California Department of Water Resources
FINAL REPORT

Findings and Recommendations to Develop the Six-Year Activity Plan for the Department's Drainage Reduction and Reuse Program

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The primary purpose of this contract was to compile documentation of the state of knowledge and understanding of drainage water reuse studies, research and demonstration projects. This was to help identify appropriate technologies that can be recommended for implementation at the farm level. Findings and recommendations of this work are to be used to develop the six-year activity plan for the Department of Water Resource Drainage Reduction and Reuse Program. The specific objectives of the work were (1) to collect, analyze and evaluate published reports and unpublished data on studies, field experiments, and demonstrations on the reuse of agricultural drainage water for irrigation in the drainage problem areas of the western San Joaquin Valley, and (2) to identify and prioritize the need for additional study, research and field demonstration proposals and projects that should be implemented in the next 6 years.

A review of some aspects of the scientific basis for drain water use for irrigation is presented before reviewing specific field research and demonstration projects. Key items identified in the scientific basis section include the fact that models have been developed which will allow the simulation of (1) crop yield, (2) amount and concentration of water leaving the root zone, and (3) salt and water distributions within the root zone on a temporal basis based on the salinity and amount of irrigation water applied. The model can be used to simulate the behavior for any crop for which salinity crop tolerance coefficients have been established.

Groundwater hydrology, particularly as it relates to the amount and chemical composition of water collected in subsurface drainage systems, is of paramount importance in understanding the present and long-term consequences of irrigating with saline water. Although models and other theories can be used to estimate the concentration of water moving below the root zone, the concentration of water collected in the drainage system can differ dramatically from the concentration leaving root zone. This is the result of the path that water takes after it leaves the root zone towards the drain line. Water midway between two drainage lines will sweep tens of feet below the water table before ascending up into the drain line. Water originating closer to the drain line will arrive at the drainage line at a shorter time.

The significance of these travel times as related to the western San Joaquin Valley is as follows. The alluvial materials historically originated below the sea and therefore contain high concentration of salts and other elements associated with a marine environment. The water collected in a drainage system is a combination of the groundwater and water that has left the root zone. If the field has been irrigated with nonsaline water, the drainage water collected will, in most cases, contain a higher quantity of salt than was applied with the irrigation water. In a sense the historic salts are being "mined" and brought to the surface with the drainage water. Because of the huge reservoir from which drainage waters are derived the rate of dissolution of precipitated salts such as gypsum and the large travel times, the "excessive" salts can be mined for several decades or centuries. This is the reason that selenium continues to be removed in the drainage water even though the fields have been irrigated for years with water with almost no selenium. In one sense, because the salts and chemicals such as selenium contained in the drainage water exceeded the amount that was applied with the irrigation water; the groundwater quality could be considered to be improved by irrigation and drainage.

When saline waters are used for irrigation and become highly concentrated before they leave the root zone, the captured water in the drainage system will contain less salt than what left the root zone. In this case, salts are being added and "stored" in the groundwater system. This process causes salts to accumulate in the groundwater which will eventually result in a continual increase in the concentration of the drainage water.

From a salt balance point of view, imported irrigation waters also import salt. Reusing drainage waters for irrigation results in a continual accumulation of salts. However, because of the large reservoir for salts in the groundwater the consequences of adding additional salts will be manifest in a very slow manner.

Another significant scientific principle is that the evapotranspiration rate is dependent upon the plant size as well as the climate. Reducing the plant size reduces the transpiration. Therefore, if a plant is stressed by salinity, less water will be transpired than expected. This was a significant factor in the utility of eucalyptus trees to dispose drainage water.

The initial concept for disposing drainage water was to use eucalyptus trees to transpire water and produce a marketable product. Numerous plantings of eucalyptus were made throughout the Valley. Some of the plantings were simply to test various clones. In general, eucalyptus trees have not proved to be effective for drainage water disposal in the western San Joaquin Valley. The major deterrents were (1) lower salt tolerance than originally anticipated, (2) susceptible to frost damage, and (3) susceptible to low oxygen status associated with wet soils. Based on the salt tolerance of eucalyptus, the salinity level of drainage water and the leaching fraction that could be achieved under the soil conditions, the trees only transpired from 60 to 70 per cent of the potential transpiration. Efforts to increase the leaching fraction by applying more water negatively affected the plants by inducing low oxygen status in the soil. The accumulated effects of all these factors, is that eucalyptus are no longer considered to be a crop used for drainage water disposal.

Two major drainage water use demonstration projects have been established at a site near Mendota and at the Red Rock Ranch. The Mendota Project was initiated in approximately 1986 consisting of trees, most of which were eucalyptus. A few halophytes were also investigated at that site. The frost in 1990 killed the eucalyptus trees and the project was reinitiated in approximately 1992. The more recent demonstration included trees, halophytes and an evaporator pond.

The design of the Red Rock Ranch project was guided by results from the Mendota site. A significant feature of the Mendota site study was that it was conducted on relatively small plots with drain lines placed immediately below the plots and a very low permeable clay layer existing ten to twelve feet in depth. Under these conditions, the chemical composition of the drainage water would be very similar to that leaving the root zone. However, the data from the halophyte plots at Mendota suggest some complex subsurface hydrological effects which negates meaningful interpretation of the composition of the drainage water collected under the halophytes. For example, the salt concentration in the drainage water was equal to the salt concentration of the irrigation water applied without any concentrating effect from evapotranspiration. At the same time, the total mass of salts collected in the drainage lines was approximately half of the total mass of salts applied to the plants.

The Integrated Farm Drainage Management Project (IFDM) was conducted on 640 acres at the Red Rock Ranch. Initially, the soil salinity on this land was high and productivity very low. The concept was to install subsurface drainage lines which would allow the reclamation of the land by leaching with good quality water, so that salt sensitive crops could be grown. Approximately 75 percent of the farm was to be used for growing salt sensitive crops. The drainage water was then to be sequentially used on an area growing salt tolerant crops, followed by salt tolerant trees which were later planted to salt tolerant grasses, followed by halophytes and ultimately disposal in a solar evaporator. The entire concept was to collect dry salts in the solar evaporator which could, after some processing be marketed at an economic value. The concept of an evaporator pond is to apply water only at the rate at which it evaporates, thus not ponding any water to attract water fowl.

Reclamation of 75 percent of the farm was successful, and the land has been productive for growing a range of crops. One of the most significant findings from the Red Rock Project is verification of the significance of travel times for water reaching drainage lines. More salt was collected in the drain lines than was applied with irrigation water. In the salt sensitive areas there was net removal of salts from the groundwater. With the sequential reuse of drainage water, the total amount of salt in the drainage water was less than was applied by irrigation. Thus, there was a net increase of salinity added to the groundwater as the drain water was sequentially used. At the end only about six percent of the salt was deposited in the evaporator pond as compared to the expected amount based on salts added to the farm. In a consistent manner, the salt concentration in the drainage water only rose gradually from 8,011 to 8,872 to 12,016 to 11, 189 mg/L with each sequential reuse. None of the drainage waters was sufficiently concentrated, requiring the use of halophytes. Of critical importance, however, is the fact that salts added to the groundwater system will eventually be returned in the drainage waters. Thus one can expect a gradual long term increase in salinity of the drainage waters which constrains the sustainability of the system.

The experience at Red Rock Ranch has focused the complexity of properly designing an evaporator pond. The design of an evaporator pond to prevent any ponding is extremely complex. One would need information on the temporal variations in evaporation rate (which would vary annually), and drainage water volume. These data could be used to calculate the pond area that would evaporate all the water delivered daily. This constraint dictates that the pond be large and rather inefficient because much of the time the potential for evaporation is likely to exceed the rate of water discharge.

The pond size could be made more efficient if there was a large capacity to store drainage water and then deliver it on a daily basis consistent with the evaporation rate. Another factor which largely constrains the utility of evaporator ponds is that salts do accumulate. They are dissolved creating a very high concentration by rain water collected in the pond. Since rain is associated with low evaporation rate, very concentrated water could exist in the pond for some period of time during a rainy season. The concentration of selenium can exceed 1 mg/L which creates a violation of the Toxic Pits Act.

Periodic episodes of excessive water containing selenium in the halophyte and evaporator pond area, creating some bird damage has jeopardized the drainage discharge permit. Efforts are presently underway to adjust the system to be within environmental compliance.

The Grasslands area farmers have the benefit of being able to discharge drainage water into the San Joaquin River as long as they meet discharge limits. The magnitude of the discharge limits, however are decreased yearly. Largely through improved irrigation management the Grasslands farmers have been able to reduce discharge into the river by about 40 percent. Some reduction has been achieved by blending drainage water into the main surface water supply. For example, Panoche Drainage District blends drainage water into their canal water to a level of 600 ppm total dissolved solids. This water is suitable for growing all crops in the area. Direct drainage water reused (with possibly minor blending) on forages has recently been tested in various Grasslands projects. However, these efforts are in their initial stages and it is too early to draw any firm conclusions.

Available information on salt tolerance of a large number of diverse crops is presented in the report. The main conclusion is that there are numerous crops that could be considered for irrigation with saline waters. A large range of management options are available for farmers to cope with the salinity/drainage issue. The ultimate selection should be based on the economically optimal set of choices.

Although there is much scientific information available to guide the management of the salinity/drainage issue in the western San Joaquin Valley, there are areas where additional research is justified.

Management to reduce drainage volumes is firmly recognized as a positive management option. Great progress has been made towards modifying irrigation to reduce drainage volumes. An additional option to be explored, however is to have an active control on the drain line outlet. Some of the advantages of controlling the drainage outlet are to store water in the profile for potential crop use, or for discharge on a more timely basis to disposal sites. Also, control of the drainage outlet will alter hydraulic gradients which potentially could reduce upslope to downslope water migration and also increase downward migration of water below the field. The required research is more than engineering to develop the control systems, the research should be directed towards the total management practices including a monitoring technique to determine when and how much leaching is required on a timely basis.

The data particularly at Red Rock Ranch clearly illustrate the complex interaction between water and chemicals leaving the root zone and then being collected in the drainage lines. The underground hydrology including travel times to drainage lines needs to be more quantitatively established. This analysis is critical to project the long-term consequences of using drainage water for irrigation. Because of the complex geologic system accurate quantitative projections cannot be reasonably expected. Nevertheless, reasonable projected estimates are important in guiding policy decisions relative to short-term benefits and long-term consequences of agricultural drainage water reuse.

Numerous combinations of management options are available. Each combination of options invokes a set of costs and benefits. Additional economic analysis to identify the economically optimal combination of management is required for planning purposes. The research identified, however is important for providing accurate input information into the economic analysis.

Whether boron is going to be a limiting factor in the reuse of drainage waters is presently disputed. This question needs to be more firmly resolved. Additional information is important on; (1) relationship between visual leaf symptoms and yield associated with boron damage, (2) dynamic interacting relationships between boron concentration in irrigation water, adsorption of boron, boron uptake, boron effects on yield, and the leaching of boron, and (3) whether boron damage will ever exceed salinity damage when using saline drainage water.

Reusing drainage water is building up the salinity in the groundwater which will have long term consequences from a sustainability point of view. A salt balance, whereby salts added equals salts removed, with proper consideration for precipitation or dissolution of salts, is necessary for sustainable agriculture. Since salts are imported with irrigation water, a means of ultimately isolating salts from productive agricultural fields is required for sustainability. One option is to transport the salts out of valley. This option has strong political opposition. The only in-valley solution is to place the salts in evaporation ponds. However, this option is constrained by selenium and the damage to wildlife.

Therefore, basic research to reduce the ecological hazard of surface waters containing selenium is important. Additional basic information on selenium food chain transfers and ecotoxicological hazard is critical. This research might include evaluation of brine shrimp or other invertebrate harvesting to interrupt the food chain.

Because selenium is the toxicant of concern, extended research to develop practical selenium removal methods is justified. The initial results of flowing water through hay bales to greatly reduce the selenium concentration are promising but needs additional testing and refinement.

Science can provide the information to guide management and policy decisions. Science may even be able to project the long-term consequences of a policy decision, however science alone is inadequate because science does not include human or economic values that underlie the decisions societies make. The major policy issue in the present context is the trade off between short-term benefits of reusing water with the long term serious consequences of degrading the groundwater and land. Mesopotamia is the often repeated classic example about a society that transformed very productive agricultural land into a desert. A consideration that is frequently overlooked is that this transition occurred over centuries of time. Because it took centuries of time, rather than decades was it any less an historical disaster?

INTRODUCTION

The primary purpose of this contract was to compile a documentation of the state of knowledge and understanding of drainage water reuse studies, research, and demonstration projects. The purpose was to help identify appropriate technologies that can be recommended for implementation at the farm level. Findings and recommendations of this work are to be used to develop the sixth-year activity plan for the Department of Water Resources Drainage Reduction and Reuse Program.

The specific objectives of this work were: (1) to collect, analyze and evaluate published reports and unpublished data on studies, field experiments and demonstrations on the reuse of agricultural drainage water for irrigation in the drainage problem areas of the western San Joaquin Valley and (2) to identify and prioritize the need for additional study, research and field demonstration proposals and projects that should be implemented in the next 6 years.

A vast array of resources were utilized in compiling this report. Several individuals whose names are listed elsewhere in this report were interviewed. Quarterly, annual and final reports on projects and/or contracts on water reuse studies were very helpful in documenting results of studies which have not been published in technical journals. Four boxes of material stored at the DWR Fresno Office were shipped to us. These boxes contained a variety of documents. There was a collection of research papers and other general information on trees, halophytes, or other plants that might be useful for irrigation with saline drainage water. There was a collection of San Joaquin Valley Drainage Water data. Of particular value where the raw data and field notes on various agroforestry case studies established in the Valley. This material provided "new" information not included in other reports or generally available.

The challenge of sustaining agriculture in irrigated, semi-arid regions of the world where salinity is an issue can be documented back to the early recorded history of society. Extensive research has been devoted to this topic. Indeed, some countries established national laboratories specifically dedicated to the research of soil salinity related issues. Among these is the USDA-ARS, George E. Brown Jr. Salinity Laboratory located at Riverside, California. Therefore, extensive research information on irrigation with saline waters is available. The presence of selenium in the drainage water is a unique feature associated with the problem in the western San Joaquin Valley that has not been addressed in previous generations. Indeed, the presence of selenium places tremendous constraints on the various options available for managing drainage waters.

The first section of this report will provide a scientific basis for drain water use for irrigation. This section will contain the basic information which can be compared to and in some cases, explain the results of the field demonstration projects.

This report will be organized based on the following rationale. The initial promoted means of using drainage water for irrigation was on trees with the greatest emphasis placed on eucalyptus trees. The term "agroforestry" was utilized to describe this approach. Therefore, the first section following the scientific basis will review the various cases where trees were planted on various locations. A more completely designed and monitored system on drain water reuse for irrigation was established at a Mendota Site. A description of the project and report on the major findings will be included in the next section of the report. The establishment of the Integrated On-Farm Drainage Management (IFDM) program at the Red Rock Ranch was initiated following the Mendota Site project and will be the next section of this report. The Grasslands Bypass Project whereby farmers in the Grassland areas, have developed management plans to meet selenium load discharge limits into the San Joaquin River is a more recent development and will be summarized in a section following the Red Rock Ranch Demonstration.

A major section of this report will review what is known of several crops which might be considered to be irrigated with saline waters. The section will cover agronomic crops, vegetable crops, forages, trees and halophytes.

The final section will provide a brief assessment of research needs.

SCIENTIFIC BASIS FOR DRAINWATER USE FOR IRRIGATION

Introduction

Nature is controlled by inviolable, chemical, physical and biological laws. Advances in technology have resulted from research designed to discover these laws and then applying these laws to achieve the desired result. However, natural systems such as agricultural production include a vast array of physical, chemical and biological laws which interact in a very complex manner which are difficult to define and describe. Therefore, precise prescription for management to achieve a specific goal is difficult. Nevertheless, the probabilities of success in prescribing the best management operations are increased by applying the best scientific knowledge.

One major goal of our contract was to compile a comprehensive summary of research and demonstration projects that have been conducted during the last 20 years on use of saline drainage water for irrigation of agronomic crops as well as salt tolerant crops in the western San Joaquin Valley. In principle, the purpose of a demonstration project is to demonstrate the application of basic scientific knowledge in a practical field situation. A successful demonstration project is defined as one in which the results are consistent with the projected results based upon scientific knowledge. If the behavior of a demonstration project differs from the projected results, it implies that the basic scientific laws were not completely understood as they were applied to the system under consideration. A demonstration project from which the results differ from expectation may have the value of identifying shortcomings of the scientific understanding.

The purpose of this section of our report is to summarize some of the basic principles that should have application for agricultural drainage water use. This section is presented first so that it can serve as a basis for discussing the results from the demonstration projects which will be reported later in the report.

General Principles

All irrigation waters have some level of dissolved salts. Irrigation water is applied to soils from which pure water is released to the atmosphere through transpiration and/or evaporation. Thus, salts tend to concentrate in the root zone. Increasing salt concentration in the root zone will eventually decrease plant growth. Different crops have different degrees of tolerance to salinity in the root zone and therefore the level of salinity that can be accommodated in the root zone without yield reduction is crop specific. Nevertheless, there is an upper limit that can be accommodated by any plant.

Maas and Hoffman (1977) reviewed published research results of studies designed to compare plant growth to root zone salinity. They found that the data could be represented by curves such as depicted in figure 1. Growth is not reduced until a critical (threshold) salinity is reached and then the yield declines linearly with increasing salinity. The response is characterized by two coefficients: the threshold salinity and the slope of the lines for salinities greater than the threshold value. These coefficients are commonly referred to as the Maas and Hoffman Coefficients. Values of these coefficients for several crops can be found in various publications such as Maas and Grattan (1999). The more salt tolerant crops have higher threshold values. The slope of the declining curve is not necessarily reflective of the threshold value. A low slope identifies a crop that has relatively low decrease in yield as the salinity increases beyond the threshold value.

The salt concentration in the root zone can be controlled by occasionally applying more water than can be stored in the root zone and thus leach salts downward below the roots. Ideally, the amount of water applied for leaching purposes should be kept at a minimum because plant nutrients, particularly nitrates, are also leached from the roots along with the salts. Also high levels of leaching causes the water table to rise more rapidly and causing more drainage water in areas where subsurface drainage systems have been installed.

The optimal amount of applied irrigation water depends upon the salinity of the irrigation water, plant tolerance to salinity and the evapotranspiration (ET) of the crop. Although it is obvious that the amount of water required for leaching increases as the salinity of irrigation water increases, or as the plant tolerance for salinity decreases, the quantitative prescription of irrigation management cannot be established from this general understanding.

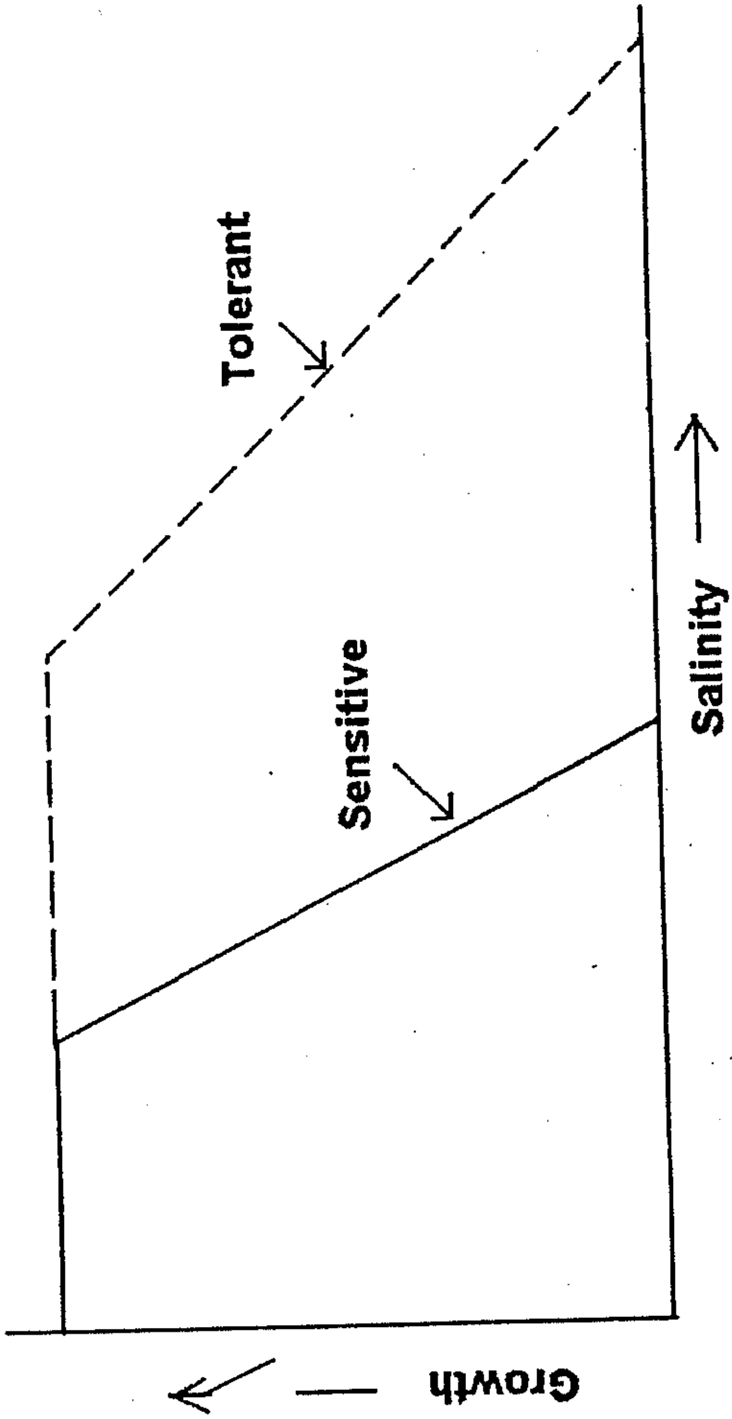


Figure 1. Generalized relationship between growth and average root zone salinity for salt-sensitive and salt-tolerant plants

One research approach is to conduct field experiments in which variable water application rates of different irrigation water salinities are applied and the yields are measured. However, several variables must be evaluated such as the amount of water applied, the salinity of the irrigation water, plant tolerance to salinity and the evapotranspiration rate. These variables make a complete field experiment almost impossible. As a result, most field experiments have been designed to investigate the effects of only one, or at most two, variables at one time.

Another approach is to develop models that appropriately combine all of the physical, chemical and biological laws applicable to the system in a manner to simulate the consequences of the various management options. A reliable model has the advantage of simulating the consequences of numerous management options in a short time which would take years and a huge budget to accomplish through field experimentation. Nevertheless the output from all models must be consistent with field observations and to the extent possible, quantitatively compared with field experiments, before they can reliably be used.

The next section reports the development and validation of a model. Later in the report, the model will be utilized to develop some basic principles involved with drainage water use.

Model Development

The model presented here is one component of the ENVIRO-GRO model (Pang and Letey, 1998). A basic component of the model is an equation describing the water flow through soil. The general water flow is described by:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(\theta)\frac{\partial H}{\partial z}\right] - A(z,t) \qquad [1]$$

where θ is the volumetric water content, t is time, z is depth, K (θ) is hydraulic conductivity, H is soil hydraulic head, and A (z,t) is a plant root extraction term. The first term ($\partial\theta/\partial t$) represents the rate of change of water content at a particular depth. The change in water content is dependent upon (1) the rate of water flow in and out of volume as described by the first term on the right hand of the equation, minus (2) the amount of water removed from the soil through root extraction and transferred to the leaf surface where it is transpired.

Salts in the water are considered to be conservative with no dissolution, precipitation, or plant uptake. Movement of salts is governed by the well-established convection-dispersion equation.

$$\frac{\partial(\theta C_s)}{\partial t} = \frac{\partial}{\partial z}\left[D_s(\theta,v)\frac{\partial C_s}{\partial z} - vC_s\right] \qquad [2]$$

Where C_s is salt concentration, v is the pore water velocity, and D_s is a combined diffusion and hydrodynamic dispersion coefficient of salt. The equation basically specifies that the change in concentration with time and any position is dependent upon the transport of salt with the flowing water and the movement of the salt by diffusion. The combination of equations of 1 and 2 describe the water and salt flow whereby the water and salt distribution in the root zone are computed.

The plant root extraction term (A) is what connects the plant to the soil system. The water uptake function is defined as:

$$A(z,t) = T_p(t)\Gamma\ (z,t)\sigma(h,\pi) \qquad [3]$$

Where T_p is the potential transpiration rate, Γ is a plant root distribution function, σ is a crop matric potential-salinity stress function, h is soil matric potential (related to soil dryness), and π is soil osmotic potential related to salt concentration. The terms in parenthesis merely identify that the value of the main variable is dependent upon the values identified in the parentheses. For example, A(z, t) identifies that the water uptake from the root may differ at different depths (z) and at different times (t).

The potential transpiration rate (T_p) is defined as the transpiration that would occur if the plant was not under stress from deficient water or excessive salinity. It is readily recognized that the transpiration of a crop, such as cotton, will change as the plant changes in size and maturity. The common procedure that has been adopted to quantify crop water use is to multiply the potential transpiration that is demanded from climatic conditions (T_c) times an empirically determined crop coefficient (K_c) which changes with time to account from canopy coverage or different stages of crop development. Thus T_p in equation 3 is substituted by the commonly recognized variables (T_c K_c).

The root distribution (Γ), must be specified by the user. In otherwords, there is nothing in the model which prescribes the rate at which roots will grow. The user must have an understanding of the typical rate of root growth and distribution of roots in the soil profile and program that into the model.

The third term in equation 3, identifies how the soil matric potential (h, related to soil dryness) and π (osmotic potential which is related to the salt concentration in the root zone) affect the water uptake by the plant. This term is defined as:

$$\sigma\ (z,t) = \frac{1}{1+\left[\frac{\beta h\ (z,t) + \pi(z,t)}{\pi 50}\right]^3} \qquad [4]$$

where β accounts for the differential response of the crop to the matric and osmotic influences and is equal to the ratio of π_{50} and h_{50}; where h_{50} and π_{50} are the values of h and π at which the maximum transpiration is reduced by 50 percent. Note that when h and π equal zero, Γ in equation 4 becomes equal to 1. The placement of a value of 1 for σ

in equation 2 specifies that the plant water uptake will be equal to the potential transpiration without any reduction due to stress.

Equation 4 specifies that any value of h and/or π greater than 0 creates stress which results in σ having a value less than 1. This result is inconsistent with the well-recognized fact that plant growth is not reduced until the soil dryness or salinity level reaches a critical stage after which growth is reduced. Thus, the model was programmed in a manner (that will not be described here) to incorporate values of h_t and π_t which are the threshold values.

It is recognized that if part of the root system has adequate water and another part of the root system in stressed that the plant will compensate for the stress by taking more water from the zone in which water is not limiting. Thus, the model was programmed such that water to meet the transpiration demand was taken up from root zones with adequate water until the entire root system had combined matric potential and salinity levels above threshold values.

Thus far, the model has not been linked with plant growth. The total transpiration is the summation of the sink term (A) over time and depth and is related to crop dry matter production in a linear relationship:

$$\mathbf{RY = RT} \qquad [5]$$

Where RY is yield relative to yield under nonstress conditions and RT is water uptake relative to potential transpiration under nonstressed conditions. A linear relationship between dry matter production and transpiration as expressed in equation 5 has been documented in many research studies. Marketable yields are of primary concern to growers. For crops that have a linear relationship between dry matter production and marketable yield, equation 5 is valid for computing relative marketable yield. If the relationship between dry matter and marketable yield is not linear than a relationship between the two yields must be known.

Because transpiration is related to plant size, another adjustment had to be made in the model. For a nonstressed plant, the potential transpiration was calculated to be equal to the climatic transpiration times a crop coefficient. However, the crop coefficients are empirically determined under nonstressed conditions. If the plant undergoes stress it will grow more slowly and the value of K_c must be adjusted accordingly. Thus the model is programmed for continual feedback whereby if there is stress on the plant due to salinity or dryness, then the value of the crop coefficient is adjusted to accommodate the reduced growth.

As previously stated, numerous experiments reveal that dry matter production and transpiration are linearly related. Although this fact is commonly recognized it is commonly overlooked in estimating transpiration in the field. Transpiration of a crop is usually computed only from the climatic condition and specific crop. Although these two variables primarily control transpiration, crop size can have a significant effect which has practical implications.

The general water balance equation is:

$$AW = ET + DP + \Delta S \qquad [6]$$

Where AW is the applied water that infiltrates the soil, ET is evapotranspiration, DP is deep percolation and ΔS is the change in soil-water storage. Over the long term ΔS goes to zero.

Any factor that reduces plant size also reduces ET, and the consequences is that DP increases for a given value of AW. Therefore DP will be greater than estimated if the effect of plant size is ignored. In a saline environment the following dynamic process is put in motion. Increased salinity ⟶ decreased plant size ⟶ decreased ET ⟶ increased DP ⟶ increased salt leaching ⟶ less salt in the root zone. Thus nature has provided positive feedback systems which is a partially protective mechanism.

Although it is outside the scope of this report, this dynamic process has other implications on water quality. Consider the case of nitrogen. If nitrogen is deficient ⟶ Less plant growth ⟶ less ET ⟶ more DP ⟶ more nitrate leaching ⟶ less nitrogen in the root zone. In this case there is a negative feedback system. The net effect is that reducing nitrate leaching by reducing nitrogen application may not achieve the intended result.

Model Validation

Very few experiments have been conducted which have both variable water application and salinity of irrigation water. The most extensive study was conducted in Israel on corn. The experimental variables were four irrigation water salinities (ECi = 1.7, 4.0, 5.3, 7.9 dS/m) and four irrigation-timing intervals (3.5, 7, 14 and 21 days). The comparison between the predicted relative yield from the model and the measured relative yield from the experiment are presented in figure 2. Note that there was very good agreement between the model prediction and measured results over the entire range of crop yield. This result suggests that the model can be used with confidence in simulating the consequences of irrigation and salinity management on crop yield.

Generalized relationships between yield, salinity, and applied water

Examples of simulated relative yield of a salt-sensitive crop (corn) and a salt-tolerant crop (cotton) as affected by the salinity of the irrigation water and the amount of water application is depicted in figure 3. The number on each curve represents the electrical conductivity in dS/m of the irrigation water. The horizontal scale represents the applied irrigation water divided by the pan-evaporation to standardize the curves for different climatic conditions.

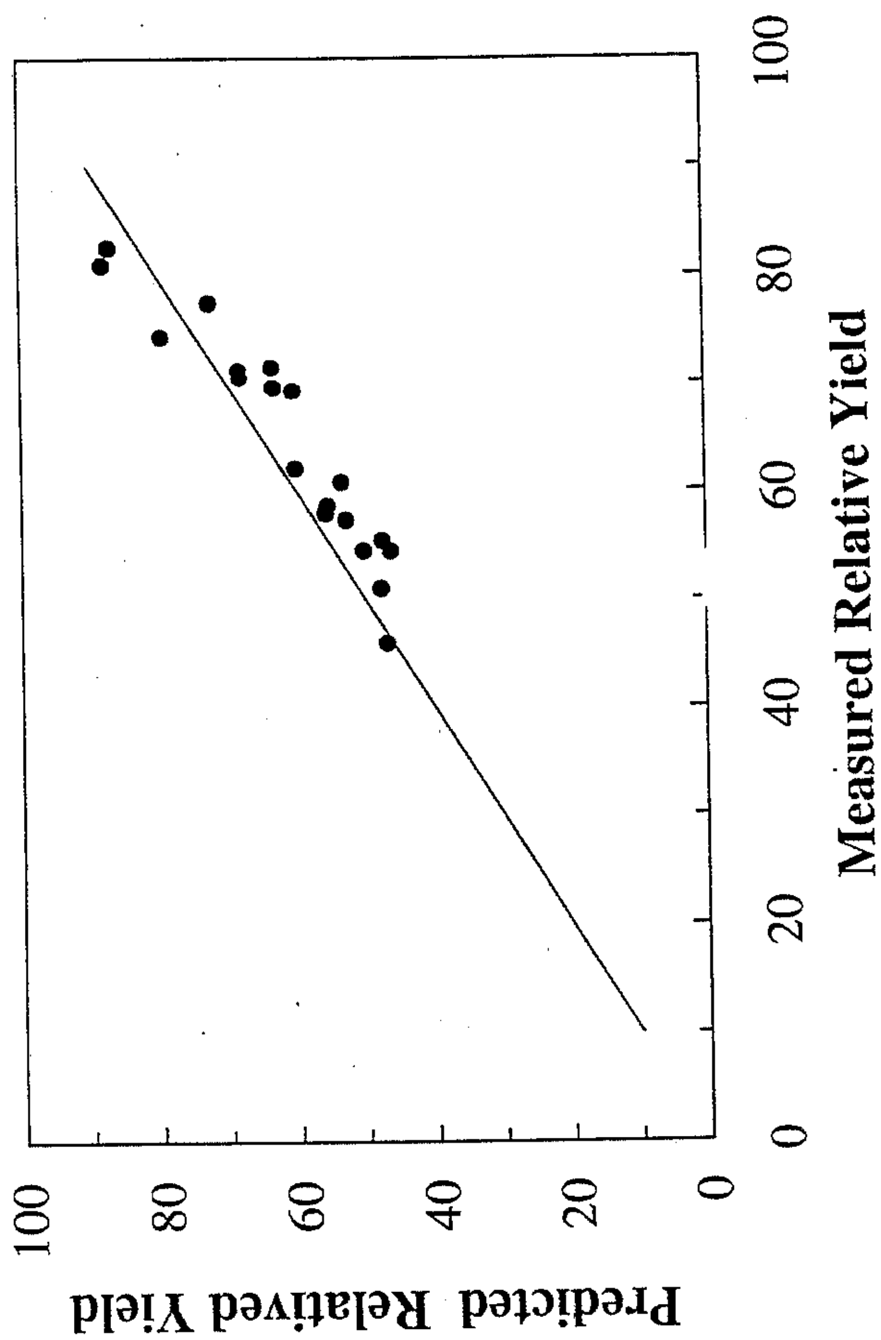


Figure 2. Comparison between predicted relative yield of corn from model simulation to experimentally measured results

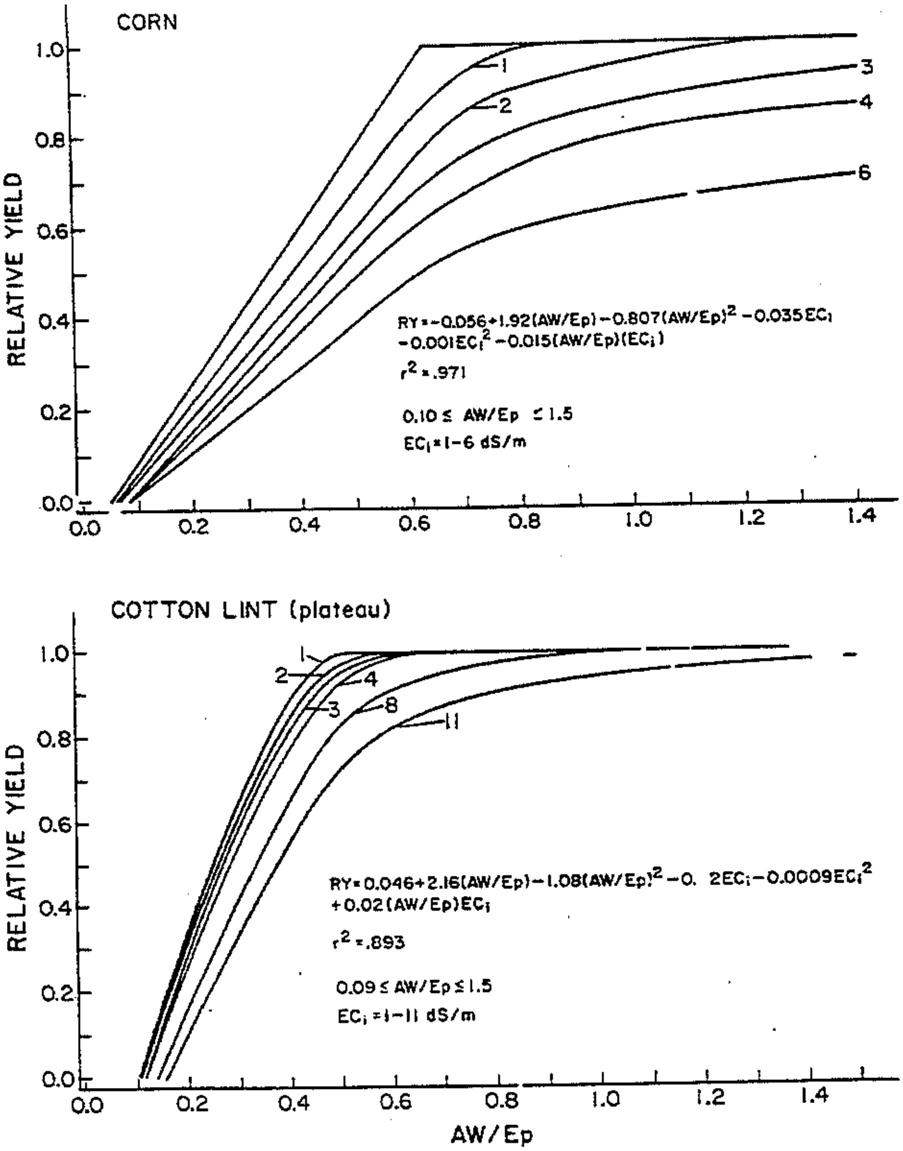


Figure 3. Relationships between yield and applied water for waters of different salinities. Numbers on curves refer to EC of irrigation water; AW and Ep represent applied water and pan evaporation.

Note that for a given water application, the crop yield decreases with increasing salinity. Also for a given salinity level the crop yield increases with increasing water application which contributes to leaching of salts. Note that for corn, relatively large decreases in yield occur with increasing irrigation water salinity. Maximum yield cannot be achieved irrigating with waters greater than 2 dS/m. Indeed, reaching maximum crop yield irrigating with a water of 2 dS/m would require a tremendously high water application that would not be feasible in the field. The results for corn depicted in figure 3 are generally consistent with the results from the field experiment in Israel depicted in figure 2. The lowest irrigation salinity used in the experiment was 1.7 dS/m. Based on figure 3 a relative yield between about .8 and .9 would be predicted depending somewhat on the amount of water application. Note that in figure 2 the maximum yield achieved in the experiment with the lowest saline water was in the .8 to .9 range.

In contrast to corn, relatively small decreases in cotton yield result from increasing irrigation water salinity, or relatively small amounts of higher salinity water needs to be applied to achieve the maximum yield. An irrigation water with a salinity as high as 8 dS/m could be used to grow cotton with relatively small decrease in yield.

These curves could be generated for any crop for which the salt tolerance (Maas and Hoffman) coefficients have been determined.

Generalized Drainage Theory

When the water table approaches the soil surface, a subsurface drainage system must be installed to prevent water logging of the root zone. A generalized depiction of the water table height at different times in relationship to the tile spacing is depicted in figure 4. Note that the scale is not the same in both directions. The depth of the drain may be 6 feet and the spacing between the drains are in 100s of feet. The main points to be made are that the drop in water table is more rapid over the drain and decreases with increasing distance from the drain line. Therefore, there will be more leaching immediately over the drain lines which decreases when moving away from the drain lines. The depth and spacing of the drain lines influence the dynamic behavior of the water table. The draw down of the water table will be more rapid with closer tile spacing and more rapid with deeper tile depth. No flow into the drain line will occur if the water table is not higher than the drain depth.

The path that the water travels toward the drain line is depicted in figure 5. This figure is taken from Jury (1975) who discussed the travel time of chemicals to subsurface drainage outlets. The horizontal axis represents a scaled distance from the drainage line. S equals half of the drain line spacing. For drain lines spaced 200 feet apart, S would equal 100 feet and the point on the graph identified as 0.9 would represent 90 feet from the drain line for this case. The vertical axis represents a scaled depth. For the 200 foot tile spacing a value of 0.5 on the vertical scale would be 50 feet. The graph represents an idealized case for a homogeneous soil system. In reality the actual curves could be somewhat different, but the main concepts that will be discussed later still apply.

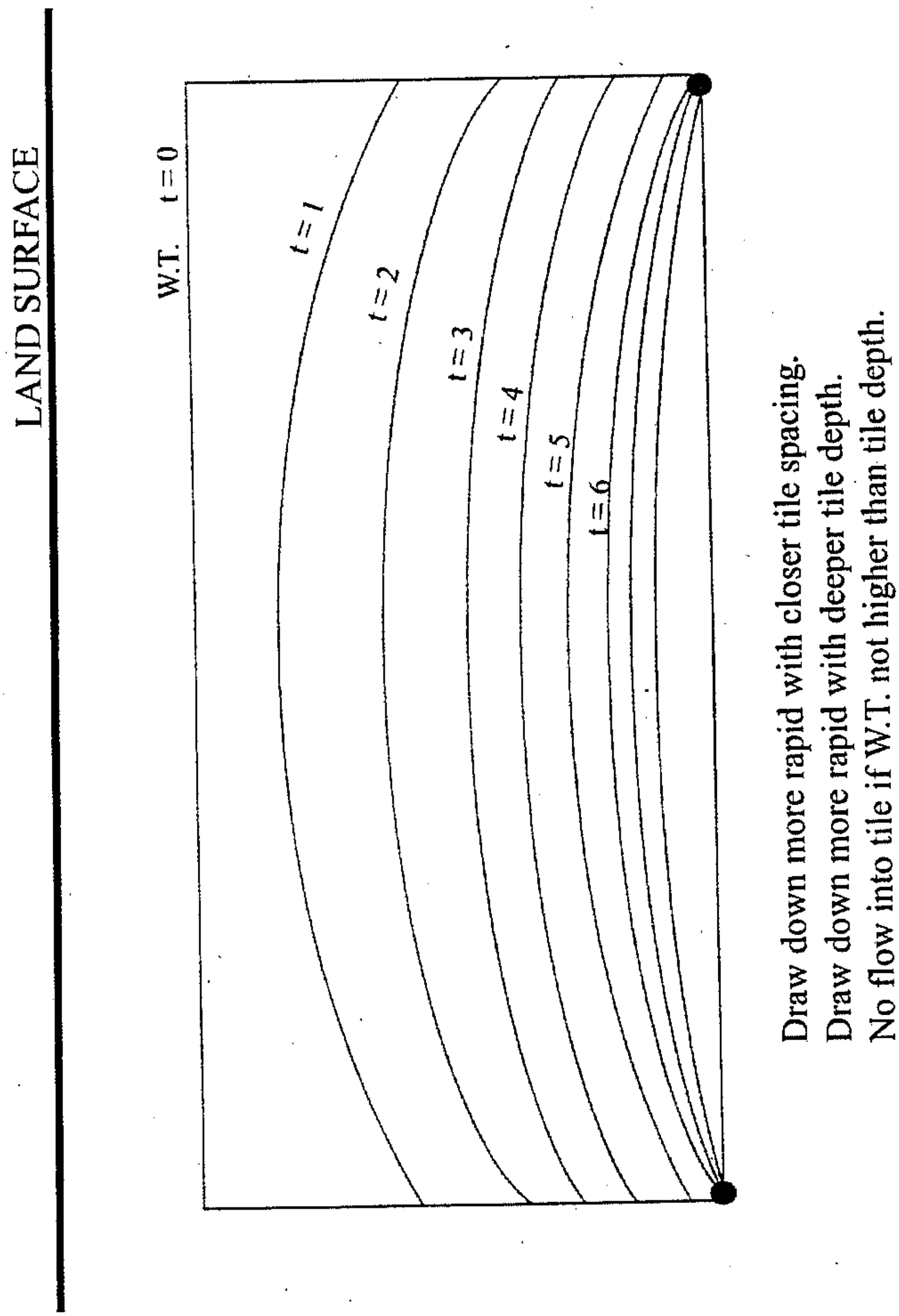


Figure 4. The general shape of the water table between tile lines for increasing time of drainage

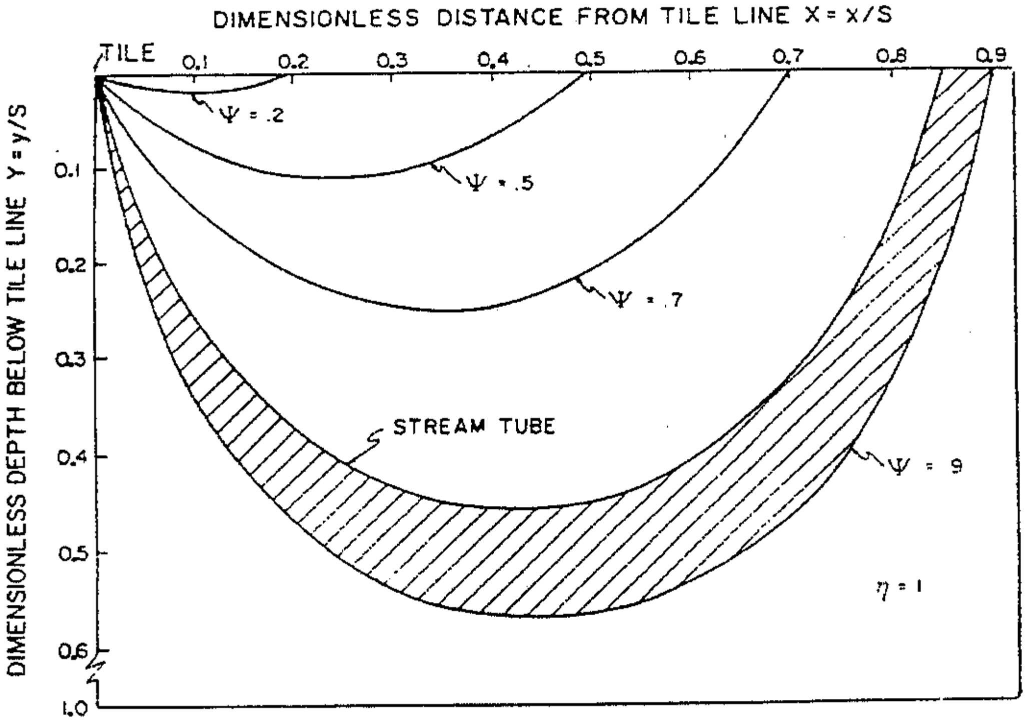


Figure 5. Streamlines followed by water flowing in steady state to the tile line. Shaded area shows path followed by water injected between X = 0.85 and X = 0.90.

The model presented above can be used to compute the amount of water and the salt concentration of water moving below the root zone. The water leaving the root zone must traverse a path as depicted in figure 5 before it reaches the drain line. Leachate immediately above the drain line goes directly to the drain. However, the leachate midpoint between the drain lines must travel hundreds of feet before it reaches the drain line. Thus, chemicals leaving the root zone midpoint between the drain line may not be collected in the drain line until decades later. The chemical composition of the drainage water is an accumulation of waters received from different parts of the field generated at different times. The chemical composition of the drainage water will largely reflect the composition of the shallow groundwater. However, the term "shallow" could include depths of tens of feet.

This information has significant implications to the sequential reuse concept for managing agricultural drainage waters. The concept as typically presented reflects the concentration of the drainage water from a field to be equal to the expected drainage water leaving the root zone. This will not be the case. This point will be amplified again when evaluating the sequential reuse concept.

General Hydrology

The land surface slopes upward moving west from the trough in the valley. A very low permeable 20 to 120 feet thick clay layer exists between 400 and 900 feet below the land surface and is commonly referred to as the Corcoran clay layer. The Corcoran clay layer separates a confined aquifer beneath it from the unconfined aquifer which resides above the layer.

Prior to receiving surface water supplies, irrigation water was derived from groundwater pumpage. From the period between about 1950 and 1965 approximately 100 million acre feet of water were pumped annually. After surface water supplies became available in the late 1960s, groundwater pumpage was greatly reduced and most of the irrigation water was from surface supplies. The amount of water irrigated each year from the surface supplies exceeded the amount when water pumpage was the only supply. The irrigation supply exceeded crop evapotranspiration and the water leaving the root zone migrated downward and caused the water table to rise. As the water table approached the land surface, it became obvious that a drainage system would be required. The depth of the water table, relative to land surface is smallest nearest the trough and tends to increase moving in a westward direction. However, because the land surface also increases, the actual elevation of the water table gradually increases going from the trough to the westward direction until a point is reached where the water table elevation decreases moving further west.

Letey and Oster (1993) used data reported by the Westlands Water District on the area of water tables at various depths for the period between 1967 and 1982. Based on these data, the average rise in water table between 1967 and 1976 was 0.58 ft/yr. The computed rate increased to 0.66 ft/yr between 1976 and 1982. For comparison, data collected from piezometers at the UC Westside Field Station was used to compute that the average water table rise was 0.66 ft/yr between 1962 and 1986 and 0.88 ft/yr between 1970 and 1986. Computations using data from USBR wells on Stone Land Company between 1975 and 1986 resulted in a water table rise of 0.80 ft/yr. Thus the calculated rates of rise were fairly consistent from the different sources of information.

A key question is, how much decrease in deep percolation below the root zone would.be necessary to arrest the rise of water table. The rate of water table rise can be computed from:

$$\textbf{W.T. Rise} = (\textbf{DP} \pm \textbf{F}_{\textbf{lat}} - \textbf{F}_{\textbf{c}})/\textbf{S} \qquad [7]$$

Where DP represents the deep percolation, F_{lat} is the net lateral flow into the area. F_c is leakage through the Corcoran clay layer and S is the specific yield. The specific yield is related to how much water is required to raise the water table a given depth, considering the fact that part of the space is filled with solids and the other is already partially filled with water.

Assuming S to equal 0.1 and using the rate of water table rise ranging between 0.58 and 0.88 ft/yr as reported above, results in:

$$\textbf{DP} \pm \textbf{F}_{\textbf{lat}} - \textbf{F}_{\textbf{c}} = .058 \text{ to } .088 \text{ ft/yr} \qquad [8]$$

The result is that if the lateral flow and flow through the Corcoran clay layer remain constant a very small decrease in deep percolation would arrest the rate of water table rise.

However, after the drainage system was installed in Westlands, the amount of water collected in the drainage system was approximately 0.68 ft/yr. This is approximately 10 times the amount expected based on equation 7.

Various factors could have contributed to collecting more drainage water than would be anticipated based upon the rate of water table rise prior to installation of the drainage system. One explanation is that the farmers changed irrigation to create more deep percolation. However, there is no evidence that the farmers significantly altered their irrigation practices from times when the water table was quite deep until the time when they installed the drainage system. The other possibilities are increases in the lateral flow and/or decrease in the flow in the Corcoran clay. Both of these are probable. The drainage system would intercept much of the water that moved downward through the Corcoran clay. Also, as depicted in figure 5, the flow lines extend quite deep below the water table depth and rise up to the drain line. This could increase the hydraulic head gradient from the up slope area and increase the lateral flow.

These factors have significance on the advisability of using control on drainage line outlet to reduce drainage volumes which will be discussed in a later section of this report.

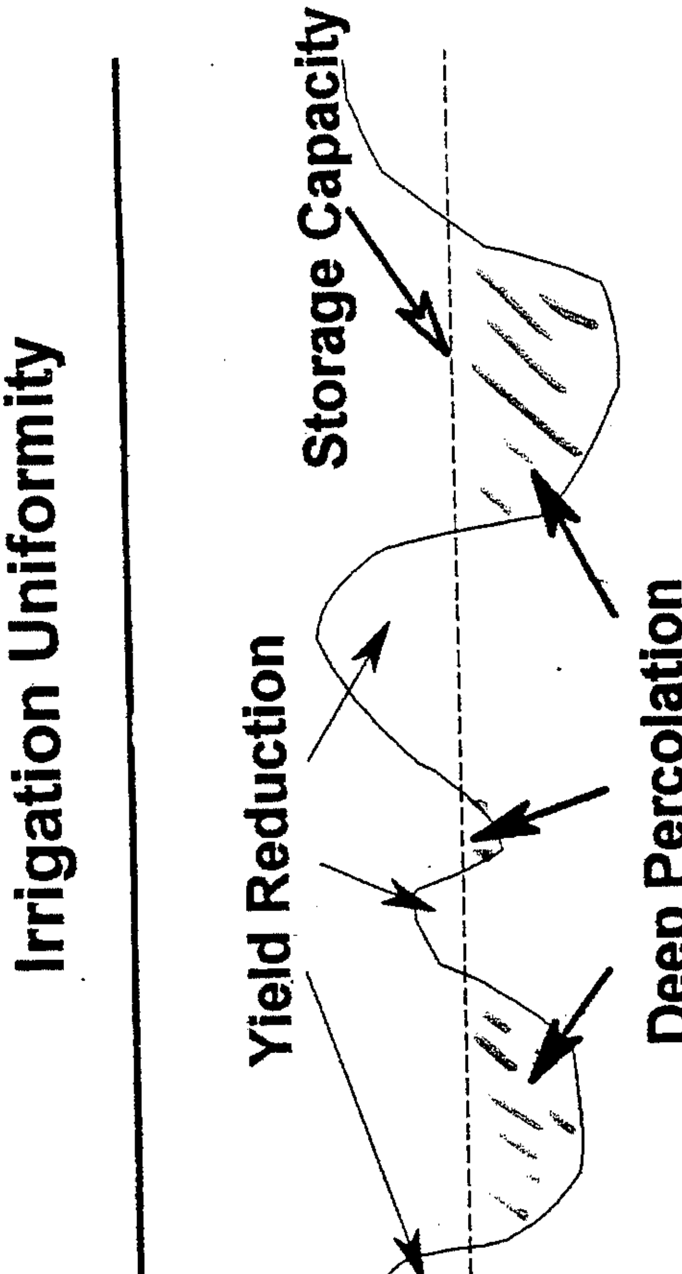


Figure 6. Illustration of the opportunity for both deep percolation and deficit water for crop yield when irrigation is not uniform

Irrigation Control

Reducing the amount of drainage water by reducing irrigation is a well-recognized strategy. However, evaluation of the irrigation management strategy is more complex than simply reducing the amount of water that is applied. The uniformity of irrigation is equally, if not more important, than the amount of water in dictating drainage volumes. A uniform irrigation would be defined as equal amounts of water entering the soil at all parts of the field.

Figure 6 illustrates the consequences of nonuniform irrigation. The ideal irrigation would be to recharge the storage capacity to replace water extracted by the crop between the irrigation events. Even though one targets a recharge of the storage capacity, if the irrigation is nonuniform, the storage capacity will be exceeded in some parts of the field and not filled in other parts of the field. The result is deep percolation in some parts of the field, and yield reduction because of deficit water on other parts of the field. The effect of nonuniform irrigation is two-fold -- yield reduction and high drainage.

Irrigation systems can be classified into pressurized and nonpressurized systems. A pressurized irrigation system is one where the water is delivered through pipes under pressure and discharged through various types of orifices such as sprinklers or drip emitters. A nonpressurized system would be the release of water and allowing gravity flow to move the water across the field such as in a furrow or border system. Pressurized systems allow accurate control over the amount of water applied because it is controlled by a valve. Surface irrigation systems allow less control over the amount of applied water because water has to be applied sufficiently to flow across the entire field. Applications of small amounts of water per irrigation event is not generally possible with surface systems.

There are two sources of nonuniformity associated with surface irrigation system. These are depicted in figure 7. One source of nonuniformity is referred to as opportunity time. Since water is on the upper end of the field longer than at the lower end of the field, more water would have the opportunity to infiltrate at the upper end as compared to the lower end of the field. A second source of variability is variability in soil properties which affect infiltration rates. The penetration of water is dependent upon the infiltration rate of the soil and this can be highly variable across the field. Thus, there is a combination of opportunity and soil variability which can influence the uniformity of application.

The uniformity of pressurized systems is controlled by the design and proper maintenance of the system. However, sprinkler system uniformity can be greatly affected by wind patterns. On the other hand, microirrigation systems such as drip can be uniform based on the appropriate design.

In principle, the microirrigation systems are "best" because they allow precise control over the amount of water applied and if properly designed and maintained can deliver the water very uniformly. The sprinkler system has the advantage of having control over the amount of water applied but the uniformity of application is dictated by wind conditions. Surface irrigation systems allow the least control over the amount of water application

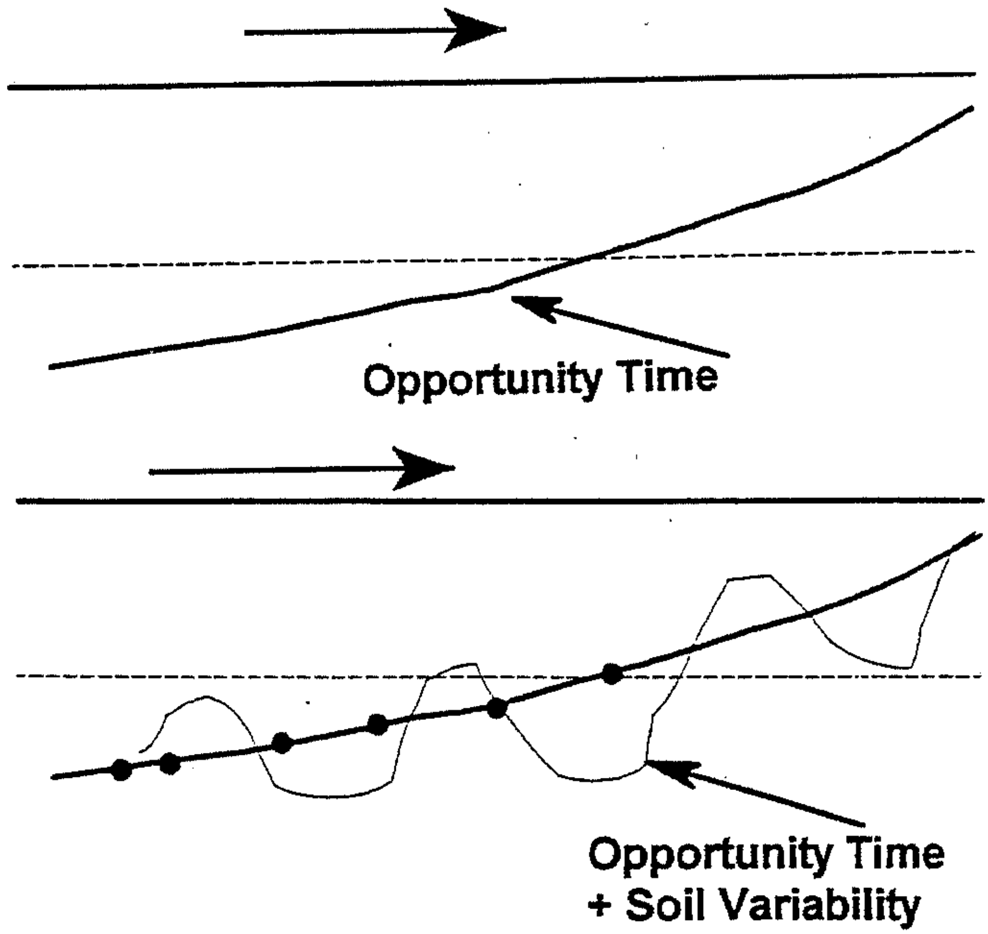


Figure 7. Illustration of depth of water penetration as water flows down a furrow from left to right. Upper curve is for soil with uniform infiltration rate and lower curve is for soil with variable infiltration rate.

and uniformity of irrigation. However, the costs for these systems are directly related to their potential benefits. Therefore, the economically optimal irrigation system is not always obvious. Indeed, a study by Letey et al. (1990) concluded that if there is no cost for drainage water disposal, surface irrigation systems would be more economical than the pressurized systems. However, if there were considerable costs associated with drainage volumes then the economically optimal system shifted to pressurized systems.

Reports have been made that a surface irrigation system can be properly managed to have uniformity almost equal to the pressurized systems. These statements are based upon numerical uniformity values for the different systems. Which raises the question, how is uniformity measured? For surface systems, the rate of advance of water down the furrow is measured and these numbers are inserted into equations developed to compute the nonuniformity associated with opportunity time. These measurements do not include the nonuniformity associated with soil variability, which can be considerable. Therefore the numerical values for furrow systems are over-estimates of the true uniformity. Uniformity of sprinkler systems is measured by distributing containers in a collection area and measuring the amount of water collected in each container. The numerical result is dependent upon the size of the container. Using larger containers, will result in a higher uniformity value than using smaller containers. Thus, the number is already recognized as being somewhat subjective, based upon the measuring technique. Even a drip system is very nonuniform if the measurement is made on a very small scale. The water released at the emitter is very high and the water between emitters is very low. Nevertheless, a plant root system can integrate differences in water in different parts of the root zone and even things out.

A few facts become evident. Meaningful measurement of uniformity is difficult. For one thing the size of the root system must be considered from a practical point of view. A tree with a large root system can accommodate considerable nonuniformity of water application under the canopy. Whereas a shallow-rooted vegetable crop would be greatly impacted by the same distribution. It is also evident that the numerical values from the surface systems are over estimates of uniformity whereas the numerical measurements on the pressurized systems are designed to give rather low uniformity numbers.

These comments should not be interpreted as being critical of the mobile labs used to measure the uniformity of irrigation systems. These analyses can be very useful in comparing one surface irrigation system against another surface irrigation system and they are useful in helping to design management strategies to improve the uniformity of these systems. The main point to be emphasized is that measured uniformity values for different irrigation technologies cannot be quantitatively compared. Thus, any report that compares the uniformity of different irrigation technologies by numerical values cannot be accepted as being quantitatively valid.

Drain Outlet Control

Drainage flows can be controlled through irrigation management. Potentially, very low drainage volumes could be achieved with a properly designed and maintained drip irrigation system. However, surface irrigation is likely to be used a very high percentage of the time because of the cost. Control over the drain line outlet provides an additional opportunity for reducing drainage volumes. Most drain lines are installed at depths of six or greater feet. The water table can be higher than that depth without detrimental effects on crop production.

The benefit of controlling drainage outlet has generally been considered from the point of view of retaining water in the profile allowing the plants to extract water from the saturated zone. In other words, water that would normally flow out the drain line is retained in the profile and made available for the plant. This results in a savings of irrigation water as well as a reduction in drainage volumes.

Each irrigation with good quality water moves the salts that have concentrated in the root zone downward towards the bottom of the root zone. This process maintains the upper profile relatively free of salts allowing the roots to proliferate in that zone and extract the required water. Plants generally have the ability to extract extra water from sections of the root zone with adequate water to compensate for reduced uptake from saline portions of the root zone.

Controlling the drainage line outlet may have other benefits in addition to retaining water for plant use. Another section of this report identified that the amount of water causing the rate of water table rise before drainage systems were installed was considerably less than was collected in the drain lines after the system was in place. It was hypothesized that installing the drainage line intercepted some water that previously was leaking through the Corcoran clay and also possibly creating hydraulic gradients increasing lateral upslope flow. Closing the drains is the same as not having the drains installed and the hydraulic gradients adjust accordingly. Thus, in addition to retaining water in the profile for the plant growth, two additional potential benefits are inducing more water leakage through the Corcoran clay and reducing lateral flows from upslope areas.

The consequences of nonuniform irrigation may be partially mitigated by drainage control. Nonuniform irrigation at the surface conceivably could be partially offset by lateral flow created by differential hydraulic head gradients within the field from areas where the infiltration rate is high to the area where the infiltration rate is low.

Storage of water is one other potential benefit of drainage outlet control. As previously stated, the water table can be maintained at a depth higher than the drain line depth. This zone represents a storage capacity that is lost when the lines are allowed to flow freely and lower the water table to the tile line depth. There are examples for need of storage capacity. Total annual discharge of chemicals into the San Joaquin River can be increased by real time management. Real time management refers to the temporal discharge based upon the assimilative capacity of the river. The assimilative capacity of the river varies through the year. The typical drainage volumes may not coincide with the assimilative capacity on a temporal basis. Storage may be required. Storage within the profile is preferred to surface storage because it does not have environmental consequences.

Storage could be important is the use of evaporator ponds. The concept of evaporator ponds is to discharge water into the pond at the rate at which it evaporates, thus not creating any ponded water to attract birds. Again, the rate of evaporation varies throughout the year and is not coincident with the natural flows from drain lines. The opportunity to store in the profile and then discharge it at times when it could be evaporated without ponding in the evaporator pond is another potential benefit of drainage outlet control.

Much of what has been stated in this section about drain outlet control is, at this time, speculative. Nevertheless there is some scientific basis justifying the speculation. Research and demonstration projects to verify or refute the speculated benefits proposed in this section is a high priority. Some studies have been done on drainage release control with some derived benefits reported. However, the present studies are inadequate to address all the various issues that have been proposed here.

Drainage Reuse Strategies

Using drainage water for irrigation can serve two purposes – one is to dispose of drainage water that would otherwise be costly to dispose, the other is to use drainage water from the positive prospect of growing a crop for economic value. The latter approach has the added benefit of reducing the requirement for good quality irrigation water. In reality, these two purposes are complementary and the optimal choice is based on economics.

There are three basic choices for a farmer to manage both good quality and drainage water resources: (1) the waters can be mixed together to get a water with average salinity (blending strategy); (2) use different waters to grow crops with different sensitivity in a crop rotation on the same field (cyclic strategy); (3) select part of the farm to use good quality water to grow salt-sensitive crops and another part of the farm to use saline water and grow salt-tolerant crops.

Rhoades was one of the initial scientists to promote the merits of the cyclic as opposed to the blending strategy (Rhoades et al. 1992). The greatest benefit of using the cyclic rather than the blending strategy is that a combination of salt-sensitive as well as salt-tolerant crops can be grown. Blending might result in a average salinity that would be prohibitive for use in growing the more salt-sensitive crops. Bradford and Letey (1992) used model simulations to demonstrate the validity of cyclic versus blending strategy in growing both salt-tolerant (cotton) and salt-sensitive (corn) crops. In a crop rotation, using the same amount of saline and nonsaline water in blending and cyclic strategies, the cotton yields were the same for both strategies. However the corn yield was lower under the blending strategy as compared to the cyclic.

Bradford and Letey (1992) also reported that the same results could be achieved by the blending and cyclic strategies for a given crop. They selected a perennial alfalfa crop for the simulation and determined that the long-term average yield was the same whether the waters were blended or applied cyclically. One significant finding of the simulation, however was that by applying saline and nonsaline waters on alternate years, the lower yield resulted during the year when the nonsaline water was applied. This finding is significant because it illustrates the dynamic nature of salinity and crop management. When saline water was applied, the salinity builds up in the soil profile during the crop season and therefore the initial salinity was high the following year when good quality was applied. Good water quality leached the salts during the growing season so that on the next year when saline water was applied the profile was initially low in salinity. The result is that the salinity in the soil at the beginning of the crop season is very important. If the profile is free of salts, the effects of adding saline water may not be detected during the first year until the soil salinity is increased. Likewise, if the profile is salt-laden at the beginning of the season, this will have impact on the production even though nonsaline water is used during the growing season because there is a time delay before the soil becomes free of salts. The important point being is that salinity in the soil profile in the beginning of the growing season is very important and that there is a time delay between changing irrigation water quality and the build up or removal of salinity within the profile to which the plant will respond.

The third option of selecting a part of the field to use good water on salt-sensitive crops and another part of the farm to use saline water for growing salt-tolerant crops is conceptually the same as the cyclic strategy. The only difference being that the cyclic strategy implies using the same plot of land with the opportunity to have a crop rotation with salt-sensitive and salt-tolerant crops. The other option is simply to devote a given land area to either growing salt-sensitive or salt-tolerant crops. Segregating the farm into areas growing salt-sensitive and salt-tolerant crops entails less operational complications than the cyclic strategy on the same field. The cyclic strategy entails having a water delivery system for fresh and salt water. Whereas the segregated approach requires a less complex delivery system.

Thus far the blending concept has been discussed on the basis of blending all the water supplies. Dinar et al. (1986) computed optimal ratios of blending nonsaline water with saline water of different salinities for different crops. Except for the most sensitive crops and extremely high water salinity, some blending of the waters was optimal for many crops. Providing the optimal mix of fresh and saline waters for irrigating individual crops is probably not operationally feasible. However, it is important to recognize that drainage waters do have utility for growing economic crops. For example, note in figure 1 that irrigating cotton with an irrigation water of EC = 4dS/m is not much different than irrigating with water of 1 dS/m. Indeed, waters with as high as 8 dS/m can be used for growing cotton. Therefore using saline water for growing cotton is almost as efficient as using fresh water.

Soil Chemical Factors

The chemical composition of the irrigation water, fertilizer application and the presence of calcite and gypsum in a soil affect salt balance. The chemical composition of the aqueduct water is such that when applied to calcareous soils of the Westside San Joaquin Valley, it will dissolve calcite from the soil at leaching fractions exceeding about 0.17. At lower leaching fractions some of the calcium and bicarbonate contained in the irrigation water will tend to precipitate. The application of ammoniated forms of nitrogen fertilizer will tend to increase calcite dissolution, because the oxidation of ammonia to nitrate releases hydrogen which neutralizes a portion of the bicarbonate in irrigation water.

Some of the Westside San Joaquin Valley soils are also gypsiferous, i.e. in their native state they contained gypsum. This gypsum may still be present within and below the rootzone. The calcium and sulfate content of the aqueduct water is such that it will dissolve this gypsum as it moves through the rootzone. But when gypsum dissolves, Ca is released and it exchanges with adsorbed Na so that the soil water becomes a $Na\text{-}SO_4$ type water of high salinity, much greater than the solubility of gypsum, ECs in the range of 8 – 25 dS/m (Tanji et al., 1972). Leaching fractions would need to be very low, about 0.02, in order to prevent gypsum dissolution. How much dissolves depends upon the amount of exchangeable sodium and magnesium present in the soil. As this dissolution occurs, the drainage waters become enriched in sodium, magnesium and sulfate. If gypsum is present along the path along which irrigation water flows through the soil, its dissolution will act as a salt source until it is all dissolved. This could take a long time to occur. For gypsiferous soils irrigated with the aqueduct water available along the Westside San Joaquin Valley, gypsum dissolution will result in greater amounts of salt in the drainage water than in the irrigation water for a long time to come.

Soil Physical Properties

Thus far the discussion on using drainage waters for crop production has been on plant response. Another potential hazard of using drainage waters for irrigating crops is a deterioration of the soil physical properties through dispersion creating hard crusts and soils with very low infiltration rates. Indeed, the early field experiments on using saline water for growing cotton (Raines et al. 1987) was impacted by poor seed germination associated with deteriorated soil physical conditions when the higher salinity waters were used for irrigation. No efforts were made in that experiment to mitigate the effects of water quality on soil physical properties.

The sodium adsorption ratio (SAR) of the irrigation water is the critical parameter related to soil physical conditions. The SAR is related to the chemical composition of the water by:

$$\mathbf{SAR} = \frac{\mathbf{Na^+}}{\mathbf{[(Ca^{++} + Mg^{++})/2]^{1/2}}} \qquad [9]$$

Where the concentrations of sodium, calcium and magnesium are expressed in milliequivalents per liter. The monovalent sodium tends to cause soil dispersion, whereas the divalent cations tend to cause the soil to become flocculated. The detrimental effects of drainage water with high SAR on soil physical properties can be mitigated by adding a calcium source such as gypsum.

Actually, the high electrolyte concentration of saline waters prevents dispersion even for waters with high SAR values. The problem arises when the highly saline water is followed by good quality water, which then causes the dispersion. Therefore, the critical period for soil dispersion is during the rain period, when basically distilled water is added to the soil which can destroy the soil physical properties. Thus the timing of gypsum application is most efficient when applied to the surface prior to the rainy season. Guidelines are available for appropriate gypsum application to preserve soil physical properties. Those details will not be presented in this report.

Some uncertainty exists whether growing forages such as Bermuda grass with a very dense root system and with the soil land surface being completely covered can prevent the break down of soil physical conditions. Certainly these soils would be less susceptible to dispersion than bare soils often associated with other crops, particularly those that are cultivated or plowed before the rainy season. Additional studies are required to establish the extent to which soil physical properties will be preserved if forages are irrigated with drainage waters without the application of an amendment such as gypsum.

CASE STUDIES - AGROFORESTRY

Introduction

Cervinka et al. (2001) reported that 700,000 trees have been planted in the San Joaquin Valley (SJV) between 1986 and 1997. In 1986 these sites were classified as "agroforestry demonstration". The proposed use was to utilize the agricultural drainage water to irrigate the trees. *Eucalyptus camaldulensis* was selected as the main species because it was anticipated that it would provide an economic wood product and the tree was reputed to have evapotranspiration rates greater than pan evaporation. The hypothesis was that the trees would utilize vast quantities of the drainage water, concentrating the salt and partially eliminating the need for drainage water disposal in the SJV. One person has verbally reported that 500,000 trees died as the experimenters learned to grow trees with drainage water. Although this number cannot be quantitatively verified a large number of trees have died from various causes including frost damage.

The following summarizes the available information on fifty-one sites that were utilized for tree planting during the study period. Four paper storage boxes were obtained from the California Department of Water Resources. The information was sorted into one box representing agroforestry in the San Joaquin Valley. Data varies considerably from one site to the next; some sites having only a name and the number of acres planted to trees. Others have additional data on species of trees and number of trees planted. Some also have soil sampling data, groundwater data, irrigation water quantities and quality taken at the beginning of the project. A few have some data from three years or more. In the beginning there seems to have been more interest in quantification of the sites than occurred in later years. In general there is a lack of consistency in the data collection and a lack of organization once the data had been collected. Irrigation water quality and quantity is one of the main areas lacking in data. At a few sites leaf sample data was also collected, but no clear relationship can be reconstructed between these data and the exact location at the site from which samples were taken.

Part of the reason for large number of tree deaths was the severe freeze in the winter of 1990-91. The clones of *Eucalyptus camaldulensis* and *Casuarina* had various abilities to tolerate the freeze (most having no freeze tolerance). After 1990, clones were selected from the surviving trees that were more tolerant of both freezing temperatures and salinity. Many of the sites were then replanted, but if there is data on this it has been unavailable to this project. There was also a change in emphasis on trees from utilizing drainage water for irrigation to interception of underground drainage water and serving as "vertical pumps".

In most instances the following data are simply presented as found. In a few cases the author has editorialized and noted the lack of data and the missed opportunities for information that may have enhanced further work of this type. Cervinka et al. (2001)

conclude that prior to planting soil sampling should be done and that soil salinity, EC_e, should not exceed 15 dS/m, SAR should be less than 40, and boron should be less than 30 ppm. They also state, drainage water (if used for irrigation) and shallow groundwater should have EC less than 12 dS/m, SAR less than 30, and boron content less than 10 ppm. The descriptions, which follow, may indicate the basis of these conclusions. The conclusions, however, do not reflect the influence irrigation with saline water will have on soil physical conditions.

The following three tables summarize the sites based upon information available. The first table lists those agroforestry plantations known to have been irrigated with saline drainage water. Later in the report, Table 2 lists those sites that had "test blocks" for the propagation of salt tolerant trees. Lastly,Table 3 lists sites where the trees were planted for the purpose of intercepting groundwater flows. There is some duplication, such as TLDD being represented on both the saline drainage water list and the test block list. It should also be noted that Mendota and Red Rock Ranch are not portions of this case study report, but are separate sections. It should also be noted that there were sites listed as case studies which were simply planted on saline soils, but where no evidence was provided as to irrigation with saline water. Tables within the individual agroforestry sites have not been numbered separately.

Table 1: Agroforestry sites known to have been irrigated with saline drainage water.

Site Name	Size Acres	Total Trees	Saline Irrig.	EC Ds/m	Euc.	Cas.	Soil	GW	Ht. m	DBH cm	Leaf	Notes
Mendota	14.7	10,475	Yes	9.4	Yes	Yes	Yes	Yes			Yes	
Dink Allen	5.0	7,000	Yes	7.0	Yes	Yes	Yes	Yes			Yes	
Peck Ranch	8.2	8,630	Yes		Yes	Yes	Yes	Yes	165	2.5	Yes	Gone
Thomsen	15.0	17,875	Yes	5.0	Yes	Yes	Yes	Yes	241	2.94	Yes	Gone
Rodriques	31.2	19,000	Yes	12.4	Yes	No	Yes					
Stratford P.U.	7.0	11,200	Yes	12.4	Yes	No	Yes		0			Dead 87
Tulare Lake DD *	35.0	29,000	Yes	8.0	Yes	Yes	Yes	Yes	161			Test blk
Westlake Farms	38.0		Yes	17.0	Yes		Yes	Yes			Yes	Test blk
Verdigal	8.0	11,800	Yes	7.0	Yes	Yes	Yes	Yes	264		Yes	
Red Rock	13.0		Yes	10.0	Yes		Yes	Yes				Dead 97
Totals	175.1	114,980										

* at TLDD it has been reported that 120 acres were planted to trees. This may have been planned at one time, but realistically only about 35 acres were planted.

Dink Allen Ranch (Fresno County)

This is a five-acre site near Ashlan and Lyon Avenues northwest of Mendota, California. 6500 *Eucalyptus camaldulensis* and 500 *Casuarina* (other) were planted July 9, 1986 in a plot 100 feet wide by ½ mile long. That first year the trees were irrigated with water from a sump that at least once tested at 7.0 dS/m. The quantities of irrigation water were not metered but were estimated at 1.5 acre-ft per irrigation. There is apparently no report as to the status of the trees during the first growing season.

These are comments the following year: "… trees looked good in March 87; doing well June 1987." Morris Martin reported July 1, 1987, "Viewed 5 acre planting at Dink Allen. This planting is doing very well with an average height of about five feet tall – well cared for – survival about 95%. *Casuarina* doing well – good being in the outer row windward side as it serves as a windbreak for other trees. *Casuarina* grows firmer and straighter under windy conditions. Weed control is good. They have used Fusalade and Goal as well as Roundup." The growth (height and diameter breast high) was also measured at this time. Tree heights ranged from 52-206 cm (133 avg.) and DBH from 0 – 6.5 cm (1.06 avg.).

The reports on the irrigation water are also better in 1987/88.

Date	EC dS/m	Quantity
06 Sept. 87	8.87	Unmetered irrigation
22 Oct. 87	2.82 (tailwater mix)	
02 Mar. 88	9.41	Unmetered irrigation
08 June 88	10.93	Partial irrigation – south end
15 June 88	11.81	Ditto
28 June 88	10.32	Unmetered irrigation

The brief notes on the condition of the trees continue: "Jan. 88 frost damage, Mar. 88 regrowth, May 88 vigorous regrowth."

The trees in this area were a part of the wildlife study conducted by the biology department at CSU-Fresno and two monitoring wells were checked periodically from Oct. 1986 through 1992. Depth to water ranges from 3 to 6.5 ft and the EC from 6 to 14 dS/m basically dependent upon the time of year. This data is available, but is of little value standing alone.

Some notes from the wildlife study. Wheat had been grown in the area in 1984 and cotton in 1985. (Before the planting of trees.) By the end of the wild life study in May 1989 the trees were nearly 7 meters in height. There was a mature row of tamarisk trees (50 meters wide) located near the northeast corner of the site, across a farm road that contributed to the wildlife diversity at the site.

From other information it is known that after the December 1990 freeze some of the frost tolerant trees at this site were selected for further use in SJV drainage water reuse experimentation. Clones 4543, 4544 and 4545 were selected from this site – perhaps other clones as well. In the spring of 1990 the trees were flooded. Vashek Cervinka (2001, personal communication) reports that the site is in current use as an agroforestry site.

On July 27 1992, Engineering Research Institute Labs reported the following from plant tissue taken from the Allen Plot.

Analysis	Units	Results of 12/91 sample	Results of 4/92 sample
Boron	mg/kg	320	240
Calcium	mg/kg	2480	3330
Magnesium	mg/kg	2140	2470
Sodium	mg/kg	160	400
Potassium	mg/kg	14300	15200
Chloride	mg/kg	87	64
Nitrogen, nitrate	mg/kg	820	5
Nitrogen, total	mg/kg	6600	7620
Phosphorus, PO_4	mg/kg	567	754
Arsenic	mg/kg	0.8	0.2
Selenium	mg/kg	0.4	0.4
Molybdenum	mg/kg	Not detected	Not detected

There may be other samples from previous years, but there is little value to these isolated leaf sample results, other than perhaps to indicate the boron concentration in the leaf tissue over time. Leaf sample reports are not reproduced for any other site in this report. Some additional data is available in the boron section of the final report for this project.

This also is a case of missed opportunity. Clearly the trees were irrigated with some drainage water. The trees appear to have done well – at least in the initial phases of the demonstration planting. In this case, it appears that no before and after soil information is available. Data was not kept on the quantities of irrigation water used. Unanswered questions are: Is boron accumulating in the soil as well as in the plant tissue. What were the levels of boron in the irrigation water? What are the levels of boron in the soil? Is there any follow-up information on the growth and health of the trees. They (at least some) were 7 meters tall in 1989. Someone collected leaf tissue in 1991 and 1992, were any notes taken on the trees themselves?

Sumner Peck Site (Fresno County)

Information available states that trees were planted at this site beginning in July 1985. 7700 *Eucalyptus camaldulensis* and 855 *Casuarina* (other) were planted the first year and 75 *Casuarina cunninghamiana* were added to the plot totaling 8.2 acres in 1986. The workplan for this site states that cotton was growing in 1984 and that the site is located next to evaporation ponds in operation at the time. The stated purpose is "Production of tree crops on saline soils to utilize subsurface drainage water."

Soil samples taken in January 1986 indicate that the soils were moderately saline with the surface 12 inches having EC = 6.2-6.7 dS/m and SAR 4.5. The salinity tended to decrease to 36 inches, having EC = 3.7 dS/m in the third foot. Details of fourteen soil samples taken in May 1986 are available, but a map locating the samples was not found. Most of these samples are similar to the information above, but two samples did have higher EC values in the 12-24 and 24-48 depth range 6.37-9.74 and 11.94-12.57 dS/m respectively. Water samples from shallow wells were collected starting in the fall of 1985. The water table was approximately two feet below the surface and EC of the water samples ranged from 5.8 to 6.4 dS/m. The water table began dropping in December and was below six feet by June 1987 and below nine feet during August and September that year.

A statement is found that the trees were irrigated with ½ water table or low quality irrigation water. Other comments: "Cotton defoliant damage again in 1987? Loss of smaller individual trees can be traced to rodent damage and trees completely water from the evaporation pond." For 1987 a note indicates 2 acre-ft for the past year as the amount. A note dated Sept. 29, 87 states "irrigation seemed heavy". Notes as to the condition of the trees are as follows: " 3/87 lots of weed competition. Approx. stand density 50%. "Cotton defoliant damage in the fall of 1985 and in 1986." 10/87 plot work underway in dry evaporation pond. Fall 87 many eucalyptus yellowish may be high covered by weeds. 1/88 frost damage present. 3/88 regrowth of frost damaged tips."

February 5, 1987 trees were measured for height and DBH. Casuarina avg. height 7'8" and 1.0" DBH; eucalyptus avg. 5'6", DBH 0.9". No further data or statements on the trees.

There is extensive data on the soil, water table depth and leaf analysis. Vashek Cervinka reports that this site has been abandoned as an agroforestry site. The trees were removed at some point after the 1990 freeze.

Water sample shown below (Unknown as to irrigation water or water sample from monitoring well):

Date	pH	EC dS/m	SAR adj	* CO3- meq/l	No3-N mg/l	Cl meq/l	Na meq/l	Ca + meq/l	B mg/l	Se PPB	Na mg/L
5/5/88	7.5	7.6	11.5	10.1	11	18	55	45.7	3.1	118	2900

* total carbonate ion in solution (dissolved CO_2, HCO_s^-, CO_3^{2-})

Thomsen Site (Fresno County)

In late May to early June 1986, 8700 Lake Albacutya *Eucalyptus camaldulensis* and 475 *Casuarina cunninghamiana* were planted at this site on seven acres of land. In 1987, an additional 8700 Lake Albacutya *Eucalyptus camaldulensis* were planted bringing the total acreage to 15. Notes from this site are: Mar. 87 "trees look very good, staked trees." June 87 – "Trees planted 6/15 in six rows, ½ mile long 6.5'-5.5', 3 acres next to sump one mile S and ½ mile E of first planting." Sept. 87 "Original planting pruned prior to irrigation Beds prepared for additional planting." Oct. 87- "Planted 3 acres space 6.5' x 5' in hi water table area, has been tiled to SL drain. "Next to sump." Many seedlings showing necrosis and defoliation." Fall 87 "Heat and water stress in summer caused some leaves to turn brown and the tops of some trees to bend. Tops were removed in effort to encourage vertical growth, but did not work and are not recommended. Trees facing west are not as tall and robust as trees farther in." Jan 88- "Frost damage present." Mar. 88 "Regrowth of frost damaged tips." June 88 "Staked young trees."

Good quality Westlands water was used to irrigate the trees during the first year. Total amount 1.5 feet. Other irrigation dates are 15 May 87, 02 Sept. 87, 19 Sept. 87, 11 Feb. 88 and 30 June 88. The 02 Sept. 87 irrigation was from a sump with EC 4.93 dS/m. All other irrigation was apparently with tailwater.

Depth to water table and EC readings are available starting 29 Oct. 1986 and ending in 1992. EC ranges from 6.5 to 9.5 dS/m, depths from 3.5 to 7 feet below the surface. More detailed water analyses are available for samples from these observation wells for 04 May 87, 22 Oct. 87 and 05 May 88. EC for these samples range from 7.2-7.7 dS/m and SAR adj. from 27 to 36. Additional samples taken 12/16/91 and 4/9/92 indicate lower SAR 13-22, but higher EC 16 and 13.2 dS/m.

Water management information and a wildlife study was performed by CSU-Fresno at this site. The wildlife study stated that the trees were 10-12 meters in height by 1989. This study also reports that tomatoes were grown on the site 2 years prior to the planting of trees. There was a sump pond on the east side that ran 2/3 the length of the tree plot. Vashek Cervinka reports that this site was closed in 1992 after the 1990 freeze.

There is extensive additional data for this site. It is mainly data on monitoring wells, which were taken by CIT staff (depth and EC). It is believed they were attempting to determine the effect of irrigation with drainage water upon the water table, but without excellent documentation of the quantity and quality of the irrigation water and a complete knowledge of subsurface flows the fluctuation of EC and water table depth over time has little scientific value.

Haynes & Sons (Kings County)

This is a site that was planted over several years with a variety of trees beginning in January 1986 with the planting of 3194 *Eucalyptus* (species not given). In April that year 250 Poplar trees were planted and on May 1, 1986, 4600 Lake Albacutya *Eucalyptus camaldulensis* were planted. (May 28 replanted 10%) An additional 200 Lake Albacutya *Eucalyptus camaldulensis* and 70 mesquite from UCR were planted on June 9, 1986. July 3, 1986 planted 300 *Casuarina* (species not named) and replanted 288 trees on July 18. In April 1987 14,850 Lake Albacutya *Eucalyptus camaldulensis* were planted bringing the total acreage at that time to 11.3 acres.

Notes: "Lost 33% of January planting, mainly due to frost. Over irrigating south end, but corrected." 10/86 "Rabbits destroyed 95% of Casuarina immediately after planting, installed protectors. Mesquite spacing 10' x10', Poplars just staying alive – grasshopper damage." 3/87 "Rabbits eat all Casuarina without guards some small Euc. Cut down, but not eaten." 5/87 "due to dry year rabbit damage is severe." Fall 87 "East side tends to be drier. Most of E section has fast growth rates, yet entire site is inconsistent growth and survival. Variable growth rates and hi mortality on W, esp. close to alkali vegetation." 12/87 "Field 1 numerous cottonwood seed. 1 tree in field 2 row six is seeding, part of field disked. Field 4 has more sunflower and grass than other fields. Field 5 Bermuda grass is in patches with forbs, dry (wording not clear) … N. end doing quite well some trees chewed by rabbits."

Additional notes: "Saline sodic soil with Ca+Mg 32 mg/l, trees do well w/ EC 20.2 or 13,184 ppm, take longer w/ 0 Ca+Mg. Irrigation water canal in 1986 EC = 0.04 (25ppm); well EC avg. 1.4 (895ppm). Irrigated once per week Apr. – June 1986 (over irrigation) cut back to twice per month July – Oct. Less irrigation in 1987." No statements are recorded as to quantity of the irrigation water nor was it identified as to quality by pump or canal.

Note from field 1 in March 1987 –"Trees average five ft. 31% died, 69% survived." May 1987 "Field 3 excellent irrigated at two weeks, others fair to good."

Soil samples take 10/1/86

Sample	Depth	PH	EC	Cations	Ca+Mg	Na	SAR	ESP	Notes
	Inches		dS/m	meq/l	meq/l	meq/l			
1	0-8	9.5	9.6	118	1.0	117	165		Dead
2	0-8	8.5	5.0	56	7.1	48.9	26	28	Alive
3	0-8	8.2	52.6	700	67	633	109		Dead *
4/87	0-12	9.0	25.5	340	18	322	107		Dead

* Trees at this location had been planted twice and died both times.

There is considerable data on depth to water table and EC readings of the water at these depths for this site. This data is not presented as a portion of this report as it is basically irrelevant.

A sample of the entire soil profile at well #1 taken 12/86 is as follows:

Sample	Depth	pH	EC	Cations	Ca+Mg	Na	SAR	ESP	Notes
	Inches		dS/m	meq/l	meq/l	meq/l			
1	0-12	8.4	18	230	30.3	200	52	45	Trees
2	12-24	8.5	33	450	60	390	71	68	3'-4'
3	24-36	8.5	32	420	90	330	49	45	Tall
4	36-48	8.6	80	1100	210.5	890	271		Planted
5	48-52	8.4	53	790	140.5	650	78	75	5/6/86

Trees were all doing well and 3 – 4 ft. in height when this sample was taken. This writer wonders if they continued to do well since the profile does not meet the requirements presented in the introduction of this report.

Frank Rodriques (Kings County)

This site was planted in June 1988 and included 19,000 *Eucalyptus camaldulensis* on 31.23 acres. The tree spacing was 6' x 10' on a field that had previously been in wheat. The site location is in Twp 20 Rng 20, Sec. 23, and elevation 240 ft. The soil types are Armona and Vanguard: texture type: loam, texture modifier: sandy loam.

Irrigation water available:

	Pump	Tile sump	Clark Evap. Pond
EC dS/m	1.47	12.4	22.0
Ca + Mg (meq/l)	0	1.70	NT
pH (glass electrode)	8.4	7.9	8.5

Soil samples from four bad spots the owner picked out in the field.

Sample	Depth	pH	EC	Cations	Ca+Mg	Na	SAR	Notes
	Inches		dS/m	meq/l	meq/l	meq/l		
1	0-12	9.8	6.0	72	1.0	71	100	
2	0-12	9.7	15.0	190	1.0	189	267	
3	0-12	9.0	7.2	85	2.0	83	117	
4	0-12	9.6	14.2	178	1.0	177	250	

No other data from this site. Did the trees survive under these conditions?

Stratford Public Utility (Kings County)

At this seven-acre site 11,200 Lake Albacutya *Eucalyptus camaldulensis* were planted at this site in September 1987. Seven tons per acres of gypsum was applied prior to planting. Four days after planting there is a note that all the first days planting were showing toxic stress. By September 30, 1987, twenty days after planting the note states, "ALL TREES DIED!"

The intent of this planting was apparently for irrigation with sewage water. The water analysis of water standing in the border 48 hours after irrigation, high in salinity, may indicate a problem severe enough to cause the immediate death of the trees. EC 12.4 dS/m, SAR 38, pH 8.7.

The soil samples from the table below were taken from the field where the trees were planted. The first eight samples were taken in April 1987 and the others during the period September 10-14 when the trees were planted. In general these EC readings in the upper twelve inches are higher than this species can tolerate. It is not surprising that all the trees died especially with the lack of aeration in the standing water.

Sample	Depth	pH	EC	Cations	Ca+Mg	Na	SAR	Notes
	Inches		dS/m	meq/l	meq/l	meq/l		
NE cor.	0-12	8.3	72.0	1050	257	793	70	
NE cor.	12-24	8.3	32.0	480	80	400	63	
SW cor.	0-12	7.8	36.0	500	253	247	22	
SW cor.	12-24	8.0	30.0	400	178	222	24	
NW cor.	0-12	8.1	28.0	380	94	286	42	
NW cor.	12-24	8.0	18.7	250	65	185	32	
SE cor.	0-12	8.0	27.0	370	143	227	27	
SE cor.	12-24	8.1	37.0	520	196	324	33	
1	0-12	8.0	34	480	185	295	30	
2	0-12	8.2	47	700	140	560	70	
3	0-12	8.3	70	1000	260+	740		
4	0-12	7.9	70	1000	260+	740		

Tulare Lake Drainage District

Beginning May 1, 1987 a mixture of trees were planted at this location. 2000 Lake Albacutya (25 rows) and 100 Mt. Bernstead (2 rows) *Eucalyptus Camaldulensis* were planted together with 200 *Casuarina glauca* (3 rows) and 400 other types of eucalyptus (from Foote)(4 rows). The acreage here was only 3.4. All were spaced in a 5'x 6' pattern. In November the tree growth for six and one half months was measured. By 1992 TLDD was reporting 30 acres (29,000+ trees) of *Eucalyptus* and 5 acres of *Casuarina glauca, C. obesa* and tamarisk. The majority of the *Eucalyptus* trees have been reported as dead as of the summer of 2000. Photos from the air show the *Casuarina* as a thick dark band of trees compared to the thin stands of *Eucalyptus*. Doug Davis, manager of TLDD, states that trees are not an economical option for drainage water reuse and has progressed to using forage. The *Casuarina* is reported as still doing well and they have been irrigated with drainage water every year except one since 1992.

The *Eucalyptus camaldulensis* plantings after the freeze in the winter of 1990 included clones from Lake Albacutya, Lake Coorong, TLDD TP-A, Allan, Gowan, Foote and Gowan, and Menzes. Later, clones 4543, 4544, 4573 and 4590 were also planted.

Water samples were collected at this site on 10/30/91 and 1/6/93. These indicate EC in 5.6-8.4 dS/m range and SAR in 20-24 range. However, the latter sample shows carbonates at 62,700 mg/l. Carbonate concentrations on all samples collected on 1/6/93 were unreasonable when compared to total dissolved solids. The irrigation water was reported as 15,000 ppm TDS and was not applied until after the trees were established for one year. There should be more information available on this project since it was a major project in the early 1990's.

Sachs reports in a letter to Cervinka dated July 3, 1990 that he was awaiting a planting scheme from Gary Rose of TLDD. This was to be set up as a site similar to the demonstration site at Mendota. Cervinka reports that in 1991, 44 acres were planted which were in addition to four acres planted in 1987. Sachs reports that 300 *Eucalyptus camaldulensis* Lake Coorong, and 15-20 each of *Acacia saligna, E. mannifera, E. australiana, E. leucoxylon, E. polybactea, E. polyanthemos and E. longiflora* were delivered to this and other sites.

Oster et al. (1999b) performed a detailed experiment at this site including ripping and gypsum applications. His findings indicate that *Eucalyptus camaldulensis* trees cannot tolerate the combination of high salinity and poor drainage. Lack of aeration in the soil, i.e. low oxygen diffusion rates, was fatal to the trees. This work provided the first field data showing conclusively that lack of aeration in the rootzone is a dominant factor in the survival of eucalyptus trees when irrigated with saline drainage water. It also indicated that the effects of gypsum on aeration and tree growth were large.

Westlake Farms (Kings County)

This site has trees planted and Oster reports that these may be doing better than other trees planted elsewhere in the valley. Information available indicates that 38 acres were planted starting in 1988. A map sketch dated 10/90 shows Lake Albacutya *Eucalyptus camaldulensis* were planted, but makes no mention of any other tree species. Some trees were described as 12 to 18 ft in height. Other portions have notes like "sparse," "scrubby" and "yellow scrubby".

The map relates to the following set of soil data:

Location	Depth	EC	Cations	Ca + Mg	Na	SAR	Notes
	feet	dS/m	meq/l	meq/l	meq/l		
NW ¼	0-1	19.3	249	66	183	31.8	Dry/sparse, better than south
NW ¼	1-2	19.2	248	61	187	33.8	
NW ¼	2-3	19.3	251	70	181	30.5	
SW ¼	0-1	19.2	250	61	189	34.2	Scrubby
SW ¼	1-2	15.4	195	35	160	38.2	
SW ¼	2-3	12.8	160	8	152	76	
SE ¼	0-1	19.2	250	68	182	31.5	*E. camaldulensis* height 18 ft.
SE ¼	1-2	21.4	270	65	205	35.9	
SE ¼	2-3	21.0	280	74	206	33.9	
E. Middle	0-1	19.2	250	65	185	32.4	*E. camaldulensis* height 12 ft.
E. Middle	1-2	15.1	190	34	156	37.9	
E. Middle	2-3	12.8	160	9	151	71.2	
N. Central	0-1	25	325	86	239	13.1	Height 16 ft. Green & seeding.
N. Central	1-2	27	360	80	280	44.3	
N. Central	2-3	12.8	160	6	154	89	
NE ¼	0-1	15.7	198	57	141	26.4	*E. camaldulensis* height 15 ft.
NE ¼	1-2	19.2	248	57	191	35.7	
NE ¼	2-3	14.4	184	22	162	48.7	
S. Middle	0-1	19.2	250	59	191	35.1	Yellow scrubby / second planting
S. Middle	1-2	14.7	185	44	141	30	
S. Middle	2-3	12.8	160	6	154	89	

There does not appear to be any relationship between soil condition and tree growth in this data. Water samples were analyzed 10/30/91, 4/9/92 and 1/6/93. Data from these is provided below:

Date	pH	EC	SAR	HCO_3	NO_3	Cl	SO_4	Na	Ca+Mg	B	Se
		dS/m	adj	meq/l	mg/l	meq/l	meq/l	meq/l	meq/l	mg/l	PPB
10/31/91	8.1	41.5	67	590	230	8140	14,900	10,800	300	22	0.015
4/9/92	7.4	49.8	55.6	291	160	8190	34,800	13,100	555	20	ND
1/6/93	8.1	2.8	40	47,500	65.6	4570	10,700	5500	230	21	0.014

The data from the 1/6/93 is presented as provided. It should be obvious that it is full of errors particularly in bicarbonate.

It is assumed that these data are from observation wells in the tree plantation. It is of little value without some correlated information.

Roy Sachs (1989, 1990) reported in letters to Cervinka, "This appears to be a very harsh site, some of the Alice Spring seedlings are growing in areas where most other seedlings have failed." He intended to collect cuttings from these in October 1989. He collected seeds from two *Eucalyptus gomphacephala* (Gomp1 and Gomp2), which was described, as shrub like, but growing vigorously. He stated that the site had a large loss of trees due to desiccation and beetles. He also selected an Israeli seedling *Eucalyptus camaldulensis-trabuti* hybrid for further evaluation. *E. camaldulensis* clones doing best at this site were 11, 341, and 218.

Verdigal (Kings County)

Beginning in June 1986, 8800 Lake Albacutya *Eucalyptus camaldulensis* and 100 *Casuarina cunninghamiana* were planted at this site. Later, in July 500 *Casuarina* (other) were planted and in June 1987 3000 Lake Albacutya *Eucalyptus camaldulensis* were replanted. The total site acreage was 8 as of April 1988.

Notes: 7/86 "Euc from CDF not doing as well as the others, Cas. died two times in one area. Dug down on replants so that the water .1 to 2 ft, around plant. Replant after irrigation, better survival rate." 3/87 "13% death rate, 87% survival. Some trees died back or were damaged by cotton defoliant. Cas. just alive due to Na in the soil." 5/87 "New regrowth looks good, other plantings better due to irrigation." 9/87 "Replanted some euc's (6/87), prob. reason for death – hi SAR due to Na in soil." 10/87 "Trees died in hot spots due to hi soil salinity. Other than hot spots trees seem to be doing well. Pheasants and sparrows are using the site." It should be noted that soil samples taken Oct. 1986 where trees were dying show EC 19.2-32.0 with SAR 120-194. (These extremely high values were reported!) There is a note that eucalyptus were planted three times and died three times at the sample with the highest levels of both EC and SAR. Other sites also report high tree death rates when SAR is extremely high.
Soil EC at time of planting 4.2 to 15.4 dS/m. Gypsum applied some time back.
Irrigation water: Canal water EC = 0.04 dS/m used first. Irrigation pump water EC = 3.2 dS/m and drainage water, 5.0 to 7.0 dS/m. In 1986 there were six irrigations after planting; drainage water was not used until mixing it with well water on 8/4 and 8/18, the last two irrigations in the first season. Confusing note 3/87 (8 irrigations) 5/87 once this year, then irrigated on 8/12/87.

Water samples were collected from this site in 1987 – 1989. This data is presented in the table below:

Date	pH	EC dS/m	SAR	* CO3- meq/l	No3-N mg/l	Cl meq/l	Na meq/l	Ca + meq/l	Mg meq/l	B mg/l	Se PPB
5/4/87	7.6	6.56	68.8	22.8	4.6	10.8		7.2	8.1	1.3	ND
10/13/87	7.6	7.9	40.4	29.2	1.8	13	96	11.3		2.8	ND
4/25/88	8.1	7.7	44.7	25.9	0.6	11.5	91	8.3		3	ND
1/4/89	7.6	19.8	26.8	10.9	0.4	3.4	25.7	14		1.3	ND
7/18/89	7.7	2.61	68.8	8.9	0.2	6.9	49.6	4.8		1.2	ND
11/1/89	6.8	2.21	50.5	238	47	73	20.4	2.8	1.6	0.9	ND
11/1/89	7	2.33	57.4	397	16	81	22.3	2.7	1.9	1.1	ND

* total carbonate ion in solution (dissolved CO_2 , HCO_3^-, CO_3^{2-})

Table 2: Agroforestry sites which served as test blocks for clone development.

Site Name	Size Acres	Total Trees	Saline Irrig.	EC dS/m	Euc.	Cas.	Soil	GW	Ht. M	DBH cm	Leaf	Notes
Meyers	28.0	38,000	No									Test blk
Lemoore NAS	15+				Yes			Yes				Test blk
Tulare Lake DD *	35.0	29,000	Yes	8.0	Yes	Yes	Yes	Yes	161			Test blk
Westlake Farms	38.0		Yes	17.0	Yes		Yes	Yes			Yes	Test blk
Carvalho	10.0											Test blk
Silviera	5.0	1,500										Test blk
Diener	3.0											Test blk
Barret	5											Test blk
Totals	139.0											

- also appeared in Table 1

Marvin Meyers (Kings County)

At this site, 28 acres were planted starting 8/20/87 with 38,000 trees including 400 Mondel pine. Planted for erosion control –west of I-5. (info in Thompsen file). Sachs in July 1990 reported: "Clones 52 & 53 from Peck Ranch and trabuti were thriving. Not many other clones were that good – in some areas kill was total, but we can't be certain of the cause of death and poor growth. We must learn more about the site – EC of irrigation water, drainage (remember the wet spot where nothing was growing), irrigation frequency."

Lemoore NAS (Kings County)

Trees were planted at this site, but the only data found for the trees were notes by Roy Sachs, who reported that trees did well despite dense weed growth. The best trees were *Eucalyptus camaldulensis* clones 218, 11, 16 and 203 – but these trees were not salinized. The plantation was started in 1988 with one acre; in 1991 15 additional acres were planted. (No data on tree species etc.) On 10/31/91 and 4/9/92, water samples were taken at the site. The 1991 sample shows EC = 7.5 dS/m and SAR 46 which may indicate a marginal site for trees, however the 1992 sample has EC = 7.3 dS/m and SAR 12.7, indicating more satisfactory conditions. There are also some soil and leaf samples available for this period.

Bloemhof (Kern County)

Trees were first planted at this site on June 26, 1986 and include 26,000 *Eucalyptus camaldulensis* (Naperby). Later on July 3, 86, 5500 Mt. Bernstead E. camaldulensis and 1000 *Casuarina* (other) were planted, bringing the total to 31,500 trees on 18.7 acres.

Notes: 6/86 "planted trees in the bottom of furrows so they would get water. Weather hot and dry – high mortality." 7/86 "replants look good, replants on west side of the field." 10/86 "plantings hit hard by hi Na in soil, rabbit damage, prefer Cas. tree guards installed. Survival 10-20%." 6/87 "planting appears to be very marginal, would recommend that more water be applied, grower not available for comment." (Some areas with no trees, but lush weed growth. Maybe we should be selecting the weeds in this area.)

Irrigation water is EC 0.6 dS/m. Quantities not provided.

Analysis of groundwater below the trees is provided below:

	10/28/86	EC		1/15/87	EC		6/87	EC	
Well #	Depth	dS/m	SAR	Depth	dS/m	SAR	Depth	dS/m	SAR
1	7.6 ft.	88	210	Dry	29?	97?	5.3 ft.	45	179
2	7.6	63	159	8.8 ft.	5.6	18	5.8	62	221
3	8.7	27	87	8.6	41	177	6.2	32	126
4	7.2	47	123	8.6	50	156	6.8	69	224
5	8.1	88	219	8.7	0	-	6.3	26	111
6	8.0	30	77	8.9	47	169	5.1	68	212
7	7.9	71	23	8.4	54	188	5.3	7	27

? There is also a note on well 5 that it was dry on the day of sample collection. If the well was dry – how was a sample obtained. Would there be a mix-up in the samples, because #5 has no EC reading and #1 does?

Soils samples taken on 9/17/87 are provided in the table below:

Sample	Depth	EC	Ca +Mg	Na	SAR	Total salt	Notes
	Inches	dS/m	meq/l	meq/l		meq/l	
1	3-8	37	45	465	98	510	Saline –sodic
2	3-8	5.8	46	22	4.6	68	Saline
3	3-8	28	35	255	61	380	Saline –sodic
4	3-8	24.5	34	299	73	333	Saline –sodic

Way Farms (Kern County)

On May 9, 1986, 11,900 Lake Albacutya *Eucalyptus camaldulensis* were planted at this site. Earlier on April 23 600 poplar trees had been planted. The total acreage planted to trees was 11.5 acres. In October it was reported that this planting was doing exceptionally well with average heights of 5'-6'; trees were smallest in areas with highest salinity. Oregon poplar 6' high and look strong. January 1987 report – "North end has experienced leaf damage due to overspray of cotton defoliant. Several trees in the north end have brown leaves that could be a combination of frost and defoliant." In March 1987 it was reported that the lower 1/3 of field had standing water. Note 6/87 "Appear to have recovered from cotton defoliant damage. Healthier than in Jan. variation in growth still noticeable, NE portion of field remains marginal in tree production and size. Plagued with weeds." Report June 23, 89 – "Rick Wegis said trees were irrigated only 1 ½ years after planting. They have been using groundwater since taking up water from drain ditch to the west. Weeds not as bad as previous summer"

EC soil readings at this site were predominantly below 10 dS/m, but one 3"-6" sample taken 10/28/86 had an EC_e reading of 15.6 dS/m with total salts 200 meq/l, Ca+Mg 36 meq/l and SAR 39. This may indicate the soil conditions in the more marginal area.

Water analysis data (assumed to be from observation wells, but could be drainage water.)

Date	pH	EC dS/m	SAR adj	* CO3- meq/l	No3-N mg/l	+ Cl meq/l	Na meq/l	Ca + meq/l	Mg meq/l	B mg/l	Se PPB
5/7/87	7.3	2.57	25.8	9.5	0.3	10		5.7	2.2	1.5	ND
12/3/87	7.8	3.6	43.6	9.9	7.1	17.6	34.5	7.4		2	ND
5/26/88	7.8	6.8	30.4	18.8	2.2	3	73	11.5		3.5	ND
6/23/89	6.9	7.35	102.1	13.1	0.2	29.7	77.8	6.5		4	ND
				mg/l	mg/l	mg/l					
02/08/91	7.6	8.17	16.5	665	1.1	1624	70	8.9	5.1	2.9	ND
02/08/91	7.8	11.8	62.7	640	4.5	2588	108	10.9	6.1	4.5	ND
5/9/91	8.5	9.12	188	2201	0.2	1453	105.8	11.6	3.5	4.8	ND
5/9/91	8.9	5.9	213.1	1519	10.4	858	67	2.8	0.7	3.9	2.4
12/16/91	7.8	9.3	31.8		25	1700	91.3				2.0

Sulfate was 1100 meq/L in the 5/7/87 sample. It was the only sulfate analysis in this group.

* total carbonate ion in solution(dissolved CO_2, HCO_3^-, CO_3^{2-}); + wide variation in chloride data may be differece between laboratories- note the change in units

Williams (Kern County)

On May 13, 1986, 7500 Lake Albacutya *Eucalyptus camaldulensis* and 7500 Alice Springs *E. camaldulensis* were planted at this site totaling 13 acres. Then in June 80 mesquite from UCR were added and on July 8, 1986 1000 *Casuarina* (other) were hand planted immediately followed by irrigation water. It was reported in June 86 that the eucalyptus were doing poorly with a 50% loss. "When the soil dries it forms cracks and some roots were torn apart, frequent irrigation to keep the ground moist." This is followed by a note 3/87 " high mortality, probably due to high Na in the soil, 100 (degrees?) F+ during planting, mortality now stabilized."

One soil sample from 6/23/86 indicates soil EC 0-6" 8.4 and 12" 44 dS/m. Other samples taken Nov. 86 from 3"-8" layer indicate respective EC's 14.6, 24, 15.4, and 7.6. In January 1987 the trees were 6-6.5 ft. in height.

These trees were irrigated with water EC 0.3, three times using 24 hour sets, in 1987 as of Sept. The last irrigation that year was reported as June 4.

Buttonwillow Land and Cattle Company (Kern County)

In May 1986 5144 Lake Albacutya *Eucalyptus camaldulensis* were planted on this 4.5 acre site. The trees were hand watered with one quart of water per tree. By the end of the month it was apparent that the upper one third of the field had soil conditions, which were fatal to the trees. The soil conditions reported at the time of planting were upper third cloddy and rough, last ¾? good. Note 1/87 "initial die off stabilized, hi EC and SAR in mortality area (1/3 of area)." 6/87 "Status has remained the same since last report."

The irrigation water, sampled 5/26/88 at this site has EC 0.75 and SAR 15. Boron is 0.5 mg/l.
Soil sample information presented in the table below.

Sample	pH	EC	Total Salts	Ca +Mg	Na	SAR	Notes
		dS/m	meq/l	meq/l	meq/l		
S-1	8.5	45	640	34.4	606	146	Very strongly saline & sodic
S-2		25	350	33.2	317	77	Very strongly saline & sodic
S-3		8.7	100	36	64	15	Mod. Saline –slightly sodic
S-4		6.9					Slightly saline

One would assume from the other comments that the first two samples are from the upper end of the field in which the trees were planted.

Note in file: "Larry Frey decided not to participate in the agroforestry program after 1987 citing economic concerns." It is assumed that Larry Frey is the owner/manager of Buttonwillow Land and Cattle Company.

David Tonigianni (Kern County)

Eucalyptus camaldulensis trees were planted at this site on May 16-17, 1991. This was followed by pepper trees planted in field #3 on June 27. This landowner is reported to have production losses on 65-100 acres. Seven acres, on a portion of three fields, of this land was selected for agroforestry. Trees were also planted along sections of the Kern River flood channel at this time. They irrigated each of the first two weeks after planting then not irrigated again until after five weeks. Thereafter the trees were irrigated only when crop and time constraints allowed. Trees were irrigated with 0.6 dS/m water

Field	Depth	EC	EC
	Feet	dS/m	dS/m
#3 (NE) (NW)	0-1	18.8	9.4
	1-1 1/2	11.7	7.4
	3-3 ½	9.7	8.8
#5A (N) (S)	0-1	6.4	5.2
	1-2	6.7	6.1
	2-3	8.9	5.0
#6A (N) (S)	0-1	24.2	14.0
	1-2	13.4	13.4
	2-3	12.2	9.9

A field visit Oct. 1, 1991 produced the following report:

Field 3 –

The Gowan average 2-4 feet in height and most are showing signs of chlorosis. The Allen[1] appear to be ½ to 2/3 the size of the Gowan. In some places half of the Allen are dead. Only 7 of 58 California pepper trees have survived. They are a foot or less in height.

Field 5A

Approximately 75% of the Menezes average 3-4 feet in height, of the remaining some are two feet and a few have hit the five foot mark. The survival rate is high 80-90%. Some chlorosis is visible; however, it is not as evident as in field 3. The shorter trees show more chlorosis than the taller trees.

Field 6A

The Allen average 2 ½ to 3 feet in height while the Menezes are a little shorter in this field than in field 5A. The Menezes are showing some signs of chlorosis. More Menezes have died in the northern 1/3 of the field while the Allen is shorter in the northern half of the field than in the south. The northern end has higher sodium than the southern end.

[1] In some instances this clone is listed as Alan, Allan and at other times Allen. It is assumed that it was a clone selected from the Dink Allen tree plantation; some of the successful clones such as 4543, 4544 and 4573 were called Allan clones.

Carrollo Site (Kings County)

Carrollo (Carrillo) site in Hanford, Kings County, California provides some insight into the use of trees in sites where the soils may be unsuitable. In this case 18,410 trees were planted on 10.2 acres between April 1 and July 20, 1986. The tree species planted were 17,710 *Eucalyptus camaldulensis* (both Lake Albacutya and Mt. Bernstead clones), 100 *Eucalyptus* (other)[2], 600 *Casuarina* (other)[3], and 100 *Pinus eldarica*. The trees were irrigated nine times in 1986 using canal water with EC = 0.04 dS/m water (25 ppm). The groundwater below the trees fluctuating in depths dependent upon a nearby canal is also non-saline with the highest values being just over 1 dS/m. Observations of the trees were apparently made throughout the 1986-growing season. The records indicate that on October 6, 1986 that trees in some areas had died while others were doing well. It was noted that the better trees were 6-7 ft tall while the poorly performing trees were only 7-12 inches tall. Both *Eucalyptus* and *Casuarina* species were affected in the same manner, which seemed dependent upon the location in the field.

What was the factor causing this difference? Prior to planting, in February 1986, soil samples were collected at four locations, which are provided in the table below.

Sample	Depth	EC dS/m	Cations meq/l	Ca+Mg meq/l	Na meq/l	SAR	ESP
S-2	0-12"	4.7	53	3.0	50	41	38
S	3-18"	3.2	35	4.0	31	22	23
S-3A	6-24"	6.8	80	10	70	31	31
S-3B	24-36"	2.8	30	4.0	26	18	20
Water 1	5 ft.	0.53	5.3	4.0	1.3		

Cations, Ca+Mg and Na are measured in meq/l. Na concentrations were determined by subtraction. The water is assumed to be shallow groundwater.

On March 31, 1986 soils was sampled at one location with more careful consideration being given to collection of samples at various depth separately. The soil is listed as a silt loam and the results of the test are provided in the table below.

Sample	Depth	EC dS/m	Cations meq/l	Ca+Mg meq/l	Na meq/l	SAR	ESP
	0-10"	4.6	52	2.0	50	50	52
	10-20"	2.1	22	2.0	20	20	21
	20-30"	0.59	5.9	2.0	3.9		
	30-40"	0.76	7.6	4.0	3.6	5.0	5.2
	40-50"	0.51	5.1	2.0	3.1	4.7	5.0

2 When the *Eucalyptus* species is given as "other" it may be any one of the following species: *E. rudis, E. robusta, E. occidentalis, E. grandis, E. viminalis, E. tereticornis* and possibly others as well.

3 When the *Casuarina* species is listed as "other" it may be either *C. obesa* or *C. equisetifolia*.

On May 12, 1986 water samples were collected at three observation wells. Depths were recorded for all as 4.1 feet and the EC readings were: 1.42, 0.52 and 0.51 dS/m respectively. It was also noted that water stayed on the surface for three days after irrigation. Additional planting or replanting was done on May1, May 27 and June 2, 1986.

In July the trees in some areas had apparently died once again; soil samples were collected in these areas.

Sample	Depth	EC dS/m	Cations meq/l	Ca+Mg meq/l	Na meq/l	SAR	ESP
*	0-12"	3.5	38	1.0	37	52	53
-pH 8.6	0-12"	7.5	85	2.0	83	83	84
-pH 8.4	0-12"	2.54	27	2.0	25	25	26
-pH 9.2	0-6"	9.6	118	1.0	117	167	
-pH 9.5	6-12"	9.3	113	1.0	112	160	

It has become apparent that the soils are sodic and that the irrigation water with such high quality is making matters worse by destroying the physical properties of the soil. Gypsum (phosphogypsum) was apparently applied after the July soil samples. In a report dated 12/86 it is stated, " In two rows gypsum was placed around each tree, it took 2 weeks for the yellowing to disappear from the leaves. 2 months after the application of gyp the two treated rows outgrew the others."

In October soil samples were collected from the same area as the July samples so before and after gypsum treatment information is available.

July sample	Depth	- pH	EC dS/m	Cations meq/l	Ca+Mg meq/l	Na meq/l	SAR	ESP	Notes
-pH 8.6	0-12"	9.0	6.7	80	6.0	74	43	45	Trees died 2X
-pH 8.4	0-12"	9.1	1.56	15.6	3.0	12.6	10	12	Tree grew 4'to7'
None	0-12"	8.9	2.1	22	22	0	0	0	Tree 3' tall
None	12-24"	8.0	3.8	43	3.0	40	32	33	Ditto
None	0-12"	9.3	8.6	105	1.0	104	147		Trees died 2X

A note dated May 1987 indicates that 20 tons of gypsum was applied to eucalyptus only with the statement, "In sodic problem areas, trees are responding to gypsum treatment." The map shows additional trees were planted on June 2, 1987 and that 100 "elderica" pines were planted on June 17, 1987. An additional note that 700 *Eucalyptus camaldulensis* were replanted on the southern portion of the property in July 1987. In one file the last information provided is water depths and EC information from the observation wells dated August 12, 1987. However Dellavalle Laboratory reported June 17, 1988 on a water sample, a soil sample and a leaf sample submitted to them in April 1988. These latter results indicate good quality water with low boron (0.1 mg/l) and selenium (not detected). The soil sample appears comparable to the better samples provided above EC_e 4.0 dS/m, ESP 31. Boron is given as 1.4 mg/l and selenium was apparently not detected. The leaf sample contains 40 ppm boron and 41 ppm selenium indicating some ability to concentrate these substances from the soil. No information is provided as to the location or purpose of these samples, thus they are not useful for making any additional conclusions.

This case study provides an example of an interesting location where useful information on the growth of trees in sodic soils could have been better documented with additional sample work and analysis of the growth and development of the trees over time. Instead, we find a year of very intriguing summations with a few supporting samples, but no followup in subsequent years; at least no data from such follow-up. Had saline drainage water been available at this site and been used to irrigate the trees there may have been better results from the beginning and an entirely different set of conclusions drawn from the data.

Data from water samples:

Date	pH	EC dS/m	SAR adj	* CO3- meq/l	No3-N mg/l	Cl meq/l	Na meq/l	Ca + meq/l	Mg meq/l	B mg/l
5/4/87	7.5	0.52	2.2	4.9	0.8	0.2	1.5	2.1	2.2	0.2
10/13/87	7.9	0.36	1.2	4	ND	0.2	0.8	4		0.1
4/25/88	7.7	0.42	0.5	6	ND	ND	0.7	4.8		ND
7/18/89		2.55	0.9			59.2	2	9.4		0.4
1/23/91		0.76	7.1	5.9	1.1	39	2.8	3.9	1.3	0.5

* total carbonate ion in solution

Most of the data in the Corrolo report is based upon notes by Frank Menzes.

Kings Boys Ranch (Kings County)

On June 17, 1986, 2200 Lake Albacutya *Eucalyptus camaldulensis* were planted at this site on 1.93 acres. The comments following the planting, though brief suggest an unsuccessful project. "Hard time establishing; Euc. Lost 50%" In July 1986 they may have replanted with Mt. Benstead *Eucalyptus camaldulensis.* Then in March 1987 the following: "Soils hi in Na, low in Ca+Mg, water standing in furrows since Oct. 1" They placed pit run gypsum around each tree. The average growth at this time was 2.2 ft with the Mt. Benstead apparently outgrowing the Lake Albacutya.

Soil sampling prior to the replant in July 1986 is as follows.

Sample	pH	EC dS/m	Cations meq/l	Ca+Mg meq/l	Na meq/l	SAR
Alive	9.2	8.4	100	2.0	98	98
Dead	10.7	18.6	240	1	239	341

Irrigation water from the canal was EC 0.1, and from the pump EC 1.7, pH 9.5, Ca+Mg 1.0, Na 16, N 0.15 (no units given). Well EC is also given as 1.27. There were apparently eleven irrigations in 1986, but no quantities are provided.

Table 3: Agroforestry sites where trees were planted to intercept subsurface water.

Site Name	Size Acres	Total Trees	Saline Irrig.	EC dS/m	Euc.	Cas.	Soil	GW	Ht. m	DBH cm	Leaf	Notes
Robertson		12	No									Intercept
Edwards		20	No									Intercept
Pryse		492	No									Intercept
Martin		492	No									Intercept
Rio Vista		450	No		Yes	No						Intercept
Jones	1											Intercept
Panoche Gin	1	1,641										Intercept
Mendota Sewer Farm		1,505										Intercept
Buena Vista WD	35											Intercept
San Luis Water D	4.5	4367										Intercept

Miscellaneous sites:

1. Orton site (Kings County) 6000 *Eucalyptus camaldulensis* were planted July 1987 on four acres. No other data.

2. Riley site (Kings County) 6000 Lake Albacutya *Eucalyptus camaldulensis* were planted at this site on five acres. Soil data from April 1988. No other data.

3. Rio Vista Farm (Kings County) 450 Lake Albacutya *Eucalyptus camaldulensis* were planted at this site on five acres in August 1987. (Two rows 2600 ft. long) No other data.

4. Rowan (Kings County) 3671 Lake Albacutya *Eucalyptus camaldulensis* were planted at this site on two acres in September 1987. There is detailed spacing and number of rows, trees per row data, but nothing else.

5. Stanton (Kings County) 3000 Lake Albacutya *Eucalyptus camaldulensis* were planted at this site of two acres in July 1987. No other data.

6. Van Groninger (Kings County) planted 70 Lake Albacutya *Eucalyptus camaldulensis* in July 1987. No other information.

7. Gowans Farm (Fresno County) Trees planted starting in 1986 along the aqueduct, near Jeffrey Ave. 1060 *E. camaldulensis* and 528 *Casuarina.* Water table at 24", EC 2-3 dS/m range prior to planting. Irrigated with good water in 1986, no data after July 87. Note: "aqueduct keeps water table high". Sachs reported in 1990, "Tagged two eucalyptus trees, one in border area where soil salinity seems quite toxic (even inhibiting *Casuarina*) and the other vigorous tree where most trees are growing vigorously." Would like to collect seeds and/or cuttings from both trees.

8. Claussen () Ten acres planted to trees in 1989.

9. Danny Newton (Newton Brothers)(Kings County) started planting in 1989, by 1990 had fifteen acres planted. Sachs reported mixed results in July 1990. Trees did best in sandy soil. Newton planned to irrigate with wastewater from Lemoore NAS.

10. Carvallo (Carvalho) (Fresno County) *Eucalyptus camaldulensis* Lake Coorong and other eucalyptus planted on ten acres of trees planted in May/June 1989. On May 24, 89 *Casuarina (?)* from ten provenances in Australia were planted. Gypsum applied liberally in and around planting holes. Irrigation was present within an hour of planting. Trees looked good – Lake Coorong best. No other information on this site.

11. Silviera site (Fresno County) Five acres planted July 28, 1989 with 1500 eucalyptus clones. Sachs noted in July 1990, " very weedy, but all trees growing vigorously. I think the clones are outperforming the CDF seedlings, but we should do measurements this summer or next. Someone should contact Silviera to see if he plans to weed–last year I think he went down rows with a cultivator." Silviera apparently also is growing forage and irrigating with drainage water.

12. Diener (Fresno County) apparently had a project prior to RRR IFDM consisting of three acres (may be the older trees near the sump at RRR). Two acres planted in 1989 and one additional acre in 1990. In July 1990, Sachs reported, "Trees have doubled in height since last summer, they are irrigated with 3000 ppm water according to John. Clones 11, 24, and 218 are performing best, but there are promising other clones. Trees now have roots into the water table. Clone 21 had 100% death rate in the first year."

The following grouping of people in the Alpaugh area, Fresno County, had trees planted as interceptor windbreaks, and to utilize drainage water once established. The soils in this area were once under Tulare Lake and include the Westcamp, Westhaven, and Houser soil series.
13. Donny Jackson (4-J Ranch) 532 *E. camaldulensis* clone 4543 and 404 *E. camaldulensis,* clone 4580 were planted along the canal as vertical pumps on June 18, 1992.
14. Charles Robertson 12 trees in yard planted 6/19/92.
15. Bob Edwards 20 trees planted in yard, along canal on 6/19/92.
16. Calvin Pryse 266 *E. camaldulensis* (4580) and 228 (4543) were planted along a canal on 6/17/92.
17. Steve Martin 228 *E. camaldulensis* (4543) and 266 (4580) were planted along a canal on 6/17/92.
18. Beverly Roth 1100 *E. camaldulensis* clones 4501 and 4570 were planted along edge of pasture and near horse track on 8/15/92.
Someone named Greenleaf (2 acres) and another named Phipps (0.1 acres) also had trees planted in Tulare County under the agroforestry program in 1991.

Additional site names and acreage in Kings County: Barrett (5), Jones (1), Mansiny (10), Nelson (1) and Postupak (5) planted between 1988 and 1991.

Additional site names and acreage in Fresno County: Airway Farms (1), Bravo Farms (7), Britz Farm, Panoche Farms (2), Panoche Gin (1) and Rabb (10) planted between 1989 and 1991.

In addition to these 35 acres of trees were planted by the Buena Vista Water District in Kern County during 1991 for interception purposes and 4.5 acres were planted by the San Luis Water District in Merced County.
Any information on tree planting subsequent to 1991, other than Red Rock ranch remained unavailable to this writer.

HISTORY OF THE MENDOTA SITE

The following is a brief history of the drainage water reuse (agroforestry) experiments/demonstration at the Mendota site in the Westside of the San Joaquin Valley. With a grant provided by the California Department of Water Resources (DWR) the California Department of Food and Agriculture (CDFA) started an "agroforestry demonstration" south of Mendota, California. Other agencies involved were the USDA – Soil Conservation Service, later changed to the USDA- Natural Resources Conservation Service (USDA-NRCS), the Westside Resource Conservation District (WRCD), California State University –Fresno, Center for Irrigation Technology (CSUF-CIT), and the University of California – Davis Department of Land, Water and Air Resources (UCD-LAWR).

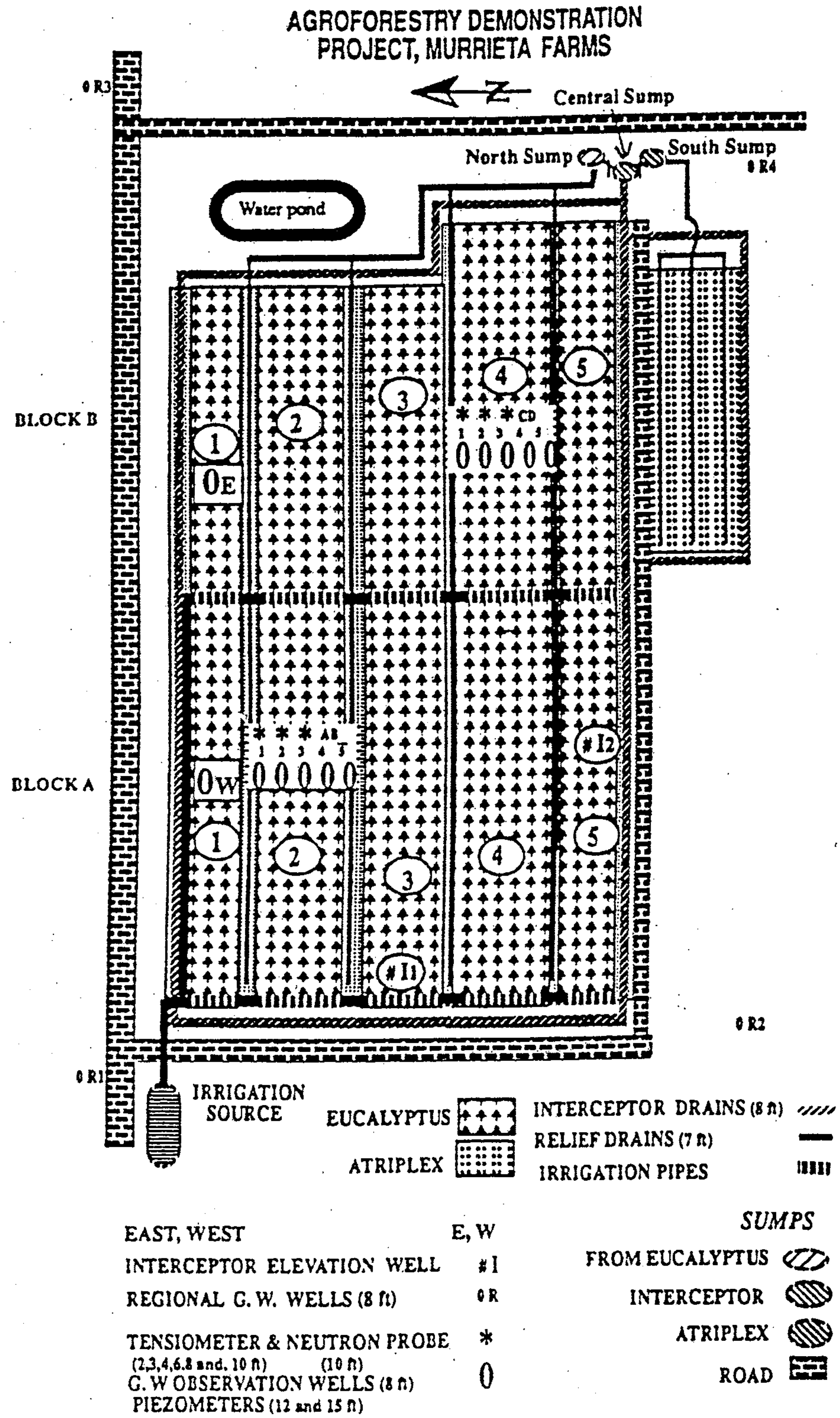
The site is located in Section 19, T14S, R15E, in Fresno County. It is 28.3 acres and drainage water was available for irrigation from the Westland tile drainage system. The soils at the site are described as finely textured clay soils in the upper 7.5 feet underlain by clayey to loamy soils ranging from silty clays to sandy clay loams. Soil auguring indicated the possible presence of an impermeable layer in the 10 to 12 feet depths over the entire plot. (Tanji et al., 1989a, 1989b)

Eighty-nine rows of *Eucalyptus camaldulensis* were planted at the site beginning in July 1985 along with six rows of *Casurina,* and one row of *Eucalyptus grandis* with seventy-two plants of Elderica pine (*Pinus eldarica*). This tree plantation apparently totaled 23.3 acres and the first planting was complete in 1986. The *Eucalyptus camaldulensis* were obtained at Lake Albacutya and Alice Spring in Australia and propagated from seeds. *Casuarina cunninghamiana* and *C. glauca* were planted in six rows and were grown from seeds obtained from Israel, Egypt and Australia. (Calif. Dept. of Food and Agriculture, 1993a)

The first data available to this writer are bimonthly groundwater depths and EC readings taken from two locations starting in the fall of 1986. Water table depth apparently varied from four to nine feet until after the installation of the tile drainage system in 1987. During this early period EC readings from these wells did not exceed 25 dS/m. The drainage plans were prepared by Dan Johnson of the USDA-NRCS were dated October 1987. (Tanji et al., 1989b; Calif. Dept. of Food and Agriculture, 1993a)

Planted in 1988 were 5 acres of *Atriplex* (saltbush) described as a halophyte, which is a selenium accumulating plant. This was irrigated by drainage water collected from the trees and from a perimeter drain that surrounded the entire site. Figure 8 provides general location of the trees, halophytes and the tile drainage system. It also shows the location of the first two observation wells, OW and OE; the location of ten new observation wells in the tree area AB 1-5 and CD 1-5; and four regional wells R 1-4; two wells in the Interceptor tile I1 and I2. There were three additional observation wells located in the halophyte area that are not shown in the

Figure 8. Layout of agroforestry demonstration project at Murrieta Farms



drawing.[4] Tensiometers and neutron probes were also installed in the area of the AB 1-5 and CD 1-5 observation wells.

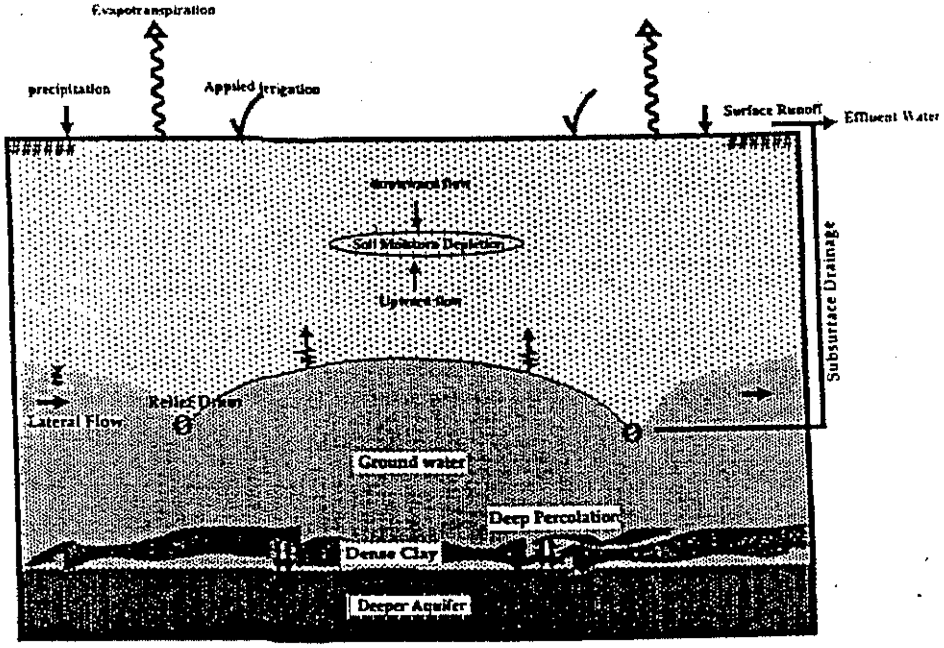
The soil materials taken during the installation of these later observation wells in 1987 were chemically analyzed. Average EC and boron data were provided in a progress report dated June 1989 (Tanji et al., 1989a). These data shows that the EC was between 5 and 10 dS/m in the top 18 inches and increased to between 10 and 20 dS/m in lower elevations. Boron levels were near 4 ppm (mg/kg, dry material basis) in the upper 0.6 feet, but increased to higher levels at deeper elevations. From the graphic information the maximum levels appear to be between 30 and 40 ppm at a depth of 7 feet. One must be aware that the trees in this area may have been irrigated with drainage water prior to this sampling. These soil samples were also apparently analyzed for soluble cations and anions as well as As, Mo and Se (Tanji et al., 1989a).

After the installation of the observation wells CSUF-CIT began measuring the depth to groundwater and obtaining the EC readings on a biweekly basis. Wind speed, daily reference ET and rainfall information was kept at a nearby CIMIS weather station off Highway 33 on the Murrieta Farm. On October 5, 1988 water samples were collected from the tile effluent sumps and from the applied irrigation water. The irrigation water had EC of 8 dS/m, boron of 10 ppm, and was dominated by sodium, sulfate and chloride ions. The drainage water from the trees had EC 26 dS/m, boron 45 ppm and was also dominated by the three ions sodium, sulfate and chloride. This latter water was the material applied as irrigation water for the *Atriplex*. (Tanji et al. 1988).

Tanji and Karajeh modified a conceptual hydrosalinity model that had earlier been used in the Panoche Water District (California) to fit the experimental conditions at this site. Figure 9 describes the water flow and pathways envisioned in a tile-drained agroforestry system. This conceptual model was first tested against data from 1986/87. Irrigation water applied was estimated as 14.4 inches and rainfall 8.9 inches. ET_o for the period September 1986 through August 1987 was 58.8 inches. This meant that the trees were under irrigated and that a portion of their evapotranspiration had to come from groundwater uptake. Through personal communication with persons involved in this project it was appertained that, the trees received irrigation water during this period only when one of the farm operators was free from other obligations. The conceptual hydrosalinity model was tested for sensitivity by holding all variables except one constant while changing this last variable +- 50%. This model and the results were to have been discussed later as more data became available in subsequent years, but collection of data apparently ceased after the 1990 freeze.

[4] Although data has been provided there does not seem to be a reference elevation to compare datum well to well. If the land were perfectly flat, then this would make no difference.

Figure 9. Cross section of a hypothetical tile drained field with a shallow ground water showing water pathways into and out of the crop root zone. Taken from California Department of Food and Agriculture (1993a).



In 1989, irrigation water applied April through August was 21 inches. Precipitation and ET_o for the period September 1988 through August 1989 were respectively 5.8 inches and 64.8 inches. Once again the trees were severely under irrigated. Since the *Atriplex* had to rely on drainage water from the tree area and the perimeter drains it also was under irrigated. (Tanji et al. 1989b) In 1990, the irrigation water applied was increased to 40.8 inches. Precipitation and ET_o for September 1989 through August 1990 were respectively 7.7 inches and 58.8 inches. This would indicate that the trees were still dependent upon water from the shallow water table (Tanji et al., 1990).

During the period 1989 – 1991 the crop coefficient (K_c) for the evapotranspiration of the *Eucalyptus* was determined using the equation, K_c = measured ET (eucalyptus)/ CIMIS ET_o. During 1989 data was collected between April and September. Ten days of data were selected as reasonably confident for calculations. The K_c was highest soon after irrigation and lowest just prior to irrigation. The highest K_c value was 0.82 calculated on 27 April, five days after irrigation. The lowest value was 0.20 calculated from data on 12 July, twenty-three days after irrigation (Tanji et al., 1989b). In 1990, crop coefficients were determined from data obtained April through September. The K_c range for 1990 was 0.75 to 0.93 and 0.83 was assigned as the overall most confident value. The authors state: "If we assume 0.83 as our more confident value, then ET from the agroforestry site was 38.0 inches during the summer interval. (Applied water was

41.3 inches.) Assuming the root zone was at full capacity in early April, the leaching fraction was only eight percent."

Based upon the low quantities of irrigation water applied 1987-1990 Tanji et al. (1990) made the recommendation, "Drainage water should be applied in the low evaporative demand months (i.e. winter) to over come the poor water infiltration problems encountered at this site. This will help reduce the average root zone salinity." The main problem with this strategy in the San Joaquin Valley is selenium in the water can cause embryo deformations in the birds that use the valley as a flyway in the winter. The Regional Water Quality Control Board will not allow standing water, containing selenium. The heavy clay soils do not allow for the rapid infiltration of the applied water.

Nevertheless in the January 1991, 4.4 inches of irrigation water was applied.[5] Another 5.9 inches of irrigation water was applied in February and the rainfall January through April in 1991 totaled 4.9 inches. These applications caused an improvement in the soil electroconductivity by dropping the EC in the surface six inches on the western side of the tree plantation from over 20 dS/m in 1990 to approximately 15 dS/m in 1991 (California Dept of Food and Agriculture, 1992). Similar improvements were made for the EC in the entire 8 ft soil profile. It should be noted that this leaching did not significantly improve the boron concentrations in the soil profile.

Meanwhile in December 1990, the San Joaquin Valley experienced a record freeze. The trees experienced 139 hours of subfreezing temperatures with the lowest readings –11.5° Centigrade. These were the lowest temperatures since the beginning of the century according to USDA-NRCS records. The eucalyptus trees were severely damaged and by November1991 it was apparent that more than sixty percent of the trees would make no recovery. (California Dept. of Food and Agriculture, 1993b). The evapo-transpiration readings taken for the trees in 1991 were obviously affected by the lack of canopy. In April the estimated K_c was 0.18 – 0.20, in May 0.19 – 0.20, in June it averaged 0.37 and by September was only 0.60. Weed growth may have contributed to ET nearly as much as the trees during this period (California Dept. of Food and Agriculture, 1993b).

Soil salinity levels increased until 1990, when the leaching fraction was increased to 25 –30 percent to reduce the accumulated salinity of the soil profile. By 1995/96 the EC_e levels were returned to comparable1989 levels (Cervinka et al, 2001). The boron concentration in the top 3.28 feet doubled over this time period and the sodium levels increased nearly six times. Karajeh et al., (1998) concluded that sodicity and boron may be the sustainability issues of greater importance than salinity.

Beginning in the fall of 1991 irrigation ceased and all scientific data collection was suspended from November 1991 through April 1992. The tree area was allowed to dry and the trees harvested. It is estimated that 200 tons of dry matter were harvested from the 23.3 acres. Attempts were apparently made to sell this material but in the end

[5] From the information available it is not clear if this was low saline irrigation water or the drainage water used for irrigation at the site.

the WRCD ended by paying $8000 for the harvest. The WRCS, CDFA, and USDA-NRCS personnel also had to pile and burn the unharvested brush from the area.

The last biweekly data taken by CSUF-CIT available to this writer was dated June 18, 1992. Finally, in August 1992 the area was ready for replanting the trees. Instead of Australian seedlings new improved *Eucalyptus camaldulensis* clonal specimens were planted. Those specifically chosen for the Mendota site were 4501, 4543, 4544, 4573, 4580, 4581 to 4586, 4588 and 4590 which were judged to be more salt and frost tolerant than their predecessors (California Dept. of Food and Agriculture, 1993b). Also planted at this time was athel (*Tamarix aphylla*).

The planting beginning in 1992 marked an entire new phase to the project. There were now 17.2 acres of trees instead of 23.3 acres and the halophytes were now increased to 6.0 acres and a solar evaporator installed over an area of 3.36 acres. Examination of the new layout, in Figure 3, would indicate that both the halophytes and the trees were planted in the earlier tree area. The former halophyte area was converted to a three-celled solar evaporator. There also appears to be a shift in the granting agency as the group is now reporting to the US Bureau of Reclamation. Trees were also planted in 1993 and 1994 (Martin et al., 1994). Irrigation of the trees began on June 7, 1994. A total of 21.8 acre-ft of drainage water was applied for thirty-eight days ending on September 29, 1994. A portion of this may have been WWD water.[6]

The halophytes were divided into five blocks. Block HA contained athel and salt cedar (*Tamarix aphylla* and *T. ramosissima, T. parviflora T. chinensis*). Block HB contained volunteer native plants. Block HC contained iodine bush (*Allenrolfea occidentalis*) and cordgrass (*Spartina* sp.). Block HD contained iodine bush and cornflower ( )[7]. Block HE contained two varieties of saltgrass (*Distichlis spicata*).[8] Irrigation of these halophytes began on September 14, 1994. A total of 1.6 acre-ft of drainage water from the trees was applied for thirteen days ending on November 1, 1994. (Martin et al., 1994).

Other project work during 1994 included installation of new drain lines in the halophyte area, soil sampling, depth to groundwater measurements, groundwater sampling, soil water content measurements and soil salinity monitoring with an (EM38) electromagnetic device. The existing ten monitoring wells in the tree area were evaluated based upon their location and condition. It was decided to keep three of these wells and an additional four wells were installed in the spring of 1994. Depth to saturated soils and EC measurements were taken every two weeks. Only a general summary of these data are available. The data presented would indicate that depth to groundwater and EC were relatively stable in each individual well, but varied considerably from well to well (Martin, November 1994).

[6] Table 6.1 from the November 1994 report provided EC data for the WWD water during the period August 26 to September 14 under the heading "trees".
[7] This writer was unable to determine the scientific name from information available in the reports.
[8] By March 1996 the list of plants in the halophyte area had changed.

A summary of the design criteria and measured results between 1994 and 1997 are presented in table 4. The difference between the design criteria and the recalculated design are changes in acreage assigned to the trees and halophytes. The data presented in table 4 are from the final project report submitted in 2001. There are some slight differences in numbers reported in the 2001 report than appeared in earlier annual reports.

A review of the data presented in table 4 reveals a few significant factors. The amount of water applied to the trees was less than the designed amount. Even so, the leaching fraction in 1996 and 1997 exceeded the designed value. This result is explained on the basis of reduced tree growth resulting in less ET. The designed ET was based on trees growing to their maximum capacity and this did not occur.

These results illustrate the complexity and dynamic interaction between the salinity of the irrigation water, amount of irrigation water applied, crop tolerance to salinity and significant feedback mechanisms between plant response and soil conditions. Letey and Knapp (1995) reported the results of model simulations of eucalyptus growth under saline conditions. Based on the expected salt tolerance of eucalyptus they projected that large amounts of water with the salinity level of the drainage waters would have to be applied to achieve full growth and maximum ET. Indeed, their results were fairly consistent with measured results at the Mendota site.

The soil hydraulic properties are a limiting factor in being able to apply the copious amounts of drainage water that would be required to maximize eucalyptus production using highly concentrated drainage waters. This is particularly a problem since eucalyptus are recognized as being very sensitive to decreased aeration caused by water logging. Cervenka et al. (2001) state, "the poorest tree growth was due to over watering". This statement would appear to be inconsistent with the results that much less water was applied to the trees than was projected in the design. Nevertheless, it is consistent with the fact that based on soil water transmission properties, the soils may have been excessively wet. Thus, one of the major constraints in using eucalyptus for drainage water use is identified. Based on their salinity tolerance, very large volumes of water must be applied of highly concentrated drainage waters to maintain maximum ET. And yet, this is not possible under most soils. Attempts to apply the extra water can have the counter effect of decreasing plant growth due to inadequate aeration.

Figure 10: Layout of Mendota Project after 1992

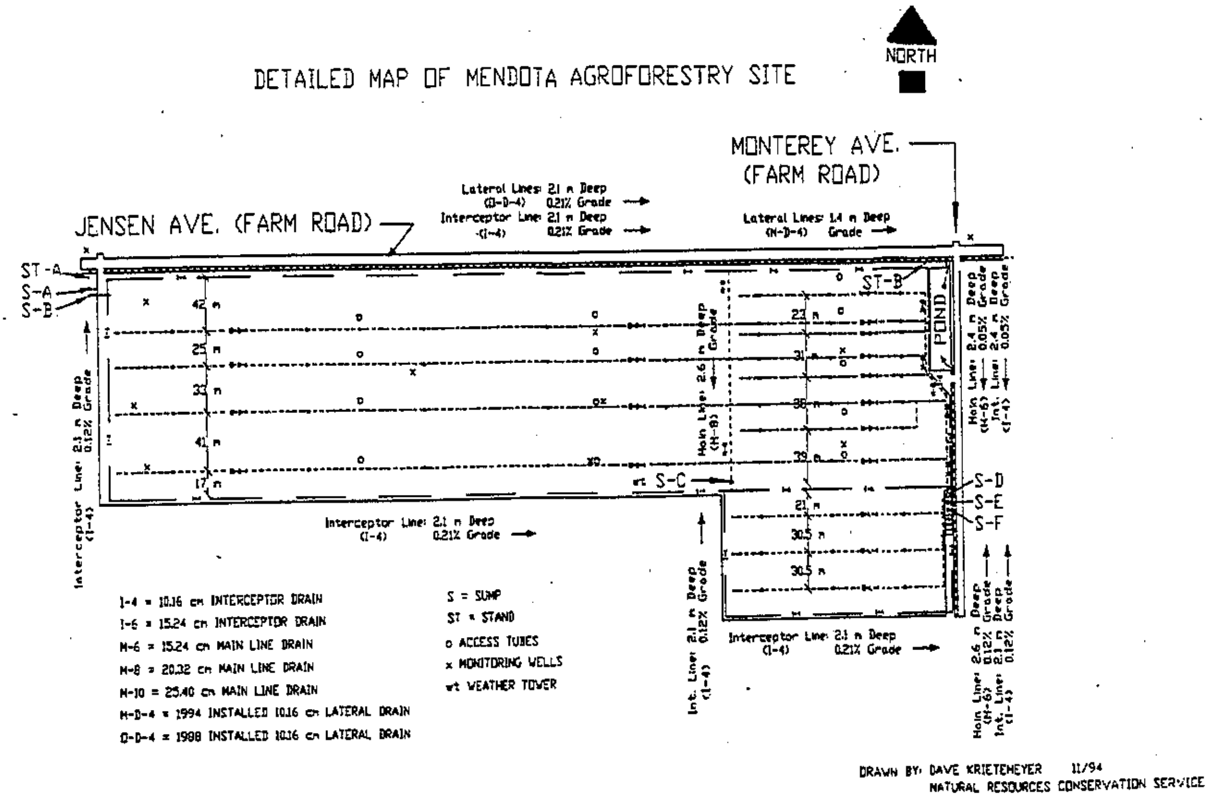


Table 4: Summary of design criteria and measured results between 1994 and 1997.

	Design Exhibit 5.2	Recalculate Design	1994	1995	1996	1997	1998
			Actual Data by Year below				
Tree Area							
Acres	16.4	14.7	14.7	14.7	14.7	14.7	14.7
ET (Ft/yr)	4	4					
LR %	25	25					
LF %	30	30	6.8	24.2	40.8	40.4	
Water for Leaching (Ft.)	2	2.0					
Applied Water (Ft. *)	6	6.0					
Volume (Acre-ft)	98	87.8	21.82	60.59	64.39	53.86	
salinity EC	9	9	8.8	8.4	8.2	8.9	
salt concentration (mg/L)	7650	7560	7392	7056	6888	7476	
Total Salt Mass (tons)	1000	896.3	199.0	565	586	532	
Total Drainage (AF)	30	26.9	1.49	14.66	26.29	21.7	
salinity EC	27	27	31.7	31.5	29.3	29	
salt concentration (mg/L)	25200	24840	29164	28980	26956	26680	
Total Salt Mass (tons)	1000		53.6	513	854	699	
Operational Days			113	212	236	192	
Halophytes							
Acres	6.73	6	6.0	6.0	6.0	6.0	6.0
ET (Ft/yr)	2	2					
LR %							
LF %	45	45		67.5	39.9	57.6	
Water for Leaching (Ft.)	2	2					
Applied Water (Ft. *)	4	4					
Volume (Acre-ft)	30	26.7	1.49	14.66	26.29	21.7	
salinity EC	27	27	31.7	31.5	29.3	29	
salt concentration (mg/L)	25200	24840	29164	28980	26956	26680	
Total Salt Mass (tons)	1000	891.5	53.6	513	854	699	
Total Drainage (AF)	13	11.6		9.9	10.5	12.5	6.5
salinity EC	61	61		28.2	27.7	28.8	
salt concentration (mg/L)	56000	56120		25944	25484	26496	
Total Salt Mass (tons)	1000	891.5		310	324	399	
Operational days			38	187	270	153	
Solar Evaporator							
Acres	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Evaporation Rate 65% pan	54 inches	54 inches					
Acre- Feet	15	15					
Total Applied Water	13	11.6		9.9	10.5	12.5	6.5
Total Salt Mass (tons)	1000	891.5		310	324	399	
Operational days				91	217	293	122

* No explanation is given for the reduction in acreage of tree and halophyte areas.

The data from the halophyte area has some disturbing features. The EC of the drainage water is almost identical of the EC of the applied water to the halophytes. These data would suggest there was additional water collected in the drain line in addition to that leached through the halophyte soil profile. This would have contributed to the very high leaching fractions which were measured. Collecting "extra" water which could dilute the drainage water would however, contribute at least some additional mass of salts collected in the drainage system. However, the amount of salt mass collected in the drainage system is only about a half of the salt that was applied to the halophytes. These results are inconsistent.

The erratic nature of the data collected on the halophyte area, renders any conclusions from the halophyte area as being meaningless.

In summary, the demonstration at the Mendota site allows the following conclusions: Eucalyptus trees have significant deficiencies as a crop to be irrigated with agricultural drainage waters in the western San Joaquin Valley. Lack of frost tolerance makes them a significant risk. They do not have an extremely high level of salt tolerance and therefore very large amounts of drainage waters must be applied to maintain salinity in the root zone, which will allow maximum growth and ET. These amounts of water however are most likely to exceed the soil water transmission properties of the soils, which reduces percolation and increases the probability of water logging. Eucalyptus are sensitive to water logging creating an additional hazard. Based on experience at the Mendota site and in other places eucalyptus are no longer projected as the plant to be used for drainage water disposal.

Unfortunately, the data from the halophyte area have such a high level of inconsistencies that no meaningful conclusions can be drawn from these data.

RED ROCK RANCH IFDM PROJECT

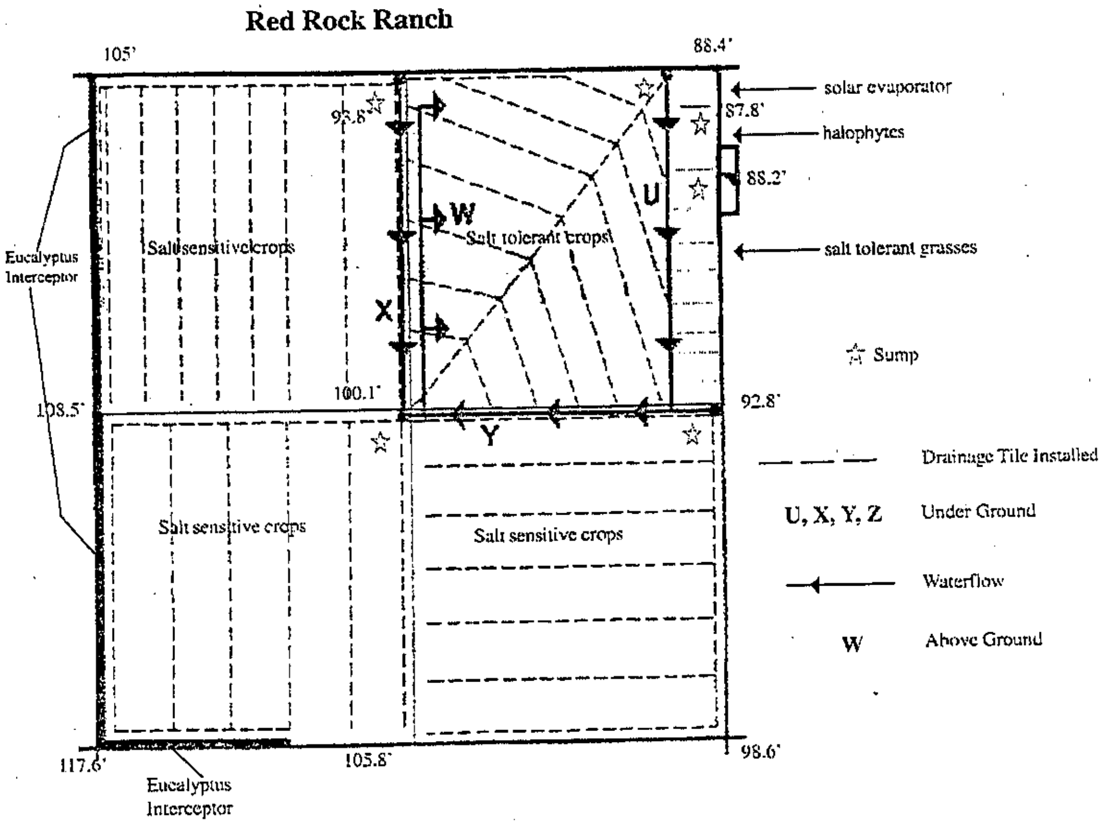
The Red Rock Ranch (RRR) site is located in Fresno County approximately 3 miles south of Mt. Whitney Avenue and 2 miles west of Colusa Road. The site lies in the Westlands Hydrologic area (no. 551.10) in the South Valley Floor Hydrologic unit as depicted in the DWR hydrologic maps. RRR operates in the WRCD and in the Westlands Water District (WWD). The project site lies within the alluvial fan and floodplain of Cantua Creek, east of the California Aqueduct. The predominant soil at the site is Ciervo clay.

The purpose of this project was to demonstrate the effectiveness of IFDM (Integrated on-Farm Drainage Management) to the farming community, regulatory agencies and others. As a result RRR is an important site for further trials of various crops and drainage reuse techniques. This project on 640 acres was designed in the period 1991 to 1994. The system was based upon a sequential reuse saline drainage water to irrigate crops of increasing salt tolerance. The design is partially based upon the "agroforestry demonstration project" near Mendota. Approximately 75% of the farm was set aside for "salt sensitive crops", 20% for "salt tolerant crops", 2% originally for "salt tolerant trees" and later planted to "salt tolerant grasses", 1% each to halophytes and solar evaporator. (See figure 11, a map of the farm showing these areas.)

The drainage waters from each one-quarter section devoted to salt sensitive crops was collected in a sump at the northeast corner of each area. These waters were delivered to the southwest corner of the salt tolerant crops area where it was used to irrigate these crops. Drainage from the salt tolerant crop area was collected in a sump in the northeast corner and this water was pumped and delivered to the salt tolerant grass area. Drainage water from the salt tolerant grasses was collected in a sump and delivered to the halophyte area. Finally, the drainage from the halophytes was collected in a sump and delivered to the solar evaporation pond.

Interceptor tree planting along the southern and western perimeters of the farm began in 1993 and continued until at least 1995, expanding to the 12-acre area set-aside for "salt tolerant trees". In 1995 drainage systems were installed in the southwest ¼, northeast ¼, "salt-tolerant trees", "halophytes" and the "solar evaporator" areas. The drainage system was installed in the southeast ¼ in 1996 and in the northwest ¼ in 1997. Thus, the Red Rock IFDM first operated as a complete "system" in 1998. See the chronology of events on the following pages.

Figure 11: Site Layout for Red Rock Ranch



Chronology of Events

1991-1994	Field Monitoring and Design Activities
1993-1995	Tree planting activities

1995	Installation of drains in NE ¼ (salt tolerant cropping area)
	    Cotton planted in this area
	Installation of drains in SW ¼ (first salt sensitive cropping area)
	    Wheat then alfalfa planted in this area
	Installation of drains and monitoring wells in tree and halophyte areas
	Installation of solar evaporator

1996	Set up 3 blocks in the NE ¼ (salt tolerant cropping area)
	    Crops: 1. corn. cotton 2. canola, broccoli 3. wheat
	Installation of drains in SE ¼ (second salt sensitive cropping area)
	    Wheat and tomatoes planted in this area
	Alfalfa in SW ¼ irrigated to leach salts
	Installed irrigation timers for solar evaporator and halophyte area
	Installed sprinkling system for solar evaporator
	Monitoring of wildlife by USFWS

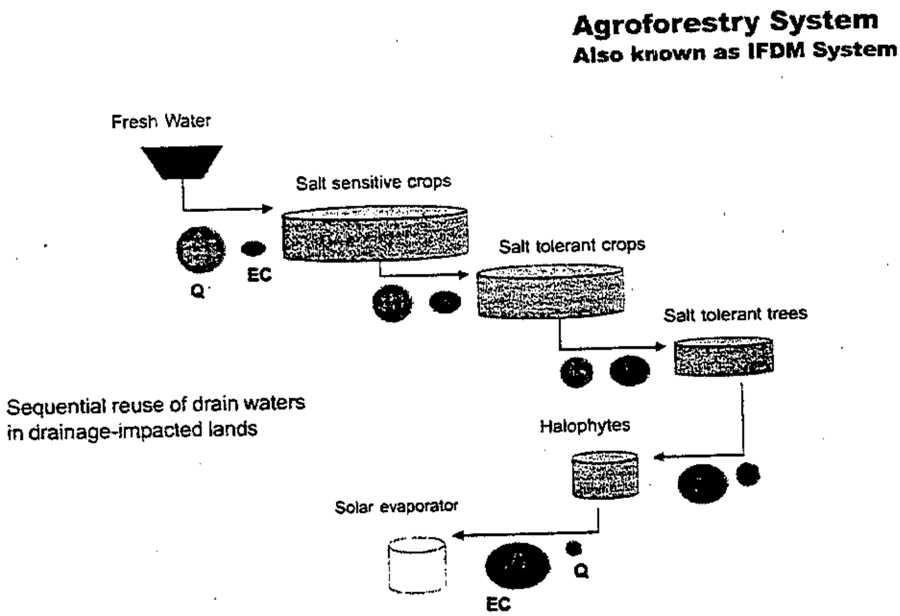
1997	Installation of drains in NW ¼ (third salt sensitive cropping area) Wheat then alfalfa planted in this area Trees in salt area are dead, replanted Planting of halophytes Crops in salt tolerant crop area: sugar beets, sugar beets, cotton Salt leaching in alfalfa in SW ¼ Corn and broccoli planted in SE ¼
1998	Removal of trees and replanting Design of solar still (greenhouse for evaporating drainage water) Land level and divide halophytes into 11 blocks; automatic irrigation Crops in salt tolerant crop area: wheatgrass, alfalfa(seed), sugar beets SW ¼ alfalfa taken out and broccoli cropped SE ¼ safflower, onions NW ¼ salt leaching of alfalfa Only year to date with somewhat complete actual data from site
1999	Removal of trees and replaced with salt tolerant grasses Crops in salt tolerant crop area: wheatgrass, alfalfa(seed), wheat SW ¼ tomatoes SE ¼ onions NW ¼ salt leaching of alfalfa Additional tree planting on eastern side of salt tolerant crop area
2000	Installation of solar still

Crops in salt tolerant crop area: wheatgrass, alfalfa(seed), fallow, cotton
SW ¼ cotton
SE ¼ wheat, tomatoes
NW ¼ salt leaching of alfalfa, later sprayed and replaced
Soil analysis by CSU-Fresno begins
Salt tolerant grasses irrigated with saline drainage water (first time)
Monitoring of wildlife by USFWS

2001 Removal of liner from the solar evaporator area
Crops in salt tolerant crop area: wheatgrass,
SW ¼
SE ¼
NW ¼

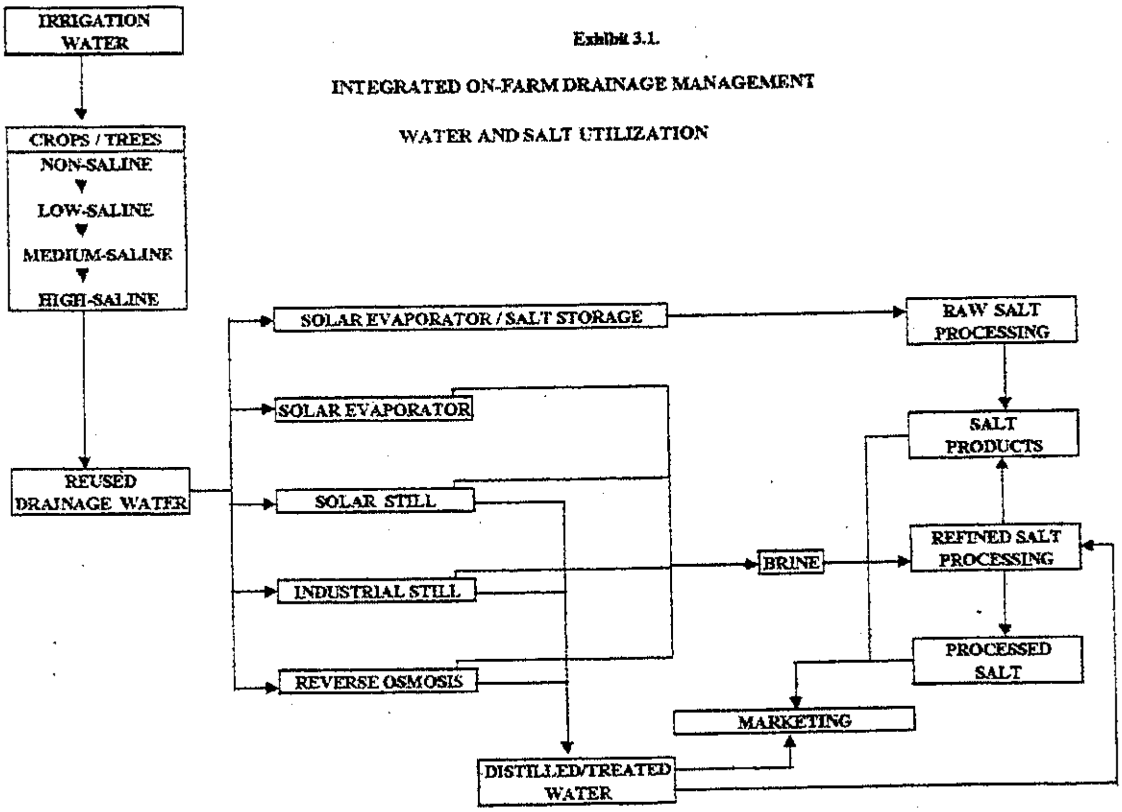
The intention was for each sequential reuse to decrease the volume of drainage water collected and to increase the concentration of salts and selenium. This flow through sequence is shown in Figure 12.

Figure 12: Sequential Drainage Reuse Chart



A total IFDM schematic proposal includes other optional operations as diagramed in Figure 13. Only portions of this diagram have been incorporated into RRR.

Figure 13: Diagram of Complete IFDM System Proposal



Results for this project are primarily provided in a report dated October, 1999 (Cervinka et al., 1999) and by additional information provided by Cervinka (personal communication), and Westside Resource Conservation District (1996a, 1996b and 1999). The design, projected and actual data are presented in table 5. The "design data", are from exhibit 7.7 and "projected data" are from exhibit 13.7 as presented by Cervinka et al., (1999). The actual data for the years 1995 through 2000 are taken from many sources, but 1998, the most complete information, is from exhibit 13.8 Cervinka et al., (1999). Less complete results were available for the other years except 2000 which have been recently provided electronically. The reason for having some different projected data from design data is not clear. One main difference is that the salt concentration of the initial irrigation water was assumed to be 400 mg/L in the design and 250 mg/L in the projected data. The 250 mg/L is lower than generally reported for irrigation waters in the area, so comparisons between design and results will be presented for the 400 mg/L irrigation water.

Table 5: Design, projected and actual data from Red Rock Ranch

	Design Exhibit 7.7	Projected Exhibit 12.1	Actual Data by Year below						
			1995	1996	1997	1998	1999	2000	Average
Salt Sensitive Crops									
Acres	480	470	470	470	470	470	470	470	
Irrigation Water (Ft.)	2.5	2.5				3.5	3.2	3.0	
Total Volume (Acre-Ft)	1200	1175				1650	1482	1410	
salt concentration (mg/L)	400	250							
Total Salt Mass (tons)	644	400							
Tail Water (Ft.)		0.4							
Volume (Acre-Ft)		188							
Total Salt Mass (tons)		72							
Leaching Fraction	10%	10%				4.6		4.6	
Leachate Volume (AF)		99							
Groundwater Volume		25							
Total Drainage (AF)	120	123				76.3		64.25	
salt concentration (mg/L)	4000	2755	5535	12210		9583	8203	5017	8110
Total Salt Mass (tons)	644	472				959		581	770
Salt Tolerant Crops									
Acres	130	130	130	130	130	130	130	130	
Applied Water (Ft. *)	2.5	2.7				2.7		1.5	
Volume (Acre-ft)	325	351				350		192.8	
salt concentration (mg/L)	1729	1144							
Total Salt Mass (tons)	754	558							
Leaching Fraction	20%	12%				7.4		11.2	
Leachate Volume (AF)		42							
Groundwater Volume		11							
Total Drainage (AF)	64	53				25.9		21.07	
salt concentration (mg/L)	'8646	8453	11205	8370		8105	7950	8730	8872
Total Salt Mass (tons)	754	624				259		227	243
Salt Tolerant Grasses									
Acres	11.65	13	13	13	13	13	13	13	
Applied Water (Ft.)	6	4.1						1.6	
Total Volume (AF)	64	53						21.1	
Total Salt Mass (tons)	754	624							
Leaching Fraction	25%	30%						14.8	
Total Drainage (AF)	16	22				6.6		3.13	
salt concentration (mg/L)	34585	21652	12150	13140		14462	10788	9540	12016
Total Salt Mass (tons)	770	660				118		37	78
Halophytes									
Acres	4.13	5	5	5	5	5	5	5	
Applied Water (Ft.)	4	4.4				1.32		0.63	
Total Volume (AF)	16	22				6.6		3.13	
Total Salt Mass (tons)	770	660							
Leaching Fraction	45%	38%				37		132	
Total Drainage AF	7	11	4.6	3.89	3.47	2.46		4.12	
salt concentration (mg/L)	76855	43043	13095	11790	11250	10966	9503	10530	11189
Total Salt Mass (tons)	762	678	74.3	56.6	48.2	33.3		54	44
Solar Evaporator									
Acres	1.64	2	2.1	2.1	2.1	2.1	2.1	2.1	
Total Applied Water	7	11	4.6	3.89	3.47	2.46		4.12	
Total Salt Mass (tons)	762	678	74.3	56.6	48.2	33.3		54	53
Operational days			135	164	200	109			

* Applied water a mixture of tailwater, drainage from salt sensitive crops and canal water.

Avg. of Total Salt Mass in Solar Evaporator is for five years, the above figure 44 tons is for only 1998 and 2000.

Analysis of Integrated Farm Drainage Management

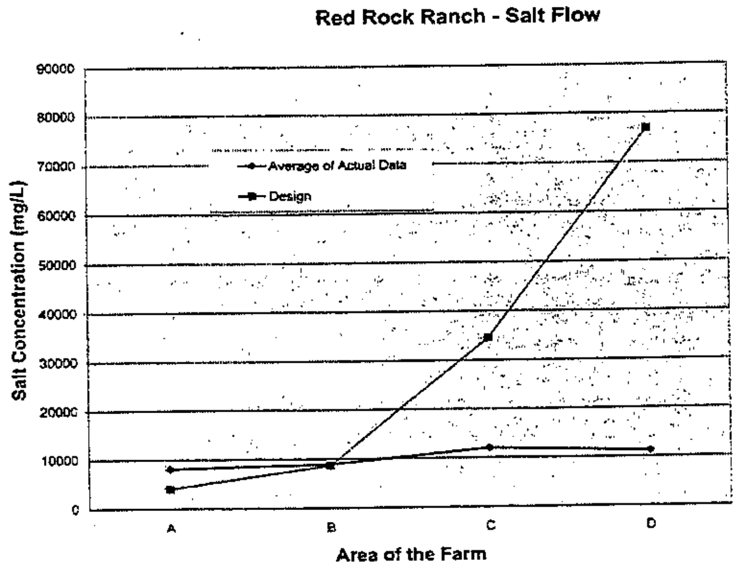
This section will use information from the scientific basis for drainage water reuse section with results achieved on the Red Rock Demonstration Farm. Particular attention will be given to the design criteria to identify adjustments, which should be made in designing new systems.

Sequential Concentration of Water

The design was based on the water collected in the drainage system being the same concentration as water leaving the root zone. For drainage systems with tile spacings as existed at the Red Rock Ranch, there is considerable travel time (years) for water leaving the root zone from some sections of the field before it arrives in the drainage line. The actual water collected in the drainage system during the first few years of installation will largely reflect the composition of the shallow groundwater. The term shallow in this context however, can refer to tens of feet.

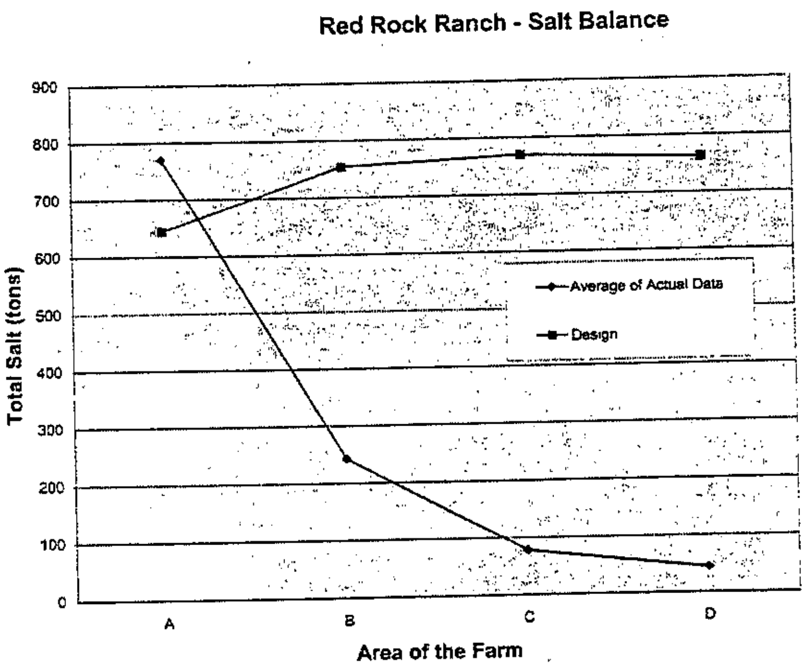
The average salt concentration in the drainage water is reported for every year except 1997. The average salt concentration in the drainage water for the years reported are compared with "design" values in figure 14. The salt concentration in the drainage water leaving the salt sensitive crops is about 2 times greater than the projected value. Note that the sequential average salt concentration in the drainage waters leaving the salt sensitive crop, salt tolerant crop, salt tolerant grass and halophyte areas only increase slightly for the 5 years of reported data. These results are consistent with projections which consider the travel time. The net result is that the projected concentrations and mass of salt moving along the different components of the system far exceeded the actual results. The mass of salt delivered to the evaporator pond represented about six percent of the projected salt mass to the evaporator pond.

Figure 14. Comparison of designed and measured salt concentration in the drainage water collected from various areas of the farm.



A-drainage water from salt sensitive crop area B-drainage water from salt tolerant crop area C-drainage water from salt tolerant grass area D-drainage water from halophyte area and placed into the evaporator pond

Figure 15. Comparison of designed and measured mass of salt in the drainage water collected from various areas of the farm.



A-drainage water from salt sensitive crop area B-drainage water from salt tolerant crop area
C-drainage water from salt tolerant grass area
D-drainage water from halophyte area and placed into the evaporator pond

The total mass of salts in the drainage water is reported for the years 1998 and 2000. The average total mass for the two years, are illustrated in comparison to the projected values in figure 15. Note that the projected mass of salt remains relatively constant as it moves through the system. In contrast, the measured results indicate a consistent decrease in salt mass as it moves through the system. At the end, only about 6 percent salt is deposited in the evaporator pond as compared to the expected amount. Clearly, a salt balance is not being achieved by the system for scientific reasons, which will be described later.

One might note that the sequential concentration of water at the Mendota Demonstration was much closer to projected figures. Also the concentration after the last use was far higher than that measured at the Red Rock Ranch. Since the Mendota site was the initial demonstration of the sequential reuse, it is understandable why these results would be used in projecting the behavior at the Red Rock Ranch. This raises the question, "what is the difference between the two systems"? The difference is that the Mendota demonstration used relatively small plots with drain lines positioned immediately below the plots. Also a dense clay layer at the 10 to 12 foot depth at Mendota would have restricted vertical flow. Therefore, water collected in the drain line system was much more reflective of the water leaving the root zone. Again, these results clearly identify the importance of considering the travel time in projecting results.

The data for selenium and boron contained in Table 6 are similar to the salt data. Although there is a trend toward increase in concentration with each sequential reuse, the increase is not great. Also the total mass of these chemicals tends to decrease with each sequential reuse.

Table 6: Boron and Selenium Data for Red Rock Ranch

	Se mg/L 1998	Se mg/L 2000	B mg/L 1998	B mg/L 2000
Salt Sensitive Crop	0.40	0.38	17.3	14.7
Salt Tolerant Crop	0.47	0.58	17.0	17.5
Salt Tolerant Grasses	1.32	0.53	28.0	16.7
Halophytes	0.95	0.63	21.0	19.0

	Se tons 1998	Se tons 2000	B tons 1998	B tons 2000
Salt Sensitive Crop	0.038	0.030	1.629	1.165
Salt Tolerant Crop	0.015	0.015	0.543	0.455
Salt Tolerant Grasses	0.011	0.002	0.228	0.065
Halophytes	0.003	0.003	0.064	0.097

Crop Selection

The design called for four different cropping systems with increasing salt tolerance ending up with halophytes. Because the salt concentration in the drainage water is approximately the same from all of the drainage systems, there is no need for progressive salt tolerance. Certainly the use of halophytes is not justified because of their generally very low economic return. Furthermore, the drainage water concentrations never reached levels high enough to be most appropriate for halophytes. Indeed there were reports that drainage water from Mendota had to be transported to Red Rock to carry out some of the small scale research projects on halophytes.

Basically, the farm can be divided into only two sections. One section used for good quality irrigation water and another section used for irrigation with drainage water or a combination of drainage and surface waters. Depending upon the flexibility of irrigation water conveyance systems to deliver drainage and good quality waters, either in a blended or cyclic fashion, a fairly wide range of crops could be selected for growing on the portion of the farm devoted to using drainage water.

The model described in the science section could be used to simulate the consequences of various management strategies using various crops and combined use of drainage and surface water supplies.

Evaporator Pond

The design for the evaporator pond size was done by taking a very conservative estimate on the amount of water that evaporates on an annual basis and the amount of drainage water leaving the halophytes to be evaporated. The concept of an evaporator pond is that water is delivered to the pond at a rate equal to or less than the rate of evaporation. The design approach would have been appropriate if the evaporation rate and drainage discharge were constant throughout the year. The approach would have been valid even if these rates were not constant throughout the year, but the ratios of the two were constant throughout the year. Neither of these assumptions is valid. Therefore, the pond was severely undersized resulting in occasional ponded water in the pond and adjacent halophyte areas causing some bird damage.

The design of an evaporator pond to prevent any ponding is extremely complex. One would need information on the temporal variations in evaporation rate (which could vary annually) and drainage water volume. These data could be used to calculate a pond area that would evaporate all the water delivered daily. This constraint dictates that the pond be large and rather inefficient because much of the time, the potential for evaporation would exceed the rate of discharge.

Another factor, which largely negates the utility of evaporator ponds, is that salts accumulate. They are dissolved, creating a very high concentration, by rainwater collected in the pond. Since rain is associated with low evaporation rate, very concentrated water can exist in the pond for some period of time during a rainy season.

The maximum amount of the water that can be evaporated annually, therefore minimizing the pond size, is achieved by having free standing water in the pond each day. With sequential reuse of drain water a relatively small land area would be required for the farm. Consideration would be required to accommodate rain and the actual drainage reuse plan. With free standing water, bird damage would have to be mitigated by netting the pond.

Another proposed purpose for evaporator ponds was to accumulate "dry" salt so that it could be marketed. This goal would be negated in a pond, which had continual water. Various uses for the salt have been suggested and investigated during recent years. Most attention has been given to the use of sodium sulfate. Examples of potential uses tested are as a component in glass or in dyes. Thus far, no economically practical use has been identified. Although hope of finding an economic use for the salt should not be completely dropped, the probabilities of success appear to be getting very small. Unless this goal is realized, one of the reasons for an evaporator pond is eliminated.

Long Term Effects

Conceptually, most if not all of the drainage water could be reused for economic crops with the proviso of an appropriate drainage water collection and redistribution systems that would allow for blending or intermittent use with good quality water. This system will work because the salts in the drainage water are put back into the ground; and because of considerable travel time, will not return to the drainage outlets immediately. However because the travel times to the drainage line vary with distance from the drain line, the concentration will gradually and continuously increase. Thus, the salinity of the water to be reused will increase with time and the system will become constrained. Ultimately salt must be removed from the farm or isolated in one segment of the farm to achieve an infinitely sustainable system.

A major policy issue is the trade-off between short-term benefits of reusing water with long-term serious consequences of degrading land. Mesopotamia is the often-repeated classic example about a society that transformed very productive agricultural land into a desert. A consideration that is frequently overlooked is that this transition occurred over centuries of time. Because it took centuries of time rather than decades, was it any less an historical disaster?

Environmental Issues at RRR

Two environmental issues are pertinent to the Red Rock Ranch project. (1) Standing waters that stimulate invertebrate production and attract birds can be harmful to birds if the water contains only a few micrograms per liter of selenium. (2) Water containing 1 mg/L or more of selenium is classified as being "toxic" and is regulated by the Toxic Pit Cleanup Act. The purpose of this act is to protect groundwater quality.

The Central Valley Regional Water Quality Control Board (CVRWQCB) in 1994 issued waste discharge requirements (WDR's) to the Diener Family Trust and the Westside Resource Conservation District (WRCD). One condition of this permit was biological monitoring of the site because of potential impacts to wildlife by the high concentrations of selenium anticipated to be discharged into the solar evaporator. California Department of Water Resources (DWR) biologists have been monitoring the site since the permit was issued in 1994. US Fish and Wildlife Service (USFWS), personnel have also been monitoring the site, but on a more sporadic basis.

Wildlife information for the RRR site has been provided in a conversation with Joe Skroupa of the USFWS and from reports by the DWR. DWR staff visits are more of an observational nature than analytical. The permit issued by the CVRWQCB requires no standing water is to be allowed in the drainage reuse and solar evaporator portions of the project. Ponding of water is prohibited in the solar evaporator for the two following reasons:

1. It provides attractive aquatic habitat that is high in selenium. Birds feeding in such water would likely demonstrate teratogenic and other reproductive defects.
2. Discharge to the RRR solar evaporator often exceeds 1 ppm Se. Water equal to or in excess of 1 ppm Se can not be ponded in this manner as it would be a violation of the Toxic Pits Cleanup Act (TPCA).

Joe Skorupa (personal communication, Feb. 21, 2001) reported performing extensive observation and egg collecting in 1996 at RRR. The main bird species being studied was Black necked stilt. Fifty-six percent of the embryo's examined were deformed and only two percent of the eggs were viable. This is the highest rate of Se induced avian teratogenesis reported at any site in the world. In 1996, the eggs had an average of 58 mg/kg selenium. The selenium concentration in the drainage water for that year was reported in the ranged from 1041 to 1214 mg/L. Puddles in the solar evaporator were reported to have over 11 mg/L Se. Skorupa was unable to make routine visits to the site from 1997 to 1999. He collected two to four eggs during this period, which was not enough for a clear statistical sample.

Clu Cotter of the DWR made frequent visits to the site in 1998, stating his purpose was to look primarily for impacts to shore birds. These impacts would come from ingesting invertebrates that were living in the halophyte plots or the solar evaporator. Most importantly, he checked for invertebrates in standing pools of water. Water standing for more than three days can harbor a large number of aquatic invertebrates. His second purpose was to comment on the water management and operation of the Zon propane guns to disturb the nesting birds. Cotter reported that he did not see any invertebrates in the solar evaporator at RRR. There were fewer water management problems at RRR than at the Mendota site, primarily due to the automatic operation of the sprinkler system. He did see one aquatic invertebrate in a pool in the halophyte plots on one occasion. (WRCD report, January 1999)

In 2000, funding was again established for more complete monitoring by the USFWS. Between April 2000 and March 2001 a total of 24 biological site monitoring visits were made to RRR. During the year 2000, nesting by thirteen species of birds was documented in the RRR drainage management area, including 84 nesting attempts. (not including the salt sensitive crop area) 149 eggs were collected and analyzed, 79 of which contained assessable embryos, only 4 of which had abnormalities. These abnormalities were judged to be only one-tenth the levels found in 1996. The species of concern, black necked stilt, had 2 of 37 abnormalities, both of which were presumed to be due to selenium.

Only partial results of selenium analysis were available from eggs collected. The LAWR laboratory did analyze 4 of the stilt eggs and obtained an average of 16 ppm Se on a dry weight basis, this compares favorably to 58 ppm found in 1996. However, Skorupa cautioned that these eggs were collected early in the breeding season, when the solar evaporator was flooded with rainwater, and he anticipated eggs collected later would contain higher levels.

DWR staff observed 14 species of birds at RRR in 2000. Small mammal burrows and amphibians were also observed at the site. This work is continuing. On April 22, 2001, twelve species of birds were observed at the site, by a DWR environmental specialist. Two house finch nests were found under the cover of Zon cannons at locations in the solar evaporator and the halophyte plots. The surface, of the solar evaporator and the halophyte plots, was dry to the extent that wind gusts were causing dust and salt to blow off these areas. The salt tolerant grass plots were damp with a few scattered small puddles, but no invertebrates were observed or nesting sites located in this area.

Contributing Factors to Environmental Problems

No provision for drainage water storage was made except for the sumps. Because the change in elevation across the fields, the drain lines on the upper end of the field are at higher elevations than the land surface elevation at the lower end of the field. (Figure 11) Water will flow into drainage lines as long as the water table is above the drain line. Once in the drain line, the water flows rapidly to the sump and can "flood" the lower end of the field.

During some winter months, the amount of water collected in the last two sumps exceeded the capacity to be discharged on the halophyte area and into the evaporation pond without free standing water. The result was some embryo abnormalities and violation of the Toxic Pits Cleanup Act.

Mitigating Options

Options to reduce wildlife hazard and meet environmental regulations are available. Control valves on drain line laterals to restrict flow in the line would allow water storage capacity in the soil to be utilized. From the total farm perspective the amount of salt, selenium, boron and water collected in the last two sumps is very small.

Recycling this water onto the salt tolerant crops and salt tolerant grass areas would only marginally increase the amount of salt and boron distributed to these areas and have very little impact on productivity.

Utility of the Toxic Pits Cleanup Act

The enactment of the TCPA was not motivated by a problem associated with selenium. Nevertheless selenium has become ensnared in the regulation. Human made laws should be evaluated as to whether they accomplish the purpose for which they were enacted. In this case the purpose was to protect groundwater quality.

Ponding water is not in violation of the TPCA if the selenium concentration is less than 1 mg/L. One might assume that 1 mg/L is the concentration at which water become "toxic". Yet concentrations several orders of magnitude lower can cause wildlife damage. Wildlife must be protected from water with concentrations much lower, so wildlife damage would not be any greater from waters more concentrated than 1 mg/L. From a wildlife perspective, TCPA is irrelevant. The drinking water standard is ~~10~~ 50 micrograms per liter, thus from a drinking water standard is also irrelevant.

Therefore, prime consideration is given to groundwater protection. Selenium percolates downward to ground water from which it was extracted in the first place. Furthermore, most of the selenium in evaporation ponds has been measured to be in the sediment and relatively small layers immediately below the pond. Relatively small amounts of selenium percolate downward to groundwater from these sources.

The results at Red Rock Ranch reveal that more than 90% of the selenium in the drainage water extracted from the salt sensitive crop area has already been returned to the land and possibly to the groundwater. Less than 10% ends up in the pond that would be protected by the TCPA. Thus, the Toxic Pits Cleanup Act has very little impact upon the resultant groundwater quality. However, it does impose some potentially very costly facilities to meet compliance.

GRASSLANDS PROJECT

This project has a primary purpose of reducing the total quantity of salt and selenium being discharged to the San Joaquin River by a group of drainage/water districts in the Grasslands subarea. The participants include Broadview Water District, Charleston Drainage District, Firebaugh Canal Water District, Pacheco Water District, Panoche Drainage District, Widren Water District and Camp 13 Drainers, which include approximately 97,000 acres (39,300 ha). The total tiled area is 48,254 acres of which 37,954 acres is tiled into the Grasslands bypass project. Summers Engineering has established that historical drainage from the area was 57,000 acre-feet per year (Grasslands Bypass, 2001).

In March 1996 this group entered into an agreement to use a portion of the San Luis Drain (SLD) to bypass sensitive wildfowl areas that had previously been utilized for drainage water discharge. As a portion of this agreement the users agreed to monthly and yearly load limits on selenium being discharged through the SLD. On July 24, 1998 the Regional Board adopted a control plan and issued waste discharge requirements, including selenium load limits. The Grasslands users have implemented a variety of practices to reduce the total quantity of salt and selenium. Some of these practices are: formation of a regional drainage entity, newsletters and addition communications with the growers (primarily from the aspect or reducing the quantity of applied irrigation water), a monitoring program, blending of some drainage water back into irrigation water supplies in all member districts, and an active land management program to utilize subsurface drainage on salt tolerant crops.

From the perspective of drainage water reuse only the "blending" and the "active land management" are actual reuse projects. It should be noted that the monitoring and source reduction aspects of the program have been successful and have contributed greatly to reducing the quantity of drainage water from the area. In the 1999 water year drainage volume had been reduced by 39% over the pre-project levels of 1996. It should be noted that the 1999 water year had significantly less rainfall in the area than the 1997 and 1998 water years during which the Grasslands participants were unable to meet the salt and selenium discharge requirements. Each individual drainage district manages the blending program. Some districts, such as Panoche, have made agreements with their growers that the blended irrigation water will not exceed 600-ppm total dissolved solids (TDS). Others have agreed to 800 or 900 ppm limits. Broadview Water District has a long history of blending some drainage water into their irrigation water supplies (Wichlens et al. 1988a).

A major problem of blending brought to the attention of this writer is the fact that the high quality water and the drainage water have significantly different densities and will not mix well unless agitated. The story is told of one grower near the blending point in the ditch who essentially burned up his tomato crop by applying unmixed irrigation water to his field. His headgate took the water from the bottom of the ditch, thus providing mainly the higher density drainage water. Firebaugh has learned that agitation of the water to make certain it is well "blended" is an important aspect of the program (Jeff Bryant, personal communication).

For the water year 1999, 7,903 acre-feet of drainage water was blended back into the irrigation water system. Summers Engineering reports that this is near the ultimate goal based upon the limitation of blended water quality. Firebaugh recycles 24 of 34 sumps. It should be noted that the TDS of the drainage water blended back into the system is 6.0 dS/m that is slightly higher than the average salt concentration in the area's drainage water. The reason for this is that the sumps with the highest concentrations were selected for "blending".

The active land management (ALM) portion of the project is the most extensive drainage water reuse program currently in progress in the SJV. Each member district apparently has some water reuse project as a portion of the overall plan, but the main project is in Panoche where ultimately 3852 acres of cropland has been set aside as the district reuse facility. When completely built, this area will receive 12,000 acre-feet of drainage water, approximately 3.25 ft per acre.

Bermuda grass was being irrigated strictly with 100% drainage water 4.5 dS/m. Salt tolerant alfalfa and Sudan grass were irrigated with a blend of drainage water 4.5 dS/m and well water 1.5dS/m. The district attempts to keep the blended mixture in the 2.0 –2.2 dS/m range. (Personal Communication, July 2000).

Summers Engineering has reported that at the end of water year 2000, 1123 acres had been planted as follows: 530 acres pasture mix; 471 acres alfalfa; 133 acres alfalfa with pasture. At the end of water year 2001, 2141 acres of land will have been planted as follows: 920 acres pasture mix; 471 acres alfalfa; 122 acres alfalfa with pasture; 72 acres alfalfa for seed; 300 acres alfalfa seed with pasture; 220 acres asparagus. They have reported that the newly seeded fields are irrigated with the better quality water until they are established, thus only a small portion of the fields have been irrigated with drainage water as of this writing.

There is no present subsurface drainage system for the land being used. Soppe et al., (2000) report that the area is drained by open earthen ditches, but lacks an outlet due to the landowner's decision not to participate in the Grasslands Bypass project. Summers Engineering reports that "future phases call for the installation of subsurface systems with implementation of treatment and salt disposal components." It is believed that ultimately this will become a regional in-valley disposal system with solar evaporators and salt harvesting.

As of December 2000, a total of 5843 acre-feet (AF) of drainage water had been disposed of at the ALM site during the previous two-year period. This drainage water had contained 845 lbs of selenium and 22.5 tons of salt. The highest three months of drainage water application were June 2000 (458AF), August 1999 (434AF) and August 2000 (400AF). No drainage water was applied to the land in November or December of either year. The concentration of the drainage water varied between 3.1 and 5.6 dS/m during the 2000 calendar year.

Broadview Water District has obtained land in the lower end of the district. A small portion of this land has been used since October 1998 as flow through channels to remove selenium. Treatment 3 with straw bales planted with saltgrass (*Distichlis spicata*) and rabbitsfoot grass (*Polypogon monospeliensis*) has been successful in removing 73% of the selenium. Data from October 2000 indicated that improvements in the system, high tonnage of straw bales alone, may have raised the removal levels to 84-85%. An added benefit is that nitrate is also nearly 100% removed. The compact nature of the system allows it to be covered with netting to protect wildlife from entering the contaminated water.

A grass plot of Willcox alkali sacaton {*Sporobolus auriudes* (Torr.) Torr}, and a six acre pasture plot of tall fescue (*Festuca arundinacea*), trefoil (*Lotus corniculatus*), clover (*Trifolium fragiferum*), Salado alfalfa {*Medicago sativa* (var. "Salado")} and alkali sacaton were also planted on this site. Both plots have been irrigated with subsurface drainage water from the Broadview district. Cattle (22 in one verbal report) were pastured on the mixed plot in the summer of 2000 and appeared to do well. No data as to weight gain or numbers are available. Broadview is expanding the pasture project, planting poplar, eucalyptus, and Casuarina trees in the spring 2001. Alfalfa plots and native vegetation test plots will be planted in the fall 2001. This will expand the drainage water reuse area to approximately ninety acres.

The written report July 2000 states that Firebaugh Canal Water District has no district wide blending reuse program. Jeff Bryant, manager of the district reported that four or five of sixteen drainage sumps are plumbed back into the irrigation system part of the season and 19 other sumps are recycled at all times. The average salinity of the irrigation water is 0.6 dS/m and the average drainage water is 5.0 dS/m. The main contribution that this district appears to be making is source reduction instead of drainage water reuse. After melon crops, Sudan grass (*Sorghum sudanease*) is planted to take up excess water from the soil profile and the shallow water table. The Sudan grass is planted in June after the melon harvest, cut in July and then pastured with sheep in September. Safflower is also used for this purpose during the winter months.

Bryant also reported that some growers planted trees in the district that were irrigated with drainage water, but all of these have died or were sprayed. Some growers are also planting forages for irrigation with drainage water, but this is on an individual basis. (Jeff Bryant, 2000, personal communication)

In general, all of these projects have begun only recently and are now just getting totally installed. At the present time, because of discharge limitations placed on the project, the intent is to dispose of drainwater and not discharge to the San Joaquin River. There is, however, a comprehensive In-valley planning effort underway through cooperation with the Department of Water Resources and the U.S. Bureau of Reclamation to analyze impacts of the drainwater use on the 4000 acre In-valley disposal area and to plan for future phases to maintain the long-term ability to dispose of drainwater.

In summary, originally 57,000 acre-feet of drainage were discharged from the area. By the end of the 2000 water year the discharge to the river had been reduced by 41%. Approximately, 8000 acre feet had been blended back into the irrigation system and 2300 acre-feet reused on salt tolerant crops. The difference should be an indication of source reduction, around 13,000 acre-feet. When fully operational the goal appears to be 0.385 x 57,000acre-ft = 22,000 acre-ft discharged to river; 0.315 x 57,000 acre-ft = 18,000+ acre-ft reused or treated; 0.30 x 57,000 acre-ft = 17,000 acre-ft source reduction or conservation. Ultimately improvements in drainage water reuse and source reduction will decrease the quantity discharged to the river, thus reducing the quantities of salt, selenium and boron entering the river system. Treatment systems, such as the one at Broadview may reduce the need to discharge selenium and even reduce the quantity of nitrates entering the SJR.

It is too early to evaluate the total success or failure of these systems, but the group has been meeting the river discharge goals that were set in 1996 and has established positive goals for the future.

POTENTIAL CROPS FOR DRAIN WATER REUSE

There are crops presently grown in the Westside San Joaquin Valley that would lend themselves for either direct drain water reuse or in combination with good quality water. It would be more convenient for growers to adapt drain water reuse practices on crops they are currently producing, than to introduce halophyte species such as allenrolfea, kenaf, salicornia and atriplex. Salicornia and atriplex will be discussed because extensive research and trials have been made.

Cotton already extensively grown may be irrigated with water having the salinities common to drain water, which is available in large portions of the valley. Rather than using high quality water after the plant has passed its early growth stages farmers could utilize available drain water. Sugar beets, safflower, pistachios, small grains, some vegetables and forages would also be available for irrigation with the drain water. Forages appear to have a great potential for drainage water reuse, since the vegetative mat they produce protects the soil surface from crusting during the winter rains and perennial grasses do not need to be started from seedlings each year.

There are economically grown salt-tolerant plants that have not been included in this presentation because they may not be frost tolerant, or have other growth characteristics that would make them unsuitable for the San Joaquin Valley. An example of this is date palm with a threshold salinity of EC = 4.0 dS/m and a slope of 3.6 % yield decline per unit EC. There are others that could be mentioned.

What follows is a discussion of these salt tolerant crops and some of the recent research. Boron tolerance information is also provided in the discussion.

Cotton

Cotton, a variety of plants of the genus *Gossypium*, belonging to the Malvaceae family and native to most subtropical parts of the world, has been producing fiber for mankind about six thousand years. Its first known cultivation was in the Indus valley about 4000 B.C.E. The centers of origin are believed to be Indo-China and tropical Africa in the Old World. Asiatic cottons have thirteen chromosomes (Martin and Leonard, 1949).

Gossypium is also native to South and Central America and in the western hemisphere it was used for clothing and rope in Peru and Mexico. There is evidence in a cave in New Mexico that irrigated cotton may have been grown in the Rio Grande valley approximately 300 B.C.E. (Anonymous, 2000) The modern varieties used in the United States appear to be derived from these cottons. Upland cotton, *G. hirsutum*, has creamy white flowers and a fiber length of ¾ to 1-¼ inches. Sea Island and/or American Egyptian cotton, *G. barbadence*, has yellow flowers with a purple center spot and fiber length between 1 1/2 and 2 inches (Martin and Leonard, 1949). These cottons have 26 chromosomes. When cotton cultivation moved into the irrigated valleys of the western United States the primary variety was Acala. The large flowers attract insects and the plants are easily cross pollinated so it is difficult to maintain pure varieties.

In the San Joaquin Valley (SJV) of California the primary cotton varieties included in the 1999 field trials were "Approved Acalas", "Approved Pimas", "CA Uplands", "CA Pima" plus other experimental varieties. (Hutmacher et al., 2000) Acala varieties CPCSD Maxxa and Phytogen–33 were grown for comparison purposes. It should be noted that the trials did not include all varieties approved for use in the SJV. The Westlands Water District reported 127,340 acres of Acala/Upland varieties and 75,980 acres of Pima varieties for the 1999 crop year. This constitutes nearly 35% of the total acreage planted to crops in the Westlands in 1999. (Westlands Water District, 1999) In the Tulare Lake basin the main crops are cotton and safflower and from personal observation acreage of cotton is also quite high in western Kern County.

It has long been known that cotton is very tolerant to saline/sodic soil conditions. In the two part linear equation developed by Maas and Hoffman (1977) cotton lint was given a threshold value EC = 7.7 dS/m a slope of 5.7% per dS/m. (See detailed discussion of the Maas Hoffman equation in the scientific section of this paper.) This is important when considering drainage water reuse, since relatively high yields may be obtained by irrigating with the drainage water which can have EC = 6 to 12 dS/m.

Grattan (1994) cites cases in Israel where cotton is grown using irrigation water of 4.6 dS/m and in Uzbekistan with $EC_w = 7.8 - 9.4$ dS/m.

In a case reported by Wichlens et al. (1988a) irrigators in the Broadview Irrigation District in the SJV obtained good quality canal water in 1957. During subsequent years they installed drainage tiles to nearly 80% of the lands in the district, but had no outlet for their drainage system. The district began blending drainage water back into the irrigation supply. By 1983 the drainage water had increased in salinity to 2800 mg/l TDS. Although the fields were leached, the blended irrigation water reapplied to the land caused a shift in production from salt-sensitive crops to cotton. Cotton acreage doubled from the 1968-72 period to the 1978-82 period, while the tomato acreage decreased by 70%. During the same period Fresno County overall had increases in both cotton and tomato acreage. The point to be made is that growers were able to grow cotton on a district wide basis by blending drainage water into the irrigation supplies. Yields of cotton lint, on a per acre basis, actually increased by ten percent during the period cited above.

Rhoades and LeMert (1982 unpublished) blended 9 dS/m drainage water with 0.7 dS/m aqueduct water in the SJV. The 50/50 blend resulted in a 36% decrease in cotton lint yield when compared to the good quality water. Using the drainage water alone caused a 50% yield reduction from 1770 kg/ha to 900 kg/ha. However, using good quality water during the seedling stage and the blended drainage water thereafter resulted in only a 20% yield reduction. (cited by Shalhevet, 1984) This brings an important point to be made when using saline drainage water with cotton (or many plants). Seed germination appears to be a salt tolerant process; seedling emergence is salt sensitive.

Grattan (1994) cites Ayars et al. utilizing drip rather than surface irrigation methods used drainage water to irrigate cotton on a cyclic basis. For three consecutive years drainage water ($EC_w = 8.0$ dS/m) was used for irrigation after seedlings were established. Subsequent to this wheat was planted and irrigated with good quality water $EC < 0.5$ dS/m. Sugar beets were then planted after the wheat and again irrigated with the saline drainage water after the seedlings were established. This experiment resulted in no difference in yield from plots irrigated entirely with the good quality water.

Shennan et al. (1987) designed an experiment to test the long-term feasibility of using drainage water irrigation in a rotation of processing tomatoes and cotton. The study tested two designs of cyclic irrigation: 1) one year of saline drainage water (EC = 7.3-7.7 dS/m, 5 mg/l B) applied to a tomato crop after first flower, followed by two years of aqueduct water applied to cotton crops; and 2) drainage water applied to tomato and the first cotton crop after pre-irrigation with aqueduct water and aqueduct water alone applied to the second year cotton crop. Each irrigation treatment began at the three points in the cropping sequence. After four years of investigation saline drainage water did not cause a yield decrease in the cotton or tomatoes (Grattan et al., 1991). However, in the fifth year the drainage water treatment did cause a reduction in tomato fruit yield (Grattan, 1994).

The above study did indicate that salt and boron had accumulated in the soil profile below 60 cm. Above 60 cm there is a yearly lag in salt accumulation and leaching. Grattan (1994) concluded that salt sensitive crops following salt tolerant crops could be adversely affected by the salinity in the soil profile in the year following irrigation with saline drainage water. It should be noted that there were no long-term detrimental effects on the yield of cotton lint in this experiment.

Mitchell et al., (2000) report on using cover crops and gypsum in the winter together with a cyclic reuse of drainage water in the cotton/tomato rotation. Saline water, EC = 6.9 dS/m was used to provide 70% of the irrigation water for the two crops. There was no apparent loss in cotton lint yield during the third year of the rotation, but there was a 33% decrease in yield for processing tomatoes in the second year. Significantly, there were decreases in cotton seedling emergence and increased problems with seedling disease when the cover crops were utilized and incorporated. Soil EC_e increased from around 2 dS/m to approximately 6 during the three year period of this experiment.

Additional information regarding the possibility of using cotton as a salt tolerant crop in a drainage reuse scheme comes from Frenkel et al. (cited in Shalhevet, 1984). They had crop production functions for cotton as $Y_r = 0.223 + 0.17D_i$ when the crop was irrigated with 3 dS/m water and as $Y_r = 0.204 + 0.16D_i$ when the crop was irrigated with 8 dS/m water. Y_r is the relative yield and D_i is the quantity of irrigation water applied in mm.

Letey and Dinar (1986) also calculated crop production function for cotton dry matter production. Since their model was based upon the linear relationship between dry matter production and ET and the threshold salinity and slope of the two part equation were presented as cotton lint production, it was necessary to determine a relationship between cotton lint and cotton plant dry matter. The literature showed that this was not a linear relation but was a quadratic formula. For cotton dry matter production they provide a threshold of 6.1 dS/m and a slope of 6.9% for the two part equation. The result presented seemed to imply that higher lint yield may occur with the use of saline water as opposed to non-saline water. This was explained to occur because the saline water tends to inhibit vegetative growth at high values which in turn leads to higher lint production.

One problem encountered when using saline irrigation water in a sprinkler system is leaf damage to the crop. Grattan (1994) cites Maas et al., who sprinkled a cotton crop with a salt water mixture (60 eq/cubic meter sodium chloride plus sodium sulfate). They found no leaf burn on the cotton plants even though there was damage to other crops at this concentration. Benes et al. (1996) found that maize and barley could be sprinkled with saline water if non-saline water was used to wet the crop prior to the use of saline and then again to rinse the crop at the end of the irrigation period. This would only be feasible if there were immediate access to both saline and non-saline water for the sprinkler system.

In a related study which basically falls into source reduction instead of drainage water reuse Ayars grew cotton that was irrigated to become established and then forced to use saline water from a shallow water table to meet the crop needs at the later stages of growth. They found that cotton grown by this method is capable of using water with higher salinities and soil saline conditions measured by the saturation extracts (EC_e) than had previously been believed possible. Osterbaan (1982), in a field study in Pakistan also found that drainage below 60cm depth was unnecessary to grow cotton. Combinations of these type studies with drainage water reuse may enable growers in the SJV to profitably continue growing cotton on lands which are now considered nearly unsuitable for production.

Boron (B) must also be considered when choosing crops for irrigation with SJV drainage water. Fortunately, cotton is also listed as very tolerant to B (Maas and Grattan, 1999; Hanson et al. 1999) with threshold values boron concentration of 6.0 – 10.0 mg/L, after which yield reduction occurs. Data was not available on the slope of the yield reduction. Eaton (1944) found 130% more growth when plants were irrigated with B concentration in the 5 to 15 ppm range when compared with plants grown when B concentration was 1 ppm or less. Best growth occurred at the 10-ppm concentration. Eaton noted deficiency symptoms when plants were grown with only 0.03 to 0.04 ppm B in the solutions, thus it is not an actual nutrient deficiency problem in the 1 ppm solution.

Sugar Beets

From a listing by Maas and Grattan (1999) sugar beets (*Beta vulgaris*) is one of the most salt tolerant of the regular crops grown in the San Joaquin Valley of California. The threshold salinity is given as 7.0 dS/m and the slope of the two part equation is 5.9 % per dS/m which is comparable with cotton. Letey and Dinar (1986) show that irrigation water salinities in the range of 11 dS/m will still provide 90% yield for sugar beets. Ayers and Westcott (1976) have noted that salinity in the germination area of sugar beets should not exceed 3 dS/m, thus placing caution in early season use of saline water.

Sugar beets are a relatively new field crop compared to some, which have been grown by mankind for thousands of years. Beets have been grown and were eaten for their sweetness many years prior to 1747 when the German chemist, Marggraf, found the sugar in the beet was sucrose, the same as that found in sugar cane. Louis Vilmorin of France then selected beet progeny for their sugar content raising the percentage sugar from about 7.5% up to 16-17%. (Martin & Leonard, 1949)

The first successful commercial factory in the United States was erected at Alvarado, California in 1870. Sugar beet culture spread throughout the irrigated valleys of the west and into the coastal plains of the Great Lakes region. They are primarily grown in a climatic belt where the summer mean temperature ranges from 67 to 72 degrees F which contributes to the maximum sugar content. Sugar beets are the only feasible sugar crop grown in cool climates and in the southern valleys of California and Arizona the crop is grown as a winter crop. In 1999, there were 7,432 acres of sugar beets grown in the Westlands Water District. (WWD Crop Report, 1999)

In the SJV, sugar beets may be planted in October to November, grow to maturity from December to April and mature for harvest thereafter. This time period lends itself to application of saline drainage water for irrigation at a time when the water levels in the soil are high and drainage water disposal is a problem. Studies have show that the drainage water in the SJV can be used to irrigate the crop, but should be used after the seedling establishment period. A concern that has arisen and must be addressed is the problem of nitrates in the drainage water and residual nitrate in the soil profile. If nitrates are too high during the period of maturation sugar beets will have a lower sugar content.

Specifically, in the Imperial Valley of California, Rhoades et al., (1988) applied saline drainage water (TDS = 3500 mg/l) to sugar beets as a part of a melon, wheat, sugar beet rotation. The crop was established using Colorado river water (TDS = 900 mg/l) but the saline drainage water provided nearly 75% of the total crop irrigation requirement. Using the drainage water caused no decrease in yield when the crop was compared with checks receiving only Colorado River water. In another experiment, Kaffka et al. (1999) irrigated sugar beets with shallow saline groundwater pumped at the Westside Field Station in Five Points, CA. Boron (B) must also be considered when using SJV drainage water for reuse. Sugar beets are tolerant of B concentrations in the soil solution up to 4.9 mg/l before a decrease in yield is noted.

Small Grains

The small grains barley, rye and triticale have been shown to be tolerant to salt and may have utility in a drainage reuse system. Most data shows wheat as moderately tolerant (Maas and Grattan, 1999) but semidwarf and durum wheat are shown as tolerant. Oats are less salt tolerant but may also be considered as possible forage crops in a drainage reuse system using blending. One advantage of the crops from the family is that they can be planted in the fall and utilize the saline drainage water in the winter and spring when the greatest quantity of the drainage water is available. A disadvantage is that these crops require only small applications of water for growth and maturation and that their water requirements are often met by normal rainfall and water stored in the soil profile. These crops are also on the low end of the economic return scale in agriculture. Barley can yield 100 bu/acre and can economically compete with corn in providing nutrients for animal production.

Table 7: Salt tolerance of small grains based upon the two part linear equation (Maas and Grattan, 1999)

Crop		**Electrical Conductivity of Soil Saturated Extract**		**Rating**
Common name	Scientific name	Threshold dS/m	Slope % dS/m	
Barley	Hordeum vulgare	8.0	5.0	T
Oats	*Avena sativa*			T
Rye	*Secale cereale*	11.4	10.8	T
Sorghum	*Sorghum bicolor*	6.8	16.0	MT
Triticale	*X Triticosecale*	6.1	2.5	T
Wheat	*Tritium aestivum*	6.0	7.1	MT
Wheat (semidwarf)	*T. aestivum*	8.6	3.0	T
Wheat, Durum	*T. turgidum*	5.9	3.8	T

Barley for forage has a threshold salinity of EC_e = 5.3 dS/m and does not have a 50% loss in yield until EC_e = 13.0 dS/m. Mass and Grattan (1999) found that barley is less tolerant during the seeding stage and the EC_e should not exceed 4-5 during this period. Barley grown for grain is even more tolerant of saline soil conditions.

There appears to be a wide variation in threshold salinity comparisons. Some additional data is presented in table 8 below.

Table 8: Threshold Salinity Comparisons by Various Researchers after Meri (1984)

Researchers	Barley (g)	Barley (f)	Wheat (g)	Oats (g)
Maas & Hoffman (1977)	8.0	6.0	6.0	-
Hoffman & Van Genuchten (1982)	5.5	4.6	7.0	5.8
Rhoades & Merrill (1976)	5.4	5.3	5.9	5.1

Prior to use of drainage water for reuse one must also consider boron concentration in the irrigation water and the tolerance of plants to boron. (See discussion of B elsewhere in this report.) See Table 9 below showing boron tolerance for the small grains discussed above:

Table 9: Boron tolerance of small grains

Crop	Tolerance based on:	Maximum concentration in soil water in mg/l Threshold value	Boron tolerance rating
Barley	Grain yield	3.4	MT
Oats	Grain (immature)	2.0-4.0	MT
Sorghum	Grain yield	7.4	VT
Wheat	Grain yield	0.75-1.0	S

Information was not available for rye or triticale. S – sensitive; MT – moderately tolerant; T- tolerant; VT – very tolerant. (Based upon Hanson et al., 1999)

Sprinkler irrigation with 60 eq/cubic meter (sodium sulfate and sodium chloride) water caused leaf burn on barley. Other small grain crops apparently were not tested.

In the Imperial Valley of California Rhoades et al., (1988) conducted field experiments to test the cyclic irrigation practice of applying saline drainage water for irrigation. He used wheat, sugar beets and melons in a two-year rotation. Colorado River water (900 mg/l TDS) was used for irrigation of the melons and for preplant and early growth of theother two crops. Drainage water (3600 mg/l TDS) was used for the remaining irrigations of wheat and sugar beets supplying approximately 75% of the total water needs. After two years there was no reduction in yield for the saline irrigated crops when compared with a similar rotation irrigated only with Colorado River Water.

Wheat was also used in a rotation experiment in the San Joaquin Valley, but it was irrigated only with good quality water (EC <0.5 dS/m) even though other crops in the rotation were irrigated with saline drainage water. (Ayars et al., 1986a,b) There are indications that flour made from wheat irrigated with saline water is of higher quality than wheat flour from normal irrigations.

It would appear one research need is to conduct an experiment in the San Joaquin Valley testing the possibility of using saline drainage water directly to irrigate small grain crops during the winter season. It may be necessary to have a preplant irrigation with non saline water to improve germination and early seedling growth if the drainage water to be used has EC > 4.0 dS/m. A study also could be made on the economic returns of barley irrigated with saline drainage water compared with corn grown with non-saline water. Perhaps the saline water/barley combination could replace corn in feed thus reducing the requirement for good quality water to grow this low value crop.

The origins of barley have not been well defined. It is known that the first writing in Sumer lists barley. It is widespread and common in early Neolithic sites, including Ali Kosh in the south Iranian Deh Luran Plain, Jarmo in the Zagros Mountians, Catal Huyuk in Anatolian Turkey and Beidha in the southern Jordanian rift (Renfro, 1973). Naturally wild barley, *Hordeum vulgaris var. spontaneum*, is the most wide spread of the cereals, growing in the hills of the Levant, Turkey, the Zagros and even into the western Himalayas and Tibet. The wild varieties seem to prefer the hotter steppe and desert, but modern varieties have been widely adapted to climate and soil differences. Two domestic cultivars, six row *H. vulgare* and two row *H. distichum*, are grown in the modern era. All have fourteen chromosomes.

Several archeological sequences in the Near East, including Deh Luran Plain in Iran, have more equal amounts of wheat and barley in the earliest sequences. Later, as we approach more modern times the proportion of barley tends to increase and this has been attributed to the over irrigation and salinization of the soils. (Hole and Flannery, 1967) Perhaps the salt tolerance observed in the species is due to genetic selection over thousands of years.

The history of wheat is even more complex than barley. Emmer, a type of wheat is found in Egyptian tombs and is also known in historic Greece, Persia, and Turkey. Einkorn is another early form of wheat, having seven chromosome pairs as compared to emmer with fourteen (Martin and Leonard, 1949). Modern genetic studies have begun to unravel wheat history by actual study of the gene sequencing. Cytogenetic studies indicate that emmer, *Tritium turgidum subsp. Dicoccum,* forms the ancestral stock for the modern high yielding bread wheat, *Tritium aestivum*. This latter grain has crossed with *Aegilops squarrosa*, having natural range form eastern Turkey to Azerbaijan through Pakistan (Renfrew, 1973). It is believed that the modern bread wheat could not have been formed naturally and is believed to be a product of domestic agriculture.

Rye, *Secale cereale*, originated in Turkestan and was unknown to the Egyptians and Greeks. *S. anatolium* is a wild form from Syria, Armenia, Persia, Afghanistan, Turkestan and the Kirghiz steppe. *S. montanum* is a wild form from southern Europe. It is believed that cultivation of this plant originated as a weedy mixture in the cultivated wheat and barley fields (Martin and Leonard, 1949).

Crosses between rye and wheat probably occurred naturally, but the offspring were usually weak non- productive plants. By selective breeding in Europe during the period 1870- 1930 some rye wheat crosses were developed that became agriculturally useful. During the 1930's the name triticale was first used for some of these crosses. The name did not catch on with the public until an episode of Star Trek in the 1960's used the grain in intergalactic trade.

Safflower

Safflower (*Carthamus tinctorius*) is an annual, erect, glabrous herb, one to three feet in height with substantial branching. Flowers can be white, yellow, orange or red. The seed is smooth, four angled, white or cream colored and resembles a small sunflower seed. Safflower seed weighs 30 to 48 pounds per bushel with good quality seed weighing at 45. The whole seed contains oil, which is the main product for which the plant is grown. The residual meal after the oil has been pressed can be used for animal feed and is comparable to cottonseed meal in quality. Historically a red dye was extracted from the flowers in India that may have contributed to the species name. The plant was grown agriculturally in Egypt 3500 years ago.

Safflower is a salt tolerant plant, which does not have a fifty percent yield loss until the EC_e reaches 15 dS/m (Maas and Grattan, 1999). Data for the two part equation for relative yield was not available in the literature, but one source provides a threshold value of $EC_e = 5.3$ dS/m with 10% yield loss at 8.0; 25% yield loss at 11.0; and 50% yield loss at 14.0 dS/m (Utah State University Extension,). Ayers and Westcott (1976) reported a 10% yield loss at ECe 6.2 dS/m; 25% at 7.6 and 50% at 9.9. Bernstein (1964) assessed the salt tolerance of the plant in plots in Riverside, California finding it to be moderately tolerant. Raines et al. (1987) grew safflower in successive rotational cycles in the San Joaquin Valley with each successive cycle increasingly salinized. This experiment showed (1) decreasing yields with increasing salinity and (2) attributed the yield decrease to both reduced plant growth and a reduction in plant stand.

Kaffka and Bassil (1999) state that the Rains et al. (1987) experiment did not adequately document the salinity conditions in the soil and water for the safflower experiment. He is studying a safflower/sugar beet rotation on plots at the UC Westside Research and Extension Center. Plots are furrow irrigated with CVP high quality water (EC_i <1 dS/m) or saline water ($EC_i = 6.7$ dS/m) from a shallow well located on site. Seven plots are irrigated one year with high quality water and the following year with saline water, or vice versa. These cross-over plots represent moderate saline conditions. The soil has been sampled to a depth of 2.7 meters and moisture conditions are tracked during the growing season with neutron probes.

Results from the 1998 growing season follows: Effective EC_e was estimated to be 2.1 dS/m for the control plots and 7.2 dS/m for the saline plots. Consumptive water use (ET) between April and July averaged 515 mm in the control plots and 435 mm in the saline plots. Seed yield was not correlated with water use over the range 400 to 580 mm, but total dry weight and height of plants directly correlated with water use. This implies that saline conditions reduced plant size, but did not affect harvestable yield. The oil content was slightly increased in the saline plots. Kaffka and Bassil (1999) concluded that safflower tolerated salinity, without yield loss, better than reported previously. It should be noted that both 1997 and 1998 had rainfall amounts greater than normal for this area of the SJV. Kaffka also reported that the early part of the 1998 growing season was unusually cool due to the El Niño climate pattern.

In the Tulare Lake Drainage District cotton and safflower are the two main crops grown on the undrained heavy clay soils of the basin. Safflower is a deep-rooted plant with the ability to dry out the soil profile when it becomes over saturated. Growing safflower allows the growers to plant cotton and have economic returns where drainage systems are not available in the heavy clay soils of the Tulare Lake Basin. (Doug Davis, personal communication)

Vegetables

Vegetables listed in the 1999 Westlands Water District Crop Acreage report are: artichokes, asparagus, beans, broccoli, cabbage, carrots, cauliflower, sweet corn, cucumbers, garlic, lettuce, melons, onions, peppers, spinach, and tomatoes. This provides a listing of potential crops that are acclimated to the SJV. However, with the exception of asparagus, most vegetable crops are not salt tolerant. See table below:

Table 10: Salinity and Boron Tolerance of Vegetables

Crop	Threshold Salinity dS/m	Slope	Rating for Saline Tolerance	Boron Tolerance based on	Maximum concentration in soil water in mg/l	Boron Tolerance Rating
Artichoke	6.1	11.5	MT	Laminae DW	2.0-4.0	MT
Asparagus	4.1	2.0	T	Shoot DW	10.0-15.0	VT
Beet (red)	4.0	9.0	MT	Root DW	4.0-6.0	T
Broccoli	2.8	9.2	MS	Head FW	1.0	MS
Cabbage	1.8	9.7	MS	Plant DW	2.0-4.0	MT
Carrot	1.0	14.0	S	Root DW	1.0-2.0	MS
Celery	1.8	6.2	MS	Petiole FW	9.8	VT
Corn, sweet	1.7	12.0	MS			MT
Cucumber	2.5	13.0	MS	Shoot DW	2.5	MT
Eggplant	1.1	6.9	MS			
Garlic	3.9	14.3	S	Bulb yield	4.3	T
Lettuce	1.3	13.0	MS	Head FW	1.3	MS
Muskmelon	1.0	8.4	S	Fruit yield	2-4	MT
Onion bulb	1.2	16.0	S	Bulb yield	8.9	VT
Onion seed	1.0	8.0	S	Yield DW		
Parsley				Plant DW	4.0-6.0	T
Pepper	1.5	14.0	MS	Fruit Yield	1.0-2.0	MS
Potato	1.7	12.0	MS	Tuber DW	1.0-2.0	MS
Radish	1.2	13.0	MS	RootFW	1.0	MS
Spinach	2.0	7.6	MS			
Squash scallop	3.2	16.0	MS	Fruit Yield	4.9	T
Squash zucchini	4.7	9.4	MT	Fruit Yield	2.7	MT
Tomato	2.5	9.9	MS	Fruit Yield	5.7	T
Turnip	0.9	9.0	MS	Root DW	2.0-4.0	MT
Turnip greens	3.3	4.3	MT	Shoot DW		

The above table is taken from Mass and Grattan, 1999. The ratings: S – sensitive; MS – moderately sensitive; MT- moderately tolerant; T – tolerant; VT very tolerant

Tomatoes and melons have been irrigated with saline water (E.C. 8.0 dS/m and 6 mg/l B) and it was noted that fruit quality is improved (Shannon and Francois, 1978; Pasternak et. al., 1986). Processing tomatoes used in cyclic drainage water reuse schemes have also shown some promise as an economically viable crop for some drainage water reuse (Shennan et al., 1987). Other crops for which saline drainage water has been used for irrigation are: brassicas (cabbage, cauliflower), carrots, celery, onions, peppers, (Ayers and Westcot, 1985).

The chart for saline and boron tolerance for vegetables seems to indicate two important considerations 1) the combination of saline conditions and boron eliminate most vegetables from consideration for reuse and 2) that crops different from the ones tried above may offer potential for saline drainage water reuse. Prominent among those crops with both some tolerance for saline conditions and boron are: asparagus, red beets and zucchini squash.

Oster et al. (1999a) list asparagus as one of the salt tolerant forages in the group of warm season and cool season salt tolerant crops recommended for the SJV. Two hundred acres of asparagus was planted in the spring 2001 by Panoche Water District as part of their drainage water reuse program. In January 2001, while interviewing Mike Andrews of Rainbow Ranch, it was learned that asparagus is one of the main productive vegetable crops in his area of southwestern Kern county. He is installing an IFDM system for the purpose of eliminating his evaporation ponds. He had not anticipated using asparagus as a salt tolerant crop, but Abraham Meri, visiting from Israel, recommended that he try it, perhaps even in the third stage of drainage water reuse, i.e. using the drainage water from the salt-tolerant crop area to irrigate asparagus. Francois, (1987) indicated that asparagus is more tolerant of saline conditions after the first year of growth, thus it may be necessary to establish with non-saline water prior to irrigation with drainage water.

Sugar beets are grown commercially in the SJV and are recommended elsewhere as a portion of the drainage water reuse system. Red beets are not grown commercially and are somewhat less salt tolerant, but may have some potential as a drainage water reuse crop. Moderately salt tolerant squash could also be considered under certain circumstances.

Forage Crops

Oster et al., (1999a) wrote, "saline-sodic drainage water likely is a resource for forage production along the land-locked, Westside of the San Joaquin Valley in California because many forages are salt-tolerant." The proposal included a combination of salt-tolerant crops for both the winter cool season and the summer warm season. The crops proposed for forage are small grains, sugar beets, brassicas, safflower and grasses. This would enable the livestock producer to have available both high energy and high protein feed on a year around basis.

Oster et al., (1999a) provided a table of potential salt tolerant crops listed in order of salt tolerance. The data is based upon Maas and Grattan (1999) and other research performed at the US Salinity Laboratory. The table is partially reproduced as table 11 below.

Other than testing the saline tolerance of these crops it would appear that not much actual data has been kept on applying drainage reuse water to these crops. Most of the data is anecdotal. The Jones ranch has been applying drainage water to Jose tall wheatgrass for several years, harvesting the crop and feeding it to cattle. They have not kept any data on quantities applied or yield data.

Other research on forages is just reaching points where actual data is to be generated. A portion of the salt-tolerant crop area at Red Rock Ranch has Jose tall wheatgrass and the area where eucalyptus trees were planted has now been converted to grass plots. Cervinka (personal communication) has reported that these plots were irrigated with non-saline canal water until May 2000. The species planted in these plots are: creeping wild rye (*Elymus* spp.), "Solado" alkali sacaton (*Sporobolus airoides*), Alta tall fescue (*Festuca elatior*), perla kolea grass (*Phalaris aquatica*), birdsfoot trefoil (*Lotus corniculatus*), Harding grass (*Phalaris tuberosa*), Argentine tall wheatgrass (*Agropyron elongatum*)(*Thinopyrum elongatum*), Jose tall wheatgrass (*A. elongatum*), puccinellia (*Puccinellia distans*), Alkar tall wheatgrass (*A. elongatum*), and saltgrass (*Distichlis spicata*).

Oster et al. (1999a) and Kaffka et al., (1999a,b) report on a forage project using small plots at the Westlake Farm in the SJV. Three warm season grasses, saltgrass (*Distichlis* spp.; NyPa Inc., Tucson, AZ), Bermudagrass (*Cyandon dactylon*, cv. Santa Ana) and seashore paspalum (*Paspalum* spp.) were first tested for saline tolerance at the US Salinity Lab. All three species grew well when irrigated with saline water up to 20 dS/m. Growth rates declined slowly when the salt concentration was increased above that level. In small test plots at the Westlake farm the same species were grown but over seeded in the fall with annual ryegrass or fescue. For total yield the best warm season/cool season forage mixture was Bermudagrass-ryegrass. The authors are continuing with a full field scale study at the Westlake farm but only preliminary data will be available for the 2000 season.

Table 11: Listing of potential salt tolerant forages for the San Joaquin Valley drainage reuse systems.

Forage Crop	Common name	Growth Season, Habit	Salt Tolerant Rating	Salt Tolerance Coefficients Threshold	slope	ECe (70) dS/m	LR %
Puccinellia distans	Puccinella		T			32	<10
Distichlis spicata	Saltgrass	Summer Perennial	T			>15	<10
Paspalum vaginatum	Alkali grass	Summer perennial	T			10-22 23	<10
Asparagus officinalis	Asparagus	Perennial	T	4.1	2.0	19	15
Tritium aestivum cv. Probred	Wheat	Winter Annual	MT	4.5	2.6.	16	15
Tritium durum	Durum wheat	Winter Annual	MT	2.1	2.5	14	20
Agropyron elongatum	Tall wheatgrass	Winter Perennial	T	7.5	4.2	15	20
Beta vulgaris	Sugar beet	Annual	T	7.0	5.9	12.	20
Triticale cv.Canabea	Triticale	Annual	T	8.1	8.8	12	20
Festuca elatior	Fescue	Winter				12	25
Cyndon dactylon	Bermudagrass	Summer	T	6.9	6.4	12	25
Leptochloa fusca		Summer Perennial	T	3.0	3.4	12	25
Carthamus tinctorus			MT			11	25
Agropyron cristatum cv. Fairway	Crested wheatgrass	Winter	T	7.5	6.9	12	25
Agropyron sibiricum cv. Standard	Siberian wheatgrass	Winter	MT	3.5	4.0	11	25
Hordeum vulgare	Barley	Winter	MT	6.0	7.1	10	30
Sorghum sudanense	Sudan grass	Summer	MT	2.8	4.3	10	30
Festuca elatior		Winter	MT	3.9	5.3	10	30
Salsola iberica		Annual	MT				
Spartina spp.	Cordgrass	Perennial	T				
Atriplex spp.		Perennial shrub	T				
Kochia prostrata		Perennial Shrub	T	17			
Phalaris tuberosa			MT	4.6	7.6		
Halosarcia spp.		Perennial	T				
Prosopis spp.	Mesquite						
Acacia spp.							
Brassica napus	Rape or Canola	Annual	MT				
Melilotus alba			MT				
Melilotus	Sweet clover	biennial	MT				

Additional forage plots are located at the Broadview Irrigation District and near the evaporation ponds in the Tulare Lake Drainage District (TLDD). Personal observation by this writer in the summer of 2000 indicated that grass stands were doing well and that cattle were grazing on the Broadview plots in August. The grasses grown at Broadview were *Sprobolus airoides* (Torr.) Torr, aka Willcox alkali sacaton; *Distichlis spicata*, saltgrass and *Polypogon monospeliensis*, rabbitsfoot grass. They also have a field of Medicago sativa (var. "Salado") and are including it in all their new plantings. Broadview reported in January 2001 that the cattle made good gains (personal communication). There is no actual data for yields, palatability or nutrient content for these projects at this time.

At TLDD *Distichlis spicata*, saltgrass and *Cyandon dactylon,* Bermudagrass, were observed by this writer growing well in the summer of 2000. In 1992, TLDD reported on growing NyPa Wild Wheat (*Distichlis* spp.) and other forages (not named) irrigated with water of salinity EC = 15 dS/m. These plots were reported as "doing well".

As a portion of the Grasslands Bypass Project (aka Active Land Management Program), land in the Mercy Springs water district is leased by the Panoche Drainage District. This land is drained by open earthen ditches but the Mercy Springs district chose not to participate in the bypass project; thus, there is no active outlet for drainage water. Panoche District has planted the fields to moderately sensitive alfalfa (*Medicago sativa*), moderately tolerant Sudan grass (*Sorghum sudanense*) and tolerant Bermuda grass (*Cyandon dactylon*). These crops are irrigated with a mixture of tailwater, groundwater pumped from a well near the southwest corner of the district and subsurface drainage water from the Panoche District. The water is applied mainly during the winter season when drainage water cannot be discharged to the San Luis Drain.

Data is kept on the quantity of applied water, the total dissolved solids (TDS) and soil salinity. The goal was to apply blended water with TDS not greater than 2000 mg/l (EC = 2.7 dS/m) but data from Jan.-Mar. 1999 indicated that the actual average salinity was closer to 3000 mg/l EC = 4.0 dS/m) and some applications were in the 4000-5000 (EC = 6.0 dS/m) range. In 1998 preliminary soil salinity samples were taken and at the end of 2000 the fields will be resampled to calculate a salt balance. The depth to water table in the area was between 1.2 and 1.8 meters below the surface during the period 07/24/1998 to 03/15/2000. Data is not available on yield, forage quality etc.

In the 1980's there was concern that there were not enough warm season grasses being grown in California. Warm season grasses, because of their tropical origins reach peak productivity later in the summer when cool season grasses decline in productivity due to the warm temperatures. Bermudagrass, sudangrass and dallisgrass (*Paspalpum dilatatum*) were grown extensively and rhodesgrass (*Chloris gayana* Kunth) and kikuyugrass (*Pennisetum clandestinum*) had been tried.

UC Davis researchers selected 20 varieties, a mixture of warm season and cool season forages, to measure their productivity and forage value. These were planted on

April 14-15, 1980 grown and harvested for two years. One drawback of warm season crops is their inability to tolerate freezing winter temperatures. Lowest winter temperature at the test site was –4 °C. All of the grasses in the trial made it through the first winter, but four varieties of buffelgrass (*Cenchrus cilaris* L.) and (*C.setigerus* Vahl.) did not survive. Seven other buffelgrasses survived the winter and had vigorous regrowth in the spring. Rhodesgrass, kikuyugrass and bermuda grass vigorously resumed spring growth. Elephant grass (*Pennisetum purbureum*) and pearl millet hybrids (*Pennisetum americanum*) regrew from old growth following the winter but by mid March it was evident the yields would drop off from the previous year. Elephant grass was the highest average yield for the two years, 17.9 tons/acre, but it also had the lowest level of crude protein, 6.4%, and nearly the highest fiber.

Bermudagrass (Tifton 44) had the second highest yield, 10.0 tons/acre and relatively high crude protein, 13.5%. Bermudagrass (CCI) had 18.5% crude protein and yields of 8.0 tons/acre. Other high yielders were sudangrass, limpograss (*Hemarthria* spp.), dallisgrass, guineagrass and kikuyugrass all having at least one variety yielding more than 8.0 tons/acre. Since these were productive it might be well to investigate the salt tolerance of these species for reuse in a forage production system.

Research in other countries on forages may have progressed much further than the research in the SJV.

From the Mediterranean basin, Le Houerou (1996) reports the following list for which large scale experiments have shown that most are able to produce 5 –20 tonnes of Dry Matter/ha/yr of good quality fodder with brackish water having EC = 5-15 dS/m.

Perennial grasses:

Festuca arundinacea *(tall fescue)*
Sporobolus ioclados
Puccinellia cilata Bor.
Chloris gayana (Rhodes grass)
Paspalum distichum
Phalaris aquatica *(alkali sacaton)*
Phalaris trucata
Elymus elongates (wild rye)
Cynodon dactylon L var *hirustissimum* (Lit. & Maire) and var *villosum* Regel (Bermuda grass)

Perennial legumes:

Trifolium fragiferum (strawberry clover)
Lotus coniculatus (birdsfoot trefoil)
Lotus roudairei (trefoil)
Hedysarum carnosum (fleshy sainfoin)
Tetragonolobus maritimus

Annual grasses:
Lolium rigidum Gaudin (ryegrass)
Hordeum vulgare L. (barley)
Sorghum sudanense (Piper) Stapf
(Sudan grass)

Annual legumes:
Melilotus albus
Melilotus italicus
Melilotus officinalis (L.) Lam.
(sweet clover)
Medicago spp. (alfalfa and the medics)
Trifolium resupinatum (Persian clover)
Trifolium yanninicum (yannina subclover)

Le Houerou reports that halophyte grass genera *Aeuropus, Sporobolus, Puccinellia*, and species *Ammophila arenaria* L. Link and *Agropyron* spp. (*Agropyron* are now called *Thinopyron* or *Lophopryron*) were able to grow when the soil solution was was EC 10-15 dS/m or above. The annual *Hordeum maritimum* was also growing under the above soil conditions. He also believes that species of *Haloxylon, Kochia* and *Maireana* are possible forage species and recommends the biennial fodder legume *Hedysarum carnosum.*

Malcolm (1996a) reports from Australia, "Halophytic grasses of forage value include *Sporobolus* spp., *Aeluropus* spp. and *Distichlis* spp. all of which possess salt glands." Other highly salt tolerant grasses include *Puccinellia* spp. which avoid highest salinity levels at sites by going dormant in the summer. *Paspalpum vaginatum* Sw. (salt water couch) is very tolerant of waterlogging. *Diplachne fusca* (L.) Beauv. is tolerant of prolonged waterlogging and high pH, but is less salt tolerant than other halophytes. Malcom recommends *Puccinellia cilata* Bor. for both mild and moderate saline sites. He recommends *Thinopyrum elongatum* (tall wheatgrass) and *Cynodon dactylon* (L.) Pers. (Bermuda grass) for only mild sites. He does not recommend any grasses for severely salt affected sites. No discussion is made of irrigation of these plants with saline water.

Malcom (1996a) does mention *Trifolium fagiferum* (strawberry clover) as a plant suited to mild saline sites without waterlogging to provide a legume in the pasture mix. He (Malcom 1996b) also recommends addition of nitrogen to the *Puccinellia* and *Thinopyron* pastures in the amount of 23 kg/ha in autumn and 45-60 kg/ha in late winter. He reports the resulting growth of grasses on salt-affected lands has supported 48 dry sheep equivalents per ha for two months and after being harvested provided 300kg/ha of seed for sale.

Marcar (1987) working in Australia also reported on the salt tolerance of the genus *Lolium* (ryegrass) during germination and growth. He grew three representative species; Wimmera (*L. rigidum*), Italian (*L.multiflorum*) and perennial (*L. perenne*) of ryegrass in solutions of increasing salinities and compared them with known salt tolerant species saltmarshgrass (*Puccinellia ciliata*) and tall wheatgrass (*Elytrigia pontica*)[9]. Marcar found that germination was insensitive for all species with NaCl concentrations

[9] I have obtained at least three scientific names for the common name tall wheatgrass, *Agropyron elongatum, Thinopyron elongatum* and now *Elytrigia pontica*. Are they the same?

up to 200 moles/meter^3 (about 14.6 dS/m). Seeds were germinated in petri dishes and plants were grown in pots with coarse river sand. Higher concentrations were tolerated only by the two control species and *L. multiflorum*. During growth only the two tolerant grasses did well; ryegrasses were found to be only moderately tolerant of salt.

In Israel (Pasternak and Nerd, 1996) at least two types of experiments have been attempted. At a seawater irrigation trial south of Ashquelon a number of plants were irrigated with seawater EC=54 dS/m and with 15% seawater, EC=9 dS/m. Of eight grass species tried only three, *Aeluropus lagopoides*, *A. littoralis* and *Distichlis palmeri* performed well under the seawater strength and none of these were considered as suitable for forage. The authors recommend *Distichlis palmeri* for grass in landscape areas to be irrigated with seawater, but warn the grass may be prickly. The other species used were *Elymus sabulosus, Leptochola fusca, Paspalpum vaginatum, Puccinellia cilata* and *Sporobolus virginicus*, which apparently survived and grew with the 9 dS/m irrigation water.

In a trial at the Ramat Negev Experimental Station the performance of five know salt tolerant grasses and alfalfa were tested under a range of irrigation water salinity levels from 1.2 – 10 dS/m. The forage species were Rhodes grass (*Chloris gayana* Kunth) cv. common, Bermuda grass (*Cynodon dactylon* L. Pers.) cv. Suwanee, Kallar grass (*Leptochola fusca* L. Kunth.), salt (spike) grass (*Distichlis spicata* L.), seashore paspalpum (*Paspalpum vaginatum* Swartz), and alfalfa (*Medicago sativa* L.) cv. Gilboa. Dry matter yield equations are given below for two years 1990 and 1991. Salt grass, Bermuda grass and *Paspalpum vaginatum* were the most salt tolerant. The first two species showed no yield decrease at soil EC_e of 14 dS/m. Salt grass is by far the most salt tolerant and drought tolerant. Pasternak and Nerd recommend this latter species for domestication and improvement for both forage and pasture.

Table 12: Effect of soil salinity on dry matter production of six forages in 1990 and 1991.

Forage	1990 Yield Eq.	R sq. value	1991 Yield Eq.	r sq. value
Alfalfa	Y= 0.099X + 2.63	0.95	Y= 0.106X + 2.85	0.70
Bermuda	Y= 0.005X + 2.67	N.S.	Y= 0.003X + 3.88	N.S.
Kallar Grass	Y= 0.097X + 2.71	0.80		
Paspalpum	Y= 0.006X + 3.09	N.S.	Y= 0.114X + 4.60	0.68
Rhodes	Y= 0.083X + 3.57	0.69	Y= 0.319X + 6.57	0.91
Salt grass	Y= 0.005X + 2.57	N.S.	Y= 0.075X + 2.85	0.68

Ahamad and Ismail (1996) report that various species of *Agropyron* and *Elymus* are well adapted grasses in winter rain areas. *A. desertorum* and *E. hispidus* subsp. *hispidus* are being grown in Iran. *A. cristatum* (crested wheatgrass) and *E. hispidus* subsp. *hispidus* are grown in Morrocco. *Thinopyrum elongatum* (Host) D.R. Dewey aka. (*Agropyron elongatum,* tall wheatgrass) grows well in the mild winter and semi arid regions of Tunisia. It can tolerate 7.5 dS/m without reduction in growth.

In India, Kallar (Karnal) grass (*Leptochloa fusca*) and Para grass (*Brachiaria mutica*) were grown with and without pyrites on alkali loams in Kanpur. In Jobner Rhodes grass (*Cloris gayana*), blue panic (*P. antidotale*) and Para grass were irrigated with saline water EC = 16 dS/m yielded respectively 41.5, 31.1 and 31.0 Mg/ha. Other grasses tried were Bermuda grass (*Cynodon* dactylon), Napier grass ( ), (*Cenchrus ciliaris*), *Panicum laevifolium*, Gatton panic (*P. maximum*), and *P. virginatum*.
Chhabra (1996) recommends *Suaeda maritime, Leptochloa fusca, Cynodon dactylon, Sporobolus marginatus, Brachiaria mutica, Chloris gayana Panicum maximum* and *Panicum antidotale* for alkali soils. For saline soils *Sporobolus pallida, Cynodon dactylon, Agropyron elongatum*, eel grass (*Zostera marina*), cord grass (*Spartina alternifolia*) and Jaojoba/Hohoba/goatnut (*Simmondsia chinensis*).

Kallar Grass (***Leptochloa fusca***)

This grass has been known at least since 1929 when it was described and its distribution reported in Egypt, India, Sri Lanka, Tropical Africa, Asia (Sind & Pakistan), and Australia. Earlier it was known as *Diplachne fusca* in the Gramineae family. In 1954, it was found growing in rice fields and in marshy places in the Lahore district, Pakistan. (Malik, 1986).

Malik et al. (1986) also report that it is a C-4 plant meaning that it can convert up to 6% of the received solar energy and take up carbon dioxide at very low concentrations. It also can survive salinities up to 40 dS/m and can fix up to 80% of its own nitrogen requirements. It has been successfully grown on soils with EC_e of 12-14 dS/m, SAR 150 and pH 9-10. It has been determined that it can be economically grown in salinities up to 22 dS/m which is near the relative yield 50% reduction point. Malik et al., reported that the yield curve was determined by growing the plant in gravel filled pots with salinity variations from 3 to 40 dS/m using an artificial salt mixture of NaCl, Na_2SO_4, $CaCl_2$, and $MgCl_2$ in a 4:10:5:1 ratio. Yield reductions began immediately at the lowest salinities and Oster has estimated the yield reduction slope as -9.1 (personal communication). Unlike other salt tolerant species the plant does maintain a high K^+/Na^+ ratio by exuding sodium chloride through the leaves.

The germination from seed is generally poor, but fresh cutting buried in wet soils do root and grow profusely. The plant grows to a height of 4 to 5 feet and produces up to 40 tons of green biomass per ha.

Atriplex

Glenn et al., (1981) in examination of Arizona's agricultural water budget proposed using C-4 halophytes to provide a forage to replace alfalfa in livestock production. Using a water cost ratio defined as g H_2O/ g DW, which is the quantity of water transpired per unit dry matter produced. This can be measured in three different ways: one may compare the transpiration and photosynthesis for a single leaf; or measure the dry matter verses the total water used in potted plants; or compare dry matter yield to irrigation water used under field conditions. Glenn noted that in the latter type study it is not always easy to measure the water losses due to deep percolation, runoff and surface evaporation which tends to overestimate water consumption by the plant. Instantaneous measurements on a single leaf may not account for water and carbon losses at night, therefore, it is not surprising that the three methods may yield different results.

Glenn et al., (1981) report that in general it has been found by researchers that C-4 plants in general have water use efficiencies of nearly twice the C-3 crops. They also report that Atriplex has transpiration to dry matter ratios ranging from 87 to 232 compared to alfalfa at 814. Goodin (1979) in west Texas comparing alfalfa with *Atriplex canescens* found that equivalent yields of *Atriplex* were obtained using only 15-20% of the water used by alfalfa. Consider also that *Atriplex* species may also be able to grow in water considerably saltier than salt sensitive alfalfa and a substantial change in agricultural water use may be accomplished by changing forage crops.

As part of the Environmental Research Laboratory (ERL) experiments near Puerto Penasco, Sonora, Mexico several halophyte plants were grown using hyper saline irrigation water (40,000 ppm) and then tested for nutritional value (Glenn et al., 1982). *Atriplex barclayana, A. lentiformis* and *Salicornia europaea* were grown with the nutrient enriched seawater. Havested material was sun dried, stored at room temperature, seeds and fruits separated, by hand; then, the material was ground in a Wiley mill through a 20 mesh screen. The plant material was then chemically analyzed using a commercial laboratory in Tucson, AZ by standard analytical procedures. Protein contents of the plants were *Atriplex barclayana* 18.7%; *A. lentiformis,* 12.4%; and *Salicornia europaea,* 14.4%. Ash and cation contents were relatively high in the mature plants and oxalate ions were a problem when the material was fed to chicken and mice at rates that exceeded 15% of the total diet. To eliminate the poisoning effects the *Atriplex barclayana,* and *A. lentiformis* plant material had to be soaked in a saturated calcium hydroxide solution.

O'Leary et al., (1985) report on growing *Atriplex barclayana, A. lentiformis A. nummularia, A. canescens, A. glauca, A. polycarpa, A. repanda, A. patula, Batis maritima, Cressa truxillensis* and *Salicornia europaea* using seawater for irrigation at the ERL site in Mexico. They noted that the highest productivity, 1800-1500 g/m^2, came from the native species. (*A. nummularia, A. glauca, A. repanda* and *A. patula* are non-native.) The highest yielding species was *A. lentiformis* and it had 16.7% protein, 1.3% fat, and 14.1% fiber all favorable, but it also had 26.8% ash and 3.6% oxalate diminishing its favorability as animal feed. Frequent cutting also diminished the yield for the plant with 20% mortality when cut three or more times per season. *Atriplex nummularia* and

A. barclayana were 160 to 170% more productive when they were harvested more frequently putting them into favorable comparison to alfalfa grown with non-saline water. The plants were fed to goats and were found to be acceptable and palatable. Due to the high ash content it is best that they make up not more than 25% of the animals total diet.

The ERL group also evaluated *Atriplex nummularia* and *A. lentiformis* using brackish water from an artesian geothermal well at Safford, AZ. (Watson et al., 1987) The water had EC 9.3 – 10.3 dS/m, SAR 44, sulfate ion 22-31 meq/l and fluorine 5-8 ppm making it totally unsuitable for irrigating most commercial agricultural crops. The soil was initially a non-saline, non-sodic as defined by Handbook 60 (US Salinity Laboratory Staff, 1954) but within eight weeks after the first irrigation had become saline-sodic. The highest biomass yields were 14.7 tonnes/ha *A. lentiformis* and 12.3 tonnes/ha for the *A. nummularia*. The quality of the forage seemed to decrease as the season progressed, but oxalate ion also decreased with time. The feed value of *A. nummularia* was superior to *A. lentiformis*. The authors believe that both species show a potential for forage production using water unsuitable for other crops.

In the San Joaquin Valley (SJV) Watson from the ERL set up test plots at Murrieta farms and other locations to screen *Atriplex* for use in Agroforestry/IFDM sites (Watson, 1990a, 1990b). Names and origins of the *Atriplex* accessions used in the 1988 field trials are listed in Table 13.

Table 13: Names and origins of the *Atriplex* accessions and place of origin.

Species	Origin
A. barclayana (Benth.) Dietr.spp barclayana	Baja California, Mexico
A. barclayana ssp *sonorae* (Standil.) Hall & Clem.	Baja California, Mexico
A. undulata Dietr.	Argentina, South America
A. deserticola Phil.	Chile, South America
A. cinerea Poir. ssp *bolusii* (C.H. Wr.) Aell	Cape Peninsula, South Africa
A. vestita (Thunb.) Aell	Cape Peninsula, South Africa
A. halimus ssp *halimus* L.	Israel
A. lentiformus ssp *breweri* (Wats.) Hall and Clem.	S&S Seed, Carpenteria, CA
A. lentiformis (Torr.) Wats. ssp *lentifomris*	Plant Materials Center, Tucson, AZ
A. canescens ssp *macropoda* (Rose & Standl.) Hall and Clem	Baja California, Mexico
A. canescens (Pursh.) Nutt. cv 'Marana'	Plant Materials Center, Lockford, CA
A. canescens (Pursh.) Nutt. ssp *canescens*	Arizona
A. nummularia Lindl.	Pecoff Brothers, Escondido, CA
A. polycarpa (Torr.) Wats.	Native Plants Inc., Lehi, UT
A. rosea L.	Baja California, Mexico
A. holocarpa F. Muell.	Australia
A. angulata Benth	Australia
A. lindleyi ssp *inflata* F. Muel.) P.G. Wilson	Australia

Plants were started in random plots by both sowing of seed and transplanting of individual stems. The plants were planted in rows with a 0.76m width spacing with seed being sown at a depth of o.5 –1.0 cm. The spacing between transplants in the rows was 0.61 – 0.91m. There was 90% or greater survival by the transplants and seedlings were present after one month with additional seedlings appearing throughout the growing season.

Since the main purpose for using halophytes in the SJV is to reduce the volume of drainage water, it is important to determine water use. In green house studies with A. nummularia at Davis, CA, Sachs et al. (1990) determined that irrigation with saline water in the concentration range EC = 10-12 dS/m would reduce water consumption from about 1.25 acre-ft per year to just below 1.0 acre-ft per year (20-25% reduction in water use). The soil leachate from these trials performed in sandy soils had concentrations EC = 20-22 dS/m. Little reduction in growth rate as measured by stem elongation was reported, but the researchers reported that their estimates of water use were conservative and were based upon plants irrigated to field capacity with a 50-75% leaching fraction with excellent drainage.

Trials at Murrieta Farms indicated average first cut yields of 3000 kg/ha. Many species recovered and provided at least two harvests during the initial year. It was demonstrated that it is possible to cut and bale these plants as with ordinary forages. Harvest yields and nutritive value were highest for *Atriplex barclayana* (Benth.) Dietr.

Watson (1990b) stated, " Even though *Atriplex* can tolerate soil salinities and levels of trace elements significantly higher than those suitable for irrigated field crops, the long term effect of continuous irrigation with saline drainage water on productivity and forage quality would need to be determined. The soil/water management practices to provide adequate drainage and other soil-related aspects are critical factors in using saline drainage water for irrigating halophytes (Glenn and O'Leary, 1985: O'Leary 1986). The hazards of soils becoming excessively saline or sodic and the appropriate reclamation strategies would also need to be considered. Although studies of *Atriplex* irrigated with highly saline water have been documented, little is known about the relative growth potential and salt tolerance for the different *Atriplex* species under long term cultivated conditions. Establishing salt tolerance data for the different species and developing guidelines for irrigation, drainage and cultural management practices re required before introducing *Atriplex* to irrigated farming on a larger scale."

Watson and O'Leary (1993) reported on irrigation of Atriplex species with saline water (EC = 18 dS/m) in the SJV. Plants were cut and baled four times over a 27 month period. Yields were as high as 9.9 tons/ha per cutting, with total yields for the four cuttings approaching 20 tons/ha. The material had to be blended with alfalfa to make it palatable to livestock.

Atriplex was also grown at the Red Rock Ranch site in the SJV. It is growing with other halophytes and is being irrigated with drainage water 12 – 15 dS/m. The species being used is not clearly spelled out, but *A. canascens,* ('Marana' fourwing saltbush) *A. lentiformis* ('Casa' quail bush) and *A. patula* var. *hastada* (fat-hen) are listed in the report (Cervinka et al., 1999). Benes from California State University – Fresno is determining the ET coefficients for the halophyte plants and reports that she is working with *A. nummularia* (old man saltbush). This research is finding that the Atriplex has greater ET than saltgrass, but less than Salicornia. They are unable to attach quantitative ET results to these species without further data (personal communication, 2000).

In 1990's,during the Atriplex trials in the SJV the Integrated Pest Control Branch of the California Department of Food and Agriculture raised the issue that *Atriplex* is a host plant for the leafhopper (BLH) that spreads the curly top virus (CTV) to sugar beets. It may be incompatible for sugar beets and *Atriplex* to be grown on an extensive basis although it is a native species to the area. In a report to the Tulare Lake Drainage District, Duffus et al. (1991) found *A. barclayana, A. camarones, A. canescens, A canescens* subspecies *macropoda, A. cinera, A. deserticola, A. halimus, A. nummularia* and *A. sagittifolia* were all found to be poor hosts of the BLH and should not be considered threats to CTV control efforts. The naturally infected species are *A. argenta, A. bracteosa, A. fruticulosa, A. patula* and *A. rosea.* There is an additional list of Atriplex species that could be experimentally infected.

Atriplex introduced into many Mediterranean areas (Algeria, Tunisia, Morocco and Libya). Several thousand ha have been planted in the basin. *Atriplex nummularia, A. halimis* and *A. lentiformis* have shown good tolerance to drought. Also in Libya, A. canescens and Acaia saligna have been planted together on several thousand acres of grazing lands and have shown a 100% increase in dry matter production with irrigation.

In Australia, *A. ammicola* Wilson and *A. undulata* De Dist are promising shrub species for reclaiming salt affected lands. *A. nummularia* is being promoted in New South Wales as a crop for recovery of native pastures. Condon and Sipe, (unpublished) state that with intermittent heavy grazing it is 8 to 10 times better than native pastures and 2-4 times better than sown pastures in these areas. It can be as productive as Lucerne (alfalfa) with much less water use.

Trumble et al. (2000) have been screening 62 *Atriplex* lines for their ability to selectively accumulate selenium in the presence of high sulfate content, which is characteristic of the drainage water in the SJV. Insect bioassays were also conducted on 30 of the lines to determine if there would be a risk in insect proliferation to pest levels. The goal was phytoremediation of selenium using *Atriplex* without increasing the potential of spreading insect problems to existing agronomic crops. Although the reseach is ongoing, they have concluded that *A. patula patula, A. spongios*a, 415862, A. hortensis hortensis, A. hortensis 379088 and *A. hortensis* 379092 are promising phytoremediators of selenium and produce high biomass. The preliminary analysis also indicates that these species may aid in removing insect pests from the region.

Salicornia

Salicornia has been known for some time in Europe as samphire, its older name being "poor man's asparagus". Sir Thomas More wrote almost 500 years ago that "samphire improved many a knave's pottage … affording him a relish to accompany his mouthful of salt meat" (Clark, 1994). It is today considered a gourmet food and is eaten in the south of France and the British Isles, particularly East Anglia. Elizabeth Schnieder in Uncommon Fruits and Vegetables: a common sense guide, has written, "when young it is crisp, pleasantly deep sea tasting, an unusual summer pleasure". Another description is, "very crunchy and salty like brined baby string beans" (Clark, 1994). However, others maintain that the name samphire is reserved for *Crithmum maritimum,* also known as sea fennel, which grows on the sea cliffsides of Great Britain and in northwest Europe.

Salicornia bigelovii is native to the western coast of North America and was investigated as a potential halophyte food crop by the Environmental Research Laboratory (ERL) in Tucson, Arizona beginning in the 1970's. The ERL researchers screened nearly 800 halophyte plants for potential sea water and brackish water productivity and determined *Salicornia bigelovii* the winner in terms of oilseed and green-matter productivity. It was found to grow well using sea water for irrigation at a research station in Sonora, Mexico. More importantly, the seeds were found to have an oil content of 30% by weight (compared to 17-20% for soybeans) and the Salicornia oil was 72% linoleic acid – a healthy polyunsaturated fat (Clark, 1994). The residual seed meal also found to contain 40% protein and be palatable for livestock.

For ten years *Salicornia bigelovii* was selectively developed along the coast of the Gulf of California (Sea of Cortez); the seeds from the best plants selected progressively sowing sturdier, better producing plants. Trial plots were also grown in the United Arab Emirates, Egypt, Kuwait and Saudi Arabia. At Jubail Industrial City in Saudi Arabia, a 2 ha field trial produced oil seed yields as high as 3.5 tons/ha (equivalent to 70 bu/acre). The salt content of the irrigation water used, 40,000 ppm, would have killed most other plants, but *Salicornia* has been shown to tolerate 50,000 ppm water without blighting. The Saudi government was so pleased with the test results that they funded project at Ras al-Zawr to grow 250 hectares of *Salicornia.* They have five 50 ha center pivot irrigation systems pumping 28 cubic meters of sea water per minute. It takes 6 ½ hours for the arms to complete one circuit and they are often kept running continuously. ERL has advised the Saudi's to irrigate with 25% more water than the crop requires to flush the salt below the root level of the crop and back into the sea (Clark, 1994). Yields in 1993-94 were not as large as those anticipated from the results at the smaller plots. Since there are no oil production facilities in Saudi the crop was harvested and baled for dairy forage. Some crunchy green tips were air lifted to Europe for test marketing. Other large scale production of *Salicornia bigelovii* has begun in India and by 1994 inquiries had been made by Iran, Somalia, Egypt and Syria.

In the San Joaquin Valley (SJV) of California, Grattan et al. (1999) obtained seed from the researchers in Arizona to begin to determine the growth characteristics of *Salicornia bigelovii* when irrigated with sulfate dominated groundwaters found in the

SJV. Two field plots were planted in June 1995: a 1 ½ acre plot near Mendota and a 2 ½ acre plot near Five Points. At Mendota the plot was irrigated with water having a salinity of 30 dS/m (approximately 2/3 the salinity of sea water). A good stand was established and the plants appeared to thrive. The larger plot failed to grow and it was later determined that saline water is required for establishment of this plant (Grattan, personal communication)

Also in 1995 greenhouse experiments were begun at the Westside Research and Extension Center in Five Points, CA. Plants were grown in SJV drainage water and seawater at three different salinity levels: 10-20 dS/m, 20-40 dS/m and 40-60 dS/m. Plant height, fresh weight and root and shoot biomass were monitored. Early indications were that *Salicornia bigelovii* did not grow quite as well in the SJV saline water as it did with sea water. (Mitchell et al. 1995)

"A drainage water reuse concept has been proposed for the San Joaquin Valley of California where saline drainage water is used to irrigate progressively more salt-tolerant crops whereby halophytes are the final crop in the sequence, prior to disposal. *Salicornia bigelovii* has emerged as a promising halophyte" Grattan et al. (1999). Not only has it been shown that this native coastal plant can grow and thrive in the desiccating conditions of the valley when irrigated with Na-sulfate drainage water (29 dS/m and > 25 mg/L B), but this leafless plant can maintain evapotranspiration (ET) rates comparable to reference (ET_o).

This plant also has economic potential. Under irrigation with diluted seawater, its seed has been reported to produce an oil high in polyunsaturated fat comparable to soybean. After oil extraction the remaining high protein meal (43% protein) can be fed to animals (Glenn et al., 1991). When harvested prior to seed maturity it has been successfully fed to small ruminants.

Greenhouse studies were undertaken to find if SJV drainage water could be used to irrigate Salicornia and to study its tolerance to boron. Results in 1996, 1997 and 1998 seemed to indicate favorable response to the drainage water.

Field studies were undertaken on a one acre agroforestry study site about three miles south of Mendota. Salicornia was planted June 1, 1995 and has subsequently reseeded naturally. Vegetative growth was large in 1996 but less favorable in 1997. Seed yield was disappointing when compared to the results Glenn obtained in Sonora, Mexico. The plant does have high ET rates and may still have significant use as a final stage halophyte in a drainwater reduction program.

Pistachios

This information based upon "Potential for Utilizing Blended Drainage Water Irrigating West Side, San Joaquin Valley Pistachios" Ferguson, L., et al. UC Salinity Drainage Program 1997-98 Annual Report.

The results demonstrate pistachios tolerate irrigation with blended drainage water up to 8.0 dS/m. (Blended water up to 12.0 dS/m was also used in crop season 1997, but results were not provided in this report.)

Four major rootstocks are used in the SJV. "Previous studies investigating the salt tolerance of pistachio have been conducted using pistachios other than Kerman (*Pistacia vera* L., cv. Kerman) in a greenhouse setting with sodium chloride laced irrigations (see Ferguson et al. 1998 for references). Ferguson et al. (1998) also report that Behboudian (1986), again in a greenhouse setting with sodium chloride laced irrigations, using 1 year old P. Atlantica rootstock budded with 'Kerman' concluded that *P. vera* is highly salt tolerant and Picchioni (1990) reported three of the currently planted, though less popular, pistachio rootstock seedlings did not manifest significant reductions in growth until electrical conductivity of the irrigation water (EC_w) of 13.8 dS/m and an electrical conductivity of the saturated soil extract (EC_e) of 17.9 dS/m were imposed in a two season outdoor lysimeter test.

Ferguson, et al., (2000) reported on the salinity tolerance in tanks. Generally, all rootstocks were tolerant of salinities up to EC = 8 dS/m. Beyond that level there were reductions in biomass accumulation and trunk diameter for all of the rootstocks except Atlantica. Atlantica showed more tolerance to the EC =12 dS/m by having no reduction in biomass and only a 7% reduction in trunk diameter. By EC = 16 dS/m all rootstocks had growth reductions of at least 50%. The important conclusion of the salinity tank trials was that the rootstocks appeared to have reverse tolerance as that observed in the field trials. Rootstock PGI appeared to have the best salt tolerance in the field, but had the poorest in the tank trials. It is suspected that since the tanks were well drained and the fields may not have been, there was a combination of salt tolerance and water logging tested in the fields that was not tested in the tank experiment.

Further reports in the literature suggest pistachios are highly tolerant of boron and have the ability to tolerate sodium through the mechanism of root and basal stem storage (Walker et al., 1987)."

Grattan in personal communication May 22, 2000, stated that he thought the above experiments were biased by the fan irrigation system. There may have been times during the growing season when the plant roots could have reached soil portions with an non-saline water supply. Sand tank experiments, underway at the salinity lab, may provide more complete answers.

AGROFORESTRY AS A METHOD OF DRAINAGE WATER REUSE

A Review of Literature

Agroforestry, has been defined by Cervinka (1999) as, "the practice of growing certain types of trees with drainage water. The trees act to dispose of applied drainage and shallow groundwater through foliar evaporation and at that time produce a marketable commodity". Since most of the review information is for the purpose of drainage water reuse in the San Joaquin Valley of California and Cervinka has been one of the primary proponents of agroforestry in that area, it is his definition that will be used in this discussion.

Many have planted non-native exotic trees in various locations in California going back even to the original Spanish settlers in the late 18th century. One of the modern experiments with trees in California soils with high levels of salinity may have been in the Napa Valley starting in 1972. (Donaldson et al., 1983) Here fifty-five eucalyptus species were planted, of which only 26 remained after eight years in saline, flooded soils. See Table 3 later in this report, for the listing of the twenty-six species. Fifty-one other tree species were planted only three of which survived and even these were deemed, "surviving but not acceptable" when judged in May 1982. One interesting note in the presentation is a caption for a picture: "Many trees on the salty plain seemed to thrive for six or more years before succumbing. This may be an individual trait, not species failure, since others of the same species survive and are highly acceptable. *Eucalyptus sargentii* (above) adjacent to the dying *Eucalyptus camaldulensis* (left) continues to grow as a superior specimen."

Eucalyptus camaldulensis, river red gum, was the predominant species for which agroforestry had been proposed for the use of saline drainage water in the San Joaquin Valley (SJV) of California. Since this species originated in Australia, it might be worthwhile to review information as it may relate to salinity problems on that continent. The July 2000, National Geographic picture on pages 6 and 7 is titled, "A graveyard of skeletons with gray arms raised in good-bye" (Parfit and Wolinsky, 2000). In predominantly gray blue colors it portrays dead trees and their reflections in a shimmering lake. You can almost feel the sadness in looking at bare trees without life. The caption of the picture reads, "Once a leafy grove in Western Australia, this salt lake rose from the ground when the nearby woodlands were cleared for farms. Thirsty trees had absorbed rainwater and kept the water table from rising, but after they were cut, the water surfaced and brought salt with it. The result: saline ponds and dead fields".

The following table (Table 14) is taken from a CSIRO guide for selecting trees native to Australia. The tree size would have over lapping ranges. Shrubs and small trees may be considered to be less than ten meters (33 feet) in height, medium trees 10 – 30 meters (33-99 ft.) and tall or large trees more than thirty meters (99 feet) height at maturity. The frost tolerance is not clear in the guide, perhaps one reason would be that Australian winter temperature does not appear to be as cold as North American temperature. The most tolerant seem to tolerate conditions only a few degrees below 0°C (32°F). The most frost tolerant trees appear to be the least salt tolerant.

Table 14: Taken from CSIRO guide for selecting trees native to Australia

Scientific name	Common name	Size	Salt tolerance +	Frost tolerance
Acacia ampliceps	Salt wattle	Small	10-15 : 20	Intolerant
A. cyclops	West coast wattle	Shrub	10-15 : 20	-3 °C
A. melanoxylon	Swamp blackwood	Tall	5 : 5	-9 °C
A. salicina	Willow wattle	Small	10 : 15	-5 °C
A. saligna	Orange wattle	Shrub	5 : 10	-4 °C
A. stenophylla	River cooba	Small	10-15:15-20	-4 °C
Casuarina cristata	Belah	Tall	10 : 15	-5 °C
C. cunninghamiana	River sheoak	Tall	5-10 : 10	-8 °C
C. glauca	Swamp sheoak	Medium	10-15 : 15	-4 °C
C. obesa	Swampy oak	Small	10-15 : 20	-3 °C
Eucalyptus aggregata	Black gum	Small	0-5 : 5	-8 °C
E. botryoides	Southern mahogany	Tall	0-5 : 5	-8 °C
E. brockwayi	Dundas mahogany	Medium	0-5 : 5	-3 °C
E. camaldulensis	River red gum	Tall	0-5 : 10-15	-6 °C
E. camphora	Swamp gum	Small	0-5 : 5	-9 °C
E. cladocalyx	Sugar gum	Small	0-5 : 5-10	-4 °C
E. globulus	Southern blue gum	Large	0-5 : 5-10	-4 °C
E. grandis	Rose gum	Tall	0-5 : 5-10	Sensitive
E. kondininensis	Kondinin blackbutt	Medium	15-20: 20	-3 °C
E. largiflorens	Black box	Medium	5-10 : 10	-6 °C
E. leucoxylon	Yellow gum	Medium	5-10 : 10	-5°C
E. occidentalis	Flat-topped yate	Medium	10 : 15-20	-4 °C
E. robusta	Swamp mahogany	Large	5-10 : 10	-6 °C
E. sargentii	Salt river gum	Small	10-15 : 20	-3 °C
E. spathulata	Swamp mallet	Shrub	10-15 : 15	-4 °C
E. tereticornis	Forest red gum	Tall	5-10 : 10-15	-6 °C
Melaleuca halmaturorum	Swamp paperbark	Shrub	10-15 : 20	-5 °C
M. leucadendra	Long leaved paperbark	Tall	10-15 : 15	Intolerant
M. linarilfolia	Narrow leaved tea	Shrub	5-10 : 10	-6 °C
M. quinguenervia	Broad leaved tea	Small	5-10 : 15	Sensitive

+ The salt tolerance is listed as ECe in dS/m. The first set of terms indicated the soil salinity conditions when growth is reduced. The second set of numbers (after the colon) indicated salinity conditions at which tree mortality begins. From : Marcar, N., D. Crawford, P. Leppert, T. Jovanovic, R. Floyd and R. Farrow, 1995 Trees for saltland: a guide to selecting native species for Australia. CISRO Australia.

The guideline is set up to recommend plantings where salinity has already affected the soil conditions. The Australian reader would intend to plant the trees into those conditions and then irrigate if necessary to establish the trees. The guide does not appear to have the intent of actually irrigating the trees with water that has high salinities. For conditions in the San Joaquin Valley of California only the most frost tolerant should be selected. If the user intends to irrigate with saline drainage water, then only the most tolerant (i.e. those that can tolerate EC_e = 15 –20+ dS/m prior to the onset of mortality).

One should not select trees based upon this table alone. If plans are being made for irrigation with drainage water, one should also consider the trees ability to withstand water logging. The common names can help here, if they are called "swamp" or "river" it is often for good reason. A tree, which can tolerate moderate salt and water logging, will often succumb to the combination of both. *Eucalyptus camaldulensis* is an example of this. Research has shown that it can withstand months of flooded soil as long as the water is non-saline. The combination of saline water and poor aeration is fatal.

Another problem is that some trees can tolerate saline soils under acid or neutral soil chemistry. *Casuarina cristata* and *cunninghamiana* become chlorotic when grown on calcareous soils.

The guide book lists other species of the *Acacia, Allocasuarina Eucalyptus* and *Melaleuca* that are slightly to moderately salt tolerant and may be useful in salt affected soils, but does not provide the detail necessary to include them in the above table. It also lists a few *Eucalyptus* species that show some promise in Western Australia, but do not have enough research to make recommendations.

The only two Australian non-native tree species discussed in the CISRO document were *Populus euphratica*, which is only moderately salt tolerant and *Tamarix aphylla* (athel), which was not recommended due to its habit of dripping salt onto the soil surface.

Cervinka and others have tried various species of trees for agroforestry. Among those tried in the SJV were *Eucalyptus camaldulensis, E. gomphacephala, E. trabuti, E. rudis, Populus sp, Casuarina glauca, C. cumminghamiana, Tamarix aphylla* (athel), *Mesquite* (Cervinka et al. 1999). Various hybrid clones of both *Populus* and *Eucalyptus* were also grown and or tried in greenhouse salinity trials. (Shannon et al., 1998) Accumulated research for each of these genera will be presented in the following pages of this report. Some consideration will be given to the history of the selection for salt tolerance, water logging or flooding, and frost tolerance. Economic considerations for each will also be considered.

As indicated above it is sometimes difficult to separate the research into separate species, but an attempt will be made to do so for the remainder of this report. Some special comments by individuals are also provided in the appendix at the end of this document.

Eucalyptus

A very good review of the worldwide ecological effects of eucalyptus has been provided by Poore and Fries (1985). According to these authors there are over 600 species of eucalypts with some 80 countries having planted more than 4 million hectares outside the natural range of the species in Australia. This review contains a discussion on the water cycle as affected by water use and the effect of trees on soils, but does not provide information on the salt tolerance of the species.

There is no data in the usual handbooks such as Maas and Hoffman (1977), Maas and Grattan (1999); thus, one must find salt tolerance elsewhere in the scientific literature. Predominant salt tolerant studies on the species are available from Australia as presented in the introduction to this review, listing sixteen species of eucalyptus. Another table (Table 2) from Australia lists the salt and flood tolerance of twenty-two species.

Table 15: Salt and flood tolerance

Eucalypt Species	Salt Tolerance dS/m	Flood Tolerance
E. occidentalis	20 to 30	A
E. cornuta	10 to 20	B
E. incrassata	10 to 20	C
E. halophylia	10 to 20	C
E. platypus var. heterphylia	10 to 20	C
E. sargentii	10 to 20	C
E. spathulata	10 to 20	C
E. salicola	10 to 20	C
E. stricklandii	10 to 20	C
E. astringens	2 to 10	C
E. botryoides	2 to 10	B
E. camaldulensis	2 to 10	A
E. campaspe	2 to 10	C
E. diptera	2 to 10	C
E. diversifolia	2 to 10	C
E. gomphotephala	2 to 10	C
E. intertexta	2 to 10	B
E. kitsoniana	2 to 10	A
E. largiflorens	2 to 10	B
E. leucoyton	2 to 10	C
E. microtheca	2 to 10	B
E. porosa	2 to 10	C

Flood tolerance: A- can withstand flooding of a month or more.
B- can withstand flooding of less than one month.
C- must have a well drained soil – no flooding.

Source: www.vti.waite.adelaide.edu.au/agroforestry/salinity.htm

These two lists, Table 14 and Table 15, have only five species in common: *E. occidentalis, E. sargentii, E. spathulata, E. camaldulensis* and *E. largiflorens.* Comparing the above chart, Table 15, to the results of Donaldson et al., (1983) Table 16 shown below, from California one finds only seven species satisfactorily common to both lists. They are *E. occidentalis, E. cornuta, E. incrassata, E. sargentii, E. spathulata, E. camaldulensis* and *E. microtheca. E. platypus* was one of the twenty six species to survive in the Donaldson plots, but was judged to be "not acceptable". The point to be made is that only four species are common to all three lists, Table 14, Table 15 and Table 16.

Table 16: Eucalyptus grown in Napa County, CA On salty flooded soils (Donaldson et al. 1983).

Eucalyptus species	Notes	
E. bauerana	Surviving and Acceptable	o
E. bicolor	Surviving and Acceptable	f
E. camaldulensis var rostrada	Surviving and Acceptable	f
E. cornuta	Surviving and Acceptable	
E. cosmophylla	Surviving and Acceptable	
E. fruticetorum	Surviving and Acceptable	o
E. grossa	Surviving and Acceptable	o
E. incrassata	Surviving and Acceptable	
E. lansdowneana	Surviving and Acceptable	o
E. mellidora	Surviving and Acceptable	
E. microtheca	Surviving and Acceptable	
E. occidentalis	Surviving and Acceptable	
E. populifolia	Surviving and Acceptable	
E. rudis	Surviving and Acceptable	f
E. sargentii	Surviving and Acceptable	
E. spathulata	Surviving and Acceptable	
E. tetraptera	Surviving and Acceptable	
E. aggregata	Surviving, but not Acceptable	f
E. albens	Surviving, but not Acceptable	
E. anceps	Surviving, but not Acceptable	
E. blakelyi	Surviving, but not Acceptable	
E. burdettiana	Surviving, but not Acceptable	
E. eremophila	Surviving, but not Acceptable	
E. falcate	Surviving, but not Acceptable	
E. platypus	Surviving, but not Acceptable	
E. rugosa	Surviving, but not Acceptable	

o- planted for observation only donated by others

f- survived 1972 freeze as one-year old plants

It should also be noted that there were twenty-nine species not listed that were grown but did not survive the ten year period.

Other studies are (Pepper and Craig, 1986) who assessed the resistance of twelve species of Eucalyptus in Western Australia and found "the best survival, health and growth of species at high soil salinity was by *Eucalyptus occidentalis, E. sargentii,* and *E. platypus* var. *hetrophylla.* The most salt sensitive of the trees tested were *E. rudis, E. camaldulensis*, and *E. robusta.* At soil salinities greater than 10 dS/m *E. camaldulensis* had low survival and trees showed poor health an vigor. *E. robusta* died at soil salinities less than 7.5 dS/m."

Van der Moezel et al., (1988) found that *E camaldulensis* actually grows better under salt free, but water logged conditions than in a well-drained sand. Marcar (1993) found *E camaldulensis* performed significantly better than *E. globulus*, E. *robustus*, and *E. tetracornis* when subjected to the combination of salt and water logging. The salt content of the solution used in the Marcar study was in the range of 10-15 dS/m.

Choukr-Allah (1996) states, "*Eucalyptus occidentalis* and *E. sargentii* Maiden, useful landscape trees, can stand a salinity over 30 dS/m and there may be other equally tolerant species."

These studies would indicate that even though there are a great number of species of eucalyptus, there are only a few that are salt and flood tolerant. Even here there is some inconsistency in the data, but the results in other countries should provide an indication of the most saline and flood tolerant species for use in saline drainage water reuse experiments.

In the San Joaquin Valley of California, the main species used in the "agroforestry" plots was *Eucalyptus camaldulensis*. Cervinka states that his selection of *E. camaldulensis* is based upon "its high salt tolerance"; he goes on to say, "the seeds were obtained from the areas of Lake Albucutya and Alice Springs in Australia" (Cervinka, 1987).

Sachs et al. (1990) performed some of the early California salinity screening and reported that seeds harvested from eucalyptus trees on the Gowan Ranch interceptor line and screened with saline water EC 10-12 dS/m and 15 ppm boron, showed superior salt tolerance than the Australian seedlings brought by Cervinka. For all trees, even the best seedlings, growth was reduced 50-70% over controls grown in non-saline nutrient solutions used as controls. The *Eucalyptus camaldulensis* seedlings from Lake Albucutya had 80-90% failure under saline conditions due to severe phytotoxicity and lack of stem elongation. Seedlings from Lake Coorong, also in Australia, had 70% failure rates. Some clones of *E. camaldulensis* that may have been selected earlier from these provenances showed no phytotoxic symptoms, but did have significantly reduced growth rates.

Other eucalyptus species tested by Sachs et al. (1990) were *E. australiana, E. mannifera, E. gomphocephala, E. polybactea, E. largiflorens* and *E. leucoxylon.* All were able to tolerate and grow in saline irrigations waters of 4-5 dS/m except *E. australiana*, which had damaged seedlings and a 50% reduction in growth at this salinity. There was a 100% death rate for *E. australiana* grown in irrigation waters of EC = 10-12 dS/m. The *E. leucoxylon* was judged to be the most salt tolerant of this group. As noted above all species had 50-70% reduction in growth when the irrigation water with stronger salinities was used. The water use by *E. gomphocephala* was estimated to be 50% of those plants grown under non-saline conditions.

Jorgensen et al. (1993) provide data on the Mendota site stating that the irrigation water used was from a portion of the Westlands Water District Drain. The average values were EC = 10 dS/m, 12 mg/l boron, 400 mg/l selenium and SAR = 11. This water was put on 9.43 ha of *E. camaldulensis* starting in 1987. From 1987 – 1989, the water was applied when farm labor was available, not on any regular or scientific basis. Jorgensen stated that this met neither the tree needs nor the leaching requirement during this period. Soil ECe levels climbed to 30 dS/m averaged over the top 2.4 meters of soil profile. Beginning in the 1990 season water was applied to meet the ET requirements of the trees plus a 16% leaching requirement. The salinity levels ECe, declined to 18 dS/m by June 1991 and to 10 dS/m by 1998. Trees were harvested in the summer of 1992 and sold as chips. Part of the plantation was then planted with superior eucalyptus clones selected since the first planting. The remainder was to be studied for regrowth rates. (Information on this is also included in the history of the Mendota site.)

Selection of clones:

Eucalyptus camaldulensis has been shown to have considerable genetic diversity and individuals of this species hybridize with other Eucalypt species. Thomson et al. (1988) conducted an evaluation of 53 seed sources from the natural range of *E. camaldulensis* and determined the mean salinity causing mortality ranged from 358 to 636 mM NaCl (32.4 – 57.6 dS/m). Trees derived from the initial uniform seedlings may show a 2 to 3 fold difference in growth rate in the field. Using this genetic diversity *E. camaldulensis* clones have been developed and tested for tolerance to salinity in the SJV (Sachs and Cartwright, 1989; Grieve et al., 1999; Grattan et al., 1996a, 1996b, 1996c, 1997).

After the 1990-91 freeze *Eucalyptus camaldulensis* clones were selected by Vashek Cerevinka, CA Dept. Food and Agriculture and Frank Menezes USDA-NRCS, Fresno, CA. These selections were based upon consultation with collaborators from the plots planted in the 1980's (See Case Studies portion of this report). M. Shannon and C. Grieve selected the following clones for further testing based upon observations taken during a field trip to the SJV on April 24 & 25, 1995: Clones 4501, 4543, 4544,4573, 4590 (Twyford Plant Labs, Santa Paula, CA), clones 2007 and 2016 (NyPA Inc., Tucson, AZ) and clone 2002 (Roy Sachs). The source of the clones is shown inside parentheses. These clones were then tested for salt tolerance using sulfate dominated irrigation water in the greenhouse at the Salinity Laboratory in Riverside, California.

Grieve and Shannon (1999) reported on the screening of four *Eucalyptus camaldulensis* clones 4543, 4544, 4573 and 4590, along with a clone of *E. rudis* with the designation 4501 for San Joaquin Valley salinity tolerances. Salinities ranged from 2 to 28 dS/m and greenhouse treatments were replicated three times. All plants survived and were harvested after seven weeks. Measurements of plant height were taken weekly and the plant biomass was determined at harvest. The salinities for which there was a 50% biomass reduction were 16.4 for 4573, 17.1 for 4543, 17.7 for 4544, 29.0 for 4590 and 30.0 for 4501. The clones easily fall into two categorical groups for salt tolerance. Over the range of salinities 4 – 20 dS/m clones 4573, 4590 and 4501 maintained higher relative growth rates (RGR) than 4543 and 4544; however, at the highest salinity 4544 had significantly higher RGR than those of clones 4543 and 4590.

Grattan et al. (1997) report, "Results from the short-term study that screened the salt-tolerance of different clones of *Eucalyptus camaldulensis* indicate that the salt-tolerance within this species is rather variable." The response of clone 4544 was mostly linear. According to the guidelines of Ayers and Westcot, (1985), the species falls within the moderately tolerant range, but a direct classification is difficult due to the nature of the experiment. There was a linear relationship between tree height and stem girth, but the slope changed with the growth of the trees. High levels of salinity reduced tree height and the 28 dS/M treatment affected the trees immediately after salinity was imposed. With the highest salinity, evapotranspiration was only half the level of the non-salinized nutrient solution.

High salinity did seem to have a great influence on the toxic affects of Boron. B toxicity was apparent on the leaf margins when high Boron was present with low salinity, but this evidence was reduced at the higher salinity levels.

Also an elaborate sand tank facility has been constructed at the USDA-ARS Salinity Laboratory on the UC Riverside campus. Two eucalyptus saplings (clone 4544) were transplanted into each tank on June 17, 1994. Salinity treatments were imposed after the trees reached 2m in height. One tree was harvested after one year (see 1995-96 report) to make a detailed analysis of treatment effect on growth and mineral and biomass partitioning within the shoot. Growth and biomass data were used to develop allometric relationships to accurately estimate plant foliar biomass based upon trunk and branch diameters for subsequent studies. The second tree remained in the tank to develop detailed information on water consumption, biomass production, water relations and long-term tree performance.

Grattan et al. (1996c; 1997) reported the data indicated that the threshold salinity was approximately 8 dS/m and 50% yield loss occurred at approximately the 22 dS/m treatment. Boron at 25 mg/L decreased the yields significantly for the non-saline treatments, but had no effect when the saline treatments were 22 dS/m or higher.

TLDD Project

At the Drainage Water Reuse Facility, about 25 miles South of Corcoran, CA a project sponsored by the U.S. Bureau of Reclamation was started with tree planting in October, 1994 (Oster et al., 1999b). The site is owned and operated by the Tulare Lake Drainage District. Three varieties of clonal Eucalyptus trees were planted in three 5.6 acre checks at a 14 foot row spacing and 6 feet in-row spacing (520 trees/ac). Irrigation with saline/sodic drainage water (EC 8.5 dS/m; SAR 33.4) began in 1996.

The hypothesis tested was that fall applied gypsum or a combination of fall applied gypsum and ripping would maintain or restore adequate soil physical properties for tree growth. The results demonstrated that gypsum was essential to maintaining good tree growth due to beneficial impacts on water infiltration and soil aeration in the winter and spring.

Growth rates in the trees were negligible until the fall of 1996. Average wood yields were measured in 1998 in cords per acre. Total yields for plots treated with gypsum (1.33) were significantly higher than the plots which had been treated with ripping alone (0.61), or by ripping plus gypsum application (0.75). Irrigation water was measured and rainfall was estimated from a nearby weather station. The average total applied water was 39.5 inches. The leaching fraction was 0.23; consequently the average annual amount used by the crop was about 30 inches. This does not provide the anticipated benefit of the consumption of drainage water by the agroforestry project.
In the above experiment, clonal lines differed. Only 57% of clonal line 4544 survived the first year. Percentage survival rates for clonal lines 4573 and 4543 were 73% and 75% respectively.

Based upon measurement of oxygen diffusion rates this was the first field study that conclusively shows poor soil aeration reduces the growth and productivity of eucalyptus.

Evapotranspiration:

Originally, one of the reasons for the selection of *Eucalyptus camaldulensis* was based upon its high rate of evapotranspiration(ET) and rapid growth rates (Donaldson, et al., 1983). If the growth and ET rates were lowered by saline environments, then reasons for the original selection may have been premature. Dong et al. (1992) reported on a 9.4 ha site in Mendota, CA that even though the literature showed crop coefficients (Kc) for full cover non-stessed *Eucalyptus camaldulensis* was 1.2 or higher, the highest reading at Mendota was Kc=0.83. There are other indications in the literature that ET for trees under salt stress may be only 80% or less that of unstressed trees (Poore and Fries,1985). Dong attributed this reduction in ET to salinity stress in the soil and possible boron toxicity.

Eucalyptus Economics

Sadorsky, P. et al, (1992-93) show that existing prices for bone-dry eucalyptus wood may not provide economic benefits to the farmer. The analysis was based upon the wood selling at $120 per bdt (bone dry ton) even though the highest actual price was for firewood in LA selling for $107/bdt. At these optimal conditions using unblended drainage water for a sixteen-year period the annualized net present value (ANPV) was only $62.62. Use of more expensive irrigation water to blend with the drainage water made the ANPV become negative. Subsequent analysis by the same authors (1992-93) determined improved ANPV by including the benefits of disposing of the drainage water, but this analysis was still based upon eucalyptus wood selling at higher prices than presently exist in California.

At the TLDD site Oster et al. (1999b) made the following assessment: "Assuming the linearity of production measured for two years, yields were projected through the year 2003. Assuming one tree of six being harvested each year, the highest projected annual wood yields would be 0.20 cords/ac in 1998 and 0.77 cords/ac in 2003. Based upon the price of firewood at the TLDD site ($30 - $50 per cord) the project would not generate enough income to offset the annual operating costs of $137.50 per acre or a share of the development cost of $1180/ac. Analysis indicates that the tree/ evaporation pond option is about 1.8 times more expensive than the evaporation pond option alone."

Casuarina

Casuarina species have gained recognition as useful trees to be planted in stressful environments. In China, *C. equisetifolia* has been planted on coastal sand dunes subject to infertility and salt spray (Turnbull, 1983). *C. glauca* and *C. cunninghamiana* have also been planted outside their native habitat, Australia. In the United States they have been judged useful for stabilizing sand dunes, eroded landscapes, reclaiming partially water logged soils (both fresh and brackish), and are useful as shade trees, windbreaks, and shelterbelts. They have been judged as a source of high quality fuel wood. In addition, they have the ability to fix nitrogen in the soil.

In California *Casuarina* has been successfully planted for windbreaks and fuelwood. Between 1987 and 1989 provenance trials were made on *C. cunninghamiana* and *C. glauca*. Some of the trial sites included salt affected lands in the San Joaquin Valley. (Miles, 1990)

Casuarina obesa, C. equisetifolia, C. cunninghamiana and *C. glauca* have been grown on various drainage water reuse (agroforestry) plots in the San Joaquin Valley (Cervinka et al., 1999). They have been irrigated with saline drainage water ranging from 6 to 20 dS/m. *C. glauca* is not frost tolerant; it was damaged by frost in 1990 and did not recover. *C. cunninghamiana* was frost damaged and did recover, but not as well as the eucalyptus species being tested (Cervinka et al., 1999). In January 2001, Cervinka verbally stated that all Casuarina were deemed not suitable for this use mainly due to their inability to survive and prosper in the SJV. Records from 1990-91 indicate that some provenances of this species did survive the freezing temperatures encountered, particularly when they had been irrigated sufficiently prior to the cold weather.

The only screening of this species for salt tolerance and water logging has been found in Australia (El-Lakany and Luard, 1983; Van der Moezel et.al., 1989). El-Lakany and Luard, (1983) found that *C. glauca, C. equisetifolia* and *C. obesa* were the most tolerant. Van der Moezel et.al., (1989) tested five species in a glasshouse for twelve weeks and found all species could tolerate water logging due to the aerenchyma in the roots. *C. obesa* and *C. glauca* were the best species tolerant of both salt levels (NaCl) up to 56 dS/m and water logging. It should be noted that relative growth was decreased to 20-35% of the control in the *C. glauca* and to 40-60% of control in the *C. obesa*. *C. equisetifolia, C. cristata* and *C. cunninghamiana* had few seedlings survive the full twelve week period of testing. However, it should be noted that the onset of these seedling deaths did not begin until salt levels reached 49 dS/m.

Van der Mosezel et al., (1988) has also compared the growth of C. obesa and six species of eucalyptus when exposed to water logging and salt. The experiment compared the species with a control of nutrient solution in well-drained sand, water logged sand, salt added to nutrient and well drained and finally combined salt and water logging. With water logging alone, the *Eucalyptus camaldulensis* actually grew better than control. When salt was added growth ceased for the eucalyptus. Saline and freely drained conditions actually killed the E. kondininensis outright, whereas the others at least survived. Under the combined stress of water logging and salt all the eucalyptus species died during the experiment.

For a time, examination of aerial photos at TLDD seemed to indicate that *C. obesa* and *C. glauca* were performing better than all other trees. However, D. Davis (personal communication 2001) indicated that these trees were brought back to health by irrigation with non-saline water. They are once again being irrigated with saline drainage water of about 8 dS/m and growth rates have declined. At the TLDD site casuarina do seem to have better survival rates than the eucalypts.

Chhabra (1996) reports that *C. equistifolia* grown on soils with a pH of 9.5 to 10 and ESP of 25-50 had high performance. However, others from India (Tomar and Patil, 1998) report that *C. equistifolia* and the eucalypts did not perform as well as *Acacia nilotica* and *Prosopis juliflora* under saline conditions.

Pasternak and Nerd (1996) report that *Casuarina glauca* and *Casuarina stricta*[10] were able to grow successfully in 100% seawater in experimental plots at Asquelon.

[10] Casuarina stricta has apparently been renamed *Allocasurina verticillata* (Lam.) (drooping sheoak). The Australian book, Trees for the saltland, states that it tolerates wind, frost, drought, water logging and moderate salinity.

Tamarix

Another salt tolerant plant grown in the Agroforestry plantations of the San Joaquin valley was Athel (*Tamarix aphyllà*). Athel is a large evergreen tree growing to about 40 feet and is reported to be less weedy than other tamarix species. Eight species of *Tamarix* have been introduced into North America primarily as ornamental trees and shrubs for windbreaks and shade. In addition to athel, the species found in the southwest are *T. chinensis, T. parviflora, T. ramosissima* and *T. gallica* (DiTomaso, 1996). Salt-cedar are faculative phreatophytes (deep rooted to reach the water table); hence, they may be ideal as "vertical pumps". Johnson (1986) reported that a million acres of Tamarisk uses more water than all the communities in southern California.

Tamarix do well under a variety of stress conditions, including heat, cold, drought, flood and high concentrations of dissolved solids. They survive lengthy drought by dropping their leaves and mature plants have been known to survive complete submergence for a period of seventy days (Kerpez and Smith, 1987). *Tamarix* is not an obligate halophyte, but have been known to survive in groundwater where the concentration of dissolved solid approaches 15,000 ppm (Carman and Brotherson, 1982). The species exudes excess salt crystals from openings in its leaves (Neill, 1985). Salt concentration has been reported as high as 41,000 ppm in this guttation sap. Salt accumulates on the soil surface, combining with needles to serve as an allopathic barrier preventing the germination of most other species. In some communities salt grass (Distichlis spicata) serves as the understory (Brotherson and Winkel, 1986).

The major drawback to *Tamarix* species as agroforestry or drainage water reuse plants in the San Joaquin Valley is their reputation for spreading and tapping into limited water supplies in the desert. They crowd out native streamside and wetland communities. John Diener, owner of an agroforestry plantation in the San Joaquin Valley, has stated that athel tend to obstruct tile lines very aggressively. In California much more effort is presently being expended on clearing *Tamarix* and restoration of the areas it has invaded (Johnson, 1986; Egan, 1996). Indeed an entire workshop was devoted to "Salt Cedar Management and Riparian Restoration" in 1996. Athel (*T. aphylla*) is apparently not as invasive as its more shrublike relatives, *T. chinensis*, because its seeds are not viable after a few weeks. It requires warm moist salt free soils to germinate and may not spread into cropland areas. However, the biological controls being studied and released to control the more weedy salt cedars could adversely affect the tree and its own salt releasing allopathic properties could harm other plants in an agroforestry plantation.

Cervinka has stated that Athel recovers well from frost damage and that they may be benefical when the salt concentration is greater than EC = 20dS/m (Cervinka et al., 1999.) Australian papers have reported its salt tolerance for the range EC = 20 to 30 dS/m and have stated that it can survive a month of flooded conditions.

Horton, (1977) reports that the aggressive *Tamarix* is *T.chinensis* Lour. He states that it does not perform well when the water table is less than five feet or more than twenty feet in depth. When the water table is less than five feet saltgrass (*Distichlis* *stricata)* and Bermuda grass (*Cynodon dactylon* L. Pers.) compete well for the moisture, but when the water table drops below five feet the *Tamarix* grow dramatically and shades out the grasses. If the water table drops below twenty feet in *Tamarix,* a large portion of the shrubs will be killed.

Water use was found to decrease from 300 cm/yr to 100 cm/yr as EC of the irrigation water was increased from 10 to 40 dS/m at 25 °C (Van Hylckama, 1970). Since one of the main reasons for the irrigation of trees with saline is to dispose of the excess, this decrease in ET would indicate that substantially larger acreages of tamarisk would be required.

Tamarix are used for furniture in the Middle East, but have no economic use in the United States. The high salt content makes it a poor source of firewood.

Prosopis (Mesquite)

Considerable work has been accomplished determining the salinity tolerance of *Prosopis* species utilizing sand culture pot experiments. The species tested were: *P. glandulosa* var. *torreyana P. velutina; P. articulata; P. chilensis; P. pallida* and *P. tamarugo* (Felker et al. 1981). All were able to tolerate 6000 mg/L (EC 7.3 dS/m) salinity with no reduction in growth. *P. velutina* was the only species that poorly tolerated 12,000 mg/L (EC 13.0 dS/m). *P. articulata, P. pallida* and *P. tamarugo* grew in 18,000 mg/L (19.6 dS/m) saline solution and grew slightly in 36,000 mg/L (39.1 dS/m). *P. articulata* had the best biomass production at high saline levels producing 169g compared to 380g with the control. It should also be noted that the *P. glandulosa* had biomass reduction from 332g in control to 54 g at the highest salinity levels and *P. tamarugo* had only 1.9g of biomass with the control. These were the first legumes known to tolerate and grow in salinities as high as seawater, but as noted from the low weights are very small plants. Maas and Grattan (1999) list *Prosopis tamarugo* as tolerant, but no other *Prosopis* are listed in the tables of plants tolerant of salinity.

Adams et al. (1979) provided salt tolerance of *Prosopis* species, based upon trials in Kuwait, as follows:

P. juliflora aka. *glandulosa*	50 dS/m
P. tamarugo	35 dS/m
P. juliflora var. *velutinus*	30 dS/m
P. chilensis and P.velutina	16 dS/m

Among the salt tolerant trees selected for growing in the Negev Desert in Israel are *Prosopis alba, P. juliflora* and *P. nigra* (Pasternak and Nerd, 1996). No data are provided as to the tolerance of these trees or the salinity of the soil in which they were grown. The same authors report that *P. nigra* and *P. pallida* were grown near Ashquelon using full strengh seawater (54 dS/m) and 15% seawater (9 dS/m), but results of these plantations were not clearly reported for the Prosopis species.

Prosopis tamarugo is described as a very salt tolerant South American native tree planted in Chile for livestock. Seed pods and forage are harvested from the tree. It has relatively slow growth until well established. *P. chilensis* is also a South American tree planted for animal feed in arid regions. It grows to fifty feet in height, is thornless, and was the best biomass producer in University of California-Riverside trials. *P. alba* is a valuable South American fuelwood tree, that can also be used for windbreaks, fodder, timber and ornamental purposes. It is said to be only moderately salt tolerant in UCR trials (Virgina et al., no date).

P. velutina is a native tree of Arizona. In trials at Brawley, CA it was found to be a good producer of seed pods. It is said to have come from rainfed upland regions where salinity is not a problem. *P. pallida* and *P. articulata* occur along the arid coastal regions of Hawaii and Baja California, where groundwater probably mixes with seawater. The drawback of *P. articulata, P. pallida* and *P. tamarugo* was they did not seem to be as frost tolerant as other species (Felker et al., 1981). Felker et al.(1983) reported that *P.*

pallida, *P. juliflora* and *P. africana* were killed by –5 °C temperatures at Riverside, California in the winter of 1978-79.

Economics of ***Prosopis***

Felker (1984) stated that mesquite producing 7 dry tons per acre per year should be able to economically produce a sustainable forest which would generate power at a 500 Mwatt facility as long as haul distances were not greater than 15 miles. He also stated that it has been shown that mesquite can produce up to 6.3 dry tons per acre. Thus, due to the short haul distance and the fact that Prosopis does not produce the required tonnage it should be understandable that wood production for power generation by this species is not economical. The salt tolerance information Felker et al.(1981) provide show a decrease in biomass production when the trees are irrigated with saline waters.

In another study (Felker et al., 1983) reported that *P. chilensis* had the highest biomass production on irrigated plots at Riverside, California producing the above mentioned figure of 6.3 dry tons per acre per year for a period of 2½ years after planting. The worst accessions produced only 1/20 the biomass of *P. chilensis*. The driest plots of the species had water use efficiencies of 345 parts water to 1 part biomass. Felker compares this with domesticated legumes that have efficiencies in the range of 500 to 900 and produce comparable tonnage of dry matter. They believe the nitrogen fixing abilities of the trees, the use of pods for livestock feed and wood production would make *Prosopis* an economically feasible crop in arid regions, but have not produced convincing figures or demonstrated the potential.

Populus

Cervinka reported that he had grown native poplar, *Populus fremontii,* and hybrid poplars in various locations in the valley as part of his agroforestry program (Cervinka et al. 1999). His presentation did not provide any information as to the success or failure of this species as a plant for drainage water reuse. Donaldson et al., (1983) reported that *Populus euprhatica* survived but was not acceptable in his salty, flooded soils in the Napa Valley of California. Later, Donaldson reported that these plants originally from the Euphrates river delta region in Iraq had performed well and were still living at the experimental site in 1999. (Donaldson, personal communication)

Shannon et al. (1999) have reported on *Populus* species tested for salt tolerance at the Salinity Laboratory in Riverside, CA. They noted a significant variation among the clones, but the salinities for which the dry weight (i.e. growth) was reduced ranged from 3.3 to 7.6 dS/m. These writers have concluded that the *Populus* hybrids tested were significantly less salt tolerant than eucalyptus (Shannon et al., 1999). The known parent species used in this study were *Populus trichocarpa, P. deltoides,* and *P. nigra.* Based upon this experiment, if one had to grow hybrid poplars on saline soils a cross between *P. deltoides* and *P. nigra* known as hybrid DN-34 would be the most tolerant.

From the above range of salt tolerance one might easily conclude that it would be best to utilize the land and the drainwater to grow cotton than to attempt to plant the less economical hybrid poplar.

The species is used elsewhere in agroforestry programs utilizing municipal wastewater as the irrigation supply. It seems to serve well in this purpose but due to its relatively low salt tolerance is probably unsuitable for use with the drainage water in the San Joaquin Valley.

Acacia

Another nitrogen fixing plant, which could be considered for the Agroforestry plantations are the various acacia species. According to information from Australia *Acacia saligna* (golden wreath wattle) can tolerate 20-30 dS/m; *A. stenophylla,* also known as river cooba, is said to tolerate 10 to 20 dS/m and is adapted to heavy clay soils and semi-arid conditions; *A. salicinia,* (cooba) said to tolerate 2-10 dS/m saline growing conditions but tends to sucker and form thickets. Other Acacia species said to be saline tolerant are: *A. auriculiformis,* (black wattle), a tree said to grow a straight stem to 30 meters (100 ft) and provide good fuelwood, and *A. kourittii.*

Two species reported to do well in poorly drained soil are *A. pendula* Myall, a hardy slow growing shade tree to 60 feet, and *A. harpophylla* (Brigalow), a hardy farm tree to 66 feet good for windbreaks. Both are also drought and frost resistant, but no information was provided on the tolerance of saline conditions.

A. stenophylla has been used under saline soil conditions in Pakistan. *A. nilotica* has been used in India.

Sachs reported planting *Acacia saligna* at several sites in the San Joaquin Valley (Sachs, 1990). This writer has been unable to find information regarding the species or it performance. One apparent problem with using *Acacia* in the SJV is its inability to withstand freezing temperatures.

Eldarica Pine

When the Mendota agroforestry demonstration plot was started in 1985 it was reported that 72 Eldarica pine were planted in July. Cervinka reported (personal communication) that all pine trees planted at the Mendota did not survive the saline drainage water irrigations.

Pinus eldarica (perhaps also related to *P. brutia,* Calabrian pine and *P. halepensis,* Allepo pine) is a species native to the Caucasus region and is said to be drought and salt tolerant. In the native region they grow between 200 and 600 meters elevation and in an area receiving from 10 to 14 inches (250-350 mm) of total rainfall. The mean summer temperature is about 30 degrees Centigrade and they are subjected to freezing in the winter months. These are similar to many conditions in western North America (Mirov, 1967). Komarov (1934) described the native area as alkaline and poor in nutrients. It has been planted in a broad region from Iran to Pakistan.

Introductions to the arid mountains of North America have exhibited remarkable growth and survival characteristics beyond any native pines when grown in conditions of high temperature and low rainfall, such as Arizona and New Mexico. In 1972-75 the state of Arizona obtained seeds from Quetta, Pakistan and distributed them throughout the state. They were found to tolerate summer temperatures, between 40 and 45 degrees Centigrade, and in 1976 survived three consecutive nights with lows of –15 degrees at an altitude of about 5000 feet in north central Arizona.

Much of this information was obtained from an undated, unpublished draft apparently presented as a proposal for provenance testing.

AGROFORESTRY SUMMARY

The proposed use of these trees in the San Joaquin Valley has taken two different directions, namely their use as salt tolerant plants when saline drainage water is used for irrigation and as vertical pumps. In both cases the trees ability to transpire large amounts of water is the primary reason for their adaptation to the agroforestry system. Economic benefits were also considered, but only as a secondary reason. Researchers in Australia have also been actively attempting to use trees and other woody species for the same purposes. In the SJV the primary purpose in the beginning was the use as salt tolerant plants to dispose of drainage water (Cervinka 1987), while in the land down under the original purpose seems to be the use as vertical pump (Biddiscombe et al., 1985; Greenwood, 1986). It might be well at this point to define the use as vertical pumps. Essentially, what is meant is that the trees are planted in slightly saline or non-saline soil where there is a shallow water table, within 1-3 meters of the surface. The trees are irrigated to become established and ultimately, their root system reaches the water table. The mature trees then draw upon the groundwater for their needs, hence controlling the level of the groundwater.

In Cervinka's program development for the SJV, trees had been planted on thirteen farms by 1987. Planting started in 1985 and the plantations had been irrigated with "fresh water immediately after planting" and "with drainage water after the first year". Research was also ongoing to select the most salt tolerant plant clones (Sachs and Cartwright, 1989), but the early salinity tolerance studies for *Eucalyptus camaldulensis* suggested that the levels of salt in the drainage water reduced growth rates by 70% in even the best selections.

In the winter of 1990 most of the eucalyptus were killed by a freeze dropping temperatures in the valley to 11 degrees Fahrenheit. Essentially, what was learned from the plantations established prior to this time was that growth rates and evapotranspiration (ET) dropped when the trees were irrigated with saline drainage water. Letey and Knapp (1995) used models to simulate Agroforestry water management, which also predicted the lowering of growth rates and ET. They showed that over time the drainage water applications quantities would increase leading to greater deep percolation,which would lead to the use of more land to dispose of the drainage water (Letey and Knapp, 1995). Since the primary purpose of these plantations was to dispose of drainage water lower growth and lower ET's defeat the purpose of planting trees, regardless of the species or the salt tolerance. The saline drainage water can cause the degradation of soil physical properties over time, reducing the water infiltration rates and reducing yield (Note: These physical properties are primarily at the surface. Tree canopy and lower story vegetation could actually prevent some of the degradation.)

This justifiably raises the question, if the soil physical properties are degraded using saline drainage water for irrigation does it matter what crop is to be grown and what the salt tolerance is for that crop?

Australian studies show that when trees are used as vertical pumps for long periods of time that the salt in the root zone gradually increases. Unless there is a mechanism to wash the salt from the tree root zone, it will ultimately increase until the salinity level is at a point beyond the tree's tolerance. First, the tree stops growing and transpiring removing its function as a vertical pump. Then, the tree dies. In November 1995, Tanji sampled trees and soils for salinity and boron. At the Britz farm in the San Joaquin Valley, five-year old *Eucalyptus camaldulensis* Lake Abacutcha, grown as "vertical pumps" were dead or dying. The soil profile under the worst looking tree was sampled and clearly showed a bulge in boron concentration from below the surface to about four feet. The highest boron reading was 37.8 mg/L at the 18 to 24 inch depth. EC_e readings also showed the same bulge with highest reading at the same depth of 22.3 dS/m. Similar symptoms could be observed at the Red Rock Ranch with two year old trees, not dying, but sickly. Soils below these trees also were beginning to show the bulge in EC_e and boron concentration.

Based upon the Austrailan work by Marcar et al. (1995) for drainage water reuse in the San Joaquin Valley of California, Birkle would make the following recommendations.

Acacia stenophylla is the most salt tolerant of the listed Acacias. It grows well on heavy clay soils and can tolerate freezing down to -6 °C and some water logging.

Acacia salicina is slightly less salt tolerant but also can withstand water logging, drought and some freezing. .

Casuarina obesa tolerates mild freezing, drought, alkaline conditions and highly saline soils. The second *Casuarina* choice would be *glauca* as others of this species "become chlorotic in calcareous soils".

Eucalyptus kondininensis would be the first choice for the eucalypts based upon the information in the guidebook because it can tolerate some frost, drought, heavy clay and alkaline conditions. The drawback, it is slow growing and reaches only 10-15m (33-50 feet) in height.

Eucalyptus occidentalis is also drought hardy, frost tolerant and can grow in wet poorly drained soils. It can grow to 10-20 meters (33-66 feet) in height.

Eucalyptus sargentii is also drought tolerant, mildly frost tolerant, favors alkaline soil and is tolerant of periodic flooding.

Eucalyptus spathulata is less salt tolerant than the previous three, but is said to be adaptable to most soils and will tolerate heavy, alkaline, wet conditions. It is moderately frost tolerant.

Eucalyptus camaldulensis *is the most prominent tree that has been grown on agroforestry, (IFDM) sites in the San Joaquin Valley, but as mentioned above it has been found to be intolerant of the combination of soil flooding and saline water. The guidebook also indicates there is reduced growth when the soil EC exceeds 5 dS/m. It does mention that there are provenances that may be better suited to salt conditions. One prominent statement I find that may influence the choice of this tree is that it is <u>not well adapted to calcareous soils</u>.*

Melaleuca halmaturorum is the only member of this species to attempt growing for utilization of saline drainage water. It will tolerate water logging and is moderately frost tolerant.

The overall objective of the proposed research in the SJV was to determine the long-term feasibility of agroforestry (i.e. eucalyptus trees) as a method for reducing drainage volumes. It appears that water use is curtailed more than 50% for most conditions when saline water is used for irrigation.

Even though the SJV agroforestry projects have been concentrating on *Eucalyptus camaldulensis*, much of the salt tolerance in Australia and other countries seems to point to other species as being significantly more tolerant than *E. camaldulensis.* There seems to have been only limited trials on these other species in the SJV. There is additional support for using species other than Eucalyptus in drainage water reuse strategies.

Clones 4501 and 4573 of *Eucalyptus camaldulensis* appear to have greater salinity tolerance than the others such as 4544 and yet they were not used extensively in the field or the follow-up sand tank testing. There is some indication that clone 4590 may have the best relative yield with EC in the 4 –20 range, actually peaking at EC = 10 dS/m.

No woody species except possibly pistachio appears to have the economics for drainage water reuse. Bottom line, agroforestry as defined by Cervinka is not sustainable on either an economic basis or when salt tolerance is considered.

Other countries:
India

Chhabra Soil Salinity and Water Quality Chapter Grasses and Trees as Alternate Strategies.

Table 17: Relative tolerance of tree species to alkali soil conditions

Alkali condition	pH/ESP range	Tree species (scientific name)
High	9.5-10.0 ESP 25-50	Mesquite (*Prosopis juliflora*) Acacia (*Acacia nilotica*) Casuarina (*Casuarina equistifolia*)
Medium	9.0-9.5 ESP 15-25	Eucalyptus (*Eucalyptus tereticornis*) Alvizia (*Albizia lebbeck*) Alvizia (*Albizia falcataria*) Pongamia (*Pongamia pinnata*) Arjun (*Ternubakua arjuna*) Sesbania (*Sesbania aegyptica*) Zizphus (*Zizphus jujuba*)
Low	8.5-9.0 ESP < 15	Parkinsonia (*Parkinsonia aculeate*) Azadirachta (*Azadirachta exotica*) Azadirachta (*Azadirachta indica*) Tamarind (*Tamarindus indica*) Shisham (*Dalbergia sissoo*) Mulberry (*Morus alba*)

The table is based on work in India in 1970 by Yadav and Singh conducted in the Vrij Bhumi Forest Division of Uttar Pradesh. All species failed to grow on soils where the pH was above 10 and salts were above 3.42%[11] (43 dS/m) in the top 15 cm. Prosopis juliflora could tolerate pH up to 10 and salts up to 1% (12.5 dS/m). Irrigation was apparently with good quality water and the statement is made "physical removal of salts is of great help, especially in the first year, can be useful." Most of the trees were sensitive to excess water in the rootzone; temporary waterlogging can kill young plants.

In a section on the afforestation of saline soils – choice of species.Chhabra (1996) reports that on dry $Cl^-SO_4^{-2}$ solonchaks of Israel (EC_e varying between 12 and 17 dS/m *Eucalyptus camaldulensis* and *Pinus helepensis* were found to be the most tolerant trees planted. Also, in other research *Tamarix ramosissima* and *Terminalia tetranda* could root successfully in horizons that contained up to six per cent salt. Others trees, which have been successful in saline conditions are: *Acacia nilotica, Albizia lebbeck,*

[11] 1% concentration is 10,000 ppm; If this is TDS (total dissolved solids) division by 800 will approximate the EC in dS/m. Thus, 1% salt is approximately 12.5 dS/m.

Parkinsonia aculeate, Prosopis sicigera and *Zisyphus jujuba*. Where the combination of high salinity and shallow water table exist together *Casuarina equistifolia, Tamarix articulata* and *Prosopis juliflora* have been found to perform well. Chhabra also reports that Tomar and Gupta (1986) reported that *A. nilotica, A. tortillas, A. auriculiformis, C. equistifolia* and *E. camaldulensis* can be successfully grown in moderate salinity 10-22 dS/m.
Related work reported Minhas, P.S., O.P. Sharma and S.G. Patil (eds), (1998) 25 years of research on management of salt affected soils and use of saline water in agriculture, Central soil salinity research institute, Karnal, India Printed at Yugantar Prikashan, New Delhi.

Chapter 9, Tomar, O.S. and S.G. Patil, (1998) Alternative land uses

The areas of India with salt lands exist in arid, semi-arid and hot sub-humid regions. Young plants may suffer injuries from frost during winter. 70-80% of total rainfall in July- September, but it is very erratic. Irrigation water is not available for afforestation so it is important to utilize poorer quality water. Irrigation water used EC 12-29 dS/m causes some reduction in biomass on *Acacia nilotica* and *Prosopis juliflora*. They may use as little as 10% of open pan evaporation.

Suitably grown in Gangawati province (22 species of trees on sodic vertisols) were *P. juliflora, A. nilotica, Cassia siamea, Albizzia lebbeck, Azadirachta indica* and *E. tereticornis*. C. equistifolia and Acacia auriculiformis did not survive due to prevailing high temperatures and non-availability of irrigation water. On alluvial sodic soil at Kanpur A. nilotica and P. juliflora were better than Eucalyptus spp. and Casuarina equistifolia. (pH 10.1-10.4, EC_e 4.8 –5.6 dS/m, ESP 74.5 –79.3)

Results of a study at Sampala, Tomar found on highly saline, water logged soil Prosopis juliflora, Acacia nilotica, A. farnesiana, A. tortillas, Casurarina glauca, Parkinsonia aculeate and Tamarix sp. were suitable.

Table 18: Salt tolerance in water logged condition of some firewood tree species

Salinity levels of satisfactory growth takes place (EC_e dS/m)	Tree species
Promising (>25)	*Acacia farnesiana, Parkinsonia aculeate, Prosopis juliflora, Salvadora persica, S. oleoides* and *Tamarix* sp.
Moderately Promising (15-25)	*Acacia nilotica, C. glauca 13987, C. glauca 13144, C. obesa 27, C. equisitifolia*
Moderately sensitive (5-15)	*A. tortilis, A. pennatula, Callistemon lanceolatus, Eucalyptus camaldulensis, E. tereticornis, Leucaena leucocephala, Pithecellobium dulce, Pongamia pinnata, Terminalia arjuna*
Sensitive (<5)	Not listed – no value to drainage water reuse.

Israel

Pasternak and Nerd (1996) report on experimental work with halophytes at a site 8 km south of Ashquelon. Tree and other crops were irrigated in some plots with seawater (54 dS/m) and in control plots with 15% seawater (9 dS/m). The only trees which performed better in the 100% seawater and did better the second year than the first year were: *Tamarix aphylla, Casuarina glauca, Casuarina stricta*[12], and *Melaleuca halmaturorum.* Trees that did well in the fifteen percent seawater were *Eucalyptus sargentii, Tamarix articulata, T. chinensis, T. juniperina* (Mapu), *T. nilotica, T. tetragonya, T. tetragoniodes, T. implexicoma, Prosipis nigra and P. pallida.*

The writers recommend all the *Tamarix, Eucalyptus sargentii,* and *Melaleuca halmaturorum* for use as landscape trees where irrigation may be with seawater, but do not list *Casuarina* or explain why this species was left from their list.

In the Negev, Paternak and Nerd (1996) recommend the following salt tolerant, heat tolerant and drought tolerant trees for planting. *Casuarina glauca, C. stricta* (good for windbreaks), *Acacia horrida* (good thorns for an outer boundary for plantations), *Prosopis alba, P. juliflora, P. nigra, Eucalyptus spathulata* (small, very attractive), *E. torquata* (medium size –hardy- very attractive flowers), *E. lancelata, Salvadora persica* (likes a warm climate –very hardy), and a small, decorative, flowering tree, *Moringaceae oleifera.* The *Prosopis* were labeled as, multipurpose trees – highly recommended.

[12] Casuarina stricta has apparently been renamed *Allocasurina verticillata* (Lam.) (drooping sheoak). The Australian book, Trees for the saltland, states that it tolerates wind, frost, drought, water logging and moderate salinity.

RESEARCH PRIORITIES

A vast body of research-based knowledge has been developed since selenium has been recognized as a major constraint in drainage water disposal. To some extent it is equally important to apply the research knowledge that has been developed to solve problems as to develop new research topics. This statement is not intended to imply that there are no further research needs. It is simply stated to emphasize that what we do know is equally important as to what we do not know.

The following broad topics are areas where additional research would be particularly useful in adopting the optimal management strategies. This report is not intended to be all-inclusive so any research topic not listed should not be apriori considered to be not important.

Drainage Outlet Control

Management to reduce drainage volumes is firmly recognized as a positive management option. Most research efforts on this topic have been directed towards irrigation management. In other words, controlling the amount of drainage water produced by controlling the amount of water applied.

Drain lines placed six or more feet deep are deeper than required to maintain water table elevation control. In other words, the water table does not need to be lowered to these depths to maintain crop production. Therefore, control on the drainage outlet is another means of reducing drainage volumes. Drainage outlet control in this report is used in the sense of placing a control on the drain line which can be opened allowing flow or closed preventing flow. In other words, an active process of managing drainage outlet and not merely placing a control whereby the water table level is raised before flow occurs.

As stated in other parts of this report, control of drainage outlet may have other potential benefits in addition to storing water in the profile, which may be used by the crop. Potentially hydraulic gradients are imposed which reduce the upslope to downslope water migration and increased downward migration of water below the field.

Possibly the greatest benefit, however, is that it provides a mechanism to remove the most amount of salt with the least amount of water from the root zone. Traditional leaching fraction concepts are based on steady state rather than the dynamic conditions which occur under irrigated agriculture. Water is extracted through the root zone reducing the soil water content and increasing the salt concentration. When irrigation water is applied, the flowing water transports the salt downward and restores the soil water content in the root zone with a fresh supply. This process flushes the salts to the bottom of the root zone and keeps a majority of the root zone free from salinity. There is no need for drainage if the irrigation simply resupplies the profile with the water lost through evapotranspiration between irrigations. This allows high concentrations of salts to result in the lower part of the root zone which can eventually be flushed out by a relatively small amount of water when the drain line is opened.

The above-described process can work as long as the irrigation water salinity is relatively low. It becomes less effective when using saline irrigation waters because the upper part of the root zone is exposed to the high salinity irrigation water.

The required research is more than engineering to develop the control systems. Nevertheless, this is a significant component of the required research. This is particularly true on sloping lands where control is required on individual laterals and possibly even on segments of laterals.

The research should be directed towards the total management practices. In other words, the above-stated processes for the continual flushing to the lower part of the root zone and monitoring techniques to determine when and how much leaching is required needs to be developed in a comprehensive total management package.

Extensive field research is required and therefore the budget requirements are sizable. Some components of the research can be accomplished in lysimeters. The dynamic computer model can be used to guide the experimental variables and monitoring needs.

Travel Times

Present models are adequate for simulating the consequences of different irrigation management practices on the amount of water and salt leaving the root zone. Improved analyses of the movement of water and salt after they leave the root zone is required to establish long term consequences. Specifically, long term projections on the salinity of water collected in drainage systems from a reuse system is important. As part of this analysis, it would be useful if the consequences were determined of having open or closed drain lines on hydraulic gradients and consequent stream lines of water flow in the saturated zone.

Because of the complex geologic system accurate quantitative projections cannot be reasonably expected. Nevertheless, reasonably accurate projected estimates are important in guiding policy decisions over short-term benefits and long-term consequences of agricultural drainage water reuse.

Economics

Numerous combinations of management options are available. Each combination of options invokes a set of costs and benefits. Additional economic analysis to identify the economically optimal combination of management is required for planning purposes.

Research on Boron

During our interviews, some individuals expressed that boron was going to be the limiting factor in the reuse of drainage waters and others who stated that boron is not an issue. These statements were made by reputable scientists which leads to the conclusion that additional research or at least interpretation of existing data is required to conclusively answer the question concerning boron hazard.

The difference in opinion appears to be based on two factors. The optimistic position is based on the interpretation that most boron tolerance coefficients that are reported are based on visual plant damage symptoms rather than yield. They argue that the plant symptoms develop with time and are not evident until the latter part of the growing season and may not significantly affect yield. Possibly a stronger argument that the optimists present is that more recent research identifies that the presence of salinity reduces boron damage. They propose that most of the early research on boron effects on plant growth were done in nonsaline solutions. It is conceivable that the salinity of drainage water will always be the limiting factor and not boron on the ultimate crop yield.

The more pessimistic view is that boron concentrations in drainage water exceed the published boron tolerance coefficients. Furthermore, boron is adsorbed by the soil and therefore is not readily leached through the soil profile as the other salts are. This phenomenon provides the opportunity for boron to accumulate in the root system more rapidly than salinity and eventually have its negative effect.

What is relatively well-known about boron is: (1) boron is taken up by plants and carried along the transpiration stream; (2) boron concentrates as water transpires; (3) highest boron concentrations occur in leaves at the end of the transpiration stream; (4) visual symptoms occur in zones of very high leaf tissue/boron concentration; (5) crops vary in boron tolerance; (6) increasing water salinity reduces toxic effects of boron and (7) boron is adsorbed by soil.

What is less known about boron is: (1) relationship between visual leaf symptoms and yield; (2) dynamic relationships between boron concentration in irrigation water adsorption of boron soil-solution concentration, boron uptake, boron effects on yield and the leaching of boron and (3) whether boron damage will ever exceed salinity damage when using saline drainage water.

The important information that is needed is to have boron tolerance coefficients related to yield rather than visual symptoms, and that the boron tolerance coefficients be evaluated as a function of salinity.

Soil Physical Properties

The hazard of destroying soil physical properties through the reuse of saline waters is well-recognized for most crops. The knowledge is far more limited in a cropping system of forages. Research to determine the effectiveness of forage root systems in protecting soil physical conditions when irrigated with drainage water is important.

Basic Salinity Tolerance Coefficients

Salinity tolerance coefficients are available for many crops. However, if any crop is contemplated to be used in a drainage reuse system for which the tolerance coefficients have not been established, it is important that they be determined. Although experiments can be run with these crops in a field experiment, the results are limited to the management variables used within the experiments. With the basic salinity tolerance coefficients, the computer model can be used to simulate the consequences of a wide range of management options which would not be practical on a field scale.

Reduce Ecological Hazards Associated with Using Evaporation Ponds

Except for ecological hazards evaporation ponds have many positive attributes for managing the salinity drainage problems in the Western San Joaquin Valley. Therefore, basic research to reduce the ecological hazard is important. Additional basic knowledge on selenium food chain transfers and ecotoxicological hazard is critical. This research might include the evaluation of brine shrimp or other invertebrate harvesting to interrupt the food chain. Initial studies reveal that brine shrimp harvesting might be ecologically and economically viable. Research to develop basic management practices conducive to high brine shrimp production is justified. This research may be directed toward developing a system to concentrate drainage water and then utilize the water for brine shrimp production.

Because selenium is the toxicant of concern, extended research to develop practical selenium removal methods is justified. The initial results of flowing water through hay bales to greatly reduce the selenium concentration is promising, but needs additional testing and refinement.

Drainage Re-Use Contact List

Task Order 5

Contract 98-7200-B80933

April 1, 2000 - June 30, 2001

Date &Time	Person's Name	Representing	Place of Meeting
May 8, 2000 PM	David Cone	Broadview Water Dist.	Broadview
May 9, 2000 AM	John Diener	Red Rock Farms	Westside Exp. Sta.
May 22, 2000 PM	Steve Grattan	UC Davis	Water Resource Ctr
May 24, 2000 AM	Catherine Grieve	USDA Salinity Lab	Salinity Laboratory
June 1, 2000 PM	Phil Nixon	Lost Hills Drainage District	Lost Hills District, Bakersfield Office
June 2, 2000 AM	Vashek Cervinka	DWR	DWR -Fresno
June 2, 2000 AM	Frank Menezes	USDA-NRCS	DWR -Fresno
June 2, 2000 AM	Red Martin	Westside RCD	DWR -Fresno
June 2, 2000 AM	Clarence Finch	NRCS -Retired	DWR -Fresno
June 2, 2000 AM	Steve Juarez	DWR	DWR -Fresno
June 2, 2000 AM	Kathleen Buchnoff	DWR	DWR -Fresno
June 2, 2000 AM	Jose Faria	DWR	DWR -Fresno
June 2, 2000 AM	John Shelton	DWR	DWR -Fresno
June 5, 2000 AM	Raul Ramirez	USDA-NRCS	Phone
June 7, 2000 PM	Blake Sanden	UC-CE Kern Co.	Bakersfield
June 8, 2000 AM	Doug Davis	Tulare Lake Drain District	TLDD Office in Corcoran
June 8 & 9, 2000	Ceil Howe Jr.	Westlake Farms	Westlake Farms
June 8, 2000 PM	Bruce Roberts	UC-CE King Co.	Hanford
June 9, 2000 PM	Dan Bartel	Buena Vista Water District	BV Office in Button Willow June 9, 2000

Date &Time	Person's Name	Representing	Place of Meeting
June 29, 2000	Vashek Cervinka	DWR	Davis
June 30, 2000	Steve Jones	USBR	Sacramento
June 30, 2000	Wayne Verrill	DWR	Sacramento
August 8, 2000	"Chase"	Panoche Water Dist.	Phone
August 14, 2000	Kenneth K. Tanji	UC-Davis	Davis
August 14, 2000	Steve Grattan	UC-Davis	Davis
August 14, 2000	Wes Wallander	UC-Davis	Davis
August 14, 2000	Manucher Alemi	DWR	Sacramento
August 15, 2000	Joe Summers	Summers Engineering	Hanford
August 15, 2000	Joe McGahan	Summers Engineering	Hanford
August 15, 2000	Bruce Roberts	UC-CE	Hanford
August 15, 2000	Marlon Port	NRCS	Hanford
August 16, 2000	Lonnie Wass	Regional WQCB	Fresno
August 16, 2000	Anthony Toto	Regional WQCB	Fresno
August 16, 2000	Jim Ayars	USDA-ARS	Fresno
August 16, 2000	Gary Banuelos	USDA-ARS	Fresno
August 17, 2000	Mike Delamore	USBR	Fresno
August 17, 2000	David Wooley	USBR	Fresno
August 21, 2000	David Zoldoske	CIT CSU-Fresno	Fresno
August 21, 2000	Sharon Benes	CSU-Fresno	Fresno
August 21, 2000	Greg Jorgensen	CIT CSU-Fresno	Fresno
August 22, 2000	Jeff Bryant	Firebaugh Water District	Mendota
August 23, 2000	Rod Gosling	Westside Pump	Phone
August 24, 2000	Kevin Johansen	Provost & Pritchard	Fresno
August 24, 2000	Thad Bettner	Westlands Water District	Fresno

Date &Time	Person's Name	Representing	Place of Meeting
August 25, 2000	Jim Cooper	DWR	RRR at Five Points
January 16, 2001	Mike Andrews	Rainbow Ranch	Rainbow Ranch
January 17, 2001	Vashek Cervinka +	DWR	Met with Cervinka and group in Fresno
March 27, 2001	Many People	Conference	Sacramento
March 28, 2001	Many People	Salinity/Drainage Conference	Sacramento
March 29, 2001	Many People	Workgroup	Sacramento
May 8, 2001	Many People	Workshop	Fresno

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