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).

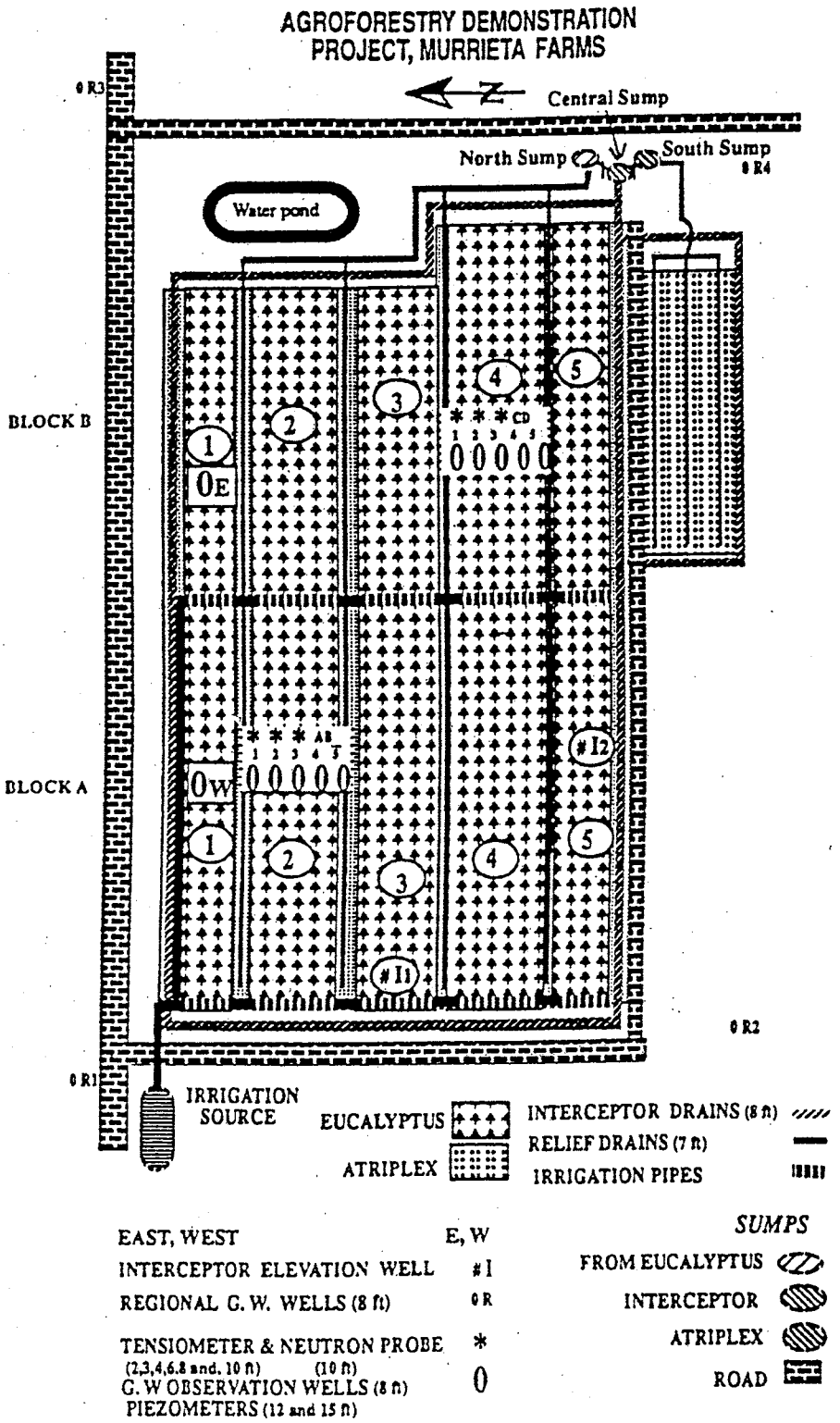
The site is located in Section 19, T14S, R15E, in Fresno County. It is 28.3 acres and drainage water was available for irrigation from the Westland tile drainage system. The soils at the site are described as finely textured clay soils in the upper 7.5 feet underlain by clayey to loamy soils ranging 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.

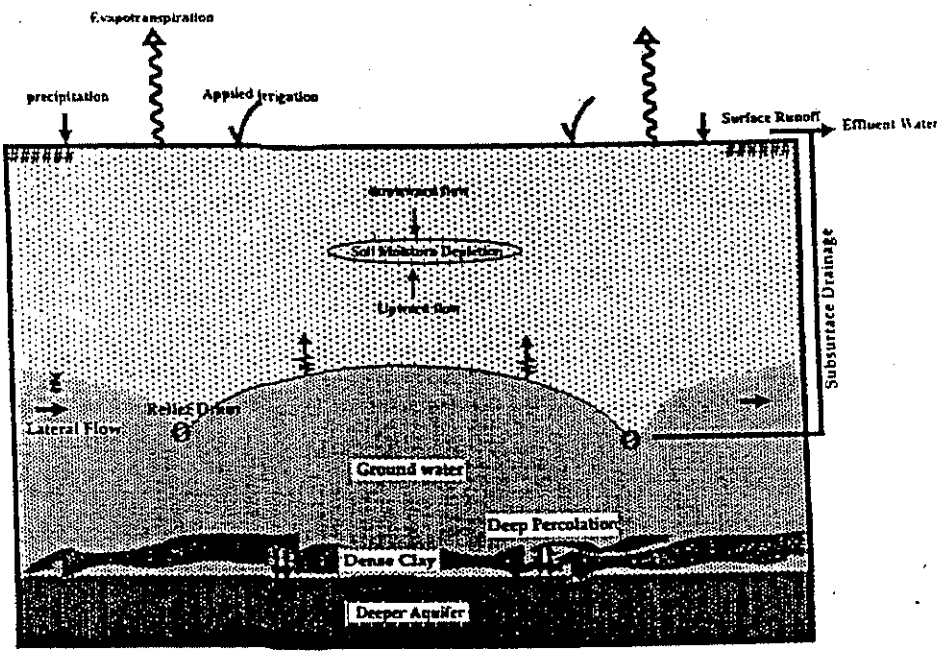
The soil materials taken during the installation of these later observation wells in 1987 were chemically analyzed. Average EC and boron data were provided in a progress report dated June 1989 (Tanji et al., 1989a). These data shows that the EC was between 5 and 10 dS/m in the top 18 inches and increased 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).

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[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

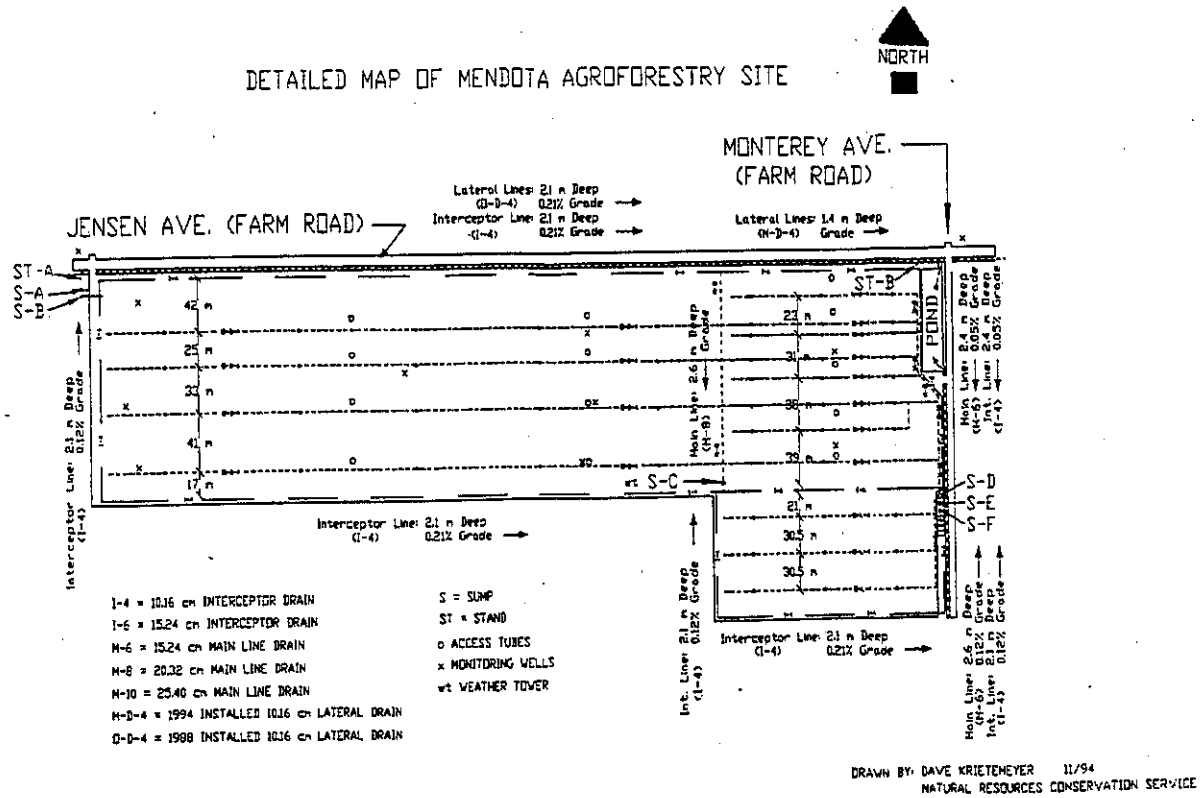

Table 4: Summary of design criteria and measured results between 1994 and 1997.

	Design Exhibit 5.2	Recalculate Design	Actual Data by Year below 1994	1995	1996	1997	1998
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.