**CENTRAL ARIZONA SALINITY STUDY --- PHASE I**

Technical Appendix Chapter Q

**Soil Salinity Levels of Gila River Indian Community soils**

**Background:** Irrigation development on about 53,000 acres of new lands on the Gila River Indian Community (GRIC) could result in leaching of salts into the regional aquifer. The total irrigation project was planned for 146,000 acres originally but is currently sized at about 130,000 acres based on water supply limitations(1) . A total of 77,000 acres have an irrigation history and have probably been leached of native salts(2). The difference between the historically irrigated acreage and the total acreage is 53,000 acres.

In order to better understand and predict the magnitude of this possible occurrence a review of existing soil and vadose zone (refer to definitions section) data was conducted. This data was used to prepare a salinity curve for non-irrigated land that will be developed for irrigation. One curve was developed for upper alluvial fans sites dominated by creosote bush while a separate curve was prepared for relict basin and basin rim soils dominated by desert saltbush vegetation. While extensive soil, and soil substrata data was available from US Bureau of Reclamation (USBR) Land Classification and drainage logs, the Natural Resources Conservation Service ( NRCS) soil survey(3), and other sources, only limited data was available for vadose zone salinity below a depth of about 30 feet below grade.

The salinity of the vadose zone was estimated to be in balance with the groundwater that once occupied these substrata. Under historic conditions the vadose zones were very thin. As the water table receded deep aggressive root systems of desert scrubs such as mesquite, wolfberry, and saltbush followed the water table down to depths of 30 feet or more. Evidence of this thick root zone includes highly saline soils to depths of 20-30 feet. Evapotranspiration of these deep-rooted plants tended to concentrate salts in the remaining soil water. This soil water was finally consumed as the water table receded even lower beyond the reach of all roots. Eight deep soil borings evaluated by Reclamation commonly found dry soil conditions to depths over 30 feet below grade. Dry soil conditions extended to depths of about 34-37 feet below grade in four of the deeper borings, however some soil moisture was encountered below this depth.

The thick dry soil layers have implications for calculating the time it will take deep percolation waters and salts to reach the water table. The deep percolation will have to fill almost all the micropore space in the soil above a soil depth of 35 feet below grade as well as the macropores that commonly transmit water downward. The total porosity of the aquifer materials probably ranges from about 40-50 percent, while the specific yield probably ranges between 10 and 20 percent. Deep percolation will only need to fill the macropores below a depth of 35-40 feet. The vadose zone anticipated under irrigated conditions extends from a depth of approximately 6 feet or so to the static water table level, which ranges from about 50 –100 feet in much of the reservation. As the water table continues to be drawn down by pumping the thickness of the vadose zone will increase. For the purpose of this report, the vadose zone at equilibrium conditions, under irrigation, is expected to extend between 6 to 200 feet below grade.

A separate salinity curve was developed for the post irrigation development on previously irrigated lands. This curve assumed irrigation with a combination of Central Arizona Project (CAP) water, Gila river water, other surface waters and groundwater. A leaching fraction of 25 percent on irrigated lands was assumed based on data in reference(1). This leaching fraction is somewhat higher than the current leaching fractions on nearby irrigated lands but is lower than State of Arizona goals. Because the future project will use groundwater as a source of irrigation, the 25 percent leaching fraction is realistic since this level is needed to maintain groundwater quality suitable for irrigation. This level of leaching is judged to be readily attainable on properly designed and managed flood irrigation systems.

The two current dryland salinity curves were compared to the projected irrigated curve to determine the net loss or gain of salts to the aquifers following irrigation development. (Attachment 1). Generally these curves indicate dissolution and removal of salts to a depth of about 17 feet below grade, then extensive salt storage capacity to a depth of about 200 feet below grade. The salt storage capacity of the 17-200 foot substrata zone should minimize any leaching of native salts to the aquifers under irrigated lands.

Based on current development maps it appears that conversion of dryland to irrigated lands will occur on two primary landforms. These landforms are described below.

## GRIC Land Characteristics

### Basin rims and relict basins

These lands constituent about 90 percent of future project development or about 48,000 acres. The average rainfall in the area typically leaches salts from the top 2 feet of soil but salinity rises sharply below this depth. Salinity in the intermittent slick spot areas is elevated to the soil surface. Soil amendments and leaching operations are needed on most of these lands to reduce soil salt and sodium content prior to successful irrigation. Salt tolerant shrubs such as desert saltbush, wolfberry, and mesquite dominate these lands. Scattered slick spot areas are barren and have iodine bush around the perimeter. These soils are highly saline down to a depth of about 17 feet below grade. Electrical conductivities (ECe) of the soil saturation extracts are in the 10 to 100 decisiemens per meter (ds/m) range and average about 25 ds/m, which indicates soil water salinities of about 50 ds/m. The depth of these saline deposits vary, however, at depths below 30 feet, the salinities must be lower since existing groundwater which has receded from the deeper vadose zones in recent years has an ECe in the 2.0 ds/ m range. This value is roughly equivalent to a soil saturation extract value of about 1.0 ds/m. The average value of 17 soil samples collected below the zone of salt accumulation was 1.02 ds/m. Many of the deeper drainage logs do show indications of a soil salinity decrease from 12-30 feet below grade. Depth to groundwater maps presented in recent reports[1] suggests the current depth to groundwater ranges from 50-100 feet below grade. Historic groundwater records[3] indicate pre development groundwater depths were about 10- 50 feet below grade. Based on the recent decline in groundwater levels, it is assumed that soil salinity in the 25-200 foot depth zone should be at levels in equilibrium with the groundwater.

The source of the elevated salinity to depths of 12-30 feet is uncertain, however it is postulated that the very deep root zones of the desert shrubs must have pulled water from the water table. The plants used the water for evapotranspiration but the salts were left behind in the soil. As the water table was drawn down by groundwater pumping out of the reach of the deep rooted plants some of the plants died and the other plants are now severely stressed by a combination of excess salts and lack of water.

**Alluvial fans and Fan Terraces**

Alluvial fans and fan terraces will constitute about 10 percent of the planned irrigated lands. Approximately, 50 percent of the currently developed lands in the Sacaton ranch area are of this type. The soils are coarse textured and generally non-saline. Native vegetation is dominated by Creosote bush. Some of these lands will probably be developed for drip irrigated orchards. Large, deep cut and fills would be needed to develop gravity irrigation on these sloping lands into field size level basins. The average ECe of these lands is about 5 ds/m to a depth of 20 feet. Based on analysis of existing soil boring logs it appears the salinity of the upper vadose zone above 50 feet is about 1ds/m. The salinity of the lower vadose zone is also estimated at 1ds/m based on soil materials being in balance with current ground water salinities.

The NRCS soil survey lists the Denure soil series as representative of this land type. These soils are not listed as saline. They are characterized as non-saline, coarse textured soils. According to the NRCS soil survey [3], these soils cover over 30,000 acres of land on the reservation.

**USBR Data Summaries**

A summary of USBR data collected on GRIC is presented below: Weighted average soil salinity values, as well as the observed depth of the salinity drop off were evaluated. Many of the logs extending to a depth of 20 feet below grade or less did not exhibit any salinity drop off to the observed depth. The soil data was sorted by vegetation type. Of the 43 logs examined, the estimated breakdown by vegetation type is listed on the next page:

**Table 1 - Vegetation type**

| Vegetation type | Landform | Relative Extent of newly developed acres |
|---|---|---|
| Saltbush, wolfberry scrub, mesquite | Relict basins, 0-3 percent slopes, uneven | 90 % |
| Creosote bush | Alluvial fans and fan terraces, 2-6 percent slopes | 10% |

**Table 2 – Reclamation Data summary**

| Parameter | Number of observations | Average | 95% range low | 95% range high |
|---|---|---|---|---|
| Weighted Average Ece to salinity reduction point. Basin lands | 30 | 25.1 ds/m | 20.8 ds/m | 29.4 ds/m |
| Ece below 17.2 feet. Basin lands. | 17 | 1.02 ds/m | 0.79 ds/m | 1.25 ds/m |
| Depth to Salinity reduction point. Basin lands. | 11 | 17.2 feet | 12.7 feet | 21.7 feet |
| Fan Terrace lands, weighted average Ece to salt reduction point. | 3 | 5.1ds/m | ID | ID |

Ece = electrical conductivity of the saturation extract.
ID = insufficient data

**<u>NRCS Soil Survey Data Summary</u>**

The following table presents soil data from the NRCS soil survey. This data is commonly for a soil depth of 0- 5 feet below grade.

**Table 3 - Soil Series Salinity Summary**

| Soil unit principal soil | Average Ece at 5 feet ds/m | Landform (NRCS) | Extent acres (x 1000) |
|---|---|---|---|
| Shontic | 17 | Relict basins | 40 |
| Casa Grande | 25 | Relict basins | 53 |
| Redun | 31 | Relict basins | 21 |
| Denure-Pahaka | 2-5 | Fan terraces | 33 |
| Yamato | 42 | Higher floodplain | 18 |
| Indio | 22 | Higher floodplain | 19 |

The soils listed in Table 3 make up the bulk of the current and future irrigated acreage. The NRCS data generally supports and is very similar to data collected by the USBR. The NRCS soil survey narrative indicates that groundwater was much shallower in the survey area prior to about 1870. Evidence in soil profiles indicate shallow groundwater was present in vast areas of the floodplain, and in relict basin lands surrounding the floodplain. Water tables were probably shallower than 10 feet over much of the survey area prior 1900. Since the advent of upstream irrigation diversion, dams controlling floodwater, and the extensive groundwater pumping in the reservation, the groundwater table has been lowered to depths ranging from about 50 feet to over 100 feet below grade in the interior of the reservation[(1)]. One deep boring drilled in 1996 by Reclamation drainage crew's encountered groundwater at about 29 feet below ground surface. None of the other 7 borings drilled encountered any evidence of groundwater or capillary fringe conditions above a depth of 40 feet. The GRIC water use plans call for continued use of ground water and a gradual draw down of the static water table. Stabilization of groundwater levels at roughly 200 feet may occur as gradients to off reservation aquifers are reduced, and project pumping comes into balance with recharge and off reservation subsurface flows.

The NRCS soil survey of the area indicates the most common soil series on the relict basins is the Casa Grande soil. This soil comprises over 50,000 acres of land in the irrigation areas. The typical soil profile of this soil indicates that salts have been leached to an ECe level of less than 4 ds/m near the soil surface to about 16 ds/m at a soil depth of 11-18 inches however below this depth the profile has a salinity of about 25-29 ds/meter to a depth of 60 inches. These values agree very well with the values found at the 43 USBR deep boring sites.

## Project Water Management Planning Data Summary.

Current groundwater quality and depth conditions as well as future water management plans, were estimated from data contained in the Draft Gila River Indian community water management plan[(1)]. A summary of data presented in the draft water management plan, and considered in this paper, is as follows:

1. Depth to groundwater 50-100 feet below ground surface
2. Average groundwater salinity 1200 mg/l range 500- over 2500 mg/liter
3. Average surface water salinity all sources 860 mg/l
4. CAP water salinity 550 mg/liter, expected to increase by 15 percent.
5. Groundwater pumping will increase to about 260000 acre-feet per year, which will draw the water table down over time.
6. The average recharge of the Gila river to GRIC aquifers is estimated at 44000 af/year
7. Conveyance efficiency 90 percent
8. On farm efficiency 70 percent
9. Leaching Fraction 25 percent

10. Safe yield of aquifers 157000 af/year.
11. Full water allocation 653,492 af/year
12. Water applied per acre is about 5-acre feet/year on irrigated land.
13. Total project development limited to 130000 acres due to water supply issues.
14. Irrigation application uniformity goal is 80 % plus.
15. Deep percolation from irrigation will reach the water table within 3-6 years.
16. Salt movement to the water table will be somewhat slower about 6-12 years.

**<u>Anticipated Post Irrigation Soil and Vadose Zone Salinity curve</u>**

The calculations presented below were used to determine the average salinity of water infiltrating the soils. Infiltrated Water ECe determination assumptions:

3 feet of surface water at Eciw 1.34 ds/m
2 feet of groundwater at ECiw 1.88 ds/m
0.5 feet of rainwater at ECe 0.0 ds/m
Weighted average water quality 1.41 ds/m

The post irrigation development salinity curves are based on the following assumptions:

The leaching fraction will be about 25 percent of applied water
The salinity of CAP water will be about 0.85 ds/m.
The survey areas rainfall is about 8 inches per year of which 6 inches infiltrates the soil and is available for crop use and leaching.
Lands are irrigated with 60 percent CAP water and 40 percent groundwater.
Salts in soil water will be at equilibrium with drainage waters.
No dissolution or precipitation of gypsum or carbonate salts in soil or vadose zone.
Deep percolation from irrigation and rain is equal to 25% of applied water or roughly 163,000 acre feet / year. A portion of this deep percolation will flow beyond the reservation boundaries since current groundwater gradients are generally indicate subsurface flows to the northwest and north. As the reservations groundwater levels are drawn down these gradients should decrease which would in turn reduce the volume of these flows.

The time for the vadose zone to come to equilibrium with the new project irrigation development is estimated at 5-20 years; however the project soils to a depth of 6 feet below grade should be near dynamic equilibrium within five years of initial irrigation development. Based on a leaching fraction of 25 percent, the ECe of the vadose zone water below a depth of about 6 feet should be equal to the weighted average ECe of the infiltrated irrigation plus the rainwater divided by the leaching fraction. (1.41/ 0.25 or about 5.6 ds/m) This ECsw should extend down the water table at an estimated depth of 200 feet. The equivalent ECe would be roughly half of the ECdw or about 2.8 ds/m.

Since plants extract nearly pure water from root zone soils and leave behind most of the soluble salts, soil salinity should increase successively from a depth of 1-6 feet as plants use less water from the soil. The most commonly assumed plant water use pattern assumes plants extract 40 percent of their water from the top foot of soil, 30 percent from the second foot of soil, 20 percent from the third foot of soil, and about 10 percent from the fourth foot of soil. Soil waters moving up from the $5^{th}$ and 6 th foots also are used by plants, however under irrigated conditions very little water is used below the $6^{th}$ foot. This analysis also assumes some water use in the 4-6 foot zone based on measured ECe and chloride levels at the 4-6 foot depth on the Maricopa field station and other local irrigated fields. Once the percolating waters and salts reach a depth of 6 feet they enter what is commonly referred to as the vadose zone. This zone extends to the water table.

Based on the water extraction pattern presented above and a leaching fraction below the root zone of 25 percent, the equivalent leaching fractions for the root zone and vadose zones, and the estimated soil salinity levels following irrigation development are listed below.

**Table 4 Salinity conditions – post irrigation development**

| Soil depth | percent LF | Soil Salinity (Ecsw ds/m) | Soil Ece ds/m |
|---|---|---|---|
| 1 foot | 65 | 1.66 | 0.83 |
| 2 foot | 55 | 2.56 | 1.28 |
| 3 foot | 45 | 3.13 | 1.57 |
| 4 foot | 30 | 4.70 | 2.35 |
| 5 foot | 27 | 5.22 | 2.61 |
| 6 foot | 25 | 5.64 | 2.82 |
| vadose | 25 | 5.64 | 2.82 |
| wt depth | 25 | 5.64 | 2.82 |

LF = leaching fraction
CAP water /Groundwater, blended at 60-40. Adjusted for 6 inches of rainfall infiltrating soil. Ec 1.41 ds/m

**Pounds of salt subject to leaching**

An estimate of the weight of salts in the top 17.1 feet of soil can be calculated for both the basin rim lands and the fan- terrace lands. The following assumptions were used for this estimate:

One acre foot of soil weighs 4 million pounds. (bulk density 1.47 grams/cc)
The average saturation percentage in substrata materials is 30 percent. (Sandy loam)

Relict basins Calculation:

Average Ece 25.1 * .64 = 16064 parts per million saturation extract
Parts per million soil Dry weight basis = 16064 * .30 = 4819 ppm soil
Salts per acre foot of soil = 4 * 4819 = 19276 pounds per acre foot
Salts per acre = 17.1 * 19276 = 329620 or about 165 tons per acre

Using the same calculations the salts contained in the top 17.1 feet of fan terrace lands is estimated at 66,963 pounds per acre or about 33 tons per acre. Based on an estimated acreage split of 48,000 relict basin lands and 5,000 acres of fan terrace lands the total tonnage of soluble salts available for leaching from newly developed irrigated lands would be about 8.1 million tons.

## **Salinity interactions in the Vadose zone**

Below a depth of about 17 feet the salinity of the substrata drops off dramatically. The salinity of the substrata below this depth should be related to the salinity content of the groundwater that was withdrawn from the aquifer materials. Based on limited upper vadose zone data the salinity level of the aquifer materials between 17.2 feet and 200 feet are estimated at 1ds/m. The low salinity associated with this thick vadose zone interval creates a large salt storage zone. The difference in the anticipated Ece under irrigation (2.82 ds/m) and the current ECe (1.0 ds/m) will permit the storage of a large mass of salts. These salts will be leached from the upper saline soil zones above 17.2 feet as well as from salts in the irrigation waters. The total estimated salt storage capacity in this zone is equivalent to an ECe of about 1.8 ds/m or a percent soluble salt content of about .035 percent or 1400 pounds per acre-foot. The total salt storage anticipated in the 17-200 foot zone is estimated at 183 feet * 1400 pounds/ foot = 256,200 pounds or about 128 tons per acre. Since the top 17 feet of soil and substrata will also contain some residual stored salts, about 10 tons. The total anticipated salt storage in the soil and vadose zone under the newly developed 53,000 acres would be about 7.3 million tons. This leaves a net salt outflow to groundwater prior to dynamic equilibrium conditions of about 8.1 million tons – 7.3 million tons = .8 million tons of salt. The six attached graphs depict the general soil and substrata salinity conditions before irrigation development and after dynamic equilibrium conditions are reached.

## **Definitions**

Vadose Zone- The substrata zone between the root zone and the saturated zone (water table). Water in this zone is not concentrated due to the evapotranspiration process.
ECe- electrical conductivity of the soil saturation extract.
ECsw- electrical conductivity of the soil water.
ECdw- electrical conductivity of the drainage water.
ECiw- electrical conductivity of the irrigation water.
TDS mg/liter = total dissolved solids = Approximately equal to the ECe in ds/m times 640.

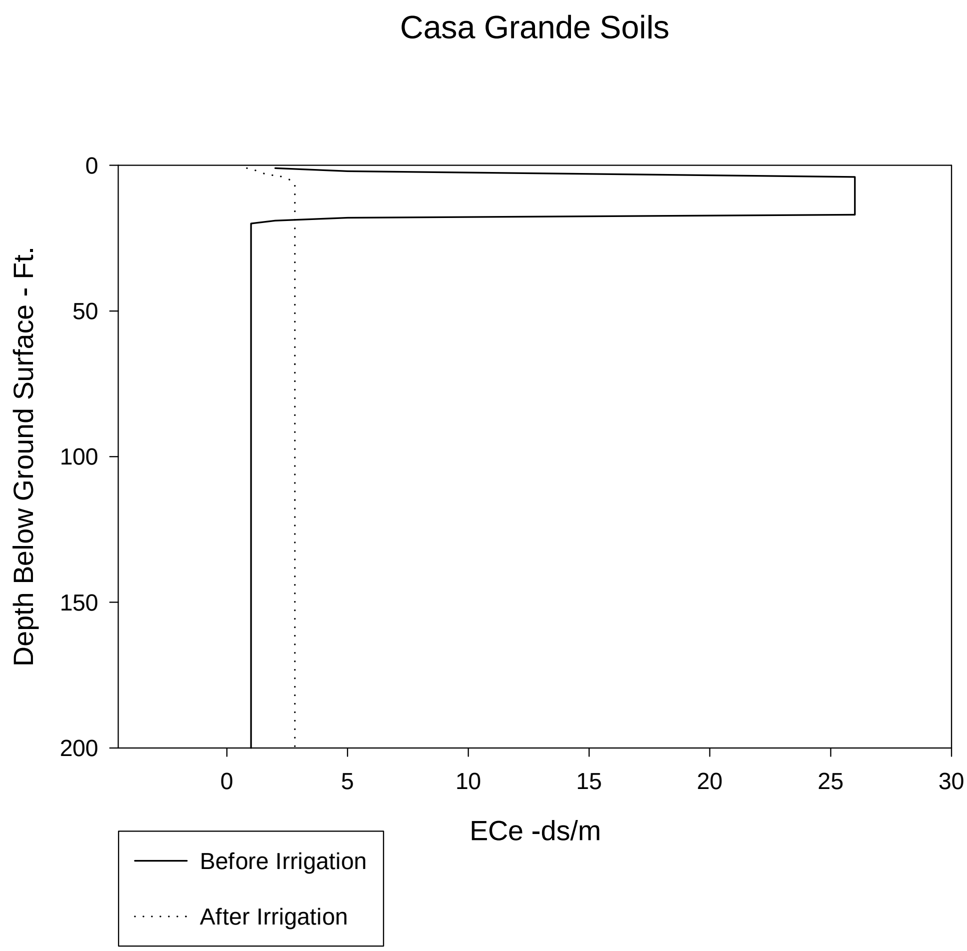
## References


**(1)** Gila River Indian Community Draft comprehensive Water Management Plan, Keller- Bliesner Engineering, LLC, Associated Earth Sciences, INC, Northwest Economic Associates, August 10, 2001.

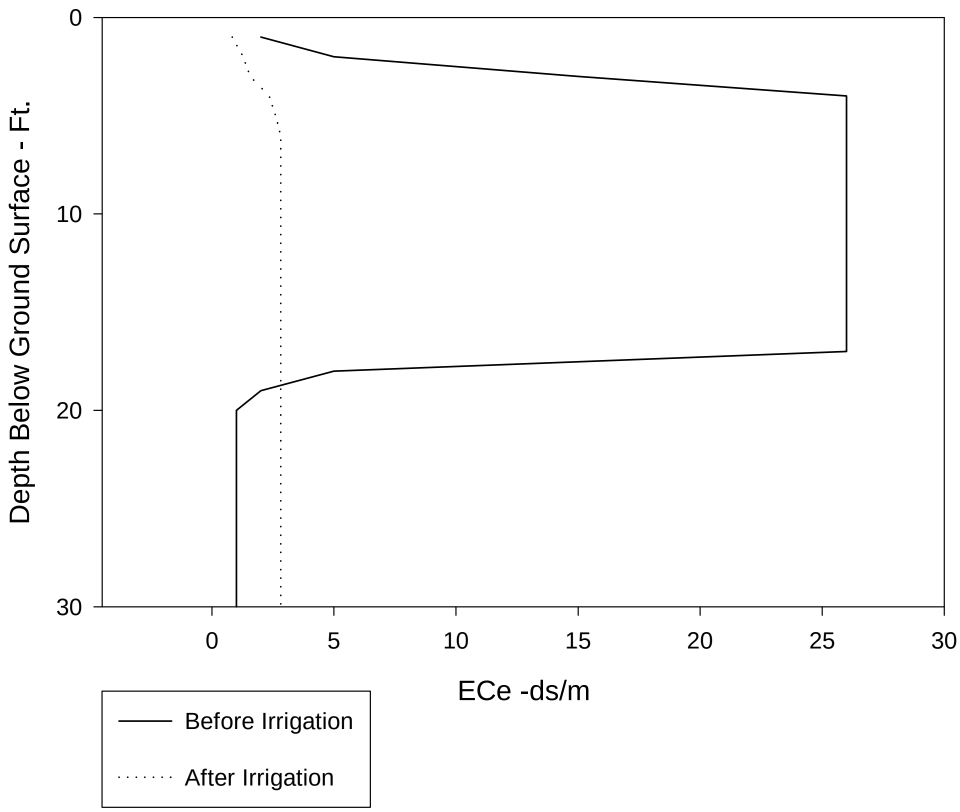
**(2)** Land Class Parameters, Gila River Indian Community, Pima Maricopa Irrigation Project, Ecoplan Associates, October, 1998.

**(3)** Soil survey of Gila River Indian Community, Arizona, Parts of Maricopa and Pinal Counties, USDA, NRCS, no date. Fieldwork in 1986.

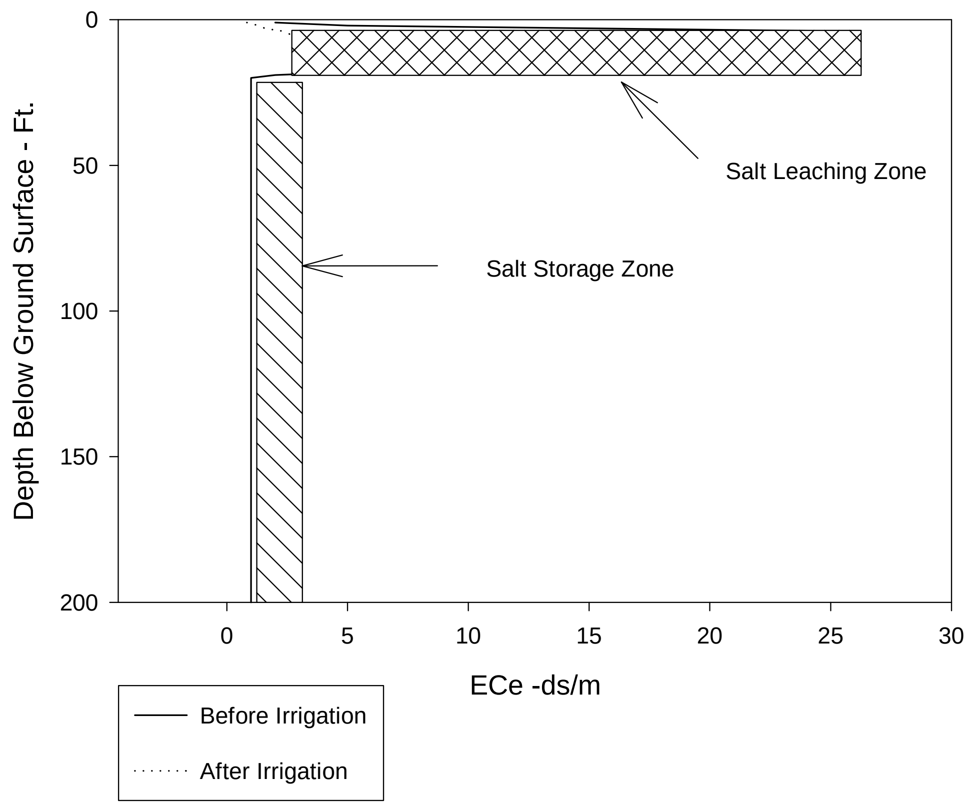
**Attachment 1 - Representative soil salinity curves for before and after irrigation conditions.**



Casa Grande Soils



Casa Grande Soils



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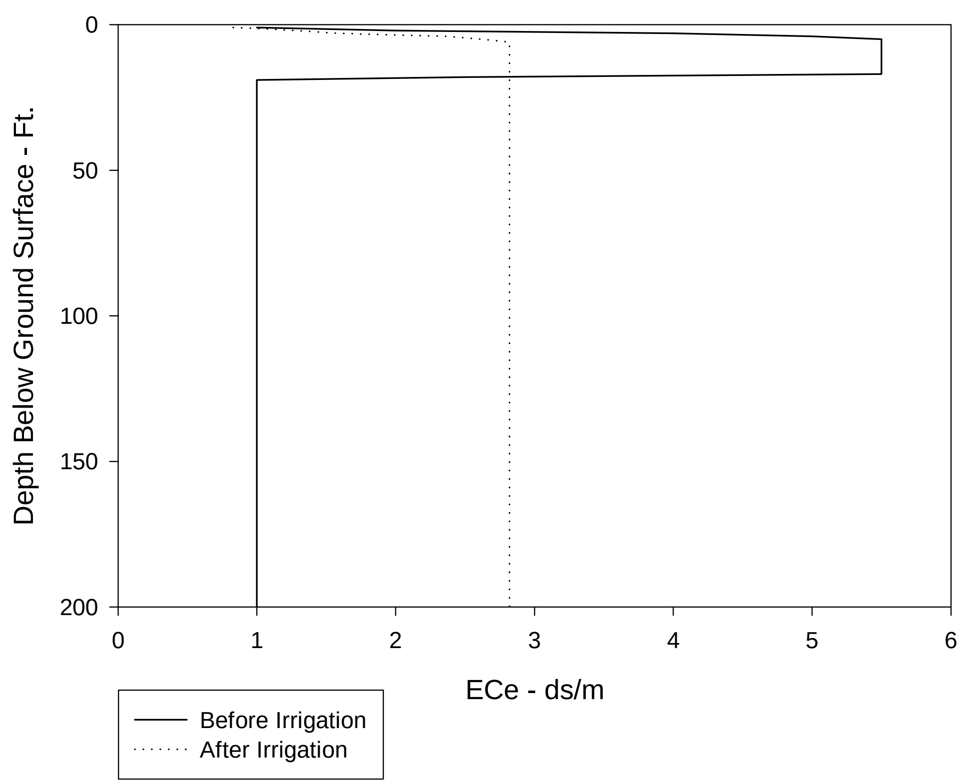

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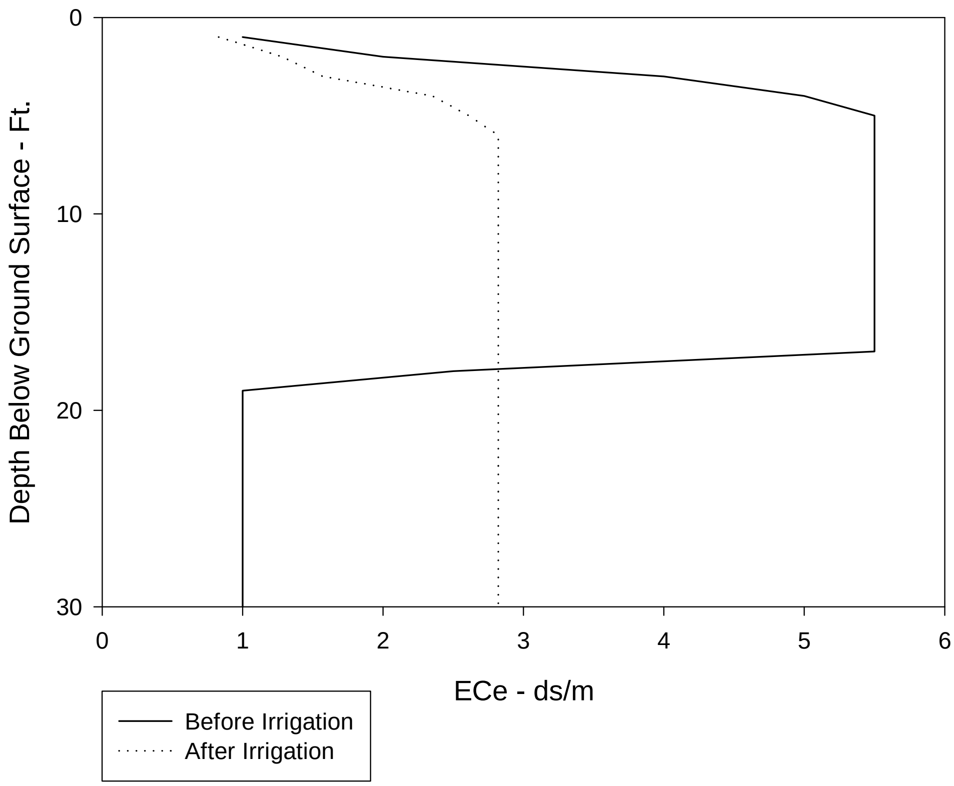

Denure Soils