A Technical Advisor's Manual
Managing Agricultural Irrigation Drainage Water

A guide for developing Integrated On-Farm Drainage Management Systems

Developed for the
State Water Resources Control Board
by the
Westside Resource Conservation District
in conjunction with the
Center for Irrigation Technology,
California State University, Fresno

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Dedication

This drainage management manual is dedicated to the memory of Frank Menezes, who died in 2001. Frank was an agronomist with the Natural Resources Conservation Service in Fresno, and was one of the pioneers in helping develop Integrated On-Farm Drainage Management systems to manage saline drainage problems.

Frank was a valuable asset to the San Joaquin Valley's Westside agricultural community, focusing on salinity and drainage management – in particular, development of the Integrated On-Farm Drainage Management system.

Frank's technical knowledge, practical understanding of farmers' and ranchers' needs, and warm and engaging manner made him one of the Westside's most respected and beloved individuals. Because of his tireless efforts in helping develop and implement IFDM systems on Red Rock Ranch and at other sites, this publication is dedicated to Frank Menezes.

Although many people contributed to the production of this drainage manual, three people must be recognized for their longtime commitment to the development of Integrated On-Farm Drainage Management systems.

Since 1985, Dr. Vashek Cervinka, California Department of Food and Agriculture, Clarence Finch, United States Department of Agriculture Natural Resources Conservation Service, and Morris A. "Red" Martin, United States Department of Agriculture Natural Resources Conservation Service, have been major forces in the development of agroforestry and on-farm drainage reuse to help manage salinity and shallow groundwater levels. Their early efforts and institutional knowledge of salinity and drainage on Westside soils – much of it documented in this manual – provides farmers with a viable option to ensure continued production of high quality food and fiber crops. Although all three have retired from their agencies, they continue to be involved in the development of IFDM systems while working with the Westside Resource Conservation District.

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About this manual

This manual is part of a two-part educational and outreach program to educate landowners and technical advisors about the advantages, disadvantages, costs, environmental regulations and other considerations in developing and implementing an Integrated On-Farm Drainage Management program for salinity control.

The first part of the educational program focused on the production and distribution of a guidance manual designed for landowners. It was released in 2004.

This manual is the second component of the program, and is designed to provide technical consultants and support personnel with the tools they need to assist farmers with developing and implementing an effective IFDM program.

An IFDM system can serve as a viable alternative for landowners who may not choose to participate in a voluntary land retirement program for drainage-impacted lands. Once irrigation systems have been optimized to maximize water use efficiency and to minimize the production of subsurface drainage water, an IFDM system can be designed to enable the landowner to process the resulting drainage water on-farm. Interest in IFDM is increasing.

The merits of IFDM have been recognized by the U.S. Environmental Protection Agency and the State Water Resources Control Board through the award of a Clean Water Act Section 319(h) Grant to educate farmers and to train professionals about IFDM implementation. Both manuals were funded by the grant, targeting the needs of the landowners, water/drainage district managers, engineers and technical professionals.

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A Technical Advisor's Manual

Managing Agricultural Irrigation Drainage Water:

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Chapter 1. Introduction

A. Background

Soil salinity management in irrigated agriculture is a problem that has persisted for millennia. The "first" civilization of Sumeria is thought to have perished, in part due to the salinization of the soil in the area known as Mesopotamia between the Tigris and Euphrates River in what is present day Iraq.

The modern technique of below ground (below the crop root zone) subsurface drainage systems made of perforated clay or plastic pipe forestalls salinization, but discharge of the salty waste water from the collection system requires an outlet to an appropriate disposal area.

Disposal techniques used in the San Joaquin Valley in the past included, discharge to surface water, evaporation ponds and deep well percolation. Early use of these techniques did not take under consideration the impact to the environment.

In the mid-1980s, a significant new development cast a doubt on the efficacy of surface water and evaporation disposal systems. This development was the problem of poor egg hatches and deformed newborn offspring of various waterfowl species at Kesterson Reservoir in western Merced County. At the time, Kesterson Reservoir was the terminal evaporation facility of the federal San Luis Drain, a feature of the federal Central Valley Project that was designed to manage the subsurface drainage from the San Luis Unit lands in western Kings, Fresno and Merced counties. The original drain design was meant to be discharged into the estuary of the San Joaquin – Sacramento River Delta system, but was stopped short due to changing financial conditions and emerging environmental laws, rules and regulations.

The investigation into the cause of the environmental problems revealed that the drainage water from the western San Joaquin Valley had the potential to contain sufficient levels of the naturally-occurring element selenium (Se) to cause a mutagenic condition in birds. The environmental problems at Kesterson Reservoir lead to the closure of the San Luis Drain and subsurface drainage water disposal from the lands served by the drain was terminated in 1986.

The closure of the drain resulted in an extensive research effort by the U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, with the California Department of Water Resources and the University of California. Recently, USDA Agricultural Research Service and California State University, Fresno researchers are identifying sources of drainage water and alternatives for disposal. Much of this research is devoted to identifying the sources of drainage, the potential for reuse of saline drainage water as an irrigation supplement, the impact of saline water on plant and soil quality, and biologic systems to reduce selenium (Se) in the water. The last problem to be solved is the final disposal of concentrated saline brine and the solid salt. This problem is still being studied and several alternatives are under investigation to confirm their efficacy.

After five years of study, the USBR San Joaquin Valley Drainage Program report (1990) identified several actions that should be taken to alleviate and/or eliminate the drainage water disposal problem. The first action was source control, improving irrigation water management to reduce deep percolation losses. The second action was to use drainage water as supplemental irrigation for salt-tolerant crops. Both actions lead to a reduction of the total drainage water volume. The third action was land retirement. Drainage is eliminated because there is no longer any irrigation water being applied to the soil surface. Even with widespread land retirement there are still many acres requiring drainage service.

The Westside Resource Conservation District (WRCD) has been a sponsor and coordinator of research trying to identify environmentally friendly and economically viable methods of drainage water disposal since the early 1980s. This guide along with the Landowner's Manual is the culmination of the effort to develop a system to provide on-farm drainage water disposal in an environmentally sound manner.

Definition

Integrated on-Farm Drainage Management (IFDM) is an integrated water management system designed to manage irrigation, surface, and subsurface drainage flows within a farming unit and to provide the ultimate disposal of all drainage water including saline water in an environmentally sound manner.

This definition varies slightly from the one in the Landowner's Manual and the one found in the regulations. The above definition is very broad and includes the essence of the other definitions. It is important to understand at the outset what is involved with the IFDM concept, since this will drive the design and operation. Both surface and subsurface drainage were included in the definition because surface drainage (tailwater) will generally be low in salt and will be readily available for use on other fields without any significant changes in on-farm water management. This also implies that surface and subsurface drainage water should be separated into two flow streams, which is a requirement in many irrigation districts on the west side of the Valley.

Implicit in this definition is the consideration that source control is a significant component of an IFDM system. If a drainage water disposal system is being developed, then the goal of the integrated system should be to minimize the drainage water volume by implementing source control. Reuse of drainage water also will be a component to provide additional reduction of the drainage volume in an economic manner. The component needed for the ultimate disposal still must be completely developed. The ultimate disposal may be either on a salt-tolerant crop or in a solar evaporator.

There is no single design for a solar evaporator. Currently, various configurations of solar evaporators are being tested, and designs are being developed based on those tests. The State of California has written regulations covering the solar evaporator design, construction, operation and closure requirements, which will be presented in the Appendix along with an example solar evaporator design.

It must be emphasized at this point that there is **no standard design** for an IFDM system. The designer will be developing an irrigation and drainage water management system that disposes of saline drainage water on the farm. The manner and components of the system will be developed based on the existing equipment, crops grown and long-term goals of the farmer. For the sake of simplicity, the IFDM system described in this manual is a multi-component process implemented with reuse of subsurface drainage water. The process involves the application of "good" quality water to salt-sensitive crops and saline water to salt-tolerant crops. The number of reuse opportunities will be a part of the design and may vary from one to three reuses.

The need for data related to the on-farm water management and the regional groundwater hydrology will become apparent to the designer during project development. Water quality data for the irrigation water supply and shallow groundwater are needed for the design to meet regulatory requirements. The experience gained at pilot IFDM sites suggests that the electrical conductivity (EC) of the shallow groundwater may be a good approximation of the quality of the drainage water that will be produced by the drainage system in that field.

An IFDM system currently serves as a viable alternative for on-farm subsurface drainage water disposal system throughout the San Joaquin Valley. Evaporation ponds are being used in some locations, but the requirements for mitigation and compensation wetlands, and the environmental monitoring limit the viability of ponds to those areas with very low levels of selenium.

B. Salt Management

Salt management is a significant aspect of an IFDM system operation. It is closely linked to water management and requires the manager to develop a new set of skills and thought processes. It is important for the designer to recognize the need for salt balance in the root zone.

The salt balance, as a long-term steady state concept, was developed to prevent soil salinization and it states that the amount of salt entering the irrigated area has to be moved through the system and discharged, **salt out = salt in**. This is intended to ensure the sustainability of irrigated agriculture, and theoretically, this is true in systems that do not have large stores of native salt in the soil profile below the crop root zone. This is not the case in the San Joaquin Valley. A salt mass comparison between the input to all the fields and the output to the solar evaporator will not be an accurate representation of the salt dynamics in an IFDM system in the Valley.

In the San Joaquin Valley, the subsoil contains a large mass of salt that is mobilized by the operation of subsurface drains collecting deep percolation from irrigation. As a result, more salt leaves the system routinely than is applied in the irrigation water. Nevertheless, this does not mean that a salt balance has been achieved. Instead, it means that salt is being mined from somewhere in the soil profile.

The large salt mass in the groundwater masks any concentrating effect occurring in the deep percolate as a result of crop water use. Instead, the deep percolate is mixed with the shallow groundwater and the resulting salinity is that of the groundwater. This means that the EC of the successive reuses will reflect the groundwater quality and not the concentrated deep percolate.

Once the root zone has been leached to the salinity level needed to sustain production, it will be an integral part of the system management to control salinity levels through wise water management. It will no longer be acceptable to let subsurface drains run freely and apply excessive amounts of water to reduce soil salinity, once salinity levels in a particular field have been reduced to the desired levels. This type of operation will result in excessive accumulation of salt in the solar evaporator with no benefit to production.

The fields in an IFDM system will require periodic salinity assessment and management to correct any salt accumulation in the root zone. Leaching may need to be scheduled in the initial startup to take advantage of the disposal capability of an IFDM system. In the vernacular of the times, we will have to develop a new paradigm for salinity management. The point of measurement for a salt balance needs to be the root zone for a particular field.

There are two other terms that are used in salt management to quantify the leaching process. These are the leaching requirement (LR) and the leaching fraction (LF). Both terms often are used interchangeably, but in fact, they are not interchangeable. The LR describes the amount of water needed to maintain the salinity level in the root zone, and is often calculated using irrigation salinity and the desired soil water salinity measured in the soil. It is a theoretical calculation while the LF is a measure of the amount of water lost to deep percolation and is calculated after the fact. It is calculated using the measured EC of the irrigation water and the measured EC of the soil water.

The LR is given as $LR=EC_{iw}\ EC_{dw}$ where EC_{iw} is the electrical conductivity of the irrigation water and EC_{dw} is the desired electrical conductivity of the soil water in at the bottom of the root zone. The LF is given as $LF = EC_{iw}^{*}/EC_{dw}^{*}$ where the "*" indicates the actual values that were measured after the irrigation.

The distinction becomes important during the design phase for the irrigation and drainage system. There is a need for some deep percolation to maintain the salinity in the root zone, but there is no need for excessive amounts. As part of the design process, the designer will have to determine the amount of deep percolation needed for salinity control. As a first step, the percentage addition can be estimated using the EC of the irrigation water and a value for the soil salinity that will not result in crop losses. Then the irrigation system is selected and estimates made of the efficiency of the system. If the irrigation inefficiency is greater than the theoretical LR there is no need to add extra water to the estimated irrigation requirement. However, if the LR is greater than the irrigation inefficiency an increment will have to be added to the irrigation amount. This will be demonstrated in Chapter 3. The estimated inefficiency of the irrigation system will be the input to the design of the drainage system and will be the ultimate disposal volume, so it is critical to minimize the volume of deep percolation at this step. This also demonstrates the effect of using progressively more saline water for irrigation on the LR.

C. Regional Groundwater Flow

One of the problems facing the designer will be the influence of regional groundwater flow on the drainage system operation. Because of the fluvial nature of the soils on the west side of the Valley, there are many embedded sand stringers. These geologic features have the ability to move water throughout the region such that water captured by a drainage system may not have originated on the farm. This will make the design particularly difficult when it comes to estimating the drainage flow to be accommodated within the IFDM system.

Aerial photographs and farmer knowledge of the site, and soil surveys will help identify the problem areas and may suggest design alternatives. Deep-rooted tree species are often used to alleviate this condition by intercepting subsurface flows.

D. Source Control

Source control is simply limiting deep percolation losses from irrigation applications, supply canals and any other structure that conveys water and is possible to manage. There is very limited potential for controlling deep percolation from precipitation, but there are some water management alternatives. One management alternative that allows some available soil water storage for rainfall is using sprinklers at pre-plant irrigation and limiting the depth of application to not completely replace soil water. Adopting this practice may require a change in early season water management to ensure germination and crop stand development.

Source control is emphasized throughout this document as being the critical component in the design process and in the operation of the system.

E. Active Management

There must be active management of the entire IFDM system for it to be sustainable. This means that water management on the farm has to have a significant focus. The irrigation and drainage systems must have an integrated approach. The irrigation must be scheduled and the irrigation schedule must include the impact of the drainage system operation on crop water use from shallow groundwater. The irrigation system design has to be strictly followed. Poor implementation will result in poor distribution uniformity, excess deep percolation losses and potential yield loss.

Active drainage system management also is required. This will be further discussed in the drainage design section in Chapters 3 and 6. This will be a new concept to most managers. Drainage systems generally have been designed to operate continuously and draw the water down. There has not been consideration given to managing irrigation and drainage systems as a single entity. As the crop develops, there is a potential for significant crop water use from shallow groundwater that must be considered when making irrigation decisions. In-situ crop water use may result in less irrigation over the season and may reduce drainage water. Managing surface water to limit standing water and tailwater also will be required. If the surface water contains selenium there is the potential for impacts on wildlife that may have regulatory consequences.

IFDM System Description and Example of Operating IFDM System

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Chapter 2. IFDM System Description and Example of Operating IFDM System

A. Introduction

In the IFDM system, the most significant component that has regulatory requirement is the solar evaporator. In this chapter, an IFDM system will be described in general terms. The regulatory aspects of an IFDM system are detailed in the Appendix pages A-26 to A-30, A-51 to A-57, A-65 to A-97 of this manual, as well as in the Landowner's Manual.

B. Basic Description of IFDM System

An IFDM system is an on-farm water and salt management system, using saline drainage water for irrigation as a means to manage salinity and to dispose of saline drainage water. There is no set configuration or design of an IFDM system. The following component description is based on the experimental IFDM system currently in use at Red Rock Ranch (RRR) and is only presented here to highlight potential considerations for the design of an IFDM system. The RRR system includes a border strip of trees to intercept regional groundwater flow, crop production areas for salt-sensitive crops, salt-tolerant crops and halophytes and a solar evaporator. Each of the production areas has a subsurface tile system that drains to a sump, sump pumps and piping to move the collected subsurface drainage water to each of the cropping areas or to the salt harvest area.

In the first production area, irrigation or surface (tailwater) water is used to irrigate salt-sensitive crops. This generally will be the largest production area in a system. The subsurface drainage water from the salt-sensitive area is collected and may be blended with fresh water or tailwater for use on the next production area, which is cropped with salt-tolerant plants. Drainage water from this production area is collected and used to irrigate salt-tolerant crops, such as forage grasses and halophytes. Drainage water from the halophyte production area is discharged to the solar evaporator (salt harvest area) for final disposal, leaving dry salt as a product, which may be disposed of, marketed or stored.

Since all of the production areas will have subsurface drainage and pumping systems installed, there is no requirement to maintain a fixed position for each of the aforementioned production areas. It may be possible to move these areas around within the system. This will depend on the salinity status in the soil profile and the groundwater quality. This would entail developing practices such as the cyclic use of saline and good quality water as proposed by Rhoades (1989).

1) Border Strips of Trees

The rows of trees used to intercept regional flow should be located up-gradient of the area where the IFDM system is being constructed. There is potential to use large quantities of water with trees having deep extensive root systems. Trees also are useful along crop areas where shallow groundwater problems arise. Eucalyptus, Athel and Casuarina trees are selected for their ability to use large volumes of water and are frost- and salt-tolerant (survive with water with TDS of 8,000-10,000 ppm). Trees also are useful as windbreaks and in the control of spray drift.

2) Crop Production Areas

IFDM systems have been designed with up to three distinct production areas and a solar evaporator. The number of production areas used in the final design will be determined by the quality and quantity of the drainage water and the proposed cropping plan.

The purpose of crop areas is to:

- Maximize economic production.
- Use drainage water as a resource to produce crops, while saving energy and water.

As the IFDM system design and operation has evolved, there has been a customizing of the terminology to better describe the various steps in the process. Early work referred to the reuse areas as stages, but the term production areas, in relation to the quality of water being used and the number of reuses of drainage water, will be used in this manual.

The first production area of the IFDM system is irrigated with good quality water and supports production of salt-sensitive crops. The subsurface drainage system provides the drainage necessary for salt management and the collected drainage water is used for irrigation in the next production area. Surface drainage (tailwater) in this area should be captured and used for irrigation on other areas requiring good quality low-salinity water. Generally, the best fields with the least salinity problems will be selected for inclusion in the first production area. If needed, some leaching will be done to enable production of salt-sensitive crops. Crop examples in the first production area may include a rotation of salt-sensitive crops i.e., vegetables and alfalfa.

The second production area of the IFDM system is the first step in drainage water volume reduction and is the first reuse area. Crops with a higher salt tolerance are irrigated with subsurface drainage water collected from the salt-sensitive crops. Crop examples in the first reuse area include cotton and forage grasses of moderate-to-high salt tolerance. If the salinity of the drainage water is too high for cotton and similar crops, some blending can be done to match crop salt tolerance and EC of the irrigation water. The area used in production of salt-tolerant crops will be determined by the volume of drainage water collected from the first production areas. The use of water with higher salinity levels will require additional deep percolation (leaching requirement) to maintain the salt levels in the soil profile, which will require careful design of the drainage system. Surface runoff can be recycled to the same field through a tailwater return system or on to the next reuse area. Runoff from the reuse area should be minimized.

The production area of the IFDM system that contains the most salt-tolerant forage crops is irrigated with the subsurface drainage water collected from the first reuse. Crops in this area tend to be more salt-tolerant than most agronomic crops and may result in a limited economic value for this area, which suggests that this production area should be minimized. Deep percolation losses also will increase with higher salinity levels in the irrigation water, which will have to be considered in the drainage design. Halophytes can be grown and this area is a disposal site for the last possible reduction of drainage water volume. Most of the halophytes currently have little economic value. Again, surface runoff should be minimized.

At each step in the process, the goal is to reduce the total volume of water being collected under each production area so the minimum amount of water is collected and ultimately discharged to the solar evaporator. It should be noted that there is no mention of the concentration of salt in the drainage water collected under each production area as would be expected in a purely theoretical calculation. This is because in the San Joaquin Valley the total mass of salt in the soil profile below the root zone masks any concentrating effect that may occur as a result of crop water use. By the time the deep percolation has moved to the drainage system, the deep percolation has mixed with the shallow groundwater and reflects the groundwater salinity. This means that in the San Joaquin Valley there is probably not a need for growing halophytes. It may be possible to confine the production to the salt-sensitive crops and moderately salt-tolerant crops with the disposal being accomplished by successive reuse on the salt-tolerant crops and finally discharge to a solar evaporator. This is a potential that should be evaluated during the design.

3) Solar Evaporator (Salt Harvest Area)

The Salt Harvest Area is the final treatment point of saline drainage water in the IFDM system. As a result of the evaporation that occurs in the solar evaporator, a dry salt product will be produced.

Solar Evaporator Regulations under Title 27 define solar evaporator, water catchment and standing water. The salt harvest area consists of a solar evaporator or solar evaporator and water catchment basin. "Solar evaporator" means an on-farm area of land and its associated equipment that meets all of the following conditions:

1. It is designed and operated to manage agricultural drainage water discharged from the IFDM system.
2. The area of the land that makes up the solar evaporator is equal to, or less than, two percent of the area of the land that is managed as the IFDM system.
3. Agricultural drainage water from the IFDM system is discharged to the solar evaporator by timed sprinklers or other equipment that allows the discharge rate to be set and adjusted as necessary to avoid standing water within the solar evaporator or, if a water catchment basin is part of the solar evaporator, within that portion of the solar evaporator that is outside the basin.
4. The combination of the rate of discharge of agricultural drainage water to the solar evaporator and

subsurface tile drainage under the solar evaporator provides adequate assurance that constituents in the agricultural drainage water will not migrate from the solar evaporator into the vadose zone or waters of the state in concentrations that pollute or threaten to pollute the waters of the state.

The operation and management regulations are covered in Title 27 and the designer must fully comply with this statute. Additionally, there are several water quality acts and regulatory considerations that are included in the design and operation. All the pertinent regulations and environmental acts are provided in the Appendix.

C. Example IFDM System – AndrewsAg Inc. (previously Rainbow Ranch) IFDM project

1) Background Information

AndrewsAg Inc. is a diversified farming operation that grows, packs and ships vegetable crops and grows cotton in the southern San Joaquin Valley.

Prior to 1999, their only option for in-region disposal of subsurface drainage water from 1,034 acres was through the use of 100 acres of evaporation ponds. The operation, maintenance and monitoring costs associated with these ponds were too high to be economically viable. In addition to these costs, AndrewsAg was required to establish and maintain a 125-acre pond, for compensation habitat. These economic factors forced them to consider other management strategies for drainage disposal while maintaining agricultural productivity and meeting environmental requirements. Two possible alternative choices were either to retire the farmland or develop an IFDM system on this farm. The IFDM system was the preferred choice.

The transition to the IFDM system started in 1999. Project objectives included: (1) closing the evaporation pond; (2) managing drainage water, salt and selenium on the farm with regard to environmental requirements; (3) using drainage water for the commercial production of salt-tolerant crops, grasses and halophytes; (4) sustaining agriculture and the production of high value salt-sensitive crops; and (5) converting the operation of the evaporation pond into a solar evaporator.

2) Initial IFDM System Design

Subsurface drainage systems had been installed in the cropped area (1,034 acres) prior to 1999. After consultation with Michael Andrews, owner of AndrewsAg, the IFDM system was designed as follows:

- salt-sensitive crops on 752 acres
- salt-tolerant crops on 242 acres
- halophytes on 40 acres of drained crop area.
- The cells 2A & 2B (20 acres) of the existing evaporation pond were reserved for a solar evaporator.

The schematic of the system is given in Figure 2-1.

Additional sumps, pumps and pipes were installed at strategic parts on the property for the management of the reused drainage water. A larger area of both halophytes and solar evaporator was chosen to provide for the future expansion of the IFDM system.

The development of the IFDM system proceeded using these steps:

1. Discontinued discharge of drainage water into evaporation ponds to dry the cells.
2. Created a temporary 10-acre solar evaporator for discharging drainage water before installing a permanent solar evaporator.
3. Planted halophytes in the 40-acre northern area of fields.
4. Installed two new sumps for reuse of drainage water.
5. Established a permanent solar evaporator.
6. Transferred salt from the remaining cells of the evaporation pond into the new solar evaporator.

Initially, the IFDM system included this cropping system:

Salt-sensitive crops	752 acres	72.7 %
Salt-tolerant crops	242	23.4
Halophytes	40	3.9
Total	1034	100.0

It is important to note that much of the surrounding land is fallow, and there is little-to-no influence of subsurface regional flow at this farm.

3) Description of Current IFDM System

Over the last couple of years, some changes have occurred in the IFDM system. One change was the increase in total farm acreage when an additional 160 acres of land was purchased and added to the salt-sensitive production area of the IFDM system. Additionally, the salt-sensitive production area increased from the conversion of some land originally used to grow salt-tolerant crops. There was a shift from surface irrigation to drip irrigation that resulted in higher irrigation efficiency and lower drainage water yields, and, consequently, the area of salt-sensitive crops was increased in acreage and the salt-tolerant crop area could be reduced. This highlights the need for a detailed evaluation of existing and proposed irrigation practices as part of the design process.

The revised and present cropping system now includes:

Salt-sensitive crops	1,022 acres	85.6 %
Salt-tolerant crops	132	11.1
Halophytes	40	3.4
Total	1,094	100.0

The IFDM system was designed to operate with the following management strategies: either reuse drainage water twice (to salt-tolerant crops and then halophytes) or only once (to halophytes). Lettuce, asparagus, bell peppers, melons, carrots, garlic and onions are grown in the area of salt-sensitive crops. Cotton is grown in the area of salt-tolerant crops. Native saltgrass, NYPA saltgrass and iodine bush are grown in the halophyte section. Sprinklers (the same sprinklers and spacing as described in the solar evaporator design specifics, except for 24-inch riser height) are used to distribute drainage water in the halophytes to prevent water ponding and to increase salt leaching.

4) Physical Description of the AndrewsAg Inc. Solar Evaporator

The solar evaporator consists of a 20-acre spray field (photograph no. 1) supplied by a close coupled turbine pump mounted on a concrete sump (photograph no. 2). The site has been graded to meet the regulations as required to control potential rainfall developed runoff. As can be noted from photograph no. 1, the site is relatively flat and devoid of vegetation.

The spray field is irrigated by a buried solid-set sprinkler system. Specifics of the design are as follows:

Sprinkler: Rainbird model SLL2OVH, 1/2-inch
Steel impact sprinkler with 7/64-inch nozzle

Sprinkler Performance: 2.32 gpm at 45 psi
Wetted radius, 28 feet

Spacing: 30 feet by 45 feet (triangular)
Estimated uniformity coefficient 85%
Application rate, 0.17 in/hr. (gross)

Riser: 1/2- inch schedule 80 PVC pipe by 12 inches long

Lateral Pipe: 2-inch schedule 40 PVC pipe with solvent welded joints

Mainline Pipe: 6-inch schedule 40 PVC pipe with solvent welded joints and fittings

Valves: Manual valves were installed to allow for the individual operation of the 8.0 and 12.0 acre blocks

Pumping Plant: Capacity, 900 gpm at approximately 140 ft. TDH

Operation: The sump collects the drain tile discharge from the halophytes. As the sump fills up, a float switch actuates the pump thereby sending the drainage flow to one of the spray field blocks. The operation is managed visually such that before surface free water is observed, the valves are adjusted manually, sending the pump discharge to the second spray field block.

Tile drainage water from the halophytes is collected in the holding basin shown in photograph no. 3. The pump shown transfers this water to the concrete sump shown in photograph no. 2. This provides some needed surge capacity, thereby allowing for efficient operation of the system. The sprinklers are mounted on short risers to ensure that the salt spray does not leave the site. The sprayed water quality is a natural herbicide, as no vegetative growth can be observed on site. The spray field is located in the bottom of former evaporation ponds. Lumps of salt that were transferred from the former evaporation ponds are visible in photograph no. 1.

Photograph 1: View of the spray field featuring a buried solid-set design

Photograph 2: Spray field pumping plant showing a close-coupled turbine pumping plant mounted on a concrete pipe sump. Note spare pump.

Photograph 3: Holding basin collecting the drainage discharge from the halophyte area and the booster pump that transfers the water to the spray field pumping plant.

This IFDM system is operating with satisfactory results and is being used as a model design framework for new IFDM systems. The original objectives have been achieved by (1) improving irrigation efficiency and management, (2) sequentially reusing drainage water on salt-tolerant crops and halophytes, and (3) discharging the final volume of drainage water into a solar evaporator.

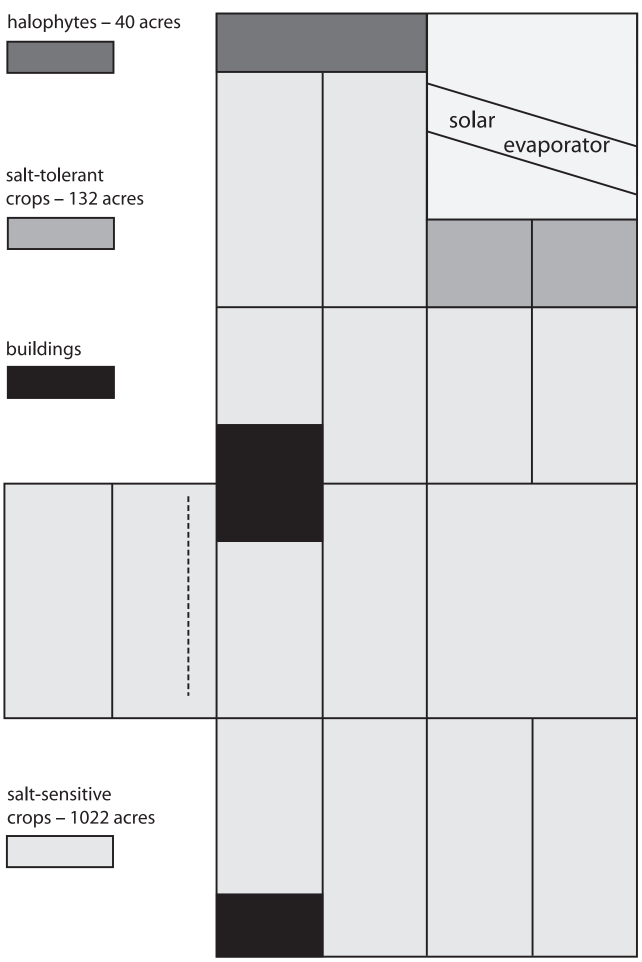

Figure 2-1. Schematic layout of AndrewsAg IFDM System.

IFDM System Design Considerations

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Chapter 3. IFDM System Design Considerations

A. Introduction

The design of an IFDM system requires the input from a number of professionals: soil scientists, agronomists, and irrigation and drainage engineers. It requires input from practicing growers with the general knowledge required to operate successful farming operations and a farmer with the ability and interest needed to introduce and work with innovative new concepts.

The objective of this chapter is not to describe the detailed design of an irrigation or drainage system. Instead, it will highlight procedures and considerations needed to arrive at the specification of a design. The procedures and investigations needed to make a detailed design of an irrigation or drainage system are well developed and are available from a wide variety of manuals and technical books. A sample calculation of the design flows associated with typical irrigation systems and their management is provided in Appendix pages A-10 to A-21. This sample highlights the data needed for the design of irrigation systems and the flow inputs necessary for drainage system design.

The final product of the design phase is a general arrangement drawing that, with related detailed drawings and specifications, describes a complete IFDM farming unit. A related document describes the operation and maintenance procedures required to ensure the IFDM system will operate properly as designed.

Several steps are needed to complete the design of an IFDM system. The following sections will outline the steps to be considered as the designer goes through the process. Most of the steps are obvious and are part of a routine investigation and design. These are provided solely for assistance in the process and are not to be construed as being a requirement of the design.

B. Analysis of Existing On-Farm Irrigation and Drainage Systems Operation

One of the first steps is the design to determine need and potential scope of a drainage water disposal problem based on an analysis of existing water management conditions. It is essential to consider that an IFDM system might be necessary to continue a farming operation, but this will be at a cost. The net return on the farm will be maximized by keeping the size of the least productive components of the IFDM system as small as possible. This suggests that "source control" will be a critical component of the implementation of an IFDM system.

C. IFDM Analysis and Design Checklist

The following checklist gives suggested steps in the determination of the need for and scope of an IFDM system and the selection of the appropriate components. The intent is to give the consultant an overview of the process needed to complete a successful design of an IFDM system, but is not meant to be considered the only way. Designs and considerations taken during the design will be provided in subsequent chapters for the purposes of illustration only. The resulting analysis and design are the sole responsibility of the designer in consultation with the farmer. The design process will likely follow these steps:

- Farmer inquiry – The farmer requests the assistance from the consultant.
- Regulatory review – After discussion with the farmer, the consultant reviews the applicable water quality regulations and directives covering the design, installation, and monitoring of the IFDM system with particular emphasis on the requirements for the solar evaporator.
- Review and analysis of the existing irrigation and drainage systems – The consultant in cooperation with the farmer will analyze the existing irrigation and drainage system operation to determine the water quantity and quality status. The initial analysis can be done using a simple water balance based on farmer-supplied data. This analysis should be completed prior to advancing to the design. In addition to the irrigation system analysis, the existing drainage systems need to be analyzed (see Appendix pages A-7 to A-8 for system analysis questions). Any mobile lab data on irrigation efficiency would be used at this stage. At this point, the farmer's future goals for cropping and irrigation management should be determined.

- Based on the analysis of existing systems, develop preliminary cost estimates to upgrade or to change the irrigation system to minimize deep percolation and surface runoff. Cost estimates are needed for installation of new drainage systems and retrofitting existing systems for water table management and the construction of a solar evaporator.
- Farmer decides to proceed.
- Meet with Regional Water Quality Control Board (RWQCB) staff to discuss conditions and regulations and file a Notice of Intent and request permits to install IFDM system (Fig. 3-1).
- Complete detailed design of the IFDM system. At this stage, there will need to be detailed soil investigations along with monitoring of groundwater depth and quality. Decisions must be made about existing and long-term cropping patterns. A whole farm plan should be developed that identifies fields included in the project and all the project components. Should consider 1-, 3-, 5-, and 10-year plans for irrigation system development.
- Final Design – detailed construction specifications, management and operation plans.
- Operational plans for each of the components need to be developed. Detailed information is needed to complement the irrigation system if new systems are purchased. If drainage system management is included in the project, then operation guidelines will need to be developed and provided.
- Monitoring – This will be a requirement of the Regional Water Quality Control Board but will be important for the correct operation of the entire system. Water balance data will need to be collected. Soil salinity will need to be monitored in each area. If reclamation is a part of the design, monitoring of the soil salinity will be essential to manage the irrigation and drainage. These data may be used to determine whether it is time to switch irrigation systems or change cropping to higher value crops.
- There will be reporting requirements for operation of the solar evaporator – Develop forms and schedules to comply with state and local requirements.

Once it has been determined that a new IFDM system will be installed, one of the first steps is to apply for and obtain a permit to construct and operate a solar evaporator. The permitable applicant of a solar evaporator facility has been defined by the State Legislature as a single owner or operator of a geographically contiguous property that is used for the commercial production of agricultural commodities with an IFDM system.

It may be helpful to meet with RWQCB staff prior to submitting a Notice of Intent (NOI) to discuss the regulations and learn about any changes.

File the Notice of Intent (NOI) with the Regional Water Quality Control Board (RWQCB).

The NOI consists of an one-page form (included on page A-95 of the Appendix), plus supporting documentation (see sample Table of Contents for Technical Report for the Design of the IFDM system, Design of the Solar Evaporator, and Operational Plan for the Solar Evaporator on page 3-14).

Fig. 3-1 Procedure of applying for and obtaining a permit to construct and operate a solar evaporator

RWQCB has 30 days to review the NOI and inspect the proposed location.

⇩

NOI in compliance with Solar Evaporator regulations.
(If not in compliance, RWQCB shall issue a written response to the applicant identifying the reasons for non-compliance.
The applicant can then take steps to revise the NOI in order to bring it into compliance.)

⇩

RWQCB issues Notice of Planned Compliance (NPC).

⇩

Begin construction of the solar evaporator and IFDM system.

⇩

Construction completed (request inspection).
RWQCB has 30 days to conduct compliance inspection.

⇩

In compliance with NOI and NPC.
(If the solar evaporator is not in compliance after inspection. RWQCB staff will issue a written response, identifying the reasons for non-compliance. The applicant can then take steps to modify the solar evaporator in order to bring it into compliance with the NO and NPC.)

⇩

RWQCB issues Notice of Authority to Operate (NAO).
(According to the regulations, a NAO may not be issued on or after January 1, 2008.)

D. Review of Existing Farm Irrigation and Drainage System Design and Management

At this step, the designer gathers the data needed for analysis of the existing on-farm irrigation and drainage water management. This is done through a series of interviews with the farmer and with farmer-supplied records covering cropping pattern, salt-affected areas, water deliveries to specific crops, irrigation equipment used, and any irrigation system analysis by the mobile laboratory. Data also will be needed on any existing subsurface drainage systems including fields drained, configuration of drainage system, and pumping records from the drainage systems and drainage water quality.

After the initial meeting, subsequent discussions should address the topic of future plans with regard to cropping patterns, and irrigation system selection and operation. An IFDM system is a water management system designed to discharge and eliminate a minimum volume of water. Therefore, it is critical to determine the quantities and origins of the water to be managed by the proposed system.

There are basically two main sources of excess subsurface drainage water on a farm. The first source will be deep percolation from irrigation management and a lesser extent rainfall, and the second source is lateral flow from adjacent areas. It will be reasonably straight-forward to estimate the losses from the first source, while contributions from lateral flow will be more difficult and will require calculations based on secondary sources.

If the DWR mobile lab has done studies on irrigation efficiency and distribution uniformity in the farmer's fields, these will give reliable data on the existing state of water management. It also would provide suggested areas for improved irrigation water management. These should form the basis for the next step in the analysis, which is a simple water balance on the farm and fields of interest. This should be done for several years of record to discern water flow patterns related to crop and irrigation system management interactions. This analysis will need to be completed for all fields being considered for inclusion in the system.

It is important to note that total elimination of deep percolation is not desirable since some deep percolation is required for leaching to maintain soil salinity at desired levels. The question is how much is required? This will be determined by the existing soil salinity, the desired soil salinity, and the irrigation water quality.

This leads to an evaluation of the soil parameters on a given field that will impact the management over the long-term. The analysis should determine the following: Are there any areas with consistently poor yields and problems with stand establishment? If so, what are the probable causes, salinity accumulation, water logging, soil structure? What is the condition of the grade of the soil surface? Simply grading or leveling the surface may be enough to eliminate the problem. Is water logging the result of the lack of surface water control or a rise of the water table?

Salinity problems must be identified so specific remedial action can be applied. Leaching and specific soil amendment program should be specific to the site to minimize the cost of resources. Any available soil data should be consulted to identify layer, compaction, and geologic features, i.e. sand stringers. Soil maps and aerial photographs will assist in this process.

The last part of the analysis will focus on the shallow groundwater response and management for the drained fields. The first question will be to determine the design configuration. How deep are the laterals? What is the lateral spacing? What size are the laterals?. What is the lateral configuration relative to the surface grade? Are the laterals placed to run perpendicular to the surface grade or parallel to it? What is the quality of the water being pumped from the drainage system? What is the monthly pumping rate from the field? How does this correlate to irrigation management? Consider plotting volumes of applied irrigation water and volumes of drainage flow on a monthly basis and look at the ratio. Is it consistent, or does it vary during the season and how does it vary?

In the fields with no subsurface drainage system, what is the depth to the water table throughout the year? Does it negatively impact field operations? Is the water table close to the soil surface in the spring and recede over the cropping season? What is the quality of the groundwater?

After collecting these data the designer should be able to develop a water management strategy as a basis for a preliminary analysis for a discussion with the farmer. These analyses can then be used as a basis for a final design for any required structures and water management recommendations. The initial analysis also should include a map of the farm. Any available regional groundwater flow data should be detailed on this map. At this point, the designer can make some preliminary estimates on designs for any system modifications or new systems that may be required.

The designer needs to determine what improvements can be made on the existing system and what will be the impact of these improvements on the deep percolation losses. As a first estimate research publications and Cooperative Extension Bulletins will provide a guide to reasonable values for irrigation efficiency and distribution uniformity for various systems and soil types. At the end of the analysis for each field, the deep percolation and subsequent drainage volume should be summed to begin the calculation for field sizes for the final stages in the system.

The comparison of the potential improvements in water management between the existing and proposed irrigation systems should be reasonably straight forward by using a water balance approach based on the data from the grower and suggested irrigation efficiencies and crop water used data available from Cooperative Extension. The drainage system will be more complicated, since fields without a system will require a decision to install a system and on what criteria. Will the existing irrigation system and management be maintained or changed? The design must be completed using both criteria. The management assumed for the irrigation will drive the drainage design criteria and the ultimate design.

The drainage system design will require answers for the minimum root depth to be protected, the ultimate water table depth, leaching requirement/leaching fraction, and whether the water table position will be controlled. Crop water use from shallow groundwater is a possibility that must be included in the operation and design. There is also the possibility the soil may need to be used as a reservoir to regulate drainage flow later in the season. All of this will affect the lateral depth and spacing, and ultimately the initial cost and operation. The designs can be done using a transient analysis design program from the USBR.

The analysis for an existing drainage system is more complicated because the design criteria used in the initial construction may be significantly different than those that will be adopted for an IFDM system. The design may have been based on the deep percolation losses from a furrow irrigated cotton field with a 1/2-mile run length and no tailwater return system. Additionally, the laterals were installed parallel to the field surface grade. The final IFDM design might be for a tomato crop irrigated with a drip system. As a result, there will be reduced deep percolation losses, so there may be storage capacity, which may be advantageous but the installed configuration will make it difficult to take advantage of that fact.

The data from the analysis of the irrigation and drainage system will need to be evaluated to quantify the existing system and project benefits resulting from improved irrigation and the cost associated with drainage improvement. The ultimate number will be the volume of water for disposal through each of the reuse areas and the evaporator.

The analysis to this point has focused on those areas to be included in the salt-sensitive crop production area that will be the principle source of drainage water requiring disposal. After the preliminary designs for the first production area have been completed, the analysis can proceed to the first reuse area where saline water will be used for production of salt-tolerant crops. The cropping and size of the first reuse area will depend on the salinity and volume of the drainage water being collected from the initial use. The subsurface drain specifications in the first reuse area may differ from those in the initial production areas because of the need to move potentially larger volumes of water through the soil profile. The cost of new drains in the first production area can be minimized by having high levels of water use efficiency and minimum deep percolation losses. Existing drainage systems were probably designed for deep percolation from less efficient irrigation system and would be adequate for the first reuse area deep percolation losses. Subsequent reuse areas with halophytes also will require extensive drainage systems because of the need to move even larger volumes of water through the profile to maintain soil salinity level. A field with high salinity should be considered for the last reuse area prior to discharge to the solar evaporator. This will require minimum leaching at startup and lower LF to sustain production.

The solar evaporator location will require careful siting. Ideally, it will be placed on unusable or severely salt-affected soil. However, state regulations will govern the siting by requiring the site be protected from overland flows resulting from runoff created by the 25-year 24-hour rainfall event. This may require construction of channels and berms around the site. Historical runoff data and topographic data will be required for the analysis. (See Appendix pages A-22 to A-25 and the CD describing DWR's solar evaporator design.)

Alternative irrigation and drainage design strategies should be developed based on the farmer's experience with drainage flow and water table response and alternative water management practices. Field data might demonstrate a high shallow water table condition early in the growing season with increasing depth to water later in the season where the theoretical calculation would suggest a different scenario. This will have a significant impact on the operation of the IFDM system and the total drainage flow. This is particularly true with furrow irrigation or system operated with low frequency that requires soil water storage to supply crop water. The soil water storage volume increases as the plant root zone develops and the applied irrigation does not completely refill the root zone, and the deep percolation is eliminated. This is not the case early in the season when furrow irrigation applies water in excess of the available soil water storage and large deep percolation results. There may be very little deep percolation with a sprinkler or drip system because the total infiltrated water is not controlled by the soil but by the system operation. In this case the depth and time of deep percolation may be better predicted. This is one example of the considerations that need to be explored with the landowner.

E. Irrigation System Selection

To date, IFDM systems have used surface, overhead sprinkler, and drip/micro irrigation systems in various production areas and in the solar evaporators. A critical requirement of the system selected is that it must be highly controllable and efficient. This section describes irrigation systems that are being used in IFDM systems in the San Joaquin Valley of California. In this case, the systems selected have a demonstrated capability to deal with relatively low intake rates on flat to slightly rolling field conditions. Irrigation expertise should be consulted to verify the suitability of systems selected on specific projects.

The quality of the irrigation system performance has a major affect on the economic feasibility of installing an IFDM system. The lack of quality in the irrigation system performance results in larger drainage flows from each production area with larger flows being delivered to the solar evaporator and the increased costs associated with processing them. Quality in this case is defined as the ability of the irrigation system to apply water uniformly in a controlled manner that minimizes deep percolation. While the individual production areas function primarily for the purpose of generating crop revenue, a secondary purpose is to reduce the volume of water through evaporation and evapotranspiration thereby minimizing the volume of water and salt sent to the evaporator. In the context of the IFDM system, other losses, such as pattern and operational losses and tailwater, are not in fact losses because of the presence of the drainage system and tailwater return systems. They are significant however in that they affect the required design capacity of the hydraulic components. In the case of the solar evaporator, special windbreaks, including physical barriers, may be required downwind of the spray field.

Representative irrigation system alternatives and their operational characteristics are:

- **Buried Drip Irrigation**: Drip irrigation systems have been gaining favor in the Valley because of their inherent qualities of good water control and efficiency despite their relatively high cost. Recently the development of GPS equipment has allowed for buried drip systems while still accommodating the cultivation of a variety of row crops and extending the life of the system now estimated to be 4-5 years. Representative system specifications are as follows:

  Wall thickness, 10-mil.
  Outlet spacing, 12-in.
  Flow rate, 0.22 gpm per 100 ft at 8 psi
  Application rate, 0.042 in./hr (at 60 in. row spacing)
  Tape Size, 7/8-in.
  Depth of bury, 8- to 15-in.
  Tape length, 1,200-ft –to-1,300-ft
  Field slope, 0.1 to 0.2%
  Performance data: Pattern loss, 10-15%

Note: Pattern loss assumed to be 10% in the sample calculation in Appendix (pages A-10 to A-21). Pattern loss results from a variation in emitter discharge caused by friction losses in the tubing and between sub-mains.

- **Sprinkler Irrigation**: For a variety of reasons, Valley farmers favor portable aluminum pipe systems in a semi-solid set configuration using low capacity sprinklers. In some cases, pipe is rented for the cropping season, installed as solid-set, with irrigation achieved by valve operation only. In other situations, the mainline is installed for the cropping season to service portable, hand-move laterals. Portable systems are favored because of their inherent flexibility, particularly as relates to accommodating farming operations. In some cases, chemically aggressive waters can significantly shorten the useful life of portable aluminum piping systems. Recent development of portable PVC irrigation systems could provide a satisfactory alternative in this situation. Representative system specifications are as follows:

  ____ Sprinkler Metal Body, Impact Drive
  ____ Nozzle size, 1/8- in.
  ____ Flow rate, 3.0 gpm (with or without flow control)
  ____ Application rate, 0.24-in./hr

  Aluminum, quick coupling, irrigation piping

  ____ Spacing, 30ft x 40ft
  ____ Lateral size, 3in. to 1,320ft or 4in. to 2,640-ft
  ____ Mainline, 10- in. by 30 ft length

  Pumping unit

  ____ Sprinkler operating pressure, 50 psi
  ____ Capacity, 1,600 gpm/160 ac system (or 0.53 in./hr gross capacity)
  ____ Discharge pressure, 60-70 psi

Performance data: Spray loss, 3.0-6.0%

Note: Spray loss was assumed to be 3% in the sample calculation in Appendix (pages A-10 to A-21). However, this *needs to be verified with knowledge of actual on-site weather conditions (wind, humidity, temperature, and sprinkler drop spectrum). With deep seepage collected by the tile drainage system, spray losses from sprinklers represent the only absolute loss of irrigation water within the system.*

Operational loss, 5-12%

The value reflects water loss in filling the piping network, losses through leaky gaskets in pipe joints, and losses caused by sprinkler differential pressure operation.

Pattern losses, 5-15%

The value reflects water lost below the root zone as a result of the sprinkler non-uniformity of application. Sprinkler distribution patterns are required to simulate actual field performance in the test laboratory. An analysis of this data provides design parameters.

- **Surface Irrigation**: Because of the favorable terrain and relatively low soil infiltration rates, surface irrigation systems have been the principal systems used in the Valley. The preferred water supply configuration uses gated pipe supplying furrows. In general, the field has been graded and smoothed using laser-guided systems to provide the desired furrow slope. Representative system specifications are as follows:

Gated Pipe

____ 8-10-in. portable aluminum mainline with adjustable gates spaced to align with the furrows.

Graded Furrows

____ Aligned parallel with the field boundary

____ Length, 1,320-ft (1,280 ft net)

____ Slope, 0.001 or 0.1%

____ Spacing, 30-, 40-, and 60-in.

Hydraulic Performance

____ Pump capacity, 5.5 cfs/160 ac

____ 200 furrows operating at 12-13 gpm

____ Application rate

Furrow Spacing	Gross Application Rate
(in.)	(in./hr)
30	0.37
40	0.28
60	0.19

____ Gross capacity, 15.4 gpm/ac or 0.82 in./d

Performance Data: Tailwater loss, 4.0-8.0%

Pattern loss, 18.0-26.0%

Losses need to be verified by mobile laboratory studies or as simulated computer studies. Pattern losses are captured by the drainage system for processing in the solar evaporator. This effectively eliminates the usually efficiency penalties associated with furrow irrigation.

After considering the farming operation and long-range goals the farmer, and designer will select the irrigation systems to be used in each part of the IFDM system and proceed with the design using current methods. As the design develops, the farmer and designer should look into the availability of cost-share funds for improved water management through the purchase of irrigation equipment.

F. Farming Unit Design

An example of an approach to determine irrigation and drainage flows for a hypothetical IFDM system sited on 640 acres is provided in Appendix (pages A-10 to A-21). It highlights the impact on water management associated with irrigation system selection, water quality, and cropping patterns. The calculation involves estimating the water requirements, the deep percolation losses, and the resulting size of the production areas for salt-tolerant plants and halophytes. Integration is involved in that after irrigation of salt-sensitive crops there will be successive reuse of drainage water on the salt-tolerant crops and halophytes for disposal. The total number of reuses prior to disposal in the solar evaporator or salt sequestering facility will depend on the irrigation management and the size of each production area.

G. Development of the Farming Unit General Arrangement Drawing

This drawing locates accurately all of the permanent farming unit structures including for example, buildings, civil works, field boundaries, windbreaks, and drainage and is supplemented by detailed drawings where larger scales are required. The drawing gives information on prevailing winds as they affect this setting of specific facilities. It also locates and identifies nearby facilities that could be affected by the operation of the IFDM system. Sprinkler spray drift and dust from farming operations are examples of concerns to be managed. This drawing references the availability of other drawings that could provide information useful to the design engineer for example:

a) Contour maps
b) Soil maps
c) Salinity impacted soils
d) Ground and surface water impacted areas
e) Land use designation maps
f) Historic site identification

This drawing, with related detail drawings, provides a basis for dealing with contractors when portions of the infrastructure are contracted out. It represents a document, which allows for careful engineering review of the interrelated facilities that together make up an IFDM system.

A study by Krauter (2005) found that salt-laden spray drift from the solar evaporator can drift over 600 ft downwind. (See Appendix page A-96 for project summary.) Fine particles (PM_{10} or $PM_{2.5}$) may be transported farther and remain aloft longer, potentially leading to air quality concerns as the amount of water evaporated in the region increases. Efforts can be made to reduce this drift by strategically located natural and mechanical windbreak. The problem also may be managed by careful siting of the solar evaporator. It should be sited internal to the farming unit boundaries such that no spray can leave the farming unit. In addition, the downwind fields should be planted with salt-tolerant crops that are better able to tolerate the salt buildup on the leaves. Further, the solar evaporator design capacity may be high enough to permit the system to shut down during the characteristically high wind periods in the afternoon.

Some systems must be in place to manage storm runoff generated by a 25-year, 24-hour storm on the solar evaporator site. One possible solution would be the installation of graded terraces down slope of the evaporator site. The terraces could deliver the discharge to an operational storage reservoir (also known as a "water catchment basin"). In general, there should be no standing water that persists longer than 48 hours.

When surface irrigation systems are installed, tailwater reuse systems are required to control the movement of tailwater and help maintain the efficiency of the system. The design must deal with any potential off-site surface storm water movement that could impair the effectiveness of system components. Contour maps will help identify vulnerable locations. Operational reservoirs and pumping facilities should be sited out of harms way from storm runoff. Study the movement of groundwater through the site. Consider planting windbreak trees and barrier crops to mitigate the movement of soil and water over the site. Windbreak trees could be especially effective on the upslope boundary of the groundwater surface. In addition to providing a windbreak function they would utilize a portion of the encroaching water of unknown quality.

H. Water Management Options

The objective of the water management in an IFDM system is to move salts through the root zone in the various stages of the system, which will require careful water management. This can be done by implementing one of the following: a water balance procedure; using a soil water sensor; or experience. A water balance procedure keeps track of applied and lost water and sets threshold of water use from stored soil water and then initiates irrigation to replenish this lost water. This will require data from weather stations or through the weekly bulletin provided by the Westlands Water District.

Soil water sensors can be used to set thresholds to initiate irrigation, the limitation with instruments is that data is lacking on the amount of water needed to be applied so another measure is needed.

In some cases, the grower has a history of farming specific soils and crops. He has managed specific fields and recognizes the signs of moisture stress in the crops. This is probably the poorest method to use and will result in excess applications.

While water management schemes are fundamentally crop orientated, they must also manage the following farming enterprise realities:

- Controlling water to influence crop maturity.
- Availability of operating labor.
- Integration of irrigation operation with overall IFDM objectives.

I. Drainage System Design Guidelines for IFDM

1) Introduction

Drainage is used in irrigated agriculture to provide control of shallow groundwater, to maintain an aerated zone in the soil, and to provide for the removal of deep percolate containing salt. These are functions that will be required in an IFDM system. In the past, drainage systems were designed to operate continuously to ensure that the water table position was maintained at a level that would insure aeration and salinity control. Recent research has demonstrated that drains can be managed to restrict flow particularly after irrigation without creating an aeration or salinity problem.

This section will discuss the design of subsurface drainage systems for incorporation in an IFDM system. It will not be a detailed discussion of the mechanics of the design since that topic is well described in technical manuals developed by the U.S. Bureau of Reclamation (USBR) and the Natural Resources Conservation Service (NRCS). The American Society of Agricultural Engineers has also developed an engineering practice (EP) that describes the design, and construction of subsurface drainage systems for irrigated lands. This EP was developed based on the USBR guidelines.

The focus of this chapter will be subsurface drainage but the designer should remember surface drainage also will be a concern. There are details in both the USBR and NRCS technical manuals that describe the design of surface drainage systems. Much of the surface drainage requirements can be met by simply grading of the soil surface. More consideration for surface drainage will have to be given to the area around the solar evaporator and provision will have to be made to control the 25-year, 24-hour flood event. An example design developed by the DWR is provided in Appendix pages A-22 to A-25 and on the CD,and details the procedure for determining the design flood and a possible method of control.

2) Subsurface drainage system design

A subsurface drainage system is designed to maintain a minimum depth to the water table at the mid-point between two drainage laterals and a depth of approximately four feet has been used for most soils as being adequate to prevent soil salination. During the design the mid-point water table depth is the closest that the water table will get to the soil surface on a yearly basis. The remainder of the year the depth to the water table will be greater than four feet. This is the basis for the transient analysis used by the USBR and is the analysis generally used in irrigated agriculture. The analysis method has been computerized by the Irrigation Decision Support Group at Colorado State University and the program titled Agricultural Drainage Planning Program (ADPP) is available on the web at www.ids.colostate.edu. This is the program that was used in the analysis later in this chapter.

The design of a drainage system is reasonably straightforward. It requires a detailed investigation of the field being drained and then an analysis of the cropping and water management to determine the deep percolation. Decisions must be made with regard to the depth of installation and the design can proceed. Use of a program will enable the designer to evaluate alternative designs quickly.

The topography of the area also will be analyzed to identify the potential for surface flows that may impact the design. Detailed site evaluations will determine the geology of the area and the soil type in the field of interest. The geology is critical because it will determine the potential for lateral flow of groundwater but it also determines the location of any impermeable barriers. These barriers are the physical features of the soil profile that restrict deep percolation and cause the perched water table conditions that need to be controlled. If drainage systems are present in the area, data from the design of those systems will be a starting point to determine the extent of any required additional investigations.

The topographic investigation also will determine the surface grade and the low point in the field. The drainage sump will be located at this point. The drainage systems and sumps will be used in the recycling program of an IFDM system. Open channels are used to collect drainage flow discharged from sumps and move the water to another area for blending and recycling. However, this may be problematic in an IFDM system because of the requirement to limit standing water.

The soils data will be used to determine the specific yield (SY) and the water holding capacity of the soil. The specific yield is defined as the volume of water released from a known volume soil under the force of gravity and the inherent soil tensions. This is a dimensionless number that is required in the design process and can be determined in the laboratory or from graphs. The USBR design manual gives a graph of the SY as a function of saturated hydraulic conductivity. The soil water-holding capacity will be used in the water balance calculations to determine the potential for deep percolation losses.

The soil salinity status also will be determined at this time and will be the basis for any required reclamation and for the crop selection. In an IFDM system much of this information will already be known since the fields are in production.

One critical piece of data will be the saturated hydraulic conductivity, and this will have to be determined for each field where a subsurface drainage system will be installed. In the initial design phase of the IFDM system, the saturated hydraulic conductivity can be estimated from the soil type. It will be critical to have field studies to confirm the saturated hydraulic conductivity for the final design. This value determines the flow in the system and underestimating the value will result in lateral spacings that are too close and conversely if the value is too high, the laterals will be too far apart and adequate control will not be possible.

After the physical parameters are established for the site, the water balance components have to be established. These will include the precipitation, the irrigation water losses, and the lateral flows into the region. Laterals flows are difficult to quantify and will probably not be a major component of the drainage flow.

The precipitation and irrigation can be quantified by constructing a precipitation and irrigation schedule that quantifies the volume and timing of water application events. The irrigation schedule will be developed as part of the irrigation system design. The irrigation schedule will include the date of application and the projected deep percolation losses. This becomes a direct input into the drainage design. The precipitation input to the design can be handled similarly to the irrigation schedule by accumulating rainfall and applying it monthly during the winter.

The irrigation schedule must be done for each crop and irrigation system combination that is projected to be used on the site to determine which one will have the largest deep percolation potential. Recall from the irrigation design section the differences in projected deep percolation losses resulting from the inefficiencies of each type of irrigation system. When the inefficiencies are added in terms of the total crop water use the projected deep percolation will indicate which irrigation system cropping pattern will be the most critical in the design process. For example, using surface irrigation on a perennial crop would probably have a greater deep percolation potential than surface irrigation on a short season annual.

The result of the design will be a specification of the depth and spacing of the laterals, the location of the drainage sump, and the construction details for the subsurface drainage pipe. These details are well covered in the aforementioned manuals and within the consultants experience and will not be detailed here. The most commonly used drainage pipe is corrugated plastic, which can be installed by either plowing or trenching. The need for an envelope material around the pipe will be determined based on the soil type at the depth of installation and on local experience. The diameter of the pipe will be designed based on the deep percolation losses. The size for laterals in the field is typically 4-to-6 inches with 10-to-12-inch pipe being used for the sub-main collector to move water to the sumps. The pipe size can be varied in the field to account for increasing flow volumes. There are design graphs to assist in the sizing of laterals and mains. The sump design is straightforward and will require the installation of a pump adequate to handle the design flow and limit switches to control the depth. Additional piping and control valves are needed to enable the transfer of drainage water around the site for recycling.

3) Example Designs

Several subsurface drainage system designs will be done using parameters typical of the geologic conditions on the west side of the San Joaquin Valley. The soil is a silty clay loam with a water table that is within four feet of the soil surface. The winter rainfall is minimal and generally is not a factor in deep percolation losses. The principal irrigation system is surface irrigation. The examples will demonstrate the effect on lateral spacings for a combination of deep percolation losses that result from a single irrigation system or combination of systems. The actual system employed is irrelevant to the design. The important fact is the depth of deep percolation resulting from the design.

In this example, the crop is cotton and a fully developed root zone of approximately four feet is assumed. Depending on the year, there are typically three-to-five irrigations a year on cotton, each one applying about five inches of water. The first simulation assumes a uniform deep percolation loss based on surface irrigation with an irrigation efficiency typical of surface irrigation (75%). This means approximately 1.25 inches is deep percolation losses from each event. The second simulation uses sprinklers for the pre-plant and first irrigation to reduce total deep percolation losses. The next simulation uses sprinkler irrigation for the entire season. The last simulation demonstrates the effect of drip irrigation on the system design. Sprinkler irrigation is used for pre-plant irrigation for salinity control. Each of the simulations includes a pre-plant irrigation occurring in January. The pre-plant is done either by surface irrigation or sprinkler. The purpose of the simulations is to emphasize the impact of good water management on the drainage system design. The input data are summarized in Table 1, along with the resulting drain spacing.

The saturated hydraulic conductivity was set equal to three feet/day. The specific yield is 0.13. The drainage laterals were installed at a depth of seven feet. The barrier was assumed to be at 10 feet, and the aerated zone was 4 feet.

Table 3-1. Drain design simulation summary.

Date	Deep percolation (in)			
	Base (surface)	Sprinkler then surface	Sprinkler only	Sprinkler then drip
Jan. 1	1.5	.9	.9	.9
May 15	1.25	.75	.75	.4
May 29	1.25	1.25	.75	.4
July 26	1.25	1.25	.75	.4
August 17	1.25	1.25	.75	.4
Drain Spacing (ft)	313	339	431	536

The lateral spacing for drains installed on the west side of the Valley typically have spacing similar to the base value given in Table 3-1. When the early irrigations were improved, there was a modest increase in drain spacing for the sprinkler followed by surface irrigation. This value may be further increased if a detailed analysis is done to determine the actual deep percolation losses in the last two irrigations of the season. Research in the Valley has shown that deep percolation nearly ceases by the end of the growing season.

Simply changing from surface irrigation to sprinkler irrigation resulted in an increase in drain spacing by over 100 feet. There may be improved yields that result from improved aeration with the use of sprinklers. Likewise, there should be additional benefits from managing surface runoff from sprinklers.

The most dramatic improvement results from switching to drip irrigation while using sprinkler irrigation for salinity control in the pre-plant irrigation. In the example design, the lateral spacing increased by over 200 ft. This would result in a considerable savings in the construction of a new system. There has been a major shift to drip irrigation on the west side of the Valley because of the lack of drainage service and the ability of a well managed drip system to limit deep percolation losses.

These above simulations were done only based on the volume of applied irrigation water and not with a consideration of water quality. However, the water quality aspects of an IFDM system are related to the leaching fraction in an individual production area. In the production area with salt-sensitive crops, the above designs would be typical of the lateral spacing for the given irrigation system when using good quality water. The question is what happens when poor quality water is used. In those cases, the leaching requirement is determined as demonstrated in the irrigation design section and compared to the actual leaching fraction that is estimated to occur as a result of the irrigation inefficiency. If the LR < LF, no additional water is required beyond what is needed to meet the crop requirement using the given water quality. It was demonstrated in the irrigation design section in Appendix pages A-10 to A-21 that with the groundwater quality found on the Valley's west side, surface irrigation inefficiency will result in adequate deep percolation. This would be comparable to the base condition given in Table 3-1. This suggests that many of the existing drainage systems will be adequate to meet the drainage water requirements in the salt-tolerant crop production area.

To summarize, the existing procedures used in the design of subsurface drainage systems in the Valley will be adequate for the design of the lateral spacings of the drainage systems to be used in an IFDM system. Careful irrigation management will be essential to limiting the cost of new drainage systems.

4) Drain system layout for water table control

This is one area that is a major departure from existing practice in the design and installation of subsurface drainage systems. Past practice has been to design systems for continuous operation, which means drains that discharge to surface ditches were allowed to flow without interruption. When a drainage system discharged to a sump, the pump was operated continuously and was controlled by a set of limit switches that controlled the water level in the sump. There was never any intention of controlling the water table position in the field because of the concern for salination of the root zone. In these situations, the field laterals were installed parallel to the surface grade of the field and a sub-main collected the flow from each drain and carried it to the sump. The lateral depth and grade and sub-main depth and grade were adjusted to ensure that the drainage flow went to the sump.

The above configuration of laterals and sub-mains limits the ability to control the water table in the field without installing control structures in multiple locations in the field. If the water table position is controlled only at the tail end of the field, that portion of the field will be water-logged while the head end has no control. To correct this, the drainage laterals must be installed perpendicular to the surface grade and the sub-main collector will be parallel to the surface grade. In this case, the grade needed for flow will have to be created during the installation process by having the lateral depth increase across the field. This means that the drains may be 5.5 feet deep on one side and seven feet deep on the downstream end. Control structures can be added to each lateral or intermittently along the sub-main to control the water table. These structures can be placed off the edge of the field out of the way of cultural operations. Research by Ayars (1999) has demonstrated the operation of control structures on properly configured laterals. The results from the study demonstrated that the irrigation requirement was reduced when the water table was managed.

If the designer opts for deep drains with control structures there will be an opportunity to store water in the soil profile during periods of low potential ET. Deep, wide drain lateral spacing will not result in deep flow lines if the water table is controlled.

As the manager becomes familiar with the system, he or she will recognize that late in the season the crop may be using water from shallow groundwater and the irrigation schedule will have to be modified to account for this contribution. The general effect will be to lengthen the time between irrigations. Research by Kite and Hanson (1984) and Ayars and Schoneman (1986) has demonstrated that crops will use significant quantities of water from the water table. The research by Kite and Hanson (1984) demonstrated one less irrigation on cotton as did the research of Ayars and Schoneman (1986). The management problem will be to develop irrigation scheduling methodologies that account for the in-situ contribution. Kite and Hanson (1984) used leaf water potential to schedule the irrigation of cotton and Ayars and Hutmacher (1994) developed crop coefficients that accounted for the in-situ use.

However, there is much work that still must be done to develop data for a wide range of crops and groundwater conditions. In the interim, the manager should be aware of the potential and observe the system to see if there are any opportunities to induce in-situ crop water use. The best potential use area will probably be in the salt-tolerant production area. In this case, the crop salt-tolerance and the groundwater quality will be a closer match than in the salt-sensitive cropping area. Ayars and Hutmacher (1994) demonstrated that a crop will use significant quantities of water from saline water with an EC twice the value of the threshold that yield reductions occur.

5) Drainage system design for salt management

This will be a new approach for the designer and farmer to consider. For the most part, the drainage design criteria are developed to provide an aerated zone and by default to protect the soil from salinization by controlling the water table depth to minimize the upward flow of saline water from the water table. These are still valid criteria. However, with an IFDM system, some consideration needs to be given to modifying the criteria to reduce salt loading, Ayars et al. (1997). In general, the deeper and wider drainage laterals are installed, the greater will be the flow lines into the profile. This will result in large salt loading if there are large salt stores in the profile, which is the situation in the Valley and many other places in the world.

One alternative is to use a shallower drain placement that will have shallower flow lines compared to a deep installation with the same spacing. Shallower placement also will result in reduced drainage flow in uncontrolled drainage systems, which is often called over-drainage. Shallower drain lateral placement also will result in the mid-point water table depth being closer to the surface. This may require additional management for salinity control. Providing outlet control on a deep installation also will limit the depth of the flow lines. Deeper placement will provide other options concerning water management and storage.

When shallow placement is considered, switching to irrigation systems with high efficiencies will maintain good lateral spacing. A lateral spacing of 549 feet was calculated using a lateral depth of five feet and a mid-point water table depth of three feet. The deep percolation schedule used was the sprinkler - drip combination given in Table 3-1. In situations where there is some leakage through the impermeable barrier or lateral flow from the area, a shallow drainage system might be suitable. These shallower systems will require careful management, but many farmers in the drainage-impacted areas already have experience with managing salt in undrained land that would contribute to the management of these systems.

6) Drainage flow calculations

The Agricultural Drainage Planning Program can be used to estimate drainage flow. The ADPP program is first used to calculate the drainage spacing using the transient analysis. One of the outputs from this program is the calculated daily height of the water table above the drains for a design. This number can be used along with the flow equation for drain discharge from spaced laterals found in the USBR drainage manual to estimate daily flow. The resulting daily discharge can be calculated and summed with the flows from the other drainage systems in the IFDM system to calculate the discharge from the system. The calculation described above assumes that there is always drainage flow but this is often not the case in the field. This procedure will provide a conservative estimate of the flow from the individual drainage systems, which can be summed.

Using the above-described procedure and the data from the base design case described in Table 3-1, it was estimated that the flow from 160 ac. was 74 ac-ft. from an applied water of approximately 440 ac-ft. Drainage flow also was estimated for the case using sprinkler for irrigation and drip for the in-season irrigation. The total estimated flow was 36 ac-ft from 160 acres.

7) Summary

Designing a subsurface drainage system to be used in the drainage water recycling component of an IFDM system requires minor modifications from the existing drainage design procedures that have been developed by the USBR and the NRCS. The biggest change will be in adopting an active management program for the drainage system that integrates the operation of the irrigation system. The general layout of the drainage system will have to be changed to accommodate controlling the water table, and control structures will have included in the design. These control structures will include a weir structure that can be raised and lowered as needed.

The drainage system will have to be managed differently throughout the year. Early in the year, the goal may be to store water because there is no demand for irrigation or the evaporative demand is low, while later in the season water is stored to meet crop water requirements. There may be a time that the water table is dropped to allow some leaching. The opportunities are endless and the drainage system should be included as an active part of the overall water management scheme in an IFDM system.

J. Solar Evaporator Design

When setting out to design a solar evaporator, the designer must first understand that each situation (farm) is different, and there is no one way to design and specify a universally acceptable solar evaporator. The following are suggestions and guidelines for the process of designing a solar evaporator.

1. Start by reviewing the state Solar Evaporator Regulations. The regulations specify the design, construction, operation, and closure requirements.

(See Appendix pages A-79 to A-88 for the regulations.)

2. Gather information from the Landowner/Operator

The following categories of information will be required by the designer during the solar evaporator design. Much of the information will have been gathered during the initial studies of the IFMD location. These data are needed to site the evaporator out of a flood zone and to quantify the flood risk on the property. As noted in the regulations the distance between the bottom of the evaporator and the position of the water table is critical in the design to ensure that percolation from the evaporator will not impact groundwater quality. The rainfall data are needed to quantify the potential storage requirements in the system.

- Drainage problems affecting the farm area
- Surface flow from adjacent properties during heavy rainfall
- Rainfall
- Flooding from streams
- High water table areas
- Barriers affecting surface flow

3. Gather data required for the Technical Report; which is a part of the Notice of Intent that must be submitted to the RWQCB along with the solar evaporator design.

The following is a sample Table of Contents for a technical report and operational plan for the design of a solar evaporator (developed by the Department of Water Resources in February 2005 with minor revisions by CIT in August 2005). The table lists the types of information that an engineer may need to consider in the technical report and operational plan as part of the Notice of Intent application permit process.

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4. Review designs of solar evaporators on other farms. (Eg. AndrewsAg and Red Rock Ranch)

Chapter 2 describes the general design of the solar evaporator at AndrewsAg. The 20-acre solar evaporator at AndrewsAg was established in two of the cells of the former 100 acres of evaporation ponds.

The Department of Water Resources has recently completed a new design for the solar evaporator at Red Rock Ranch. (See Appendix pages A-22 to A-25 for project abstract and CD for design information).

One of the major differences between the solar evaporators at the two farms is that one stores the salt evaporite (AndrewsAg), and the other processes the salt for harvest and utilization (Red Rock Ranch).

Each solar evaporator design will be tailored to the farming operation and site characteristics. The ultimate design will be the responsibility of the designer.

See Appendix (pages A-79 to A-88) for solar evaporator regulations.

Drainage Water

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Chapter 4. Drainage Water

A. Introduction

This chapter focuses on the water that is collected from subsurface tile drainage systems, specifically the water quality, characteristics and water management alternatives. The quality of water is extremely important, because it determines if, how and where the water can be used. Constituents in drainage water may include salts, toxic trace elements and nutrients. The quality of water can limit its potential uses, as well as increase the cost of treatment and the operation and maintenance of treatment equipment and facilities. Water quality and utility declines as salinity (measured as electrical conductivity (EC) or as total dissolved solids (TDS)) increases.

B. Agricultural Drainage Water Characteristics:

1) Tailwater and Tilewater

There are two types of drainage water that result from irrigated agriculture. These are tailwater and tilewater.

- Tailwater (surface drainage water) is water that was applied to irrigate crops, but does not infiltrate the soil and is collected as runoff.
- Tilewater (subsurface drainage water) is water that was applied to irrigate crops, infiltrates through the soil profile, and is collected by the subsurface drains. This water is pumped from the drains to the surface and then emptied into a surface drainage ditch or collector pipe.

When not specified, drainage water usually refers to subsurface drainage.

Subsurface drainage water is usually of lower quality than the original irrigation water because it has traveled through the soil column and picked up various compounds and substances such as salts, soil particles, inorganic trace elements and organic compounds. As a result, subsurface drainage water from different locations will have different compositions. For example, in most regions of the west side of the San Joaquin Valley sodium sulfate is more predominant than sodium chloride, but there are areas where the chloride form is more abundant (SJV Drainage Program Report, 1990). Trace element levels also can differ markedly. At Red Rock Ranch (near Five Points), the drainage water is very high in selenium, whereas at Westlake Farms (near Stratford), selenium is lower, but molybdenum is very high.

2) Salts

Salts are usually found in irrigation and drainage water, but the composition and concentration varies. Salts commonly found in subsurface drainage water include sulfates, chlorides, carbonates, and bicarbonates of the elements sodium, calcium and magnesium. The salts originate from chemical weathering of minerals found in the soil's parent material, which in the case of the Valley's west side, is marine in origin (alluvial fan from the coastal range), and is therefore high in salts. To a lesser extent, irrigation water and groundwater also add salt to soil. The primary source of the imported irrigation water for the west side is surface water from the Sacramento-San Joaquin Delta. Although very low in salt, the volume of water imported results in an average of 800,000 tons of salt being imported to the northern San Joaquin Valley each year. Approximately 335,000 tons of salt leave by way of the San Joaquin River and the rest remains primarily in the soil. Similarly, about 2 million tons of salt are imported into the southern San Joaquin Valley by way of its irrigation water delivery system and the Valley's geology. Because the Valley is a hydrologically closed basin, most of the salt remains (DWR, 2001). Additional sources of salt to west side soils include local precipitation and runoff, pesticides, fertilizers and soil amendments such as manure, gypsum and lime.

3) Water Salinity

Common ways of expressing water salinity are **EC** (electrical conductivity) expressed in decisiemens per meter (dS/m) or **TDS** (total dissolved solids) expressed in parts per million (**ppm**) or milligram per liter (**mg/L**), which is equivalent to ppm.

EC may sometimes be expressed using older units of millimhos per centimeter (mmhos/cm) or micromhos per centimeter (µmhos/cm), which are equivalent to dS/m and 1,000 times dS/m, respectively. And for water salinity, an alternative unit for TDS is milliequivalents per liter (**meq/L**) rather than ppm or mg/L.

Conversion factors for EC ⇨ TDS increase as the salinity increases. (See table below.) The conversion factors recommended for the west side San Joaquin Valley are different than those given in Ayers & Wescot (1985), the most commonly used water quality guide. The difference is attributed to the larger sodium sulfate component, as compared to sodium chloride, in west side drainage waters. Among drainage waters, variation in conversion factors between EC and TDS has been found, reaching as high as 1,200 to 1,400 for highly saline drainage waters having an exceptionally high sodium sulfate composition (i.e. a 30 dS/m sample could have a TDS of 36,000 to 42,000 ppm. However, for the most part, the conversions shown will apply.

Table 4-1. EC ⇨ TDS Conversion Table

TDS (ppm) = 740 x EC (dS/m); when EC is less than 5 dS/m
TDS (ppm) = 840 x EC (dS/m); when EC is between 5 and 10 dS/m
TDS (ppm) = 920 x EC (dS/m); when EC is greater than 10 dS/m

TDS (meq/l) = 10 x EC (dS/m)

The table below gives general recommendations for the use of irrigation waters based on salinity. More detailed information is given in Table 5-1 in Chapter 5.

Table 4-2. Salinity-Irrigation Water Table

Below 0.5 dS/m	Salinity is not a problem for the crop. Depending on soil texture, water penetration problems could occur due to low salt content.
0.5 to 1.5 dS/m	No hazard-to-low salinity hazard.
1.5 to 3.0 dS/m	Low-to-medium salinity hazard. May be used for salt-sensitive crops, but at the high end of this range may not be advisable and/or yield reduction is likely.
Above 3.0 dS/m	Salinity hazard. Most suitable for salt-tolerant crops. Leaching is essential.

Highly saline water may be used for irrigation, given proper crop selection and soil and water management. However, these guidelines provide a starting point for evaluating whether a water source does or does not pose a salinity hazard. There are examples where irrigation water with salinity greater than 3 dS/m has been successfully used for irrigation even with crops that are not classified as "salt-tolerant".

4) Water Sodicity (sodium in the water)

Sodicity refers to the amount of sodium in the water. This can be expressed as the exchangeable sodium percentage (**ESP**). More commonly, the sodium is expressed in relation to the calcium and magnesium levels in the water. This is called the sodium adsorption ratio or **SAR**. The equation is:

$$SAR^{*} = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

**when Na, Ca, and Mg are given in meq/L*

Irrigation water with a sodium adsorption ratio (SAR) $\geq$ 10 or an exchangeable sodium percentage (ESP) 13 is likely to infiltrate poorly when applied to a medium-or-fine-textured soil, particularly if the salinity of the water is low. However, the infiltrability of water is really a function of both SAR and EC. A high SAR water with very low salinity (< 0.5 dS/m EC) will infiltrate much slower than a water of the same SAR and higher salinity.

A complete table listing combinations of sodium adsorption ratio (SAR) and salinity (ECw) and the degree of restriction on use of the water is given in Ayers and Westcot (1985) and is discussed in a handy manual entitled "Agricultural Salinity and Drainage Manual" (Hanson, Grattan, and Fulton, 1999).

5) Toxic Trace Elements

Because the soils on the west side originated from marine sediments, they contain salts and potentially toxic trace elements (selenium, molybdenum, arsenic, uranium, and boron) that dissolve in irrigation water and leach into groundwater. Most of the elements originate naturally from the soils, but imported irrigation water also may contain some trace elements. Among those listed below, boron is the trace element of greatest concern for crop production. Where salinity is a problem on the west side, boron toxicity is often a problem as well. These trace elements are classified as "substances of concern" because of their potential to negatively impact water quality, public health, agricultural productivity and/or fish and wildlife (SJV Drainage Program Report, 1990).

- **Selenium** is found in varying concentrations in much of the soil and water on the west side San Joaquin Valley. It is the element of greatest concern. At high concentrations, selenium is toxic to wildlife and it was traced to the waterfowl poisonings that led to closure of the San Luis Drain.
- **Molybdenum** is an essential trace element for plants and some animals, but it can be toxic to ruminant animals. The CVRWQCB recommendation for molybdenum in water for agricultural usage is 10 ppb (SJV Drainage Program Report, 1990).
- **Boron** is found in varying concentrations in much of the soil and water on the west side of the San Joaquin Valley. Many agronomic crops are sensitive to boron. Although it has been found to reduce the growth rate of chicks, wildlife risks are lower than for the other trace elements listed.
- **Arsenic** is a mammalian toxin.
- **Uranium** is radioactive element found in specific locations throughout the valley.

6) Nutrients

Nutrients, such as nitrogen in organic and inorganic forms (ammonium and nitrate) and phosphate in organic and inorganic forms, may be found in drainage waters. Careful water and fertilizer management are needed to minimize nutrient losses from soil, which potentially results in reduced growth and yields and compromises water quality. However, the leached nutrients could be considered an asset if the subsurface drainage water containing these nutrients is collected and applied to other crops, as in an IFDM system.

C. Utilizing Drainage Water for Irrigation

Several management schemes exist for use of saline water source in an irrigation program. These schemes differ regarding where, when, and how the saline water is applied to the grower's field, and whether non-saline water is included in the cropping system. Alternative scenarios are given in the following sections. It will be part of the designer's job to select the appropriate scheme for the proposed system.

1) Sequential Use

In this scheme, part of the farm, or sub-region, is designated as the reuse area. It consists of a sequence of fields within the boundaries of a farm, or an irrigation district, that are irrigated with saline water (see Grattan and Rhoades, 1990). That is, the drainage collected under one field – which is more saline than the irrigation water – is then used to irrigate the next field in the sequence and so on. The main purpose is to obtain an additional economic benefit from the available water resources, minimize the area affected by shallow water tables, and reduce the volume of drainage water that requires disposal. IFDM is one type of sequential reuse.

Two other methods have been field-tested for utilizing saline water. Both require an ample supply of good quality water and saline water to be available for irrigation throughout the season.

2) Blending

Blending involves mixing saline water and high quality water together to achieve an irrigation water of suitable quality based on the salt tolerance of the chosen crop. The blended water is then used for irrigation. The AndrewsAg IFDM system blends fresh water and drainage water for their salt-tolerant cotton. Blending is not attractive if saline water does not supply at least 25 percent of the total irrigation water requirement for the crop. That is, the costs and risks of the increased management associated with adding salts to the irrigation supply will likely outweigh the benefits from increasing the total water supply by only a slight-to-modest amount.

3) Cyclic Use

The "cyclic" method was first introduced and tested by Rhoades (1984). Saline drainage water is used solely for certain crops and only during certain portions of their growing season. The objective of the cyclic strategy is to minimize soil salinity (i.e. salt stress) during salt-sensitive growth stages, or when salt-sensitive crops are grown.

With a cyclic strategy, the soil salinity profile is purposefully reduced by irrigation with good quality water, thereby facilitating germination and permitting crops with lesser tolerances to be included in the rotation. The cyclic strategy keeps the average soil salinity lower than that under the blending method, especially in the upper portion of the profile, which is critical for emergence and plant establishment (Grattan and Rhoades, 1990).

4) Combining Strategies

These strategies are not mutually exclusive. In fact, a combination may be most practical in some cases. For example within a sequential reuse scheme, blending and/or cyclic methods may be used on occasion to germinate and establish the salt-tolerant crops. This is particularly true for the establishment of salt-tolerant perennial forages, some of which may require at least a full year of freshwater irrigation prior to applying the saline drainage water. Also, the blending and cyclic strategies are primarily suitable for drainage water that is relatively low in salinity (< 8 dS/m= 6700 ppm TDS). Another example is in the AndrewsAg IFDM which is a sequential re-use but for the cotton, fresh water and drainage water has been blended, for example in a ratio of two-thirds freshwater and one-third drainage water when drainage flows were low.

5) Single Use

A few examples exist, e.g. the San Joaquin River Water Quality Improvement Project (SJRIP) operated by Panoche Drainage District, where drainage water is used only a single time for the irrigation of salt-tolerant crops and forages. In this case, at the onset of the project, only a small portion of the 4,000-acre re-use area had subsurface drainage and the main objective was to displace some of the drainage water being discharged to the San Joaquin River under on a special agreement (Grasslands Bypass Project) in order to meet water quality objectives. Although not the preferred system for long-term sustainability, single use may be employed in the initial stages of a drainage water re-use project when a means of drainage water disposal is needed and a long-term commitment and funds for the installation of a complete drainage system have not been secured. However, in order to control soil salinization, maintain the permeability of the soil and productivity of the plants growing in the re-use area, and stay in compliance with environmental regulations, it is likely that tile drains would need to be installed throughout the re-use area. Eventually, it would need to convert to a multiple re-use system similar to IFDM.

Crop Selection for IFDM Systems

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Chapter 5. Crop Selection for IFDM Systems

A. Introduction

Many salt-tolerant crops, forages and halophytes play important roles in IFDM systems. This chapter provides a summary of potential candidates based on the literature and the most recent research findings from field and greenhouse studies in California. This chapter is less detailed than the crop selection chapter in the IFDM Landowner's Manual. If more detailed recommendations are needed, refer to the Landowner's Manual.

The cropping pattern selected by the operator will be the one that provides the most economic benefit. Therefore, this chapter focuses on those crops with the highest economic value.

As the production areas are defined, the soil type and quality, and the potential irrigation water quality will guide the plant selection. For the freshwater-irrigated acreage, the crops being used will be typical agronomic crops ranging in salt tolerance from sensitive to tolerant. In the reuse areas, forages and salt-tolerant agronomic or industrial crops, such as canola or cotton, can be grown. If needed, there may be a last reuse area where halophytes (highly salt-tolerant, undomesticated plants) will be grown. The following section provides guidance on plant selection for IFDM:

B. Choosing the Appropriate Plants

Candidate plants vary in salt tolerance, plant vigor, desirability and compatibility with local farming operations. Some crops will be more appropriate in a particular area while others may be more appropriate in other areas.

The desired characteristics of plants to be irrigated with saline drainage water include:

- Salinity and boron tolerance
- High production potential (biomass/area)
- High water use (ET)
- Tolerance to frequent flooding – *if using flood irrigation*
- Marketability of harvested biomass
- Perennials or long season annuals (preferred)
- Frost tolerance
- Non-invasive plant
- Plant is NOT a host for insect vectors of plant viruses

In the process of choosing plants, keep in mind the areas of the IFDM system where they will be grown, as well as the soil conditions, and the purpose of that area. In the first production area – an area irrigated only with fresh canal water – there is an opportunity for salt-sensitive plants to be grown, resulting in higher potential profit. In the reuse areas where drainage water is applied to the plants, criteria such as salt and boron tolerance are paramount.

Prior to any plant selection, representative water samples should be taken from a groundwater monitoring well or a drainage sump that represents the quality of the water source that will be used for irrigation. These samples should be sent to a reputable commercial laboratory for analysis of EC, B, Na, Ca, Mg, Cl, SO_4 and SAR. Results of the analyses are the initial guide for plant selection. Soil type, and the availability of non-saline canal water for irrigation, blending, or reclamation leaching are also important considerations.

Table 5-1. A comparison of salinity tolerance† for various plants in an IFDM system.

Plants	Irrigation water salinity (EC_w) (fresh, blended, or drainage)
Salt-sensitive vegetables	below 2 dS/m ††
Salt-tolerant vegetables & flowers	below 4.5 dS/m††
Salt-tolerant field crops *(cotton, canola, barley, sugarbeet)*	below 7 dS/m††
Salt-tolerant forages	8-14 dS/m†††
Halophytes	15 dS/m and above
Salt-tolerant trees	5-10 dS/m

† Refer to Maas Hoffman tables (Appendix pages A-31 to A-40) for salinity tolerance rankings.

†† Irrigation waters above these threshold values may be used in certain cases, but optimal water and soil management is needed and some yield reduction is likely. Likewise, yield reductions can also occur with waters below the threshold values.

††† Jose Tall Wheatgrass, Paspalum, and Bermuda grass may tolerate short- term irrigation with more saline water.

C. Salt and Boron Tolerance of Traditional Crops

Salinity and boron tolerance are the main factors influencing plant selection in IFDM systems. The Maas-Hoffman tables (Maas & Grattan, 1999) provide salinity tolerance rankings for many traditional fiber, grain, forage, vegetable, horticultural and woody crops. Halophytes are not listed, and only limited information is available for salt-tolerant forages. These tables may be found at the USDA George E. Brown Salinity lab website (http://www.ussl.ars.usda.gov/) or in Appendix (pages A-31 to A-40).

IFDM systems utilize saline water. Therefore, the starting point for plant selection is actually the applied water salinity (drainage or drainage blend), rather than the soil salinity. The soil salinity (ECe) resulting from irrigation with water of a given salinity (ECw) is difficult to predict because of the influences of soil texture, ET, drainage, duration of saline irrigation, and leaching fraction. A reasonable estimate provided by Ayers and Westcot (1985) is: (ECe) = 1.5 x irrigation water salinity (ECw); assuming a continuous leaching fraction of 15-20%. With increasing years of drainage water irrigation, information on the soil salinities tolerated by candidate plants becomes more critical.

Cotton, barley and canola are among the most salt-tolerant field crops. For example, if the soil salinity threshold for cotton is 7.7 dS/m ECe, the estimated limit for irrigation water salinity that could be applied to cotton over the long-term without yield loss would be 5.1 dS/m. Canola is even more salt-tolerant than cotton, having a soil salinity threshold of 11.0 dS/m ECe. Canola shows promise both as a selenium accumulator and as a biodiesel crop (G. Banuelos, USDA-WMRL, Parlier, CA, personal communication).

Asparagus, artichokes, red beets, and zucchini squash are among the most salt-tolerant vegetables. However, most drainage waters should be blended with fresh water to keep the salinity of the irrigation water low enough to achieve reasonable production for these vegetables.

Maas and Hoffman also compiled boron tolerance tables (Maas & Grattan, 1999) that list threshold values for numerous agronomic crops based on the boron concentrations in the "soil water." Some salt-tolerant crops, for example cotton, sugarbeets, asparagus and red beet, are also tolerant ("T") or moderately tolerant ("MT") to boron. Alfalfa is boron-tolerant and although it is listed as moderately sensitive ("MS") to salinity, new varieties with somewhat higher salt tolerance are now available. Tomato and garlic also are boron tolerant; but they are moderately sensitive and sensitive ("S"), respectively, to salinity. These boron tolerance tables do not have listings for salt-tolerant forages or halophytes.

With soil boron concentrations of 4-8 ppm (mg/L) in the saturated paste extract and/or drainage waters of similar concentration, only boron-tolerant agronomic plants should be planted. For drainage waters of 10-15 ppm boron, blending could be utilized, as is done at AndrewsAg in southern Kern Co. Boron toxicity was not observed in trials in the SJV, in which annual crops were irrigated with saline-sodic drainage water containing 7 to 10 ppm (mg/L) boron. These included cotton, melon, sugar beet, tomato and wheat (data summarized in Grattan & Oster, 2003). However, for permanent crops such as tree fruits and nuts, the potential for boron toxicity remains as a major limitation on their use in IFDM systems, even if they should have adequate salt tolerance.

D. Salt -Tolerant Forages

A number of salt-tolerant grass and leguminous forages have been evaluated in experiments conducted in both the greenhouse and field. Table 5-2 below qualitatively ranks these candidate forages for characteristics that are desirable for IFDM. The maximum ECw values are based on good drainage and do not reflect maximum yields, but rather, they refer to the suggested maximum that can be used to achieve reasonable production under good management conditions. Ideally, a forage production system should include both warm- and cool-season types, and legumes along with the grasses. Except for the trefoils, it is generally recommended that species be planted separately, rather than inter-planting. The challenge is to manage the stand, i.e. cutting frequency and height, to maximize both the productivity (biomass accumulation) and the forage quality. Generally, as biomass accumulates (more time is allowed between cuttings), forage quality decreases. A summary table showing data on forage performance at Red Rock Ranch can be found in Appendix 5 (page A-41).

Research thus far suggests that, in general, salinity does not reduce forage quality (Robinson, et al., 2004), but it can increase ash and nitrate, both of which are undesirable. Also, more frequent monitoring of elemental composition is required for drainage water-irrigated forages because if excessive concentrations of selenium, sulfur, molydenum or nitrate should occur, they could cause nutritional problems for the animals (Grattan et al., 2004). In the case of selenium, extremely high concentrations in the forage could be advantageous should the material be processed into a selenium supplement. Animals on the east side San Joaquin Valley and in other production areas are commonly given selenium supplements at considerable cost to the producer.

Table 5-2 compares candidate forages for IFDM using the desired characteristics. The forage quality rankings are on a relative scale comparing only the forages listed and only under conditions of saline irrigation. The irrigation water salinity (ECw) values listed assume good drainage.

	Recommended[1] ECw (dS/m)	Forage Quality	Growing Season[2]	Length of Growing Season	Suitability for Hay or Grazing[3]	Seed or Transplant Availability[4]	Competitive Ability
Tall grass forages							
'Jose' Tall Wheatgrass	≤ 12	High	Weakly cool	Long	Grazing or hay	Good (seed)	Good
Creeping wildrye var. *'Rio'*	≤ 9	Medium low	Weakly cool	Long	Grazing or hay	Fair (seed; plugs better)	V. Good
Tall fescue var. *'Alta'*	≤ 8	Medium high	Weakly cool	Medium long	Grazing or hay	Good (seed)	Average to Good
Alkali sacaton, var. *'Solado'*	≤ 10	Low	Warm	Medium	Grazing	Fair (seed; plugs better)	Good
Perlagrass	≤ 9	Medium	Cool	Medium	Grazing or hay	Fair (seed; plugs better)	Poor
Puccinellia	≤ 10	High	Strictly cool	Short	Grazing or hay	Fair (seed)	Average
Turfgrass or forage							
Bermuda grass	≤ 10	Medium	Warm	Medium	Grazing or hay	Good (seed)	Average to good
Paspalum	≤ 11	Medium high	Warm	Medium long	Grazing or hay	Good (sod or stolons)	Average to good
Leguminous forages							
Salt-tolerant alfalfas	≤ 7	High	Warm	Long	Hay	Very good (seed)	Average to good
Trefoil – narrow leaf	≤ 8	High	Weakly cool	Short	Grazing or hay	Fair (seed)	Average

[1] With irrigation waters less than 8 dS/m, a crop or forage with lower salt tolerance but higher profit potential, may be the better choice. At the high end of the salinity range, productivity may be significantly reduced. Estimates are based on available scientific data and/or personal communications.

[2] "Weakly cool": forage grows best in the spring and fall. Does not go dormant in the summer, but growth is greatly reduced.

[3] Listings are best current estimates. Response to grazing under saline irrigation has not been thoroughly tested for many of these forages.

[4] "Good": commercial sources readily available and can supply large amounts. " Fair": commercial sources may not be available, but small amounts can be procured from the USDA Plant Materials Center (PMC) in Lockeford, CA or from special purveyors.

'Jose' Tall wheatgrass *(Thinopyrum ponticum,* formerly *Agropyron elongatum,* var. *'Jose')* is considered to be a top candidate because of its demonstrated performance under highly saline conditions at Red Rock Ranch (6.8 to 7.1 MT/ha/yr of DM at a soil salinity of 17-19 dS/m ECe). It has relatively high forage quality, a long growing season, and seed is readily available.

Creeping wildrye, also called Beardless wildrye *(Leymus triticoides* or *Elymus triticoides* var. *'Rio')* growing in less saline soil (11 to 13 dS/m ECe) at Red Rock Ranch had high biomass production (11.5 to 13.0 MT/ha/yr of DM), but forage quality was lower than for 'Jose' Tall wheatgrass. Selenium accumulation can be very high, e.g. up to 11 ppm (mg/kg DM), in a mature stand irrigated with saline drainage water for five years.

Paspalum *(Paspalum vaginatum* vars. *'Polo', 'PI 299042',* and *'SeaIsle 1')* is also a top contender. It has good productivity and forage quality under saline irrigation and being a warm-season grass, it complements the production of cool-season grasses, such as tall wheatgrass and creeping wild rye. Paspalum has not been extensively tested in the field under irrigation with drainage water, but it was a top performer in sand tank studies where synthetic drainage water was applied (Robinson et al., 2004). Paspalum is now established at Red Rock Ranch and at the SJRIP operated by Panoche Drainage District.

Bermudagrass *(Cynodon dactylum,* vars. *'Common', 'Giant'* and *'Tifton')* has performed well in a beef cattle grazing study at Westlake Farms (Kaffka et al., 2004) where it is growing under irrigation with saline drainage water and in soils having salinities of 13 dS/m ECe in the top 12 inches. Forage quality was considered acceptable-to-good for beef cattle. The animals had good weight gains at a stocking rate of 1.5 steers/acre and with copper supplementation to overcome a molybdenum-induced copper deficiency.

E. Halophytes

Halophytes are largely undomesticated plants that are native to saline coastal marshes or inland salt flats. They are truly salt-requiring. Some halophytes can be irrigated with water as saline as seawater. Halophytes are suitable for irrigation with highly saline water ($\geq$ 15 dS/m; 12,000 ppm TDS) and/or for highly saline soils (ECe $\geq$ 20 dS/m; 16,000 ppm TDS). Salicornia and Allenrolfea are the most salt-tolerant, thriving in soils of 50-60 dS/m ECe in the top 12 inches. All of the halophytes listed are warm season plants.

At present, these halophytes have limited economic value. But even if no revenue is generated from their cultivation, the value of these plants in an IFDM system is their suitability for irrigation with concentrated drainage water, thereby allowing additional volume reduction prior to the final discharge into a solar evaporation system. Profit is instead gained from the freshwater-irrigated area of the IFDM in the form of improved yields and expanded crop choices resulting from the soil improvement provided by subsurface drainage.

A table of potential halophytes is provided based on desirable characteristics (Table 5-3). Salt and boron tolerance are not included because halophytes are highly tolerant to both.

Table 5-3 compares candidate halophytes based on desirable characteristics for IFDM.

	Suitable ECw[1] (dS/m)	Ease of Establishment[2]	Maintenance[3]	Competitive ability	Availability of seeds or transplants[4]	Water use (ET)	Economic potential	Selenium uptake	Comments
Annuals									
Salicornia Bigelovii	$\geq$15	More difficult*	Medium	Fair	Poor (proprietary seed)	High	Medium	V. High	* not well-adapted to hard surface crust, best sown onto wet soils in late fall/winter
Perennials									
Saltgrass	$\geq$15	Average (one year)*	None*	Very good	Good (rhizomes or native stands or commercial sources)	Lower	Low	Medium	* new shoots must form on rhizome. Plugs from seed establish faster
Allenrolfea	$\geq$15	Average (one year)*	Low	Good	Fair (sprigs from native stands)	No data	V. Low	High	*new shoots form from sprigs and/or from fallen seed.
Atriplex spp.	$\geq$15	Average	Medium*	Very good	Good (seed; or better container-grown plants from seed or cuttings from native stands)	Medium	Low	Low	* shrubs get very large, best to cut every year or two, but not below 12”
Cordgrass	$\geq$15	Average	Low*	Good	Good (clumps from native sources or plugs from commercial seed)	No data	Low	Medium	* Cutting not required, but may increase ET.

[1] ECw = electrical conductivity of the irrigation water in dS/m

[2] Establishment details can be found in Appendix 5 (pages A-44 to A-50). Scale is relative to saline conditions in which the success rate for establishing vegetation is generally lower than for agronomic plantings on non-saline sites.

[3] Maintenance scale: “Low” = little care, “Medium” = may require re-seeding (salicornia) or trimming (atriplex), “High” = frequent trimming or re-seeding required.

[4] Availability: “Good” = commercial sources readily available and can supply large amounts. “Fair”= commercial sources may not be available, but plant material can be collected from native stands or small amounts requested from the USDA Plant Materials Center (PMC) in Lockeford, CA. “Low” = special purveyors and/or formal agreements may be required (salicornia and ‘Nypa Forage’ (saltgrass)).

Saltgrass, allenrolfea and salicornia are the most promising halophytes thus far. Saltgrass ranks high because once established, maintenance is minimal, and it provides a very dense vegetative cover with an extensive rhizome system that opens up the soil and improves water infiltration and drainage. The dense cover also impedes water evaporation and salt accumulation at the soil surface.

Allenrolfea, or iodine bush, has performed exceptionally well in the IFDM at AndrewsAg. It has competed reasonably well with invading halophytes and selenium accumulation is high. At Red Rock Ranch, Allenrolfea is slowly spreading westward into the most saline areas of the halophyte block.

Salicornia is the halophyte with the greatest potential for economic return and it is a high water user. It also readily accumulates selenium. However, Salicornia establishment can be difficult in fine-textured soils that form a hard surface crust and its utilization is greatly hampered by the lack of available seed. With the exception of collection in the wild, nearly all seed sources remain proprietary and are not commercially available. On the Pacific Coast, the native range of *Salicornia bigelovii*, the annual species, extends only as far north as Santa Barbara; thus local collection is not possible.

Atriplex spp. also grow well under irrigation with saline drainage water and in the challenging soil conditions normally encountered in IFDM halophyte plots. At present, however, Atriplex plantings are not allowed by CDFA due to concerns that it may harbor the sugarbeet yellows virus. Although it has been suggested that Atriplex is no more likely to harbor the virus than would other native vegetation, the restriction is being maintained.

F. Trees

Drainage water is mainly applied to salt-tolerant crops, forages, and halophytes, and only occasionally to trees. Exceptions may be when drainage flows are very high or when drainage water salinities are low (5-8 dS/m). For example, drainage water could be used to irrigate eucalyptus, though ideally with blending and with a subsurface drain line under the tree block. Pistachio trees were irrigated with drainage water with an ECw of 8 dS/m by micro-sprinklers for more than eight years; but because boron concentrations were very low in these experiments, uncertainty remains about pistachio's tolerance to boron (B. Sanden, UC Cooperative Extension, personal communication).

Trees that are most promising for IFDM systems include: eucalyptus (*Eucalyptus camaldulensis*, 'River Red Gum', clones 4573, 4543, 4544); athel (*Tamarisk aphylla*); and casuarina (*Casuarina cumminghamiana*). Among this group, athel is the most salt-tolerant.

One disadvantage with trees is the long-term investment in establishing orchards and the overall uncertainty of survival over the long-term as the tree is exposed to multiple abiotic stresses (eg salt, boron, water stress, water-logging, and frost). In addition, soil type, climate and salinity of the water will affect the water use (ET) of the trees. ET may be reduced at higher salinities.

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IFDM System Management

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Chapter 6. IFDM System Management

A. Introduction

During the design and development of an IFDM system, the farmer and designer must decide on system management because each system will be different. The final design presented to the farmer should have a description of the management required to ensure success of the operation. It is not practical to attempt to describe the management for an undefined system. However, it is possible to describe the areas where management will be required as a starting point for the development of individual plans.

There are several major areas that will require management plans. The first is the irrigation system. If the farmer is continuing with an existing system then the designer will have evaluated the current practice and will have made suggestions as to what, if anything, can be improved. If there is to be a new type of irrigation system installed, then the designer will have to develop a specific set of operational and management plans.

The second area of management is salt. The farmers on the west side of the San Joaquin Valley typically manage salt by applying excess water and leaching it from the soil profile. When drainage was possible, the effort was made to leach the soil without any regard to the volume of salt being moved through the profile, but this will have to change.

The third area of management is the drainage system. This will be a completely new concept for the farmer. In the past, drains were designed to run continuously without regard to the consequences. The drains were often installed deep into the soil profile to ensure that salination of the root zone and soil surface would not occur. This will not be an acceptable practice in an IFDM system.

The fourth area is the solar evaporator. This will be a major change because it is new to the farmer and the operation will be monitored and regulated by the State of California. The consequences of mis-management in the other areas (irrigation, salt, and drainage system) will be the loss of productivity and extra water for disposal. Poor management of the solar evaporator will have specific and defined consequences that will be determined by the State.

Finally, selenium management in the soils and crops will have to be considered in the overall plan. This will not be a straightforward process but will be included in the salt management, the water management, and the crop selection.

B. Irrigation Management

Irrigation management strategies may have the single greatest impact on the operation of an IFDM system. Adopting management practices to control deep percolation losses (source control) will affect the size and complexity of the solar evaporator, as well as the area required for production of salt-tolerant crops. As indicated in previous sections, the less deep percolation, the smaller will be the area needed for production of salt-tolerant crops.

Research shows the pre-plant irrigation and the first seasonal irrigation are the most inefficient irrigations, when using surface irrigation. Efficiencies are improved when using sprinklers for these two irrigations. Using sprinklers for pre-plant irrigation results in less deep percolation losses and the water is more uniformly applied. Sprinkler irrigation also is more effective in leaching salts than surface irrigation for a given quantity of water. The goal of the pre-plant irrigation is to manage the salt in the soil surface for germination and in the root zone, while minimizing drainage water volume.

The first irrigation of the season also is problematic with surface irrigation because the available soil water storage is very low when plants are small and use little stored soil water. Surface irrigation will result in excess deep percolation. Opting for sprinklers on the first irrigation can solve the problem since the depth of application is controlled by the sprinkler runtime and not the infiltration rate of the soil surface as with surface irrigation. Controlling water volumes on the first irrigation is always problematic and can hinder production by saturating the root zone during a critical stage in the early growth of the crop. Sprinkler irrigation limits the amount of water applied, and therefore, limits drainage volumes while maximizing plant growth potential.

For drip irrigation, consideration must be given for management of the salt and crop germination. This might require use of sprinklers for germination. Pre-plant irrigation has been effectively used for salt control so this will not be a problem. Depending on the crop, it may be possible to use transplants, which will limit the need for water for germination.

For surface irrigation, there is a requirement related to standing water and wildlife safety. This should not be a problem since standing water would suggest that the field needs to be graded to eliminate the water, which will have a secondary effect of reducing water logging. The question is how to manage any tailwater ponds that are incorporated in the design of the system. This will be addressed in the design of the system and in the management plans approved by the State.

No standing water is one of the criteria to be addressed in the management plan. State law prohibits standing water for more than 48 hours. (Appendix Draft (Title 27/SB1372) Solar Evaporator Regulations, pages A-79 to A-88) Some management options to address this are proper irrigation scheduling, shorter runs/smaller blocks, maintaining infiltration rate with an amendment program, and proper leveling. Proper leveling will ensure that surface runoff will occur, and that excess water may be collected in a tailwater pond. The volume of runoff will be reduced by maintaining the infiltration rate.

Blending of saline and good quality water may become an issue at some point in IFDM system management. In some cases, the saline water will need to be blended to reduce the salinity to match the salt tolerance of the crop. This was discussed in the section on alternatives for using saline water in Chapter 4. There will need to be provisions in the design of the irrigation and drainage systems to blend water. Several alternatives can be explored, and the current systems operating in the San Joaquin Valley can be used as examples.

Water can be mixed in a sump and discharged to the field or the separate sources can be mixed in the pipe delivering water. The method selected will be determined by the physical layout of the system. If the runoff of the blended water contains salt and other elements that may be of regulatory concern, a management system must be developed. Reapplying the runoff water on a salt-tolerant crop will be the simplest method. If the saline water doesn't need to be blended then the cyclic method proposed by Rhoades (1989) would be an efficient technique to consider. The production areas containing salt-tolerant crops being irrigated with saline water will require some fresh water to manage the salt in the root zone.

Another aspect of irrigation management that may not be familiar to the manager is setting yield goals less than maximum yield and irrigating to this reduced yield level. This may result in maximum profits. This becomes apparent when a crop production function is considered. The last increment of yield to maximize production is the least efficient when water use is considered, so a reduction in applied water will not result in an equivalent reduction in yield. This may result in reduced cost of production without a significant yield loss. In this case, the farmer is irrigating for economic irrigation efficiency, which is defined at the farm level as the irrigation management that results in maximum profit.

A side benefit of this approach is that deep percolation losses are reduced. Often, the last increment of irrigation water is applied to compensate for irrigation inefficiency, and by not applying this increment, there is only minor yield reductions and less deep percolation. In an IFDM system, significant deep percolation reduction will have a positive impact in the reduction of drainage water for disposal.

C. Salt Management

Farmers are aware of the basics of salt management. Salt in the soil is not good and it must be eliminated for production of salt-sensitive crops. The management solution has been to install subsurface drains and apply water to leach the salt and to keep on applying water. This will remove the salt from the root zone and from areas deep in the soil. However, this is no longer an acceptable practice unless the management goal is to accumulate a large mass of salt on the farm.

The approach with an IFDM system is to manage the salinity in the root zone such that the crop production can be maintained and the salt load from the drains is minimized by controlling the deep percolation losses. Salinity is a problem in the root zone, but not in the portion of the soil profile not habituated by roots. When possible, consideration should be given to salt storage in the soil profile if this can be done without negatively impacting yield. More salt stored in the soil profile results in less salt to be managed at the solar evaporator. During excessive precipitation, excess salts stored in the soil profile will be moved through the subsurface drainage system and toward the solar evaporator. In a controlled drainage system, it may be desirable to store salts and then periodically leach them under controlled conditions.

Management strategies will change over time. Even in the first production area, high initial soil salinity may call for a more salt-tolerant crop rotation and an intensified reclamation program. Later on, as soil salinity moderates and soil salts are relocated away from the root zone, a more salt-sensitive crop rotation may be implemented along with stringent source control and reduced leaching fraction. Management is not a static quantity. It will be constantly in a state of flux and the management plans will have to change as the farmer gains experience with the system. The driving force for change will be the constantly changing environmental conditions and economic climate.

The salt management strategy will be dictated by the cropping pattern and the drainage water quality. The drainage water quality will remain fairly constant with time but the cropping may change as the soil in an area is reclaimed to a desired level so the cropping can be changed.

Soil Amendments

Farmers are familiar with the application of soil amendments to improve infiltration and soil permeability to water. With long-term application of saline-sodic drainage water to IFDM reuse areas, infiltration and soil permeability to water may decline appreciably. Surface applications of gypsum, soil sulfur or sulfuric acid are likely to be required and at rates higher than those used in conventional agriculture. Organic amendments also may have potential to mediate the negative effects of sodic irrigation waters. However, this has not been demonstrated.

D. Drainage System Management

Drainage system management will be a major departure from the farmer's experience. In the past, the drains were allowed to run continuously and it was assumed that this was required to prevent soil salinization and water-logging. However, research shows this is not the case, and the water table can be controlled at depths of approximately four feet below the soil surface without adverse impacts. This type of control limits the total drainage flow, and as a result also reduces salt load being discharged.

This type of control requires the drainage system laterals to be installed perpendicular to the surface grade and have a control structure. This control structure will have a weir board or device that can be positioned to maintain the water table at the desired level. Depending on the field size and layout, several control structures may be required.

Shallow groundwater levels can be manipulated to enhance leaching or to encourage the crop to use shallow groundwater as a water source. The ability of the crop to tolerate salt varies during the course of the growing season. The crop can use a tremendous volume of drainage water if it is within reach of the roots. This also suggests that for annual crops, the water table may be set closer to the ground surface early in the season and lowered as the season progresses to ensure adequate aeration of the root zone. Care will have to be exercised to ensure that the crop root zone is not waterlogged for an extended period following irrigation when the water table is controlled close to the root zone.

It is important the drainage system is operated in concert with the irrigation system. These two systems must become an integrated water management system.

E. Solar Evaporator

Solar evaporator management will be a new experience for farmers because it is the one components of IFDM that is new to them. There is a learning curve for all concerned to understand how the system works and how it is included in the operation of the farm. It is critical the designer develop detailed scenarios on the management. The experience of AndrewsAg and others with operating systems will be valuable as the management program develops (See Chapter 2).

Solar evaporator management must comply with §22940.SWRCB-Solar Evaporator Operation Requirements:

a *Limitation on Standing Water – The solar evaporator shall be operated so that, under reasonable foreseeable operating conditions, the discharge of agricultural drainage water to the solar evaporator will not result in standing water, outside the water catchment basin. Agricultural drainage water from the IFDM system shall be* *discharged to the solar evaporator by timed sprinklers or other equipment that allows the discharge rate to be set and adjusted as necessary to avoid standing water in the solar evaporator.*

b Prevention of Nuisance – The solar evaporator shall be operated so that, under reasonably foreseeable operating conditions, the discharge of agricultural drainage water to the solar evaporator does not result in:
(1) The drift of salt spray, mist, or particles outside the boundaries of the solar evaporator, or
(2) Any other nuisance condition.

c Prohibition of Outside Discharge – The operation of a solar evaporator shall not result in any discharge of agricultural drainage water outside the boundaries of the solar evaporator.

d Salt Management – For solar evaporators in continuous operation under a Notice of Authority to Operate issued by a Regional Water Quality Control Board, evaporte salt accumulated in the solar evaporator shall be collected and removed from the solar evaporator if and when the accumulation is sufficient to interfere with the effectiveness of the operation standards of the solar evaporator as specified in this section. One of the following three requirements shall be selected and implemented by the owner or operator:
(1) Evaporite salt accumulated in the solar evaporator may be harvested and removed from the solar evaporator and sold or utilized for commercial, industrial, or other beneficial purposes.
(2) Evaporite salt accumulated in the solar evaporator may be stored for a period of one-year, renewable subject to an annual inspection, in a fully contained storage unit inaccessible to wind, water and wildlife, until sold, utilized in a beneficial manner, or disposed in accordance with (3).
(3) Evaporite salt accumulated in the solar evaporator may be collected and removed from the solar evaporator, and disposed permanently as a waste in a facility authorized to accept such waste in compliance with the requirements of Titles 22, 23, 27 and future amendments of the CCR, or Division 30 (commencing with section 40000) of the Public Resources Code.

e Monitoring – Monitoring and record keeping, including a groundwater monitoring schedule, data, and other information or reporting necessary to ensure compliance with this article, shall be established by the RWQCB in accord with §25209.14 of Article 9.7 of the Health and Safety Code.

f Avian Wildlife Protection – The solar evaporator shall be operated to ensure that avian wildlife is adequately protected as set forth in §22910 (a) and (v). The following Best Management practices are required:
(1) Solar evaporators (excluding water catchment basins) shall be kept free of all vegetation.
(2) Grit-sized gravel (<5 mm in diameter) shall not be used as a surface substrate within the solar evaporator.
(3)Netting or other physical barriers for excluding avian wildlife from water catchment basins shall not be allowed to sag into any standing water within the catchment basin.
(4) The emergence and dispersal of aquatic and semi-aquatic macro invertebrates or aquatic plants outside the boundary of the water catchment basin shall be prevented.
(5) The emergence of the pupae of aquatic and semi-aquatic macro invertebrates from the water catchment basins onto the netting, for use as a pupation substrate, shall be prevented.

g Inspection – The RWQCB issuing a Notice of Authority to Operate a solar evaporator shall conduct authorized inspections in accord with §25209.15 of Article 9.7 of the Health and Safety Code to ensure continued compliance with the requirements of this article. The RWQCB shall request an avian wildlife biologist to assist the RWQCB in its inspection of each authorized solar evaporator at least once annually during the month of May. If an avian wildlife biologist is not available, the RWQCB shall nevertheless conduct the inspection. During the inspection, observations shall be made for compliance with §22910 (a) and (v), and the following conditions that indicate a reasonable threat to avian wildlife:
(1) Presence of vegetation within the boundaries of the solar evaporator;
(2) Standing water or other mediums within the solar evaporator that support the growth and dispersal of aquatic or semi-aquatic macro invertebrates or aquatic plants;

(3) Abundant sustained avian pressure within the solar evaporator that could result in nesting activity;
(4) An apparent avian die-off or disabling event within the solar evaporator;
(5) Presence of active avian nests with eggs within the boundaries of the solar evaporator.

If active avian nests with eggs are found within the boundaries of the solar evaporator, the RWQCB shall report the occurrence to the USFWS and DFG within 24 hours, and seek guidance with respect to applicable wildlife laws and implementing regulations. Upon observation of active avian nests with eggs within the boundaries of the solar evaporator, all discharge of agricultural drainage water to the solar evaporator shall cease until

(a) the nests are no longer active, or (b) written notification is received by the owner or operator, from the RWQCB, waiving the prohibition of discharge in compliance with all applicable state and federal wildlife laws and implementing regulations (i.e., as per applicable exemptions and allowable take provisions of such laws and implementing regulations.)

See Appendix pages A-79 to A-88 for complete regulations.

Compliance with the regulations may be achieved by managing water volumes, allowing drying periods, and equipment used to control and pump the water, as well as recording the required monitoring data. The reporting requirements provided in the agreement with the RWQCB will define the equipment required to provide the necessary data.

Monitoring of the IFDM system consists of two parts, monitoring required by law and monitoring for management purposes. Monitoring required by law to provide data to the regional board and the state board is outlined in the permit for the IFDM system. The amount of monitoring for management purposes is up to the discretion of the farmer.

Drainage water volumes must be recorded and quality reported. This data may be useful to adjust irrigation practices. Soil monitoring is not required, but is recommended because it enables the tracking of the progress of the IFDM system (evaluate whether soil conditions are improving or declining) and provides information for fertilizer and nutrient applications. Salinity monitoring by EM-38 surveys are not required, but may be helpful to evaluate salinity conditions in soil over time.

The most important management task will be to ensure the reports are made to the regional and state boards as and when required.

F. Selenium Management

This will also be a learning process for operators of IFDM systems since selenium will be present in the drainage water, the soil, the groundwater, the plants being irrigated with saline water, and finally in the effluent and salt in the evaporator. The opportunities for management will be in the areas of salt management in the soil, leaching, and in the crop selection. Selenate is mobile in water and will move freely with the drainage water. When drainage water is used for irrigation the selenium will be transported to new areas and may accumulate in the soil profile.

This accumulation can be regulated by leaching and crop selection. Several crop species have been identified as accumulators and will extract selenium from the soil. These plants can be used as food supplements in animal production. It also should be noted that selenium will volatilize from the plants and soil.

Monitoring, Recordkeeping and Reporting

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Chapter 7. Monitoring, Recordkeeping and Reporting

A. Introduction

Monitoring requirements will be determined by the need to either meet the regulatory requirements specified by the Central Valley Regional Water Quality Control Board (RWQCB) or to assist the manager in the operation of the IFDM system. As a result, there will be significant differences in the types of data collected and the frequency of data collection.

Monitoring of irrigation water quality and depth of application, soil salinity, groundwater depth and quality, volume and quality of drainage flows, and the subsequent recordkeeping practices are essential components of a successful IFDM program. Water quality data are needed to identify changes or trends in water quality as the water moves through the IFDM system. Groundwater monitoring data is a required component of the Notice of Intent (NOI) application to be filed with the RWQCB prior to installing the solar evaporator. The groundwater monitoring data will be used to establish the baseline information to compare subsequent data submitted by the operator. While much of the emphasis in the monitoring program is on the need to meet the regulatory requirements, the data collected will be valuable to the operator for use in managing the IFDM system. Monitoring reports will help characterize the system operation and identify specific water quality problems. Data from these reports can be used to determine California Environmental Quality Act (CEQA) baseline data.

The soil and water data collected at the beginning of the monitoring program will describe the baseline condition of the land and water resources prior to implementing IFDM and will be the basis for the IFDM project design. These data will identify constituents that may affect the operation or that will require special consideration in the future. The designer will use these data to select the fields to be used for each production area of the IFDM system, and to design a management program to reclaim fields if necessary and ensure the long term sustainability of the project.

One of the most important outcomes will be to use the water quality data to determine whether project compliance and implementation goals are being met. A critical aspect will be for the operator to evaluate the management scheme and to project the long-term health of the system.

B. Data Quality

The quality of data collected is described by its accuracy, precision, completeness, representation and comparability. Multiple factors influence the data quality, including sampling methods, the way samples are handled and analyzed, and the way data are handled. To ensure high quality data the IFDM operator will have to develop a plan of action, generally called a quality assurance program plan. The RWQCB may require a Quality Assurance Program Plan (QAPP) for each IFDM project. Quality assurance (QA) includes measures that are performed to ensure that there is minimal error and that data are valid and reliable. The two measures of QA are quality control (QC) and quality assessment. A QAPP is an important planning document for environmental data collection because it details the project management, standard operating procedures (SOPs), QA (QC and quality assessment measures), and data assessment measures that will be implemented throughout the project. In general, California certified laboratories will have QAPP for the samples brought to the laboratories. If their personnel are used in the data collection, the potential for mishandling samples and improper sample collection will be reduced.

The California Environmental Protection Agency SWRCB Water Quality website, www.swrcb.ca.gov/swamp/qamp.html, (see Appendix page A-55) outlines the sections and appendices of a Surface Water Ambient Monitoring Program (SWAMP) QAPP. The California Department of Water Resources (1998) Guidelines for Preparing Quality Assurance Project Plans is a helpful reference for QAPP development and preparation.

The complete monitoring program will include groundwater, surface drainage, subsurface drainage, the solar evaporator and the soil status. All of these data are not necessary to meet the regulatory requirements, but they will be essential for the successful operation of the IFDM system.

C. Monitoring & Reporting Program

IFDM systems must be designed and operated to prevent threats to water quality, fish and wildlife, and public health. Monitoring and recordkeeping requirements, including a groundwater monitoring schedule, data, and any other information or reporting, will be specified by the RWQCB. A properly designed monitoring program will aid in assessing any impact of the IFDM system operation on surface and groundwater quality, and fish and wildlife.

1) Groundwater Monitoring

Groundwater monitoring will be required to manage the shallow groundwater at the IFDM site and to measure any impact of the system operation on groundwater quality. Additionally, a person operating a solar evaporator will be required to collect adequate groundwater data in the vicinity of the evaporator to monitor the operation of the evaporator. All indicator parameters and constituents of concern must be collected from monitoring wells installed by the operator. Groundwater monitoring includes measurements for water level depth, specific electrical conductivity, standard minerals, and trace elements as specified by the RWQCB. The data also may be used to evaluate potential off-site influences on the area.

2) Subsurface Agricultural Drainage

Water collected from the production area prior to application to the solar evaporator will need to be measured for volume and quality. Applied water monitoring will include mean daily flow measurements, specific electrical conductivity, standard minerals and trace elements as specified by the RWQCB.

Consideration also should be given to measuring the volume of water collected from the drains under each production area and the EC under each area. This will provide the information needed to best manage the system. The quality measurements for water collected under the production areas may be limited to EC and standard minerals that will impact the agriculture success, i.e. Na and B.

3) Solar Evaporator Subsurface Drainage

Construction of a solar evaporator may require the installation of a subsurface drainage system under the evaporator to collect any leakage from the evaporator (see Solar Evaporator Design Requirements (c) Protection of Groundwater Quality, Appendix page A-86). Solar evaporator subsurface drainage systems (tile drains) are monitored for mean daily flow and specific electrical conductivity as specified by the RWQCB. In addition, evaporite salt should be sampled and analyzed for composition to monitor accumulation of metals and other elements.

4) Sampling Plan

The sampling plan will be developed in response to the regulatory and management requirements for the operation of the IFDM system. This should be done in consultation with an approved laboratory. Sampling plans are written procedures that provide details on how sampling is conducted (SOPs) and are incorporated as part of the QAPP. A typical sampling plan should include details on the following, as appropriate:

- Sample locations (map or diagram)
- Sample type
- Sample frequency
- Number of samples
- Duration of sampling
- Sample volume
- Sample collection methods and holding times
- Equipment to be used for sample collection
- Sample containers
- Pretreatment of containers
- Type and amount of preservative to be used
- Blanks, duplicates/triplicates, spiked samples, replicates
- Chain of custody procedures
- Any other pertinent matter, which will have a bearing on the quality assurance in collecting and handling samples (DWR, 1994)

5) Who will perform the monitoring and how?

One of the critical details is selection of the responsible person for sample collection in accordance with the sampling plan. This person should be knowledgeable and trained in monitoring protocols, and should be selected to collect representative water samples, perform specific field measurements, and prepare samples for laboratory analyses using accepted methodology. This may be a representative of a laboratory contracted to complete the collection and analysis or someone employed by the IFDM operator. In the second instance, that person should receive training to ensure that sampling is done properly.

6) What parameters will be measured?

All indicator parameters and constituents of concern must be identified in the sampling plan by the operator and submitted to the RWQCB for approval. The baseline sampling data will provide information to determine the constituents of concern and constituents of importance. A typical sampling plan may include but not be limited to the following constituents:

a. Trace Elements
   - Selenium
   - Boron
   - Arsenic
   - Molybdenum

b. Standard Minerals
   - Calcium
   - Magnesium
   - Sodium
   - Potassium
   - Alkalinity
   - Sulfate

c. Specific Electrical Conductivity and pH
   Some water quality parameters must be measured in the field during sample collection for laboratory analysis. Field measurements are recorded for specific conductance, pH, air and water temperatures, and weather observations. Agricultural observations, such as, the type of crop and crop height are noted and submitted with the water samples to the analytical laboratory. Weather data can be found at the nearest station of DWR's California Irrigation Management Information System, (CIMIS), at: www.cimis.water.ca.gov.

d. Other
   Other elements of concern may be identified from the baseline monitoring data or as required by the RWQCB. Some elements are site-specific or found in elevated concentrations in designated areas of the San Joaquin Valley and these will have to be included in the sampling.

7) Approved Laboratories

The California Environmental Laboratory Improvement Act requires that an environmental laboratory producing analytical data for California regulatory agencies (including RWQCB) must be accredited through a Department of Health Services accreditation program for environmental health laboratories. The accredited labs also are known as certified through the Environmental Laboratory Accreditation Program (ELAP).

To select an ELAP certified laboratory in your area that can perform analyses on all required constituents, you must first identify the required Field of Testing (FOT)/ Field of Accreditation (FOA) numbers. The RWQCB will determine what constituents will be required and identify the corresponding FOT/FOA numbers.

- The following website shows a table of FOT/ FOA numbers, brief descriptions and levels of complexity. www.dhs.ca.gov/ps/ls/ELAP/pdf/FOT_Desc.pdf
- The following website shows a list of ELAP certified labs by county and name. To select a lab, look through the list of labs in your county and make sure that the lab that you select is accredited to perform analyses on all required FOT/FOA numbers. www.dhs.ca.gov/ps/ls/ELAP/html/lablist.htm

8) Where are the monitoring sites?

The sampling sites will be located to ensure that the data are representative of the operations of the IFDM system and the environmental aspects. Monitoring sites that are accessible, easy to find and reachable in bad weather will allow for measurements to be taken at the desired time. It will be necessary to assign a name and provide a description of each of the sampling locations and to develop a diagram with reference points on how to find the monitoring site. It might not be possible for all sampling sites to be continuously accessible. In this case, provisions need to be made for automated sampling.

9) Sampling frequency

Sampling frequency will be determined by the RWQCB. In general, sampling should be frequent enough to describe all important water quality changes or trends. Initially, more frequent monitoring may be needed to establish the baseline conditions. Once established, the frequency of monitoring may be reduced by the RWQCB according to the laboratory test results.

It is important to summarize the data to clearly illustrate compliance with all applicable regulatory requirements. Arrange the data in tabular form so the required information is readily discernible. Certain technical information must be submitted with the monitoring report. Daily evapotranspiration values of the nearest weather station from which information is available and copies of the laboratory analyses are to be submitted as part of the report. Weather data can be found at DWR's California Irrigation Management Information System, CIMIS, at: www.cimis.water.ca.gov

Any person operating a solar evaporator should submit annual groundwater monitoring data and information at the earliest possible time, according to a schedule established by the RWQCB. The regional board shall notify the operator of each solar evaporator of the applicable submission schedule.

D. Automated Systems for Data Collection

Significant technological achievements have made it possible to customize monitoring programs equipped with automated systems for data collection. This section will present the basic equipment for the design of automated systems to measure the volume of monitored discharge, water levels, and salinity measurements. The general concept is to select a datalogger and accessory equipment to measure sensor output signals, process the measurement over some time interval, and store the processed results. Using the datalogger support computer software, the user can access the datalogger unit with a pocket PC or laptop computer, download the data, analyze it for quality, and store the data in a database.

1) Manual vs. Instantaneous Readings

a. Benefits

Automated systems can provide various benefits to a monitoring program.

First, automated systems provide the capability to collect data in remote sites. Inclement weather may make it difficult, and sometimes impossible, to collect manual readings in a timely manner.

Secondly, precision measurements are a valued component in the monitoring plan. Instantaneous readings will allow for the increased number of readings and reduce the likelihood of reading or recording a "blunder" value. The output data will be analyzed to determine if any improvements in the IFDM system design or operational changes that benefit the management of an IFDM system are warranted. Also, the data will be used to determine whether or not the project is operating in compliance with permit conditions.

Lastly, automated systems can be used to meet QA/QC requirements.

b. Costs

Initially, the purchase of equipment for automated monitoring programs may appear costly. However, the potential exists to reduce costs in long-term monitoring programs by designing a monitoring program using equipment that can provide data quality with the following characteristics: reliable, continuous, and unattended. Automated systems will require additional expertise and cost for the operator that may not be warranted. This will be determined based on the extent and scope of the required sampling plan. All monitoring instruments and devices identified in the monitoring program must be installed, calibrated as necessary, and maintained to ensure continued accuracy and reliability of the devices. The maintenance and operation of automated systems requires skilled personnel that may not normally be part of a farming operation.

c. Weatherproof Enclosure

An enclosure houses the measurement and control module and power supply. Enclosures should have the following characteristics: fiberglass; water-tight; dust-tight, corrosion-resistant; and for outdoor use.

d. Programmable Datalogger

Dataloggers provide the capability for flexibility in data collection and analysis by providing the ability to collect data hourly, daily, or on longer intervals. The data maybe useful in water use efficiency analysis, such as, water conservation and water quality. The datalogger is programmed to read the parameter, such as temperature, at some specified time interval before it can make any measurements and then sends the reading to a storage location (a datalogger program must be created). The manufacturer's Operator's Manual will present a basic understanding of the datalogger operation and provide instructions for programming, data retrieval, installation, and maintenance.

e. Power Supply

A datalogger can be powered with sealed rechargeable batteries that can be float-charged by ac power or a solar panel. When using a solar panel light energy is converted to electricity or direct current with the output being controlled by a regulator that may be either a part of the panel or a separate device. The regulator functions to block any current flow from the battery to the regulator and limits the source current to the battery. The solar panel is oriented to receive maximum incident solar radiation.

f. Flow Measurement Device

Flowmeters are used for agricultural irrigation measurement applications, such as water management, sprinkler irrigation systems, and drip irrigation systems. Propeller flowmeters should comply with the applicable provisions of the American Water Works Association Standard No. C704-91 for propeller type flowmeters.

g. Electrical Conductivity Probe

An electrical conductivity probe or sensor can be used to measure the electrical conductivity (EC) of water in pipelines and open ditches. These probes can measure conductivity over a wide range of values. The appropriate range will have to be established as part of the initial investigations. A conductivity interface is required.

h. Pressure Transducer

The depth to groundwater is measured using a pressure transducer, which is a device that converts pressure into an analog electrical signal. Although there are various types of pressure transducers, one of the most common is the strain-gage base transducer. Several manufacturers have developed inexpensive devices for continuous measurement of groundwater depths. These devices store the data for intermittent downloads. Groundwater level data combined with the irrigation data will provide information on the quality of irrigation system management. It will enable the manager to characterize the deep percolation losses under each system by characterizing the water table response to irrigation.

Economic Analysis of Integrated On-Farm Drainage Management

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Chapter 8. Economic Analysis of Integrated On-Farm Drainage Management

A. Introduction

The goal of integrated on-farm drainage management is to eliminate the need for discharging subsurface drainage water from a farm to surface water. This is accomplished by improving irrigation practices to reduce deep percolation and by collecting and evaporating subsurface drainage water through plants or in a solar evaporator constructed on the farm. The size of the solar evaporator is a function of irrigation management practices, the volume of drainage water collected and the evaporation rate. Farmers can minimize the area required for the evaporator by implementing irrigation practices that reduce deep percolation and the volume of water collected in subsurface drains.

Improving water management practices and installing subsurface drains will increase the cost of farming, while generating benefits that might include higher yields and long-term improvements in soil quality. The cost of irrigation water can be reduced if farmers purchase or pump less water after improving their water management practices. The benefits will vary substantially among farms, according to differences in crop production choices, agronomic practices, and the initial quality of soil and water resources. The component costs of implementing IFDM will be somewhat similar among farms, but the total cost will vary with differences in the size of the solar evaporator and the amount of land used to produce non-marketable, salt-tolerant crops.

The primary goal of this chapter is to describe the costs of implementing IFDM. A partial-budget analysis of cost implications is presented, rather than addressing all aspects of farm-level costs and returns. The framework described will enable farmers and their advisors to evaluate the potential financial implications of implementing IFDM. Farm-specific information regarding cost components, total costs and expected benefits can be analyzed using this framework. In some cases, IFDM will appear to be financially viable, while in others it might increase the net cost of farming. In all cases, farmers should think broadly regarding the full range of incremental costs and benefits they might attribute to implementing IFDM, both in the near term and over time.

The largest components of the cost of implementing IFDM are the costs of installing a subsurface drainage system (if a system is not already installed), the cost of installing a solar evaporator, and the cost of producing non-marketable, salt-tolerant crops, forages or halophytes. The opportunity cost of land used for the solar evaporator and the land used for producing non-marketable crops also must be considered. In some farm operations, these costs will be substantial. Farmers can minimize the total cost of implementing IFDM by reducing drainage water volume to minimize the size of the solar evaporator required, and by minimizing the area required for producing non-marketable crops.

The partial-budget analysis presented here is conservative, focusing on cost components without emphasizing potential benefits. As noted above, the cost components will be somewhat similar among farms, while benefits will vary with key assumptions regarding crop yields and prices. The goal is to present an objective analysis of the cost components without imposing a positive or negative view regarding the financial viability of IFDM. Farmers and their advisors will have better information available to evaluate farm-specific costs and returns. The empirical analysis demonstrates the methodology for considering all pertinent costs and benefits. Farmers and their advisors can use this framework and the spreadsheet in Appendix 8 (pages A-58 to A-63) and on the Appendix CD to examine farm-specific costs and benefits. In addition, they can conduct sensitivity analysis by varying assumptions regarding potential costs and benefits and examining the net financial impact of implementing IFDM.

B. Components of an IFDM System

A typical IFDM system includes three or four of the following components: 1) production of primary crops for sale in agricultural markets, 2) production of salt-tolerant plants (salt-tolerant crops, forages, and halophytes), 3) a subsurface drainage system, and 4) a solar evaporator. Drainage water generated by irrigating the marketable crops can be used to irrigate the salt-tolerant plants, or it can be discharged directly to the solar evaporator. Using drainage water to irrigate salt-tolerant plants will reduce the volume of drainage water requiring evaporation, but the land allocated to those crops might generate little or no income in some years, depending on crop selection. Farm-level net revenue will be higher when farmers can produce higher valued, marketable crops on all of their irrigated land, while discharging the subsurface drainage water directly to the solar evaporator.

All four components of the typical IFDM system are considered in the empirical analysis that follows. Some farmers will choose not to include salt-tolerant crops, forages, and halophytes, so they can maximize the area planted in marketable crops. The framework will enable farmers to evaluate the economic implications of that strategy and of alternative system designs. Farmers can reduce or eliminate the area required for low-value, salt-tolerant plants by improving irrigation practices and reducing deep percolation. The farm-level costs of making those improvements can be compared with the potential reduction in the cost of an IFDM system, made possible by reducing or eliminating production of the most salt-tolerant plants.

C. Conceptual Framework

In this analysis, the entire cost burden of the IFDM system, including the fixed and variable costs of the subsurface drainage system, the solar evaporator and the production of any low value salt-tolerant plants, is placed on the land used to produce marketable crops. As a result, the average cost of the IFDM system (per acre of marketable crops) rises with the proportion of the irrigated area used to produce low-value, salt-tolerant plants. In some years, farmers might receive revenue from the sale of salt-tolerant crops and forages, but that source of revenue is not included in this analysis. If land is allocated to salt-tolerant plants with little economic value, the opportunity cost of that land and any variable costs of production must be recovered from production of marketable crops on the remaining land area.

The annual fixed costs of the IFDM system include the amortized costs of the subsurface drainage system and the solar evaporator. The rental or opportunity cost of land used for the evaporator and for production of non-marketable, salt-tolerant plants also is included in the annual fixed costs. The initial cost of the subsurface drainage system includes engineering analysis, design, and construction. The initial cost of the solar evaporator also includes engineering analysis and construction, and the costs of the pipes, pumps, and sprinklers needed to distribute the drainage water. The rental rate or opportunity cost of land is included in the fixed cost of the solar evaporator. That cost also is included for any land allocated to the production of low-value, salt-tolerant plants.

The variable costs of an IFDM system include the operation and maintenance of the subsurface drains and the solar evaporator. Included also is the cost of an IFDM system manager, who monitors operation of the subsurface drainage system and the solar evaporator. The manager also supervises the production and irrigation of any low-value, salt-tolerant plants. The costs of producing low-value, salt-tolerant crops and forages are included in the variable costs of the IFDM system for scenarios that include production of those crops.

The annual benefits or returns to the IFDM system include the incremental production values made possible by providing subsurface drainage, and the avoided cost of disposing drainage water in some other, more costly, manner. Those benefits are not estimated in this analysis. However, the benefits can be substantial in arid regions where subsurface drainage systems are required to maintain productivity, and where public agencies regulate the discharge of agricultural drainage water into streams and other waterbodies. Benefits also might be large where IFDM systems enable farmers to maintain or improve soil productivity, while minimizing the re-use of saline drainage water on land used for primary crops. Those enhancements will enable some farmers to increase their annual revenues by replacing low-valued grains and forages with higher valued, salt-sensitive crops, such as fruits and vegetables on some of their land.

As described above, only the costs of installing and operating an IFDM system are considered. Other costs of crop production are not considered. This is a partial-budget analysis of the decision to install an IFDM system by a farmer seeking to provide drainage service and to dispose the collected drainage water within his or her farming operation. The goal is to present a framework farmers can use to evaluate their options regarding installation of an IFDM system. The farm-level costs of an IFDM system are described for a range of assumptions regarding the size of the solar evaporator and the proportion of irrigated land used to produce low-value, salt-tolerant plants. The estimated costs used can be replaced by precise values that describe actual costs for individual farming operations when those data are available.

D. Empirical Analysis

Key components of the partial-budget analysis include the following: 1) the estimated costs of installing, operating and maintaining the subsurface drainage system and the solar evaporator, 2) the proportions of land area required for the solar evaporator and for production of salt-tolerant plants, 3) the opportunity costs, taxes, and assessments on land used for the evaporator and for production of low-value, salt-tolerant plants, and 4) the interest rate and length of time used to amortize the initial costs of the drainage system and the solar evaporator. The estimated average cost of the IFDM system will increase with the proportion of land allocated to salt-tolerant plants and the size of the solar evaporator, and with the rental rate or opportunity cost of land. The average fixed cost will be smaller for lower interest rates and for longer periods of amortization.

A 640-acre farm is used in this empirical analysis, assuming that 600 acres of the farm are served by a subsurface drainage system. Irrigated production of marketable crops and salt-tolerant plants occurs on those 600 acres, while the solar evaporator is constructed somewhere within the remaining 40 acres. The sizes of the solar evaporator were assumed to range from 0.5% to 2% of the irrigated area, or from 3-to-12 acres. The proportions of irrigated area planted in non-marketable crops in this analysis include zero, 10% and 20% for low-valued, salt-tolerant crops and forages, and zero, 1%, 2%, and 4% for halophytes. Hence, the area planted in marketable crops ranges from all 600 irrigated acres if no land is allocated to salt-tolerant plants, to 456 acres if 120 acres are planted in low-value, salt-tolerant crops and forages, and 24 acres are planted in halophytes.

The estimated cost of installing a subsurface drainage system on 600 acres of land is $240,000, or $400 per acre. The actual cost will vary among farms with differences in drainage conditions and land characteristics, and the availability of government programs that reimburse a portion of the costs. The assumed cost of installing a simple solar evaporator is $1,000 per acre of land used for the evaporator. The initial costs of the drainage system and the evaporator are amortized over 20 years and 10 years, respectively, using an interest rate of 6.25%, which is the ten-year average rate of return to production assets from current income in California agriculture (Hutmacher et al., 2003). The amortized costs are $36 per acre of irrigated land for the drainage system and $137 per acre of land used for the solar evaporator (Table 1). The estimated annual costs of operation and maintenance for the drainage system and solar evaporator are $5 and $120 per acre, respectively.

The estimated rental rate or opportunity cost of land is $150 per acre, and the estimated sum of annual taxes and assessments on the land is $25 per acre. These costs are added to the annual cost of land used for the solar evaporator and for producing low- value, salt-tolerant plants. Hence, the estimated annual cost of owning and operating the solar evaporator is $432 per acre of land used for the evaporator (Table 1).

The annual fixed cost of producing salt-tolerant plants includes the sum of annual taxes and assessments on the land and the rental or opportunity cost. The variable costs include the labor, fertilizer, pesticides and other inputs required to maintain the plants. The fertilizer and pesticide requirements will be smaller for low-value, salt-tolerant plants than for primary crops for two reasons: 1) the salt-tolerant plants will be irrigated with drainage water that contains some of the nutrients required to support plant growth, and 2) the salt-tolerant plants likely will attract fewer pests that need to be suppressed using pesticides. Farmers will use larger amounts of chemical fertilizers and other inputs in years when they plan to sell their salt-tolerant crops and forages. Input use will be minimal in years when the crops are grown only for the purpose of disposing of subsurface drainage water.

An estimate of $339 per acre is used for the annual production cost for low-value, salt-tolerant crops and forages, which is the estimated operating cost for producing winter forage in the San Joaquin Valley (Campbell-Mathews et al., 1999). Hence, the sum of the annual costs for land planted in salt-tolerant crops and forages is $514 per acre (Table 1). The estimated annual production costs for halophytes are only $25 per acre, given that those crops will not be produced for sale. The sum of the estimated annual costs for land planted in halophytes is $200 per acre (Table 1).

In some years, salt-tolerant crops and forages might be sold for a price that equals or exceeds the cost of production, but in most years, the net returns from that activity likely will be negative. Given this conservative approach, any revenue from low-value, salt-tolerant crops, forages or halophytes is not considered. However, farmers and their advisors can include such estimates when evaluating farm-specific financial implications of implementing IFDM. In general, it will be desirable for farmers to minimize drainage water volume by improving irrigation practices, and to use all of their irrigated land for production of higher valued crops. Farmers planning to produce salt-tolerant plants for sale can consider their expected revenues when estimating the likely costs and returns of investing in an IFDM system.

As noted above, the optimal size of a solar evaporator will vary with the volume of drainage water requiring disposal and with the local evaporation rate. The area of land allocated to production of low-value, salt-tolerant plants also will vary among farmers, according to their preferences regarding crop production and marketing alternatives, and with their ability and desire to reduce drainage water volume through improvements in irrigation water management. To reflect this potential variability, a range of proportions for the land area allocated to low-value, salt-tolerant plants and the solar evaporator is examined. The size of the solar evaporator ranges from 0.5% to 2.0% of the irrigated area, or from 3 to 12 acres. Three proportions of land area in low-value, salt-tolerant crops or forages (zero, 10%, and 20%) are considered, and the proportion of area planted in halophytes ranges from zero to 4%.

Three scenarios pertaining to the three proportions of land in salt-tolerant forages are described in Tables 2 through 7. The net areas of irrigated land used to produce higher valued, marketable crops are shown in Table 2, for the ranges of assumed values regarding the areas allocated to producing halophytes and salt-tolerant crops and forages. The estimated total, annual costs of owning, operating, and maintaining the solar evaporator and allocating land for the production of salt-tolerant plants are shown in Table 3. The estimated annual cost for the 640-acre farm ranges from $1,297 to $5,190 if no land is used to produce salt-tolerant plants and from $67,777 to $71,670 if 20% of the irrigated land is used to produce low-value, salt-tolerant crops or forages and 4% of the irrigated land is used to produce halophytes. The annual cost rises substantially with the proportion of land allocated to the production of low-value, salt-tolerant crops or forages, given the estimated annual cost of $514 per acre for that activity (Table 1).

The estimated annual costs presented in (Table 3) are divided by the net areas used to produce higher valued crops (Table 2) to determine the estimated average cost per acre imposed on production of the higher valued crops. Those estimates range from $2 to $9 per acre if no land is used to produce low-value, salt-tolerant plants, and from $149 to $157 per acre if 20% of the irrigated land is used to produce salt-tolerant crops or forages and 4% of the irrigated land is used to produce halophytes (Table 4). These cost estimates will be helpful for farmers who already have installed a subsurface drainage system, but are seeking an alternative method for disposing the collected drainage water. Those farmers will need only to: 1) install and operate the solar evaporator, 2) decide how much land, if any, to allocate to the production of low-value, salt-tolerant plants, and 3) hire an IFDM system manager to monitor and operate the system. The estimated costs in Table 4 pertain to the first two components of that decision.

The estimated annual costs of an IFDM system manager, per acre of irrigated land used to produce higher valued, marketable crops are shown in Table 5. Those costs, which pertain to an annual salary of $35,000, range from $58 per acre if no land is used to produce low-value, salt-tolerant plants to $77 per acre if 20% of the irrigated land is used to produce low-value, salt-tolerant crops or forages and 4% of the irrigated land is used to produce halophytes. Hence, the incremental annual cost of implementing an IFDM strategy for farmers who already have a subsurface drainage system will range from $60 ($58 + $2) to $234 ($77 + $157) per acre of irrigated land used to produce marketable crops. Estimates pertaining to specific assumptions regarding the size of the evaporator and the area used to produce salt-tolerant plants can be obtained by summing the pertinent cost estimates in Tables 4 and 5.

The estimated annual cost of owning, operating, and maintaining the subsurface drainage system is $40.58 per acre (Table 1). The average cost, per acre of marketable crops, increases with the proportion of irrigated land allocated to low-value, salt-tolerant plants. The average cost ranges from $41 per acre if no land is used to produce low-value, salt tolerant plants, to $53 per acre if 20% of the irrigated land is used to produce salt-tolerant crops or forages and 4% of the land is used to produce halophytes (Table 6).

The estimated annual cost of all components of the IFDM system is determined by summing the pertinent cost estimates in Tables 4, 5, and 6. The summary cost estimates range from $101 to $108 per acre of irrigated land used to produce higher valued, marketable crops if no land is used to produce salt-tolerant plants, and from $279 to $287 per acre if 20% of the irrigated land is used to produce salt-tolerant crops or forages and 4% of the irrigated land is used to produce halophytes (Table 7). All of the cost estimates appearing in Table 7 are between $100 and $300 per acre of irrigated land used to produce marketable crops.

E. Discussion

The estimated average cost of owning, operating, and maintaining an IFDM system increases substantially with the proportion of irrigated land allocated to the production of low-value, salt-tolerant plants. The cost estimates for Scenario B, in which 10% of the irrigated land is used to produce low-value, salt-tolerant crops or forages, are about 65% higher than those for Scenario A, in which no land is used for that activity (Table 7). The cost estimates for Scenario C, in which 20% of the irrigated land is used to produce low-value, salt-tolerant crops or forages, are more than double those for Scenario A. These results describe one component of the farm-level economic incentive to improve water management and reduce drainage water volume. The costs of collecting, managing, and disposing drainage water can be reduced substantially if only a small area is required for producing alternative crops. In addition, the revenue received from sales will be higher when a larger proportion of the irrigated land is used for producing primary, higher valued crops.

The incremental costs of improving irrigation water management can be evaluated in comparison with the incremental benefits of reducing the average cost of implementing the IFDM strategy. For example, successful efforts to reduce the area required for low-value, salt-tolerant crops or forages from 20% to 10% of the irrigated area will reduce the average annual cost of the IFDM system by about $90 per acre of land used to produce higher valued crops (Table 7). Eliminating the area allocated to salt-tolerant plants will reduce that cost by an additional $70 per acre.

The cost of an IFDM system can be reduced also by utilizing land that has a smaller rental rate or opportunity cost for the solar evaporator and for production of salt- tolerant plants. Some land in drainage problem areas might already be impacted by a saline high water table and its rental rate or opportunity cost will be smaller than that of other land in the region. If drainage-impacted land is used for the solar evaporator and for production of low-value, salt-tolerant forages and halophytes, the average cost of the IFDM system will be reduced. For example, the estimated average cost declines from $108 to $106 per acre when the land cost decreases from $150 to $50 per acre, when 2% of the land is allocated to the solar evaporator and no land is used for producing salt-tolerant plants (Table 8). More notably, the average cost declines from $287 to $253 per acre when the rental rate or opportunity cost declines from $150 to $50 per acre, when 2% of the land is allocated to solar evaporator, 20% of the land is used to produce low-value, salt-tolerant crops or forages, and 4% of the land is used to produce halophytes.

The estimated average costs of installing and operating an IFDM system are relatively high, when compared with the potential net returns from some of the field crops produced in the San Joaquin Valley. For reasonable values of crop yields and prices, the estimated net returns above cash costs for alfalfa hay, cotton and tomatoes for processing are $401, $166 and $498, respectively (Table 9). The estimated net returns above all costs are $1, $62 and $402 per acre for those crops, respectively. The estimated average annual cost of an IFDM system in which 10% of the irrigated land is used to produce salt-tolerant crops and forages, 1% of the land is used to produce halophytes, and the size of the solar evaporator is 1% the size of the irrigated area, is $176 per acre (Table 8). That cost would generate negative net returns in the production of alfalfa or cotton, while reducing the annual net returns in tomato production from $402 per acre to $226 per acre.

Cash costs generally include annual operating expenses and the taxes and assessments on land. Non-cash costs include the amortized costs of durable equipment, such as a solar evaporator and a subsurface drainage system. The cash and non-cash components of the estimated annual cost of a selected IFDM system are presented in Table 10. The largest cash cost components are the salary for the IFDM system manager ($65.54 per acre) and the costs of production for salt-tolerant crops and forages ($38.09 per acre). The largest non-cash components are the amortized cost of the subsurface drainage system ($39.98 per acre) and the rental or opportunity cost of land used for producing low-value, salt-tolerant crops and forages ($16.85 per acre). The total cash operating cost for the selected IFDM system is $110.88 per acre, while the sum of the non-cash operating costs is $3.37 per acre. The sum of non-cash overhead expenses is $61.75 per acre. Those sums appear also in the bottom half of Table 9.

The estimated total cash cost for the IFDM system ($114.25 per acre) is about twice as large as the non-cash overhead cost ($61.75 per acre). Hence, the installation of an IFDM system will have uneven impacts on the cash and non-cash components of crop production costs and the associated measures of net returns. For example, the installation of the selected IFDM system will increase the total cash cost of producing alfalfa from $571 to $685 per acre, or by about 20% (Table 9). The non-cash overhead cost of producing alfalfa will increase from $400 to $462 per acre (15.5%). The estimated net returns above operating costs will decline from $478 to $367 per acre (23.2%), while the estimated net returns above cash costs will decline from $401 to $287 per acre (28.4%). The estimated net returns above all costs will decline from $1 to $-175 per acre. Similar calculations can be obtained for other crops using the information in Table 9.

Farmers and their advisors can use the framework described in this section to evaluate the farm-specific implications of implementing IFDM. Alternative values describing key components of the costs and benefits of IFDM can be entered in the spreadsheet tables provided in Appendix 8 (pages A-58 to A-63) and on the Appendix CD. The net financial implications for some farmers will be more attractive than the results pertaining to the example.

F. Conclusions

The average cost of installing, maintaining and operating an IFDM system, per acre of land used to produce marketable crops, increases substantially with the proportion of land area allocated to the solar evaporator and to production of low-value, salt-tolerant plants for this example. If only 0.5% of the area is required for the solar evaporator and all of the irrigated land is used to produce marketable crops, the estimated average annual cost is $101 per acre, for rental rates ranging from $50 to $150 per acre (Table 8). The average annual cost ranges from $158 to $177 per acre of land in marketable crops when 10% of the irrigated land is used to produce low-value, salt-tolerant crops or forages. If 20% of the irrigated land is used to produce low-value, salt-tolerant crops or forages, the estimated annual cost ranges from $247 to $287 per acre.

The estimated average annual cost of installing and operating an IFDM system is substantial, in comparison with the estimated costs of production and net returns for some of the field crops grown in the San Joaquin Valley. The estimated net returns above total costs become negative for alfalfa and cotton when adjusted for the average cost of an IFDM system. The estimated net returns above total costs remain positive for processing tomatoes, although they are reduced by about 44%. All of these estimates pertain to one configuration of an IFDM system and the values assumed. The estimated impacts on crop production costs and net returns will be different for other configurations and cost estimates.

Farmers can reduce the average cost of implementing IFDM by improving irrigation water management and by choosing land parcels with small rental rates or low opportunity costs. In some cases, farm-level improvements in water management will generate higher costs of production that will offset a portion of the reduction in the cost of implementing IFDM. However, annual net revenue might increase with reductions in water deliveries and improvements in crop yields. Farmers also might generate revenue by selling low-value, salt-tolerant forages and other crops in some years. **A complete evaluation of farm-level IFDM strategies will include analysis of these additional, potential sources of costs and revenues**.

The economic implications of implementing IFDM will be more favorable for farmers who already have installed a subsurface drainage system, and who seek a method for disposing the collected drainage water within their farming operation. Those farmers might need to modify their existing drainage system by inserting flow control structures or installing new pumps and pipes to carry drainage water to a solar evaporator, but they will not need to invest in a completely new drainage system. If those farmers can reduce drainage water volume sufficiently to avoid the need for including salt-tolerant plants in their IFDM system, the incremental cost of implementing that strategy will be about $70 per acre of land used to produce marketable crops. That estimate is determined by subtracting $36 per acre for the drainage system investment cost from the cost estimates that appear in the first column of Table 7. A further reduction in cost can be achieved if the system can be managed by a part-time staff person, rather than a full-time manager. That adjustment might be possible if the volume of drainage water collected each year is small enough that the IFDM strategy can be implemented successfully without the irrigation of low-value, salt-tolerant plants.

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Table 8-1.

The estimated costs of Installing, operating, and maintaining the solar evaporator and the estimated annual costs of land used for the evaporator, salt-tolerant crops, forages, and halophytes

Item	Initial Cost	Annual Costs
	($/acre)	($/acre)
The Subsurface Drainage System		
Estimated installation cost	400.00	
Amortized installation cost		35.58
Operation and Maintenance		5.00
Sum of Estimated Annual Costs for the Drainage System		40.58
The Solar Evaporator	($/acre)	($/acre)
Estimated installation cost	1,000.00	
Amortized installation cost		137.48
Operation and maintenance		120.00
Taxes and assessments		25.00
Rental or opportunity cost		150.00
Sum of Estimated Annual Costs for the Evaporator		432.48
Land Used for Salt-tolerant Crops and Forages		($/acre)
Taxes and assessments		25.00
Rental or opportunity cost		150.00
Annual production costs		339.00
Sum of Estimated Annual Costs for Salt-tolerant Crops		514.00
Land Used for Halophytes		($/acre)
Taxes and assessments		25.00
Rental or opportunity cost		150.00
Annual production costs		25.00
Sum of Estimated Annual Costs for Halophytes		200.00

Table 8-2.

The net area of land in production of higher valued crops, for different assumptions regarding the size of the solar evaporator and the proportion of of area planted in salt-tolerant crops, forages, and halophytes

Proportion of Area in Halophytes (%)	Scenario A	Scenario B	Scenario C
		(acres)	
0	600	540	480
1	594	534	474
2	588	528	468
4	576	516	456

Notes:

Scenario A:	No Salt-Tolerant Crops or Forages
Scenario B:	10% of Land in Salt-Tolerant Crops or Forages
Scenario C:	20% of Land in Salt-Tolerant Crops or Forages

Table 8-3. The estimated total, annual cost of owning, operating, and maintaining a solar evaporator and using land to produce salt-tolerant crops, forages, and halophytes

The Solar Evaporator		Scenario A No Salt-Tolerant Crops or Forages				Scenario B: 10% of Land in Salt-Tolerant Crops or Forages				Scenario C: 20% of Land in Salt-Tolerant Crops or Forages			
Proportion of Area	Number of Acres	Proportion of Area in Halophytes (%)				Proportion of Area in Halophytes (%)				Proportion of Area in Halophytes (%)			
		0	1	2	4	0	1	2	4	0	1	2	4
(% of area)	(acres)	($/year)				($/year)				($/year)			
0.5	3	1,297	2,497	3,697	6,097	32,137	33,337	34,537	36,937	62,977	64,177	65,377	67,777
1.0	6	2,595	3,795	4,995	7,395	33,435	34,635	35,835	38,235	64,275	65,475	66,675	69,075
1.5	9	3,892	5,092	6,292	8,692	34,732	35,932	37,132	39,532	65,572	66,772	67,972	70,372
2.0	12	5,190	6,390	7,590	9,990	36,030	37,230	38,430	40,830	66,870	68,070	69,270	71,670

Assumptions used in creating this table

The irrigated, agricultural area considered in this example is:		**600** acres.
The proportions of irrigated area in salt-tolerant forages are:	Scenario A:	**0** percent.
	Scenario B:	**10** percent.
	Scenario C:	**20** percent.

Table 8-4. The estimated annual cost of owning, operating, and maintaining a solar evaporator and using land to produce salt-tolerant crops, forages, and halophytes, per acre of irrigated land

The Solar Evaporator		Scenario A No Salt-Tolerant Crops or Forages				Scenario B: 10% of Land in Salt-Tolerant Crops or Forages				Scenario C: 20% of Land in Salt-Tolerant Crops or Forages			
Proportion of Area	Number of Acres	Proportion of Area in Halophytes (%)				Proportion of Area in Halophytes (%)				Proportion of Area in Halophytes (%)			
		0	1	2	4	0	1	2	4	0	1	2	4
(% of area)	(acres)	($/acre)				($/acre)				($/acre)			
0.5	3	2	4	6	11	60	62	65	72	131	135	140	149
1.0	6	4	6	8	13	62	65	68	74	134	138	142	151
1.5	9	6	9	11	15	64	67	70	77	137	141	145	154
2.0	12	9	11	13	17	67	70	73	79	139	144	148	157

Assumptions used in creating this table

The irrigated, agricultural area considered in this example is: **600** acres.

The proportions of irrigated area in salt-tolerant forages are:
- Scenario A: **0** percent.
- Scenario B: **10** percent.
- Scenario C: **20** percent.

Table 8-5.

The estimated annual cost of an IFDM system manager,
per acre of irrigated land used to produce marketable crops

Proportion of Area in Halophytes (%)	Scenario A	Scenario B	Scenario C
		($/acre)	
0	58	65	73
1	59	66	74
2	60	66	75
4	61	68	77

Notes:	
Scenario A:	No Salt-Tolerant Crops or Forages
Scenario B:	10% of Land in Salt-Tolerant Crops or Forages
Scenario C:	20% of Land in Salt-Tolerant Crops or Forages

Table 8-6.

The estimated annual cost of owning, operating, and maintaining a
subsurface drainage system that serves 600 acres, per acre of land in
higher valued, marketable crops

Proportion of Area in Halophytes (%)	Scenario A	Scenario B	Scenario C
		($/acre)	
0	41	45	51
1	41	46	51
2	41	46	52
4	42	47	53

Notes:	
Scenario A:	No Salt-Tolerant Crops or Forages
Scenario B:	10% of Land in Salt-Tolerant Crops or Forages
Scenario C:	20% of Land in Salt-Tolerant Crops or Forages

Table 8-7. The estimated annual cost of owning, operating, and maintaining an IFDM system, per acre of irrigated land, including the estimated cost of the subsurface drainage system

The Solar Evaporator		Scenario A No Salt-Tolerant Crops or Forages				Scenario B: 10% of Land in Salt-Tolerant Crops or Forages				Scenario C: 20% of Land in Salt-Tolerant Crops or Forages			
Proportion of Area	Number of Acres	Proportion of Area in Halophytes (%)				Proportion of Area in Halophytes (%)				Proportion of Area in Halophytes (%)			
		0	1	2	4	0	1	2	4	0	1	2	4
(% of area)	(acres)	($/acre)				($/acre)				($/acre)			
0.5	3	101	104	107	114	169	174	178	187	255	261	267	279
1.0	6	103	106	109	116	172	176	180	189	258	263	269	282
1.5	9	105	108	112	118	174	178	183	192	260	266	272	284
2.0	12	108	111	114	120	177	181	185	194	263	269	275	287

Assumptions used in creating this table

The irrigated, agricultural area considered in this example is:		**600** acres.
The proportions of irrigated area in salt-tolerant forages are:	Scenario A:	**0** percent.
	Scenario B:	**10** percent.
	Scenario C:	**20** percent.

Table 8-8.

The estimated average annual cost of owning, operating, and maintaining an IFDM system to support irrigated production on 600 acres of land

	Land Rental Rate or Opportunity Cost ($/acre)		
	150	100	50
Proportion of Area in Evaporator	Average Cost	Average Cost	Average Cost
(%)	($/Acre)	($/Acre)	($/Acre)
No production of salt-tolerant crops, forages, or halophytes			
0.5	101	101	101
1.0	103	103	102
1.5	105	105	104
2.0	108	107	106
10% of irrigated land in production of salt-tolerant crops or forages, and 2% of land in production of halophytes			
0.5	178	171	164
1.0	180	173	166
1.5	183	175	167
2.0	185	177	169
20% of irrigated land in production of salt-tolerant crops or forages, and 4% of land in production of halophytes			
0.5	279	263	247
1.0	282	265	249
1.5	284	268	251
2.0	287	270	253

Table 8-9.

Estimated costs of production for selected crops in the San Joaquin Valley and the estimated costs of installing and operating an IFDM system, in dollars per acre, per year

Cost Category	Alfalfa 2003	Acala Cotton 2003	Processing Tomatoes 2001	DOV Raisins 2003	Almonds 2003	Pistachios 2000
Estimated Costs of Crop Production						
Total Operating Costs	494	730	1,203	1,127	2,148	1,333
Cash Overhead Costs	77	167	223	262	191	326
Total Cash Costs	571	897	1,427	1,389	2,339	1,660
Non-Cash Overhead Costs	400	104	97	1,191	738	1,177
Total Costs	971	1,001	1,523	2,580	3,077	2,837
Total Revenue	972	1,063	1,925	2,550	2,860	1,975
Net Returns Above Operating Costs	478	333	722	1,423	712	642
Net Returns Above Cash Costs	401	166	498	1,161	521	316
Net Returns Above Total Costs	1	62	402	-30	-217	-861
Estimated Costs of an IFDM System						
Operating Costs	111	111	111	111	111	111
Cash Overhead Costs	3	3	3	3	3	3
Total Cash Costs	114	114	114	114	114	114
Non-Cash Overhead Costs	62	62	62	62	62	62
Total Cost of the IFDM System	176	176	176	176	176	176
Adjusted Net Returns						
Net Returns Above Operating Costs	367	222	611	1,312	601	531
Net Returns Above Cash Costs	287	51	384	1,047	407	201
Net Returns Above Total Costs	-175	-115	226	-206	-393	-1,037

Notes:

These costs pertain to an IFDM system in which 10% of the irrigated land is used to produce salt-tolerant crops and forages, 1% of the irrigated land is used to produce halophytes, and the size of the solar evaporator is 1% of the size of the irrigated land.

The adjusted net returns reflect the subtraction of costs pertaining to the IFDM system.

Sources:

The estimated costs of production are from the following sources:

Alfalfa:Vargas et al., 2003; Acala Cotton: Hutmacher et al., 2003; Processing Tomatoes: May et al., 2001; DOV Raisins: Vasquez et al., 2003; Almonds: Freeman et al., 2003; Pistachios: Kallsen et al., 2000.

DOV denotes Dried-on-Vine Raisins.

The estimated costs for processing tomatoes and pistachios have been adjusted to represent costs in 2003 using the Consumer Price Index for all Urban Consumers.

Table 8-10.

Cash and non-cash components of the estimated average annual cost of an IFDM system

Cost Category	Subsurface Drainage System	Solar Evaporator	Salt-tolerant Crops and Forages	Halophytes	System Manager	Total Costs
	($/acre)	($/acre)	($/acre)	($/acre)	($/acre)	($/acre)
Operating Costs	5.62	1.35	38.09	0.28	65.54	110.88
Non-Cash Operating Costs		0.28	2.81	0.28		3.37
Non-Cash Overhead	39.98	3.23	16.85	1.69		61.75
Total Costs	45.60	4.86	57.75	2.25	65.54	176.00

Notes:

These costs pertain to an IFDM system in which 10% of the irrigated land is used to produce salt-tolerant crops and forages, 1% of the irrigated land is used to produce halophytes, and the size of the solar evaporator is 1% of the size of the irrigated land.

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Chapter 9. Future Research

A. Introduction

Successful operation of IFDM systems requires a good understanding of irrigation water management, crop management, salt management, drainage system management, operation of a solar evaporator, and selection of crops and plant materials. Information is available to the operator on most of these topics, but nothing is static and crops change, irrigation systems evolve, and new practices are being developed for the integrated management of irrigation and drainage systems. The ultimate disposal of saline drainage water in a solar evaporator and the disposal of salt products still require extensive research. The fate of contaminants in the soil water and plant continuum is not well defined and requires additional study.

A listing of the research projects funded by Prop. 204 money from the California Department of Water Resources and State and Federal funds from the U.C. Center for Water Resources demonstrates that the areas of concern indicated above are currently being researched. Results from these studies will have application to the operation of IFDM systems in the future. More information can be obtained from the DWR and UCR websites, respectively: http://www.sjd.water.ca.gov/drainage/prop204/index.cfm; and http://www.waterresources.ucr.edu/index.php?content=sdp/research/researchSD.html.

B. Examples of Funded Research Projects

1) Drainage Water Reuse

Drainage Water Irrigation Monitoring for an Integrated on-Farm Drainage Management Component at Red Rock Ranch, Fresno County

Monitoring Wildlife Impacts at IFDM Demonstration Projects

Development of Wildlife Management Criteria for the Operations of IFDM Projects

Using Forages and Livestock to Manage Drainage Water in the San Joaquin Valley

Crop Production with In-situ Use of Shallow Saline Groundwater-Reuse of Drainage Water, and Active Drainage System Management

Suitability Assessment of Salt-Tolerant Forages and a Halophyte for Sequential Drainage Water Reuse Systems: Plant Water Use (ET), Forage Quality, and Productivity

Feasibility Determination and Design of a Wintering Waterfowl Wetland Habitat Using a Low-Selenium Saline Agricultural Drainage Water Supply

Characterization and Utilization of Saline Biomass

Developing Biofuel and Selenium-Enriched Forage from Canola Irrigated With Selenium-Laden Drainage Waters on the Westside of Central California

Greenhouse Evaluation of Salt-Tolerant Forages Growing in Red Rock Ranch

Animal Evaluation of Salt-Tolerant Forages Irrigated With Saline Drainage Water: Forage Quality, Persistence Under Grazing, Digestibility and Intake by Animal

2) Salt Separation and Utilization

Water and Salt Recovery by Solar Distillation

Investigate and Evaluate Alternative Systems of Salt Separation, Purification, Utilization, or Disposal

Salt Utilization in Glass Making

Phase I: Application and Feasibility of Salinity Gradient Solar Pond Technology in the San Joaquin Valley. Phase II: California Salt Gradient Solar Pond in the San Joaquin Valley

Feasibility Pilot Demonstration for Producing Commercial Salt Products from Saline Subsurface Drainage Water Using the Ion Exchange Process

3) Drainage Water Treatment

Grassland Drainage Area Algal-Bacterial Selenium Removal Facility

Removal of Selenium from Drainage Water in Lined Reduction and Open Oxidation Channels: A Field Study

Reducing Selenium Loads and Ecotoxic Risk in IFDM Systems Using Solar Evaporation Basins that Combine Invertebrate Harvest with Algal Volatilization of Selenium

Critical Process Requirements for Membrane Desalination of Agricultural Drainage Water at Selected Locations in the San Joaquin Valley

4) Source Reduction

Impacts of Drainage Re-Use on Water District Salinity Budgets: A Case Study of Two Westside Irrigation Water Districts

An Economic Analysis of Solar Evaporators and Evaporation Ponds

U.C. Center for Water Resources

5) Salinity/Drainage Projects

Interaction of Se Biogeochemistry with Foodchain Disruption in Full-Scale Evaporation Basins

Selenium Removal from Agricultural Drainage Water by Selenate-Reducing Bacteria

Does Saline Drainage Water Affect Crop Tolerance to Boron?

Integrated Drain Water Management in the Central Valley

Phytoremediation of Selenium-Contained Drainage Sediments and Chemical Characterization of Potentially Exotoxic Se Forms

Drainage Manual References

Chapter 1: Introduction

San Joaquin Valley Drainage Program (1990) A management plan for agricultural subsurface drainage and related problems on the Westside San Joaquin Valley: Final report by the San Joaquin Valley Drainage Program. U.S. Department of the Interior and California Resources Agency, Sacramento, CA, 183 pages.

Chapter 2: IFDM System Description and Example of Operating IFDM System

Title 27 Environmental Protection. Division 2. Solid Waste. Subdivision 1. Consolidated Regulations for Treatment, Storage, Processing, or Disposal of Solid Waste. Chapter 7. Special Treatment, Storage, and Disposal Units, Subchapter 6. Solar Evaporators, Article 1. Solar Evaporator Regulations (Draft Revised 7/7/03).

Rhoades, J.D. (1989) Intercepting, isolating and reusing drainage waters for irrigation to conserve water and protect water quality. Agr. Wat. Man. 16. pp. 37-52

Chapter 3: IFDM System Design Considerations

Ayars, J.E., M.E. Grismer and J.C. Guitjens (1997) Water quality as design criterion in drainage water management system. Journal of Irrigation and Drainage Engineering 123(3): 148-153.

Ayars, J.E. and R.A. Schoneman (1986) Use of saline water from a shallow water table by cotton. Trans. of the ASAE 29, pp. 1674-1678.

Ayars, J.E. and R.B. Hutmacher (1994) Crop Coefficients for Irrigation Cotton in the Presence of Groundwater. Irrig. Sci. 15(1): 45-52.

Ayars, J.E. (1999) Integrated management of irrigation and drainage systems. In: M.F.A. Goosen and W.H. Shayya (eds) Water Management, Purification & Conservation in Arid Climates. Vol. 1. Technomic Press, Lancaster, PA, pp. 139-164.

Kite, S.W. and B.R. Hanson (1984) Irrigation scheduling under saline high water tables. California Agriculture 38, pp. 12-14.

Title 27 Environmental Protection. Division 2. Solid Waste. Subdivision 1. Consolidated Regulations for Treatment, Storage, Processing, or Disposal of Solid Waste. Chapter 7. Special Treatment, Storage, and Disposal Units, Subchapter 6. Solar Evaporators, Article 1. Solar Evaporator Regulations (Draft Revised 7/7/03).

Chapter 4: Drainage Water

Ayers, R.S., and D.W. Westcot (1985) Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 Rev.1, Food and Agriculture Organization of the United Nations, Rome. 174 pages.

California Department of Water Resources (2001) Salt balance in the San Joaquin Valley. Water Facts No. 20.

Grattan, S.R., and J.D. Rhoades (1990) Irrigation with saline groundwater and drainage water. In: K.K. Tanji (ed) Agricultural Salinity Assessment and Management, Manuals and Reports on Engineering Practice No. 71 American Society of Civil Engineers, New York, pp. 432-449.

Hanson, B., S.R. Grattan, and A. Fulton (1999) Agricultural Salinity and Drainage. Division of Agriculture and Natural Resources (ANR) resources publication #3375, University of California. Available for purchase at: http://anrcatalog.ucdavis.edu/

Rhoades, J.D. (1984) Use of saline water for irrigation. California Agriculture special issue: Salinity in California. Calif. Agric. 38 (10):42-43.

San Joaquin Valley Drainage Program (1990) A management plan for agricultural subsurface drainage and related problems on the Westside San Joaquin Valley: Final report by the San Joaquin Valley Drainage Program. U.S. Department of the Interior and California Resources Agency, Sacramento, CA, 183 pages.

Chapter 5: Crop Selection for IFDM Systems

Ayers, R.S., and D.W. Westcot. (1985) Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 Rev.1, Food and Agriculture Organization of the United Nations, Rome. 174 pages.

Grattan S.R., C.M. Grieve, J.A. Poss, P.H. Robinson, D.L. Suarez, and S.E. Benes (2004) Irrigating Forages with Saline Drainage Water: III. Implications for Ruminant Mineral Nutrition. Agricultural Water Management. 70(2): 137-150.

Grattan, S.R. and J.D. Oster (2003) Use and Reuse of Saline-sodic Waters for Irrigation of Crops. In: S.S. Goyal, S.K. Sharma, and D.W. Rains (eds) Crop Production in Saline Environments. Journal of Crop Production Vol. 2, Haworth Press, New York.

Kaffka, S., J. Oster, and D. Corwin (2004) Forage production and soil reclamation using saline drainage water. Proceedings of CA Alfalfa Symposium 2004. pp. 247-53. Available at: http://alfalfa.ucdavis.edu.

Maas, E.V. and S.R. Grattan. (1999) Crop yields as affected by salinity. In: R.W. Skaggs and J. van Schilfgaarde (eds) Agricultural Drainage. American Society of Agronomy, Madison, WI; Agronomy No. 38: pp. 55-108.

Robinson P.R., S.R Grattan, G. Getachew, C.M. Grieve, J.A. Poss, D.S. Suarez, and S.E. Benes (2004) Biomass accumulation and potential nutritive value of some forages irrigated with saline-sodic drainage water. Animal Feed Science and Technology 111: 175-189.

Chapter 6: IFDM System Management

Title 27 Environmental Protection. Division 2. Solid Waste. Subdivision 1. Consolidated Regulations for Treatment, Storage, Processing, or Disposal of Solid Waste. Chapter 7. Special Treatment, Storage, and Disposal Units, Subchapter 6. Solar Evaporators, Article 1. Solar Evaporator Regulations (Draft Revised 7/7/03).

Chapter 7: Monitoring, Recordkeeping, and Reporting

California Department of Water Resources (1994) Quality assurance technical document 2: Sampling manual for environmental measurement projects. Division of Local Assistance, Department of Water Resources, Sacramento, CA.

California Department of Water Resources (1998) Guidelines for preparing quality assurance project plans. Division of Local Assistance, Department of Water Resources, Sacramento, CA. Available at http://wq.water.ca.gov/qa/publicat/qa6.pdf, August 24, 2005.

Title 27 Environmental Protection. Division 2. Solid Waste. Subdivision 1. Consolidated Regulations for Treatment, Storage, Processing, or Disposal of Solid Waste. Chapter 7. Special Treatment, Storage, and Disposal Units, Subchapter 6. Solar Evaporators, Article 1. Solar Evaporator Regulations (Draft Revised 7/7/03).

California Environmental Protection Agency, State Water Resources Control Board, Surface Water Ambient Monitoring Program (SWAMP), Quality Assurance and Quality Control, Quality Assurance Project Plan (Quality Assurance Management Plan). Available at http://www.swrcb.ca.gov/swamp/qamp.html, August 18, 2005.

California Irrigation Management Information System (CIMIS). Department of Water Resources Office of Water Use Efficiency. Available at http://www.cimis.water.ca.gov, August 24, 2005.

California Department of Health Services, Description of Field of Testing (FOT)/Field of Accreditation (FOA). Available at http://www.dhs.ca.gov/ps/ls/ELAP/pdf/FOT_Desc.pdf, August 24, 2005.

California Department of Health Services, Division of Laboratory Science. Environmental Laboratory Accreditation Program, Certified Laboratory Lists. Available at http://www.dhs.ca.gov/ps/ls/ELAP/html/lablist.htm, August 24, 2005.

Chapter 8: Economic Analysis of Integrated on-Farm Drainage Management

Campbell-Mathews, M., R. Vargas, S. Wright, C. Collar, M. Canevari, L. Jackson, B. Marsh, K. Klonsky, and P. Livingston (1999) Sample costs to produce winter forage, San Joaquin Valley. University of California Cooperative Extension, Davis, California.

Freeman, M.W., M.A. Viveros, K.M. Klonsky, and R.L. DeMoura (2003) Sample costs to establish an almond orchard and produce almonds, San Joaquin Valley south, micro-sprinkler irrigation. University of California Cooperative Extension, Davis, California.

Hutmacher, R.B., R.N. Vargas, S.D. Wright, B.A. Roberts, B.H. Marsh, D.S. Munk, B.L. Weir, K.M. Klonsky, and R.L. DeMoura (2003) Sample costs to produce cotton (acala variety) 40-inch row, San Joaquin Valley. University of California Cooperative Extension, Davis, California.

Kallsen, C.E., B.A. Holtz, L.C. Hendricks, L. Ferguson, S.G. Sibbett, R.H. Beede, K.M. Klonsky, and R.L. DeMoura (2000) Sample costs to establish and produce pistachios, San Joaquin Valley, low-volume irrigation. University of California Cooperative Extension, Davis, California.

May, D.M., B.L. Weir, J.J. Nunez, K.M. Klonsky, and R.L. DeMoura (2001) Sample costs to establish and produce processing tomatoes, San Joaquin Valley, double-row seeded. University of California Cooperative Extension, Davis, California.

United States Department of Labor (2003) Bureau of Labor Statistics, Consumer Price Index for All Urban Consumers. Available at www.bls.gov, December 15, 2003.

Vargas, R.N., S.C. Mueller, C.A. Frate, M. Canevari, M. Campbell-Mathews, K.M. Klonsky, and R.L. DeMoura (2003) Sample costs to establish and produce alfalfa, San Joaquin Valley, 300 acre planting. University of California Cooperative Extension, Davis, California.

Vasquez, S.J., G.M. Leavitt, W.L. Peacock, L.P. Christensen, S.R. Sutter, K.J. Hembree, K.M. Klonsky, D.G. Katayama, and R.L. DeMoura (2003) Sample costs to establish a vineyard and produce dried-on-vine raisins, early maturing varieties, open gable trellis system, San Joaquin Valley. University of California Cooperative Extension, Davis, California.

Chapter 9: Future Research

California Department of Water Resources, Proposition 204 Approved Projects for 2000-2001. Available at http://www.sjd.water.ca.gov/drainage/prop204.proj00_01/index.cfm, July 11, 2005.

California Department of Water Resources, Proposition 204 Approved Projects for 2001-2002. Available at http://www.sjd.water.ca.gov/drainage/prop204.proj01_02/index.cfm, July 11, 2005.

California Department of Water Resources, Proposition 204 Approved Projects for 2002-2003. Available at http://www.sjd.water.ca.gov/drainage/prop204.proj02_03/index.cfm, July 11, 2005.

California Department of Water Resources, Proposition 204 Approved Projects for 2003-2004. Available at http://www.sjd.water.ca.gov/drainage/prop204.proj03_04/index.cfm, July 11, 2005.

UC Center for Water Resources, Salinity/Drainage Projects Approved for Funding 2002-2003. Available at http://www.waterresources.ucr.edu/index.php?content=sdp/research/SDProjects02-03/SDresearch02-03.html, July 11, 2005.

Appendix Material

Farming Unit Design

Ayers, R.S. and D.W. Westcot (1985) Water quality for agriculture. FAO Irrigation and Drainage Paper 29 Rev. 1. Food and Agriculture Organization of the United Nations, Rome, 174 pages.

California Department of Water Resources (1986) Crop water use in California, Bulletin 113-4 (April).

California Irrigation Management Information System (CIMIS). Department of Water Resources Office of Water Use Efficiency. Available at http://www.cimis.water.ca.gov, August 24, 2005.

Doorenbos, J. and W.O. Pruitt (1977) Crop water Requirements. FAO Irrigation and Drainage Paper 24. Food and Agriculture Organization of the United Nations, Rome.

United States Soil Salinity Laboratory Staff (1954) USDA Handbook 60, Diagnosis and improvement of saline and alkali soils, 160 pages.

Solar Evaporator for Integrated on-Farm Drainage Management System at Red Rock Ranch, San Joaquin Valley, California

Chapter 6.5 of Division 20 of the Health and Safety Code, relating to water, Article 9.7, Section 25209.11.

Drainage Water and Its Effects on Wildlife

Bradford, D.F., L.A. Smith, D.S. Drezner and D.J. Shoemaker (1991) Minimizing contamination hazards to waterbirds using agricultural drainage evaporation ponds. Environmental Management 15(6):785-795.

California Department of Water Resources and San Joaquin Valley Drainage Program (1998) A status report on drainage management in the San Joaquin Valley. Division of Planning and Local Assistance, DWR, 65 pages.

CH2M-Hill, H.T. Harvey & Associates and G.L. Horner (1993) Cumulative impacts of agriculture evaporative basins on wildlife. Prepared for DWR.

Eisler, R. (1985) Selenium hazards to fish, wildlife, and invertebrates: A synoptic review. Laurel, MD, Patuxent Wildlife Research Center - U.S. Fish and Wildlife Service.

Friend, M., and C. Franson (eds) (1999) Field manual of wildlife diseases: General field procedures and diseases of wild birds. US Department of the Interior, US Geological Survey, ISBN: 0-607-88096-1 http://www.nwhc.usgs.gov/pub_metadata/field_manual/field_manual.html

Gordus, A.G., H.L. Shivaprasad and P.K. Swift (2002) Salt toxicosis in ruddy ducks that winter on an agricultural evaporation basin in California. Wildlife Disease Association 38(1):124-131.

Koller L.D. and J.H. Exon (1986) The two faces of selenium-deficiency and toxicity are similar in animals and in man. Can. J. Vet. Res. 50 (3):297-306.

Lemly, A.D. and G.J. Smith (1987) Aquatic cycling of selenium: Implications for fish and wildlife. Fish and Wildlife Leaflet 12. U.S. Fish and Wildlife Service. Washington D.C.

Lemly, A.D. (1996) Selenium in aquatic organisms. In: W.N. Beyer, G.H. Heinz and A.W. Redmond-Norwood (eds) Environmental contaminants in wildlife, interpreting tissue concentration. SETAC special publication series. Lewis, Boca Raton, FL, Chapter 19, pp.427-445.

Luoma, S.N. and T.S. Presser (2000) Forecasting selenium discharges to the San Francisco Bay-Delta Estuary: Ecological effects of a proposed San Luis Drain extension. Open file report 00-416. US Department of the Interior, US Geological Survey. http://www.water.usgs.gov/pubs/of/ofr00-416/

Marshack, J.B. (1998) A Compilation of water quality goals, Calif. Environmental Protection Agency and Regional Water Quality Control Board Central Valley Region. Current version available on the web at: http://www.swrcb.ca.gov/rwqcb5/availabledocuments/wq_goals/wq_goals/pdf.

Ohlendorf, H.M. and J.P. Skorupa (1993) Food-chain transfer of trace elements to wildlife. In: R.G. Allen and C.M.V. Neale (eds), Management of irrigation and drainage systems: Integrated perspectives. American Society of Civil Engineers, New York, pp. 596-603.

Ohlendorf, H.M. and J.P. Skorupa (1989) Selenium in relation to wildlife and agricultural drainage water. In: S. C. Carapella, Jr. (ed.), Proceedings of the fourth International Symposium on Uses of Selenium and Tellurium, pp. 314-338. Selenium-Tellurium Development Association, Darien, CT.

Salmon T.P. and R.E. Marsh (1991) Effectiveness and cost of minimizing bird use on agriculture evaporation ponds. California Department of Water Resources Contract No. B-57211, 118 pages.

San Joaquin Valley Drainage Program (1999) Task 4 Evaporation Ponds: Final Report. Feb 1999. Evaporation Ponds Technical Committee. San Joaquin Valley Drainage Program and UC Salinity/Drainage Program.

Title 27 Environmental Protection. Division 2. Solid Waste. Subdivision 1. Consolidated Regulations for Treatment, Storage, Processing, or Disposal of Solid Waste. Chapter 7. Special Treatment, Storage, and Disposal Units, Subchapter 6. Solar Evaporators, Article 1. Solar Evaporator Regulations (Draft Revised 7/7/03).

URS (2000) Draft environmental impact statement and environmental impact report: Vol I and II. Prepared for U.S. Bureau of Reclamation and San Luis & Delta Water Authority.

Maas-Hoffman Tables are from:

Agricultural Drainage, ASA Monograph 38. 1999. J. van Schilfgaarde and R.W. Skaggs (eds.) American Society of Agronomy. Madison, WI, pp. 71-81, 83-85, and 92-94.

Laws and Regulations

See text in Appendix for contact information.

Glossary

Amendment. See ***Soil amendment***; see ***Water amendment***.

Anion. Negatively charged constituent or ion in the water. Chloride, sulfate, and bicarbonate are anions.

Application uniformity. See ***Distribution uniformity***.

Attainable leaching fraction. The smallest average leaching fraction required under a given set of conditions to satisfy crop needs and control salinity in the least-watered parts of the field.

Cation. Positively charged constituent or ion in the water. Sodium, calcium, magnesium, and potassium are cations.

Cation exchange capacity. Relative capacity of positively charged ions (cations) attached to clay particles in a given soil to be exchanged for other types of cations in the soil solution. Too much sodium on the clay particles relative to calcium and magnesium can cause the clay to swell, making the soil less permeable to water.

Chlorosis. Yellowing or bleaching of leaves, often induced by a nutrient deficiency, specific-ion toxicity, or disease.

Continuous ponding. The process of reclaiming saline soils by ponding water on the soil surface until enough salt has been removed from the crop root zone.

Crop water use. The amount of water used by a specific crop in a given period of time.
See also ***Evapotranspiration***.

Deep percolation. The phenomenon of irrigation water flowing through the soil past the root zone where it is lost to crop production.

Distribution uniformity (DU). A measure of how uniformly water is applied over a field, calculated as the minimum depth of applied water, divided by the average depth of applied water, multiplied by 100.

Electrical conductivity. The extent to which water conducts electricity, which is proportional to the concentration of dissolved salts present and is therefore used as an estimate of the total dissolved salts in soil water. Electrical conductivity is expressed in millimhos per centimeter (mmhos/cm) or decisiemens per meter (dS/m):

EC_i, EC_{iw}, or EC_w = electrical conductivity of the irrigation water
EC_{sw} = electrical conductivity of the soil water
EC_e = electrical conductivity of the saturated soil extract

Evapotranspiration. The amount of water used by a specific crop in a given period of time, comprised of water evaporating from the soil and water transpiring from the plants. Crop evapotranspiration estimates are available from the California Department of Water Resources CIMIS program and from University of California Cooperative Extension offices as either historical averages or real-time estimates.

Exchangeable Sodium Percentage (ESP). The percentage of exchangeable sodium that occupies the total cation exchange capacity of the soil. ESP can be calculated from the following formula:

$$ESP = \frac{Exchangeable\ (meq/100g)}{Cation\ exchange\ capacity\ (meq/100g)} x\ 100$$

Foliar absorption rate. Rate at which constituents in water are absorbed by plant leaves.

Glycophytes. A group of plants adversely affected by salinity. Most crop plants are glycophytes.

Halophytes. Plant group capable of tolerating relatively high levels of salinity.

Hydraulic conductivity. The ease with which water flows through the soil, determined by the physical properties and water content of the soil.

Infiltration rate. The rate at which water infiltrates the soil, usually expressed in inches or centimeters per hour.

Interceptor drain. Usually a single drain line installed perpendicular to the direction of groundwater flow, used to remove shallow groundwater flowing from upper-lying areas or to intercept seepage from waterways.

Intermittent ponding. A method of reclaiming saline soil by ponding small amounts of water on the soil surface in a wetting and drying cycle.

Ion. A positively or negatively charged constituent in water. Cations are positively charged ions and anions are negatively charged ions. Sodium, calcium, magnesium, and potassium are cations, and chloride, sulfate, and bicarbonate are anions.

Irrigation efficiency. A measure of the portion of total applied irrigation water beneficially used – as for crop water needs, frost protection, salt leaching, and chemical application – over the course of a season. Calculated as beneficially used water divided by total water applied, multiplied by 100.

Leaching. Applying irrigation water in excess of the soil moisture depletion level to remove salts from the root zone.

Leaching fraction. The fraction of infiltrated water applied beyond the soil moisture depletion level, which percolates below the root zone as excess water.

Leaching requirement. The leaching fraction needed to keep the root zone salinity level at or below the threshold tolerated by the crop. The leaching fraction is determined by the crop's tolerance to salinity and by the salinity of the irrigation water.

Necrosis. Plant condition indicated by the presence of dead tissue, often induced by an extreme nutrient deficiency, disease, or specific ion toxicity.

Parallel drainage system. Drainage system consisting of buried perforated pipe placed at equal intervals throughout a field for draining away subsurface water caused by deep percolation through the overlying land. Also called a relief drainage system.

Piezometer. Device for monitoring groundwater depth and movement by measuring the hydraulic head at a point below the water table or water level.

Polymers. Soil amendments reputed by manufacturers to react with lime in the soil to supply free calcium.

Pre-irrigation reclamation method. A method of estimating the amount of irrigation water needed for leaching to reduce soil salinity to acceptable levels during pre-irrigations.

Relief drainage system. See ***Parallel drainage system***.

Saline/sodic soil. Soil affected by both excess salt and excess sodium.

Salinity. Soil condition in which the salt concentration in the crop root zone is too high for optimum plant growth and yield.

Sodicity. Condition in which the salt composition of the soil within the crop root zone is dominated by sodium, which affects soil structure and water infiltration.

Sodium adsorption ratio (SAR). Relationship between the concentration of sodium (Na) in the irrigation water relative to the concentrations of calcium (Ca) and magnesium (Mg), expressed in meq/l as follows:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

Soil amendment. A substance added to the soil primarily to improve its physical condition.

Specific-ion toxicity. Injury to the plant caused by a specific constituent, usually chloride, boron, or sodium, that has accumulated in a particular part of the plant, such as leaves and stems.

Total dissolved solids (TDS). A measure of the dissolved solids in soil water, expressed in either parts per million or milligrams per liter, used to estimate the relative salinity hazard of the water.

Uniformity. See ***Distribution uniformity***.

Water amendment. Chemicals added to water to improve soil-water properties, such as water infiltration.

This glossary is from Agricultural Salinity and Drainage, Water Management Series Publication Number 3375, 1999, Division of Agriculture and Natural Resources. Authored by Blaine Hanson, Stephen R. Grattan and Allan Fulton. Used by permission from Stephen R. Grattan.

Appendix Table of Contents

Appendix CD

System Analysis and Project Resources Inventory

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Questions for irrigation system analysis for each field being considered for an IFDM system

1. What type of irrigation is currently being used?
2. Will it continue to be used? If not what will be used?
3. For surface system
   - ❑ furrow run length
   - ❑ source of water – well, water district, open channel, piped
   - ❑ head ditch – lined or unlined
   - ❑ gated pipe, siphons
   - ❑ tailwater recovery system – pits, number of fields collected
   - ❑ surface grade of field (%) – how maintained?
   - ❑ mobile lab analysis
4. For sprinklers systems
   - ❑ size of laterals and mains
   - ❑ solid-set or movable – hand or automated
   - ❑ sprinklers sizes
   - ❑ lateral and sprinkler spacing
   - ❑ operating pressure
   - ❑ age of system
   - ❑ source of water – well or district
5. For drip systems
   - ❑ surface or subsurface – depth of installation for SDI
   - ❑ lateral spacing
   - ❑ type of drip tubing – discharge rate
   - ❑ water source
   - ❑ operating pressure
6. Cropping pattern – continue or change?
7. Depth of application applied for each crop?
8. Surface runoff (y or n) how much?
9. Preplant irrigation (y or n) how much?
10. Irrigation Scheduling (y or n) what method?
11. Multiple irrigation system for crop? i.e. sprinkler then furrow
12. Salinity problem areas?
13. Water-logging problems?
14. Shallow groundwater (y or n) depth to groundwater?
15. Drainage system in field? (y or n) controlled?

Summary table of the existing system and projected improvements by field

Parameters	Before	After
System type		
System configuration		
Total Application		
Surface runoff		
Irrigation Efficiency		
Maximum allowable depletion		
Leaching fraction		
Crops		
Surface grade		
Operation and maintenance costs		

Questions for surface and subsurface drainage system analysis for each field being considered for an IFDM system

1. Surface drains (y or n)?
   - ❑ depth and spacing – cross-sectional shape
   - ❑ collect subsurface drainage water (y or n)?
   - ❑ collect water from subsurface drainage sumps
   - ❑ discharge point
   - ❑ Tailwater pit (y or n) size,
2. Subsurface drains
   - ❑ Lateral depth and spacing
   - ❑ Lateral diameter
   - ❑ Lateral configuration (gridiron, herringbone, random)
3. Main line depth, size and location.
   - ❑ How many fields served
4. Control structures (y or n)?
   - ❑ how many and where located?
   - ❑ what type of control structures?
5. Sumps and pumped drains (y or n)?
6. Discharge to open drains (y or n)?
7. Drain lateral configuration relative to surface grade. (parallel or perpendicular)
8. Water table response to irrigation and with time during growing season
9. Drainage sump outlet – metered flow

Summary table of drainage system design and operation

Parameters	Existing	Proposed
Area drained (ac)		
Annual discharge (ac- ft)		
Drainage intensity (ft drain pipe/acre)		
Drainage water quality (dS/m)		
Drain lateral spacing (ft)		
Drain lateral depth (ft)		
Drain lateral diameter (in)		

IFDM Project Resources Inventory

The following is a listing of items to be inventoried and available as required for system design calculations and development of drawings:

a) Farming unit legal boundaries map (including easements and right-of-ways)
b) Existing field boundaries map
c) Existing irrigation and general farm unit infrastructures (including tail water reuse and drainage facilities)

- ❑ Contour maps
- ❑ Soils maps
- ❑ Current cropping patterns & history
- ❑ Sites to be preserved (e.g. wetlands and historical sites)
- ❑ Location of representative CIMIS sites
- ❑ Location of nearest IFDM system
- ❑ Location of neighboring installation that could be potentially sensitive to IFDM activities
- ❑ Location of nearest groundwater monitoring sites (with available records and studies on groundwater movement and quality)
- ❑ Location of irrigation water supply infrastructure (surface and ground) and water quality records
- ❑ Location of major surface water storm drainage ways and structures that could impact the farming unit

d) Electrical power supply facilities available to the farming unit
e) Farming unit imported irrigation water entitlements of contracts
f) Inventory of existing farming unit irrigation equipment (spiles, sprinklers, pipe, valves, gated pipe, micro-sprinklers, portable drip, pumping units, etc.)
g) History and current status of land forming practices on specific fields.
h) Current farming practices relative to improving root zone permeability and effective water storage.
i) Identify ground water movements both onto and off the farming unit that could impact the volume or quantity of groundwater to be handled by the IFDM system.

A salt balance calculation should be attempted for the farming unit. This balance quantifies, on an annual basis, the volume of salts imported with the irrigation water. An effort also is made to quantify the salts, if any, currently being exported from the farming unit. The difference in the amounts is the salts being sequestered on the farming unit. This volume must be managed by the IFDM system. First improved water management can reduce the total volume of salts imported. Second a process of concentrating the irrigation water ultimately results in the production of solid crystals in the solar evaporator.

Farming Unit Design

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The following is an example of an approach to determining irrigation and drainage flows for a hypothetical IFDM system sited on 640 acres. It highlights the impact on water management associated with irrigation system selection, water quality, and cropping patterns. The calculation involves estimating the water requirements, the deep percolation losses, and the resulting size of the production areas for salt tolerant plants and halophytes. Integration is involved in that after irrigation of salt sensitive crops there will be successive reuse of drainage water on the salt tolerant crops and halophytes for disposal. The total number of reuses prior to disposal in the solar evaporator or salt sequestering facility will depend on the irrigation management and the size of each production area.

It must be emphasized that while the following calculation protocol is meant to be general, scientifically rigorous, and accurate, it is based on **arbitrary** choices of specific crops and irrigation systems and water management schemes. Consequently, the numerical results of using other cropping and irrigation systems assumptions will give different numerical results. Other basic assumptions are:

1. All of the estimated deep percolation losses are collected by the drainage system. This is a very conservative estimate and serves to give an upper bound on the estimate of flow to the solar evaporator. Deep percolation losses were assumed to occur uniformly throughout the irrigation season. This might be a good approximation of deep percolation under a drip system but not a furrow system.
2. Time delays between the application of irrigation water and the appearance of that water in the tile drainage outlets is a period short enough to not affect the fundamental integrity of the design protocol.
3. Irrigation water applications, both timing and amount, are designed and scheduled using modern moisture balance calculations.
4. Canal supply water has a conductivity of 0.40 dS/m.
5. Other related assumptions and calculations are based on the climate, topography, and soils of the west side of the San Joaquin Valley.

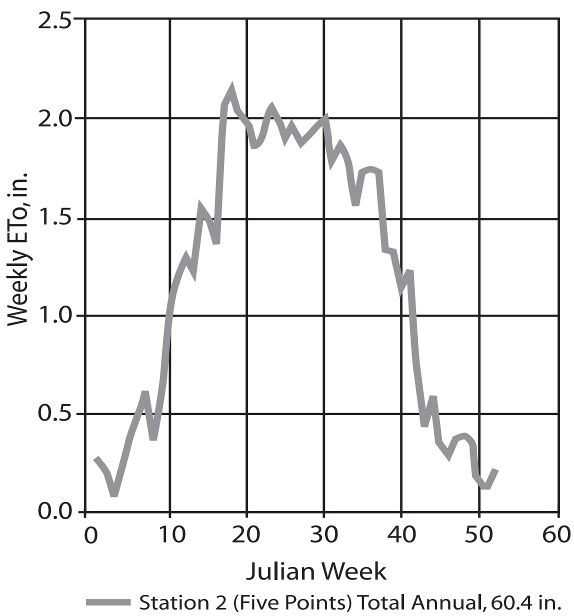

Fig. 1. Weekly Eto at West Side Research and Extension Center CIMIS Station.

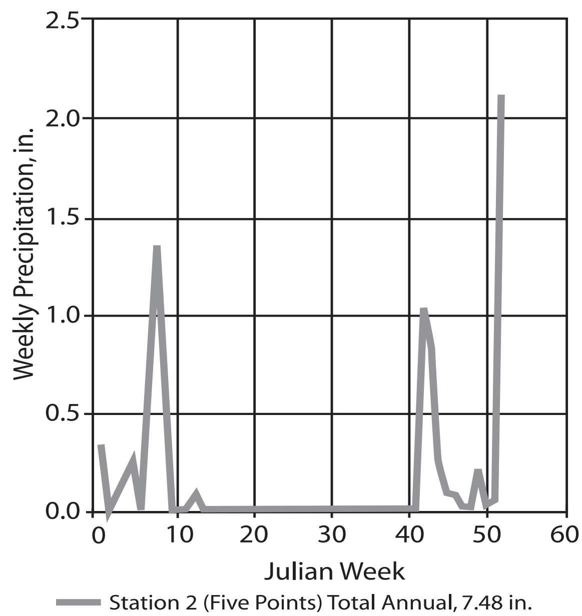

Fig. 2. Weekly precipitation at West Side Research and Extension Center CIMIS Station.

The calculations begin with an overall understanding of the climatic condition existing of the site. Figure 1 shows the weekly ETo readings for 2004. The potential evapotranspiration was 60.46 in. The rainfall in 2004 was 7.48 inches. The ETo readings will be used to calculate crop water requirements. CIMIS Station 2 at Five Points is used in the calculation and is representative of the west side of the San Joaquin Valley. Rainfall amounts are also useful in water balance and other calculations (e.g. predicting storm runoff.) Figure 2 shows the weekly precipitation readings for 2004.

Combining data from Figures 1 and 2 allows for the following observations:

The annual deficit between precipitation and ETo was 52.92 in. which means that irrigation is necessary for crop production and there is the potential for disposal of drainage water through crop water use.

From Julian weeks 10 thru 41, there was no rainfall. This simplifies the water balance calculation and minimizes the risk of storm water runoff from the solar evaporator/salt concentrator (SE/SC) installation. This period represents the growing period when the most agronomically productive crops will be irrigated.

Shown in Table No. 1 are the assumptions used in the calculation protocol described in the following section:

Table No. 1 Summary of assumptions associated with cropped areas used in sample calculations

Crop	Irrigation Method	Plant Date	Harvest Date	Comments
Alfalfa	Sprinkler	Cont.	Cont.	
Cotton	Furrow	03/28/04	10/15/04	Gated pipe
Tomatoes	Drip (tape)	03/03/04	8/11/04	
Jose Tall Wheat grass	Basin	Cont.	Cont.	Ditch
Halophytes/ Salt-Tolerant Forages (etc.)	Basin	Cont.	Cont.	

Planting and harvesting dates were assumed but are easily changed in the calculations protocol. Scientific symbols, data sources, and documents are identified in Table No. 2:

Table No. 2 Data Sources and Documents Identified

Symbol	Units	Definition	Source
ETo	in./day	Reference evapotranspiration	CIMIS web site
Kc	Ratio	Crop coefficient	1) "Crop water use in California" Bulletin 113-4, CADWR, April, 1986 2) "Crop water requirements" Irrigation and Drain. Paper #24, FAO, 1977
ETc	in./week	Net crop water requirements	ETc= ETo (Kc)
ECw	dS/m	Irrigation Water salinity	"Water quality for agriculture" Paper #29, FAO, 1985
ECe	dS/m	Soil water salinity	

Refinements in crop coefficients from other sources are easily factored into the calculations protocol. This is especially true of the salt tolerant crops as scientists attempt to identify crops with more commercial value (e.g. salt tolerant grasses being developed for turf and landscape uses.)

Table No. 1 identifies the crops used in the sample calculations. Alfalfa, cotton and tomato will be the crops in the initial production areas that are irrigated with good quality water. Jose Tall Wheat Grass and Halophytes/Salt-Tolerant Forages etc. will be the crops in the reuse areas that are irrigated with drainage water.

Alfalfa Field (160 acres) Initial use Design Calculations Summary

Crop: Alfalfa
Irrigation System: Sprinkler, portable solid set
Sprinkler Losses: -spray, 3%
-pattern, 10%
-operational, 5%

Deep percolation efficiency, 100%
Operational efficiency, 86% (6 days/week operation)
Irrigation water salinity, 0.4 dS/m

$LR = EC_w / (5*(EC_e) - EC_w)$

Calc: Leaching Requirement (LR)
Use EC_E= 2.0 dS/m to provide 100% of yield-potential

$$LR = \frac{0.40}{5(2.0) - 0.40}$$

LR = 0.042 or 4.2 %

This is the LR formula found in FAO 29 and is not as conservative an estimate as found in Handbook 60 and thus results in a reduced estimate of the leaching requirement.

Calc: Application Efficiency (AE), %

AE = (1-.03) (1-.10) (1-.05)
= (.97) (.90) (.95)
AE = 0.829 or 82.9 %

At this point the designer should compare the leaching requirement LR to the actual leaching fraction (LF) calculated as 100% - AE. This is an indication whether the LF resulting from the operation of this type of irrigation system will be adequate to meet the LR. In this case the LF will be approximately 17% which is greater than the LR indicated in the above calculation. Therefore there is no need to include additional water into the following calculations.

Calc: Irr. Supply Flow Rate, gpm

$$Q_S = \frac{ETc}{(0.829)} \frac{(18.9)(160)}{7}$$

Q_S = ETc (521.1) gpm

Note: Q_P, pumping flow rate, gpm

$$Q_P = \frac{Q_S}{.86} = \text{ETc } (605.9), \text{ gpm}$$

This is the weekly average discharge to the field based on crop water requirement which is the basis for the computed average weekly deep percolation.

Calc: Deep percolation flow Rate, gpm

$$Q_d = ETc \; \frac{1}{(.90)(.95)} - 1 \quad \frac{(18.9)(160)}{7}$$

$$Q_d = ETc \cdot (73.3), gpm$$

The average equivalent drain flow if all the deep percolation is collected is given by the above equation. This represents the upper limit on flow from the drainage system. Perennial crop such as alfalfa and grasses will require water throughout the year. However, the winter requirement is very low and will probably be met with rainfall. The irrigation season will not start until March or April.

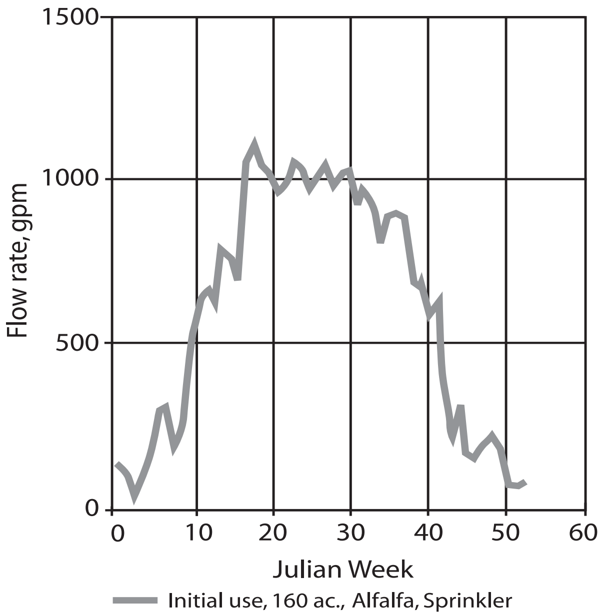

Fig. 3. Irrigation supply flow rate for alfalfa field

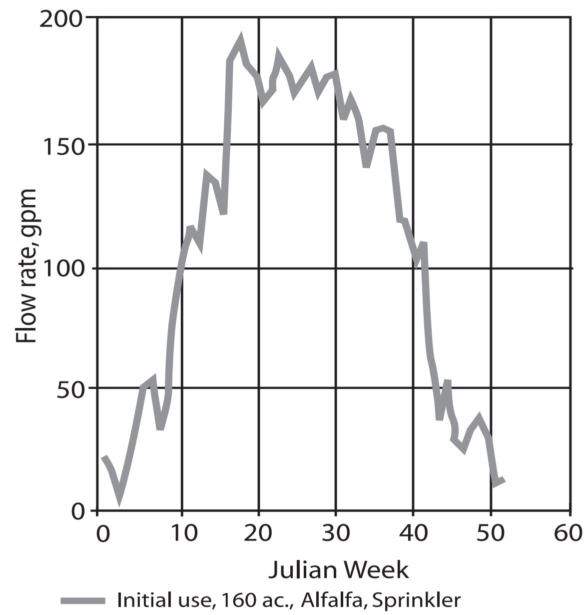

Fig. 4. Drainage flow rate for alfalfa field

Note that the weekly ETc values were determined by using a Kc value of 0.95 and the ETo values from Figure 1. The use of a Kc of 0.95 would not account for any harvests occurring. The supply flow and the drainage flows are given in Figures 3 and 4 for comparison.

The midsummer supply flow rate to the alfalfa field is about 1000 gpm (2.23 cfs.) The sprinkler system pumping flow rate operating 6 out of 7 days per week is about 1200 gpm (2.67 cfs.) What will be required for the drainage design is to determine an irrigation schedule that gives the dates of irrigation and depth of irrigation with the assumed deep percolation losses. This will be used by the drainage designer to complete the design of the drainage system.

Cotton Field (160 acres) Initial use Design Calculations Summary

Crop: Cotton
Irrigation System: Furrow/ gated pipe
System Losses: -tail water, 5%
-pattern, 20%
Deep percolation efficiency, 100%
Operational Efficiency, 86% (6 days/ week operation)
Irrigation water salinity, 0.4 dS/m

<u>Calc</u>: Leaching Requirement
Use EC_E= 7.7 dS/m to provide 100% of yield-potential

$$LR = \frac{0.40}{5(7.7)-0.40}$$

LR = 0.010 or 1.0 %

Note that as the permissible ECe increases for good quality water the LR is reduced.

<u>Calc</u>: Application Efficiency, %

$$AE = (1-.05)\,(1-.20)\,(1-.01)$$
$$= (.95)\,(.80)$$
$$AE = 0.76 \text{ or } 76\ \%$$

Note the projected losses exceed the LR and again no additional water is required in the flow computation.

<u>Calc</u>: Irr. Supply Flow Rate, gpm

$$Q_S = \frac{ETc}{(0.76)}\,\frac{(18.9)\,(160)}{7}$$

Q_S = ETc (568.4), gpm

Note: Q_P, pumping flow rate, gpm

$$Q_P = \frac{Q_S}{.86}$$

<u>Calc</u>: Drain System Flow Rate, gpm

$$Q_d = ETc\left(\frac{1}{(.80)} - 1\right)\frac{(18.9)\,(160)}{7}$$

$Q_d = ETc(108)$, *gpm*

<u>Calc</u>: Tail Water Flow Rate, gpm

$$Q_T = ETc\ (568.4)\ (.05)$$
$$= ETc\ (28.4),\ gpm$$

Tail water quality should be the same as the supply water quality, 0.4 dS/m.

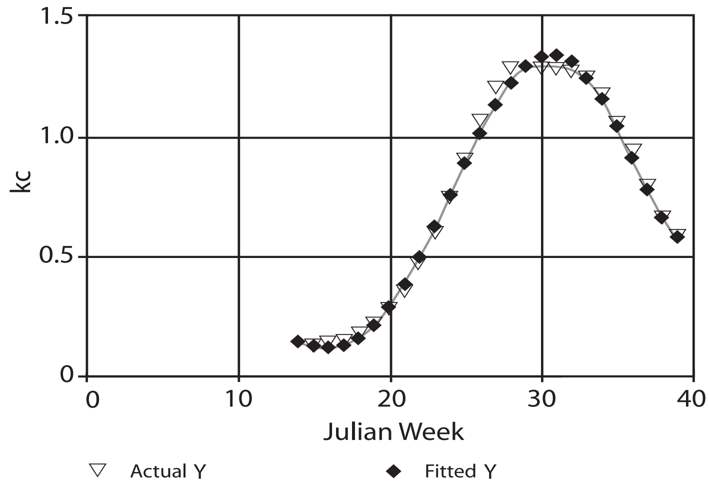

Fig. 5. Kc values vs. Julian weeks for cotton field

This calculation follows the same sequence as for the alfalfa field. The average weekly Kc values for cotton are shown in Figure 5. The ETo values from Figure 1 are multiplied by the Kc values in Figure 5 to give the ETc values.

These ETc values are used in the calculation protocol to give in turn the “Irrigation Supply Flow Rate,” “Drainage System Flow Rate” (see Figure 6,) and the “Tail Water Flow Rate” (see Figure 7.)

The relationship between the “Supply Flow Rate” and the “Drainage System Flow Rate” suggests a reduction in water volume of again about 80-81%. With this surface system, a tail water discharge is expected. Since the tail water quality should match the water supply quality (0.4 dS/m) it could be safely introduced into the original supply for use on salt sensitive crops.

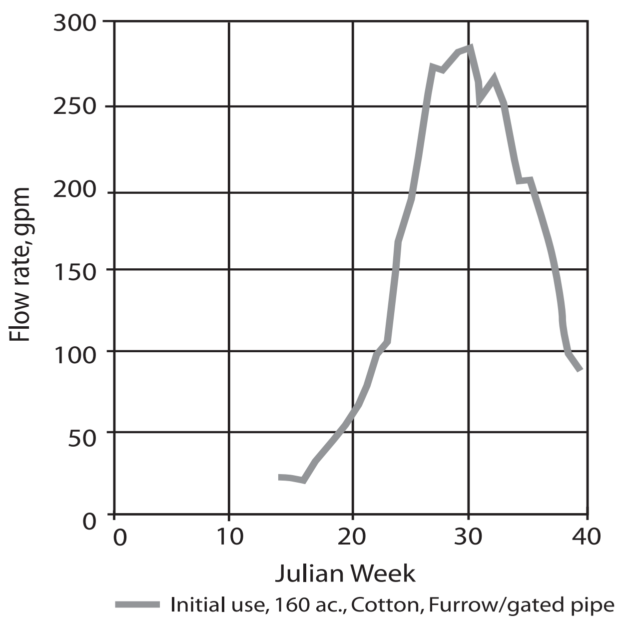

Fig. 6. Drainage system flow rate for cotton field

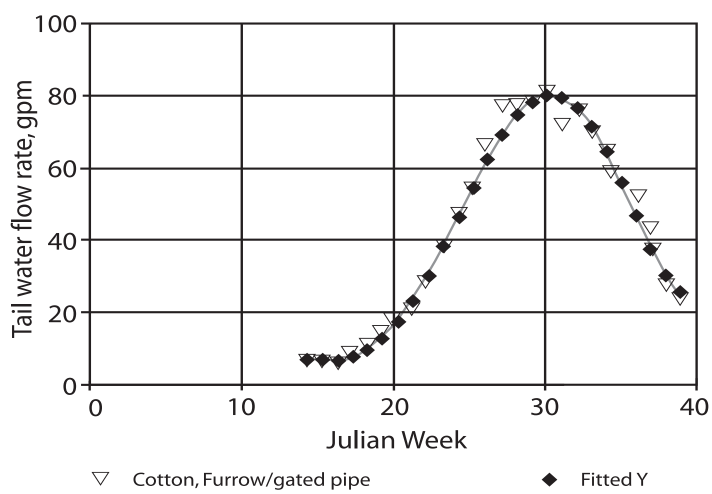

Fig. 7. Tail water flow rate vs. Julian weeks, cotton field

The design example gives the following details for the tomato field:

Tomato Field (160 acres) Initial use Design Calculations Summary

Crop: Tomatoes

Irrigation System: Non-pressure compensated buried drip tape

Sprinkler Losses: -pattern, 10%

Deep percolation efficiency, 100%

Operational efficiency, 100%

Irrigation water salinity, 0.4 dS/m

Calc: Leaching Requirement

$$LR = \frac{0.40}{5(2.5)-0.40}$$

$$LR = 0.033 \text{ or } 3.3\%$$

Calc: Application Efficiency, %

$$AE = (1-.10)$$
$$= (.90)$$

$$AE = 0.9 \text{ or } 90\%$$

There are adequate deep percolation losses with a drip system to meet the LR. However, fields irrigated with a drip system may require periodic leaching if there is inadequate rainfall.

Calc: Irr. Supply Flow Rate, gpm

$$Q_S = \frac{ETc}{(0.90)} \frac{(18.9)(160)}{7}$$

$$Q_S = \text{ETc } (480) \text{ gpm}$$

Calc: Drainage System Flow Rate, gpm

$$Q_d = ETc \left(\frac{1}{(.80)} -1 \right) \frac{(18.9)(160)}{7}$$

$$Q_d = ETc(48), gpm$$

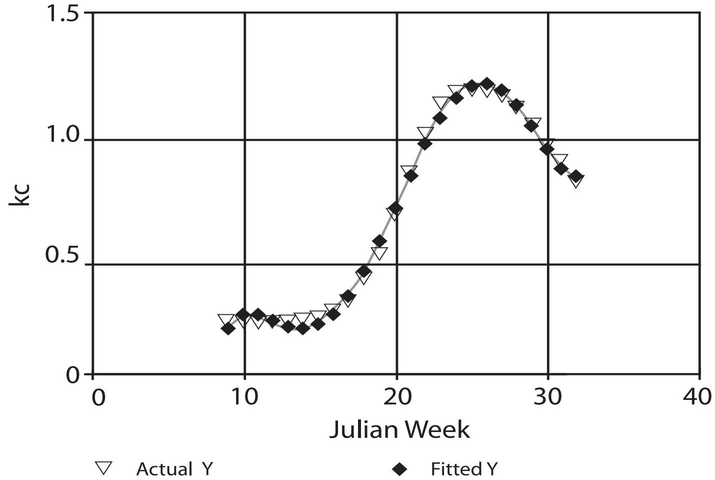

Fig. 8. Kc values vs. Julian weeks for tomato field

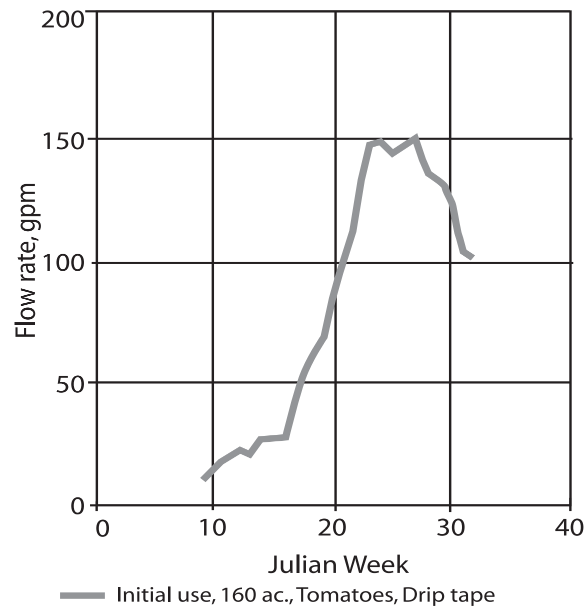

Fig. 9. Drainage system flow rate for tomato field

The calculation follows the same sequence as for the alfalfa and cotton fields. The Kc values are shown in Figure 8. The ETo values from Figure 1 are multiplied by the Kc values in Figure 8 to give the ETc values. These ETc values are used in the calculation protocol to give in turn the "Irrigation Supply Flow Rate," and the "Drainage System Flow Rate" (see Figure 9.)

The relationship between the "Irrigation Supply Flow Rate" and the "Drainage System Flow Rate" suggests a reduction in water volume of between 85-90%.

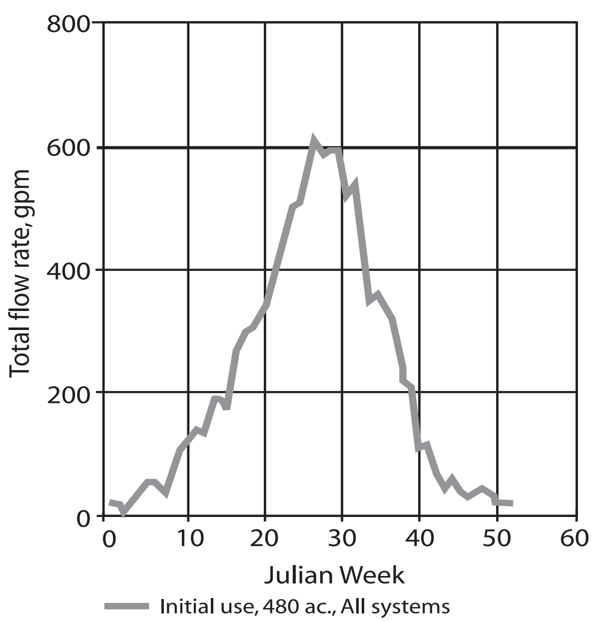

Fig. 10. Drainage system flow rate from alfalfa, cotton, and tomato fields (Initial Production Areas)

The calculations required for first reuse area relate directly to the drainage flow rates and water quality from the first production areas. Shown in Figure 10 is the total of the calculated drainage system flow from the alfalfa, cotton, and tomato fields. This is the type of analysis that will be needed to develop a water management program and cropping alternatives.

The shape of the curve reflects the long seasonal contribution by the alfalfa and the shorter seasonal contribution by the cotton and the tomatoes.

The design protocol gives the following details for the first reuse area.

First reuse area Calculations Summary

Crop: Jose Tall Wheat Grass
Irrigation System: Basin, ditch
Sprinkler Losses: -pattern, 20%
-tail water, 5%
Deep percolation efficiency, 100%
Operational efficiency, 86% (6 days/week operation)
Irrigation water salinity, blended from Initial use as follows:

Calc: Leaching Requirement

$$LR = \frac{0.70}{5(12)7.0} - 0.13 \qquad \text{OR}$$

LR= 0.130 or 13.0%

Calc: Application Efficiency %

AE = (1-.20)(1-.05)
= (.80)(.95)

AE = 0.76 or 76%

This is a point where it is important to compare the LR to the AE. In the first reuse the irrigation water quality was blended to about 7 dS/m and the increase was to 12 dS/m which is approximately the ground water quality at many locations on the west side SJV. A 13% leaching requirement was indicated and the inherent irrigation efficiency as 76% which means there was approximately 24% of the water moving through the soil so the LR was meet.

Calc: First reuse area requirements, ac.

$$Q_S = \frac{ETc}{(0.76)} \frac{(18.9)\ (A, acres)}{7} \qquad \text{OR}$$

$$A = \frac{Q_S}{ETc}\ (0.28),\ acres$$

Calc: Irr. Supply Flow Rate, gpm

$$Q_S = \frac{ETc}{(0.76)} \frac{(18.9)\ (A)}{7},\ \text{gpm}$$

$$Q_S = (ETc)(A)(3.55)\ \text{gpm}$$

Calc: Drain System Flow Rate, gpm

$$Q_d = ETc\left(\frac{1}{(.80)} - 1\right)\frac{(18.9)\ (A)}{7}$$

$$Q_d = ETc(.67),\ gpm$$

In this calculation the Q_S will be the drainage flow collected from the initial production areas as shown in Figure 10. The data in Figure 10 will vary with time as will ETc. The problem is that there is an inverse relationship between Q_S and ETc. Drainage flow data from the SJV show high drain flows in winter reflecting pre-plant irrigation and spring from the first irrigation. These data were collected during times when furrow irrigation was the prevalent irrigation method. Switching to sprinklers and reducing the applied water should result in reduced drainage flows. The ETc is also lowest in winter when supply will be greatest. Provision will have to be made to store drainage flows as shallow ground water for discharge later in the year when ETc rates have increased.

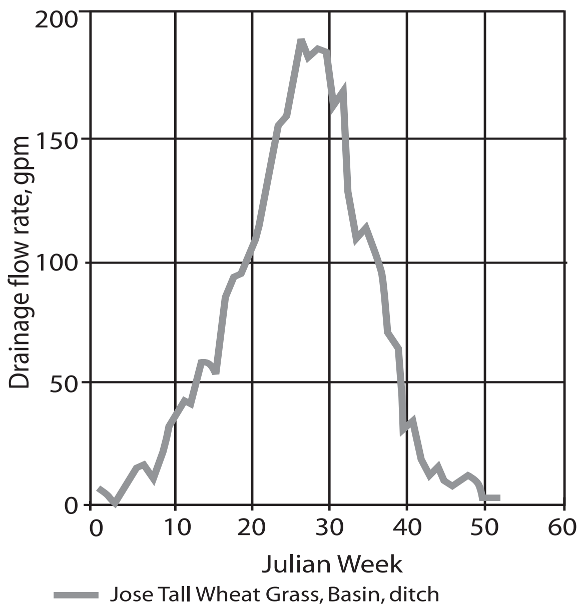

Fig. 11. Drainage system flow rate from first reuse area

Water applications on the reuse fields will have to be carefully managed to keep it from becoming a "salt dump." Calculated full applications will have to be made to provide the leaching fraction and move the salts through the root zone to the drainage system. A sizable fraction (50-70%) of the area may have to be left dormant during late fall and early spring. The "Drainage System Flow Rate" from the first reuse is shown in Figure 11.

Halopyte/Salt-Tolerant Forages (etc.) use Area Calculations Summary

Crop: Halophytes / Salt-Tolerant Forages (etc.)
Irrigation System: Basin, ditch
Irrigation System Losses: -pattern, 20%
-tail water, 5%
Deep percolation efficiency, 100%
Operational efficiency, 100%
Irrigation water salinity, 7.58 dS/m

Calc: LR, Ratio

$$LR = \frac{7.58}{5(13.0) - 7.58}$$

Note: Use ECe of 13 dS/m which allows for a yield potential of 75% for tall wheat grass.

LR = 0.132 or 13.2 %

Calc: App. Eff., %

$$AE = (1-.20)(1-.05)$$
$$= (.80)(.95)$$

AE= 0.760 or 76.0 %

Calc: Halophyte / Salt-Tolerant Forages (etc.) Area Requirement, ac.

$$Q_S = \frac{ETc}{(0.760)} \frac{(18.9)\ (A, acres)}{7} \qquad \text{OR}$$

$$A = \frac{Q_S}{ETc}\ (0.28),\ acres$$

Calc: Irr. Supply Flow Rate, gpm

$$Q_S = \frac{ETc}{(0.760)} \frac{(18.9)\ (A)}{7}\text{, gpm}$$

$$Q_S = \text{ETc (A)(3.55), gpm}$$

Calc: Drain System Flow Rate, gpm

$$Q_d = \text{ETc} \left(\frac{1}{(.80)} - 1 \right) \frac{(18.9)\ (A)}{7}\text{, gpm}$$

$$Q_d = \text{(ETc)(A)(0.675), gpm}$$

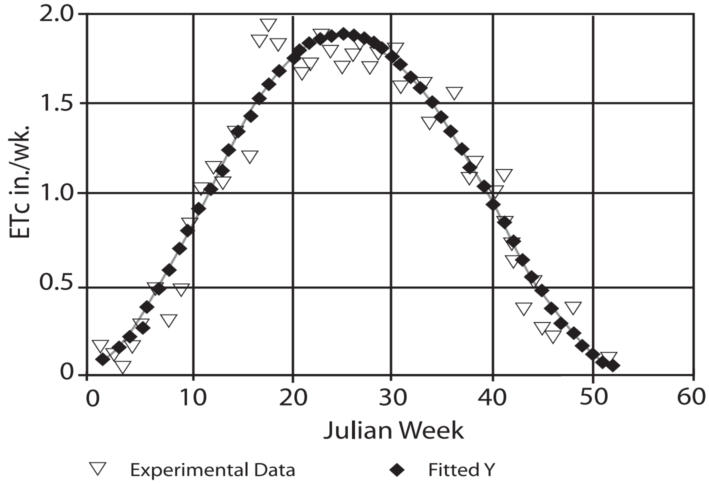

Fig. 12. ETc (in./wk.) vs. Julian weeks, Halophytes and Tall Wheat Grass

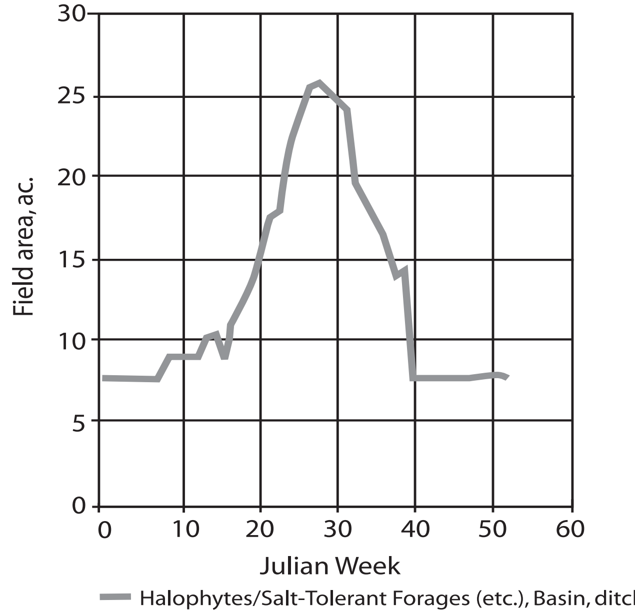

Fig. 13. Halophyte/Salt-Tolerant Forages (etc.) field area requirements

Shown in Figure 12 are the ETc values for crops having a crop coefficient (Kc) of 0.90. This is a reasonable estimate for halophytes/salt-tolerant forages, such as tall wheat grass. The ETc values are combined with the drainage system flow rates from Figure 11 in a formula (see Halophyte/Salt-Tolerant Forages [etc.] Area Calculations Summary) to allow for the calculation of the halophyte area requirements as shown in Figure 13.

The last calculation to be made in this section is the "Drainage System Flow Rate" for the halophytes/salt-tolerant forages (etc.). The results of that calculation are shown in Figure 14. The peak flow will occur during the summer months when there is the largest potential to dispose of water through evapotranspiration. The basic objective of an IFDM system is to dispose of saline drainage (in an environmentally sound manner) and to maintain a sustainable agronomic system. This will require careful water management to avoid sequestering salts in the root zone.

The examples of the design using different irrigation systems and water qualities demonstrates an approach to the decisions required as an IFDM system is developed. The deep percolation flow that was assumed to be the drainage flow is conservative on the high side and the actual timing of flows will be later than anticipated and lower than presented. The calculation shows other hydraulic data useful in the design and operation of the system (e.g. pumping flow rates.)

Each designer will have to develop their own procedures to estimate the flows. If the farm has existing drains with data describing the flow as a function of irrigation management and time through the seasons it will be a straightforward matter to sum the flows from each field as a function of time. Knowing the irrigation system management and crop it will be possible to make a good estimate of the effect of improving irrigation management and reducing deep percolation losses.

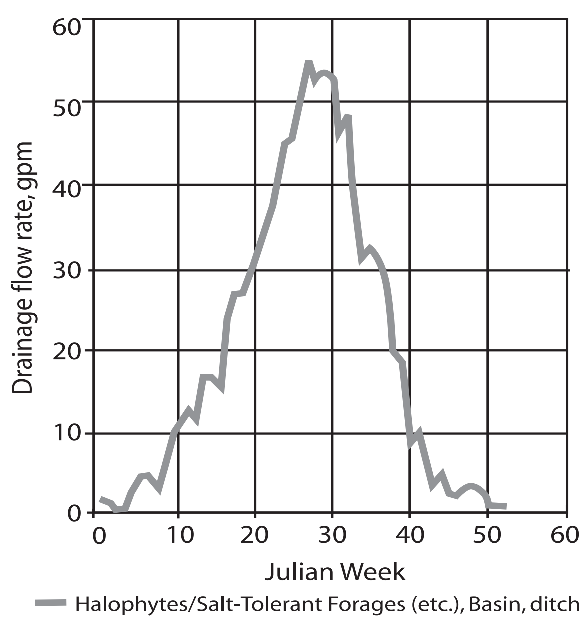

Fig. 14. Drainage system flow rate for halophytes/salt-tolerant forages.

Solar Evaporator for Integrated on-Farm Drainage Management System at Red Rock Ranch, San Joaquin Valley, California

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Abstract

A pilot solar evaporator demonstration project results to manage and concentrate subsurface drainage water effluent from a large scale farming operation is presented. The goal of this project is to collect information to develop a farm scale solar evaporator for the 640-acre Integrated On-Farm Drainage Management (IFDM) system at Red Rock Ranch and future IFDM systems in the San JoaquinValley of California. IFDM is a farming system that sequentially reuses subsurface drainage water to grow salt-tolerant crops. An enhanced evaporation system (solar evaporator) is the terminus of the system to achieve zero-liquid discharge. An IFDM system as defined in Article 9.7 Health and Safety Code, Section 25209.11, (c), (1-4), includes a solar evaporator. Highly concentrated agricultural subsurface drainage water collected from the IFDM system is discharged to the solar evaporator using timed spray sprinklers. Additional requirements for a solar evaporator are listed in Section 25209.11, (e), (1-4).

Objective

The purpose of this study was to gather, analyze, and evaluate data on evaporation rates of subsurface drainage water using various evaporative surfaces, nozzles, materials, and equipment so that a farm scale solar evaporator could be designed and constructed. The pilot solar evaporator was used to perform the following: 1) evaporate drainage water and recover salts, 2) to determine the optimum weather parameters for operating a solar evaporator, and 3) examine methods to control the potential for salt drift. The data obtained from the pilot solar evaporator will be used to design and construct a solar evaporator for the 640-acre farm at Red Rock Ranch.

Approach

In order to construct the pilot-scale solar evaporator at Red Rock Ranch, the following steps were performed: 1) test different types of nozzles (spray patterns, angles, and pressures) and surface materials, 2) evaluation of test data, 3) design, 4) construction, 5) operate and maintain the solar evaporator and collect data during seasonal conditions for evaporation rates, weather, wind and salt drift.

Data Collection

Figure 1 shows the module used to collect data on evaporation rates of subsurface drainage water using various evaporative surfaces, nozzles under various pressures, materials, and equipment. Nozzles were also tested by Center for Irrigation Technology for pressure, water discharge, mist dimensions (height, radius, mist density). The evaporative area was constructed at a 2% gradient for this study, calculated using Manning equation. The evaporative surface and reservoir were lined with plastic to prevent seepage. Three surface

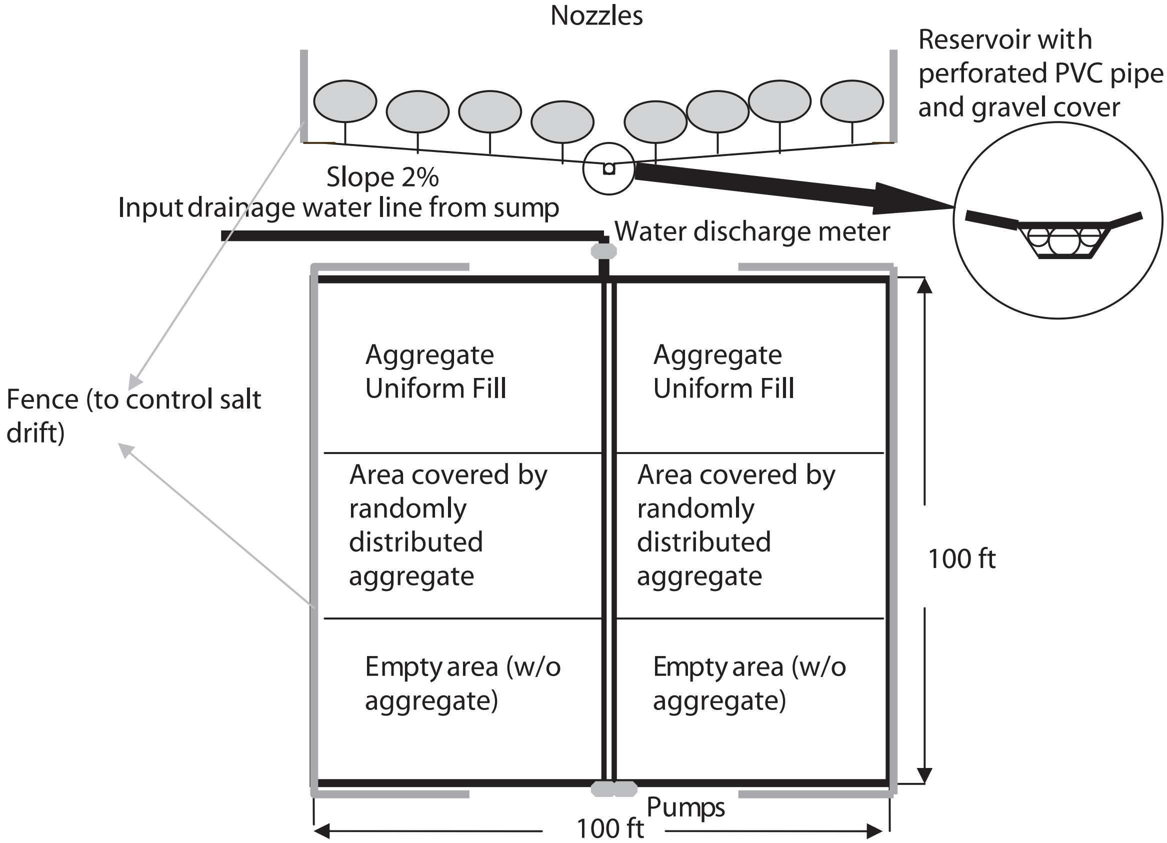

Figure 1: Project Module Profile and Plan.

materials were initially tested on the 100 ft x 100 ft evaporative area as follows: 1) 2-inch aggregate uniform fill; 2) 2-inch randomly distributed aggregate; and 3) surface w/o aggregate. Accessory equipment included two five-horse power pumps and various nozzles.

All quantitative and qualitative parameters (water discharges and pressures, rates of evaporation, chemical analysis for brines and salts) were measured using different types of meters, tools, and equipment.

Construction of Pilot Solar Evaporator

Once the optimum surface material was determined, the total evaporator surface area was reconstructed. The reservoir received drainage water to be evaporated and water recycled during the evaporation process. The reservoir consisted of perforated PVC pipes with a gravel cover. Testing of various nozzles was ongoing. A fence was installed in an attempt to control salt drift. A photo of the pilot solar evaporator and accessory equipment is shown in Figure 2. The pilot solar evaporator was operated over a one year period to collect data during seasonal conditions.

Figure 2: Pilot Solar Evaporator

Results

Two inch aggregate was selected as the optimum surface material for the evaporator surface constructed with a 2% gradient. Two industrial nozzles manufactured by BETE, BETE TF 12-170 and BETE TF 12-180 were the most effective in enhancing evaporation. These spray nozzles are made of brass, energy efficient, and clog-resistant. Spray characteristics are hollow cone spray pattern, spray angles 170 and 180 degrees, and flow rates 2.12-7.35 gpm for water pressures 5-60 psi. The data collected from the pilot project will be used to construct the farm solar evaporator.

During spring and fall seasons daily evaporation from SE-SC was 0.7-1.1 inch, but increased to 1.3-4.2 inches (Figures 3-A, 3-B) during summer months. Figure 3-B illustrates the evaporation from solar evaporator to the actual daily evaporation by CIMIS station, nozzle heights at 0.25 ft through 2.0 ft. The optimum time to operate the solar evaporator was found to be from May through September.

Salt was recovered from drainage water in four steps. The first step increased salt concentrations from 10-48 g/l; the second from 48-107 g/l; the third from 107-220 g/l; and the final step from 120-250 g/l or higher. The remaining brine, salt concentration 200-250 g/l, was evaporated using BETE TF 12-170 spray nozzles. Figure 4 shows the salts recovered from the operation of the pilot solar evaporator project.

The effect of wind on salt drift needs to be further studied. In June 2004, CIT researchers began a field study to monitor salt emissions of the solar evaporator. The field samples are being analyzed and the results of the analysis will be used with a dispersion model to calculate particle emission factors.

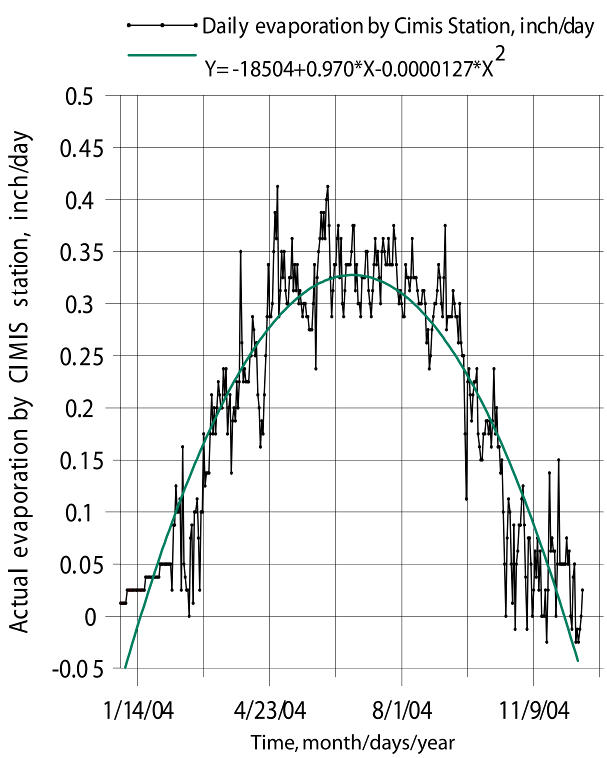

Figure 3-A

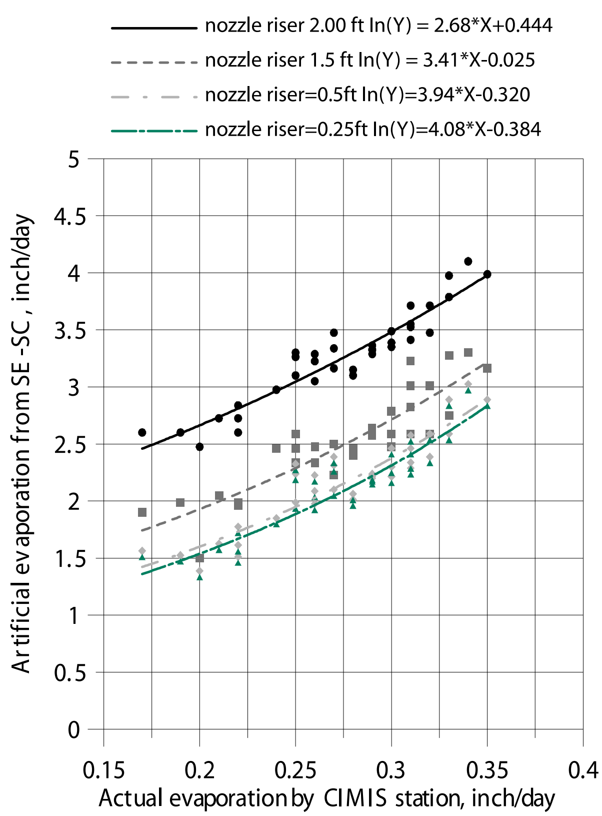

Figure 3-B

Figure 4: Salts Recovered from the Pilot Solar Evaporator

Conclusions

The data presented in this paper demonstrate that a simple and efficient, easy to operate; solar evaporator can be developed as a viable tool to manage agricultural subsurface drainage water within the boundaries of the 640-acre IFDM system at Red Rock Ranch. The data collected from this pilot study will provide a solid reference to designers to develop similar enhanced evaporation systems for IFDM projects and for management of brine effluents.

Reference

Chapter 6.5 of Division 20 of the Health and Safety Code, relating to water, Article 9.7, Section 25209.11

See Appendix CD for California Department of Water Resources PowerPoint Presentation of the Design of the Solar Evaporator for Integrated On-Farm Drainage Management System at Red Rock Ranch.

Drainage Water and Its Effect on Wildlife Resources

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I. Introduction

A goal of IFDM is to dispose of highly saline agricultural subsurface drainage water in an environmentally sound way that does not impact wildlife. Draft Title 27 Solar Evaporator Regulation states, *"The solar evaporator shall be operated to ensure that avian wildlife is adequately protected."*

Depending on the design and management of the solar evaporator, wildlife, such as shorebirds and waterfowl, may be attracted to the solar evaporator if standing water or scattered puddles are allowed to form. The saline subsurface drainage water may contain elevated selenium, which is the primary constituent of concern, and the hyper-saline water itself may impact wildlife.

II. Laws that Address Wildlife Issues

• California Code of Regulations (CCR) Draft Title 27 Solar Evaporator Regulations established minimum requirements for the design, construction, operation and closure of solar evaporators as components of IFDM systems with the intent of protecting wildlife from exposure to salt and selenium.

• California Environmental Quality Act (CEQA): environmental impact analysis is a component of CEQA, and delineates mitigation and monitoring requirements that may have to be incorporated into an IFDM system in order to ensure adequate CEQA compliance.

• Migratory Bird Treaty Act (MBTA) is enforced by both the USFWS and the CDFG.

• Federal Endangered Species Act (FESA) and the California Endangered Species Act (CESA) were created to protect species from extinction and are enforced by the USFWS and the CDFG, respectively.

The Central Valley Regional Water Quality Control Board currently is developing regulations regarding monitoring. The following is from Draft Title 27 Solar Evaporator Regulations, §22940:

Inspection – The CVRWQCB issuing a Notice of Authority to Operate a solar evaporator shall conduct authorized inspections in accord with §25209.15 of Article 9.7 of the Health and Safety Code to ensure continued compliance with the requirements of this article. The CVRWQCB shall request an avian wildlife biologist to assist it in its inspection of each authorized solar evaporator at least once every May. If an avian wildlife biologist is not available, the CVRWQCB shall nevertheless conduct the inspection. During the inspection, observations shall be made for compliance with §22910 (a) and (v), and the following conditions that indicate an unreasonable threat to avian wildlife:

(1) Presence of vegetation within the boundaries of the solar evaporator;

(2) Standing water or other mediums within the solar evaporator that support the growth and dispersal of aquatic or semi-aquatic macro invertebrates or aquatic plants;

(3) Abundant sustained avian presence within the solar evaporator that could result in nesting activity;

(4) An apparent avian die-off or disabling event within the solar evaporator;

(5) Presence of active avian nests with eggs within the boundaries of the solar evaporator.

A qualified wildlife biologist or agent identified by the Central Valley Regional Water Quality Control Board, may conduct the following biological surveys:

• Monitor for aquatic invertebrate activity if standing water is present for greater than 48 hours;
• Monitor bird activity (bird census, year round, monthly to twice per month);
• If nesting is detected, monitor nesting activity and nest fate (every 1-2 weeks from mid- March through July);

- If nesting is detected, collect egg selenium concentration data;
- Collecting and research take permits from the CDFG and USFWS are required for the collection of mammals, birds and their nests and eggs, reptiles, amphibians, fish and invertebrates.
- According to Draft Title 27 Solar Evaporator Regulations, §22940:

If active avian nests with eggs are found within the boundaries of the solar evaporator, the RWQCB shall report the occurrence to the USFWS and DFG within 24 hours, and seek guidance with respect to applicable wildlife laws and implementing regulations. Upon observation of active avian nests with eggs within the boundaries of the solar evaporator, all discharge of agricultural drainage water to the solar evaporator shall cease until (a) the nests are no longer active, or (b) written notification is received by the owner or operator, from the RWQCB, waiving the prohibition of discharge in compliance with all applicable state and federal wildlife laws and implementing regulations (i.e., as per applicable exemptions and allowable take provisions of such laws and implementing regulations).

III. Constituents of Concern

A. Selenium

Selenium originates from the natural weathering of cretaceous shale (rocks that have the highest selenium concentration 500-28,000 ppb); however, there are two human-related activities that have resulted in the mobilization and introduction of selenium into aquatic systems. The first activity is the irrigation of selenium-containing soils for crop production in arid to semiarid areas of the country. The other source is from the procurement, processing (i.e. oil refineries), and combustion of fossil fuels (Lemly and Smith, 1987).

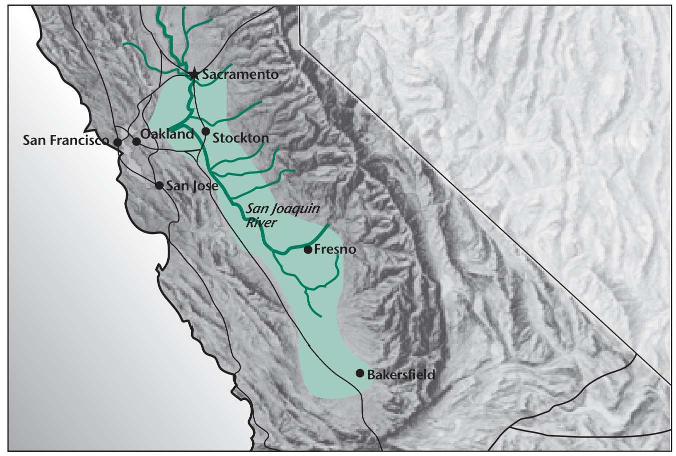

Figure 1. Land area with aquatic systems that maintain various levels of constituents of concern for wildlfe.

Selenium is a double-edge sword. Animals needs trace levels of the mineral in their diet for survival, but at levels slightly above trace amounts it can be very toxic. In addition, clinical signs for selenium deficiency are similar to selenium toxicity. Many veterinarians have misdiagnosed selenium toxicity as a selenium deficiency, resulting in adding selenium supplements to a patient's diet, which increased the toxicity response to a higher level.

The signs of acute selenium poisoning in laboratory animals include garlic breath, vomiting, dyspnea (difficulty or shortness of breath), tetanic spasms of the muscles, and respiratory failure (Koller and Exon, 1986). Acute poisoning of livestock is associated with plant material containing 400-800 ppm selenium (Eisler, 1985). "Alkali disease" is a livestock disease resulting from chronic selenium exposure; it is characterized by a lack of vitality, anemia, stiffness of joints, deformed and sloughed hooves, roughened hair coat, and lameness (Koller and Exon, 1986).

The most common signs of selenium poisoning in wild birds are emaciated adults, poor reproduction rates, embryonic deaths and deformities (missing or abnormal body parts, such as wings, legs, eyes, and beaks, and fluid accumulation in the skull), and adult mortality (Friend and Franson, 1999). In order to diagnose selenium poisoning, factors such as a history of potential exposure, gross developmental defects, microscopic lesions (evidence of chronic liver damage), and selenium concentrations in tissues, food, water and sediment must be examined.

Plants and invertebrates in contaminated aquatic systems can accumulate selenium, which can sometimes reach levels that are toxic to birds and other organisms that eat them (Friend and Franson, 1999) as shown in Figure 1.

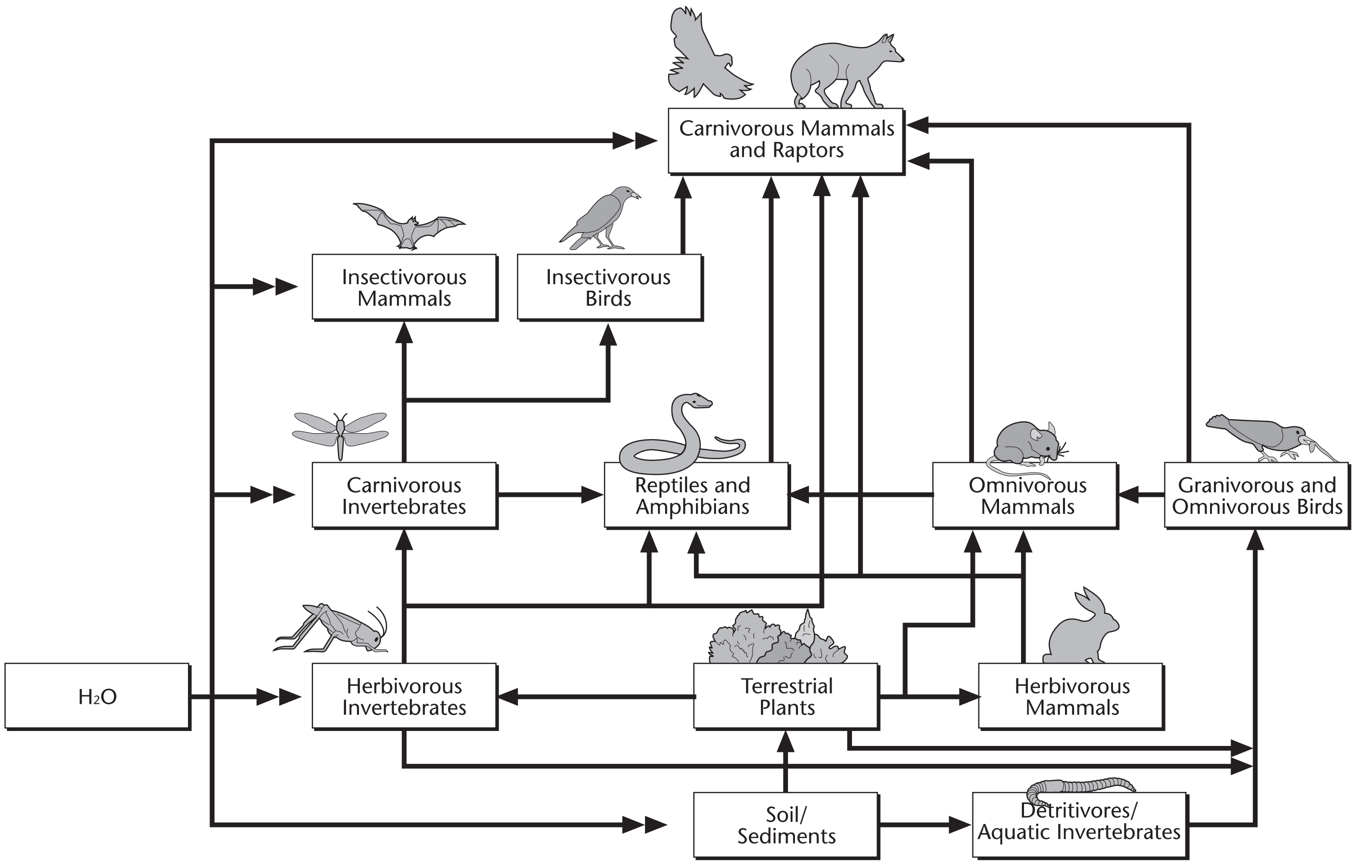

Figure 2. Bio-accumulation of selenium flow-chart for wildlife.

B. Boron

Boron is an essential trace nutrient necessary for plants and animals, as well as for some species of fungi, bacteria and algae. Boron is naturally occurring and is found in varying concentrations in San Joaquin Valley soils and water. There is some evidence that elevated boron may decrease the growth rate of chicks. Also different plant species, including agricultural crops, have different tolerances to boron concentrations in soil and water.

C. Molybdenum

Molybdenum is an essential micronutrient. Evaporation ponds in the southern San Joaquin Valley often contain high concentrations of molybdenum (Ohlendorf and Skorupa, 1993). There is little information about the negative effects of molybdenum on avian and mammalian wildlife.

D. Arsenic

Arsenic is a teratogen (causes deformities) and carcinogen (causes cancer), which can cause fetal death and malformation in many mammal species but may be an essential nutrient in small amounts. High levels of arsenic have been found in the water and sediments of some agricultural subsurface drainage evaporation basins, in the soil, and in underground water tables in the San Joaquin Valley. However, to date, elevated concentrations of arsenic have not been found in wild bird eggs. In addition, some aquatic invertebrate species have been negatively affected by arsenic in the evaporation basins (Ohlendorf and Skorupa, 1993).

E. Salinity and Salt Toxicosis

Evaporation basins are used to collect and dispose of highly saline subsurface drainage water produced in the Tulare Basin, and to a limited extent, on the Westside of the San Joaquin Valley. Aquatic invertebrates, such as brine shrimp, thrive in the hyper-saline water and attract many birds. Waterfowl, particularly the ruddy duck, have been affected by salt encrustation of feathers and salt toxicosis by loafing and feeding in deep hypersaline water evaporation basins. Salt toxicosis (sodium poisoning) generally occurs in times of drought or cool winter temperatures when there is no access to fresh water. The symptoms of salt toxicosis include conjunctivitis (swelling of the eyelids), lens opacity, cataract formation, and vascular congestion in various organs such as the oropharynx (throat), lungs, kidney, and spleen, and most prominently in the meninges of the brain, and myocardial and skeletal muscle degeneration (Gordus et al., 2002). Gordus et al. (2002) found that ambient temperatures below 4°C and hyper-saline water >70,000 mmhos/cm resulted in salt encrustation and salt toxicosis in ruddy ducks.

IV. Water Quality Objectives

Table 1. Water quality objectives for the protection of wildlife. Please note that the following threshold values may change based on future State and Federal regulatory water quality objective requirements. Note: mg/L equals microgram per liter and mg/L equals milligrams per liter.

	Target Water Quality	**Water Quality Needs Further Study**	**Unacceptable**
	No Effect	**Level of Concern**	**Toxicity**
Selenium (µg/L)[a]	<2	2-5	>5
Arsenic (µg/L)	<5	5-10	>10 [b]
Boron (mg/L)	<0.3	0.3-0.6	>0.6 [c]
Molybdenum (µg/L)	<10	10-19	>19 [b]

[a] Draft Environmental Impact Statement (EIS)/Environmental Impact Report (EIR), Grassland Bypass Project, 2001-2009 (URS 2000).

[b] Preliminary Draft Water Quality Criteria for Refuge Water Supplies Title 34 PL 102-575 Section 3406 (d) 1995. The California Regional Water Quality Board Agriculture Water Quality Objectives for molybdenum is 10 mg/L (A Compilation of Water Quality Goals, Marshack 1998).

[c] Proposed California Regional Water Quality Board Boron and Salinity Objectives for Full Protection of Beneficial Uses in the Lower San Joaquin River at Vernalis. The California Regional Water Quality Board agriculture water quality objective for boron is 0.70 to 0.75 mg/L (A Compilation of Water Quality Goals, Marshack 1998).

V. Biological Sampling

A. Aquatic Invertebrates

Many studies have shown that aquatic invertebrates (insects, snails, worms, etc.), can accumulate high levels of selenium from water and sediment. Sampling and measuring the selenium concentrations of aquatic invertebrates is one of the best indicators for monitoring predator exposures in cases where information is difficult to obtain directly from predator species (Luoma and Presser, 2000). Sampling of aquatic invertebrates may need to be performed if there is standing water that has elevated selenium concentrations, has an established population of invertebrates, and a significant number of birds are observed feeding and using the flooded area.

B. Bird Eggs

Many cases have shown that aquatic birds that feed and nest at subsurface drainage water disposal sites have above normal rates of embryo mortality and teratogenesis and adult mortality, as seen at Kesterson Reservoir (Ohlendorf & Skorupa, 1989).

Collecting bird eggs is the most efficient method for determining selenium impacts to birds that feed and nest at a solar evaporation basin. This is because bird eggs are easy to find and collect, the loss of one egg collected from a nest is not enough to negatively impact a population, embryos are the most sensitive life stage to selenium poisoning, and egg selenium concentrations represent a direct selenium exposure relationship to the adult female over time (Lemly, 1996).

VI. Maintaining a Bird-Free Solar Evaporator

Factors that make solar evaporators attractive or unattractive to birds are:

• Size of the solar evaporator – Larger solar evaporators are more attractive than smaller solar evaporators.

• Location – Is the site within or near a local flyway corridor or wildlife area or refuge? The Valley historically supported extensive wetlands that provided important stop-over foraging and resting habitat for migratory birds. As a result, any artificial "wetlands" that currently occur within the Valley are very attractive to water birds due to the limited wetland acreage remaining.

• Depth of water – Shallow water attracts shore birds and dabbling ducks, and deep water attracts ruddy ducks and eared grebes.

• Standing water – Aquatic invertebrates can become established, which is a food base for water birds.

• Design and management – Certain designs and management techniques enhance the attractiveness of a pond to birds. Avoidance measures to greatly reduce the negative impacts on waterbirds were developed by several researchers in cooperation with DFG and USFWS, (San Joaquin Valley Drainage Program, 1999), (Bradford et al. 1991), (CH2M Hill et al. 1993), (Salmon and March, 1991), (California Department of Water Resources and San Joaquin Valley Drainage Program, 1998).

These measures include:

• Design – Steep banks, flat or level bottoms, no uneven bottoms or high spots, no windbreaks, islands or internal berms present.

• Management – An effective program may reduce the likelihood of a solar evaporator attracting waterbirds to a site.

• Hazing (propane cannons and cracker shells) is one avoidance measure that may be effective in reducing migratory birds foraging and nesting in or around the solar evaporator during the early spring and summer months. Note: Shorebirds and dabbling ducks, such as northern shovelers, mallards and pintails, are easier to haze compared to eared grebes and diving ducks, such as ruddy ducks. Hazing should be discontinued after a nest has become established and eggs have been laid so the nest is not abandoned.

• To prevent aquatic invertebrates from becoming established, do not allow water greater than 1 cm in depth to stand for more than 48 hours.

• Keep dikes, banks and pond bottoms weed free. Manual weed control should not take place during the nesting season unless a qualified wildlife biologist has determined the area to be nest free.

• Appropriate monitoring program should be in place that support an Adaptive Management Program.

Maas-Hoffman Table 1: Salt Tolerance of Herbaceous Crops[1]

Crop		Salt tolerance parameters				References
Common name	**Botanical name[‡]**	**Tolerance based on:**	**Threshold[¶] (Ec_e)**	**Slope dS/m**	**Rating[#] % per dS/m**	
Fiber, grain, and special crops						
Artichoke, Jerusalem	*Helianthus tuberosus* L.	Tuber yield	0.4	9.6	MS	Newton et al., 1991
Barley[††]	*Hordeum vulgare* L.	Grain yield	8.0	5.0	T	Ayers et al., 1952 Hassan et al., 1970a
Canola or rapeseed	*Brassica campestris* L. [syn. B. *rapa L.*]	Seed yield	9.7	14	T	Francois, 1994a
Canola or rapeseed	*B. napus* L.	Seed yield	11.0	13	T	Francois, 1994a
Chick pea	*Cicer arietinum* L.	Seed yield	—	—	MS	Manchanda & Sharma, 1989; Ram et al., 1989
Corn[§§]	*Zea mays* L.	Ear FW	1.7	12	MS	Bernstein & Ayers, 1949b (p. 41-42); Kaddah & Ghowail, 1964
Cotton	*Gossypium hirsutum* L.	Seed cotton yield	7.7	5.2	T	Bernstein, 1955 (p. 37-41), 1956 (p. 33-34); Berntein & Ford, 1959a (p. 34-35).
Crambe	*Crambe abyssinica*	Seed yield	2.0	6.5	MS	Francois & Kleiman, 1990 Hochst. Ex R. E. Fries
Flax	*Linium usitatissimum* L.	Seed yield	1.7	12	MS	Hayward & Spurr, 1944
Guar	*Cyamopsis tetragonoloba* (L.) Taub.	Seed yield	8.8	17	T	Francois et al., 1990
Kenaf	*Hibiscus cannabinus* L.	Stem DW	8.1	11.6	T	Francois et al., 1992
Millet, channel	*Echinochloa turnerana*	Grain yield	—	—	T	Shannon et al., 1981 (Domin) J.M. Black
Oat	*Avena sativa* L.	Grain yield	—	—	T	Mishra & Shitole, 1986; USSL[‡‡]
Peanut	*Arachis hypogaea* L.	Seed yield	3.2	29	MS	Shalhevet et al., 1969
Rice, paddy	*Oryza sativa* L.	Grain yield	3.0[¶¶]	12[¶¶]	S	Ehrler, 1960; Narale et al., 1969; Pearson, 1959; Venkateswarlu et al., 1972
Roselle	*Hibiscus sabdariffa* L.	Stem DW	—	—	MT	El-Saidi & Hawash, 1971
Rye	*Secale cereale* L.	Grain yield	11.4	10.8	T	Francois et al., 1989
Safflower	*Carthamus tinctorius* L.	Seed yield	—	—	MT	Francois & Bernstein, 1964b
Sesame[##]	*Sesamum indicum* L.	Pod DW	—	—	S	Yousif et al., 1972
Sorghum	*Sorghum bicolor* (L.)	Grain yield	6.8	16	MT	Francois et al., 1984 , Moench
Soybean	*Glycine max* (L.) Merrill	Seed yield	5.0	20	MT	Abel & McKenzie, 1964; Bernstein et al., 1955b (p. 35-36); Bernstein & Ogata, 1966
Sugarbeet[†††]	*Beta vulgaris* L.	Storage root	7.0	5.9	T	Bower et al., 1954
Sugarcane	*Saccharum officinarum* L.	Shoot DW	1.7	5.9	MS	Bernstein et al., 1966; Dev & Bajwa, 1972; Syed & El-Swaify, 1972
Sunflower	*Helianthus annuus* L.	Seed yield	4.8	5.0	MT	Cheng, 1983; Francois, 1996
Triticale	*X Triticosecale* Wittmack	Grain yield	6.1	2.5	T	Francois et al., 1988
Wheat	*Triticum aestivum* L.	Grain yield	6.0	7.1	MT	Asana & Kale, 1965; Ayers et al., 1952; Hayward & Uhvits, 1944 (p. 41-43)
Wheat (semidwarf)[‡‡‡]	*T. Aestivum* L	Grain yield	8.6	3.0	T	Francois et al., 1986
Wheat, Durum	*T. Turgidum* L. var. *durum* Desf.	Grain yield	5.9	3.8	T	Francois et al., 1986

Maas-Hoffman Table 1: Salt Tolerance of Herbaceous Crops[1] *(continued)*

Crop		Salt tolerance parameters				References
Common name	Botanical name‡	Tolerance based on:	Threshold¶ (Ec_e)	Slope dS/m	Rating# % per dS/m	
Grasses and forage crops						
Alfalfa	*Medicago sativa* L.	Shoot DW	2.0	7.3	MS	Bernstein & Francois, 1973a; Bernstein & Ogata, 1966; Bower et al., 1969; Brown & Hayward, 1956; Gauch & Magistad, 1943; Hoffman et al., 1975
Alkaligrass, Nuttall	*Puccinellia airoideS*	Shoot DW	—	—	T*	USSL staff, 1954 (Nutt.) Wats. & Coult.
Alkali sacaton	*Sporobolus airoides* Torr.	Shoot DW	—	—	T*	USSL staff, 1954
Barley (forage) ††	*Hordeum vulgare* L.	Shoot DW	6.0	7.1	MT	Dregne, 1962; Hassan et al., 1970a
Bentgrass, creeping	*Agrostis stolonifera* L.	Shoot DW	—	—	MS	Younger et al., 1967
Bermudagrass§§§	*Cynodon dactylon* L. Pers.	Shoot DW	6.9	6.4	T	Bernstein & Ford, 1959b (p. 39-44); Bernstein & Francois, 1962 (p. 37- 38); Langdale & Thomas, 1971
Bluestem, Angleton	*Dichanthium aristatum* (Poir.) C.E. Hubb. [syn. *Andropogon nodosus* (Willem.) Nash]	Shoot DW	—	—	MS*	Gausman et al., 1954
Broadbean	*Vicia faba* L.	Shoot DW	1.6	9.6	MS	Ayers & Eberhard, 1960
Brome, mountain	*Bromus marginatus* Nees ex Steud.	Shoot DW	—	—	MT*	USSL staff, 1954
Brome, smooth	*B. inermis* Leyss	Shoot DW	—	—	MT	McElgunn & Lawrence, 1973
Buffellgrass	*Pennisetum ciliare* (L.) Link. [syn. *Cenchrus ciliaris*]	Shoot DW	—	—	MS*	Gausman et al., 1954
Burnet	*Poterium sanguisorba* L.	Shoot DW	—	—	MS*	USSL staff, 1954
Canarygrass, reed	*Phalaris arundinacea* L	Shoot DW	—	—	MT	McElgunn & Lawrence 1973
Clover, alsike	*Trifolium hybridium* L.	Shoot DW	1.5	12	MS	Ayers, 1948a
Clover, Berseem	*T. alexandrinum* L.	Shoot DW	1.5	5.7	MS	Asghar et al., 1962; Ayers & Eberhard, 1958 (p. 36-37); Ravikovitch & Porath, 1967; Ravikovitch & Yoles, 1971
Clover, Hubam	*Melilotus alba* Dest. var. *annua* H. S. Coe	Shoot DW	—	—	MT*	USSL staff, 1954
Clover, ladino	*Trifolium repens* L	Shoot DW	1.5	12	MS	Ayers, 1948a; Gauch & Magistad, 1943
Clover, Persian	*T. resupinatum* L	Shoot DW	—	—	MS*	de Forges, 1970
Clover, red	*T. pratense* L.	Shoot DW	1.5	12	MS	Ayers, 1948a; Saini, 1972
Clover, strawberry	*T. fragiferum* L.	Shoot DW	1.5	12	MS	Ayers, 1948a; Bernstein & Ford, 1959b (p. 39-44); Gauch & Magistad, 1943
Clover, sweet	*Melilotus sp.* Mill.	Shoot DW	—	—	MT*	USSL staff, 1954
Clover, white Dutch	*Trifolium repens* L	Shoot DW	—	—	MS*	USSL staff, 1954
Corn (forage) §§	*Zea mays* L.	Shoot DW	1.8	7.4	MS	Hassan et al., 1970b; Ravikovitch, 1973; Ravikovitch & Porath, 1967
Cowpea (forage)	*Vigna unguiculata* (L.) Walp.	Shoot DW	2.5	11	MS	West & Francois, 1982
Dallisgrass	*Paspalum dilatatum* Poir.	Shoot DW	—	—	MS*	Russell, 1976
Dhaincha	*Sesbania bispinosa* (Linn.) W.F. Wright [syn.	Shoot DW	—	—	MT	Girdhar, 1987; Karadge

Maas-Hoffman Table 1: Salt Tolerance of Herbaceous Crops[1] *(continued)*

Crop		Salt tolerance parameters				References
Common name	**Botanical name‡**	**Tolerance based on:**	**Threshold¶ (Ec_e)**	**Slope dS/m**	**Rating# % per dS/m**	
Grasses and forage crops (con't)						
Fescue, tall	*Festuca elatior* L.	Shoot DW	3.9	5.3	MT	Bower et al., 1970; Brown & Bernstein, 1953 (p. 44-46)
Fescue, meadow	*Festuca pratensis* Huds.	Shoot DW	—	—	MT*	USSL staff, 1954
Foxtail, meadow	*Alopecurus pratensis* L.	Shoot DW	1.5	9.6	MS	Brown and Bernstein, 1953 (p. 44-46)
Glycine	*Neonotonia wightii* [syn. *Glycine wightii* or *javanica*	Shoot DW	—	—	MS	Russell, 1976; Wilson, 1985
Gram, black or Urd bean	*Vigna mungo* (L.) Hepper [syn. *Phaseolus mungo* L.]	Shoot DW	—	—	S	Keating & Fisher, 1985
Grama, blue	*Bouteloua gracilis* (HBK) Lag. Ex Steud.	Shoot DW	—	—	MS*	USSL staff, 1954
Guinea grass	*Panicum maximum* Jacq.	Shoot DW	—	—	MT	Russell, 1976
Hardinggrass	*Phalaris tuberosa* L. var. *stenoptera* (Hack) A.S.	Shoot DW	4.6	7.6	MT	Brown & Bernstein, 1953 (p. 44-46) Hitchc.
Kallargrass	*Leptochloa fusca* (L. Kunth [syn. *Diplachne fusca* Beauv.]	Shoot DW	—	—	T	Sandhu et al., 1981
Lablab bean	*Lablab purpureus* (L.) Sweet [syn. *Dolichos lablab* L.]	Shoot DW	—	—	MS	Russell, 1976
Lovegrass¶¶¶	*Eragrostis sp.* N. M. Wolf	Shoot DW	2.0	8.4	MS	Bernstein & Ford, 1959b (p. 39-44)
Milkvetch, Cicer	*Astragalus cicer* L.	Shoot DW	—	—	MS*	USSL staff, 1954
Millet, Foxtail	*Setaria italica* (L.) Beauvois	Dry Matter	—	—	MS	Ravikovitch & Porath, 1967
Oatgrass, tall	*Arrhenatherum elatius* (L.) Beauvois ex J. Presl & K. Presl	Shoot DW	—	—	MS*	USSL staff, 1954
Oat (forage)	*Avena sativa* L.	Straw DW	—	—	T	Mishra & Shitole, 1986; USSL‡‡
Orchardgrass	*Dactylis glomerata* L.	Shoot DW	1.5	6.2	MS	Brown & Bernstein, 1953 (p. 44-46); Wadleigh et al., 1951
Panicgrass, blue	*Panicum antidotale* Retz.	Shoot DW	—	—	MS*	Abd El-Rahman et al., 1972; Gausman et al., 1954
Pigeon pea	*Cajanus cajus* (L.) Huth [syn. *C. indicus* (K.) Spreng.]	Shoot DW	—	—	S	Subbaro et al., 1991; Keating & Fisher, 1985
Rape (forage)	*Brassica napus* L.		—	—	MT*	USSL staff, 1954
Rescuegrass	*Bromus unioloides* HBK	Shoot DW	—	—	MT*	USSL staff, 1954
Rhodesgrass	*Chloris Gayana* Kunth.	Shoot DW	—	—	MT	Abd El-Rahman et al., 1972; Gausman et al., 1954
Rye (forage)	*Secale cereale* L.	Shoot DW	7.6	4.9	T	Francois et al., 1989
Ryegrass, Italian	*Lolium multiforum* Lam.	Shoot DW	—	—	MT*	Shimose, 1973
Ryegrass, perennial	*Lolium perenne* L.	Shoot DW	5.6	7.6	MT	Brown & Bernstein, 1953 (p. 44-46)
Ryegrass, Wimmera	*L. Rigidum* Gaud.		—	—	MT*	Malcolm & Smith, 1971
Saltgrass, desert	*Distichlis spicta* L. var. *stricta* (Torr.) Bettle	Shoot DW	—	—	T*	USSL staff, 1954
Sesbania	*Sesbania exaltata* (Raf. V.L. Cory	Shoot DW	2.3	7.0	MS	Bernstein, 1956 (p. 33-34)
Sirato	*Macroptilium atropurpureum* (D.C.) Urb.	Shoot DW	—	—	MS	Russell, 1976

Maas-Hoffman Table 1: Salt Tolerance of Herbaceous Crops[1] *(continued)*

Crop		Salt tolerance parameters				References
Common name	**Botanical name[‡]**	**Tolerance based on:**	**Threshold[¶] (Ec_e)**	**Slope dS/m**	**Rating[#] % per dS/m**	
Grasses and forage crops (con't)						
Sphaerophysa	*Sphaerophysa salsula* (Pall.) DC	Shoot DW	2.2	7.0	MS	Francois & Bernstein, 1964a (p. 52-53)
Sudangrass	*Sorghum sudanense* (Piper) Stapf	Shoot DW	2.8	4.3	MT	Bower et al., 1970
Timothy	*Phleum pratense* L.	Shoot DW	—	—	MS*	Saini, 1972
Trefoil, big	*Lotus pedunculatus* Cav.	Shoot DW	2.3	19	MS	Ayers, 1948a,b (p. 23-25)
Trefoil, narrowleaf birdsfoot	*L. corniculatus* var *tenuifolium* L.	Shoot DW	5.0	10	MT	Ayers, 1948a, b (p. 23-25)
Trefoil, broadleaf birdsfoot	*L. corniculatus* L. var *arvenis* (Schkuhr) Ser. ex DC	Shoot DW	—	—	MS	Ayers, 1950b (p. 44-45)
Vetch, common	*Vicia angustifolia* L.	Shoot DW	3.0	11	MS	Ravikovitch & Porath, 1967
Wheat (forage)[‡‡‡]	*Triticum aestivum* L.	Shoot DW	4.5	2.6	MT	Francois et al., 1986
Wheat, Durum (forage)	*T. turgidum* L. var. durum Desf.	Shoot DW	2.1	2.5	MT	Francois et al., 1986
Wheatgrass, standard crested	*Agropyron sibiricum*	Shoot DW	3.5	4.0	MT	Bernstein & Ford, 1958 (p. 32-36)
Wheatgrass, fairway crested	*A. cristatum* (L.) Gaertn. (Willd.) Beauvois	Shoot DW	7.5	6.9	T	Bernstein & Ford, 1958 (p. 32-36)
Wheatgrass, intermediate	*A. intermedium* (Host)	Shoot DW	—	—	MT*	Dewey, 1960 Beauvois
Wheatgrass, slender	*A. trachycaulum* (Link) Malte	Shoot DW	—	—	MT	McElgunn & Lawrence, 1973
Wheatgrass, tall	*A. elongatum* (Hort) Beauvois	Shoot DW	7.5	4.2	T	Bernstein & Ford, 1958 (p. 32-36)
Wheatgrass, western	*A. Smithii* Rydb.	Shoot DW	—	—	MT*	USSL staff, 1954
Wildrye, Altai	*Elymus angustus* Trin.	Shoot DW	—	—	T	McElgunn & Lawrence, 1973
Wildrye, beardless	*E. triticoides* Buckl.	Shoot DW	2.7	6.0	MT	Brown & Bernstein, 1953
Wildrye, Canadian	*E. canadensis* L.	Shoot DW	—	—	MT*	USSL staff, 1954
Wildrye, Russian	*E. junceus* Fisch.	Shoot DW	—	—	T	McElgunn & Lawrence, 1973

Maas-Hoffman Table 1: Salt Tolerance of Herbaceous Crops[1] *(continued)*

Crop		Salt tolerance parameters				References
Common name	**Botanical name**[‡]	**Tolerance based on:**	**Threshold**[¶] **(Ec_e)**	**Slope dS/m**	**Rating**[#] **% per dS/m**	
Vegetables and fruit crops						
Artichoke	*Cynara scolymus* L.	Bud yield	6.1	11.5	MT	Francois, 1995
Asparagus	*Asparagus officinalis* L.	Spear yield	4.1	2.0	T	Francois, 1987
Bean, common	*Phaseolus vulgaris* L.	Seed yield	1.0	19	S	Bernstein & Ayers, 1951; Hoffman & Rawlins, 1970; Magistad et al., 1943; Nieman &, 1959; Osawa, 1965
Bean, lima	*P. lunatus* L.	Seed yield	—	—	MT*	Mahmoud et al., 1988
Bean, mung	*Vigna radiate* (L.) R. Wilcz.	Seed yield	1.8	20.7	S	Minhas et al., 1990
Cassava	*Manihot esculenta* Crantz	Tuber yield	—	—	MS	Anonymous, 1976;Hawker & Smith, 1982
Beet, red[†††]	*Beta vulgaris* L.	Storage root	4.0	9.0	MT	Bernstein et al., 1974; Hoffman & Rawlins, 1971; Magistad et al., 1943
Broccoli	*Brassica oleracea* L. (Botrytis group)	Shoot FW	2.8	9.2	MS	Bernstein & Ayers, 1949a (p. 39); Bernstein et al., 1974
Brussel Sprout	*B. oleracea* L. (Gemmifera Group)		—	—	MS*	
Cabbage	*B. oleracea* L. (Capitata Group)	Head FW	1.8	9.7	MS	Bernstein & Ayers, 1949a (p. 39); Bernstein et al., 1974; Osawa, 1965
Carrot	*Daucus carota* L.	Storage root	1.0	14	S	Bernstein & Ayers, 1953a; Bernstein et al., 1974; Lagerwerff & Holland, 1960; Magistad et al., 1943; Osawa, 1965
Cauliflower	*Brassica oleracea* L. (Botrytis Group)		—	—	MS*	
Celery	*Apium graveolens* L. var Dulce (Mill.) Pers.	Petiole FW	1.8	6.2	MS	Francois & West, 1982
Corn, sweet	*Zea mays* L.	Ear FW	1.7	12	MS	Bernstein & Ayers, 1949b (p. 41-42)
Cowpea	*Vigna unguiculata* (L.) Walp.	Seed yield	4.9	12	MT	West & Francois, 1982
Cucumber	*Cucumis sativus* L	Fruit yield	2.5	13	MS	Osawa, 1965; Ploegman & Bierhuizen, 1970
Eggplant	*Solanum melongena* L. var *esculentum* Nees.	Fruit yield	1.1	6.9	MS	Heuer et al., 1986
Garlic	*Allium sativum* L.	Bulb yield	3.9	14.3	MS	Francois, 1994b
Gram, black Or Urd bean	*Vigna mungo* (L.) Hepper [syn. *Phaseolus mungo* L.]	Shoot DW	—	—	S	Keating & Fisher, 1985
Kale	*Brassica oleracea* L. (Acephala Group)		—	—	MS*	Malcolm & Smith, 1971
Kohlrabi	*Brassica oleracea* L (Gongylodes Group)		—	—	MS*	
Lettuce	*Lactuca sativa* L.	Top FW	1.3	13	MS	Ayers et al., 1951; Bernstein et al., 1974; Osawa, 1965
Muskmelon	*Cucumis melo* L. (Reticulatus Group)	Fruit Yield	1.0	8.4	MS	Mangal et al., 1988 Shannon & Francois, 1978
Okra	*Abelmoschus esculentus* (L.) Moench	Pod yield	—	—	MS	Masih et al., 1978; Paliwal & Maliwal, 1972
Onion (bulb)	*Allium cepa* L.	Bulb yield	1.2	16	S	Bernstein & Ayers, 1953b; Bernstein et al., 1974; Hoffman & Rawlins, 1971; Osawa, 1965

Maas-Hoffman Table 1: Salt Tolerance of Herbaceous Crops[1] *(continued)*

Crop		Salt tolerance parameters				References
Common name	**Botanical name**[‡]	**Tolerance based on:**	**Threshold**[¶] **(Ec_e)**	**Slope dS/m**	**Rating**[#] **% per dS/m**	
Vegetables and fruit crops						
Onion (seed)	*Allium cepa* L	Seed yield	1.0	8.0	MS	Mangal et al., 1989
Parsnip	*Pastinaca sativa* L.		—	—	S*	Malcolm & Smith, 1971
Pea	*Pisium sativum* L.	Seed FW	3.4	10.6	MS	Cerda et al., 1982
Pepper	*Capsicum annuum* L.	Fruit yield	1.5	14	MS	Bernstein, 1954 (p. 36-37); Osawa, 1965, USSL[‡‡]
Pigeon pea	*Cajanus cajan* (L.) Huth [syn. *C. indicus* (K.) Spreng.]	Shoot DW	—	—	S	Keating & Fisher, 1985; Subbarao et al., 1991
Potato	*Solanum tuberosum* L.	Tuber yield	1.7	12	MS	Bernstein et al., 1951
Pumpkin	*Cucurbita pepo* L var. *Pepo*		—	—	MS*	
Purslane	*Portulaca oleracea* L.	Shoot FW	6.3	9.6	MT	Kumamoto et al., 1992
Radish	*Raphanus sativus* L.	Storage root	1.2	13	MS	Hoffman & Rawlins, 1971; Osawa, 1965
Spinach	*Spinacia oleracea* L.	Top FW	2.0	7.6	MS	Langdale et al., 1971; Osawa, 1965
Squash, scallop	*Cucurbita pepo* L. var *melopepo* L. Alef.	Fruit yield	3.2	16	MS	Francois, 1985
Squash, zucchini	*C. pepo* L. var *melopepo* (L.) Alef.	Fruit yield	4.9	10.5	MT	Francois, 1985; Graifenberg et al., 1996
Strawberry	*Fragaria x ananassa* Duch.	Fruit yield	1.0	33	S	Ehlig & Bernstein, 1958; Osawa, 1965
Sweet potato	*Ipomoea batatas* (L.) Lam.	Fleshy root	1.5	11	MS	Greig & Smith, 1962; USSL[‡‡]
Tepary bean	*Phaseolus acutifolius* Gray		—	—	MS*	Goertz & Coons, 1991; Hendry, 1918; Perez & Minguez, 1985
Tomato	*Lycopersicon lycopersicum* (L.) Karst. Ex Farw. [syn. *Lycopersicon esculentum* Mill.]]	Fruit yield	2.5	9.9	MS	Bierhuizen & Ploegman, 1967; Hayward & Long, 1943; Lyon, 1941; Shalhevet & Yaron, 1973
Tomato, cherry	*L. lycopersicum* var. *Cerasiforme* (Dunal) Alef.	Fruit yield	1.7	9.1	MS	Caro et al., 1991
Turnip	*Brassica rapa* L. (Rapifera Group)	Storage root	0.9	9.0	MS	Francois, 1984a
Turnip (greens)		Top FW	3.3	4.3	MT	Francois, 1984a
Watermelon	*Citrullus lanatus* (Thunb. Matsum. & Nakai	Fruit yield	—	—	MS*	de Forges, 1970
Winged bean	*Psophocarpus tetragonolobus* L. DC	Shoot DW	—	—	MT	Weil & Khalil, 1986

[†] These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary, depending upon climate, soil conditions, and cultural practices.
[‡] Botanical and common names follow the convention of Hortus Third (Liberty Hyde Bailey Hortorium Staff, 1976) where possible.
[§] FW = fresh weight, DW = dry weight.
[¶] In gypsiferous soils, plants will tolerate EC_e's about 2dS/m higher than indicated.
[#] Ratings are defined by the boundaries in Fig. 3-3. (Ratings with an * are estimates.)
[††] Less tolerant during seedling stage, EC_e at this stage should not exceed 4 or 5 dS/m.
[‡‡] Unpublished U.S. Salinity Laboratory data.
[§§] Grain and forage yields of DeKalb XL-75 grown on an organic muck soil decreased about 26% per deciSiemen/meter above athreshold of 1.9 dS/m (Hoffman et al., 1983).
[¶¶] Because paddy rice is grown under flooded conditions, values refer to the electrical conductivity of the soil water while the pants are submerged. Less tolerant during seedling stage.
[##] Sesame cultivars, Sesaco 7 and 8, may be more salt tolerant than indicated by the S rating.
[†††] Sensitive during germination and emergence, EC_e should not exceed 3 dS/m.
[‡‡‡] Data from one cultivar, Probred.
[§§§] Average of several varities. Suwannee and Coastal are about 20% more tolerant, and common and Greenfield are about 20% less tolerant than the average.
[¶¶¶] Average for Boer, Wilman, Sand, and Weeping cultivars (Lehman seems about 50% more tolerant).

Maas-Hoffman Table 2: Salt Tolerance of Woody Crops[2]

Crop		**Salt tolerance parameters**				**References**
Common name	**Botanical name**[‡]	**Tolerance based on:**	**Threshold**[¶] **(Ec_e)**	**Slope dS/m**	**Rating**[#] **% per dS/m**	
Almond	*Prunus duclis* (Mill.) D.A. Webb	Shoot growth	1.5	19	S	Bernstein et al., 1956; Brown et al., 1953
Apple	*Malus sylvestris* Mill.		—	—	S	Ivanov, 1970
Apricot	*Prunus armeniaca* L.	Shoot growth	1.6	24	S	Bernstein et al., 1956
Avocado	*Persea americana* Mill.	Shoot growth	—	—	S	Ayers, 1950a; Haas, 1950
Banana	*Musa acuminata* Colla	Fruit yield	—	—	S	Israeli et al., 1986
Blackberry	*Rubus macropetalus* Doug. ex Hook	Fruit yield	1.5	22	S	Ehlig, 1964
Boysenberry	*Rubrus ursinus* Cham. and Schlechtend	Fruit yield	1.5	22	S	Ehlig, 1964
Castorbean	*Ricinus communis* L.		—	—	MS*	USSL staff, 1954
Cherimoya	*Annona cherimola* Mill.	Foliar injury	—	—	S	Cooper et al., 1952
Cherry, sweet	*Prunus avium* L.	Foliar injury	—	—	S*	Beeftink, 1955
Cherry, sand	*Prunus besseyi* L., H. Baley	Foliar injury, stem growth	—	—	S*	Zhemchuzhnikov, 1946
Coconut	*Cocos nucifera* L.		—	—	MT*	Kulkarni et al., 1973
Currant	*Ribes sp.* L	Foliar injury, stem growth	—	—	S*	Beeftink, 1955; Zhemchuzhnikov, 1946
Date palm	*Phoenix dactylifera* L.	Fruit yield	4.0	3.6	T	Furr & Armstrong, 1962; (p. 11-13); Furr & Ream, 1968; Furr et al., 1966
Fig	*Ficus carica* L.	Plant DW	—	—	MT*	Patil & Patil, 1983a; USSL staff, 1954
Gooseberry	*Ribes sp.* L.		—	—	S*	Beeftink, 1955
Grape	*Vitis vinifera* L.	Shoot growth	1.5	9.6	MS	Groot Obbink & Alexander, 1973; Nauriyal & Gupta, 1967; Taha et al., 1972
Grapefruit	*Citrus x paradisi* Macfady.	Fruit yield	1.2	13.5	S	Bielorai et al., 1978
Guava	*Psidium guajava* L.	Shoot and root growth	4.7	9.8	MT	Patil et al., 1984
Guayule	*Parthenium argentatum* A. Gray	Shoot DW rubber yield	8.7 7.8	11.6 10.8	T T	Maas et al., 1988
Jambolan plum	*Syzgium cumini* L.	Shoot growth	—	—	MT	Patil & Patil, 1983b
Jojoba	*Simmondsia chinensis* (Link) C.K. Schneid	Shoot growth	—	—	T	Tal et al., 1979; Yermanos et al., 1967
Jujube, Indian	*Ziziphus mauritiana* Lam.	Fruit yield	—	—	MT	Hooda et al., 1990
Lemon	*Citrus limon* (L.) Burm. F.	Fruit yield	1.5	12.8	S	Cerda et al., 1990
Lime	*Citrus aurantiifolia* (Christm.) Swingle		—	—	S*	
Loquat	*Eriobotrya japonica* (Thunb.) Lindl.	Foliar injury	—	—	S*	Cooper & Link, 1953; Malcolm & Smith, 1971
Macadamia	*Macadamia integrifolia* Maiden & Betche	Seedling growth	—	—	MS*	Hue & McCall, 1989
Mandarin orange;	*Citrus reticulata* Blanco tangerine	Shoot growth	—	—	S*	Minessy et al., 1974
Mango	*Mangifera indica* L.	Foliar injur	—	—	S	Cooper et al., 1952

Maas-Hoffman Table 2: Salt Tolerance of Woody Crops[2] *(continued)*

Crop		Salt tolerance parameters				References
Common name	**Botanical name‡**	**Tolerance based on:**	**Threshold¶ (Ec_e)**	**Slope dS/m**	**Rating# % per dS/m**	
Natal plum	*Carissa grandiflora* (E.H. Mey.) A. DC.	Shoot growth	—	—	T	Bernstein et al., 1972
Olive	*Olea europaea* L. fruit yield	Seedling growth,	—	—	MT	Bidner-Barhava & Ramati, 1967; Taha et al., 1972
Orange	*Citrus sinensis* (L.) Osbeck	Fruit yield	1.3	13.1	S	Bielorai et al., 1988; Bingham et al., 1974; Dasberg et al., 1991; Harding et al., 1958
Papaya	*Carica papaya* L.	Seedling growth, foliar injury	—	—	MS	Kottenmeier et al., 1983; Makhija & Jindal, 1983
Passion fruit	*Passiflora edulis* Sims.		—	—	S*	Malcolm & Smith, 1971
Peach	*Prunus persica* (L.) Batsch	Shoot growth, fruit yield	1.7	21	S	Bernstein et al., 1956 Brown et al., 1953; Hayward et al., 1946
Pear	*Pyrus communis* L.		—	—	S*	USSL staff, 1954
Pecan	*Carya illinoinensis* (Wangeth) C. Koch	Nut yield trunk growth	—	—	MS	Miyamoto et al., 1986
Persimmon	*Diospyros virginiana* L.		—	—	S*	Malcolm & Smith, 1971
Pineapple	*Ananas comosus* (L.) Merrill	Shoot DW	—	—	MT	Wambiji & El-Swaify, 1974
Pistachio	*Pistachia vera* L.	Shoot growth	—	—	MS	Sepaskhah & Maftoun, 1988; Picchioni et al., 1990
Plum; prune	*Prunus domestica* L.	Fruit yield	2.6	31	MS	Hoffman et al., 1989
Pomegranate	*Punica granatum* L.	Shoot growth	—	—	MS	Patil & Patil, 1982
Popinac, white	*Leucaena leucocephala* (Lam.) De Wit [syn. *Leucaena glauca* Benth.]	Shoot DW	—	—	MS	Gorham et al., 1988; Hansen & Munns, 1988
Pummelo	*Citrus maxima* (Burm.)	Foliar injury	—	—	S*	Furr & Ream, 1969
Raspberry	*Rubus idaeus* L.	Fruit yield	—	—	S	Ehlig, 1964
Rose apple	*Syzgium jambos* (L.) Alston	Foliar injur	—	—	S*	Cooper & Gorton, 1951 (p. 32-38)
Sapote, white	*Casimiroa edulis* Llave	Foliar injur	—	—	S*	Cooper et al., 1952
Scarlet wisteria	*Sesbania grandiflora*	Shoot DW	—	—	MT	Chavan & Karadge, 1986
Tamarugo	*Prosopis tamarugo* Phil.	Observation	—	—	T	Natl. Acad. Sci., 1975
Walnut	*Juglans* spp.	Foliar injury	—	—	S*	Beeftink, 1955

† These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary, depending upon climate, soil conditions, and cultural practices. The data are applicable when rootstocks are used that do not accumulate Na^+ or Cl^- rapidly or when these ions do not predominate in the soil.

‡ Botanical and common names follow the convention of Hortus Third (Liberty Hyde Bailey Hortorium Staff, 1976) where possible.

§ In gypsiferous soils, plants will tolerate EC_e's about 2 dS/m higher than indicated.

¶ Ratings are defined by the boundaries in Fig. 3-3. Ratings with an * are estimates.

<u>Maas-Hoffman Table 3</u>: Boron Tolerance Limits for Agricultural Crops

Crop		**Boron tolerance parameters**				**References**
Common name	**Botanical name**	**Tolerance[†] based on:**	**Threshold[‡] g m-3**	**Slope % per g m-3**	**Rating[§]**	
Alfalfa	*Medicago sativa* L.	Shoot DW	4.0-6.0		T	Eaton, 1944
Apricot	*Prunus armeniaca* L.	Leaf & stem injury	0.5-0.75		S	Woodbridge, 1955
Artichoke, globe	*Cynara scolymus* L.	Laminae DW	2.0-4.0		MT	Eaton, 1944
Artichoke, Jerusalem	*Helianthus tuberosus* L.	Whole plant DW	0.75-1.0		S	Eaton, 1944
Asparagus	*Asparagus officinalis* L.	Shoot DW	10.0-15.0		VT	Eaton, 1944
Avocado	*Persea americana* Mill.	Foliar injury	0.5-0.75		S	Haas, 1929
Barley	*Hordeum vulgare* L.	Grain yield	3.4	4.4	MT	Bingham et al., 1985
Bean, kidney	*Phaseolus vulgaris* L.	Whole plant DW	0.75-1.0		S	Eaton, 1944
Bean, lima	*Phaseolus lunatus* L.	Whole plant DW	0.75-1.0		S	Eaton, 1944
Bean, mung	*Vigna radiata* L. R. Wilcz.	Shoot length	0.75-1.0		S	Khundairi, 1961
Bean, snap	*Phaseolus vulgaris* L.	Pod yield	1.0	12	S	Francois, 1989
Beet, red	*Beta vulgaris* L.	Root DW	4.0-6.0		T	Eaton, 1944
Blackberry	*Rubus sp.* L	Whole plant DW	<0.5		VS	Eaton, 1944
Bluegrass, Kentucky	*Poa pratensis* L.	Leaf DW	2.0-4.0		MT	Eaton, 1944
Broccoli	*Brassica oleracea* L. (Botrytis group)	Head FW	1.0	1.8	MS	Francois, 1986
Cabbage	*Brassica oleracea* L. (Capitata group)	Whole plant DW	2.0-4.0		MT	Eaton, 1944
Carrot	*Daucus carota* L.	Root DW	1.0-2.0		MS	Eaton, 1944
Cauliflower	*Brassica oleracea* L. (Botrytis group)	Curd FW	4.0	1.9	MT	Francois, 1986
Celery	*Apium graveolens* L. var. dulce (Mill.) Pers.	Petiole FW	9.8	3.2	VT	Francios, 1988
Cherry	*Prunus avium* L.	Whole plant DW	0.5-0.75		S	Eaton, 1944
Clover, sweet	*Melilotus indica* All.	Whole plant DW	2.0-4.0		MT	Eaton, 1944
Corn	*Zea mays* L.	Shoot DW	2.0-4.0		MT	El-Sheikh et al., 1971
Cotton	*Gossypium hirsutum* L.	Boll DW	6.0-10.0		VT	Eaton, 1944
Cowpea	*Vigna unguiculata* (L.) Walp.	Seed yield	2.5	12	MT	Francois, 1989
Cucumber	*Cucumis sativus* L.	Shoot DW	1.0-2.0		MS	El-Sheikh et al., 1971
Fig, kadota	*Ficus carica* L.	Whole plant DW	0.5-0.75		S	Eaton, 1944
Garlic	*Allium sativum* L.	Bulb yield	4.3	2.7	T	Francois, 1991
Grape	*Vitis vinifera* L.	Whole plant DW	0.5-0.75		S	Eaton, 1944
Grapefruit	*Citrus x paradisi* Macfady.	Foliar injury	0.5-0.75		S	Haas, 1929
Lemon	*Citrus limon* (L.) Burm. f.	Foliar injury, plant DW	<0.5		VS	Eaton, 1944; Haas, 1929
Lettuce	*Lactuca sativa* L.	Head FW	1.3	1.7	MS	Francois, 1988
Lupine	*Lupinus hartwegii* Lindl.	Whole plant DW	0.75-1.0	S		Eaton, 1944
Muskmelon	*Cucumis melo* L. (Reticulatus group)	Shoot DW	2.0-4.0		MT	Eaton, 1944; El- Sheikh et al.,1971
Mustard	*Brassica juncea* Coss.	Whole plant DW	2.0-4.0		MT	Eaton, 1944
Oat	*Avena sativa* L.	Grain (immature) DW	2.0-4.0		MT	Eaton, 1944
Onion	*Allium cepa* L.	Bulb yield	8.9	1.9	VT	Francois, 1991
Orange	*Citrus sinensis* (L.) Osbeck	Foliar injury	0.5-0.75		S	Haas, 1929
Parsley	*Petroselinum crispum* Nym.	Whole plant DW	4.0-6.0		T	Eaton, 1944
Pea	*Pisum sativa* L.	Whole plant DW	1.0-2.0		MS	Eaton, 1944
Peach	*Prunus persica* (L.) Batsch.	Whole plant DW	0.5-0.75		S	Eaton, 1944; Haas, 1929

Maas-Hoffman Table 3: Boron Tolerance Limits for Agricultural Crops *(continued)*

Crop		Boron tolerance parameters				References
Common name	**Botanical name**	**Tolerance† based on:**	**Threshold‡ g m-3**	**Slope % per g m-3**	**Rating§**	
Peanut	*Arachis hypogaea* L.	Seed yield	0.75-1.0		S	Gopal, 1971
Pecan	*Carya illinoinensis* (Wangenh.) C. Koch	Foliar injury	0.5-0.75		S	Haas, 1929
Pepper, red	*Capsicum annuum* L.	Fruit yield	1.0-2.		MS	Eaton, 1944
Persimmon	*Diospyros kaki* L.f.	Whole plant DW	0.5-0.75		S	Eaton, 1944
Plum	*Prunus domestica* L.	Leaf & stem injury	0.5-0.75		S	Woodbridge, 1955
Potato	*Solanum tuberosum* L.	Tuber DW	1.0-2.0		MS	Eaton, 1944
Radish	*Raphanus sativus* L.	Root FW	1.0	1.4	MS	Francois, 1986
Sesame	*Sesamum indicum* L.	Foliar injury	0.75-1.0		S	Khundairi, 1961
Sorghum	*Sorghum bicolor* (L.)	Grain yield	7.4	4.7	VT	Bingham et al., Moench 1985
Squash, scallop	*Curcurbita pepo* L. *var melopepo* (L.) Alef.	Fruit yield	4.9	9.	T	Francois, 1992
Squash, winter	*Curcurbita moschata Poir*	Fruit yield	1.0	4.3	MS	Francois, 1992
Squash, zucchini	*Curcurbita pepo* L. *var melopepo* L. Alef.	Fruit yield	2.7	5.2	MT	Francois, 1992
Strawberry	*Fragaria sp.* L.	Whole plant DW	0.75-1.0		S	Eaton, 1944
Sugar beet	*Beta vulgaris* L.	Storage root FW	4.9	4.1	T	Vlamis & Ulrich, 1973
Sunflower	*Helianthus annuus* L.	Seed yield	0.75-1.0		S	Pathak et al., 1975
Sweet potato	*Ipomoea batatas* (L.) Lam.	Root DW	0.75-1.0		S	Eaton, 1944
Tobacco	*Nicotiana tobacum* L.	Laminae DW	2.0-4.0		MT	Eaton, 1944
Tomato	*Lycopersicon lycopersicum* (L.) Karst. ex Farw.	Fruit yield	5.7	3.4	T	Francois, 1984b
Turnip	*Brassica rapa* L. (Rapifera	Root DW group)	2.0-4.0		MT	Eaton, 1944
Vetch, purple	*Vicia benghalensis* L.	Whole plant DW	4.0-6.0		T	Eaton, 1944
Walnut	*Juglans regia* L.	Foliar injury	0.5-0.75		S	Haas, 1929
Wheat	*Triticum aestivum* L.	Grain yield	0.75-1.0	3.3	S	Bingham et al., 1985; Khundairi, 1961

† FW = fresh weight, DW = dry weight.

‡ Maximum permissible concentration in soil water without yield reduction. Boron tolerances vary, depending upon climate, soil conditions, and crop varieties.

§ The B tolerance ratings are based on the following threshold concentration ranges: <0.5 g m^{-3} very sensitive (VS), 0.5 to 1.0 g m^{-3} sensitive (S), 1.0 to 2.0 g m^{-3} moderately sensitive (MS), 2.0 to 4.0 g m^{-3} moderately tolerant (MT), 4.0 to 6.0 g m^{-3} tolerant (T), and >6.0 g m^{-3} very tolerant (VT).

Summary of forage performance under IFDM management at Red Rock Ranch

Benes et al., 2005* and **Suyama** et al., 2005**

All forages were irrigated with saline drainage water, except alfalfa which was irrigated with either freshwater or a DW blend. Data are averages for Fall 2002 to 2004.

Forages[†]	Field	DW irrigation (yrs.)	ECw	ECe	Soil Boron (mg/kg)	SAR	BM Production (MT/ha/yr)[††]	Forage Quality[†††] ME (MJ/kg DM)	CP	NDF	Ash	Se (mg/kg)
			(dS/m)						(%)			
Tall Wheatgrass	1	5	7.2	19.1	25.1	38.0	7.1	9.32	15.6	56.5	9.7	6.12
Tall Wheatgrass	2	5	9.8	17.6	23.0	35.3	6.8	9.22	11.3	62.1	8.0	7.38
Creeping wildrye	1	2	8.6	13.3	18.7	29.4	10.6	8.24	16.4	60.9	8.7	2.98
Creeping wildrye	2	5	9.8	12.9	18.7	28.1	12.3	7.91	13.9	65.1	8.1	10.72
Puccinellia	1	5	9.8	15.0	23.2	29.9	5.5	9.56	17.7	60.4	8.8	4.37
Tall fescue	1	5	9.8	12.1	16.8	27.3	4.5	9.32	19.0	54.4	11.5	7.41
Alkali sacaton	1	5	9.8	12.4	15.8	26.7	6.7	6.72	12.1	72.2	9.3	6.88
Alfalfa/DW	1	1	6.7	6.9	7.1	17.5	16.7	9.62	23.7	37.5	9.9	1.45
Alfalfa/FW	2	0	1.1	4.7	3.6	12.2	19.1	9.85	24.8	34.8	10.3	0.80

† Tall wheatgrass var. 'Jose', Creeping wild rye var. 'Rio', Puccinellia ciliata, Tall fescue var. 'Alta', Alkali sacaton ('solado'), and Alfalfa vars. 'salado' & '801S' (50:50 mix) irrigated either with drainage water (DW) or fresh water (FW).

†† Metric tons dry matter per hectare per year.

††† Forage quality parameters include: metabolizable energy (ME), crude protein (CP), neutral detergent fiber (NDF) and ash.

*Benes S., Suyama H., Robinson P., Getachew G., Grattan S.R., and C. Grieve (2005). Forages Growing in Saline Drainage Water Re-use Systems on the Westside San Joaquin Valley of California: water use, productivity, and nutritional value. Proceedings of the International Salinity Forum: Managing Saline Soils and Water: Science, Technology, and Management. April 25-27, 2005. Riverside, CA. Oral Presentation Abstracts, pp. 55-58.

**Suyama H., Benes S., Robinson P., Getachew G., Grattan S.R., and C. Grieve (2005). Biomass Production and Nutritional Value of Forages Irrigated with Saline-sodic Drainage Water in a Greenhouse Study. Proceedings of the International Salinity Forum: Managing Saline Soils and Water: Science, Technology, and Management. April 25-27, 2005. Riverside, CA. Poster Abstracts, pp. 175-178.

Sources for Plant Materials

Government – Forages or Halophytes

1. USDA Plant Materials Center (PMC), Lockeford California. (209) 727-5319.

2. Westside Resource Conservation District (WSRCD). (559) 227-2489.

Commercial* – Salt Tolerant Forages

1. America's Alfalfa. Tel: (800) 873-2532. Material: 'Salado' and 'Ameristand 801S' salt tolerant alfalfa.

2. K-F Seeds. 4307 Fifield Road. Brawley, CA 92227. Tel: (760) 344-6391, FAX: (760) 344- 6394. Materials: Bermudagrass seed. Varieties 'Giant' and 'Common'.
'Tifton' is also recommended, but may not be available from this company.

3. S&W Seed Co. P.O. Box 235, Five Points, CA 93624. Tel: (559) 884-2535 swseedco@pacbell.net. Web: www.swseedco.com.
Materials: "Westside Wheatgrass", a commercialized variety of 'Jose' Tall Wheatgrass and 'SW 9720' Salt tolerant alfalfa.

4. West Coast Turf. PO Box 4563, Palm Desert, CA 92261. Tel: (800) 447-1840, (760) 346-TURF, and FAX: (760) 360-5616. Material: Seashore Paspalum ('SeasIsle 1') sod or chopped stolons.

Commercial* – Halophytes

1. NyPa International. Dr. Nick Yensen. 727 N. Ninth Ave., Tucson, Arizona 85705. Tel: (520) 624-7245, FAX: (520) 908-0819, email: nypa@aol.com. Web: http://expage.com/nypa.
Materials: "NyPa forage", a commercialized saltgrass (Distichlis spicata).
Tulare Lake Drainage District, Corcoran, CA. Tel: (559) 992-3145 may also be contacted to obtain NyPa forage.

2. Saline Seed, Inc. Contact: Mr. Daniel Murphy, 1900 Mountain Valley Lane Escondido, California 92029. Tel: (760) 294-3079, Fax: (760) 294-3081, e-mail: danielmurphyusa@yahoo.com. Web: http://salicornia.com/
Materials: Salicornia and other halophytes and salt tolerant forages.

*List is not inclusive and does not represent an endorsement of these companies.

CA Department of Water Resources Agroforestry Database Description

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Clarence Finch
United States Department of Agriculture-Natural Resources Conservation Service (retired)

The California Department of Water Resources, San Joaquin District , has developed a database for trees, shrubs and herbacous species planted on drainage-impacted areas in the western and southern parts of the San Joaquin Valley. This database includes a set of GIS layers showing mapped locations of these plots, along with purpose of planting, date of planting, street locations, county, partnerships, species planted, water and/or soil quality data if available, etc., contained in associated GIS tabular data.

These data also are contained in Excel spreadsheets (see Appendix CD). The intent of the Department is that these data, including GIS, will be available on the Internet, in order to facilitate planning for water table interception, recycling drainage water or harvest in drainage-impacted areas. A searchable database containing all known documents related to drainage issues, also is planned to be a significant part of the Web-based information.

IFDM Plant Management Guide

Clarence Finch & Frank Menezes
With revisions by **Sharon Benes** *and* **Vashek Cervinka** *(12-2003)*

Salt-tolerant Grasses and Halophytes

This guide uses the term "salt-tolerant grasses" for plants tolerating drainage water of EC from 8 to 15 dS/m, and the term "halophytes" for plants tolerating drainage water above EC 15 dS/m. Using water salinity of EC 15 as a separating limit is rather artificial, but it can be said that halophytes tolerate higher salinity than salt-tolerant grasses.

This selection of forages, halophytes, and trees for saline drainage management for the Westside San Joaquin Valley was based on literature review from the USA, Australia, Israel, and other countries, field evaluation trials, and a survey of salt-tolerant plants in semi-arid world regions. The set of plants used in both areas is the result of a multiple-year selection process. These plants are being selected not only for salt management purposes, but also for their biological interaction with conventional farm crops to avoid introducing species that could be potential weeds or host plants for insect vectors of plant viruses.

Salt-tolerant grasses and halophytes should preferably be perennial plants to manage higher flows of drainage water during the winter/spring period. The other required characteristics include high water demand, tolerance to frequent flooding, frost tolerance, and marketability of harvested biomass. Salt-tolerant grasses and halophytes should preferably be mainly used for the re-use of drainage water so as to reduce its volume. They are grown on a relatively small area of the farm (2%-8%). Trees are most commonly used in strips to intercept subsurface lateral flows of groundwater and/or to locally drop the water table. Commercial value is of primary importance for the areas under irrigation with freshwater or low salinity water where vegetables and salttolerant field crops (cotton, wheat, canola, sugar beets, and possibly, alfalfa) are grown. However, economic value can be a secondary consideration in the selection of salt-tolerant grasses, halophytes, and trees.

Recommended plant management

Prepare soil by leveling the planting area to achieve uniform water distribution in the fields of salt-tolerant grasses and halophytes. This is essential for plant growth and salt leaching, as well as for minimizing water ponding that could potentially attract wildlife. When establishing the plants in an area with slope, divide this the area into blocks by throwing up borders (ridges of soil) to confine the water and level each block for uniform water distribution. If an area is too steep to level to a uniform grade for irrigation and leaching, use sprinklers to irrigate. Good stands require weed-free soil conditions.

Establish plants by seeding or by planting rooted plants (plugs). Use a drill on a "vegetable type" seedbed or on a seedbed prepared with a corrugated roller. Broadcast seed on a leveled, disked corrugated surface of shallow furrow (such as tomato beds). It is recommended to plant plugs in the bottom of the rills (furrows). This reduces the salt load around the base of the plants and allows water to reach the plants more quickly. Alternatively, in a raised bed system, the seed or cuttings should be placed on the edges of the bed, avoiding the center of the bed which is the zone of maximum salt accumulation.

There are a number of methods for planting rooted plants such as by shovel, dibble, or by a mechanical vegetable planter. The most successful method is either the tree planter or the vegetable planter because they open up the soil, and the plant is placed deeper in the soil. Timing of planting is very important. Cool season grasses should be planted in the fall. Warm season plants in the spring.

When planting rooted plants, irrigation should follow as soon as possible after planting. Fresh water (less than 3 dS/m) should be used to irrigate until salt-tolerant plants are well established. Some perennials have to be planted and established for about a year before applying water over 10 dS/m. Salicornia and other halophytes may require saline water to be established. Once plants are established, border (flood) irrigation is recommended to effectively leach salts. Sprinklers are also effective for leaching salts below the root zone and/or on land that is too steep to flood. Irrigation frequency depends on plant, soil, and climatological conditions. Cycles of watering and drying are important. Yellowing of plants may be caused by overwatering or salt build-up.

Mowing helps to control weeds. Mowing height can be critical to plant survival. The following are the recommended mowing heights for plants:

- Bermudagrass and Saltgrass 10 cm (4 inches)
- Tall Wheatgrass, Alkali Sacaton, Beardless wildrye, 20 to 25 cm (8 to 10 inches) and Cordgrass
- Atriplex and Allenrolfea 25 to 50 cm (10 to 20 inches)
- Harvest salt-tolerant grasses and halophytes for hay or seeds. Grazing can be a preferable method of management. Do not graze when soils are wet, as compaction will reduce water infiltration.

Salt-Tolerant Grasses and Halophytes

(Brief Description)

Jose Tall Wheatgrass (Elytrigia elongata) (Agropyron elongatum)

Tall wheatgrass is a tall growing, erect, late maturing, perennial bunch grass. Plants range from 60 to 150 cm (2 to 5 feet) tall and the grass produces large erect seed heads that develop a good crop of seed. Growth starts in the spring and continues into late summer. The plant can be established in the fall by broadcast or drill, on a weed-free firm seedbed. Good stands can be established on saline-alkali sites by planting in bottoms of furrows and irrigating every 4 to 5 days until the seedlings have emerged to a height of 10 to 15 cm (4 to 6 inches). Established plants have been growing in soils with up to ECe of about 25 dS/m. It can be irrigated with drainage water of EC ranging from 8 to 13 dS/m. Tall wheatgrass is utilized by all kinds of livestock as pasture, hay or silage. It is important to maintain a stubble height of 20 cm (8 inches) when cutting for hay, silage or mowing down old seed head growth. This plant is excellent habitat for wildlife providing safe escape and excellent nesting cover, especially for pheasants.

Jose Tall Wheatgrass

Creeping wildrye ('Rio'), also called Beardless wildrye (Leymus triticoides or Elymus triticoides).

Creeping wildrye is a native perennial grass 60 to 150 cm (2 to 5 feet) tall growing singly or in small clumps. Due to its scaly underground rhizomes, it often spreads over large areas. While most native stands do not produce viable seed, the 'Rio' selection consistently produces viable seed. The plant can be established by seed in the fall, also by the underground rhizomes or by container grown plants. Established plants of creeping wildrye have been growing with EC 10 to 12 dS/m drain water. This forage is eaten by cattle and sheep and is excellent escape and nesting cover for wildlife.

Alkali Sacaton ('Salado') (Sporobolus airoides)

Alkali sacaton is a warm season native perennial bunchgrass. Plants range from 60 to 75 cm (2 to 2.5 feet) tall with curving leaves. Seed heads form a widely spreading panicle nearly onehalf the entire height of the plant. Plants may be 20 to 30 cm (8 to 12 inches) in diameter at ground level. The plant is established in the spring by seed or container-grown plants. Due to small seed, a good firm moist seedbed is required. Established plants have been growing with EC of 10 to 14 dS/m drain water. Alkali sacaton is good forage for cattle and horses and fair for sheep. This forage is sometimes called "salado," which should not be confused with a new salt tolerant variety of alfalfa, also called "salado".

Koleagrass ('Perla') (Phalaris tuberosa var. hirtiglumis)

Koleagrass is a tall, robust, rapid developing perennial bunchgrass. Plants range from 60 to 150 cm (2 to 5 feet) tall with short stout rhizomes originating from the base. Perla is established in the fall by seeding on a firm, weed free seedbed, or by container-grown plants. Established plants have been growing with EC of 10 to 12 dS/m drain water. Perlagrass is a very palatable grass relished by all kinds of livestock. It starts growth in the fall with moisture and continues to grow into the winter months. Due to this growth habit the plant supplies fall and winter feed for livestock and excellent cover for wildlife, especially pheasants.

Tall Fescue ('Alta' and 'Goar') (Festuca arundinacea)

Tall Fescue is an aggressive, erect, deeply rooted perennial bunch grass. The plant is from 60 to 100 cm (2 to 3 feet) tall and produces heavy sod and fibrous root material. Growth starts in the spring and continues into late winter. The plant is established in the fall from seeds by broadcast or drill on a weed-free firm seedbed. Once established, it can be irrigated with drainage water of EC 8 to 12 dS/m. Tall fescue is utilized by all kinds of livestock as pasture or hay. It is an excellent shade and nesting cover for wildlife.

Bermuda grass

Bermuda grass is a perennial crop that is moderately salt tolerant, and drought resistant. It is established by seed and spreads by rhizomes. Bermuda grass forms dense turf and can be grazed or cut for hay harvesting.

Creeping Wildrye

Alkali Sacaton

Halophytes

Pickleweed ('Samphire') (Salicornia bigelovii)

Pickleweed is a low growing very succulent annual plant that is 15 to 38 cm (6 to 15 inches) tall with green scale-like leaves. The plant is established from seed by broadcast or drilling on a well- prepared firm seedbed, similar to establishing alfalfa stands. In fact, the seed is similar in size to alfalfa. Seeding is recommended after the frost period in the spring; however in the SJV, seed can be applied in the late fall / early winter: it will lie dormant and germinate in about March. The stand can be flood or sprinkler irrigated. The plant requires salty water of EC 20 to 30 dS/m. Surface soil in this stand may have an ECe as high as 50 dS/m. Salicornia can be irrigated with lower EC water, provided that the soil salinity is considerably higher than 20 dS/m; however, its growth and seed production will be less. Pickleweed may have multiple uses. One of its main uses is for seed production. When processed it produces oil which contains polyunsaturated fat close to the level of safflower oil and better than soybean oil. The meal from the oil processing can be used as a feed source for poultry and livestock. The young top portions of the plant are used as a salad green and a tasty vegetable in areas of the world where it is irrigated with brackish water or with seawater.

Saltgrass (Distichlis spicata)

Saltgrass is a gray green to blue green, perennial grass with strong extensively creeping rhizomes. The mature plant can grow to 45 cm (18 inches) tall. The plant can be established by seed. The most common method of establishment is from rhizomes. Rhizomes can be single or chunks of sod. Plants establish much faster from sod. Spring establishment is the most desirable. Established plants have been growing in soils with an ECe of 30 dS/m. In its natural state plants are commonly found on roadsides, ditch banks and along salt marshes adjacent to coastal tidal marsh areas. The plant is grazed by livestock.

Cordgrass (Spartina species)

A perennial bunch-like, coarse-textured grass 30 to 100 cm (1 to 3 feet) tall and up to 30 to 75 cm (1 to 2.5 feet) thick at the base. Some plants have extensive creeping rhizomes. The plant can be established from rooted cuttings that were grown in plastic cone containers. Planting stock is taken from a clump of a mature plant and the small base of the plant is rooted in cone containers. Rooted plants can be established at any time of the year, but the best time is during the fall and spring. Cordgrass has been grown with drainage water with an EC of up to 35 dS/m. In its natural state, plants are growing in salt marshes and tidal flats. On the Atlantic coast, marsh hay consisting of mostly cordgrass is used for packing or bedding. The species of cordgrass grown are (Spartina alternaflora and Spartina gracilia) and 2 accessions of (Spartina patens) named 'Flageo' and 'Avalon' that has rhizomes.

Iodine bush (Allenrolfea occidentalis)

Iodine bush is an erect bush 30 to 180 cm (1 to 6 feet) tall, multiple branched. The green foliage is somewhat fleshy, with scale-like leaves. Establishment can be from seed or containergrown plants. Seed can be planted by broadcast or drill in late winter. Plantings in the fall can be made by seed, but weed competition at this time makes stand establishment difficult. Due to very small seed, the plants have very weak seedling vigor and a firm, weed-free condition must prevail during establishment. Container-grown plants can be established in the fall or spring. Seed can be easily harvested from native stands in the early winter. Established plants have been growing in soils with up ECe of 60 dS/m and with water of EC 30 dS/m. In its natural state, livestock have grazed the plant and have eliminated stands in dryland pastures when other vegetation has been used up. Its use in feed supplements has not been investigated extensively.

Iodine Bush

Saltbush (Atriplex species)

Atriplex is an erect spreading perennial shrub with dense foliage. It ranges from 2 to 6 feet in height and in width. Seed maturity is from October to December. The plant can be established from seed, bare-root or container-grown plants. Seed can be planted by broadcast or drill in late winter, January through March. A good firm seedbed is required. Broadcast seeding may appear inadequate the first year, but small plants at the end of the first year produce strong plants the second year. The best way to establish this shrub is from container-grown plants. Transplanting can be done in fall or spring. Established plants tolerate drainage water EC ranging from 28 to 30 dS/m. Livestock use Atriplex as browse or as a feed supplement, especially when fed in selenium deficient areas. In its natural state it provides excellent cover for upland game and rabbits. Atriplex can be a host for the sugar beet leafhopper, which may carry a virus that causes a curly top disease in sugar beets, and in vegetable crops like tomatoes, beans, and cantaloupe. Some of the Atriplex species used are A. lentiformis and A. nummularia.

Saltbush

Trees

Eucalyptus

Trees use and evaporate drainage water. This is achieved through the sequential reuse, by intercepting the flow of drainage water from upslope, or through the uptake of shallow groundwater. Trees can be viewed as biological pumps.

The role of Eucalyptus trees is to lower water tables and to occasionally receive reused drainage water, and thus, to assist in reducing the volume of drainage water to be managed.

Eucalyptus camaldulensis, River Red Gum, has been the superior tree selected and is now propagated as clones by a nursery in Southern California. The best Eucalyptus clones are 4573, 4543, and 4544. These are identification numbers assigned to selected trees by the Eucalyptus Improvement Association.

Both salt-tolerant plants and trees use drainage water and reduce its volume. The trees take up saline groundwater to lower water tables, intercept sub-surface water flows, sequentially reuse drainage water, and create a biological barrier between low-saline and high-saline areas. Drainage water is mainly applied to salt-tolerant plants and only occasionally to the trees (e.g., during high flows of drainage water).

Planting and care of trees

Three methods of planting trees to reduce saline conditions on cropland are used. The trees intercept subsurface water flow, consume groundwater to lower water tables, and sequentially reuse drainage water. The tree blocks also serve as windbreaks, buffer strips, filter strips, and reduce dust problems.

The planting area should be leveled to avoid water ponding. Standing water can damage the trees and could become a potential environmental concern by attracting shore birds. If standing water can infiltrate or be drained off the area in three days or less, dead leveling may be an option. If dead leveling is not used, the recommended slope is .025/100 feet. If standing water is a problem at the end of the irrigation run, a tailwater return system is recommended to reduce tree loss from waterlogging. As with most trees or crops, eucalyptus trees perform best under optimum soil and water conditions with deep, well-drained soil.

Timing of plantation establishment is important for a complete drainage water reuse system. If fresh water or water less then EC 3 dS/ m is available, then trees can be planted at the same time as halophytes.

Before planting trees, soils should be ripped or chiseled if the water table is not near the surface. Disk the area to control weeds and prepare soil for planting. Trees are planted in the bottom of furrows or on the leveled land. Planting the trees in the bottom of the furrows reduces salt load around the tree base as the sale accumulates on the top of the furrows. Planting the trees on the leveled land provides for the efficient salt leaching. Both methods can provide for the uniform distribution of water. Tree spacing within the row should be a minimum of eight feet. Tree row spacing will be determined by the width of equipment that will be used in the planting area. Allow two feet on each side of equipment (disk, mowers, spray rigs, etc.). For example, a 10-foot wide disk would require a row spacing of 14 feet. A wider spacing of 5 x 3 m (15 x 10 feet) is preferable. Trees can be planted using a mechanical tree planter. The ripper shank on the planter breaks up the soil and provides better root development for the new tree. If a tree planter is not available, hand planting can be done in a ripped or chiseled furrow. Proper spacing of trees is an advantage of hand planting.

Background information

In countries such as Australia, Egypt, Israel, and other arid regions, salt-tolerant trees have been irrigated with saline water. In 1985 the California Department of Food and Agriculture, the USDA-Soil Conservation Service, and the International Tree Crops Institute decided to try this concept in California. Eucalyptus seed was imported from the Province of Lake Albacutya in Victoria, Australia. The California Department of Forestry and private nurseries propagated seedlings.

Seedlings were first planted in Fresno and Kings Counties, primarily on farmland areas with high saline conditions that could not produce a crop. Survival was low on soils with high sodium levels. Sodium Absorption Ratios (SAR) exceeding 50 were primarily in Kings County.

Pistachio

In 1986 seedlings were propagated from seeds imported from Central Australia, Alice Springs, and surrounding areas. Some of these seedlings were interplanted in areas where the Lake Albacutya ones had died. They survived and selected trees were planted in areas with high saline and sodium conditions to determine their tolerance. Many other varieties of trees were planted in the same conditions. These included Eucalyptus from many provinces in Australia, Cottonwoods, Hybrid Cottonwoods, Athel, Salt cedar, Mesquite, Acacia, and Casurina obesa, cunninghamiana, glauca, and equisetifolia. Some of the varieties were irrigated with saline water of 6 to 20 dS/m and others with fresh water.

Other trees were also tried, including hybrid Willows and several varieties of Eucalyptus camaldulensis, rudis, robusta, occidentalis, grandis, viminalis, and tereticornis. Seedlings from old, established trees in Fresno and Kings Counties were also tried.

When the IFDM (Agroforestry) project started in the WRCD area (spring 1985), eucalyptus seeds were imported from Australia, Israel or Egypt, and the quality of propagated trees was inconsistent. To improve the quality of eucalyptus trees for IFDM/Agroforestry sites in the San Joaquin Valley, a selective breeding program was initiated in 1987. The IFDM/Agroforestry project team has worked closely with the California Eucalyptus Improvement Association (EIA) in its effort to coordinate the selection and propagation of superior trees. Trees are selected for salt tolerance, rate of growth, vigor, and frost tolerance. This selection effort has been successful, and most eucalyptus trees planted on irrigated farms since 1990 have been propagated from plant tissues and seeds developed in California. Selected trees have been systematically evaluated each year since 1989, and 22 trees have been chosen for tissue culture propagation. Two orchards have also been planted in experimental designs that facilitate the evaluation of growth characteristics of selected trees. Seed orchards have been established at several farms in the San Joaquin Valley, and at the USDA-NRCS Plant Material Center in Lockeford, California.

The IFDM program is oriented toward higher diversification of salt-tolerant trees and crops planted for salt management. Casuarina trees have been planted since 1985, but their performance has not always been satisfactory. Casuarina glauca is not frost tolerant; it was damaged by frost in 1990, and did not recover. Casuarina cumminghamiana has been frost damaged on several farms, and its recovery rate was lower than that of eucalyptus trees. Several individual trees performed very well under extremely difficult conditions (frost, salt, and drought). Athel (Tamarix aphylla) trees are well established in the valley, being mainly used as windbreaks. They are salt-tolerant and recover well from frost damage. They may be beneficial on farms where salinity levels are above EC 20. Eucalyptus seeds collected in 1994 from highly saline seeps in Australia and nearby surrounding areas are now being tested alongside the best clones.

Eucalyptus has been the most common salt-tolerant tree used for the management of salt and drainage. Positive results have been obtained from the management of trees over a 12-year period. Trees initially propagated on various sites in the Valley from seeds imported from Australia did not have uniform characteristics, as the growth rate and salt and frost tolerance varied significantly. The selection of superior trees through the valuable guidance of the Eucalyptus Improvement Association started in 1987/88. The best trees (4543, 4544, 4573, and 4590) were selected and are now propagated as clones by a nursery in Southern California. The selection and testing process continues with additional eucalyptus varieties.

Since 1985, more than 700,000 trees have been planted for the management of salt on irrigated farmland in the San Joaquin Valley. Eucalyptus camaldulensis is mainly planted at this time because of its salt tolerance, high water requirements, and relatively easy care.

The difference between Tamarisk Athel and Tamarisk Salt Cedar

Tamarisk Athel is an upright tree reaching up to 60 feet tall, with a dense spreading crown and several heavy large limbs. It is a fast-growing, evergreen tree. Its diameter is about 2.5 feet. The propagation method is vegetative. It commonly occurs on salt flats, springs, and other saline habitats. It is drought resistant and is tolerant of alkaline and saline soils. It uses large volume of water; a large tree can absorb about 200 gallons of groundwater per day. It does not colonize sites by seed.

Tamarisk Salt Cedar is a shrub growing up to 20 feet tall. It is considered a weed that produces a large amount of seeds and spreads in a wide area. It commonly occurs on salt flats, springs, and other saline habitats. It is drought resistant and is tolerant of alkaline and saline soils. It uses a large volume of water.


Tamarisk (Athel)

Reporting Requirements

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It is important to summarize the data to clearly illustrate compliance with all applicable regulatory requirements. Arrange the data in tabular form so the required information is readily discernible. Certain technical information needs to be submitted with the monitoring report. Daily evapotranspiration values of the nearest weather station from which information is available and copies of the laboratory analyses are to be submitted as part of the report. Weather data can be found at DWR's California Irrigation Management Information System, CIMIS, at: www.cimis.water.ca.gov.

Any person operating a solar evaporator should submit annual groundwater monitoring data and information at the earliest possible time, according to a schedule established by the RWQCB. The regional board shall notify the operator of each solar evaporator of the applicable submission schedule.

A. Examples of Water Monitoring Plans

The following three sections are examples of water monitoring plans listing some of the possible constituents that may need to be monitored. The RWQCB will determine the constituents that you will need to be monitored on your farm.

1. Applied Water Monitoring[1]

A station shall be established for measurement and collection of representative samples to measure the subsurface agricultural drainage water applied to the solar evaporator. Applied water monitoring may include the following:

Constituents	Units Measurement	Monitoring Type of Monitoring	Frequency
Mean Daily Flow	gpd	Meter	Continuous
Specific Electrical Conductivity	µmhos/cm or dS/m	Grab	Weekly
Standard Minerals[2]	mg/L	Grab	Quarterly
Trace Elements			
Selenium	µg/L	Grab	Monthly
Boron	µg/L	Grab	Quarterly
Arsenic	µg/L	Grab	Quarterly
Chromium	mg/L	Grab	Quarterly
Molybdenum	µg/L	Grab	Quarterly
Vanadium	µg/L	Grab	Quarterly

[1] Analysis of certain constituents may require specialized field procedures (e.g. filtration and preservation) and are recommended to be performed by a qualified technician.
[2] Standard minerals may include calcium, magnesium, sodium, potassium, alkalinity and sulfate.
µg/L = micrograms per liter
mg/l = milligrams per liter
µmhos/cm = micromhos per centimeter

2. Groundwater Monitoring[1]

Shallow groundwater should be monitored for all indicator parameters and constituents of concern. Samples should be collected from the installed wells and analyzed for the following:

Constituents	Units Measurement	Type of Monitoring	Monitoring Frequency
Depth	feet (tenths)	Measured	Quarterly
Specific Electrical Conductivity	µmhos/cm or dS/m @ 25C	Grab	Quarterly
Standard Minerals[2]	mg/L	Grab	Quarterly
Trace Elements			
Selenium	µg/L	Grab	Quarterly
Boron	µg/L	Grab	Quarterly
Arsenic	µg/L	Grab	Quarterly
Chromium	µg/L	Grab	Quarterly
Molybdenum	µg/L	Grab	Quarterly
Vanadium	µg/L	Grab	Quarterly

[1] Analysis of certain constituents may require specialized field procedures (e.g. filtration and preservation) and are recommended to be performed by a qualified technician.

[2] Standard minerals may include calcium, magnesium, sodium, potassium, alkalinity and sulfate.

3. Solar Evaporator Subsurface Drainage System (Tile Drain) Monitoring

If the solar evaporator is equiped with a subsurface drainage system, the drain should be monitored for the following:

Constituent	Units	Type of Measurement	Monitoring Frequency
Mean Daily Flow	gpd	Meter	Continuous
Specific Electrical Conductivity	µmhos/cm or dS/m @ 25C	Grab	Quarterly

B. Biological Monitoring

If standing water or other factors known to result in potential impacts to breeding and/or feeding birds are anticipated or have been demonstrated at a given IFDM site, the RWQCB, CDFG, and/or USFWS may determine that avian monitoring is required. Adequate avian monitoring at sites typically consists of the following:

1. Timing

Biological surveys should be conducted weekly during the predicted avian breeding season, which is approximately from February 1 through August 31. During the non-breeding season, from September 1 through January 31, surveys will be conducted monthly. Monitoring should be conducted in a way that does not keep birds actively incubating eggs off of the nest during the heat of the day, since this can result in clutch failure. All wildlife monitoring will be conducted by, or under the direct supervision of, a qualified wildlife biologist with, or able to obtain, permits, from the USFWS and the CDFG to collect the eggs.

Measuring Conductivity

2. Survey Components

Biological surveys will consist of:

1. Bird usage in the drainage management area, which includes the solar evaporator, halophyte plots, agroforestry plot or interceptor trees, sumps (including tail water), salttolerant grasses and adjacent crops will be documented by a qualified wildlife biologist. Data collected will at least include, but not be limited to, bird species present, approximate numbers of each bird species present, and any mating behaviors.
2. During the nesting season (approximately February 1 through August 31), a thorough search for nests and nesting activities should be conducted by a qualified wildlife biologist in and around the solar evaporator, halophyte plots, interceptor trees, sumps, and salt-tolerant grasses. Nests will be flagged, and nest fate monitoring will include counting nests, eggs and young. If shorebird nesting occurs on-site, one recurvirostrid (avian family which includes the Blacknecked Stilt and the American Avocet) egg will be randomly collected from each detected nest, with no more than a total of five random eggs from five separate nests being collected from a given IFDM site during a given nesting season, unless directed to do otherwise by USFWS and CDFG. The collected egg contents will be chemically analyzed for moisture content, total recoverable selenium, and, if necessary, the concentration of other trace elements by a USFWS-approved laboratory. The egg contents also will be assessed for embryonic deformities by a USFWS-approved laboratory. Eggs will be collected according to USFWS egg collection protocol.
3. Presence of any ponded water in or around the solar evaporator, halophyte plots, interceptor trees, salt-tolerant grasses and/or adjacent crops will be documented. An estimate of percent coverage and approximate depth of the ponded water will be noted.
4. Presence of any aquatic invertebrate species in or around the solar evaporator, halophyte plots, agroforestry plot, salt-tolerant grasses and/or adjacent crops should be documented. The type of invertebrates present should be identified to the family level, and abundance (dense, scattered, few) in each location should be noted. Presence of live algal mats in any of these designated areas should also be reported.
5. The presence or evidence of other wildlife species in or around the solar evaporator, halophyte plots, interceptor trees, salt tolerant grasses and/or adjacent crops should be documented.

3. Reporting Requirements

The results of each survey component will be submitted to the Central Valley Regional Water Quality Control Board. Results will be submitted within a week of the survey date. The weekly reports will not include results of egg analyses, since obtaining complete results usually requires several months. Survey results should be summarized in four quarterly reports. The quarterly reports should be submitted to the Board as follows:

Reporting Period	Due Date
January-March	1 May
April-June	1 August
July-September	1 November
October-December	1 February

The USFWS Sacramento Office Contaminants Division and CDFG Southern Sierra Region Office in Fresno should also receive copies of all monitoring reports.

C. Soil Monitoring

Soil monitoring is not required, but is recommended because it enables the tracking of the progress of the IFDM system (evaluate whether soil conditions are improving or declining) and provides information for fertilizer and nutrient applications. Generally, soil testing is performed once per year to measure EC, pH, and required anions and cations. Things to consider before sampling include:

- Field area (acres/sample)
- Sampling procedure
- Sampling depth

• Timing of sampling
• Sampling tools
• Sample handling
• Information forms
• Labs

There are numerous references for soil monitoring.

D. Salinity Monitoring

EM-38 surveys are not required, but may be helpful to evaluate salinity conditions in soil over time. See Figures 1 and 2.

Figure 1. EM-38 survey equipment

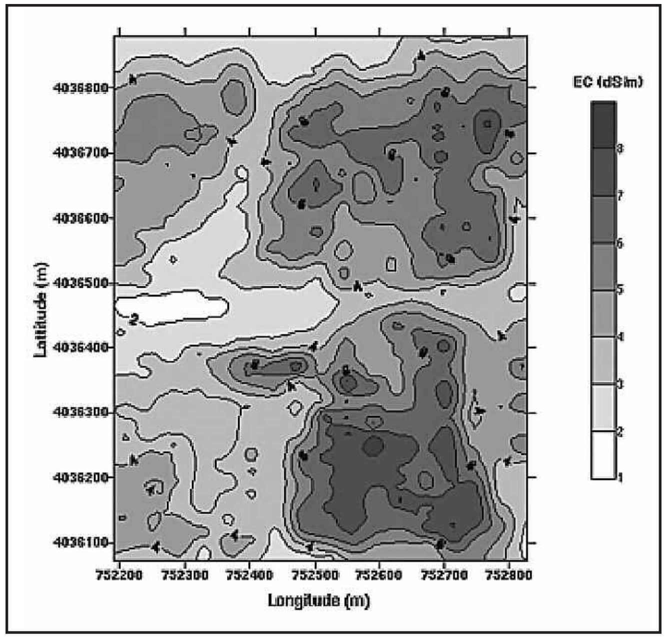

Figure 2. Salinity map created from EM-38 survey data. Values represented in this map are ECe (dS/m).

California Environmental Protection Agency

State Water Resources Control Board Water Quality Website

The California Environmental Protection Agency SWRCB Water Quality website www.swrcb.ca.gov/swamp/qamp.html outlines the sections and appendices of a Surface Water Ambient Monitoring Program (SWAMP) QAPP. The following table of contents is from the website:

Table of Contents

A helpful reference for QAPP development and preparation is DWR's "Guidelines for preparing a QAPP."

Winston H. Hickox
Secretary for Environmental Protection

California Regional Water Quality Control Board
Central Valley Region
Robert Schneider, Chair

Fresno Branch Office
Internet Address: http://www.swrcb.ca.gov/~rwqcb5
3614 East Ashlan Avenue, Fresno, California 93726-3533
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Gray Davis
Governor

18 April 2002

Mr. Gerald Stoltenberg
Westside Resource Conservation District
P.O. Box 205
Five Points, CA 93624

DRAINAGE WATER BLENDING, WESTSIDE RESOURCE CONSERVATION DISTRICT, FRESNO COUNTY

Thank you for your letter of 18 March 2002, which asks for clarification on the regulatory requirements for the blending of drainage water used for the irrigation of salt tolerant crops.

Drainage water is a waste that can create nuisance conditions and/or affect the beneficial uses of waters of the state. The Regional Water Quality Control Board, Central Valley Region, (Regional Board) regulates discharges of wastewater that can affect waters of the state, including waste used for irrigation by agriculture. Examples include: packing house wastewater, food processing wastewater, biosolids, municipal wastewater reclamation, etc. While the Regional Board has the authority to regulate this waste using Waste Discharge Requirements (WDRs), drainage water is generally reused for irrigation without formal regulatory controls. In fact, the beneficial reuse of the drainage water can often result in water quality benefits by reducing the discharge of pollutants to surface waters.

The Regional Board generally considers drainage water applied on-farm a Non Point Source (NPS) of pollutants. However, compliance with the Clean Water Act, the Porter-Cologne Water Quality Control Act (Division 7 of the California Water Code), and the Water Quality Control Plan for the Tulare Lake Basin, Second Edition, 1995 (Basin Plan) is not a voluntary choice. It is the Regional Board's responsibility to ensure compliance with these laws and regulations. The NPS strategy calls for three tiers of regulatory control. Tier 1: Self-Determined Implementation of Management Practices; Tier 2: Regulatory Based Encouragement of Management Practices; and Tier 3: Effluent Limitations and Enforcement Actions. Under Tier 1, the Westside Resource Conservation District could develop and implement workable solutions to NPS pollution control, which affords the opportunity to solve problems before more formal regulatory controls are taken. Potential problems can often be addressed through modifications in management measures that make formal regulatory control unnecessary. However, the reuse of drainage water must comply with the Basin Plan and State Water Resources Control Board Resolution No. 68-16, the State's "antidegradation" policy. The on-farm reuse of drainage water, if done properly and for beneficial use, should pose minimal threat to waters of the state. It may be possible to regulate the blending of drainage water for the irrigation of salt tolerant crops under the first tier if a demonstration can be made that the blended water is beneficially used for agricultural production. Examples of agricultural production would include the sale of a marketable crop or a crop grown for grazing. If the reuse of drainage water causes a nuisance, threatens to impair the beneficial uses of ground or surface waters, or is not beneficially used, then additional control and possibly enforcement actions may be needed.

The Regional Board considers the blending of drainage water to extend the water supply for agricultural production, a reasonable use of water. The blending of high quality water with poorer quality drainage water for its reuse on crops is generally accepted and encouraged. However, any operation that adds unusable drainage water to usable water and results in an unusable blend would probably be considered an unreasonable use of water.

In some cases, other regulations may apply. For example, the waste may be hazardous and subject to hazardous waste regulations contained in Title 22, California Code of Regulations, hazardous waste restrictions in the Basin Plan, and possibly the Resource Conservation and Recovery Act.

The Regional Board believes that a mechanism needs to be developed to ensure drainage water is used for agronomic benefit, protects water quality, and prevents nuisance conditions so that the discharge is not disposed of improperly. The challenge is to identify the potential problems that may develop with any reuse project and to develop practices that address the situation. Recently, you were awarded a Clean Water Act section 319(h) grant to develop an education and outreach program concerning Integrated On-Farm Drainage Management. The handbooks developed from that grant are required to outline the environmental and regulatory requirements, which should clarify what is necessary. The 319(h) grant should be used to identify management measures to achieve compliance with all applicable regulations.

If you have further questions please email or telephone Anthony Toto at totoa@rb5f.swrcb.ca.gov or (559) 445-6278.

LONNIE M. WASS
Supervising Engineer
RCE No. 38917

cc: Dr. Steve Schwarzbach, U.S. Fish and Wildlife Service, Sacramento
Ms. Frances McChesney, Office of Chief Counsel, State Water Resources Control Board, Sacramento
Mr. Walt Shannon, Division of Water Quality, State Water Resources Control Board, Sacramento
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Mr. Bill Loudermilk, Department of Fish and Game, Fresno
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Calculating Case-Specific Costs of Integrated On-Farm Drainage Management

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The estimated costs of installing and operating an IFDM system presented in this report include several items that might not be required by all farmers. Some farmers might already have installed a subsurface drainage system and they might be implementing IFDM as a method of disposing the drainage water they collect in that system. Some farmers might choose not to hire a manager for the IFDM system or to assign management responsibilities to a current employee. Farmers also might choose to minimize their costs of producing halophytes and low-value, salt-tolerant crops and forages. Any of these decisions regarding installation and operation will reduce the farm-level cost of integrated on-farm drainage management.

In this Appendix, we describe how farmers and their advisors can estimate farm-specific costs of implementing IFDM. Information pertaining to individual farmers can be entered in Table A1. That information is used to generate Tables A2 through A4. The information required from farmers in Table A1 includes:

1. The estimated rental rate or opportunity cost of land,
2. The annual cost of taxes and assessments on land,
3. The production costs for low value salt-tolerant crops and forages,
4. The production costs for halophytes,
5. The estimated life of the drainage system and solar evaporator,
6. The interest rate to use when amortizing installation costs,
7. The initial cost of the subsurface drainage system,
8. The annual cost of operating and maintaining the drainage system,
9. The initial cost of the solar evaporator,
10. The annual cost of operating and maintaining the solar evaporator,
11. The annual cost of an IFDM system manager,
12. The area served by the subsurface drainage system,
13. The proportion of area used for the solar evaporator,
14. The proportion of area used for low value salt-tolerant crops and forages, and
15. The proportion of area used for halophytes.

The farm-specific values for these 15 parameters are used to calculate the annual cost of owning and operating the subsurface drainage system and the solar evaporator, and the annual costs of producing halophytes and salt-tolerant crops and forages (Table A2). The information in Table A2 is used to describe the estimated costs of IFDM by category in Tables A3 and A4. The costs in Table A3 pertain to the areas used for each activity. The estimated cost of the subsurface drainage system pertains to the size of area drained, while the estimated cost of the solar evaporator pertains to the number of acres required for the evaporator. The estimated costs of the subsurface drainage system and solar evaporator per acre of marketable crops appear in Table A4. Reducing the proportions of land required for the solar evaporator and production of halophytes and salt-tolerant crops and forages will reduce the estimated cost of IFDM per acre of marketable crops.

Sensitivity Analysis

The parameter values appearing in Table A1 and the results in Tables A2 through A4 pertain to the example presented in the text of this report. That example includes the following parameter values:

1. Estimated rental rate or opportunity cost of land: . . . . $150 per acre
2. Annual cost of taxes and assessments on land: . . . . $25 per acre
3. Production costs for salt-tolerant crops and forages: . . . . $339 per acre
4. Production costs for halophytes: . . . . $25 per acre
5. Life of the drainage system and solar evaporator: . . . . 10 years
6. Interest rate to use when amortizing installation costs: . . . . 6.25 percent
7. Initial cost of the subsurface drainage system: . . . . $400 per acre
8. Operating and maintaining the drainage system: . . . . $5 per acre
9. Initial cost of the solar evaporator: . . . . $1,000 per acre
10. Operating and maintaining the solar evaporator: . . . . $120 per acre
11. Annual cost of an IFDM system manager: . . . . $ 35,000 per year
12. Area served by the subsurface drainage system: . . . . 600 acres
13. Proportion of area used for the solar evaporator: . . . . 1 percent
14. Proportion of area for salt-tolerant crops and forages: . . . . 10 percent
15. Proportion of area for halophytes: . . . . 1 percent

This section examines the impact of selected changes in these parameter values on the farm-level cost of IFDM.

Farmers who can use land with zero opportunity cost for locating the solar evaporator and producing halophytes and salt-tolerant crops and forages can reduce the average cost of IFDM by about $20 per acre if all other parameter values remain the same as those appearing in Table A1. The cash and non-cash operating costs remain the same, while the non-cash overhead costs decline by about $20 per acre when land with zero opportunity cost is used for those activities (Table A5). Farmers who choose not to hire a manager for the IFDM system can reduce the cost by $35,000 per year or $66 per acre of land in marketable crops (Table A5). Farmers choosing to avoid any costs of production for halophytes and salt-tolerant crops and forages can reduce the average cost of IFDM by $38 per acre of land in marketable crops (Table A5). Farmers who already have installed a subsurface drainage system can implement IFDM for about $40 per acre less than farmers who must install a new drainage system (Table A5).

We examine also selected combinations of the cost-reduction measures described above. Farmers who choose not to hire a manager for the IFDM system and place the solar evaporator, halophytes, and salt-tolerant crops and forages on land with zero opportunity cost can reduce the average cost of IFDM from $176 per acre to $90 per acre (Table A5). Farmers who also have already installed a subsurface drainage system can implement IFDM for $50 per acre (Table A5). Farmers in this category who eliminate the costs of production for halophytes and low-alue, salt-tolerant crops and forages can implement IFDM for $12 per acre (Table A5).

Farmers and their advisors can use this framework to compute the average cost of installing and operating an IFDM system, given their current drainage situation and their choices of parameter values. The estimated average cost of implementing IFDM can be compared to the estimated net returns that farmers earn in crop production to determine if the investment is IFDM is sensible. For example, a farmer earning a net return above all costs of $62 per acre in cotton production can afford to implement IFDM if a drainage system already is installed, a manager is not hired, and the opportunity cost of land for the solar evaporator and production of halophytes and salt-tolerant crops and forages is zero. The average cost of IFDM is $50 per acre in that scenario (Table A5), leaving a net return of $12 per acre to the farmer. Similar comparisons can be made for any crops and parameter values selected by farmers considering an investment in IFDM.

See Appendix CD for Electronic Spreadsheet for Calculating Case-Specific Costs for Integrated On-Farm Drainage Management.

Table A1.

Parameter values used to calculate case-specific costs of an integrated on-farm drainage system

Estimated costs of land and the production of halophytes and salt-tolerant crops and forages	Annual Costs
	($/acre)
The estimated rental rate or opportunity cost of land	150.00
Annual cost of taxes and assessments	25.00
Production costs for salt-tolerant crops and forages	339.00
Production costs for halophytes	25.00

Financial Parameters			
	Estimated Life Life (in years)	Interest Rate	Amortization Factor
Drainage System	20	0.0625	0.089
Solar Evaporator	10	0.0625	0.137

Estimated costs of installing and maintaining the subsurface drainage system and evaporator	Initial Cost	Annual Costs
	($/acre)	($/acre)
The Subsurface Drainage System		
Estimated Installation Cost	400.00	
Amortized Installation Cost		35.58
Annual Operation and Maintenance		5.00
The Solar Evaporator		
Estimated Installation Cost	1,000.00	
Amortized Installation Cost		137.48
Annual Operation and Maintenance		120.00

The annual cost of an IFDM system manager	35,000.00	per year

Parameters describing the size of irrigated area and the proportions of total area used for the solar evaporator and production of salt-tolerant crops and forages, and halophytes		
The drainage system serves:	**600**	**acres**
Proportion of area in Solar Evaporator	1	percent
Salt-tolerant crops and forages	10	percent
Halophytes	1	percent
The size of the solar evaporator will be:	6	acres.
Area in salt-tolerant crops and forages	60	acres.
Area in halophytes	6	acres.
The net irrigated in production is:	**534**	**acres.**

Table A2.

The estimated costs of Installing, operating, and maintaining the solar evaporator and the estimated annual costs of land used for the evaporator, salt-tolerant crops, forages, and halophytes

Item	Initial Cost	Annual Costs
	($/acre)	($/acre)
The Subsurface Drainage System		
Estimated installation cost	400.00	
Amortized installation cost		35.58
Operation and Maintenance		5.00
Sum of Estimated Annual Costs for the Drainage System		40.58
The Solar Evaporator	($/acre)	($/acre)
Estimated installation cost	1,000.00	
Amortized installation cost		137.48
Operation and maintenance		120.00
Taxes and assessments		25.00
Rental or opportunity cost		150.00
Sum of Estimated Annual Costs for the Evaporator		432.48
Land Used for Salt-tolerant Crops and Forages		($/acre)
Taxes and assessments		25.00
Rental or opportunity cost		150.00
Annual production costs		339.00
Sum of Estimated Annual Costs for Salt-tolerant Crops		514.00
Land Used for Halophytes		($/acre)
Taxes and assessments		25.00
Rental or opportunity cost		150.00
Annual production costs		25.00
Sum of Estimated Annual Costs for Halophytes		200.00

Table A3.

The estimated costs of an IFDM system, by category, per acre of land used for each activity

Cost Category	Subsurface Drainage System	Solar Evaporator	Salt-tolerant Crops and Forages	Halophytes	System Manager
	($/acre)	($/acre)	($/acre)	($/acre)	($/acre)
Operating Costs	5.00	120.00	339.00	25.00	58.33
Non-Cash Operating Costs		25.00	25.00	25.00	
Non-Cash Overhead	35.58	287.48	150.00	150.00	
Total Costs	40.58	432.48	514.00	200.00	58.33

Table A4.

Cash and non-cash components of the estimated average annual cost of an IFDM system, per acre of land in marketable crops

Cost Category	Subsurface Drainage System	Solar Evaporator	Salt-tolerant Crops and Forages	Halophytes	System Manager	Total Costs
	($/acre)	($/acre)	($/acre)	($/acre)	($/acre)	($/acre)
Operating Costs	5.62	1.35	38.09	0.28	65.54	110.88
Non-Cash Operating Costs		0.28	2.81	0.28		3.37
Non-Cash Overhead	39.98	3.23	16.85	1.69		61.75
Total Costs	45.60	4.86	57.75	2.25	65.54	176.00

Note: These costs pertain to an IFDM system in which:

10 percent of the irrigated land is used to produce salt-tolerant crops and forages,
1 percent of the irrigated land is used to produce halophytes, and the size of the solar evaporator is
1 percent of the size of the irrigated area.

Table A5.

Sensitivity Analysis of the Costs of an Integrated On-Farm Drainage System

Scenario	Operating Costs	Non-Cash Operating Costs	Non-Cash Overhead Costs	Total Cost
		(Dollars per Acre)		
Original Scenario	111	3	62	176
Eliminate Individual Cost Items:				
Opportunity Cost of Land	111	3	42	156
Salary of a Manager	45	3	62	110
Costs of Production for Halophytes and Salt-Tolerant Crops and Forages	73	3	62	138
Drainage System Installation	111	3	22	136
Eliminate Combinations of Items:				
Opportunity Cost of Land and Salary of a Manager	45	3	42	90
Opportunity Cost of Land, Salary of a Manager, and Drainage System Installation	45	3	2	50
Opportunity Cost of Land, Salary of a Manager, Drainage System Installation, and the Costs of Production	7	3	2	12

Funding Sources

The three main funding sources to plan, design and implement an IFDM system are private financing, bank loans and grants. Grant programs may be from a public source (federal, state, regional and/or local), or from a private source. If the public grant source is used, it is important to remember that any financial records become public documents and are open for public review, and automatically require the implementation of CEQA and/or NEPA.

Current public grant programs may include:

- A state revolving fund available to growers in Westlands Water District for capital improvements to implement source reduction (subsurface drainage and irrigation equipment).
- The Federal USDA-NRCS EQIP grant program with funds available to growers for installing subsurface drains.

There are many funding resources available for possible grants and/or loan programs. Contact the local office of the following agencies or look on the Web for more information:

Federal

U.S. Department of Agriculture – Natural Resources Conservation Service
U.S. Department of Agriculture – Agricultural Research Service
U.S. Department of the Interior – Bureau of Reclamation
U.S. Fish and Wildlife Service
U.S. Environmental Protection Agency

State

Bay-Delta Authority (formerly CALFED Bay- Delta Program)
California Department of Water Resources
State Water Resources Control Board
Central Valley Regional Water Quality Control Board
California Department of Fish and Game
California Department of Food and Agriculture
University of California Cooperative Extension Service
California State University, Fresno – Center for Irrigation Technology

Regional/ Local

Resource Conservation districts
Water and Irrigation districts

Laws and Regulations

Gerald Hatler,
Environmental Services, Department of Water Resources, ghatler@water.ca.gov
Wayne Verrill, *Environmental Science, State Water Resources Control Board*
Mike Tietze, *Hydrogeology, MFG, Inc*

I. Introduction

An Integrated On-Farm Drainage Management system strives to provide an economically feasible and environmentally sound program for managing salts on irrigated farmland. Farmers who wish to develop an IFDM system must be aware of the myriad rules and regulations that govern water quality, wildlife protections and hazardous material.

Although the list of questions and considerations may seem daunting and overwhelming, there are technical and regulatory experts who can consult and work with growers to achieve a successful IFDM system. The key to this success is to develop a cooperative working relationship with the regulatory agencies and a willingness to maintain open dialogue and communications throughout the regulatory review and necessary environmental permitting process.

The assistance of a qualified biologist and/or planner is essential to navigating the environmental permit process. Consideration of the following questions and being prepared to provide a thorough and accurate description of all project activities should make the environmental compliance process easier and assist in successfully navigating any regulatory hurdles.

Please note, this chapter is merely a guideline to the complex process of environmental law and permitting. A more detailed account of the laws and regulations will appear in the technical manual for developing an IFDM system.

II. Questions That Should be Answered Before Proceeding with a Project

The following questions are intended to highlight features of the project that are often concerns for regulatory agencies.

- Has an Initial Study (IS) or Environmental Assessment (EA) been completed or is one being done by a local or state permitting agency in accordance with the California Environmental Quality Act (CEQA) or the National Environmental Policy Act (NEPA)?
- Will the project require certification, authorization or issuance of a permit by any local, state or federal agency?
- Have all adjacent landowners been contacted and notified before conducting any activity?
- Will the project require the issuance of a variance or conditional use permit by a city or county?
- Is the project currently operating under an existing use permit issued by a local agency?
- What types of vegetation are currently present at the project site, including trees, brush, grass, etc.?
- What types of wildlife or fish may use the project site or adjoining areas for habitat (food source, nesting, migration, water, etc.)?
- Has the California Department of Fish and Game (CDFG) or the U.S. Fish and Wildlife Service (USFWS) been consulted relative to the existence of, or impacts to, threatened or endangered species on or near the project site?
- Will the project result in changes to scenic views from existing residential areas, public lands, and public roads or present a visual distraction?
- Will the project impact existing recreational opportunities?
- Will the project result in changes or effects upon historical, or archeological and cultural resources?
- Will the project result in changes or effects upon geological or paleontological resources?
- Will the project include excavation?
- Will the project change existing features of any hills or result in substantial alteration of ground contours?
- Will the project occur on filled land or on a slope of 10 percent or more?
- Will the project discharge silt or other material into a designated body of water for California or the U.S.?

- Will the project involve the application, use, or disposal of hazardous material?
- Will activities or the completed project result in significant amounts of noise or vibration levels?
- Will activities or the completed project result in significant amounts of dust, ash, smoke, fumes or odors?
- Will the project involve the burning of brush, grass, trees or materials?
- Will the project substantially increase fossil fuel or energy resource consumption?
- Have any other similar projects been planned or completed in the same general area?
- Will the project have the potential to encourage, facilitate or allow additional new growth or development or impact local services?
- Will the project result in a change to the pattern, scale or character of the general project area?
- Will the project affect existing agricultural uses or result in the loss of existing agricultural lands?
- Will the project be funded by private or public funds?

III. Regulatory Requirements

Both state and federal agencies have the regulatory authority over projects like IFDM. The affected regulations that could impact an IFDM project include:

California Environmental Quality Act (CEQA):

CEQA was passed by the California Legislature in 1970. Generally, CEQA requires state and local agencies to identify the significant and potentially significant environmental impacts of their actions and to implement measures to avoid or mitigate for those impacts. If a significant effect is anticipated, an Environmental Impact Report (EIR) is written; otherwise; a Negative Declaration is prepared.

National Environmental Policy Act (NEPA):

NEPA requires incorporating environmental considerations into the planning process for all federal projects and for projects requiring federal funding or permits. If a significant effect is anticipated, an Environmental Impact Statement (EIS) is written; otherwise, a Finding of No Significant Impact (FONSI) is prepared.

Note: *Projects that are developed by state or federal agencies, and/or funded or permitted by state or federal agencies must address CEQA and NEPA. Projects that involve state participation must conform with CEQA, while projects with federal participation must conform to NEPA guidelines. Projects with both state and federal interests are subject to environmental analyses under both acts.*

Federal Clean Water Act:

The Federal Clean Water Act established the basic structure for regulating discharges of pollutants into the waters of the United States. The act sets water quality standards for all toxic and nontoxic contaminants in surface waters, implements wetland protection programs, and charges the states to adopt standards and to establish treatments and controls to protect water quality within its borders.

Section 404, Clean Water Act:

Section 404 of the Clean Water Act regulates the location of a structure, excavation and discharge into "waters of the United States," which can include wetlands, perennial or ephemeral streams and lakes. The U.S. Environmental Protection Agency and U.S. Army Corps of Engineers have primary jurisdiction and issue permits under Section 404.

Section 402, Clean Water Act:

Section 402 requires that all point sources discharging pollutants into waters of the United States obtain a National Pollutant Discharge Elimination System Program (NPDES) permit. Point source pollutants are defined as those that come from a concentrated point of origin such as a pipe, factory, feedlot or those coming from a readily determined source, as opposed to non-point pollutants, which come from diffuse sources. The Regional Water Quality Control Board regulates the Section 402 permits.

Resource Conservation and Recovery Act (RCRA):

RCRA is the federal statute governing management and disposal of waste. In the case of salt residue from an IFDM system, the material is not a listed hazardous waste. However, it could be a characteristic hazardous waste if the leachable selenium concentration in the solid residue (or the dissolved selenium in disposed liquid) exceeds the allowable level of 1.0 milligrams per liter (mg/L) using the Toxicity Characteristic Leaching Procedure (TCLP).

Note: *The California State Water Resources Control Board is currently developing a resolution under SB 1372 (Title 27 Draft Regulations) that would simplify some of the regulatory requirements for management of salt residue from an IFDM system. The proposed resolution would allow for on-site storage of salt residue for periods of up to one year under certain conditions. It is not clear whether the resolution would exempt the salt residue from RCRA storage and management requirements for this duration if selenium levels in the residue exceed hazardous levels.*

Hazardous Waste Control Law (HWCL):

HWCL is the California statute governing management and disposal of hazardous waste. California requirements are generally similar to requirements under RCRA, except that additional requirements may apply to salt waste from an IFDM system.

Land Disposal Restrictions (LDR):

Certain hazardous wastes are banned from land disposal unless they are treated to meet certain standards. This treatment is generally performed by the disposal facility. Selenium waste waters must be treated to a standard of 1.0 mg/L prior to disposal and non-wastewater wastes must be treated to a leachable concentration of 5.7 mg/L as determined by TCLP.

Toxic Pits Cleanup Act (TPCA):

TPCA was enacted in 1984 to regulate the cleanup of pits historically used for the disposal of liquid hazardous waste in California. Because drainage discharged to solar evaporators sometimes contains naturally occurring selenium in excess of hazardous waste levels, certain requirements of TPCA were automatically triggered. This issue has been addressed by SB 1372 (Title 27 Draft Regulations), which recognizes that TPCA was not intended to address the unique circumstances and conditions pertinent to solar evaporators, and therefore exempts IFDM systems from this regulation.

Porter-Cologne Water Quality Control Act:

The Porter-Cologne Water Quality Control Act of California requires that nine Regional Water Quality Control Boards (RWQCBs) be created to regulate water quality through the establishment and enforcement of Basin Plans that define beneficial use quality objectives for water resources in their respective areas. Any waste disposal activities or releases that impact or threaten to impact the quality of "waters of the state" (either surface water or groundwater) may be regulated. Waste disposal is regulated by issuing Waste Discharge Requirements (WDRs) that specify measures that must be taken and monitoring requirements that must be followed to assure that water quality is not impacted.

Note: *Under SB 1372 (Title 27 Draft Regulations), the State Water Resources Control Board (SWRCB) will adopt a resolution that waives WDRs for IFDM systems. The resolution will require that operators of IFDM systems follow a series of simplified requirements that are essentially generic WDRs for these operations and are intended, among other things, to prevent potential impacts to water quality. If these requirements are not followed and a discharge from an IFDM system impacts or threatens groundwater or surface water quality, a RWQCB could order that the release be investigated or could issue a cease and desist order requiring cleanup.*

CCR Title 27 Landfill Regulations:

The disposal of non-hazardous, non-inert waste is regulated under Title 27 of the California Code of Regulations. Under these regulations, non-hazardous waste that has the potential to degrade water quality is defined as "Designated Waste," and must be disposed of in properly designed and classified surface impoundments with liners that are licensed to accept such waste.

RCRA Subtitle D Landfill Requirements:

Design, monitoring and closure requirements for hazardous waste landfills are outlined in Subtitle D of RCRA and in Titles 22 and 23 of the California Code of Regulations. The requirements now being considered in the resolution drafted by the SWRCB pursuant to SB 1732 are not consistent with these requirements. It is not clear whether salt residue containing selenium above TCLP, STLC and/or TTLC concentrations will be permitted to be disposed in place without these requirements being triggered.

Section 401, Clean Water Act, Water Quality Certification:

Under CWA Section 401, a landowner that applies for a federal permit or license for an activity that could result in a discharge to "waters of the United States" must also obtain a State Water Quality Certification that the discharge meets state water quality objectives. Most Water Quality Certifications are associated with CWA Section 404 permits.

Basin Plans or Water Quality Control Plans:

The development of basin plans was required by the state Porter-Cologne Water Quality Act (sections 13240-13247) and the federal Clean Water Act (section 303). The basin plans consist of designated beneficial uses to be protected, water quality objectives for groundwater and surface water and an implementation program for meeting the objectives. Basin plans are administered by the RWQCBs and are used by other agencies in permitting and resource management activities.

Federal Endangered Species Act (FESA):

This act affords regulatory protection to plant and animal species federally listed as endangered, threatened, or proposed for listing. The act includes a provision (Section 9) that prohibits parties from the import, export, possession, transport, sale, or the unauthorized "take" of any listed species, which includes harassing, harming (which includes significantly modifying or degrading habitat), pursuing, hunting, shooting, wounding, killing, trapping, capturing, or collecting wildlife or any attempt to engage in such conduct.

California Endangered Species Act (CESA):

This act establishes a state policy to conserve, protect, restore, and enhance threatened or endangered species and their habitats. CESA mandates that a state agency cannot approve a project that potentially jeopardizes the continued existence of a listed species when reasonable and prudent alternatives exist. A state lead agency must consult with CDFG during the CEQA process. CDFG will issue comments addressing their concerns and will offer reasonable and prudent alternatives for a project.

Stream Bed Alteration Agreement – Fish and Game Code, section 1600:

CDFG requires notification from agencies and/or individuals prior to taking any action that would divert, obstruct, or change the material, flow, bed, channel, or bank of any river, stream, lake or any other waterway that may provide aquatic habitat. CDFG will propose reasonable project changes if the project has the potential to negatively affect resources. CDFG will seek to protect fish and wildlife resources and may stipulate conditions to protect these resources.

Fully Protected Animals:

The state attempted to identify and provide protection to those animals that were rare or faced possible extinction prior to CESA under various legislative bills. This resulted in a list of 37 mammals, birds, reptiles and amphibians that were given Fully Protected status, (see Appendix). Under the more recent endangered species laws and regulations, most Fully Protected species also have been listed as threatened or endangered species. However, Fully Protected species may not be taken or possessed at any time and no licenses or permits (including a 2081) may be issued for their take except in rare circumstances.

Migratory Bird Treaty Act:

This act is the result of a series of conventions with Canada, Japan, Mexico and Russia establishing a federal statute that prohibits the pursuit, hunt, take, capture, kill, attempt to take, capture or kill, possess, offer for sale, sell, offer to purchase, purchase, deliver for shipment, ship, cause to be shipped, deliver for transportation, transport, cause to be transported, carry, or cause to be carried by any means whatever, receive for shipment, transportation or carriage or export at any time or in any manner, any migratory bird, unless permitted by regulations. This includes feathers, nests, eggs, other parts, or products of a migratory bird. Most birds are protected under this act.

Bald Eagle Protection Act:

This law provides for the protection of the bald eagle (the national emblem) and was later amended to include the golden eagle by prohibiting the take, possession, sale, purchase, barter, offer to sell or purchase or barter, transport, export or import at any time or in any manner a bald or golden eagle, alive or dead; or any part, nest or egg of these eagles. By definition, take includes: pursuing, shooting, poisoning, wounding, killing, capturing, trapping, collecting, molesting, or disturbing.

California Reclamation Board:

The California Reclamation Board was established to control flooding along the Sacramento and San Joaquin rivers and their tributaries, to assist in establishing and maintaining flood control works and the integrity of the existing flood control systems, and is required to enforce standards that will best protect the public from floods. The Board's jurisdiction extends over the entire Central Valley and includes the Tulare and Buena Vista basins. An encroachment permit application must be submitted to the Board for review if a project falls within the Board's jurisdictional area.

IV. Environmental Evaluation Resources

Many useful resources are available to make the environmental evaluation and permit process easier, but nothing can substitute for the assistance provided by qualified professionals. Below are just some of the resources available. Many are available online.

Note: *An attempt has been made to provide the parent website for resources rather than the actual link as websites continually change and direct links often expire within a short period of time. You may be required to navigate and search a website to find the listed resource.*

Biological Data

The Wildlife and Habitat Data and Analysis Branch of CDFG provides useful tools and resources to consultants and agency personnel to evaluate impacts to biological resources. Some of the information is available to the general public and some is provided through a subscription based service.

Species Lists

The following species lists are available from CDFG:

- *Complete List of Amphibians, Reptiles, Birds and Mammals in California*
- *State and Federally Listed Endangered and Threatened Animals of California*
- *Special Animals*
- *State and Federally Listed Endangered, Threatened, and Rare Plants of California*
- *Special Vascular Plants, Bryophytes, and Lichens List*

California Technology, Trade and Commerce Agency – California Permit Handbook

http://commerce.ca.gov

The California Technology, Trade and Commerce Agency provides an online guide (and print version) to the state's environmental permit process. The Handbook contains useful summaries, tips and contacts to help you understand the permit process.

CERES – CEQA Website

www.ceres.ca.gov

The California Environmental Resources Evaluation System (CERES), under the California Resources Agency, maintains a CEQA website that provides the CEQA guidelines, forms, and numerous CEQA resources.

Governor's Office of Planning and Research

www.opr.ca.gov

The State Clearinghouse, under the Governor's Office of Planning and Research, is the point of contact for the distribution of environmental documents prepared under CEQA. The State Clearinghouse Handbook provides information about CEQA and the environmental document review process.

California Department of Fish and Game

www.dfg.cal.gov

Reclamation Board

www.recbd.water.ca.gov

State Water Resources Control Board

www.swrcb.ca.gov

US Army Corps of Engineers, Regulatory Program

www.usace.army.mil/inet/functins/cw/cecwo/reg

US Fish and Wildlife Service, Permits

http://permits.fws.gov

V. Answers to the Most Common Questions Concerning the Solar Evaporator Regulations

Definition:

What is the regulatory definition of a solar evaporator?

Linked regulatory definitions have been established by the State Legislature for "solar evaporator, integrated on-farm drainage management system, and on-farm."

A solar evaporator is designed and operated to manage agricultural drainage water discharged from an integrated on-farm drainage management system. The integrated on-farm drainage management system (1) collects drainage water from irrigated fields and sequentially reuses that water to irrigate successive crops until the volume of residual agricultural water is substantially decreased and its salt content is significantly increased; (2) reduces the level of salt and selenium in the soil; (3) discharges the residual agricultural drainage water to an on-farm solar evaporator for evaporation and appropriate salt management; (4) eliminates discharge of agricultural drainage water outside the boundaries of the property that produces the agricultural drainage water managed by the system.

Finally, "on-farm" means within the boundaries of a geographically contiguous property, owned or under the control of a single owner or operator, that is used for the commercial production of agricultural commodities and that contains an IFDM system and a solar evaporator. These linked definitions constitute a permitable solar evaporator under the new regulations. For the complete text of the definitions, see the California Code of Regulations (CCR) §22910.

How can a solar evaporator be integrated into my existing farming operation?

An IFDM system, including a solar evaporator, can be established in the entirety or a portion of your contiguous property that is currently used or will be used for commercial agricultural production, depending on your need to manage saline shallow groundwater.

Application Process:

What is the procedure for applying for and obtaining a permit to construct and operate a solar evaporator?

At present, any person who intends to construct and operate a solar evaporator shall first file a Notice of Intent (NOI) with the Regional Water Quality Control Board (RWQCB). The NOI (see Appendix) consists of a one-page form, plus supporting documentation, including the design of the solar evaporator, calculation of the maximum rate of drainage discharge to the solar evaporator, baseline groundwater monitoring data, and a local water balance analysis (annual evapotranspiration, ET, and precipitation). The solar evaporator design must be certified by a registered professional who is a civil or agricultural engineer, or a geologist or engineering geologist.

The RWQCB shall, within 30 days of receiving the NOI, review the NOI and inspect the proposed location, and if the NOI is found to be in compliance with the regulations, issue a written Notice of Plan Compliance (NPC). If the NOI is found to not be in compliance, the RWQCB shall issue a written response to the applicant identifying the reasons for non-compliance. The applicant can then take steps to revise the NOI in order to bring it into compliance.

After receiving an NPC, an applicant may proceed with construction of the solar evaporator in conjunction with an IFDM system. Before operating the solar evaporator, the applicant must request the RWQCB to conduct a compliance inspection. The RWQCB will conduct the inspection within 30 days of receiving the request, and if the solar evaporator is in compliance with the NOI and NPC, will issue a Notice of Authority to Operate (NAO). If upon inspection, the solar evaporator is found to not be in compliance, the RWQCB will issue a written response identifying the reasons for non-compliance. The applicant can then take steps to modify the solar evaporator in order to bring it into compliance with the NOI and NPC.

For the actual text of the procedures, see the Health and Safety Code (HSC) §25209.13.

Please note that these regulations may be subject to change.

Who can submit an application?

The permitable applicant of a solar evaporator facility has been defined by the State Legislature as a single owner or operator of a geographically contiguous property that is used for the commercial production of agricultural commodities with an IFDM system.

When can an application be submitted?

An application can be submitted at any time, but an NAO cannot be issued on or after January 1, 2008.

Will an Environmental Impact Report be required?

A CEQA checklist and initial study need to be completed to determine any additional environmental regulations that might apply.

Solar Evaporator Design Requirements:

What are the requirements for choosing a site for a solar evaporator?

The solar evaporator may be located anywhere on your agricultural property within the boundary of and contiguous with your IFDM system. The solar evaporator should NOT be located on the low point of the farm, and should be placed above the 100-year floodplain, and where the criteria for groundwater protection may be met.

The criteria include a one-meter depth of soil with permeability of 1 x 10-6 cm/sec or less, and a distance of five-feet or more between the bottom surface of the solar evaporator and the highest anticipated level of underlying shallow groundwater. Sites not meeting these conditions may be engineered to achieve the same level of flood and groundwater quality protection.

What types of solar evaporator designs will be permitted?

Any solar evaporator design can be permitted if it meets the basic design requirements of the new regulations. In addition to flood and groundwater quality protection, the design must include no discharge of agricultural drainage outside of the solar evaporator; discharge to the solar evaporator must be by sprinklers or another adjustable mechanism that will prevent the occurrence of standing water; wind drift of sprinkler spray shall be prevented; and avian wildlife shall be adequately protected.

A water catchment basin may be constructed as part of the solar evaporator in order to contain standing water that might otherwise occur in the solar evaporator. The maximum size of the solar evaporator cannot exceed 2 percent of the total area of the complete IFDM system.

What is a water catchment basin?

A water catchment basin is an area within the boundaries of a solar evaporator designed to receive and hold any water that might otherwise become standing water within the solar evaporator under reasonably foreseeable operating conditions. The entire area of the water catchment basin needs to be permanently covered with netting or otherwise constructed to ensure protection of avian wildlife.

What is meant by "reasonably foreseeable operating conditions?"

"Reasonably foreseeable operating conditions" were stated by the State Legislature as defining the regulatory limits for the design of a solar evaporator, but were not quantified. The SWRCB has quantified these conditions as follows:

- the local 25-year, 24-hour maximum precipitation event,
- floods with a 100-year return period.

This means that the solar evaporator must be designed to not have standing water in the event of a 25-year, 24-hour precipitation amount, or that the water catchment basin must have sufficient volume to hold that amount of water accumulating in the solar evaporator. If a storm event occurs exceeding that amount, any associated occurrence of standing water within the solar evaporator will not be considered a violation of the regulations. In an analogous manner, inundation of the solar evaporator by a flood event exceeding the 100-year return period will also not be considered a violation of the regulations.

Is the use of a liner required?

Use of a liner is not required. Although, a liner may be used to meet the requirements for groundwater quality protection if existing soil conditions are unfavorable, and other engineered solutions are infeasible. In this case, the liner must meet the stated specifications, including a thickness of 40-millimeters.

If the groundwater quality protection requirement is met without use of a liner, an owner/operator may use a liner at his discretion, as a functional component of the solar evaporator design. In this latter case, the 40-millimeter thickness specification does not apply.

Is the installation of a subsurface drainage system required?

Subsurface drainage systems under or adjacent to a solar evaporator are not required. Subsurface drainage systems may be installed where it is deemed necessary to provide adequate insurance that groundwater quality will be protected.

Solar Evaporator Operation Requirements:

What are the operational requirements for solar evaporators?

The solar evaporator must be operated so that:

- There is **no standing water** within the evaporator, except for the water catchment basin. Application of drainage water with a timed sprinkler system should be used to set the application at rate that will not result in standing water.
- A nuisance condition such as wind-blown salt spray is not created.
- There is **no discharge of drainage water** outside the boundaries of the solar evaporator.
- Avian wildlife is adequately protected.

What steps are necessary to ensure the adequate protection of avian wildlife?

In addition to no standing water, the following Best Management Practices are required to ensure adequate protection of avian wildlife:

- Keep the solar evaporator free of all vegetation.
- Do not use grit-size gravel as a surface substrate in the solar evaporator.
- Prevent access to standing water in a water catchment basin with netting and do not allow the netting to sag into standing water in the catchment basin.
- Prevent the growth of insects in the solar evaporator, the growth and dispersal of insects from the water catchment basin, and use of the netting as a site for insect pupation.

What are the monitoring requirements?

Monitoring requirements will be established by the Regional Board at the time of the issuance of a Notice of Plan Compliance within 30 days of the submittal of a Notice of Intent to construct a solar evaporator. Groundwater and avian wildlife protection monitoring shall be required, as well as any information necessary to ensure compliance with the requirements of the regulations. Monitoring reports shall be submitted annually.

What options are available for the storage of salt accumulated in the solar evaporator?

Salt may continue to accumulate in an authorized solar evaporator as long as the accumulation does not interfere with the required operation of the evaporator. Salt may be harvested at any appropriate time and utilized or sold for beneficial of commercial purposes. Otherwise, salt can be temporarily stored in an enclosed storage unit inaccessible to wind, water and wildlife, and subject to annual inspection.

Are inspections separate from monitoring?

Yes. Monitoring and other recordkeeping is the responsibility of the operator.

Inspections are the responsibility of the Regional Board and shall be conducted at least once annually during the month of May. Inspection shall be made for observations indicating a threat to avian wildlife including:

- presence of vegetation within the perimeter of the solar evaporator;
- standing water and the growth of insects;
- presence of birds or nests with eggs within the perimeter of the solar evaporator;
- an avian die-off or disabling event associated with the solar evaporator.

Solar Evaporator Closure Requirements:

How long can I continue to operate a solar evaporator?

The Notice of Authority to Operate must be renewed every five years. Renewal can be achieved as long as the solar evaporator continues to meet the State and Regional Board requirements. As long as the Notice of Authority is renewed and is in effect, closure is not required.

If closure is necessary or desired, what requirements have to be met?

Three options are available for closure: (1) harvest of salt followed by clean closure; (2) closure in place; (3) removal of salt and disposal in an authorized waste facility. The operator will select the closure option, and submit a plan to the regional board for approval.

• **Clean closure:** The salt from the solar evaporator may be harvested and utilized following the guidelines under salt management. After the removal of the salt, the solar evaporator and surrounding area need to be restored to a condition that does not threaten wildlife, does not threaten to pollute water, and does not cause a nuisance condition.

• **Closure in place:** A cover can be constructed over the solar evaporator retaining salt inplace and making use of the existing foundation.

• **Waste Facility Disposal:** Salt may be removed and disposed permanently in an authorized waste facility. After salt removal, the solar evaporator site is clean closed as above.

For complete requirements, see CCR §22950.

Additional Details for Laws and Regulations

The material above in Laws and Regulations briefly outlines the various laws and regulations that may apply to development of an IFDM system. Additional details for each law are discussed here:

California Environmental Quality Act (CEQA): The California Public Resource Code §21000-21006 establishes the legislative intent and policy supporting the CEQA environmental disclosure and review process for projects conducted in the State of California. Public Resource Code §21065 defines a project as:

"an activity which may cause either a direct physical change in the environment, or a reasonably foreseeable indirect physical change in the environment, and which is any of the following:

(a) An activity directly undertaken by any public agency.

(b) An activity undertaken by a person which is supported, in whole or in part, through contracts, grants, subsidies, loans, or other forms of assistance from one or more public agencies.

(c) An activity that involves the issuance to a person of a lease, permit, license, certificate, or other entitlement for use by one or more public agencies."

Any project that fits the above definition, whether undertaken by a private or public entity, is subject to the CEQA process. An overview of the CEQA process is illustrated in Figure 1. Early in the process, a lead agency is designated. Generally, the lead agency is the California government agency principally responsible for approving or carrying out a project. The lead agency is responsible for preparing all necessary environmental disclosure documentation, for assuring that the documentation is legally adequate, and for encouraging public participation. Other agencies, known as responsible agencies, also may be directly involved with the CEQA process. These agencies are legally responsible for some aspect of the project or resource in the project area and will provide input to the lead agency as the project is planned and CEQA documentation is prepared. It is common for public agencies with permitting authority over a project to serve as responsible agencies. Once a lead agency is designated, an IS is prepared to help determine whether the project could have any significant effect on the environment. If a significant effect is anticipated, an Environmental Impact Report (EIR) is written, otherwise a Negative Declaration is prepared.

CEQA documentation is prepared not only to fully inform decision makers about the details and any possible impacts of a project before deciding whether to proceed, but it's also prepared to fully inform the general public about a proposed project and any potential impacts. The public disclosure aspect of CEQA is stressed in the CEQA statute, and protocols that facilitate public disclosure and interaction are provided in the CEQA guidelines (http://www.ceres.ca.gov/).

Although the CEQA process is outlined and discussed in the guidelines, it is best to let someone with a strong CEQA background determine which level of environmental analysis is appropriate for the proposed project, and to then complete the necessary actions to ensure CEQA compliance.

National Environmental Policy Act (NEPA): NEPA requires incorporating environmental considerations into the planning process for all federal projects, and for projects requiring federal funding or permits.

The purposes of this Act are: To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality [CEQ]. Sec. 2 [42 USC § 4321], Federal Code.

Unlike CEQA, NEPA allows each federal agency to develop their own NEPA guidelines; however, the CEQA requires that each agency's NEPA policy integrate environmental impact analysis into project planning and environmental disclosure documents including:

EA's and Environmental Impact Statements (EIS). Like CEQA, public disclosure and interaction are mandated by NEPA.

Federal Clean Water Act: The act specifies that federal agencies identify reasonable alternatives to a proposed project along with the preferred alternative (the proposed project), as well as describing any anticipated impacts.

Typical activities that affect water quality may include but are not limited to:

- Discharge of process wastewater and commercial activities not discharged into a sewer (factory wastewater, cooling water, etc.)
- Confined animal facilities (e.g., dairies)
- Waste containments (landfills, waste ponds, etc.)
- Construction sites
- Boatyards
- Discharges of pumped groundwater and cleanup (underground tank cleanup, dewatering, spills)
- Material handling areas draining to storm drains
- Sewage treatment facilities
- Filling of wetlands
- Dredging, filling, and disposal of dredge wastes
- Waste to land

Various agencies have been granted regulatory authority over different aspects of the Clean Water Act. Sections of the Clean Water Act most relevant to Integrated Farm Drainage Management (IFDM) projects may include:

Section 404, Clean Water Act: Waters of the United States are divided into "wetlands" and "other waters of the United States." Wetlands are defined as *"areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions"* (33 Code of Federal Regulations [CFR] 328.3[b], 40 CFR 230.3). Jurisdictional wetlands must support positive indicators for hydrophytic vegetation, hydric soil, and wetland hydrology. Other waters of the United States are defined as those that lack positive indicators for one or more of the three wetland parameters identified above and include seasonal or perennial water bodies, including lakes, stream channels, drainages, ponds, and other surface water features, that exhibit an ordinary high-water mark (33 CFR 328.4).

Section 402, Clean Water Act: Common pollutants that are subject to NPDES permit limitations are biological waste, toxic chemicals, oil and grease, metals, and pesticides. NPDES permitting is administered by the Regional Water Quality Control Board (RWQB) under the authority of the State Water Resources Control Board (SWRCB).

Resource Conservation and Recovery Act (RCRA): In California, RCRA is enforced by local Certified Unified Program Agencies (CUPAs) and the Department of Toxic Substances Control (DTSC). When it was enacted in 1976, it introduced the concept of "cradle to grave" management of hazardous waste as well as use of the Uniform Hazardous Waste Manifest. Under RCRA, in order for a substance to be considered a hazardous waste, it must first be a waste (i.e., you are done using it and/or it is inherently "wastelike"). Secondly, the waste must either (1) be on a list of wastes that are automatically considered to be hazardous; or (2) display characteristics that make it a hazardous waste (i.e., toxicity, ignitability, reactivity or corrosivity).

If the waste is hazardous under RCRA, the generator must file a notification with EPA and obtain a hazardous waste generator identification number, comply with requirements for appropriate storage of the material prior to shipment, ship the material under a Uniform Hazardous Waste Manifest using a hauler licensed to transport hazardous waste, and dispose of the material at a specially licensed treatment or disposal site. Selenium and selenium compounds are considered Acutely Hazardous Wastes under RCRA. If the amount of Acutely Hazardous Waste generated exceeds 1 kilogram (kg) in any given month, then the generator is responsible to comply with additional reporting, training, storage and waste minimization requirements.

Finally, the generator is responsible for the waste even after it is deposited in a disposal facility. This means that the generator could ultimately be responsible to contribute funds to clean up of the disposal facility, if that were to be required in the future. Of note is the fact that if a hazardous waste is recyclable, it is subject to RCRA storage and handling requirements, but there is no long-term liability. If the salt residue were a commercial product and not a waste, it would not be subject to RCRA requirements.

Hazardous Waste Control Law (HWCL) is codified in the Health & Safety Code Division 20, Chapter 6.5 and implementing regulations found in California Code of Regulations, Title 22, Division 4.5. The requirements of the HWCL are enforced by the local CUPA and/or DTSC.

Hazardous Waste Control Law (HWCL): California defines characteristic hazardous wastes based on either (or both) the soluble or total concentration of a hazardous constituent.

For selenium, this is defined as a Soluble Threshold Limit Concentration (STLC) of 1.0 mg/ L as determined by the California Waste Extraction Test or a Total Threshold Limit Concentration of 100 mg/kg. Hazardous waste generated in California is subject to additional reporting requirements and a hazardous waste generator tax levied by the state Board of Equalization. Any treatment of hazardous waste at a site to change its characteristics or render it less toxic is subject to additional regulatory and permitting requirements.

Section 404, Clean Water Act: Certain ongoing, normal farming practices in wetlands are exempt and do not require a permit. This includes, among other things, maintenance (but not construction or alteration of) drainage ditches, construction and maintenance of irrigation ditches, and construction and maintenance of farm or stock ponds. In order to be exempt, the activities cannot be associated with converting an agricultural wetland into a non-wetland or bringing a wetland into agricultural production. Other requirements define and regulate "Prior Converted Cropland" and "Farmed Wetlands."

Federal Endangered Species Act (FESA): Actions that lead to take can result in civil or criminal penalties. Authorization for "take" must be received from the appropriate federal regulatory agency (USFWS, NOAA Fisheries, etc.), if compliance with standard avoidance measures are not feasible. Section 10 outlines the process by which entities may obtain a permit for the "incidental take" of a listed species.

Under Section 7 a federal lead agency must consult with relevant federal regulatory agencies to ensure that the actions of a project do not jeopardize the continued existence of listed species. If the project has the potential to affect listed species, a federal lead agency must prepare a Biological Assessment (BA) identifying the project effects and submit it to other federal agencies for review. The reviewing federal agencies would make a determination regarding effects and proposed mitigation measures and, after consultation, issues a Biological Opinion (BO) that may authorize "take" but could lead to changes in avoidance and mitigation measures and may require modification of the project design.

If the project affects species listed jointly under the federal and state Endangered Species Acts, DFG typically participates in Section 7 consultation to the greatest extent possible. The federal BO generally reflects both state and federal findings, and DFG is encouraged in the state Endangered Species Act to adopt, when possible, the USFWS biological opinion as its own formal written determination on whether jeopardy to endangered species exists. If, however, USFWS and DFG ultimately fail to agree, the agencies may issue independent biological opinions.

California Endangered Species Act (CESA): Section 2080 of the Fish and Game Code prohibits "take" of any species that the Fish and Game Commission determines to be an endangered species or threatened species. Take is defined in Section 86 of the Fish and Game Code as *"hunt, pursue, catch, capture, or kill, or attempt to hunt, pursue, catch, capture, or kill."* CESA allows for take incidental to otherwise lawful development projects but emphasizes early consultation to avoid potential impacts to rare, endangered, and threatened species and to develop appropriate mitigation planning. Mitigation planning is intended to offset project caused losses of listed species populations and their essential habitats.

Sections 2081(b) and (c) of the California Endangered Species Act allow the Department to issue an incidental take permit for a State listed threatened and endangered species only if specific criteria are met. Title 14 California Code of Regulations (CCR), Sections 783.4(a) and (b) summarizes the criteria as: *"The authorized take is incidental to an otherwise lawful activity; The impacts of the authorized take are minimized and fully mitigated; The measures required to minimize and fully mitigate the impacts of the authorized take are roughly proportional in extent to the impact of the taking on the species, maintain the applicant's objectives to the greatest extent possible, and are capable of successful implementation; Adequate funding is provided to implement the required minimization and mitigation measures and to monitor compliance with and the effectiveness of the measures; and Issuance of the permit will not jeopardize the continued existence of a State-listed species."*

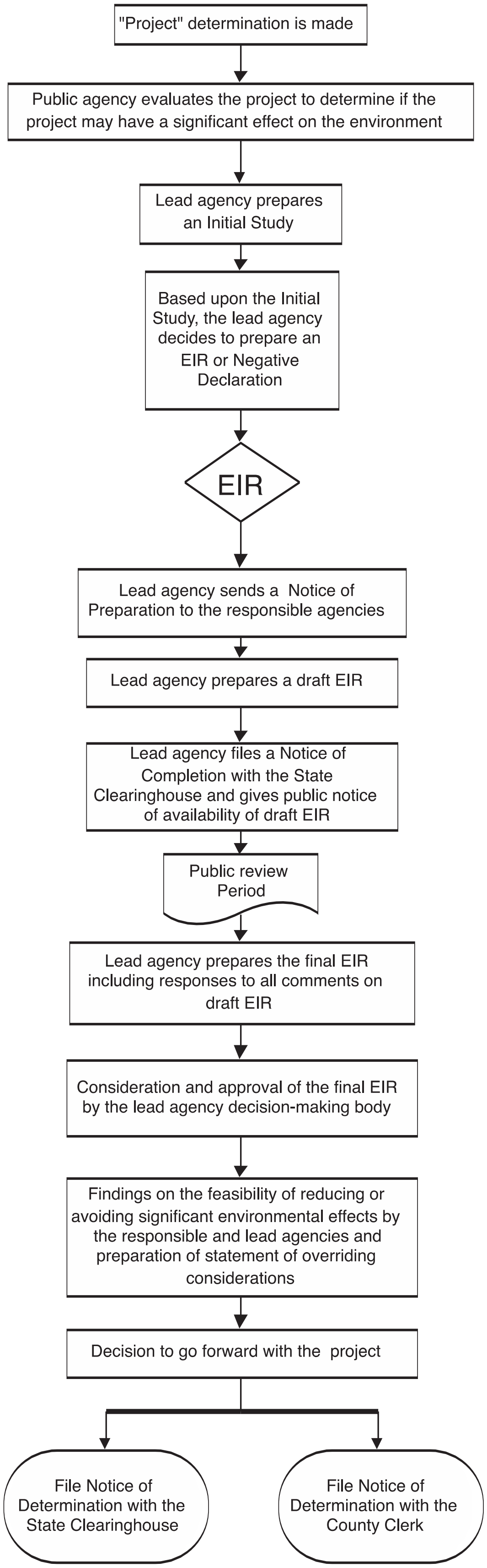
Fish and Game Code outlines the authority DFG has to protect and conserve natural resources within the state. The code has provisions for DFG authority under the CESA including regulatory authority for activities in channels, beds, and banks of lakes, rivers and streams.

Fully Protected Animals: Table 1 provides a complete list of animals with Fully Protected status.

Table 1. Fully Protected Animals.

COMMON NAME	SCIENTIFIC NAME
Fishes	
Colorado River squawfish (=Colorado pikeminnow)	*Ptychocheilus lucius*
thicktail chub	*Gila crassicauda*
Mohave chub (=Mohave tui chub)	*Gila mohavensis*
Lost River sucker	*Catostomus luxatus* (=*Deltistes luxatus*)
Modoc sucker	*Catostomus microps*
shortnose sucker	*Chasmistes brevirostris*
humpback sucker (=razorback sucker)	*Xyrauchen texanus*
Owens River pupfish (=Owens pupfish)	*Cyprinoden radiosus*
unarmored threespine stickleback	*Gasterosteus aculeatus williamsoni*
rough sculpin	*Cottus asperrimus*
Amphibians	
Santa Cruz long-toed salamander	*Ambystoma macrodactylum croceum*
limestone salamander	*Hydromantes brunus*
black toad	*Bufo exsul*
Reptiles	
blunt-nosed leopard lizard	*Gambelia sila* (=*Gambelia silus*)
San Francisco garter snake	*Thamnophis sirtalis tetrataenia*
Birds	
American peregrine falcon	*Falco peregrinus anatum*
brown pelican (=California brown pelican)	*Pelecanus occidentalis* (=*P. o. occidentalis*)
California black rail	*Laterallus jamaicensis coturniculus*
California clapper rail	*Rallus longirostris obsoletus*
California condor	*Gymnogyps califonianus*
California least tem	*Sterna albifrons browni* (=*Sterna antillarum browni*)
golden eagle	*Aquila chrysaetos*
greater sandhill crane	*Grus candadensis tabida*
light-footed clapper rail	*Rallus longirostris levipes*
southern bald eagle (=bald eagle)	*Haliaeetus leucocephalus leucocephalus* (=*Haliaeetus leucocephalus*)
trumpeter swan	*Cygnus buccinator*
white-tailed kite	*Elanus leucurus*
Yuma clapper rail	*Rallus longirostris yumanensis*
Mammals	
Morro Bay kangaroo rat	*Dipodomys heermanni morroensis*
bighorn sheep	*Ovis canadensis* - except Nelson bighorn sheep (*ssp. Ovis canadensis nelsoni*) in the area described in subdivision (b) of Section 4902 (Fish and Game Code)
northern elephant seal	*Mirounga angustirostris*
Guadalupe fur seal	*Arctocephalus townsendi*
ring-tailed cat	*Genus Bassariscus* (=*Bassariscus astutus*)
Pacific right whale	*Eubalanea sieboldi* (=*Balaena glacialis*)
salt-marsh harvest mouse	*Reithrodontomys raviventris*
southern sea otter	*Enhydra lutris nereis*
wolverine	*Gulo luscus* (=*Gulo gulo*)

Figure 1. CEQA Process.
Overview of the CEQA process



Adapted from CERES CEQA process flow chart.

STATE WATER RESOURCES CONTROL BOARD
BOARD MEETING SESSION—DIVISION OF WATER QUALITY
JULY 16, 2003

ITEM 9

SUBJECT

CONSIDERATION OF A RESOLUTION ADOPTING EMERGENCY REGULATIONS THAT ESTABLISH MINIMUM REQUIREMENTS FOR THE DESIGN, CONSTRUCTION, OPERATION, AND CLOSURE OF SOLAR EVAPORATORS AS COMPONENTS OF INTEGRATED ON-FARM DRAINAGE MANAGEMENT SYSTEMS

DISCUSSION

In 1990, the San Joaquin Valley Drainage Program recommended the implementation of sequential agricultural drainage reuse systems, now known as Integrated on-Farm Drainage Management (IFDM) systems, as one major component of a comprehensive agricultural drainage management plan to address the impact of poor quality shallow groundwater on now almost one million acres of agricultural land on the westside of the San Joaquin Valley. The plan recommended that 156,000 acres of tile-drained cropland be included in drainage reuse or IFDM systems by the year 2000 in the initial phase of the proposed 50-year plan to manage shallow groundwater and salinity in-valley and sustain productivity of agricultural lands. The recommendation was contained in *A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley*, popularly known as the Rainbow Report. In 1991, the State Water Resources Control Board (SWRCB) entered into a Memorandum of Understanding with seven other State and federal agencies to form the San Joaquin Valley Drainage Implementation Program (SJVDIP) for the purpose of implementing the recommendations of the Rainbow Report.

There are two types of evaporation systems currently used by farmers in the San Joaquin Valley to manage agricultural drainage water. The first are the large evaporation ponds in Tulare Lake Basin that receive and store drainage water directly from irrigated farmland without reuse. The second are the solar evaporators operated as part of an IFDM system. Agricultural drainage water is sequentially reused (one to three times) to irrigate salt-tolerant forage and other crops until the volume of drainage water is substantially decreased and its salt content significantly increased. The concentrated brine is then sprayed into an on-farm solar evaporator—a shallow basin that is the endpoint of the sequential reuse system. No off-farm discharge of drainage water occurs in this system. It has been proposed that crystallized salts from the solar evaporator be harvested as a commercial product; however, no markets have yet been established.

The first drainage reuse pilot project was initiated on a site near Mendota by the Westside Resource Conservation District in 1985, with the support of several State and federal government agencies. In 1994, work began on the development of a complete IFDM system for sequential drainage reuse at Red Rock Ranch in western Fresno County. Development of IFDM systems and solar evaporators has focused for the last nine years on Red Rock Ranch. The Red Rock Ranch prototype IFDM system has achieved significant improvements in root zone soil and water quality and crop productivity on about 76% of the farmed acreage, with substantial improvement in the productivity of high-value salt-sensitive crops. Productive reuse has been made of the drainage water collected on-farm for irrigating salt-tolerant forage, cotton, and other crops on another 23% of the IFDM system acreage.

A small solar evaporator was constructed as the salt end-point component of this IFDM system. Waste Discharge Requirements (WDR) for its operation were established by the Central Valley Regional Water Quality Control Board (CVRWQCB). However, naturally high selenium concentrations in the drainage discharged to the evaporator invoked regulatory provisions of the Toxic Pits Cleanup Act (TPCA 1984) and created difficulties in permitting the solar evaporator as the essential final component of the IFDM system. Red Rock Ranch experienced difficulty in efficiently operating the solar evaporator while meeting the WDR's and was served with Notices of Violation. Problems were associated with ponding sufficient to develop a growth of invertebrates (primarily brine flies) initiating a selenium-containing food chain that resulted in impacts to nesting shorebirds. The data for stilts nesting near the solar ~~pond~~ evaporator at Red I Rock Ranch represent the highest percent incidence of selenium-induced birth defects reported from field studies to date. These and other problems resulted in the cessation of operation of the original solar evaporator at the Ranch. Attempted solutions to resolve the conflict with TPCA were found to be impractical and infeasible.

Meanwhile, rising water tables and increasing soil salinity threaten root zone soil and water quality and continued productivity on westside San Joaquin Valley agricultural lands. To date, complete IFDM systems have been developed on only about 1600 acres of agricultural land. At the present time, other alternatives for the management of subsurface agricultural drainage, such as out-of-valley disposal of drainage to the Bay-Delta or Pacific Ocean, or discharge to large, conventional evaporation ponds, is either generally unavailable or infeasible. A number of growers on the westside of the San Joaquin Valley would like to institute complete IFDM systems with solar evaporators and resulting improvements in soil and water quality, but are reluctant to do so until the existing regulatory issues with respect to the Red Rock Ranch solar evaporator are resolved. Further, other growers and districts are instituting partial IFDM systems with salt-tolerant crop reuse components but with no solar evaporators as a salt endpoint. Incomplete IFDM systems without salt endpoints risk future loss of soil and water quality improvements, and impacts to wildlife.

This situation has placed the entire operation of IFDM systems and the future implementation of the Rainbow Report recommendations in question and led to the passage of Senate Bill (SB) 1372 in September, 2002. By this act, solar evaporators are exempt from the provisions of TPCA. Solar evaporators did not exist at the time of enactment of TPCA, and the provisions of TPCA do not take account of the unique circumstances and conditions pertinent to solar evaporators. SB 1372 also exempts solar evaporators from WDRs under the California Water Code, and requires the development of new emergency regulations specifically designed to address the environmental and operational conditions associated with solar evaporators, thereby facilitating the full development and completion of IFDM systems.

The new regulations establish minimum requirements for the design, construction, operation, and closure of solar evaporators and have been developed through a review of existing information on the development and regulation of solar evaporators, and through informal consultation with other State agencies, primarily the Department of Water Resources, and the Department of Food and Agriculture. Technical advice and recommendations were requested of the Department of Fish and Game and the U.S. Fish and Wildlife Service, as required by SB 1372. A fact finding field tour of existing and proposed solar evaporators was made in December, 2002, with meetings held with existing operators and prospective applicants. The tour included an innovative new solar evaporator design currently being developed and tested at Red Rock Ranch.

The new regulations closely follow the language and intent of SB 1372, adding clarity and specificity where needed or useful. Existing regulations in the California Code of Regulations are cited or referenced where appropriate. The new regulations are primarily designed to account for the no standing water provision of SB 1372. A specific definition of "standing water" has been developed based on limiting the potential for growth of brine flies that could result in biomagnification of selenium in a food chain. The "standing water" definition is thereby designed to provide adequate wildlife protection. Another important definition is "reasonably foreseeable operating conditions" that has been specified for both the design capacity of solar evaporator operating systems and natural occurrence of floods and incident rainfall. The definition of "water catchment basin" has been expanded to include a solar still or greenhouse as a fully contained component for the final separation and desiccation of salt. The new design and operation standards are intended to facilitate the development and implementation of solar evaporators as components of IFDM systems, while protecting avian wildlife and existing groundwater quality.

Adoption by the SWRCB of new solar evaporator emergency regulations has been determined by the Office of the Chief Counsel to be subject to an emergency exemption from the California Environmental Quality Act.

POLICY ISSUE

Should the SWRCB adopt emergency regulations (see attachment) that establish minimum requirements for the design, construction, operation, and closure of solar evaporators as components of IFDM systems in compliance with SB 1372?

FISCAL IMPACT

Annual costs of approximately $181,000 are anticipated for the (CVRWQCB) in FY 2003-2004, and $161,000 annually thereafter, to carry out the provisions of the new solar evaporator regulations. SB 1372 requires any Regional Water Quality Control Boards (RWQCBs) receiving a Notice of Intent to construct and operate a solar evaporator to review the application, inspect the site, identify additional data requirements, conduct facility inspections after construction, determine facility compliance with the requirements of the regulations, review annual monitoring data reports, and other tasks. Although the bill prohibits RWQCBs from approving new facilities after January 1, 2008, operation of facilities approved prior to that date would be allowed to continue and, therefore, would require continued regulatory effort by the RWQCBs. Funds from the existing Surface Impoundment Assessment Account in the General Fund (approximately $1.2 million) may be used for this purpose.

RWQCB IMPACT

Yes, mainly Central Valley Regional Water Quality Control Board.

STAFF RECOMMENDATION

Staff recommends adoption of emergency regulations that establish minimum requirements (see attachment) for the design, construction, operation, and closure of solar evaporators as components of IFDM systems in compliance with SB 1372.

STATE WATER RESOURCES CONTROL BOARD *June 16, 2003*

RESOLUTION NO. 2003-

AUTHORIZING A RESOLUTION ADOPTING EMERGENCY REGULATIONS THAT ESTABLISH MINIMUM REQUIREMENTS FOR THE DESIGN, CONSTRUCTION, OPERATION, AND CLOSURE OF SOLAR EVAPORATORS AS COMPONENTS OF INTEGRATED ON-FARM DRAINAGE MANAGEMENT (IFDM) SYSTEMS

WHEREAS:

1. The sustainability of approximately one million acres of productive agricultural land on the westside of the San Joaquin Valley is threatened by rising shallow groundwater of poor quality.
2. Recommended measures contained in *A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley*, to provide short-term agricultural drainage relief, include sequential drainage reuse or IFDM systems.
3. IFDM systems require an evaporation system as the final component for the separation and collection of salt.
4. The Legislature has found that IFDM is a sustainable system of managing salt-laden farm drainage water. IFDM is designed to eliminate the need for off-farm drainage of irrigation water, prevent the on-farm movement of irrigation and drainage water to groundwater, restore and enhance the productive value of degraded farmland by removing salt and selenium from the soil, conserve water by reducing the demand for irrigation water, and create the potential to convert salt from a waste product and pollutant to a commercial farm commodity.
5. The Legislature has found it is the policy of the state to conserve water and to minimize the environmental impacts of agricultural drainage. It is therefore in the interests of the state to encourage the voluntary implementation of sustainable farming and irrigation practices, including, but not limited to, IFDM as a means of improving environmental protection, conserving water, restoring degraded soils, and enhancing the economic productivity of farms.
6. The Legislature has directed the State Water Resources Control Board (SWRCB), on or before April 1, 2003, to adopt emergency regulations that establish minimum requirements for the design, construction, operation, and closure of solar evaporators. The SWRCB granted a delay in adoption as requested by other State agencies and stakeholders.
7. This action to adopt emergency solar evaporator regulations is exempt from the requirements of the California Environmental Quality Act pursuant to Public Resources Code section 21080(b)(4).
8. The SWRCB has developed new solar evaporator regulations in compliance with Senate Bill 1372 (SB 1372) to be located within California Code of Regulations Title 27, that facilitate the development and implementation of solar evaporators as components of IFDM systems, while protecting avian wildlife safety and groundwater quality.

THEREFORE BE IT RESOLVED THAT:

The State Water Resources Control Board adopts emergency regulations (see attachment) that establish minimum requirements for the design, construction, operation, and closure of solar evaporators as components of IFDM systems in compliance with SB 1372.

CERTIFICATION

The undersigned, Clerk to the Board, does hereby certify that the foregoing is a full, true, and correct copy of a resolution duly and regularly adopted at a meeting of the State Water Resources Control Board held on July 16, 2003.

____

Debbie Irvin
Clerk to the Board

D R A F T

Title 27. Environmental Protection

Division 2. Solid Waste

Subdivision 1. Consolidated Regulations for Treatment, Storage, Processing, or Disposal of Solid Waste

Chapter 7. Special Treatment, Storage, and Disposal Units

Subchapter 6. Solar Evaporators

Article 1. Solar Evaporator Regulations

[Note: regulations in this article were promulgated by the State Water Resources Control Board (SWRCB), are administered by the appropriate Regional Water Quality Control Board (RWQCB), and are applicable to the owner or operator of a solar evaporator for the management of agricultural drainage water discharges from an integrated on-farm drainage management system (IFDM).]

§22900. SWRCB – Applicability.

(a) General—This article applies to the discharge of agricultural drainage water from Integrated On-Farm Drainage Management (IFDM) systems to solar evaporators as defined in §22910. No SWRCB-promulgated parts of the Division 2 of Title 27 and Division 3, Chapter 15 of Title 23 of the California Code of Regulations (CCR) shall apply to the discharge of agricultural drainage water from IFDM systems to solar evaporators unless those sections are specifically referenced in this article. Any person who intends to operate a solar evaporator after ~~July 1, 2003~~ [effective date] shall comply with the requirements of this article before a Notice of Plan Compliance and Notice of Authority to Operate (§25209.13 of Article 9.7 of the Health and Safety Code) will be issued by a Regional Water Quality Control Board (RWQCB).

§22910. SWRCB – Definitions.

For purposes of this article, the following terms have the following meanings:

(a) "Adequately protected" means that:
   (1) Avian wildlife have no access to standing water in a water catchment basin.
   (2) Standing water does not occur in a solar evaporator outside of a water catchment basin, under reasonably forseeable operating conditions.
   (3) The solar evaporator, including the water catchment basin, does not become a medium for the growth of aerial aquatic and semi-aquatic macro invertebrates that could become a harmful food source for avian wildlife, under reasonably forseeable operating conditions.

(b) "Agricultural drainage water" means surface drainage water or percolated irrigation water that is collected by subsurface drainage tiles placed beneath an agricultural field.

(c) "Avian Wildlife Biologist" means any State or federal agency biologist, ecologist, environmentalspecialist (or equivalent title) with relevant avian wildlife monitoring experience (as determined by the RWQCB), or any professional biologist, ecologist, environmental specialist (or equivalent title) possessing valid unexpired State and federal collecting permits for avian wildlife eggs.

(d) "Boundaries of the solar evaporator" or "boundaries of a solar evaporator" means the outer edge of the solar evaporator or any component of the solar evaporator, including, but not limited to, berms, liners, water catchment basins, windscreens, and deflectors.

(~~d~~e) "Certified Engineering Geologist" means a registered geologist, certified by the State of California, pursuant to section 7842 of the Business and Professions Code.

(~~e~~f) "Hydraulic conductivity" means the ability of natural and artificial materials to transmit water. The term is expressed as a measure of the rate of flow through a unit area cross-section of material. The unit of measure is cm/sec.

(~~f~~g) "Integrated on-farm drainage management system" means a facility for the on-farm management of agricultural drainage water that does all of the following:

(1) Reduces levels of salt and selenium in soil by the application of irrigation water to agricultural fields.

(2) Collects agricultural drainage water from irrigated fields and sequentially reuses that water to irrigate successive crops until the volume of residual agricultural drainage water is substantially decreased and its salt content significantly increased.

(3) Discharges the residual agricultural drainage water to an on-farm solar evaporator for evaporation and appropriate salt management.

(4) Eliminates discharge of agricultural drainage water outside the boundaries of the property or properties that produces the agricultural drainage water and that is served by the integrated onfarm drainage management system and the solar evaporator.

(~~g~~h) "Liner" means:

(1) a continuous layer of natural or artificial material, or a continuous membrane of flexible and durable artificial material, or a continuous composite layer consisting of a membrane of flexible artificial material directly overlying a layer of engineered natural material, which is installed beneath a solar evaporator, and which acts as a barrier to vertical water movement, and

(2) a material that has appropriate chemical and physical properties to ensure that the liner does not fail to contain agricultural drainage water because of pressure gradients, physical contact with the agricultural drainage water, chemical reactions with soil, climatic conditions, ultraviolet radiation (if uncovered), the stress of installation, and the stress of daily operation, and

(3) a material that has a minimum thickness of 40 mils (0.040 inches) for flexible artificial membranes or synthetic liners.

(4) The requirements of this definition are applicable only if a liner is used to meet the requirements of §22920(c).

(~~h~~i) "Nuisance" means anything which meets all of the following requirements:

(1) Is injurious to health, or is indecent or offensive to the senses, or an obstruction to the free use of property, so as to interfere with the comfortable enjoyment of life or property.

(2) Affects at the same time an entire community or neighborhood, or a considerable number of persons, although the extent of the annoyance or damage inflicted on individuals may be unequal.

(3) Occurs during, or as a result of, the treatment or disposal of wastes.

(~~i~~j) "On-farm" means within the boundaries of a property, geographically contiguous properties, or a portion of the property or properties, owned or under the control of a single owner or operator, that is used for the commercial production of agricultural commodities and that contains an IFDM system and a solar evaporator.

(~~j~~k) "Pollution" means an alteration of the quality of the waters of the state by waste to a degreewhich unreasonably affects either of the following:

(1) The waters for beneficial uses.

(2) Facilities which serve these beneficial uses.

(~~k~~l) "Reasonably foreseeable operating conditions" means:

(1) within the range of the design discharge capacity of the IFDM system and the authorized solar evaporator system as specified in the Notice of Plan Compliance and Notice of Authority to Operate (§25209.13 of Article 9.7 of the Health and Safety Code),

(2) precipitation up to and including the local 25-year, 24-hour storm, and

(3) floods with a 100-year return period. Operation of a solar evaporator in exceedance of design specifications is not covered by "reasonably foreseeable operating conditions," and therefore would constitute a violation of the Notice of Authority to Operate.

DRAFT

(~~l~~m) "Regional Board" and "RWQCB" means a California Regional Water Quality Control Board.

(~~m~~n) "Registered Agricultural Engineer" means an agricultural engineer registered by the State of California, pursuant to section 6732 of the Business and Professions Code.

(~~n~~o) "Registered Civil Engineer" means a civil engineer registered by the State of California, pursuant to section 6762 of the Business and Professions Code.

(~~o~~p) "Registered Geologist" means a geologist registered by the State of California, pursuant to section 7842 of the Business and Professions Code.

(~~p~~q) "Solar evaporator" means an on-farm area of land and its associated equipment that meets all of the following conditions:

(1) It is designed and operated to manage agricultural drainage water discharged from the IFDM system.

(2) The area of the land that makes up the solar evaporator is equal to, or less than, 2 percent of the area of the land that is managed by the IFDM system.

(3) Agricultural drainage water from the IFDM system is discharged to the solar evaporator by timed sprinklers or other equipment that allows the discharge rate to be set and adjusted as necessary to avoid standing water within the solar evaporator or, if a water catchment basin is part of the solar evaporator, within that portion of the solar evaporator that is outside the basin.

(4) The combination of the rate of discharge of agricultural drainage water to the solar evaporator and subsurface tile drainage under the solar evaporator provides adequate assurance that constituents in the agricultural drainage water will not migrate from the solar evaporator into the vadose zone or waters of the state in concentrations that pollute or threaten to pollute the waters of the state.

(~~q~~r) "Standing water" means water occurring under all of the following conditions:

(1) to a depth greater than one centimeter,

(2) for a continuous duration in excess of 48 hours,

(3) as a body of any areal extent, not an average depth, and

(4) under reasonably forseeable operating conditions.

(~~r~~s) "Subsurface drainage tiles" or "subsurface tile drainage" means any system of subsurface drainage collection utilizing drainage tiles, perforated pipe, or comparable conveyance, placed below the surface of any IFDM system area including the solar evaporator.

(~~s~~t) "Unreasonable threat" to avian wildlife means that avian wildlife is not adequately protected.

(~~t~~u) "Vadose zone" means the unsaturated zone between the soil surface and the permanent groundwater table.

(~~u~~v) "Water catchment basin" means an area within the boundaries of a solar evaporator that is designated to receive and hold any water that might otherwise be standing water within the solar evaporator. The entire area of a water catchment basin shall be permanently and continuously covered with netting, or otherwise designed, constructed, and operated to prevent access by avian wildlife to standing water within the basin. A water catchment basin may include an enclosed solar still, greenhouse or other fully contained drainage storage unit. For the purposes of this definition, the term "within the boundaries of a solar evaporator" shall include a solar still, greenhouse, or other fully contained drainage storage unit adjacent to or near the portion of the solar evaporator that is outside the catchment basin.

(~~u~~w) "Waters of the state" means any surface water or groundwater, including saline water, within the boundaries of the state.

§22920. SWRCB – Solar Evaporator Design Requirements.

(a) Registered Professionals – Solar evaporators shall be designed by a registered civil or agricultural engineer, or a registered geologist or certified engineering geologist.

(b) Flooding – A solar evaporator shall be located outside the 100-year floodplain, or shall be constructed with protective berms/levees sufficient to protect the solar evaporator from overflow and inundation by 100-year floodwaters, or shall be elevated above the maximum elevation of a 100-year flood.

(c) Protection of Groundwater Quality – Solar evaporators shall be immediately underlain by at least 1 meter of soil with a hydraulic conductivity of not more than 1 x 10-6 cm/sec above the zone of shallow groundwater at any time during the year. The surface of the solar evaporator shall be a minimum of five-feet (5 ft.) above the highest anticipated elevation of underlying groundwater. A solar evaporator may be constructed on a site with soils that do not meet the above requirement, with subsurface tile drainage under or directly adjacent to the solar evaporator, a liner, or other engineered alternative, sufficient to provide assurance of the equivalent level of groundwater quality protection of the above soil requirement.

(d) Discharge to the Facility – All discharge to the solar evaporator shall be agricultural drainage water collected from the IFDM system or recirculated from the solar evaporator as a component of the IFDM system. No agricultural drainage water from the IFDM system or the solar evaporator may be discharged outside the boundaries of ~~the area of land that makes up~~ the solar evaporator

(e) Facility Size – The area of land that makes up the solar evaporator may not exceed 2 percent of the area of land that is managed by the IFDM system.

(f) Means of Discharge to the Facility – Discharge of agricultural drainage water from the IFDM system to the solar evaporator shall be by timed sprinklers or other equipment that allows the discharge rate to be set and adjusted as necessary to avoid standing water in the solar evaporator, outside a water catchment basin. The sprinklers shall be equipped with screens or shields or other devices as necessary to prevent the drift of agricultural drainage water spray outside the boundaries of the solar evaporator.

(g) Water Catchment Basin – A water catchment basin may be required:

(1) As a component of a solar evaporator if standing water would otherwise occur within the solar evaporator under reasonably foreseeable operating conditions, or

(2) If a solar evaporator is constructed with a liner. In this case, a water catchment basin shall be designed with the capacity to contain the maximum volume of water that the solar evaporator would collect under reasonably forseeable operating conditions. A water catchment basin is not required for a solar evaporator that does not have a liner, if it is demonstrated that standing water will not occur under reasonably foreseeable operating conditions.

(h) Avian Wildlife Protection – The solar evaporator shall be designed to ensure that avian wildlife is adequately protected as set forth in §22910 (a) and (~~u~~v).

§22930. SWRCB – Solar Evaporator Construction Requirements.

(a) Registered Professionals – Construction of solar evaporators shall be supervised and certified, by a registered civil or agricultural engineer, or a registered geologist or certified engineering geologist, as built according to the design requirements and Notice of Plan Compliance (§25209.13 of Article 9.7 of the Health and Safety Code).

§22940. SWRCB – Solar Evaporator Operation Requirements.

(a) Limitation on Standing Water – The solar evaporator shall be operated so that, under reasonably forseeable operating conditions, the discharge of agricultural drainage water to the solar evaporator will not result in standing water, outside of a water catchment basin. Agricultural drainage water from the IFDM system shall be discharged to the solar evaporator by timed sprinklers or other equipment that allows the discharge rate to be set and adjusted as necessary to avoid standing water in the solar evaporator.

(b) Prevention of Nuisance – The solar evaporator shall be operated so that, under reasonably forseeable operating conditions, the discharge of agricultural drainage water to the solar evaporator does not result in:
  (1) The drift of salt spray, mist, or particles outside of the boundaries of the solar evaporator, or
  (2) Any other nuisance condition.

(c) Prohibition of Outside Discharge – The operation of a solar evaporator shall not result in any discharge of agricultural drainage water outside the boundaries of ~~the area of land that makes up~~ the solar evaporator.

(d) Salt Management – For solar evaporators in continuous operation under a Notice of Authority to Operate issued by a Regional Water Quality Control Board, evaporite salt accumulated in the solar evaporator shall be collected and removed from the solar evaporator if and when the accumulation is sufficient to interfere with the effectiveness of the operation standards of the solar evaporator as specified in this section. One of the following three requirements shall be selected and implemented by the owner or operator:
  (1) Evaporite salt accumulated in the solar evaporator may be harvested and removed from the solar evaporator and sold or utilized for commercial, industrial, or other beneficial purposes.
  (2) Evaporite salt accumulated in the solar evaporator may be stored for a period of one-year, renewable subject to an annual inspection, in a fully contained storage unit inaccessible to wind, water, and wildlife, until sold, utilized in a beneficial manner, or disposed in accordance with (3).
  (3) Evaporite salt accumulated in the solar evaporator may be collected and removed from the solar evaporator, and disposed permanently as a waste in a facility authorized to accept such waste in compliance with the requirements of Titles 22, 23, 27 and future amendments of the CCR, or Division 30 (commencing with Section 40000) of the Public Resources Code.

(e) Monitoring – Monitoring and record keeping, including a groundwater monitoring schedule, data, and any other information or reporting necessary to ensure compliance with this article, shall be established by the RWQCB in accord with §25209.14 of Article 9.7 of the Health and Safety Code.

(f) Avian Wildlife Protection – The solar evaporator shall be operated to ensure that avian wildlife is adequately protected as set forth in §22910 (a) and (~~u~~v). The following Best Management Practices are required:
  (1) Solar evaporators (excluding water catchment basins) shall be kept free of all vegetation.
  (2) Grit-sized gravel (<5 mm in diameter) shall not be used as a surface substrate within the solar evaporator.
  (3) Netting or other physical barriers for excluding avian wildlife from water catchment basins shall not be allowed to sag into any standing water within the catchment basin.
  (4) The emergence and dispersal of aerial aquatic and semi-aquatic macro invertebrates or aquatic plants outside of the boundary of the water catchment basin shall be prevented.
  (5) The emergence of the pupae of aerial aquatic and semi-aquatic macro invertebrates from the water catchment basin onto the netting, for use as a pupation substrate, shall be prevented.

(g) Inspection – The RWQCB issuing a Notice of Authority to Operate a solar evaporator shall conduct authorized inspections in accord with §25209.15 of Article 9.7 of the Health and Safety Code to ensure continued compliance with the requirements of this article. The RWQCB shall request an avian wildlife biologist to assist the RWQCB in its inspection of each authorized solar evaporator at least once annually during the month of May. If an avian wildlife biologist is not available, the RWQCB shall nevertheless conduct the inspection. During the inspection, observations shall be made for compliance with §22910 (a) and (uv), and the following conditions that indicate an unreasonable threat to avian wildlife:
  (1) Presence of vegetation within the ~~perimeter~~ boundaries of the solar evaporator;

(2) Standing water or other mediums within the solar evaporator that support the growth and dispersal of aerial aquatic or semi-aquatic macro invertebrates or aquatic plants;
(3) Abundant sustained avian presence within the solar evaporator that could result in nesting activity;
(4) An apparent avian die-off or disabling event within the solar evaporator;
(5) Presence of active avian nests with eggs within the ~~perimeter~~ boundaries of the solar evaporator.

If active avian nests with eggs are found within the ~~perimeter~~ boundaries of the solar evaporator, the RWQCB shall report the occurrence to the USFWS and DFG within 24 hours, and seek guidance with respect to applicable wildlife laws and implementing regulations. Upon observation of active avian nests with eggs within the ~~perimeter~~ boundaries of the solar evaporator, all discharge of agricultural drainage water to the solar evaporator shall cease until (a) the nests are no longer active, or (b) written notification is received by the owner or operator, from the RWQCB, waiving the prohibition of discharge in compliance with all applicable state and federal wildlife laws and implementing regulations (i.e., as per applicable exemptions and allowable take provisions of such laws and implementing regulations.)

§22950. SWRCB – Solar Evaporator Closure Requirements.

(a) For solar evaporators ceasing operation through discontinuance of operation or non-renewal of a Notice of Authority to Operate issued by a RWQCB, closure and post-closure plans shall be prepared and submitted to the RWQCB and approved by the RWQCB prior to closure. Closure plans shall conform to one of the following three requirements to be selected and implemented by the owner or operator:

(1) Evaporite salt accumulated in the solar evaporator may be harvested and removed from the solar evaporator and sold or utilized for commercial, industrial, or other beneficial purposes or stored for a period of one-year, renewable subject to an annual inspection, in a fully contained storage unit inaccessible to wind, water, and wildlife, until sold, utilized in a beneficial manner, or disposed in accordance with (3). After the removal of accumulated salt, the area within the boundaries of the solar evaporator shall be restored to a condition that does not pollute or threaten to pollute the waters of the state, that does not constitute an unreasonable threat to avian wildlife, and that does not constitute a nuisance condition. Clean closure may be accomplished in accord with §21090(f) and §21400 of CCR Title 27.
(2) The solar evaporator may be closed in-place, with installation of a final cover with foundation, low-hydraulic conductivity, and erosion-resistant layers, as specified in §21090 and §21400 of CCR Title 27. Closure in-place shall include a closure plan and post-closure cover maintenance plan in accord with §21090 and §21769 of CCR Title 27.
(3) Evaporite salt accumulated in the solar evaporator may be collected and removed from the solar evaporator, and disposed permanently as a waste in a facility authorized to accept such waste in compliance with the requirements of Titles 22, 23, 27 and future amendments of the CCR, or Division 30 (commencing with Section 40000) of the Public Resources Code. After the removal of accumulated salt, the area within the boundaries of the solar evaporator shall be restored to a condition that does not pollute or threaten to pollute the waters of the state, that does not constitute an unreasonable threat to avian wildlife, and that does not constitute a nuisance condition.

Senate Bill No. 1372

CHAPTER 597

An act to amend Section 25208.3 of, and to add Article 9.7 (commencing with Section 25209.10) to Chapter 6.5 of Division 20 of, the Health and Safety Code, relating to water.

[Approved by Governor September 15, 2002.
Filed with Secretary of State September 16, 2002.]

LEGISLATIVE COUNSEL'S DIGEST

SB 1372, Machado. State Water Resources Control Board: agricultural drainage: solar evaporators.

(1) Under the Agricultural Water Conservation and Management Act, water suppliers, as defined, individually, or in cooperation with other public agencies or persons, may institute a water conservation or efficient water management program consisting of farm and agricultural related components. Existing law, the Toxic Pits Cleanup Act of 1984, prohibits a person from discharging liquid hazardous wastes into a surface impoundment if the surface impoundment, or the land immediately beneath the impoundment, contains hazardous wastes and is within 1/2 mile upgradient from a potential source of drinking water.

This bill would require the State Water Resources Control Board to adopt, on or before April 1, 2003, emergency regulations that establish minimum requirements for the design, construction, operation, and closure of solar evaporators, as defined. The bill would require any person who intends to operate a solar evaporator to file a notice of intent with the regional water quality control board. The bill would specify a procedure for the issuance of a notice of authority by the regional board to operate a solar evaporator, including requiring the regional board to inspect the solar evaporator prior to authorizing the operation of the solar evaporator. The bill would prohibit a regional board from issuing a notice of authority to operate a solar evaporator on and after January 1, 2008.

The bill would require any person operating a solar evaporator to submit annually, according to a schedule established by the regional board, groundwater monitoring data and other information deemed necessary by the regional board. The bill would require the regional board to inspect any solar evaporator at least once every 5 years to ensure continued compliance with the provisions of the bill.

The bill would exempt any solar evaporator operating under a valid written notice of authority to operate issued by the regional board, including any facility that the regional board determines is in compliance with the requirements of the bill, from the provisions of the toxic pits act and other specified waste discharge requirements imposed under the Porter-Cologne Water Quality Control Act.

Because the provisions added by the bill would be located within the hazardous waste control laws and a violation of those laws is a crime, the bill would impose a state-mandated local program by creating new crimes regarding the operation of solar evaporators.

(2) Existing law, the toxic pits act, requires the state board to impose a fee upon any person discharging any liquid hazardous waste or hazardous waste containing free liquids into a surface impoundment. The state board is required to collect and deposit the fees in the Surface Impoundment Assessment Account in the General Fund. The money within that account is available, upon appropriation, to the state board and the regional boards for purposes of administering the toxic pits act.

This bill would additionally authorize the board to expend the fees deposited in the account for the purpose of administering the surface impoundments that would be exempted from the toxic pits act by the bill, thereby imposing a tax for purposes of Article XIII A of the California Constitution.

(3) The California Constitution requires the state to reimburse local agencies and school districts for certain costs mandated by the state. Statutory provisions establish procedures for making that reimbursement.

This bill would provide that no reimbursement is required by this act for a specified reason.

The people of the State of California do enact as follows:

SECTION 1. Section 25208.3 of the Health and Safety Code is amended to read:

25208.3. (a) The state board shall, by emergency regulation, adopt a fee schedule that assesses a fee upon any person discharging any liquid hazardous wastes or hazardous wastes containing free liquids into a surface impoundment, except as provided in Section 25208.17. The state board shall include in this fee schedule the fees charged for applications for, and renewals of, an exemption from Section 25208.5, as specified in subdivision (h) of Section 25208.5, from subdivision (a) of Section 25208.4, as specified in subdivision (b) of Section 25208.4, from subdivision (c) of Section 25208.4, as specified in Section 25208.16, and from Sections 25208.4 and 25208.5, as specified in subdivision (e) of Section 25208.13. The state board shall also include provisions in the fee schedule for assessing a penalty pursuant to subdivision (c). The state board shall set these fees at an amount equal to the state board's and regional board's reasonable and anticipated costs of administering this article.

(b) The emergency regulations that set the fee schedule shall be adopted by the state board in accordance with Chapter 3.5 (commencing with Section 11340) of Part 1 of Division 3 of Title 2 of the Government Code, and for the purposes of that chapter, including Section 11349.6 of the Government Code, the adoption of these regulations is an emergency and shall be considered by the Office of Administrative Law as necessary for the immediate preservation of the public peace, health and safety, and general welfare. Notwithstanding Chapter 3.5 (commencing with Section 11340) of Part 1 of Division 3 of Title 2 of the Government Code, any emergency regulations adopted by the state board pursuant to this section shall be filed with, but not be repealed by, the Office of Administrative Law and shall remain in effect until revised by the state board.

(c) The state board shall send a notice to each person subject to the fee specified in subdivision (a). If a person fails to pay the fee within 60 days after receipt of this notice, the state board shall require the person to pay an additional penalty fee. The state board shall set the penalty fee at not more than 100 percent of the assessed fee, but in an amount sufficient to deter future noncompliance, as based upon that person's past history of compliance and ability to pay, and upon additional expenses incurred by this noncompliance.

(d) The state board shall collect and deposit the fees collected pursuant to this article in the Surface Impoundment Assessment Account, which is hereby created in the General Fund. The money within the Surface Impoundment Assessment Account is available, upon appropriation by the Legislature, to the state board and the regional boards for purposes of administering this article and Article 9.7 (commencing with Section 25209.10).

SEC. 2. Article 9.7 (commencing with Section 25209.10) is added to Chapter 6.5 of Division 20 of the Health and Safety Code, to read:

Article 9.7. Integrated On-Farm Drainage Management

25209.10. The Legislature finds and declares all of the following:

(a) The long-term economic and environmental sustainability of agriculture is critical to the future of the state, and it is in the interest of the state to enact policies that enhance that sustainability.

(b) High levels of salt and selenium are present in many soils in the state as a result of both natural occurrences and irrigation practices that concentrate their presence in soils.

(c) The buildup of salt and selenium in agricultural soil is an unsustainable practice that degrades soil, harms an irreplaceable natural resource, reduces crop yields and farm income, and poses threats to wildlife.

(d) Salt and selenium buildup can degrade groundwater, especially in areas with perched groundwater aquifers.

(e) Off-farm drainage of irrigation water with high levels of salt and selenium degrades rivers and waterways, particularly the San Joaquin River and its tributaries. This environmental damage presents a clear and imminent danger that warrants immediate action to prevent or mitigate harm to public health and the environment.

(f) Discharge of agricultural drainage water to manmade drains and ponds has resulted in environmental damage, including damage to wildlife. Proposals to discharge agricultural drainage to natural water bodies, including the San Francisco Bay, are extremely expensive and pose threats to the environmental quality of those water bodies.

(g) Water supplies for agricultural irrigation have been reduced significantly in recent years, necessitating increased efforts to use water more efficiently.

(h) Although salt can be collected and managed as a commercial farm commodity, California currently imports salt from other countries.

(i) Integrated on-farm drainage management is a sustainable system of managing salt-laden farm drainage water. Integrated on-farm drainage management is designed to eliminate the need for off-farm drainage of irrigation water, prevent the on-farm movement of irrigation and drainage water to groundwater, restore and enhance the productive value of degraded farmland by removing salt and selenium from the soil, conserve water by reducing the demand for irrigation water, and create the potential to convert salt from a waste product and pollutant to a commercial farm commodity.

(j) Although integrated on-farm drainage management facilities are designed and operated expressly to prevent threats to groundwater and wildlife, these facilities currently may be classified as surface impoundments pursuant to the Toxic Pits Act of 1984, which discourages farmers from using them as an environmentally preferable means of managing agricultural drainage water.

(k) It is the policy of the state to conserve water and to minimize the environmental impacts of agricultural drainage. It is therefore in the interest of the state to encourage the voluntary implementation of sustainable farming and irrigation practices, including, but not limited to, integrated on-farm drainage management, as a means of improving environmental protection, conserving water, restoring degraded soils, and enhancing the economic productivity of farms.

25209.11. For purposes of this article, the following terms have the following meanings:

(a) "Agricultural drainage water" means surface drainage water or percolated irrigation water that is collected by subsurface drainage tiles placed beneath an agricultural field.

(b) "On-farm" means within the boundaries of a property, geographically contiguous properties, or a portion of the property or properties, owned or under the control of a single owner or operator, that is used for the commercial production of agricultural commodities and that contains an integrated on-farm drainage management system and a solar evaporator.

(c) "Integrated on-farm drainage management system" means a facility for the on-farm management of agricultural drainage water that does all of the following:

(1) Reduces levels of salt and selenium in soil by the application of irrigation water to agricultural fields.

(2) Collects agricultural drainage water from irrigated fields and sequentially reuses that water to irrigate successive crops until the volume of residual agricultural drainage water is substantially decreased and its salt content significantly increased.

(3) Discharges the residual agricultural drainage water to an on-farm solar evaporator for evaporation and appropriate salt management.

(4) Eliminates discharge of agricultural drainage water outside the boundaries of the property or properties that produces the agricultural drainage water and that is served by the integrated on-farm drainage management system and the solar evaporator.

(d) "Regional board" means a California regional water quality control board.

(e) "Solar evaporator" means an on-farm area of land and its associated equipment that meets all of the following conditions:

(1) It is designed and operated to manage agricultural drainage water discharged from the integrated on-farm drainage management system.

(2) The area of the land that makes up the solar evaporator is equal to, or less than, 2 percent of the area of the land that is managed by the integrated on-farm drainage management system.

(3) Agricultural drainage water from the integrated on-farm drainage management system is discharged to the solar evaporator by timed sprinklers or other equipment that allows the discharge rate to be set and adjusted as necessary to avoid standing water within the solar evaporator or, if a water catchment basin is part of the solar evaporator, within that portion of the solar evaporator that is outside the basin.

(4) The combination of the rate of discharge of agricultural drainage water to the solar evaporator and subsurface tile drainage under the solar evaporator provides adequate assurance that constituents in the

agricultural drainage water will not migrate from the solar evaporator into the vadose zone or waters of the state in concentrations that pollute or threaten to pollute the waters of the state.

(f) "State board" means the State Water Resources Control Board.

(g) "Water catchment basin" means an area within the boundaries of a solar evaporator that is designated to receive and hold any water that might otherwise be standing water within the solar evaporator. The entire area of a water catchment basin shall be permanently and continuously covered with netting, or otherwise designed, constructed, and operated to prevent access by avian wildlife to standing water within the basin.

25209.12. On or before April 1, 2003, the state board, in consultation, as necessary, with other appropriate state agencies, shall adopt emergency regulations that establish minimum requirements for the design, construction, operation, and closure of solar evaporators. The regulations shall include, but are not limited to, requirements to ensure all of the following:

(a) The operation of a solar evaporator does not result in any discharge of on-farm agricultural drainage water outside the boundaries of the area of land that makes up the solar evaporator.

(b) (1) The solar evaporator is designed, constructed, and operated so that, under reasonably forseeable operating conditions, the discharge of agricultural water to the solar evaporator does not result in standing water.

(2) Notwithstanding paragraph (1), a solar evaporator may be designed, constructed, and operated to accommodate standing water, if it includes a water catchment basin.

(3) The board may specify those conditions under which a solar evaporator is required to include a water catchment basin to prevent standing water that would otherwise occur within the solar evaporator.

(c) Avian wildlife is adequately protected. In adopting regulations pursuant to this subdivision, the state board shall do the following:

(1) Consider and, to the extent feasible, incorporate best management practices recommended or adopted by the United States Fish and Wildlife Service.

(2) Establish guidelines for the authorized inspection of a solar evaporator by the regional board pursuant to Section 25209.15. The guidelines shall include technical advice developed in consultation with the Department of Fish and Game and the United States Fish and Wildlife Service that may be used by regional board personnel to identify observed conditions relating to the operation of a solar evaporator that indicate an unreasonable threat to avian wildlife.

(d) Constituents in agricultural drainage water discharged to the solar evaporator will not migrate from the solar evaporator into the vadose zone or the waters of the state in concentrations that pollute or threaten to pollute the waters of the state.

(e) Adequate groundwater monitoring and recordkeeping is performed to ensure compliance with the requirements of this article.

(f) Salt isolated in a solar evaporator shall be managed in accordance with all applicable laws and shall eventually be harvested and sold for commercial purposes, used for beneficial purposes, or stored or disposed in a facility authorized to accept that waste pursuant to this chapter or Division 30 (commencing with Section 40000) of the Public Resources Code.

25209.13. (a) Any person who intends to operate a solar evaporator shall, before installing the solar evaporator, file a notice of intent with the regional board, using a form prepared by the regional board. The form shall require the person to provide information including, but not limited to, all of the following:

(1) The location of the solar evaporator.

(2) The design of the solar evaporator and the equipment that will be used to operate it.

(3) The maximum anticipated rate at which agricultural drainage water will be discharged to the solar evaporator.

(4) Plans for operating the solar evaporator in compliance with the requirements of this article.

(5) Groundwater monitoring data that are adequate to establish baseline data for use in comparing subsequent data submitted by the operator pursuant to this article.

(6) Weather data and a water balance analysis sufficient to assess the likelihood of standing water occurring within the solar evaporator.

(b) The regional board shall, within 30 calendar days after receiving the notice submitted pursuant to subdivision (a), review its contents, inspect, if necessary, the site where the proposed solar evaporator will be located, and notify the operator of the proposed solar evaporator whether it will comply with the requirements of this article. If the regional board determines that the proposed solar evaporator will not comply with this article, the regional board shall issue a written response to the applicant identifying the reasons for noncompliance. If the regional board determines the solar evaporator will comply with the requirements of this article, the regional board shall issue a written notice of plan compliance to the operator of the proposed solar evaporator.

(c) Any person who receives a written notice of plan compliance pursuant to subdivision (b) shall, before operating the installed solar evaporator, request the regional board to conduct a compliance inspection of the solar evaporator. Within 30 calendar days after receiving a request, the regional board shall inspect the solar evaporator and notify the operator whether it complies with the requirements of this article. If the regional board finds that the solar evaporator does not comply with the requirements of this article, the regional board shall issue a written response to the applicant identifying the reasons for noncompliance. Except as provided in subdivision (e), if the regional board determines that the solar evaporator complies with the requirements of this article, the regional board shall issue a written notice of authority to operate to the operator of the solar evaporator. The regional board may include in the authority to operate any associated condition that the regional board deems necessary to ensure compliance with the purposes and requirements of this article.

(d) No person may commence the operation of a solar evaporator unless the person receives a written notice of authority to operate the solar evaporator pursuant to this section.

(e) (1) On and after January 1, 2008, a regional board may not issue a written notice of authority to operate a solar evaporator pursuant to this section.

(2) The requirements of paragraph (1) do not affect the validity of any written notice of authority to operate a solar evaporator issued by the regional board before January 1, 2008.

(f) The regional board shall review any authority to operate issued by the regional board pursuant to this section every five years. The regional board shall renew the authority to operate, unless the regional board finds that the operator of the solar evaporator has not demonstrated compliance with the requirements of this article.

25209.14. (a) Any person operating a solar evaporator shall annually, according to a schedule established by the regional board pursuant to subdivision (b), submit groundwater monitoring data and any other information that is deemed necessary by the regional board to ensure compliance with the requirements of this article.

(b) Each regional board shall adopt a schedule for the submission of the data and information described in subdivision (a) at the earliest possible time. The regional board shall notify the operator of each solar evaporator of the applicable submission schedule.

25209.15. (a) The regional board, consistent with its existing statutory authority, shall inspect any solar evaporator that is authorized to operate pursuant to Section 25209.13 at least once every five years to ensure continued compliance with the requirements of this article. In conducting any inspection, the regional board may request the participation of a qualified state or federal avian biologist in a technical advisory capacity. The regional board shall include in the inspection report conducted pursuant to this section any evidence of adverse impacts on avian wildlife and shall forward the report to the appropriate state and federal agencies.

(b) If the regional board, as a result of an inspection or review conducted pursuant to this article, determines that a solar evaporator is not in compliance with the requirements of this article, the regional board shall provide written notice to the operator of the solar evaporator of that failure, and shall include in that written notice the reasons for that determination.

(c) Chapter 5 (commencing with Section 13300) of, and Chapter 5.8 (commencing with Section 13399) of, Division 7 of the Water Code apply to any failure to comply with the requirements of this article and to any action, or failure to act, by the state board or a regional board. The regional board may, consistent with Section 13223 of the Water Code, revoke or modify an authorization to operate issued pursuant to this article.

25209.16. (a) For the purposes of Chapter 3.5 (commencing with Section 11340) of Part 1 of Division 3 of

Title 2 of the Government Code, including Section 11349.6 of the Government Code, the adoption of the regulations required to be adopted pursuant to Section 25209.12 is an emergency and shall be considered by the Office of Administrative Law as necessary for the immediate preservation of the public peace, health and safety, and general welfare.

(b) Notwithstanding Chapter 3.5 (commencing with Section 11340) of Part 1 of Division 3 of Title 2 of the Government Code, any emergency regulations adopted by the state board pursuant to Section 25209.12 shall be filed with, but not be repealed by, the Office of Administrative Law and shall remain in effect until revised by the state board.

25209.17. Any solar evaporator operating under a valid written notice of authority to operate issued by the regional board pursuant to this article, including any facility operating pursuant to Article 9.5 (commencing with Section 25208) prior to January 1, 2003, that the regional board determines is in compliance with the requirements of this article, is not subject to Article 9.5 (commencing with Section 25208) or Sections 13260 or 13263 of the Water Code. Upon determining pursuant to this section that a facility is a solar evaporator in compliance with this article, the regional board shall, as appropriate, revise or rescind any waste discharge requirements or other requirements imposed on the operator of the facility pursuant to Article 9.5 (commencing with Section 25208) or Section 13260 or 13263 of the Water Code.

SEC. 3. No reimbursement is required by this act pursuant to Section 6 of Article XIII B of the California Constitution because the only costs that may be incurred by a local agency or school district will be incurred because this act creates a new crime or infraction, eliminates a crime or infraction, or changes the penalty for a crime or infraction, within the meaning of Section 17556 of the Government Code, or changes the definition of a crime within the meaning of Section 6 of Article XIII B of the California Constitution.

California Regional Water Quality Control Board
Central Valley Region

NOTICE OF INTENT

TO COMPLY WITH THE CONDITIONS OF ARTICLE 9.7.
Commencing with Section 25209.10 of the Health and Safety Code
Integrated On-Farm Drainage Management

FACILITY

A. NAME OF FACILITY OR BUSINESS OPERATING THE FACILITY:____

ADDRESS OF FACILITY: ____
Number and Street City Zip Code

COUNTY:____

CONTACT PERSON:__________________________________ TELEPHONE NO.________________________________

B. NAME OF LEGAL OWNER OF FACILITY:____

ADDRESS OF LEGAL OWNER OF FACILITY:____
Number and Street City Zip Code

CONTACT PERSON:__________________________________ TELEPHONE NO.________________________________

C. NAME OF CONTACT PERSON TO RECEIVE REGIONAL BOARD CORRESPONDENCE:__________________________

ADDRESS OF CONTACT PERSON:____
Number and Street City Zip Code

TELEPHONE NO. OF CONTACT PERSON: ________________________________

LOCATION OF SOLAR EVAPORATOR

NUMBER OF ACRES ________ SECTION ____, TOWNSHIP ____, RANGE ____. APN __________ COUNTY _______

Provide a map of the area of the complete IFDM system (including irrigated fields for reuse) and indicate location of solar evaporator, tile lines, and monitoring wells.

DESIGN OF SOLAR EVAPORATOR

Provide a technical report prepared by an appropriately-registered California professional for the design of the solar evaporator. The report should describe of the capacity and the equipment to operate the solar evaporator. Explain features to prevent inundation from a 100-year flood. Include the tile drain design and the soil properties such as permeability, grain size distribution, percent clay, etc.
MAXIMUM ANTICIPATED RATE OF DISCHARGE TO THE SOLAR EVAPORATOR _________

OPERATIONAL PLANS FOR COMPLIANCE

Provide a plan for compliance with the requirements of article 9.7. Plans must include measures to prevent standing water, mitigate wildlife impacts, and prevent migration of constituents from the solar evaporator into the vadose zone. Include weather data and a water balance sufficient to assess the likelihood of standing water, and supporting the design of the solar evaporator.

CALIFORNIA ENVIRONMENTAL QUALITY ACT (CEQA) COMPLIANCE

HAS ANY CEQA DOCUMENT BEEN ADOPTED/CERTIFIED BY A LEAD AGENCY FOR THIS PROJECT?
______YES ______NO (IF YES, PLEASE ENCLOSE A COPY OF THE ADOPTION/CERTIFICATION)

IF NO, WILL ANY CEQA DOCUMENT BE PREPARED? ______YES ______NO

IF YES, WHO WILL PREPARE THE CEQA DOCUMENT? ____

APPROXIMATE DATE OF COMPLETION____________________

CERTIFICATION

I HEREBY CERTIFY UNDER PENALTY OF PERJURY THAT THE INFORMATION PROVIDED IN THIS NOTICE OF INTENT AND IN ANY ATTACHMENTS IS TRUE AND ACCURATE TO THE BEST OF MY KNOWLEDGE. IN ADDITION, I CERTIFY THAT THE CONDITIONS OF ARTICLE 9.7 OF THE HEALTH AND SAFETY CODE WILL BE COMPLIED WITH.

____________________________________ ____________________________________
SIGNATURE OF OWNER OF FACILITY SIGNATURE OF OPERATOR OF FACILITY

____________________________________ ____________________________________
PRINT OR TYPE NAME PRINT OR TYPE NAME

____________________________________ ____________________________________
TITLE AND DATE TITLE AND DATE

Atmospheric Salt Emissions from the Concentration of Agricultural Drainage Water by Sprinkler Evaporator

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Abstract

The Integrated On-Farm Drainage Management system that is being developed for use on the Westside of the San Joaquin Valley uses a solar evaporator as the final disposal mechanism for the salt laden water. The solar evaporator works by circulating the water through a network of horizontal fan sprinklers placed close to the ground. The effect of using these sprinklers is that evaporation is increased, but salt particulate is entrained in the air and carried away from the perimeter of the solar evaporator. The study developed a method to quantify the deposition flux downwind of the solar evaporator. The deposition downwind of the system was quantified for multiple sprinkler heights, and water sources and regression lines fit to the deposition to have a more complete understanding of the extent of the effects downwind of the system. Although no statistically significant differences were found between the regression lines, it was possible to accurately determine the deposition fluxes out to a distance of approximately 200 meters. At that point there was minimal difference between the measured deposition flux and background levels.

The salt particle loss rate from the solar evaporator during normal operation is approximately 1 kg/hr. Nearly all of that is deposited on the surface 200 meters or less from the source. The salt particles small enough to be carried beyond that point may be small enough to be regulated as PM_{10} but are such a small fraction of the total that they are 10 to 100 times less than the regulation threshold.

Conclusions

The universal constant in all sampling dates is that there is a significant drop in deposition rates as the radius increases close to the system with less chance as distance increases. This leads to the law of diminishing returns when deciding what an appropriate buffer zone around the system would be. It is clear that at 200 meters downwind of the source there is insignificant salt deposition during normal operating periods (evaporation of sump water). Although operation during the highest source strength did yield some measurable deposition at that distance, the frequency of operation in these conditions is minimal. Therefore, 200 meters appears to be the maximum amount of buffer needed downwind of the solar evaporator to prevent significant deposition from occurring on sensitive crops. It may be decided that some salt deposition is acceptable on the crop in that area and the distance could be reduced to 100 meters. This decision will depend on the crop that is planted in this area and its specific tolerance to salt deposition.

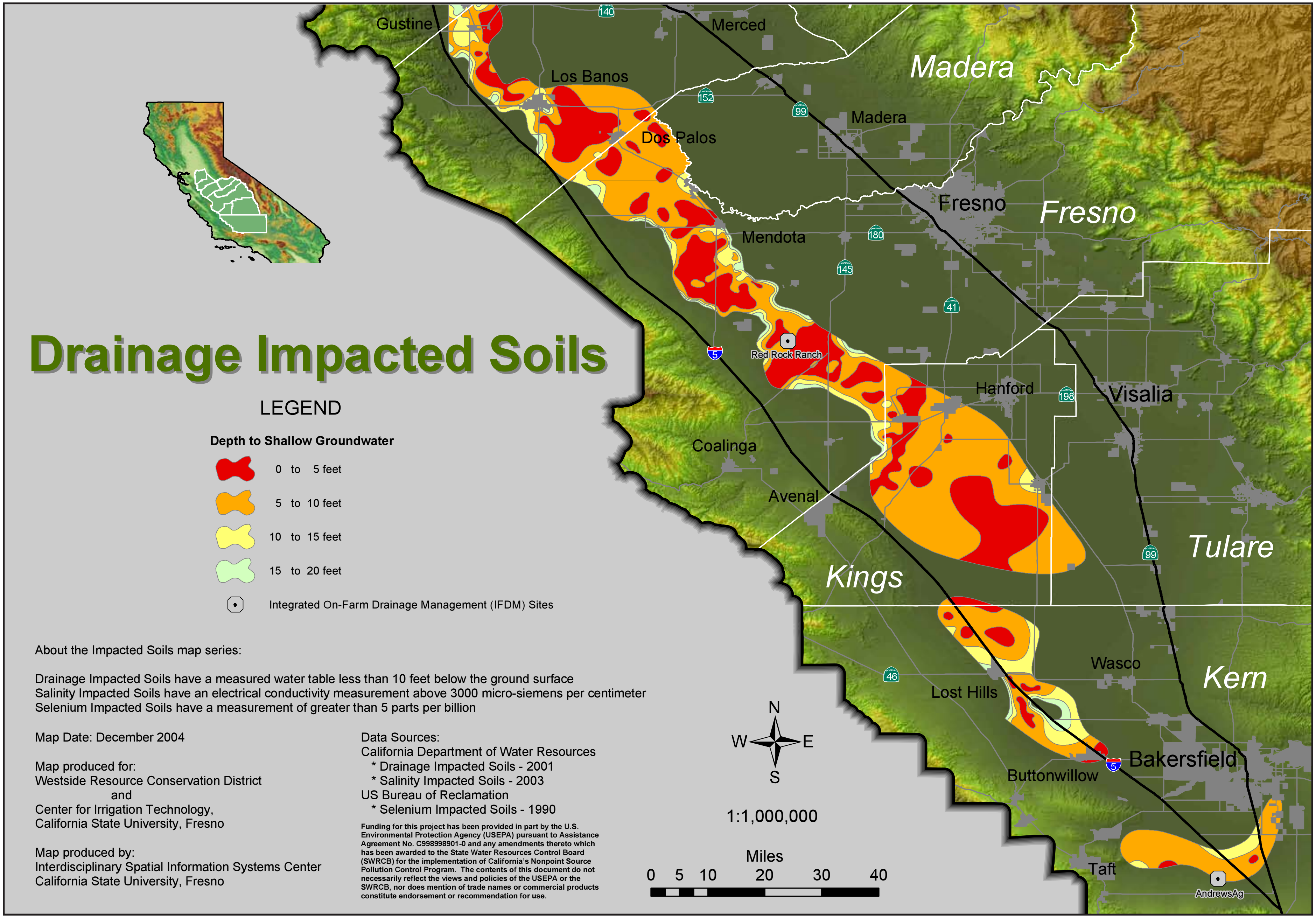
Operation of the solar evaporator with the fence in place decreases the total emissions of particles by interfering with the wind pattern at sprinkler level, thus reducing particle entrainment as well as intercepting some of the emissions before they leave the system perimeters. The fence also increases the effective emission height, thus increasing the dispersion of the plume. This will lead to higher deposition close to the solar evaporator, tailing off at a higher rate.

Analysis of the plume of salt dispersion and deposition was only conducted on the south and east sides of the solar evaporator because the prevailing wind at the site is constant from the Northwest. There should be some consideration given to a buffer zone completely surrounding the facility if the system is to be operated where the wind is more variable.

The particle emissions from the operation of the solar evaporator are a combination of those that are large enough to be deposited on the soil surface within the downwind plume and those that are small enough to remain entrained in the air. The small particles are those that could subject the solar evaporator facility to air quality regulations related to PM standards.

1. The re-deposition of salt within the downwind plume was considered to be the primary problem, as stated in the title of the project. A methodology from the literature enabled field data to be collected to measure salt deposition so that characteristic equations could be used to predict the quantity and location of the deposition. Several sampling episodes under a variety of operating conditions produced data that could be modeled to characterize the deposition. The average deposition of salts from the solar evaporator was less than 1 kg/hour and occurred within 200m of the source. A single sampling event when the most concentrated drain water was being evaporated produced the maximum of 3.5 kg/hr.
2. While it was not possible within the time and budget available to directly measure the small particles that remained in the air, it is possible to determine their significance with regard to the potential for regulation of a solar evaporator as a PM source. The particles produced by the solar evaporator were predominantly larger than those that would remain entrained as shown in the deposition patterns discussed above. The mass of deposited particles would be at least an order of magnitude and perhaps two greater than the entrained particles. The emissions of these particles which may be small enough to be classified as PM_{100} or $PM_{2.5}$ are insignificant compared to the levels that would result in regulation or even permitting of a facility. The threshold for permitting a facility is 12.5 tons of emissions/year. The threshold for regulation is 25 tons/year. The total salt emission rate (both deposited and entrained) from the solar evaporator would average about 1 kg/hr. This total, from continuous (24/7/365) operation of the solar evaporator would only be 9.6 tons/year. The particles small enough to be regulated are a very small fraction of that total so the PM emissions from the solar evaporator can be considered to be insignificant.

Results from this study have been discussed at the July and August meetings of the Agricultural Technical Committee of the San Joaquin Unified Air Pollution Control District. The conclusions regarding the emissions from the existing solar evaporator as being well below any threshold of regulation or permitting were accepted by that committee. Further discussion with air district staff regarding the effect of scaling up the evaporator to larger sizes will occur. An attempt will be made to get air district input regarding the facility size at which PM-10 emissions might reach levels requiring permitting.



Drainage Impacted Soils

LEGEND

Depth to Shallow Groundwater

- 0 to 5 feet
- 5 to 10 feet
- 10 to 15 feet
- 15 to 20 feet
- Integrated On-Farm Drainage Management (IFDM) Sites

About the Impacted Soils map series:

Drainage Impacted Soils have a measured water table less than 10 feet below the ground surface
Salinity Impacted Soils have an electrical conductivity measurement above 3000 micro-siemens per centimeter
Selenium Impacted Soils have a measurement of greater than 5 parts per billion

Map Date: December 2004

Map produced for:
Westside Resource Conservation District
and
Center for Irrigation Technology,
California State University, Fresno

Map produced by:
Interdisciplinary Spatial Information Systems Center
California State University, Fresno

Data Sources:
California Department of Water Resources
* Drainage Impacted Soils - 2001
* Salinity Impacted Soils - 2003
US Bureau of Reclamation
* Selenium Impacted Soils - 1990

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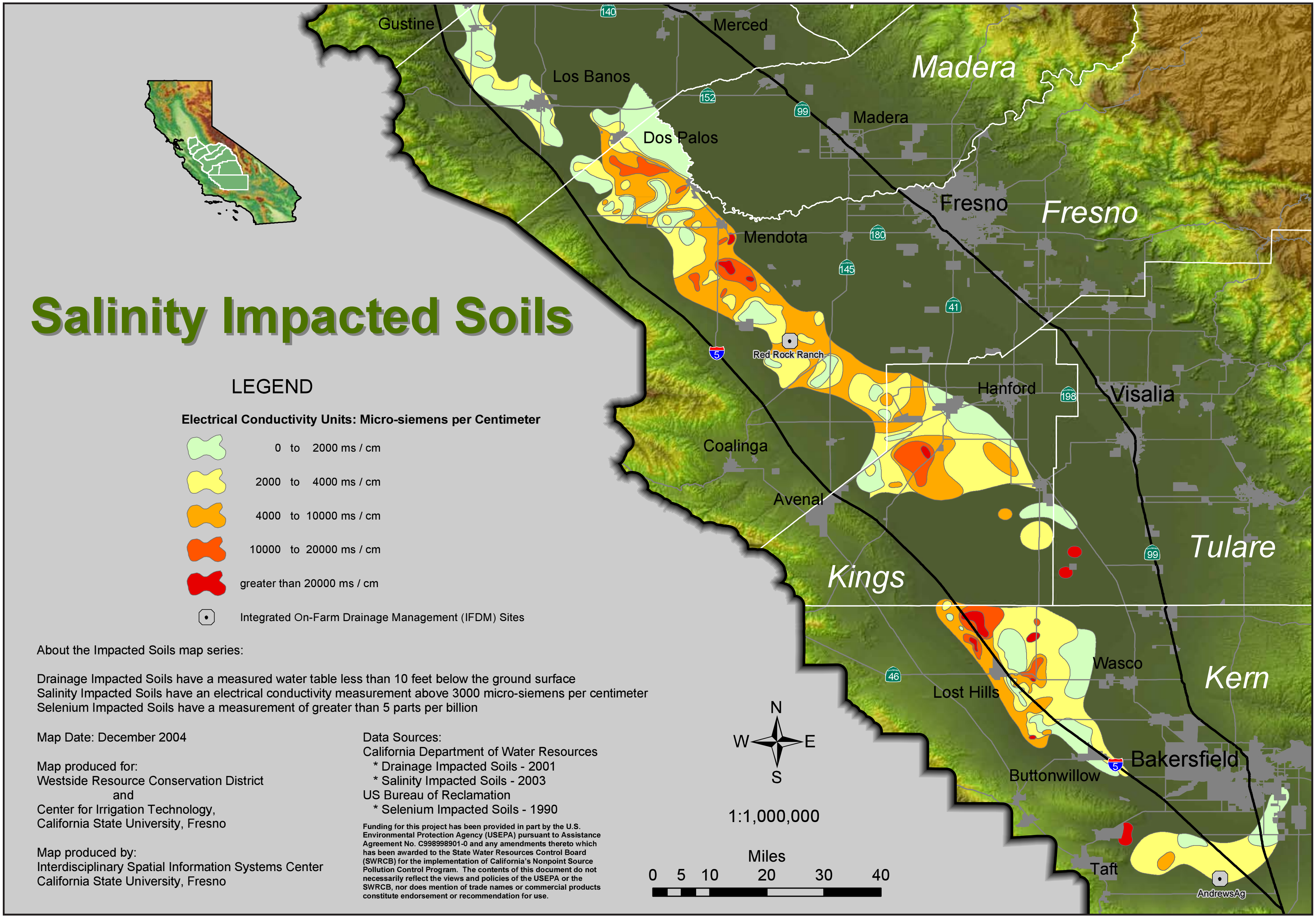
Salinity Impacted Soils
LEGEND
Electrical Conductivity Units: Micro-siemens per Centimeter
0 to 2000 ms / cm
2000 to 4000 ms / cm
4000 to 10000 ms / cm
10000 to 20000 ms / cm
greater than 20000 ms / cm
Integrated On-Farm Drainage Management (IFDM) Sites
About the Impacted Soils map series:
Drainage Impacted Soils have a measured water table less than 10 feet below the ground surface
Salinity Impacted Soils have an electrical conductivity measurement above 3000 micro-siemens per centimeter
Selenium Impacted Soils have a measurement of greater than 5 parts per billion
Map Date: December 2004
Map produced for:
Westside Resource Conservation District
and
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California State University, Fresno
Map produced by:
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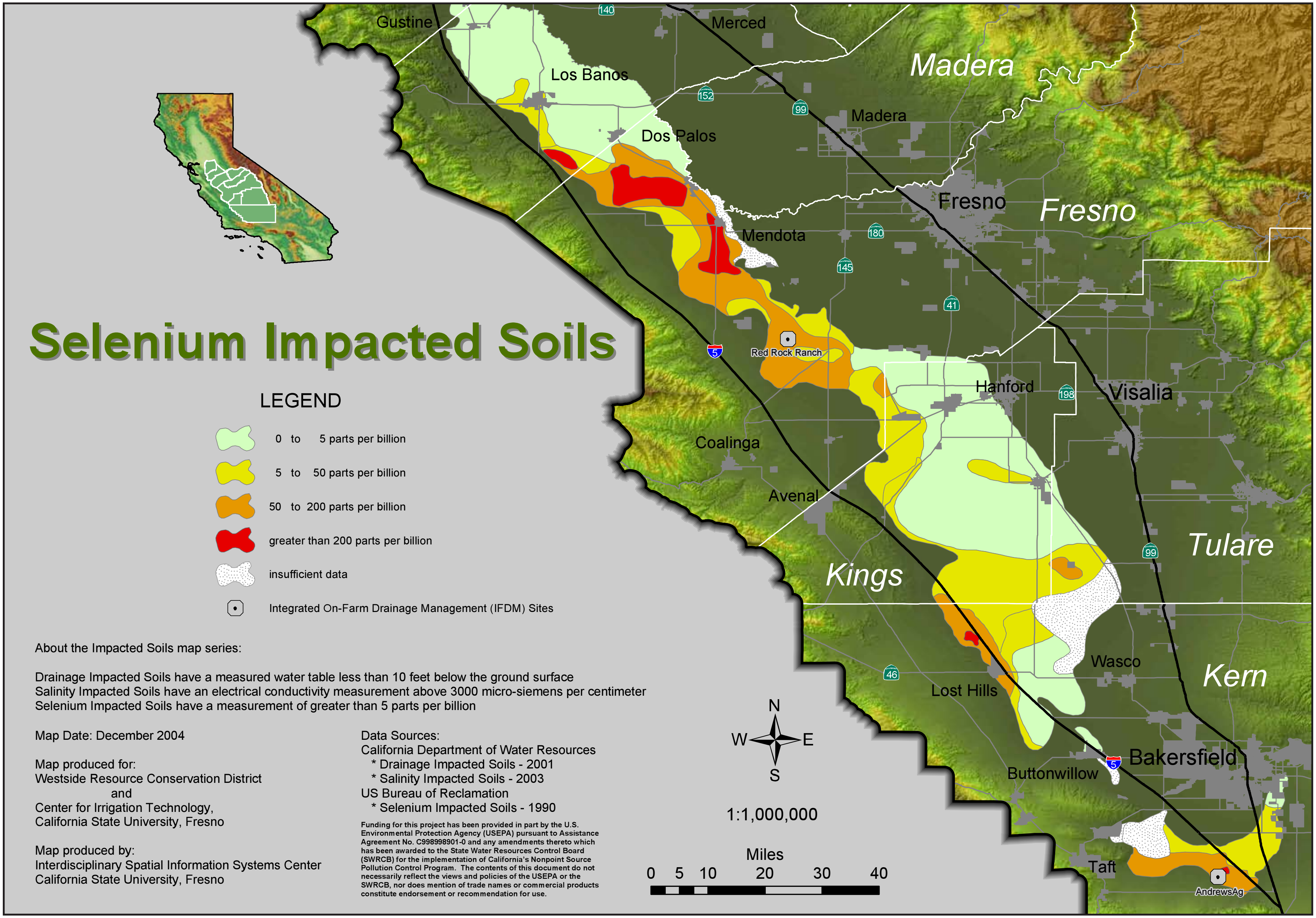
Gustine
Merced
Madera
Los Banos
Dos Palos
Madera
Fresno
Fresno
Mendota
Red Rock Ranch
Hanford
Visalia
Coalinga
Avenal
Kings
Tulare
Wasco
Kern
Lost Hills
Bakersfield
Buttonwillow
Taft
AndrewsAg
140
152
99
180
145
41
5
198
99
46
5

Selenium Impacted Soils



LEGEND

- 0 to 5 parts per billion
- 5 to 50 parts per billion
- 50 to 200 parts per billion
- greater than 200 parts per billion
- insufficient data
- Integrated On-Farm Drainage Management (IFDM) Sites

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Selenium Impacted Soils have a measurement of greater than 5 parts per billion

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