Imperial Valley

Drainwater Reclamation and Reuse Study

U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Region
Southern California Area Office

IMPERIAL VALLEY DRAINWATER RECLAMATION AND REUSE STUDY

Cooperative Study Between the Bureau of Reclamation and the Imperial Irrigation District

For Additional Information Contact:

Jim Setmire
Area Hydrologist
Bureau of Reclamation
Southern California Area Office
SCAO – 7100
Temecula, CA
Email: jsetmire@lc.usbr.gov
Phone: 909-695-5310 Fax: 909-695-5319

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CHAPTER I

Introduction

The current Salton Sea was formed from October 1905 to February 1907 following summer flooding and the failure of a temporary diversion of the Colorado River. During those 17 months, most of discharge of the Colorado River flowed into the Salton Trough. Spanning approximately 380 square miles, the Salton Sea is California's largest water body. This drainwater project is a logical extension of previous investigation of irrigation drainwater in the Imperial Valley conducted by the National Irrigation Water Quality Program (NIWQP). Irrigation drainwater is the major component of flow to the Salton Sea. This cooperative study between Imperial Irrigation District (IID) and the U.S. Bureau of Reclamation began in 1995 and primarily evaluates methods to control selenium concentrations in irrigation drainwater in the Imperial Valley.

1.1 Overview

The Sonny Bono Salton Sea National Wildlife Refuge located at its southern end of the Salton Sea provides significant wintering habitat for over one million migratory birds and is home to hundreds of other bird species including countless ducks, geese, shorebirds and large numbers of song birds. The Sea also is used for recreational activities such as fishing, camping, and boating. The elevation of the Sea is maintained primarily by inflow from the New and Alamo Rivers in the Imperial Valley and the Whitewater River draining the Coachella Valley. Water in these rivers is mainly irrigation drainwater although about 20 percent of the flow in the New River is industrial, municipal and agricultural discharge from Mexico.

In Imperial Valley (Valley) approximately 470 thousand acres of irrigated farmland receives water from the Colorado River through the All-American Canal. Water requested by area farmers is delivered to fields by an extensive network of canals and laterals. Irrigation drainwater from agricultural activities is collected in surface drains that discharge to the New or Alamo Rivers. Additionally, there are 27 drains that discharge directly to the southern end of the Salton Sea. Drainwater is primarily water from irrigation of agricultural lands in the Valley.

Irrigation drainwater contains elevated concentrations of selenium and pesticides. Because surface drains provide habitat for various birds and wildlife as well as discharge to the Salton Sea near the Sonny Bono National Wildlife Refuge, there is concern for the health of this ecosystem.

1.2 Purpose and Scope

To ensure compliance with EPA's criteria for protection of freshwater aquatic life, the Bureau of Reclamation (Reclamation) and the Imperial Irrigation District (IID) of southern California conducted a cooperative study to evaluate a wide range of technological methods used to remove selenium from water supplies.

The study focused on the following objectives:

1) Evaluate current methods and/or technologies for removal of selenium, organochlorine pesticide residues, and organophosphorus pesticides in combined surfaced flows and in subsurface drainwater as appropriate.

2) Determine feasibility of separating tailwater from subsurface drainwater with subsequent treatment of the drainwater as a component of a system to reduce selenium discharges to the Alamo River.

3) Determine feasibility of duck club ponds as a surrogate for constructed wetlands to reduce selenium and nutrient concentrations in drainwater while providing wildlife habitat.

1.3 Study Area

The study unit is located in the southeastern desert of California, see figure 1. It occupies the northern part of the Salton Trough and includes the Coachella and Imperial Valleys of California and the Mexicali Valley of Mexico. The study focused primarily on irrigation drainwater in the Imperial Valley.

The Imperial Irrigation District (IID) supplies water to approximately 470,000 acres of irrigated farmland. Water is delivered to farmers through an extensive 1,600 mile-network of canals and laterals in the Valley. The irrigation cycle begins as water is applied to a field. Water from this application is termed irrigation drainwater and is composed of subsurface drainwater, tailwater runoff, operational discharge and canal seepage. Subsurface drainwater is irrigation water that has percolated through the soil and is collected by tile drains (perforated pipe) at depths of 6 to 10 feet below land surface. These drains carry water containing elevated levels of dissolved salts and selenium (concentrated by evapotransipiration) to approximately 550 sumps and 10,000 gravity tile outlets located at the tail end of fields. Sumps are 8-ft diameter cisterns that collect water from tile drains and pump that water to surface drains in areas where the tiles are below the surface of the water in the drain. Gravity tiles outlets are collector pipes that discharge subsurface drainwater directly to surface drains. Tailwater (water in excess of crop requirements) is irrigation water that is collected and runs off the down gradient (tail) end of the field to the surface drain. Operational loss is the excess water needed to convey the requested water to the fields. Operational loss and trailwater are similar in dissolved solids and selenium concentration to Colorado River water and therefore dilute the subsurface drainwater. There are 1,470-miles of surface drains in the Imperial Valley.

1.3.1 Climate

Climate is an important factor controlling many of the physical, chemical and biological processes in the Salton Sea area. The Imperial Valley is one of the most arid areas in the United States, with an average annual rainfall of less than 3 inches; the maximum temperature exceeds 100 0F more than 110 days per year and the average annual temperature is 74 0F (Hely and others, 1966).

Evaporation in the Salton Sea is estimated at 5.78 ft/yr and evapotranspiration from a growing crop can exceed 1/3 inch per day during the hot summer months (Hely and others, 1966). Currently, about 1.34 million acre-ft of water is lost annually from the Salton Sea by evaporation. This loss is balanced by tributary inflow from the rivers and surface drains. The frost-free climate also provides an environment where year-round cropping can be practiced, thus creating the demand for irrigation water and disposal of its runoff.

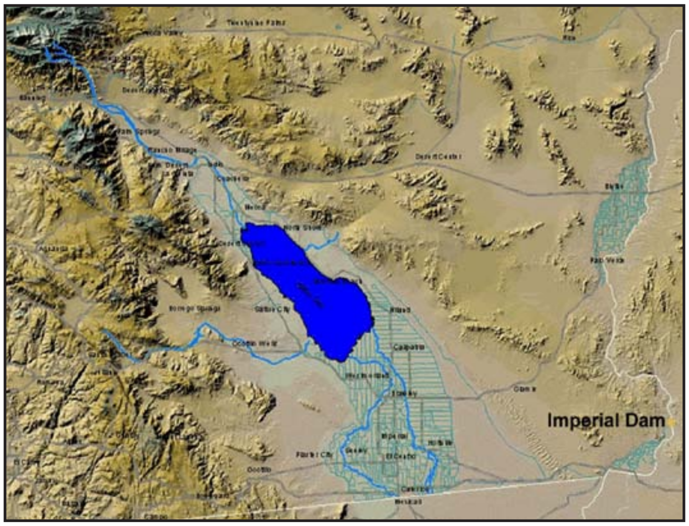

Figure 1
Map of Study Area

CHAPTER II

Study Concerns

2.1 Elevated Selenium

The Alamo River at its outlet contains elevated selenium exceeding the Environmental Protection Agency's (EPA) criteria for the protection of freshwater aquatic organisms. According to EPA criterion, freshwater aquatic organisms should not be negatively affected by selenium, if the 4-day average concentration does not exceed 5 micrograms per liter (µg/L), more than once over a 3-year period on the average. In addition, to remain within acceptable limits, the average 1-hour concentration cannot exceed 20µg/L more than once every 3 years on the average (EPA, 1987).

Over a period of one year, from August 1988 to 1989 water samples collected monthly from the Alamo River outlet showed an average selenium concentration of 8µg/L (Setmire and others, 1993). In August 1994, 50 water samples were collected from 18 surface drains (irrigation drainwater) throughout the Valley; the mean selenium concentration at that time was 6µg/L. The average selenium concentration in the sampled drains was 7.66, the minimum 1.0, and the maximum 52µg/ (Schroeder, 1995, written communication).

In addition to selenium, salt is also a problem in the Salton Sea area. Today, the annual salt loading to the Sea from both the Alamo and New River is estimated at four million tons. External salt loading and the dissolution of salts from previous flooding, coupled with an evaporation rate of 5.8 ft/yr in the Salton Sea, which has no outlet, have caused salinity levels in the Sea to increase from 3,550 mg/L in 1907 when the current Sea was formed to its present-day level of 44,000 mg/L of total dissolved solids (TDS) (Hely and others, 1966).

Elevated levels of selenium are of concern in the study area because selenium bioaccumulates in the food chain. In aquatic organisms selenium can be accumulated through water and diet. Therefore, those at greatest risk from elevated levels of selenium are the larger fish-eating birds (top of the food chain) feeding in the Sea and neighboring rivers. Selenium toxicity studies conducted by U.S. Fish and Wildlife Service have not shown major deleterious effects on wildlife at present. Nesting studies using black-necked stilts suggested minor reproductive impairment.

2.2 Impaired Drainwater

Although elevated salinity is the primary concern with the Salton Sea, there are also additional water-quality concerns. Water found in surface drains throughout Imperial Valley show high concentrations of not only selenium, but also TDS, sulfate, boron, molybdenum, lithium, chloride and sodium. In fact, most exceed the recommend values set by the National Academy of Sciences for these constituents in reuse irrigation water.

In the Valley, conservation of water through reuse of tailwater and capturing and using operational loss will cause the quality of irrigation drainwater to decrease since these waters effectively dilute the poorer quality subsurface drainwater. Subsurface drainwater is the only component of irrigation drainwater not targeted for flow reduction. Although tailwater contains wash-off of water-soluble pesticides, nutrients, and phosphorus plus fine sediments that can transport organochlorine pesticide residues and particle bound phosphorus, it is still similar in dissolved solids and selenium concentration to Colorado River water. Evaporation of irrigation water and the dissolution of salts in the soils increase the dissolved solids and selenium concentrations in subsurface drainwater from 686 mg/L and 2-3 µg/L respectively in the irrigation water from the Colorado River to 6,448 mg/L and 25 µg/L (median concentrations) in the subsurface drainwater (Setmire and others, 1993). Therefore, future reductions of the volume of operational loss, canal seepage and tailwater that effectively dilute this poorer-quality subsurface drainwater will increase the dissolved solids and selenium concentration in the surface drains.

Poor quality drainwater can potentially cause negative impacts to endangered species and wildlife in the Sonny Bono Salton Sea National Wildlife Refuge, area rivers and drains in the Valley. Negative impacts may include possible reproductive impairment in waterfowl from selenium toxicity, eggshell thinning in birds from Dichlorodiphenyldichloroethylene (DDE), reproductive effects from high boron concentrations, and loss of habitat and spawning failure due to elevated salinity.

CHAPTER III

Decontamination Processes

3.1 Literature Research

To initiate the evaluation process, a literature search was conducted to collect existing information from researchers involved in selenium remediation projects. Investigation showed that most of the relevant ongoing research activity on this subject was being conducted in California's San Joaquin Valley. Some of the selenium removal methods are discussed below.

3.2 Decontamination Proposal Solicitation

A notice was also placed in the Commerce Business Daily to solicit information on available selenium removal methods and/or technologies. Several responses were received and a six-member panel comprising representatives from Reclamation, the U.S. Geological Survey (USGS), and the IID evaluated the proposals based on three criteria:

1) Effectiveness selenium removal process

2) Applicability of the technology to large-scale treatment of irrigation drainwater (1million acre-ft)

3) Total cost of ownership to include construction and maintenance expenditures

The request for information on current technologies and/or methods to remove selenium from agricultural drainwater in Imperial Valley, California was placed in the Commerce Business Daily solicitation notice in March 1995. Other constituents of interest identified were sulfate, boron, molybdenum, manganese and lithium. Thirty five responses were received and grouped into one of five categories:

1) Ponding water to facilitate anaerobic decomposition and reduction of nitrate and selenium

2) Ion-exchange columns using various adsorbents (often included some filtration)

3) Reverse osmosis

4) Fields designed for increasing levels of salt tolerant plants and the uptake and removal of selenium

5) Removal of soil contaminated with selenium.

A rating system was developed and the project's steering committee along with an outside expert rated each of the proposals.

Many of the companies responding to the solicitation notice had experience in toxic spill cleanup or localized contamination. As a result, many of the proposals referred to small spill techniques. Unfortunately, these solutions do not effectively apply to treating over one million acre-ft per year of agricultural discharge.

Decontamination processes identified by these companies often use large volumes of materials for either adsorption or ion exchange and in turn generate vast amounts of waste products and/or reject streams requiring disposal. Disposal of large volumes of contaminated water rendered these techniques unaffordable and disposal of the waste products logistically unacceptable. Technologies relying on packed columns require periodic regeneration or replacement. Furthermore, the projected costs coupled with the cost of materials, electricity for pumping and waste stream disposal were considerably greater than any feasible operations and maintenance budget. Some proposals suggested reverse osmosis (RO) for selenium removal. While RO is effective, the high-energy requirements and costs associated with disposal of the reject stream made these systems too expensive to implement.

Various combinations of ion exchange and filtration also were proposed, but again, the volume of water to be treated and magnitude of waste products made the cost of these processes excessive. Several proposals specified proprietary enzymes or other materials that could not be evaluated, and were eliminated from consideration. Many companies responding to solicitation had processes that dealt effectively with spill cleanup or other more limited chemical removal requirements. Some involved portable systems enabling the vendor to quickly respond to an incident. None, however, were suited to the magnitude of irrigation drainwater from the Imperial Valley.

3.2.1 Groundwater Disposal

One proposal recommended injection of selenium laden subsurface drainwater to groundwater that has very low selenium concentrations. Generally, selenium concentrations in groundwater are less than 1 part per billion (ppb). This process had previously been evaluated by IID and was determined to be too expensive to test and unlikely to work because of artesian conditions throughout the Valley and the numerous clay layers.

3.2.2 Selenate Reduction

Macy and others, 1993, tested a bioreactor (packed column) to remove selenium by reduction and adsorption. This process uses a selenate-respiring bacteria Thauera selenatis to reduce selenate to selenite under anaerobic conditions. Selenite is further reduced to elemental selenium which is insoluble, effectively removing it from the drainwater. A detailed explanation of selenate respiration can be found in Oremland and others, 1989. This bioreactor required the addition of acetate as an electron donor before selenate reduction could occur.

The need to maintain controlled environmental conditions and the cost of acetate makes this particular system costly for widespread application, but the concept remains valid, especially if combined with systems that would reduce the volume of water to be treated. Acetate could be replaced by other substrates to reduce the cost. Oswald and others, 1995, developed an integrated system to remove nitrate and selenate from agricultural drainwater. Their system is designed in the shape of a racetrack with a high rate algal growth pond on the outside. The algae are collected, dried and used as a carbon source (see figures 2 - 3).

Figure 2
High Rate Algal Growth Pond

Figure 3
Deep Pond for Nitrate and Selenate Reduction

Once algae is removed from the shallow pond, it is dried, crushed and added to a pond in the center of the “racetrack” as a carbon source for denitrification and selenate reduction in the deeper anaerobic zone. Later, when algal drying and crushing became tedious, molasses was added as an inexpensive source of carbon (electron donor) for the reduction. This system has been in operation for several years and effectively removes both nitrate and selenate. However, it does require adequate depth in the center pond to produce anaerobic conditions and a retention time of about 8 days. Retention time required is usually temperature dependent, colder temperatures tend to slow down the bacterial processes (see figures 4 – 5).

Figure 4
Inflow to Treatment System

Figure 5
Molasses Injection for Carbon Source

3.2.3 Selenium Volatilization

Terry and others, 1995 (written communication) tested degassing of dimethyl selenide in wetland vegetation, to remove selenate from water and avoid dealing with selenium-contaminated soils. Constructed wetlands were planted with vegetation selected for their high rate of degassing dimethyl selenide.

While formation and degassing of dimethyl selenide is a well-documented pathway for selenium, the kinetics of the process does not appear to be sufficient to remove large quantities of selenium necessary to treat agricultural drainwater. The effectiveness of the process is also difficult to determine. The research plot must either be enclosed so gasses can be collected and measured, or the amount degassed must be calculated, by quantifying the load of selenium in the inflow and outflow and subtracting the selenium tied up in sediments, roots, and vegetation. This determination has errors that likely exceed the quantity of selenium lost by degassing of dimethyl selenide.

3.2.4 Agroforestry

In 1994, Cervinka developed an agroforestry concept wherein agricultural drainwater is recycled using multiple landscapes. The process is simple; drainwater from one crop becomes irrigation water for the next crop and so on. The crops are strategically positioned so that each succeeding crop has a greater salinity tolerance, with halophytes being the final water user. The final crops in the system accumulate selenium to elevated concentrations. High-salinity water beyond the tolerance of the halophytes is sent to solar evaporation ponds for final processing. Selenium in the form of selenate is concentrated in the same manner as sulfate and other ions. This concept received a favorable ranking from the review panel, but it requires large areas of cropland, modification of current cropping patterns, and on-farm management for implementation to be successful. Furthermore, new markets for crops such as halophytes would have to be developed to make this system financially workable.

3.2.5 Nanofiltration

Nanofiltration is a filtration technique that uses membranes to separate different fluids or ions. Kharaka and others, 1996 used nanofiltration membranes for sulfate removal in the Paradox Valley, of Colorado. Selenate is a divalent oxyanion with chemical properties similar to sulfate. Kharaka reasoned that nanofiltration would be effective at removing selenate from agricultural water in a similar manner to sulfate. In the Grasslands sub area of the San Joaquin Valley, nanofltration removed over 95 percent of the selenium and other multivalent anions from drainwater along with molybdenum, uranium, dissolved organic macromolecules, and some dissolved organic macromolecules (Kharaka, 1996). This was an effective method to remove selenate. Co-removal of multivalent cations is necessary to maintain charge balance.

Many argue that nanofiltration is very similar to reverse osmosis. However, according to Kharaka, "nanofiltration membranes yield greater reclaimed-water output, require lower operation pressure and less pretreatment, and therefore, are more cost effective than traditional reverse osmosis membranes."

In April of 1997, Kharaka assembled a team to test the effectiveness of nanofiltration to remove selenate in subsurface drainwater from three sumps in the Valley. Arrangements were made with US Filter to provide an operator, nanofiltration unit, and several types of membranes and inhibitors. A USGS mobile field laboratory was transported from Menlo Park, CA to provide analytical services to assess real-time performance of the nanofiltration unit and facilitate field adjustments to the unit. Imperial Irrigation District provided a site for the experiments, the District also wired the site for sufficient power to run the unit, and provided a tank truck to convey the drain water. The tank was filled with water from the selected sump and driven to the IID field station to provide the source water to test the nanofiltration unit (see figure 6).

Figure 6
Nanofiltration Unit

3.26 Other Removal Processes

Reverse osmosis (RO) was also proposed as a means to remove selenium from agricultural discharge. Although RO produces extremely high-quality water, it has very high energy costs. Coupled with the cost of disposing of the reject stream, RO received a low rating from the evaluation team.

Other process evaluated included trying to enhance selenium volatilization of selenium in areas having high selenium concentration in soils. Various wetting and drying options were attempted to encourage the degassing of selenium. These projects met with questionable success, in part because of the difficulty in determining the quantity of selenium leaving the soils as dimethyl selenide, hydrogen selenide and other alkyl selenides. In some cases, selenium lost to groundwater was not measured.

CHAPTER IV

Lewis Drain Demonstration Project

4.1 Project Goals

The Lewis Drain Treatment System (LDTS) was a demonstration project to:

1) Assess the effectiveness of selenium removal by selenate reduction in an anaerobic system

2) Determine the effectiveness of a flat surface drain system to reduce sediment loading to the rivers.

The first step was to separate tailwater and subsurface drainwater in a short drain system and the second step was to treat the subsurface drainwater. The LDTS represented a substantial component of the Valley's Comprehensive Drainwater Reclamation and Reuse Project. The objective of the demonstration project was to reduce the volume of water treated for selenium removal by separating tailwater from subsurface drainwater, while providing an opportunity to test the reuse potential of tailwater. The Lewis Drain was an ideal drainage to test these objectives because it is a short surface drain receiving tailwater and subsurface drainwater from four fields. Subsurface drainwater from the four fields is collected at sumps located at the end of the fields and piped to the LDTS.

4.2 Design

The current LDTS design evolved over a number of years. The initial conceptual plan required use of the existing surface drain for nitrogen and selenate reduction in subsurface drainwater. Further, a parallel tailwater trench was designed to convey runoff from the fields. This water would be collected downstream in a serpentine pond where sediment would settle, pesticides in the water would be exposed to photolysis, and the water would be stored for possible reuse. Subsurface drainwater would be discharged to the surface drain which would have gates installed to pool water to sufficient depth causing anaerobic conditions in the bottom of the drain where reduction of nitrate and selenate would occur.

The next evolutionary stage of the design reversed much of the initial concept, retaining the tailwater in the surface drain for pump back, and connecting the four sumps via a pipe. An additional pump was placed in the fourth sump to

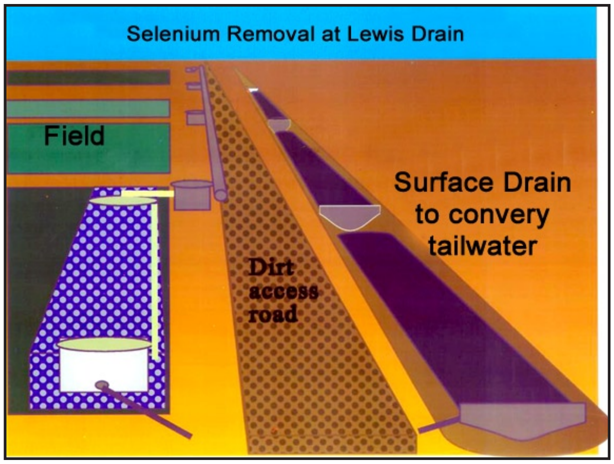

Figure 7
Schematic of Lewis Drain Site

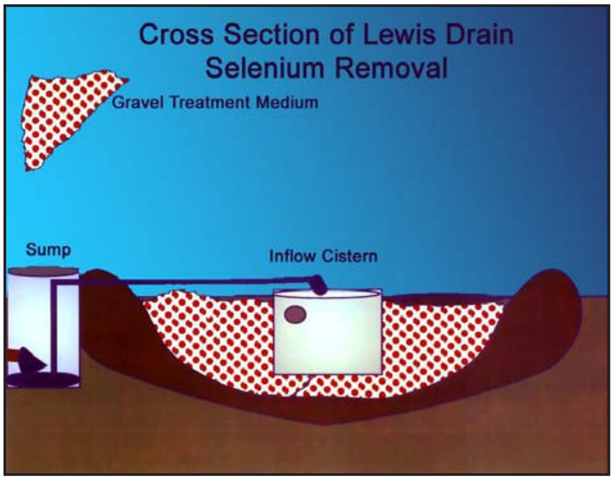

Figure 8
Schematic Cross Section of Treatment Trench

discharge the accumulated subsurface drainwater to the treatment system (see figures 7 and 8). A gravel selenium removal system was designed to treat about 70% of the subsurface drainwater discharge from the four sumps (S-341, S-215, S-263, and S-493). The size of the system was to be sufficient to accommodate an eight-day retention time for the average flow.
The design retention time was based on the biological treatment process described in Oswald and others, 1995, which tested an anaerobic pond for selenium removal. Their laboratory and field experience indicated that eight days is adequate for denitrification and selenate reduction. Subsurface flow wetlands described by Kadlec and Knight (1996) for denitrification typically have retention times of four days. Oremland and others, 1989 showed significant reductive removal of selenate from anaerobic sediment slurries incubated under hydrogen in 4 - 7 days.

The LDTS consisted of an excavated trench 1,100 feet long, 26 feet wide, and 5 feet deep, filled with 6,000 cubic yards of _ to 3/8 inch gravel. Studies of sand/gravel filtration systems on Washington Island, Wisconsin, indicated that _ to 3/8th-inch gravel functioned well for denitrification and had a minimum of plugging due to growth on the media. The surface of the trench was covered with an impermeable plastic tarp and backfilled with soil from the excavation to prevent aeration, hopefully eliminating the depth generally needed to generate anaerobic conditions in a pond. The trench had a slope of about 0.1%, gentle enough to prevent turbulent flow around the gravel. Water flow rate through the trench depended upon subsurface drainwater flow to the discharge sump (see figure 11).

Figure 9
Outflow from Lewis Drain Treatment System

Figure 10
View Along Trench

As the down gradient sump filled, a float-activated pump discharged the collected subsurface drainwater to center one of three connected concrete cisterns (8 ft in diameter). These cisterns stored the drainwater for release to a single cistern overlying the head of the gravel trench. If the volume of drainwater exceeded the inflow capacity of the trench, the water was returned to the sump and discharged to the surface drain by a second pump. Discharge from the trench was measured at a concrete weir with a stage recorder. Three ports (wells) were installed over the length of the trench to collect water samples for monitoring.

The second goal of the Lewis Drain Study was to assess the effectiveness of a flat surface drain to reduce sediment loading to the rivers.

Project staff was unable to make arrangements to use land downstream of the Lewis Drain for surface-water treatment. Therefore, the existing surface drain was widened by 13 feet, dredged, and cleared of vegetation. At the downstream end of the four fields, culverts with gray boards (removable in sections) were installed to control water elevation. Since organochlorine pesticide residues such as DDE are adsorbed on fine sediments, the goal was to retain the sediment-laden tailwater within the drain long enough for the fine sediment to settle out.

After many delays, water flowed to the LDTS in January of 1999. The goal of the gravel-filled trench was to remove nitrogen and selenium from subsurface drainwater by bacterial reduction. Several species of bacteria such as Thauera selenatis and Pseudomonas stutzeri have been shown to reduce selenate to selenite and/or elemental selenium. Although drainwater contained several mg/L of dissolved organic carbon (DOC), which was hoped would serve as an energy source (electron donor) for bacterial reduction, the absence of biological oxygen demand (BOD) indicated that the DOC in the drainwater was refractory and not readily available by the microorganisms.

To provide a useable source of organic carbon, it was decided to add methanol to the system. The methanol was metered into drainwater entering the trench in an amount more than sufficient to consume the available dissolved oxygen, thereby creating anaerobic conditions required to reduce nitrate and selenate. Dissolved oxygen, nitrogen species, and selenium at inlet, outlet, and intermediate points in the trench were sampled to determine whether removal was occurring. Periodic measurements of BOD and DOC also were made. Because there was no apparent nitrate or selenate removal in the treatment trench during FY 1999, only limited samples were collected to determine whether any water quality changes were occurring in the treatment trench. Analyses included selenium, nitrite, nitrite plus nitrate, ammonia, Kjeldahl nitrogen, orthophosphate, and dissolved organic carbon and dissolved oxygen.

Figure 11
Down Gradient Sump Discharging to Treatment System

Figure 12
Widened Surface Drain with Gray Boards in Place

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CHAPTER V

Duck Club Sampling

5.1 Site Explorations

Wetlands were identified as one possible method for reducing selenium concentration in the Valley. In the Valley, no wetland systems exist for selenium removal, but there are several duck clubs throughout the area. Although duck clubs were not specifically designed for removing contaminants from water, they do provide similar wetland like functions. One such function is the creation of habitat. As a result, excess drainwater from the Valley could be used to sustain duck clubs and develop habitat areas.

Until recently, there has been an abundance of agricultural drainwater flowing to the Salton Sea, resulting in a continued rise in the Sea's elevation. In 1997, this continued rise reached a critical state when many of the trailer parks surrounding the Salton Sea were inundated. The Sea's elevation reached a maximum of about –225.5 ft below mean sea level. During this period, IID offered to divert water from surface drains to duck club in the Imperial Valley. By diverting some of the water to the duck clubs, the excessive flow to the Sea would be reduced. These diversions were meant to be flow-through systems, retaining water for some period and affording an opportunity for evaporation to reduce discharge to the Sea. In the Imperial Valley, the only source of water for wetland or duck club enhancement projects was agricultural drainwater. Projects involving federal money had to satisfy National Environmental Protection Acts (NEPA) before approval. The Finding of No Significant Impact (FONSI) for using drainwater in water bird/water fowl habitats meant that some monitoring had to be completed to determine if selenium, sediment or biota was accumulating in the water. To satisfy this requirement, the "BP" and "O" duck clubs were selected for monitoring activities (figures 13 and 14).

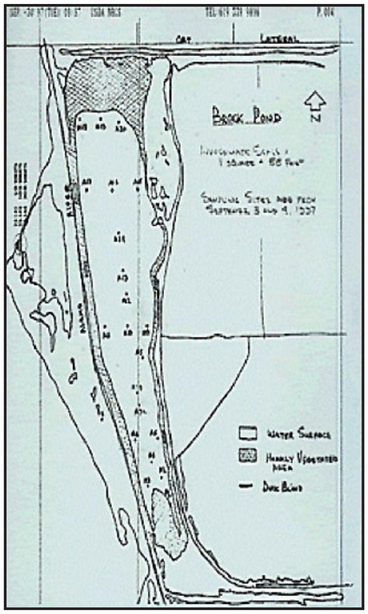

Figure 13
Schematic of Brock Pond

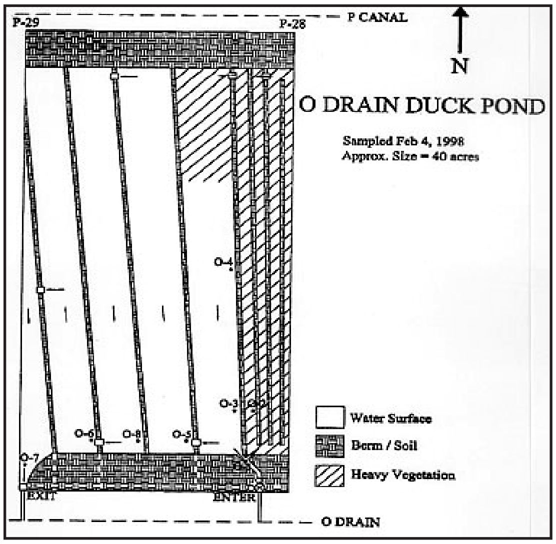

Figure 14
Schematic of "O" Duck Club

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CHAPTER 6

Discussion and Results

6.1 Lewis Drain Demonstration Findings

The underlying goal of the LDTS was to test on a field scale a means to remove selenium from agricultural drainwater. A number of technologies have been successful during bench tests, but few made the transition to field-level testing. Since elevated selenium concentrations are restricted to subsurface drainwater, it was decided that treating only subsurface drainwater would reduce the size of the treatment facility and minimize any reject water.

A water sample collected from the inflow to the LDTS on February 1, 2001 had no detectable BOD, an ammonia concentration as N of 0.05 mg/L, no detectable nitrite and 16 mg/L of nitrate-nitrogen. In the absence of an electron donor (no BOD), there was no reduction of DO, nitrate and selenate. After evaluating the problem, a decision was made to inject methanol into the system to provide an electron donor (useable carbon source). One year lapsed from the time that a design for methanol injection was completed and the injection system was installed. Once methanol injection began, it appeared that some ammonia was produced, although concentrations were quite low. Dissolved-oxygen concentrations seemed to decrease within the treatment trench while the target compound, selenate, showed only a minor decrease from a median of 24.5 _g/L for 48 samples in the inflow to a median of 21.2 _g/L at the end of the trench for the period 10/23/98 to 5/17/01.

For a short interval from June 12, 200 to April 26, 2001, there was some apparent selenate reduction and the LDTS seemed to be heading toward achieving its purpose (figure 15 and 16).

The contractor that supplied the methanol changed shortly after injection began and the new company couldn't deliver until modifications were made at the site. As the system became operational, a dense slime grew on the gravel in the delivery cistern and the system was down again until this growth could be removed. Upon restarting, a leak developed in the trench causing a section of the surface drain's bank to slough off into the drain, again shutting down the system. At this point, the project was out of time so the LDTS was terminated. With the proper design, denitrification and selenate reduction could be a viable means to remove selenium from drainwater. However, the application requires closer attention to the requirements of reducing bacteria than was possible in this attempt. The widened surface drain designed to remove suspended sediment likely will remain in place. The pipe collecting subsurface drainwater from the four fields might also be retained for possible use as a pilot site for field-testing nanofiltration for selenium removal, perhaps as part of the selenium TMDL process.

A second component of the LDSTS was a cursory evaluation of organochlorine pesticide residues, specifically DDE, in the redesigned surface drain. Soil cores were collected in September 2000 from each of the four fields (figure 17) that discharge to the Lewis Drain. Soil samples were collected from the top 6 inches using a hand auger. The soil is assumed to be well mixed insofar as it is periodically turned over to depths greater than 1.5 to 3.0 feet. Core samples also were collected at three sites from each of the four surface drain segments receiving tailwater from the fields (figure 18). DDE concentrations in the soil cores from fields one through four were 76, 95, 6.6 and 36_g/kg respectively.

DDE concentrations in the bottom-sediment samples from the surface drain were all near or below reporting limits of 4.0_g/kg. These results were interesting in two ways. First, even though DDT application was banned in 1972, metabolite residues are still present in soil from fields in the Imperial Valley. These fields were not selected with any bias toward prior application of DDT, but only because they comprise the Lewis Drain drainage. Second, soils with the adsorbed DDE are available for erosion and transport to surface drains. However, no DDE was detected in bottom sediment from the Lewis drain. The

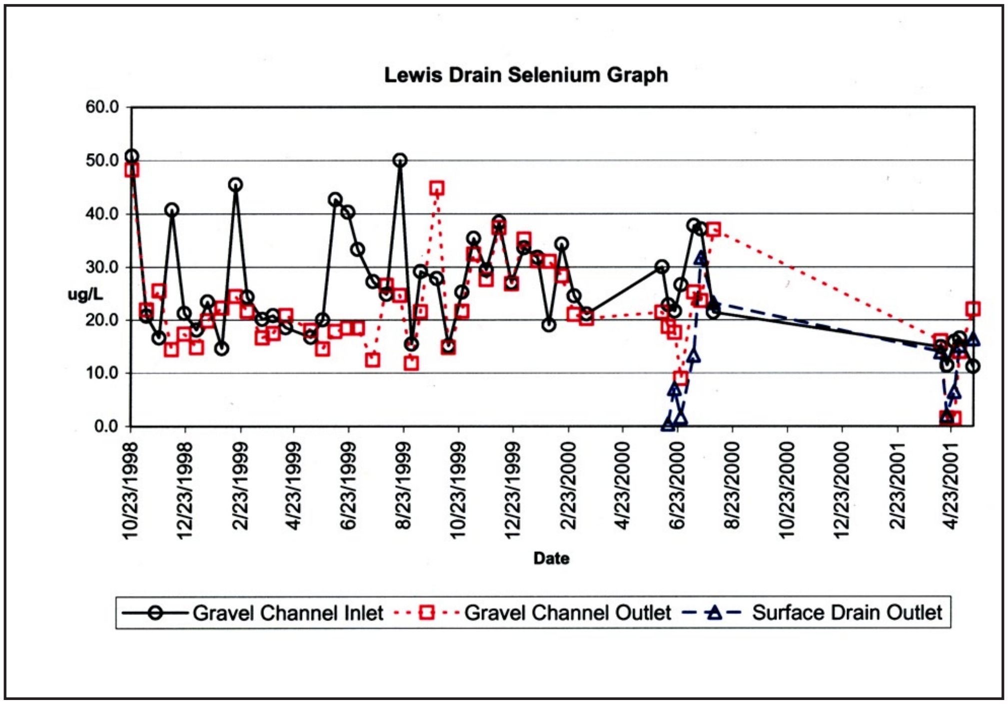

Figure 15
Lewis Drain Selenium

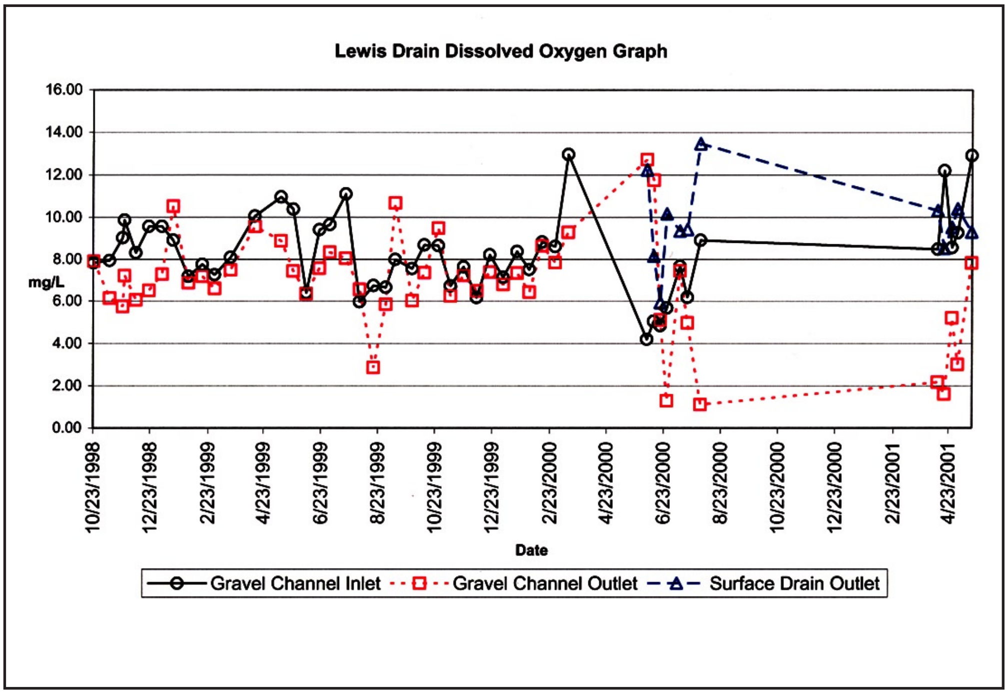

Figure 16
Lewis Drain Dissolved Oxygen

Figure 17
Sample for DDE in Soils

Figure 18
Sampling for DDE in Bottom Sediments of the Lewis Drain

presence of the DDE in the fields points to the need to control erosion and transport of sediment from fields to protect birds using the Salton Sea from eggshell thinning. Previous studies by Setmire and others, 1993, had reported the presence of DDE and other DDT metabolites in the avian fauna and bottom sediment from the Salton Sea. It is also clear from additional bottom-sediment samples collected in 1998 by Schroeder and others, written communication, that DDE is present in the fine sediments at the deeper parts of the Salton Sea (figure 19).

Although a silt TMDL is in place for the Salton Sea basin, it may not be fully protective of avian fauna of the Sea with regard to organochlorine pesticide residues insofar as it does not currently require significant reduction in suspended sediment. The surface-water component of the Lewis Drain was designed to enhance sedimentation within its reaches to prevent the transport of particles containing DDE. It is surprising, therefore, that no DDE was detected in bottom sediment from the drain. Further analysis may be needed to determine the size fraction of soil in the field that contains the adsorbed DDE and compare it to the size fraction of the bottom sediments. Also, it is possible that dredging of the drainage channel exposes deep soils that are contaminant free and act as “dilutants” to any eroded soil that accumulates in the drain.

6.2 Duck Club Sampling

Brock Pond is an older single-cell pond that has received drainwater for decades. The oblong pond is about 1,850 ft long, increasing from a width of 160 ft near the inflow to 450 ft near the outflow. Water depths range from about 0.3 ft at the inflow to 3.0 ft at the center of the pond. The average depth is about 2.5 ft. Water samples were collected September 3 and 4, 1997, at 20 sites using a modified Van Dorn water bottle. Bottom-sediment samples were collected at 17 sites using a piston corer with clear plastic-liner insert. The top 2 inches of material were extruded from the cores for analyses. At site 5, the core was sampled from the top 2 inches and from 2-4 inches. Selenium concentrations in water ranged from 2 to 5µg/L at the inflow. Selenium concentrations in bottom sediments ranged from 1.6 mg/kg to 5.3 mg/kg with a median of 3.5 mg/kg. At site 5, the selenium concentration was 5.3 mg/kg in the top 2 inches and 1.6 mg/kg in the next 2 inches. In spite of the shallow depth, there was a significant vertical gradient for selected field data in the water column due to the extensive phytoplankton growth. The median DO concentration and saturation was 19.3 mg/L and 200%, respectively, at the top of the water column and 6.6 mg/L and 82% at the bottom. Median water temperature decreased from 31.1 to 28.8 degrees C, specific conductance increased from 4175 to 4578 microsiemens, and pH from 8.8 to 7.9 from the top to the bottom in the water column.

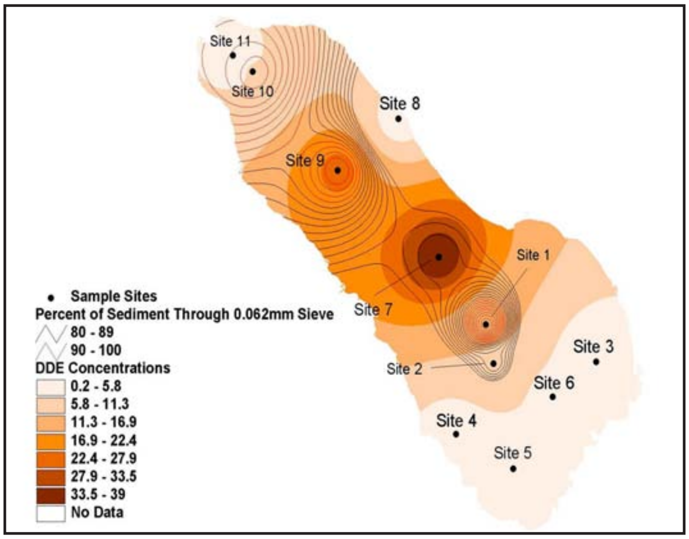

Figure 19
Sample Sites

On the evening of February 4, 1997, light traps were placed at six selected sites to collect aquatic invertebrates. The traps consisted of 4-L polyethylene jars with the bottom cut out and a funnel glued in place. A six-volt- flashlight was attached to the large mouth opening of the jar. The jars were filled with water, inverted to immerse the funnel, attached to metal fence posts, and placed in the water so the invertebrates would swim up the funnel toward the light and be trapped in the jar. The traps were retrieved on the morning of February 5. Very few aquatic invertebrates were present in any of the light traps. Site A-3 had sufficient biomass for analysis. This site was located in a shallow area with crags and a dead tree where the water was more of a chocolate brown from resuspended sediment in the surface drain compared to the green color from the abundant phytoplankton at the remaining sites. Two other sites, A-5 and A-11 had sufficient biomass for selenium analyses. Selenium concentrations in aquatic invertebrates were 1.56 mg/kg at A-3, 5.55 mg/kg at A-5 and 2.45 mg/kg at A-11.

"O" Duck Club was a new-multiple channel pond near the Salton Sea. It was converted from an agricultural field and received inflow from irrigation drainwater. The pond consists of very shallow parallel rows with depths of 0.5 ft or less. The outflow from one row becomes the inflow for the next row. "O" was sampled once during the winter. Water, bottom sediment, vegetation and invertebrates were collected for analysis. Selenium concentrations in water showed no apparent pattern and ranged from 1 to 6 µg/L with a median of 3 µg/L. Because drainwater in the "O" Duck Club ponds had variable selenium inflow and long retention times, water samples collected during one day throughout the pond were not indicative of processes occurring within the pond. Therefore, no comparison could be made between inflow and outflow concentrations. Bottom sediment sampled collected throughout the pond had selenium concentrations ranging from 0.28 to 1.59 mg/Kg, with a median of 0.5 mg/kg for seven samples, and invertebrate samples had selenium concentrations ranging from 0.35 to 1.59 mg/Kg with a median of 0.7 mg/Kg for 6 samples.

6.3 Nanofiltration

Research personnel from the USGS in Menlo Park and San Diego along with a USBR hydrologist and a nanofiltration operator from US Filter tested the ability of nanofiltration to remove selenium in drainwater from three selected drains in the Imperial Valley having a range in selenium concentration and differences in relative proportion of chloride and sulfate. Several different types of filters and organic surfactant agents to inhibit precipitation of calcium salts were tried. Results from the tests are expressed in terms of rejection efficiencies according to the equation $RE = (1-Ce/Cf) \times 100$ where Ce is the concentration of the solute in the effluent (product stream) and Cf the concentration in the feed stream (Kharaka, 2000). Kharaka (2000) indicates “the concentrations of Se in the concentrated (feed) stream increase with increasing water recovery, but those in the effluent (product) stream remain low. “ “Results give RE values >95 % for Se, SO4, U, Mo, and organics. The efficiencies calculated are also high for Ca and Mg but lower for Na and other monovalent cations.”

The following data are from Kharaka and others, 2000 from a field experiment conducted in the Imperial Valley during April 1997. Subsurface drainwater in sump S-243 had a selenium concentration of 42_g/L. When processed through a FT-45 membrane with no inhibitor, a rejection efficiency of 91.2 percent was achieved. The product water selenium concentration was 3.2_g/L (reject stream) and final feed stream concentration was 244_g/L. Subsurface drainwater from S-241 had a Se concentration of 59 µg/L, 66 percent rejection efficiency (RE), final product water Se concentration of 1.9 and feed stream Se concentration of 169 _g/L. For S-241 using the inhibitor Aquafeed 600, a RE of 90.5 percent was achieved with a final product water Se concentration of 25_g/L and a feed-stream Se concentration of 354_g/L. Water from S-226 with a Se concentration of 63_g/L was processed using two different inhibitors. With no inhibitor, the RE was 79.5 percent with a final product-water Se concentration of 1.0 µg/L and a feed-stream Se concentration of 221_g/L. With the Aquafeed 600 inhibitor, the RE was 95.6 percent with a final product- water Se concentration of 10_g/L and a feed-stream Se concentration of 346_g/L. A Desal membrane with Dequest 2054 inhibitor produced a RE of 91.3 percent with a final product-water Se concentration of 2.0_g/L and a feed-stream Se concentration of 500_g/L.

These results show that nanofiltration can be a very effective way to remove selenium from agricultural drainwater although it is not inexpensive. Kharaka and others (2000) provide some estimates for cost. The volume of poor-quality water from the feed stream is significantly less than the high-quality product water, leaving disposal of the reject by evaporation a viable possibility.

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CONCLUSIONS

The study investigated a variety of methods to remove selenium from irrigation drainwater. Nanofiltration was the most successful. Field test of nanofiltration demonstrated rejection efficiencies (removal) over 90 percent. Adding precipitation inhibitors benefited some membranes tested allowing the concentration of selenium in a smaller water volume before failure of the membrane occurred. Nanofiltration membranes reject multivalent ions such as selenate. Because nanofiltration requires significantly less pressure than reverse osmosis, it might be cost effectively applied to treat subsurface drainwater. High rejection efficiency leaves relatively small volumes of waste stream to dispose. These systems could be place adjacent to sumps and discharge very low-selenium water to surface drains. The reject water could be discharged to nearby evaporation ponds and further evaporated to dryness.

The Lewis Drain Treatment System was a field demonstration of another technology relying on anaerobic reduction of nitrate and selenate. While the process remains feasible, implementation did not create appropriate conditions for reduction to occur. Retention time in the pond may have been insufficient and the slope of the trench precluded maintaining water in the system and the gravel wetted at all times. A “flatter” system would have been preferable. Additionally, a source of carbon in subsurface drainwater is needed as an electron donor for reduction. Sufficient carbon is needed for bacteria to remove dissolved oxygen before anaerobic reduction of nitrate and selenate follow. Methanol injection to provide a carbon source was tried, but too late in the project to determine its efficacy. The LDTS was beset with design and operational problems. Other selenium removal methods could be easily tested using this system since the sumps remain connected. Nanofiltration would be an excellent technology to test over a longer period than was accomplished during the 1997 field test. Other technologies such as packed column bioreactors also could be tested over a longer time to determine maintenance requirements and costs, the main considerations being quantity and cost of a carbon source, regenerating the column, and maintaining proper environmental conditions for bacteria.

Although duck clubs, which perhaps could be extrapolated to apply to wetlands, appear to remove selenium, they must be designed to prevent bioaccumulation of selenium to levels of concern in biota. Selenium loading to wetlands seems to accumulate in bottom sediments and in benthic invertebrates, algal mats and vegetation such as bulrush. The question of bioavailability remains to be fully studied.

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