain bioaccumulation, and reproductive effects through dietary intake-subsurface irrigation drainage contains concentrations of contaminants that are several hundered to several thousand times the toxicity thresholds for fish and wildlife (4, 7, 54, 65). For example, selenium concentrations can range as high as 1400 &liter in drainwater (5), but as little as l-3 μg/liter can bioaccumulate in aquatic food chains and impair the reproduction of waterfowl (66, 67). Moreover, liquids containing selenium at concentrations of 1000 μg/liter or more are designated by EPA as hazardous waste, subject to strict regulations governing handling and disposal (68). This hazardous waste criterion for selenium has been exceeded in samples of subsurface agricultural drainage collected at Federal irrigation projects in California and Wyoming (5, 55). Irrigation drainage is a known hazard to humans as well as fish and wildlife, and advisories have been issued by state health agencies to alert the public to this toxic threat (69).

EPA considers subsurface irrigation drainage to be a non-point source problem and, as such, does not recognize it as a specific class of pollution subject to regulation under the National Pollutant Discharge Elimination System (NPDES) permit process (18, 70). This position seems to result from the notion that agriculture-related pollution originates from such a wide geographical area that it cannot be traced to a specific "point" or "end-of-pipe" source, or effectively regulated using point source treatment technologies. A non-point source designation is probably correct for most water quality problems associated with ***surface*** runoff of irrigation tailwater and rainfall. It is usually difficult to identify a specific source for contaminants, sediments, etc., present in this type of surface-water discharge. However, the contaminant profile and elaborate collector systems associated with ***subsurface*** drainage make it a totally different wastewater. The primary contaminants associated with subsurface drainage-i.e., selenium, boron, molybdenum, and salts-are not an important part of surface irrigation runoff (2-5). The trace elements and salts in subsurface drainage originate from a diffuse source but the drainage collector systems-clay tiles, plastic pipe, drainage ditches and canals-serve to consolidate many small return flows into a single discharge (Fig. 2). Selenium, for example, is elevated in soils formed from weathered Cretaceous shale deposits, which are widespread in the western states (56). Irrigation water leaches selenium from the soil and concentrates it in the resultant drainwater which, in turn, is further concentrated and combined with other flows in the drainage collector network (2, 42, 7 1). This collector network is analogous to a sewer system feeding into a municipal wastewater treatment facility-both begin as many "sources," but this multitude of sources is combined to produce a single flow of wastewater that can be contained for treatment.

A point source for subsurface irrigation drainage can be easily located at the terminus of the drainwater collection and conveyance network of a given field, farm, or water district (Fig. 3). This information was extensively used by USDOI scientists to pinpoint sampling sites and obtain irrigation drainage for chemical analysis and toxicity testing purposes (Fig. 3). Environmental consultants and engineers have taken advantage of the point source nature of subsurface drainage in developing and evaluating treatment technologies (72, 73). They recognize the fact that subsurface drainage is an "end-of-pipe" waste that can be located, manipulated, and contained for treatment and disposal purposes, Ironically, the article in which EPA characterized subsurface drainage as a "non-point nightmare" included, as its only drainwater illustration, a photograph of the waste being discharged from the end of a pipe (18).

Regulatory Strategy

Subsurface irrigation drainage is a wastewater containing high concentrations of trace elements, salts, and nitrogenous compounds (2-5). It is a complex effluent containing. a mixture of toxic or potentially toxic substances. In this respect, it is quite similar to many industrial discharges and it should be regulated the same way. The NPDES premit process, a joint effort between EPA and individual states, was developed to control the discharge of complex effluents into surface waters. This process provides a water quality-based method for toxics control that focuses on desired conditions in the receiving water (70). The use of NPDES permits is particularly appropriate when it is necessary to reduce effluent toxicity associated with multiple contaminant im-

FIG. 2. Photograph illustrating the controlled, point-source nature of subsurface irrigation drainage. A network of subsurface pipes in the field collects excess irrigation water as it percolates downward. This drainage is discharged through lateral pipes into a main canal that runs along the perimeter of the field. The drainage from several fields may be combined into a single flow before it is discharged into surface waters or disposed in on-farm evaporation ponds. Treatment of the drainage to remove contaminants is possible at several points along this collection and distribution system.

pacts-i.e., additive, synergistic, or antagonistic effects-that would not be effectively controlled through single-substance regulations (e.g., individual water quality standards for heavy metals, organic compounds, etc.). Subsurface irrigation drainage produces multiple contaminant impacts on aquatic species (37, 38, 59, 60), and should be regulated with this fact in mind. Current state and national water quality criteria applicable to single contaminants do not protect against the combined effects of trace elements and unusual ionic ratios which are important in determining the toxicity of irrigation drainage to aquatic life (38, 59). Therefore, a drainwater discharge should be regulated as a complex effluent, subject to the terms and conditions of the NPDES permit process.

A straightforward, four-step approach can be used to deal with the irrigation drainage problem: (1) locate and evaluate all sites where subsurface drainage is produced from

FIG. 3. Samples of subsurface irrigation drainage being taken from an "end-of-pipe" discharge in California's San Joaquin Valley. The drainage is a complex effluent containing trace elements, salts, and other substances that are toxic to fish and aquatic birds. Regulatory intervention is necessary to ensure that this drainage is effectively treated before it is discharged into surface waters or on-farm evaporation ponds that can be utilized by wildlife.

irrigated agriculture; (2) prescribe levels of contaminant reduction and control, through the NPDES process, sufficient to protect fish and wildlife resources at sites where problems are occurring or are likely to occur; (3) evaluate the success of corrective actions with compliance monitoring; (4) monitor non-problem sites for possible change in status. The first element of the approach is being completed for several Federal irrigation projects by USDOI's Irrigation Drainage Program (55). In this program, individual sites are prioritized based on the preponderance of characteristics that are known to contribute to drainage problems—e.g., presence of irrigated agriculture, geology, hydrology, soil type, climate, etc. The selected sites are sampled and evaluated on a screening level using chemical and biological criteria to indicate potential toxicity to fish and wildlife (55). Intensive chemical and biological studies, which can include whole-effluent bioassays with aquatic organisms and reproductive studies with wildlife, follow at the most contaminated locations to provide detailed information on the toxic threat as well as implications for remedial or cleanup activities (55). Individual states should use USDOI's program as a model to evaluate all state-owned and private irrigation projects that discharge subsurface drainage into surface waters or create aquatic habitat accessable to wildlife (i.e., on-farm evaporation ponds). State programs should also evaluate the dozens of Federal irrigation projects that will probably not be investigated by USDOI.

The second element, toxics control, should proceed using the Federal-state water-quality-based NPDES permit system. Under this system, EPA has delegated primary authority for issuing, reviewing, and renewing NPDES permits to individual states (70). Most of the authority for enforcement actions on permit violations also rests with the states. EPA's main role is to provide guidance for the permitting process (74). However, the Agency may become involved in the enforcement process if the actions taken by a state are not sufficient to correct permit violations in a timely manner.

Permits for subsurface irrigation drainage should be issued on the basis of specified water-quality objectives to be attained at the "end-of-pipe" or "end-of-canal," with no allowance given for dilution factors and mixing zones in receiving waters. This is a departure from the typical scenario followed in the NPDES process for complex effluents, which is to derive discharge limits based on waste-load allocation, mass balance for specific contaminants, and anticipated minimum dilution during dry seasons (74). However, the fact that irrigation drainage contains high concentrations of selenium, which has somewhat unique toxicological properties and environmental dynamics, demands that this wastewater be given special consideration.

The aquatic cycling of selenium is extremely complex and involves strong bioaccumulation steps that greatly magnify the overall potential for toxic impacts (75). Moreover, selenium is a potent teratogen, and induces embryo-larval deformities and reproductive failure in fish and wildlife without affecting adults (30, 52, 76). Data from several field sites investigated by USDOI illustrate the ability of selenium to accumulate to toxic levels in wildlife tissues from what appears to be safe waterborne concentrations based on EPA national water quality criteria (55, 77-79). This field evidence suggests that even slight increases in selenium-i.e., additions of only 0.5–1.5 &liter-may be all that is necessary to begin the bioaccumulation/toxicity cascade. Considering the fact that uncontaminated surface waters in irrigated regions already contain as much as 1.0 μg/liter selenium (5, 80, 81), and the threshold for toxicity resulting from bioaccumulation falls in the range of l-3 &liter (66, 67, 82), receiving waters have almost no capacity to provide effective dilution.

Subsurface irrigation drainage requires stricter controls than many other types of wastewater. Allowing dilution factors and mixing zones is not a prudent approach to managing the environmental risk associated with selenium. Irrigation drainage must be effectively treated to remove selenium before it enters receiving waters. Moreover, the definition of receiving waters should be extended to include on-farm evaporation ponds because they constitute wildlife habitat and, if contaminated, place migratory waterfowl in jeopardy, which is a violation of the Federal Migratory Bird Treaty Act (62, 66, 67). Total dissolved concentrations of selenium in the actual drainwater discharge should not exceed 2.0 &liter at any time (66, 67, 82). Otherwise, bioaccumulation and poisoning of fish and wildlife is a high probability.

Certain treatment technologies for selenium have the potential to reduce other priority drainwater contaminants-e.g., boron, molybdenum, salts, and nitrogenous compounds-thereby reducing the need for secondary treatment (72, 73). These other drainwater contaminants may also have a greater safety factor-i.e., the margin between concentrations that normally occur in aquatic habitats and those that are toxic to fish and wildlife-which suggests that dilution by receiving waters could be explored as a reasonable method of disposal following selenium removal. However, the toxicity data base for trace elements such as molybdenum and boron is quite small, and additional experimental study is necessary before this approach could be verified as environmentally safe.

The third element of the regulatory strategy is to conduct periodic compliance monitoring to ensure that treatment activities are effectively reducing contaminant levels in the discharge. This can be done by measuring concentrations of selenium and other contaminants, coupled with bioassay tests to check for whole-effluent toxicity; both are integral components of the NPDES process (70, 74). The last element of regulation is to monitor non-problem sites for possible change in status. Changes in water use or general climatic conditions can influence local hydrology and affect the amounts of selenium and other contaminants in irrigation drainage, pushing concentrations over the toxicity thresholds for fish and wildlife with little warning (55). Adequate site monitoring programs, consisting of screening-level measurement of selenium and boron in water and biota, can identify these changes and quickly reveal locations where further action is needed. Properly executed, this regulatory strategy should have the ability to detect, respond to, and control water-quality problems associated with subsurface irrigation drainage before serious environmental damage occurs.

Need for Active EPA Involvement

Section 101(a) of the Federal Water Pollution Control Act of 1972 (Public Law 92-500) established that "it is a national policy that the discharge of toxic pollutants in toxic amounts be prohibited." Under this Act, EPA has the responsibility to review scientific information and publish national water-quality criteria, and provide guidance and assistance to states in the implementation of enforceable standards and control measures for toxic materials in the environment. At the present time, no measures are in place for regulating irrigation drainage as a complex effluent, on either a state or national level, and no enforcement has occurred except for closure of the San Luis Drain and Kesterson National Wildlife Refuge in 1986. However, these actions were in response to concerns about liability of the Secretary of the Department of the Interior under the Federal Migratory Bird Treaty Act, not because of water-quality-based regulatory intervention targeted at irrigation drainage (9, 39).

California, which has experienced widespread environmental toxicity from irrigation drainage, has adopted a plan for regulating drainwater discharges into the San Joaquin River (64). However, this plan falls far short of providing effective environmental protection because the water-quality criteria identified in the plan as being necessary to protect public health and wildlife were not accepted. Instead, less restrictive objectives were adopted because of the projected economic impacts to agriculture associated with a 70% reduction in drainage necessary to attain the more restrictive standards. Thus, the potential for toxicity due to individual contaminants, as well as the overall threat of combined toxicity, bioaccumulation, and reproductive effects in fish and wildlife still remain. In San Francisco Bay, attention has turned from irrigation drainage to oil refinery effluents as a source of selenium contamination. Selenium is a major contaminant in subsurface irrigation drainage and this drainwater is the primary source of selenium in the San Joaquin River (5, 7, 80). Discharges from the San Joaquin River can contribute over four times the mass load of selenium to the Bay as compared to the refineries (32 kg/day vs 7 kg/day: 83). It seems clear that oil refineries contribute to the selenium problem but it is equally clear that aggressive regulation of irrigation drainage will be necessary to effectively control selenium inputs to the Bay environment.

In the eight other states where environmental toxicity due to irrigation drainage has occurred or is predicted based on contaminant concentrations (Oregon, Nevada, Utah, Wyoming, Montana, South Dakota, Colorado, and Kansas), no steps are being taken to define the full extent of the problem or develop plans to control it through regulatory measures. It is unlikely that actions such as those undertaken thus far in California will occur in other locations because these other states are, in general, less environmentally progressive and responsive to water-quality issues. Moreover, the problem areas that have been identified are associated with Federal irrigation projects administered by the Bureau of Reclamation. Implementation of regulations by individual states would require close coordination and cooperation between several Federal and state agencies. The prompt, aggressive action so vital to effective regulation often becomes slow and complicated in multiagency efforts because of differences in political priorities and objectives (17, 39).

The need for direct involvement by EPA in establishing and enforcing environmentally sound regulations for subsurface irrigation drainage at the state level seems clear. Individual states have either not taken action to control drainage or, where action has been taken, the proposed criteria and methods of toxics control are not sufficient to protect against environmental toxicity. Moreover, EPA has a legal mandate under the Clean Water Act to take the lead in implementing regulations governing water quality when wastes and priority pollutants are being released in demonstrated toxic amounts (70). Irrigation drainage satisfies both these criteria-selenium is an EPA priority pollutant (84, 85), and this article chronicles the toxicity to fish and wildlife that has occurred in California and other states over the past decade.

CONCLUSIONS

Subsurface agricultural irrigation drainage is a hazardous waste that can severely impact the environment. Studies conducted by the U.S. Department of the Interior have documented that irrigation drainage is a serious toxic threat to fish and wildlife resources in nine western states. Poisoning of waterfowl by drainwater contaminants, which has occurred in at least six locations on national wildlife refuges, is a violation of the Migratory Bird Treaty Act under Federal law. Critical wetlands and waterfowl populations are threatened in both the Pacific and Central flyways. The public is also at risk and health warnings have been issued in some locations. Corrective actions at the state level will be weak and, in some cases, probably nonexistent. It is essential for EPA to recognize subsurface irrigation drainage as a specific class of pollution, subject to the same regulatory process as other complex effluents under NPDES permits. The EPA, in cooperation with the Department of the Interior and individual states, must take immediate, aggressive steps to ensure that adequate controls on this wastewater are implemented.

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