State Water Resources Control Board
Hearing Name IID Transfer - Phase 1
Exhibit: 2
For Ident: _____ In Evidence: _____

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STATE WATER RESOURCES CONTROL BOARD

STATE OF CALIFORNIA

IMPERIAL IRRIGATION DISTRICT and SAN DIEGO COUNTY WATER AUTHORITY,

Petitioners.

STATEMENT OF EXPERT QUALIFICATION AND WRITTEN TESTIMONY OF DR. WOLDEZION MESGHINNA IN SUPPORT OF IID-SDCWA JOINT LONG-TERM TRANSFER PETITION

WRITTEN TESTIMONY OF DR. WOLDEZION MESGHINNA

1. My name is Dr. Woldezion Mesghinna and I am the president and principal engineer of Natural Resources Consulting Engineers, Inc. ("NRCE"), an international civil, environmental, and water resources consulting firm. Though we have offices in Eritrea (Africa), California, and New Mexico, our main office is located in Fort Collins, Colorado, at 131 Lincoln Avenue, Suite 300.

2. I have my doctorate in Irrigation & Drainage Engineering, and a master's degree in Civil Engineering. I have over 31 years of experience in civil, irrigation, and water resources engineering work in the U.S. and overseas. Copies of my Curriculum Vitae and that of my associate Dr. Assad Safadi, who was my chief assistant on the Imperial Irrigation District ("IID") project discussed below, are attached to this testimony as Exhibit "A." They accurately reflect our expert qualifications and are incorporated herein. Our most recent work product is an extensive report on IID water use entitled, "Assessment of Imperial Irrigation District's Water Use" ("Water Use Report"). A true and accurate copy is attached to this testimony as Exhibit "B," and is incorporated herein. The following testimony is provided under oath, as specified at the end of this document.

3. The purpose of my testimony is to provide the State Water Resources Control Board ("SWRCB") and its staff with a summary of the research and opinions developed by myself and NRCE under my supervision, as stated in more detail in the Water Use

Report and in our earlier report on IID water conservation entitled, "History of Water Conservation Within the Imperial Irrigation District," a true and correct copy of which is attached as IID Exhibit "3" and is incorporated herein ("Water Conservation Report"). Both the Water Use Report and the Water Conservation Report represent NRCE's analysis and opinion of IID water use and water conservation history. I will be present at the hearing to answer any questions the SWRCB might have concerning NRCE's work or opinions.

4. This testimony is organized by first presenting a short review of our engagement with IID, along with a summary of our conclusions, and then the general basis for our conclusions. Of course, the full text of my testimony and opinions is in the Water Use Report and the Water Conservation Report, with only the highlights touched on here.

A. GENERAL PROFESSIONAL BACKGROUND

5. Though the attached Exhibit "A" document details the professional qualifications of both NRCE and myself, it may be helpful to the SWRCB for me to quickly summarize such here.

6. I received my doctorate in Irrigation and Drainage engineering from Utah State University, and I have a master's in Civil Engineering (Hydrology and Hydraulics) from Cornell University, as well as a bachelor of science in civil engineering from Cornell. I am a registered professional engineer in four states (California, Colorado, Wyoming, and Arizona).

7. I have extensive experience analyzing water resources issues, and testifying about such issues for many clients. Though the projects I have worked on are voluminous and are

detailed more fully in my attached Curriculum Vitae, some sample projects include: testimony on behalf of the Bureau of Indian Affairs and the U. S. Department of Justice in the Bighorn River system adjudication in Wyoming; testimony regarding the Yakima River tributaries in Washington; testimony for the U.S. Department of Justice regarding the lower Colorado River and the quantification of Indian water rights; testimony for the U.S. Department of Justice for general stream adjudications on numerous streams in Arizona, and I have been designated as an expert witness on various river basins in New Mexico, California, Washington, Nevada, Montana, Idaho, and Utah; water hydrology studies for numerous water rights holders across the West; development of water use plans for various irrigation projects; and operational management analysis of various river basins in the Western United States.

8. I formed NRCE in 1989, and since that time it has become a large and accomplished engineering firm focusing on water use issues. Our professional staff consists of 30 persons, five of whom have doctorates, and most of whom have various degrees and/or licenses in engineering fields. The attached Exhibit "B" Water Use Report lists our staff on page 6 of Appendix 1.

B. <u>NRCE'S ENGAGEMENT WITH IID</u>

9. NRCE was engaged by IID for two main purposes during two different time periods. First, in 1998 NRCE reviewed IID's water conservation history and prepared the Water Conservation Report. That report is summarized later in this testimony.

10. Then, over the past three years, NRCE reviewed IID's agricultural water use and irrigation efficiency. Our study involved extensive review of: (a) voluminous IID data, both from IID and other sources such as the Bureau of Reclamation; (b) other scientific studies of IID made in differing periods; (c) IID's delivery and on-farm systems; and (d) other irrigation districts located in the Lower Colorado River Basin. Additionally, NRCE did its own extensive IID fieldwork in 2000. The final product of our work is the attached Exhibit "B" Water Use Report, which includes our professional opinions on IID water use and is incorporated herein.

11. In total, between our work on the Water Use Report and the Water Conservation Report, NRCE utilized about 13,000 professional man hours to develop a comprehensive overview of IID's water use and conservation history, and to determine whether IID's water use was reasonable and beneficial. We not only reviewed all of IID's applicable records and did our own fieldwork, but we also reviewed and analyzed over 100 applicable professional publications and reports in completing our research.

C. **NRCE WATER USE REPORT**

12. NRCE performed a detailed analysis of IID's water supply, demand, delivery systems and irrigation, using records from 1988 to 1997 as well as a comparative water use study of several other irrigation districts located within the Southwest and the Lower Colorado River Basin. We also conducted our own field evaluation in 2000. The 1988 to 1997 study period was the most recent 10-year period with complete and extensive data

available when we commenced the scope of work encompassed in the Water Use Report.

13. Our conclusions about IID's water use are predicated upon a number of factors, the most important of them are summarized here:

a) During the study period (1988-1997), IID's on-farm efficiency averaged 83%, while its overall efficiency was about 74%. In other words 83% of the water delivered to the headgates of farmers was used for crop evapotranspiration (ET), leaching, and other crop production uses. The California Department of Water Resources (DWR) assumes that California's statewide on-farm irrigation efficiency will be 73% by the year 2020 and could reach 80% through better irrigation management and improved facilities (DWR 1998). The irrigation efficiency of IID has thus already surpassed the State's future efficiency estimate, 20 years ahead of time. To attain such irrigation efficiency, IID growers often apply lower amounts of water than they really need, thus limiting tailwater, but also accepting lower yields.

b) The irrigation efficiency of IID is so high that even other irrigation projects that are served by some of the most technologically advanced irrigation systems, including drip irrigation, exhibit only about the same level of irrigation efficiency. To the extent that water loss occurs in IID, it is generally justified as a corollary to farming in a hot climate with heavy cracking soils.

c) IID's average conveyance and distribution efficiency from 1988 to 1997 was determined to be approximately 89%. In other words, about 11% of the water diverted by IID from the Colorado River was lost to evaporation and unrecovered seepage and spills rather than being delivered to farm headgates. The 89% conveyance efficiency is high, especially given the size of IID's irrigation project and the complexities of its water distribution system.

d) Tailwater is a vital and necessary component of Imperial Valley irrigation. The cracking nature and low permeability of the majority of IID soils, and the fact that growers have to attempt to apply adequate irrigation water on the entire field, result in tailwater at the tail end of the field. In fact, due to the low permeability of the heavy cracking soils in IID, it is often difficult to adequately leach salts from the soil during regular irrigation applications. The nature of most of IID's soils requires more leaching water than stated in traditional leaching formulae, which equations are more applicable to non-cracking soils. Though both horizontal and vertical leaching occur during regular irrigation, only a portion of the salts in the soil are leached at such time, while the remaining portion remains in the root zone, thereby requiring additional leaching between crops.

e) When irrigation water is applied at the head of the field, it picks up salts from the soil as it moves to the lower end of the field. Based on field studies, it was determined that the salinity of the tailwater is about 30% higher than the water delivered at the head of the field, which indicates significant horizontal leaching is taking place in IID because of the nature of its soils.

f) During regular irrigation on IID's medium and heavy soils, based on field tests, only 4.5% of the applied water drains vertically, removing about 30% of the salt introduced by the irrigation water, while about 17% of the applied water ends up as tailwater that removes approximately 22% of the salt introduced by the irrigation water. This leaching process is compounded by the fact that the Colorado River, by the time it reaches IID, contains significantly increased mineral salt concentrations. Excess salts in light soils are more easily removed than salts in heavy cracking soils, such as those found in IID, because the permeability of the light soils is adequate for vertical leaching.

g) On many IID farms with medium and heavy cracking soils, it would be wise for growers to apply even more water during irrigation for leaching and crop consumptive use purposes than they currently do, because this would increase crop yields. However, since higher water application could result in higher tailwater, growers tend to apply barely enough water for crop use and for partial leaching of salts. As a result of insufficient leaching, some of the irrigated fields in IID, especially the lower end of those fields, become too saline for high crop production, thus decreasing the productivity of valuable acreage.

h) Based on field studies, during which the three processes of leaching for cracking soils (vertical leaching during crop irrigation, leaching irrigation between crops, and horizontal tailwater leaching during crop irrigation) were looked at, it was determined that approximately 0.73 acre-feet per acre is used for leaching on an annual basis. The leaching requirement for light soils was estimated to be about 0.58 acre-feet per acre per year. About 87% of IID irrigated lands have limited permeability in the root zone, while the remaining 13% are light soils.

14. Based on the above results and the other matters addressed in our report, it is our opinion at NRCE that the overall irrigation water use in IID at the present time is reasonable and beneficial. Despite its unique environmental conditions, IID has one of the highest on-farm irrigation efficiencies relative to the other irrigation districts served by the Lower Colorado River, and has a higher on-farm irrigation efficiency than the assumed expected efficiency by the State of California for the year 2020. Though IID has been criticized by some for its water use, in NRCE's opinion, such criticisms are

uninformed and unwarranted. A well studied look at IID's water usage evidenced that IID and its growers manage reasonably well in difficult environmental circumstances, and in fact could justify using more water for leaching and crop consumptive use than they currently utilize.

15. The following summary chart from the U.S. Bureau of Reclamation statistics (1990) showing comparative distribution system efficiencies illustrates IID's distribution efficiency relative to the other irrigation districts in the area:

Irrigation Project	Irrigated Area (Acres)	Distribution System Efficiency
Welton Mohawk IDD	60,324	90%
Imperial Irr. District	463,030	89%
Coachella Valley Water District	61,052	87%
Yuma Valley Division	45,761	73%
Salt River Valley	54,174	40%

16. It is obvious from the above statistics that despite having to irrigate about eight times more acreage than the other districts listed, and having a much older canal infrastructure than most, IID does better than almost all of them, and is within 1% of Wellton Mohawk. Further, even though the Coachella Valley Water District ("CVWD") has extensive buried pipelines in its conveyance system, IID still has a higher distribution efficiency.

17. Our general methodology in reaching the above conclusions as to the reasonableness of IID's water use can be briefly summarized as follows:

a) In evaluating IID's water use, we considered all inflows and outflows for IID, including measured inflows of the Colorado River diverted from the All-American Canal. We also measured inflows entering IID from Mexico, estimated minor inflows due to subsurface and local runoff, reviewed all measured outflows, and estimated minor subsurface and surface inflows into the Salton Sea. In addition, all the non-agricultural consumptive uses in IID were estimated. IID consumptive use was determined based on this information.

b) IID's water use was first analyzed by NRCE using the water balance method. A volume balance analysis was performed for the entire District as a system-wide unit, as well as two subsystems that include the conveyance and distribution level subsystem and the on-farm level subsystem. The primary objective in the water balance method approach is to estimate the total water consumptive use. This method is appropriate for the Imperial Valley because of the Valley's unique physical setting and hydrogeologic conditions as a closed basin.

c) Determination of the IID on-farm and overall irrigation system efficiencies required examination of irrigation water beneficially used. There are various uses of irrigation water that are beneficial in addition to directly satisfying crop water consumption demands. In IID, other beneficial uses of irrigation water include seedbed and land preparation, germination, cooling, and leaching for salinity control.

d) Development of realistic leaching estimates for IID required a detailed soil analysis, both from documentary records and in person. It also necessitated analyzing salt levels in the water, as well as reviewing climatic conditions and general farming practices. For the majority of soils in IID, given the characteristics of the soil water movements and the low permeability of the cracking soils, we concluded that the conventional leaching formulas are not applicable. The salinity of IID's water, coupled with the nature of its soils, requires higher amounts of leaching water than traditional formulae for non-cracking soils would conclude.

e) Our conclusions about the difficulties of salt leaching in IID are in accord with the majority of professional literature about agriculture in IID. To the extent we differ from some critics of IID, such as Dr. Marvin Jensen, it is with good cause. As explained in detail in Appendix 9 of our Water Use Report, Dr. Jensen made certain assumptions that did not account for leaching in medium and heavy cracking soils and changes in irrigation water salinity, which ultimately negated his conclusions.

18. In addition to our analysis of IID's water use, we also reviewed whether or not a proposed transfer of up to 200,000 acre-feet to the San Diego County Water Authority ("SDCWA"), with the corresponding change in place of diversion from Imperial Dam to the upstream Lake Havasu, would adversely affect other legal users of water.

19. We reviewed the historic water use of all Colorado River appropriators downstream of the Colorado River Aqueduct and above Imperial Dam, as well as the effect of a 200,000 acre-foot per year reduction on the All-American Canal. After reviewing all the data, we determined that at all times during the 10-year study period (1988-1997) there was sufficient hydraulic head at all diversion structures to deliver their normal capacity. We thus determined that IID's proposed transfer of 200,000 acre-feet of conserved Colorado River water to San Diego would have no meaningful adverse impact on other water right holders downstream of the proposed Lake Havasu diversion.

20. In recent months IID and various other water agencies have worked out an additional water transaction in which a potential 100,000 acre-feet per year might go to CVWD and/or MWD. Though our initial study did not include such a recent transaction, we were later asked by IID to determine if there would be any impact to other legal users of water if some or all of that 100,000 acre-feet per year were to go to CVWD. Based upon all of the work we performed, the answer is clearly that there would be no impact on other legal users of water. All Colorado River water that currently flows to CVWD does so via IID's diversion at Imperial Dam, and it is not until the water

has traveled some miles down IID's All American Canal that CVWD water is diverted into the Coachella Canal. To the extent that IID diverts more water into the Coachella Canal and lets less flow on into IID, this does not affect any other Colorado River users. We were not asked to express an opinion on whether or not a diversion to MWD of up to another 100,000 acre-feet per year into the Colorado River Aqueduct would adversely affect other Colorado River water right holders, and we understand that MWD would not receive any water under the proposed settlement unless CVWD first declined it.

21. The following is a very short summary of our hydrology work, and our Water Use Report provides the detailed hydrology:

a) U.S. Bureau of Reclamation data was used as a basis for determining the various users and their diversion and return amounts in the reaches of the Colorado River and the All American Canal.

b) The study period from 1988 to 1997 was selected so there would be flow variations representative of the long-term conditions in the study area. It was important for the study period to include extreme years of low river flows since further reduction of river flow in low flow conditions may deplete the water supplies of some of the river users. The historical flow records from 1935 to 1997 show that the lowest Parker Dam annual release (5,533,851 acre-feet) was in 1993 and is thereby covered in the study period.

c) NRCE's flow adequacy analysis shows that during the 10-year study period there was sufficient water in the system to meet all the demands of the other water right holders even though the Colorado River supply was hypothetically reduced by 277 cfs for the IID water transfer. The results of the hydraulic analysis indicate that the reduction in flow would not hydraulically affect the deliveries of the normal historical diversions through the various turnout structures along the Colorado River and the All-American Canal. Hence, NRCE has determined that the transferring of IID's conserved water to San Diego has no meaningful impact on the other water right holders with respect to supply and hydraulics.

D. **NRCE WATER CONSERVATION REPORT**

22. In addition to the Water Use Report, NRCE earlier performed a review of IID's conservation history, the Water Conservation Report, which is IID Exhibit "3," and which contains our research and opinions regarding IID's past conservation. The purpose of this analysis was to review the conservation history in IID, determine how much water conservation had been achieved to date, and prepare for the more extensive Water Use Report. It was a reconnaissance-level review, as opposed to the more extensive water use analysis that was to follow. Nonetheless, we believe it will be helpful to the SWRCB in its hearings related to the proposed water transfer from IID to San Diego, and acquisition by CVWD.

23. Here is a short summary of what we found in our review of IID's conservation history, all of which is explained in more detail in our report:

a) IID's current irrigation technology and conservation programs include concrete canal and ditch lining, laser precision land leveling (where applicable), regulating reservoirs and interceptor canals, seepage recovery programs, tile drains, and automated delivery systems.

b) By the mid-1980's, IID farmers had lined 80% of their ditches with concrete; today over 90% of the ditches are lined. Ditch lining conserves water by reducing seepage and it gives farmers more control over the amount of water delivered to the fields. However, the cost to IID farmers is roughly $192 million[1] for the 2,600 miles of farm head ditches.

c) In order to keep the water table below the root zone and allow for critical leaching to take place, IID farmers have installed about 34,000 miles of tile drains. Tile drain installations have collectively cost IID farmers at least $224 million in present day dollars.

d) In certain areas where it can be effective, IID farmers have spent $150 million[2] on initial land leveling, and spend $30 to $60 per acre on leveling touch-ups every three to five years.

e) Typically, farmers spend as much on water management labor as they do to purchase water.

[1] Using 1998 costs.
[2] Using 1998 costs.

f) Some IID farmers have also been able to invest in techniques such as ponding water on the tail of a field during land preparation; controlling furrow inflow and outflow to reduce tailwater runoff; reusing tailwater; sprinkler and drip irrigation; and deep tillage. However, these methods are generally costly and are not necessarily suited to all soils, parcels, and/or crops.

g) IID has made significant improvements to its automated delivery system, appointed a Water Conservation Advisory Board to make recommendations regarding water conservation, and has installed several tailwater recovery systems. IID also provides zanjero and hydrographer training at Cal Poly San Luis Obisbo, requires certification of all farmers handling IID irrigation deliveries, and in the past 15 years has commissioned or participated in numerous studies of potential water conservation.

h) When IID found that two areas of its major canals had sandy soil, it spent $495,000 to install recovery drains in those sections. The recovery drains pump seepage water back into the canals and collectively conserve 24,000 acre-feet of water annually.

i) IID has lined over 1,169 miles[3] of its canals.

j) IID built four regulating reservoirs at a cost of $3 million. The purpose is to capture excess water that a farmer has ordered, so it does not have to spill out of the canal; instead, it is stored in a regulating

[3] This includes the 200 miles lined under the 1988 MWD Agreement.

reservoir. The savings from these four reservoirs amounts to roughly 18,000 acre-feet of water per year.

k) In order to prevent aquatic weeds from clogging drains and canals, IID raises and introduces 20,000 sterile weed-eating Triploid Grass Carp into the All-American Canal each year.

l) With MWD's funding, IID has successfully implemented numerous conservation measures. For example, IID lined an additional 200 miles of canals, conserving 26,000 acre-feet of water in 1997; replaced wooden headgates with non-leak metal ones; and constructed six regulating reservoirs to capture excess canal water, two of which collectively conserved 9,700 acre-feet of water in 1997. Additionally, as part of the MWD program: (1) IID built a Water Control Center to house its Supervisory Control and Data Acquisition System ("SCADA"). The SCADA system monitors flows and water levels in the major canals and reservoirs and allows remote operation of 95 water control structures (i.e. delivery gates and main canal gates) to decrease canal spills and provide more efficient water deliveries; (2) IID constructed three interceptor canals. An interceptor canal catches excess lateral water that would otherwise spill into a drain. The interceptor carries the excess water to a regulating reservoir, where it can be used to meet deliveries. In 1997, two of these interceptor canals conserved 6,650 and 8,460 acre-feet of water, respectively; (3) as a result of increased technology and water system upgrades, IID farmers can now order water in 12-hour time blocks. This system not only provides farmers more flexibility, but it also helps farmers conserve water by encouraging them to more accurately match their water orders to existing soil and crop needs; and (4) IID constructed twenty-five tailwater recovery systems. These systems collect tailwater from small field reservoirs and pump the water back to the head of the field.

m) IID participates in federal and state conservation programs. For example, IID supports the California Irrigation Management Information System ("CIMIS"). CIMIS' automated weather stations collect temperature, solar radiation, humidity, and wind speed data, which are used to estimate crop evapotranspiration. IID has also provided irrigation scheduling workshops and has participated in a number of irrigation research projects at the Imperial Valley USDA Irrigated Desert Research Station. IID has supported the USDA Natural Resources Conservation Service and has funded conservation-related research programs through the University of California Cooperative Service.

24. The above summaries of NRCE's work really just give the barest outlines of our analysis. I urge the SWRCB and its technical staff to read the NRCE reports, particularly the Water Use Report, to fully understand our opinion that IID is irrigating efficiently in difficult circumstances, and is thus reasonably and beneficially utilizing its water rights.

I declare under penalty of perjury under the law of the state of California that the foregoing is true and correct. Executed on March 21, 2002, at Fort Collins, Colorado.

DR. WOLDEZION MESGHINNA

Woldezion Mesghinna, Ph.D., P.E. *President and Principal Engineer*

Education

Ph.D., Irrigation & Drainage Engineering,
Utah State University; Logan, Utah; December 1978

M.E., Civil Engineering (Hydrology & Hydraulics),
Cornell University; Ithaca, New York; May 1973

B.S., Civil Engineering,
Cornell University; Ithaca, New York; May 1972

Professional Registrations

Professional Civil Engineer, California, #C-031962, 1980
Professional Civil Engineer, New Jersey, #GE 38267, 1994
Professional Civil Engineer, Colorado, #30081, 1994
Professional Civil Engineer, Wyoming, #PE6787, 1994
Professional Civil Engineer, Arizona, #28952, 1995

Experience

President and Principal Engineer; Natural Resources Consulting Engineers, Inc.; Fort Collins, Colorado; March 1989-Present: Dr. Mesghinna formed Natural Resources Consulting Engineers, Inc. (NRCE) in 1989.

Water Supply Studies

- Comprehensive water supply analysis of several major rivers including the Deschutes, Melotious, Crooked, and Warm Springs, and Shitike Creeks in Oregon. The various impacts of upstream water users on these streams were determined, especially the Deschutes River. The results of this study helped the Warm Springs Tribes craft their negotiated settlement water claims and conduct actual negotiations with the State of Oregon and the U.S. government.
- Quantified the water supply of the Sif Oidak District of the Tohono O'odham Nation in Arizona. This involved the determination of irrigable acreage and water requirements, the investigation of the extent of past floods on reservation areas, and the evaluation of the impact of regional urbanization on flood frequency. The effects of groundwater pumping on the area's aquifers were also determined.
- Evaluated the impact of historic gold mining operations on water quantity and quality on the Fort Belknap Indian Reservation in Montana.
- Carried out operational management of the Wind River watershed in Wyoming including an analysis of reservoir systems, irrigation uses, and fishery water requirements.

- Quantified water requirements needed to restore and maintain historic wetland areas on the Duck Valley Indian Reservation in Idaho. The various water supply sources were analyzed and comprehensive water use plans were studied.
- Studied the irrigation return flow and depletion for the future lands of the Wind River Indian Reservation in Wyoming to quantify an in-stream flow water claim.
- Quantified present and future water uses for the Klamath Allottees Water Users Association and provided advice and counsel in matters relating to the adjudication/negotiation of water rights for the Association.
- Analyzed both surface water and groundwater resources within the Tule River Indian Reservation. This involved a study of the arability of Reservation lands, the determination of the available water supply of the Tule River, and the quantification of the water requirements for both agricultural and nonagricultural water uses.
- Provided technical direction and coordination of the Tribal Water Code development, the development of a river accounting model, and the performance of interim Tribal Water Engineer duties for the Fort Hall Indian Reservation.
- Completed an appraisal-level engineering design for a delivery and recharge facility including costs for a number of alternatives for the San Xavier Groundwater Recharge Project.
- Assessed the natural resources including historic and undepleted surface flows of the Jemez River, alluvial and deep groundwater irrigability of lands, consumptive use of the adaptable crops in the area, and based on engineering and economic feasibility of a comprehensive water development plan, the amount of water the Jemez Tribe would claim under a negotiated settlement scenario was determined.

Irrigation/Agriculture

- Planned and designed the rehabilitation and reconfiguration of the conveyance distribution and drainage systems for the Wind River Indian Irrigation Project and determined the amount of water that could be saved as well as the associated capital costs.
- Designed the Tohono O'odham Nation, Arizona 9B and Avra Valley Irrigation Systems. The suitability of these areas was determined for different types of irrigation systems and the designs of the water conveyance and on-farm systems proposed for the 9B farm were analyzed. Preliminary designs for the water conveyance and distribution systems associated with the irrigable acreage identified in the land classification of the Avra Valley site were developed.
- Completed a comprehensive Aligidir Irrigation Project Development Plan devised for the Gash River near the city of Tessenei, Eritrea. The plan determined a sustained available water supply, the irrigability of lands, an environmental impact assessment, and determined economic feasibility. Sediment traps, a diversion structure; conveyance and distribution systems; and an off-stream dam and reservoir were also planned.
- Completed a scheme for stream flow and climatic network locations within Eritrea and installed and trained local and Water Resources Department of Eritrea personnel to operate and maintain the equipment.

Water Supply/Irrigation Projects

- Measured seepage losses on all selected reaches of major canals on the Wind River Indian Reservation. Surface and subsurface conditions of private ditches were assessed, and a recommendation as to minimizing and/or avoiding water logging problems was made. A list of all irrigation structures in need of replacement or maintenance was prepared and a plan of action was suggested.
- Completed an extensive analysis regarding the available water supply conditions, flood hazards, and the land capability for irrigation purposes within the Fort Mojave and Colorado River Indian Reservations. the ultimate number of practicably irrigable lands under conditions of the 1960's were also determined. Dr. Mesghinna testified extensively in court to defend his findings.
- Performed a multipurpose study of the Tekezze-Setit River Basin. This included the estimation of available water supply, the development of land classification specifications, the location of various dam and reservoir sites along the river, the assessment of proposed irrigable lands, the determination of the criteria for the environmental study, the review of the final study, and the overall coordination of economics, mapping, hydropower, and geotechnical, conveyance, and distribution systems.
- Prepared a comprehensive water development plan for the Navajo, Hopi, and San Juan Southern Paiute Indian Reservations in Arizona. The tasks included determination of the undepleted flow of the Little Colorado River, availability of groundwater within the Coconino and Navajo Aquifers, present and historical irrigation water use determination, future irrigation engineering studies (both appraisal and feasibility level), feasibility-level M&I and recreation water development design and plans; and drainage engineering services. Dr. Mesghinna is presently serving as the technical coordinator of the federal studies pertaining to the adjudication of the Little Colorado River System.
- Analyzed the available surface water supply from the Owyhee River in Nevada and Idaho, specifically, the undepleted flow analysis was determined based on Reservoir operation, determination of the depletion due to agricultural and non-agricultural water uses, return flows, etc. The study was conducted as part of an irrigation and drainage development plan for the Duck Valley Indian Reservation in Idaho and Nevada.
- Acted as a lead engineer for the planning, design, and construction management and supervision of a 230 foot high RCC dam. The project also includes a 15 km long pipeline extending from the dam to the water treatment plant. The pipeline empties into a water treatment plant with a treated water capacity of 2000 m^3 located in the outskirts of Asmara, Eritrea. The entire project is nearing completion and is expected to be commissioned by May 2002.
- Conducted a reconnaissance comprehensive water development plan for the Eastern plains of Eritrea, including land classification for development of irrigation schemes, availability of surface and groundwater resources, investigation of suitable dams and reservoirs, and estimation of capital, operation, and maintenance costs.
- Evaluated the water resources of Rio Acoma in New Mexico, including groundwater and surface water supplies, present, historic, and future water uses for both agricultural and non-agricultural uses, and determination of natural flow of the River at a point near the Pueblo of Acoma.

Supervising Engineer; Stetson Engineers, Inc.; San Rafael, California; 1978-1988:
Dr. Mesghinna supervised hydrologic analysis and water supply investigations; determined agricultural water requirements; and designed irrigation systems.

Water Supply Studies

- Quantified the water resources and potential water requirements of the Fort Belknap Indian Reservation. This involved the development of a feasibility-level irrigation engineering study, the determination of water requirements, and the quantification of natural surface flow for reserved water rights litigation.
- Performed a water availability study of the Upper Missouri River and tributaries using the HEC-4 hydrologic model. This included the simulation of monthly stream flows for missing flow records and ungaged locations and river and reservoir system operation studies.
- Analyzed the reservoir system operation for several operating scenarios on both the Eel and Russian Rivers of California using the HEC-3 hydrologic model.

Irrigation/Agriculture

- Participated in the adjudication of the Big Horn River Systems of Wyoming and the agricultural system development plan including the design of a conceptual irrigation system and associated cost analysis, for approximately 60,000 acres. Also determined future and historic irrigation water requirements for the Wind River Indian Reservation.
- Performed several studies for the Fort Hall Indian Reservation in Idaho in connection with the "President's Water Policy Implementation 10-Year Plan for Review of Indian Water Claims", involving water supply, irrigation water requirements, and related studies. Provided technical assistance to the Tribes in connection with negotiations with the State of Idaho.

Water Supply/Irrigation Projects

- Conducted a surface water depletion study and engineered an agricultural development plan, including conceptual irrigation system design, for the Yakama Indian Reservation in Washington.
- Completed a comprehensive surface water hydrology study, including the determination of natural flow, water quality, and sedimentation, in connection with water rights litigation for the Jicarilla Indian Reservation, and the San Ildefonso, Santa Clara, San Juan, and Taos Pueblos of New Mexico.
- Completed a comprehensive water resource analysis, including hydrological analysis of the various streams and agricultural engineering study as part of the comprehensive water development plan for the Nez Perce Indian Reservation in Idaho.
- Calculated the available water supply for the Jemez River Indian Reservation including the determination of probable maximum flood for the design of a reservoir and spillway. Hydropower feasibility was also assessed .

Engineer; Woodward-Clyde Consultants; Clifton, New Jersey; 1973-1978:
Dr. Mesghinna worked on many projects requiring geotechnical and hydrological engineering evaluation and analysis.

- Analyzed the flooding potential of Sawmill River for the Yonkers City Urban Development Project.
- Investigated and evaluated groundwater resources for the development of groundwater in New Mexico.
- Designed a dewatering system for the installation of a subaqueous tunnel at the LNG Terminal of Cove Point, Maryland.

- Performed well testing and estimated groundwater characteristics for the cooling lake at Braidwood Nuclear Power Station in Illinois.
- Completed subsurface investigation, soil sampling, rock coring, and permeability testing for the Amos Dam of West Virginia.
- Reviewed and evaluated the timber pile foundation design and settlement for various structures located in the meadowlands of the New Jersey Sports Complex.
- Performed temperature-controlled creep load tests on steel pipe piles and designed piles for the Trans-Alaska Pipeline in Alaska.

International Experience

During the period from 1966 to 1970, Dr. Mesghinna was employed in Ethiopia as an engineer in the design, planning, and construction of various school buildings, clinics, and hospitals. These projects were sponsored by the Swedish International Development Authority (SIDA) and the United National High Commission for Refugees (UNHCR). He was first employed as a Site Supervisor for the construction of a school building, then as a District Engineer and Acting Regional Engineer in charge of three building sites. As such, he was responsible for the planning of all operations, supervision of construction, design and product development, contract development and construction agreements, the production of construction cost estimates, and the performance of site investigations and surveys.

Expert Witness Experience

Dr. Mesghinna successfully completed professional witness testimony on behalf of the Bureau of Indian Affairs and the U.S. Department of Justice (DOJ) in the adjudication of the Big Horn River System in Wyoming. His testimony concerned future and historic water requirements and future and historic irrigation system design for the Wind River Indian Reservation. Furthermore, Dr. Mesghinna completed testimony on behalf of the DOJ concerning the lower Colorado River, in which his task was to prove that the U.S. government had properly quantified the Indian reserved water rights in the early 1960's. More specifically, he provided testimony on flood analysis, land classification, and irrigation system selection/design. Dr. Mesghinna served as an expert witness on behalf of the DOJ for general stream adjudications on the Silver Creek, Upper Salt River, and San Pedro Drainage Basins in Arizona; the Walker River Basin in Nevada; the Little Colorado River Basin; the Zuni River Basin in New Mexico; and the San Jacinto River Basin in Southern California. Dr. Mesghinna has been instrumental in several water rights settlement negotiations in the Western United States and has helped to settle water rights claims amounting to more than three million acre-feet. Examples include the Fort Hall, Fort Peck, Warm Springs, Las Vegas Paiute and Fort McDowell Indian Reservations.

Relevant Computer Skills

- Hydrologic Models: Extensive computer programming experience in hydrologic modeling, including:
  - Development and testing of a crop yield prediction model
  - Development of various computer programs for:
    - Crop consumptive use determination
    - Irrigation system design
    - Irrigation pipe network design
    - Subsurface drainage design
    - Canal seepage analysis
    - Natural flow analyses for river basins
- Earned certificates of completion from the Agricultural Extension program of the University of California at Davis for water surface profile computation and flood hydrograph analysis computer programs using HEC-2 and HEC-1.

Awards and Honors

- College of Engineering "Distinguished Alumnus", Utah State University, 1992
- City of Richmond "Distinguished Service Award", Richmond, California, 1993

Languages

- Tigrignia (native)
- Italian
- Amharic

Assad Safadi, Ph.D. — *Senior Vice President*

Education

Ph.D., Agricultural and Irrigation Engineering,
Utah State University; Logan, Utah; April 1991

M.S., Soils and Irrigation,
University of Jordan; Amman, Jordan; February 1987

B.S., Soils and Irrigation,
University of Jordan; Amman, Jordan; January 1985

Experience

Senior Vice President; Natural Resources Consulting Engineers, Inc.; Fort Collins, Colorado; July 1991-Present:

Agriculture

- Identifies suitable crops and cropping patterns.
- Develops models to estimate crop water requirements for over twenty projects in New Mexico, California, Arizona, Idaho, Oregon, Nevada, Utah, and Washington.

Irrigation

- Designs irrigation systems and estimates irrigation efficiencies.
- Designs reconnaissance- and feasibility-level on-farm irrigation systems for Indian water rights cases in Nevada, Idaho, California, New Mexico, and Arizona.

Expert Witness Testimony

- *Testified on behalf of the United States on agricultural water use in Arizona v. Gila River (Arizona, 1995); United States v. Abousleman et al. (New Mexico, 1996 and 1999); and Washington State Department of Ecology v. Aquavella et al. (Washington, 1994).*

Water Resources

- Performs water quality analyses.
- Estimates natural flows and identifies diversion points.

Natural Resources

- Analyzes climatic parameters.
- Soil and land classifications.

Economics

- Economic feasibility analyses.
- Financial analyses/crop budgeting.

Water Rights Litigation

- Project manager on more than one dozen Indian water rights cases.
- Provides technical guidance to federal and Tribal attorneys during water rights litigation and/or negotiation cases.
- Coordinates the technical work among the various government

experts in the *Arizona v. Little Colorado River*; *United States v. Walker River Irrigation District*; *Mannatt v. United States*; and the *Soboba v. Metropolitan Water District* litigation cases.

- Lead technical expert in water rights negotiations for the Pueblos of Jemez in New Mexico, the Owens Valley Tribes in California, the Moapa Paiute Tribe in Nevada, and the Fort Yuma Indian Reservation in Arizona and California.
- Quantifies water claims.

Senior Vice President

- Lead technical negotiation expert for the United States in Soboba v. Metropolitan Water District (California), United States v. Walker River Irrigation District (California and Nevada), and United States v. Abousleman et al. (New Mexico).
- Responsible for delegating and coordinating the work load among the staff members at NRCE's Fort Collins and Berkeley offices.

Post-Doctorate Researcher/Teacher/Research Assistant; Department of Agricultural and Irrigation Engineering, Utah State University; Logan, Utah; January 1988-June 1991:

- Calibrated new crop coefficients for use with the Soil Conservation Service's modified Blaney-Criddle equation for various sites within the State of Utah.
- Lectured on crop yield modeling, development of irrigation scheduling models, and irrigation uniformity/yield interaction for a course on Field Irrigation Management.
- Helped develop computer programs for the calculation of crop evapotranspiration and pattern search techniques for crop coefficients derived from lysimeter research data collected from Utah, Idaho, and Wyoming.
- Worked on climatic data from Somalia.
- Attended and participated in Utah Experiment Station project meetings.
- Installed and programmed automated weather stations.

Teaching and Research Assistant; Department of Soils and Irrigation, University of Jordan; Amman, Jordan; September 1984-February 1987:

- Taught Principles of Soil Science, Fertilizers and Soil Fertility, and Soil Physics Labs.
- Taught on types and amounts of fertilizers to be applied and their application, as well as the analysis of soil and plant nutrients (N, P, K, and micronutrients).
- Demonstrated how to determine the physical properties of soils, reviewed field practices to be used in the calibration of neutron meters, and performed and demonstrated irrigation scheduling using tensiometers as well as various sampling techniques.
- Conducted laboratory analyses of the physical properties of soils (e.g., bulk density, hydraulic conductivity, and soil moisture characteristic curves).
- Conducted field experiments to study the effects of sewage sludge and chicken manure on sweet corn production and heavy metals content in soils and plants.

Relevant Computer Skills

- *Graphics Software:* Grapher, Surfer
- *Statistical Software:* TSP, LINDO
- *Programming Languages:* FORTRAN, BASIC

Languages

- Arabic (native)
- French

Awards and Honors

- King of Jordan "Top of the Class Award", B.S. Degree; University of Jordan, 1985
- King of Jordan "Top of the Class Award", M.S. Degree; University of Jordan, 1987
- College of Engineering "Distinguished Alumnus Award"; Utah State University, 1998

Publications

Safadi, A.S. "Determination of Water Supplied from the Jemez River System and the Nacimiento Creek to meet the crop demand of the Nacimiento Community Ditch Association (NCDA)." *Prepared for the U.S. Department of Justice,* Denver, Colorado, August 11, 1999.

Safadi, A.S. "Determination of Crop Water Requirements and Irrigation Water Requirements of Presently Irrigated Lands: Toppenish, Simcoe, and Satus Creeks Sub-basins, Yakama Indian Reservation, Yakima, Washington." *Prepared for the U.S. Department of Justice,* Washington, D.C., November 28, 1994.

—. "Yakima River and its Tributaries' Depletions, Yakama Indian Reservation, Yakima, Washington." *Prepared for the U.S. Department of Justice,* Washington, D.C., November 28, 1994.

—. "Crop Water Requirements for the Pomerene Water Users Association (PWUA), San Pedro River Watershed, Arizona." *Prepared for the U.S. Department of Justice,* Washington, D.C., September 28, 1994.

—. "Squash and Cucumber Yield and Water Use Models." Ph.D. Dissertation, Utah State University, Logan, Utah, 1991.

—. "Comparison of Water Use Efficiency Under Drip, Sprinkler, and Gravity Irrigation Systems." *Paper Presented to the University of California Cooperative Extension Service,* Holtville, California. 1990.

Safadi, A.S., and Hill, R.W. "Squash and Cucumber Irrigation-Yield Simulation Models." *Paper No. 90-2614 Presented at the American Society of Agricultural Engineers' Winter Meeting,* Chicago, Illinois. 1990.

Safadi, A.S. and Battikhi, A.M. "A Preliminary Study on the Effects of Soil Moisture Depletions Under Black Plastic Mulch and Drip Irrigation on Root Growth and Distribution of Squash in the Central Jordan Valley." *DIRASAT*, University of Jordan, Amman, Jordan. 1988.

Safadi, A.S. "Irrigation Scheduling of Squash Under Drip Irrigation and Black Plastic Mulch in the Central Jordan Valley." M.S. Thesis, University of Jordan, Amman, Jordan. 1987.

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ASSESSMENT OF IMPERIAL IRRIGATION DISTRICT'S WATER USE

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I. INTRODUCTION

Imperial Irrigation District (IID) is a large irrigation district located in the Imperial Valley of Southern California, near the Colorado River and the Arizona border. IID is in charge of ordering and distributing approximately 3.2 million acre-feet of water from the Colorado River every year. IID's irrigation system is large and complex and includes the 82-mile All American Canal (AAC) as well as almost 1,700 miles of other canals, numerous reservoirs, over 1,400 miles of drain ditches, and almost 33,600 miles of tile drains.

The primary objective of this study by Natural Resources Consulting Engineers, Inc. (NRCE) was to evaluate the overall agricultural water uses within IID and determine whether such water uses are reasonable and beneficial. In addition, NRCE evaluated whether the proposed transfer by IID of up to 200,000 acre-feet per year of conserved water to the San Diego County Water Authority (SDCWA) would have an adverse impact on junior water right holders on the Lower Colorado River.

NRCE conducted a detailed analysis of IID's water supply, demand, delivery systems and irrigation, using records from 1988 to 1997 as well as a comparative water use study of several irrigation districts located within the Southwest and the Lower Colorado River Basin. NRCE also conducted its own field evaluation in the summer of 2000.

NRCE has concluded that IID's agricultural water uses are reasonable and beneficial. Despite its unique environmental conditions, IID has one of the highest on-farm irrigation efficiencies relative to the other irrigation districts served by the Lower Colorado River, and has a higher on-farm irrigation efficiency than the assumed expected efficiency by the State of California for the year 2020. According to a United States Bureau of Reclamation (USBR) study conducted in the late 70s, the on-farm irrigation efficiencies for the various irrigation districts in the Lower Colorado Basin ranged from 32 to 78%, and IID had the highest average on-farm efficiency of 78%. NRCE also determined that IID's proposed diversion of 200,000 acre-feet of conserved Colorado River water would have no meaningful adverse impact on other water right holders downstream of the proposed Lake Havasu diversion.

In evaluating IID's water use, NRCE considered the available water supply, water quality, and the major facilities that convey and distribute irrigation water to IID. In addition, NRCE analyzed the water requirements for the various crops grown in the District, taking into account the climate and the agricultural land resources of IID, and IID's delivery system.

IID's water use was first analyzed by NRCE using the water balance method. A volume balance analysis was performed for the entire District as a system-wide unit, as well as two subsystems that include the conveyance and distribution level subsystem and the on-farm level subsystem. The primary objective in the water balance method approach is to estimate the total water consumptive use. This method is appropriate for the Imperial Valley because of the Valley's unique physical setting and hydrogeologic conditions as a closed basin.

Determination of the on-farm and overall irrigation system efficiencies required examination of irrigation water beneficially used. There are various uses of irrigation water that are beneficial in addition to directly satisfying crop water demands. In IID, other beneficial uses of irrigation water include seedbed and land preparation, germination, cooling, and leaching for salinity control.

After completing its study, NRCE determined the following:

- During the study period (1988-1997), IID's on-farm efficiency averaged 83%, while its overall efficiency was about 74%. In other words 83% of the delivered water to the headgates was used for crop evapotranspiration (ET), leaching, and other crop production uses. The California Department of Water Resources (CDWR) assumes that statewide on-farm irrigation efficiency will be 73% by the year 2020 and could reach 80% through better irrigation management and improved facilities (CDWR 1998). The irrigation efficiency of IID has thus already surpassed the State's future efficiency estimate, 20 years ahead of time. To attain such irrigation efficiency, IID growers often apply lower amounts of water than they really need, thus limiting tailwater, but also accepting lower yields.

- The irrigation efficiency of IID is so high that even those irrigation projects that are served with some of the most technologically advanced irrigation systems, including drip irrigation, exhibit about the same level of irrigation efficiency. To the extent that water loss occurs, it is generally justified as a corollary to farming in a hot climate with heavy cracking soils.

- Based on the data assembled for NRCE's water budget study, IID's conveyance and distribution efficiency was determined by dividing the irrigation water delivered to the farms by the net supply of irrigation water to all the canals off the AAC. The average conveyance and distribution efficiency from 1988 to 1997 was determined to be approximately 89%. In other words, about 11% of the water diverted from the AAC was lost to evaporation and unrecovered seepage and spills before the irrigation water reached the farm headgates. The 89% conveyance efficiency is high, especially given the size of IID's irrigation project and the complexities of its water distribution system management.

- Tailwater is a vital and necessary component of the Imperial Valley's irrigation practice. Due to the low permeability of the heavy cracking soils in IID, it is difficult to adequately leach salts from the soil during regular irrigation applications. The nature of most of IID's soils requires more leaching water than stated in traditional formulae, of which the equations are more applicable to non-cracking heavy soils. Though both horizontal and vertical leaching occur during regular irrigation, only about 52% of the salts in the soil are leached at such time, while the other 48% remain in the root zone, requiring additional leaching between crops.

- During regular irrigation on IID's medium and heavy soils, only 4.5% of the applied water drains vertically, removing about 30% of the salt introduced by the irrigation water, while about 17% of the applied water ends up as tailwater that removes approximately 22% of the salt introduced by the irrigation water. This leaching process is compounded by the fact that the Colorado River, by the time it reaches IID, contains significantly increased mineral salt concentrations. Excess salts in light soils are more easily removed than salts in heavy cracking soils, such as those found in IID, because the permeability of the light soils is adequate for vertical leaching.

- On many IID farms with medium and heavy cracking soils, it would be best for growers to apply even more water during irrigation for leaching and crop consumptive use purposes than they currently do, because this would increase crop yields. However, since higher water application could result in higher tailwater, growers tend to apply barely enough water for crop use and for partial leaching of salts. As a result of insufficient leaching, the lower end of the field becomes too saline for crop production, thus decreasing the productivity of valuable acreage.

- When irrigation water is applied at the head of the field, it picks up salts from the soil as it moves to the lower end of the field. It was determined that the salinity of the tailwater is about 30% higher than the water delivered at the head of the field, which indicates significant horizontal leaching is taking place in IID because of the nature of its soils.

- Considering the three processes of leaching for cracking soils (vertical leaching during crop irrigation, leaching irrigation, and horizontal tailwater leaching), it was determined that approximately 0.73 acre-feet per acre is used for leaching on an annual basis. The leaching requirement for light soils was estimated to be about 0.58 acre-feet per acre per year. About 87% of IID irrigated lands have limited permeability in the root zone, while the remaining 13% are light soils.

Based on the above results and the other matters addressed in this report, it is NRCE's opinion that the overall irrigation water use in IID is reasonable and beneficial. Though IID has been criticized by some for its water use, in NRCE's opinion such criticisms are uninformed and unjustified. A reasonable look at IID's water usage shows that IID and its growers manage reasonably well in difficult environmental circumstances, and in fact could justify using more water for leaching and crop consumptive use than they currently utilize.

REFERENCES:

California Department of Water Resources. (1998). *The California water plan update bulletin 160-98 Volume 2*. Department of Water Resources, State of California, Sacramento, California, p.6-12.

II. OVERVIEW OF IID AND ITS IRRIGATION

In this section, a general overview of IID and its irrigation is presented. The following chapters contain a detailed analysis of IID's agricultural water usage.

A. The Colorado River

The main water source for irrigation and municipal uses within IID is the Colorado River.

Water is diverted from the Colorado River at Imperial Dam for use in IID and is conveyed by the AAC. The AAC runs west for about 82 miles just north and approximately parallel to the border of Mexico. Although a large portion of the sediment carried by the Colorado River is intercepted by a system of reservoirs upstream of Imperial Dam, a substantial amount of silt is nevertheless carried by the river flow downstream of the major Colorado River reservoirs. To reduce the amount of sedimentation diverted via Imperial Dam, a series of desilting basins are employed. These basins remove about 70,000 tons of silt per day from the Colorado River water prior to diversion into the AAC. The desilted water flows past the Pilot Knob check structure, where a portion of the water returns to the river to satisfy water needs for Mexico. A gauging station has been installed just downstream of the Pilot Knob check structure to measure the flow in the canal.

The AAC serves IID and the Coachella Valley Water District (CVWD) and has a capacity of about 15,515 cubic feet per second (cfs). Towards the end of the canal, near the Westside Canal, its size shrinks to about 2,665 cfs. Almost all of IID's water has been supplied through the AAC since 1942. The AAC is an earthen canal with no artificial lining for reducing seepage losses of water. The maximum canal width at the water surface is 232 feet, having a depth of about 20.6 feet and a bottom width of 160 feet. Upstream of the first major diversion from the AAC to IID (at the EHL Canal), water is diverted to the Coachella Canal to serve CVWD. The amount of water diverted to the Coachella Canal is approximately 10% of the total IID diversion amount.

Although the Colorado River water is a blessing to the dry Southwestern United States, it also carries a large amount of unwanted dissolved salts. The amount of salt carried by the Colorado River increases as it flows downstream. At its headwaters, the Colorado River has a salinity concentration of about 80 microsiemen per centimeter (μs/cm). At Imperial Dam, the salt concentration is about 1,200 μs/cm in recent measures. Return of irrigation drainage water to the river is one cause of the increase in salinity. When water is diverted from the Colorado River for irrigation, a large portion of the return flow from the irrigated lands returns to the river while some becomes groundwater recharge and some is lost to crop evapotranspiration (ET). Natural factors, such as various geologic formations, contribute to the increase in salinity as well. Salt addition to the river from natural sources, plus the effects of evaporation and the use of water from the river system, results in an increased concentration of salts as the river flows downstream. Therefore, because the water available to IID at Imperial Dam has already been used and reused many times, it contains a higher salinity concentration than points upstream. Colorado River water at Imperial Dam has an average salinity of more than one ton of salt per acre-foot. Drainage water from the Imperial Valley, with a salinity of about 4 tons per acre-foot (Total Dissolved Solids (TDS) of about 3,000 ppm), enters the Salton Sea.

The river salinity level just above Imperial Dam was compared to the salinity at Lee's Ferry, which is approximately 640 miles upstream, to illustrate the salinity concept mentioned above. The United States Geological Survey (USGS) has been monitoring the flow as well as the salinity level at Lee's Ferry (USGS gage #938000) and above Imperial Dam (USGS gage #9429490) for many years. The salinity level of the Colorado River water at Imperial Dam was not measured until 1971. The historic salinity of the Colorado River at Lee's Ferry and at Imperial Dam, since 1971, are shown on Table II-1.

As one can see from Table II-1, the Imperial Dam diversion point on the Colorado River has considerably more salinity than that at Lee's Ferry. The average salinity at Lee's Ferry and Imperial Dam for the period from 1971-1997 are 0.828 and 1.224 ds/m, respectively. The average flows at Lee's Ferry and above Imperial Dam are 14,802 cfs and 10,719 cfs, respectively. The average river flow decreased by 28% between Lee's Ferry and Imperial Dam, while the salinity level increased by 48%.

Due to the high salinity levels of the Colorado River water, IID's growers need to apply water in excess of the amount required for ET in order to maintain acceptable soil salinity. The effects of the highly saline irrigation water from the Colorado River are compounded by the nature of the heavy cracking soils of IID, which require a higher water application, compared to lighter soils, to leach the salts below the root zone. This will be discussed in detail in later sections of this report.

Table II-1 Annual Average Colorado River Flows and Salinity Levels at Lee's Ferry and at Imperial Dam From 1971-1997.

Year	Lee's Ferry (#09380000)		Above Imperial Dam (#09429490)	
	Salinity (ds/m)	Flow (cfs)	Salinity (ds/m)	Flow (cfs)
1971	0.858	12,788	1.431	8,071
1972	0.863	12,873	1.356	8,155
1973	0.889	12,492	1.334	7,844
1974	0.865	12,276	1.330	8,713
1975	0.832	12,377	1.310	8,329
1976	0.846	12,948	1.312	8,338
1977	0.891	10,157	1.310	7,978
1978	0.940	12,440	1.322	7,870
1979	0.912	11,201	1.304	8,092
1980	0.842	15,605	1.234	11,538
1981	0.843	10,840	1.295	10,544
1982	0.913	12,454	1.280	7,504
1983	0.821	26,497	1.191	17,359
1984	0.752	28,065	1.087	27,403
1985	0.663	23,326	0.982	22,542
1986	0.679	25,819	0.926	20,321
1987	0.710	15,905	0.999	14,315
1988	0.817	10,811	1.072	9,533
1989	0.757	11,074	1.140	8,311
1990	0.861	10,914	1.168	8,287
1991	0.921	11,581	1.243	7,924
1992	0.921	11,025	1.223	7,129
1993	0.897	11,391	1.230	6,554
1994	0.797	11,095	1.280	8,169
1995	0.807	14,096	1.260	7,692
1996	0.732	15,235	1.270	8,354
1997	0.719	21,099	1.147	10,318
Average	0.828	14,802	1.224	10,719

Data sources for the above data are:
National Climatic Data Center (NCDC) EarthInfo CD (1995)
USGS Water Resources Data Books (1961-1970)
USGS Office in Tempe, AZ (1999).

B. IID's Water Delivery System

IID has utilized its state and federal water rights for almost a century to irrigate the Imperial Valley, turning a near-desert region into a highly productive farmland. IID operates and maintains most of the water diversion, conveyance, and distribution systems that deliver Colorado River water to 461,706 acres of irrigated and idle lands as well as to municipal customers within the Imperial Valley. The control of this water begins at Hoover Dam, where ordered water is released by the USBR. IID's water supply is therefore an upstream-controlled system in which the Colorado River serves to convey water from Hoover Dam to Imperial Dam, a distance of 300 miles. The diversion at Imperial Dam includes a number of related components which consist of the dam itself, the AAC headworks and desilting basins, the California sluiceway, Gila Gravity Main Canal Headworks, Senator Wash Dam and Reservoir, and Laguna Dam. The USBR constructed and owns all these facilities.

From the diversion at Imperial Dam, water flows down the AAC a distance of 53 miles until the flow is split between the EHL Canal and the continuing branch of the AAC. From these canals, water is distributed throughout the districts of Holtville, North, and Southwest Divisions by means of six main canals: EHL, Central Main, Westside Main, Briar/New Briar, Rositas and Vail, as shown on Plate II-1. This distribution system is owned and operated by IID and includes seven regulating reservoirs and three interceptor reservoirs. The system also includes 430 control structures, about 1,400 miles of open drain, and 33,600 miles of buried drainpipe (or tile drains).

A few things that distinguish IID from the other districts on the Lower Colorado River are its distance from the upstream point of control and diversion, the fact that the overwhelming majority of its irrigated lands have very low permeability and crack when dry, and its reliance on a single source of water. CVWD is also distant from the point of diversion on the Colorado River, but only Improvement District #1 within CVWD receives Colorado River water for irrigation. CVWD, as a whole, derives a portion of its irrigation water from groundwater sources, whereas IID derives no significant amount of irrigation water from groundwater or sources other than the Colorado River. Because of this reliance, IID operates under a very difficult set of water supply conditions that are not shared by other districts.

All of IID's daily water orders must be anticipated a minimum of four days in advance and are released 400 miles upstream from the place of use. Normally, upstream-controlled systems are not capable of perfectly matching supply with demand. Operation of this type of irrigation system requires more water to be released at the point of control (Hoover Dam) than is needed to satisfy the order. The only way to overcome this problem is to create significant storage facilities within the local portion of the conveyance and distribution system, and thus change the control of the system from upstream to downstream, or at least minimize the travel time of water orders. IID has accomplished some of this by the construction of regulating reservoirs that help compensate for inevitable problems in delivery quantity and timing. However, these facilities do not have the capability to store several days supply; thus, IID is still under upstream control.

Within IID, the process of a water order is based on staff estimates of demand. These estimates are based on historical demand, weather conditions, and cropping patterns. These factors and judgment form the basis for coordination of water releases made by the USBR. Normally, growers order water from IID one to two days in advance of delivery, and water orders are available to the irrigators, in 12-hour time blocks at a set flow rate determined by IID.

IID's complete water balance includes input from the AAC, the Alamo and New Rivers, precipitation, and a very small portion of groundwater. However, the source of water for irrigated lands is the AAC and effective precipitation. The AAC irrigation water represents the sole source of salts introduced to the irrigated lands, as the flows from the Alamo and New Rivers are not diverted for field application.

Figure II-1 shows the process of how water becomes available to meet a particular water order (Imperial Irrigation District Water Transportation, Hoover Dam to User). This figure illustrates the path and time it takes the water to flow from Hoover Dam to a given field in IID.

Once irrigation water is applied to the fields, it is evaporated directly from the soil surface and is transpired by plants (evapotranspired), leaving the salts behind. The residual water remaining and draining from the fields therefore has a higher salt concentration than the original supply. It is essential that enough water remain after the ET process that significant drainage from the field is generated. Drainage water must carry away salts introduced by the irrigation water so that a balance of salt within the root zone of the soil is maintained that does not exceed the maximum tolerable concentration for the crops being grown. Drainage water from IID fields is collected by subsurface and surface drains that either enter the Salton Sea by direct pumpage, or empty into the New and Alamo Rivers, which eventually discharge into the Salton Sea.

1. *Imperial Dam*

Imperial Dam serves primarily as a water control structure for diversion and does not create significant storage itself. The original 85,000 acre-feet of storage capacity that resulted from the construction of the dam quickly filled with sediment; the dam can only be considered a water control structure, not a storage facility. Diversion from Imperial Dam takes place on both sides of the Colorado River. On the California side, 15,155 cfs capacity is available to the AAC, and on the Arizona side, 2,200 cfs capacity is available to the Gila Gravity Main. The dam can pass a flood flow of 180,000 cfs, which is described as the "assumed maximum flood." The water surface elevation of the pool is 23 feet above the river's normal water surface.

11D Exhibit 2B oversized
map inserted here

2. *All American Canal*

The AAC flows West-Southwest for about 82 miles and along the way provides water to the Yuma Project, CVWD, and IID. The following are the main turnouts and drops located on the AAC between Imperial Dam and the eastern boundary of IID (see Plate II-1):

1. Reservation Main Turnout
2. Titsink Turnout
3. Yaqui Turnout
4. Pontiac Turnout
5. Yuma Main Canal (Siphon Drop)
6. Pilot Knob Wasteway
7. Coachella Canal
8. Drop One
9. Drop Two
10. Drop Three
11. Drop Four
12. EHL Canal

Just below the AAC headworks, the channel is about 360 feet wide and has a capacity of 15,155 cfs. The Yuma Main Canal turnout has a capacity of 2,000 cfs and serves the Yuma Project. The AAC's capacity is reduced to 13,155 cfs at this point and remains at this capacity for six miles downstream to Pilot Knob, at which point all water may be returned to the Colorado River and made available to serve the water rights of Mexico, if necessary, by means of the Pilot Knob Wasteway. The capacity of the AAC from Pilot Knob downstream 15.5 miles to the Coachella Canal turnout, is 10,155 cfs. Along the additional 44 miles, the canal capacity is reduced from 7,755 to 2,655 cfs as water is turned out into the main canals of IID.

The water received by IID from the AAC passes four drop structures that are located downstream of the Coachella Canal turnout. Within IID, water is divided and distributed among the six main distribution canals, including East Highline (EHL), Central, Briar/New Briar, Westside Main, Rositas, and Vail Canals.

3. *East Highline Canal*

EHL is the first canal within IID, it is also the largest in capacity at 2,700 cfs, and the longest at 45 miles. The canal is unlined and originates at the eastern boundary of the irrigated lands of IID, flowing from the AAC (about Township 16 South) north to the Galleano regulating reservoir (about Township 10 South). As the name suggests, the EHL runs along the east boundary of the irrigated lands served by IID, and except for a few small parcels of land, almost all the land served by EHL lies to the west of the canal but east of the Alamo River.

4. *Central Main Canal*

The turnout for the Central Main Canal is located on the AAC near Calexico, California. The canal is unlined and flows northward, serving IID lands located around Heber, El Centro, Imperial, and Brawley, between the New and Alamo Rivers. The canal is about 27 miles long and has a capacity of 1,300 cfs.

5. *Westside Main Canal*

The Westside Main Canal begins at the western most extreme side of the AAC, is unlined, and flows northward serving the lands around Seeley and Westmorland, west of the New River. The Westside Main Canal is unlined, 44.6 miles long, and has a capacity of 1,300 cfs.

6. *Briar/New Briar Canal*

Water for the Briar/New Briar Canal is turned out of the AAC east of Calexico. It serves the area from the border of Mexico to Brawley, and from El Centro to Holtville. The canal is 5.2 miles long, lined with concrete, and has a flow capacity of 320 cfs.

7. *Rositas Canal*

The Rositas Canal is about 11 miles long and is partially lined. Water is turned out of the EHL at a capacity of about 300 cfs and serves lands within the central portion of IID, between lands served by the Central Main and EHL.

8. *Vail Canal*

This lined canal is 4.6 miles long and receives water from the EHL east of Calpatria. The Vail Canal traverses a portion of the area served by the EHL as it flows west and supplies the area north of Westmorland, west of Calpatria and southwest of the Salton Sea. The canal is lined and has a capacity of about 300 cfs.

9. *Canal Laterals*

The canal laterals are part of the irrigation distribution system that delivers irrigation water to the individual farms from the main canals. These canal laterals are either lined or earthen, varying in length and capacity depending on the location. A typical canal lateral has a flow capacity ranging from 60 to 90 cfs. IID operates and maintains approximately 1,500 miles of laterals and delivers water through approximately 5,600 delivery gates (turnouts) for irrigation purposes.

10. *Drainage*

The extensive drainage system of IID plays an important role in the overall operation of the irrigation system. There are both surface and subsurface drains constructed throughout IID. The surface drains are divided into three main areas consisting of the Alamo River System, the New River System, and additional drains that flow directly into the Salton Sea. The surface lateral drain system is laid out to provide a drainage outlet for each governmental subdivision, which are each approximately 160 acres in size. The drainages are normally located parallel to the canal laterals with depths generally ranging between 6 to 10 feet to accommodate tile drain discharge. If a drain cannot be maintained at a sufficient depth, a sump and pump are provided to collect the excess water.

11. *Regulating and Interceptor Reservoirs*

IID has constructed ten reservoirs for the purpose of improving water supply management and to conserve water. Six of these reservoirs were constructed as part of the IID/Metropolitan Water District (MWD) Agreement, where MWD helped fund IID's water conservation-related developments in return for the conserved water being transferred for use by MWD. These ten reservoirs are summarized in Table II-2.

Table II-2 IID Constructed Reservoirs.

Reservoir	Origination	Location/Connection	Capacity (Acre-Ft)
1. Carter	1988 IID/MWD	End of Westside Main	350
2. Galleano	1991 IID/MWD	End of EHL	425
3. Bevins	1992 IID/MWD	Plumb/Oasis Interceptor	253
4. Young	1996 IID/MWD	Mulberry/D-Lateral Interceptor	275
5. Russel	1996 IID/MWD	Middle Vail Supply Canal	200
6. Willey	1997 IID/MWD	Trifolium Interceptor	300
7. Singh	1976 IID	Lower 1/3rd of EHL	323
8. Fudge	1982 IID	Lower Central Main	300
9. Sheldon	1977 IID	Middle Westside Main	476
10. Sherber	1983 IID	End of Rositas Supply Canal	470

The Bevins, Young, and Trifolium Reservoirs are associated with the Plumb-Oasis, Mulberry/D-Lateral, and Trifolium interceptor systems[1], which intersect the drainage paths of 8, 11, and 15 laterals, respectively. The function of these reservoirs is to store water that has been captured by the interceptors; hence they are called interceptor reservoirs. The water stored here would have otherwise spilled out at the end of the supply system. The captured water is pumped back to other points within IID or reintroduced into the water supply for reuse. This reduces orders for water, and the saved water can be used elsewhere by other entities, including MWD, by means of a diversion upstream of Parker Dam.

The reservoirs not connected to interceptor laterals are considered regulating reservoirs. These reservoirs help maintain the desired flow within the canal system by regulating the irrigation supply at a point above the end of the system. This is accomplished by providing storage capacity within the system. Such capacity dampens transient flow conditions by compensating for some excess (or deficiency) in supply flow, thereby reducing spill (or shortage).

C. Water Ordering and Canal Delivery Operations

The Water Control Center (WCC) of IID, which operates the main canals, is responsible for requesting water and coordinating Colorado River water releases made by the USBR. The order of Colorado River water from the USBR is based on IID staff estimates of demand, which are

[1] An interceptor system is a canal that is constructed between the ends of supply laterals and their associated drains. It collects water which would have spilled and become part of the drain-water produced by the project.

based on historical demand, weather conditions, cropping patterns, and IID's Watermaster's judgment. The WCC submits an annual water order to the USBR in October for the following calendar year. For the weekly water requirement, the WCC staff submits a "Master Schedule" to the USBR each Wednesday for the upcoming week (Monday through Sunday); however, this schedule may be modified with 72 hours advance notice to the USBR. This few days lead in water orders is necessary because there is considerable lag time between when the water is released from Hoover Dam and when it arrives at the EHL diversion. The travel time between various locations on the Colorado River varies depending on the physical characteristics of that particular reach such as cross-section, slope, flow rate, etc. The travel time of water between Hoover and Davis Dam is about six hours. The travel times between Davis and Parker Dam and Parker and Imperial Dam are about 24 and 72 hours, respectively. The travel time in the AAC between Imperial Dam and the EHL diversion is about four and a half hours. Therefore, it takes a total of about four and a half days for the ordered water to travel from Hoover Dam to the EHL. Furthermore, extra time will have to be allowed to distribute the water within IID, which may take over three-quarters of a day for the more distant turnouts in the system.

1. *Water Scheduling Within IID*

Three decentralized divisions (Divisions) operate the lateral canals and distribution system within IID. Each Division submits a daily order to the WCC by noon for development of the following day's operating plan. The Divisions also assist the WCC in preparing the Master Schedule that is submitted weekly to the USBR by estimating orders from the growers two days ahead of time based on the weekly trend of orders received daily from the growers. The water clerks at each Division log in the growers' daily orders according to lateral and individual zanjero run, which is a stretch of ditches leading to individual farms. For each water order, the user account number, the amount of flow, and the order duration are all recorded in the Division Water Order Register. If requested flows will exceed the lateral canal capacity, certain orders can be delayed within a three-day limit. Orders that have been running receive first priority while orders that have been delayed or "carried over" from the previous day's schedule have the next priority with the longest carry over receiving the highest priority. For all other orders, priority is determined by when the order is received or by the discretion of the water clerks.

On a daily basis, the WCC allocates the following day's water supply, less 300 cfs reserved for carryover orders, among the Divisions based on use patterns and estimated orders submitted by the Divisions on previous days. The WCC evaluates water requests with respect to system capabilities and supply; it also determines how the 300 cfs carryover water should be allocated among the Divisions. The dispatcher from the WCC notifies each Division of its revised allotment for the following day after the analysis of the water orders has been concluded. Each Division then adjusts the schedule for the next day's deliveries according to the revised allotments received from the WCC.

Orders from the growers for change of quantity, or cut-off orders may be placed before the 4:30 p.m. deadline of the preceding day. Once the daily water orders are received, the WCC staff schedules the required changes throughout the main canal system for the next day's deliveries. The changes on the main canals are then made by remote control from the WCC. The main canals and lateral headings are considered flow control locations that maintain scheduled deliveries, whereas check gates are used to maintain target water levels between flow control locations.

The flow required in each canal is recorded on the Division's Daily Water Distribution Work Sheet and compared with the estimated order for that canal. Each canal's estimated order is based on the total water requirement predicted by the WCC and distributed among the Division's lateral canals based on the current use pattern. The Division water clerk then totals up all the orders and calls the WCC to verify the estimated order or request a change. After the WCC has received all the orders from the Divisions, it modifies the original estimated allocations for the various divisions according to supply and demand, if it needs to, and notifies the Divisions of their revised allotments. The water clerk in each division will make any final adjustments to the individual deliveries of each zanjero run. Once the final delivery adjustments are completed for the following day, the water clerks continue to estimate orders for the next two subsequent days based on running order and carryovers.

All data are logged at the WCC on Daily Water Allotment Sheets, which play an important role in estimating the weekly Master Schedule as well as daily water orders. The Watermaster's daily water order adjustments are based on three main factors: water allotment sheets, which give the current trend of water orders; the day of the week (less water is required on weekends); and the current and projected weather conditions. The Watermaster considers the longer period weather forecast (i.e., 10 to 12 days) and the seasonal irrigation demands according to the cropping patterns and crop status (i.e., crop growing stages). Comparisons of weekly water demands in previous years to current weekly orders are also performed to gain a historical perspective in trends other than the current conditions before the final determinations are made for the Master Schedule. The Master Schedule also accounts for estimated conveyance losses along the canals.

2. *12- and 24-hour Delivery Period*

Due to the IID/MWD Conservation Program, growers are now allowed to order water in increments of 12-hours, rather than increments of 24-hours as previously required by IID. The 12-hour delivery period policy provides irrigators with more flexibility in turning off the water when needed. A more flexible irrigation delivery system will result in higher on-farm irrigation efficiencies if properly managed. The 12-hour delivery period policy stipulates that orders may be placed for multiple day 12-hour sequences or in 12-hour increments with 24-hour runs. The orders for 12-hour sequences must be limited to 7 cfs; however, for the 24-hour runs, delivery flow rate is limited only by the capacity of the user's ditch. Orders for the 24-hour runs must be placed before 12:00 noon the preceding day for the next morning run. However, orders for the 12-hour runs may be placed before 12:00 noon of the same day for the afternoon run. If additional water is needed after the 12-hour period, a four hours advance notice must be given. The grower may also arrange his order to be reduced or removed prior to the full 12-hour period with at least two hours advance notification. However, charges are still based on the full 12-hour run amount. If the grower shuts off the water at the farm turnout prior to the full 12-hour run without authorization, a penalty charge is incurred in addition to the regular full amount charge. With the 24-hour runs, the flow rates of the orders may be adjusted during the last 12 hours of the run with some restrictions applied.

3. *Daily Canal Operations*

Every morning, at about 6:00 a.m., the hydrographer, who operates and regulates the flows at the lateral canal headings, diverts a certain amount of water from the main canal to the lateral canals. Flow rates required at each lateral heading are determined by the summation of orders from the growers on that lateral plus an extra 1 cfs of water, called carriage water, to cover operation losses. The ditch riders, or zanjeros, receive schedules of water orders regarding where, when, and how much water for each delivery, and make the necessary check and turnout gate adjustments starting from the upstream end of a lateral. Since most farm turnouts are adjacent and upstream of check gates, the sluice check gates are lowered to raise the water levels immediately upstream of check gates so that enough head will be available at the turnout where the deliveries are to be made. However, the flow conditions through the check gates are either overflowing (i.e., weir flow), or underflowing (i.e., orifice flow), or a combination of both depending on the situation. With overflow conditions at the check gate, water is flowing over the top of the gate functions as a weir so that depth fluctuations upstream of the check may be minimized. If a pump is used downstream of a check gate, it must also have additional orifice underflow like a sluice gate. This ensures that the downstream reach of the canal will not run dry and fall below the pump inlet, thus damaging the pump, when the upstream water level drops below the top of the check gate.

Later on, about mid-day, the zanjeros return to the lateral and re-adjust the delivery gates to fine tune the system into equilibrium or/and to make changes for the 12-hour delivery runs. The zanjeros are replaced by patrolmen after their shifts to monitor system operations and respond to special requests and situations. The zanjeros and patrolmen also monitor the fields to check if any of the irrigation regulations have been violated by the irrigators such as excess tailwater and ponding in the lower ends of the fields and direct discharge into drains. The zanjeros' major objective in operating the delivery system is to deliver the right flow of water ordered by the various growers on the laterals to the farm turnouts with minimum head fluctuations in the laterals. In reality, the zanjeros may need to make several trips back to the laterals for gate adjustment before the laterals become stabilized if more flow changes are required.

In summary, a typical daily lateral run of a zanjero is as follows:

1. The zanjeros working the morning shift meet each morning at about 5:00 a.m. at the Division office where they pick up the water orders they are responsible for. Each zanjero's delivery area consists of an area served by several laterals. On each lateral he/she may have a couple of new deliveries to make, a couple of deliveries to stop, and a couple of deliveries that continue.

2. The zanjero totals the flowrate of all deliveries on a lateral then meets with a hydrographer on the main supply canal at about 6:00 a.m. The hydrographer adjusts the flow into the lateral to meet the deliveries being made that day plus an estimated amount based on seepage, evaporation, and operational spills. This process is repeated for each lateral in each service area.

3. The zanjero, beginning at the head of each lateral, travels to the first headgate that needs to be changed (either to shutdown, open, or adjust the flow). Once the flow from the main canal

reaches the headgate, the zanjero measures the headgate delivery and the flow proceeding down the lateral, making sure that the delivery is equal to the amount ordered and that the flow remaining in the lateral is sufficient to make the downstream lateral deliveries. The zanjero follows the water down the laterals making the needed adjustments to the delivery headgates and the lateral gates and checks. During this time he/she also measures tailwater runoff at the tailwater boxes that are running water.

4. At the end of their shift, the zanjeros are replaced by patrolmen who monitor the system operation and respond to special needs such as the 12-hour runs. If there are 12-hour runs, the patrolmen in the afternoon-evening shift need to make flow adjustments at the headgates to account for differences in the flow.

Since supply is fixed according to the weekly Master Schedule and demand may vary depending on daily orders, the daily demand and available supply normally do not match. Therefore, when demand exceeds supply, orders are carried over to the next day, but not beyond two days. When supply is greater than demand, the extra water will be used to satisfy the carryover water orders from the preceding days. In addition to shifting the water orders back and forth to match the supply and demand, the water storage in the main canal regulating reservoirs are utilized to balance the discrepancies.

For an upstream controlled system, it is inevitable to expect operational spillage if highly flexible and reliable water deliveries are to be maintained. However, in order to minimize operational spillage and increase flexibility, IID's main canal system is segmented into six operating reaches with a regulating reservoir at the downstream end of each of the reaches. The reservoirs act as buffers for the flow mismatches between actual demand and available supply. Extra flow from the upstream main canal reach is stored in the reservoir and later released to the canal reach downstream according to scheduled deliveries. Such flow mismatches are a result of many factors, which could include flow reduction or early shutting off by farmers, measurement errors, and/or changes in canal losses. The six main canal operating reaches and their corresponding reservoirs are:

1. AAC, Drop 1 to Central Main Canal Check (pool upstream of the check serves as a small regulating reservoir).

2. EHL Canal Reach 1, canal heading at the AAC to Nectarine Check, Singh Reservoir.

3. EHL Canal Reach 2, Nectarine Check to Niland Extension Heading, Galleano Reservoir.

4. Central Main Canal, canal heading at the AAC to No.4 Check, Fudge Reservoir.

5. Westside Main Canal Reach 1, AAC Central Main Check to No.8 Check, Sheldon Reservoir.

6. Westside Main Canal Reach 2, No.8 Check to Trifolium Extension Heading, Carter Reservoir.

The six reservoirs are designed to enhance the efficiency, flexibility, and reliability of the main canal system. For the laterals in IID, there are four reservoirs associated with the three lateral interceptor systems. The interceptor is a lined canal located at the ends of a series of laterals to collect the operational discharge and leftover water deliveries derived from early turnout shutoffs. The interceptor conveys the collected unused water to a reservoir for storage to be used in another part of the distribution system. These interceptor facilities reduce the amount of wasted operational spillage from the laterals and improve the flexibility of the distribution system. There are ten reservoirs in IID with a total storage capacity of more than 3,300 acre-feet. These reservoirs were built to provide efficient and timely water deliveries for the distribution system.

4. *Summary of IID Delivery Operations*

IID operates and maintains a very complex upstream controlled distribution system that delivers an average of about 7,800 acre-feet (1988-1997) of ordered water on a daily basis in a highly flexible manner. The complexity of the system is accentuated by the large amount of daily water orders that have to be delivered and the long travel times required for the water to move from one point to another in the canal network in a relatively flat terrain setting.

The supply source of IID is Hoover Dam, more than four days away. IID's weekly Master Schedule is expected to be ordered on Wednesdays from the USBR for the following week's supply. The Master Schedule is based on the WCC's estimated demand for the coming week. The actual day to day water orders from growers do not occur until the day preceding the day they need water at the latest. Therefore, the actual demand of the coming week may be different from that predicted by the WCC. However, once the water is released from Hoover Dam, flow adjustments may be made, utilizing the various storage reservoirs along the Lower Colorado River. Once the ordered water has arrived at IID, the mismatch between actual demand and available supply will have to be either absorbed by the ten reservoirs within IID or spilled over as waste if supply exceeds demand.

When considering efficiency, there is a trade-off between operational spillage and the flexibility of the delivery system. One may reduce operational spillage, but delivery flexibility and reliability may be affected resulting in lower on-farm performance or efficiency. Nevertheless, the IID distribution system efficiency is high and is estimated at about 89% as detailed in Chapter V of this report. The staff and canal operators in IID have overcome formidable obstacles in achieving such a highly efficient canal network system mostly by accurately predicting the weekly water demand, maneuvering the carryover water orders back and forth, and redistributing the water between reservoirs and canals. This high efficiency is accomplished with the help of the many conservation efforts implemented in IID such as the lining of canals, installation of non-leak gates, gate automation, lateral interceptor projects, and reservoirs.

D. IID's On-farm Irrigation Systems

The soils, topography, and crops in the Imperial Valley are particularly well suited for surface irrigation methods, including border, furrow, corrugation, or basin techniques. Other irrigation methods in the valley include sprinkler and drip irrigation systems. The overwhelming majority of the crops grown in the Imperial Valley are irrigated by surface irrigation methods, as nearly all the presently irrigated soils and crops are well suited for surface irrigation. Additionally, surface or gravity irrigation is economical, energy efficient, and water efficient when properly managed. Sprinkler irrigation is being used in IID for seed germination, crop establishment, land preparation purposes, and occasionally for leaching. Drip irrigation is used when it is determined to have an economic advantage, depending on such factors as crop type, water quality management, yield, and economic return.

Irrigators and engineers are often challenged when choosing irrigation systems for certain soils. Selection of the appropriate irrigation method is based on analyses of topography, soil depth, salinity, intake rate, water holding capacity, irrigation water quality and availability, climate, crops, natural resources, labor availability, energy sources and costs, available technology, and system costs. An ideal irrigation system would apply water uniformly throughout a field in the amount needed for crop ET and leaching. However, all irrigation systems are less than ideal and have demands in addition to the water required for crop ET and leaching. Surface irrigation water requirements for most conditions in IID include deep percolation and tailwater (i.e. surface runoff).

Most of the irrigated lands in IID have very flat topography, requiring some or no major land leveling. The flatness of the area makes it conducive to gravity or surface irrigation systems, such as border, furrow, or basin irrigation methods. Since the dominant soil type is characterized by a very low intake rate, it is preferable to apply irrigation water using surface irrigation rather than other irrigation methods. Since the soils are quite tight, the length of run of the majority of the fields can be very long.

The desert region of the Southwest is often associated with sandy, coarse soils. However, the central irrigated area of IID is an old lake bed mainly below sea level, which is quite level and contains very deep, fine textured soils. Unlike the central portion of IID, both the East and West Mesas have predominantly coarser desert soils. The dominant soil type in IID is Imperial -- silty clay and nearly level -- followed by Imperial-Holtville-Glenbar, which is also nearly level with textures of silty clay, silty clay loam, and clay loam. The majority of the soils in IID, have very low vertical permeability, and are characterized by cracks as deep as three feet.

At the time of the development and construction of IID's conveyance, distribution, and on-farm systems, sprinkler and micro/drip irrigation were not developed yet, leaving gravity or surface irrigation as the preferred option. However, even with the various irrigation technologies currently available, surface irrigation remains the most practical technique, though certain conditions and locations in the Imperial Valley are suitable for sprinkler and micro/drip irrigation. In contrast, the crops and soil conditions in CVWD are more adaptable to micro/drip irrigation techniques, resulting in approximately 50 percent of the CVWD's irrigated acreage being under drip and sprinkler irrigation. Cropping conditions in IID and CVWD vary greatly throughout the year and may necessitate the use of more than one irrigation method on the same field during the year or production cycle.

Sprinkler irrigation in IID is limited primarily to land preparation, leaching, seed germination, and crop establishment. The following conditions contribute to limited sprinkler use in IID: high evaporation rates in the summer, low intake rates of heavy soils, the high salinity level of Colorado River water (which can cause foliar damage from salt buildup on some crops as well as negative quality impacts on some crops), and the high cost of labor, equipment, and energy. Sprinklers are the preferred method of irrigation for farming areas with undulating topography and soils with low water holding capacity.

Micro/drip irrigation is used on crops (permanent and otherwise) that have an economic return that can support the use of drip irrigation systems, such as citrus, grapes, asparagus, tomatoes, melons, and sweet corn. Drip irrigation increases the ability to control the soil moisture because shallow and frequent irrigation can be applied. This is particularly advantageous to help reduce deep percolation on coarse soils. This advantage is less pronounced on heavy soils with high water holding capacities. Drip irrigation is sometimes used with plastic mulches to increase soil temperature and accelerate plant growth, stimulating harvest during profitable market windows. Many growers have found that after producing a crop using drip irrigation, a deep irrigation that uses surface or sprinkler irrigation techniques are required to leach accumulated salts.

The tight soils (soils with low infiltration or intake rates) in IID require that the water remain on top of the soils for a relatively long time to allow adequate infiltration of water into the root zone. If the furrow inflows were terminated as soon as the leading edge of the applied water reached the end of the furrow, the lower portion of the field would be short of water. This would result in yield reduction or crop loss and soil salinity buildup. Tailwater is a natural result when water flows into the furrow for a sufficient time to allow adequate infiltration at the lower portion of the field. Thus, tailwater is a necessary part of irrigation in IID.

In addition, the intake opportunity time is different along the length of a field, due to the advance time and recession time of the water moving from the head to the tail end of the field. This varying intake opportunity time results in different amounts of water entering the soil. In order to adequately irrigate the lower portions of the field and avoid crop loss from standing water, it is necessary, under most conditions, in IID for water to run off the field.

Many additional factors influence irrigation requirements and the resulting efficiencies. In IID, several types of crops require 6 to 12 inches of applied water for tillage and leaching purposes prior to planting. Much of this water is used for leaching or is stored in the soil and is available for crop use after planting. For example, after planting sugar beets or other row crops, irrigation water is applied to allow the water to wet to the ridge of the furrow to provide moisture for seed germination. The germination and establishment of sugar beets requires that the soil's wetting front moves past the seed line, which is located below the furrow ridge, to move salts away from the seeds. This irrigation requires more water than is necessary for crop ET. Yet without germination, there is no crop production. After germination, when plants still have a shallow root system, they may require a shallow irrigation for establishment.

In addition, most of IID's soils are characterized by a very low intake rate and swell when wet and crack when dry. When tractors and other heavy equipment compress the tight soil, it further reduces the furrow intake rate. Thus, on adjacent furrows, the intake rate becomes highly variable, requiring adjustments in furrow inflow rates. Salinity and density also influence the infiltration rate of the high clay-content soils. The salinity concentration in the soil at the tail end of the field is often higher than that at the head of the field. This affects the infiltration rate and adds to the irrigation uniformity problem primarily caused by the difference in intake opportunity time along the length of the field.

E. IID Soil Preparation

Most fine-textured irrigated soils have water requirements associated with tillage and seedbed preparation operations. Tillage operations and their objectives vary, depending on producer preferences, crop rotations, soil characteristics, and other factors. After harvest of certain crops, a deep tillage operation is performed followed by a deep irrigation. The deep irrigation serves to promote leaching, fill the soil water profile, and improve soil tillage characteristics.

The wetted soil surface evaporation procedure used to determine the evaporation component of ET is also applicable during the soil preparation stage. Deeply tilled soils have a higher drying potential because of the increasing bulk surface area of the soil exposed to the atmosphere and the increased depth of the soil profile exposed for drying. The constant rate drying period is extended due to increased exposure to capillary drawn water in the soil profile. Deep tillage operations increase soil porosity in the upper layers, providing additional opportunity for vapor diffusion and heat transfer, resulting in increased moisture loss from the soil. Deeply tilled soils and large furrows expose lower soil layers to evaporate drying and increase the total evaporative depth in the soil profile. Depending on the tillage operation, the evaporative depth may be substantially deeper during soil preparation than during crop irrigation.

Each tillage operation consumes irrigation water through increased opportunity for evaporation by exposing moist soil to additional evaporation. The quantity of evaporation will depend on the type and depth of soil preparation, time of year, and length of time before seedbed preparation and cropping.

F. Seed Germination and Crop Establishment in IID

Seed germination water use includes special irrigation techniques that use water above the amount required for plant ET and the amount required as part of the crop production system. Many vegetable crops, and a limited amount of field crops such as alfalfa and sugar beets, are sprinkler irrigated for seed germination, crop establishment, and cooling in the late summer and fall. Sprinkler irrigation provides the required frequent shallow irrigation that cannot be effectively applied using surface irrigation techniques. Vegetable crops, such as lettuce and onions, are sprinkled for three to six days following planting to facilitate effective germination. Carrots may require ten days to two weeks of sprinkle irrigation to germinate and to establish the crop. The sprinkling process creates large wetted soil surface areas that are subject to increased evaporation.

Field crops that are furrow irrigated during establishment, such as sugar beets, must remain flooded for long periods of time for the wetting front to reach the seed in the raised seedbed. During that period, the soil profile is generally full of water from pre-plant and germination irrigations. The result is higher than normal amounts of tailwater and/or deep percolation and a large wetted soil surface area that increases evaporation.

Irrigation during crop establishment requires more water, relative to crop ET, than irrigation of fully established crops. For example, it may be necessary to heavily irrigate a new stand of alfalfa when the plants are very small with shallow roots. While the moisture deficit in the soil may be only an inch, the smallest practical irrigation may be about four inches. It is also necessary to irrigate sugar beets a few days after the germination irrigation to soften the soil surface crust to allow the seedlings to emerge. Both of these irrigation events expose large surface areas to evaporation, increasing the overall crop ET requirement.

G. Leaching Requirement

The accumulation of salt in the root zone and on the foliage from soluble salts in the irrigation water can affect plant growth and yields at varying degrees depending on crop tolerance. Salinity is one of the most important parameters in assessing the quality of irrigation water.

Salinity, pertaining to irrigation water, is defined as the total amount of dissolved inorganic ions and molecules. As salts accumulate in the soil as a result of using saline water, it deters crop growth by reducing the ability of plant roots to absorb water. Research results indicate that soil salinity does not reduce crop yield measurably until a threshold level of soil salinity is exceeded. Beyond this threshold, which varies for different crops, yields decrease linearly as salinity increases.

Tolerance to salinity can vary with growth stage. Many crops are most sensitive during early seedling growth and then become more tolerant at later growth stages. In general, most crops are more sensitive to salinity under hot, dry conditions than under cool, humid conditions. High atmospheric humidity alone tends to increase the salt tolerance of some crops, while high humidity generally benefits salt-sensitive more than salt-tolerant crops (Hoffman and Rawlins, 1971; Hoffman and Jobes, 1978).

The crop tolerance level guidelines toward salinity were obtained from studies done by various researchers referenced in the 1990 American Society of Civil Engineers (ASCE) Manual No. 71 entitled *Agricultural Salinity Assessment and Management* (ASCE, 1990). Table II-3 shows the threshold levels of soil salinity for the various crops grown in IID. It is important to recognize that the threshold data presented in Table II-3 does not give an accurate indication of the actual soil salinity threshold for every field condition. The actual response of a crop to soil salinity varies with other conditions of growth, such as climatic and soil conditions, agronomic and irrigation management, crop variety, and stage of growth, etc.

Table II-3 Soil Salinity Thresholds for IID Crops (ASCE, 1990).

Crops	Salinity Threshold (dS/m)
Alfalfa	2.0
Bermuda Grass	6.9
Cotton	7.7
Oats & Barley	7.0
Rye Grass	5.6
Sudan Grass	2.8
Sugar Beets	7.0
Wheat, Durum	5.9
Misc. Field Crops	2.0
Broccoli	2.8
Cabbage	1.8
Carrots	1.0
Cauliflower	2.2*
Corn	1.7
Lettuce	1.3
Cantaloupes	2.2*
Honeydew	2.2*
Water Melons	2.2*
Onions	1.2
Onion Seed	1.5
Tomatoes	2.5
Potatoes	1.7
Misc. Garden Crops	1.5
Asparagus	4.1
Jojoba	2.0
Citrus	1.7
Permanent Pasture	1.5
Peach Tree	1.7

* NRCE estimates based on the median salinity threshold (1.3-3.0ds/m) for moderately sensitive crops.

In order to dilute the salt concentration in the soils being irrigated with saline water, it is required that the applied irrigation water should exceed the crop water requirement amount, so that the soil salinity may be lowered below the threshold level. This process is called leaching. The leaching requirement is the minimum fraction of the total amount of applied water that must pass through the root zone to prevent a reduction in crop yield. The general expression for the leaching requirement is as follows:

$$LR = \frac{\Delta d}{\Delta a} = \frac{Ca}{Cd} \qquad \textbf{(II-1)}$$

where:

LR = Leaching requirement

Δ_d = Required equivalent depth of water passing below the root zone

Δ_a = Equivalent depth of applied water (irrigation plus rainfall)

C_a = Weighted-mean salt concentration of the applied water

C_d = Required salt concentration of the drainage water

Electrical conductivity (EC) is easily measured and is also linearly related to salt concentrations of a relatively diluted soil solution. Therefore, EC measurements are substituted for concentrations, C, in these relationships. The expression above is generally known as the leaching fraction if the Δ_d and Δ_a are the actual values rather than the required one.

Numerous steady-state leaching requirement models were developed to estimate what fraction of infiltrated irrigation water is required to maintain the desired average root zone salinity. However, the traditional leaching requirement equation is defined as (Rhoades, 1974):

$$LR = \frac{EC_{iw}}{(5EC_e - EC_{iw})} \qquad \textbf{(II-2)}$$

where,

EC_{iw} = Irrigation water salinity

EC_e = Average EC of the saturation extract for a given crop that produces a ten percent yield decrement

Hence, the net irrigation requirement (not including non-uniformity or tailwater) is:

$$Net\ Requirement = \frac{ET_{iw}}{1 - LR} \qquad \textbf{(II-3)}$$

where, ET_{iw} = ET from irrigation water

The above leaching requirement concept is used as maintenance leaching to maintain the root zone EC_e at some desired level. The threshold salinity of a particular crop is usually used as the value of EC_e for calculating the leaching requirement for that crop. There is another type of leaching practiced in IID called reclamation leaching in which a salinized soil is reclaimed by lowering the EC_e to a desired level. IID soil salinity levels are impacted by a combination of maintenance leaching and reclamation leaching. Hoffman (1980) developed the following equation for reclamation leaching:

$$\frac{(EC_e required - EC_{iw})}{(EC_e initial - EC_{iw})} = \frac{k}{\left(\frac{DRrec}{Ds}\right)} \qquad \textbf{(II-4)}$$

where,

EC_e required	=	Soil salinity desired after reclamation
EC_e initial	=	Soil salinity existing prior to reclamation
DRrec	=	Required depth of deep percolation to achieve the reclamation leaching
Ds	=	Depth of soil to be reclaimed
K	=	Coefficient (varies with soil type and texture)

The parameter, k, is affected by soil type and texture. Thus, for a non-cracking sandy loam soil, k=0.1, and for a cracking, clay, or silty clay soil, k=0.3.

As will be discussed in detail in the following chapters, due to the conditions that prevail in IID, applying the traditional estimate of the leaching requirement is inappropriate because the traditional leaching requirement equation described above is based on standard common field conditions. The traditional leaching requirement equation is only a function of irrigation water salinity and the value of the desired root zone soil salinity. It does not account for how different soil properties may impact the leaching process.

REFERENCES:

American Society of Civil Engineers. (1990). "Agricultural salinity assessment and management." *American Society of Civil Engineers, Manuals and Reports on Engineering Practices No. 71*, New York, NY.

Hoffman, G. J. (1980). "Guidelines for reclamation of salt-affected soils." *Proceedings, 2nd Inter-American Conference on Salinity and Water Management Technology*, Juarez, Mexico.

Hoffman, G. J. and Jobes, J. A. (1978). "Growth and water relations of cereal crops as influenced by salinity and relative humidity." Agron. J. 70: 765-769.

Hoffman, G. J. and Rawlins, S. L. (1971). "Growth and water potential of root crops as influenced by salinity and relative humidity." Agron. J. 63: 877-880

NCDC EarthInfo CD (1995). "Daily values." *National Climatic Data Center database on CD-ROM*, Boulder, Colorado.

Rhoades, J. D. (1974). "Drainage for salinity control," edited by J. Van Schilfgaarde. *Journal of Drainage for Agriculture,* American Society of Agronomy, No. 17, 433-462.

USGS Water Resource Data Books (1961-1970). "U.S. Geological Survey Water Data Report AZ-61-1 to AZ-70-1 and CA-61-1 to CA-70-1", Arizona and California.

Water Quality Data (1999). U.S. Geological Survey, provided by staff member Cheryl Partin, Tempe, Arizona.

III. CLIMATIC EFFECTS ON IID IRRIGATION

The Imperial Valley is in a hot desert region with temperatures exceeding 100° Fahrenheit for more than 100 days every year. It is characterized by a temperate fall, winter, and spring, and a hot, harsh summer. When the valley's high temperatures are combined with the humidity derived from the irrigated agriculture, a tropical atmosphere is produced that often seems hotter than the actual temperature. The availability of water from the Colorado River, along with rich agricultural lands, and a favorable agro-climate have made the Imperial Valley one of the most productive agricultural regions in the world.

A. General Weather Conditions

The annual mean air temperature is about 73° Fahrenheit. The highest monthly mean air temperature was 95.9° Fahrenheit in August 1969 and the lowest mean air temperature was 42.3° Fahrenheit in February 1939. The hottest air temperature ever recorded was 121° Fahrenheit on July 28, 1995, and the coolest air temperature was 16° Fahrenheit on January 22, 1937. Cool winter nights occasionally cause overnight and morning frosts. In 9 out of the 10 years that were studied, the frost-free period for the valley lasted more than 300 days, and in 3 out of the 10 years it lasted more than 350 days. The Imperial Valley averages only 8 days of frost per year. Daily sunshine is more abundant in the Imperial Valley than anywhere else in the United States, with an average of more than 8 hours a day throughout the year.

The average annual precipitation recorded for the valley from 1914 to 1998 was 2.93 inches. The highest annual precipitation recorded was 8.52 inches in 1939 and the lowest was 0.16 inches in 1956. The period with the most rainfall starts in November and ends in March. June is the driest month. The only snowfall recorded in the Imperial Valley occurred on December 12, 1932, with 2.5 inches in Imperial and 4 inches in the southeastern part of the valley.

Prevailing winds are westerly during the winter and spring. Wind speeds of 15 to 20 miles per hour (mph) are common on windy days with gusts exceeding 30 mph. During hot summer months, southeast breezes with wind speeds below 15 mph bring humid air from the Gulf of California.

The Imperial Valley has an average annual relative humidity of 29 percent. The highest humidity occurs from late summer through the winter months. In August, the average relative humidity reaches a maximum of 40 percent, while in March and April the average relative humidity is about 24 percent.

In addition to three California Irrigation Management Information System (CIMIS) weather stations, there are six weather stations reported by the National Weather Service (NWS) in the Imperial Valley. These stations are located in Brawley, Calexico, El Centro, Imperial, Niland, and Ocotillo. The NWS climatic station in Brawley, located near the center of the valley, is used in this analysis for long-term representation of the typical climatic conditions of the valley. Figure III-1 shows the long-term (1928-1997) average maximum, minimum, and mean air monthly temperatures for Brawley, while Figure III-2 depicts long-term (1928-1997) average monthly precipitation. The monthly mean air temperatures in Brawley varies from 54°

Fahrenheit in January to 91° Fahrenheit in June and July. Average annual rainfall is 2.68 inches peaking at 0.43 and 0.41 inches in December and January, respectively.

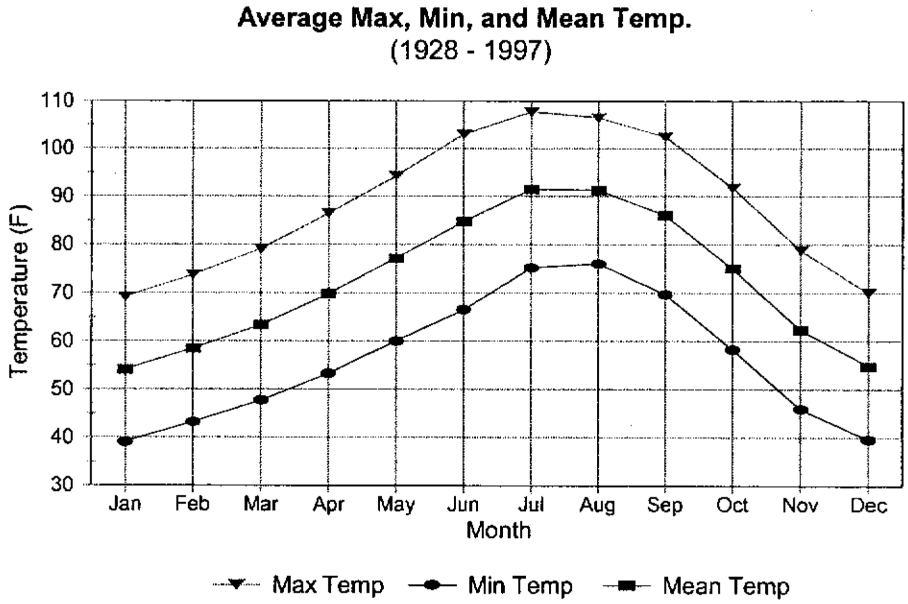


Figure III–1 Long-term Average Monthly Maximum, Minimum, and Mean Air Temperatures (1928–1997) in Brawley, California.

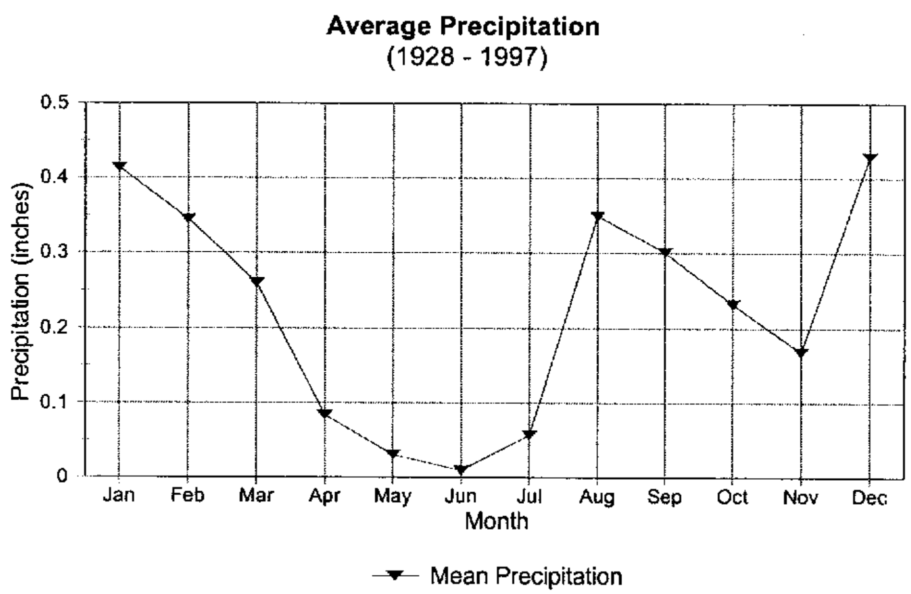


Figure III–2 Long-term Average Monthly Precipitation (1928–1997) in Brawley, California.

B. Reference Crop Evapotranspiration (ET_o)

ET is the sum of water evaporated from the soil and plant surface as well as water transpired by growing plants. Evaporation is the natural process by which water is transformed from a liquid to a vapor from a free water surface. Transpiration is the physiological process by which water, in the form of vapor, is released to the atmosphere through plant leaves. Therefore, crop evapotranspiration is the amount of water a crop needs for growth.

ET_o is defined as the potential ET rate from a reference crop under optimal conditions. Grass and alfalfa are the two crops that have been used around the world as reference crops. For this study, the ET_o was determined using grass as the reference crop. The reference crop is defined as clipped grass with a fixed height, which is actively growing, completely shading the soil, and well watered. The ET_o is developed to provide a reference to which ET from other crops can be related so that the ET of a specific crop can be estimated without defining a separate ET level for each crop and stage of growth. Since the ET_o is independent of crop type, stage of growth, and management practices, the only factors that affect ET_o are climatic parameters. Therefore, ET_o represents only the evaporating power of the atmosphere at a specific location and time of the year, irrespective of crop and soil characteristics.

1. *California Irrigation Management Information System (CIMIS) Data*

Three CIMIS weather stations in the Imperial Valley are used as sources for the weather parameters required to estimate crop water requirement. CIMIS is a network of automated weather stations that were used for the estimation and dissemination of ET_o data. Relevant CIMIS data is attached in Appendix 4.

2. *ET_o Estimation Methods*

Based on the results of a large number of ET field studies worldwide (Jensen et al., 1990; Allen et al., 1994b) and the incorporation of more physiologically and aerodynamically based parameters, the Penman-Monteith method has been recommended by an Expert Consultation held in May 1990 (Smith et al., 1991) as the standard for determining ET_o. The new method has been proved to have a global validity as a standardized reference for grass ET and has found recognition both by the International Commission for Irrigation and Drainage and by the World Meteorological Organization (Smith et al., 1991). Jensen et al., (1990), in their evaluation of the various ET estimating methods in arid locations such as Davis and Brawley, California, have ranked the Penman-Monteith method as the most accurate monthly ET_o estimates among the twenty ET estimating methods evaluated. The ranking method for evaluation was based on the standard error of estimate calculated between monthly ET_o estimates and lysimeter measurements. Some of the top ranking methods are 1982 Kimberly-Penman, FAO-24 Radiation, 1963 Penman (original Penman wind function), and FAO-24 Penman methods. The Penman-Monteith, 1982 Kimberly-Penman, and 1963 Penman had the lowest standard errors of estimate over all months (0.41, 0.45, and 0.54 mm/day, respectively) compared to the lysimeter-measured ET_o.

NRCE has selected the FAO Penman-Monteith (FAO P-M) method as presented in the FAO Irrigation and Drainage Paper #56 (FAO#56) (Allen et al., 1998) (i.e., an update and revision to the former FAO#24) for calculating the reference ET_o instead of using the CIMIS Penman equation. A detailed explanation of this method is provided in Appendix 5.

C. Crop Evapotranspiration

The FAO-PM method was implemented to compute the grass ET_o under ideal conditions where the crop completely shades the soil, has a fixed height, and never lacks water. To determine potential ET_c or the crop water requirement of a specific crop, an additional factor, commonly known as a crop coefficient, is introduced to convert the evaporation rates of grass to that of the actual crop. The crop coefficient values are a function of crop type, crop growth stages, weather conditions, and soil ET. The methodology of this single crop coefficient approach was followed as outlined in the FAO#56 (Allen et al., 1998). Cropping patterns and their respective growing seasons were also determined for the study area for each of the years from 1988 to 1997. Effective precipitation was estimated to derive the net irrigation requirement (NIR).

1. *Single Crop Coefficient Approach*

Factors that affect ET_c are weather parameters, crop characteristics, environmental conditions, and management practices. In the crop coefficient approach, ET_c of a particular crop may be determined simply by multiplying the grass reference ET_o by the crop coefficient, K_c, as shown in the following equation:

$$ET_c = K_c\left(ET_o\right) \qquad \textbf{(III–1)}$$

where:

ET_c = Crop evapotranspiration (mm/day)

K_c = Crop coefficient (dimensionless)

ET_o = Reference crop evapotranspiration (mm/day)

Thus, the ET_c equation is composed essentially of two components. The K_c term basically represents an integration of the effects of the differences in crop characteristics and the environmental conditions between a specific crop and the grass reference. It is essentially the ratio of ET_c and the grass ET_o, (ET_c/ET_o). The ET_o term of the ET_c equation (Equation III-1) incorporates most of the effects of the local weather conditions on the grass reference crop.

There are two approaches that may be used to determine ET_c based on the crop coefficient methodology. In the single crop coefficient approach, single-valued crop coefficients are used to represent the combined effects of soil evaporation and crop transpiration rate. Therefore, the value of the single crop coefficient, K_c, is developed by averaging it over time. This time-averaged crop coefficient may only be used to evaluate ET_c on weekly or longer time period basis since it cannot reflect the daily effects of soil evaporation due to irrigation or precipitation.

In the dual crop coefficient approach, the K_c coefficient is divided into two separate individual coefficients (i.e., K_{cb} and K_e) as indicated in Equation III-2 to account for the effects of crop transpiration and soil evaporation, respectively.

$$K_c = K_{cb} + K_e \qquad \textbf{(III–2)}$$

Where:

K_c = Crop coefficient (dimensionless)

K_{cb} = basal crop coefficient

K_e = soil water evaporation coefficient

The K_{cb} coefficient represents the baseline potential K_c without effects from soil wetting events. The K_e coefficient is the soil surface evaporation component of the overall crop evapotranspiration. The value of K_e is dependent on the amount of soil wetting. The value is higher just after irrigation or rainfall, and it decreases as the soil surface dries. A daily water balance analysis is required to estimate the value of K_e. For this study, the single coefficient approach was implemented for the ET_c analysis. It is sufficiently accurate for our purposes since we are only concerned about the estimates of average ET_c on a monthly basis.

a. Crop Characteristics

The types and varieties of crops affect ET_c, even though the crops may have identical environmental conditions. These crop-dependent variations in ET_c are caused by differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover, and crop rooting characteristics. The characteristics of a crop such as its albedo, crop height, aerodynamic properties, and physiological properties, are all contributing factors that determine the value of the crop coefficient. Plants that have closer spacings and taller canopy height and roughness have crop coefficient (K_c) values greater than 1. For example, for mature corn and sorghum, which are tall, their K_c values may be 15 to 20% higher than the reference crop (i.e. a K_c value of 1.15-1.20). However, for plants with large leaf resistances that have leaves with stomata on only the lower side of the leaves such as citrus and deciduous fruit trees, the K_c values are smaller.

b. Crop Growth Stages

Unlike the grass reference crop, which has a hypothetical fixed height, the ground cover, leaf area, and height of an agricultural crop changes as the crop grows. The ET_c also varies as it develops into maturity because of these physiological changes. Consequently, the crop coefficient, K_c, varies accordingly over the growing period.

A crop's growing period may be divided into four growth stages. A crop coefficient curve consisting of four straight lines is developed to model the four major growth stages in a specific crop (see Figure III-3). The initial growth stage covers the period from the planting date to approximately 10% ground cover. $K_{c\ ini}$ represents the initial K_c value just after planting of annuals or shortly after the initiation of new leaves for perennials.

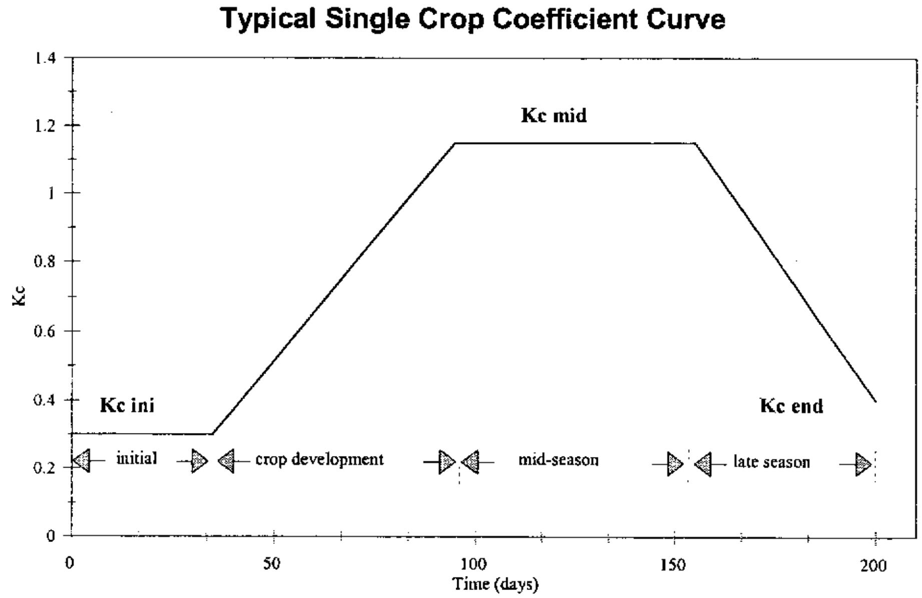


Figure III-3 Typical Single Crop Coefficient Curve With its Four Stages of Growth.

The crop development stage is 10% ground cover to effective full cover. During the crop development stage K_c increases from $K_{c\ ini}$ at the beginning of rapid plant development to a maximum threshold, $K_{c\ mid}$ at or near the peak of plant development. It is then followed by the mid-season stage which begins at effective full cover and continues to the start of maturity as the crop continues to grow at a relatively constant $K_{c\ mid}$ level until it reaches the beginning of the late season when leaves begin to age and dry up.

The late season stage covers the period from the beginning of crop maturity to harvest and K_c decreases to a point represented by $K_{c\ end}$, which is the end of the growing period. The value of $K_{c\ end}$ is very much influenced by the crop and water management practices during the crop's late season stage. If the crop is frequently irrigated until the crop is harvest fresh, the $K_{c\ end}$ value will be high but if the crop is allowed to dry out before harvesting, the $K_{c\ end}$ value will be low. Table III-1 contains the standard single crop coefficients pertinent for the study for the various growth stages as referenced in FAO#56 (Allen, et al., 1998). Table III-1 also includes a set of crop coefficients which have been adjusted for the conditions in IID. The various procedures performed for the K_c adjustments are discussed in the following sections.

Table III–1 Published FAO#56 Single Crop Coefficients for Standard Conditions and Adjusted Crop Coefficients for the Conditions of the Imperial Valley.

	FAO #56 (Std Cond.)			For Imperial Valley (Adj)		
	K_c ini	K_c mid	K_c end	K_c ini	K_c mid	K_c end
Field Crops						
Alfalfa *	0.40	0.95	0.90	0.40	1.01	0.96
Alfalfa Winter	---	---	---	0.40	1.09	1.02
Alfalfa Seed	0.40	0.50	0.50	0.40	0.58	0.56
Bermuda Grass Hay *	0.55	1.00	0.85	0.55	1.05	0.90
Bermuda Grass Seed	0.35	0.90	0.65	0.35	0.96	0.72
Cotton	0.35	1.15	0.50	0.35	1.17	0.57
Oats & Barley	0.30	1.15	0.25	0.30	1.18	0.25
Rye Grass *	0.95	1.05	1.00	0.95	1.08	1.06
Sudan Grass *	0.50	0.90	0.85	0.70	0.97	0.92
Sugar Beets	0.35	1.20	0.70	0.75	1.22	0.77
Wheat	0.70	1.15	0.25	0.70	1.21	0.34
Misc. (use field corn)	0.30	1.20	0.60	0.30	1.26	0.69
Garden Crops						
Broccoli	0.70	1.05	0.95	0.70	1.06	0.97
Cabbage	0.70	1.05	0.95	0.70	1.06	0.98
Carrots	0.70	1.05	0.95	0.80	1.07	1.00
Cauliflower	0.70	1.05	0.95	0.70	1.06	0.96
Corn, Ear	0.30	1.15	1.05	0.70	1.24	1.15
Lettuce – Early	0.70	1.00	0.95	1.05	1.03	0.96
Lettuce – Late	0.70	1.00	0.95	1.05	1.01	0.97
Cantaloupes-Fall	0.50	0.85	0.60	0.50	0.89	0.61
Cantaloupes-Spring	0.50	0.85	0.60	0.55	0.91	0.66
Honeydew	0.40	1.00	0.75	0.70	1.06	0.82
Water Melons	0.40	1.00	0.75	0.70	1.06	0.82
Onions	0.70	1.05	0.75	0.85	1.08	0.82
Onion Seed	0.70	1.05	0.80	0.85	1.08	0.87
Tomatoes	0.60	1.20	0.80	0.60	1.28	0.89
Potatoes	0.50	1.15	0.75	1.00	1.18	0.81
Misc. (use peppers)	0.70	1.15	0.90	0.70	1.17	0.94
Permanent Crops						
Asparagus	0.50	0.95	0.30	0.50	1.02	0.30
Citrus	0.70	0.65	0.70	0.70	0.74	0.75
Duck Ponds				0.40	0.70	0.40
Jojoba				0.50	0.65	0.50
Fish Farms				0.70	0.70	0.70
Permanent Pasture + Misc.	0.40	0.95	0.85	0.40	1.00	0.89
Peach Trees (bare soil)	0.55	0.90	0.65	0.55	1.00	0.68

* Seasonal average K_c

Primary Sources: $K_{c\ ini}$: Doorenbos and Kassam (1979)
$K_{c\ mid}$ and $K_{c\ mid}$: Doorenbos and Pruit (1977), Pruitt (1986)
Wright (1981, 1982), Snyder et al. (1989a, 1989b)

c. Climatic Conditions

The aerodynamic properties of a crop vary not only from crop to crop, but also with wind speed and relative humidity. Therefore, the crop coefficients, K_c, are not only crop dependent, but also climate dependent. The effects of wind and relative humidity on K_c become more dramatic when the crop is substantially taller than the fixed height grass reference. The lower the relative humidity and the higher the wind speed, the higher the K_c value for a specific crop. The FAO#56 standard K_c values indicated in Table III-1 are based on standard conditions of a sub-humid climate with a minimum relative humidity of 45% and an average wind speed of 2.0 m/s (4.47 mph). When local weather conditions deviate from the standard conditions, the K_c values need to be modified accordingly. Guidelines are described in the FAO#56 (Allen, et al., 1998) for adjusting the standard K_c values as a function of weather factors due to wind speed and relative humidity and crop height. The published standard K_c values were modified for non-climatic conditions in the Imperial Valley. The adjustments to $K_{c\ mid}$ and $K_{c\ end}$ of the mid and end season growth stages for the various crops in IID were determined using the following equations:

$$Kc_{mid} = Kc_{mid}\,(std.\ conditions) + [\ 0.04\,(u_2 - 2) - 0.004\,(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \qquad \textbf{(III–3)}$$

$$Kc_{end} = Kc_{end}\,(std.\ conditions\ ) + [\ 0.04\,(u_2 - 2) - 0.004\,(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \qquad \textbf{(III-4)}$$

where:

$K_{c\ mid,\ end}$ (std. conditions)	=	$K_{c\ mid,\ end}$ values published in FAO#56 for standard conditions
u_2	=	mean value for daily wind speed at 2 m height over grass during the mid-season or end-season growth stage (m/s), for 1 m/s ≤ u_2 ≤ 6 m/s
Rh_{min}	=	mean value for daily minimum relative humidity during the mid-season or end-season growth stage (%), for 20% ≤ RHmin ≤ 80%
h	=	mean plant height during the mid-season or end-season stage (m) for 0.1 m ≤ h ≤ 10 m

Equation III-3 is only applicable when the published $K_{c\ end}$ (standard conditions) is greater than 0.45. Otherwise, when $K_{c\ end}$ (standard conditions) is less than 0.45, $K_{c\ end}$ is equal to $K_{c\ end}$ (standard conditions). The adjusted $K_{c\ mid}$ and $K_{c\ end}$ for the Imperial Valley are listed next to the standard K_c's in Table III-1 and were used to determine crop ET_c.

During the initial stage of crop growth, ET is primarily dominated by soil surface evaporation because of the small leaf area and little ground shading. Since the single crop coefficient approach integrates both the effects of soil water evaporation and crop transpiration into a single crop coefficient, the $K_{c\ ini}$ value will be small when the soil is dry and large when the soil is wet, such as following an irrigation or rainfall event. The $K_{c\ ini}$ for the various agricultural crops shown in Table III-1 represents values that are evaluated under standard growing conditions with typical cultivation and irrigation management practices. Since the irrigated settings in the Imperial Valley are unique, the $K_{c\ ini}$ values would also need to be adjusted for the local conditions in IID. When the plant is just starting out, there is not much vegetative cover to shade the ground. Thus, after an irrigation or rain event, the evaporative loss on the wet soil surface will be high such that the $K_{c\ ini}$ may exceed 1. When the soil surface is dry, evaporation is minimal and $K_{c\ ini}$ may drop as low as 0.1. To appropriately estimate the value of $K_{c\ ini}$, the time interval between wetting events, the evaporative power of the atmosphere (ET_o), and the magnitude of the wetting events will need to be considered. It is common in the Imperial Valley to flood irrigate the field a few days between crops for leaching as well as to apply water prior to planting (pre-plant) to fill up the root zone for land preparation. The prevailing special irrigation practices for the crops in IID before planting and during the initial stage of growth are presented in Appendix 6A (Mayberry, (2000) and UCCE, (1997 and 1999)).

Many of the vegetable crops require frequent sprinkle irrigation in the first few weeks of germination to keep the soil moist and the crops cool. The common practice for small-seeded vegetables, which include lettuce, broccoli, cauliflower, and cabbage, is to sprinkle irrigate with a program of 24-hours on and 24-hours off, and then 12-hours on and 12-hours off, followed by 6-8 hours of irrigation per day for a total of about 5-7 days. Carrots and onions take longer to germinate so sprinkle procedures are extended to around 10-14 days. The $K_{c\ ini}$ values for crops which have frequent irrigations in the initial growth stage were determined by using the curves presented in Appendix 6B. The time intervals between wetting events were estimated by dividing the amount of days in the crop initial growth period by the approximated frequency of irrigation events. Since the normal application rate for sprinkler irrigation is about 0.1 inch per hour, the average infiltration depths for the irrigation events were assumed to be greater than 40 mm (1.6 inches). Soils of medium and fine soil textures were assumed for the crops. The modified $K_{c\ ini}$ are listed in Table III-1 along with the other adjusted crop coefficients for the various growth stages.

The amount of bare soil evaporation may also be significant following special pre-plant irrigations such as leaching and other pre-plant flooding practices. Due to the scarcity of precipitation amount and frequency in the Imperial Valley, the amount of surface soil water evaporation due to precipitation was assumed to be negligible. Therefore, only the amount of soil surface evaporation resulting from special irrigations was estimated according to the calculation procedures described in the FAO#56 (Allen et al., 1998) for determining bare soil ET.

D. Cropping Patterns, Acreage, and Growing Seasons

IID produces a diverse array of agricultural crops. The personnel at the various water divisions of IID log the crop acreage information for each of the fields into a cropping database on a daily basis. According to the Monthly Crop Acreage Report of IID, the crop acreage recorded on the

13th day of the month in the daily database is used to represent the average crop acreage grown for that month. The Monthly Crop Acreage Reports for the various crop categories from January 1989 to January 2000 were received from IID. NRCE also acquired and examined an IID database that contains the planting and harvest dates of all the crop categories listed by field reported for the years 1989 to 1998.

1. *Cropping Patterns and Acreage*

IID has categorized a total of 170 specific crops and 15 more land uses for its crop acreage database. The crop categories are classified into three main crop groups, which are field crops, garden crops, and permanent crops. For the purpose of simplifying the calculations involved in determining ET_c, the 170 crop categories were lumped into 31 major crop categories. Accordingly, there are 10 categories in the field crop group, 14 crop categories in the garden crop group, and 7 categories in the permanent crop group. There is also a miscellaneous crop category for each crop group that consists of the remaining crops that are not one of the 31 major crop categories.

Appendix 6C contains the seasonal crop acreages for all of the 31 crop categories summarized from the IID Monthly Crop Acreage Report for the calendar years 1989 to 1998. When a crop's growing season overlaps two consecutive years, the crop's seasonal acreage is assigned to the year in which the crop is harvested. For example, carrots are normally planted in the fall and harvested in the following spring. So, for the 1989 to 1990 growing seasons, the maximum monthly acreage reported in the 1989-1990 season will be used to indicate the annual crop acreage for 1990. Since the IID Monthly Crop Report is based on the calendar year starting in January of 1989, the crop acreages which have the 1988-1989 growing season (i.e., crops planted in 1988 and harvested in 1989) would not be fully accounted for due to the lack of 1988 acreage data. Therefore, the crop water requirement analysis was performed only for the calendar year period from 1990 to 1997.

In regard to the annual field crops, the seasonal crop acreages shown in Appendix 6C are based on the maximum monthly acreage values for the growing season. However, for perennial forage crops such as alfalfa, alfalfa seed, bermuda grass, bermuda grass seed, sudan grass, and sudan grass seed, the acreages presented in Appendix 6C were obtained by averaging the monthly crop acreage values over the 12-month season except for sudan grass which is represented by the maximum monthly acreage. The monthly acreage summary for alfalfa, bermuda grass, sudan grass, and their respective seed crops is shown in Appendix 6D. The forage perennial crops vary quite substantially from month to month. Thus, ET computations for the perennial crops were computed based on monthly acreage values. The annual garden crops seasonal crop acreages shown in Appendix 6C, were estimated by the maximum monthly acreages because the maximum acreage is the total actual acreage of the annual crops grown. Since permanent crops do not vary significantly from month to month, the averages of the monthly acreages were representative.

2. *Growing Seasons*

The growing season, which is closely tied to temperature, has a major influence on the seasonal plant water use. The growing season is frequently considered to be the period between killing frosts. However, in the Imperial Valley, different crops are grown throughout the year in the warm desert climate. The yearly growing seasons from 1988 to 1997 for the major crops in this study were determined based on the actual planting and harvest dates for the various fields recorded in the cropping database supplied by IID.

For each growing season, the planting date was estimated by the date at which 50% of the total planted acreage of an annual crop category had been planted. Similarly, the harvest dates of a crop category were determined by choosing the date at which 50% of the total crop acreage had been harvested. Most of the growing seasons computed were within the range of the typical planting and harvesting dates published in Circular 104-F (1996-1997), and Circular 104-V (1998-1999) of the University of California Cooperative Extension (UCCE, 1997, and UCCE, 1999). The University of California web site for Vegetable Research and Information Center (http://vric.ucdavis.edu/) also provides general information on cropping dates and irrigation practices. There are some years in which the growing seasons of a crop were inadequately recorded or computed out of the normal range. For consistency, these out of range dates were replaced by the average dates of the other plant-harvest dates that were within the normal range.

The lengths of the four distinct growth stages for the IID crops are based on the general growth stage lengths provided in the FAO#56 (Allen, et al., 1998) for the various regions in the world with minor adjustments. The desert region of California is one of the regions included in the crop growth stage data for many of the crops. The estimated planting and harvest dates and the periods of crop growth stages for each of the years in the study are listed in Appendix 6E. Due to the cultural practices of allowing some crops to dry out before harvesting (i.e., early irrigation cutoff), the lengths of the late season stages for crops like wheat, sugar beets, onions, and rye grass have been shortened to account for the low ET_c rate at the end of the season. The number of days cut short in the late season growth stages were estimated to be about 20, 15, 10, and 35 days for wheat, sugar beets, onions, and rye grass, respectively.

E. Effective Precipitation

Growing season effective precipitation (EP_g) is that portion of the total precipitation (P_T) that satisfies or reduces ET_c requirements. The remainder of the rainfall is lost either by deep percolation below the root zone, surface runoff, or direct evaporation of water intercepted by the plant foliage. Therefore, the rainfall that can be effectively used by crops is dependent upon the amount, timing, and intensities of rainfall, soil permeability, the soil's water-holding capacity, runoff characteristics, and the rate of ET_c. Hence, in order to determine the amount of irrigation water that the crop actually needs, it is important to estimate the portion of monthly precipitation that the plants can directly use. In general, rainfall effectiveness increases with higher ET rates, greater allowed soil moisture depletions, and larger soil water storage capacities. Table III-2 shows the weighted average monthly precipitation for the three CIMIS stations in IID.

Table III-2 Weighted Average Monthly Precipitation (inches) in IID (1988-1997).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1988	0.22	0.77	0.00	0.18	0.00	0.00	0.00	0.56	0.00	0.10	0.00	0.00	1.82
1989	1.00	0.00	0.02	0.00	0.00	0.00	0.00	0.31	0.00	0.12	0.00	0.04	1.50
1990	0.12	0.12	0.09	0.02	0.16	0.11	0.00	0.54	0.32	0.33	0.00	0.00	1.81
1991	0.59	0.50	0.67	0.00	0.00	0.00	0.06	0.00	0.24	0.04	0.10	1.30	3.50
1992	0.59	1.00	2.25	0.22	0.24	0.00	0.00	0.00	0.00	0.45	0.00	1.39	6.13
1993	3.45	1.09	0.18	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.63	0.00	5.37
1994	0.12	0.45	0.52	0.00	0.31	0.00	0.00	0.08	0.14	0.05	0.19	0.70	2.56
1995	1.36	0.05	0.16	0.09	0.05	0.00	0.12	0.07	0.00	0.17	0.00	0.03	2.11
1996	0.04	0.16	0.21	0.00	0.01	0.00	0.04	0.07	0.00	0.15	0.03	0.10	0.80
1997	0.47	0.04	0.05	0.21	0.05	0.12	0.07	0.05	1.48	0.06	0.09	0.57	3.26
1988-1997	0.80	0.42	0.42	0.07	0.08	0.02	0.03	0.17	0.22	0.15	0.10	0.41	2.89

Effective rainfall for a given growing season may be estimated using the USDA-SCS (1970) technique as:

$$EP_g = f(D)(1.25\, P_T^{0.824} - 2.93)(10^{0.000955\, ET}) \qquad \textbf{(III–5)}$$

subject to $EP_g \leq P_T$

where,

EP_g = average monthly effective precipitation (inches)

P_T = average monthly total precipitation (inches)

ET = average monthly crop ET (inches)

D = normal depth of depletion prior to irrigation (set at 3.0 inches in this study)

$f(D) = 0.53 + 0.0116D - 8.94\times10^{-5}D^2 + 2.32\times10^{-7}D^3$.

F. Net Irrigation Requirement (NIR)

The NIR equals ET_c less the amount of water contributed by effective precipitation during the growing season. In essence, the net irrigation requirement is the water that needs to be replaced after the soil moisture in the root zone has been depleted due to consumptive use by the crop. The NIR is estimated on a monthly basis as:

$$NIR = ET_c - EP_g \qquad \textbf{(III–6)}$$

where,

NIR = average monthly net irrigation requirement (inches)

ET_c = average monthly crop evapotranspiration (inches)

EP_g = average monthly effective precipitation (inches)

The ET_c for each of the crop categories was determined on a daily basis based on Equation III-1 using the daily ET_o calculated from the FAO P-M equation and the crop coefficient curve developed in the previous section. The daily ET_c estimates were then summed up to represent monthly ET_c values. Appendix 6F shows the monthly ET_c for the 31 crop categories for calendar years 1990 to 1997. The monthly NIR tabulated in Appendix 6G were computed by subtracting the monthly effective precipitation from the estimated monthly ET_c. Table III-3 is a summary of the annual crop water requirement volumes for the cropping patterns in IID from 1990 to 1997 including other irrigation practices water requirements. The values were computed using the calculated ET_c and the estimated crop acreages as shown in Appendices 6F and 6C, respectively. The average contribution of EP_g to the crop water requirement is relatively small accounting for about 2.5% of the crop consumptive use.

Table III-3 Annual Volumes (acre-feet) of Crop Evapotranspiration (ET_c), Effective Precipitation (EP_g), and Net Irrigation Requirement (NIR) (1990-1997).

	1990	1991	1992	1993	1994	1995	1996	1997	1990-1997
ET_c	2,189,022	1,915,359	1,815,303	1,928,090	2,110,738	2,112,166	2,173,592	2,114,972	2,046,155
EPg	34,148	45,707	114,939	94,953	35,264	34,320	6,762	47,217	51,664
NIR	2,154,875	1,869,651	1,700,364	1,833,137	2,075,474	2,087,846	2,166,830	2,067,754	1,994,491

Less than ideal management and environmental conditions such as high salinity, low soil fertility, low soil water content, impermeable soil horizons, pests, and diseases may all contribute to reducing the optimal ET_c, or yield. Standard ideal conditions were assumed when predicting the potential ET_c using the crop coefficient approach. The resulting ET_c represents the upper envelope of ET_c where no limitations are placed on crop growth due to water deficit, crop density, disease, weed, insect, or salinity effects.

In the case of the Imperial Valley, due to the characteristics of heavy cracking soils in most of the valley soils (discussed in detail in the next section), it is difficult, if not impossible, to completely satisfy the root zone water deficiency in an irrigation event under the on-farm irrigation management practices. Such shortage of available water in the root zone and the effects of high soil salinity will result in less than optimal crop production or potential ET_c.

Research data on crop water use and related yields for alfalfa and corn indicate that potential yields and corresponding ET_c under ideal conditions may be 20 and 10% greater than actual field yields and corresponding ET_c for alfalfa and corn, respectively (Hill et al., 1983). In other words, ET_c of forage crops grown under field conditions may be 20% lower than the theoretically estimated ET_c. For the other crops, the field ET_c would need to drop 10% from the theoretical estimates to reflect actual field ET_c.

Table III-4 is a summary of the annual water requirement volumes for the cropping patterns in IID from 1990 to 1997 after incorporating other irrigation practices water requirements and ET_c reductions to reflect actual field conditions.

Table III-4 Annual Volumes (acre-feet) of the Reduced Crop Evapotranspiration (ET_c), Effective Precipitation (EP_g), and Net Irrigation Requirement (NIR) (1990-1997).

	1990	1991	1992	1993	1994	1995	1996	1997	Average
ET_c	1,865,625	1,621,563	1,535,804	1,630,525	1,775,654	1,787,638	1,847,281	1,794,577	1,732,333
EPg	32,390	44,527	111,414	88,462	33,912	33,728	6,549	44,936	49,490
NIR	1,833,235	1,577,035	1,424,390	1,542,063	1,741,742	1,753,909	1,840,732	1,749,641	1,682,843

1. *Diversion Requirement*

The water that must be supplied to a given crop is equal to the ET_c. Some of this water requirement is satisfied by EP_g; thus, the NIR was developed by subtracting EP_g from ET_c. In addition to the NIR, which is to satisfy the crop's water uptake, there are other water requirements that the crops need for proper plant growth in the Imperial Valley. Special irrigations are scheduled throughout the growing season to meet the extra water demands for reclamation and maintenance leaching, and pre-plant and germination irrigations as discussed in other sections of this report. The amount of water typically applied in the Imperial Valley for pre-plant and germination irrigations were estimated and are listed in Appendix 6A (Mayberry, 2000 and UCCE, 1997 and 1999). The annual volumes required for all irrigations, including special irrigations, are included in Table III-3 and III-4.

Since efficiency is never 100 percent, allowances must be made to compensate for matters such as surface runoff, deep percolation, canal seepage, evaporation, and canal operations. Further, as examined in detail in Chapter IV, the nature of IID's soils requires additional leaching. Subsequently, more irrigation water is required than that of NIR plus the special irrigations. In order to determine IID's diversion requirement (the total water supply at the point of diversion for IID) the on-farm and canal distribution efficiencies must be estimated. The on-farm efficiency is the ratio of water stored in the root zone to the applied water at the field turnout, while the canal distribution efficiency is the ratio of water delivered at the field turnout to the irrigation water delivered from the AAC to IID canals.

REFERENCES:

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. (1998). "Crop evapotranspiration guidelines for computer crop water requirements," *FAO Irrigation and Drainage Paper No. 56*, FAO, Rome, Italy.

Allen, R.G., Smith, M., Perrier, A., and Pereira, L.S. (1994). "An update for the calculation of reference evapotranspiration." *ICID Bulletin 43(2),* 35-92.

Doorenbos, J. and Kasam, A.H. (1979). "Yield response to water." *FAO Irrigation and Drainage Paper No. 33*, FAO, Rome, Italy.

Doorenbos, J. and Pruitt, W.O. (1977). "Crop water requirement." *FAO Irrigation and Drainage Paper No. 24. (rev.)*, FAO, Rome, Italy.

"Guidelines to production costs and practices for Imperial County." (1996-1997). (1997). *UCCE Field Crops Circular 104-V*, University of California, Imperial County, Cooperative Extension, Holtville, CA.

"Guidelines to production costs and practices." (1998-1999). (1999). *UCCE Vegetable Crops Circular 104-V*, University of California, Imperial County, Cooperative Extension, Holtville, CA.

Hill, R.W., Johns, E.L., and Frevert, D.K. (1983). "Comparisons of equations used for estimating agricultural crop evapotranspiration with field research." U.S. Department of the Interior, Bureau of Reclamation.

Jensen, M.E., Burman, R.D., and Allen, R.G. (Ed). (1990). "Evapotranspiration and irrigation water requirements." *ASCE Manuals and Reports on Engineering Practices No. 70*, American Society Civil Engineers, New York, NY.

Mayberry, K.S. (2000). Personal communications. Vegetable Specialist, University of California Cooperative Extension (UCCE), Imperial, California.

Pruitt, W.O. (1986). "Traditional methods 'evapotranspiration research priorities for the next decade'." *ASAE Paper No. 86-2629.*

Smith, M.R., Allen, R.G., Monteith, J.L., Pereira, L.S., and Segeren, A. (1991). "Report on the expert consultation on procedures for revision of FAO guidelines for predicting crop water requirements." FAO, Land and Water Developmental Division, Food and Agricultural Organization of the United Nations, Rome, Italy.

Snyder, R.L., Lanini, B.J., Shaw, D.A., and Pruitt, W.O. (1989a). "Using reference evapotranspiration (ET_0) and crop coefficients to estimate crop evapotranspiration (ET_c) for agronomic crops, grasses, and vegetable crops." Cooperative Extension, Univ.

California, Berkeley, California, Leaflet No. 21427.

Snyder, R.L., Lanini, B.J., Shaw, D.A., and Pruitt, W.O. (1989b). "Using reference evapotranspiration (ET_0) and crop coefficients to estimate crop evapotranspiration (ET_c) for trees and vines." Cooperative Extension, Univ. of California, Berkeley, California, Leaflet No. 21428.

Irrigation water requirements, technical release no. 21 (TR#21). (1970). USDA-SCS United States Department of Agriculture, Soil Conservation Service.

Wright, J.L. (1981). "Crop coefficients for estimates of daily crop evapotranspiration. Irrigation scheduling for water and energy conservation in the 80s." American Society of Agricultural Engineers (ASAE).

Wright, J.L. (1982). "New evapotranspiration crop coefficients." *Journal of Irrigation and Drainage Diversion*, ASCE, 108:57-74.

IV. THE NATURE OF IID'S SOILS CREATES AN INCREASED WATER NEED

Earlier studies have indicated that the heavy, cracking nature of most of IID's soils creates an additional need for water to leach mineral salts. To confirm the findings of previous research and to obtain additional data concerning on-farm irrigation management and efficiency, NRCE conducted field irrigation evaluations during July and August of 2000. The evaluations were also used to document differences in irrigation practices and efficiencies between heavy cracking, medium, and light soils. Of particular concern was the assessment of the salinity balance of the field required to maintain agricultural productivity. Appendix 7 is a review of IID's fieldwork. NRCE's fieldwork showed that:

- The majority of IID's soils require more leaching water than the standard leaching equation indicates.
- Prior critics of IID's tailwater generally ignored the critical effect of the nature of the soil.

A. Previous Studies Related to the Behavior of IID Cracking Soils Support the Need for Tailwater for Horizontal Leaching

The tendency of the heavy soils of Imperial Valley to crack when dry is a very important feature that distinguishes them from other soils, in that the formation of cracks greatly changes the manner in which irrigation and leaching water behave within the soil. Once cracked, the root zone of the field is no longer homogenous but is instead a set of soil peds within a matrix of air or water, if saturated. The rate at which water moves through the cracks is extremely rapid compared to the movement of water through the soil ped. This has ramifications relating to infiltration, water availability to crops, and the leaching process. Many papers have been written on this subject, and most are relatively recent in publication. Normally accepted irrigation practices and technology do not adequately reflect IID-types of field conditions, as this newer research indicates.

The following are summaries of some of the investigations of soil/water behavior under conditions of heavy cracking soils. The results and conclusions of these investigations strongly suggest that these soil conditions require special consideration with regard to water uses and leaching requirements.

Kaddah and Roades, 1976. <u>Salt and Water Balance in Imperial Valley, California</u>.

Kaddah and Rhoades (1976) reported that:

> "In the well drained soils in the valley, salts leach during the crop season as well as the preplanting irrigation(s). In many of the fine textured soils of the valley, however, infiltration is so slow that it is difficult to apply enough water to even meet ET needs. Salt leaching in such soils as well as other saline soils usually is achieved only between cropping seasons through preplanting

> irrigation(s) or with continuous ponding for a few weeks or a few months."

Crop production could potentially be limited by soils with low permeability. This is evident during times of high crop water demand when low permeability prevents adequate irrigation water infiltration to meet crop ET and leaching requirements. Therefore, crop yields could be reduced unless the effects are compensated by special management techniques.

M.E. Grismer, 1986. <u>Irrigation, Drainage, and Soil Salinity in Cracking Soils</u>.

Field evaluations of cracking soils found within the Imperial Valley done by Grismer in (1986), show that soil cracks control water movement and salt leaching within a field and should therefore be considered in irrigation and drainage design and management. Grismer stated:

> "Spatial and temporal variability of water movement and soil salinity in cracking field soils results in unique and complex problems not well understood. Problems of particular concern to designers of irrigation and drainage systems for such fields are related to managing water application uniformity, adequate leaching of the root zone for salinity control, and satisfactory aeration of the root zone. Although soil cracking is a common phenomenon, available information is predominantly observational. It has been recognized that cracking is beneficial to drainage and soil aeration, and as such, it is important to crop productivity (Penman and Schofield, 1941). Similarly, in Egypt, large cracks appearing during the summer fallow periods provide channels for movement of excess salt from the root zone."

Grismer made additional conclusions based on field experiments on heavy clay soils:

1) "Results of the evaluations identified that water movement within soil cracks controlled the water application uniformity, soil profile wetting, salt leaching, and drain system response to irrigation.
2) Drain response to applied water occurred during the irrigation event despite extremely low permeability of the soil."

It is clear from these field evaluations that cracking soils in the Imperial Valley have tremendous impact on the design and management of irrigation and drainage systems. The aerial distribution of cracks and the depth of such cracks on the heavy soils of IID are also extensive. For example, Grismer noted:

> "From observations of a linear advance trajectory of the border irrigation field, crack volume was estimated as 1600 meter cube per hectare. Maximum water contents at depths of approximately 0.7 meters (2.3 feet) immediately following irrigation appeared to correspond with the effective crack depth. From these

> observations, cracks comprised nearly 23% of the field surface area. Drain response to applied water occurred during the irrigation event despite extremely low permeability of the soil. Soil salinity exceeded drain water salinity implying occurrence of minimal leaching."

Conventional wisdom assumes that water movement through the soils of a field takes place via pore transmission and not as a result of macro discontinuities within the root zone. However, the extreme cracking nature of most of the Imperial Valley soils results in a multi-modal process of irrigation and drainage water transmission, which is not solely dependent on the pore permeability of the continuous soil phase. Due to the fact that the clay soils of IID are predominantly cracking soils, the surface permeability of these soils is dramatically increased when cracks are present. Yet, the degree to which water can infiltrate to and below the root zone is slowed at the depth of the cracks. Therefore, improvement in vertical penetration and leaching and root growth is limited by the low permeability of the uncracked soil below the cracked portion of the root zone. In other words, existence of cracks in the clay soils increases infiltration and water availability to plant roots within the cracked portion of the soil profile, and therefore enhance the solubility of soil salts.

Grismer and Bali, 1996. <u>Continuous Ponding and Shallow Aquifer Pumping Leaches Salts in Clay Soils.</u>

Grismer and Bali (1996) also conducted experiments involving continuous ponding of water on heavy clay soils within the Imperial Valley. The authors noted:

> "In the continuous ponding experiment, we measured steady infiltration rates of approximately 0.1 in/hr from both the staff gauges in the ponded area and the ring infiltrometers. This value is very close to the independently measured hydraulic conductivity of the clay. Inside the ponded area, soil water contents increased at all but the 6-foot depth over the first 10 days of continuous ponding and then stabilized. We noted, however, that 2 weeks were required for the soil water content to approach saturated values at the 2- and 3-foot depths. Soil water contents at the 5- and 6-foot depths decreased slowly as a result of lowering the water levels of the shallow aquifer. The average soil water content outside the ponded area remained practically constant at the 3-, 4- and 5-foot depths, increased and then decreased after 1 week of flooding at the 1- and 2-foot depths, and decreased at the 6-foot depth."

They also determined that the salinity of the root zone of the soil profile was lower after ponding. The authors stated:

> "At all locations, soil salinity tended to increase with depth both before and after flooding. In the top 2 feet, however, soil salinity remained roughly the same inside the ponded area or increased

> (outside the ponded area). The average salinity for the 4-foot soil profile as a whole decreased by 19.1% within the ponded area and by 12.5% outside the ponded area. This overall improvement in the soil salinity suggests that the 1-month period of ponding was sufficient to translocate some of the soil salt mass to a greater depth and perhaps into the shallow sand aquifer. Indeed, we found a slight though significant increase in drain-water salinity after about 14 days of continuous ponding, when water contents at all soil depths approached a constant value (fig 6). No such changes in soil salinity were observed during the 3-year irrigated experiment (though there was an overall slight decrease in drain-water salinity) nor during the previous decades of measurements prior to installation of the skimming well system."

The researchers found that the salinity of the soil tended to increase with depth, with the exception of the upper two feet which remained "roughly the same inside the ponded area or increased outside the ponded area." It was determined that it took from several days to nearly two weeks of continuous ponding to saturate the upper 3 feet of soil, as well as several days or weeks to leach salts from the soil. In order to sufficiently leach salts from heavy clay soils, continuous ponding of water was required for about a month. Therefore, it can be concluded that heavy clay soils with very low infiltration rates require several days for the root zone to recharge, while many days or weeks are required to leach salts from the root zone.

The heavy clay soils of the Imperial Valley are so tight that vertical penetration of water is quite slow and requires long-term ponding of irrigation water for effective vertical leaching of salts below the root zone. Due to the low infiltration rate of the heavy cracking soils, it becomes difficult to recharge the root zone of the soil in a timely fashion. This has direct impacts on crop yields, since at times the rate of recharge is less than the rate of crop consumptive use.

Oster, Meyer, Hermsmeier and Kadah, 1984. <u>Imperial Valley: Irrigation, Drainage, and Runoff</u>.

Oster et al. (1984) stated:

> "How much surface runoff water reaches the Salton Sea? About 0.4 million acre-feet, based on an Agricultural Research Service (ARS) and Imperial Irrigation District (IID) irrigation efficiency study conducted on nine fields for five years (1977-1981). This volume represents about 16 percent of the on-farm water deliveries in the Imperial Valley and about 29 percent of the total inflows to the Salton Sea. The data also suggest on-farm infiltration of applied water was from 0.2 to 0.4 million acre-feet less than the amount required to meet full crop evapotranspiration."

Oster et al. (1984) have concluded that a portion of the applied irrigation water is not infiltrating into the root zone but instead contributes to runoff. According to Oster et al. (1984), these tight soils deprive crops from receiving 200,000 to 400,000 acre-feet of water per year throughout

IID. Due to the heavy cracking nature of the majority of the soils in IID, about 16% of the applied irrigation water runs off rather than contributing moisture to the root zone or assisting with the leaching of salts vertically. Given this study, it is apparent that without considering leaching between cropping, horizontal leaching, and irrigation leaching, the irrigation efficiency is already 84%.

Lonkerd, Ehlig, and Donovan, 1979. Salinity Profiles and Leaching Fractions for Slowly Permeable Irrigated Field Soils.

Lonkerd et al. (1979) conducted a study that also sheds light on the matter of irrigation, soils, and leaching. These authors endeavored to "determine the amount and variability status of salinity leaching fractions in four representative Imperial Valley soils planted to alfalfa, cotton, lettuce, sugar beet, and wheat."

The four soil series considered in their study include: 1) Holtville, which is a primarily fine textured soil overlying loam soils; 2) Imperial, which is a fine textured soil; 3) Indio, which has a control section of coarse silty soils; and 4) Meloland, which has a coarse loamy texture overlying fine textured soils. In their study, Lonkerd et al. took soil samples in 30-cm increments to a depth of 150 cm. The soil samples were used to determine soil saturation percent (SP), EC_e of the soil water extract, chloride ion concentration (Cl_e) of the soil, and water content (Pm) of the soil. Finally, they determined the leaching fraction (%) based on the equation:

$$LF = Cl_{iw}/CL_e \times FC/SP \qquad \textbf{(IV-1)}$$

where,

LF	=	Leaching Fraction
Cl_{iw}	=	Chloride ion concentration of the irrigation water
Cl_e	=	Chloride ion concentration of the soil
FC	=	Soil water content at field capacity
SC	=	Soil saturation percent

A table showing the constituents and estimated leaching fraction, for the combination of all four types of soils and crops, as presented by Lonkerd et. al. (1979), is shown in Table IV-1. The table clearly shows that Imperial and Meloland (the tight soils) have a low calculated leaching fraction while Indio and Holtville soils (relatively light soils) have relatively high calculated leaching fractions. Based on this study, it can be found that the tight soils are not adequately leached. Lonkerd et al. (1979) also found that:

> "These data indicated average rooting depth of 60 to 90 cm for alfalfa and lettuce. Similar data indicated average rooting depths of 60 to 90 cm for cotton, 60 to 120 cm for sugar beets, and 30 to 60 cm for wheat. Plants had shallower roots in the finer textured than in the coarse textured soils."

The research also found that:

> "Indio and Holtville soils, with the highest water infiltration rates, had the highest leaching fractions. Imperial and Meloland soils, with the lowest water infiltration rates, had the lowest leaching fractions."

Lonkerd et al. (1979) showed that heavy soils with inadequate leaching are soils with low water infiltration capacity. They also found that the rooting depth of crops is shallower in heavy soils when compared to light soils. These findings are in agreement with other researchers who studied the soils of IID. Because soil salinity nearly always increases with depth in heavy soils, plant roots develop more fully in the shallow portion of the root zone.

Table IV-1 Leaching Fraction for Soil Series in IID (Lonkerd et al., 1979).

Soil Series	Crop	Cores	EC_e		Cl_e		LF	
			Range	Median	Range	Median	Range	Median
			------mmhos/cm-------		--------meq/liter-------		------------%------------	
Holtville	Alfalfa	33	4.2-13.9	7.3	12-106	36	3-23	9
	Cotton	41	3.3-21.5	12.4	6-232	43	1-42	6
	Lettuce	56	1.4-23.1	4.4	3-180	13	2-76	27
	Sugarbeet	18	1.7-26.6	4.7	4-235	9	1-49	28
	Wheat	37	1.5-15.8	5.8	4-79	18	3-50	12
Imperial	Alfalfa	21	8.5-18.9	12.5	26-185	67	2-11	5
	Cotton	11	8.8-17.2	13.2	30-108	73	2-5	3
	Lettuce	26	2.1-16.3	9.0	4-120	19	1-44	7
	Sugarbeet	115	3.3-30.8	11.9	7-290	44	1-24	4
	Wheat	100	3.5-30.8	10.0	5-371	38	1-42	5
Indio	Alfalfa	71	5.1-20.6	10.4	13-133	48	2-22	6
	Cotton	33	3.5-26.2	11.6	10-282	52	1-26	4
	Lettuce	74	1.2-30.8	5.1	3-352	12	1-100	28
	Sugarbeet	7	2.6-8.8	6.5	9-31	19	9-38	15
	Wheat	35	1.6-13.7	4.0	5-76	10	3-48	23
Meloland	Alfalfa	14	8.5-18.9	14.1	65-174	95	2-5	3
	Cotton	17	1.3-14.4	10.7	2-88	34	2-86	5
	Lettuce	10	5.5-18.4	12.3	14-151	72	2-18	4
	Sugarbeet	11	2.8-25.1	9.3	8-271	36	1-17	5
	Wheat	7	5.5-15.3	11.5	13-95	56	3-16	4

Mitchell and Van Genuchten, 1993. <u>Flood Irrigation of a Cracked Soil</u>.

Mitchell and Van Genuchten (1993) studied water infiltration patterns of cracked soils for both fallow and cropped lands irrigated by flood irrigation within IID. The researchers concluded that:

> "Water intake processes were similar for two fallow irrigations and alfalfa irrigation with 63, 58, and 74% respectively, of the total infiltrated water entering the soil during the crack filling stage. High efficiencies for flood irrigation can be attributed to the dominant crack filling stage followed by a low final infiltration rate. Small increases in infiltration during the absorption stage is a phenomenon that may result from soil surface swelling. The final infiltration rates of this study (0.6 and 0.4 mm per hour) are less than 1.0 mm per hour threshold suggested by the U. S. Salinity Laboratory Staff (1954) as the minimum necessary for crop production on irrigated soils. This threshold may not be appropriate for cracking soils, which initially have large water intake rates."

Based on the above findings, approximately two thirds of the applied water infiltrated and filled soil cracks. In the same study, they also found that for flood irrigation, during the crack filling phase, the infiltration rate is equal to the water application rate less surface storage. However as more irrigation water is applied and the cracks become filled, a portion of the additional water flows laterally down the field and becomes tailwater.

Mitchell and Van Genuchten (1993) further stated that:

> "Flood irrigation of most noncracking soils usually results in the head field receiving excess water, and the tail end insufficient water. For cracking soils, the tail end of the field receives a large amount of water in a short time period due to CF [crack filling], while the low final IR [infiltration rate] limits leaching at the head end, even if ponded for long periods. Another advantage of cracking soils is the lateral, subsurface flow of water in cracks, which ensures that the water reaches all areas of the field."

The infiltration process of cracking soils differs from the commonly regarded surface irrigation because in the non-cracking soils the deepest water infiltration occurs at the head of the field, while lower moisture is stored at the tail end of the field. This results from the need to apply enough water to ensure adequate supply at the tail end of the field. In order to ensure an adequate supply, more than the required amount must pass over the head end, resulting in greater opportunity time and more infiltration. On a permeable well-drained soil, this water infiltrates below the root zone of the field. The cracking nature of IID soils, however, results in rapid transmission and dispersion of applied irrigation water on flood irrigated fields.

Shouse et al., 1997. Salt Transport in Cracking Soils: Bromide Tracer Study.

Shouse et al. (1997) conducted a study of two IID fields; one was Imperial silty clay (a heavy cracking silty clay soil), while the other field consisted of Glenbar fine sandy loam (a non-swelling sandy loam soil). The primary objective of their study was to determine the effect of crack flow on the quality of tailwater and therefore examine the contribution of field cracks to the leaching of salts. Similar to other researchers in the field, they concluded that light textured soils infiltrate applied irrigation water into the root zone easily with very little of it becoming tailwater. The Darcy-Richards standard equations are applicable to these conditions. However, the flow regime associated with heavy cracking soils was determined to be significantly different from that of light textured soils. Cracks occurring in some of the heavy cracking soils allow applied irrigation water to enter with the flow being governed by the cracks' depths and distribution. Unlike the flow regime in non-cracking soils (which is primarily downward), cracks allow the infiltration and lateral transmission of water. In cases where cracked soils have limited permeability below the cracked layer, most water transmission will be lateral in nature as opposed to vertical. Therefore, leaching of these soils must take place laterally as well. If the vertical percolation of water is limited, it can be expected that lateral movement of water will provide the only means of leaching. In these cases, as cracks are filled with water, salts move horizontally and upward towards the surface of the tail end of the field. When this occurs, there is little vertical percolation of water downward. The researchers concluded that the Darcy-Richards flow theory does not apply to the cracking soils of IID soils. Shouse et al. (1997) stated that:

> "The flow of water in noncracking soils can be predicted by simulation models based on the Darcy-Richards flow theory. This theory does not apply to water flow in cracking soils" (Bouma and Loveday, 1987; Kosmas et al., 1991)

The authors concluded that:

> "Our basic premise is that a significant part of the salt balance is related to horizontal leaching in the cracks. We think that the irrigation water infiltrates rapidly into the cracks and dissolves salts at the crack-air interface and transports this salt down the furrow."

Shouse et al. (1997) further concluded that:

> "Clearly traditional salt movement concepts for porous media are not applicable to cracking soils. The traditional concept of vertical leaching of salt depending on the leaching fraction simply is not valid. From a practical point of view, one must recognize there is horizontal leaching as well as vertical leaching of salts in these soils. This must be a consideration in the management of these soils."

Based on the conclusions reached by Shouse et al. (1997) as well as other researchers and NRCE's own field studies, it is clear that a large portion of irrigation water, applied to such cracking soils, enters the cracks and flows horizontally, picking up salts from the root zone. The runoff that flows to the end of the field must therefore be considered as part of the leaching fraction, similar to the deep percolating portions of the infiltrated water associated with non-cracking soils. The main difference between leaching cracking and non-cracking soils is that the cracking soils' leaching takes place both horizontally and vertically, while with non-cracking soils, salt leaching occurs only vertically.

Rhoades et al., 1997. Salt Distributions in Cracking Soils and Salt Pickup by Runoff Waters.

Rhoades et al. (1997) conducted an extensive study on IID fields with two primary objectives:

> "One was to measure salinity in the soil and runoff water to obtain evidence of the extent of and potential for salt pickup in tailwater and of the influence of soil properties in this regard. The other was to obtain information on the dynamics of salt transport in cracking and non-cracking soils so that the feasibility of tailwater recycling could be assessed more reliably."

This study is particularly interesting because it directly addresses the potential impacts of water use reduction by "improvements in efficiency." The authors stated:

> "One means of reducing runoff to the sea [Salton Sea] is to install tailwater recovery systems, whereby the water is recirculated on the same field or farm. Generally, the value of the 'conserved water' will not justify the costs of the recovery system unless fees are imposed against excessive discharges. Because the economic value of water is higher for urban use, and water supplies in California are limited, there is opportunity for a mutually beneficial cooperative agreement between agricultural and urban sectors in this regard. The urban sector can pay for the tailwater recovery system in return for receiving water in an amount equivalent to that conserved.
>
> Such an arrangement has been considered for implementation in the Imperial Valley. However, salinity is an old nemesis there and the farmers are concerned that salinity levels will increase unduly in their soils through the recycling of tailwater for irrigation. The source of water for irrigation is the Colorado River, which has an electrical conductivity (EC) of about 1.3 dS/m. Prevalent 'textbook logic' would lead to the conclusion that salt pickup via tailwater flow should be negligible because the 'leading edge' of water that flows over the soil is thought to infiltrate into the soil and to 'carry' the readily soluble salt with it. The salt in the soil is not expected to diffuse upward significantly when the water is percolating downward. With this prevalent view of the transport processes, one would not expect to find a significant increase in the salinity of the tailwater compared to the irrigation water other than that which might be derived from the dissolution of suspended sediment gained through furrow erosion."

In these studies, nine fields with different types of soils were subdivided according to heavy, medium, and light soils. These categories reflect degrees of permeability and shrink-swell potential. The study determined that in both the medium and heavy textured soils there may be a significant loss of yield due to salinity. They also determined that the average concentration of salts in the heavy cracking soil profiles increased laterally and not vertically or from the head to the tail end of the field. This finding is supported by the fact that in fields of heavy soil, the salinity of the shallower portion (the root zone) of the tail end of the field was higher than that of the head end of the field.

Rhoades et al. (1997) concluded that:

> "Salinity increases observed across the fields with heavy textured soils show that irrigation/leaching is markedly non-uniform across such fields, possibly reflecting the major attempt in the Imperial Valley in the recent past decade to reduce irrigation runoff, as well as the phenomenon of lateral solute transport. The magnitude of the salinity levels observed in the medium and heavy textured soils, especially in the lower sections of the selected fields, would be expected to result in substantial losses in alfalfa yield and in significant losses in the yields of sugar beets and other such relatively salt-tolerant crops. The excessive levels of salinity in the lower sections of the fields with heavy textured soils indicate insufficient water application/leaching is being achieved in these areas/field with prevalent management practices to achieve optimum crop production."

The findings of Rhoades et al. (1997) are consistent with other studies that have shown that heavy cracking soils are difficult to manage because of the very low infiltration capacity of the soil after initial crack filling. They are also difficult to manage because such low permeability induces a shortage of stored moisture in the root zone as well as inadequate leaching of salts. Rhoades et al. (1997) further concluded:

> "The concentration of salt in the irrigation water increased as it flowed across the field. The increase however was much greater for the heavy textured soil, which exhibit large cracks and fractures. We conclude that substantial amounts of salts can be picked up by such lateral flowing water from highly cracking soils and discharged in the tailwater, though the actual amounts could not be quantified in this study since the runoff volumes were not determined. This inference is supported by the very large increase observed in the tailwater electrical conductivity as compared to the electrical conductivity of the applied water. Increases in EC of 0.5 dS/m or more were almost always observed in the tailwaters emanating from heavy textured soils. Such increases in EC cannot be explained by evaporation of water as it flows across the field."

It was determined that the mean salinity of soil profiles across border flooded light textured fields, ranged from 1.0 to 2.5 dS/m, while the mean salinity of medium textured fields ranged from 2.5 to 5.0 dS/m, and the heavy textured fields ranged from 5.0 to 13.0 dS/m. Based on these results, the concentration of salts in the root zone of heavy cracking soils is 5 times more than light textured soils and 2 times more than medium textured soils. If one assumes that the conventional equation for determining the leaching requirement represents the permeability of the light textured soils, the heavy soils would have 5 times more salts to leach than the light textured soils.

The following is a brief summary of what has been found regarding the heavy cracking soils in previous studies:

1. The majority of the soils within IID are characterized as having a heavy-texture that shrinks when dry and swells when wet.

2. Soil cracks in the Imperial Valley greatly control water movement and salinity. Soil cracks and their attributes must be considered in irrigation design and management.

3. Heavy textured soils are characterized with cracks, constituting a relatively large surface area and having a maximum depth of about 2.3 feet.

4. Heavy cracking soils require several weeks of continuous ponding in order to fully saturate the root zone and leach the excess salts found in the effective root depth of the soil profile. During the continuous ponding, the infiltration rate was measured to be about 0.1 inches per hour.

5. The source of the irrigation water for IID is Colorado River water, with a salinity concentration of about 1.2 dS/m.

6. When irrigation water is applied at the head of a field with heavy cracking soils, the water fills the cracks as it moves towards the lower end of the field.

7. In addition to vertical leaching, horizontal leaching of cracking soils takes place as water moves from the head to the tail end of a field.

8. The quality of the applied water deteriorates as it moves from the head of the field to the tail end of the field because the salinity concentration of the irrigation water increases due to horizontal leaching.

9. The salinity concentration of both the entire soil root zone and the shallower root zone increases as water flows from the head of the field to the lower portions of the field.

10. The heavier soils, such as Imperial and Meloland, have much higher concentrations of salinity in their respective root zone compared to lighter soils such as Holtville and Indio.

11. The lighter soils such as Holtville and Indio have shown to have much higher leaching fractions (growing the same types of crops) compared to heavier soils such as Imperial and Meloland.

12. In some of the heavy cracking soils, studies have shown that the salinity concentration of the drain water is lower than the salinity concentration of the root zone. As a result, the heavy cracking soils are not being leached satisfactorily; more water is required to do so.

13. In light, well-drained soils, leaching of salts occurs during the growing season as well as during the preplanting irrigation. For the heavy, fine textured soils however, infiltration is so low that it is difficult to apply enough water to meet the crop consumptive use, and it is more difficult to leach the excess salts from the root zone of the soil.

14. The fact that the heavy cracking soils have a very low infiltration rate indicates that the crops are deprived from receiving 200,000 to 400,000 acre-feet of water per year throughout IID. In essence, due to the low permeability of the soil, the consumptive use of the crops is short by about 200,000 to 400,000 acre-feet annually.

15. During the crack-filling stage of the heavy cracking soils of IID, about two thirds of the applied water fills up the cracks. However, once the cracks are filled, the infiltration rate goes down to between 0.01575 in/hr and 0.0236 in/hr. Therefore, during the initial crack filling stage, the rate of application could equal the infiltration rate of the soil less water stored on the surface.

16. A substantial amount of salt is removed by tailwater when irrigation water flows from the head of the field to the lower end of the field in heavy cracking soils.

Because of the above results, it is important to understand how tailwater should be characterized. In the minds of most people, tailwater at the end of the field is simply regarded as wasted runoff. In locations not having the heavy cracking soils of IID, the magnitude of tailwater should not be as great. However, given the cracking nature of the heavy silty clay soils, when irrigation water is applied at the head of the field, water penetrates into the cracks and once the cracks are filled, the water flows along the gradient towards the end of the field. Field studies have shown that the salinity content of the irrigation water increases as the irrigation water moves from the head of the field towards the tail end. In essence, portions of the salt within the soil are leached by the tailwater. Hence, although tailwater is a necessary irrigation practice such that the lower portions of the field are adequately irrigated, more importantly, tailwater is improving the productive capacity of the irrigated field by leaching some of the salts in the soil through horizontal leaching.

For light non-cracking soils, the leading edge of the irrigation water penetrates downward into the root zone. Once the root zone reaches more than field capacity, the infiltrated water becomes deep percolation. With proper irrigation management, tailwater on light non-cracking soils is less than that of heavy cracking soils due to differences in the intake rate. Typical water infiltration patterns for both heavy cracking and light textured soils are shown in Figure IV-1.

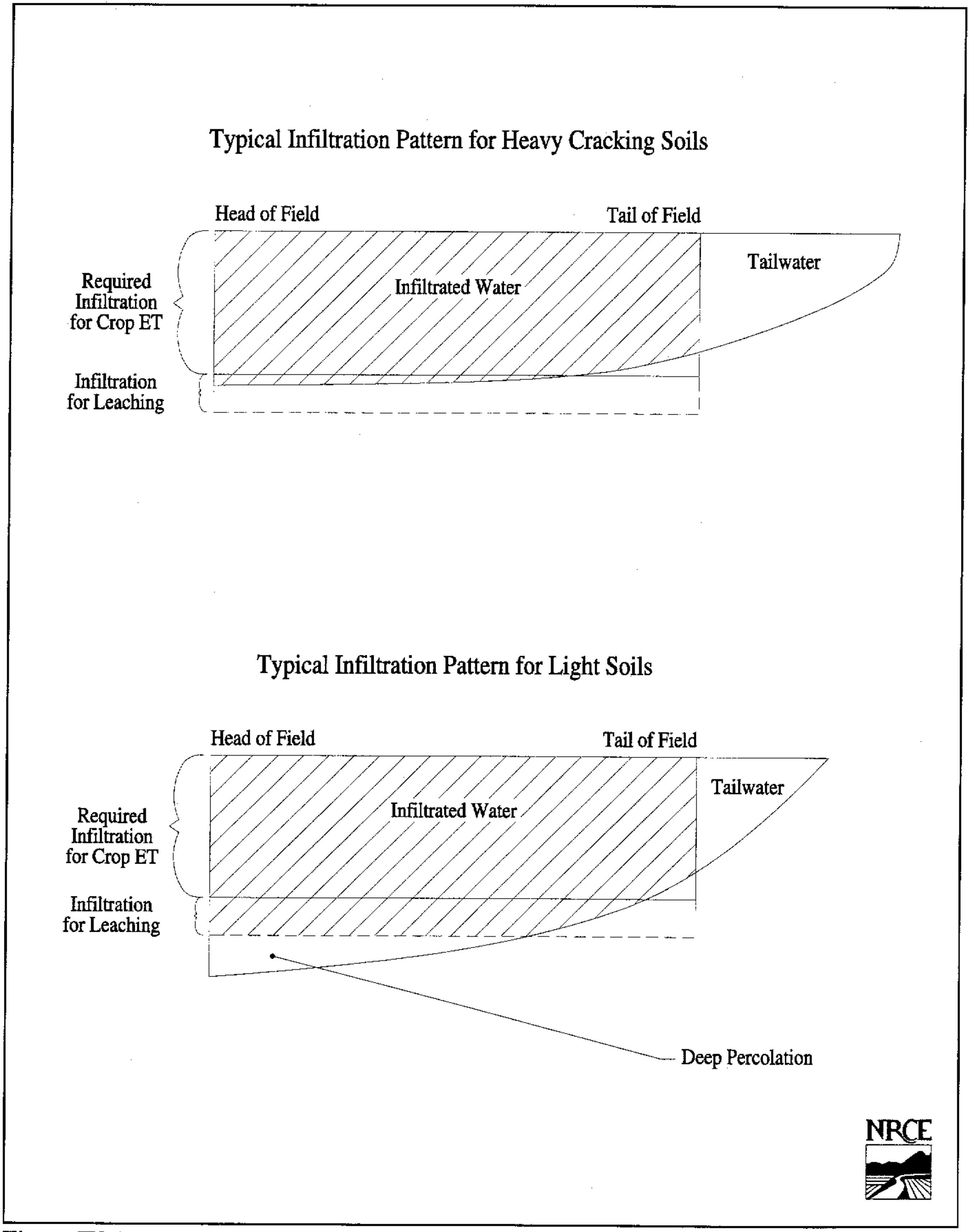


Figure IV-1. Water Infiltration Patterns for Surface Irrigation

B. IID Tailwater Studies

IID conducted a field study to evaluate the feasibility of reducing tailwater using a pump back system. The study was undertaken from 1985 to 1990 on a number of fields. The study collected data relating to the amount of irrigation water delivered, the salinity concentration of the irrigation water, the amount of tailwater, and the salt concentration of the tailwater.

The primary soils of the fields that were included in the study were silty clay, silty loam, and sandy loam. The major crops grown were field and vegetable crops. Table IV-2 shows the quality of the delivered water verses tailwater. Table IV-3 indicates that all three types of soils show an appreciable amount of tailwater. Even the sandy loam soil in which surface runoff or tailwater is usually low and where deep percolation is high shows that about 21% of the delivered water ended up as tailwater. This can be attributed to the primary crops grown on this sandy soil being vegetable crops, which require frequent irrigation to meet optimum moisture conditions and seed germination as well as to assist in cooling of the plants and the immediate environment.

Table IV-2 Inflow and Outflow of Irrigation Water and Water Qualities.

Soil Type	Water Delivered (Acre-Feet)	Tailwater (Acre-Feet)	Delivered Water Salinity (mg/l)	Tailwater Salinity (mg/l)	Crops Grown
Silty Clay	3,182	677	618	819	Field crops
Silty Clay	5,322	746	618	852	Field crops
Silty Clay	3,042	1234	618	884	Field crops and vegetables
Silty Clay/Silty Loam	2,615	350	618	689	Primarily field crops and some vegetables
Sandy Loam	2,681	567	618	657	Primarily vegetables and some field cops

Table IV-3 Total Salts Introduced and Removed by Tailwater.

Soil Type	Water Delivered (Acre-Feet)	Tailwater (Acre-Feet)	Total Salts Introduced (Tons)	Total Salts Removed (Tons)	Total Salts Remaining in Soil + Removed by Vertical Leaching (Tons)	% of Tailwater	% of Salt Removed by Tailwater
Silty Clay	3,182	677	2,674	754	1,920	21	28
Silty Clay	5,322	746	4,473	864	3,609	14	19
Silty Clay	3,042	1,234	2,557	1,484	1,073	41	58
Silty Clay/ Silty Loam	2,615	350	2,198	328	1,870	13	15
Sandy Loam	2,681	567	2,253	506	1,747	21	23

The three fields with heavy soils (silty clay) show that a weighted average of about 32% of the total salt introduced to the fields was removed or leached by the lateral flow of the tailwater. Table IV-3 shows that the tailwater, which is regarded by some people as wastewater, removed a substantial amount of the salts introduced to the irrigated fields. The weighted average of the tailwater that leaches the salts is about 23% of the weighted average of the delivered water. Hence, 23% of the delivered water is laterally removing 32% of the introduced salts by the irrigation water to the irrigated fields.

In general, irrigated fields, especially gravity irrigated fields, with the exception of level border/furrow and basin irrigation systems, show runoff at the end of the fields. Some inefficiencies are expected to happen with any irrigation practice, including the most advanced irrigation technology. Given the fact that most of the soils at IID are difficult to leach vertically, some leaching for the upper root zone is undertaken horizontally. Therefore some portion of the tailwater should be regarded as leaching water for excess salts.

The silty clay/silty loam soil could probably be regarded as heavy to medium soil and as shown in Table IV-3, the amount of salt removed is about 15% of the total salt introduced to the field and 13% of the total water delivered was used to leach that amount of salt. As discussed earlier, the field with sandy loam soil was primarily planted with vegetable crops and a large portion of the tailwater was the result of frequent irrigation and crop cooling requirements.

The results of IID's tailwater pump back studies show that more than 30% of the total salts introduced by irrigation water are removed by tailwater due to the lateral component of the leaching process. If, on average, approximately 30% of the introduced salts in any irrigation event are leached laterally, then the remaining 70% have to be leached vertically.

C. Irrigation Efficiency and Salinity Management

To evaluate the previously discussed research results, NRCE conducted ten irrigation evaluations. Seven of the irrigation fields evaluated are considered to be typical for heavy cracking and medium soils, while one irrigation on heavy soils was not considered typical because of the length of time that water was applied (24 hour set time and about 35 hours of intake opportunity time). One irrigated field with sandy soils was evaluated, and finally, one leaching irrigation on heavy soils was evaluated. Heavy and medium soils have a soil layer(s) in the top four feet with a permeability rate of less than 0.2 inches per hour. The following information summarizes the distribution of water and salt for the irrigations; detailed information concerning the irrigation evaluations is contained in Appendix 7.

1. *Heavy and Medium Soils*

Table IV-4 lists the average values from the seven irrigation evaluations on heavy to medium soils. The average irrigation depth of water applied was 4.37 inches with 3.43 inches being stored in the root zone, 0.74 inches as tailwater, and 0.20 inches going to deep percolation. Vertical leaching removed 29.8 percent of the salt applied during the irrigation while horizontal leaching (tailwater) removed approximately 22.3 percent.

Table IV-4 Summary of Irrigation Data for Seven Irrigation Evaluations on Fields with Heavy and Medium Soils (Fields 1, 2, 3, 6, 7, 8, 9).

	Water Balance Data		Salt Balance Data	
	Average Depth (inches)	Average (%)	Avg. EC of Water (ds/m)	Average (%)
Total Irrigation Depth	4.37	---	0.99	100
Stored in Root Zone	3.43	78.5	---	47.9
Tailwater Runoff	0.74	17.0	1.30	22.3
Deep Percolation (tile water)	0.20	4.5	6.56	29.8
Irrigation Efficiency	---	83.0	---	---
The irrigation efficiency assumes that all the deep percolation is used for leaching excess salts below the root zone.				

Vertical and horizontal leaching remove slightly over half of the salts applied during irrigation. It is apparent that deep percolation was insufficient for adequate vertical leaching. Therefore, the 4.5% deep percolation is considered to be a part of the leaching requirement.

It was also observed that tailwater picks up salt from the soil as it moves down the field. The salinity of the tailwater is approximately 30 percent higher than the water delivered to the field. This occurs because cracks in the soil allow water to move in and out of the soil, picking up salts as it moves down the field. Considering the salt balance for a single irrigation, the tailwater accounts for 43 percent of the salts leaving the field. Based on this high percentage of salt removal, tailwater has an obvious leaching benefit. Considering the total salt outflow, the tailwater salt removal is slightly less than vertical leaching (43 v. 57 percent of the salt removed).

NRCE estimated that for medium and heavy cracking soils, approximately 3.4 percent of the headgate delivery was used for horizontal leaching. This is calculated as the ratio of salt removal: tailwater over tile water, multiplied by the tile water outflow percentage (22.3/29.8 *x* 4.5). Tailwater improves the already high irrigation efficiency from 83 to 86 percent for the irrigations evaluated on medium and heavy cracking soils. The irrigation efficiency is the water stored in the root zone available for crop water use (78.5%), plus vertical leaching (4.5%), plus the estimated horizontal leaching (about 3.4%). The salinity of the deep percolation is much higher than the salinity of the tailwater. Although the 4.5% deep percolation removed more salt than the 17% tailwater, tailwater also provides adequate irrigation and significantly benefits crop production by removing a critical portion of the salt from the upper root zone.

2. *Sandy Soils*

An irrigation on a sandy soil field was evaluated to provide a comparison for the irrigation of heavy and medium soils. The heavy and medium soils comprise the majority of land in IID. Summary results of the irrigation are shown in Table IV-5. It is much easier to leach salts in the sandy soils than in heavy soils because vertical leaching is not hindered by low permeability. Although only 58 percent of the salts added to the field were removed during this irrigation, the salinity levels in the field are still low and the long-term leaching is adequate. A review of the irrigation history on this field shows that adequate water has been applied for leaching (see Appendix 7 Field 4).

Table IV-5 Summary of Irrigation Data for the Irrigation Evaluation on a Field With Sandy Soil (Field 4).

	Water Balance Data		Salt Balance Data	
	Depth (inches)	Average (%)	Avg. EC of Water (ds/m)	Average (%)
Total Irrigation Depth	4.60	100.0	1.00	100
Stored in Root Zone	3.70	80.0	---	42
Tailwater Runoff	0.00	0.0	---	0
Deep Percolation	0.90	20.0	3.0	58
Irrigation Efficiency	---	85.5	---	---
Irrigation Efficiency is based on 5.5 percent of deep percolation being for leaching. The bottom portion of the field was not adequately irrigated or leached.				

The irrigation efficiency was high; however, the leaching was in excess of the amount required in the upper portion of the field and there was no leaching in the bottom of the field. Similarly, the bottom portion of the field was under irrigated. The irrigation was inadequate to meet crop needs and was not considered a typical irrigation. Although the deep percolation was 20 percent of the water applied, only about 5.5 percent was estimated to provide leaching due to the uniformity of water application. Based on soil moisture sampling, probing, and irrigation advance rate, it was estimated that 50% of the field received the 11% leaching requirement and therefore 5.5% of the irrigation. The leaching requirement of 11% is based on an equation developed by Rhoades (1974) with the EC of the irrigation water (EC_{iw})=1.0 and the threshold of the soil water EC for the crop (EC_c)=2.0. The Rhoades leaching requirement equation is discussed later in this chapter.

3. *Leaching/Land Preparation Irrigation on Heavy Soils*

Irrigations during crop production were inadequate to maintain a salt balance in the heavy soils. It is a common practice to provide a leaching irrigation between crops, especially on heavy and medium textured soils. A leaching irrigation was evaluated to determine the water and salt balance for the irrigation. The results of the irrigation evaluation are shown in Table IV-6. The irrigation followed the harvest of a sugar beet crop in soils with high salinity. The field had also been leached one year before the evaluated leaching irrigation.

Table IV-6 Summary of Irrigation Data for the Leaching Irrigation Evaluation on a Field With Heavy Soils (Field 10).

	Water Balance Data		Salt Balance Data	
	Depth (inches)	Average (%)	Avg. EC of Water (ds/m)	Average (%)
Total Irrigation Depth	9.80	100	1.02	100
Stored in Root Zone	4.70	48	---	---
Tailwater Runoff	0.00	0	---	---
Deep Percolation	3.60	37	11.45	412
Evaporation	1.50	15	---	---
The irrigation occurred over 9 days. The tile drain flow removed approximately four times the salt that was added with the irrigation water.				

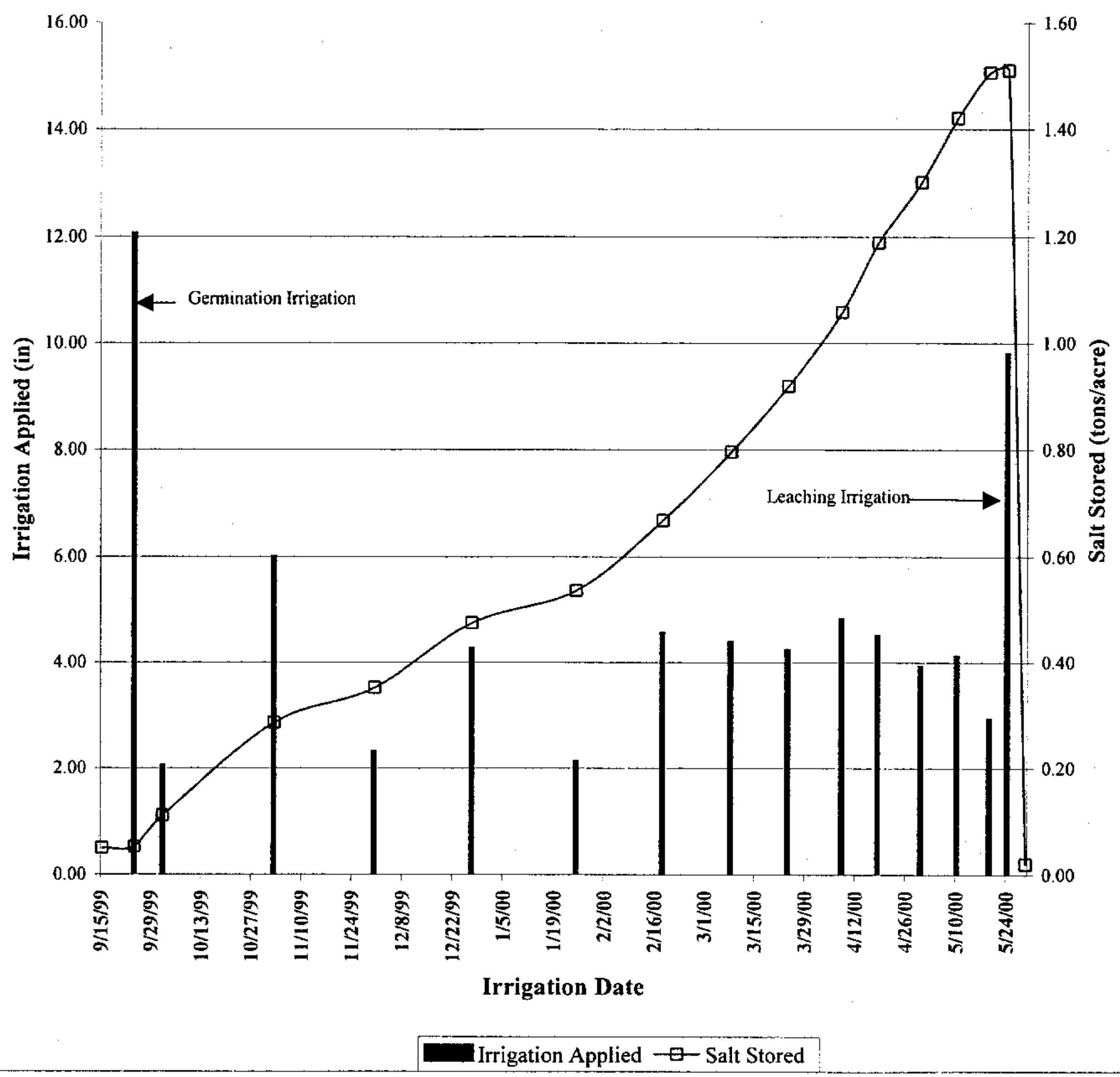
A total of 9.8 inches were applied during a 9-day irrigation. Prior to leaching, the field had been deep ripped, disked, leveled, diked, and corrugated, making the soil quite dry. Based on the inflow and outflow, 4.7 inches were stored in the root zone. It was also estimated that approximately 1.5 inches of the applied water were utilized for evaporation. The tile drainage measurements indicated that about 3.6 inches were deep percolated during and after the irrigation.

The first 3 to 4 days were required to wet the entire field while approximately the last 5 days were used to continue the leaching process. The entire field was irrigated in one set with the advance flow taking 3 to 4 days, during which time the inflow averaged 5.2 cfs. The flow rate for the remaining 5 days averaged 2.4 cfs. A portable pumpback system was installed to convey water from the tail end of the field to the field head ditch, as tailwater is not permitted during a leaching irrigation. Although no salinity was removed by the tailwater, salinity measurements of the tailwater were periodically measured and recorded. The EC of tailwater ranged from 1.3 to 2.2 ds/m.

The leaching irrigation effectively removed a large quantity of salt from the root zone. Based on the inflow and tile drain measurements of flow and salinity, approximately 59 tons of salt were applied, while 249 tons of salt were removed from the 81-acre field. Based on the average of the irrigations evaluated, about 0.2 tons per acre of salt accumulates in the soil after each irrigation. Thus, the leaching irrigation removed salts that would accumulate during 11 or 12 irrigations. For example, there were 13 irrigations for the sugar beets grown between the leaching irrigations that occurred between July of 1999 and June of 2000. Figure IV-2 shows the accumulation and leaching of salts between leaching irrigations, based on the irrigation history of the field evaluated.

A review of the irrigation history on the evaluated fields indicates that water applications during leaching irrigations ranged from 6.5 to 15.6 inches, with an average of 12.4 inches. Occasionally, a leaching irrigation occurred in two phases separated by a few days (however, it is still considered to be one leaching irrigation). Based on the average leaching of approximately 12 inches, about 5.8 inches of deep percolation would result (total irrigation of 12 inches less 1.5 for evaporation and 4.7 inches for soil storage).

Figure IV-2 Salt Accumulation on Heavy Soils During Sugar Beet Production and Salt Removal during Leaching Irrigation in Field 10.



4. *IID Soil Analysis*

The physical characteristics of a given soil are very important in any irrigation planning, design, and management. Tables IV-7 and IV-8 list the permeability ranges of soil layers of the soil mapping units within IID. Table IV-7 lists the permeability of the top soil layer and Table IV-8 lists the range of permeability and the limiting soil permeability in the top four feet of the soil. Tables IV-7 and IV-8 are shown on Plates IV-1 and IV-2, respectively. It was assumed that the soils with a soil layer having limiting permeability ranging from 0.06 to 0.2 inches in the top four feet are considered medium and heavy cracking soils. Many soils with low permeability have high shrink-swell potential that result in cracking and swelling depending on dry/wet conditions. Initial filling of the cracks slows down the advance rate and provides infiltration in the upper root zone. Crack-filling takes place rapidly, but once filled, irrigation water infiltrates vertically very slowly. Water flowing to the end of such fields is regarded as wastewater by some critics, and because of this IID has taken various measures to reduce tailwater. However, water runoff from fields with heavily cracked soils is not a waste, as has been claimed.

The intake rate of the soil needs to allow for both the penetration of the consumptive use requirement and the leaching requirement. Table IV-7 shows the permeability characteristics of the soils as they closely relate to the intake rates. The lower the permeability, the longer the application time required for irrigation water to fill the root zone to field capacity.

As shown in Table IV-7, the permeability range of the major IID soil type, Imperial, is only 0.06 to 0.2 inches per hour. Large portions of the Holtville, Imperial-Glenbar, Meloland, and Meloland-Holtville soil types also have permeability rates of 0.06 to 0.2 inches per hour. In such cases, if water was applied for 24 hours continuously, the total infiltrated water would be 1.44 inches to 4.8 inches per day, or an average of 3.12 inches per day. At this infiltration rate, it would be impossible to replenish the soil moisture deficit in a reasonable time period. However, since these soils tend to crack when dry, a large portion of the applied water initially fills the cracks in the soil. Once the cracks are filled with irrigation water, the rate of infiltration becomes very low and the irrigator continues to apply water to fill the root zone and provide partial vertical leaching. This leads to more moisture stored in the root zone of the soil, but also causes runoff or tailwater at the end of the field.

The conventional theory and equation for determining leaching requirements is certainly applicable for light soils with adequate infiltration rates because the leading edge of the applied water moves (infiltrates) downward, replenishing the depleted root zone, while the excess moisture, beyond field capacity, moves below the effective root zone leaching the excess salts in the soil. Hence, light soils follow this one-dimensional (downward flow) conventional theory. However, when irrigation water is applied on IID's heavy cracking soils with low permeability, the water flow is unconventional because the applied irrigation water tends to have a two-dimensional flow. The irrigation water first fills the cracks of the soil then it moves laterally through the cracks and along the surface, eventually becoming tailwater with the remaining water flowing downward to fill the root zone. If the root zone attains field capacity, the excess water flows past the root zone carrying salts with it.

Table IV-7 IID Soils Within Irrigated Boundary Sorted by Permeability of Top Soil Layer.

Map Unit	Dominate Soil	Minor Description	Acreage	Permeability Range Top Layer (Low and High) inches/hour		Group Acreage	Group Percentage
109	Holtville	Silty Clay	2,589	0.06	0.20		
110	Holtville	Sillty Clay, wet	72,966	0.06	0.20	Low Permeability	
111	Holtville	Imperial Silty Clay Loams	3	0.06	0.20		
112	Imperial	Silty Clay	317	0.06	0.20		
113	Imperial	Silty Clay, Saline	2,500	0.06	0.20		
114	Imperial	Silty Clay, Wet	119,682	0.06	0.20		
115	Imperial	Glenbar Silty Clay Loams, wet, 0 to 2 percent slope	150,924	0.06	0.20		
116	Imperial	Glenbar Silty Clay Loams, 2 to 5 percent slope	1,375	0.06	0.20	350,356	62.1%
106	Glenbar	Clay Loam, wet	3,798	0.20	0.60		
107	Glenbar	Complex	969	0.60	2.00	Medium Permeability	
117	Indio	Loam	1,208	0.60	2.00		
118	Indio	Loam, wet	13,837	0.60	2.00		
119	Indio	Vint complex	6,435	0.60	2.00		
123	Meloland	and Holtville Loams, wet	13,047	0.60	2.00	39,294	7.0%
101	Antho	Supperstition Complex	31	2.00	6.00		
103	Carstias	Gravely Sand, 0 to 5 percent slope	237	6.00	20.00	High Permeability	
121	Meloland	Fine Sand	1,253	2.00	6.00		
122	Meloland	Very fine Sandy Loam, Wet	98,810	2.00	6.00		
124	Niland	Gravelly Sand	1,364	6.00	20.00		
125	Niland	Gravelly Sand, wet	6,543	6.00	20.00		
126	Niland	Fine Sand	459	6.00	20.00		
128	Niland	Imperial Complex, Wet	3,118	6.00	20.00		
130	Rositas	Sand, 0 to 2 Percent Slope	775	6.00	20.00		
132	Rositas	Fine Sand, 0 to 2 Percent Slope	2,927	6.00	20.00		
133	Rositas	Fine Sand, 2 to 9 Percent Slope	19	6.00	20.00		
135	Rositas	Fine Sand, Wet, 0 to 2 Percent Slope	11,797	6.00	20.00		
136	Rositas	Loamy Fine Sand 0 to 2 Percent Slope	29	6.00	20.00		
137	Rositas	Silt Loam, 0 to 2 Percent Slope	8	6.00	20.00		
142	Vint	Loamy Very Fine Sand, Wet	31,790	2.00	6.00		
143	Vint	Fine Sandy Loam	3	2.00	6.00		
144	Vint	Indio Very Fine Sandy Loams, Wet	15,369	2.00	6.00	174,532	30.9%
		Total	564,182			564,182	100%

Table IV-8 IID Soils Within Irrigated Boundary Sorted by Permeability of Limiting Layer in the Top Four Feet.

Map Unit	Dominate Soil	Minor Description	Acreage	Limiting Layer Permeability Range (Low and High) inches/hour		Group Acreage	Group Percentage
109	Holtville	Silty Clay	2,589	0.06	0.20		
110	Holtville	Sillty Clay, wet	72,966	0.06	0.20	Low Permeability (Medium and Heavy Soils)	
111	Holtville	Imperial Silty Clay Loams	3	0.06	0.20		
112	Imperial	Silty Clay	317	0.06	0.20		
113	Imperial	Silty Clay, Saline	2,500	0.06	0.20		
114	Imperial	Silty Clay, Wet	119,682	0.06	0.20		
115	Imperial	Glenbar Silty Clay Loams, wet, 0 to 2 percent slope	150,924	0.06	0.20		
116	Imperial	Glenbar Silty Clay Loams, 2 to 5 percent slope	1,375	0.06	0.20		
121	Meloland	Fine Sand	1,253	0.06	0.20		
122	Meloland	Very fine Sandy Loam, Wet	98,810	0.06	0.20		
123	Meloland	and Holtville Loams, wet	13,047	0.06	0.20		
124	Niland	Gravelly Sand	1,364	0.06	0.20		
125	Niland	Gravelly Sand, wet	6,543	0.06	0.20		
126	Niland	Fine Sand	459	0.06	0.20		
128	Niland	Imperial Complex, Wet	3,118	0.06	0.20		
144	Vint	Indio Very Fine Sandy Loams, Wet	15,369	0.06	0.20	490,320	86.9%
106	Glenbar	Clay Loam, wet	3,798	0.20	0.60		
107	Glenbar	Complex	969	0.20	0.60	Medium Permeability (Light Soils)	
117	Indio	Loam	1,208	0.60	2.00		
118	Indio	Loam, wet	13,837	0.60	2.00		
119	Indio	Vint complex	6,435	0.60	2.00	26,247	4.7%
101	Antho	Supperstition Complex	31	2.00	6.00		
103	Carstias	Gravely Sand, 0 to 5 percent slope	237	6.00	20.00	High Permeability (Light Soils)	
130	Rositas	Sand, 0 to 2 Percent Slope	775	6.00	20.00		
132	Rositas	Fine Sand, 0 to 2 Percent Slope	2,927	6.00	20.00		
133	Rositas	Fine Sand, 2 to 9 Percent Slope	19	6.00	20.00		
135	Rositas	Fine Sand, Wet, 0 to 2 Percent Slope	11,797	6.00	20.00		
136	Rositas	Loamy Fine Sand 0 to 2 Percent Slope	29	6.00	20.00		
137	Rositas	Silt Loam, 0 to 2 Percent Slope	8	6.00	20.00		
142	Vint	Loamy Very Fine Sand, Wet	31,790	2.00	6.00		
143	Vint	Fine Sandy Loam	3	2.00	6.00	47,616	8.4%
		Total	564,182			564,182	100%

Two maps are included to illustrate the extent of heavy soils within IID. Plate IV-1 shows IID soils with low (0.06–0.2 inches per hour), medium (0.2–2.0 inches per hour), and high (greater than 2.0 inches per hour) permeability rates based on permeability of the surface soil layer. The percentages of each permeability group are 62, 7, and 31% respectively, for low, medium, and high permeability rates. Plate IV-2 shows the area within IID containing a soil layer in the top 4 feet that limits drainage and leaching of salts. The permeability groups are divided into low, medium, and high as discussed for Plate IV-1. The percent areas based on limiting permeability are 87, 5, and 8% respectively, for low, medium, and high permeability rates. Tables IV-7 and IV-8 list the soil mapping units and areas of surface with limiting permeability, respectively. These tables include all areas classified on Plates IV-1 and IV-2, some of which are not irrigated.

As noted earlier, the amount of water needed to satisfy the requirements of a given crop increases with the increase of salinity in the irrigation water. Hence the production of a sustained crop yield requires the application of more water as salinity of irrigation water increases. As the majority of the soils in IID have very low permeability, portions of the applied water will become runoff or tailwater. While the soils of IID are some of the most productive soils in the nation, they require a high level of management, skill, and effort to successfully irrigate.

In the heavy cracking soils of IID, unlike conventional irrigation, the leading edge of the applied irrigation water initially fills up the cracks while a portion of the water infiltrates into the root zone and beyond. The irrigation water leaches primarily the upper root zone of the soil profile along the cracks as well as the surface of the soil, especially after the cracks are filled with water. This unique phenomenon, in which the lateral flow of the irrigation water is in part leaching the upper root zone of the soil profile, is different from conventional leaching (via vertical water flow). The runoff water is a necessity because more water has to be applied at the lower portion of the field to adequately irrigate the field and to leach the higher salt concentrations. In essence, the tailwater is not only a necessity for sufficient irrigation in the lower field, but also for horizontal leaching of the upper root zone of the field. Therefore, the tailwater should be regarded as a beneficial use for leaching purposes.

D. Parameters That Should be Considered When Estimating Leaching Requirements for Crops Grown in the Heavy Cracking Soils of IID

Based upon the foregoing discussions related to heavy cracking soils, salinity management, and the primary factors affecting leaching of salts below the root zone, it is possible to develop a methodology for estimating salt leaching in IID. This analysis is as follows:

1. *Tailwater as a Leaching Component*

Leaching of salts from the root zone of non-cracking, light soils occurs vertically. Current methods for estimating leaching requirements are largely based on this assumption. However, this common practice is incorrectly applied to all soil conditions. It should not be applied to the heavy cracking soils found in IID because leaching of salts from the root zone for a large portion of the soils in the District occurs both vertically and horizontally. To correct for this mischaracterization, a portion of the tailwater must be included as part of the leaching fraction, in addition to being required for adequate irrigation of the lower portion of the field.

Based on the extensive tailwater studies conducted by NRCE and IID, about 17% of the applied irrigation water results in tailwater (IID, 1990). It can be said, based on the analysis conducted in the following sections of the report, that approximately 3.4% of the total headgate delivery water for heavy cracking soils was used for horizontal leaching. The occurrence of tailwater, associated with the leaching of fields comprised of heavy to medium cracking soils, must be regarded as a beneficial use of water in a similar manner to the use of water associated with subsurface drainage for purposes of leaching excess salts exiting from buried tile drains. The difference between subsurface drainage water and the leaching portion of the tailwater is that the subsurface drainage used for leaching salts flows beneath the ground and is not visible, while the tailwater is visible.

2. *Leaching Fraction as a Function of Field Length*

Because the salinity of irrigation water increases as it moves from the head to the tail end of the field, the leaching requirement will not be constant, as it will vary (increase) with the distance the water has traveled along the field's length. This is true since the salinity of the irrigation water increases with the distance water travels. The estimated leaching requirement, at any given point along the field's length, therefore increases as a function of field length. Therefore, when one estimates the amount of water necessary to meet the leaching requirements of a field of heavy cracking soils, the high salinity of the irrigation water must be taken into consideration. Hence, when one estimates the amount of water necessary for leaching requirements, the salinity content of the irrigation water should be the weighted average of the salinity content of the water applied at the head and at the tail end of the field as opposed to the salinity content of the original irrigation water that is conventionally used.

3. *Vertical Leaching Comparison*

The conventional equation that is traditionally used to estimate leaching requirements is a function of the salinity content of the irrigation water and the sensitivity of crops to salinity concentration of the soil. This equation assumes that leaching occurs only vertically and soil characteristics have no influence in the determination of the amount of leaching required. In other words, whether the soil is light or heavy, the equation does not take into consideration the differences in soil texture. The behavior of the majority of soils in IID (the soils being very tight and cracking) do not correspond to the realities under which the equation for determining leaching requirement was developed.

Studies have shown that the infiltration rate of the light non-cracking soils in IID is about 1 foot per day while the infiltration rate for heavy cracking soils is approximately 0.03 to 0.05 feet per day and up to 0.1 feet per day. Based on the ratios of the infiltration rates, it has been determined that the light soil allows water to penetrate into the soil 10 to 20, and up to 33, times faster than that of the heavy cracking soil after initial filling of cracks. Therefore it would require 10 to more than 30 times longer for sufficient water to infiltrate for vertical leaching on heavy cracking soils. However, it is impractical to apply water for this long of a period during the cropping period because it would drown or scald (damage resulting from plants being in hot water for extended periods) most crops.

E. Estimation of Leaching Requirements

For soils other than the heavy cracking soils in IID, the conventional equation by Rhoades (1974) may be used to determine the leaching requirement. Based on this equation, the leaching requirement estimate is dependent on two parameters: the salinity content of the incoming irrigation water and the sensitivity of the crop to salinity. However, when the cracking soils of IID are considered, there are distinct considerations one must analyze prior to applying this equation as a tool to estimate the leaching fraction. Rhoades conventional equation is as follows:

$$LR = \frac{EC_{iw}}{5EC_e - EC_{iw}} \qquad \textbf{(IV–2)}$$

where,

LR = Fraction of irrigation water that must be leached through the root zone to control soil salinity at any specified level

EC_{iw} = Electrical conductivity of the irrigation water

EC_e = Threshold electrical conductivity of the most sensitive crop to be grown in a rotation on that field.

1. *Horizontal Leaching Effect of Cracked Soils*

For conventional, non-cracking soils, the salinity content of the incoming irrigation water does not significantly change as the irrigation water moves from the head of the field to the tail of the field. Therefore, Equation IV-2 can use the salinity content of the Colorado River at the headgate delivery points. However for the cracking soils, field measurements consistently showed that the salinity content of the irrigation water invariably increases as it flows from the head to the tail end of a field. This being the case, the EC_{iw} in the equation has to increase longitudinally. In its most simplified form, the median or average value of the salinity content of the water should be used in the equation; therefore, the EC_{iw} value should be increased.

The following is an illustration of the resulting leaching requirement estimate based on actual data measured by IID from 1985 to 1990. The salt concentration of the delivered irrigation water at the head of the field was 0.97 ds/m, while at the tail end it was 1.33 ds/m. Assuming that the increase of the salt content across the field is linear, the average value for the field would be 1.15 ds/m. Substituting in the 1.15 ds/m and using an alfalfa crop with an EC_e of 2.0, the comparative results would be as follows:

Light Non-cracking Soils:

$$LF = \left(\frac{0.97}{5x2.0 - 0.97}\right)100 = 10.7\% \qquad \textbf{(IV-3)}$$

IID Cracking Soils:

$$LF = \left(\frac{1.15}{5x2.0 - 1.15}\right)100 = 13.0\% \qquad \textbf{(IV-4)}$$

Based on the above results, IID cracking soils require about 20% more leaching water compared to light non-cracking soils for alfalfa crops. As the salt tolerance of the crop becomes higher, the difference between the estimated leaching requirement for the cracking and non-cracking soils decreases. This illustration is used for comparative purposes only; again, due to horizontal leaching, NRCE has determined the Rhodes equation cannot be directly applied to the medium and heavy cracking soils in IID.

2. *Vertical Leaching on Heavy-cracking Soils*

As discussed earlier, field studies have shown that about 22% of the salts introduced by irrigation water to a typical field with cracking soils is removed by the tailwater. If one assumes that the remaining 78% of the salts have to be removed by the process of vertical leaching, one has to estimate the amount of water required to leach those salts using the conventional leaching equation adjusted for IID soils, as discussed above.

Based on NRCE's irrigation evaluation during the summer of 2000, it was determined that the average vertical leaching for the medium and heavy soils during crop irrigation was about 4.5% of the headgate delivery. If, for example, the headgate delivery during crop irrigation is about 5.0 acre-feet per acre, the vertical leaching would be 0.23 acre-feet per acre. It was also determined that the 4.5% vertical leaching removed 29.8% of the total salts introduced by the irrigation water.

3. *Vertical Leaching Between Crops*

The third component of leaching is the amount of water used to leach the accumulated salts between the final harvesting and planting of new crops. NRCE has estimated this to be 0.48 acre-feet per acre. Many crops are perennial (alfalfa, bermuda, asparagus, etc.) and are not planted each year. Therefore the leaching irrigation does not apply to all the acreages each year.

4. *Leaching During Crop Irrigation*

The irrigation evaluation on the fields studied showed that the tailwater was on average about 17% of the headgate delivery. The total salts removed by the 17% tailwater was estimated to be 22.3% of the total salts introduced. When one considers medium and heavy soils, the equivalent amount of a portion of the tailwater used to remove salts relative to that of the vertical leaching is 3.4% (22.3 x 4.5/29.8) of the headgate delivery, amounting to 0.17 acre-feet per acre per year (3.4% x 5.0).

Hence, the total amount of water used for leaching purposes during crop irrigation is 0.23 + 0.17 = 0.4 acre-feet per acre. The 0.4 acre-feet per acre represents both horizontal and vertical leaching during irrigation.

F. Application of Field Irrigation Evaluations to IID Drainage

The following analysis of on-farm leaching and deep percolation is based on information obtained from NRCE's field irrigation evaluations and IID's average annual water budget for the 1988 to 1997 period. It is recognized that only a few irrigations have been evaluated and that the information is not necessarily representative of all conditions throughout IID. However, the data is reasonable and does not contradict other available data and analysis.

The results of the analysis are included in Tables IV-9 and IV-10. The estimated on-farm irrigation efficiency is 83%. It is estimated that overall only 2.7% of the headgate deliveries (with 1.3% of headgate deliveries on heavy soils and 1.4% on light soils) are in excess of the leaching requirement. Excess deep percolation results from non-uniformity of soil (varying intake rates) and non-uniformity of irrigation (for example, excess irrigation at head of field) which cannot be avoided. The excess deep percolation leaches salt, but may not be needed to maintain acceptable crop production. Though there may be this small unavoidable excess on the lighter soils, most of the predominant heavy cracking soils do not receive enough leaching water.

Table IV-9 Disposition of On-farm Leaching and Deep Percolation in IID (Typical Year).

Description	Fraction of Area	Area (acres)	Fraction of Sub-area	Area (acres)	DP During Crop Irrigation (in/yr)	DP During Leaching Irrigation (in/yr)	DP Total (in/yr)	Total Water (Kaf)
Non-limiting permeability	0.13	60,060						
Leaching			1.00	60,060	7.00		7	35
Other deep percolation			1.00	60,060	7.00		7	35
Limited permeability	0.87	401,940						
Alfalfa leached every 4 years			0.32	128,621	3.20	1.45	4.65	50
Bermuda leached every 5 years			0.06	24,116	2.80	1.16	3.96	8
Annual crops leached every year			0.62	249,203	2.40	5.80	8.20	170
Other deep percolation from non-uniformity of irrigation and soils.			1.00	401,940	0.98	0.00	0.98	33
SUBTOTAL for Limited Permeability				**401,940**				**261**
TOTAL		**462,000**			**Total Tile Water**			**331**
Total Leaching		**263**	**Kaf**		**Total Tile Water**		**0.69**	**Feet**
Total Other		**68**	**Kaf**		**Total Tile Water**		**8.26**	**Inches**

Other deep percolation is the closure term to balance the deep percolation with that estimated by the water balance.
Shaded values are input values.
DP = deep percolation; Kaf = 1,000 acre-feet

Table IV-10 On-farm Water Balance (Average of 1988 through 1997).

Description	Water (Kaf)	Percent of Headgate Deliveries	Notes
Total Headgate Deliveries	2,503	100.0	Average of 1988-1997
On-Farm Irrigation CU	1,746	69.8	Average of 1988-1997
Total Tailwater and Tilewater	**757**	30.2	Total headgate deliveries minus on-farm CU
Tailwater (17 percent)	**426**	**17.0**	
Leaching Heavy Soil	75	3.0	87 percent of land times 3.4 percent equivalent horizontal leaching.
Other Tailwater	351	14.0	Tailwater not used for leaching
Tile Water	**331**	**13.2**	Total tile water
Leaching Heavy Soil	228	9.1	From Table IV-9 (50+8+170)
Leaching Light Soils	35	1.4	From Table IV-9
Remaining Tile Water	68	2.7	Tile water not used for leaching
Irrigation Efficiency		**83.3**	
Total Leaching Water	**338**	13.5	Horizontal and Vertical Leaching
Vertical Leaching	**263**	10.5	Vertical Leaching Only

Total headgate deliveries and on-farm irrigation consumptive use based on IID water balance.
Shaded values are input values.
Kaf = 1,000 acre-feet, CU = consumptive use

The analysis presented in Tables IV-9 and IV-10 used the following assumptions and information:

Table IV-9 assumptions and analysis:

- The average annual net cropped area is 462,000 acres.
- 13% of the net cropped area has light soils with permeability greater than 0.2 inches per hour throughout the top four feet based on the Soil Conservation Service (SCS) Soil Survey.
- The other deep percolation for light soils is an assumption based on typical irrigation uniformity.
- The average leaching requirement of the light soil is estimated to be 7 inches per year. This estimate is 10.7% of headgate deliveries based on the leaching fraction.
- 87% of the net cropped area has medium and heavy soils in the top four feet, which limit permeability to less than 0.2 inches per hour based on the SCS Soil Survey.
- The leaching of the heavy soil is based on NRCE's field irrigation evaluations during which about 0.2 inches of leaching occurred per irrigation during the cropping period, as well as an estimated irrigation leaching of 5.8 inches during a typical leaching irrigation.
- Thirty-two percent of the heavy soil area is in alfalfa, six percent in Bermuda grass, and 62 percent is other crops. The crops are irrigated 16, 14, and 12 times per year, for alfalfa,

Bermuda grass, and other crops, respectively. The number of irrigations were obtained from IID irrigation delivery records and are very similar to those used in crop production budgets developed by the University of California (UC, 1996). For example, the average annual deep percolation during the crop irrigation is 3.2 inches (0.2 in/irrigation x 16 irrigations).

- The leaching irrigation on heavy soils occurs once each year for annually or multiple cropped acreage, once every four years for alfalfa, and once every five years for Bermuda grass. For example, the average annual deep percolation for alfalfa is 1.45 inches (5.8 inches per leaching/4 years between leaching).

- The annual average (1988-1997) headgate deliveries are 2,503,000 acre-feet and the average annual on-farm irrigation consumptive use is 1,746,000 acre-feet.

Table IV-10 assumptions and analysis:

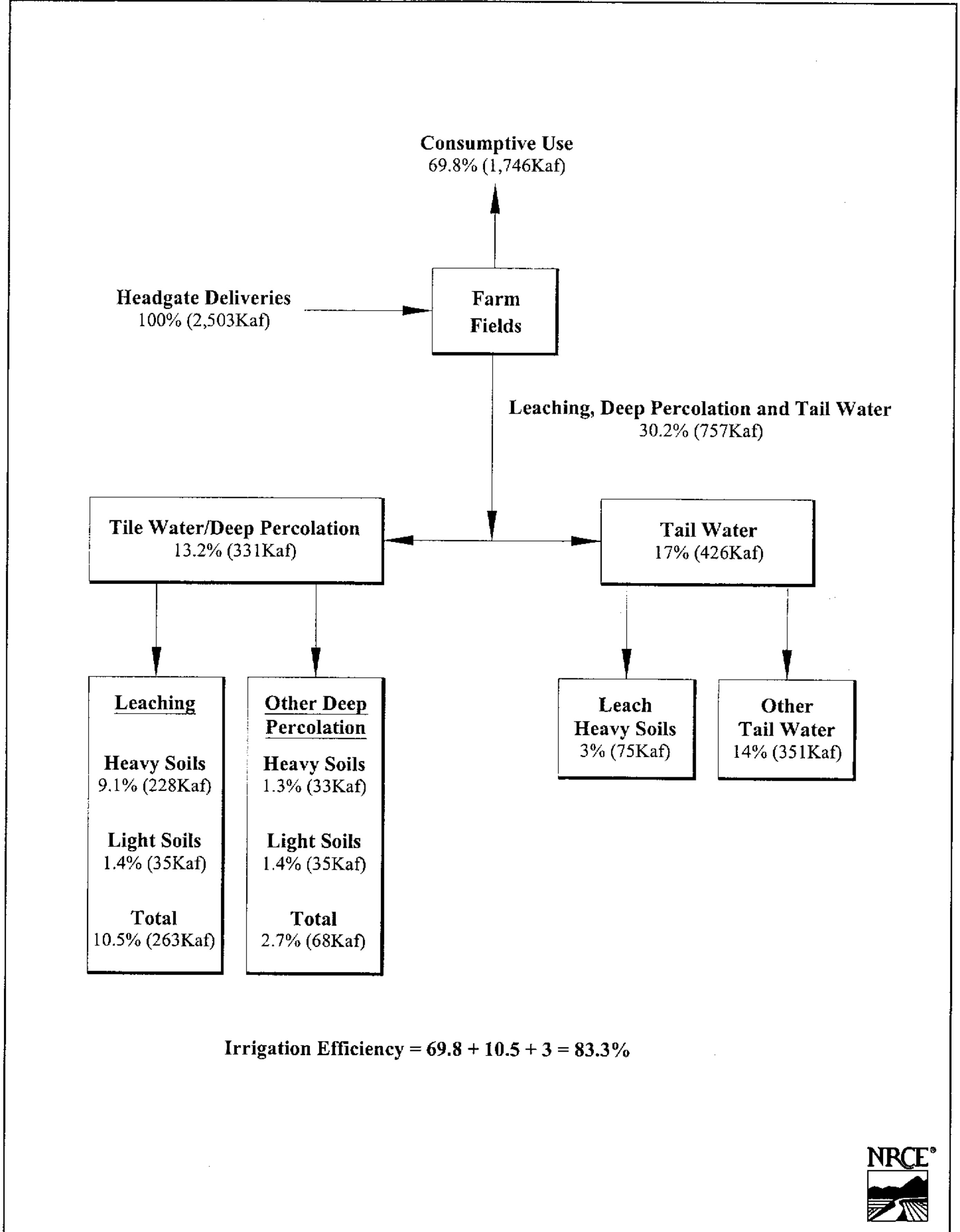
- Tailwater is estimated to be 17 percent of headgate deliveries based on NRCE's field irrigation evaluations and IID data.

- Tailwater used for horizontal leaching of heavy soils (87% of the net cropped area) is estimated at 3.4 percent of headgate deliveries, as previously described.

- Other deep percolation on medium and heavy soils is equal to total deliveries minus on-farm consumptive use minus tailwater minus leaching deep percolation on medium and heavy soils, minus leaching deep percolation on light soils minus other deep percolation on light soils. This value is (2,503-1,746-426-228-35-35=33 kaf). The 33 kaf/year is equivalent to 0.98 in/year on the heavy soils.

The results of the analysis are illustrated in Figure IV-3. The figure shows the disposition of water from the headgate to irrigation consumptive use, tailwater, and tile water; and then divides the tailwater and tile water between leaching and other deep percolation and tailwater.

Figure IV-3 Distribution of On-Farm Water Deliveries (Average of 1988-1998).



REFERENCES:

Bouma, J., and Loveday, J. (1987). "Characterizing soil water regimes in swelling clay soils. Vertisols: their distribution, properties, classification and management." Texas A&M University Press, College Station, TX, 83-96.

Grismer, M. E. (1986). "Irrigation, drainage, and soil salinity in cracking soils." *Soil and Water, No. 68.* Publication of the Cooperative Extension, Univ. of California.

Grismer, M. E., and Bali, K.M. (1996). "Continuous ponding and shallow aquifer pumping leaches salts in clay soils." *California Agriculture, Vol. 51, Number 3.*

Imperial Irrigation District. (1990). Inter-office Memorandum: "Percent of Tailwater by Crop." Addressed to the Water Conservation Advisory Board, dated August 9, 1990, from Secretary, WCAB.

Kaddah, M. T. and Rhoades, J.D. (1976). "Salt and water balance in Imperial Valley, California." *Soil Science Society American Journal*, 40:93.

Kosmas, C., Moustakas, N., Kallianou, C., and Yassoglou, N. (1991). "Cracking patterns, bypass flow and nitrate leaching in Greek irrigated soils." Geoderma, 49, 139-152.

Lonkerd, W. E., Ehlig, C.F., and Donovan, T.J. (1979). "Salinity profiles and leaching fractions for slowly permeable irrigated field soils." *Soil Science Society American Journal,* 43:287-289.

Mitchell, A. R. and Van Genuchten, M. Th. (1993). "Flood irrigation of a cracked soil." *Soil Science Society American Journal,* 57:490-497.

Oster, J. D., Meyer, J. L., Hermsmeier, L. and Kaddah, M. (1984). "Imperial valley: irrigation, drainage, and runoff." *Soil and Water*, University of California Cooperative Extension publication No. 60, Fall 1984.

Shouse, P. J., Letey, J., Jobes, J., Fargerlund, J., Burch, S. L., Oster, J. D., Rhoades, J. D., and O'Halloran, T. (1997). "Salt transport in cracking soils: bromide tracer study." *Journal of Irrig. and Drainage Eng.*, ASCE, 123(5):329-335.

Rhoades, J. D. (1974). "Drainage for salinity control" In: *Drainage for Agriculture.* Van Schilfgaarde J. (ed)., American Society of Agronomy. Monogragh No. 17, pp 433-462.

Rhoades, J. D., Lesch, S. M., Burch, S. L., Letey, J., LeMert, R. D., Shouse, P. J., Oster, J. D., and O'Halloran, T. (1997). "Salt distributions in cracking soils and salt pick-up by runoff waters." *Journal of Irrigation and Drainage Engineering*, ASCE, 123(5), 323-328.

University of California Cooperative Extension (1998-1999). Guidelines to production costs and practices (1998-1999), *Vegetable Crops Circular 104-V*, University of California, Imperial County, Cooperative Extension, Holtville, CA.

V. IID'S WATER BUDGET

This section of the report takes the principles detailed in previous chapters and applies them in the context of IID, with a water budget.

A. IID's System Wide Water Budget

The gross water consumptive use in the Imperial Valley may be estimated using the volume balance method. This approach is appropriate for the Imperial Valley because of the valley's unique hydrogeologic condition and physical location as a closed basin. A general mathematical expression of the volume balance method for a particular control volume is described as follows:

$$V_{outflow} = V_{inflow} - V_{consumption} \pm V_{\Delta\, storage} \qquad \textbf{(V-1)}$$

The inflows into the system, V_{inflow}, may include precipitation, surface inflows such as natural streams and irrigation water deliveries, and subsurface inflow, which is primarily groundwater flow. The outflows, $V_{outflow}$, of the system are represented by surface outflows, which include natural streams as well as drainage water, and subsurface outflows, which are primarily groundwater flows. The water consumption, $V_{consumption}$, is evaporation from open water such as ponds, reservoirs, and lakes; ET of agricultural crops and other plants, and non-agricultural water uses for domestic, industrial, and municipal purposes. The change of water storage, $V_{\Delta\, storage}$, is the change of subsurface water stored in the soil.

The volume balance analysis was performed by NRCE for the whole IID as a system wide unit, as well as two subsystems which include the conveyance and distribution level subsystem and the on-farm level subsystem. The water consumption on agricultural land was separated out from the total water consumption in IID. The irrigation water consumption on agricultural land was determined by removing the rainfall contribution to ET from the water consumption on agricultural land so that only irrigation water may be considered. Figure V-1 is a schematic diagram illustrating the system-wide water budget with its pertinent inflow and outflow components.

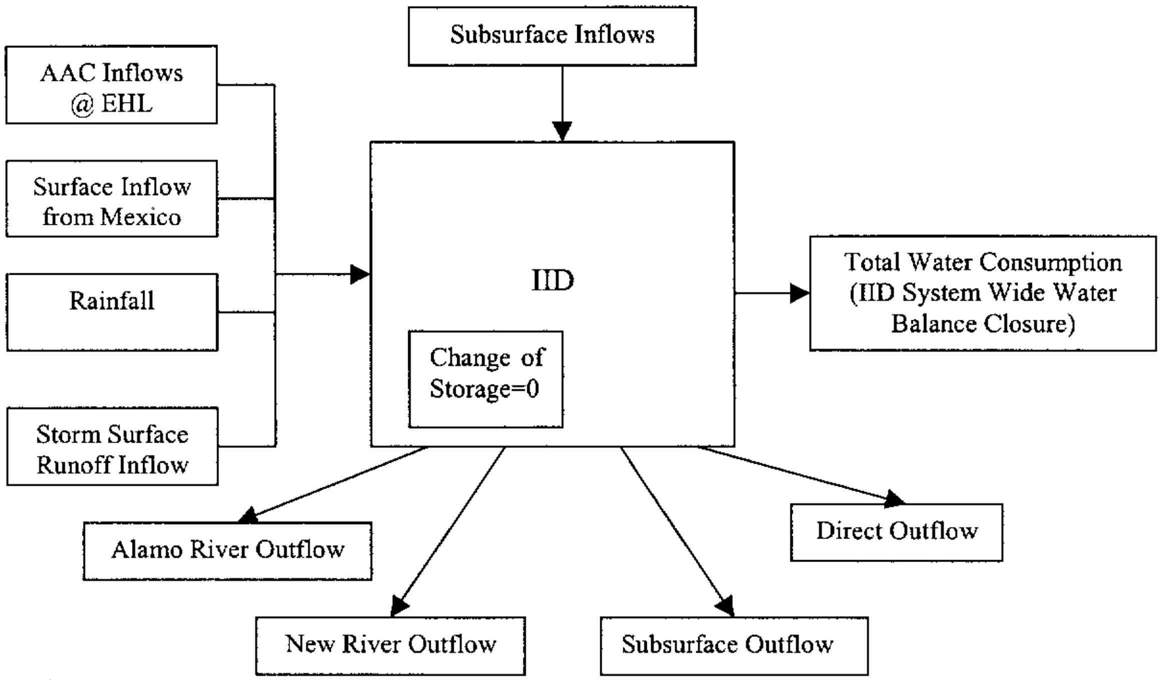


Figure V–1 Schematic Diagram of IID's System Wide Water Volume Balance With Total Water Consumption as the Closure Term.

1. *Boundaries of IID Controlled Volume Study Area*

The IID system-wide controlled volume is the study area that is defined as the irrigated area within the Imperial Valley. The southern boundary is the Mexico Border, and the eastern boundary is the EHL Canal. The Salton Sea creates the north and northwest borders of the controlled volume area. The western boundary is the outermost irrigated farms. The upper vertical boundary is the land surface that includes agricultural crops, trees, and phreatophytes. The lower boundary is defined as the impervious layer well below the local groundwater table.

2. *Inflow*

There are three major inflow sources entering the IID system. The New and Alamo Rivers flowing from across the Mexican border, the AAC, and precipitation. Other minor surface and subsurface inflows such as surface runoff of storm events in the surrounding area and groundwater inflow into the valley are also considered. Table V-1 shows total inflow in kilo-acre-feet units.

Table V-1 Annual inflow values for the period of 1988 to 1997 (in kilo-acre-feet).

Year	AAC Inflow at Pilot Knob	Outflow to Coachella Canal	IID Deliveries from Coachella Canal	IID Deliveries from AAC	Surface Inflow from Mexico	Other Surface Inflows	Sub-surface Inflows	Rainfall (inches)
1988	3,279	-325	-4	-3	229	2.4	20	1.82
1989	3,377	-351	-4	-3	155	2.0	20	1.5
1990	3,420	-359	-3	-3	135	2.4	20	1.81
1991	3,211	-308	-4	-6	133	4.6	20	3.5
1992	2,876	-297	-4	-4	145	8.1	20	6.13
1993	3,085	-307	-4	-3	192	7.1	20	5.37
1994	3,369	-319	-4	-2	147	3.4	20	2.56
1995	3,391	-321	-4	-2	150	2.8	20	2.11
1996	3,486	-327	-4	-2	120	1.1	20	0.8
1997	3,492	-324	-4	-0.5	162	4.3	20	3.26
Average	3,299	-323	-4	-2.9	157	3.8	20	2.89

3. *Outflow*

The natural drainage outlet for IID is the Salton Sea. The majority of the subsurface drainage, uncollected tailwater, canal spills, etc. are all collected by the Alamo and New Rivers which eventually drain into the Salton Sea. A small portion of these flows go directly to the sea. Flows that do not travel to the Salton Sea are either evaporated into the atmosphere, consumed by plants through ET, used by municipal and industrial (M&I) uses, or other uses.

IID maintains gaging stations on the Alamo and New Rivers that record water levels every 15 minutes on a data logger. Direct outflow to the Salton Sea consists of pumped subsurface drainage water from farms at the edge of the Salton Sea that are below sea level as well as some IID canal spills. The pumping flows were estimated by IID based on power records and assumed pump efficiencies. The canal spill volumes were estimated by either head readings over weirs or head differentials across submerged gates.

The USGS conducted a number of studies regarding groundwater flow from the Imperial Valley to the Salton Sea in the 1960s. According to USGS Professional Paper 486-C (1996), the estimated groundwater flow was less than 2,000 AF per year. However, due to the rising Salton Sea level and the increase in drainage pumping to the Sea, the groundwater gradient has been decreasing in recent years. Therefore, the groundwater flow to the Salton Sea has been estimated to have an average value of 1,000 acre-feet per year. Table V-2 shows the annual values for the outflow parameters of IID's system.

Table V-2 Measured and Estimated Outflows From IID (kilo-acre-feet).

Year	Alamo River to Salton Sea	New River to Salton Sea	Direct Outflow to Salton Sea	Subsurface Outflow to Salton Sea
1988	559	489	100	1
1989	594	431	96	1
1990	618	431	91	1
1991	594	411	88	1
1992	546	397	81	1
1993	617	460	89	1
1994	641	443	109	1
1995	646	473	115	1
1996	641	437	114	1
1997	637	487	107	1
Average	609	446	99	1

4. *Storage Changes*

The changes in subsurface water storage in the Imperial Valley are considered to be minimal on a long-term basis. This assumption is supported by the valley's high groundwater tables, limited groundwater pumping, and consistent cropped acreage from year to year. However, due to the changes in crop mix and rainfall amounts in different years, a certain degree of error is expected with the volume balance analysis (if no change in subsurface storage for a given year is assumed). Changes in soil water storage from month to month over the growing season may be significant due to crop water demand and irrigation and rainfall events, which are not evenly distributed throughout the growing season.

5. *IID Water Consumption*

The total water consumption component of IID's system-wide water volume balance may be expressed as follows:

$$V_{total\ water\ consumption} = V_{inflow_{surf}} + V_{inflow_{subsurf}} + V_{rain} - V_{outflow_{surf}} - V_{outflow_{subsurf}} \pm V_{\Delta\ storage} \qquad \textbf{(V-2)}$$

The $V_{total\ water\ consumption}$ is an unknown remainder, which needs to be calculated from other known measured and estimated parameters. The change of storage, $V_{\Delta\ storage}$, is essentially zero, on an annual basis. A schematic drawing of the above water balance equation containing the inflow and outflow components is shown in Figure V-1.

The total water consumption in IID, $V_{total\ water\ consumption}$, includes other uses in IID besides crop water ET on agricultural lands. These other uses were taken out of the total water consumption so that the actual amount of water used for irrigation could be determined. The components that comprise the total water consumption are categorized as follows: agricultural water consumption, M&I and other uses, canal and reservoir evaporation, rainfall ET on non-agricultural land, and evaporation and ET from drains, rivers, and phreatophytes.

The agricultural water consumption is now the unknown component (i.e., remainder term) of this total water consumption water balance. Moreover, water consumption on agricultural land is supplied by both irrigation water and rainfall. If the actual irrigation water consumption is to be determined, the consumptive use supplied by rainfall (rainfall ET) on agricultural land has to be subtracted out from the water consumption on agricultural land. Figure V-2 is a schematic diagram of the various components of the total water consumption of IID. The following sections describe how NRCE determined these other uses and water consumption for IID.

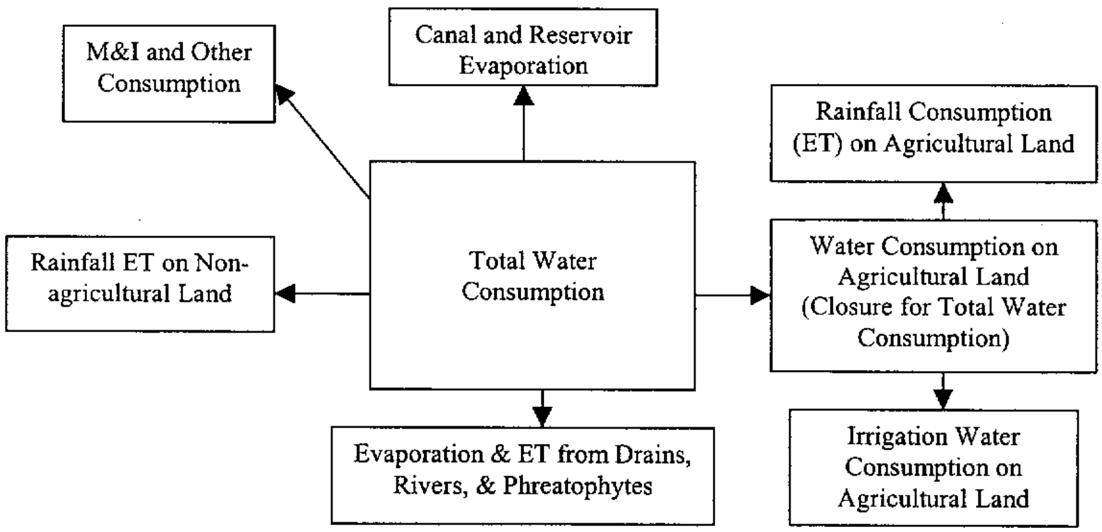


Figure V-2 Schematic Diagram of IID System Wide Inflow and Outflow with Water Consumption on Agricultural Land as a Closure Term.

a. Other Water Uses In IID

IID delivers surface water to cities for domestic purposes and several industries within its service area. IID recorded delivery amounts from 1988 to 1992 were reported in Styles (1993).

IID also delivers water to other users in the valley such as homes, farmsteads, and small businesses in rural areas. Some of the water amounts used in this category were estimated using average water use values provided by IID and Styles (1993). Water delivered to feedlots and community green areas was also included in this category. The values of other uses have been derived from the Styles (1993) report. Table V-3 lists the annual amounts of the various other water uses in IID including M&I uses.

Table V-3 Other Water uses within IID (kilo-acre-feet).

Year	Municipal	Industrial	Rural	Feedlots	Green Areas	Total
1988	28	7	11	7	10	63
1989	28	9	11	7	10	65
1990	27	14	11	7	10	69
1991	28	15	12	7	10	72
1992	29	15	12	6	10	72
1993	30	15	12	7	10	74
1994	31	15	12	7	10	75
1995	34	15	12	7	10	78
1996	34	15	12	7	10	78
1997	32	17	12	7	10	78
Average	30	14	12	7	10	72

b. Non-Agricultural Consumption

Not all of the water delivered to cities and industries is consumed, some is returned to the drainage system. Styles (1993) reported that return flow from delivered M&I water is about 30% according to records of measured return flows in wastewater treatment plants and deliveries. The flow records show that the range of wastewater treatment capacity relative to supply capacity was between 19% to 37%. Therefore, the M&I water consumptive use was assumed to be 70% of the deliveries. It is also reasonable to assume that consumptive uses other than M&I were equal to deliveries because minimal returns were assumed.

c. Canal and Reservoir Evaporation

Evaporation from canals and reservoirs in IID was also considered in the water volume balance. The area of canals and reservoirs used to calculate evaporation was estimated by Styles (1993) based on canal length and assumed average water surface widths. The rate of evaporation was estimated based on the ET_o with adjustment factors for type of water surface and lateral canals that are only full part of the year. The factor used to adjust the ET_o for canals, farm ponds, and reservoir evaporation was 1.1. The estimate of ET_o is specified in another section of this report.

d. Evaporation From Drains, Rivers, and Phreatophyte ET

IID has a large system of drains and natural rivers that consume water by evaporation and ET of phreatophytes (vegetation) along these waterways. The areas for these sources of water use were estimated by Styles (1993). The area of the open water surfaces for drains were based on the length of drains from a CH2MHill draft EIR (1993) and assuming 10 foot average width as estimated by Freeman (1993). The area of vegetation along drains was estimated as 1.56 acre/mile of drain as reported by Dodd (1993) and Freeman (1993). The areas of open water surfaces and vegetation of the rivers (i.e., Alamo and New Rivers) were estimated from SPOT images provided by IID (Styles, 1993). The evaporative demand of the open water surfaces and the ET of the phreatophytes along the rivers were determined based on ET_o with multiplication factors of 1.0 and 1.1 for drains/rivers and phreatophytes, respectively.

e. ET from Rainfall on Non-agricultural and Agricultural Land

Rainfall is part of the system's inflow. However, part of it is lost to evaporation and ET from vegetation on non-agricultural land. These land areas include cities, roads, canal banks, farmsteads, etc. It is estimated that 60 to 90% of the rainfall received on both agricultural and non-agricultural lands will be consumed. An estimated average of about 75% of rainfall will be either evaporated or transpired on non-agricultural land. ET from rainfall on agricultural land was estimated to range from 85 to 100% of the actual annual rainfall in the study area.

f. Reference Crop Evapotranspiration (ET_o)

The climatic data from the three CIMIS stations (Calipatria, Seeley, and Meloland) in the Imperial Valley were used to compute the ET_o based on the FAO P-M equation. Detailed procedures of the calculations are in Chapter II of this report. The total annual ET_o values of IID for the study period are listed in Table V-4.

Table V-4 Annual Reference ET_o (feet) of IID Based on the FAO P-M Equation.

Year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
ET_o (feet/year)	7.10	7.44	6.85	5.87	5.89	6.52	6.67	6.8	7.23	6.75	6.71

g. Land Areas

The total assessed land area of the water budget study was 656,306 acres. This was derived from IID's summaries of acreage report. The net acreage includes all units except for areas 230 feet below sea level, undeveloped areas of Imperial, West Mesa, East Mesa and Pilot Knob Units, and 2,636 acres of irrigated land east of the EHL and its service area. Basically, all land outside the valley floor was not considered, except for a small area of agricultural land east of the EHL.

The total acreage may be categorized into various land use groups. Net irrigated, fallow, and idle lands are considered agricultural land. Fallow land is defined as farmable area, but not farmed, whereas idle land is also farmable land, but between crops. These acreages are reported in IID's monthly crop summaries. The annual acreage differences for agricultural land is within 2% during the study period from 1988 to 1997. However, if land is idle for only part of the year, it is likely that it was not included in the reported annual acreage. Area covered by phreatophytes, water surface areas of IID canals and reservoirs, and surface drains are all the other acreage categories estimated by Styles (1993). The land area that is not part of agricultural land or part of other water surface areas mentioned above is defined as a non-agricultural land. This area includes towns, highways, railroads, farmsteads, ditchbanks, and drainbanks (non-vegetated, county roads, field roads, canal roads, feedlots, etc.) Table V-5 shows the annual acreage evaluated for each of the categories above for each of the years in the study period (1988-1997). Constant acreage for each category was assumed throughout the study except for agricultural lands and the corresponding non-agricultural lands that varied slightly from year to year.

Table V-5 Acreages of Land Categories in IID Study Area.

Acreage of Land Category	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Agricultural land (irrigated, idle, and fallow)	486,476	486,565	485,863	482,833	480,567	480,270	477,705	478,515	477,615	478,158
Irrigated and idle land	458,329	463,764	466,524	465,824	464,344	463,884	458,584	456,904	458,754	460,146
Phreatophytes	11,424	11,424	11,424	11,424	11,424	11,424	11,424	11,424	11,424	11,424
Canals and reservoirs	3,401	3,401	3,401	3,401	3,401	3,401	3,401	3,401	3,401	3,401
Rivers and drains	2,357	2,357	2,357	2,357	2,357	2,357	2,357	2,357	2,357	2,357
Non-ag. land	152,648	152,559	153,261	156,291	158,557	158,854	161,419	160,609	161,509	160,966
Total	656,306	656,306	656,306	656,306	656,306	656,306	656,306	656,306	656,306	656,306

6. *Results of Water Volume Balance*

The water volume balance approach for computing total water consumption on agricultural land are shown in Tables V-6 through V-10 for the study period from 1988 to 1997. Table V-6 shows the calculation of the water entering the study area through the AAC. The lowest inflow volume was in 1992 and the highest inflow volume was in 1997 with annual inflows of 2,475,000 and 3,068,000 acre-feet, respectively.

Table V-6 Determination of AAC Inflow to IID (kilo-acre-feet).

Year	Delivery to AAC at Pilot Knob	Water Delivered to Coachella Canal	Deliveries to IID Farms above EHL	Seepage (PK* to EHL)	Evaporation (PK* to EHL)	AAC Inflow @EHL
1988	3,279	-325	-3	-94	-6	2,851
1989	3,377	-351	-3	-94	-6	2,922
1990	3,420	-359	-3	-94	-6	2,957
1991	3,211	-308	-6	-94	-5	2,798
1992	2,876	-297	-4	-94	-5	2,475
1993	3,085	-307	-3	-94	-5	2,675
1994	3,369	-319	-2	-94	-6	2,948
1995	3,391	-321	-2	-94	-6	2,969
1996	3,486	-327	-2	-94	-6	3,057
1997	3,492	-324	-1	-94	-6	3,068
Average	3,299	-324	-3	-94	-6	2,872

* PK = pilot knob

Tables V-7 and -8 are the total inflow and outflow, respectively, of IID. The range of total inflow to IID over the study period is from 2,984,000 to 3,433,000 acre-feet, while the range of outflow is from 1,024,000 to 1,235,000 acre-feet. The volume of the total water consumption is the remainder in the IID system wide water budget as indicated in Table V-9. The change in storage is assumed to be zero on an annual basis. The lowest total water consumption is in 1992 and the highest is in 1997 with volumes of 1,960,000 and 2,201,000 acre-feet, respectively. Table V-10 and V-11 show the calculation for estimating water consumption on agricultural land and irrigation water consumption. The total water consumption on agricultural land is the total amount of water that the crops consumed through ET. The volumes range from 1,738,000 to 1,988,000 acre-feet with an average of 1,852,000 acre-feet over the study period. Finally, the irrigation water consumption is the Net Irrigation Requirement (NIR) that the crops need for ET less the effects of rainfall. The lowest and highest irrigation water consumption volumes are 1,528,000 and 1,868,000 acre-feet, respectively with an average of 1,747,000 acre-feet. The annual inflow, outflow, total water consumption, and irrigation water consumption volume of IID's system-wide water balance from 1988 to 1997 are shown in Figure V-3. Over the study period from 1988 to 1997, the total system inflow has a significant drop in 1992, most likely due to the white fly infestation in IID. Consequently, similar trends are reflected in the other system flow components.

Table V-7 Sum of Inflows to IID (kilo-acre-feet).

Year	AAC Inflow	Surface Inflow from Mexico	Rainfall Volume	Other Surface Inflows	Subsurface Inflows	Total Inflow
1988	2,851	229	100	2	20	3,202
1989	2,922	155	82	2	20	3,181
1990	2,957	135	99	2	20	3,214
1991	2,798	133	192	5	20	3,147
1992	2,475	145	335	8	20	2,984
1993	2,675	192	294	7	20	3,189
1994	2,948	147	140	3	20	3,258
1995	2,969	150	116	3	20	3,257
1996	3,057	120	44	1	20	3,241
1997	3,068	162	179	4	20	3,433
Average	2,872	157	158	4	20	3,211

Table V-8 Sum of Outflows From IID (kilo-acre-feet).

Year	Alamo River Outflow to Sea	New River Outflow to Sea	Direct Outflow to Sea	Subsurface Outflow to Sea	Total Outflow
1988	559	489	100	1	1,149
1989	594	431	96	1	1,122
1990	618	431	91	1	1,140
1991	594	411	88	1	1,094
1992	546	397	81	1	1,024
1993	617	460	89	1	1,167
1994	641	443	109	1	1,194
1995	646	473	115	1	1,235
1996	641	437	114	1	1,193
1997	637	487	107	1	1,232
Average	609	446	99	1	1,155

Table V-9 Total Inflow, Outflow, and Water Consumption for IID System Wide Water Volume Balance (kilo-acre-feet).

Year	Total Inflow	Total Outflow	Change of Storage	Total Water Consumption
1988	3,202	-1,149	0	2,053
1989	3,181	-1,122	0	2,059
1990	3,214	-1,140	0	2,074
1991	3,147	-1,094	0	2,053
1992	2,984	-1,024	0	1,960
1993	3,189	-1,167	0	2,022
1994	3,258	-1,194	0	2,064
1995	3,257	-1,235	0	2,022
1996	3,241	-1,193	0	2,048
1997	3,433	-1,232	0	2,201
Average	3,211	-1,155	0	2,056

Table V-10 Estimate of Total Water Consumption on Agricultural Land in IID (kilo-acre-feet).

Year	Total Water Consumption	Canal and Reservoir Evap.	M&I Consumption	ET from Drains, Rivers, Phreatophytes	ET from rainfall on Non-Ag Land	Total Water Consumption on Ag Land
1988	2,053	-27	-49	-100	-17	1,861
1989	2,059	-28	-51	-104	-14	1,861
1990	2,073	-26	-54	-96	-17	1,880
1991	2,053	-22	-56	-82	-34	1,859
1992	1,959	-22	-56	-83	-61	1,738
1993	2,022	-24	-58	-91	-53	1,795
1994	2,064	-25	-59	-93	-26	1,862
1995	2,022	-25	-60	-95	-21	1,820
1996	2,049	-27	-60	-101	-8	1,852
1997	2,201	-25	-60	-95	-33	1,988
Average	2,056	-25	-56	-94	-28	1,852

Table V-11 Determination of Irrigation Water Consumption on Agricultural Land in IID (kilo-acre-feet).

Year	Total Water Consumption on Ag. Land	Rainfall Water Consumption on Ag. Land	Total Irrigation Water Consumption on Ag Land
1988	1,861	-68	1,793
1989	1,861	-59	1,802
1990	1,880	-73	1,807
1991	1,859	-135	1,723
1992	1,738	-210	1,528
1993	1,795	-190	1,604
1994	1,862	-91	1,771
1995	1,820	-79	1,741
1996	1,853	-29	1,823
1997	1,988	-120	1,868
Average	1,852	-105	1,747

IID System-Wide Water Balance

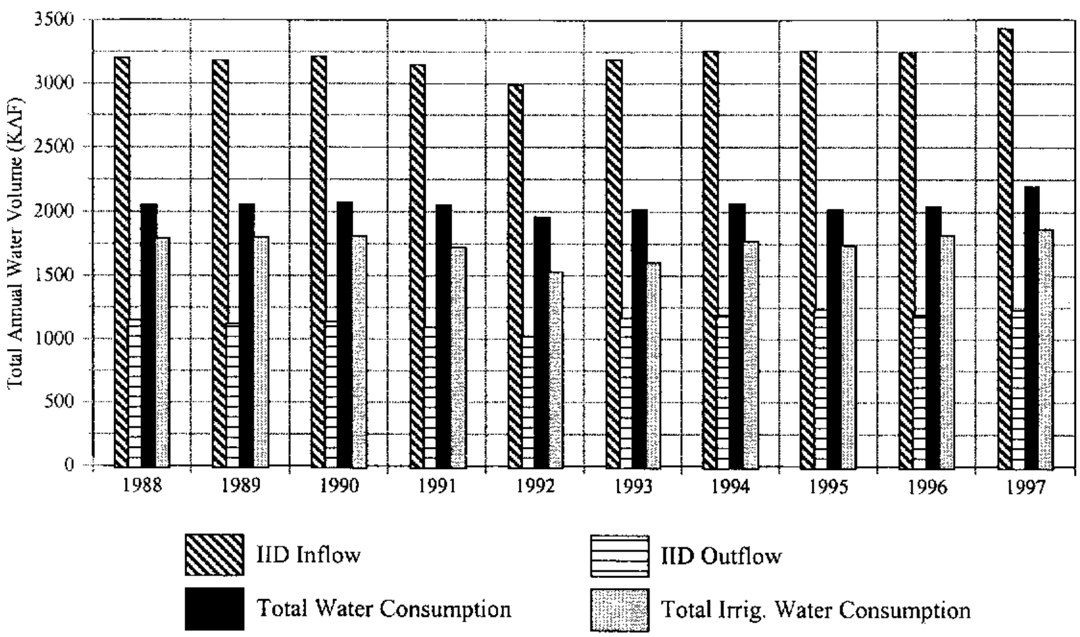


Figure V-3 Water Volumes for the Components of IID's System-wide Water Balance.

The volumes of the various flow components of the system-wide water balance were divided by the total system inflow volume to determine their relative percentage to the total inflow. IID's system outflow ranges from 34 to 38% relative to the total inflow. The total water consumption varies from 62 to 65% relative to the total inflow. The percentage range of the total irrigation water relative to the total inflow is between 50 and 57%. A comparison of the above parameters in percentages relative to the inflow is presented in Figure V-4. The percentage of total annual water consumption relative to the total system-wide inflow decreases slightly by about 2 to 5% after 1992. Detailed calculations of the water volume balance are shown in Appendix 8.

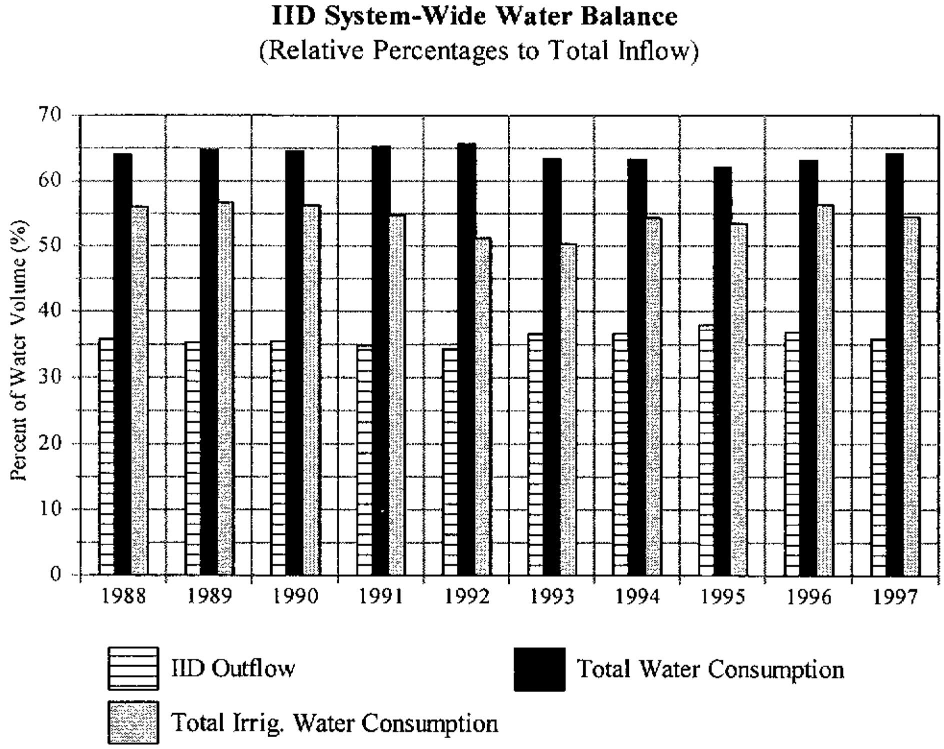


Figure V-4 Relative Percentages of Water Volume for IID's System-Wide Balance Components.

a. Canal Subsystem Water Budget

The canal subsystem consists of the AAC and a network of delivery canals within the IID study area. The inflow of the canal subsystem is delivered through the AAC at the EHL. The outflow components are water deliveries to users, spills, seepage, and evaporation. Figure V-5 is a schematic diagram showing the canal subsystem water balance. Each of the components was estimated independently except for the closure term, which is the water delivered to agricultural users.

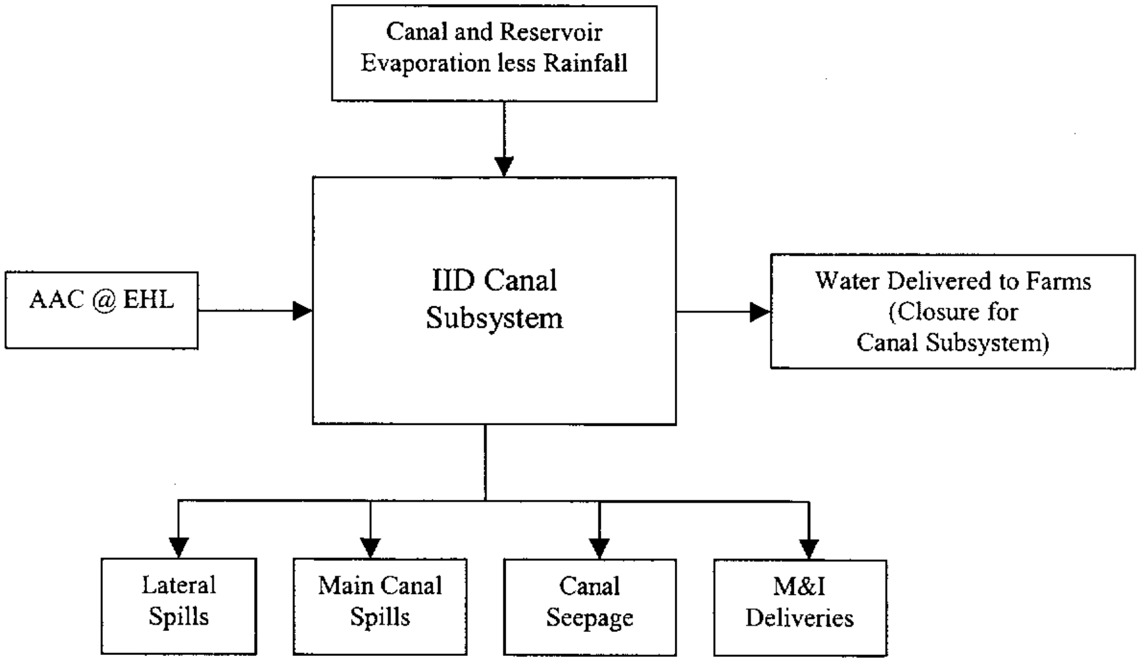


Figure V-5 Schematic Diagram of IID's Canal Subsystem Water Volume Balance and its Components.

b. Inflow

The supply of the irrigation water is computed by subtracting the M&I deliveries from the AAC inflow to the canal subsystem.

c. Outflow

(1) Canal Seepage

Seepage of main canals and laterals were estimated by IID staff based on a relatively thorough analysis of the losses for various canals. Lateral canal seepage was determined as part of the water conservation verification agreement between IID and MWD. Some of the IID main canals have pumps that bring seepage water back into the canal. The seepage values used in this study only include unrecovered canal seepage. The annual canal seepage for the study period varies from 76,000 to 104,000 acre-feet, with an average value of about 90,000 acre-feet

(2) Spills

Spills by the main canals were measured by IID staff and they vary in volume from 1,000 to 7,000 acre-feet annually, averaging approximately 5,000 acre-feet. Estimates for lateral spills were measured by IID as a percentage of delivered water, based on measured spills from a sample of 29 lateral canals in IID. These 29 sample laterals were randomly selected by IID, and represent approximately 10% of the total volume of water delivered.

Lateral spill data was reported as a fraction of the volume delivered to the lateral. A weighted average fraction of "volume-spilled" was determined using the spill data. This weighted average fraction was then multiplied by the "water delivered to all laterals" to obtain the total-volume-spilled by laterals. The volume delivered to lateral canals (that were part of IID's lateral interceptor systems) was removed from the total-delivered-volume to calculate the spill-volume. The volume spilled by the interceptor laterals was then added back into the total-calculated-spill-volume. These steps were taken so that the spill fraction determined from the random 29 sample laterals would not be applied to the interceptor laterals because of differences in spilling procedures. The lateral spills range from 80,000 to 103,000 acre-feet, averaging about 89,000 acre-feet per year.

7. *Results of Canal Subsystem Water Balance*

The goal of the water volume balance was to estimate the remainder term of the water balance, which is the irrigation water delivered to users within IID. The estimated values of the canal subsystem components in the water balance are shown in Table V-12. A graphical representation of IID's canal subsystem water volumes are shown in Figure V-6. The total irrigation water delivered, which is the remainder of the water volume balance, also known as the closure term, ranges from 2,203,000 to 2,768,000 acre-feet annually. The trend of the annual irrigation water delivery closely follows the water deliveries made into the AAC system throughout the study period. Detailed calculations of the water volume balance are found in Appendix 8.

Table V-12 Estimates of Irrigation Canal Subsystem Components (kilo-acre-feet).

Year	AAC Inflow to Canal System	M&I Deliveries	Canal & Reservoir Evap. less Rainfall	Canal Seepage	Main Canal Spills	Lateral Canal Spills	Irrigation Water Delivered-Remainder
1988	2,851	-63	-26	-104	-7	-84	2,568
1989	2,922	-65	-27	-104	-6	-80	2,639
1990	2,957	-69	-25	-100	-7	-87	2,668
1991	2,798	-72	-21	-94	-7	-82	2,522
1992	2,475	-72	-20	-89	-4	-86	2,203
1993	2,676	-74	-23	-81	-3	-91	2,402
1994	2,949	-75	-24	-77	-3	-99	2,668
1995	2,969	-78	-25	-76	-4	-103	2,682
1996	3,057	-78	-27	-76	-4	-103	2,768
1997	3,067	-78	-24	-76	-1	-85	2,803
Average	2,872	-72	-24	-88	-5	-90	2,592

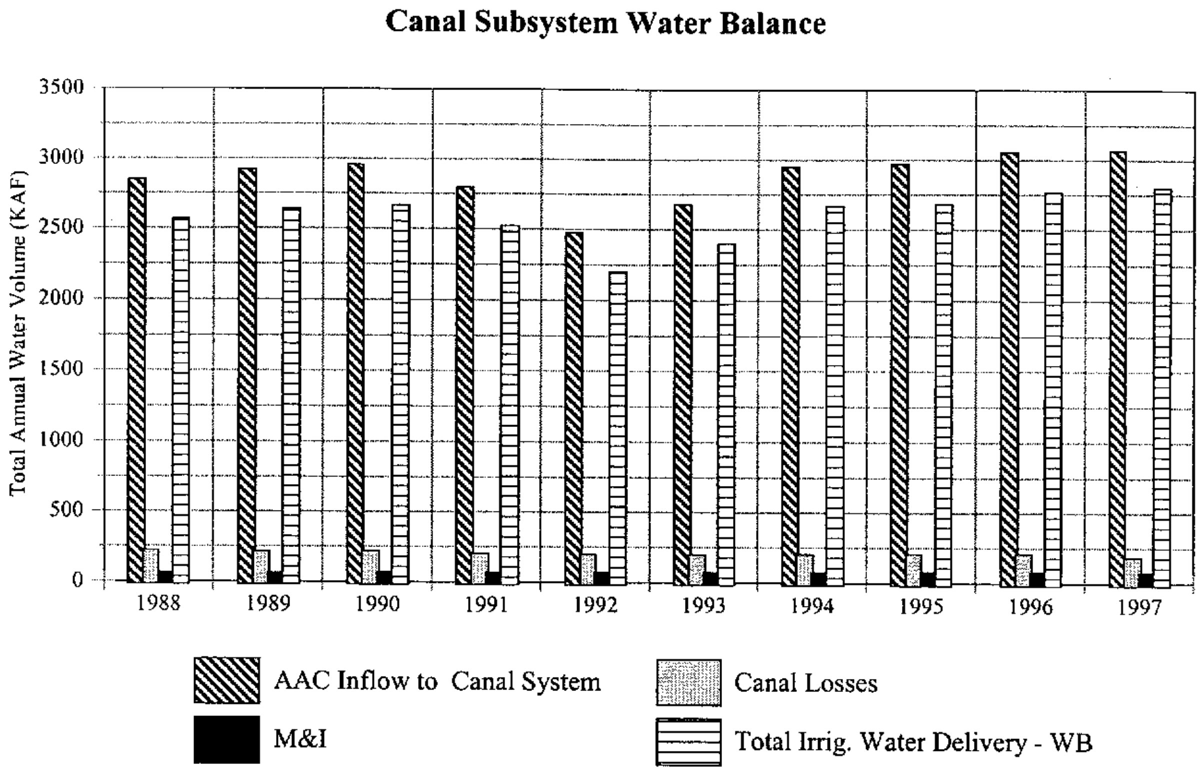


Figure V-6 Water Volumes for the Components of IID's Canal Subsystem Water Balance.

The amount of water delivered to farms is reported by IID in the Recapitulation Report, 1988-1997. A comparison between the independent estimates of irrigation water delivery to farms and the values of the irrigation water delivered through the water balance procedures are shown in Table V-13. There appears to be a systematic bias with an average difference of approximately 3.6%. However, the water delivery results from both the water balance method and the independent estimates as reported by IID were used in the water budget analysis for comparisons.

Table V-13 Comparisons of Irrigation Water Delivered to Farms as Reported and as the Remainder of the Canal Subsystem Water Balance (kilo-acre-feet).

Year	Irrigation Water Delivered to All Users-Reported	Deliveries from Coachella Canal, East of EHL	Deliveries from AAC, East of EHL	Irrigation Water Delivered within Study Area-Reported	Irrigation Water Delivered-Water Balance Remainder	Percent Difference (%)
1988	2,482	4	3	2,475	2,568	3.8
1989	2,565	4	3	2,558	2,639	3.2
1990	2,611	3	3	2,604	2,668	2.5
1991	2,448	4	6	2,438	2,522	3.4
1992	2,106	4	4	2,098	2,203	5.0
1993	2,329	4	3	2,322	2,402	3.4
1994	2,577	4	2	2,570	2,668	3.8
1995	2,581	4	2	2,575	2,682	4.2
1996	2,715	4	2	2,709	2,768	2.2
1997	2,690	5	1	2,684	2,803	4.4
Average	2,510	4	3	2,503	2,592	3.6

B. On-farm Subsystem Water Budget

The analysis of the on-farm water volume balance was intended to derive the amount of irrigation tailwater and deep percolation on the aggregated farms from the known inflow and outflow parameters of the on-farm subsystem. A portion of the water entering the on-farm system is absorbed by crops while the remaining water returns to the drainage system as tailwater, and/or deep percolation. A diagram of the on-farm subsystem schematic is shown in Figure V-7. The inflow to the subsystem includes water delivered to farms and the amount of rainfall on agricultural land. The outflow components are rainfall consumption, rainfall runoff and deep percolation, irrigation water consumption, tailwater, and deep percolation. The closure term, or the remainder of the on-farm subsystem water volume balance, is the irrigation drainage water from the farms.

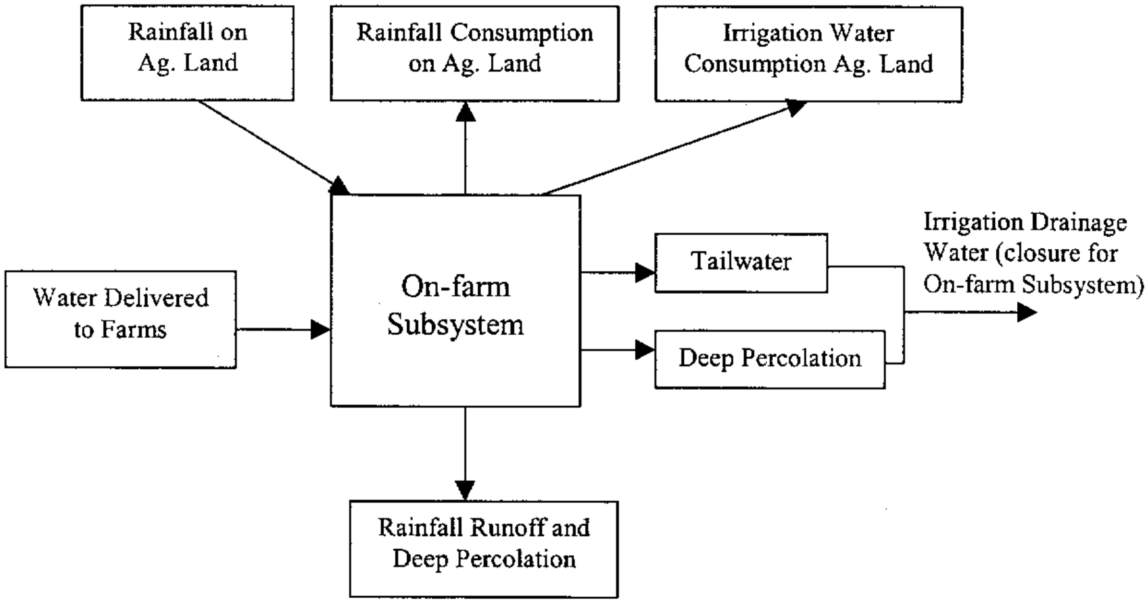


Figure V-7 Schematic Diagram of the On-farm Subsystem Water Volume Balance and its Components.

1. *Inflow for Agricultural Lands*

The amount of irrigation water delivered was estimated using the results of the canal subsystem water balance remainder, as described in the last section. The amount of rainfall is the weighted average rainfall recorded by the three CIMIS stations in the valley.

2. *Outflow for Agricultural Lands*

Tailwater and deep percolation are calculated together as the amount of irrigation water that enters into the drainage and river system. The split between tailwater and deep percolation is not determined based on the on-farm water balance, and IID currently does not record overall tailwater volumes in detail. Therefore, the split between tailwater and deep percolation is too difficult to estimate. The runoff and deep percolation induced due to rainfall on the agricultural land equals total rainfall minus rainfall consumption on agricultural land.

3. *Results of Water Volume Balance*

The computed volumes of on-farm tailwater flow and deep percolation are listed in Table V-14. The on-farm tailwater flow and deep percolation were computed based on two data sets. One set uses the closure term of the canal subsystem water balance, which is the estimated total irrigation water deliveries, while the other set uses IID's reported irrigation water deliveries. The results are presented graphically in Figures V-8 and V-9. Using the canal subsystem water balance analysis, the sum of irrigation tailwater and deep percolation varies from 675,000 to 945,000 acre-feet, while using IID's reported irrigation water deliveries, the volume ranges from 570,000 to 886,000 acre-feet. The percentage of irrigation water consumption and irrigation tailwater and deep percolation to on-farm water delivery was computed for both cases. The tailwater and deep percolation percentage ranges from 30 to 35% relative to the estimated farm water delivery; while, the percentage ranges from 27 to 32% relative to IID's reported farm deliveries. The annual percentage results are presented in Figure V-10.

Table V-14 Estimates of Irrigation Tailwater and Deep Percolation (kilo-acre-feet).

Year	Total Irrigation Water Delivered-Water Balance Remainder	Total Irrigation Water Delivered-Reported by IID	Total Irrig. Water Consumption-IID System-wide Remainder	Tailwater and Deep Perc.-Based on Estimated Deliveries	Tailwater and Deep Perc.-Based on Reported Deliveries
1988	2,568	2,475	1,793	775	682
1989	2,639	2,558	1,802	837	756
1990	2,668	2,604	1,807	861	797
1991	2,522	2,438	1,723	799	715
1992	2,203	2,098	1,528	675	570
1993	2,402	2,322	1,604	798	718
1994	2,668	2,570	1,771	897	799
1995	2,682	2,575	1,741	941	834
1996	2,768	2,709	1,823	945	886
1997	2,803	2,684	1,868	935	816
Average	2,592	2,503	1,746	846	757

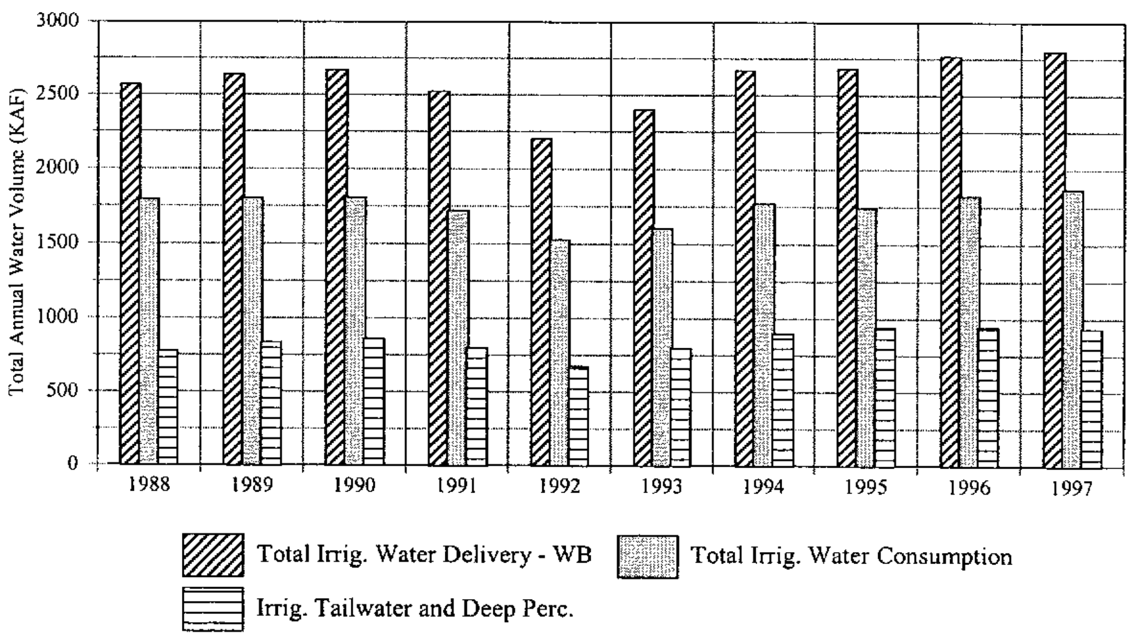


Figure V-8 Water Volumes for the Components of IID On-farm Subsystem Water Balance Using Total Irrigation Water Delivery Based on the Canal Subsystem Water Balance to Estimate Tailwater and Deep Percolation.

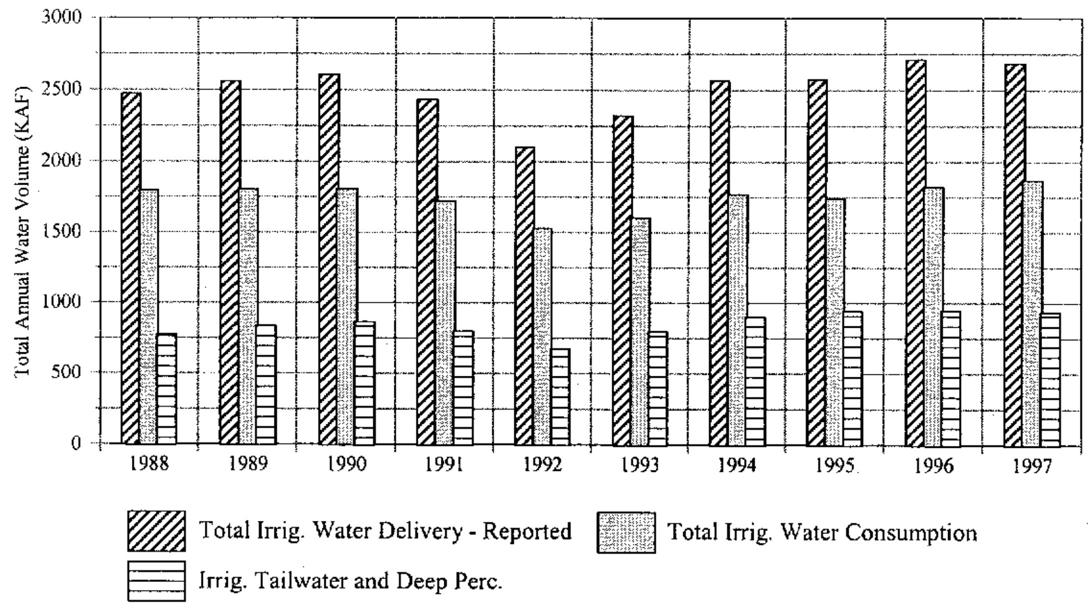


Figure V-9 Water Volumes for the Components of IID's On-farm Subsystem Water Balance Using IID Reported Total Irrigation Water Delivery Volumes to Estimate Tailwater and Deep Percolation.

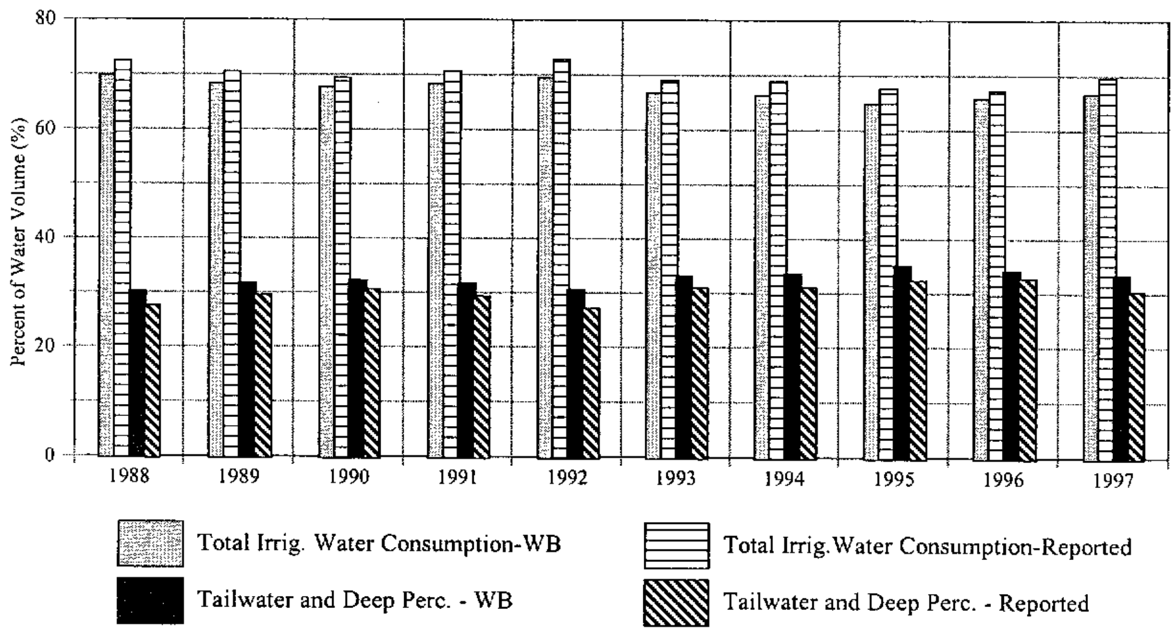


Figure V-10 Relative Percentages of Water Volumes for IID On-farm Subsystem Water Balance Components.

C. Irrigation System Performance

The results of the water budget analysis, NRCE's field water use evaluation, and previous studies undertaken by other researchers may be used to determine the irrigation water use performance of IID. Three irrigation performance parameters were used to evaluate IID's irrigation systems: the overall irrigation system efficiency, the distribution system efficiency, and the on-farm irrigation system efficiency.

1. *Overall Irrigation System Efficiency*

The overall irrigation system efficiency is defined as follows:

$$\text{Overall Irrigation Efficiency} = \frac{\text{Irrigation Water Beneficially Used}}{\text{Net Irrigation Water Supply}} \times 100 \qquad \textbf{(V-3)}$$

The overall irrigation efficiency can also be defined as the distribution system efficiency multiplied by the on-farm system efficiency. There are various uses of irrigation water that are considered beneficial in addition to satisfying crop water demands. In IID, other uses of irrigation water include seedbed and land preparation, germination, cooling, and leaching for salinity control.

The leaching requirement of the various crops is a complex issue due to the unique soil characteristics in the Imperial Valley, these requirements are discussed in detail and determined in Chapter IV of this report. The leaching of excess salts from the soil occurs both during normal irrigations and during off-season irrigations. The concept of leaching is to maintain an acceptable salinity in the soil root zone for the crops being produced. This requires that salt added with the irrigation water be removed by the leaching water. Therefore, annual leaching requirements depend on the irrigation water salinity as well as the level of salinity tolerance of the crop.

The annual leaching for the 1988 to 1997 period was estimated in part based on the field irrigation evaluations described in Chapter IV. It was assumed that the leaching requirements for sandy soils estimated based on the Rhodes (1974) equation IV-2 were satisfied. However, NRCE's data (Appendix 7) and other published data indicate that the soil salinity is higher than desired for most of the medium and heavy cracking soils (USGS, 1990). In other words, for the medium and heavy soils the estimate of annual leaching for the 1988 to 1997 period is not necessarily the full leaching requirement.

The leaching requirement is a function of the irrigation consumptive use and the salinity of the irrigation water. Therefore, the estimated annual leaching is based on a percentage of the irrigation consumptive use calculated by the water balance and then adjusted for irrigation water salinity, rather than a percentage of the measured headgate deliveries. The 1988 to 1997 average of estimated leaching components in Table IV-10 are expressed as a percentage of headgate deliveries, which is appropriate for determination of irrigation efficiencies. Table V-15 expresses on-farm water balance components as a percentage of irrigation consumptive use. The percentages of irrigation consumptive use and salinity factors (the ratio of annual irrigation water salinity to the 10-year average salinity) are used to determine annual leaching. Table V-16 lists the annual irrigation water salinity and the ratio value.

Table V-15 On-farm Water Balance (Average of 1988 through 1997).

Description	Water (Kaf)	Percent of Irrigation Consumptive Use	Notes
Total Headgate Deliveries	2,503		Average of 1988-1997
On-Farm Irrigation CU	1,746	100	Average of 1988-1997
Total Tailwater and Tilewater	**757**		Total headgate deliveries minus on-farm CU
Tailwater (17 percent)	**426**	24.4	
Leaching Heavy Soil	75	4.3	Equivalent horizontal leaching.
Other Tailwater	351	20.1	Tailwater not used for leaching
Tile Water	**331**	19.0	Total tile water
Leaching Heavy Soil	228	13.1	From Table IV-9 (50+8+170)
Leaching Light Soils	35	2.0	From Table IV-9
Remaining Tile Water	68	3.9	Tile water not used for leaching
Irrigation Efficiency			
Total Leaching Water	**338**	19.4	Horizontal and Vertical Leaching
Vertical Leaching	**263**	15.1	Vertical Leaching Only

Total headgate deliveries and on-farm irrigation consumptive use based on IID water balance.
Shaded values are input values.
Kaf = 1,000 acre-feet, CU = consumptive use

Table V-16 Ratio of Annual EC of Irrigation Divided by Average EC of Irrigation Water for the 1988-1997 Period.

Year	EC Irrigation Water (ds/m)	Ratio Value
1988	1.07	0.89
1989	1.14	0.95
1990	1.17	0.97
1991	1.25	1.04
1992	1.22	1.02
1993	1.23	1.02
1994	1.28	1.06
1995	1.26	1.05
1996	1.27	1.06
1997	1.15	0.95
Average	1.20	

The leaching requirement of light soils, estimated to be about 13% of the total irrigated land, or 60,060 acres, was determined according to the conventional leaching requirement equation by Rhoades (1974) as indicated in Equation IV-2. The average (1988-1997) annual leaching requirement for the light soils was estimated to be approximately 35,000 acre-feet. Based on the percent of crops on light soils, the leaching requirement for the light soils was 2.0% of IID's total irrigation consumptive use. To factor in the changes in salinity, the leaching requirement estimated by irrigation consumptive use was adjusted by the annual salinity divided by average salinity for the 1988 through 1997 period.

The other 87% of the irrigated land consists of medium and heavy-cracking soils. The salt leaching process for the medium and heavy soils during the irrigation season is accomplished both horizontally through tailwater runoff and vertically through deep percolation. However, during the off-season, leaching irrigations are applied to leach excess salt in the rootzone through deep percolation. For the medium and heavy soils in IID, the average annual volume used for salt leaching was determined to be about 303,000 acre-feet/year, which includes both horizontal and vertical leaching. The average horizontal leaching component was determined to be approximately 75,000 acre-feet/year (4.3% of IID's irrigation consumptive use), whereas, the average vertical leaching component during crop irrigation and between crops was determined to be about 228,000 acre-feet/year (13.1% of IID's irrigation consumptive use). As described in the previous paragraph, annual leaching on the medium and heavy cracking soils varies in proportion to the annual crop consumptive irrigation use and the salinity level of the irrigation water. Based on the percent of medium and heavy cracking soils, the estimated annual vertical and horizontal leaching requirements for the soils were 13.1% and 4.3% of IID's annual irrigation consumptive use, respectively. As discussed earlier, the leaching requirement for the light soils was estimated to be about 2.0% of the total irrigation consumptive use. These percentages are 10-year averages. To factor in the changes in salinity, the leaching requirement based on irrigation consumptive use was adjusted by the annual salinity divided by average salinity for the 1988 through 1997 period.

The annual volumes of the leaching components are found in Table V-17. The details of how each of these leaching components were estimated were described in Chapter IV of this report. The total average annual volume used for leaching of light, medium, and heavy soils is about 338,000 acre-feet per year (an average of 13.5% of IID's headgate deliveries, or 19.4% of irrigation consumptive use).

Table V-17 Volumes Used for the Determination of the Overall Irrigation System Efficiency (kilo-acre-feet unless otherwise noted).

Year	AAC Inflow at EHL	M&I Deliveries	Net IID Irrigation Supply	Total Irrigation Water Consumption	Total Estimated Leaching for Medium and Heavy Soils	Total Estimated Leaching for Light Soils	Total Beneficial Use	Overall Irrigation System Efficiency (%)
1988	2,851	-62	2,789	1,793	277	32	2,102	75
1989	2,922	-66	2,856	1,802	296	34	2,133	75
1990	2,957	-70	2,887	1,807	304	35	2,147	74
1991	2,798	-72	2,726	1,723	310	36	2,068	76
1992	2,475	-73	2,402	1,528	270	31	1,826	76
1993	2,675	-75	2,600	1,604	285	33	1,921	74
1994	2,948	-76	2,872	1,771	327	38	2,136	74
1995	2,969	-79	2,890	1,741	316	37	2,094	72
1996	3,057	-79	2,978	1,823	334	39	2,195	74
1997	3,067	-78	2,990	1,868	309	36	2,213	74
Average	2,872	-73	2,799	1,746	303	35	2,084	74

The numerator of the overall irrigation efficiency shown in Equation V-3 is computed by finding the sum of all beneficial uses required for crop production, which include the irrigation consumptive use calculated by the water balance and the leaching estimated as previously described. The total irrigation water consumption derived from the system-wide water budget analysis was used to represent irrigation water consumptive use.

The net irrigation water supply is obtained by subtracting the M&I deliveries from the AAC inflow at the EHL. Table V-16 shows the components used to determine the overall irrigation system efficiencies and the efficiency results from 1988 to 1997. The overall irrigation system efficiency ranges from about 72 to 76%, with an average of about 74%.

2. Distribution System Efficiency

The distribution system for the study area includes all the main canals and laterals in IID starting just above the EHL diversion on the AAC. The net irrigation water supply is the AAC flow into the study area at EHL minus the M&I deliveries. The conveyance efficiency of the AAC between Imperial Dam and the EHL diversion is not included in the distribution system efficiency evaluation. The distribution system efficiency is defined as the following:

$$\text{Distribution System Efficiency} = \frac{\text{Irrigation Water Delivered to Farms}}{\text{Net Irrigation Water Supply}} \times 100 \qquad \textbf{(V-4)}$$

There are two sets of data values for the irrigation water delivered to farms as discussed earlier in this chapter. One set of irrigation water farm deliveries was the closure/remainder term in the canal subsystem water balance. This estimate was undertaken to compare it with the recorded farm deliveries, which are fairly close, having an average difference of about 3.6%, as shown in Table V-13. IID's reported farm deliveries were used to evaluate the system efficiencies, rather than the closure term of the canal subsystem water balance. The distribution efficiencies are listed in Table V-18 and vary from 87 to 91%, with an average of 89%.

Table V-18 Volumes of Water used for the Determination of the Distribution Irrigation System Efficiency (kilo-acre-feet unless otherwise noted).

Year	AAC Inflow at EHL	M&I Deliveries	Net IID Irrigation Supply	Irrig. Water Delivered-Reported by IID	Distribution System Efficiency-Based on Reported Deliveries (%)
1988	2,851	-62	2,789	2,475	89
1989	2,922	-66	2,856	2,558	90
1990	2,957	-70	2,887	2,604	90
1991	2,798	-72	2,726	2,438	89
1992	2,475	-73	2,402	2,098	87
1993	2,675	-75	2,600	2,322	89
1994	2,948	-76	2,872	2,570	89
1995	2,969	-79	2,890	2,575	89
1996	3,057	-79	2,978	2,709	91
1997	3,067	-78	2,990	2,684	90
Average	2,872	-73	2,799	2,503	89

The various components of the distribution system losses are canal seepage, surface water evaporation, and operational spills. IID began lining canals in 1955 to reduce canal seepage losses and under the IID/MWD Agreement of 1988, more canals were lined to further reduce canal seepage losses. Figure V-11 shows the cumulative miles of lined canals from 1988 to 1997 along with the decreasing canal seepage losses in that same period. Currently, IID has lined 1,169 miles of a total of 1,681 miles of main and lateral canals.

The distribution system losses for the study period average 3.1% for canal seepage, 0.9% for canal and reservoir evaporation, and 3.4% for canal spills. These loss parameters were independently estimated based on the closure term of the canal subsystem water balance and their derivations were discussed earlier in the canal subsystem water budget section of this chapter. As indicated in Table V-12, the majority of the operational spills originate from the lateral canals. Operational spills are caused by many factors such as early reduction or shutting off of turnout deliveries by the farmers, measurement errors, and/or changes in canal losses.

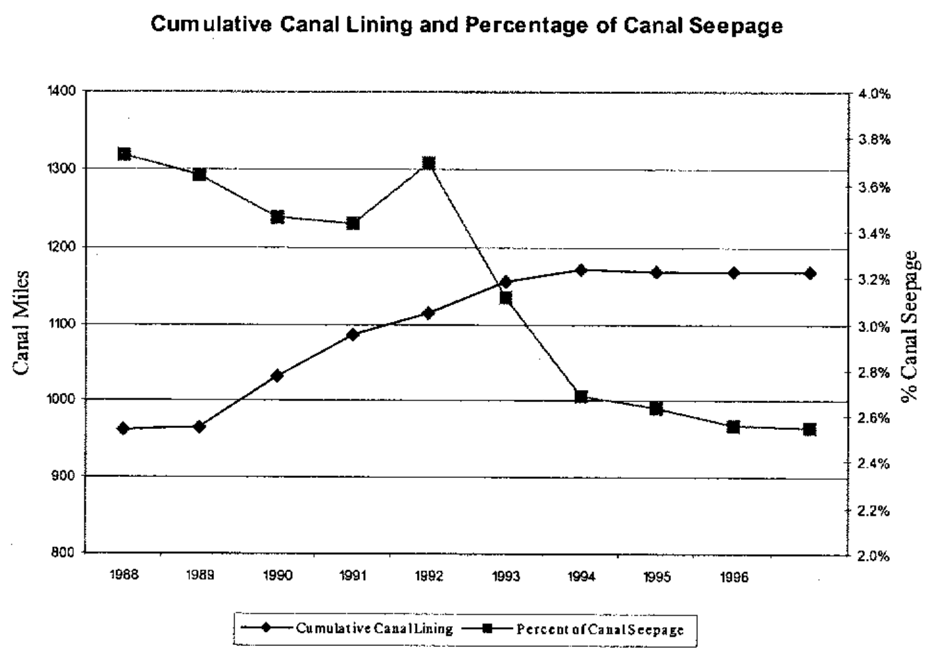


Figure V-11 Comparing Cumulative Canal Lining with Percentage of Canal Seepage Losses With Respect to Total Canal Inflow.

The sum of distribution losses relative to the total irrigation water is 7.4% based on the independent estimates and 11% based on IID's reported farm deliveries. Therefore, the distribution losses based on the reported farm deliveries are about 3.6% higher than the independently estimated losses. This is attributed to the 3.6% difference in irrigation water deliveries when determining the figures with the two different data sets, as previously discussed. Since NRCE's analysis is based on actual IID reported farm delivery values, the estimated percentage losses for each of the distribution system components were adjusted to account for the 3.6% discrepancy. The result was an increase of the total distribution system losses from 7.4% to 11% resulting in an 89% distribution system efficiency, as indicated in Table V-18.

Based on IID's reported irrigation water delivery amounts, the final adjusted seepage, evaporation, and spill losses become 5, 1, and 5%, respectively.

3. *On-Farm Irrigation System Efficiency*

The on-farm irrigation system efficiency is basically the relative percentage of on-farm irrigation water beneficially used versus the amount of water delivered to the farms. It may be expressed as the following:

$$On-farm\ Irrigation\ System\ Efficiency = \frac{Irrigation\quad Water\ Beneficially\ Used}{Irrigation\ Water\ Delivered\ to\ Farm} \times 100 \qquad \textbf{(V-5)}$$

To evaluate the aggregate on-farm system efficiency for the district, the total amount of irrigation water that was considered beneficial for crop production, is the numerator of the above equation. The water volumes for these on-farm beneficial uses are listed in Table V-17. They consist of the total irrigation water consumption and the leaching requirement. The other special irrigation water is already included in the total irrigation water consumption as derived from the water budget analysis. The computed on-farm efficiencies range from 81.0 to 87.2% with an average of 83.3%. The results and components of the efficiency computations are shown in Table V-19. The relatively high on-farm irrigation efficiencies in 1991 and 1992 likely occurred due to the abnormal cropping conditions resulting from insect infestations and other factors. In these years, many crops were stressed due to insect damage and irrigation patterns were altered, this likely led to deficit irrigation and inadequate leaching, both of which increase irrigation efficiency at the expense of crop production.

Table V-19 Volumes of Water used for the Determination of the On-farm Irrigation System Efficiency (kilo-acre-feet unless otherwise noted).

Year	Irrig. Water Delivered-Reported by IID	Total Irrigation Water Consumption	Total LR* for Medium and Heavy Soils		Total LR* for Light Soils	On-farm Irrigation System Efficiency-Based on Reported Deliveries (%)
			Vertical Leaching	Horizontal Leaching		
1988	2,475	1,793	209	69	32	84.9
1989	2,558	1,802	223	73	34	83.4
1990	2,604	1,807	229	75	35	82.4
1991	2,438	1,723	233	77	36	84.8
1992	2,098	1,528	203	67	31	87.2
1993	2,322	1,604	214	70	33	82.7
1994	2,570	1,771	246	81	38	83.1
1995	2,575	1,741	238	78	37	81.3
1996	2,709	1,823	251	83	39	81.0
1997	2,684	1,868	233	76	36	82.4
Avg	2,503	1,746	228	75	35	83.3

*LR = leaching requirement

4. *Irrigation Water Use Efficiency Comparisons*

The reasonableness of IID's irrigation performance may be shown by comparing the various estimated irrigation water efficiencies determined above with a range of efficiencies that are considered acceptable in the irrigation industry as well as with published efficiencies of similar irrigation districts or projects. The distribution system efficiency determined for IID was compared with accepted values in literature and distribution system efficiencies of various irrigation districts in the Southwest. The estimated on-farm irrigation efficiency for IID was also compared with expected industry standards and measured efficiencies from other districts in the Lower Colorado River.

a. Distribution System Efficiency

The distribution system efficiency of IID averaged 89% from 1988-1997, as shown in Table V-17. About 11% of the irrigation water diverted to IID was lost in conveyance between the main canal diversion and the headgate delivery. The majority of the losses are attributed to canal seepage and operational spills. Operational spills, which have the highest percentage loss, were estimated at about 5%. According to the ASCE Manuals and Reports No. 57, "Management, Operation and Maintenance of Irrigation and Drainage" (Johnston and Robertson, 1991), canal operational spills should not exceed 5% of total water diverted for each season in a well-managed irrigation system. Thus, IID's operational spills are within the limit expected for an efficient canal delivery system. Considering the standard criteria in the industry, the complexity of the system, the long travel times (i.e., 4 - 5 days) that are required to convey the water from the source, and the volume of water that the system delivers on a daily basis (i.e., 7,800 acre-feet per day (1988-1997)), IID's average operational spills of 5% is reasonable.

In regard to seepage loss, almost 70% of the distribution canals have already been lined in the sections with the highest seepage losses. It would not be economically viable or cost effective without outside funding to improve seepage losses by lining the canals further. The losses due to canal surface water evaporation are rather minimal at about 1% and are unavoidable unless pipelines are used.

Some of the larger irrigation projects in the Southwest region (more than 40,000 irrigated acres) were selected to compare distribution system efficiencies against IID's. These irrigation projects all receive water through USBR facilities and have similar distribution systems, cropping patterns, and climate as that of IID. The project data for irrigated acreage, net supply, farm deliveries, and distribution system efficiencies are presented in Table V-20. These records are published in the USBR 1990 Summary Statistics (USBR, 1990). The distribution system efficiencies range from 40 to 90% among the five projects listed with a median of 87%. IID has the second highest distribution system efficiency at 89% only 1% lower than Wellton-Mohawk Irrigation and Drainage District (Wellton-Mohawk IDD). IID has approximately 8 times more irrigated acreage than Wellton-Mohawk IDD and thus is more difficult to operate and manage, yet its distribution system efficiency is very comparable. Since the CVWD has a network of primarily buried pipelines as its distribution system, as well as open-channel canals for conveyance, its distribution efficiency is expected to be higher. However, IID's canal distribution network is shown to have a higher efficiency by 2%, as indicated in Table V-20. Hence, it can be concluded that IID's distribution efficiency of 89% is very reasonable as compared to other districts in the region. The 1988 to 1997 average distribution system efficiency is also 89% (see Table V-17).

Table V-20 Irrigation Distribution System Efficiency of Various Projects According to the USBR (1990).

Irrigation Project	Irrigated Area (acres)	Net Supply (ac-ft)	Irrigation Water Delivery (ac-ft)	Distribution System Efficiency (%)
Wellton-Mohawk IDD	60,324	442,140	397,836	90
Imperial Irrigation District	463,030	2,974,647	2,654,689	89
Coachella Valley WD *	61,052	299,237	260,060	87
Yuma Valley Division	45,761	360,020	263,048	73
Salt River Valley	54,174	840,921	333,859	40

* The distribution system in the Coachella Valley is primarily buried pipeline.

b. On-farm Irrigation System Efficiency

In regard to on-farm irrigation efficiency, it is difficult to make a fair comparison between what is accepted in the irrigation industry and the values determined in this analysis. This is mainly due to the many ways in which irrigation efficiency may be quantified. For example, a large portion of the measure of irrigation efficiency convention used in literature or in the irrigation industry is typically based only on crop water demands and the amount of water applied over the field (i.e., water stored in the root zone divided by applied water). Whereas, in areas where salinity concentration of water is relatively high like in IID, irrigation efficiency is based on water beneficially used and applied as described in Equation V-5. The water beneficially used includes water that would fully satisfy the crop water demands as well as meeting cultural water requirements such as leaching requirements to maintain a favorable salt balance in the root zone. Therefore, the conventional irrigation efficiency values commonly cited in literature cannot be directly compared to values determined in this study because they are based on different assumptions and irrigation effectiveness.

In a report by the USBR and the Bureau of Indian Affairs (1978), it is stated that the overall on-farm efficiency for a well designed surface irrigation system with land leveling, delivery pipeline, and drainage system is typically about 70%. Fangmeier and Biggs (1986) state that a well designed surface irrigation system is expected to have a range of efficiencies averaging between 60-70%. A guide of estimated application efficiencies for various irrigation systems is included in Martin et al. (1990). It gives an efficiency range of 50 to 85% for graded borders. The most recent development in quantifying on-farm water use efficiencies is to incorporate the concept of on-farm distribution uniformity as a factor in determining potential application efficiency. Burt et al. (2000) defines potential application efficiency of the low quarter (PAE_{lq}) as the ratio of the water infiltrated such that the crop water requirement is met at the low quarter of the field to the water applied. They proposed that under ideal conditions a well designed and operated sloping border strip with runoff most likely would have a PAE_{lq} value of about 85%. However, under non-ideal conditions, the practical PAE_{lq}'s will be about 75%. The actual low quarter application efficiency (AE_{lq}) measured in the field is inevitably even lower than the PAE_{lq} due to management errors.

One must also note that the total irrigation water consumption for crop production accounts for all water needs, such as crop water demands as well as cultural irrigation practices, which are not considered in the conventional efficiency determination. Another factor to consider is the fact that many of the fields in heavy cracking soils may be under-irrigated in the lower portions of the fields. The inadequate application of water needed to meet crop water demands in the lower ends of the fields may give a higher irrigation efficiency value than if the crop's water needs are fully satisfied throughout, which is an assumption for most of the irrigation efficiencies defined in literature.

From 1975 to 1978, the USBR performed a series of studies regarding on-farm irrigation efficiencies in the various districts in the Lower Colorado River Basin based on crop water demands and leaching requirements (USBR, 1979). Table V-20 lists the results of the irrigation efficiency evaluations for 11 districts in the region. Among the districts from 1975 to 1978, the on-farm irrigation efficiencies ranged from 32% to 78%. IID had the highest efficiency averaging 78% over the 4-year period. The Yuma County Users Association (YCWUA) had the second highest irrigation efficiency averaging 72%. The USBR data presented in Table V-20 are more than 20 years old and could have changed since then due to technological advances, water conservation programs, and better water management. The average IID on-farm irrigation efficiency from 1988 to 1997 was determined to be about 83% (see Table V-19), which shows a definite improvement in on-farm irrigation performance from the late seventies.

Table V-21 On-farm Irrigation System Efficiencies of Various Irrigation Districts (%) According to the USBR (1979).

Irrigation Districts	1975	1976	1977	1977	Average
Imperial Irrigation District	73	80	81	77	78
Yuma County Water User Assoc.	64	80	71	72	72
Colorado River Indian Reservation	57	65	76	64	66
Yuma Irrigation District	62	63	61	61	62
Wellton-Mohawk I&D District	55	52	63	64	59
Reservation Div. Irrigation District	45	47	58	60	53
Coachella Valley Water District	51	50	55	53	52
Palo Verde Irrigation District	46	33	45	42	42
North Gila Irrigation District	29	40	46	42	39
Unit "B" Irrigation District	33	32	35	38	35
Yuma Mesa Irrig. & Drain. District	33	33	29	32	32

The CDWR expects an average on-farm irrigation efficiency of 73% by the year 2020 assuming an on-farm distribution uniformity of 80% (CDWR, 1998). The on-farm irrigation efficiency index defined by the CDWR uses similar concepts as developed in this study where both crop water demands and cultural requirements as in leaching requirements are accounted for in the beneficial water use parameter. IID's ten-year average on-farm irrigation efficiency from 1988 to1997 of 83% is already above the 73% estimated efficiency for 2020.

The 73% expected on-farm irrigation efficiency is assumed for all regions in California and is averaged across crop types, farmland characteristics, and management practices. Therefore, there could be a range of efficiencies depending on the various factors mentioned including the types of irrigation systems used. In 1991, a survey was conducted by the University of California, Davis to determine the percentages of crop acreage that were irrigated by the various irrigation methods in California (CDWR, 1994). Surface and sprinkler irrigated acreage accounted for about 67 and 24%, respectively, whereas, acreage with drip and subsurface irrigation accounted for about 9% of the total irrigated acreage. Efficiencies achieved with surface irrigation will most likely be in the lower end of the range as opposed to drip irrigation, where the efficiency will be expected to be in the higher end. Since IID is predominately surface irrigated and is expected to be in the lower end of the efficiency range, hypothetically lower than 73%, its efficiency of 83% has surpassed the average expected efficiency of 73% by a large margin.

As mentioned earlier, many of the lower parts of the fields in IID may be under-irrigated. Such phenomenon would inflate the results of the irrigation efficiency since tailwater runoff is minimized. Therefore, IID's higher on-farm efficiency may have been achieved at the expense of under-irrigation in the lower ends of the fields since for the most part, farmers are conscious of the assessment of triple charges in the event of excessive tailwater runoff. However, IID's determination of "excessive" was made without the benefit of a study such as this.

c. Overall Irrigation System Efficiency

The overall irrigation system efficiency on a district wide basis can also be estimated as the product of the on-farm and the distribution system efficiencies. The overall irrigation system efficiency is therefore a function of the two efficiency components. As indicated in Table V-17, the overall irrigation system efficiency of IID varied from 72 to 76% with an average of 74% for the study period. Since we have just shown that both the distribution and on-farm efficiencies in IID are considered very reasonable and its water use is beneficial, it can be concluded that the overall irrigation system efficiency of 74% for the whole district is also reasonable.

D. Review of Other IID Water Use Assessment Reports

The USBR commissioned two studies to review and evaluate water use within IID. The reports resulting from these studies are:

- Jensen, M.E. (1995). *Water Use Assessment of the Imperial Irrigation District. Final Report* (1995 Jensen Report).
- Jensen, M.E. and Walter, I.A. (1997). *Assessment of 1987-1996 Water Use by the Imperial Irrigation District Using Water Balance and Cropping Data. Draft.* (1997 Draft Jensen-Walter Report).

The two reports were initiated in response to USBR concerns regarding the increased diversions to IID concurrent with implementation of conservation measures within IID. The 1995 Jensen Report and 1997 Draft Jensen-Walter Report attempt to explain the reasons behind the increased diversions, but their analyses fail to conclusively support their stated findings. The 1995 Jensen Report, in particular, presents conclusions and statements that poor irrigation practices and management are responsible for the increased diversions and that immediate implementation of on-farm improvements is required. Upon investigation by NRCE, however, these 1995 Jensen Report conclusions were found to be unsubstantiated.

Comments contained in the review were formulated by comparing the results contained in the 1995 Jensen Report and 1997 Draft Jensen-Walter Report to other analysis, findings, and water balances. The primary sources of water use information are the Boyle report by Styles (1993), the Water Study Team report (1998), and IID data. NRCE's water balance to estimate crop consumptive use of irrigation water and leaching requirements was based on the methods described in this report. NRCE's estimation of the leaching requirement is in part based on the information obtained during irrigation evaluations. A primary difference in leaching requirements is the inclusion of horizontal leaching on heavy cracking soils during crop irrigation and accounting for changes in irrigation water salinity. Total leaching requirements for heavy cracking soils include vertical leaching during crop irrigation, horizontal leaching during crop irrigation, and vertical leaching between crops during leaching irrigations. Appendix 9 contains a report concerning NRCE's review of the 1995 Jensen and 1997 Jensen-Walter Reports.

1. <u>*1995 Jensen Report*</u>

The 1995 Jensen Report investigates water use in IID for the period 1989 through 1994 and evaluates irrigation performance based on estimated crop water use. The water use analysis in the 1995 Jensen Report does not compare favorably with the other water use analyses by NRCE, Boyle, and the Water Study Team. The other water use analyses use a water balance to estimate irrigation consumptive use. Jensen's criticisms of on-farm irrigation practices are not supported by the water use assessment. The conclusions stated in the 1995 Jensen Report regarding on-farm water use and the effectiveness of water conservation measures that IID and MWD recently implemented are also of great concern. The 1995 Jensen water use analysis calculates crop ET based on climatic data and crop acreage. The leaching is estimated as a fixed percentage of crop ET without regard to changes in irrigation water salinity. The methodology and results of the 1995 Jensen Report inaccurately reflect characteristics of actual IID water use. Additionally, Jensen identifies water use trends based on a water use analysis inconsistent with the water balance results.

The 1995 Jensen Report background information misstates the relationship of water conservation within IID to IID's diversions from the Colorado River. The 1995 Jensen Report states:

- *Actual water savings must be measurable as reduced diversions and/or reduced loss of water to nonrecoverable locations such as the Salton Sea* (page 2).

- *Recent trends in diversions indicate that Reclamation must take a more proactive role to ensure that diversions will not exceed those required for beneficial use and that the estimated water savings from conservation programs translate into actual reductions in diversions or nonrecoverable return flows* (page 2).

- *In a recent agreement between the Imperial Irrigation District (IID) and the Metropolitan Water District (MWD) of Southern California (IID and MWD, 1989), MWD agreed to finance a conservation program in IID, particularly improving water storage and delivery systems. In return, IID agreed to reduce its requests for Colorado Water in an amount equal to the quantity of water conserved by the Program. IID has also implemented other water conservation measures. However, diversions in 1994 were essentially the same as in 1990* (page 38).

The statement that "water savings must be measurable as reduced diversions" misinterprets the flexible nature of IID's water right. It is true that "water savings must be measurable." Indeed, the IID/MWD Agreement provides an extensive process for verification of the amount of water conserved by the various conservation measures implemented pursuant to that Agreement. For example, the average annual amount, as verified by the Conservation Verification Consultants, conserved during the six-year period (1990-1996) was 63,108 acre-feet. The projected amount for 1998 is 107,160 acre-feet. This is the verified amount of conserved water that IID agreed to make "available for MWD's use" (Agreement, Section 6.2, 32).

Actually, according to Section 6.2 (h), p.35:

- *The extent of IID's obligation to make the water available to MWD is to reduce its diversion from the Colorado River below that which it would otherwise have been absent the projects of the Program (in an amount equal to the quantity of water conserved by the program) to permit the water so made available to be delivered by the Secretary to MWD.*

IID's water demands vary from year to year based on cropping conditions, climate and the salinity of the irrigation water. Compared to 1990, the net IID irrigation supply diverted from the Colorado River is lower than that of 1994 even though the salinity of the irrigation water increased in 1994, which in turn should have increased IID's diversions from the Colorado River. Therefore, even though water was actually being conserved under the IID/MWD agreement, there are other factors that influence IID diversions from the Colorado River. In fact, the on-farm irrigation efficiency in 1994 (83.1%) was slightly higher than in 1990 (82.4%) based on NRCE's analysis of water use, which accounts for salinity changes in the irrigation water.

2. <u>*1997 Draft Jensen-Walter Report*</u>

The 1997 Draft Jensen-Walter Report is the result of a follow-up effort to update and correct the 1995 Jensen Report. A water balance approach was used as the basis for the 1997 Draft Jensen-Walter Report, and represented a substantial improvement over the methodology used in the 1995 Jensen Report. However, despite the improved methodology, the 1997 Draft Jensen-Walter Report, like the 1995 Jensen Report, states conclusions concerning on-farm water management and the effectiveness of water conservation measures that IID recently implemented, which are not conclusively supported by the analysis.

The 1997 Draft Jensen-Walter Report states:

- *IID has initiated a number of water conservation efforts which have reduced losses in the distribution system. However, diversions to IID were not decreased as a result of the conservation effort* (page 4).

Determination of the amount of water conserved is not directly related to the amount diverted. The amount conserved is equal, under the agreement, to the amount transferred from IID to MWD for its use, as verified by the Conservation Verification Consultants. The total amount diverted by IID on an annual basis depends upon factors such as crop water use, M&I demands, and leaching requirements.

Leaching water requirements are estimated as a fixed fraction of water consumption in the 1997 Draft Jensen-Walter Report. Using a fixed fraction for leaching does not adequately account for crop salinity tolerance differences, variable irrigation water quality over time, and variable soil textures, and is therefore not a sustainable approach. Adequate salinity management is a key component to sustainable crop production. The average annual salinity of the water delivered to IID increased by about 27 percent from 1987 to 1996 (see Table II-1). This increase in the water supply salinity has increased the leaching requirement and corresponding water use. Hence, the increase in irrigation water supply diversion from the Colorado River due to the salinity content of the water supply should be taken into consideration in the Jensen-Walter water use analysis. In addition, due to the leaching inefficiencies of the majority of the soils in IID, leaching practices tend to increase the amount of the leaching requirement compared to the conventional requirements of leaching.

The primary reason for the 1997 Draft Jensen-Walter Report's conclusion of a decrease in on-farm irrigation efficiency is that Jensen and Walter estimated tailwater as a water balance closure term. The leaching requirement and tailwater, as estimated by Jensen-Walter, is much lower than the estimates made by other studies. Using common years of study (1988-1996) the average leaching requirement for the nine years as estimated by Jensen-Walter is about 260,000 acre-feet, while estimates of average leaching requirements by Boyle, updated by Jensen-Walter; the Water Study Team; and NRCE are 320,000 acre-feet, 302,000 acre-feet, and 337,000 acre-feet, respectively (see Table V-21). Hence the Jensen-Walter leaching requirement, which is a beneficial use, is much lower than all the other studies. It is also very clear, as shown on Table V-21 and Figure V-12, that Jensen-Walter's leaching requirement estimate does not reflect the salinity content of the Colorado River irrigation water supply while the other studies show definite trends of the amount of the leaching water estimates reflective of the quality of water supply.

Table V-22 Estimated Annual Leaching.

Year	1997 Jensen-Walter (Kaf)	Boyle Updated 1997 (Kaf)	Water Study Team (Kaf)	NRCE (Kaf)
1988	265	271	280	309
1989	277	323	292	331
1990	288	344	306	340
1991	246	302	303	345
1992	223	246	265	301
1993	248	251	287	317
1994	264	343	327	365
1995	262	377	322	353
1996	265	425	338	372
Average	260	320	302	337

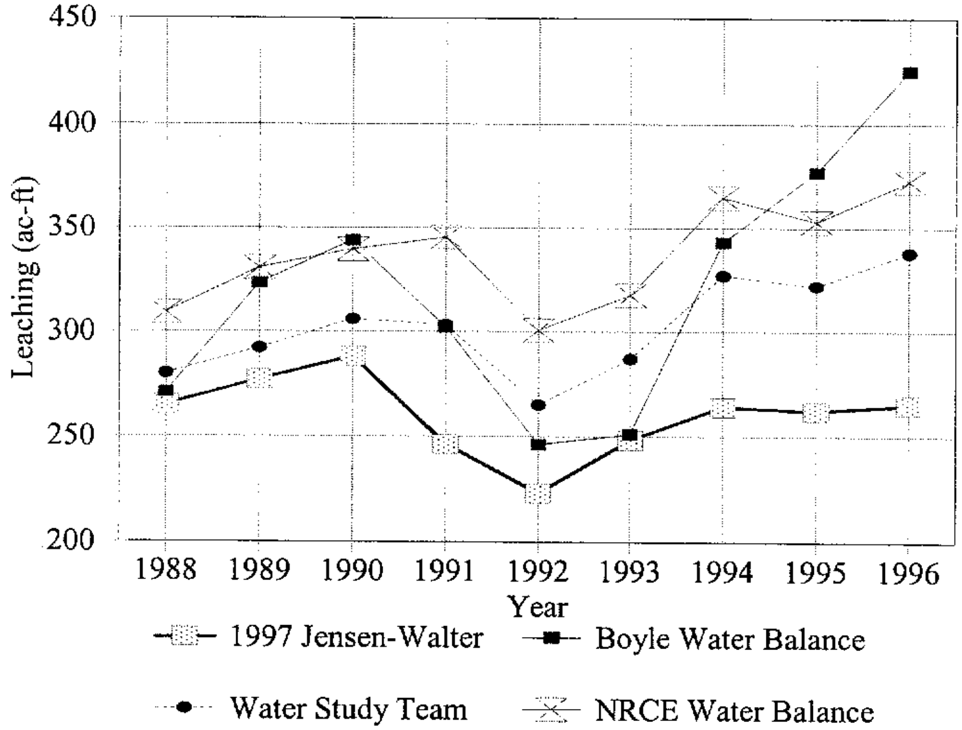


Figure V-12 On-farm Leaching Estimates Based on 1997 Jensen-Walter, Boyle, Water Study Team, and NRCE Water Balance.

Table V-22 shows the estimated irrigation consumptive use based on the water balance approach for the above mentioned four studies. Again, using the common available irrigation consumptive use data (1988-1996), the average irrigation consumptive use is similar, with less than a 1 percent difference. If one subtracts the sum of irrigation consumptive use and the leaching requirement from total headgate deliveries, the result would be tailwater and excessive deep percolation. Headgate deliveries are shown on Table V-23. In the IID case, due to the majority of the soils, being of very low permeability, excessive deep percolation is a very small fraction to that of tailwater. As shown on Table V-23 and Figure V-13, it is clear that the Jensen-Walter method has much higher tailwater not used for leaching and excess deep percolation compared to the other three methods. Since the Jensen-Walter methodology for estimating the leaching requirement does not take the salinity content changes of the irrigation water into consideration, the resulting leaching requirement is very low compared to all the other studies, even though the irrigation consumptive use and headgate deliveries are basically the same for all methods.

Table V-23 Estimated Irrigation Consumptive Use From Water Balance

Year	1997 Jensen-Walter (Kaf)	Boyle Updated 1997 (Kaf)	Water Study Team (Kaf)	NRCE (Kaf)
1988	1,799	1,799	1,809	1,793
1989	1,809	1,809	1,815	1,802
1990	1,817	1,817	1,815	1,807
1991	1,727	1,727	1,728	1,723
1992	1,502	1,502	1,538	1,528
1993	1,683	1,683	1,610	1,604
1994	1,787	1,787	1,780	1,771
1995	1,754	1,754	1,755	1,741
1996	1,810	1,810	1,839	1,823
Average	**1,743**	**1,743**	**1,743**	**1,732**

Table V-24 Estimated Tailwater not Used for Leaching and Excess Deep Percolation.

Year	1997 Jensen-Walter (Kaf)	Boyle Updated 1997 (Kaf)	Water Study Team (Kaf)	NRCE (Kaf)
1988	429	423	386	373
1989	491	445	451	425
1990	506	450	483	457
1991	476	420	407	370
1992	381	358	295	269
1993	400	397	425	401
1994	524	445	463	434
1995	565	450	498	481
1996	637	477	532	514
Average	490	429	438	414

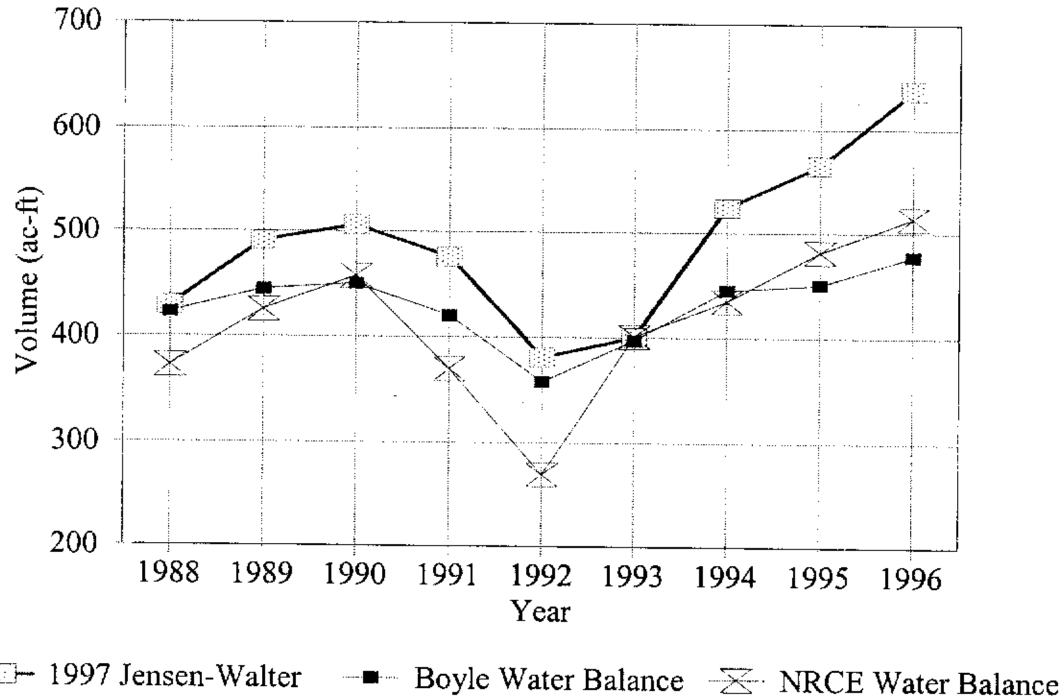


Figure V-13 Tailwater not Used for Leaching and Excess Deep Percolation Estimates Based on 1997 Jensen-Walter, Boyle, Water Study Team, and NRCE Water Balance.

A reduction in the leaching requirement increases tailwater and excessive vertical leaching. For example, the primary reason for the Jensen-Walter estimate of increased tailwater in 1996, is due to the underestimate of the leaching requirement, which is due to an increased salinity content of the irrigation water. The leaching requirement, as estimated by Jensen-Walter is 265,000 acre-feet, while the average leaching requirement for the other three methods is 378,000 acre-feet. Hence, a difference of 113,000 acre-feet per year of water is subtracted from the total beneficial use (irrigation consumptive use plus the leaching requirement) and added to the amount of water that is unused escaped tailwater. This would translate into reducing the numerator (total beneficial use). Dividing the reduced beneficial use by the headgate delivery results in a low irrigation efficiency.

As a water balance closure term, tailwater allegedly increased from 387,000 acre-feet in 1987 to 645,000 acre-feet in 1996, as listed in Appendix B of the 1997 Draft Jensen-Walter Report. Based on the above discussion, and since there was no major shifts in irrigation methods, this large increase in tailwater, as estimated by Jensen and Walter, is an unreasonable conclusion.

The 1997 Draft Jensen-Walter Report also states:

- *Agricultural tailwater, computed as a closure term instead of the leaching requirement, increased about 16,200 acre-feet per year, or 3.3% per year. This is the main trend in IID water balance components* (page 2).

The identified main trends of increasing tailwater and the reported decreasing on-farm efficiencies are invalid due to inadequate accounting for changes in leaching requirements. As shown on Figures V-12 and V-13, the leaching (beneficial use) estimate by Jensen-Walter is much lower than the other three studies, while the tailwater and excess deep percolation (non-beneficial use) estimated by Jensen-Walter are much higher than the rest of the studies. Since the Jensen-Walter leaching requirement is estimated by multiplying the crop consumptive use by a constant factor and adding 5% of tailwater, the resulting leaching requirement is not reflective of the varying irrigation water quality. This would result in a low leaching requirement and high tailwater, and therefore, low irrigation efficiency. That is the primary reason for the Jensen-Walter excessive estimate of tailwater.

The 1997 Draft Jensen-Walter Report also states:

- (The data) *clearly show that improvements in water delivery policies and on-farm irrigation systems and practices have not been made concurrent with improvements in the distribution system* (page 16).

In fact, according to the water balance, the changes in diversions to IID are in response to changes irrigation consumptive use and increased leaching requirements. Additionally, annual changes in on-farm irrigation efficiencies do not indicate that major changes are needed in farm irrigation systems and practices. Profitable crop production is a critical factor in determining the appropriate on-farm irrigation efficiency.

3. <u>Summary</u>

The 1995 Jensen Report and 1997 Draft Jensen-Walter Report investigate water use in IID. Both reports draw conclusions regarding irrigation operations in IID that the analysis or other available data fail to support. The following comments concern the most notable conclusions made in the reports:

- Jensen describes the increased diversion from the Colorado River during the period of investigation as indicative of a lack of water conservation. However, changes in diversions in IID during this period were due to changes in crop water demands, changes in cropping patterns, and increased salinity, rather than a degradation of irrigation operations in IID. Therefore, IID's diversion amount from the Colorado River does not necessarily reflect the amount of water savings obtained due to water conservation measures accumulated as a result of the IID/MWD agreement of 1989.

- The analyses used for the 1995 Jensen Report and 1997 Draft Jensen-Walter Report rely on a constant fraction for leaching that inadequately accounts for changes in cropping patterns, salinity of the Colorado River, and soil textures.

- During the period of investigation, on-farm efficiencies have remained relatively stable, based on the water balance method, and have not sharply decreased as concluded in both the 1995 Jensen Report and the 1997 Draft Jensen-Walter Report.

For a more complete review of these reports, please see Appendix 9.

REFERENCES:

Burt, C. M., Clemmens, A.J., Bliesner, .R., Merriam, J.L., and Hardy, L. (2000). Selection of Irrigation Methods for Agriculture, ASCE, Reston, Virginia, 129 p.

California Department of Water Resources. (1998). *The California Water Plan Update Bulletin 160-98 Volume 1.* Department of Water Resources, State of California, Sacramento, California, 256p.

California Department of Water Resources. (1994). *The California Water Plan Update Bulletin 160-93 Volume 1.* Department of Water Resources, State of California, Sacramento, California, 398p.

CH2MHill (1993). *Draft Environmental Impact Report for East Lowline Trifolium Interceptors and Completion Project - Imperial Irrigation District.* (from Styles, 1993).

Conservation Verification Consultants. (1997). "Imperial Irrigation District-Metropolitan Water District of Southern California, Water Conservation Agreement. Projected 1997 Water Conservation Agreement. Projected 1997 Water Conservation Savings with Supporting Documentation in Tabular Summaries."

Dodd (1993). Summary of Vector Trace Analysis, Imperial Irrigation District. (from Styles, 1993).

Fangmeier, D. D., and Biggs, E. N. (1986). "Alternative Irrigation Systems." Rep. 8555. Cooperative Extension Service, University of Arizona, Tucson, Arizona.

Freeman (1993). "IIDPHREA: Summary of Evapotranspiration and Phreatophyte Water Use Values Used in IID Water Balance, Imperial Irrigation District." (from Styles 1993).

Imperial Irrigation District (IID) and Metropolitan Water District of Southern California (MWD). (1989). "Agreement for the Implementation of a Water Conservation Program and Use of Conserved Water."

Jensen, M. E. (1995). "Water Use Assessment of the Imperial Irrigation District. Special Report prepared for the U.S. Bureau of Reclamation. Boulder City, NV." 74 p.

Jensen, M. E. and Walter, I.A. (1997). "Assessment of 1987-1996 Water Use by the Imperial Irrigation District using Water Balance and Cropping Data. Special Report prepared for the U.S. Bureau of Reclamation. Boulder City, NV." 101 p.

Johnston, W. R. and Robertson, J. B. (editors) (1991). Management, operation and maintenance of irrigation and drainage systems. *ASCE Manuals and Reports on Engineering Practice No. 57*, Reston, Virginia, 432 p.

Martin, D. L., Stegman, E. C., and Fereres, E. (1990). "Irrigation scheduling principles." Chapter 7 in *Management of Farm Irrigation Systems* (Monograph), Hoffman, G. J., Howell, T. A., and Solomon, K. H. (eds.), ASAE, St. Joseph, Michigan, 1040p.

Mayberry, Keith S. (2000). Personal communications. Vegetable Specialist, University of California Cooperative Extension (UCCE), Imperial, California.

Rhoades, J. D. (1974). "Drainage for salinity control" In: *Drainage for Agriculture.* Van Schilfgaarde J. (ed.), American Society of Agronomy. Monogragh No. 17, pp. 433-462.

Setmire, J. G., et al. (1990). "Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Salton Sea area, California, 1986-1987." *U.S. Geological Survey Water Resources Investigations Report 89-4102.*

Styles, S. W. (1993). "On-Farm Irrigation Efficiency - Special Technical Report for Imperial Irrigation District." Boyle Engineering Corporation, Imperial, CA, 232 p.

Technical Working Group. (1994). "Water Use Assessment. Coachella Valley Water District and Imperial Irrigation District. Phase I Report. Draft."

US Bureau of Reclamation. (1990). *Summary of Statistics: Water, Land, and Related Data,* United States Bureau of Reclamation.

US Bureau of Reclamation. (1979). Exhibit C from an "Affidavit of Maurice N. Langley ..." in Civil Action No. 76-10957 in US District Court, US Bureau of Reclamation unpublished data.

US Bureau of Reclamation and Bureau of Indian Affairs. (1978). "Water conservation opportunities study," USBR and BIA, Washington, D.C. (referenced on pg 37 of *Principles of Farm Irrigation System Design* by James, L.G. (1988))

US Geological Survey. (1968). "Professional Paper 486-C" (Title Unknown). This publication was referenced in Styles, 1993.

University of California Cooperative Extension. (1998-1999). "Guidelines to production costs and practices (1998-1999)," *Vegetable Crops Circular 104-V*, University of California, Imperial County, Cooperative Extension, Holtville, CA.

University of California Cooperative Extension. (1996-1997). "Guidelines to production costs and practices (1998-1999)," *Field Crops Circular 104-F*, University of California, Imperial County, Cooperative Extension, Holtville, CA.

Water Study Team. (1998). "Imperial Irrigation District Water Use Assessment for the Years 1987 to 1996." Prepared for Imperial Irrigation District by the Water Study Team (Drs. Richard Allen, Charles Burt, Albert Clemmens, and Kenneth Solomon, and Mr. Ed Craddock). March 1998.

VI. EVALUATION OF IID GROWER MARKET POWER

The Imperial Irrigation District (IID) has negotiated a Water Conservation and Transfer Agreement (Agreement) with the San Diego County Water Authority (SDCWA). Among other terms, the Agreement stipulates that IID would conserve 200,000 acre-feet of water per year (afy) and subsequently transfer that conserved water to SDCWA. In exchange, SDCWA would compensate IID growers for the transferred water to defray any grower conservation-related costs. Dornbusch Associates was subcontracted to evaluate the financial impact on the IID growers in the absence of a compensation agreement. The following is a brief summary of the Dornbusch Associates' report (2002). The full report of the economic analysis may be found in Appendix 10.

As the legal and institutional process to implement the transfer agreement has unfolded, a number of issues regarding IID's water resource management have been the focus of debate. One of these issues relates to how IID growers would be financially impacted if they were mandated to conserve water without receiving any offsetting third-party compensation such as that from SDCWA stipulated in the transfer agreement proposal.

The Dornbusch report evaluates the extent to which IID growers could realistically pass on conservation-related increases in their cost of water by unilaterally increasing their crop prices. To answer this question, Dornbusch qualitatively and quantitatively analyzed the markets in which IID growers sell their crops, and for IID's most prevalent crop, alfalfa hay, also used a modified version of the Central Valley Production Model (CVPM) that the California Department of Water Resources developed to evaluate the impacts of water shortages and water price increases on California agriculture.

The Dornbusch analysis indicates that IID growers do not have power in their respective crop markets due to a range of competitive marketplace dynamics, including packer/shipper concentration, geographic scope, and falling trade barriers, among other factors. Consequently, IID growers cannot be expected to pay for the cost of water conservation by unilaterally increasing the prices they receive for their crops. Crop costs of production have continued to increase, while in most cases crop prices have remained stagnant or declined. Accordingly, any continued escalation in crop production costs, including any costs to implement water conservation measures, is likely to further erode IID grower profitability leading to a decline in farm property values, and adversely impacting the overall regional economy.

REFERENCE:

Bass, J. and Merchant, J. (2002). "Evaluation of IID Grower Market Power." Dornbusch Associates, Berkeley, California.

VII. THE PROPOSED TRANSFER WILL NOT INJURE JUNIOR WATER RIGHTHOLDERS

IID and San Diego County Water Authority (SDCWA) have a proposed agreement to transfer a maximum of 200,000 acre-feet per year of conserved Colorado River water from the Imperial Valley to the San Diego area. It is anticipated that San Diego will divert the agreed transfer water from Lake Havasu through the Colorado River Aqueduct, which is part of the delivery system of the MWD of Southern California.

In accordance with the IID/SDCWA water transfer agreement, the transfer water will be delivered to San Diego via the Colorado River Aqueduct. Under IID's prior water transfer agreement with MWD, IID has already been transferring various amounts of water to MWD through the Colorado River Aqueduct since 1990.

The extra diversion at the Colorado River Aqueduct will reduce the flow that would normally be in the river and in the AAC. Therefore, NRCE was asked to determine the impact, if any, of up to 200,000 acre-feet per year being diverted for SDCWA at Parker Dam, as opposed to remaining in the Colorado River for diversion into the AAC and Imperial Dam, and whether other diverters will be affected. Since the Colorado River Aqueduct diversion is just above Parker Dam on Lake Havasu, the study is primarily concerned with diverters on the Colorado River between Parker and Imperial Dams and on the AAC between Imperial Dam and the EHL Canal turnout.

The impact study analysis essentially addresses two issues. One is whether the water needs of all other water users off the Colorado River and the AAC will be met if the flows were hypothetically reduced by 200,000 acre-feet per year. Historical diversions for the study period from 1988 to 1997 were examined to determine this. Another concern is whether the diversion structures are hydraulically capable of diverting the required historical amounts with lower hydraulic heads due to the hypothetically reduced flows in the reaches. As detailed below, NRCE has determined that the proposed IID/SDCWA water transfer will have no meaningful impact on other appropriators.

A. IID/SDCWA Water Transfer Agreement

The transfer agreement requires that IID undertake water conservation measures in order to generate the amount of water needed for the transfer. IID would then transfer its conserved water to SDCWA in exchange for payments equal to the cost of water conservation efforts for at least 45 years. The contract may be extended for another 30 years by either agency. An incentive amount to encourage IID farmers to participate in the water conservation programs on a voluntary basis would also be added to the overall water cost.

The amount of transfer for Agreement Year 1 would be 20,000 acre-feet and would increase in increments of 20,000 acre-feet per year until the "Stabilized Primary Quantity" is reached. The "Stabilized Primary Quantity" is the annual delivery amount between 130,000 and 200,000 acre-feet per year that IID determines to make available. This amount may not be changed once it has been established. However, if the total conserved water produced is lower than 130,000 acre-feet due to farmers' low voluntary participation in the water conservation programs, the IID/SDCWA water transfer agreement would not be implemented.

B. Colorado River Flow Information

1. *Diversions and Return Flows*

The data recorded in the "Decree" (USBR, 1988-1997) were used as a basis for determining the various users and their diversion and return amounts in the reaches of the Colorado River and the AAC. This process is also known as the "Decree method" for balancing the Lower Colorado River flow system. This annual publication contains the methodology that the Bureau adopted and has used since 1964 to account for all the diversion and return flows of the water users in the Lower Colorado River Basin. The amount of diversions and return flows is tabulated on a monthly basis, measured by acre-feet in this document. However, there are also unmeasured subsurface return flows to the river that are not credited to a specific user when employing the "Decree" accounting methodology. The unmeasured subsurface return flow to the river is estimated to be an annual average of approximately 250,000 acre-feet in the Lower Colorado Basin (USBR, 1998, Carson, 1999).

Most of the diversion flow records from the "Decree" are measured values except for some of the river and well pumpages, which are estimated using monthly power records or assumed water duties. All surface return flows to the river from surface drains and spills are also measured in the field. These surface return flows may be diverted later by other users downstream. A schematic diagram of the stretch of the Lower Colorado River from Hoover Dam to IID showing the various user diversions and returns is shown in Figure VII-1.

a. Parker Dam to Imperial Dam

The locations for all pertinent diverters in the river reach between Parker and Imperial Dam can be seen in Plate VII-1.

The Colorado River Indian Reservation (CRIR) Main Canal is the first major diversion in this reach. It diverts irrigation water from the Headgate Rock Dam to supply the CRIR on the Arizona side. Annual diversions range from 586,359 to 713,839 acre-feet. There is also river pumpage from the California side of the CRIR that ranges from 4,205 to 9,793 acre-feet. Drainage and spills from CRIR, on the Arizona side, are returned to the river through Gardner Lateral spill, CRIR Poston wasteway, as well as Palo Verde and CRIR Lower Main drains, which are located downstream of Palo Verde Dam. Annual return flows vary from 229,024 to 263,146 acre-feet. There is no measured return water to the river from pumpage on the California side of CRIR.

Brooke Water (Consolidated Water Utilities) pumps water out of the river on the Arizona side at locations between Parker and Headgate Rock Dams. Its pumpage ranged from 327 to 403 acre-feet on an annual basis between 1988 to 1997. The town of Parker pumps water directly from the river and from wells. Annual pumpage varies from 916 to 1,635 acre-feet. No return flow by the Brooke Water or the town of Parker users is accounted for in the Decree methodology.

IID Exhibit 2B oversized
map inserted here.
Figure VII-1 Schematic Diagram
for the study area

The other large diverter downstream of the CRIR is the Palo Verde Irrigation District (PVID) which diverts water from Palo Verde Dam via the Palo Verde Canal. Annual diversions range from 737,100 to 953,010 acre-feet. Drainage and spill water from PVID are returned to the river through a series of ten outlets: PVID Olive Lake drain, PVID F Canal spill, PVID D-10-11-2 spill, PVID D-10-11-5 spill, PVID D-23 spill, PVID D-23-1 spill, PVID C Canal spill, PVID C-28 upper spill, and PVID Outfall drain). Total annual returns range from 402,633 to 495,669 acre-feet.

Other users downstream of Palo Verde Dam pump directly from the river or from wells in the flood plain. The pumps downstream of the Palo Verde diversion also have no measured return flow. Ehrenberg Improvement Association is located east of Blythe across the river on the Arizona side, and its annual pumpage ranges from 229 to 499 acre-feet. The Cibola Valley Irrigation District and the Cibola National Wildlife Refuge's annual pumpage ranges from 18,987 to 30,883 acre-feet and 8,772 to 17,752 acre-feet, respectively. The Imperial National Wildlife Refuge is one of the end users on the reach between Parker and Imperial Dam. Annual well pumpage from this Refuge varies from 24 to 10,329 acre-feet.

Table VII-1 contains the diversions and returns on the Colorado River between Parker Dam and Imperial Dam as recorded in the "Decree". The flow values in the use category were calculated by subtracting the return flows from the diversions. Some of the users do not have return flows back to the river, thus, diversions essentially become consumptive uses. In Table VII-1, the negative monthly consumptive use values of some of the water districts indicate that there are more returns by the users than withdrawals. This is caused by lag time in the return flow of unused water. The water withdrawn in a particular month may not be returned until the following months. These effects are considered and incorporated into the overall scheduling of river releases from Hoover Dam. In Table VII-1, most of the negative monthly consumptive uses occur in the month of January. This is because January had the lowest withdrawals while part of its returns are from December when withdrawals were larger.

There are some small pumpers in this reach that are located on either side of the river. These diversion amounts are lumped together in Table VII-1 as "Other California Users below Parker Dam" and "Other Arizona Users below Parker Dam." The Arizona users are Hillcrest Water Company, Rayner, Jack Jr., Arakelian, George, and BLM Permitees, and their pumpage ranges from 5,023 to 19,257 acre-feet. The California users are Lye, C.L., BLM Permitees, and Picacho Development Corp and their annual pumpage range from 31 to 1,057 acre-feet. The "Decree" records contain a miscellaneous diversion and use category, for 1988 to 1993, which incorporates all the other unspecified small users and the unaccounted flow balance.

b. Imperial Dam to the East Highline Canal Turnout

The Bard Irrigation District of the Yuma Project Reservation Division (Bard and Indian units) diverts water from the AAC to the Reservation Main, Titsink, Yaqui, Pontiac, and Ypsilatnti Canals for irrigation purposes. There are also other smaller turnouts on the Yuma Main Canal which provide irrigation water to the Yuma Project Reservation Division. The Reservation main annual diversions range from 53,924 to 60,420 acre-feet during the study period from 1988 to 1997. Titsink, Yaqui, and Pontiac Canals have annual diversions ranging from 353 to 574 acre-feet, 8,678 to 10,380 acre-feet, and 6,981 to 8,609 acre-feet, respectively. The Ypsilanti Canal is

Table VII-1 Diversions and Returns (Acre-feet) on the Colorado River Between Parker and Imperial Dams.

WATER USER	CATEGORY	STATION NAME AND GAGE ID	YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Brook Water (Consolidated Water Util.)	Diversion	- Pumping from the river	1988	20	20	24	24	31	33	39	34	31	28	23	20	327
			1989	21	19	25	29	34	37	42	39	36	29	23	21	355
			1990	21	19	24	28	34	37	39	36	32	29	26	24	349
			1991	23	22	23	25	33	34	41	40	32	30	24	20	347
			1992	22	20	21	27	35	37	39	36	33	28	24	20	342
			1993	20	19	23	28	36	38	41	38	35	30	25	23	356
			1994	24	21	24	29	33	41	45	40	36	31	26	23	373
			1995	22	20	24	28	33	37	43	43	39	33	30	25	377
			1996	26	24	27	32	40	41	43	44	37	33	26	25	398
			1997	25	24	31	31	43	39	45	44	36	32	28	25	403
Colorado River Indian Reservation – AZ	Diversion	- CRIR Main Canal (#9428500) and pumping from the river	1988	10,471	35,666	61,856	51,771	73,554	82,731	88,174	72,686	56,371	38,520	28,245	26,247	626,292
			1989	14,831	35,387	82,188	69,776	77,020	88,070	91,821	76,140	61,667	38,355	26,784	28,960	690,999
			1990	6,120	38,786	65,267	60,082	75,997	92,149	100,053	79,594	52,107	40,693	30,384	31,688	672,920
			1991	11,593	43,416	39,029	60,656	73,716	84,622	97,958	85,269	47,233	37,554	27,606	30,870	639,522
			1992	11,170	28,566	39,347	59,342	69,107	86,119	97,043	69,044	41,847	36,653	27,363	20,758	586,359
			1993	982	9,790	57,750	68,070	73,790	81,120	87,720	70,840	45,920	38,480	29,620	39,290	603,372
			1994	21,705	38,212	49,428	64,600	72,734	88,498	88,340	86,813	58,481	43,274	30,829	30,560	673,474
			1995	2,241	15,385	62,917	66,721	76,544	85,792	95,852	91,318	61,047	42,525	28,921	34,781	664,044
			1996	23,703	42,796	69,805	68,242	82,174	91,052	93,884	85,138	56,573	40,401	25,541	34,530	713,839
			1997	8,797	43,255	56,449	60,329	77,388	78,498	83,875	75,800	52,312	39,402	28,839	26,712	631,656
	Return	- Gardner Lateral spill (#09428505)	1988	13,730	16,093	21,150	22,124	23,640	21,383	24,764	29,313	23,497	23,636	18,889	17,993	256,212
		- CRIR Poston wasteway (#09428510)	1989	16,020	15,450	23,280	22,810	23,600	20,350	24,920	26,900	26,030	23,974	20,368	19,444	263,146
		- Palo Verde drain (#09429030)	1990	13,619	15,841	20,586	21,344	22,042	23,426	27,963	26,812	23,725	21,982	20,470	16,885	254,695
		- CRIR Lower Main drain (#09429060)	1991	14,382	17,675	21,182	20,447	22,043	21,922	24,824	28,007	22,769	19,655	18,520	17,392	248,818
			1992	11,966	15,711	18,314	17,919	20,923	19,900	24,096	25,913	20,839	18,932	17,842	16,669	229,024
			1993	12,459	10,232	17,507	21,640	22,312	23,996	22,677	23,875	20,902	19,771	17,740	18,368	231,479
			1994	14,086	17,758	22,395	21,851	23,028	22,903	24,470	24,934	24,380	21,548	18,445	17,950	253,748
			1995	12,111	10,189	17,836	22,012	22,627	21,611	24,848	25,909	23,534	20,354	18,872	19,039	238,942
			1996	13,172	15,575	19,554	19,391	21,361	20,772	22,476	25,247	23,149	20,649	18,081	18,074	237,501
			1997	12,526	13,878	18,613	20,167	21,886	23,095	23,926	24,894	22,626	19,955	18,429	18,940	238,935
	Use		1988	(3,259)	19,573	40,706	29,647	49,914	61,348	63,410	43,373	32,874	14,884	9,356	8,254	370,080
			1989	(1,189)	19,937	58,908	46,966	53,420	67,720	66,901	49,240	35,637	14,381	6,416	9,516	427,853
			1990	(7,499)	22,945	44,681	38,738	53,955	68,723	72,090	52,782	28,382	18,711	9,914	14,803	418,225
			1991	(2,789)	25,741	17,847	40,209	51,673	62,700	73,134	57,262	24,464	17,899	9,086	13,478	390,704
			1992	(796)	12,855	21,033	41,423	48,184	66,219	72,947	43,131	21,008	17,721	9,521	4,089	357,335
			1993	(11,477)	(442)	40,243	46,430	51,478	57,124	65,043	46,965	25,018	18,709	11,880	20,922	371,893
			1994	7,619	20,454	27,033	42,749	49,706	65,595	63,870	61,879	34,101	21,726	12,384	12,610	419,726

WATER USER	CATEGORY	STATION NAME AND GAGE ID	YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Colorado River Indian	Use (cont.)		1995	(9,870)	5,196	45,081	44,709	53,917	64,181	71,004	65,409	37,513	22,171	10,049	15,742	425,102
Reservation – AZ			1996	10,531	27,221	50,251	48,851	60,813	70,280	71,408	59,891	33,424	19,752	7,460	16,456	476,338
			1997	(3,729)	29,377	37,836	40,162	55,502	55,403	59,949	50,906	29,686	19,447	10,410	7,772	392,721
Colorado River Indian Reservation – CA	Diversion	- Pumping from the river	1988	131	119	220	313	325	469	629	676	418	450	235	220	4,205
			1989	132	457	396	375	472	430	719	591	522	457	588	340	5,479
			1990	191	352	277	479	508	560	699	513	680	437	451	232	5,379
			1991	298	392	521	813	896	1,249	1,178	1,025	788	628	350	312	8,450
			1992	305	259	388	1,162	1,215	738	1,292	1,433	1,437	1,267	107	190	9,793
			1993	50	676	1,108	985	860	958	1,544	877	116	219	198	196	7,787
			1994	160	175	225	654	758	912	845	1,028	1,053	359	269	263	6,701
			1995	52	210	570	800	1,028	1,232	1,607	1,277	1,419	349	241	55	8,840
			1996	522	134	1,108	913	515	856	881	752	574	384	339	343	7,321
			1997	84	228	397	385	659	651	555	556	263	243	388	88	4,497
Town of Parker	Diversion	- Pumping from the river	1988	55	58	78	72	108	703	141	116	96	97	62	49	1,635
			1989	45	53	77	100	114	129	140	131	111	93	59	55	1,107
			1990	55	44	75	81	99	120	131	126	99	83	59	58	1,030
			1991	52	57	53	10	101	117	127	106	96	87	60	50	916
			1992	46	45	47	74	99	123	136	108	93	80	56	45	952
			1993	43	39	62	84	107	123	135	127	113	93	55	56	1,037
			1994	58	52	68	86	105	138	135	136	118	88	63	86	1,133
			1995	68	48	69	84	111	129	137	141	127	94	72	64	1,144
			1996	62	62	81	97	121	133	137	138	110	100	60	51	1,152
			1997	49	52	77	84	84	108	113	106	84	172	54	47	1,030
Palo Verde Irrigation District	Diversion	- Palo Verde Canal near Blythe (#09429000)	1988	29,245	53,630	87,512	71,424	98,064	110,302	128,451	99,502	69,795	51,962	47,299	51,464	898,650
			1989	27,210	57,920	82,375	95,129	96,200	107,486	121,192	107,248	82,732	58,743	48,322	50,869	935,426
			1990	30,920	54,930	74,300	82,800	100,900	111,700	116,400	103,400	76,330	62,490	47,640	55,670	917,480
			1991	29,920	53,070	43,250	82,250	92,010	104,900	109,900	98,760	78,150	68,490	45,300	45,920	851,920
			1992	28,590	44,910	52,710	82,900	100,600	108,600	102,200	62,180	61,330	50,870	42,000	31,270	768,160
			1993	6,340	21,130	59,510	77,360	85,030	89,130	98,220	84,860	69,170	57,410	38,690	50,250	737,100
			1994	31,460	40,000	54,980	71,580	77,730	90,940	91,850	103,200	79,920	65,730	50,580	42,400	800,370
			1995	13,490	32,330	69,720	83,520	95,310	102,800	110,700	106,900	81,620	61,540	46,540	57,330	861,800
			1996	39,170	57,400	78,400	97,800	104,500	107,200	113,600	103,100	76,930	68,440	48,870	57,600	953,010
			1997	32,700	58,990	75,330	84,360	105,000	107,300	108,500	110,100	74,250	67,120	49,460	44,410	917,520
	Return	- PVID Olive Lake drain (#09429130)	1988	28,250	29,462	34,515	36,396	37,629	41,467	44,725	48,590	42,487	40,352	35,239	35,717	454,829
		- PVID F Canal spill (#09429155)	1989	26,932	30,200	34,931	37,515	44,774	56,440	46,122	44,397	43,635	41,898	38,805	37,728	483,377
		- PVID D-10-11-2 spill (#09429160)	1990	28,274	29,770	36,000	36,095	41,029	41,590	44,372	46,247	41,932	41,890	35,742	34,924	457,865
		- PVID D-10-11-5 spill (#09429170)	1991	28,830	29,640	32,979	34,428	36,509	37,084	41,952	43,380	41,233	40,539	37,249	35,132	438,955
Palo Verde Irrigation District	Return	- PVID D-23 spill (#09429180)	1992	28,001	30,691	35,045	33,479	41,484	41,584	42,065	40,613	36,083	36,206	33,226	34,994	433,471
		- PVID D-23-1 spill (#09429190)	1993	17,559	24,519	29,159	33,046	37,451	38,182	39,044	40,171	37,896	38,335	33,134	34,137	402,633
		- PVID C Canal spill #09429200)	1994	25,745	27,203	31,815	31,903	36,019	35,824	36,774	39,095	40,503	40,834	35,880	36,299	417,894

WATER USER	CATEGORY	STATION NAME AND GAGE ID	YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
		- PVID C-28 upper spill (#09429210)	1995	27,325	25,519	31,112	34,204	38,455	38,340	42,262	43,867	41,858	41,137	35,247	35,875	435,201
		- PVID Outfall drain (#09429220)	1996	27,818	30,493	33,442	37,803	43,439	43,220	44,029	46,511	43,654	39,947	34,824	34,258	459,438
		- PVID C-28 lower spill (#09429230)	1997	26,388	30,597	37,025	37,557	41,696	43,305	47,150	49,859	52,519	47,270	44,005	38,298	495,669
	Use		1988	995	24,168	52,997	35,028	60,435	68,835	83,726	50,912	27,308	11,610	12,060	15,747	443,821
			1989	278	27,720	47,444	57,614	51,426	51,046	75,070	62,851	39,097	16,845	9,517	13,141	452,049
			1990	2,646	25,160	38,300	46,705	59,871	70,110	72,028	57,153	34,398	20,600	11,898	20,746	459,615
			1991	1,090	23,430	10,271	47,822	55,501	67,816	67,948	55,380	36,917	27,951	8,051	10,788	412,965
			1992	589	14,219	17,665	49,421	59,116	67,016	60,135	21,567	25,247	14,664	8,774	(3,724)	334,689
			1993	(11,219)	(3,389)	30,351	44,314	47,579	50,948	59,176	44,689	31,274	19,075	5,556	16,113	334,467
			1994	5,715	12,797	23,165	39,677	41,711	55,116	55,076	64,105	39,417	24,896	14,700	6,101	382,476
			1995	(13,835)	6,811	38,608	49,316	56,855	64,460	68,438	63,033	39,762	20,403	11,293	21,455	426,599
			1996	11,352	26,907	44,958	59,997	61,061	63,980	69,571	56,589	33,276	28,493	14,046	23,342	493,572
			1997	6,312	28,393	38,305	46,803	63,304	63,995	61,350	60,241	21,731	19,850	5,455	6,112	421,851
Ehrenberg Improvement Association	Diversion	- Pumping from the river	1988	11	11	15	16	23	27	28	21	22	20	18	17	229
			1989	12	14	17	24	26	39	43	48	30	29	24	18	324
			1990	14	11	19	21	25	31	33	32	25	21	15	15	262
			1991	18	18	21	20	27	34	34	35	31	27	19	21	305
			1992	19	17	18	29	32	37	41	36	34	28	22	17	330
			1993	19	15	20	30	34	36	46	40	34	28	20	22	344
			1994	21	20	22	29	35	44	45	45	39	32	25	22	379
			1995	20	20	27	35	39	45	48	55	43	36	29	26	423
			1996	23	18	31	34	41	50	54	52	41	34	24	24	426
			1997	29	28	37	38	41	51	58	57	47	36	46	31	499
Cibola Valley Irrigation District	Diversion	- Pumping from the river	1988	383	249	3,052	1,570	2,374	4,185	4,832	2,834	2,349	1,223	625	660	24,336
			1989	387	1,482	3,323	2,320	2,198	3,967	4,493	3,637	2,516	828	487	554	26,192
			1990	527	1,355	3,074	1,807	2,365	4,292	4,669	3,279	2,047	1,335	991	1,256	26,997
			1991	1,085	1,189	1,106	209	2,107	2,379	2,587	2,212	2,003	1,815	1,252	1,043	18,987
			1992	111	636	2,501	1,481	2,467	3,273	3,401	2,831	1,209	1,333	976	54	20,273
			1993	40	40	1,644	2,742	2,369	3,715	4,658	2,722	1,749	1,340	653	473	22,145
			1994	1,575	1,262	2,152	2,323	2,841	3,444	3,760	3,615	2,841	2,380	1,690	1,663	29,546
			1995	104	1,045	2,686	2,347	3,351	4,428	5,383	4,523	2,633	1,484	639	587	29,210
			1996	1,024	1,445	2,537	3,355	4,467	4,554	4,409	3,210	1,660	1,674	683	206	29,224
			1997	411	3,001	1,671	2,823	4,005	4,470	5,059	4,535	2,137	1,275	714	782	30,883
Cibola National Wildlife Refuge	Diversion	- Pumping from the river	1988	175	198	408	776	634	1,091	847	724	678	1,747	1,963	869	10,110
			1989	701	211	162	1,175	950	1,227	859	1,055	998	1,311	1,973	1,474	12,096
			1990	607	223	354	490	854	1,128	739	750	1,123	1,174	1,515	1,372	10,329
			1991	1,641	1,162	519	682	2,923	1,350	1,369	986	2,012	1,767	1,859	1,482	17,752
			1992	1,489	1,157	1,094	839	1,042	1,530	975	1,189	1,630	2,074	1,489	1,623	16,131
			1993	635	509	868	937	1,146	1,389	1,515	1,458	1,146	960	682	671	11,916
			1994	1,007	1,143	405	729	646	773	756	686	1,193	691	398	345	8,772
			1995	252	229	368	1,056	763	1,214	1,009	1,131	929	1,081	1,596	738	10,366
			1996	597	532	851	784	1,005	1,479	2,003	1,328	1,930	1,428	1,806	724	14,467
			1997	625	327	563	1,384	1,085	1,827	1,798	1,778	1,735	1,555	1,583	814	15,074

WATER USER	CATEGORY	STATION NAME AND GAGE ID	YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Imperial National Wildlife Refuge	Diversion	- Pumping from wells	1988	2	2	2	2	2	2	2	2	2	2	2	2	24
			1989	11	9	15	17	20	24	27	26	20	17	12	12	210
			1990	607	223	354	490	854	1,128	739	750	1,123	1,174	1,515	1,372	10,329
			1991	380	417	388	73	739	834	907	775	702	636	439	366	6,656
			1992	427	342	583	629	769	932	1,017	979	769	644	458	451	8,000
			1993	483	384	655	707	865	1,049	1,144	1,101	865	725	515	507	9,000
			1994	480	384	655	707	865	1,049	1,145	1,102	866	725	515	507	9,000
			1995	534	427	729	786	962	1,165	1,272	1,223	961	806	572	563	10,000
			1996	533	427	728	787	962	1,166	1,272	1,224	961	805	572	563	10,000
			1997	426	342	582	629	769	932	1,017	978	769	644	458	450	7,996
Other Arizona Users Below Parker Dam	Diversion	- Pumping from the river and wells	1988	345	786	2,554	1,603	1,802	1,832	2,369	3,008	2,001	1,425	860	672	19,257
			1989	901	715	1,219	1,316	1,609	1,951	2,128	2,048	1,609	1,348	958	943	16,745
Hillcrest Water Co.			1990	430	1,141	945	638	970	1,729	1,793	1,781	1,550	719	578	576	12,849
Rayner, Jack Jr.			1991	273	1,251	487	327	478	475	1,692	1,061	1,119	472	358	814	8,805
Arakelian, George			1992	123	110	806	290	345	1,052	1,605	925	413	329	279	224	6,499
BLM Permitees			1993	388	311	529	572	699	847	924	890	699	586	416	410	7,269
			1994	136	29	812	225	403	668	1,105	689	518	152	221	65	5,023
			1995	164	145	882	645	656	470	671	682	529	275	294	557	5,970
			1996	544	364	977	545	631	1,043	1,153	1,043	732	543	253	226	8,054
			1997	306	165	426	902	650	916	1,166	886	554	338	383	394	7,086
Other California Users below Parker Dam	Diversion		1988	13	10	17	19	23	27	30	29	23	19	13	13	236
			1989	13	11	18	19	24	29	31	30	24	20	14	14	247
Lye, C.L.			1990	15	12	20	22	27	33	36	34	27	23	16	16	281
BLM Permitees			1991	2	2	2	0	3	4	4	4	3	3	2	2	31
Picacho Development Corp.			1992	13	10	18	19	23	28	31	29	23	19	14	14	241
			1993	47	37	64	69	84	102	111	107	84	70	50	49	874
			1994	35	51	74	91	104	138	150	121	101	109	48	35	1,057
			1995	8	10	12	8	9	18	18	18	17	7	10	12	147
			1996	27	28	47	45	55	65	70	66	54	50	35	37	579
			1997	44	46	49	32	65	85	72	67	76	45	65	44	690
Miscellaneous	Diversion		1988	(1,445)	658	925	140	679	572	983	(340)	(197)	(951)	(356)	(553)	115
			1989	(1,506)	1,225	2,283	2,966	2,859	(710)	1,380	(2,478)	(3,646)	(517)	(526)	(1,126)	204
			1990	3	6	12	15	18	18	25	25	15	14	8	6	165
			1991	1	0	1	1	1	(1)	1	0	1	1	(1)	(1)	4
			1992	(1)	(1)	0	0	0	(1)	1	(1)	0	0	(4)	(1)	(8)
			1993	0	(1)	0	0	0	0	0	0	0	0	0	0	(1)
Miscellaneous	Use		1988	(1,443)	660	927	52	681	574	985	(338)	(194)	(949)	(354)	(551)	50
			1989	(1,506)	1,225	2,283	2,966	2,859	(710)	1,380	(2,478)	(3,646)	(517)	(526)	(1,126)	204
			1990	3	6	12	15	16	16	23	22	13	12	8	6	152
			1991	1	0	1	1	1	(4)	(2)	0	1	1	(1)	(1)	(2)
			1992	(1)	(1)	0	0	0	(2)	(1)	(3)	0	0	(4)	(1)	(13)
			1993	0	(1)	0	0	0	(1)	(1)	(2)	(1)	0	0	0	(6)

a new diversion on the AAC, located about 1.5 miles downstream of the Yuma Main Canal diversion. It replaced the Walaipai Canal in 1995. The old Walaipai Canal was located off the Yuma Main Canal above the USGS flow gage (#09524000), which measures the flow in the Yuma Main Canal (see Figure VII-2). Walaipai and Ypsilanti Canals diverted annual flows of 4,995 to 15,564 acre-feet and 3,600 to 9,945 acre-feet, respectively. The return flows from the Yuma Project Reservation Division drain into the Colorado River. Therefore, its return flows do not contribute to the AAC.

The Yuma Main Canal turnout is about 13.7 miles downstream of the Imperial Dam. The Yuma Main Canal delivers water to the Yuma Valley in Arizona through the Colorado River siphon. The Yuma Main Canal supplies water to both the Yuma Project Reservation Division, administered by the Bard Irrigation District, and to the Yuma Project Valley Division, administered by the Yuma County Water Users Association (YCWUA). It also supplies municipal water to the City of Yuma as well as the Yuma Union High School and Alex Camille, Jr., two small users in the city. The Cocopah Indian Reservation receives part of its water supply from the Yuma Main Canal as well. The rest of the Cocopah Indian Reservation water supply is pumped from groundwater wells. Annual diversions for the Yuma Main Canal vary from 431,604 to 742,143 acre-feet, with the excess water flowing back to the Colorado River through the Yuma Main wasteway.

The Pilot Knob Power Plant and wasteway near Pilot Knob diverts water from the AAC and returns it back to the river for Mexico. Its annual flows range from 98,844 to 1,844,486 acre-feet. The Coachella Canal turnout diverts water to the CVWD, and is located above Drop No. 1, about 36 miles downstream of Imperial Dam. Its diversions range from 308,740 to 368,900 acre-feet. IID receives approximately 2,390,033 to 3,090,295 acre-feet of water below Drop No. 1, annually.

2. *Analysis of 200,000 Acre-foot Reduction due to Transfer*

NRCE assessed the potential impacts to the downstream water users that would occur if the Colorado River flow was hypothetically reduced by an annual amount of 200,000 acre-feet below Parker Dam. It was thought that the flow reduction could potentially affect the downstream water users in two ways. First, water right holders may be unable to divert needed water due to inadequate flow in the Colorado River. Second, there may be insufficient hydraulic head at the diversion structures. NRCE's analysis showed that neither of these factors would affect the downstream water users.

The study period from 1988 to 1997 was selected to allow for flow variations representative of the long-term conditions in the study area. It was important for the study period to include extreme years of low river flows since further reduction of river flow in low flow conditions may deplete the water supplies of some of the river users. The historical flow records from 1935 to 1997 show that the lowest Parker Dam annual release (5,533,851 acre-feet) was in 1993 and is thereby covered in the study period.

IID Exhibit 2B oversized map inserted here. Figure VII-2 Locations of Streamflow Gaging Stations for the Study area Below Hoover Dam

a. Flow Adequacy

In this section, flow analyses were performed on a daily basis to evaluate whether reducing the river flow, starting at Parker Dam, would cause shortages for the downstream users historical diversions. Since the water transferred to the SDCWA is generally for municipal water use, it is assumed that the 200,000 acre-feet per year of water will be distributed evenly throughout the year. This is equivalent to about 277 cfs of water on a daily basis.

(1) Flow Accounting System on the Colorado River

The reach on the Colorado River between Parker Dam and Imperial Dam was the first reach evaluated. USGS gage (#09427520) below Parker Dam was used in the flow accounting analysis as the source of inflow for the reach system. The USGS gage above Imperial Dam (#09429490) was used as the end outflow measurement of the system. Diversions and return flows by the users are considered other outflows and inflows to the system, respectively. Closure is the change of river storage and other losses such as evaporation and phreatophyte consumption. These are components that are not directly measured. An expression of the system's flow balance for this reach may be described as follows:

$$OUTFL_{Imperial} = INFL_{Parker} - diversions - losses - \Delta\, storage + returns \qquad \textbf{(VII-1)}$$

where,

$OUTFL_{Imperial}$ = Measured Colorado River flow above Imperial Dam

$INFL_{Parker}$ = Measured Parker Dam releases

diversions = Measured and estimated diversions of users

losses = Evaporative losses and phreatophyte use along the Colorado River

Δ storage = Change in river storage

returns = Measured return flows from the users

Figure VII-2 is a schematic showing the corresponding USGS gages used to measure the various diversions and returns. The CRIR Main Canal gage (#09428500) was used for the daily diversions of the CRIR. Its return flows are measured by gages #09428505, #09428510, #09429030, and #09429060. The PVID diversions are measured by the Palo Verde Canal gage #09429000. There are ten gages that measure the spills and drainage water of PVID: #09429130, #09429155, #09429160, #09429170, #09429180, #09429190, #09429200, #09429210, #09429220, and #09429230. The rest of the users in this reach are pumpers and subsequently their pumpage data are available only on a monthly basis from the "Decree" records. These monthly flow amounts are estimated either by monthly power records or fixed water duty values.

The estimated daily water use values used in this study were estimated by evenly distributing the monthly amounts into a daily average. No return flows were assumed for the pumpers. The annual releases from Parker Dam varied from 5,533,931 acre-feet in 1993 to 7,507,587 acre-feet in 1988. The total consumptive use in the reach between Parker and Imperial Dams varied from 754,572 acre-feet in 1992 to 1,041,511 acre-feet in 1996.

The estimated river losses and change of river storage were calculated by subtracting all the net historical uses (diversion-return) from the difference in flow between INFLParker, flow below Parker Dam (gage #09427520) and OUTFLImperial, flow above Imperial Dam (gage #09429490). Since the distance between Parker Dam and Imperial Dam is about 143 miles, there is an estimated travel time of approximately 3 days (Grimes, 1999) between the two locations. Therefore, the change in river storage can be a large factor in the daily flow balance between the gages (i.e., #09427520 and #09429490) below Parker Dam and above Imperial Dam. The required historical diversions of the Gila Gravity Main Canal and the downstream river flows were calculated by subtracting the AAC flow (#09523000) from the flow above Imperial Dam (#09429490).

(2) Daily Flow Analysis on the Colorado River

A daily flow amount of 277 cfs was subtracted from the Parker Dam gage (#09427520) to represent the hypothetically reduced Parker Dam daily releases. The users' historical diversions, river losses, and change of river storage were then subtracted from the reduced Parker Dam releases to compute the remaining flow in the river just above the Imperial Dam plus the return flows. The river losses and the change in river storage in a reduced flow system may hypothetically be different than the amounts developed from the historical discharges. However, they are assumed to be the same in this analysis since the difference would be minimal.

The water entering Imperial Dam discharges into the AAC, the Gila Gravity Main Canal, and the Colorado River below the Imperial Dam. The flow analysis with the reduced flow shows that the lowest daily river flow available at Imperial Dam for the AAC was 1,063 cfs. This was hypothetically the lowest amount of daily flow remaining in the river at Imperial Dam after satisfying all the demands of the users above Imperial Dam as well as the combined flow demands of the Gila Gravity Main Canal and the discharge downstream of Imperial Dam. In the analysis, the hypothetical flow amount of 1,063 cfs would have occurred on January 1, 1993, when the Parker Dam release was 2,060 cfs, and the CRIR Main Canal was in the process of shutting down for cleaning and repairs. At this time of the year, most diversions on the river are small due to the less agriculturally active winter season. It is apparent from the historical data that the river had sufficient flows to provide all the required historical diversions on a daily basis between Parker Dam and the Imperial Dam even when the flows were reduced by 277 cfs. The 1,063 cfs remaining in the system was what was left for the AAC users. However, if there had been no flow left in the system at Imperial Dam after the 277 cfs flow reduction, then it could have been concluded that there was insufficient flow to satisfy all the historical diversions of the upstream river users, the river downstream, and the Gila Gravity Main Canal. Such a scenario assumes that all the upstream reservoirs are basically empty.

(3) Flow Accounting System on the All American Canal

The AAC reach pertinent to the study extends from below Imperial Dam to just above IID's EHL turnout. The inflow to this system is the AAC diversion at Imperial Dam (#09523000). The AAC flow above the EHL Canal turnout is the end outflow of the system. Since there is no measurement of the AAC flow just upstream of the EHL turnout, the downstream end of the daily flow balance analysis would be at the USGS gage #09527500, which measures the AAC flows below Pilot Knob Power Plant and wasteway. The Pilot Knob gage is about 15 miles upstream of the Coachella Canal turnout and 32 miles upstream of the EHL turnout. There is basically no diversion off the AAC between Pilot Knob, Coachella, and EHL Canals except for minor diversions of 1,000-6,000 acre-feet/year by IID located between the EHL and the Coachella Canal. Return flows from the users in this reach do not contribute to the flow in the AAC since they return back to the Colorado River. Therefore, the flow accounting balance does not consider the return flows from the users. The balance of flow may be expressed in the following:

$$OUTFL_{Pilot\ Knob} = INFL_{Imperial} - diversions - losses - \Delta\ storage \qquad \textbf{(VII–2)}$$

where,

$OUTFL_{Pilot\ Knob}$	= Measures the AAC flow below Pilot Knob Power Plant and wasteway
$INFL_{Imperial}$	= Measures the AAC inflow at Imperial Dam
diversions	= Measures diversions along the AAC
losses	= Evaporative and canal seepage losses and phreatophyte use
Δ storage	= Change in canal storage

The flow accounting procedure for the AAC is similar to the Colorado River reach previously described. The canal losses and change in canal storage can be lumped together as the closure term. They can be determined by subtracting the various diversions and the Pilot Knob gage (#09527500), $OUTFL_{Pilot\ Knob}$, downstream of Pilot Knob wasteway from the AAC inflow (#09523000), $INFL_{Imperial}$ as indicated in the above equation. The diversions for the Yuma Project Reservation Division on the AAC were determined by summing the measured flows of Reservation Main (#09523200), Titsink (#09523400), Yaqui (#09523600), Pontiac (#09523800), and Ypsilanti (#09526200) Canals. The Yuma Main Canal diversion for the YCWUA and others is measured by gage #09524000 on the Yuma Main Canal and the Walaipai Canal gage #09523900 which was discontinued in 1995 (see Figure VII-2).

(4) Daily Flow Analysis on the All American Canal

The reduced AAC daily flows at Imperial Dam calculated from the previous analysis on the Colorado River reach are carried over to represent the hypothetical reduced inflow of the AAC due to the upstream water transfer scheme. The measured diversions and previously calculated losses were subtracted from the reduced AAC inflow values to simulate flows just downstream of the Pilot Knob Power Plant and wasteway. After satisfying all the upstream users, the computed daily flows downstream of Pilot Knob are the remaining flows in the AAC to supply the demands of IID and CVWD. These flow values were evaluated to determine whether there would be enough flow left in the canal to satisfy the CVWD diversion.

The portions of the flow below Pilot Knob delivered to IID and CVWD are reported by IID's Water Control Section. After the historical diversion of CVWD was subtracted from the reduced canal flow below Pilot Knob, the lowest remaining daily flow for IID was 42 cfs in the study period. This occurred on January 18, 1993 when the AAC was diverting about 2,350 cfs and the flow below Pilot Knob was 382 cfs. IID received 319 cfs while CVWD received 63 cfs. Therefore, hypothetically, if the historical canal flow of 382 was reduced by 277 cfs, a flow of 105 cfs remains. This flow amount may be used to satisfy the 63 cfs of historical CVWD diversion. The left over flow of 42 cfs would then be the reduced diversion amount for IID since the historically flow of 319 cfs was scheduled. This exercise confirms that, after a flow reduction of 277 cfs for the lowest flow at Pilot Knob, there is still a flow of 42 cfs remaining below Pilot Knob for IID after all the upstream users have been satisfied, including CVWD. According to the 10-year historical flow records, the low flows normally occurr in late December and early January when the irrigation water demands were low.

Since the water delivery system for the Lower Colorado River is demand-based, more water may be diverted if supply is not limiting. For example, in this case, if the remaining flow of 105 cfs is not able to satisfy the historical diversion of CVWD, more water may be ordered from the reservoirs to meet the demand. Due to a 3-day lag time in water travel time, the active storage at Lake Havasu on January 15, 1993 was examined to determine whether there was sufficient storage in the lake to supply additional water to CVWD or others. The average daily active storage of Lake Havasu on January 15, 1993 was 552,100 acre-feet which was more than sufficient to cover the additional 277 cfs (i.e., 550 acre-feet/day) of water that would have been in the system before the diversion at the Colorado River aqueduct. The water surface elevation was at 447.06 feet, which was higher than the 1993 minimum water surface elevation of 445.97 feet with storage capacity of 532,400 acre-feet.

b. Hydraulic Limitation

In this part of the analysis, the diversion facilities were investigated to determine whether the reduction in flow would have lowered the hydraulic head beyond the normal operating range of the various turnouts. If the hydraulic heads were too low, the gravity-fed diversion facilities would not be able to divert the same amount of water as recorded in the historical data. However, the impact on the pumping facilities due to lowering of the hydraulic head would only increase the amount of energy needed for pumping.

(1) Reach on the Colorado River

The diversion structures and operations procedures in this reach were examined. Other than various pumping facilities, there are two major diversion dams on the river. The Headgate Rock Dam was built just downstream of the CRIR Main Canal intake structure to raise the water surface elevation in the river so that the CRIR Main Canal would have enough hydraulic head for the required diversions. The Palo Verde Dam functions in the same way as the Headgate Rock Dam for the Palo Verde Canal. The control gates of the dams are operated automatically to maintain constant water surface elevations on the upstream side of the dams except for very high flows. Normally once a year, at the end of December or the beginning of January, major drawdowns at the dams are expected while the canals are shut down. The water at the dams is lowered for inspection and repairs if necessary.

The control gates of the dams are designed to maintain constant water surface elevations upstream of the dams irrespective of their flows through the gates. The gate settings adjust automatically to allow various flows through the gate structures while keeping the upstream head constant. For example, when a lower incoming flow is entering the dam, the water level upstream of the dam would decrease. However, with the constant water level control gates, the gates would automatically reduce the gate opening to raise the upstream head (water level) to compensate for the drop in flow so that it can be kept at the same level as before the flow is reduced. The free-flow gate discharge equation may be used to illustrate the gate discharge, gate opening, and upstream head relationships. It is expressed as follows:

$$Q = C_d * A * \sqrt{2g * H} \qquad \textbf{(VII-3)}$$

where,

Q = Gate discharge (ft^3/s)

C_d = Discharge coefficient (dimensionless)

A = Area of the gate opening (ft^2)

g = Acceleration of gravity (ft/s^2)

H = Upstream head (distance from the center of the gate opening to the water surface upstream of the gate)

According to the gate discharge equation, the gate discharge is a function of both the upstream head and the gate opening. If the discharge, Q, is to be reduced, the gate opening, A, has to be reduced as well while the upstream, H, may be kept constant. Therefore, a flow reduction of 277 cfs in the river should not affect the canal diversions just above the dam control gates because the water surface elevations would be kept the same except for minor fluctuations.

For the Headgate Rock Dam, the target water surface elevation at the forebay is 364.40 feet. The automated gates are capable of limiting the upstream head variation to within ± 0.2 feet except on days when the dam is going through major drawdowns for repairs and inspection (Glen, 1999). The daily water surface elevation data behind Headgate Rock Dam was obtained to demonstrate the effectiveness of the control gates in keeping a constant water surface elevation at varying flows. The Parker Dam release, which is not very far upstream of the Headgate Rock Dam, may be used as the inflow reference into the dam. During 1992, which was one of the lower flow years in the study period, the minimum daily Parker Dam release was 1,550 cfs on December 30 (excluding major lake drawdown in January) while the daily average water surface elevation at Headgate Rock Dam was measured at 364.460 feet. In the same year, the maximum Parker Dam discharge was 14,600 cfs on June 29. The corresponding water surface elevation was 364.300 feet. The discharge difference is 13,050 cfs while the maximum deviation of the water surface elevations from the target water surface elevation of 364.40 was only 0.1 feet. Hence, it can be concluded that lowering the river flow by 277 cfs would not affect the diversions from the dam, because 277 cfs of flow is within the range of operational flows in which the upstream water surface elevation would be kept constant.

For the Palo Verde Dam, its target water surface elevation is set at 283.50 feet. According to Mr. Burt Bell, the dam operation supervisor, the upstream dam water surface elevation is designed to fluctuate between 283.40 to 283.60 feet (i.e., ±0.1 feet of tolerance) except during special drawdowns (Bell, 1999). The same principle in regard to the automated control gate for constant water leveling may be applied to the Palo Verde Dam and Canal. Therefore, due to the similarity in the operations of the two dams, the same conclusion may be reached on the capability of the gates in keeping a constant upstream water surface elevation. As a result of a constant water surface elevation at the diversion dam, there would be no effect on the Palo Verde Canal diversion due to low flows.

(2) Reach on the All American Canal

On the AAC between Imperial Dam and EHL turnout, turnouts located along the canal do not have any check structures except for the Pilot Knob Power Plant and Coachella Canal turnout. Both the Pilot Knob Power Plant and the Coachella Canal turnout have check structures just below the turnouts so they can maintain certain water surface elevations upstream of the turnout structures. However, water surface elevations on the upstream side of other turnout gates without check structures would vary depending on the flow of the canal. In order to guarantee that the amount of diversion from a particular turnout would not be affected by reduced flow in the canal, the water surface elevation for the reduced flow must be higher than the minimum head required for that particular flow amount. If the lowest flow in the canal has water surface elevations above the minimum operating water surface level of the turnout gates, then we can conclude that there will be no effect on the turnout flows. The minimum operating water surface level of a turnout gate is defined as the minimum hydraulic head required for the turnout to operate at its design flow capacity.

The daily flows in the AAC at the various turnouts were estimated based on the reduced canal inflow and the amount of water that had been diverted upstream. The estimated canal flows at the turnouts were calculated sequentially by subtracting the upstream turnout diversions and losses from the reduced AAC inflow at Imperial Dam beginning from the Reservation Main Canal (as shown in figure VII-2), which is the most upstream diversion. The minimum daily AAC flows at the various turnouts for the study period were determined only when the turnouts were in operation. The sill elevations, minimum operating water surface elevations, and sizes of the turnout gate structures were also determined based on the as-built engineering design drawings obtained from the USBR (USBR, 1936). The exception was the new Yuma Main Canal intake, which was built by a private contractor. The new Yuma Main Canal intake structure was built in 1987 by the YWCA. Table VII-2 shows the physical design configuration of the six diversion structures on the AAC between Imperial Dam and Pilot Knob, which do not have checks below them. The table also includes the estimated lowest daily flow in the AAC at each of the turnouts for the period from 1988 to 1997. The Titsink, Yaqui, and Pontiac turnouts were not delivering any substantial amount of water since the measured diversions were very low at a daily average of about 0.3 cfs. A typical turnout gate structure located along the AAC is shown in Figure VII-3.

Table VII-2 Design Configuration and Operating Criteria for the AAC Turnout Structures and Historical Canal Flows and Diversions (1988-1997).

Turnout	Turnout Design Configuration						Minimum AAC Flows at Turnouts During Deliveries			
	Distance from Imperial Dam (miles)	Gate Size	T.O. Capacity (cfs)	Sill Elev (feet)	Min Operating WS Elev (feet)	Design WS Elev (feet)	Date	Min Flow at T.O. 1988-1997 (cfs)	Min Flow -277 at T.O. 1988-1997 (cfs)	T.O. Discharge (cfs)
Reservation Main	5.8	3.2' X 4'	175	155.98	165.00	172.64	2/9/93	1,375	1,098	24
Titsink Canal	7.2	2.5' X 2.5'	26.4	164.58	167.21	172.21	1/30/93	1,498	1,221	0.29
Yaqui Canal	11.1	2.5' X 2.5'	30	163.24	166.12	171.12	1/1/93	1,189	912	0.33
Pontiac Canal	13.1	2.5' X 2.5'	30	162.27	165.16	170.16	1/1/93	1,161	884	0.35
Yuma Main	14.7	D=14'	2000	--	--	167.00	1/1/93	1,139	862	369.52
Ypsilanti Canal	16.0	4' X 4'	80	159.15	165.00	167.70	12/25/95	1,141	864	17

T.O. = Turnout, WS = Water Surface

In order to evaluate how the hypothetically reduced AAC flows would affect historical turnout diversions hydraulically along the canal, the corresponding water surface elevations just upstream of the turnouts must be determined and compared to the minimal operation water surface elevations of the turnouts. However, according to IID's River Master, Mr. Bobby Moore, a constant pool elevation of 167.30 feet above mean sea level (amsl) is maintained at the Pilot Knob check at all times, even at very low flows, to serve the upstream turnouts on the AAC (Eckhardt, 2000). The minimum required operational flow for the AAC at Imperial Dam is 500 cfs. Station 50, which is approximately 5,000 feet downstream of Imperial Dam has a water surface elevation of 167.75 feet asml at 500 cfs. Therefore, at the minimum flow of 500 cfs, the water surface elevations of the AAC range from 167.30 feet to 167.75 feet between the Pilot Knob check and the Imperial Dam. This means that as long as the flow in the AAC is kept at 500 cfs from Imperial Dam, the water surface elevation anywhere in the canal will be between 167.30 feet to 167.75 feet. The range of minimum operating water surface elevations for the unchecked turnouts between Imperial Dam and Pilot Knob vary from 165.00 to 167.21 feet asml as shown in Table VII-2 above. Comparing the two sets of water surface elevations, the

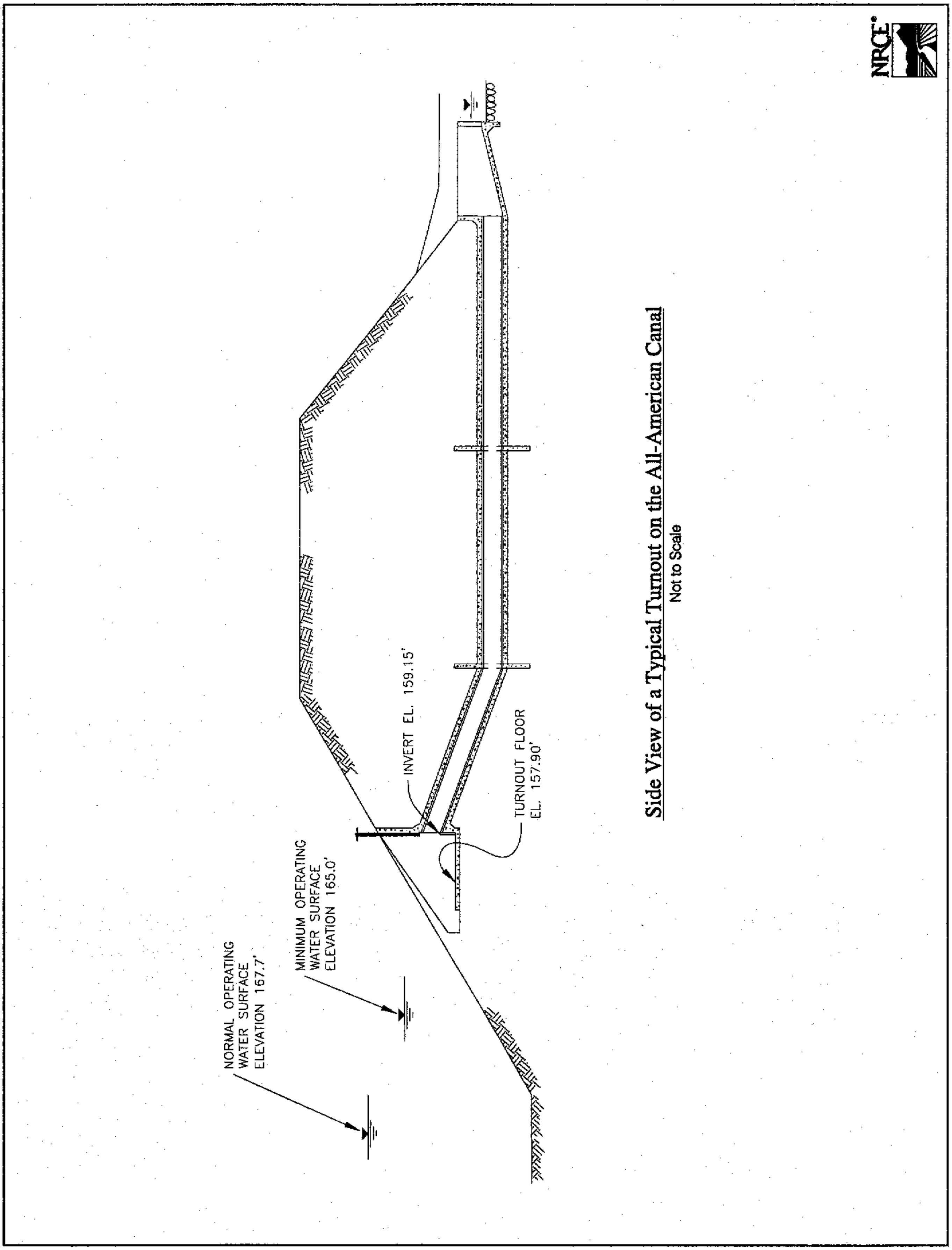


Figure VII-3 Side View of a Typical Turnout on the All-American Canal

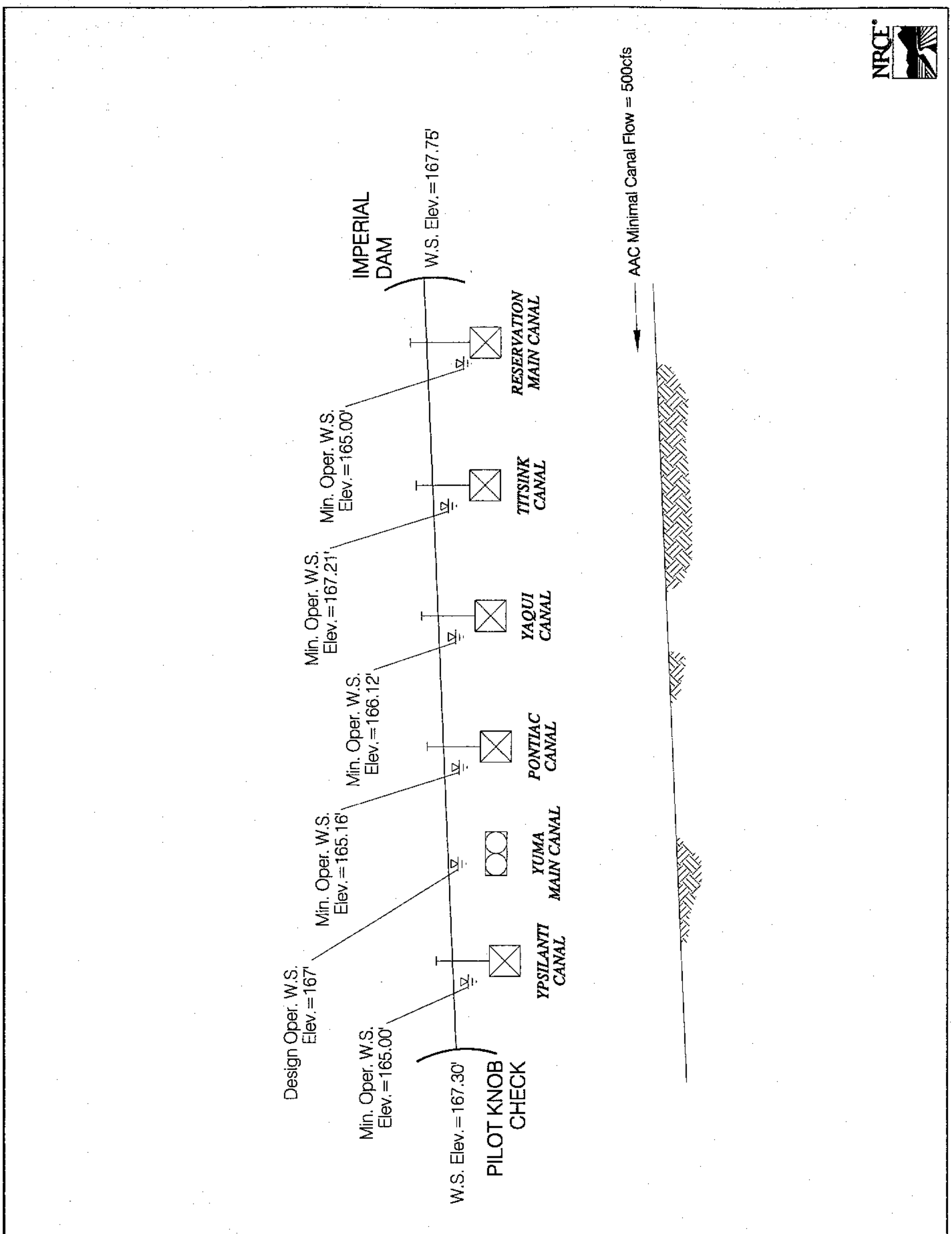


Figure VII-4 Minimum Operating Water Surface Elevation for the Turnouts on the AAC and the Water Surface Elevations of the AAC at Imperial Dam and Pilot Knob Check Structure at Minimum Flow.

minimum operating water surface elevations for the turnouts are all below 167.3 feet asml, which is the lowest water surface elevation possible in the canal between Imperial Dam and Pilot Knob at minimum operating flow. Hence, the turnout discharges will not be limited by the hydraulic heads. This is because the water surface elevations in the AAC will always be above the design minimum operating water surface elevation of the turnout structure. A sketch of the minimum operating water surface elevations for the turnouts and the water surface elevations of the AAC at the minimum flow of 500 cfs is shown in Figure VII-4. The next step is to evaluate whether the AAC historical flows at Imperial Dam and the various turnout locations were higher or lower than the required minimum 500 cfs.

During the study period from 1988 to 1997, the lowest average daily flow recorded at Imperial Dam was 1,340 cfs on January 1, 1993. Subtracting the 277 cfs of flow reduction from 1,340 cfs ends up with 1,063 cfs, which is still higher than the minimum operational flow of 500 cfs. Additionally, taking a step further by examining the estimated historical AAC flows at the various turnouts, the lowest flows after the 277 cfs flow reduction range from 862 to 1,221 cfs, which were all above 500 cfs as indicated above in Table VII-2. These daily flow data analyses show that historically from 1988 to 1997, not only were the hypothetically reduced AAC flows always above the required 500 cfs minimum at Imperial Dam, the flows in the canal between Imperial Dam and Pilot Knob were also above 500 cfs. It can be concluded from these results that, even with a flow drop of 277 cfs in the AAC, there is still sufficient hydraulic head upstream of the diversion structures to deliver the normal design capacity of the turnouts and that the minimum flow conditions were not violated. Therefore, the hypothetical flow reduction in the AAC during the 10-year study period had no impact on the historical diversion amounts with respect to the hydraulic head limitation.

In summary, the flow adequacy analysis shows that during the 10-year study period there was sufficient water in the system to meet all the demands of the other water right holders even though the Colorado River supply was hypothetically reduced by 277 cfs for IID. The results of the hydraulic analysis indicate that the reduction in flow would not hydraulically affect the deliveries of the normal historical diversions through the various turnout structures along the Colorado River and the AAC. Hence, NRCE has determined that the transferring of IID's conserved water to San Diego has no meaningful impact on the other water right holders with respect to supply and hydraulics.

REFERENCES:

Bell, B. (1999). Personal communications, Operation Supervisor, Palo Verde Dam, CA.

Carson, R. (1999). Personal communications, United States Bureau of Reclamation, Boulder City, NV.

Ekhardt, J. (2000). Letter from John Ekhardt, dated June 26, 2000. Imperial Irrigation District, Imperial, California.

Glen (1999). Personal communications, dam operator, Headgate Rock Dam, CA.

Grimes, C. (1999). Personal communications, River Operations Department, United States Bureau of Reclamation, Yuma Field Office, Yuma, AZ.

USBR (1936). As-built engineering design drawings for the "Boulder Canyon Project, All American Canal System-California."

USBR (1988-1997). "Compilation of records in accordance with Article V of the Decree of the Supreme Court of the United States in Arizona V. California dated March 9, 1964." United States Bureau of Reclamation, Boulder Canyon Operations Office, Lower Colorado Region, Boulder City, NV.

USBR (1998). "Colorado River system consumptive uses and losses report (1986-1990)." A report by the United States Bureau of Reclamation, Upper and Lower Colorado Regions.

VIII. CONCLUSION

Based on the study conducted by NRCE, the water use in IID is reasonable and beneficial. The irrigation water use efficiency test was one of the primary tests we considered when analyzing whether IID's water use is reasonable and beneficial. Prior to discussing the irrigation efficiencies in IID, it would be appropriate to discuss some of the most important factors that affect irrigation efficiencies in IID, some of which are unique to the Imperial Valley.

The overwhelming majority of the irrigated lands in IID have medium to heavy cracking soils. These soils are unique to the Imperial Valley (compared to the other major irrigation districts in the Lower Colorado River area) and are characterized with cracks that are as deep as 2.3 feet. When irrigation water is applied to these lands, a large portion of the applied water enters the cracks and then slowly enters the micro pores of the soil. As water is applied, it advances down the field filling the cracks several feet to several yards ahead of the surface flow.

For the majority of the soils in the world, including those soils in the Lower Colorado River Basin (with the exception of the majority of the soils in IID), applied water infiltrates downward into the root zone at the head of the field and the depth of the downward infiltration gradually decreases as one moves towards the lower end of the field. However, in the heavy cracking soils of IID, only a small portion of the applied water moves slowly downward beneath the bottom of the cracks, while most of the applied water moves laterally towards the tail end of the field. Because of this phenomenon, runoff accumulates after the soil cracks are filled, creating a high potential for tailwater occurrence; the higher the tailwater, the lower the irrigation efficiency.

Tailwater problems are further exacerbated by the amount of salt accumulation in the irrigation water due to the return flows from irrigated lands upstream of Imperial Dam. Because of the low permeability of IID's soil, it becomes very difficult for the irrigator to apply sufficient water to satisfy the crop water requirements and leach excess salts below the root zone. Quite often, the growers are torn between applying adequate water to satisfy the crop water needs and leaching requirements, and acting cautiously to avoid being assessed triple charges if the tailwater is more than 15% of the applied water. This is an every day dilemma faced by the overwhelming majority of IID growers.

These day-to-day problems that the farmers of IID encounter should be considered when assessing the reasonable and beneficial uses of water at IID. In other words, if IID irrigation uses are to be compared with other irrigation districts, one must consider some of the indisputable problems faced by IID and its growers. Most of the problems briefly discussed are physical problems that IID and its farmers, and in fact any one else for that matter, cannot change, as they are the objective realities under which irrigation is practiced at IID.

Irrigation efficiency provides a measure of the amount of water beneficially used relative to the amount of water applied. In the case of IID, irrigation water use efficiency can be estimated in three stages: (1) conveyance and distribution system efficiency, (2) on-farm irrigation efficiency, and (3) overall irrigation water use efficiency.

The conveyance and distribution systems efficiency was determined by dividing the amount of water delivered at the headgates of the farms by the amount of irrigation water delivered to IID's main canals. The losses of water occur primarily on the main canals, laterals, regulating reservoirs, and related canal and lateral structures. These losses are primarily due to seepage, spills, and evaporation from those facilities. The average conveyance and distribution efficiency based on recorded data spanning from 1988 to 1997 for the entire District system has been estimated to be 89%. In other words, of the total amount of irrigation water diverted to the IID system, 89% of the water was delivered at the farm headgates while 11% was unaccounted for due to losses between the point(s) of diversion from the AAC to the farm headgates. The estimated losses for the components are 5, 5, and 1% for canal operational spills, canal seepage, and water surface evaporation, respectively.

The reasonableness of the distribution losses for IID was shown by comparing the percentage losses with other standards in the irrigation industry and other estimates of distribution system efficiencies from similar irrigation districts in the Southwest. Based on published standards, canal operational spills of over 5 to 10% for most systems are considered excessive. However, IID's operational spill was estimated at 5%, which is just under the cited criteria. A certain amount of operational spillage is unavoidable if the delivery system is to remain flexible and reliable.

The loss of water due to seepage for the entire IID distribution system is estimated to be about 5%. During the last several years, IID has lined about 1,400 miles out of a total of about 1,700 miles of canals. The remaining unlined lateral canals are located mainly on impervious or semi impervious soils with little seepage. However, most of the main canals are still unlined and a large portion of the estimated seepage occurs through those main canals. Since the unlined main canals are the main arteries of the water conveyance that supply water to the laterals year round, it is for the most part physically impossible to line those canals while they are under operation. Even if all the canals were to be lined, there will still be seepage loss, although it is expected to be lower than a system with unlined canals. It should be remembered that after IID and MWD agreed to improve the distribution system, from 1988 to 1997, about an average of 28,000 acre-feet (amounting to 1%) of water savings per year has been achieved by canal lining. Hence, based on recorded data, seepage loss in the distribution system is on the decline. However, even if an average (1988 to 1997) seepage loss of about 5% occurs, it is acceptable and reasonable for a complex distribution system.

Distribution system efficiencies from four other districts were estimated using published data. They range from 40 to 90% with a median of 73% including IID's 89%. Even though the Wellton-Mohawk Irrigation and Drainage District has a slightly higher distribution efficiency, estimated at 90% (compared to 89% for IID), its irrigated acreage along with the other districts' is about eight times smaller than that of IID. In light of these comparisons and since IID is a much larger irrigated area resulting in a much higher water use demand and complex operation, IID's distribution system efficiency is considered to be reasonable.

The on-farm irrigation efficiency was determined by dividing the amount of beneficially used irrigation water for crop production by the amount of water delivered to the farms. The water that is beneficially used consists of water required for crop ET, other water uses for cultural practices (special irrigations), and the leaching requirement. Special irrigations and the leaching requirement are necessary since they are part of the elements for proper crop production and for maintaining a favorable salt balance in the root zone, which is required for long-term agricultural sustainability.

The on-farm irrigation water consumption, which includes the crop ET demand and water use for cultural practices from the special irrigations, was determined using the water budget approach. The leaching requirement, which is one of the beneficial uses, was estimated based on conventional leaching requirement methodology and methods developed in this study as a result of NRCE's field investigations. The on-farm irrigation system efficiency was determined to range from 81 to 87% with an average of 83% for the period from 1988 to 1997. In other words, 83% of the irrigation water delivered to the farm headgates was beneficially used and 17% was considered to be unused water. As irrigation water is applied to the farm, some is stored in the root zone to be used up by the crops; some is consumed by soil evaporation during normal irrigation periods, pre-plant, and seed germination irrigations; and the rest ends up as tailwater runoff and/or deep percolation.

However, the losses in soil evaporation are justified as beneficial use because they are the result of needed irrigations, which are essential to plant growth. Some of the tailwater and deep percolation water losses are also considered beneficial due to the fact that they function as a leaching requirement. During the study period, the estimated average leaching requirement was about 13% of the irrigation water delivered, while the crop consumptive use was about 70%.

Comparisons between IID's on-farm irrigation system performance, as determined in this study, and what is reported in some of the literature as being reasonable, requires some rearrangement of the estimated irrigation efficiency numbers. The reason is that there are many ways in which on-farm irrigation system efficiency may be defined. Some estimate irrigation efficiency simply by dividing the crop water requirement by the water applied to the field. Other definitions consider the crop water requirement, leaching requirement, and other uses as beneficial uses and are incorporated in the calculation of on-farm efficiencies, as done in this study.

There are still some who determine on-farm efficiency based on the average amount of water infiltrating the quarter of the field that receives the least amount of the total applied water. According to the various sources in literature, a well maintained and managed field is expected to achieve an on-farm irrigation efficiency between 50 and 85% for surface irrigated systems, assuming salinity is not a problem or water for leaching is negligible. IID's 10-year average on-farm efficiency was calculated to be 83%, which compares favorably within the expected range of on-farm system efficiencies as cited in the literature.

A survey of on-farm irrigation efficiencies of irrigation districts in the Lower Colorado River area, including IID, in the late 1970s revealed efficiencies ranging from 32 to 78%. Of the eleven irrigation districts that were compared, the on-farm irrigation efficiency of IID was the highest at 78%, topping all the irrigation districts in the list. Likewise, the overall irrigation district efficiency ranged from a low of 29% to a high of 70%. Again, of the eleven irrigation districts, the district wide irrigation efficiency of IID was the highest at 70%.

The CDWR has a similar way of quantifying on-farm irrigation efficiency as used in this study. One of its goals is to help improve the performance of on-farm irrigation systems throughout California. The CDWR has an assumed on-farm application efficiency of 73% expected by the year 2020, averaged across crop types, irrigation systems, and management practices (CDWR, 1998). The CDWR assumed efficiency could reach 80% with improved irrigation management and irrigation equipment. With regard to the 83% on-farm application efficiency determined in this study, IID, as of 1997, had already surpassed the CDWR's assumed efficiency expected by the year 2020. In other words, if IID's present on-farm efficiency were to remain stagnant with no improvement for the next twenty years or more, it will still more than satisfy the expected efficiency of CDWR. Hence, the present on-farm water use by IID is reasonable and beneficial.

IID's overall irrigation system efficiency was estimated to be about 74%. The overall irrigation efficiency is equivalent to the product of distribution and on-farm irrigation system efficiencies. Since both the distribution and on-farm irrigation efficiencies are reasonable and the water use is beneficial, the district-wide overall system efficiency, and thus the overall water use in IID, is reasonable and beneficial.

When one considers the problems that both IID and its water users continue to face in distributing the irrigation water and using water at the farm level, it is indeed admirable that both the distribution and on-farm efficiencies are high and that the water use is reasonable and beneficial. Based on the recorded water uses between 1988 and 1997, and given the potential problems of mismatch between water demand by the growers and available water supply, attaining an 89% distribution efficiency displays that operators of the IID system have indeed nearly perfected the operation of the system due to their experience providing irrigation water service to their customers over the last 100 years. The difficulty of this is truly realized when one considers that the single water source is 400 miles away from the average farm and the water is ordered up to 11 days before it is used. Presently, the farmers have flexibility over the amount of water they can order and give IID only less than a day to three days advance notice of their order. These factors are compounded by the fact that there is only one water supply source such that in the event IID's water order is lower than that of the farmers, there is no back-up or supplemental water to make up for the water shortage.

Likewise, even though the overwhelming majority of the soils in IID are heavy and cracking, which make it difficult to apply enough water to satisfy crop water requirements and leach excess salts from the root zone, the IID growers attained an irrigation efficiency much higher than the irrigation efficiency goal set by the CDWR for the year 2020. Achieving a high irrigation efficiency in IID is, however, associated with some reductions in crop yields. Studies have shown that a large portion of IID's irrigated lands suffer from a very high salinity content in the soil root zone. In essence, both the tight nature of most of the irrigated soils and the high salinity content of the water limit the available soil moisture available to the crops. Under such conditions, the grower's logical response would be to apply more water to make up for the deficiency of soil moisture in the root zone in order to attain vigorous plant growth, therefore resulting in higher yields, and consequently higher profits. However, the option of applying additional water to increase the growers' crop yields is generally not a welcome solution. Applying additional water on the medium to heavy cracking soils could potentially bring the amount of tailwater above the 15% threshold. Hence, although IID growers could use more water and still maintain a higher irrigation efficiency than the assumed CDWR goal for 2020, the IID growers have chosen to optimize the resources available to them by agreeing to use less water, which results in lower yields but allows the farmers to adhere to the tailwater threshold limit and stay competitive in the market place with profitable farm enterprises. In conclusion, the water use in IID is indeed reasonable and beneficial, even if the farmers were to use more water than the amount that they are presently using.

In addition to the reasonable and beneficial use test of IID water use, the impact on the other water right holders that would occur if 200,000 acre-feet per year of IID's Colorado River conserved water was transferred via the Colorado River Aqueduct to SDCWA was assessed. Such a transfer of water would result in an average daily flow reduction of 277 cfs in the Colorado River below Parker Dam. NRCE performed a thorough flow accounting analysis based on the historical flow and diversion records (1988-1997) and evaluated the effects of flow reduction on the adequacy of flows and hydraulics of the diversion structures. The results of the flow adequacy and hydraulic analysis revealed no impact on the other water right holders along the Colorado River.

REFERENCE:

California Department of Water Resources. (1998). *The California Water Plan Update Bulletin 160-98 Volume 2.* Department of Water Resources, State of California, Sacramento, California, p.6-12.

Insert 3 oversized maps here

NRCE

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Civil, Environmental, and Water Resources Consultants

APPENDICES FOR THE ASSESSMENT OF IMPERIAL IRRIGATION DISTRICT'S REASONABLE AND BENEFICIAL USE OF WATER

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March 2002

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APPENDIX 1

Natural Resources Consulting Engineers, Inc.
Background Information

1. NATURAL RESOURCE CONSULTING ENGINEERS

A. Introduction

Natural Resources Consulting Engineers, Inc. (NRCE) is a civil, environmental, and water resources consulting firm that provides a wide variety of professional services. Dr. Woldezion Mesghinna formed NRCE in 1989 after seventeen years of domestic and international experience. NRCE is comprised of technical professionals highly experienced in diverse areas of science and engineering. While our expertise has historically focused on water resources, we also support a wide variety of related disciplines with specialized skills in addressing environmentally related business concerns.

NRCE is engaged in all levels of project development, management, and design, from preliminary data collection to construction management, and all services are customized to meet client demands ranging from appraisal-level feasibility studies to detailed engineering design reports, investigations, and expert witness testimony. NRCE has a successful history working on high profile, diverse, and complex projects. Areas of expertise include evaluation and water rights quantification of groundwater and surface water resources, assessing water use irrigation and drainage design, and the analysis of environmental impacts.

NRCE utilizes Computer-Aided Drafting (CAD) and a Geographic Information System (GIS) to produce professional plans, maps, and decision support information. The company has both acquired and developed a variety of sophisticated computer models used for hydrologic and hydraulic modeling, groundwater analysis, and system design.

B. Technical Services

1. *Irrigation and Drainage Design Management*

NRCE staff members possess a high level of expertise in irrigation and drainage design and management. We perform engineering services related to:

- Soil Survey and Land Classification Evaluations
- Climate-Soil-Crop-Water Interaction Studies
- Quantifying Irrigation Diversion Requirements
- Irrigation Scheduling and Crop-Yield Modeling
- Salinity Effects on Crop Water Use and Crop Yield
- Gravity, Sprinkler, and Drip Irrigation Systems
- Surface and Subsurface Drainage Systems
- Design of Conveyance and Distribution Systems
- Canal System Operation and Management Studies
- Irrigation Project Feasibility and Improvement Studies
- Water Use Estimation

2. *Water Resources Evaluation*

NRCE provides surface and subsurface hydrologic evaluation for design, construction, operation, and litigation purposes.

- Data Collection Network Design and Installation
- Climatic and Streamflow Depletion and Natural Flow Analysis
- Watershed Runoff and Streamflow Modeling
- Prediction of Stream Flows for Ungaged Sites
- Flood and Drought Frequency Analysis
- Groundwater Yield Evaluation and Well Design
- Groundwater Quality and Seepage Analysis
- Water Supply System Analysis

3. *Water Quality and Environmental Studies*

Many water resource issues involve water quality and environmental components. NRCE's environmental engineers and scientists perform water quality and environmental assessments including:

- Water Quality Data Collection and Analysis
- Surface Water Flow and Contaminant Transport Modeling
- Groundwater Flow and Contaminant Transport Modeling
- Stormwater Management and Drainage Studies
- Engineering and Design Services Related to Waste Permitting
- Project Management for Treatment and Monitoring Programs
- Water and Wastewater Treatment and Design
- Remediation Plans
- Stream and Lake Quality Studies

4. *Hydraulic Design and Study*

NRCE provides complete analytical and design services for conveyance structures, dams, reservoirs, and water supply and drainage systems.

- Conveyance System Evaluation and Design
- Steady and Unsteady Flow Analysis
- PMF Estimate and Dambreak Analysis
- Reservoir Routing and Operation Analysis
- Floodplain Delineation and Management
- Hydropower Hydraulic Design and Evaluation
- Dam, Reservoir, and Ancillary Structure Design
- Flood Control Structure Design
- Groundwater Well Location and Network Design

5. *Numerical and Computer Model Studies*

NRCE scientists and engineers have extensive numerical and computer modeling experience in civil, water resources, and environmental engineering. These include surface water models such as HEC-1 through HEC-6, groundwater flow and contaminant transport models Sutra, ModFlow, HST3D, as well as custom designed models for specific detailed analysis.

- Hydrological and Hydraulic Routing
- Streamflow and Reservoir Routing
- Sediment Transport, Scour, and Deposition
- Surface Water Flow and Contaminant Transport
- Groundwater Flow and Contaminant Transport
- Reservoir System Operation and Optimization
- Optimal Water Resources Allocation Models

6. *Construction Management*

NRCE assists clients in contractor selection, construction monitoring, preparation of as-built reports and operation manuals, and compliance with regulatory requirements.

- Construction Management and Inspections
- Project Management and Supervision
- Bid Advertisements, Evaluation, and Award
- Construction Observation and Monitoring
- Progress Reporting and As-built Reporting
- Operation and Management Manual Preparation

NRCE realizes that determining the site-specific aspects of a particular reclamation/remediation project are critical to developing the most technically feasible and cost-effective design. Site-specific aspects include geology, topography, climate, drainage, surface and groundwater hydrology, regional water resources, water quality, public opinion, regulatory climate, and cost.

C. NRCE Facilities

Administration and engineering analyses can be coordinated and conducted at all of the following NRCE locations:

Colorado Office
131 Lincoln Ave., Ste. 300
Fort Collins, CO 80524
(970) 224-1851

California Office
1250 Addison St., Ste. 204
Berkeley, CA 94702
(510) 841-7814

Albuquerque Office
317 Commercial Street NE, Suite 102
Albuquerque, NM 87102
(505) 244-1588

East Africa Office
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NRCE's Geographic Information System (GIS) and Computer-Aided Drafting (CAD) department produces professional plans, maps, and decision support information, as well as data transfer, relational database management, map overlay, display query, interactive graphics editing, and customized maps for engineering design and support. The CAD system utilizes AutoCAD Release 14. ArcView 3.0 GIS, including the ArcView Spatial Analyst, is used for vector, raster, and grid based data analysis. ArcCAD GIS, running within the AutoCAD environment, is used to create and analyze a wide variety of vector-based data and to create presentation maps for these coverages. ArcView and ArcCAD both use the ARCINFO data format and can directly transfer between versions of PC, NT, and Unix ARCINFO. GIS integrates the graphical data in a relational database environment and provides professionals with automated floodplain maps, water resource maps, base maps, land use maps, litigation maps, design drawings, planning and decision support maps, as well as customized information. The GIS department provides a full range of graphical and non-graphical information for precision engineering, design, planning, and evaluation.

The NRCE software library contains a broad range of application packages. The staff has extensive programming skills and capabilities to custom design or adapt commercially available or public domain computer programs. Well-tested software packages that meet industry standards and testing requirements have been purchased. In addition to various spreadsheets, communications, database, graphics, and word processing software, software and computer aided design packages developed or employed by NRCE by category include:

1. **Hydrologic and Hydraulic**
    a. Army Corps HEC-1 (Flood hydrograph package)
    b. Army Corps HEC-2 (Water surface profile)
    c. Army Corps HEC-3 (Reservoir system analysis for conservation)
    d. Army Corps HEC-4 (Monthly streamflow simulation)
    e. Army Corps HEC-5 (Simulation of flood control and conservation system)
    f. Army Corps HEC-6 (Sediment transport model)
    g. Army Corps COED (Corps of Engineers Editor)
    h. Army Corps HECDDS (Data storage system)
    i. Multiple Linear Regression Program
    j. Soil Conservation Service TR-20 Project Formulation, Hydrology
    k. Drainage basin depletion and virgin flow analysis
    l. Reservoir operations analysis and design
    m. Pipe network design (Hardy-Cross)
    n. Dam Operation and Hydropower Generation Optimization

2. **Groundwater Analysis**
    a. Well field design and simulation
    b. Pump test analysis
    c. Conjunctive use modeling
    d. MODFLOW regional groundwater flow model
    e. SUTRA groundwater contaminant transport model

3. **Agricultural System Design**
   a. Drainage spacing and design
   b. Irrigation system design
   c. Crop yield prediction
   d. Crop consumptive use
   e. Canal seepage analysis
   f. Pipeline network design (optimization approach)

NRCE possesses both streamflow and climatic data for seventeen western states. The data are from Earthinfo Inc., and utilize CD-ROM technology. With "Hydrodata", NRCE has access to U.S. Geological Survey (USGS) daily flow and water quality data, as well as annual peak flow data for all USGS gages in the seventeen western states. "Climatedata" allows access to maximum and minimum temperature, evaporation, and snowfall on a daily basis, and precipitation on both a daily and hourly basis for all stations and years computerized by the National Climatic Data Center.

NRCE is a member of the National Association for Water Data Exchange (NAWDEX) and subscribes to the Water Data Storage and Retrieval System (WATSTORE) maintained by the USGS. The firm also has access to and use of the services provided by the Environmental Protection Agency (EPA) through their STORET database.

Complete drafting facilities and libraries are maintained in Fort Collins and in Berkeley. The Berkeley office is close to the Water Resources Center Archives and other library facilities available at the University of California, Berkeley. It is also close to the USGS, Earth Resource Library in Menlo Park, further expanding the research capabilities of NRCE staff members. The Fort Collins office is in close proximity to Colorado State University, which maintains a federal repository, as well as special water resources collections.

NRCE TECHNICAL PERSONNEL

Name	Degree			Major	Professional Registration	Years of Experience
	Ph.D.	M.S./ M.E.	B.S./ B.A.		P.E./ P.G.	Experience
Mesghinna, Woldezion	✓			Irrigation & Drainage Engineering		
		✓	✓	Civil Engineering	✓	31
Safadi, Assad	✓			Agricultural & Irrigation Engineering		
		✓	✓	Soils and Irrigation		18
Hamai, Paul		✓	✓	Civil Engineering	✓	13
Allen, L. Niel	✓			Civil Engineering		
		✓	✓	Agricultural & Irrigation Engineering	✓	24
Babic, Marijan	✓	✓	✓	Civil Engineering	✓	19
Hanlin, Todd		✓	✓	Civil Engineering	✓	18
Laing, David			✓	Civil Engineering		15
Leutheuser, Rob			✓	Resource Management		31
Crouch, Thomas			✓	Geology		39
Al-Hassan, Ayman		✓	✓	Chemical Engineering		23
Wessman, Eric			✓	Agricultural Engineering	✓	
			✓	Range Land Management		18
Tzou, Chung-Te	✓			Agricultural & Biosystems Engineering		
		✓	✓	Irrigation Engineering	T	19
			✓	Physics	✓	
Myer, David Kyle		✓	✓	Civil Engineering		8

Carney, Matthew		✓	✓	Civil Engineering	✓	10
Shannon, Ted		✓	✓	Civil Engineering		7
Woodard, Laura		✓		Geology		
			✓	Geology, minor in Environmental Science and Policy		7
Debretsion, Yohannes			✓	Agricultural Engineering		19
Eshun, John		✓		Irrigation Engineering		
			✓	Agricultural Engineering		16
Hillard, Ulysses		✓	✓	Civil Engineering		9
Murdock, Daniel			✓	Biological and Irrigation Engineering		6
Scott, Kelly			✓	Biological and Irrigation Engineering		6
Galyon, Jamie			✓	Civil Engineering		2
Macan, Randy			A.A.S	Drafting and Design Technology		16
Detjens, Jay			✓	Resource Conservation (Forestry)		7
Copfer, Torrey			✓	Hydrogeology Engineering		5
Morway, Eric			✓	Civil Engineering		2
Root, Sarah				Civil Engineering, Expected Graduation May 2002		
Nemariam, Hiwot				Senior Status, School of Chemistry		11
Besanceney, Kristen			✓	Environmental Studies (Natural Resource Management)		6
Fischer, Amber			✓	Psychology		5

APPENDIX 2

The Lower Colorado River

2. THE LOWER COLORADO RIVER

The Colorado River originates in northern Colorado, with its headwaters located in the western part of Rocky Mountain National Park. The river is joined by several major tributaries, including the Green River, which originates in the Wind River Mountains of Wyoming. The Colorado River Basin encompasses portions of seven Western states: Colorado, Wyoming, Utah, New Mexico, Nevada, Arizona, and California. Spring runoff generally begins in April and continues until the month of July.

Just below Lake Mead, the Colorado River forms the boundary between Nevada and Arizona, and further downstream it serves as the boundary between California and Arizona. The Colorado River then enters Mexico just downstream of Yuma, Arizona. After crossing portions of Mexico, it finally empties into the Gulf of Mexico.

There are three major facilities that store and regulate flows on the Lower Colorado River: Hoover, Davis, and Parker Dams. They are located entirely within Nevada, Arizona, and California. Prior to the construction of the first dam, the Colorado River flowed wildly and changed course frequently, and the flood plains of the lower Colorado River were subject to fierce floods. These floods reached flow levels above 200,000 cubic feet per second (cfs) in the years of 1862, 1884, and 1921, while flood flows over 100,000 cfs were common, occurring approximately every other year (USGS, 1955). In fact, due to abnormally high flows received from the Gila River, the Colorado River's course was so drastically changed that it emptied into the Imperial Valley during the period 1905 to 1907. It was from this enormous flood that the Salton Sea was created.

The long-term average natural flow, or undepleted flow, represents the state of the river flow prior to man's water use. The estimated natural flow of the Colorado River at Lee's Ferry, is about 15.2 million acre-feet per year, according to the United States Bureau of Reclamation (USBR, 2000). The annual natural flow ranges from 5 million acre-feet in 1977 to 24 million acre-feet in 1983. As most of the river watershed is located in the arid and semi-arid regions, the flow of the Colorado River varies significantly from year to year. The entire Colorado River Basin area is about 242,000 square miles, with the unit runoff for the entire area being 1.1 inch per unit area. Most of the river flow is generated at the headwaters of the basin, where an average of more than 40 inches of precipitation occurs annually. Lower areas of the basin receive less than an average of 5 inches per year of precipitation.

Historical flow data demonstrates that prior to the construction of major dams and reservoirs, destructive floods of high magnitude occurred frequently. In the early 1930s, the U.S. government began constructing major dam and storage facilities, the first being Hoover Dam which thereby created Lake Mead. After completing this project in 1935, the regulation of the Colorado River was greatly enhanced. Once Hoover Dam was put into operation, the most devastating floods were controlled and the peak release annual discharge did not exceed 40,000 cfs. The effects of Hoover Dam on the annual average flows of the Colorado River near Topock, Arizona (USGS gage # 0942400) are illustrated in Figure 1. The average flow became 9.2 million acre-feet per year, from 1935 through 1981. The storage capacity of Lake Mead at the time of Hoover Dam's completion was about 30 million acre-feet.

Colorado River near Topock, Arizona (USGS gage #09424000)

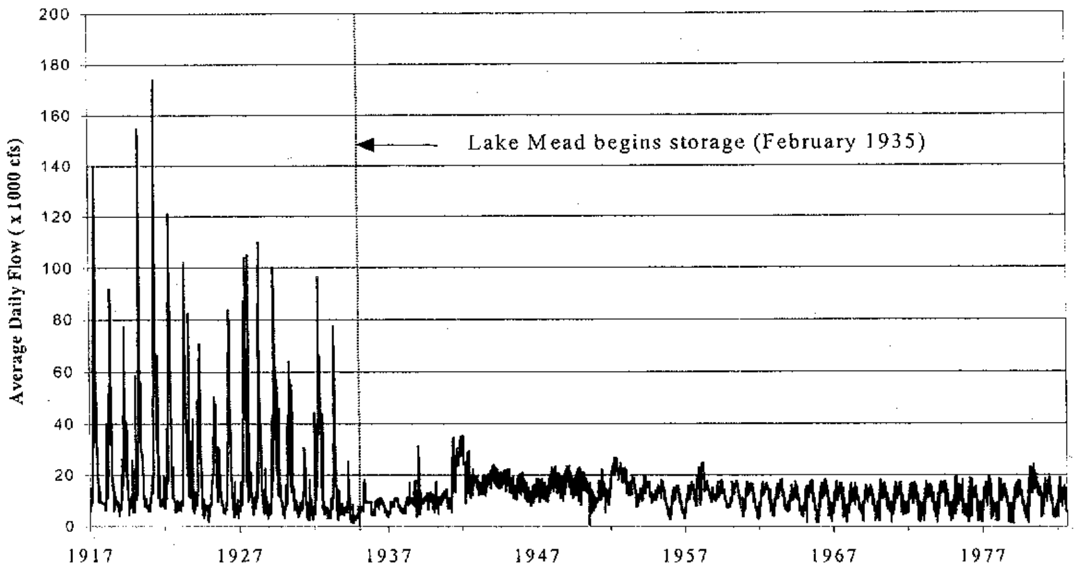


Figure 1 The Effects of Hoover Dam on the Annual Average Flows of the Colorado River Near Topock, AZ.

Prior to the construction of Hoover Dam, the Colorado River's average flow varied substantially both from month to month and from year to year. After Hoover Dam was built, the variation in monthly river flows became relatively constant from year to year. By storing high spring flows, it became possible to supply irrigation water to the large irrigation districts as well as municipal water to millions of people in southern California and central Arizona.

Parker Dam was built in 1938 and further increased control of the river. Once constructed, these two dams provided a relatively assured water supply and greatly limited damage from flooding. However, there are very few tributaries that contribute significant, unregulated flow. The Bill Williams River, with its very erratic flow regime, enters the Colorado River at Lake Havasu, and the Gila River, which drains large portions of Arizona joins the Colorado River close to Yuma, Arizona.

In between Hoover Dam and Parker Dam is the third major structure built on the lower Colorado River: the Davis Dam, which formed Lake Mohave. This dam controls the flow of the Colorado River's main stem and is used to re-regulate the flows released from Lake Mead and provide sufficient head for hydropower production at the Davis Power Plant. Moving further downstream from the Davis Dam is Lake Havasu, created by Parker Dam. In addition to flood control, Lake Havasu acts as the forebay for the Central Arizona Aqueduct and the Colorado River Aqueduct, which is owned and operated by the Metropolitan Water District of Southern California.

Together the three reservoirs have a usable storage capacity of about 28.6 million acre-feet. The total usable storage in the Lower Basin states of California, Arizona, and Nevada provides an equivalent of a two-year undepleted flow of the Colorado River. The water supply for IID, the other irrigation districts in Arizona and California, and the required water releases for Mexico and power generation are primarily dependent on the availability of storage in those Lower Basin reservoirs. Given the very high variability of the Colorado River flow from year to year, the nearly 29 million usable storage capacity available for the Lower Basin water users is relatively self-assuring.

In addition to the three major storage reservoirs on the main stem of the lower Colorado River, there are a number of diversion dams that exist mainly to divert water to irrigation districts in Arizona, California, and Mexico. Among the primary diversion facilities downstream of Parker Dam are: Head Gate Rock Dam, which controls and diverts water for the Colorado River Indian Reservation Irrigation Project (Arizona); Palo Verde Diversion Dam, which controls and diverts water for the Palo Verde Irrigation District (California); and Imperial Dam, which serves water users in Yuma, Arizona; Mexico; IID; and Coachella Valley Water District of California. It should be noted that IID was diverting water to irrigate hundreds of thousands of acres of land prior to the construction of the major dams on the Lower Colorado River.

APPENDIX 3

IID's Water Rights on the Colorado River

3. IID'S WATER RIGHTS ON THE COLORADO RIVER

IID was organized under the California Irrigation District Act in July 1911. The District was organized by acquiring the rights and properties of the California Development Company and its subsidiary Mexican company. During the early 1900s no major dams or reservoirs existed; therefore, water users were primarily dependent on the unregulated seasonal flows of the Colorado River and its tributaries.

In the early 1900s, the current federal laws governing water rights of the Colorado River were not yet in place. In fact, there was no regional or interstate water rights compact apportioning the Colorado River. The basic water rights laws of that time were doctrines of prior appropriations applicable within a given state. Because of this, it became prudent for both the Upper and Lower Basin states to apportion the Colorado River water through an interstate compact. The four Upper Basin states, Colorado, Wyoming, New Mexico, and Utah, and the three Lower Basin states, Nevada, Arizona, and California, signed what is known as the Colorado River Compact of 1922. The fundamental principle of the Compact is that the upper and Lower Colorado River states equally apportion water rights such that each side receives an exclusive beneficial use of 7.5 million acre-feet of consumptive use per year in perpetuity. The dividing line for the Colorado River between the Upper and Lower Basin states is Lee's Ferry. The U.S. government, through the Boulder Canyon Project Act, also required that California pass an act limiting itself to 4.4 million acre-feet per year consumptive use. In addition to the 4.4 million acre-feet, California had the right to use up to one half of the unappropriated surplus flow. Within seven years after the Upper and Lower states signed the Colorado River apportionment Compact, the state of California passed the required act, limiting its apportioned use to 4.4 million acre-feet. In 1944, the United States and the Republic of Mexico signed a treaty for Mexico to receive 1.5 million acre-feet of Colorado River water per annum.

The construction of major facilities, including Hoover Dam, its associated hydro-power plant, and the All American Canal, were authorized as part of the Boulder Canyon Project Act passed by Congress in December of 1928. The Boulder Canyon Project Act also required the Lower Basin states to enter into water delivery contracts with the U.S. Secretary of the Interior. As part of the Act, California would receive 4.4 million acre-feet of water per year of the total amount of water apportioned to the Lower Basin states, plus one half of the excess water agreed by the Lower Basin states. Arizona would receive 2.8 million acre-feet of water, plus one half of the surplus water as determined by the Lower states, and Nevada would receive 300,000 acre-feet annually. Even though the states never reached a final agreement on the proposed apportionment, in 1964 the U.S. Supreme Court decided in the case of Arizona v. California that the Boulder Canyon Project Act authorized the Secretary of the Interior to deliver water in accordance to the apportionment. In essence, there was no need for the Lower Basin states to agree on the proposed apportionment of their 7.5 million acre-feet of the Colorado River water, since Congress had done it for them.

The Secretary of the Interior requested California to further apportion its 4.4 million acre-feet among its water users. In 1931, in response to the Secretary's request, a Seven-Party Agreement to apportion and prioritize their water rights was created. The signatories to the California Seven-party Agreement are:

1. Palo Verde Irrigation District
2. Yuma Project
3. Imperial Irrigation District
4. Coachella Valley County Water District
5. Metropolitan Water District
6. City of San Diego
7. County of San Diego

Table 1 depicts the water apportionment and priorities of the 1931 California Seven-party Agreement. As shown in Table 1, the irrigation districts receive the first 3.85 million acre-feet, as well as use of water for an additional 16,000 acres. (Coachella later subordinated its Priority 3 right to IID in a compromise agreement.) If one adds the next apportionment by priority, the 550,000 acre-feet belonging to the Metropolitan Water District, the total California apportionment of 4.4 million acre-feet per year will be utilized. In other words, if California were to abide by the 4.4 million acre-feet apportioned to it as part of the Boulder Canyon Project Act of 1928, the only recipients of water would be the four agricultural users and the Metropolitan Water District of Southern California (and the latter would only be able to fill half the capacity in its Colorado River Aqueduct).

Table 1 Priority Established by the California Seven-Party Agreement for Water Apportionment.

Priority	Description	Acre-feet per year
1	Palo Verde Irrigation District gross area of 104,500 acres	3,850,00
2	Yuma Project not exceeding a gross area of 25,000 acres	
3(a)	IID and lands in Imperial and Coachella Valleys to be served by the All-American Canal	
3(b)	Palo Verde Irrigation District 16,000 acres of mesa lands	
4	MWD and/or the City of Los Angeles and/or others on the coastal plain	550,000
5(a)	MWD and/or the City of Los Angeles and/or others on the coastal plain	550,000
5(b)	City and/or County of San Diego	112,000
6(a)	IID and lands in Imperial and Cachella Valleys	300,000
6(b)	Palo Verde Irrigation District 16,000 acres of mesa lands	
7	Agricultural Use	All remaining water

In 1979, IID had a "perfected" right confirmed amounting to 2.6 million acre-feet annually by a supplemental decree in the *Arizona v. California* case. This perfected right is a state water right, estimated based on the lands that were actively irrigated in the year 1929. The 2.6 million acre-feet is commensurate with the lands that were actually receiving irrigation water in IID as of June 25, 1929, which amounts to 424,145 acres. The essence of the present perfected right is that during water shortages the water rights that should be satisfied first are the perfected rights. Thereby, the perfected water rights of IID are not subject to U. S. Department of Interior limitations. The perfected right is not a limitation on IID's usage, but is simply a priority right granted over other non-perfected users.

In addition to the Indian Reservations in the Lower Basin that have present perfected rights, the Palo Verde Irrigation District has a perfected right of 219,780 acre-feet annually to satisfy the consumptive use for 33,604 acres. Likewise, the Yuma Project has a perfected right to 38,270 acre-feet per year to supply the consumptive use of 6,294 acres of irrigated land.

APPENDIX 4

CIMIS Data

4. CIMIS DATA

The three California Irrigation Management Information System (CIMIS) weather stations in IID are Calipatria/Mulberry (#41), Seeley (#68), and Meloland (#87). They are shown in Figure 1 along with the shaded areas indicating the region each of the stations represents. The stations are located in or near an irrigated environment with a well-maintained grass pasture. Their installation dates, latitudes, longitudes, and elevations are as follows:

Station	Begin Date	Latitude (°)	Longitude (°)	Elevation (ft)
Calipatria/Mulberry	7/17/1983	33.04 N	115.5 W	-110
Seeley	5/29/1987	32.76 N	115.7 W	40
Meloland	12/12/1989	32.81 N	115.4 W	-40

The weather data from the CIMIS stations may be downloaded on-demand electronically by users over telephone lines. The stations' data loggers store in memory hourly weather parameters of solar radiation, air temperature, relative humidity, wind speed and direction, and precipitation after they have averaged the minute-to-minute measurements. The collected parameters are then used to compute grass reference evapotranspiration (ET_o) on an hourly basis using the CIMIS' version of the Penman equation (Penman, 1948) as modified by Pruitt and Doorenbos (proceeding of the International Round Table Conference on "Evapotranspiration", Budapest, Hungary, 1977). The hourly ET_o values were summed to produce the daily ET_o values reported by CIMIS.

For this study, the daily raw meteorological data from the three CIMIS stations were downloaded directly from the web site of the University of California Statewide Integrated Pest Management (IPM) Project Weather Database at: www.ipm.ucdavis.edu/WEATHER/ wxretrieve.html for the study period of 1988 to 1997. The meteorological data were screened for data quality and were pre-processed by IPM. All of the questionable, flagged, or missing data parameters from CIMIS were replaced with good available data from other nearby CIMIS stations or other weather stations. The filled in data for each of the three CIMIS stations comprised only about 2-3% of the total data.

The average weather parameters collected by the three CIMIS stations for the period 1990 to 1998 are plotted in Figures 2 through 6. The period was selected as 1990 to 1998 because the Meloland Station was installed in December 1989. The plotted weather parameters are average monthly maximum and minimum air temperatures, relative humidity, average solar radiation, average wind speed, and precipitation.

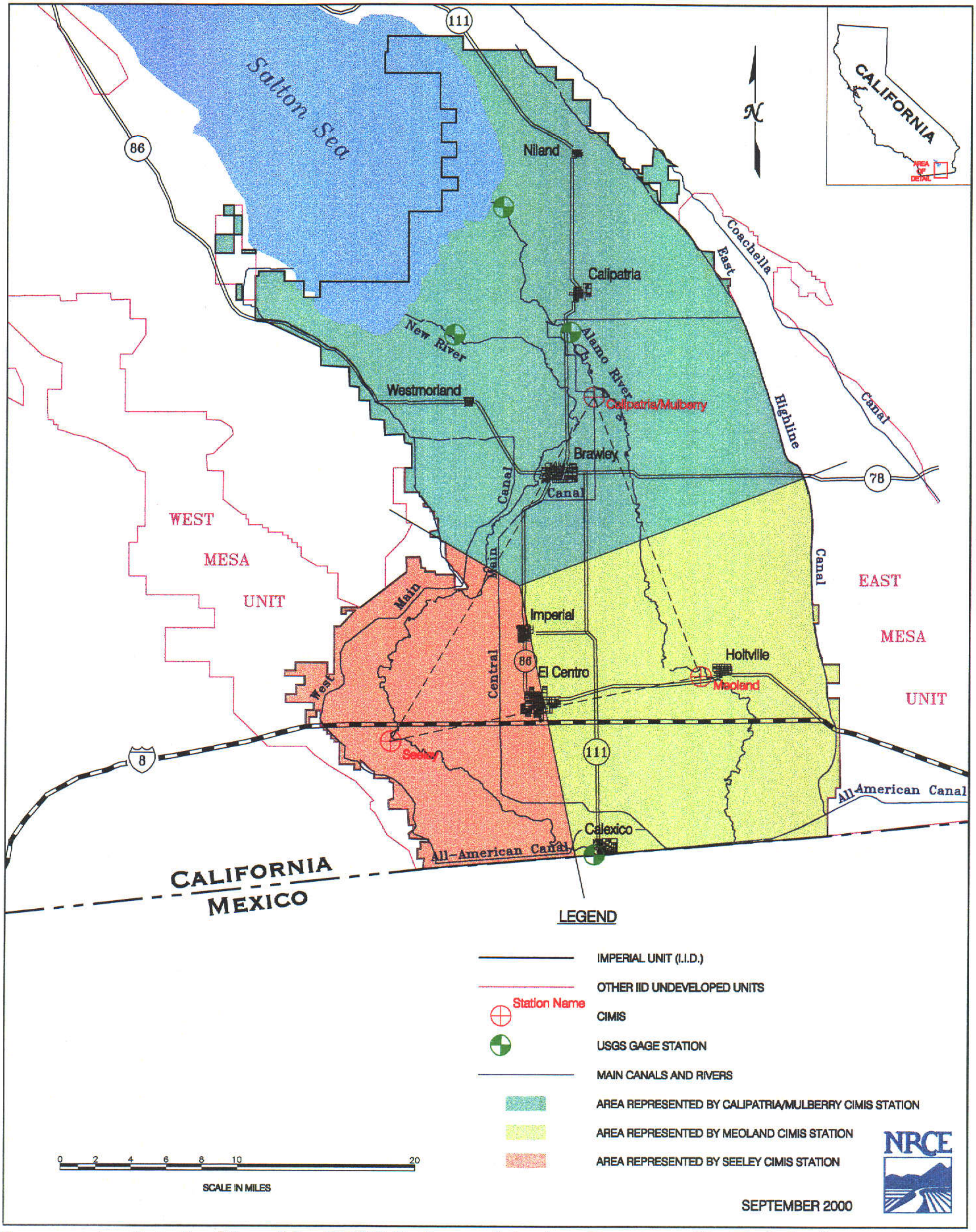


Figure 1 Location Map of the CIMIS Stations and the Area Represented by Each Station as Determined from the Thiessan Polygon Method.

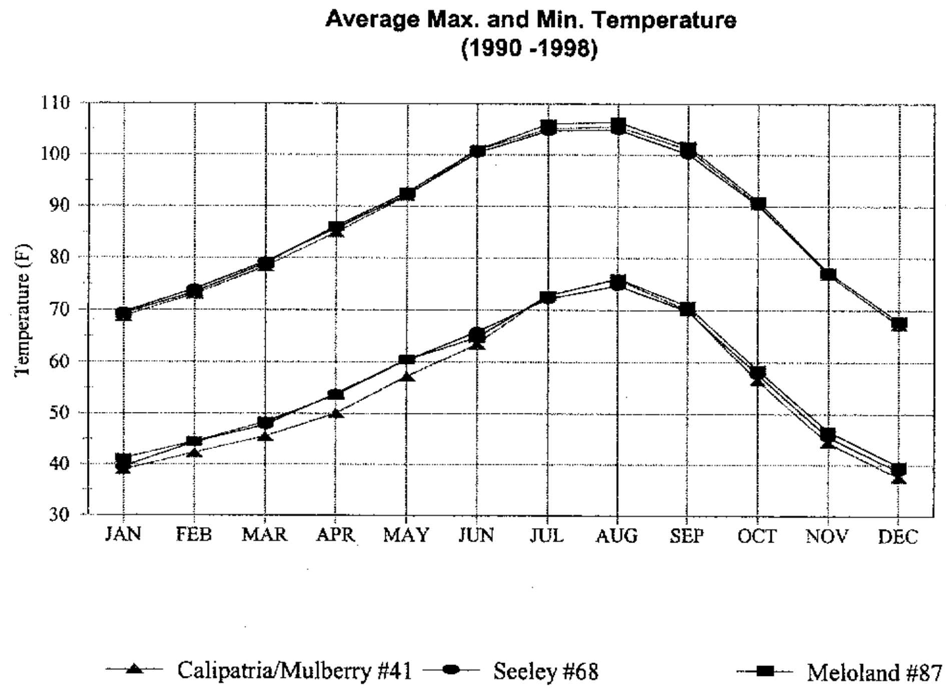


Figure 2 Average Monthly Maximum and Minimum Air Temperatures at the Three CIMIS Stations (1990-1998).

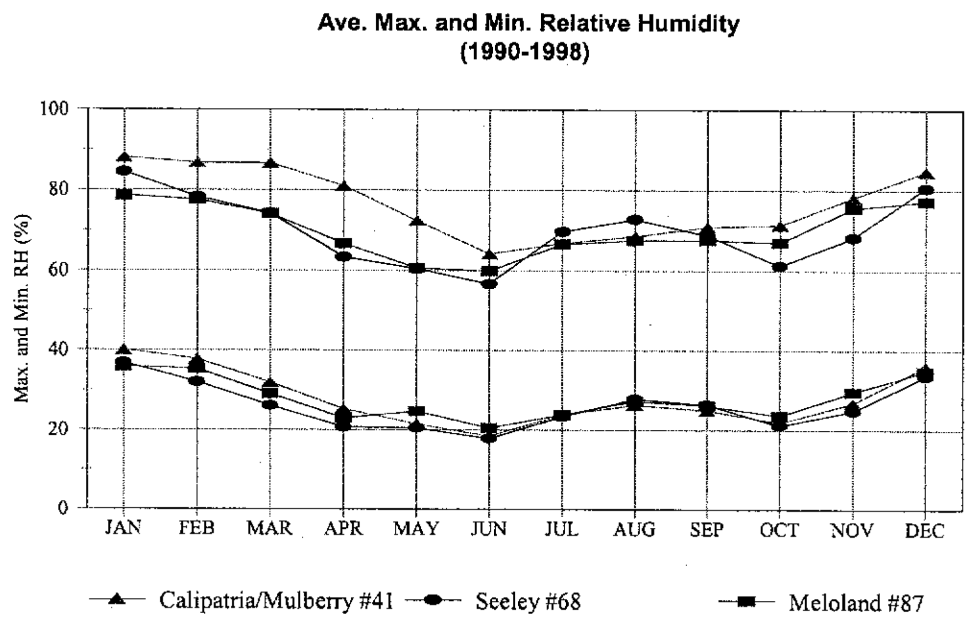


Figure 3 Average Monthly Maximum and Minimum Relative Humidity at the Three CIMIS Stations (1990-1998).

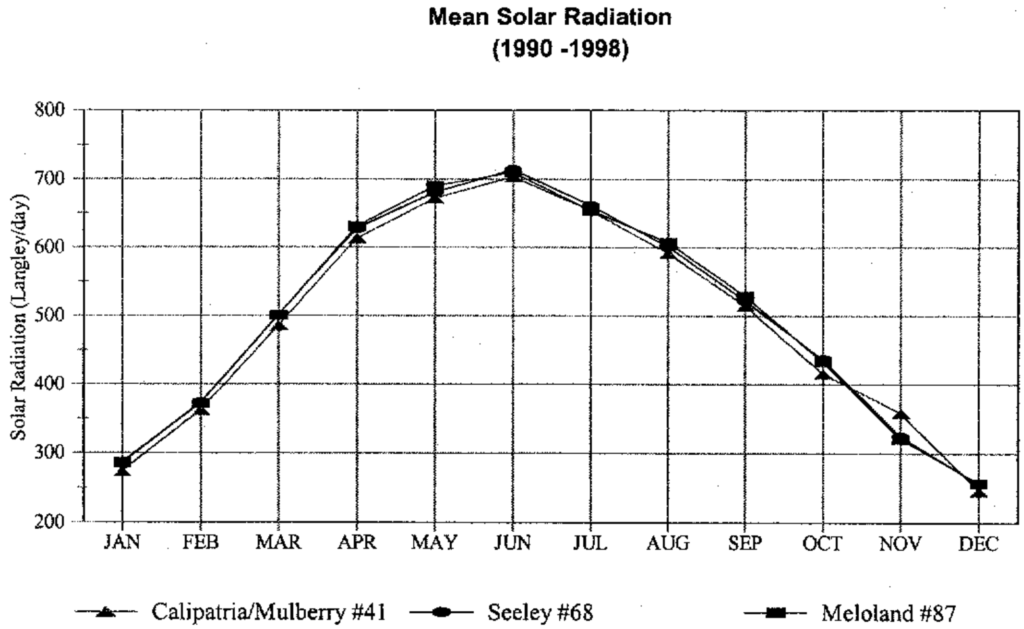


Figure 4 Average Monthly Solar Radiation (Rs) at the Three CIMIS Stations (1990-1998).

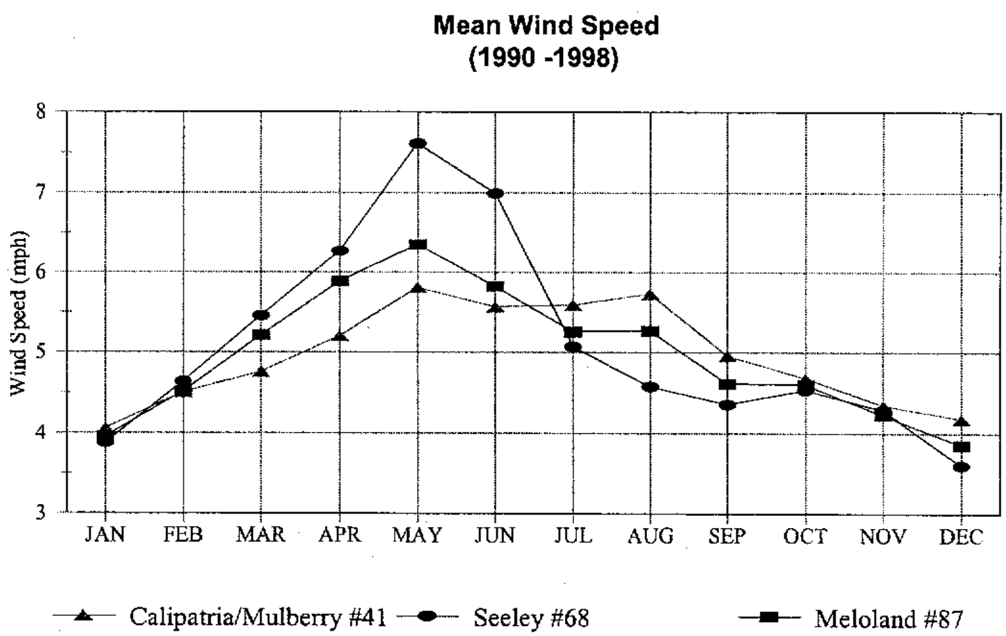


Figure 5 Average Monthly Wind Speed at the Three CIMIS Stations (1990-1998).

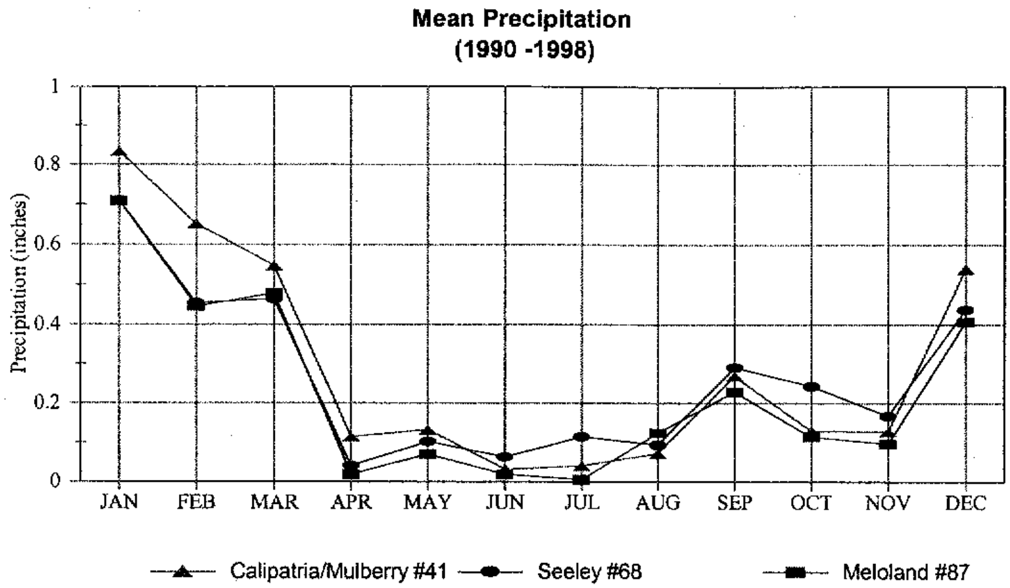


Figure 6 Average Monthly Precipitation at the Three CIMIS Stations (1990-1998).

A. Air Temperature

The average air temperatures for the three CIMIS stations are very close. The Calipatria/Mulberry #41 has a slightly lower minimum air temperature than the other stations by approximately two degrees Fahrenheit between February and June. Meloland #87 experienced the highest average monthly maximum temperatures in the summer months, which reached 106.3°F in August compared to 105.6°F and 104.9°F for Calipatria/Mulberry #41 and Seeley #68, respectively. The mean air temperature within IID is therefore quite uniform.

B. Relative Humidity

CIMIS measures relative humidity on an hourly basis. Daily summaries of maximum and minimum relative humidity (RH) measurements, average 24-hour vapor pressure, and equivalent dew point temperature are reported as well. In an irrigated agricultural setting, maximum RH should approach 100% during early morning hours due to the cooling effect of the night ET from the surrounding irrigated crops and from the effects of radiative cooling of the air during the nighttime. However, in a very arid region such as Imperial Valley, maximum RH should generally reach above 70% almost every night, and frequently approach 100%, especially during winter months and after rain storms.

The RH data from the three CIMIS stations show similar overall seasonal trends. The maximum RH ranges from about 60-85%, which is in agreement with the expected theoretical values described above. Calipatria/Mulberry #41 has a slightly higher average maximum RH of about

10% more than the other two stations from February to June. This also corresponds to higher average minimum air temperatures in the same period at the Calipatria/Mulberry #41 station.

C. Solar Radiation

The solar radiation (Rs) is measured by an instrument called the pyranometer. Errors in the measurements may be introduced occasionally due to the accumulation of dust on the instrument. This would result in a lower solar radiation reading than the true measurement. The solar radiation values for the three stations are close, ranging from an average low of 250 langleys per day in December to a high of about 700 langleys per day in June.

D. Wind Speed

The wind speeds recorded by the three stations show similar trends. The Seeley #68 station has the highest mean monthly wind speed and it has an annual average wind speed of 5.1 mph; its highest average monthly wind speed of 7.6 mph is in May. Calipatria/Mulberry #41 has an annual average wind speed of 5.0 mph and a peak of 5.7 mph. Meloland #87 wind speed also averages 5 mph with a peak average of 6.4 mph.

E. Precipitation

The range of annual precipitation among the three CIMIS sites varies from 2.71 inches to 3.48inches. Meloland #87 has the lowest rainfall at an annual average of 2.71 inches compared to 3.48 inches at Calipatria/Mulberry #41 and 3.17 inches at Seeley #68. Due to the nearness of the stations and the flat topography, the long-term precipitation over the three stations should be similar. However, the timing and magnitude of each of the precipitation events may vary from station to station.

APPENDIX 5

FAO Penman-Monteith Method

5. FAO PENMAN-MONTEITH METHOD

In 1948, Penman combined the energy balance with the mass transfer principles to derive an equation to compute the evaporation from an open water surface from standard climatological data such as solar radiation, temperature, humidity, and wind speed. In later years, this combination method was further developed by researchers to include cropped surfaces by introducing resistance factors. The Food and Agricultural Organization of the United Nations' Penman-Monteith (FAO-PM) method equation was developed to reflect the nature of the aerodynamic resistance and surface resistance in the ET process. FAO-PM methodology also defines a hypothetical reference crop of actively growing and well watered clipped grass assuming a fixed height of 0.12 m (4.7 inches), a surface resistance of 70 s/m, and albedo of 0.23. The FAO-PM equation for determining ET_o may be described as follows:

$$ET_o = \frac{0.408\Delta (Rn - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \quad \textbf{(1)}$$

where,

ET_o	=	reference crop evapotranspiration (mm/day)
Rn	=	net radiation at the crop surface (mega joules (MJ)/m^2/day)
G	=	soil heat flux density (MJ/m^2/day)
T	=	mean daily air temperature at 2 m height (^oC)
u_2	=	wind speed at 2 m height (m/s)
e_s	=	saturation vapour pressure (kilo pascal (kPa))
e_a	=	actual vapour pressure (kPa)
e_s-e_a	=	saturation vapour pressure deficit (kPa)
Δ	=	slope vapour pressure curve (kPa/^oC)
γ	=	psychrometric constant (kPa/^oC)

The four weather parameters required by the FAO-PM equation are solar radiation (Rs), air temperature, air humidity, and wind speed. They are all measured and reported by the CIMIS stations on a daily basis. A computer program called "REF-ET" version 2.15a (Allen, 1994) that computes reference crop evapotranspiration using different ET methods was used to calculate daily ET_o with the FAO-PM equation. The REF-ET program uses the Wright (1982) procedure for calculating net solar radiation (Rn) internally while the FAO-PM method implements a different procedure. Therefore, the net solar radiation (Rn) was externally calculated based on the procedures described in the FAO#56 (Allen et. al., 1998) and then supplied to the REF-ET program as input data.

The daily ET_o values for the three CIMIS station sites (Calipatria/Mulberry (#41), Seeley (#68), and Meloland (#87)) from 1988 to 1997 were calculated using the FAO-PM methodology. Prior to 1990, only Calipatria/Mulberry (#41) and Seeley (#68) were operational. The average monthly FAO-PM ET_o from 1990 to 1997 are shown in Table 1. The total annual ET_o among the three CIMIS stations are very similar with annual ET_o values of 79.19, 79.40, and 78.17 inches for Calipatria/Mulberry (#41), Seeley (#68), and Meloland (#87), respectively.

Table 1 Average Monthly FAO-PM ET_o (inches) at the Three CIMIS Stations (1990-1997).

Month	Calipatria/Mulberry #41	Seeley #68	Meloland #87
January	2.56	2.69	2.65
February	3.21	3.53	3.33
March	5.17	5.64	5.43
April	7.09	7.62	7.49
May	9.43	10.04	9.62
June	10.55	11.10	10.13
July	10.74	10.47	10.44
August	10.27	9.32	9.85
September	8.19	7.34	7.68
October	6.06	5.82	5.78
November	3.56	3.60	3.43
December	2.35	2.22	2.34
Annual	79.19	79.40	78.17

In order to determine an area based-weighted average ET_o for the whole Imperial Valley, the Theissen polygon method was applied. It is based on the assumption that for any portion of the study area, weather conditions are equal to the weather conditions measured at the closest CIMIS weather station. Therefore, the valley is divided into three regions in their respective proportions. The resulting area fraction for each of the CIMIS stations is: 47% for Calipatria/Mulberry(#41), 18% for Seeley(#68), and 35% for Meloland(#87). The weighted average monthly FAO-PM ET_o values for the Imperial Valley are listed in Table 2. In 1988 and 1989, only the ET_o values of Calipatria/Mulberry(#41) and Seeley(#68) were averaged with proportions of 72% and 28%, respectively.

Table 2 Weighted Average Monthly FAO PM ET_o (inches) for the Imperial Valley (1988-1997).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1988	2.93	4.08	6.51	7.03	10.89	10.95	10.79	9.86	8.11	6.20	4.42	3.44	85.21
1989	3.00	3.77	6.52	8.22	11.02	12.27	12.26	10.38	8.98	6.31	3.85	2.68	89.24
1990	2.95	3.49	5.87	7.67	10.92	10.91	11.30	9.27	7.66	5.55	3.89	2.67	82.14
1991	2.31	2.91	4.51	6.52	8.44	8.82	9.49	9.23	7.02	5.83	3.41	1.91	70.40
1992	2.45	3.19	4.22	6.6	8.15	9.69	9.88	9.29	7.12	4.97	3.23	1.91	70.70
1993	1.98	3.07	5.52	6.65	9.03	10.41	10.45	10.27	8.38	6.38	3.49	2.68	78.30
1994	2.84	3.08	5.16	7.41	9.36	10.53	11.30	10.1	8.5	5.98	3.87	1.88	80.00
1995	2.35	3.41	5.57	8.2	9.66	11.04	10.68	10.08	8.88	6.10	3.40	2.27	81.63
1996	3.04	3.48	5.95	8.14	11.48	11.21	10.68	11.23	8.33	6.57	3.76	2.74	86.79
1997	2.99	3.86	5.99	7.42	9.82	11.43	10.73	10.15	7.00	5.97	3.13	2.53	81.00
1988-1997	2.68	3.43	5.58	7.39	9.88	10.73	10.76	9.99	8.00	5.99	3.65	2.47	80.54

A. Comparison of FAO P-M and CIMIS Modified Penman Methodologies

The CIMIS stations estimate the grass ET_o by using a modified FAO version (Pruitt and Doorenbos, 1977) of the Penman equation (Penman, 1948) that implements a wind function developed at the University of California, Davis. The input parameters for the equation are the same as for the FAO-PM equation which are mean solar radiation (Rs) (from which net solar radiation (Rn) is calculated), air temperature, wind speed, and vapor pressure. Air temperature, wind speed, and vapor pressure (derived from air temperature and relative humidity measurements) are measured directly at each CIMIS station. Since 1989, CIMIS has begun calculating net solar radiation rather than measuring it. CIMIS had abandoned the use of net radiometers in their weather station network due to high maintenance costs and reliability. The hourly net radiation (Rn) is estimated from solar radiation (Rs), air temperature, and vapor pressure. Table 3 shows the mean monthly CIMIS ET_o values (1990-1998) from the three CIMIS stations based on the CIMIS Penman method. Table 4 lists the weighted average monthly ET_o (1988-1997) as reported by the three CIMIS stations for the Imperial Valley.

Table 3 Reported Mean Monthly CIMIS Penman ET_o (inches) at the Three CIMIS Stations (1990-1997).

Month	Calipatria/Mulberry #41	Seeley #68	Meloland #87
January	2.26	2.46	2.39
February	3.00	3.38	3.24
March	5.00	5.67	5.46
April	6.93	7.8	7.48
May	8.49	9.47	8.93
June	9.13	10.04	9.17
July	9.21	9.21	9.00
August	8.67	8.15	8.41
September	6.78	6.7	6.74
October	5.16	5.38	5.25
November	3.02	3.29	3.01
December	2.06	1.93	2.13
Annual	69.72	73.47	71.19

Table 4 Weighted Average Monthly CIMIS ET_o (inches) for the Imperial Valley (1988-1997).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1988	3.09	4.19	6.43	6.69	9.81	9.77	9.43	8.98	7.61	5.81	4.38	3.53	79.73
1989	2.90	3.89	6.56	8.11	10.29	10.60	9.85	8.70	7.66	5.27	3.18	2.42	79.43
1990	2.65	3.37	5.67	7.30	9.69	9.29	9.35	8.38	6.57	4.99	3.40	2.31	72.97
1991	2.22	3.1	4.79	6.92	8.51	8.28	8.35	8.20	6.07	5.02	3.28	1.65	66.40
1992	2.24	3.14	4.49	6.80	7.82	9.16	9.03	7.94	6.62	4.55	2.99	1.71	66.50
1993	1.78	2.98	5.32	6.91	8.45	9.51	9.40	8.91	7.28	5.44	3.00	2.34	71.31
1994	2.65	3.05	5.23	7.40	8.64	9.07	9.31	8.39	7.19	5.30	3.29	1.66	71.18
1995	2.07	3.28	5.42	7.89	9.04	9.58	9.31	8.45	7.37	5.40	2.96	1.97	72.75
1996	2.66	3.21	5.81	7.85	10.17	9.66	9.12	9.16	6.99	5.25	3.12	2.42	75.40
1997	2.61	3.67	5.81	7.36	8.75	9.88	9.26	8.58	5.98	5.05	2.75	2.11	71.81
1988-1997	2.49	3.39	5.55	7.32	9.12	9.48	9.24	8.57	6.93	5.21	3.24	2.21	72.75

B. Theory

The following equation is an expression of the CIMIS modified Penman ET_o equation on an hourly basis:

$$ET_o = W\,(Rn) + (1 - W) * VPD * (FU_2) \tag{2}$$

where,

ET_o = Grass reference crop evapotranspiration (mm)
W = Weighting function (dimensionless)

Rn	=	Net radiation (mm)
VPD	=	Vapor pressure deficit (kPa)
FU_2	=	Wind function (mm/kPa)

or

$$ET_o = \frac{\Delta(Rn) + \gamma(FU_2)(e_s - e_a)}{\Delta + \gamma} \quad \textbf{(3)}$$

where,

ET_0	=	reference crop evapotranspiration (mm/day)
Rn	=	net radiation at the crop surface ($MJ/m^2/day$)
FU_2	=	Wind function (mm/kPa)
e_s	=	saturation vapour pressure (kPa)
e_a	=	actual vapour pressure (kPa)
e_s-e_a	=	saturation vapour pressure deficit (kPa)
Δ	=	slope vapour pressure curve ($kPa/^oC$)
γ	=	psychrometric constant ($kPa/^oC$)

Basically, both the FAO-PM (Equation 1) and CIMIS Penman equations (Equations 2 and 3) are derived by applying energy balance with heat and mass transfer principles. These so-called combination equations (i.e., FAO-PM and CIMIS Penman) are all based on the first combination equation procedures developed by Penman (1948). Penman developed an equation to compute evaporation from an open water surface from standard climatic parameters such as solar radiation, temperature, humidity, and wind speed by combining the energy balance with the mass transfer method. Thus, Equations 1 and 3 have very similar mathematical structures; however, the CIMIS Penman is derived using an empirical wind function (FU_2) developed in Davis, California. The FAO-PM equation is developed by integrating concepts of aerodynamics and surface resistance. This derivation is more theoretically based and it replaces the need for an empirically based wind function term. The FAO-PM equation, as shown in Equation 1, is the result of simplifying the Penman-Monteith equation by defining the grass reference crop of fixed height 0.12 m and having a surface resistance of 70 s/m and albedo of 0.23. The FAO-PM methodology also differs from the CIMIS Penman methodology by its procedure for computing net solar radiation (Rn). The FAO-PM methodology adopts a procedure proposed by FAO (Smith et al., 1990; Allen et al., 1994) for calculating Rn on a world wide basis, while the CIMIS Penman's procedure for calculating Rn is based on a modification of the Monteith equation (Monteith, 1980).

C. ET_0 Estimates

Comparisons of the FAO-PM calculated ET_0 and the reported CIMIS Penman ET_0 may be seen in Figures 1 and 2. The monthly ET_0 values are the results of averaging the monthly ET_0 over the period from 1988 to 1997 for the Imperial Valley. In Figure 1, the monthly ET_0 from the two methods are essentially the same for the first four months of the year, then the FAO PM ET_0 begins to rise higher than the CIMIS Penman ET_0 as the year progresses from summer into fall. The largest deviation between the two methods is about 1.5 inches in the month of July. The trends of the annual ET_0 between the two methods from 1988 to 1997 is illustrated in Figure 2. The FAO-PM ET_0 is consistently higher than the CIMIS Penman ET_0 throughout the years. On the average, the annual FAO-PM ET_0 is about 7.8 inches more than (or 11% higher than) the CIMIS Penman ET_0. The graph in Figure 3 shows the ratios of the calculated average monthly FAO-PM ET_0 values to the reported CIMIS ET_0 values. The FAO-PM ET_0 values are about 1% to 17% higher than the CIMIS Penman ET_0 throughout the year. A maximum difference of 17% occurs in July and August.

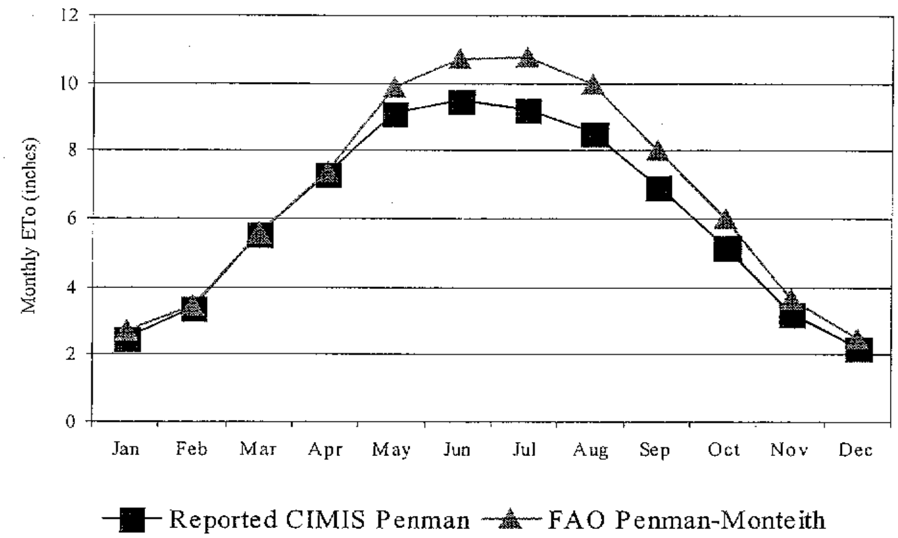


Figure 1 Comparison of Average Monthly ET_0 (inches) between the FAO-PM and CIMIS Penman Method (1988-1997).

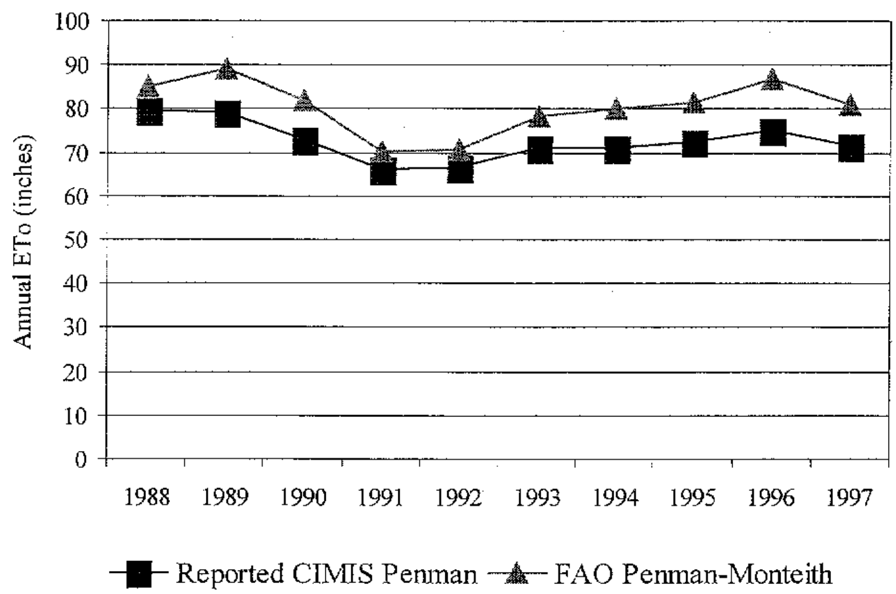


Figure 2 Comparison of Annual ET_0 Between the FAO-PM and the CIMIS Penman Method (1988-1997).

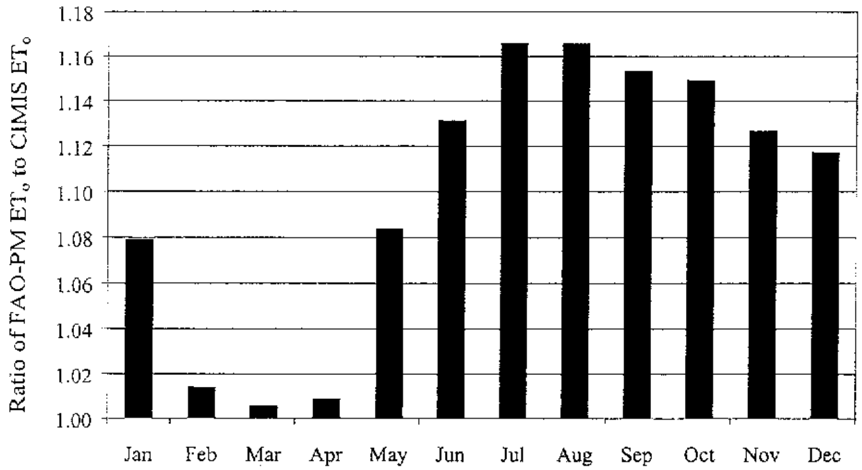


Figure 3 The Average Monthly Ratio of FAO-PM ET_o to CIMIS Penman ET_o (FAO-PM ET_o /CIMIS ET_o) (1988-1997).

REFERENCES:

Allen, R. G. (1994). Reference Evapotranspiration Calculator. Version 2.15a, Department of Biological and Irrigation Engineering, Utah State University, Logan, Utah.

Allen, R. G., Smith, M., Perrier, A., and Pereira, L.S. (1994). "An update for the definition of the reference evapotranspiration." ICID Bull., New Delhi, 43(2), p.1-34.

Monteith, J. L. (1980). "Principles of environmental physics." Edward Arnold Press, Kent, United Kingdom.

Penman, H. L. (1948). "Natural evapotranspiration from open water, bare soil and grass." Proceedings of the Royal Society London, A193, p.120-146.

Pruitt, W. O., and Doorenbos, J. (1977). "Proceedings of the International Round Table Conference on Evapotranspiration", Budapest, Hungary.

APPENDIX 6A

Typical Special Irrigation Practices and Schedules for the Imperial Valley

Typical Special Irrigation Practices and Schedules for the Imperial Valley

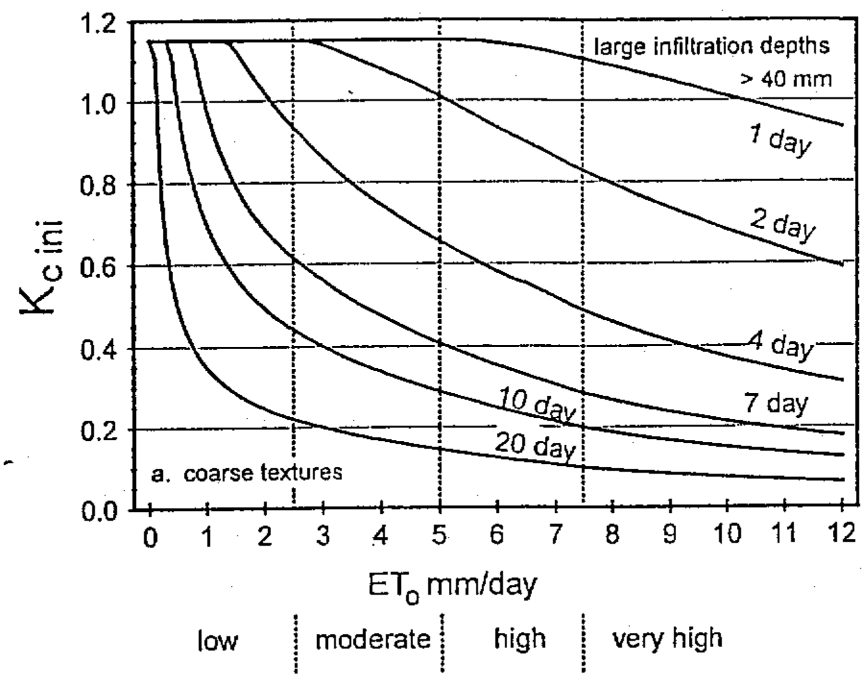
Crop	Special Irrigations	Nos. of Days before Planting	Pre-Plant Water Requirement (inches)	Germination Water Requirement (inches)
Alfalfa (based on 4-yr life)	Pre-plant and stand-establish	---	4.5	
Sudan	Germination	---		6
Bermuda (based on 5-yr life)	Stand-establish	---	6	
Wheat	Pre-plant	30 days	6	
Sugar Beets	Flood, Pre-plant, Germination	40 days, 20 days	6	6.9
Lettuce - Early	Flood, Germination	45 days	12	5.2
Lettuce - Late	Germination	---		5.2
Carrots	Flood, Germination	50 days	24	6.9
Cantaloupes - Spring	Pre-plant, Germination	10 days	12	2.4
Cantaloupes - Fall	Flood, Pre-plant	45 days, 15 days	12	
Cotton (upland and PIMA)	Pre-plant	30 days	6	
Honeydew	Pre-plant, Germination	10 days	12	5.2
Watermelon	Pre-plant, Germination	10 days	12	5.2
Onions	Flood, Furrow, Germination	60 days, 30 days	12	6.9
Onion Seed	Flood, Furrow, Germination	60 days, 30 days	12	6.9
Rye - Pastured	Pre-plant	6 days	6	
Oats and Barley	Pre-plant	21 days	6	
Misc. Field Crops	Pre-plant	5 days	6	
Tomatoes	Transplant	---		6
Potatoes	Flood, Pre-plant, planting	45 days, 15 days	12	3.6
Broccoli	Flood, Pre-plant, Germination	45 days, 15 days	12	5.2
Cabbage	Flood, Pre-plant, Germination	45 days, 15 days	12	5.2
Cauliflower	Flood, Pre-plant, Germination	45 days, 15 days	12	5.2
Corn, Ear	Flood, Pre-plant	45 days, 5 days	12	
Misc. Garden Crops	Flood, Pre-plant, Germination	45 days, 15 days	12	5.2
Asparagus (based on 8-yr life)	Pre-plant	---	1.5	

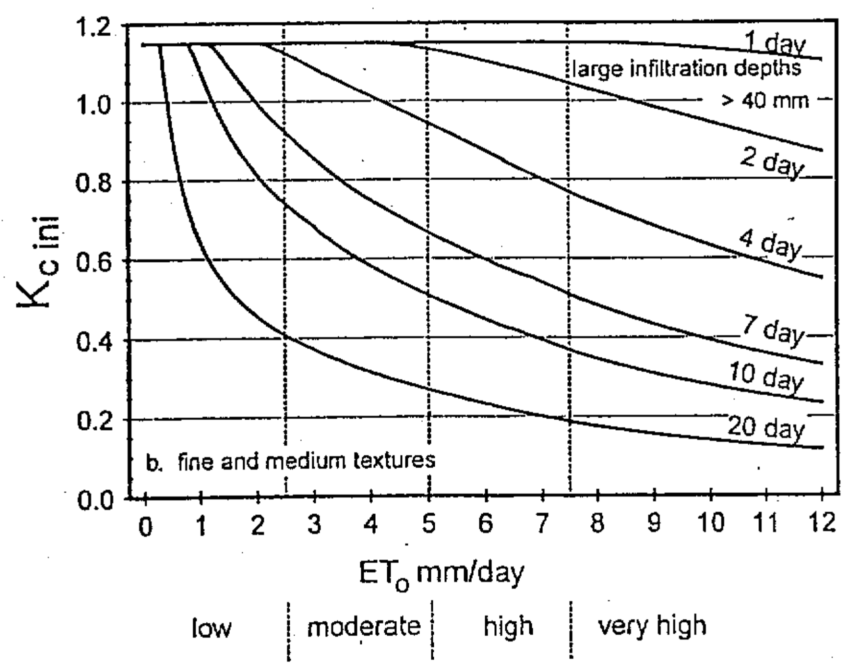
Source: Mayberry (2002) and University of California Cooperative Extension (1997 and 1999)

APPENDIX 6B

Average Kc ini as Related to the Level of ETo and the Interval Between Irrigation Events During the Initial Growth Stage for Coarse Textured Soils and Medium and Fine Textured Soils

Average $K_{c\ ini}$ as related to the level of ET_o and the interval between irrigations greater than or equal to 40 mm per wetting event, during the initial growth stage for a) coarse textured soils; b) medium and fine textured soils





Source: Allen et al. (1998)

APPENDIX 6C

Annual Summary of Crop Acreage in Imperial Irrigation District (1989-1998)

Crop Acreage in Imperial Irrigation District, 1989 - 1998.

Field Crops	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Alfalfa**	166,388	183,660	190,179	172,993	162,349	172,286	167,168	145,801	154,576	160,769
Alfalfa Seed**	952	1,502	3,490	1,661	2,088	1,654	2,883	3,040	4,613	7,188
Bermuda Grass Hay**	4,010	4,304	5,489	9,859	15,568	18,077	20,390	19,056	21,194	27,723
Bermuda Grass Seed**	15,527	14,534	14,599	17,254	18,089	17,434	18,761	20,012	19,483	20,870
Cotton	9,863	11,290	9,401	4,298	7,664	7,037	6,881	4,766	4,269	4,762
*Oats & Barley	7,430	2,805	3,895	2,073	1,444	1,835	2,669	1,325	1,926	2,748
*Rye Grass	10,090	9,076	8,203	9,591	6,389	6,029	4,685	3,015	4,671	4,968
Sudan Grass	53,826	42,537	64,680	53,424	58,123	79,144	77,534	82,242	83,872	66,630
*Sugar Beets	27,997	37,111	41,508	41,791	41,777	28,885	34,802	37,078	39,940	37,316
*Wheat	96,122	56,835	32,094	69,198	59,301	58,259	62,199	108,770	90,005	80,184
Misc.	1,022	1,244	1,283	1,225	2,870	2,255	3,613	5,932	4,712	8,331
Total Field Crops	393,228	364,898	374,821	383,367	375,662	392,895	401,584	431,037	429,262	421,488
Total Field Crops (max)	408,451	384,816	388,410	401,041	395,111	407,592	419,644	444,296	462,920	

Garden Crops	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
*Broccoli	11,526	10,818	9,464	9,576	5,005	6,379	5,420	5,654	6,373	10,083
*Cabbage	866	1,115	1,398	933	725	1,513	784	928	976	1,046
*Carrots (and mixed vegetables)	12,182	13,701	13,186	16,081	15,937	16,685	16,085	16,412	17,105	18,923
*Cauliflower	6,919	6,934	6,163	5,918	3,223	4,002	3,026	2,764	2,564	2,630
Corn, Ear	1,529	2,141	2,939	3,830	3,054	4,126	4,051	4,604	6,688	6,709
*Lettuce	32,700	34,070	31,415	24,260	18,549	20,044	19,499	21,513	21,081	21,139
Cantaloupes - Fall	9,145	9,145	10,603	7,995	654	769	13	459	846	2,138
Cantaloupes - Spring	18,094	22,837	21,078	12,793	13,645	14,095	14,355	13,540	11,397	11,656
Honeydew and other melons	2,762	2,520	2,365	793	351	706	1,041	851	1,693	1,202
Water Melons	3,709	3,339	2,402	2,376	2,945	3,400	2,719	2,596	2,420	1,816
*Onions	9,427	11,702	11,862	11,066	12,214	13,079	12,620	13,097	10,507	9,886
*Onion Seed	1,901	2,968	2,540	2,339	2,765	1,679	1,682	1,882	3,573	2,540
Tomatoes	12,264	11,432	6,366	3,923	3,768	2,400	1,898	1,888	869	637
*Potatoes	152	300	376	804	1,163	1,257	1,923	2,538	2,452	2,622
Misc.	1,991	2,756	3,090	3,388	5,120	2,331	3,340	4,785	3,530	2,559
Total Garden Crops	125,167	135,778	125,247	106,075	89,118	92,465	88,456	93,511	92,140	95,586

Permanent Crops	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Asparagas	5,179	5,751	6,307	6,310	5,972	5,448	4,703	4,464	5,182	5,539
Citrus	1,766	1,852	2,201	2,606	2,964	3,180	3,315	3,640	4,445	5,272
Duck Ponds	7,755	7,826	7,882	8,156	8,132	8,061	7,994	8,205	8,796	8,837
Jojoba	2,117	2,117	2,117	2,042	2,017	1,986	1,843	1,680	457	135
Fish Farms	763	801	907	903	1,039	1,173	1,173	1,173	1,256	1,281
Permanent Pasture	493	557	571	589	659	759	699	652	698	672
Peach Trees	408	390	282	223	184	125	9	2	2	4
Misc.	126	156	330	326	319	322	353	633	467	372
Total Permanent Crops	18,607	19,451	20,598	21,154	21,286	21,054	20,089	20,448	21,302	22,113
Total Crops:	537,002	520,127	520,666	510,597	486,067	506,414	510,129	544,996	542,704	539,187
Total Crops (max):	552,225	540,045	534,255	528,270	505,515	521,111	528,189	558,255	576,362	

All field and garden crop acreages are maximum monthly acreage for the growing season, and all permanent crop acreages are 12-month averages excepted noted otherwise.

* *Annual crops which are planted in one year and harvested in the next. The year assigned to these crops is the year of harvest.*

** *Alfalfa, alfalfa seed, bermuda grass hay, and bermuda grass seed acreages shown here are average monthly values over the 12 month period.*

Monthly data are used for alfalfa, bermuda grass and sudan grass in ET computations. The acreage for alfalfa seed is generally from a conversion of alfalfa hay acreage. (i.e., in late summer, as alfalfa seed acreage goes up, alfalfa hay acreage is reduced.)

APPENDIX 6D

Monthly Summary of Forage Crop Acreage in Imperial Irrigation District (1989-1998)

Monthly Acreage Summaries for Forage Crops in Imperial Irrigation District, 1989 - 1998.

1989	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov.	Dec.	Maximum Month	Ave.
Alfalfa, Row									17,296	17,296	26,535	26,491	26,535	21,905
Alfalfa	138,883	145,818	153,050	153,050	151,993	150,913	150,936	133,613	127,203	127,230	149,201	151,858	153,050	144,479
Alfalfa, New	28,786	18,064	10,406	10,406	8,812	7,217	7,217	6,779	4,365	4,365	3,559	3,269	28,786	9,437
Alfalfa, Seed	768	746	653	653	1,084	1,515	1,515	1,559	782	782	673	673	1,559	950
Alfalfa, Total,w/o seed	167,669	163,882	163,456	163,456	160,805	158,130	158,153	140,392	148,864	148,891	179,295	181,618	181,618	161,218
Alfalfa, Total	168,437	164,628	164,109	164,109	161,889	159,645	159,668	141,951	149,646	149,673	179,968	182,291	182,291	162,168
Bermuda Grass Hay	4,083	4,083	4,086	4,086	3,826	3,565	3,565	4,102	4,142	4,142	4,195	4,249	4,249	4,010
Bermuda Grass Seed	15,302	15,152	15,270	15,270	15,558	15,845	15,845	15,596	15,668	15,668	15,615	15,540	15,845	15,527
Bermuda, Total	19,385	19,235	19,356	19,356	19,384	19,410	19,410	19,698	19,810	19,810	19,810	19,789	19,810	19,538
Sudan Grass	4,354	4,280	16,886	16,886	34,763	52,640	52,640	44,463	35,941	35,941	10,617	6,134	52,640	26,295
Sudan Grass Seed	996	1,055	1,055	1,055	1,121	1,186	1,186	1,186	1,186	1,186	1,055	1,055	1,186	1,110
Sudan, Total	5,350	5,335	17,941	17,941	35,884	53,826	53,826	45,649	37,127	37,127	11,672	7,189	53,826	27,406
1990														
Alfalfa, Row	26,675	27,356	28,082	28,340	28,508	28,391	28,283	27,260	27,412	28,470	33,730	38,990	38,990	29,291
Alfalfa	154,108	154,411	155,098	156,645	158,637	158,979	156,411	152,488	142,916	143,169	154,244	165,319	165,319	154,369
Alfalfa, New	37	73	115	37	37	37	37	37	37	37	112	56	115	54
Alfalfa, Seed	603	574	574	354	619	618	2,519	4,523	2,905	2,337	1,578	819	4,523	1,502
Alfalfa, Total,w/o seed	180,820	181,840	183,295	185,022	187,182	187,407	184,731	179,785	170,365	171,676	188,086	204,365	204,365	183,715
Alfalfa, Total	181,423	182,414	183,869	185,376	187,801	188,025	187,250	184,308	173,270	174,013	189,664	205,184	205,184	185,216
Bermuda Grass Hay	4,249	4,072	4,050	4,362	4,362	4,326	4,299	4,299	4,498	4,423	4,379	4,334	4,498	4,304
Bermuda Grass Seed	15,540	14,994	14,915	14,810	14,285	14,430	14,588	14,476	14,254	14,024	14,037	14,050	15,540	14,534
Bermuda, Total	19,789	19,066	18,965	19,172	18,647	18,756	18,887	18,775	18,752	18,447	18,416	18,384	19,789	18,838
Sudan Grass	4,891	6,851	12,545	18,462	29,003	34,234	40,963	41,482	33,307	30,974	18,064	5,155	41,482	22,994
Sudan Grass Seed	1,055	1,055	1,055	1,055							59	113	1,055	732
Sudan, Total	5,946	7,906	13,600	19,517	29,003	34,234	40,963	41,482	33,307	30,974	18,123	5,268	41,482	23,360
1991														
Alfalfa, Row	38,990	39,039	40,375	41,068	41,581	41,528	37,420	36,351	37,458	38,770	43,152	43,446	43,446	39,932
Alfalfa	165,319	163,803	161,759	160,637	160,564	160,151	144,662	131,694	130,999	135,723	145,274	142,387	165,319	150,248
Alfalfa, New								191	191	2,164	155		2,164	675
Alfalfa, Seed	819	447	447	462	649	856	17,397	12,721	6,925	572	294	294	17,397	3,490
Alfalfa, Total,w/o seed	204,309	202,842	202,134	201,705	202,145	201,679	182,082	168,236	168,648	176,657	188,581	185,833	204,309	190,404
Alfalfa, Total	205,128	203,289	202,581	202,167	202,794	202,535	199,479	180,957	175,573	177,229	188,875	186,127	205,128	193,895
Bermuda Grass Hay	4,334	4,179	4,399	4,399	4,253	4,428	5,181	7,374	7,778	6,636	6,261	6,644	7,778	5,489
Bermuda Grass Seed	14,050	14,015	14,052	14,065	14,308	14,308	14,301	14,633	14,519	15,535	15,890	15,508	15,890	14,599
Bermuda, Total	18,384	18,194	18,451	18,464	18,561	18,736	19,482	22,007	22,297	22,171	22,151	22,152	22,297	20,088
Sudan Grass	5,155	7,674	19,565	38,376	51,337	55,917	64,513	51,273	45,660	32,442	17,882	4,047	64,513	32,820
Sudan Grass Seed	113	167	72	162	162	165	88	18	18	18	18	0	167	83
Sudan, Total	5,268	7,841	19,637	38,538	51,499	56,082	64,601	51,291	45,678	32,460	17,900	4,047	64,601	32,904
1992														
Alfalfa, Row	43,446	43,440	43,605	43,317	43,080	41,433	38,401	35,502	33,854	37,050	40,038	38,210	43,605	40,115
Alfalfa	142,387	140,764	138,713	136,914	136,701	135,902	131,106	119,568	115,688	125,550	135,308	135,937	142,387	132,878
Alfalfa, New							213						213	213
Alfalfa, Seed	294	294	261	261	384	1,212	5,012	7,099	1,923	1,503	768	926	7,099	1,661
Alfalfa, Total,w/o seed	185,833	184,204	182,318	180,231	179,781	177,335	169,720	155,070	149,542	162,600	175,346	174,147	185,833	173,011
Alfalfa, Total	186,127	184,498	182,579	180,492	180,165	178,547	174,732	162,169	151,465	164,103	176,114	175,073	186,127	174,672
Bermuda Grass Hay	6,644	6,268	6,105	6,102	6,172	6,965	9,750	12,056	13,194	15,359	14,798	14,897	15,359	9,859
Bermuda Grass Seed	15,508	15,724	16,190	16,485	16,475	16,787	17,883	18,959	19,098	18,027	17,953	17,959	19,098	17,254
Bermuda, Total	22,152	21,992	22,295	22,587	22,647	23,752	27,633	31,015	32,292	33,386	32,751	32,856	33,386	27,113
Sudan Grass	4,047	3,245	11,452	41,514	47,469	53,352	53,078	39,102	29,204	23,119	15,766	8,246	53,352	27,466
Sudan Grass Seed							72	72	36	36			72	54
Sudan, Total	4,047	3,245	11,452	41,514	47,469	53,352	53,150	39,174	29,240	23,155	15,766	8,246	53,352	27,484
1993														
Alfalfa, Row	38,185	38,179	36,987	35,886	35,621	34,441	30,303	29,665	28,900	35,292	42,791	43,630	43,630	35,823
Alfalfa	133,406	132,199	130,632	128,673	128,853	127,432	116,595	110,633	107,141	125,098	139,164	138,484	139,164	126,526
Alfalfa, New			116	116	116								116	116
Alfalfa, Seed	592	592	544	509	588	1,483	7,949	6,771	3,232	1,590	748	459	7,949	2,088
Alfalfa, Total,w/o seed	171,591	170,378	167,735	164,675	164,590	161,873	146,898	140,298	136,041	160,390	181,955	182,114	182,114	162,378
Alfalfa, Total	172,183	170,970	168,279	165,184	165,178	163,356	154,847	147,069	139,273	161,980	182,703	182,573	182,703	164,466
Bermuda Grass Hay	14,815	14,815	15,141	14,877	12,446	12,544	16,490	17,036	17,015	17,367	17,286	16,980	17,367	15,568
Bermuda Grass Seed	17,885	17,885	17,740	17,880	20,394	20,494	17,953	17,868	17,553	17,375	17,028	17,018	20,494	18,089
Bermuda, Total	32,700	32,700	32,881	32,757	32,840	33,038	34,443	34,904	34,568	34,742	34,314	33,998	34,904	33,657
Sudan Grass	5,763	5,905	18,995	41,293	49,235	57,850	57,295	52,594	41,855	31,488	15,117	8,729	57,850	32,177
Sudan Grass Seed			133	273	273	209	209	209	209		262	262	273	227
Sudan, Total	5,763	5,905	19,128	41,566	49,508	58,059	57,504	52,803	42,064	31,488	15,379	8,991	58,059	32,347

1994	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov.	Dec.	Maximum Month	Ave.
Alfalfa, Row	43,433	43,608	43,291	43,131	43,359	42,504	40,491	36,827	34,912	40,402	46,964	46,458	46,964	42,115
Alfalfa	137,888	137,035	134,787	133,504	132,822	131,541	126,718	118,691	112,612	121,640	136,603	138,211	138,211	130,171
Alfalfa, New		91	75	75	75	75	75	75	75	36	1,207	1,229	1,229	281
Alfalfa, Seed	459	114	114	114	114	1,668	6,675	5,920	3,237	502	502	428	6,675	1,654
Alfalfa, Total,w/o seed	181,321	180,734	178,153	176,710	176,256	174,120	167,284	155,593	147,599	162,078	184,774	185,898	185,898	172,543
Alfalfa, Total	181,780	180,848	178,267	176,824	176,370	175,788	173,959	161,513	150,836	162,580	185,276	186,326	186,326	174,197
Bermuda Grass Hay	17,007	16,987	16,998	17,047	16,454	16,655	17,056	19,294	19,749	20,119	19,929	19,631	20,119	18,077
Bermuda Grass Seed	16,945	16,666	16,665	16,825	17,426	17,257	17,535	18,046	17,862	17,908	18,053	18,015	18,053	17,434
Bermuda, Total	33,952	33,653	33,663	33,872	33,880	33,912	34,591	37,340	37,611	38,027	37,982	37,646	38,027	35,511
Sudan Grass	6,742	3,577	25,725	50,362	62,188	73,012	78,878	71,876	56,942	39,643	17,448	7,823	78,878	41,185
Sudan Grass Seed	192				45	179	61	61	20	206	266		266	129
Sudan, Total	6,934	3,577	25,725	50,362	62,233	73,191	78,939	71,937	56,962	39,849	17,714	7,823	78,939	41,271
1995														
Alfalfa, Row	46,522	46,269	45,808	45,245	44,953	44,284	41,076	38,617	35,930	39,002	39,582	39,757	46,522	42,254
Alfalfa	137,782	135,184	134,965	132,811	132,354	131,941	124,061	113,979	111,656	111,618	117,195	115,428	137,782	124,915
Alfalfa, New	1,208	951	846	707	127					184			1,208	671
Alfalfa, Seed	357	357	323	323	467	1,978	10,479	12,704	4,069	2,195	1,105	235	12,704	2,883
Alfalfa, Total,w/o seed	185,512	182,404	181,619	178,763	177,434	176,225	165,137	152,596	147,586	150,804	156,777	155,185	185,512	167,504
Alfalfa, Total	185,869	182,761	181,942	179,086	177,901	178,203	175,616	165,300	151,655	152,999	157,882	155,420	185,869	170,386
Bermuda Grass Hay	19,660	19,617	19,645	20,152	19,531	19,784	19,678	21,250	21,704	21,643	21,130	20,881	21,704	20,390
Bermuda Grass Seed	17,822	17,598	17,724	17,556	18,390	18,531	20,481	19,608	19,688	19,504	19,169	19,058	20,481	18,761
Bermuda, Total	37,482	37,215	37,369	37,708	37,921	38,315	40,159	40,858	41,392	41,147	40,299	39,939	41,392	39,150
Sudan Grass	6,467	4,002	16,228	37,630	48,269	71,376	77,383	72,861	56,425	39,257	19,491	8,324	77,383	38,143
Sudan Grass Seed				76	76	151	151	20	20				151	82
Sudan, Total	6,467	4,002	16,228	37,706	48,345	71,527	77,534	72,881	56,445	39,257	19,491	8,324	77,534	38,184
1996														
Alfalfa, Row	39,075	39,405	39,181	39,323	39,212	37,745	34,649	31,780	30,567	37,460	42,633	43,427	43,427	37,871
Alfalfa	113,429	112,472	111,719	110,765	110,771	108,977	102,680	93,621	91,672	102,814	118,114	118,115	118,115	107,929
Alfalfa, New														
Alfalfa, Seed	769	465	339	339	339	2,927	11,283	13,238	5,020	1,165	493	100	13,238	3,040
Alfalfa, Total,w/o seed	152,504	151,877	150,900	150,088	149,983	146,722	137,329	125,401	122,239	140,274	160,747	161,542	161,542	145,801
Alfalfa, Total	153,273	152,342	151,239	150,427	150,322	149,649	148,612	138,639	127,259	141,439	161,240	161,642	161,642	148,840
Bermuda Grass Hay	20,612	20,572	20,952	20,037	16,557	16,756	17,743	17,550	18,638	19,976	19,708	19,572	20,952	19,056
Bermuda Grass Seed	19,260	19,037	18,419	19,191	22,636	22,615	21,991	21,761	20,280	18,592	18,283	18,083	22,636	20,012
Bermuda, Total	39,872	39,609	39,371	39,228	39,193	39,371	39,734	39,311	38,918	38,568	37,991	37,655	39,872	39,068
Sudan Grass	2,989	1,727	10,672	26,585	40,729	76,084	81,896	74,890	56,485	41,755	20,902	7,639	81,896	36,863
Sudan Grass Seed								57	57	273	271	346	346	201
Sudan, Total	2,989	1,727	10,672	26,585	40,729	76,084	81,896	74,947	56,542	42,028	21,173	7,985	81,896	36,946
1997														
Alfalfa, Row	43,594	43,568	43,716	43,452	43,832	42,567	37,912	35,837	36,067	41,029	51,047	53,688	53,688	43,026
Alfalfa	117,388	116,492	116,035	115,760	115,178	113,447	104,833	99,938	98,513	101,146	120,675	119,201	120,675	111,551
Alfalfa, New														
Alfalfa, Seed	75					2,833	14,248	13,513	4,937	1,027	254	20	14,248	4,613
Alfalfa, Total,w/o seed	160,982	160,060	159,751	159,212	159,010	156,014	142,745	135,775	134,580	142,175	171,722	172,889	174,363	154,576
Alfalfa, Total	161,057	160,060	159,751	159,212	159,010	158,847	156,993	149,288	139,517	143,202	171,976	172,909	188,611	159,190
Bermuda Grass Hay	19,529	19,670	19,030	18,345	18,658	19,199	20,192	23,083	24,152	24,301	24,011	24,161	24,301	21,194
Bermuda Grass Seed	18,083	17,802	18,586	18,964	19,222	19,222	20,336	19,951	20,237	20,227	20,554	20,613	20,613	19,483
Bermuda, Total	37,612	37,472	37,616	37,309	37,880	38,421	40,528	43,034	44,389	44,528	44,565	44,774	44,914	40,677
Sudan Grass	4,842	3,912	11,235	31,524	45,299	72,622	83,562	77,018	59,949	45,546	21,548	8,401	83,562	38,788
Sudan Grass Seed	130	130	130	130	130	130	310	190	190	142	75	75	310	147
Sudan, Total	4,972	4,042	11,365	31,654	45,429	72,752	83,872	77,208	60,139	45,688	21,623	8,476	83,872	38,935
1998														
Alfalfa, Row	53,139	53,147	53,143	53,239	53,401	52,543	47,487	44,087	46,269	53,756	61,536	64,310	64,310	53,005
Alfalfa	117,879	117,360	116,751	115,944	115,780	114,907	104,120	94,146	90,304	97,185	104,850	103,944	117,879	107,764
Alfalfa, New														
Alfalfa, Seed						1,565	15,525	19,781	9,191	2,633	943	676	19,781	7,188
Alfalfa, Total,w/o seed	171,018	170,507	169,894	169,183	169,181	167,450	151,607	138,233	136,573	150,941	166,386	168,254	182,189	160,769
Alfalfa, Total	171,018	170,507	169,894	169,183	169,181	169,015	167,132	158,014	145,764	153,574	167,329	168,930	201,970	167,957
Bermuda Grass Hay	25,287	25,307	24,374	24,374	24,263	24,674	28,842	30,064	31,774	31,654	30,996	31,068	31,774	27,723
Bermuda Grass Seed	19,387	19,324	20,397	20,461	20,531	20,666	20,583	21,602	21,865	21,825	22,056	21,739	22,056	20,870
Bermuda, Total	44,674	44,631	44,771	44,835	44,794	45,340	49,425	51,666	53,639	53,479	53,052	52,807	53,830	48,593
Sudan Grass	3,433	2,325	2,916	18,034	38,554	57,113	66,568	60,158	42,185	27,435	19,135	12,147	66,568	29,167
Sudan Grass Seed							7	62	7	7			62	21
Sudan, Total	3,433	2,325	2,916	18,034	38,554	57,113	66,575	60,220	42,192	27,442	19,135	12,147	66,630	29,188

APPENDIX 6E

Summary of Estimated Planting and Harvest Dates of Annual Crops in Imperial Irrigation District (1989-1998)

Harvest and Planting Dates of IID Crops (Based on IID Provided Cropping Dates, 1989-1998)

(shaded) - estimated dates

Crop	Plant	Harvest	Initial Period	Develp. Period	Mid. Period	Late Period	Total Period	Initial Period Begin	Initial Period End	Develop. Period Begin	Develop. Period End	Mid Period Begin	Mid Period End	End Period Begin	End Period End
Sudan	04/04/90	10/06/90	20	20	141	5	186	04/04/90	04/23/90	04/23/90	05/13/90	05/13/90	10/01/90	10/01/90	10/06/90
	03/31/91	09/27/91	20	20	136	5	181	03/31/91	04/19/91	04/19/91	05/09/91	05/09/91	09/22/91	09/22/91	09/27/91
	03/24/92	09/27/92	20	20	143	5	188	03/24/92	04/12/92	04/12/92	05/02/92	05/02/92	09/22/92	09/22/92	09/27/92
	03/26/93	09/27/93	20	20	141	5	186	03/26/93	04/14/93	04/14/93	05/04/93	05/04/93	09/22/93	09/22/93	09/27/93
	03/26/94	10/05/94	20	20	149	5	194	03/26/94	04/14/94	04/14/94	05/04/94	05/04/94	09/30/94	09/30/94	10/05/94
	04/20/95	09/30/95	20	20	119	5	164	04/20/95	05/09/95	05/09/95	05/29/95	05/29/95	09/25/95	09/25/95	09/30/95
	05/13/96	09/30/96	20	20	96	5	141	05/13/96	06/01/96	06/01/96	06/21/96	06/21/96	09/25/96	09/25/96	09/30/96
	05/02/97	10/05/97	20	20	112	5	157	05/02/97	05/21/97	05/21/97	06/10/97	06/10/97	09/30/97	09/30/97	10/05/97
Wheat	01/18/90	06/05/90	14	42	56	28	140	01/18/90	01/31/90	01/31/90	03/14/90	03/14/90	05/09/90	05/09/90	06/05/90
	01/15/91	06/06/91	14	43	57	29	143	01/15/91	01/28/91	01/28/91	03/12/91	03/12/91	05/08/91	05/08/91	06/06/91
	01/14/92	06/05/92	14	43	58	29	144	01/14/92	01/27/92	01/27/92	03/10/92	03/10/92	05/07/92	05/07/92	06/05/92
	12/21/92	05/28/93	16	48	64	32	160	12/21/92	01/05/93	01/05/93	02/22/93	02/22/93	04/27/93	04/27/93	05/28/93
	12/14/93	06/02/94	17	51	68	34	170	12/14/93	12/30/93	12/30/93	02/19/94	02/19/94	04/28/94	04/28/94	06/02/94
	12/07/94	05/27/95	17	52	69	34	172	12/07/94	12/23/94	12/23/94	02/13/95	02/13/95	04/23/95	04/23/95	05/27/95
	12/11/95	05/31/96	17	52	69	35	173	12/11/95	12/27/95	12/27/95	02/17/96	02/17/96	04/26/96	04/26/96	05/31/96
	12/16/96	06/01/97	17	50	67	34	168	12/16/96	01/01/97	01/01/97	02/20/97	02/20/97	04/28/97	04/28/97	06/01/97
	12/03/97	06/01/98	18	54	72	36	180	12/03/97	12/20/97	12/20/97	02/12/98	02/12/98	04/25/98	04/25/98	06/01/98
Sugar Beets	09/23/89	06/11/90	26	66	105	66	263	09/23/89	10/18/89	10/18/89	12/23/89	12/23/89	04/07/90	04/07/90	06/11/90
	09/27/90	06/19/91	27	67	106	67	267	09/27/90	10/23/90	10/23/90	12/29/90	12/29/90	04/14/91	04/14/91	06/19/91
	09/29/91	06/21/92	27	67	107	67	268	09/29/91	10/25/91	10/25/91	12/31/91	12/31/91	04/16/92	04/16/92	06/21/92
	09/21/92	06/17/93	27	68	108	68	271	09/21/92	10/17/92	10/17/92	12/24/92	12/24/92	04/11/93	04/11/93	06/17/93
	09/20/93	06/15/94	27	67	108	67	269	09/20/93	10/16/93	10/16/93	12/22/93	12/22/93	04/09/94	04/09/94	06/15/94
	09/19/94	06/14/95	27	67	108	67	269	09/19/94	10/15/94	10/15/94	12/21/94	12/21/94	04/08/95	04/08/95	06/14/95
	09/22/95	06/20/96	27	68	109	68	272	09/22/95	10/18/95	10/18/95	12/25/95	12/25/95	04/12/96	04/12/96	06/20/96
	09/21/96	06/22/97	28	69	110	69	276	09/21/96	10/18/96	10/18/96	12/26/96	12/26/96	04/15/97	04/15/97	06/22/97
	09/22/97	06/25/98	28	69	111	69	277	09/22/97	10/19/97	10/19/97	12/27/97	12/27/97	04/17/98	04/17/98	06/25/98
Lettuce	10/09/89	03/01/90	29	50	36	29	144	10/09/89	11/06/89	11/06/89	12/26/89	12/26/89	01/31/90	01/31/90	03/01/90
	10/10/90	02/28/91	28	50	36	28	142	10/10/90	11/06/90	11/06/90	12/26/90	12/26/90	01/31/91	01/31/91	02/28/91
	10/06/91	02/16/92	27	47	34	27	135	10/06/91	11/01/91	11/01/91	12/18/91	12/18/91	01/21/92	01/21/92	02/16/92
	10/08/92	02/22/93	28	48	35	28	139	10/08/92	11/04/92	11/04/92	12/22/92	12/22/92	01/26/93	01/26/93	02/22/93
	10/09/93	02/15/94	26	46	33	26	131	10/09/93	11/03/93	11/03/93	12/19/93	12/19/93	01/21/94	01/21/94	02/15/94
	10/12/94	02/23/95	27	47	34	27	135	10/12/94	11/07/94	11/07/94	12/24/94	12/24/94	01/27/95	01/27/95	02/23/95
	10/16/95	02/20/96	26	45	32	26	129	10/16/95	11/10/95	11/10/95	12/25/95	12/25/95	01/26/96	01/26/96	02/20/96
	10/14/96	02/22/97	26	46	33	26	131	10/14/96	11/08/96	11/08/96	12/24/96	12/24/96	01/26/97	01/26/97	02/22/97
	10/11/97	02/22/98	27	47	34	27	135	10/11/97	11/06/97	11/06/97	12/23/97	12/23/97	01/26/98	01/26/98	02/22/98
Lettuce - Early	10/09/89	12/19/89	14	25	18	14	71	10/09/89	10/22/89	10/22/89	11/16/89	11/16/89	12/04/89	12/04/89	12/19/89
	10/10/90	12/19/90	14	25	18	14	71	10/10/90	10/23/90	10/23/90	11/17/90	11/17/90	12/05/90	12/05/90	12/19/90
	10/06/91	12/11/91	13	23	17	13	66	10/06/91	10/18/91	10/18/91	11/10/91	11/10/91	11/27/91	11/27/91	12/11/91
	10/08/92	12/15/92	14	24	17	14	69	10/08/92	10/21/92	10/21/92	11/14/92	11/14/92	12/01/92	12/01/92	12/15/92
	10/09/93	12/12/93	13	23	16	13	65	10/09/93	10/21/93	10/21/93	11/13/93	11/13/93	11/29/93	11/29/93	12/12/93
	10/12/94	12/18/94	14	24	17	14	69	10/12/94	10/25/94	10/25/94	11/18/94	11/18/94	12/05/94	12/05/94	12/18/94
	10/16/95	12/18/95	13	22	16	13	64	10/16/95	10/28/95	10/28/95	11/19/95	11/19/95	12/05/95	12/05/95	12/18/95
	10/14/96	12/18/96	13	23	17	13	66	10/14/96	10/26/96	10/26/96	11/18/96	11/18/96	12/05/96	12/05/96	12/18/96
	10/11/97	12/17/97	14	24	17	14	69	10/11/97	10/24/97	10/24/97	11/17/97	11/17/97	12/04/97	12/04/97	12/17/97

Harvest and Planting Dates of IID Crops (Based on IID Provided Cropping Dates, 1989-1998)

(shaded) - estimated dates

Crop	Plant	Harvest	Initial Period	Develp. Period	Mid. Period	Late Period	Total Period	Initial Period Begin	Initial Period End	Develop. Period Begin	Develop. Period End	Mid Period Begin	Mid Period End	End Period Begin	End Period End
Lettuce - Late	12/20/89	03/01/90	14	25	18	14	71	12/20/89	01/02/90	01/02/90	01/27/90	01/27/90	02/14/90	02/14/90	03/01/90
	12/20/90	02/28/91	14	25	18	14	71	12/20/90	01/02/91	01/02/91	01/27/91	01/27/91	02/14/91	02/14/91	02/28/91
	12/12/91	02/16/92	13	23	17	13	66	12/12/91	12/24/91	12/24/91	01/16/92	01/16/92	02/02/92	02/02/92	02/16/92
	12/16/92	02/22/93	14	24	17	14	69	12/16/92	12/29/92	12/29/92	01/22/93	01/22/93	02/08/93	02/08/93	02/22/93
	12/13/93	02/15/94	13	23	16	13	65	12/13/93	12/25/93	12/25/93	01/17/94	01/17/94	02/02/94	02/02/94	02/15/94
	12/19/94	02/23/95	13	23	17	13	66	12/19/94	12/31/94	12/31/94	01/23/95	01/23/95	02/09/95	02/09/95	02/23/95
	12/19/95	02/20/96	13	22	16	13	64	12/19/95	12/31/95	12/31/95	01/22/96	01/22/96	02/07/96	02/07/96	02/20/96
	12/19/96	02/22/97	13	23	17	13	66	12/19/96	12/31/96	12/31/96	01/23/97	01/23/97	02/09/97	02/09/97	02/22/97
	12/18/97	02/22/98	13	23	17	13	66	12/18/97	12/30/97	12/30/97	01/22/98	01/22/98	02/08/98	02/08/98	02/22/98
Carrots	10/18/89	05/15/90	32	53	95	32	212	10/18/89	11/18/89	11/18/89	01/10/90	01/10/90	04/15/90	04/15/90	05/15/90
	10/19/90	05/04/91	30	50	89	30	199	10/19/90	11/17/90	11/17/90	01/06/91	01/06/91	04/05/91	04/05/91	05/04/91
	10/07/91	04/28/92	31	51	92	31	205	10/07/91	11/06/91	11/06/91	12/27/91	12/27/91	03/28/92	03/28/92	04/28/92
	10/13/92	04/27/93	30	49	89	30	198	10/13/92	11/11/92	11/11/92	12/30/92	12/30/92	03/29/93	03/29/93	04/27/93
	10/09/93	04/29/94	30	51	91	30	202	10/09/93	11/07/93	11/07/93	12/28/93	12/28/93	03/29/94	03/29/94	04/29/94
	10/17/94	04/13/95	27	45	81	27	180	10/17/94	11/12/94	11/12/94	12/27/94	12/27/94	03/18/95	03/18/95	04/13/95
	10/15/95	04/10/96	27	45	81	27	180	10/15/95	11/10/95	11/10/95	12/25/95	12/25/95	03/15/96	03/15/96	04/10/96
	10/17/96	04/09/97	26	44	79	26	175	10/17/96	11/11/96	11/11/96	12/25/96	12/25/96	03/14/97	03/14/97	04/09/97
	10/14/97	04/14/98	27	46	82	27	182	10/14/97	11/09/97	11/09/97	12/25/97	12/25/97	03/17/98	03/17/98	04/14/98
Cantaloupes - Spring	02/18/90	06/22/90	25	31	44	25	125	02/18/90	03/14/90	03/14/90	04/14/90	04/14/90	05/28/90	05/28/90	06/22/90
	02/17/91	06/25/91	26	32	45	26	129	02/17/91	03/14/91	03/14/91	04/15/91	04/15/91	05/30/91	05/30/91	06/25/91
	02/01/92	06/09/92	26	33	46	26	131	02/01/92	02/26/92	02/26/92	03/30/92	03/30/92	05/15/92	05/15/92	06/09/92
	02/18/93	06/20/93	25	31	43	25	124	02/18/93	03/14/93	03/14/93	04/14/93	04/14/93	05/27/93	05/27/93	06/20/93
	01/24/94	06/19/94	29	37	51	29	146	01/24/94	02/21/94	02/21/94	03/30/94	03/30/94	05/20/94	05/20/94	06/19/94
	02/07/95	06/19/95	27	33	47	27	134	02/07/95	03/05/95	03/05/95	04/07/95	04/07/95	05/24/95	05/24/95	06/19/95
	01/19/96	06/11/96	29	36	51	29	145	01/19/96	02/16/96	02/16/96	03/23/96	03/23/96	05/13/96	05/13/96	06/11/96
	01/27/97	06/09/97	27	34	47	27	135	01/27/97	02/22/97	02/22/97	03/28/97	03/28/97	05/14/97	05/14/97	06/09/97
Cantaloupes - Fall	08/03/90	11/08/90	10	29	49	10	98	08/03/90	08/12/90	08/12/90	09/10/90	09/10/90	10/29/90	10/29/90	11/08/90
	08/01/91	10/11/91	7	22	36	7	72	08/01/91	08/07/91	08/07/91	08/29/91	08/29/91	10/04/91	10/04/91	10/11/91
	08/08/92	11/03/92	9	26	44	9	88	08/08/92	08/16/92	08/16/92	09/11/92	09/11/92	10/25/92	10/25/92	11/03/92
	08/06/93	10/25/93	8	24	41	8	81	08/06/93	08/13/93	08/13/93	09/06/93	09/06/93	10/17/93	10/17/93	10/25/93
	08/08/94	11/03/94	9	26	44	9	88	08/08/94	08/16/94	08/16/94	09/11/94	09/11/94	10/25/94	10/25/94	11/03/94
	08/28/95	11/28/95	9	28	47	9	93	08/28/95	09/05/95	09/05/95	10/03/95	10/03/95	11/19/95	11/19/95	11/28/95
	08/01/96	10/30/96	9	27	46	9	91	08/01/96	08/09/96	08/09/96	09/05/96	09/05/96	10/21/96	10/21/96	10/30/96
	08/08/97	11/05/97	9	27	45	9	90	08/08/97	08/16/97	08/16/97	09/12/97	09/12/97	10/27/97	10/27/97	11/05/97
Cotton	03/16/90	10/15/90	43	86	43	43	215	03/16/90	04/27/90	04/27/90	07/22/90	07/22/90	09/03/90	09/03/90	10/15/90
	03/21/91	10/08/91	40	81	40	40	201	03/21/91	04/29/91	04/29/91	07/19/91	07/19/91	08/28/91	08/28/91	10/08/91
	03/19/92	10/01/92	39	79	39	39	196	03/19/92	04/26/92	04/26/92	07/14/92	07/14/92	08/22/92	08/22/92	10/01/92
	03/13/93	10/12/93	43	86	43	43	215	03/13/93	04/24/93	04/24/93	07/19/93	07/19/93	08/31/93	08/31/93	10/12/93
	03/08/94	10/12/94	44	88	44	44	220	03/08/94	04/20/94	04/20/94	07/17/94	07/17/94	08/30/94	08/30/94	10/12/94
	03/09/95	10/15/95	44	88	44	44	220	03/09/95	04/21/95	04/21/95	07/18/95	07/18/95	08/31/95	08/31/95	10/15/95
	03/01/96	10/17/96	46	92	46	46	230	03/01/96	04/15/96	04/15/96	07/16/96	07/16/96	08/31/96	08/31/96	10/17/96
	03/07/97	09/30/97	42	83	42	42	209	03/07/97	04/17/97	04/17/97	07/09/97	07/09/97	08/20/97	08/20/97	09/30/97

Harvest and Planting Dates of IID Crops (Based on IID Provided Cropping Dates, 1989-1998)

- estimated dates

Crop	Plant	Harvest	Initial Period	Develp. Period	Mid. Period	Late Period	Total Period	Initial Period Begin	Initial Period End	Develop. Period Begin	Develop. Period End	Mid Period Begin	Mid Period End	End Period Begin	End Period End
Honeydew	01/30/90	06/20/90	27	40	58	18	143	01/30/90	02/25/90	02/25/90	04/06/90	04/06/90	06/03/90	06/03/90	06/20/90
	01/30/91	06/20/91	27	40	58	18	143	01/30/91	02/25/91	02/25/91	04/06/91	04/06/91	06/03/91	06/03/91	06/20/91
	01/19/92	06/14/92	28	41	61	19	149	01/19/92	02/15/92	02/15/92	03/27/92	03/27/92	05/27/92	05/27/92	06/14/92
	02/15/93	06/25/93	25	37	54	17	133	02/15/93	03/11/93	03/11/93	04/17/93	04/17/93	06/10/93	06/10/93	06/25/93
	01/22/94	06/25/94	29	43	64	20	156	01/22/94	02/19/94	02/19/94	04/03/94	04/03/94	06/06/94	06/06/94	06/25/94
	02/01/95	06/19/95	26	39	57	18	140	02/01/95	02/26/95	02/26/95	04/06/95	04/06/95	06/02/95	06/02/95	06/19/95
	01/27/96	06/25/96	29	42	62	20	153	01/27/96	02/24/96	02/24/96	04/06/96	04/06/96	06/07/96	06/07/96	06/25/96
	01/31/97	06/09/97	25	36	53	17	131	01/31/97	02/24/97	02/24/97	04/01/97	04/01/97	05/24/97	05/24/97	06/09/97
Watermelon	02/04/90	06/15/90	25	37	54	17	133	02/04/90	02/28/90	02/28/90	04/06/90	04/06/90	05/30/90	05/30/90	06/15/90
	02/14/91	06/26/91	25	37	55	17	134	02/14/91	03/10/91	03/10/91	04/16/91	04/16/91	06/10/91	06/10/91	06/26/91
	01/30/92	06/10/92	25	37	55	17	134	01/30/92	02/23/92	02/23/92	03/31/92	03/31/92	05/25/92	05/25/92	06/10/92
	02/15/93	06/17/93	23	34	50	16	123	02/15/93	03/09/93	03/09/93	04/12/93	04/12/93	06/01/93	06/01/93	06/17/93
	01/19/94	06/25/94	30	44	65	21	160	01/19/94	02/17/94	02/17/94	04/02/94	04/02/94	06/06/94	06/06/94	06/25/94
	01/27/95	06/15/95	27	39	57	18	141	01/27/95	02/22/95	02/22/95	04/02/95	04/02/95	05/29/95	05/29/95	06/15/95
	01/18/96	06/19/96	29	43	63	20	155	01/18/96	02/15/96	02/15/96	03/29/96	03/29/96	05/31/96	05/31/96	06/19/96
	01/28/97	06/23/97	28	41	60	19	148	01/28/97	02/24/97	02/24/97	04/06/97	04/06/97	06/05/97	06/05/97	06/23/97
Onions	10/31/89	06/04/90	22	43	109	43	217	10/31/89	11/21/89	11/21/89	01/03/90	01/03/90	04/22/90	04/22/90	06/04/90
	10/24/90	06/03/91	22	45	112	45	224	10/24/90	11/14/90	11/14/90	12/29/90	12/29/90	04/20/91	04/20/91	06/03/91
	10/20/91	06/05/92	23	46	115	46	230	10/20/91	11/11/91	11/11/91	12/27/91	12/27/91	04/20/92	04/20/92	06/05/92
	10/18/92	05/29/93	22	45	112	45	224	10/18/92	11/08/92	11/08/92	12/23/92	12/23/92	04/14/93	04/14/93	05/29/93
	10/16/93	06/01/94	23	46	115	46	230	10/16/93	11/07/93	11/07/93	12/23/93	12/23/93	04/17/94	04/17/94	06/01/94
	10/18/94	05/29/95	22	45	112	45	224	10/18/94	11/08/94	11/08/94	12/23/94	12/23/94	04/14/95	04/14/95	05/29/95
	10/18/95	06/02/96	23	46	115	46	230	10/18/95	11/09/95	11/09/95	12/25/95	12/25/95	04/18/96	04/18/96	06/02/96
	10/18/96	06/03/97	23	46	115	46	230	10/18/96	11/09/96	11/09/96	12/25/96	12/25/96	04/19/97	04/19/97	06/03/97
	10/18/97	06/01/98	23	45	114	45	227	10/18/97	11/09/97	11/09/97	12/24/97	12/24/97	04/17/98	04/17/98	06/01/98
Onion Seed	09/18/89	06/26/90	23	45	169	45	282	09/18/89	10/10/89	10/10/89	11/24/89	11/24/89	05/12/90	05/12/90	06/26/90
	10/01/90	06/23/91	21	43	160	43	267	10/01/90	10/21/90	10/21/90	12/03/90	12/03/90	05/12/91	05/12/91	06/23/91
	09/24/91	06/16/92	21	43	160	43	267	09/24/91	10/14/91	10/14/91	11/26/91	11/26/91	05/04/92	05/04/92	06/16/92
	09/15/92	06/11/93	22	43	162	43	270	09/15/92	10/06/92	10/06/92	11/18/92	11/18/92	04/29/93	04/29/93	06/11/93
	09/18/93	06/20/94	22	44	166	44	276	09/18/93	10/09/93	10/09/93	11/22/93	11/22/93	05/07/94	05/07/94	06/20/94
	10/02/94	06/20/95	21	42	157	42	262	10/02/94	10/22/94	10/22/94	12/03/94	12/03/94	05/09/95	05/09/95	06/20/95
	09/20/95	06/10/96	21	42	159	42	264	09/20/95	10/10/95	10/10/95	11/21/95	11/21/95	04/28/96	04/28/96	06/10/96
	09/20/96	06/20/97	22	44	164	44	274	09/20/96	10/11/96	10/11/96	11/24/96	11/24/96	05/07/97	05/07/97	06/20/97
	09/18/97	06/29/98	23	46	171	46	286	09/18/97	10/10/97	10/10/97	11/25/97	11/25/97	05/15/98	05/15/98	06/29/98
Rye - Pastured	10/10/89	06/01/90	12	35	141	47	235	10/10/89	10/21/89	10/21/89	11/25/89	11/25/89	04/15/90	04/15/90	06/01/90
	10/01/90	06/02/91	12	37	147	49	245	10/01/90	10/12/90	10/12/90	11/18/90	11/18/90	04/14/91	04/14/91	06/02/91
	10/21/91	05/30/92	11	33	134	45	223	10/21/91	10/31/91	10/31/91	12/03/91	12/03/91	04/15/92	04/15/92	05/30/92
	10/22/92	05/30/93	11	33	133	44	221	10/22/92	11/01/92	11/01/92	12/04/92	12/04/92	04/16/93	04/16/93	05/30/93
	10/11/93	06/10/94	12	36	146	49	243	10/11/93	10/22/93	10/22/93	11/27/93	11/27/93	04/22/94	04/22/94	06/10/94
	10/05/94	05/27/95	12	35	141	47	235	10/05/94	10/16/94	10/16/94	11/20/94	11/20/94	04/10/95	04/10/95	05/27/95
	10/02/95	05/17/96	11	34	137	46	228	10/02/95	10/12/95	10/12/95	11/15/95	11/15/95	03/31/96	03/31/96	05/17/96
	09/29/96	05/22/97	12	35	142	47	236	09/29/96	10/10/96	10/10/96	11/14/96	11/14/96	04/05/97	04/05/97	05/22/97
	10/24/97	06/01/98	11	33	133	44	221	10/24/97	11/03/97	11/03/97	12/06/97	12/06/97	04/18/98	04/18/98	06/01/98

Harvest and Planting Dates of IID Crops (Based on IID Provided Cropping Dates, 1989-1998)

- estimated dates

Crop	Plant	Harvest	Initial Period	Develp. Period	Mid. Period	Late Period	Total Period	Initial Period Begin	Initial Period End	Develop. Period Begin	Develop. Period End	Mid Period Begin	Mid Period End	End Period Begin	End Period End
Oats and Barley	11/14/89	05/12/90	27	45	72	36	180	11/14/89	12/10/89	12/10/89	01/24/90	01/24/90	04/06/90	04/06/90	05/12/90
	12/14/90	05/31/91	25	42	68	34	169	12/14/90	01/07/91	01/07/91	02/18/91	02/18/91	04/27/91	04/27/91	05/31/91
	11/07/91	04/28/92	26	44	70	35	175	11/07/91	12/02/91	12/02/91	01/15/92	01/15/92	03/25/92	03/25/92	04/28/92
	11/15/92	05/05/93	26	43	69	34	172	11/15/92	12/10/92	12/10/92	01/22/93	01/22/93	04/01/93	04/01/93	05/05/93
	11/05/93	04/15/94	24	41	65	32	162	11/05/93	11/28/93	11/28/93	01/08/94	01/08/94	03/14/94	03/14/94	04/15/94
	11/15/94	05/05/95	26	43	69	34	172	11/15/94	12/10/94	12/10/94	01/22/95	01/22/95	04/01/95	04/01/95	05/05/95
	11/15/95	05/05/96	26	43	69	35	173	11/15/95	12/10/95	12/10/95	01/22/96	01/22/96	03/31/96	03/31/96	05/05/96
	11/03/96	05/15/97	29	49	78	39	195	11/03/96	12/01/96	12/01/96	01/19/97	01/19/97	04/07/97	04/07/97	05/15/97
	11/16/97	04/21/98	24	39	63	31	157	11/16/97	12/09/97	12/09/97	01/17/98	01/17/98	03/21/98	03/21/98	04/21/98
Tomatoes	01/25/90	06/25/90	23	38	61	30	152	01/25/90	02/16/90	02/16/90	03/26/90	03/26/90	05/26/90	05/26/90	06/25/90
	01/29/91	06/26/91	22	37	60	30	149	01/29/91	02/19/91	02/19/91	03/28/91	03/28/91	05/27/91	05/27/91	06/26/91
	01/29/92	06/20/92	22	36	58	29	145	01/29/92	02/19/92	02/19/92	03/26/92	03/26/92	05/23/92	05/23/92	06/20/92
	01/29/93	06/19/93	21	36	57	28	142	01/29/93	02/18/93	02/18/93	03/26/93	03/26/93	05/22/93	05/22/93	06/19/93
	01/15/94	06/25/94	24	41	65	32	162	01/15/94	02/07/94	02/07/94	03/20/94	03/20/94	05/24/94	05/24/94	06/25/94
	01/23/95	07/01/95	24	40	64	32	160	01/23/95	02/15/95	02/15/95	03/27/95	03/27/95	05/30/95	05/30/95	07/01/95
	01/21/96	06/16/96	22	37	59	30	148	01/21/96	02/11/96	02/11/96	03/19/96	03/19/96	05/17/96	05/17/96	06/16/96
	01/24/97	06/22/97	23	38	60	30	151	01/24/97	02/15/97	02/15/97	03/25/97	03/25/97	05/24/97	05/24/97	06/22/97
Potatoes	12/02/89	04/19/90	28	35	49	28	140	12/02/89	12/29/89	12/29/89	02/02/90	02/02/90	03/23/90	03/23/90	04/19/90
	12/25/90	04/24/91	24	30	42	24	120	12/25/90	01/17/91	01/17/91	02/16/91	02/16/91	03/30/91	03/30/91	04/24/91
	11/18/91	04/18/92	31	38	54	31	154	11/18/91	12/18/91	12/18/91	01/25/92	01/25/92	03/19/92	03/19/92	04/18/92
	11/23/92	04/20/93	30	37	52	30	149	11/23/92	12/22/92	12/22/92	01/28/93	01/28/93	03/21/93	03/21/93	04/20/93
	11/30/93	04/22/94	29	36	50	29	144	11/30/93	12/28/93	12/28/93	02/02/94	02/02/94	03/24/94	03/24/94	04/22/94
	12/23/94	04/19/95	24	30	41	24	119	12/23/94	01/15/95	01/15/95	02/14/95	02/14/95	03/27/95	03/27/95	04/19/95
	12/05/95	04/10/96	26	32	45	26	129	12/05/95	12/30/95	12/30/95	01/31/96	01/31/96	03/16/96	03/16/96	04/10/96
	12/03/96	04/20/97	28	35	49	28	140	12/03/96	12/30/96	12/30/96	02/03/97	02/03/97	03/24/97	03/24/97	04/20/97
	11/11/97	04/17/98	32	40	55	32	159	11/11/97	12/12/97	12/12/97	01/21/98	01/21/98	03/17/98	03/17/98	04/17/98
Broccoli	09/22/89	02/12/90	36	50	43	14	143	09/22/89	10/27/89	10/27/89	12/16/89	12/16/89	01/28/90	01/28/90	02/12/90
	10/03/90	02/22/91	36	50	43	14	143	10/03/90	11/07/90	11/07/90	12/27/90	12/27/90	02/08/91	02/08/91	02/22/91
	09/26/91	02/20/92	37	52	44	15	148	09/26/91	11/01/91	11/01/91	12/23/91	12/23/91	02/05/92	02/05/92	02/20/92
	10/10/92	02/27/93	35	49	42	14	140	10/10/92	11/13/92	11/13/92	01/01/93	01/01/93	02/12/93	02/12/93	02/27/93
	10/01/93	02/22/94	36	51	44	15	146	10/01/93	11/05/93	11/05/93	12/26/93	12/26/93	02/08/94	02/08/94	02/22/94
	10/01/94	02/24/95	37	51	44	15	147	10/01/94	11/06/94	11/06/94	12/27/94	12/27/94	02/09/95	02/09/95	02/24/95
	10/06/95	02/17/96	34	47	41	14	136	10/06/95	11/08/95	11/08/95	12/25/95	12/25/95	02/04/96	02/04/96	02/17/96
	10/05/96	02/21/97	35	49	42	14	140	10/05/96	11/08/96	11/08/96	12/27/96	12/27/96	02/07/97	02/07/97	02/21/97
	10/06/97	02/27/98	36	51	44	15	146	10/06/97	11/10/97	11/10/97	12/31/97	12/31/97	02/13/98	02/13/98	02/27/98
Cabbage	10/04/89	03/15/90	41	57	49	16	163	10/04/89	11/13/89	11/13/89	01/09/90	01/09/90	02/27/90	02/27/90	03/15/90
	10/01/90	03/15/91	42	58	50	17	167	10/01/90	11/11/90	11/11/90	01/08/91	01/08/91	02/27/91	02/27/91	03/15/91
	09/12/91	03/02/92	43	61	52	17	173	09/12/91	10/24/91	10/24/91	12/24/91	12/24/91	02/14/92	02/14/92	03/02/92
	09/18/92	03/01/93	41	58	50	17	166	09/18/92	10/28/92	10/28/92	12/25/92	12/25/92	02/13/93	02/13/93	03/01/93
	09/15/93	03/17/94	46	64	55	18	183	09/15/93	10/30/93	10/30/93	01/02/94	01/02/94	02/26/94	02/26/94	03/17/94
	10/01/94	03/09/95	40	56	48	16	160	10/01/94	11/09/94	11/09/94	01/04/95	01/04/95	02/21/95	02/21/95	03/09/95
	10/01/95	03/06/96	40	55	47	16	158	10/01/95	11/09/95	11/09/95	01/03/96	01/03/96	02/19/96	02/19/96	03/06/96
	09/26/96	02/25/97	38	54	46	15	153	09/26/96	11/02/96	11/02/96	12/26/96	12/26/96	02/10/97	02/10/97	02/25/97
	09/23/97	03/02/98	40	56	48	16	160	09/23/97	11/01/97	11/01/97	12/27/97	12/27/97	02/13/98	02/13/98	03/02/98

Harvest and Planting Dates of IID Crops (Based on IID Provided Cropping Dates, 1989-1998)

(shaded) - estimated dates

Crop	Plant	Harvest	Initial Period	Develp. Period	Mid. Period	Late Period	Total Period	Initial Period Begin	Initial Period End	Develop. Period Begin	Develop. Period End	Mid Period Begin	Mid Period End	End Period Begin	End Period End
Cauliflower	09/22/89	02/20/90	38	53	46	15	152	09/22/89	10/29/89	10/29/89	12/21/89	12/21/89	02/05/90	02/05/90	02/20/90
	09/20/90	02/19/91	38	54	46	15	153	09/20/90	10/27/90	10/27/90	12/20/90	12/20/90	02/04/91	02/04/91	02/19/91
	09/17/91	02/18/92	39	54	47	16	156	09/17/91	10/25/91	10/25/91	12/18/91	12/18/91	02/03/92	02/03/92	02/18/92
	10/02/92	03/01/93	38	53	45	15	151	10/02/92	11/08/92	11/08/92	12/31/92	12/31/92	02/14/93	02/14/93	03/01/93
	09/13/93	02/27/94	42	59	50	17	168	09/13/93	10/24/93	10/24/93	12/22/93	12/22/93	02/10/94	02/10/94	02/27/94
	10/12/94	02/08/95	30	42	36	12	120	10/12/94	11/10/94	11/10/94	12/22/94	12/22/94	01/27/95	01/27/95	02/08/95
	09/27/95	02/06/96	33	47	40	13	133	09/27/95	10/29/95	10/29/95	12/15/95	12/15/95	01/24/96	01/24/96	02/06/96
	10/11/96	02/21/97	34	47	40	13	134	10/11/96	11/13/96	11/13/96	12/30/96	12/30/96	02/08/97	02/08/97	02/21/97
	10/08/97	02/25/98	35	49	42	14	140	10/08/97	11/11/97	11/11/97	12/30/97	12/30/97	02/10/98	02/10/98	02/25/98
Corn, Ear	02/04/90	05/28/90	17	34	57	6	114	02/04/90	02/20/90	02/20/90	03/26/90	03/26/90	05/22/90	05/22/90	05/28/90
	02/10/91	06/09/91	18	36	60	6	120	02/10/91	02/27/91	02/27/91	04/04/91	04/04/91	06/03/91	06/03/91	06/09/91
	01/20/92	05/21/92	18	37	62	6	123	01/20/92	02/06/92	02/06/92	03/14/92	03/14/92	05/15/92	05/15/92	05/21/92
	02/23/93	06/15/93	17	34	57	6	114	02/23/93	03/11/93	03/11/93	04/14/93	04/14/93	06/10/93	06/10/93	06/15/93
	01/08/94	06/10/94	23	46	77	8	154	01/08/94	01/30/94	01/30/94	03/17/94	03/17/94	06/02/94	06/02/94	06/10/94
	01/19/95	06/16/95	22	45	75	7	149	01/19/95	02/09/95	02/09/95	03/26/95	03/26/95	06/09/95	06/09/95	06/16/95
	02/02/96	06/28/96	22	44	74	7	147	02/02/96	02/23/96	02/23/96	04/07/96	04/07/96	06/20/96	06/20/96	06/28/96
	02/11/97	07/04/97	22	43	72	7	144	02/11/97	03/04/97	03/04/97	04/16/97	04/16/97	06/27/97	06/27/97	07/04/97
	12/19/97	06/10/98	26	52	87	9	174	12/19/97	01/13/98	01/13/98	03/06/98	03/06/98	06/01/98	06/01/98	06/10/98
Alfalfa Seed	06/10/90	09/01/90	4	9	28	42	83	06/10/90	06/13/90	06/13/90	06/22/90	06/22/90	07/20/90	07/20/90	09/01/90
	06/10/91	08/22/91	4	8	24	37	73	06/10/91	06/13/91	06/13/91	06/21/91	06/21/91	07/15/91	07/15/91	08/22/91
	06/10/92	08/21/92	4	8	24	37	73	06/10/92	06/13/92	06/13/92	06/21/92	06/21/92	07/15/92	07/15/92	08/21/92
	06/10/93	08/22/93	4	8	24	37	73	06/10/93	06/13/93	06/13/93	06/21/93	06/21/93	07/15/93	07/15/93	08/22/93
	06/10/94	09/01/94	4	9	28	42	83	06/10/94	06/13/94	06/13/94	06/22/94	06/22/94	07/20/94	07/20/94	09/01/94
	06/10/95	08/30/95	4	9	27	41	81	06/10/95	06/13/95	06/13/95	06/22/95	06/22/95	07/19/95	07/19/95	08/30/95
	06/10/96	08/27/96	4	9	26	40	79	06/10/96	06/13/96	06/13/96	06/22/96	06/22/96	07/18/96	07/18/96	08/27/96
	06/10/97	08/26/97	4	9	26	39	78	06/10/97	06/13/97	06/13/97	06/22/97	06/22/97	07/18/97	07/18/97	08/26/97

APPENDIX 6F

Monthly Potential ETc (inches) for the Crops Grown in Imperial Irrigation District (1990-1997)

Monthly ETc (in) for 1990

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	2.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.51	3.87	2.86	10.7
Alfalfa	0.00	2.09	5.99	7.94	11.09	11.19	11.33	9.36	7.63	2.74	0.00	0.00	69.4
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	4.28	6.47	5.05	0.00	0.00	0.00	0.00	15.8
Sudan	0.00	0.00	0.00	5.41	10.37	10.77	10.90	9.00	7.34	0.87	0.00	0.00	54.7
Wheat	1.33	3.12	6.98	9.48	6.11	0.00	0.00	0.00	0.00	0.00	0.00	1.12	28.2
Bermuda, spring (seed)	0.00	0.00	1.47	6.95	10.41	7.96	0.00	0.00	0.00	0.00	0.00	0.00	26.8
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.56	11.21	9.66	7.85	4.62	0.00	0.00	36.9
Sugar Beets	3.66	4.26	7.24	8.96	9.14	0.00	0.00	1.36	2.28	4.26	3.40	3.06	47.6
Lettuce - all	3.06	3.35	0.00	0.00	0.00	0.00	0.00	1.29	0.07	4.09	3.85	2.75	18.5
Carrots	3.18	3.72	6.33	8.29	5.46	0.00	0.00	0.87	0.48	1.92	3.04	2.59	35.9
Cantaloupes - Spring	0.00	1.75	3.66	6.92	9.89	7.01							29.2
Cantaloupes - Fall							1.41	5.28	6.58	4.95	0.84	0.00	19.1
Cotton (upland and PIMA)	0.00	1.23	1.32	2.78	5.97	9.23	12.32	10.80	7.42	1.94	0.00	0.00	53.0
Honeydew	1.12	2.45	5.24	8.30	11.62	6.73	0.00	0.00	0.00	0.00	0.00	0.00	35.5
Watermelon	0.74	2.38	5.15	8.30	11.60	4.93	0.00	0.00	0.00	0.00	0.00	0.00	33.1
Onions	3.23	3.76	6.40	8.37	7.87	0.00	0.00	1.31	1.33	1.32	3.25	2.74	39.6
Onion Seed	3.23	3.76	6.39	8.46	11.46	8.34	0.00	1.74	1.14	4.83	3.66	2.90	55.9
Rye - Pastured	3.21	3.74	6.36	6.70	0.00	0.00	0.00	0.00	1.24	5.45	3.93	2.89	33.5
Oats and Barley	3.08	4.10	6.98	6.71	1.38	0.00	0.00	0.00	0.00	0.00	1.22	0.66	24.1
Misc. Field Crops	1.10	1.87	6.94	9.78	6.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.9
Tomatoes	0.56	2.30	6.60	10.04	13.92	8.94	0.00	0.00	0.00	0.00	0.00	0.00	42.4
Potatoes	3.30	4.11	6.88	3.96	0.00	0.00	0.00	0.00	0.00	0.00	1.35	1.91	21.5
Broccoli	3.16	1.00	0.00	0.00	0.00	0.00	0.00	1.36	1.35	3.81	2.84	2.65	16.2
Cabbage	3.16	3.70	2.51	0.00	0.00	0.00	0.00	0.00	0.14	3.92	2.75	2.50	18.7
Cauliflower	3.17	2.30	0.00	0.00	0.00	0.00	0.00	1.36	3.21	3.94	3.08	2.76	19.8
Corn, Ear	0.81	2.58	6.48	9.73	11.71	0.00	0.00	0.00	0.00	0.00	0.00	0.52	31.8
Misc. Garden Crops (use peppers)	3.49	3.93	2.45	0.00	0.00	0.00	0.00	0.29	1.30	3.12	3.02	3.05	20.6
Asparagas	1.49	1.74	2.96	6.03	11.09	11.23	11.37	9.39	6.85	3.72	1.54	1.34	68.7
Citrus	2.09	2.43	4.14	5.50	7.81	8.04	8.28	6.87	5.60	4.17	2.78	1.95	59.7
Duck Ponds	2.09	2.40	3.39	3.37	4.38	4.42	4.47	1.55	3.33	3.71	2.60	1.88	37.6
Jojoba	1.49	1.76	3.73	5.09	7.11	7.18	7.26	6.00	4.89	3.64	2.32	1.40	51.9
Fish Farms	2.09	2.43	4.14	5.48	7.66	7.73	7.82	6.46	5.27	3.92	2.60	1.82	57.4
Peach Trees	1.64	1.92	4.05	6.91	10.96	11.10	11.23	9.28	7.57	5.63	3.72	2.11	76.1
Perm. Pasture + Misc.	0.00	0.05	3.08	7.41	10.93	11.03	11.16	9.22	7.48	4.23	0.00	0.00	64.6

Monthly ETc (in) for 1991

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.54	3.65	1.96	9.0
Alfalfa	0.00	1.75	4.68	6.70	8.49	9.04	9.60	9.37	7.11	2.68	0.00	0.00	59.4
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	3.55	5.46	3.41	0.00	0.00	0.00	0.00	12.4
Sudan	0.00	0.00	0.25	4.88	8.06	8.69	9.22	9.00	5.92	0.00	0.00	0.00	46.0
Wheat	1.28	2.71	5.49	8.00	4.56	0.00	0.00	0.00	0.00	0.00	0.00	1.15	23.2
Bermuda, spring (seed)	0.00	0.00	1.09	5.77	7.95	6.43	0.00	0.00	0.00	0.00	0.00	0.00	21.2
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.04	9.52	9.66	7.30	4.81	0.00	0.00	34.3
Sugar Beets	2.81	3.59	5.65	7.85	8.33	0.93	0.00	1.36	1.88	4.28	3.15	2.07	41.9
Lettuce - all	2.35	2.82	0.00	0.00	0.00	0.00	0.00	1.35	0.01	4.95	3.55	1.89	16.9
Carrots	2.46	3.14	4.94	6.89	0.92	0.00	0.00	1.35	0.01	3.64	2.96	1.87	28.2
Cantaloupes - Spring	0.00	1.69	2.82	5.78	7.57	6.54							24.4
Cantaloupes - Fall							1.71	6.26	6.24	1.59	0.00	0.00	15.8
Cotton (upland and PIMA)	0.00	1.09	0.88	2.32	4.51	7.55	10.58	10.76	6.21	0.79	0.00	0.00	44.7
Honeydew	1.03	2.06	4.07	7.00	8.88	5.39	0.00	0.00	0.00	0.00	0.00	0.00	28.4
Watermelon	0.00	2.12	3.60	6.80	8.88	7.48	0.00	0.00	0.00	0.00	0.00	0.00	28.9
Onions	2.49	3.17	4.99	7.05	5.86	0.00	0.00	1.35	1.35	1.98	3.05	1.89	33.2
Onion Seed	2.48	3.17	4.98	7.14	8.74	6.21	1.30	1.38	1.54	4.97	3.54	1.98	47.4
Rye - Pastured	2.47	3.15	4.96	6.31	0.00	0.00	0.00	0.00	0.00	3.07	3.49	1.98	25.4
Oats and Barley	1.26	3.19	5.44	7.73	5.09	0.00	0.00	0.00	0.00	1.34	0.90	1.10	26.0
Misc. Field Crops	1.07	1.61	5.46	8.24	4.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.8
Tomatoes	0.23	1.86	4.95	8.47	10.66	7.65	0.00	0.00	0.00	0.00	0.00	0.00	33.8
Potatoes	2.36	3.41	5.45	4.61	0.00	0.00	0.00	0.00	0.00	1.36	2.93	1.87	22.0
Broccoli	2.43	2.24	0.00	0.00	0.00	0.00	0.00	1.36	2.32	3.97	2.79	1.85	17.0
Cabbage	2.44	3.12	2.25	0.00	0.00	0.00	0.00	0.00	2.97	4.00	2.91	1.87	19.6
Cauliflower	2.44	1.91	0.00	0.00	0.00	0.00	0.00	1.36	1.17	2.62	2.59	1.86	13.9
Corn, Ear	0.79	2.11	4.49	8.20	10.38	2.57	0.00	0.00	0.00	0.00	0.00	1.24	29.8
Misc. Garden Crops (use peppers)	2.69	3.32	2.06	0.00	0.00	0.00	0.00	0.29	1.30	3.20	2.86	2.08	17.8
Asparagas	1.15	1.47	2.31	4.87	8.46	9.07	9.62	9.39	6.44	3.81	1.42	0.92	58.9
Citrus	1.61	2.05	3.23	4.63	5.96	6.49	7.01	6.87	5.22	4.22	2.57	1.34	51.2
Duck Ponds	1.61	2.03	2.66	2.87	3.35	3.57	3.78	1.56	3.11	3.74	2.41	1.29	32.0
Jojoba	1.15	1.48	2.90	4.29	5.44	5.79	6.15	6.00	4.56	3.68	2.13	0.96	44.5
Fish Farms	1.61	2.05	3.23	4.63	5.85	6.24	6.62	6.46	4.91	3.97	2.41	1.25	49.2
Peach Trees	1.26	1.62	3.12	5.73	8.36	8.96	9.50	9.28	7.04	5.69	3.44	1.47	65.5
Perm. Pasture + Misc.	0.00	0.00	2.32	6.13	8.35	8.90	9.45	9.22	6.97	4.53	0.00	0.00	55.9

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Monthly ETc (in) for 1992

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	2.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23	3.38	2.04	8.7
Alfalfa	0.04	2.00	4.28	6.70	8.27	9.83	10.03	9.42	7.23	2.70	0.00	0.00	60.5
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	3.59	5.71	3.59	0.00	0.00	0.00	0.00	12.9
Sudan	0.00	0.00	0.74	5.21	7.95	9.44	9.63	9.05	6.34	0.00	0.00	0.00	48.4
Wheat	1.23	2.94	5.04	7.99	4.66	0.00	0.00	0.00	0.00	0.00	0.77	0.91	23.5
Bermuda, spring (seed)	0.00	0.00	1.06	5.87	7.76	6.79	0.00	0.00	0.00	0.00	0.00	0.00	21.5
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.16	9.96	9.72	7.42	4.15	0.00	0.00	34.4
Sugar Beets	3.05	3.79	5.16	7.90	8.31	1.95	0.00	1.67	2.68	3.83	3.06	2.23	43.6
Lettuce - all	2.53	1.29	0.00	0.00	0.00	0.00	0.00	1.31	0.05	3.63	3.34	1.96	14.1
Carrots	2.67	3.32	4.51	6.17	0.00	0.00	0.00	1.29	0.07	2.12	2.68	1.90	24.7
Cantaloupes - Spring	0.91	1.71	3.21	5.99	7.06	3.48							22.4
Cantaloupes - Fall							1.38	4.18	6.12	4.32	0.29	0.00	16.3
Cotton (upland and PIMA)	0.00	1.16	0.83	2.34	4.57	8.52	11.26	10.65	5.72	0.00	0.00	0.00	45.1
Honeydew	1.67	2.30	4.08	7.01	8.62	4.34	0.00	0.00	0.00	0.00	0.00	0.00	28.0
Watermelon	1.05	2.20	3.89	7.01	8.57	3.00	0.00	0.00	0.00	0.00	0.00	0.00	25.7
Onions	2.69	3.35	4.56	7.06	6.43	0.00	0.00	1.35	1.35	1.58	2.87	1.99	33.2
Onion Seed	2.69	3.35	4.56	7.13	8.32	4.60	1.36	1.36	3.06	4.47	3.38	2.07	46.3
Rye - Pastured	2.68	3.33	4.54	5.68	0.00	0.00	0.00	0.00	0.00	2.29	3.23	2.06	23.8
Oats and Barley	2.81	3.65	4.90	3.70	0.00	0.00	0.00	0.00	0.00	1.12	0.69	0.86	17.7
Misc. Field Crops	1.09	1.77	5.00	8.28	5.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.3
Tomatoes	0.22	2.01	4.62	8.46	10.32	6.62	0.00	0.00	0.00	0.00	0.00	0.00	32.2
Potatoes	2.84	3.66	4.86	3.50	0.00	0.00	0.00	0.00	0.00	1.35	1.94	1.92	20.1
Broccoli	2.64	1.83	0.00	0.00	0.00	0.00	0.00	1.25	1.31	2.32	2.37	1.81	13.5
Cabbage	2.65	3.22	0.23	0.00	0.00	0.00	0.00	0.00	2.02	3.49	2.61	1.93	16.1
Cauliflower	2.65	1.74	0.00	0.00	0.00	0.00	0.00	1.35	1.36	3.33	2.43	1.84	14.7
Corn, Ear	1.42	2.68	5.08	8.20	6.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.3
Misc. Garden Crops (use pe	2.91	3.48	1.66	0.00	0.00	0.00	0.00	0.29	1.30	2.69	2.62	2.18	17.1
Asparagas	1.25	1.55	2.11	4.96	8.24	9.85	10.05	9.44	6.60	3.42	1.41	0.96	59.8
Citrus	1.74	2.17	2.95	4.63	5.81	7.05	7.32	6.91	5.30	3.70	2.41	1.44	51.4
Duck Ponds	1.74	2.13	2.42	2.85	3.26	3.87	3.95	1.65	3.15	3.26	2.26	1.34	31.9
Jojoba	1.25	1.57	2.67	4.29	5.30	6.30	6.42	6.04	4.63	3.23	2.02	1.03	44.7
Fish Farms	1.74	2.17	2.95	4.62	5.71	6.78	6.92	6.50	4.98	3.48	2.26	1.34	49.5
Peach Trees	1.37	1.71	2.86	5.77	8.15	9.73	9.93	9.33	7.16	5.00	3.23	1.57	65.8
Perm. Pasture + Misc.	0.00	0.00	2.14	6.20	8.15	9.68	9.87	9.28	7.08	3.94	0.00	0.00	56.3

Monthly ETc (in) for 1993

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	1.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.59	3.67	2.78	9.7
Alfalfa	0.00	1.89	5.59	6.75	9.16	10.56	10.60	10.42	8.50	3.22	0.00	0.00	66.7
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	3.86	6.04	4.15	0.00	0.00	0.00	0.00	14.0
Sudan	0.00	0.00	0.76	5.11	8.78	10.14	10.19	10.02	7.46	0.00	0.00	0.00	52.4
Wheat	1.65	3.48	6.68	8.01	2.43	0.00	0.00	0.00	0.00	0.00	1.10	1.25	24.6
Bermuda, spring (seed)	0.00	0.00	1.38	5.81	8.58	7.44	0.00	0.00	0.00	0.00	0.00	0.00	23.2
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.45	10.50	10.75	8.73	5.53	0.00	0.00	39.0
Sugar Beets	2.42	3.75	6.75	7.84	8.88	0.99	0.00	2.22	2.56	4.90	3.38	3.07	46.8
Lettuce - all	2.02	2.23	0.00	0.00	0.00	0.00	0.00	1.31	0.05	4.79	3.63	2.68	16.7
Carrots	2.12	3.28	5.91	6.32	0.00	0.00	0.00	1.35	0.01	3.65	2.97	2.64	28.2
Cantaloupes - Spring	0.00	1.65	3.37	5.81	8.15	6.79							25.8
Cantaloupes - Fall							1.40	5.08	7.38	4.39	0.00	0.00	18.2
Cotton (upland and PIMA	0.00	1.27	1.35	2.38	5.13	8.88	11.64	12.02	8.12	1.91	0.00	0.00	52.7
Honeydew	0.00	2.11	4.25	6.79	9.58	9.04	0.00	0.00	0.00	0.00	0.00	0.00	31.8
Watermelon	0.00	2.11	4.37	6.92	9.58	5.41	0.00	0.00	0.00	0.00	0.00	0.00	28.4
Onions	2.14	3.31	5.96	7.00	4.67	0.00	0.00	1.36	1.36	2.54	3.14	2.72	34.2
Onion Seed	2.14	3.31	5.96	7.18	8.97	3.26	1.36	1.36	2.72	5.62	3.64	2.82	48.3
Rye - Pastured	2.13	3.30	5.93	5.84	0.00	0.00	0.00	0.00	0.00	5.11	3.63	2.81	28.7
Oats and Barley	2.07	3.62	6.51	5.09	0.43	0.00	0.00	0.00	0.00	1.35	0.92	1.84	21.8
Misc. Field Crops	1.06	1.69	6.53	8.32	4.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.5
Tomatoes	0.15	1.98	6.05	8.52	11.35	6.51	0.00	0.00	0.00	0.00	0.00	0.00	34.6
Potatoes	2.24	3.62	6.40	3.91	0.00	0.00	0.00	0.00	0.00	1.33	1.47	2.61	21.6
Broccoli	2.10	2.88	0.00	0.00	0.00	0.00	0.00	1.36	1.49	4.42	2.72	2.58	17.5
Cabbage	2.11	3.19	0.24	0.00	0.00	0.00	0.00	0.00	2.87	4.42	2.78	2.54	18.2
Cauliflower	2.11	3.17	0.12	0.00	0.00	0.00	0.87	1.51	3.62	4.45	2.94	2.67	21.4
Corn, Ear	1.18	1.30	4.50	7.96	11.21	6.59	0.00	0.00	0.00	0.00	0.66	0.66	34.1
Misc. Garden Crops (use p	2.32	3.45	2.22	0.00	0.00	0.00	0.00	0.58	1.24	3.17	2.88	2.97	18.8
Asparagas	0.99	1.53	2.76	4.92	9.12	10.58	10.63	10.45	7.73	4.31	1.50	1.30	65.8
Citrus	1.39	2.15	3.86	4.66	6.44	7.57	7.74	7.64	6.23	4.75	2.60	2.01	57.0
Duck Ponds	1.39	2.11	3.16	2.89	3.61	4.16	4.18	2.04	3.64	4.16	2.46	1.83	35.6
Jojoba	0.99	1.54	3.47	4.32	5.87	6.76	6.79	6.68	5.45	4.15	2.18	1.45	49.7
Fish Farms	1.39	2.15	3.86	4.66	6.32	7.28	7.32	7.19	5.86	4.47	2.44	1.88	54.8
Peach Trees	1.09	1.69	3.75	5.78	9.02	10.46	10.50	10.32	8.42	6.42	3.49	2.21	73.1
Perm. Pasture + Misc.	0.00	0.00	2.80	6.18	9.02	10.39	10.44	10.26	8.33	5.11	0.00	0.00	62.5

Monthly ETc (in) for 1994

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	2.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.45	3.88	1.99	9.7
Alfalfa	0.00	1.95	5.29	7.59	9.45	10.82	11.43	10.21	8.53	3.35	0.00	0.00	68.6
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	4.00	6.52	5.54	0.00	0.00	0.00	0.00	16.1
Sudan	0.00	0.00	0.94	5.78	9.07	10.40	10.98	9.81	8.19	0.97	0.00	0.00	56.1
Wheat	2.55	3.65	6.32	9.01	3.09	0.00	0.00	0.00	0.00	0.00	1.24	1.22	27.1
Bermuda, spring (seed)	0.00	0.00	1.28	6.52	8.87	7.71	0.00	0.00	0.00	0.00	0.00	0.00	24.4
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.32	11.25	10.53	8.76	5.08	0.00	0.00	38.9
Sugar Beets	3.52	3.82	6.39	8.71	8.79	0.00	0.00	2.38	2.65	4.68	3.61	2.20	46.8
Lettuce - all	2.92	1.29	0.00	0.00	0.00	0.00	0.00	1.19	0.17	3.90	3.85	1.91	15.2
Carrots	3.08	3.34	5.59	6.91	0.00	0.00	0.00	1.13	0.22	1.98	3.10	1.87	27.2
Cantaloupes - Spring	1.40	1.77	4.11	6.78	8.25	5.79							28.1
Cantaloupes - Fall							1.37	4.52	7.27	5.19	0.25	0.00	18.6
Cotton (upland and PIMA)	0.00	1.32	1.56	2.77	5.61	9.44	12.70	11.76	7.96	1.83	0.00	0.00	54.9
Honeydew	1.67	2.25	4.83	7.94	9.89	8.50	0.00	0.00	0.00	0.00	0.00	0.00	35.1
Watermelon	1.84	2.27	4.89	7.94	9.89	8.84	0.00	0.00	0.00	0.00	0.00	0.00	35.7
Onions	3.11	3.38	5.64	7.93	6.28	0.00	0.00	1.36	1.35	2.00	3.32	1.94	36.3
Onion Seed	3.10	3.37	5.64	8.08	9.60	6.17	0.00	1.36	1.36	5.16	3.66	2.02	49.5
Rye - Pastured	3.09	3.36	5.62	8.04	1.62	0.00	0.00	0.00	0.67	5.43	3.91	2.01	33.7
Oats and Barley	3.35	3.68	5.26	1.47	0.00	0.00	0.00	0.00	0.00	1.18	0.79	0.84	16.6
Misc. Field Crops	1.10	1.82	6.23	9.33	5.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.7
Tomatoes	1.04	2.43	6.26	9.58	11.80	8.78	0.00	0.00	0.00	0.00	0.00	0.00	39.9
Potatoes	3.18	3.69	6.08	4.84	0.00	0.00	0.00	0.00	0.00	0.00	1.35	1.69	20.8
Broccoli	3.04	2.32	0.00	0.00	0.00	0.00	0.00	1.36	1.49	4.20	2.86	1.83	17.1
Cabbage	3.06	3.32	2.43	0.00	0.00	0.00	0.00	0.00	0.14	4.20	2.79	1.76	17.7
Cauliflower	3.06	2.87	0.00	0.00	0.00	0.00	0.00	1.13	1.35	2.83	2.83	1.87	15.9
Corn, Ear	2.23	2.86	6.27	9.29	11.57	3.86	0.00	0.00	0.00	0.00	0.00	1.25	37.3
Misc. Garden Crops (use peppers)	3.36	3.50	1.85	0.00	0.00	0.00	0.00	0.29	1.30	2.96	3.03	2.11	18.4
Asparagas	1.44	1.56	2.62	5.60	9.44	10.85	11.46	10.23	7.70	4.02	1.53	0.93	67.4
Citrus	2.01	2.19	3.65	5.24	6.64	7.76	8.35	7.49	6.25	4.47	2.77	1.35	58.2
Duck Ponds	2.01	2.15	2.99	3.26	3.73	4.27	4.51	1.77	3.73	3.98	2.60	1.31	36.3
Jojoba	1.44	1.58	3.30	4.86	6.06	6.93	7.32	6.54	5.46	3.90	2.31	0.98	50.7
Fish Farms	2.01	2.19	3.65	5.24	6.52	7.46	7.89	7.04	5.88	4.20	2.60	1.26	56.0
Peach Trees	1.58	1.73	3.55	6.48	9.31	10.72	11.32	10.11	8.44	6.04	3.72	1.51	74.5
Perm. Pasture + Misc.	0.00	0.00	2.66	6.93	9.31	10.65	11.26	10.05	8.36	4.79	0.00	0.00	64.0

Monthly ETc (in) for 1995

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	1.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49	3.50	2.49	9.5
Alfalfa	0.00	2.06	5.76	8.43	9.82	11.18	10.78	10.20	8.88	3.14	0.00	0.00	70.3
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	4.15	6.15	5.16	0.00	0.00	0.00	0.00	15.5
Sudan	0.00	0.00	0.00	2.59	7.97	10.74	10.36	9.80	8.29	0.00	0.00	0.00	49.7
Wheat	2.26	4.10	6.87	9.74	1.73	0.00	0.00	0.00	0.00	0.00	1.18	1.30	27.2
Bermuda, spring (seed)	0.00	0.00	1.50	7.23	9.20	7.83	0.00	0.00	0.00	0.00	0.00	0.00	25.8
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.46	10.66	10.52	9.12	5.25	0.00	0.00	39.0
Sugar Beets	2.90	4.23	6.95	9.62	8.64	0.00	0.00	1.67	3.27	4.64	3.16	2.72	47.8
Lettuce - all	2.42	2.69	0.00	0.00	0.00	0.00	0.00	0.35	1.00	3.05	3.45	2.39	15.4
Carrots	2.53	3.70	6.03	3.54	0.00	0.00	0.00	1.25	0.10	2.52	2.80	2.38	24.9
Cantaloupes - Spring	0.50	1.95	3.94	7.49	8.66	5.15							27.7
Cantaloupes - Fall							1.36	2.14	5.78	5.37	2.58	0.00	17.2
Cotton (upland and PIMA)	0.00	1.32	1.63	3.08	5.75	9.68	11.98	11.76	8.29	1.90	0.00	0.00	55.4
Honeydew	0.92	2.43	5.04	8.80	10.27	6.50	0.00	0.00	0.00	0.00	0.00	0.00	34.0
Watermelon	1.23	2.45	5.25	8.82	10.24	5.13	0.00	0.00	0.00	0.00	0.00	0.00	33.1
Onions	2.56	3.74	6.14	8.71	5.00	0.00	0.00	1.36	1.35	2.08	2.95	2.42	36.3
Onion Seed	2.56	3.73	6.14	8.97	10.01	6.34	1.35	1.36	2.99	5.36	3.46	2.53	54.8
Rye - Pastured	2.55	3.72	6.11	5.79	0.00	0.00	0.00	0.00	1.05	5.86	3.53	2.52	31.1
Oats and Barley	2.49	4.08	6.70	6.13	0.40	0.00	0.00	0.00	0.00	1.18	0.71	1.08	22.8
Misc. Field Crops	1.07	1.90	6.78	10.34	5.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.3
Tomatoes	0.49	2.31	6.37	10.64	12.38	11.75	0.00	0.00	0.00	0.00	0.00	0.00	43.9
Potatoes	2.44	4.03	6.67	4.66	0.00	0.00	0.00	0.00	0.00	1.28	1.21	2.25	22.5
Broccoli	2.51	2.90	0.00	0.00	0.00	0.00	0.00	1.35	1.35	3.45	2.54	2.32	16.4
Cabbage	2.52	3.66	1.24	0.00	0.00	0.00	0.00	0.00	0.14	4.23	2.50	2.23	16.5
Cauliflower	2.50	0.84	0.00	0.00	0.00	0.00	0.00	1.36	2.29	4.23	2.78	2.44	16.5
Corn, Ear	1.44	2.74	6.47	10.32	12.01	6.84	0.00	0.00	0.00	0.00	0.00	0.96	40.8
Misc. Garden Crops (use pep	2.77	3.91	2.16	0.00	0.00	0.00	0.00	0.29	1.30	3.13	2.71	2.66	18.9
Asparagas	1.18	1.73	2.85	6.26	9.79	11.21	10.81	10.23	7.95	4.06	1.36	1.17	68.6
Citrus	1.66	2.42	3.98	5.82	6.90	8.02	7.87	7.48	6.51	4.49	2.48	1.65	59.3
Duck Ponds	1.66	2.38	3.21	3.59	3.87	4.41	4.25	1.87	3.95	4.00	2.33	1.64	37.1
Jojoba	1.18	1.74	3.59	5.40	6.29	7.16	6.91	6.54	5.69	3.93	2.07	1.19	51.7
Fish Farms	1.66	2.42	3.98	5.82	6.77	7.71	7.44	7.04	6.13	4.23	2.33	1.54	57.0
Peach Trees	1.30	1.91	3.88	7.22	9.67	11.07	10.68	10.10	8.79	6.07	3.33	1.83	75.8
Perm. Pasture + Misc.	0.00	0.00	2.93	7.70	9.67	11.01	10.61	10.04	8.70	4.99	0.00	0.00	65.6

Monthly ETc (in) for 1996

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	2.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.69	3.95	2.92	11.2
Alfalfa	0.00	2.08	6.04	8.26	11.65	11.37	11.02	11.40	8.45	3.18	0.00	0.00	73.4
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	4.07	6.29	5.57	0.00	0.00	0.00	0.00	15.9
Sudan	0.00	0.00	0.00	0.00	5.13	9.88	10.59	10.95	8.08	0.00	0.00	0.00	44.6
Wheat	2.71	4.00	7.20	9.77	3.65	0.00	0.00	0.00	0.00	0.00	0.48	1.02	28.8
Bermuda, spring (seed)	0.00	0.00	1.49	7.10	10.94	8.22	0.00	0.00	0.00	0.00	0.00	0.00	27.7
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.53	10.94	11.76	8.68	5.59	0.00	0.00	40.5
Sugar Beets	3.65	4.17	7.29	9.63	11.44	1.11	0.00	1.67	2.86	4.98	3.54	3.13	53.5
Lettuce - all	3.04	2.12	0.00	0.00	0.00	0.00	0.00	0.71	0.65	3.71	3.90	2.79	16.9
Carrots	3.19	3.64	6.30	2.93	0.00	0.00	0.00	1.03	0.33	2.30	3.15	2.75	25.6
Cantaloupes - Spring	1.58	1.99	4.96	7.38	9.89	4.21							30.0
Cantaloupes - Fall							1.36	6.93	7.36	5.41	0.00	0.00	21.1
Cotton (upland and PIMA	0.28	1.06	2.08	3.16	7.19	10.08	12.33	13.14	8.17	2.42	0.00	0.00	59.9
Honeydew	1.22	2.40	5.29	8.61	12.19	9.85	0.00	0.00	0.00	0.00	0.00	0.00	39.6
Watermelon	1.86	2.50	5.71	8.64	12.19	6.92	0.00	0.00	0.00	0.00	0.00	0.00	37.8
Onions	3.22	3.68	6.44	8.67	8.65	0.00	0.00	1.35	1.35	2.29	3.34	2.81	41.8
Onion Seed	3.22	3.68	6.43	8.78	11.38	2.87	1.35	1.36	2.27	5.73	3.87	2.96	53.9
Rye - Pastured	3.20	3.66	6.40	3.10	0.00	0.00	0.00	0.00	1.49	6.33	4.00	2.94	31.1
Oats and Barley	3.13	4.01	7.02	6.16	0.50	0.00	0.00	0.00	0.00	1.35	1.04	1.49	24.7
Misc. Field Crops	1.05	1.89	7.03	10.21	7.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.5
Tomatoes	0.66	2.47	7.08	10.43	14.23	5.83	0.00	0.00	0.00	0.00	0.00	0.00	40.7
Potatoes	3.29	4.02	6.68	2.55	0.00	0.00	0.00	0.00	0.00	1.29	1.22	2.60	21.7
Broccoli	3.16	1.83	0.00	0.00	0.00	0.00	0.00	1.35	1.35	3.93	2.86	2.65	17.1
Cabbage	3.17	3.59	1.03	0.00	0.00	0.00	0.00	0.00	0.84	4.55	2.96	2.70	18.8
Cauliflower	3.14	0.45	0.00	0.00	0.00	0.00	0.00	1.13	1.35	3.17	2.78	2.58	14.6
Corn, Ear	0.95	2.41	5.84	10.04	14.25	12.54	0.00	0.00	0.00	0.00	0.00	0.35	46.4
Misc. Garden Crops (use	3.49	3.84	2.45	0.00	0.00	0.00	0.00	0.29	1.30	3.43	3.08	3.10	21.0
Asparagas	1.49	1.70	2.98	5.99	11.61	11.40	11.05	11.42	7.74	4.43	1.62	1.37	72.8
Citrus	2.09	2.38	4.17	5.70	8.18	8.15	8.05	8.36	6.20	4.84	2.81	2.05	63.0
Duck Ponds	2.09	2.35	3.41	3.54	4.59	4.48	4.35	2.05	3.67	4.30	2.63	1.92	39.4
Jojoba	1.49	1.72	3.76	5.29	7.46	7.29	7.06	7.30	5.41	4.22	2.35	1.49	54.8
Fish Farms	2.09	2.38	4.17	5.70	8.04	7.85	7.60	7.86	5.83	4.55	2.63	1.91	60.6
Peach Trees	1.64	1.88	4.05	7.06	11.48	11.26	10.92	11.29	8.37	6.53	3.76	2.28	80.5
Perm. Pasture + Misc.	0.00	0.00	3.04	7.54	11.47	11.20	10.85	11.22	8.28	5.31	0.00	0.00	68.9

Monthly ETc (in) for 1997

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	2.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.58	3.23	2.59	9.8
Alfalfa	0.00	2.35	6.08	7.52	9.96	11.59	10.89	10.30	7.10	3.11	0.00	0.00	68.9
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	4.23	6.21	4.83	0.00	0.00	0.00	0.00	15.3
Sudan	0.00	0.00	0.00	0.00	6.94	10.90	10.46	9.89	6.82	0.97	0.00	0.00	46.0
Wheat	2.56	4.44	7.25	8.95	3.58	0.00	0.00	0.00	0.00	0.00	1.28	1.69	29.8
Bermuda, spring (seed)	0.00	0.00	1.51	6.55	9.34	8.09	0.00	0.00	0.00	0.00	0.00	0.00	25.5
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.83	10.77	10.62	7.30	5.26	0.00	0.00	37.8
Sugar Beets	3.66	4.72	7.34	8.84	9.99	2.64	0.00	1.67	2.30	4.56	2.85	2.79	51.4
Lettuce - all	3.06	2.93	0.00	0.00	0.00	0.00	0.00	1.25	0.11	4.17	3.16	2.49	17.2
Carrots	3.20	4.13	6.33	1.85	0.00	0.00	0.00	1.29	0.07	2.60	2.57	2.47	24.5
Cantaloupes - Spring	1.21	2.15	4.73	6.72	8.45	3.87							27.1
Cantaloupes - Fall							1.38	4.49	6.00	5.27	0.48	0.00	17.6
Cotton (upland and PIMA)	0.00	1.32	1.80	2.86	6.29	10.78	12.41	11.57	5.62	0.10	0.00	0.00	52.8
Honeydew	0.93	2.71	5.46	7.87	10.29	3.21	0.00	0.00	0.00	0.00	0.00	0.00	30.5
Watermelon	1.24	2.71	5.30	7.85	10.42	8.49	0.00	0.00	0.00	0.00	0.00	0.00	36.0
Onions	3.23	4.17	6.48	7.91	7.42	0.00	0.00	1.36	1.35	2.18	2.70	2.52	39.3
Onion Seed	3.23	4.16	6.47	8.01	10.14	6.60	1.36	1.36	2.28	5.27	3.13	2.63	54.6
Rye - Pastured	3.21	4.15	6.45	3.88	0.00	0.00	0.00	0.00	0.00	2.33	3.04	2.61	25.7
Oats and Barley	3.23	4.55	7.07	6.91	2.09	0.00	0.00	0.00	0.00	1.12	0.63	1.16	26.8
Misc. Field Crops	1.12	2.10	7.10	9.28	5.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.2
Tomatoes	0.53	2.56	6.74	9.50	12.46	8.81	0.00	0.00	0.00	0.00	0.00	0.00	40.6
Potatoes	3.26	4.56	7.01	4.36	0.00	0.00	0.00	0.00	0.91	1.22	2.35	2.50	26.2
Broccoli	3.17	2.88	0.00	0.00	0.00	0.00	0.00	1.35	1.35	3.60	2.27	2.32	16.9
Cabbage	3.18	3.59	0.00	0.00	0.00	0.00	0.00	0.00	1.02	4.17	2.41	2.41	16.8
Cauliflower	3.18	2.89	0.00	0.00	0.00	0.00	0.00	1.31	1.36	3.24	2.27	2.33	16.6
Corn, Ear	0.95	2.57	5.19	8.90	12.19	14.15	1.72	0.00	0.00	0.00	0.00	1.21	46.9
Misc. Garden Crops (use pe	3.50	4.35	2.41	0.00	0.00	0.00	0.00	0.58	1.24	3.00	2.49	2.77	20.3
Asparagas	1.49	1.93	3.00	5.56	9.93	11.62	10.91	10.32	6.45	4.04	1.36	1.22	67.8
Citrus	2.09	2.70	4.20	5.20	7.00	8.31	7.95	7.55	5.21	4.44	2.34	1.90	58.9
Duck Ponds	2.09	2.66	3.43	3.20	3.93	4.57	4.29	1.85	3.07	3.93	2.14	1.70	36.9
Jojoba (1)	1.49	1.94	3.77	4.82	6.38	7.43	6.97	6.60	4.55	3.88	1.96	1.37	51.2
Fish Farms	2.09	2.70	4.20	5.19	6.87	8.00	7.51	7.10	4.90	4.18	2.19	1.77	56.7
Peach Trees	1.64	2.13	4.08	6.47	9.82	11.48	10.78	10.20	7.03	6.00	3.13	2.09	74.9
Perm. Pasture + Misc.	0.00	0.00	3.06	6.94	9.81	11.41	10.72	10.14	6.96	5.02	0.00	0.00	64.1

APPENDIX 6G

Monthly Potential NIR (inches) for the Crops Grown in Imperial Irrigation District (1990-1997)

Monthly NIR (in) for 1990

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	2.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.33	3.87	2.86	10.5
Alfalfa	0.00	2.08	5.99	7.94	11.01	11.19	11.33	8.83	7.38	2.54	0.00	0.00	68.3
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	4.28	6.47	4.64	0.00	0.00	0.00	0.00	15.4
Sudan	0.00	0.00	0.00	5.41	10.29	10.77	10.90	8.48	7.09	0.69	0.00	0.00	53.6
Wheat	1.32	3.11	6.98	9.48	6.05	0.00	0.00	0.00	0.00	0.00	0.00	1.12	28.1
Bermuda, spring (seed)	0.00	0.00	1.47	6.95	10.33	7.96	0.00	0.00	0.00	0.00	0.00	0.00	26.7
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.56	11.21	9.13	7.59	4.40	0.00	0.00	35.9
Sugar Beets	3.64	4.24	7.24	8.96	9.07	0.00	0.00	1.02	2.09	4.05	3.40	3.06	46.8
Lettuce - all	3.05	3.34	0.00	0.00	0.00	0.00	0.00	0.95	0.00	3.88	3.85	2.75	17.8
Carrots	3.17	3.71	6.33	8.29	5.40	0.00	0.00	0.55	0.32	1.74	3.04	2.59	35.1
Cantaloupes - Spring	0.00	1.74	3.66	6.92	9.81	7.01							29.1
Cantaloupes - Fall							1.41	4.86	6.35	4.73	0.84	0.00	18.2
Cotton (upland and PIMA)	0.00	1.22	1.32	2.78	5.90	9.23	12.32	10.26	7.17	1.75	0.00	0.00	52.0
Honeydew	1.11	2.43	5.24	8.30	11.53	6.73	0.00	0.00	0.00	0.00	0.00	0.00	35.3
Watermelon	0.73	2.37	5.15	8.30	11.52	4.93	0.00	0.00	0.00	0.00	0.00	0.00	33.0
Onions	3.22	3.75	6.40	8.37	7.80	0.00	0.00	0.98	1.15	1.14	3.25	2.74	38.8
Onion Seed	3.21	3.74	6.39	8.46	11.38	8.34	0.00	1.40	0.97	4.61	3.66	2.90	55.1
Rye - Pastured	3.20	3.73	6.36	6.70	0.00	0.00	0.00	0.00	1.06	5.22	3.93	2.89	33.1
Oats and Barley	3.07	4.09	6.98	6.71	1.33	0.00	0.00	0.00	0.00	0.00	1.22	0.66	24.1
Misc. Field Crops	1.09	1.86	6.94	9.78	6.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.8
Tomatoes	0.55	2.29	6.60	10.04	13.82	8.94	0.00	0.00	0.00	0.00	0.00	0.00	42.2
Potatoes	3.28	4.10	6.88	3.96	0.00	0.00	0.00	0.00	0.00	0.00	1.35	1.91	21.5
Broccoli	3.14	0.99	0.00	0.00	0.00	0.00	0.00	1.02	1.18	3.61	2.84	2.65	15.4
Cabbage	3.15	3.69	2.51	0.00	0.00	0.00	0.00	0.00	0.00	3.72	2.75	2.50	18.3
Cauliflower	3.16	2.28	0.00	0.00	0.00	0.00	0.00	1.02	3.01	3.74	3.08	2.76	19.1
Corn, Ear	0.80	2.57	6.48	9.73	11.63	0.00	0.00	0.00	0.00	0.00	0.00	0.52	31.7
Misc. Garden Crops (use peppers)	3.48	3.92	2.45	0.00	0.00	0.00	0.00	0.00	1.12	2.92	3.02	3.05	20.0
Asparagas	1.48	1.73	2.96	6.03	11.01	11.23	11.37	8.86	6.61	3.51	1.54	1.34	67.7
Citrus	2.08	2.42	4.14	5.50	7.74	8.04	8.28	6.41	5.38	3.96	2.78	1.95	58.7
Duck Ponds	2.08	2.39	3.39	3.37	4.32	4.42	4.47	1.21	3.14	3.51	2.60	1.88	36.8
Jojoba	1.48	1.74	3.73	5.09	7.05	7.18	7.26	5.56	4.68	3.44	2.32	1.40	50.9
Fish Farms	2.08	2.42	4.14	5.48	7.59	7.73	7.82	6.01	5.05	3.72	2.60	1.82	56.5
Peach Trees	1.63	1.91	4.05	6.91	10.87	11.10	11.23	8.75	7.32	5.41	3.72	2.11	75.0
Perm. Pasture + Misc.	0.00	0.04	3.08	7.41	10.85	11.03	11.16	8.70	7.23	4.02	0.00	0.00	63.5

Monthly NIR (in) for 1991

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.54	3.65	1.96	8.6
Alfalfa	0.00	1.43	4.16	6.70	8.49	9.04	9.60	9.37	6.97	2.68	0.00	0.00	58.4
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	3.55	5.46	3.41	0.00	0.00	0.00	0.00	12.4
Sudan	0.00	0.00	0.00	4.88	8.06	8.69	9.22	9.00	5.78	0.00	0.00	0.00	45.6
Wheat	0.91	2.38	4.95	8.00	4.56	0.00	0.00	0.00	0.00	0.00	0.00	1.15	21.9
Bermuda, spring (seed)	0.00	0.00	0.67	5.77	7.95	6.43	0.00	0.00	0.00	0.00	0.00	0.00	20.8
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.04	9.52	9.66	7.15	4.81	0.00	0.00	34.2
Sugar Beets	2.41	3.24	5.11	7.85	8.33	0.93	0.00	1.36	1.77	4.28	3.15	2.07	40.5
Lettuce - all	1.96	2.49	0.00	0.00	0.00	0.00	0.00	1.35	0.00	4.95	3.55	1.89	16.2
Carrots	2.06	2.80	4.42	6.89	0.92	0.00	0.00	1.35	0.00	3.64	2.96	1.87	26.9
Cantaloupes - Spring	0.00	1.38	2.36	5.78	7.57	6.54							23.6
Cantaloupes - Fall							1.71	6.26	6.10	1.59	0.00	0.00	15.7
Cotton (upland and PIMA)	0.00	0.79	0.46	2.32	4.51	7.55	10.58	10.76	6.07	0.79	0.00	0.00	43.8
Honeydew	0.67	1.74	3.57	7.00	8.88	5.39	0.00	0.00	0.00	0.00	0.00	0.00	27.3
Watermelon	0.00	1.80	3.12	6.80	8.88	7.48	0.00	0.00	0.00	0.00	0.00	0.00	28.1
Onions	2.09	2.83	4.47	7.05	5.86	0.00	0.00	1.35	1.24	1.98	3.05	1.89	31.8
Onion Seed	2.09	2.83	4.46	7.14	8.74	6.21	1.30	1.38	1.43	4.97	3.54	1.98	46.1
Rye - Pastured	2.08	2.82	4.44	6.31	0.00	0.00	0.00	0.00	0.00	3.07	3.49	1.98	24.2
Oats and Barley	0.90	2.85	4.91	7.73	5.09	0.00	0.00	0.00	0.00	1.34	0.90	1.10	24.8
Misc. Field Crops	0.71	1.30	4.92	8.24	4.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.5
Tomatoes	0.00	1.55	4.43	8.47	10.66	7.65	0.00	0.00	0.00	0.00	0.00	0.00	32.8
Potatoes	1.97	3.07	4.91	4.61	0.00	0.00	0.00	0.00	0.00	1.36	2.93	1.87	20.7
Broccoli	2.04	1.92	0.00	0.00	0.00	0.00	0.00	1.36	2.21	3.97	2.79	1.85	16.1
Cabbage	2.05	2.79	1.81	0.00	0.00	0.00	0.00	0.00	2.85	4.00	2.91	1.87	18.3
Cauliflower	2.05	1.59	0.00	0.00	0.00	0.00	0.00	1.36	1.06	2.62	2.59	1.86	13.1
Corn, Ear	0.43	1.80	3.98	8.20	10.38	2.57	0.00	0.00	0.00	0.00	0.00	1.24	28.6
Misc. Garden Crops (use peppers)	2.29	2.98	1.61	0.00	0.00	0.00	0.00	0.29	1.19	3.20	2.86	2.08	16.5
Asparagas	0.78	1.16	1.86	4.87	8.46	9.07	9.62	9.39	6.30	3.81	1.42	0.92	57.6
Citrus	1.23	1.74	2.76	4.63	5.96	6.49	7.01	6.87	5.08	4.22	2.57	1.34	49.9
Duck Ponds	1.23	1.71	2.20	2.87	3.35	3.57	3.78	1.56	2.99	3.74	2.41	1.29	30.7
Jojoba	0.78	1.17	2.44	4.29	5.44	5.79	6.15	6.00	4.43	3.68	2.13	0.96	43.3
Fish Farms	1.23	1.74	2.76	4.63	5.85	6.24	6.62	6.46	4.78	3.97	2.41	1.25	47.9
Peach Trees	0.90	1.31	2.65	5.73	8.36	8.96	9.50	9.28	6.90	5.69	3.44	1.47	64.2
Perm. Pasture + Misc.	0.00	0.00	1.87	6.13	8.35	8.90	9.45	9.22	6.82	4.53	0.00	0.00	55.3

Monthly NIR (in) for 1992

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	3.38	2.04	8.1
Alfalfa	0.00	1.34	2.67	6.58	8.11	9.83	10.03	9.42	7.23	2.41	0.00	0.00	57.6
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	3.59	5.71	3.59	0.00	0.00	0.00	0.00	12.9
Sudan	0.00	0.00	0.00	5.10	7.78	9.44	9.63	9.05	6.34	0.00	0.00	0.00	47.4
Wheat	0.87	2.24	3.36	7.86	4.53	0.00	0.00	0.00	0.00	0.00	0.77	0.91	20.5
Bermuda, spring (seed)	0.00	0.00	0.00	5.75	7.60	6.79	0.00	0.00	0.00	0.00	0.00	0.00	20.1
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.16	9.96	9.72	7.42	3.83	0.00	0.00	34.1
Sugar Beets	2.64	3.06	3.47	7.77	8.14	1.95	0.00	1.67	2.68	3.52	3.06	2.23	40.2
Lettuce - all	2.13	0.65	0.00	0.00	0.00	0.00	0.00	1.31	0.05	3.32	3.34	1.96	12.8
Carrots	2.27	2.60	2.88	6.05	0.00	0.00	0.00	1.29	0.07	1.84	2.68	1.90	21.6
Cantaloupes - Spring	0.55	1.06	1.69	5.87	6.90	3.48							19.6
Cantaloupes - Fall							1.38	4.18	6.12	4.01	0.29	0.00	16.0
Cotton (upland and PIMA)	0.00	0.52	0.00	2.24	4.43	8.52	11.26	10.65	5.72	0.00	0.00	0.00	43.4
Honeydew	1.29	1.62	2.49	6.89	8.45	4.34	0.00	0.00	0.00	0.00	0.00	0.00	25.1
Watermelon	0.69	1.52	2.31	6.89	8.41	3.00	0.00	0.00	0.00	0.00	0.00	0.00	22.8
Onions	2.29	2.63	2.92	6.93	6.28	0.00	0.00	1.35	1.35	1.31	2.87	1.99	29.9
Onion Seed	2.29	2.63	2.92	7.01	8.15	4.60	1.36	1.36	3.06	4.15	3.38	2.07	43.0
Rye - Pastured	2.28	2.62	2.90	5.56	0.00	0.00	0.00	0.00	0.00	2.00	3.23	2.06	20.7
Oats and Barley	2.41	2.93	3.23	3.59	0.00	0.00	0.00	0.00	0.00	0.86	0.69	0.86	14.6
Misc. Field Crops	0.73	1.11	3.32	8.14	5.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.3
Tomatoes	0.00	1.34	2.97	8.32	10.13	6.62	0.00	0.00	0.00	0.00	0.00	0.00	29.4
Potatoes	2.44	2.93	3.19	3.39	0.00	0.00	0.00	0.00	0.00	1.08	1.94	1.92	16.9
Broccoli	2.24	1.17	0.00	0.00	0.00	0.00	0.00	1.25	1.31	2.04	2.37	1.81	12.2
Cabbage	2.26	2.51	0.00	0.00	0.00	0.00	0.00	0.00	2.02	3.18	2.61	1.93	14.5
Cauliflower	2.25	1.08	0.00	0.00	0.00	0.00	0.00	1.35	1.36	3.03	2.43	1.84	13.3
Corn, Ear	1.05	1.99	3.40	8.07	6.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.2
Misc. Garden Crops (use pe	2.51	2.76	0.27	0.00	0.00	0.00	0.00	0.29	1.30	2.40	2.62	2.18	14.3
Asparagas	0.88	0.90	0.68	4.84	8.08	9.85	10.05	9.44	6.60	3.12	1.41	0.96	56.8
Citrus	1.37	1.50	1.46	4.52	5.67	7.05	7.32	6.91	5.30	3.39	2.41	1.44	48.3
Duck Ponds	1.37	1.46	0.96	2.75	3.14	3.87	3.95	1.65	3.15	2.96	2.26	1.34	28.9
Jojoba	0.88	0.92	1.19	4.18	5.16	6.30	6.42	6.04	4.63	2.93	2.02	1.03	41.7
Fish Farms	1.37	1.50	1.46	4.51	5.56	6.78	6.92	6.50	4.98	3.18	2.26	1.34	46.4
Peach Trees	1.00	1.06	1.37	5.65	7.99	9.73	9.93	9.33	7.16	4.67	3.23	1.57	62.7
Perm. Pasture + Misc.	0.00	0.00	0.71	6.08	7.98	9.68	9.87	9.28	7.08	3.63	0.00	0.00	54.3

Monthly NIR (in) for 1993

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.59	3.21	2.78	7.6
Alfalfa	0.00	1.17	5.52	6.75	9.16	10.56	10.60	10.42	8.50	3.22	0.00	0.00	65.9
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	3.86	6.04	4.15	0.00	0.00	0.00	0.00	14.0
Sudan	0.00	0.00	0.70	5.11	8.78	10.14	10.19	10.02	7.46	0.00	0.00	0.00	52.4
Wheat	0.00	2.69	6.59	8.01	2.43	0.00	0.00	0.00	0.00	0.00	0.70	1.25	21.7
Bermuda, spring (seed)	0.00	0.00	1.32	5.81	8.58	7.44	0.00	0.00	0.00	0.00	0.00	0.00	23.1
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.45	10.50	10.75	8.73	5.53	0.00	0.00	39.0
Sugar Beets	0.30	2.96	6.67	7.84	8.88	0.99	0.00	2.22	2.56	4.90	2.94	3.07	43.3
Lettuce - all	0.00	1.50	0.00	0.00	0.00	0.00	0.00	1.31	0.05	4.79	3.18	2.68	13.5
Carrots	0.04	2.51	5.82	6.32	0.00	0.00	0.00	1.35	0.01	3.65	2.54	2.64	24.9
Cantaloupes - Spring	0.00	0.94	3.30	5.81	8.15	6.79							25.0
Cantaloupes - Fall							1.40	5.08	7.38	4.39	0.00	0.00	18.2
Cotton (upland and PIMA	0.00	0.57	1.29	2.38	5.13	8.88	11.64	12.02	8.12	1.91	0.00	0.00	51.9
Honeydew	0.00	1.38	4.18	6.79	9.58	9.04	0.00	0.00	0.00	0.00	0.00	0.00	31.0
Watermelon	0.00	1.38	4.30	6.92	9.58	5.41	0.00	0.00	0.00	0.00	0.00	0.00	27.6
Onions	0.05	2.54	5.88	7.00	4.67	0.00	0.00	1.36	1.36	2.54	2.70	2.72	30.8
Onion Seed	0.05	2.53	5.88	7.18	8.97	3.26	1.36	1.36	2.72	5.62	3.19	2.82	44.9
Rye - Pastured	0.04	2.52	5.85	5.84	0.00	0.00	0.00	0.00	0.00	5.11	3.17	2.81	25.3
Oats and Barley	0.00	2.83	6.42	5.09	0.43	0.00	0.00	0.00	0.00	1.35	0.53	1.84	18.5
Misc. Field Crops	0.00	0.98	6.44	8.32	4.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.6
Tomatoes	0.00	1.26	5.97	8.52	11.35	6.51	0.00	0.00	0.00	0.00	0.00	0.00	33.6
Potatoes	0.14	2.83	6.32	3.91	0.00	0.00	0.00	0.00	0.00	1.33	1.07	2.61	18.2
Broccoli	0.02	2.12	0.00	0.00	0.00	0.00	0.00	1.36	1.49	4.42	2.29	2.58	14.3
Cabbage	0.03	2.41	0.19	0.00	0.00	0.00	0.00	0.00	2.87	4.42	2.35	2.54	14.8
Cauliflower	0.02	2.40	0.06	0.00	0.00	0.00	0.87	1.51	3.62	4.45	2.50	2.67	18.1
Corn, Ear	0.00	0.60	4.42	7.96	11.21	6.59	0.00	0.00	0.00	0.00	0.28	0.66	31.7
Misc. Garden Crops (use p	0.21	2.67	2.15	0.00	0.00	0.00	0.00	0.58	1.24	3.17	2.45	2.97	15.4
Asparagas	0.00	0.83	2.69	4.92	9.12	10.58	10.63	10.45	7.73	4.31	1.09	1.30	63.7
Citrus	0.00	1.42	3.79	4.66	6.44	7.57	7.74	7.64	6.23	4.75	2.18	2.01	54.4
Duck Ponds	0.00	1.38	3.09	2.89	3.61	4.16	4.18	2.04	3.64	4.16	2.03	1.83	33.0
Jojoba	0.00	0.84	3.40	4.32	5.87	6.76	6.79	6.68	5.45	4.15	1.76	1.45	47.5
Fish Farms	0.00	1.42	3.79	4.66	6.32	7.28	7.32	7.19	5.86	4.47	2.02	1.88	52.2
Peach Trees	0.00	0.98	3.68	5.78	9.02	10.46	10.50	10.32	8.42	6.42	3.04	2.21	70.8
Perm. Pasture + Misc.	0.00	0.00	2.74	6.18	9.02	10.39	10.44	10.26	8.33	5.11	0.00	0.00	62.5

Monthly NIR (in) for 1994

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	2.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.45	3.80	1.99	9.6
Alfalfa	0.00	1.67	4.90	7.59	9.19	10.82	11.43	10.21	8.49	3.35	0.00	0.00	67.6
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	4.00	6.52	5.54	0.00	0.00	0.00	0.00	16.1
Sudan	0.00	0.00	0.62	5.78	8.82	10.40	10.98	9.81	8.15	0.97	0.00	0.00	55.5
Wheat	2.54	3.34	5.90	9.01	2.90	0.00	0.00	0.00	0.00	0.00	1.17	1.22	26.1
Bermuda, spring (seed)	0.00	0.00	0.97	6.52	8.62	7.71	0.00	0.00	0.00	0.00	0.00	0.00	23.8
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.32	11.25	10.53	8.72	5.08	0.00	0.00	38.9
Sugar Beets	3.51	3.51	5.97	8.71	8.54	0.00	0.00	2.38	2.62	4.68	3.53	2.20	45.7
Lettuce - all	2.91	1.02	0.00	0.00	0.00	0.00	0.00	1.19	0.15	3.90	3.76	1.91	14.8
Carrots	3.07	3.04	5.18	6.91	0.00	0.00	0.00	1.13	0.20	1.98	3.02	1.87	26.4
Cantaloupes - Spring	1.39	1.49	3.74	6.78	8.01	5.79							27.2
Cantaloupes - Fall							1.37	4.52	7.23	5.19	0.18	0.00	18.5
Cotton (upland and PIMA)	0.00	1.05	1.24	2.77	5.40	9.44	12.70	11.76	7.92	1.83	0.00	0.00	54.1
Honeydew	1.66	1.96	4.44	7.94	9.63	8.50	0.00	0.00	0.00	0.00	0.00	0.00	34.1
Watermelon	1.83	1.99	4.50	7.94	9.63	8.84	0.00	0.00	0.00	0.00	0.00	0.00	34.7
Onions	3.10	3.07	5.24	7.93	6.07	0.00	0.00	1.36	1.33	2.00	3.24	1.94	35.3
Onion Seed	3.09	3.07	5.23	8.08	9.34	6.17	0.00	1.36	1.33	5.16	3.57	2.02	48.4
Rye - Pastured	3.08	3.05	5.21	8.04	1.45	0.00	0.00	0.00	0.65	5.43	3.82	2.01	32.7
Oats and Barley	3.34	3.37	4.86	1.47	0.00	0.00	0.00	0.00	0.00	1.18	0.71	0.84	15.8
Misc. Field Crops	1.09	1.54	5.81	9.33	5.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.8
Tomatoes	1.03	2.14	5.84	9.58	11.51	8.78	0.00	0.00	0.00	0.00	0.00	0.00	38.9
Potatoes	3.17	3.38	5.67	4.84	0.00	0.00	0.00	0.00	0.00	0.00	1.28	1.69	20.0
Broccoli	3.03	2.03	0.00	0.00	0.00	0.00	0.00	1.36	1.47	4.20	2.78	1.83	16.7
Cabbage	3.05	3.02	2.09	0.00	0.00	0.00	0.00	0.00	0.12	4.20	2.71	1.76	16.9
Cauliflower	3.04	2.57	0.00	0.00	0.00	0.00	0.00	1.13	1.33	2.83	2.75	1.87	15.5
Corn, Ear	2.22	2.56	5.85	9.29	11.28	3.86	0.00	0.00	0.00	0.00	0.00	1.25	36.3
Misc. Garden Crops (use peppers)	3.35	3.19	1.52	0.00	0.00	0.00	0.00	0.29	1.27	2.96	2.94	2.11	17.6
Asparagas	1.43	1.29	2.28	5.60	9.18	10.85	11.46	10.23	7.66	4.02	1.45	0.93	66.4
Citrus	2.00	1.90	3.29	5.24	6.42	7.76	8.35	7.49	6.22	4.47	2.69	1.35	57.2
Duck Ponds	2.00	1.86	2.64	3.26	3.54	4.27	4.51	1.77	3.70	3.98	2.52	1.31	35.3
Jojoba	1.43	1.30	2.95	4.86	5.84	6.93	7.32	6.54	5.43	3.90	2.23	0.98	49.7
Fish Farms	2.00	1.90	3.29	5.24	6.30	7.46	7.89	7.04	5.85	4.20	2.52	1.26	55.0
Peach Trees	1.57	1.45	3.19	6.48	9.05	10.72	11.32	10.11	8.41	6.04	3.63	1.51	73.5
Perm. Pasture + Misc.	0.00	0.00	2.32	6.93	9.05	10.65	11.26	10.05	8.32	4.79	0.00	0.00	63.4

Monthly NIR (in) for 1995

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.44	3.50	2.49	8.5
Alfalfa	0.00	2.06	5.70	8.43	9.82	11.18	10.76	10.20	8.88	3.09	0.00	0.00	70.1
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	4.15	6.13	5.16	0.00	0.00	0.00	0.00	15.4
Sudan	0.00	0.00	0.00	2.59	7.97	10.74	10.34	9.80	8.29	0.00	0.00	0.00	49.7
Wheat	1.35	4.10	6.81	9.74	1.73	0.00	0.00	0.00	0.00	0.00	1.18	1.30	26.2
Bermuda, spring (seed)	0.00	0.00	1.45	7.23	9.20	7.83	0.00	0.00	0.00	0.00	0.00	0.00	25.7
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.46	10.64	10.52	9.12	5.18	0.00	0.00	38.9
Sugar Beets	1.96	4.23	6.89	9.62	8.64	0.00	0.00	1.67	3.27	4.57	3.16	2.72	46.7
Lettuce - all	1.50	2.69	0.00	0.00	0.00	0.00	0.00	0.35	1.00	2.99	3.45	2.39	14.4
Carrots	1.61	3.70	5.97	3.54	0.00	0.00	0.00	1.25	0.10	2.47	2.80	2.38	23.8
Cantaloupes - Spring	0.00	1.95	3.89	7.49	8.66	5.15							27.1
Cantaloupes - Fall							1.35	2.14	5.78	5.30	2.58	0.00	17.1
Cotton (upland and PIMA)	0.00	1.32	1.59	3.08	5.75	9.68	11.96	11.76	8.29	1.84	0.00	0.00	55.3
Honeydew	0.08	2.43	4.99	8.80	10.27	6.50	0.00	0.00	0.00	0.00	0.00	0.00	33.1
Watermelon	0.37	2.45	5.20	8.82	10.24	5.13	0.00	0.00	0.00	0.00	0.00	0.00	32.2
Onions	1.63	3.74	6.08	8.71	5.00	0.00	0.00	1.36	1.35	2.03	2.95	2.42	35.3
Onion Seed	1.63	3.73	6.07	8.97	10.01	6.34	1.34	1.36	2.99	5.29	3.46	2.53	53.7
Rye - Pastured	1.62	3.72	6.05	5.79	0.00	0.00	0.00	0.00	1.05	5.79	3.53	2.52	30.1
Oats and Barley	1.57	4.08	6.64	6.13	0.40	0.00	0.00	0.00	0.00	1.13	0.71	1.08	21.7
Misc. Field Crops	0.22	1.90	6.72	10.34	5.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.4
Tomatoes	0.00	2.31	6.31	10.64	12.38	11.75	0.00	0.00	0.00	0.00	0.00	0.00	43.4
Potatoes	1.53	4.03	6.60	4.66	0.00	0.00	0.00	0.00	0.00	1.22	1.21	2.25	21.5
Broccoli	1.59	2.90	0.00	0.00	0.00	0.00	0.00	1.35	1.35	3.39	2.54	2.32	15.4
Cabbage	1.60	3.66	1.19	0.00	0.00	0.00	0.00	0.00	0.14	4.16	2.50	2.23	15.5
Cauliflower	1.58	0.84	0.00	0.00	0.00	0.00	0.00	1.36	2.29	4.17	2.78	2.44	15.5
Corn, Ear	0.57	2.74	6.40	10.32	12.01	6.84	0.00	0.00	0.00	0.00	0.00	0.96	39.8
Misc. Garden Crops (use pep	1.83	3.91	2.12	0.00	0.00	0.00	0.00	0.29	1.30	3.07	2.71	2.66	17.9
Asparagas	0.33	1.73	2.80	6.26	9.79	11.21	10.79	10.23	7.95	4.00	1.36	1.17	67.6
Citrus	0.78	2.42	3.92	5.82	6.90	8.02	7.86	7.48	6.51	4.43	2.48	1.65	58.3
Duck Ponds	0.78	2.38	3.16	3.59	3.87	4.41	4.24	1.87	3.95	3.94	2.33	1.64	36.1
Jojoba	0.33	1.74	3.54	5.40	6.29	7.16	6.89	6.54	5.69	3.86	2.07	1.19	50.7
Fish Farms	0.78	2.42	3.92	5.82	6.77	7.71	7.42	7.04	6.13	4.16	2.33	1.54	56.0
Peach Trees	0.44	1.91	3.82	7.22	9.67	11.07	10.66	10.10	8.79	6.00	3.33	1.83	74.8
Perm. Pasture + Misc.	0.00	0.00	2.88	7.70	9.67	11.01	10.59	10.04	8.70	4.92	0.00	0.00	65.5

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Monthly NIR (in) for 1996

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	2.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.66	3.95	2.92	11.2
Alfalfa	0.00	2.03	5.92	8.26	11.65	11.37	11.02	11.40	8.45	3.15	0.00	0.00	73.3
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	4.07	6.29	5.57	0.00	0.00	0.00	0.00	15.9
Sudan	0.00	0.00	0.00	0.00	5.13	9.88	10.59	10.95	8.08	0.00	0.00	0.00	44.6
Wheat	2.71	3.95	7.08	9.77	3.65	0.00	0.00	0.00	0.00	0.00	0.48	1.02	28.7
Bermuda, spring (seed)	0.00	0.00	1.41	7.10	10.94	8.22	0.00	0.00	0.00	0.00	0.00	0.00	27.7
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.53	10.94	11.76	8.68	5.55	0.00	0.00	40.5
Sugar Beets	3.65	4.12	7.17	9.63	11.44	1.11	0.00	1.67	2.86	4.94	3.54	3.13	53.3
Lettuce - all	3.04	2.07	0.00	0.00	0.00	0.00	0.00	0.71	0.65	3.68	3.90	2.79	16.8
Carrots	3.19	3.60	6.19	2.93	0.00	0.00	0.00	1.03	0.33	2.27	3.15	2.75	25.4
Cantaloupes - Spring	1.58	1.95	4.85	7.38	9.89	4.21							29.9
Cantaloupes - Fall							1.36	6.93	7.36	5.37	0.00	0.00	21.0
Cotton (upland and PIMA	0.28	1.02	1.99	3.16	7.19	10.08	12.33	13.14	8.17	2.38	0.00	0.00	59.7
Honeydew	1.22	2.35	5.18	8.61	12.19	9.85	0.00	0.00	0.00	0.00	0.00	0.00	39.4
Watermelon	1.86	2.46	5.60	8.64	12.19	6.92	0.00	0.00	0.00	0.00	0.00	0.00	37.7
Onions	3.22	3.63	6.32	8.67	8.65	0.00	0.00	1.35	1.35	2.25	3.34	2.81	41.6
Onion Seed	3.22	3.63	6.31	8.78	11.38	2.87	1.35	1.36	2.27	5.69	3.87	2.96	53.7
Rye - Pastured	3.20	3.62	6.29	3.10	0.00	0.00	0.00	0.00	1.49	6.29	4.00	2.94	30.9
Oats and Barley	3.13	3.97	6.90	6.16	0.50	0.00	0.00	0.00	0.00	1.32	1.04	1.49	24.5
Misc. Field Crops	1.05	1.85	6.91	10.21	7.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.3
Tomatoes	0.66	2.43	6.96	10.43	14.23	5.83	0.00	0.00	0.00	0.00	0.00	0.00	40.5
Potatoes	3.29	3.98	6.56	2.55	0.00	0.00	0.00	0.00	0.00	1.26	1.22	2.60	21.5
Broccoli	3.16	1.79	0.00	0.00	0.00	0.00	0.00	1.35	1.35	3.90	2.86	2.65	17.0
Cabbage	3.17	3.54	0.95	0.00	0.00	0.00	0.00	0.00	0.84	4.51	2.96	2.70	18.7
Cauliflower	3.14	0.42	0.00	0.00	0.00	0.00	0.00	1.13	1.35	3.14	2.78	2.58	14.5
Corn, Ear	0.95	2.37	5.73	10.04	14.25	12.54	0.00	0.00	0.00	0.00	0.00	0.35	46.2
Misc. Garden Crops (use	3.49	3.79	2.36	0.00	0.00	0.00	0.00	0.29	1.30	3.39	3.08	3.10	20.8
Asparagas	1.49	1.66	2.88	5.99	11.61	11.40	11.05	11.42	7.74	4.39	1.62	1.37	72.6
Citrus	2.09	2.34	4.07	5.70	8.18	8.15	8.05	8.36	6.20	4.80	2.81	2.05	62.8
Duck Ponds	2.09	2.31	3.31	3.54	4.59	4.48	4.35	2.05	3.67	4.26	2.63	1.92	39.2
Jojoba	1.49	1.67	3.66	5.29	7.46	7.29	7.06	7.30	5.41	4.19	2.35	1.49	54.7
Fish Farms	2.09	2.34	4.07	5.70	8.04	7.85	7.60	7.86	5.83	4.51	2.63	1.91	60.4
Peach Trees	1.64	1.84	3.95	7.06	11.48	11.26	10.92	11.29	8.37	6.49	3.76	2.28	80.3
Perm. Pasture + Misc.	0.00	0.00	2.95	7.54	11.47	11.20	10.85	11.22	8.28	5.27	0.00	0.00	68.8

Monthly NIR (in) for 1997

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Alfalfa - winter	2.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.58	3.23	2.59	9.5
Alfalfa	0.00	2.35	6.08	7.40	9.96	11.59	10.89	10.30	5.82	3.11	0.00	0.00	67.5
Alfalfa Seed	0.00	0.00	0.00	0.00	0.00	4.23	6.21	4.83	0.00	0.00	0.00	0.00	15.3
Sudan	0.00	0.00	0.00	0.00	6.94	10.89	10.46	9.89	5.56	0.97	0.00	0.00	44.7
Wheat	2.25	4.44	7.25	8.82	3.58	0.00	0.00	0.00	0.00	0.00	1.28	1.69	29.3
Bermuda, spring (seed)	0.00	0.00	1.51	6.43	9.34	8.08	0.00	0.00	0.00	0.00	0.00	0.00	25.4
Bermuda, summer hay	0.00	0.00	0.00	0.00	0.00	3.82	10.77	10.62	6.00	5.26	0.00	0.00	36.5
Sugar Beets	3.33	4.72	7.34	8.71	9.99	2.63	0.00	1.67	1.32	4.56	2.85	2.79	49.9
Lettuce - all	2.74	2.93	0.00	0.00	0.00	0.00	0.00	1.25	0.00	4.17	3.16	2.49	16.7
Carrots	2.88	4.13	6.33	1.76	0.00	0.00	0.00	1.29	0.00	2.60	2.57	2.47	24.0
Cantaloupes - Spring	0.92	2.15	4.73	6.60	8.45	3.86							26.7
Cantaloupes - Fall							1.38	4.49	4.79	5.27	0.48	0.00	16.4
Cotton (upland and PIMA)	0.00	1.32	1.80	2.76	6.29	10.77	12.41	11.57	4.44	0.10	0.00	0.00	51.5
Honeydew	0.65	2.71	5.46	7.75	10.29	3.21	0.00	0.00	0.00	0.00	0.00	0.00	30.1
Watermelon	0.95	2.71	5.30	7.72	10.42	8.49	0.00	0.00	0.00	0.00	0.00	0.00	35.6
Onions	2.91	4.17	6.48	7.78	7.42	0.00	0.00	1.36	0.42	2.18	2.70	2.52	37.9
Onion Seed	2.91	4.16	6.47	7.88	10.14	6.59	1.36	1.36	1.29	5.27	3.13	2.63	53.2
Rye - Pastured	2.90	4.15	6.45	3.78	0.00	0.00	0.00	0.00	0.00	2.33	3.04	2.61	25.2
Oats and Barley	2.91	4.55	7.07	6.79	2.09	0.00	0.00	0.00	0.00	1.12	0.63	1.16	26.3
Misc. Field Crops	0.84	2.10	7.10	9.14	5.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.8
Tomatoes	0.26	2.56	6.74	9.36	12.46	8.80	0.00	0.00	0.00	0.00	0.00	0.00	40.2
Potatoes	2.94	4.56	7.01	4.26	0.00	0.00	0.00	0.00	0.00	1.22	2.35	2.50	24.8
Broccoli	2.85	2.88	0.00	0.00	0.00	0.00	0.00	1.35	0.42	3.60	2.27	2.32	15.7
Cabbage	2.86	3.59	0.00	0.00	0.00	0.00	0.00	0.00	0.11	4.17	2.41	2.41	15.6
Cauliflower	2.86	2.89	0.00	0.00	0.00	0.00	0.00	1.31	0.43	3.24	2.27	2.33	15.3
Corn, Ear	0.67	2.57	5.19	8.76	12.19	14.14	1.72	0.00	0.00	0.00	0.00	1.21	46.5
Misc. Garden Crops (use pe	3.17	4.35	2.41	0.00	0.00	0.00	0.00	0.58	0.32	3.00	2.49	2.77	19.1
Asparagas	1.20	1.93	3.00	5.44	9.93	11.61	10.91	10.32	5.21	4.04	1.36	1.22	66.2
Citrus	1.79	2.70	4.20	5.09	7.00	8.31	7.95	7.55	4.05	4.44	2.34	1.90	57.3
Duck Ponds	1.79	2.66	3.43	3.10	3.93	4.56	4.29	1.85	2.04	3.93	2.14	1.70	35.4
Jojoba	1.20	1.94	3.77	4.71	6.38	7.42	6.97	6.60	3.43	3.88	1.96	1.37	49.6
Fish Farms	1.79	2.70	4.20	5.08	6.87	7.99	7.51	7.10	3.76	4.18	2.19	1.77	55.1
Peach Trees	1.35	2.13	4.08	6.36	9.82	11.47	10.78	10.20	5.75	6.00	3.13	2.09	73.2
Perm. Pasture + Misc.	0.00	0.00	3.06	6.82	9.81	11.41	10.72	10.14	5.69	5.02	0.00	0.00	62.7

APPENDIX 7

IID Field Evaluations

7. IID FIELD EVALUATION DATA AND PHOTOS

The main objective of the NRCE field evaluation in IID was to collect and analyze data first-hand related to any differences in the salinity leaching processes between different soil types, primarily heavy cracking and non-cracking soils. Ten field irrigations were evaluated. Photographs taken during the field evaluations along with summaries of field data are contained at the end of this appendix.

A. Site Description

The fieldwork for these evaluations was carried out at IID between June 20 and June 30, 2000, and between July 10 and July 20, 2000. Weather conditions during those periods were hot, with daily maximum temperatures exceeding 105°F, 80% of the time.

Four cropped fields were evaluated during the first period, and five cropped fields were evaluated during the second period. Eight of the fields evaluated range in size from about 50 to 81 acres, and one was about 160 acres. All fields were surface irrigated, eight of which were by the border method and one by furrow irrigation. Five fields had one-quarter mile runs and four had one-half mile runs, with a run being defined as the length along which water was applied. Alfalfa, Bermuda grass, and Sudan grass were the crops grown on the fields that were evaluated.

Typical irrigations began from early to late morning depending on the proximity of the field to the water source. The amount of water requested by the grower was delivered to the headgate of the field at an equivalent flow-rate for a period of time, normally 24 or 48 hours. The irrigators then had the task of applying the water to the fields in equivalent sets for this duration.

A tenth irrigation area was evaluated on a field that was being irrigated between crops. The field was about 80 acres with one-quarter mile runs and was evaluated during the first period.

B. Field Selection

The evaluated fields were selected to represent the major soil types of IID. NRCE was primarily interested in medium to heavy cracking and non-cracking soils, with a light soil used for comparison. Representative areas were selected by NRCE, and with the help of the district's Irrigation Management Unit (IMU), cooperating farmers were identified. These participants were part of an IMU Meter Program, in which delivery and tailwater flows were monitored and measured during irrigations. The fields evaluated were spread across the entire valley (see Plate 7-1).

C. Equipment Utilized

Materials and equipment used for the evaluations included surveying equipment, tape measures, lath stakes, flags, soil augers, salinity meters, watches, flashlights, cameras, zip lock bags, markers, notebooks, and data sheets. IMU installed flow-measuring devices, along with data loggers, at the headgates and tail-boxes of most of the fields that were evaluated. IMU also recommended a commercial soil analysis laboratory to have soil samples analyzed.

D. Field Work and Data Collection

1. *Survey and General Observations*

NRCE staff performed a pre-irrigation survey, staking the field along its length, and surveying for both the down-slope and the cross-slope. The length of the fields was measured along with the spacing of the borders and the ridges between them. The number of borders for each parcel was also recorded.

Soil samples were taken from three locations of each field, representing the top, middle, and bottom sections of the field. At each of the three locations, four soil samples were taken to represent the first four feet of the soil profile, at one-foot intervals. These samples were subsequently taken to the commercial soil laboratory for a moisture and salinity analysis. The soil sampling was repeated a couple of days after irrigation when the moisture content was assumed to be at field capacity and a similar analysis was performed.

There is soil variability within fields due to previous land leveling, which involves substantial soil movement. The redistribution of soil in the field affects uniformity both across the field and down the soil profile. Additionally, the soil is stratified because most soils in the valley were deposited by water. Observations of this effect were made regarding when and where they occurred during the auguring stage of the sampling.

Other information recorded included crop type, growth stage, and condition; irrigation method and history; field location and soil type; cultural practices; and other observations such as poor crop stand and average soil crack size and distribution.

2. *Irrigation Evaluation*

The procedures described in Irrigation System Evaluation, A Guide for Management (Utah State University, 1987) provided the basis for the irrigation evaluations. Various types of measurements and observations were made during each of these evaluations. Recorded data included start and end times of the irrigations, flow rate at the headgate, number of borders irrigated during a set, set times, and the number of sets it took to complete the irrigation. The advance and recession phases of water flow down the borders were monitored for the number of sets. Also, the salinity of the irrigation water was monitored at various stages and locations during the evaluation.

3. *Water Budget*

The water budget is a convenient tool for analyzing water management problems and opportunities. The sum of system inflows should equal the sum of system outflows plus the change in storage. In this case, the inflows consist of the water supplied or delivered to the field at the headgate. The outflow parameters include surface evaporation, tailwater, deep percolation (drainage), and losses due to seepage from the head ditches. By analyzing the water budget relationship, the difference between the inflow and outflow determines the amount of water stored in the root zone.

The inflow and outflow in eight of the fields were measured using portable metering devices attached to the headgate and tailwater boxes. The inflow and outflow of the other two field were measured manually. The major components of this measuring devices are ultrasonic level sensors for reading both upstream and downstream water levels, and in the case of the headgate, a linear transducer attached to the gate stem measures gate position. These three sensors as well as ambient air temperature and battery voltage are input into a data-logger that logs readings on ten-minute intervals. This data is later retrieved for graphing and analysis. Periodic flow-depth measurements were made at the headgate and tail-boxes to verify similar measurements recorded by the data-loggers.

Outflow from the tile drains were also recorded. Outflow from these drains was measured periodically using a five-gallon container and a stop-clock. Monitoring started before the irrigation began, recording any base flows, and continued for a period (sometimes days) following the irrigation until the outflow was thought to have returned to its original state.

4. *Salinity Balance and Distribution*

The underlying principle of salinity control in soils is the transportation of soluble salts in the soil by irrigation water. Thus, salinity can be managed if the quality of applied water is satisfactory and the flux of water through the soil can be controlled.

A salt mass balance follows two processes. Typically, the amount of salts added to the soil by irrigation should be equal to the amount of salts carried away in the drainage water. Consequently, no accumulation of salt should occur in the root zone. By knowing both the amount of salts applied to the field during the irrigation, and the amount leaving the field through tailwater or deep percolation, a determination can be made of whether or not there was adequate water for leaching.

Measurements of irrigation water salinity were made during the advance phase of the irrigation. Measurements were also made at different times at the same locations along the field, the head ditch, and at the tailwater box. This was to assess the salinity changes along the length of the field in order to shed some light on the horizontal leaching process.

After the crop was harvested and access could be made to each field, IID's Irrigation Management Unit performed a salinity assessment of each field. The assessment was made using a field salinity assessment vehicle.

5. *Infiltration Characteristics*

The border (or furrow) inflow rate, the advance rate, the recession rate, and the depth of flow allow for estimates of infiltration characteristics of the IID soils. The intake rate is highly dependent upon the soil's moisture at the time of irrigation and the degree of cracking in the soil. The medium to heavy cracking soils had a very high initial intake rate as the cracks were filled with water, then a low intake rate during the remainder of the irrigation. The light soils had a more typical intake rate with a high initial intake rate decreasing over time, but remaining higher than the heavy soil intake rate.

When irrigating soils with high infiltration rates, the rate of advance along the bottom half of the field is usually much slower than along the top half. This is due to a reduction in the unit stream size caused by the water infiltrating at the top half of the field. For soils with very low infiltration rates, the rate of advance remains relatively constant down the whole field. The amount of runoff depends on when the water is shut-off.

After the water is shut off, the flow of water recedes in the field as the water moves down the field and infiltrates into the soil. The water has receded when there is little or no water on the soil surface. The recession of water flow is difficult to measure in a densely vegetated field. The difference between the advance and recession times of water flow at a point on the field is known as the intake opportunity time. This, along with the infiltration characteristics of the soil, determines how much water infiltrated into the soil. For the most part, soils with high infiltration rates typically have less opportunity times than soils with low infiltration rates, when subjected to the same irrigation conditions.

The advance and recession rates were monitored for each parcel in order to determine and compare the intake opportunity times for the different soil types. The depths of the surface flow in the borders or furrows were also monitored and recorded throughout the irrigation. This was done to help determine the volume of water on the soil surface throughout the irrigation. By knowing the volume of water on the soil surface and the size of the stream entering the border or furrow at various times, depth of infiltrated water can be monitored and the soil's intake characteristics can be determined. In the case of furrow irrigation, the depth and basic geometry of the furrows were determined.

E. Results of Field Evaluations

NRCE developed summary results of the field irrigation evaluations. The field irrigation evaluations were done to obtain data and make observations to determine differences in the irrigation of heavy cracking, medium, and light soils.

As mentioned earlier, ten irrigation evaluations were conducted on different fields. There are over 5,000 fields in IID and tens of thousands of separate irrigations during a year. Though the evaluations discussed here are not necessarily meant to be a statistical representation of all irrigations, the data collected represents and illustrates many of the critical differences in the irrigation of medium to heavy cracking and light soils.

The discussions in this section are by topics, with specific examples used to illustrate findings. The topics discussed are:

- Field Descriptions
- Infiltration
- Distribution of Irrigation Water
- Salt Balance and Soil Salinity
- Reasonable Beneficial Use

1. *Field Descriptions*

The cropping and irrigation histories for the past four years were obtained from IID for the evaluated fields. Crops grown on the heavy cracking soils included Sudan grass, Bermuda grass, alfalfa, wheat, rye grass, and sugar beets. The medium textured soils had sugar beets, wheat, alfalfa, onions, Sudan grass, and carrots; and the light textured soils had carrots, alfalfa, and Sudan grass. Table 1 contains summary information relating to the evaluated fields. The primary and secondary soil groupings are based on the Soil Conservation Service's Soil Survey of Imperial County California – Imperial Valley Area dated October 1981.

Table 1 Field Descriptions.

Field	Crop	Primary Soil Grouping	Secondary Soil Grouping	Irrigation Method	Border/ Furrow Length (ft)	Border/ Furrow Spacing (ft)	Field Slope (ft/ft)	Field Acreage (ac)
1	Alfalfa	115	114	Border	1200	150	0.002645	72
2	Seed Alfalfa	115, 110	118	Border	1380	120	0.001931	78
3	Bermuda	114	115	Border	2670	60	0.003316	156
4	Alfalfa	135	142	Border	1330	150	0.002641	75
5	Bermuda	114	--	Border	2460	130	0.001665	52
6	Sudan Grass	110	114	Border	2450	130	0.002533	76
7	Seed Alfalfa	115	110	Border	2580	120	0.002683	73
8	Alfalfa	114	115	Furrow	1320	3.33	0.002567	72
9	Bermuda	115	--	Border	1200	75	0.001558	78
10	Leaching	115	122	Border	1250	--	--	81

There was some cracking in all the fields of the heavy and medium soils. Most of the large soil cracks were observed in the fields where the crop had been harvested and the soil was allowed to dry before and/or after the harvest. These large cracks are common on wheat stubble fields, harvested seed alfalfa fields, and harvested Sudan grass fields. During the crop growing periods, the soil cracking was not as excessive because the soil was not allowed to get very dry. However, it was observed that soils were allowed to dry after the crop was harvested and before deep ripping.

The fields evaluated rely on a tile drainage system to control the water table, with some low areas being underlain by artesian aquifers that result in an upward movement of water. It was also observed that some fields have some natural drainage, such as those near the highline canal that are high in elevation and are underlain by sandy soils.

2. *Infiltration*

Infiltration of water into the soil is required to replenish soil moisture and leach salts from the soil. The rate of infiltration impacts the uniformity of irrigation, advance rate of the water down the field, and adequacy of irrigation. Variables that influence infiltration include soil texture and structure, initial soil moisture, soil cracking, soil tillage and compaction, drainage, and soil stratification. The infiltration rate can be different for each application of irrigation water to the same field due to factors listed above, such as the initial soil moisture, which impacts cracking. Table 2 contains information relating to the infiltration of water into the soil.

Table 2 Irrigation and Infiltration Data.

Field	Border Length (ft)	Average Border Flow (cfs/ft)	Average Advance Time (hrs)	Average Intake Time (hrs)	Average Infiltrated Depth (in)	Average Intake Rate (in/hr)	Initial Infiltration to fill Cracks (in)	Intake Rate After Initial Infiltration (in/hr)
1	1200	0.0280	4.30	3.25	2.72	0.84	1.5	0.38
2	1380	0.0550	4.00	3.75	3.30	0.88	2.0	0.35
3	2670	0.0583	12.00	5.00	3.72	0.74	2.0	0.34
4	1330	0.0400	4.60	2.50	4.60	1.84	N/A	
5	2460	0.0119	35.00	35.00	4.80	0.14	1.0	0.11
6	2450	0.0550	7.25	4.75	4.60	0.97	N/A	
7	2580	0.0530	7.00	8.00	5.15	0.64	2.5	0.33
8	1320	0.0405	3.33	3.25	3.06	0.94	2.0	0.33
9	1200	0.0160	9.50	9.00	2.68	0.37	1.0	0.26
10	1250	0.0012	72.00	156.00	8.30	0.05	4.0	0.03

N/A = Field 4 has no cracks to fill; Field 6 has several different soil textures and the amount of water infiltrated to fill the cracks was variable.

3. *Distribution of Irrigation Water*

A portion of the applied irrigation water is stored in the root zone, while some leaves the root zone through vertical drainage (tile water) or tailwater (runoff). Table 3 shows a summary of the distribution of the irrigation water. The irrigation efficiency shown in Table 3 is the efficiency of water use during crop irrigation considering the amount of water stored in the root zone and tile water leaching. Horizontal leaching is not included in the determination of irrigation efficiency in this table, though in the main text of this report it is explained how such horizontal leaching plays a critical role in IID irrigation of heavier soils.

Table 3 Summary of Average Water Disposition for Field Irrigation Evaluations.

Field	Total Irrigation (in)	Stored in Root zone (in)	Tailwater Runoff (in)	Tile Water Outflow (in)	Stored in Root zone (%)	Tailwater Runoff (%)	Tile Water Outflow (%)	Irrigation Efficiency (%)
1	3.80	2.60	1.08	0.12	68	28	3	72
2	3.82	3.20	0.52	0.10	84	14	3	87
3	4.27	3.52	0.55	0.20	82	13	5	87
4	4.60	3.70	0.00	0.9	80	0	20	85[1]
5	5.08	3.95	0.28	0.85	78	6	17	87[2]
6	5.20	4.15	0.60	0.45	80	12	9	88
7	6.35	4.85	1.20	0.30	76	19	5	80
8	3.84	2.90	0.78	0.16	76	20	4	80
9	3.28	2.57	0.60	0.11	78	18	3	80
10	9.80	4.70	0.00	3.60	48	0	37	N/A

1) It was estimated that only 5% of the deep percolation in Field 4 was effectively used for leaching. About one-half of that field was not sufficiently irrigated and about half of the field was over-irrigated, i.e. irrigation exceeded the soil moisture deficit and leaching requirement.
2) It was estimated that only 8% of the tile water was required for effective leaching.

4. *Heavy and Medium Soils*

The following statements summarize the effects of soil composition on distribution of irrigation water in IID, as determined by NRCE's field evaluations:

- Heavy and medium soils are found in all fields except Field 4.

- The size and depth of cracks in cracking soils are influenced by the soil moisture; the drier the soil, the larger and deeper are the cracks. Under normal irrigation management in IID, cracking soils are not allowed to become dry enough to create excessive cracking similar to the soils after the crops are harvested. However, cracks occur between irrigations that greatly influence the infiltration of water into the soils. The driest fields, both of which were seed alfalfa, had the widest and deepest cracks.

- A significant amount of water (1.0 to 2.5 inches) enters the soil almost instantaneously during the advance phase of the irrigation to fill the cracks. After the initial water advance, the amount and rate of infiltration is low. This is demonstrated by the almost linear advance rates down the borders (i.e. the rate of advance in feet per hour is nearly the same along the first quarter of the field as the last quarter). If the infiltration rate stays high, the advance rate decreases significantly towards the end of the field.

- The infiltration rate is low after the initial crack-filling stage, on the order of .03 to 0.4 inches per hour. The infiltration rates that range from 0.2 to 0.4 inches per hour result from both vertical infiltration and horizontal infiltration into the soil columns that are surrounded by cracks. However, the vertical infiltration of these soils would likely be about 0.1 inches per hour or less after horizontal infiltration has ceased. An example of the low infiltration rate in cracking soils, after initial crack-filling, is illustrated by comparing the average depth infiltrated and intake opportunity times in Fields 3 and 5, which are both heavy soils. The average infiltration in Field 3 was measured at 3.8 inches with an intake opportunity time of 5 hours, compared to the average infiltration of Field 5 which was measured at 4.8 inches with an average intake opportunity time of 35 hours. Some of the differences can be attributed to the initial soil moisture and cracking of the soils; however, it is clear that the intake rate after the initial infiltration is very low. This is also confirmed by other studies that indicate very low infiltration rates on the order of 0.1 inches per hour in IID's heavy clay soils (Grismer and Bali, 1996). It should also be noted that for most crops, it is impractical to have an intake opportunity time of 35 hours, or even 10 hours, due to scalding and water logging of plants.

- During the first irrigation after a field has been deep ripped or tilled, the initial infiltration can be much higher as the large voids are filled with water.

- Generally, the low infiltration rate limits the ability to maintain a salt balance in the soil during the cropping period.

- The irrigation efficiencies of the irrigation evaluated ranged from 72 to 88 percent. The irrigation efficiency would be higher if horizontal leaching were included in the determination. These irrigation efficiencies include the water stored in the root zone and the vertical leaching during crop irrigation divided by the total headgate deliveries.

- Because tailwater is utilized for horizontal leaching (see main report text for details), the irrigation efficiencies are high for the cracking soils due to the following reasons:

    - Deep percolation is low and less than the amount required for leaching, therefore nearly all infiltrated water is used to meet crop ET and the leaching requirement.

    - The irrigation uniformity values are high because the intake characteristics of heavy soils limit excessive deep percolation at the head of the field.

- The percent of total water that contributed to vertical drainage or tile water ranged from 2 to 17 percent. The 17 percent value was from the irrigation with an intake opportunity time of 35 hours, which is not typical or practical for most heavy soil cropping conditions. Excluding the 17 percent tile water value, an average of about 4.5 percent of the applied water drains past the root zone.

- The tailwater on heavy soils ranged from 11 to 28 percent of the applied water, with the area weighted average being 17 percent.

- On the heavy soils, the irrigation efficiencies of half-mile runs were as high as the quarter-mile runs, because deep percolation is limited by the extremely low infiltration rate. The average percent of tailwater for the half-mile runs was less than that of the quarter-mile runs.

5. *Light Soils*

- The only field with light soils was Field 4.
- The infiltration rate is sufficient to maintain a salt balance during normal irrigations. Under these conditions, a leaching irrigation between crops is not required to maintain an acceptable salt balance.
- The infiltration rate limits runoff; in fact, the evaluated light soil field had no runoff.
- In the light soils, the border flow rate is more critical than in the medium to heavy soils. If the flow rate is not high enough, then the irrigation uniformity will be low, with the top of field being over-irrigated and the bottom being under-irrigated.
- As would be expected, the light soils have the highest percentage of tile water and the lowest percentage of tailwater.

6. *Salt Balance and Soil Salinity*

As previously discussed, it is necessary for growers to maintain proper salinity in the soil for adequate crop production. The salt balance is achieved by leaching with irrigation water. Table 4 provides the salt balance for each of the fields evaluated.

Table 4 Salt Balance for Irrigations Evaluated.

Field	Average EC of Inflow (dS/m)	Average EC of Tailwater (dS/m)	Average EC of Tile Water (dS/m)	% of Salt Stored in the Root Zone (%)	% of Salt in the Tailwater (%)	% of Salt in the Tile Water (%)
1	0.99	1.15	5.10	50.7	33.0	16.3
2	0.99	1.45	5.00	66.9	19.9	13.2
3	1.00	1.57	9.56	35.0	20.2	44.8
4	1.00		3.00	41.3	0.0	58.7
5	1.00	1.40	4.12	23.3	7.7	68.9
6	0.96	1.13	4.76	43.5	13.6	42.9
7	0.97	1.10	4.49	56.8	21.4	21.9
8	1.01	1.38	9.37	33.5	27.8	38.7
9	1.02	1.36	7.23	51.8	24.4	23.8
10[1]	1.02	1.73	11.45	-312.4	0.0	412.4

[1] In Field 10, the leaching irrigation removed four times the amount of salts applied by the irrigation.

7. *Salt Balance for Heavy Soils*

- Generally, the leaching requirement of the crop cannot be met during the cropping period. For the irrigations evaluated on heavy soils, up to 67 percent of the salt applied was not removed by either vertical leaching or tailwater.

- Analysis of the salinity balance shows that the salinity of the soil increases from 1.5 to 4 percent for each irrigation application during the cropping period. For example, in Field 4, if the EC of the soil extract averaged 3.0 and 50% porosity, there would be approximately 6.26 tons of salt per acre in the top 4 feet of soil. The irrigation that was evaluated added 0.14 tons of salt per acre, increasing the salinity by 2.8 percent.

- The salinity of the water increases as it flows down the field. For the irrigations evaluated, the average salinity of the tailwater was 12 to 47 percent higher than the inflow. The lower value of 12 percent is from a field with a high percentage of tailwater (28 percent). From random sampling of tailwater salinity in areas with heavy cracking soils, the tailwater salinity was up to three times the salinity of the inflow. Thus, for heavy soils a significant amount of salt is removed by tailwater. Random tailwater data can be found at the end of this appendix.

- The salinity of water at the bottom of a field during a leaching irrigation can be increased to double or triple the salinity of the inflow. It is believed that this occurs due to the increased surface area of soil (from clods) that is in contact with the irrigation water and the very limited amount of tailwater.

- The salinity content of the tailwater is a function of both the amount of runoff and salinity of the soil. In general, the salinity of the tailwater decreases as the amount and time of the tailwater flow increases (i.e. the higher the tailwater flow, the lower the salinity of the tailwater for a specific field condition and the longer the set time, the lower the salinity concentration in the tailwater.) The salinity of the tailwater is also higher for soil with higher salinity in the soil water.

- During the irrigation evaluations of medium to heavy soils, only about 3 to 5 percent of the total irrigation water was used for vertical leaching into the tile drains or past the root zone. Even though significant amounts of salts were removed through the tile water, the vertical leaching was insufficient due to the limited amount of water that could infiltrate the soil.The exception was Field 5, with 35 hours of intake opportunity time, which is not typical or practical for most fields and crops.

- The average salinity of the tile water on the fields evaluated with medium to heavy soils ranged from 5 to 11.5 dS/m. However, random sampling of tile water of other fields in areas with heavy soils found tile water with a salinity of over 30 dS/m.

- The salinity of the tile water is similar in magnitude to the salinity of the soil extract at about 4 feet.

- Without extensive leaching/soil preparation and irrigation between crops, the salinity of the soil would increase to a point that very few or no crops can be economically grown.

- In general, the salinity of the soil increases with depth due to greater leaching in the upper layers of the soil. The applied water moves the salt downward.

- When the soils are uniform in a field, the salinity of the soil increases from the head to the tail of the field. In general, the salinity of the soil is higher at the tail of the field due to reduced leaching and increased salinity of infiltrated water.

- The deep ripping and leaching/land preparation irrigation is necessary to maintain an adequate salt balance in the soil. This irrigation comes at a high but necessary cost to the grower. The leaching irrigation could cost from $75 to over $100 per acre. Deep ripping costs approximately $35 per acre and then there are subsequent operations including disking, leveling, and diking that occur before the irrigation. A typical irrigation requires about one acre-foot of water per acre. Because tailwater discharge is very limited with leaching irrigation or land preparation irrigation, many irrigators install a temporary pump-back system to convey the tailwater back to the head of the field for re-application. IID Regulation Number 45 states that no measurable waste is allowed except 5% on the last day of irrigation. Approximately 1.5 inches of the applied water are consumed by evaporation from the soil surface and four to six inches can be stored in the root zone. The soil is usually quite dry before a leaching irrigation due to the tillage. The soil is also allowed to dry before ripping to aid in fracturing the soil, which improves the water infiltration characteristics of the soil.

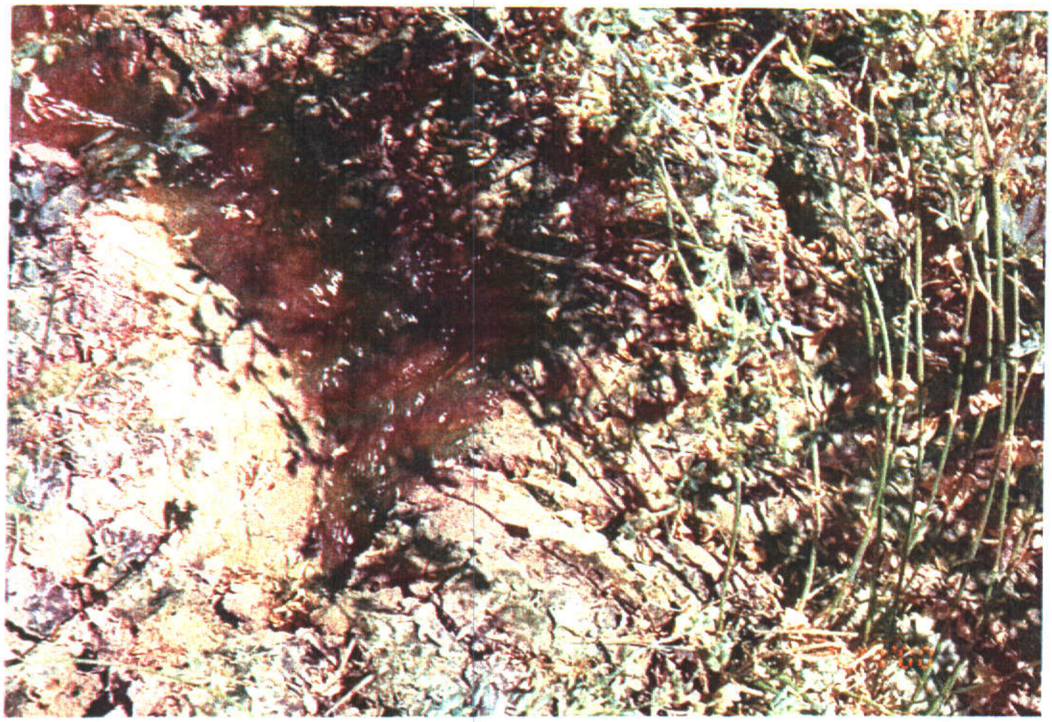
8. *Salt Balance for Light Soils*

- The light soils have lower soil salinity content than the heavy cracking soils.

- Due to the high infiltration rate of the light soils, it is possible to maintain an adequate salinity balance during crop production if adequate drainage is available.

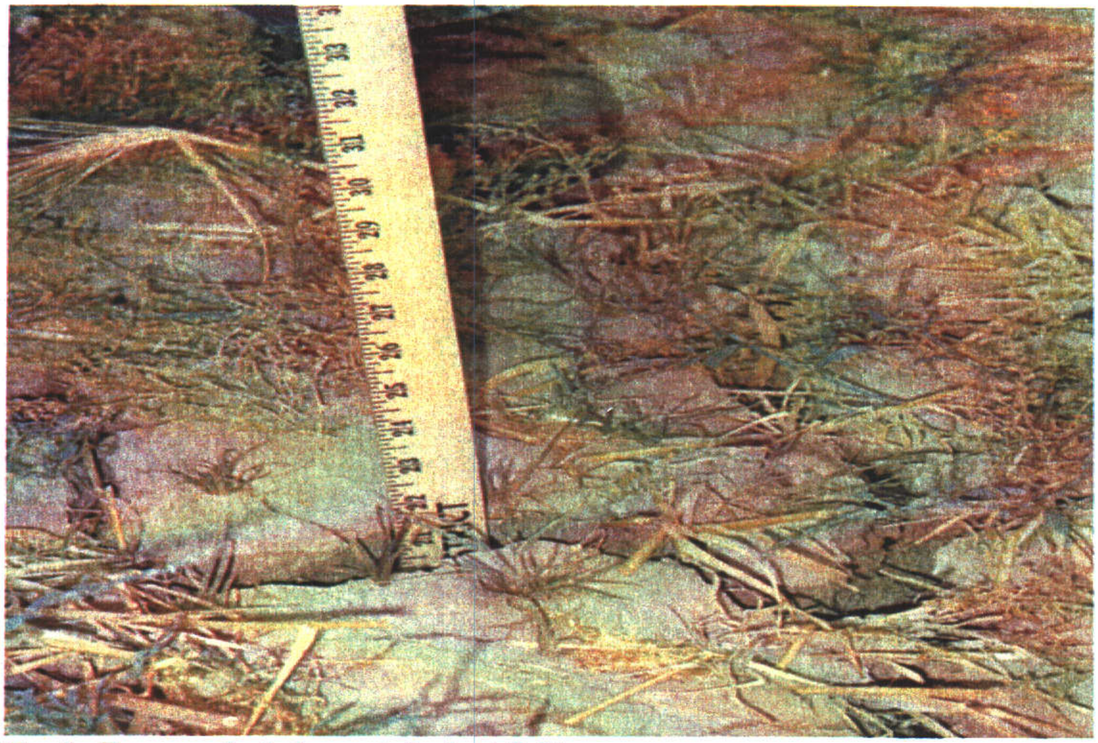
No. 1 Example of cracks in a furrow-irrigated alfalfa field.

No. 2 Advancing stream down a furrow-irrigated alfalfa field with cracks in it.

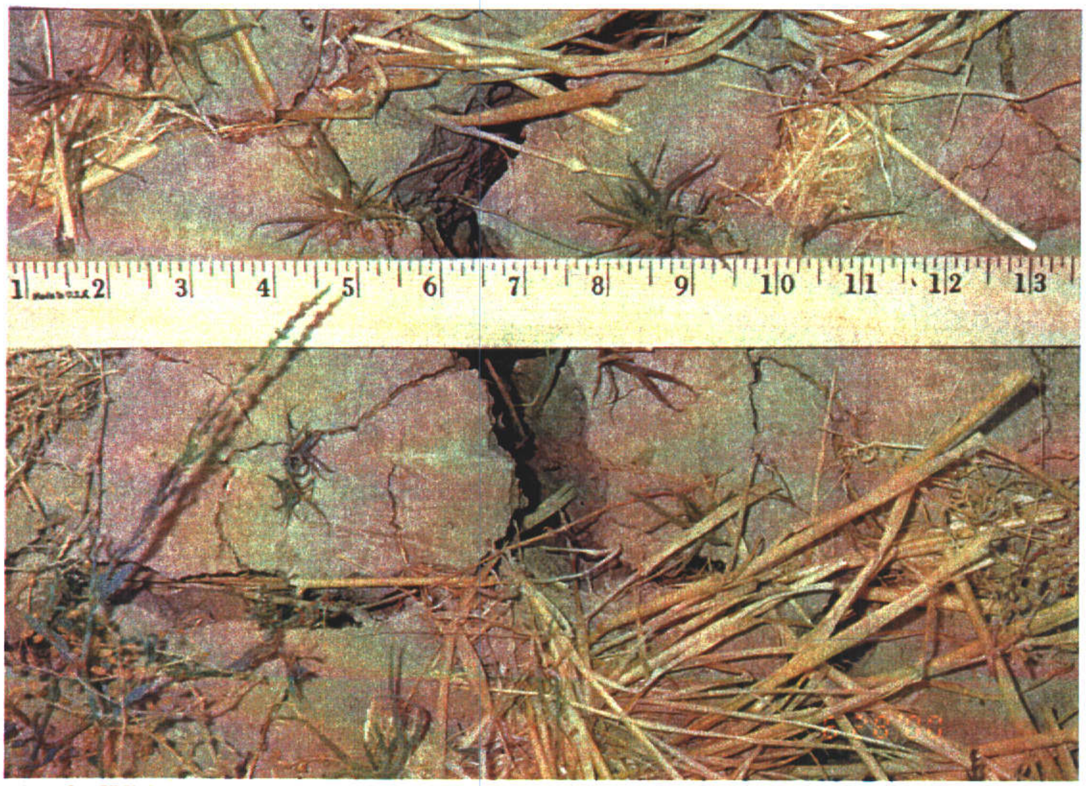


No. 3   Advancing stream down a border with some cracks present.

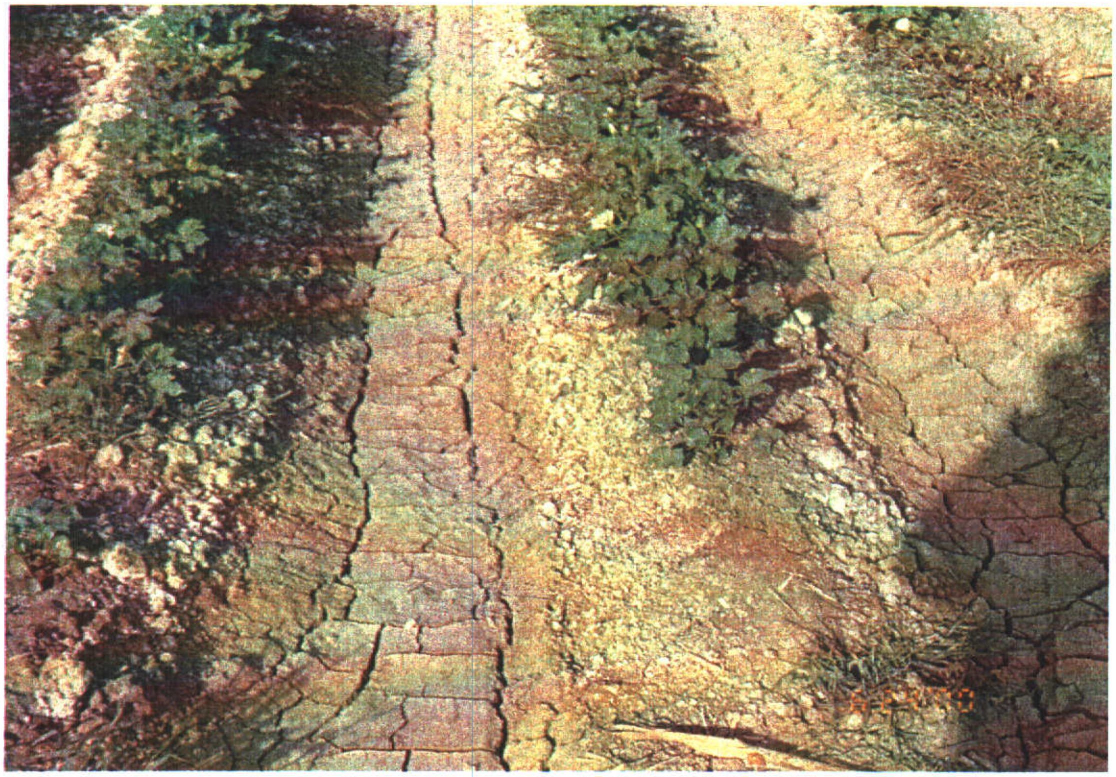
No.4   Water filling up cracks during an irrigation.



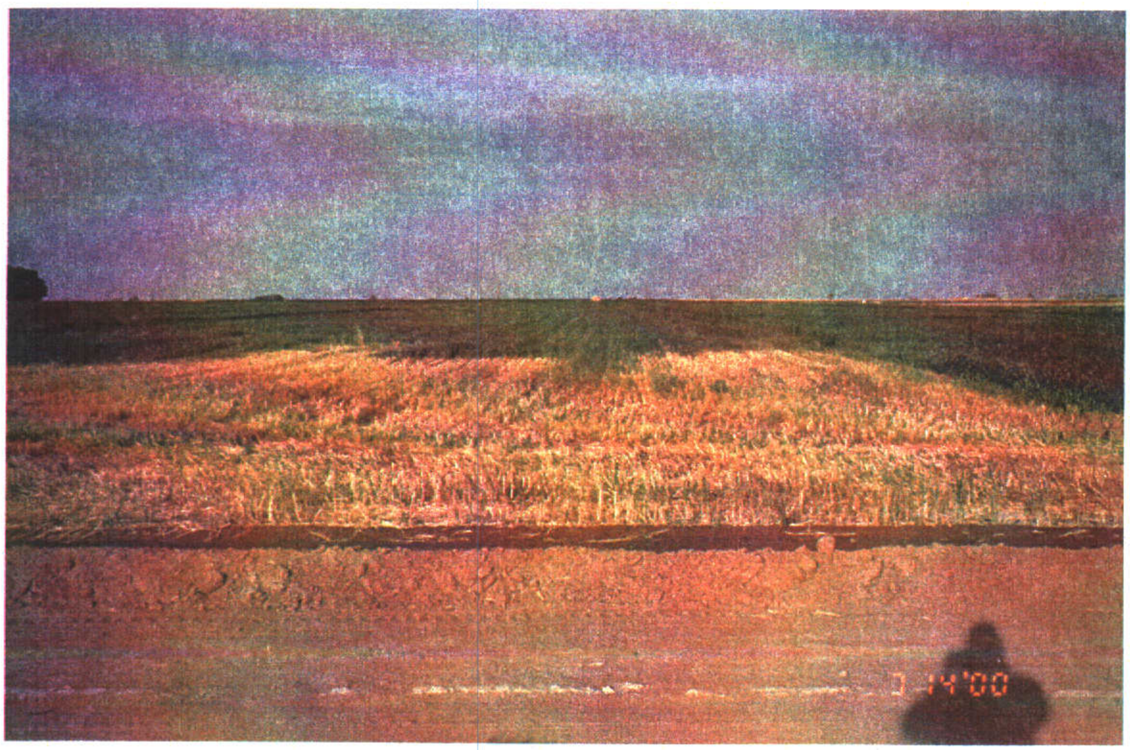
No. 5 Deep cracks in harvested wheat field.



No. 6 Wide cracks in harvested wheat field.



No.7 Furrow cracks and salt deposits in cotton field.

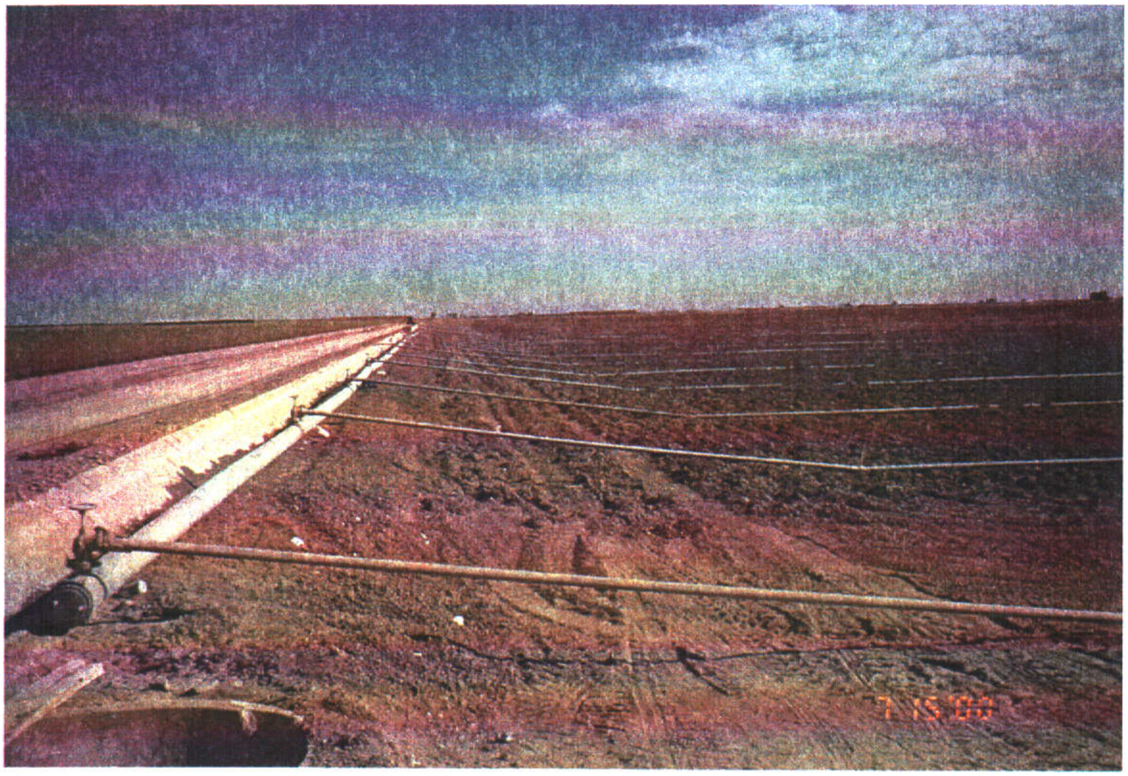


No. 8 Bottom end of field with Sudan grass field where irrigation water did not reach bottom of field.

No. 9 Leaching irrigation in progress. Top end of the field.

No. 10 Portable tail water pump back system used during a leaching irrigation.

No. 11 Tail water being pumped back to the head ditch during leaching irrigation.



No. 12 Solid-set sprinklers set up for a leaching irrigation.

No. 13 Tile water discharging into main drainage ditch.

No. 14 Field salinity assessment vehicle.

Field Irrigation Evaluation Summaries

The following data for each field (if available) are contained in this appendix:

1. Field irrigation summary sheets describing field, crop, soil, and irrigation data.
2. Field irrigation and cropping history.
3. Field layout with soil mapping units.
4. IID Irrigation Management Unit (IMU) hydrographs of irrigation evaluations.
5. Illustrations showing the salt balance, irrigation water EC comparisons, and the advance and recession curves of the irrigations.
6. Results of the soil salinity assessments carried out by IMU following the evaluations.

Other data present in separate sections in this appendix include:

1. Results of soil salinity assessments carried out on fields not included in the irrigation evaluations.
2. Random tail water salinity and flow measurements.

Field No. 1

Field Irrigation Evaluation

Data Summary

FIELD IRRIGATION EVALUATION FOR
IMPERIAL IRRIGATION DISTRICT
IMPERIAL VALLEY, CALIFORNIA.
FIELD NO. 1

FIELD DATA

Irrigated Acreage: 72 acres (ac)
Border Length: 1200 feet (ft)
Border Width: 150 ft, edge borders are about 75 ft.
Border Slope: Average, 0.002645 ft/ft

CROP DATA

Crop: First year Alfalfa, planted September of 1999 following leaching irrigation. Previously cropped as Sudan Grass
Crop Growth Stage: 18 inches (in) in height
Crop Condition: Good

SOILS DATA

Soil Texture: Imperial silty clay (60%); Imperial-Glenbar silty clay loam (30%); Holtville silty clay (10%)
Soil Depth: > 4ft
Soil Uniformity: There were some sandy layers down the profile and the texture changed spatially in the field.
Effective Crop Rooting Depth: 4 ft
Available Water Capacity: 0.17 – 0.35 in/in.
Estimated Allowable Depletion: 5 in

SOIL CONDITION

Estimated Soil Water Deficit at Beginning of Irrigation:
Average: 3.0 in
Estimated Irrigation Water Stored in Root Zone:
Average: 2.6 in

IRRIGATION DATA

Irrigation Method: Borders with gated outlets from concrete-lined head ditch.
Field and Soil Condition: Slightly cracking, about ¼ - ½ inches wide, 6 inches deep, and 8-inch spacing.: Corrugations at 40-inch centers. Previous irrigation on June 13, 2000.

Beginning Irrigation Time: June 22, 2000, 7:05 a.m.
Ending Irrigation Time: June 23, 2000, 7:45 a.m.
Beginning Outflow Time: June 22, about 11:15 a.m.
Ending Outflow Time: June 23, about 1 p.m.
Average Inflow: 11.2 cubic feet per second (cfs)
Average Outflow: 3.07 cfs

Number of Sets: 7
Set Time: 3.0 to 4.2 hours
Advance Time: 4.3 to 4.6 hours
Uniformity of Advance: Near constant rate of advance. Quite uniform.
Number of Borders per Set: 2 or 3

Irrigation Observations: Tailwater high at peak flow than usual. Could have Used longer set time and lower flow rates.
Uniformity: Good
Ponding: Slight ponding at the bottom end near the tailwater box.
Erosion: Some at bottom of the field
Estimated Irrigation Efficiency: 72 %.

Irrigation Summary		
	Average Depth[1], in	Percent of Water Applied %
Total Water Applied	3.80	
Total Water Stored in Root Zone	2.60	68
Total Runoff	1.08	28
Total Deep Percolation	0.12	3

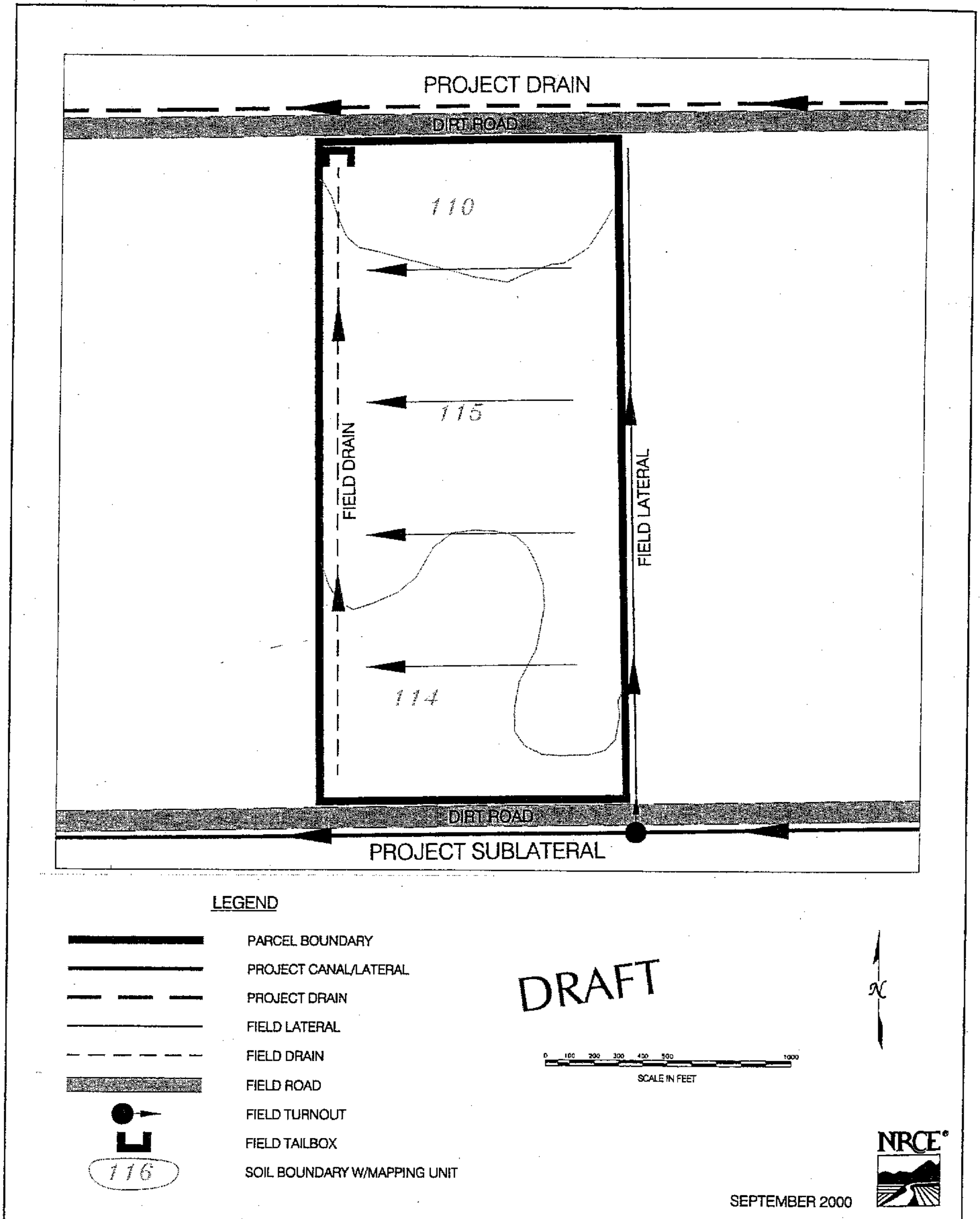
[1]Depth based on field irrigated acreage.

Field No.1 - Irrigation and Cropping History

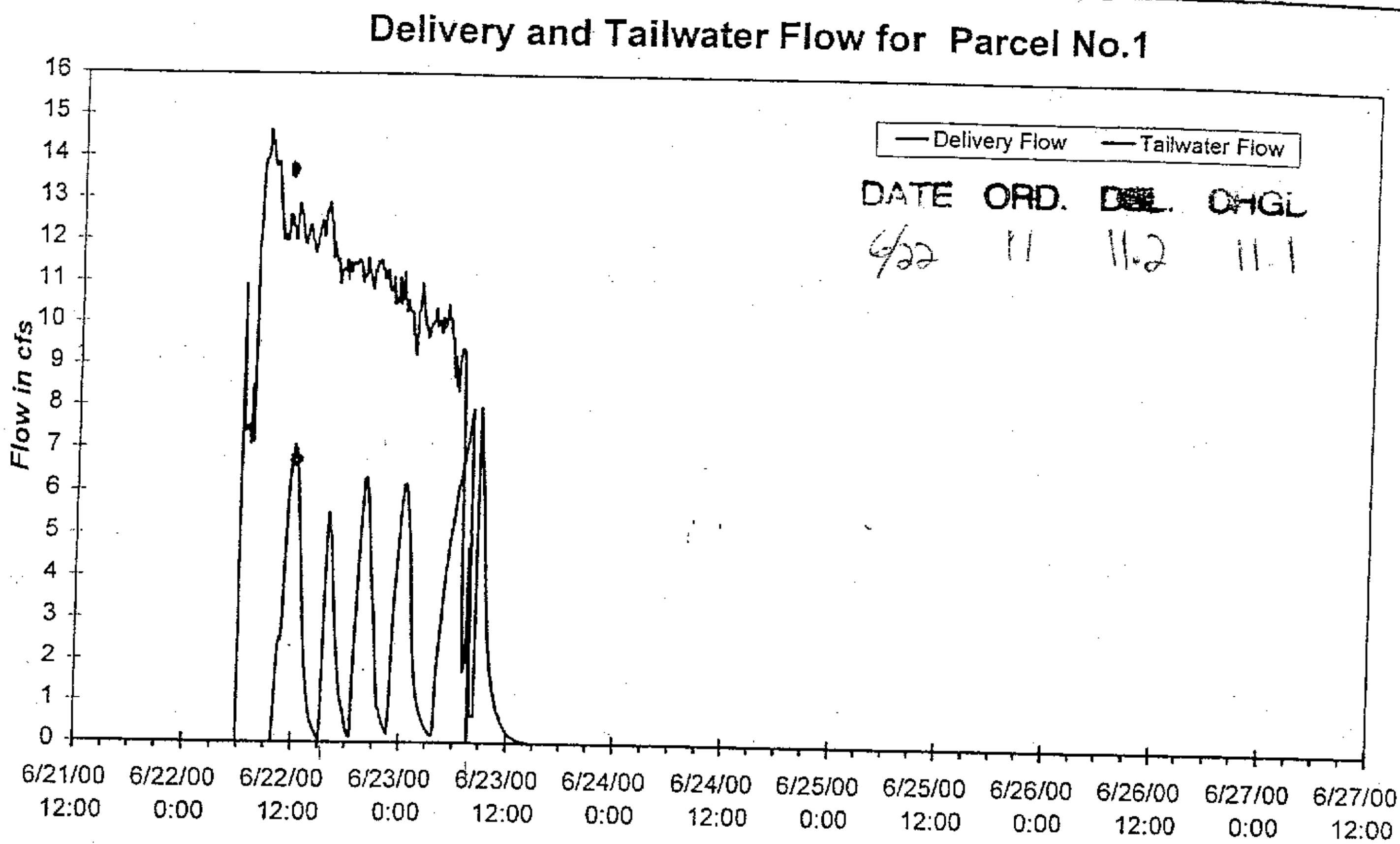
Cropped Area: 72 ac

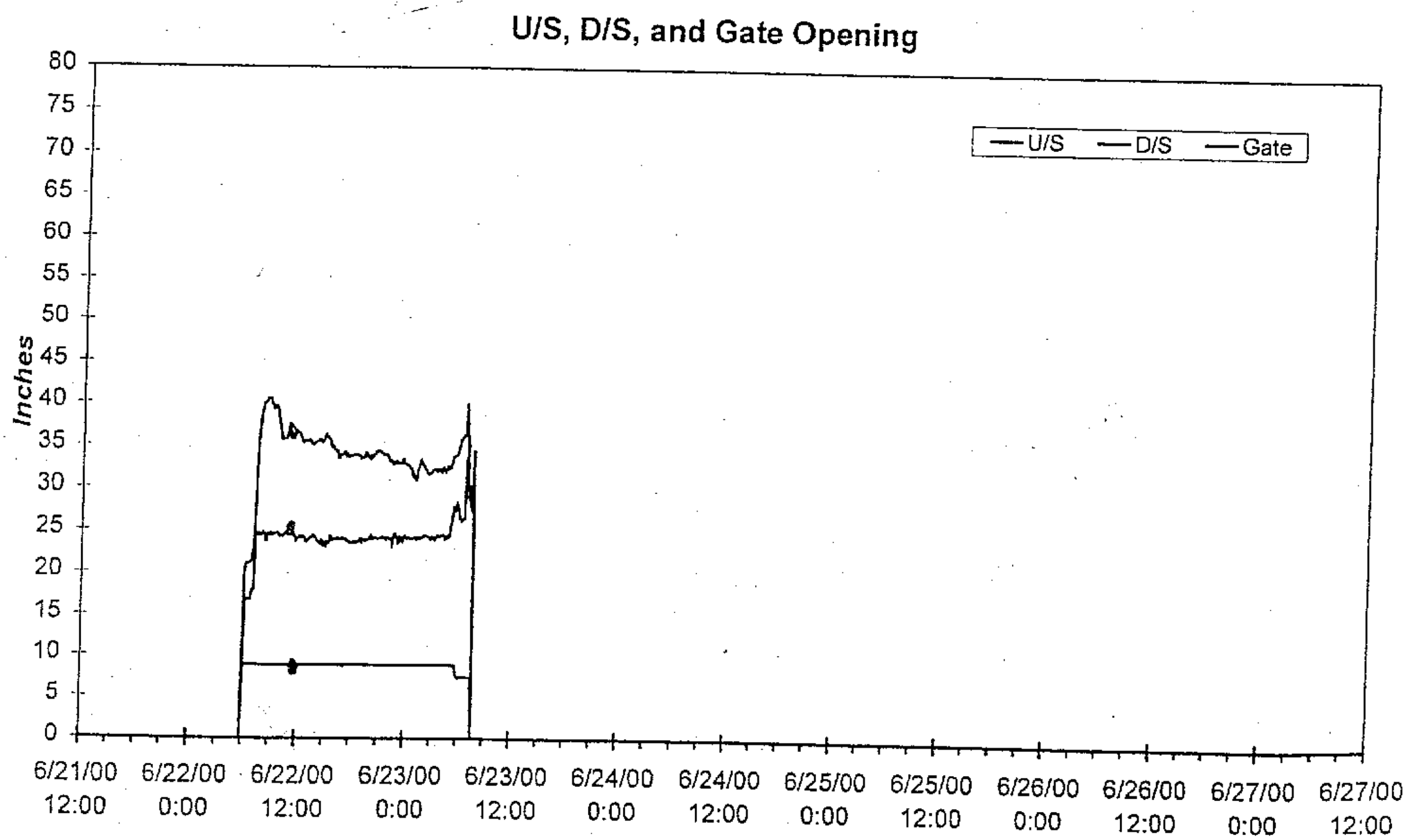
Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Sugar Beets	1/8/97		10	10.2	10.2	3.37	3.37
Sugar Beets	2/11/97	34	10	10	10	3.31	3.31
Sugar Beets	3/5/97	22	10	10.3	10.3	3.41	3.41
Sugar Beets	3/19/97	14	8	4.3	4.3	1.42	
Sugar Beets	3/20/97	1	11	10.9	11	3.64	5.06
Sugar Beets	4/2/97	13	10	10.1	10.1	3.34	
Sugar Beets	4/3/97	1	10	10.1	10.1	3.34	6.68
Sugar Beets	4/14/97	11	10	10.3	10.3	3.41	3.41
Sugar Beets	4/26/97	12	10	9.2	9.2	3.04	
Sugar Beets	4/27/97	1	10	10.1	10	3.31	6.35
Sugar Beets	5/7/97	10	10	10.3	10.3	3.41	3.41
Sugar Beets	5/15/97	8	10	10.3	10.3	3.41	3.41
Sugar Beets	5/25/97	10	10	10.2	10.2	3.37	3.37
Sugar Beets	6/3/97	9	10	10.2	10.2	3.37	3.37
Sugar Beets	6/12/97	9	9	9.1	9.1	3.01	3.01
Sugar Beets	6/20/97	8	8	8	8	2.64	2.64
Idle	6/28/97	8	6	6	6	1.98	1.98
Flooding, flat	8/1/97	34	15	15	15	4.96	
Flooding, flat	8/2/97	1	15	14.9	14.9	4.93	**9.88**
Flooding, flat	11/19/97	109	10	9.9	9.9	3.27	
Flooding, flat	11/20/97	1	10	9.9	9.9	3.27	**6.55**
Flooding, flat	1/21/98	62	12	11.9	11.9	3.93	**3.93**
Wheat	3/1/98	39	11	11.2	11.2	3.70	3.70
Wheat	3/14/98	13	11	11.4	11.4	3.77	3.77
Wheat	3/31/98	17	10	10.3	10.3	3.41	3.41
Wheat	4/10/98	10	10	10.2	10.2	3.37	3.37
Wheat	4/22/98	12	10	11.4	11.4	3.77	
Wheat	4/23/98	1	12	12.2	12.2	4.03	7.80
Wheat	5/1/98	8	14	13.9	13.9	4.60	
Flooding, flat	7/13/98	73	12	11.9	11.9	3.93	
Flooding, flat	7/14/98	1	12	6	6	1.98	**5.92**
Flooding, row	9/14/98	62	8	8.1	8.1	2.68	
Flooding, row	9/15/98	1	10	10	10	3.31	**5.98**
Onions	10/13/98	28	8	8.1	8.1	2.68	2.68
Onions	10/16/98	3	8	5.7	5.7	1.88	1.88
Onions	10/19/98	3	8	4.5	4.5	1.49	1.49
Onions	10/23/98	4	8	4.6	4.6	1.52	1.52
Onions	10/30/98	7	8	8.1	8.1	2.68	
Onions	10/31/98	1	8	8.1	8.1	2.68	5.36
Onions	12/10/98	40	8	8.1	8.1	2.68	
Onions	12/11/98	1	8	8.3	8.3	2.74	5.42
Onions	1/25/99	45	8	8.3	8.3	2.74	2.74
Onions	2/20/99	26	8	8.3	8.3	2.74	

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Onions	2/21/99	1	8	8.1	8.1	2.68	5.42
Onions	3/3/99	10	8	8.1	8.1	2.68	
Onions	3/4/99	1	8	8.1	8.1	2.68	5.36
Onions	3/12/99	8	4	4	4	1.32	
Onions	3/13/99	1	7	7	7	2.31	3.64
Onions	3/22/99	9	7	7.1	7.1	2.35	2.35
Onions	3/30/99	8	8	4	4	1.32	
Onions	3/31/99	1	8	8.1	8.1	2.68	4.00
Onions	4/8/99	8	4	4	4	1.32	
Onions	4/9/99	1	8	8.1	8.1	2.68	4.00
Onions	4/17/99	8	8	8.4	8.4	2.78	2.78
Onions	4/23/99	6	8	8.1	8.1	2.68	2.68
Onions	4/27/99	4	8	6.4	6.4	2.12	2.12
Onions	5/30/99	33	8	8.2	8.2	2.71	
Sudan Grass	5/31/99	1	7	3.2	3.2	1.06	3.77
Sudan Grass	6/8/99	8	9	9	9	2.98	2.98
Sudan Grass	6/19/99	11	10	10.3	10.3	3.41	3.41
Sudan Grass	6/28/99	9	10	10.3	10.3	3.41	3.41
Sudan Grass	7/6/99	8	11	10.9	10.9	3.60	3.60
Sudan Grass	7/15/99	9	11	10.9	10.9	3.60	3.60
Sudan Grass	7/23/99	8	11	11.2	11.2	3.70	3.70
Flooding, flat	9/19/99	58	10	10	10	3.31	
Flooding, flat	9/20/99	1	10	7.7	7.7	2.55	**5.85**
Flooding, flat	11/2/99	43	8	8	8	2.64	
Flooding, flat	11/3/99	1	8	8	8	2.64	
Flooding, flat	11/4/99	1	8	8	8	2.64	**7.93**
Alfalfa, flat	11/25/99	21	6	5.9	5.9	1.95	1.95
Alfalfa, flat	12/21/99	26	12	10.9	12	3.97	3.97
Alfalfa, flat	1/26/00	36	11	10.9	10.9	3.60	3.60
Alfalfa, flat	3/17/00	51	13	13.2	13.2	4.36	
Alfalfa, flat	3/18/00	1	13	12.9	12.9	4.26	8.63
Alfalfa, flat	4/4/00	17	10	10.2	10.2	3.37	3.37
Alfalfa, flat	4/24/00	20	13	12.9	12.9	4.26	4.26
Alfalfa, flat	5/5/00	11	10	10.2	10.2	3.37	
Alfalfa, flat	5/6/00	1	10	10.2	10.2	3.37	6.74
Alfalfa, flat	5/21/00	15	12	12.5	12.5	4.13	4.13
Alfalfa, flat	5/29/00	8	11	11.2	11.2	3.70	3.70
Alfalfa, flat	6/13/00	15	12	12.1	12.1	4.00	4.00
Alfalfa, flat	6/22/00	9	11	11.2	11.1	3.67	3.67
Alfalfa, flat	7/9/00	17	12	11.9	11.9	3.93	3.93
Alfalfa, flat	7/19/00	10	11	10.9	10.9	3.60	3.60
Alfalfa, flat	7/31/00	12	12	12	12	3.97	3.97



Field No. 1 Layout





Order = **1d-11'**
Soil Type = **115, 114**
Delivery Volume (AF) = **23.0**
Tailwater Volume (AF)= **6.5**
% Tailwater= **28%**
Crop = **Alfalfa**
Acres = **72**
Inches Applied= **3.8**

Field No. 1 - 0 to 1 ft. (auto scale)

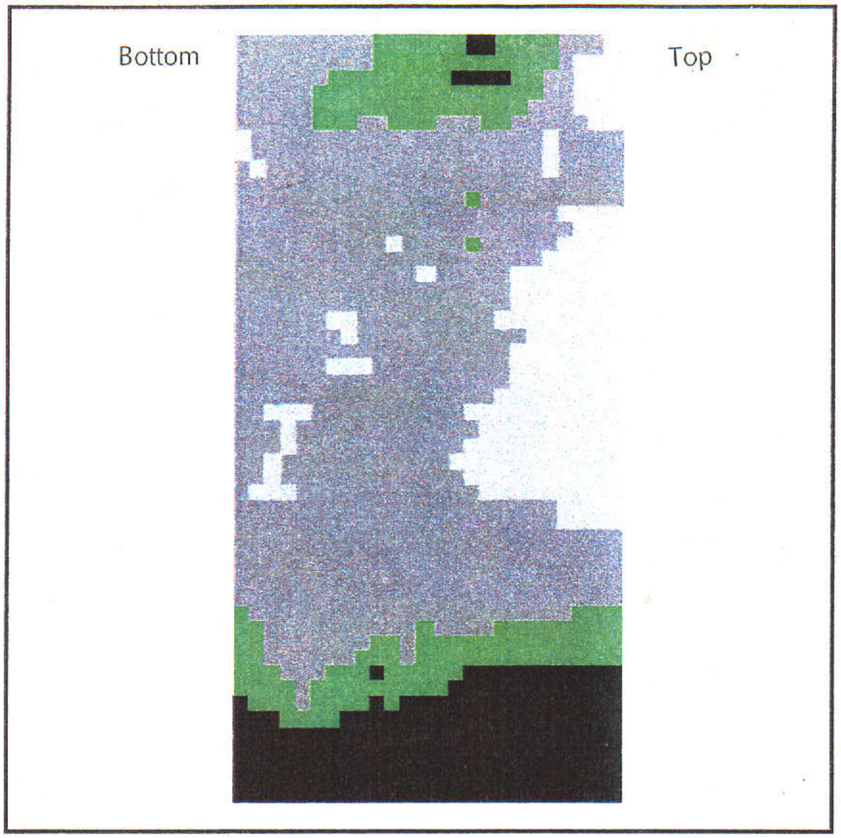
ECe(0.5)
dS/m

< 2.19
2.19 - 2.847
2.847 - 3.504
> 3.504

Data Bounds

X: min & max
645221.74
645580.22

Y: min & max
3657326.01
3658070.14



1 to 2 ft. (auto scale)

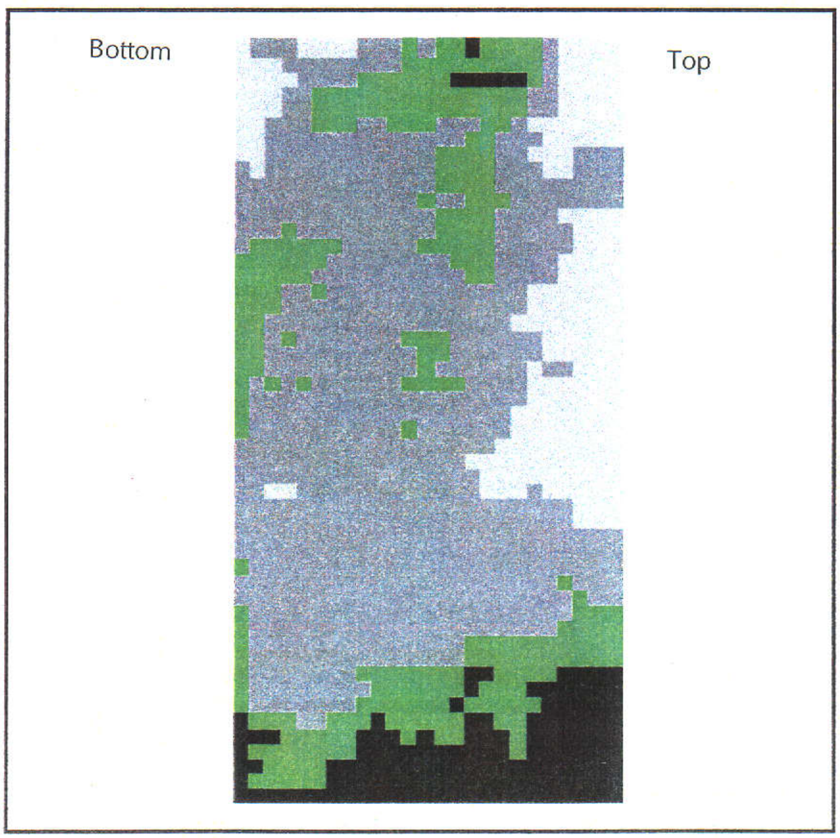
ECe(1.5)
dS/m

< 3.355
3.355 - 4.684
4.684 - 6.012
> 6.012

Data Bounds

X: min & max
645221.74
645580.22

Y: min & max
3657326.01
3658070.14



Field No. 1 - 2 to 3 ft. (auto scale)

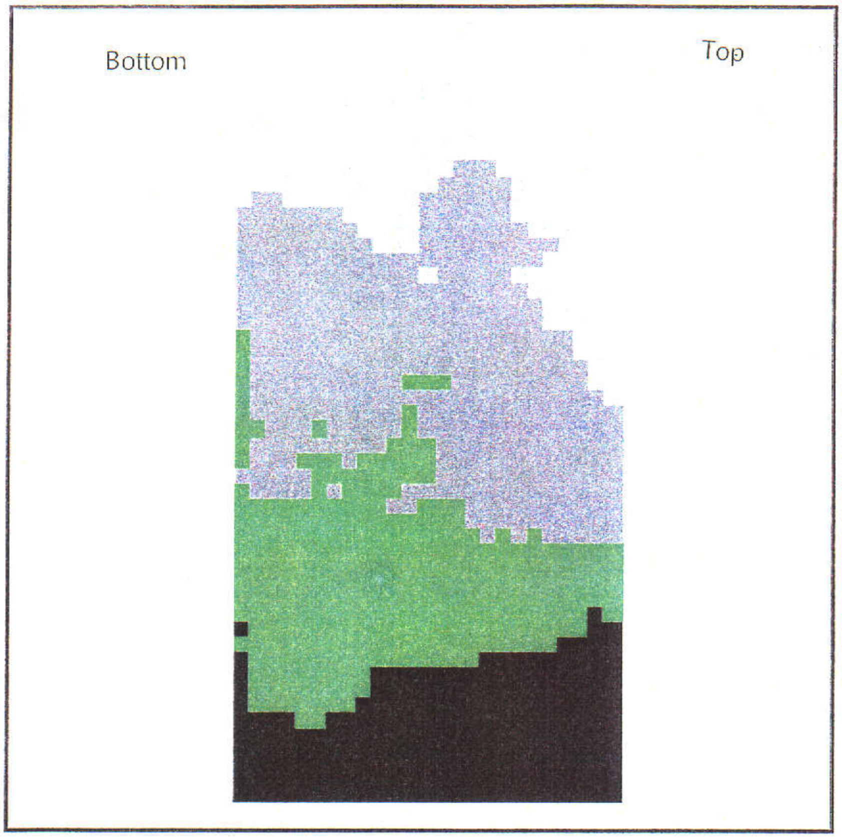
ECe(2.5)
dS/m

< 3.151
3.151 - 4.804
4.804 - 6.457
> 6.457

Data Bounds

X: min & max
645221.74
645580.22

Y: min & max
3657326.01
3658070.14



3 to 4 ft. (auto scale)

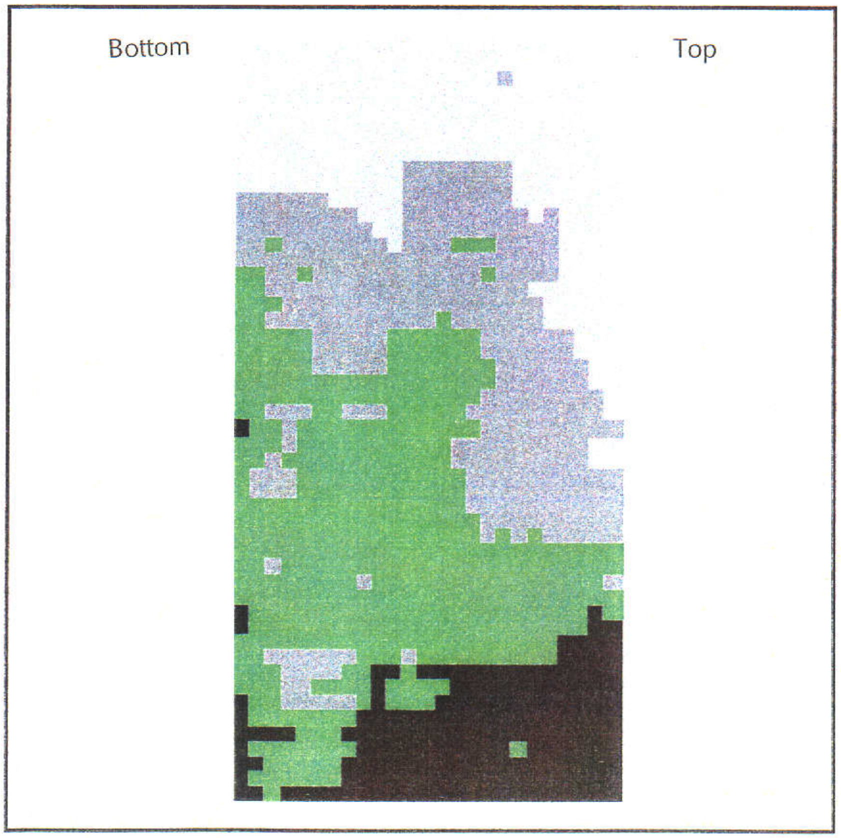
ECe(3.5)
dS/m

< 3.169
3.169 - 4.954
4.954 - 6.74
> 6.74

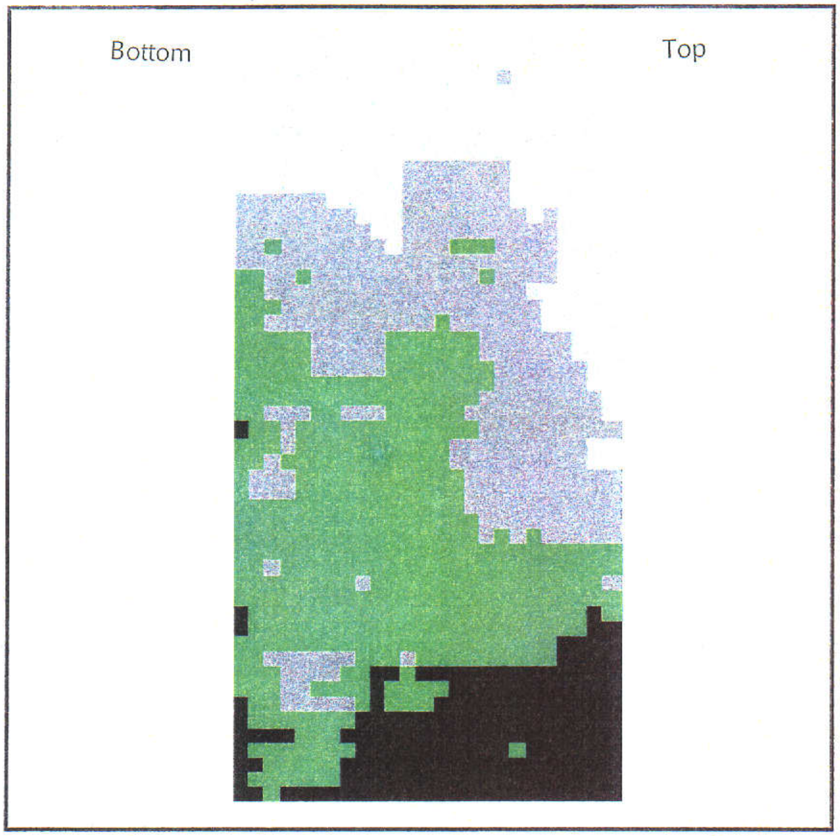
Data Bounds

X: min & max
645221.74
645580.22

Y: min & max
3657326.01
3658070.14



Field No. 1 - 4 ft. profile avg. (auto scale)



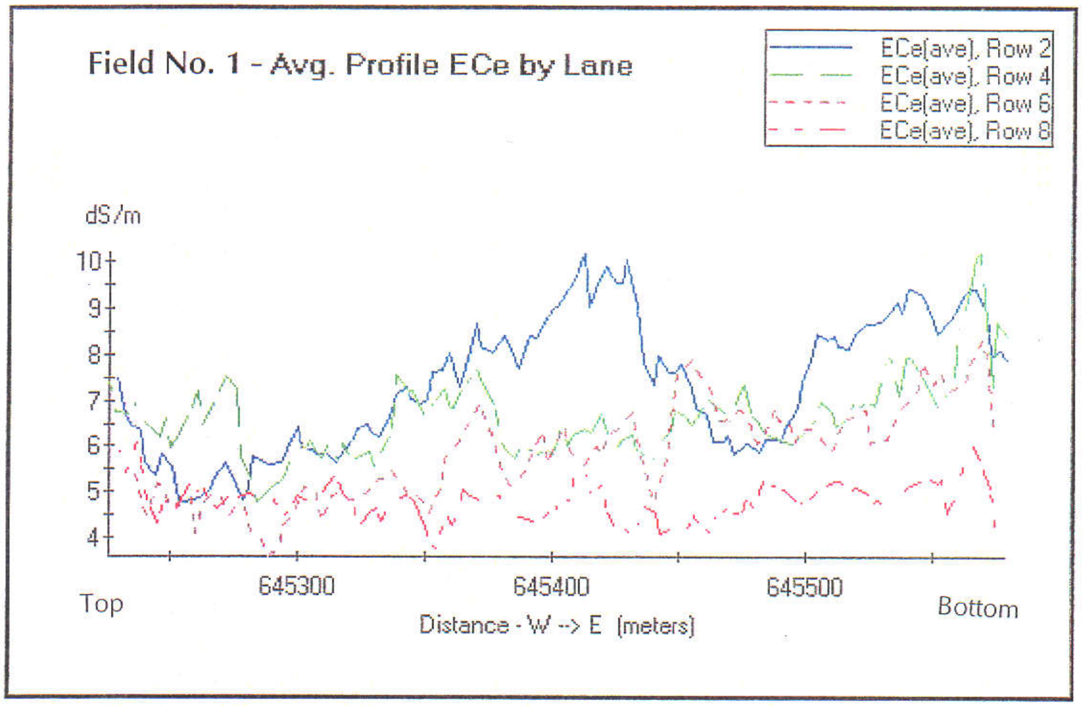
ECe(ave)
dS/m

< 3.087
3.087 - 4.358
4.358 - 5.628
> 5.628

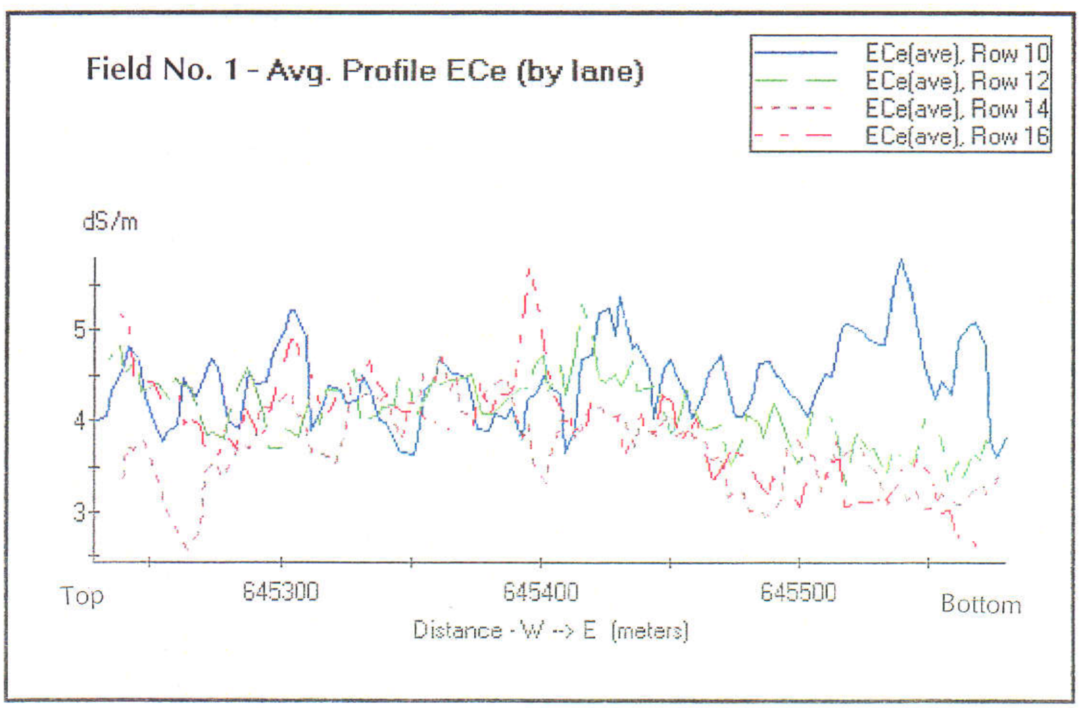
Data Bounds

X: min & max
645221.74
645580.22

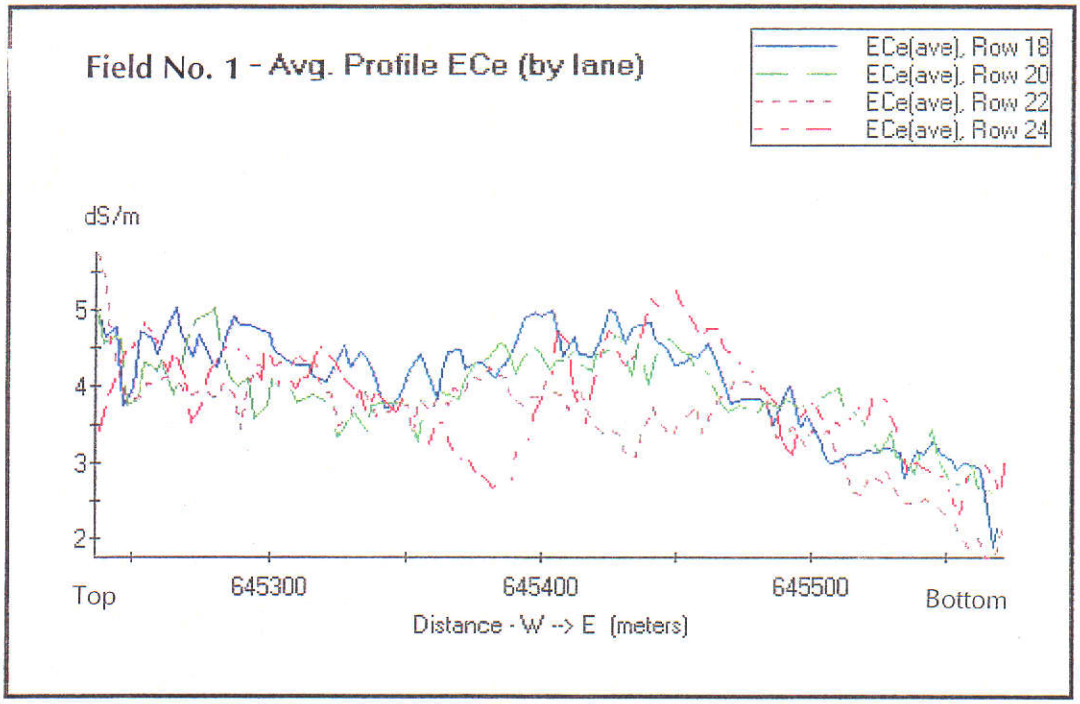
Y: min & max
3657326.01
3658070.14

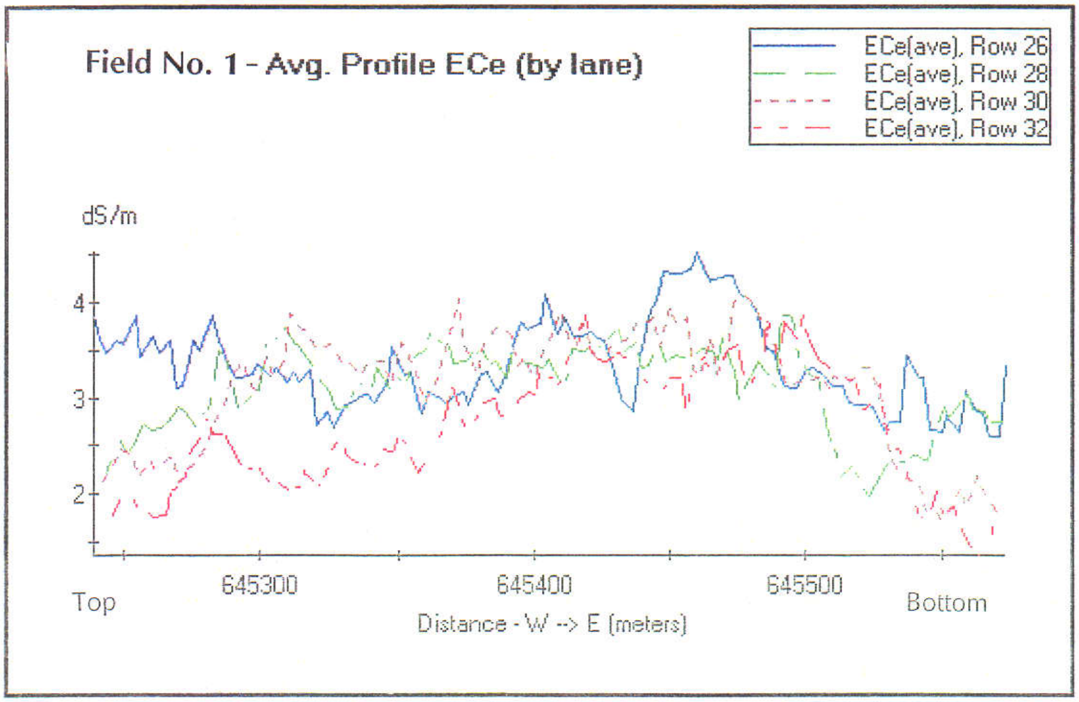


Field No. 1 - Avg. Profile ECe by Lane
ECe(ave), Row 2
ECe(ave), Row 4
ECe(ave), Row 6
ECe(ave), Row 8
dS/m
10
9
8
7
6
5
4
Top
645300
645400
645500
Bottom
Distance - W --> E (meters)



Field No. 1 - Avg. Profile ECe (by lane)
ECe(ave), Row 10
ECe(ave), Row 12
ECe(ave), Row 14
ECe(ave), Row 16
dS/m
5
4
3
Top
645300
645400
645500
Bottom
Distance - W --> E (meters)


Field No. 1 - Avg. Profile ECe (by lane)
ECe(ave), Row 18
ECe(ave), Row 20
ECe(ave), Row 22
ECe(ave), Row 24
dS/m
5
4
3
2
Top
645300
645400
645500
Bottom
Distance - W --> E (meters)


Field No. 1 - Avg. Profile ECe (by lane)
ECe(ave), Row 26
ECe(ave), Row 28
ECe(ave), Row 30
ECe(ave), Row 32
dS/m
4
3
2
Top
645300
645400
645500
Bottom
Distance - W --> E (meters)

Field No. 2

Field Irrigation Evaluation

Data Summary

FIELD IRRIGATION EVALUATION FOR
IMPERIAL IRRIGATION DISTRICT
IMPERIAL VALLEY, CALIFORNIA.
FIELD NO. 2

FIELD DATA

Irrigated Acreage: 78 acres (ac)
Border Length: 1380 feet (ft)
Border Width: 120 ft (edge borders are less than full width).
Border Slope: Average, 0.001931 ft/ft

CROP DATA

Crop: Third or forth year Alfalfa in seed. Planted prior to January 1997.
Crop Growth Stage: 24 inches (in) in height with heavy bloom seed alfalfa crop.
Crop Condition: Good

SOILS DATA

Soil Texture: Imperial-Glenbar silty clay loam (30%); Holtville silty clay (30%) Indio loam (15%); Imperial silty clay (10%).
Soil Depth: > 4ft
Soil Uniformity: Average to good
Effective Crop Rooting Depth: 4 ft
Available Water Capacity: 0.17 – 0.25 in/in.
Estimated Allowable Depletion: 4.0 in.

SOIL CONDITION

Estimated Soil Water Deficit at Beginning of Irrigation:
Average: 3.5 in
Estimated Irrigation Water Stored in Root Zone:
Average: 3.2 in

IRRIGATION DATA

Irrigation Method: Borders with gated outlets from concrete-lined head ditch.
Field and Soil Condition: Soil was quite dry before the irrigation. Some cracking in the soil. Previous irrigation on June 11, 2000.

Beginning Irrigation Time: June 23, 2000, 7:30 a.m.
Ending Irrigation Time: June 24, 2000, 7:30 a.m
Beginning Outflow Time: June 23, about 12 noon
Ending Outflow Time: June 24, about 1 p.m
Average Inflow: 12.5 cubic feet per second (cfs)
Average Outflow: 1.64 cfs

Number of Sets: 11
Set Time: 2.0 to 2.8 hours.
Advance Time: 3.4 to 4.0 hours
Uniformity of Advance: Near constant rate of advance. Quite uniform.
Number of Borders per Set: 2

Irrigation Observations:
Uniformity: Good.
Ponding: None
Erosion: None
Estimated Irrigation Efficiency: 87%.

Irrigation Summary		
	Average Depth[1], in	Percent of Applied Water, %
Total Water Applied	3.82	
Total Water Stored in Root Zone	3.20	83
Total Runoff	0.52	14
Total Deep Percolation	0.10	3

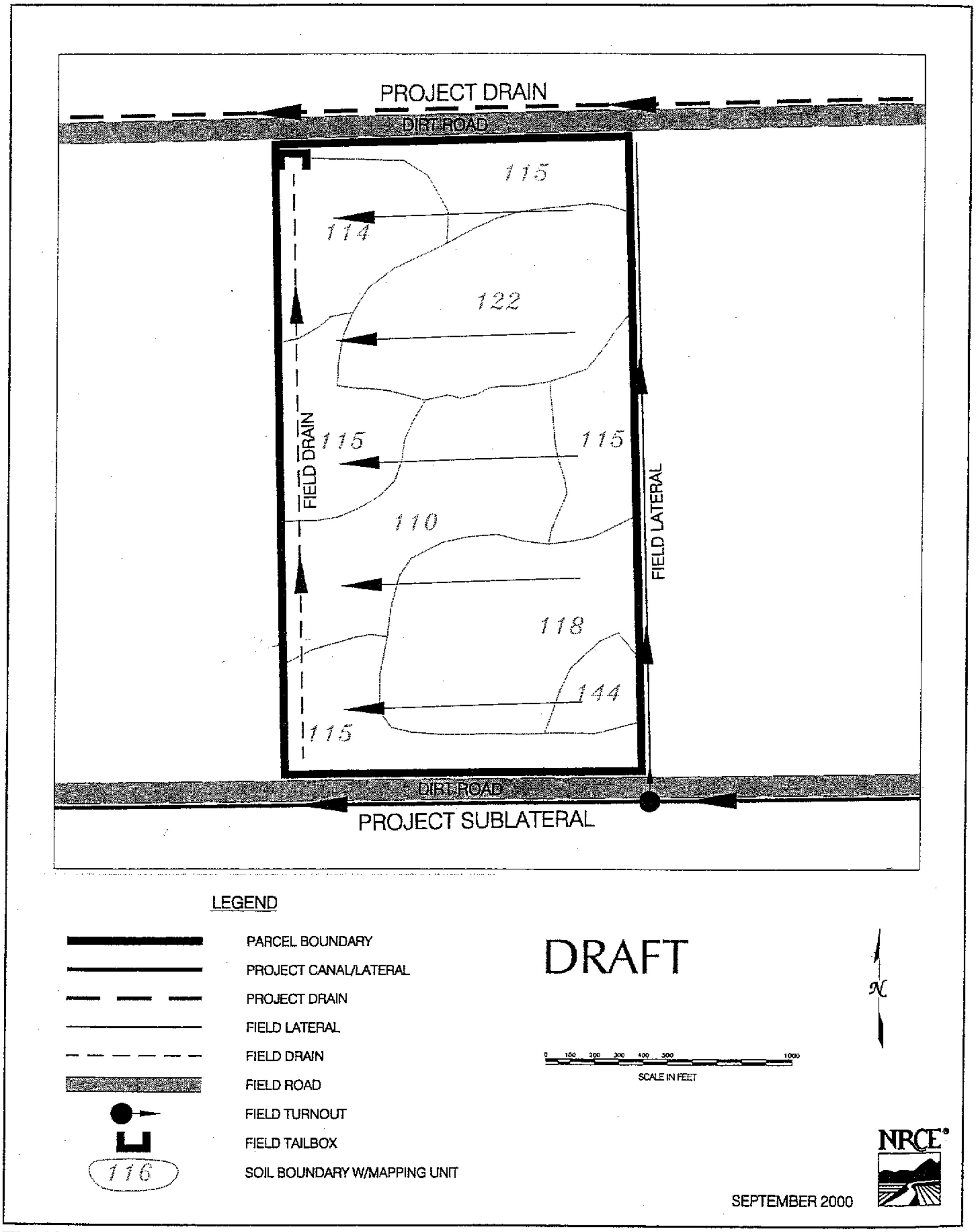
[1]Depth based on field irrigated acreage.

Field No.2 - Irrigation and Cropping History

Cropped Area: 78 ac

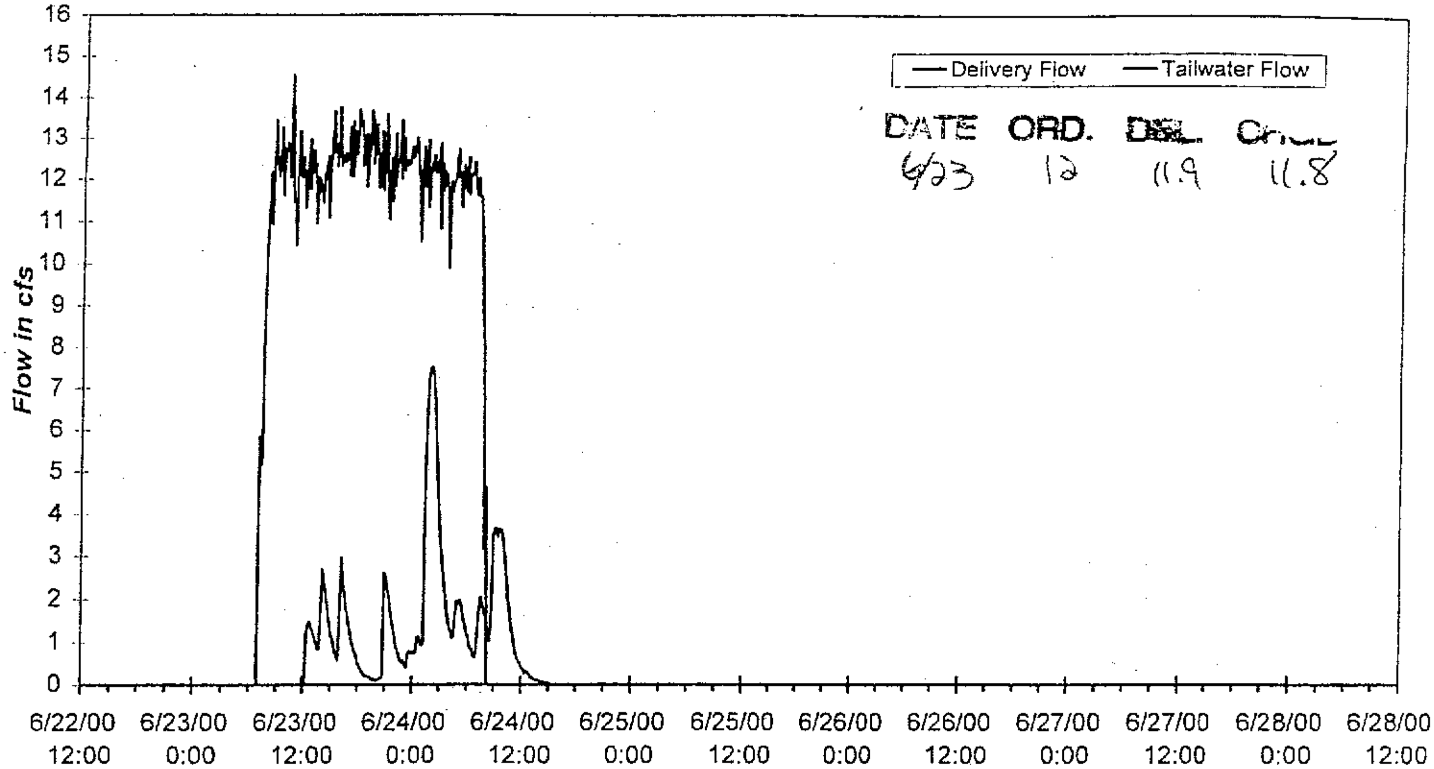
Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Alfalfa, flat	2/15/97		12	12.3	12.3	3.75	3.75
Alfalfa, flat	3/5/97	18	11	12.9	12.9	3.94	3.94
Alfalfa, flat	3/31/97	26	12	12.1	12.1	3.69	
Alfalfa, flat	4/1/97	1	5	1.9	2.5	0.76	4.46
Alfalfa, flat	4/3/97	2	4	0.8	2	0.61	0.61
Alfalfa, flat	4/12/97	9	13	13.2	13.2	4.03	4.03
Alfalfa, flat	5/1/97	19	7	1.5	1.5	0.46	0.46
Alfalfa, flat	5/5/97	4	12	11.9	11.9	3.63	3.63
Alfalfa, flat	5/14/97	9	12	11.5	12.1	3.69	3.69
Alfalfa, flat	6/3/97	20	12	12	12	3.66	
Alfalfa, flat	6/4/97	1	7	7.7	7.7	2.35	6.01
Alfalfa, flat	6/13/97	9	12	12	12	3.66	3.66
Alfalfa, flat	7/4/97	21	12	11.8	11.8	3.60	
Alfalfa, flat	7/5/97	1	5	2.7	2.7	0.82	4.42
Alfalfa, flat	7/15/97	10	12	12.4	12.4	3.78	
Alfalfa, flat	7/16/97	1	5	1.8	1.8	0.55	4.33
Alfalfa, flat	8/3/97	18	12	12.6	12.6	3.84	
Alfalfa, flat	8/4/97	1	6	1	3	0.92	4.76
Alfalfa, flat	8/17/97	13	12	11.9	11.9	3.63	
Alfalfa, flat	8/18/97	1	10	3.6	10	3.05	
Alfalfa, flat	8/19/97	1	5	2.7	2.7	0.82	7.51
Alfalfa, flat	9/29/97	41	12	12.2	12.2	3.72	
Alfalfa, flat	9/30/97	1	8	8.8	8.8	2.69	6.41
Alfalfa, flat	10/29/97	29	12	12.4	12.4	3.78	
Alfalfa, flat	10/30/97	1	5	2.4	2.4	0.73	4.52
Alfalfa, flat	12/5/97	36	12	11.9	11.9	3.63	
Alfalfa, flat	12/6/97	1	7	3.2	7	2.14	5.77
Alfalfa, flat	1/22/98	47	11	10.8	10.8	3.30	3.30
Alfalfa, flat	3/15/98	52	12	12.4	12.4	3.78	3.78
Alfalfa, flat	3/29/98	14	10	10.3	10.3	3.14	3.14
Alfalfa, flat	4/21/98	23	12	12.2	12.2	3.72	
Alfalfa, flat	4/22/98	1	5	0.9	5.2	1.59	5.31
Alfalfa, flat	5/1/98	9	12	12	12	3.66	3.66
Alfalfa, flat	5/22/98	21	12	12.2	12.2	3.72	
Alfalfa, flat	5/23/98	1	5	2.2	2.2	0.67	4.39
Alfalfa, flat	6/1/98	9	12	12.9	12.9	3.94	
Alfalfa, flat	6/2/98	1	5	0	2.5	0.76	4.70
Alfalfa, flat	6/19/98	17	12	12.4	12.4	3.78	
Alfalfa, flat	6/20/98	1	4	1.3	2	0.61	4.39
Alfalfa, flat	6/30/98	10	10	10.4	10.4	3.17	
Alfalfa, flat	7/1/98	1	5	4	4	1.22	4.39
Alfalfa, flat	7/24/98	23	12	12.4	12.4	3.78	3.78
Alfalfa, flat	8/14/98	21	12	12.9	12.9	3.94	

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Alfalfa, flat	8/15/98	1	6	3.3	6.7	2.04	5.98
Alfalfa, flat	9/16/98	32	12	12.8	12.8	3.91	
Alfalfa, flat	9/17/98	1	12	12.6	12.6	3.84	7.75
Alfalfa, flat	10/1/98	14	12	11.8	11.8	3.60	3.60
Alfalfa, flat	10/30/98	29	12	11.9	11.9	3.63	
Alfalfa, flat	10/31/98	1	5	1	5	1.53	5.16
Alfalfa, flat	12/7/98	37	12	12.1	12.1	3.69	3.69
Alfalfa, flat	12/26/98	19	12	10.9	12	3.66	3.66
Alfalfa, flat	1/20/99	25	12	12.2	12.2	3.72	3.72
Alfalfa, flat	2/23/99	34	12	10.3	11	3.36	3.36
Alfalfa, flat	3/10/99	15	12	9.3	12.4	3.78	3.78
Alfalfa, flat	4/6/99	27	12	10.8	12.3	3.75	3.75
Alfalfa, flat	4/15/99	9	12	12.9	12.9	3.94	3.94
Alfalfa, flat	4/25/99	10	12	12.3	12.3	3.75	3.75
Alfalfa, flat	5/13/99	18	12	12.2	12.2	3.72	3.72
Alfalfa, flat	5/23/99	10	12	12.9	12.9	3.94	3.94
Alfalfa, flat	6/13/99	21	12	11.9	11.9	3.63	
Alfalfa, flat	6/14/99	1	12	2.1	2.1	0.64	4.27
Alfalfa, flat	6/24/99	10	12	12.4	12.4	3.78	3.78
Alfalfa, flat	7/9/99	15	12	11.9	11.9	3.63	3.63
Alfalfa, flat	7/22/99	13	12	12.2	12.2	3.72	3.72
Alfalfa, flat	8/12/99	21	12	12.2	12.2	3.72	3.72
Alfalfa, flat	8/23/99	11	12	11.5	12	3.66	3.66
Alfalfa, flat	9/3/99	11	12	12.2	12.2	3.72	3.72
Alfalfa, flat	9/22/99	19	10	12.2	12.2	3.72	3.72
Alfalfa, flat	10/5/99	13	12	10.7	10.7	3.27	3.27
Alfalfa, flat	11/2/99	28	12	10.4	12	3.66	3.66
Alfalfa, flat	11/23/99	21	12	10.2	12	3.66	3.66
Alfalfa, flat	1/4/00	42	12	10.6	12	3.66	3.66
Alfalfa, flat	1/31/00	27	12	9.8	12	3.66	3.66
Alfalfa, flat	3/4/00	33	12	12.6	12.6	3.84	3.84
Alfalfa, flat	3/16/00	12	12	12.1	12.1	3.69	3.69
Alfalfa, flat	4/6/00	21	12	11.9	11.9	3.63	3.63
Alfalfa, flat	4/17/00	11	12	10.1	12	3.66	3.66
Alfalfa, flat	5/4/00	17	12	11.9	11.9	3.63	3.63
Alfalfa, flat	5/11/00	7	12	12	12	3.66	3.66
Alfalfa, flat	5/17/00	6	12	11.9	11.9	3.63	3.63
Alfalfa, flat	6/2/00	16	12	12.9	12.9	3.94	3.94
Alfalfa, flat	6/11/00	9	12	9.7	12	3.66	3.66
Alfalfa, flat	6/23/00	12	12	11.9	11.8	3.60	3.60
Alfalfa, flat	7/6/00	13	12	12.1	12.1	3.69	
Alfalfa, flat	7/7/00	1	4	3.5	3.5	1.07	4.76
Alfalfa, flat	7/19/00	12	12	12.1	12.1	3.69	
Alfalfa, flat	7/20/00	1	6	2.9	2.9	0.88	4.58

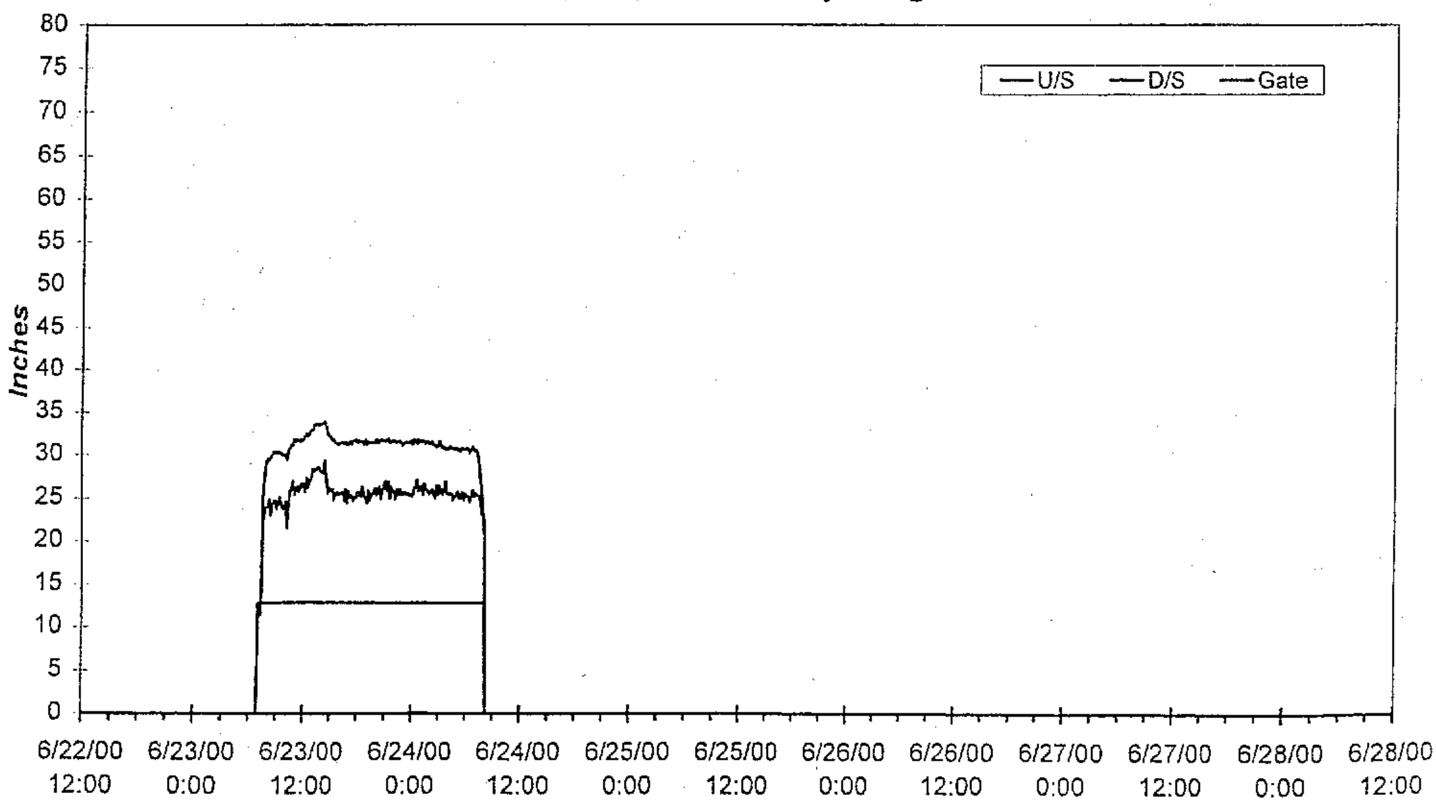


Field No. 2 Layout

Delivery and Tailwater Flow for Parcel No.2



U/S, D/S, and Gate Opening



Order = **1d-12'**	Delivery Volume (AF) = **24.8**	% Tailwater= **14%**	Acres = **78**
Soil Type = **110, 115**	Tailwater Volume (AF)= **3.4**	Crop = **Flat alfalfa**	Inches Applied= **3.8**

Field No. 3

Field Irrigation Evaluation

Data Summary

FIELD IRRIGATION EVALUATION FOR IMPERIAL IRRIGATION DISTRICT IMPERIAL VALLEY, CALIFORNIA. FIELD NO. 3

FIELD DATA

Irrigated Acreage: 156 acres (ac)
Border Length: 2670 feet (ft)
Border Width: 60 ft
Border Slope: Average, 0.003316 ft/ft

CROP DATA

Crop: Second year Bermuda Grass, planted in May of 1998.
Crop Growth Stage: 10 inches (in) in height
Crop Condition: Good

SOILS DATA

Soil Texture: Imperial silty clay (60%); Imperial-Glenbar silty clay loam (40%).
Soil Depth: Water table at about 3 ft.
Soil Uniformity: Average to good. Some sandy layers at about 3 ft.
Effective Crop Rooting Depth: 3 ft
Available Water Capacity: 0.17 – 0.35 in/in.
Estimated Allowable Depletion: Not determined.

SOIL CONDITION

Estimated Soil Water Deficit at Beginning of Irrigation:
Average: 4.0 in.
Estimated Irrigation Water Stored in Root Zone:
Average: 3.52 in.

IRRIGATION DATA

Irrigation Method: Borders with gated outlets from concrete-lined head ditch.
Field and Soil Condition: Dry with some cracking. Previous irrigation on June 16, 2000.

Beginning Irrigation Time: June 25, 2000, 8:30 a.m.
Ending Irrigation Time: June 27, 2000, 8:30 a.m
Beginning Outflow Time: June 25, about 8:30 p.m.
Ending Outflow Time: Not determined.
Average Inflow: 14.0 cubic feet per second (cfs)
Average Outflow: Not determined.

Number of Sets: 10
Set Time: 4.5 to 5.0 hours.
Advance Time: Average, 12 hours.
Uniformity of Advance: Near constant rate of advance. Quite uniform.
Number of Borders per Set: 4

Irrigation Observations: Very low intake after initial filling of cracks.
Uniformity: Good.
Ponding: None.
Erosion: None.
Estimated Irrigation Efficiency: 87%.

Irrigation Summary		
	Average Depth[1], in	Percent of Applied Water %
Total Water Applied	4.27	
Total Water Stored in Root Zone	3.52	82
Total Runoff	0.55	13
Total Deep Percolation	0.20	5

[1]Depth based on field irrigated acreage.

Field No.3 - Irrigation and Cropping History

Cropped Area: 156 ac

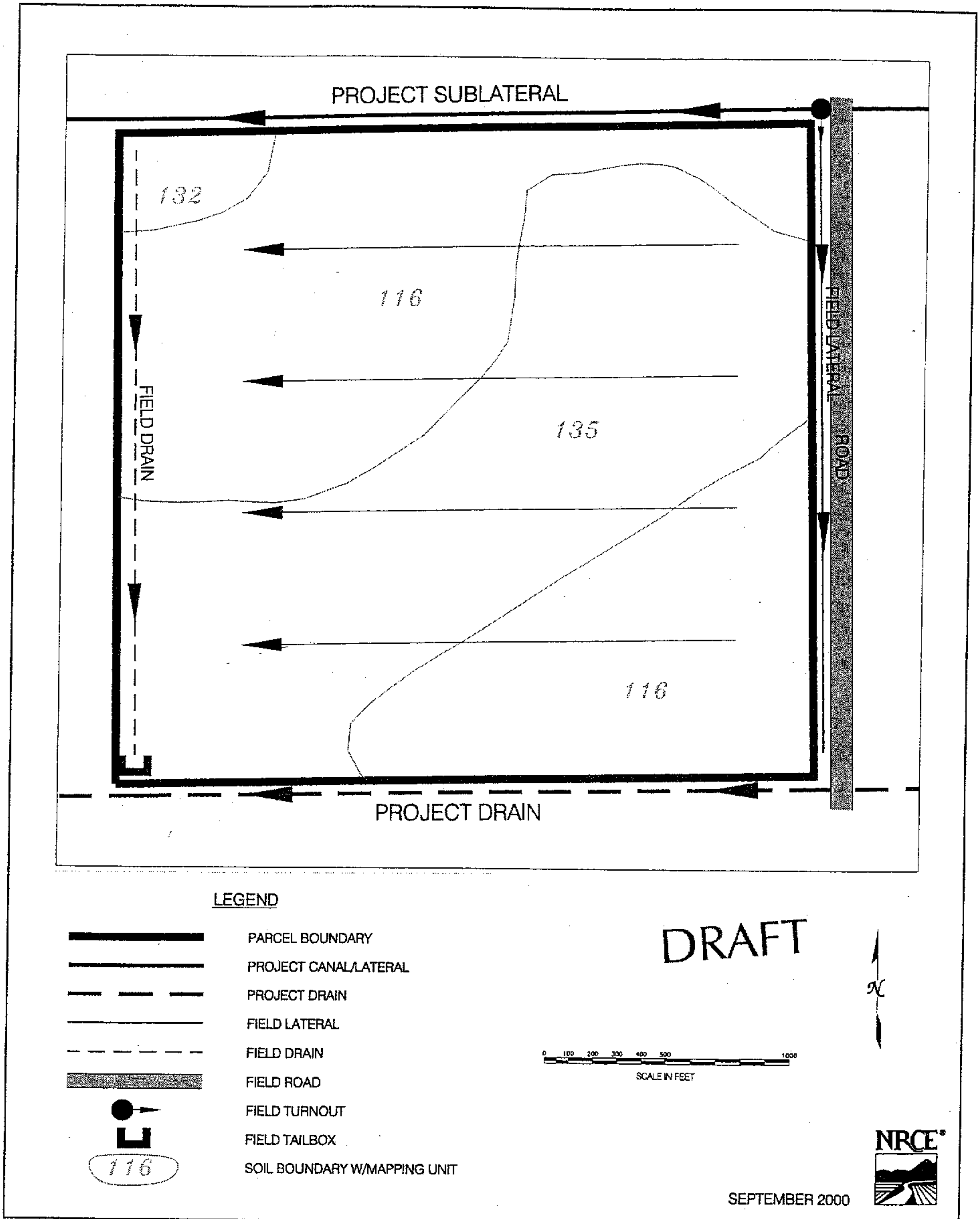
Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Rye Grass	1/1/97		5	5.5	5.5	0.84	
Rye Grass	1/2/97	1	5	5.2	5.2	0.79	1.63
Rye Grass	1/16/97	14	0.2	0.2	0.2	0.03	
Rye Grass	1/17/97	1	5	5.1	5.1	0.78	0.78
Rye Grass	1/18/97	1	4	4.2	4.2	0.64	0.64
Rye Grass	1/19/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	1/20/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	1/21/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	1/22/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	1/23/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	1/24/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	1/25/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	1/26/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	1/27/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	1/28/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	1/29/97	1	5	5.2	5.2	0.79	0.79
Rye Grass	2/7/97	9	6	6.1	6.1	0.93	0.93
Rye Grass	2/14/97	7	0.2	0.2	0.2	0.03	
Rye Grass	2/15/97	1	5	5.4	5.4	0.82	
Rye Grass	2/16/97	1	5	5.2	5.2	0.79	1.65
Rye Grass	2/18/97	2	0.2	0.2	0.2	0.03	0.03
Rye Grass	2/19/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	2/20/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	2/21/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	2/22/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	2/23/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	2/24/97	1	5	5.3	5.3	0.81	0.81
Rye Grass	2/25/97	1	6	6	6	0.92	0.92
Rye Grass	2/26/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	2/26/97	0	4	2.2	2.2	0.34	0.34
Rye Grass	2/27/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	2/28/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/1/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/2/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/3/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/4/97	1	4	4.4	4.4	0.67	0.67
Rye Grass	3/5/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/6/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/7/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/7/97	0	6	7.7	7.7	1.17	1.17
Rye Grass	3/8/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/9/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/10/97	1	0.2	0.2	0.2	0.03	0.03

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Rye Grass	3/11/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/13/97	2	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/14/97	1	4	4.1	4.1	0.63	0.63
Rye Grass	3/15/97	1	7	7.7	7.7	1.17	1.17
Rye Grass	3/16/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/17/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/18/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/19/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/20/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/21/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/22/97	1	5	5.2	5.2	0.79	0.79
Rye Grass	3/23/97	1	5	5.2	5.2	0.79	0.79
Rye Grass	3/24/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/25/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/26/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/27/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/28/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	3/29/97	1	4	4.2	4.2	0.64	0.64
Rye Grass	3/30/97	1	6	6	6	0.92	0.92
Rye Grass	3/31/97	1	3	1.5	1.5	0.23	0.23
Rye Grass	4/3/97	3	0.2	0.2	0.2	0.03	0.03
Rye Grass	4/4/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	4/5/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	4/6/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	4/7/97	1	0.2	0.2	0.2	0.03	0.03
Rye Grass	4/9/97	2	11	12.3	12.3	1.88	1.88
Rye Grass	4/10/97	1	6	6.1	6.1	0.93	0.93
Rye Grass	4/16/97	6	13	13.2	13.2	2.01	2.01
Rye Grass	4/21/97	5	12	13.4	13.4	2.04	2.04
Rye Grass	4/26/97	5	12	12.3	12.3	1.88	1.88
Rye Grass	5/1/97	5	9	9	9	1.37	1.37
Idle	11/14/97	197	10	4.4	4.4	0.67	
Wheat	11/15/97	1	12	10.2	10.2	1.56	
Wheat	11/16/97	1	12	10.3	10.3	1.57	
Wheat	11/17/97	1	12	12.5	12.5	1.91	
Wheat	11/18/97	1	5	0.5	3	0.46	6.16
Wheat	12/29/97	41	12	12.6	12.6	1.92	
Wheat	12/30/97	1	12	12.3	12.3	1.88	
Wheat	12/31/97	1	4	1.4	2.5	0.38	4.18
Wheat	2/26/98	57	11	11.6	11.6	1.77	
Wheat	2/27/98	1	11	11.5	11.5	1.75	3.52
Wheat	3/15/98	16	11	11.5	11.5	1.75	
Wheat	3/16/98	1	10	11.5	11.5	1.75	3.51
Wheat	3/30/98	14	10	12.4	12.4	1.89	
Wheat	3/31/98	1	10	10.4	10.4	1.59	3.48
Wheat	4/9/98	9	11	11.1	11.1	1.69	
Wheat	4/10/98	1	11	11.1	11.1	1.69	3.39

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Idle	5/29/98	49	9	9.1	9.1	1.39	1.39
Bermuda Grass	5/30/98	1	9	9.1	9.1	1.39	1.39
Bermuda Grass	5/31/98	1	9	9.4	9.4	1.43	1.43
Bermuda Grass	6/1/98	1	9	9.7	9.7	1.48	1.48
Bermuda Grass	6/2/98	1	9	9.1	9.1	1.39	1.39
Bermuda Grass	6/3/98	1	12	12.2	12.2	1.86	1.86
Bermuda Grass	6/4/98	1	12	12.2	12.2	1.86	1.86
Bermuda Grass	6/5/98	1	12	11.9	11.9	1.82	1.82
Bermuda Grass	6/6/98	1	12	12	12	1.83	1.83
Bermuda Grass	6/9/98	3	11	10.9	10.9	1.66	
Bermuda Grass	6/10/98	1	11	11.4	11.4	1.74	
Bermuda Grass	6/11/98	1	7	3.5	3.5	0.53	3.94
Bermuda Grass	6/17/98	6	11	11.3	11.3	1.72	
Bermuda Grass	6/18/98	1	11	11.2	11.2	1.71	
Bermuda Grass	6/19/98	1	7	3.5	3.5	0.53	3.97
Bermuda Grass	6/27/98	8	12	12.2	12.2	1.86	
Bermuda Grass	6/28/98	1	12	12.2	12.2	1.86	3.72
Bermuda Grass	7/6/98	8	12	12.5	12.5	1.91	
Bermuda Grass	7/7/98	1	12	11.9	11.9	1.82	3.72
Bermuda Grass	7/17/98	10	12	11.8	11.8	1.80	
Bermuda Grass	7/18/98	1	12	12.2	12.2	1.86	
Bermuda Grass	7/19/98	1	12	1.5	1.5	0.23	3.89
Bermuda Grass	7/29/98	10	13	13	13	1.98	
Bermuda Grass	7/30/98	1	13	13	13	1.98	
Bermuda Grass	7/31/98	1	13	13	13	1.98	5.95
Bermuda Grass	8/11/98	11	12	11.8	11.8	1.80	
Bermuda Grass	8/12/98	1	12	11.8	11.8	1.80	
Bermuda Grass	8/13/98	1	6	6.1	6.1	0.93	4.53
Bermuda Grass	9/2/98	20	14	14.8	14	2.14	
Bermuda Grass	9/3/98	1	14	14.8	14	2.14	4.27
Bermuda Grass	9/17/98	14	14	14	14	2.14	
Bermuda Grass	9/18/98	1	14	14	14	2.14	4.27
Bermuda Grass	2/23/99	158	13	12.9	12.9	1.97	
Bermuda Grass	2/24/99	1	13	12.9	12.9	1.97	
Bermuda Grass	2/25/99	1	13	13.2	13.2	2.01	
Bermuda Grass	2/26/99	1	13	13.2	13.2	2.01	7.96
Bermuda Grass	3/21/99	23	12	12.2	12.2	1.86	
Bermuda Grass	3/22/99	1	16	15.5	15.5	2.36	4.23
Bermuda Grass	4/11/99	20	14	14.4	14.4	2.20	
Bermuda Grass	4/12/99	1	14	14.4	14.4	2.20	4.39
Bermuda Grass	4/23/99	11	10	10.1	10.1	1.54	
Bermuda Grass	4/24/99	1	10	10.1	10.1	1.54	3.08
Bermuda Grass	5/16/99	22	14	14.4	14.4	2.20	
Bermuda Grass	5/17/99	1	14	17	17	2.59	
Bermuda Grass	5/19/99	2	3	1.5	1.5	0.23	5.02
Bermuda Grass	5/28/99	9	11	11.8	11.6	1.77	
Bermuda Grass	5/29/99	1	11	11.4	11.4	1.74	

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Bermuda Grass	5/30/99	1	16	16	16	2.44	5.95
Bermuda Grass	6/7/99	8	16	15.9	15.9	2.43	
Bermuda Grass	6/8/99	1	16	7.9	7.9	1.21	3.63
Bermuda Grass	6/26/99	18	14	14.4	14.4	2.20	
Bermuda Grass	6/27/99	1	14	16.2	16.2	2.47	4.67
Bermuda Grass	7/8/99	11	12	13.9	13.9	2.12	
Bermuda Grass	7/9/99	1	14	13.9	13.9	2.12	
Bermuda Grass	7/10/99	1	5	2.5	2.5	0.38	4.62
Bermuda Grass	7/20/99	10	14	14.2	14.2	2.17	
Bermuda Grass	7/21/99	1	14	14.2	14.2	2.17	4.33
Bermuda Grass	8/7/99	17	14	14.2	14.2	2.17	
Bermuda Grass	8/8/99	1	14	14.2	14.2	2.17	
Bermuda Grass	8/9/99	1	7	7.5	7.5	1.14	5.48
Bermuda Grass	8/19/99	10	16	16.4	16.4	2.50	2.50
Bermuda Grass	8/27/99	8	14	15.5	15.5	2.36	
Bermuda Grass	8/28/99	1	14	11	14	2.14	4.50
Bermuda Grass	9/15/99	18	16	16.3	16.3	2.49	
Bermuda Grass	9/16/99	1	16	16.1	16.1	2.46	4.94
Bermuda Grass	9/27/99	11	13	13.1	13.1	2.00	
Bermuda Grass	9/28/99	1	8	7.9	7.9	1.21	3.20
Bermuda Grass	2/9/00	134	14	14.4	14.4	2.20	
Bermuda Grass	2/10/00	1	14	13.9	13.9	2.12	
Bermuda Grass	2/11/00	1	14	14	14	2.14	6.45
Bermuda Grass	3/13/00	31	12	12	12	1.83	
Bermuda Grass	3/14/00	1	12	12.3	12.3	1.88	3.71
Bermuda Grass	3/28/00	14	12	12.1	12.1	1.85	
Bermuda Grass	3/29/00	1	12	12.3	12.3	1.88	3.72
Bermuda Grass	4/18/00	20	12	11.9	11.9	1.82	
Bermuda Grass	4/19/00	1	12	11.9	11.9	1.82	3.63
Bermuda Grass	5/2/00	13	12	14.1	14.1	2.15	
Bermuda Grass	5/3/00	1	12	11.9	11.9	1.82	3.97
Bermuda Grass	5/13/00	10	12	12.4	12.4	1.89	
Bermuda Grass	5/14/00	1	12	12	12	1.83	3.72
Bermuda Grass	5/28/00	14	13	13	13	1.98	
Bermuda Grass	5/29/00	1	13	13.1	13.1	2.00	3.98
Bermuda Grass	5/31/00	2	3	1.6	3	0.46	0.46
Bermuda Grass	6/6/00	6	12	12.3	12.3	1.88	
Bermuda Grass	6/7/00	1	12	12.6	12.6	1.92	3.80
Bermuda Grass	6/16/00	9	13	13.1	13.1	2.00	
Bermuda Grass	6/17/00	1	8	8.3	8.3	1.27	3.27
Bermuda Grass	6/25/00	8	12	14.6	14.6	2.23	
Bermuda Grass	6/26/00	1	12	13.4	13.4	2.04	4.27
Bermuda Grass	7/9/00	13	13	12.9	12.9	1.97	
Bermuda Grass	7/10/00	1	13	15.2	15.2	2.32	4.29
Bermuda Grass	7/23/00	13	12	11.9	11.9	1.82	
Bermuda Grass	7/24/00	1	12	12.7	12.7	1.94	
Bermuda Grass	7/25/00	1	16	16	16	2.44	6.19

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Bermuda Grass	7/30/00	5	12	11.9	11.9	1.82	
Bermuda Grass	7/31/00	1	11	10.9	10.9	1.66	3.48



Field No. 3 Layout

Field No. 3 - 0 to 1 ft.

ECe(0.5)
dS/m

< 12

12 - 15

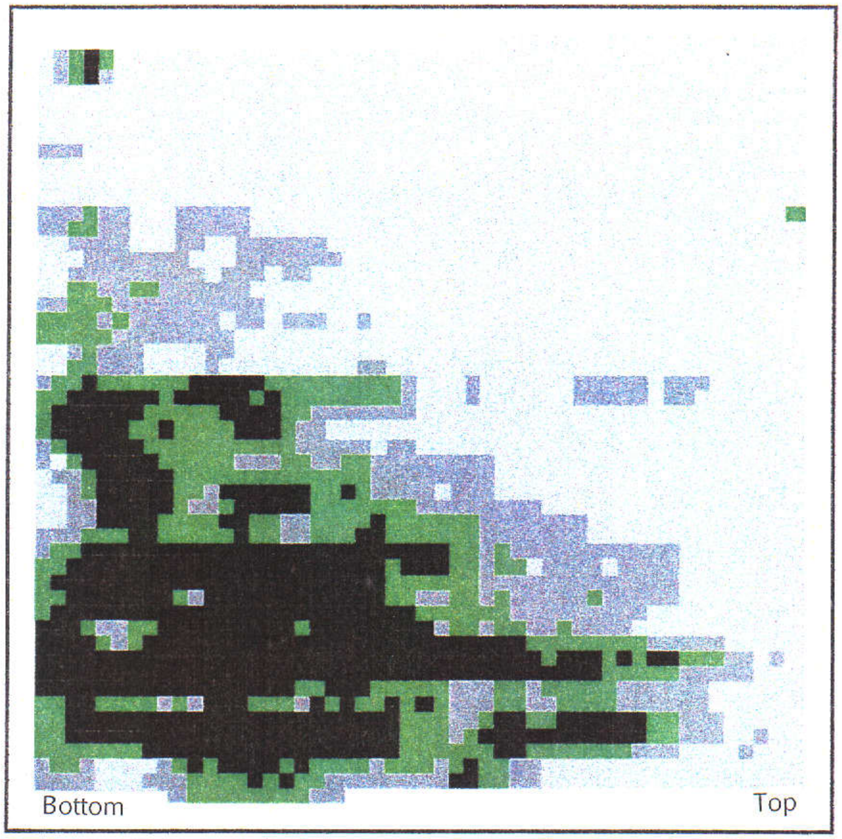
15 - 18

> 18

Data Bounds

X: min & max
643724.35
644541.68

Y: min & max
3670331.97
3671093.8



1 to 2 ft.

ECe(1.5)
dS/m

< 12

12 - 15

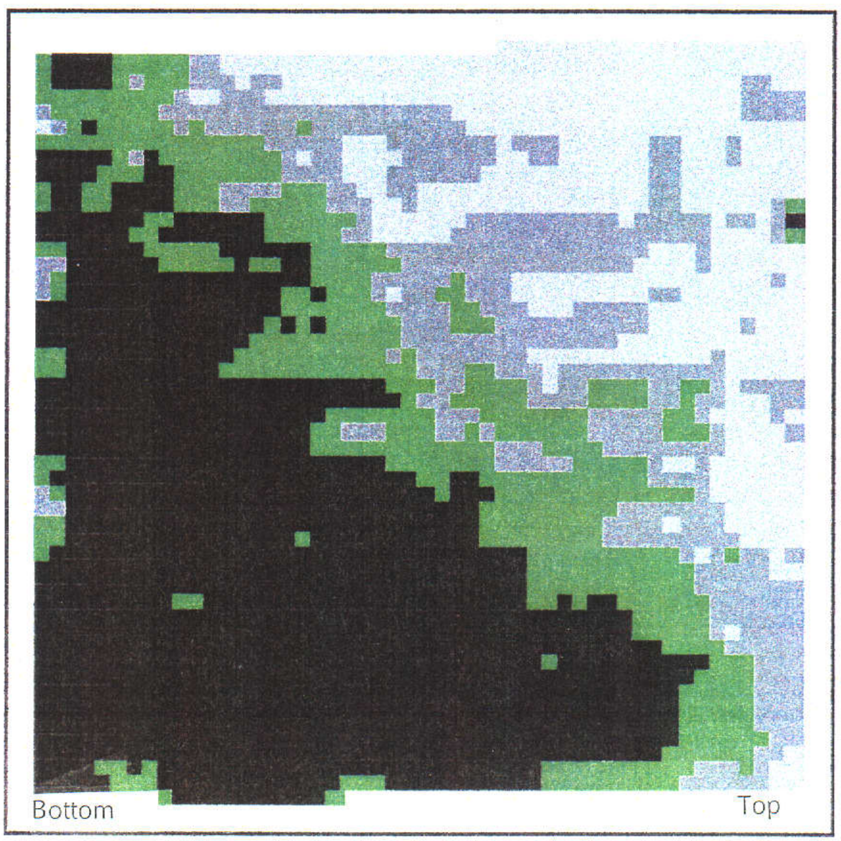
15 - 18

> 18

Data Bounds

X: min & max
643724.35
644541.68

Y: min & max
3670331.97
3671093.8



Field No. 3 - 2 to 3 ft.

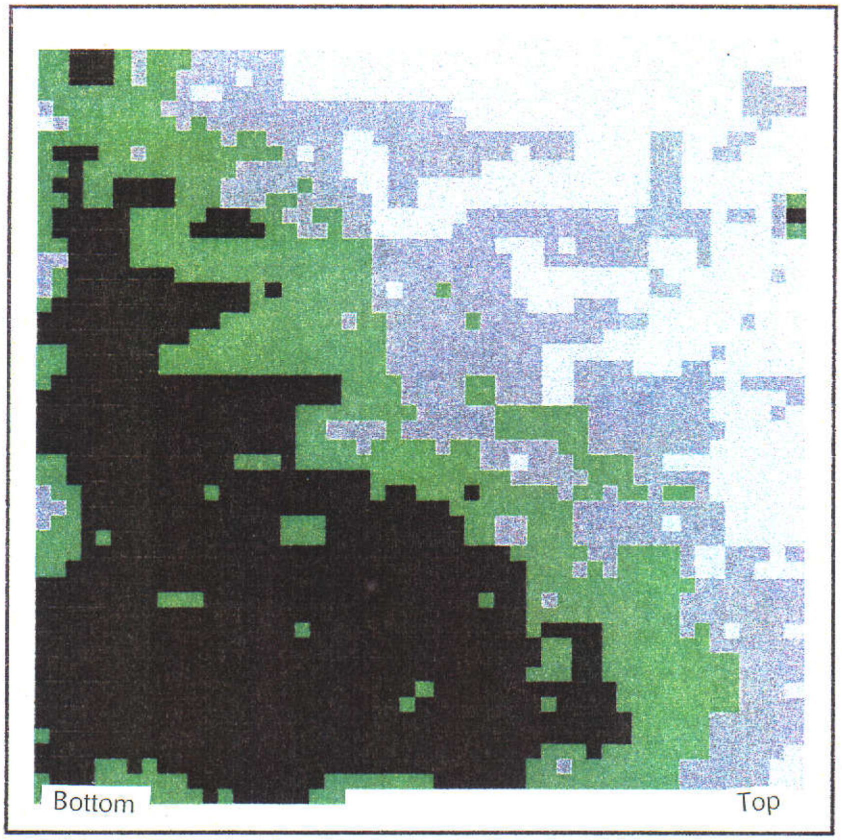
ECe(2.5)
dS/m

< 12
12 - 15
15 - 18
> 18

Data Bounds

X: min & max
643724.35
644541.68

Y: min & max
3670331.97
3671093.8



3 to 4 ft.

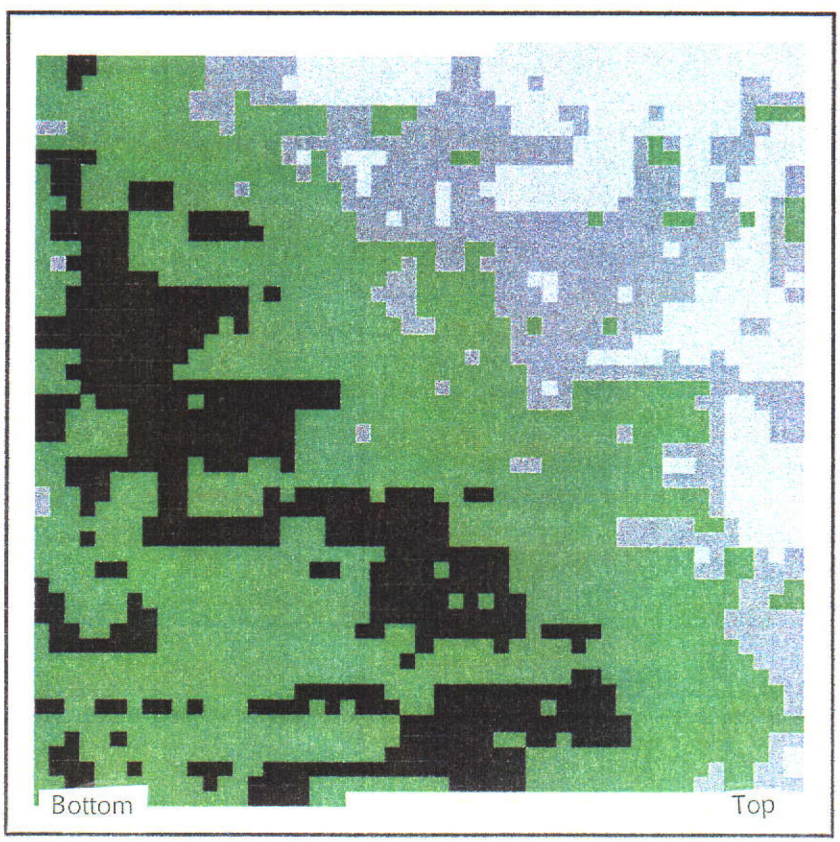
ECe(3.5)
dS/m

< 12
12 - 15
15 - 18
> 18

Data Bounds

X: min & max
643724.35
644541.68

Y: min & max
3670331.97
3671093.8



Field No. 3 - Avg. ECe in 4 ft. Profile

ECe(ave)
dS/m

< 12

12 - 15

15 - 18

> 18

Data Bounds

X: min & max

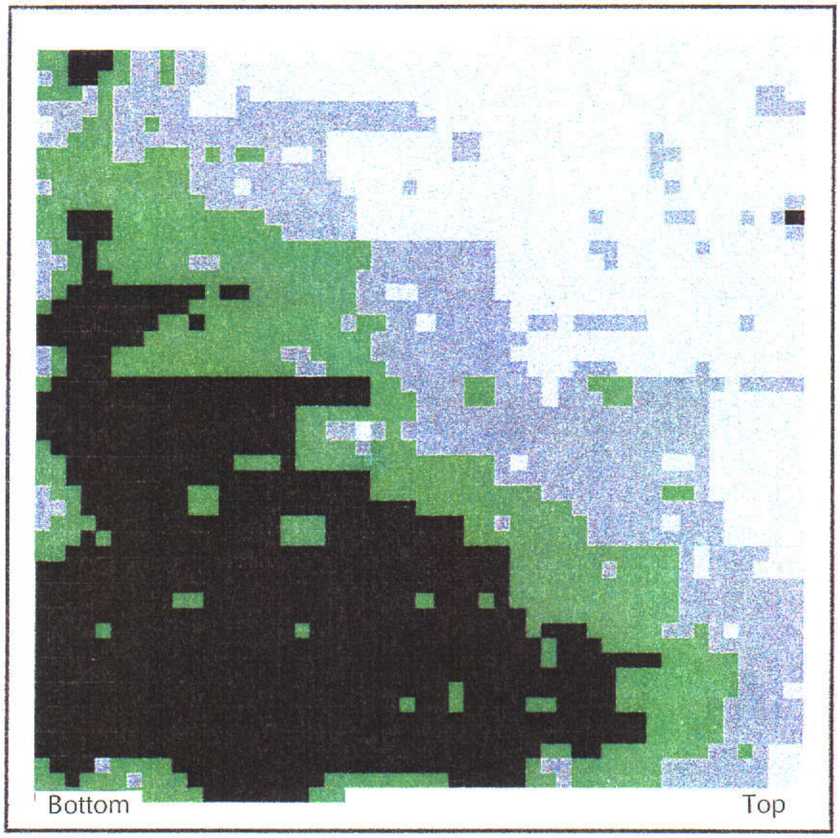
643724.35

644541.68

Y: min & max

3670331.97

3671093.8



Field No. 3 - 0 to 1 ft (autoscale)

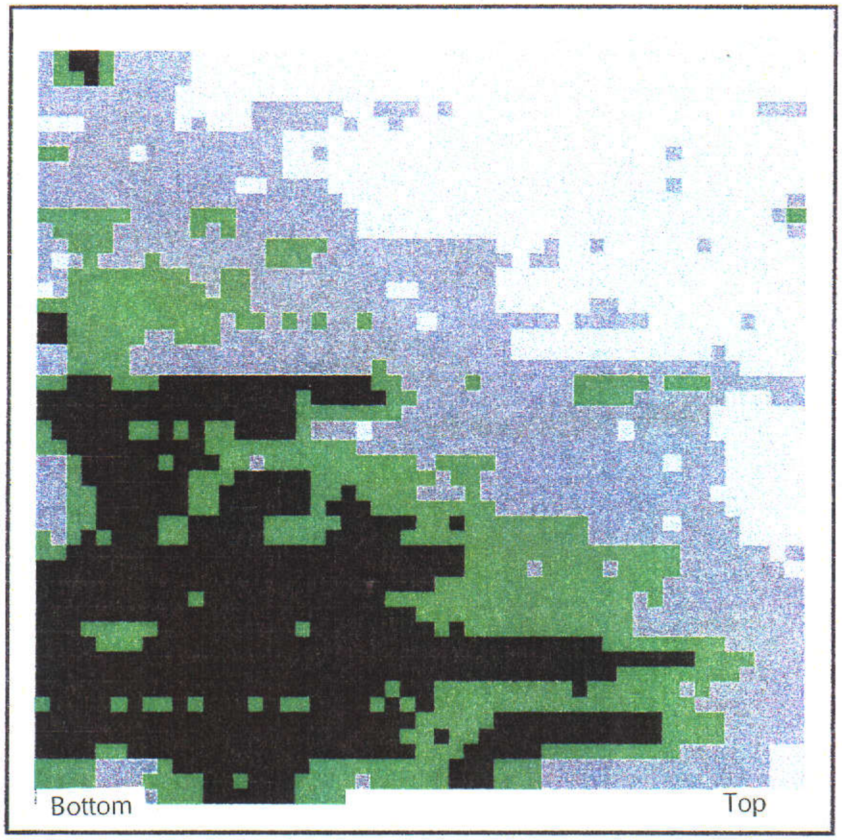
ECe(0.5)
dS/m

- < 8.07
- 8.07 - 12.42
- 12.42 - 16.77
- > 16.77

Data Bounds

X: min & max
643724.35
644541.68

Y: min & max
3670331.97
3671093.8



1 to 2 ft. (autoscale)

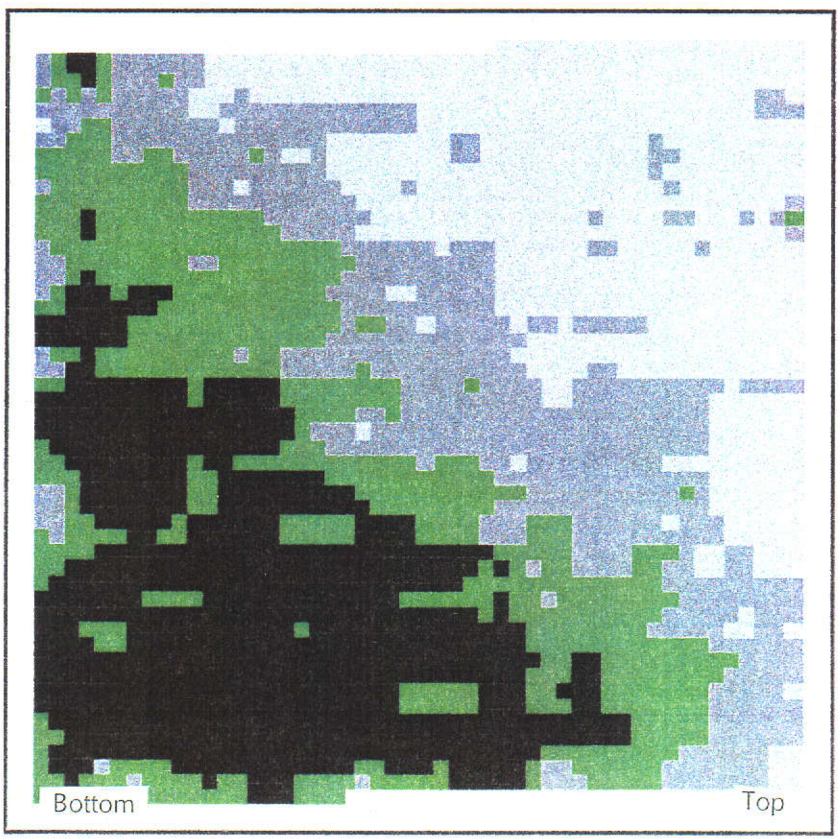
ECe(1.5)
dS/m

- < 13.13
- 13.13 - 16.98
- 16.98 - 20.83
- > 20.83

Data Bounds

X: min & max
643724.35
644541.68

Y: min & max
3670331.97
3671093.8



Field No. 3 - 2 to 3 ft. (autoscale)

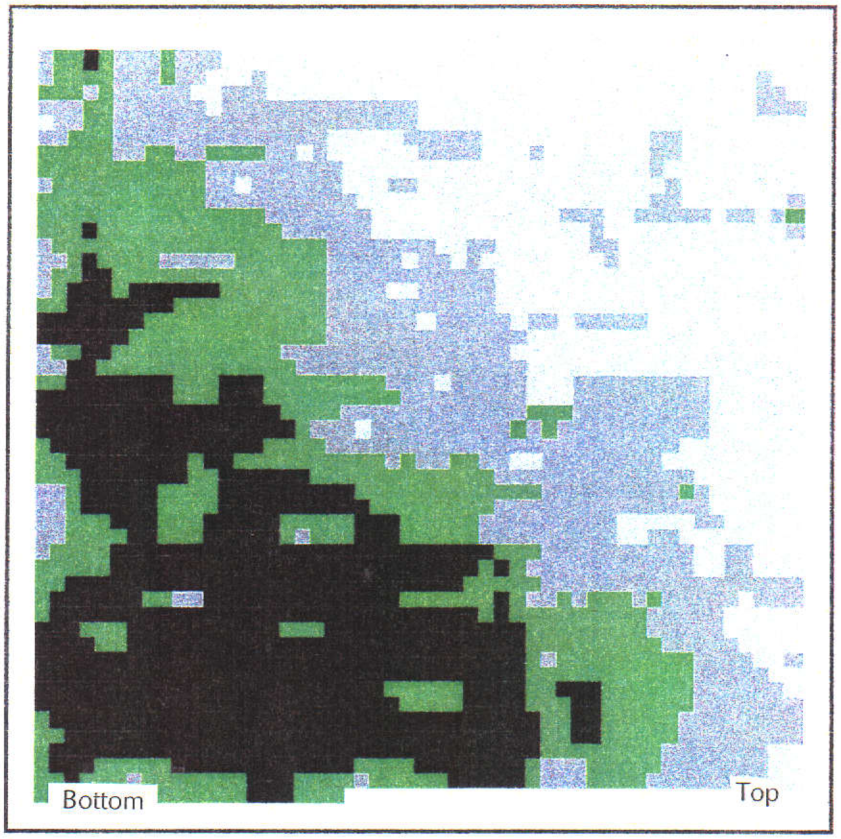
ECe(2.5)
dS/m

< 12.87
12.87 - 16.13
16.13 - 19.4
> 19.4

Data Bounds

X: min & max
643724.35
644541.68

Y: min & max
3670331.97
3671093.8



3 to 4 ft. (autoscale)

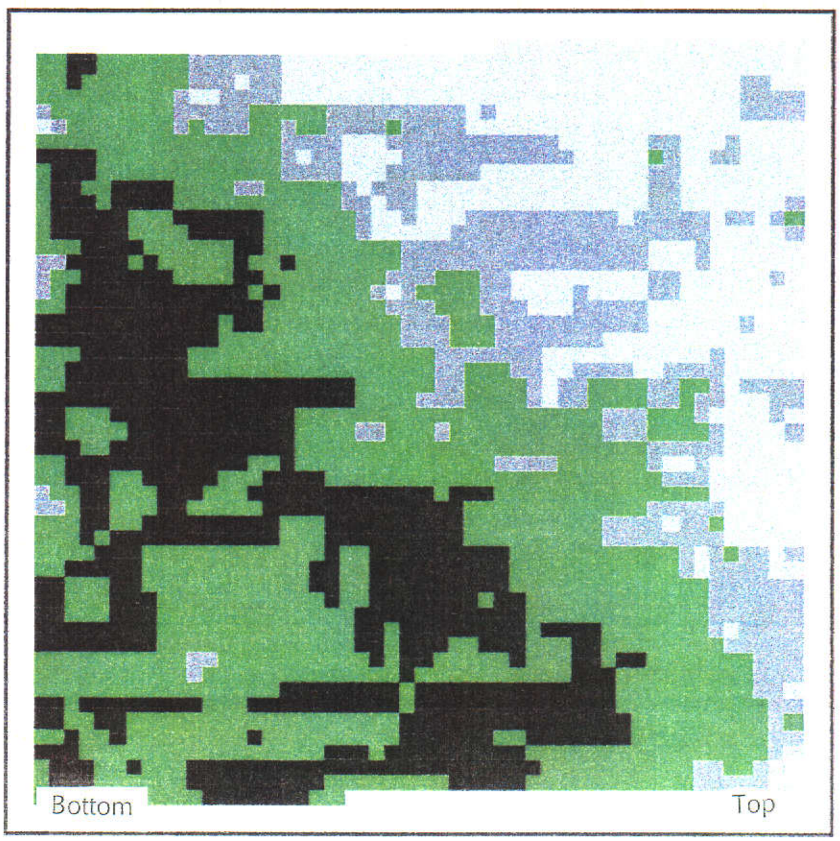
ECe(3.5)
dS/m

< 13.36
13.36 - 15.63
15.63 - 17.89
> 17.89

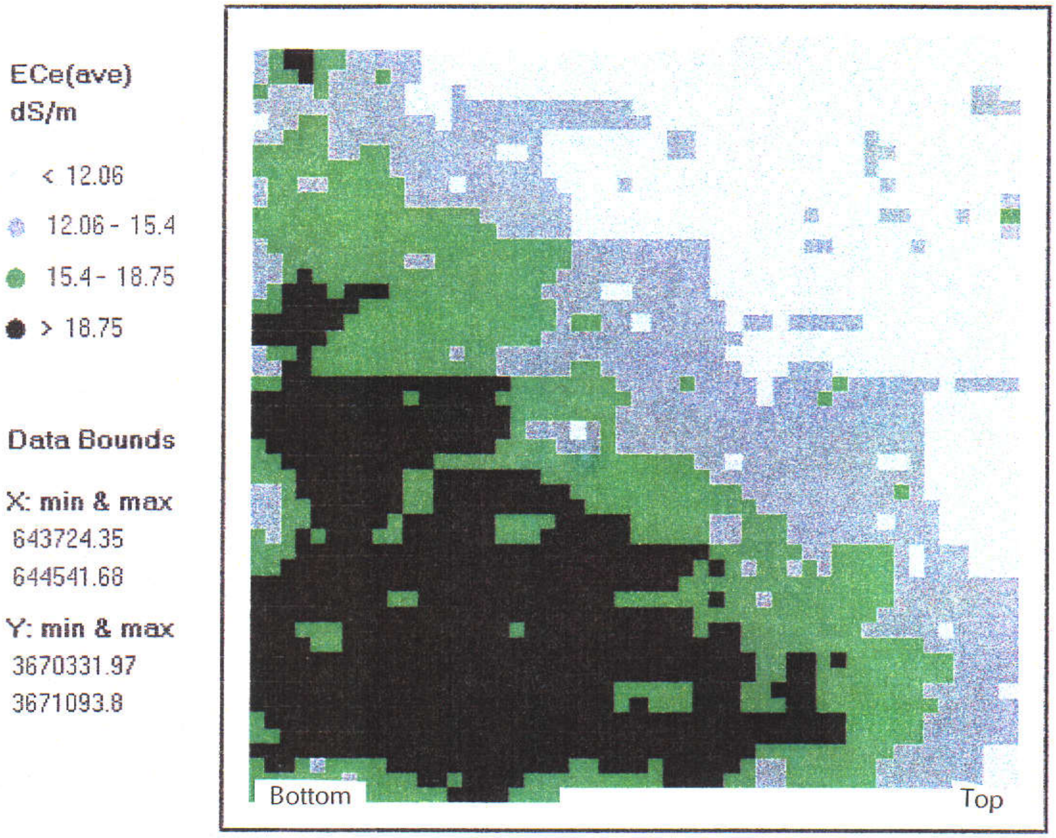
Data Bounds

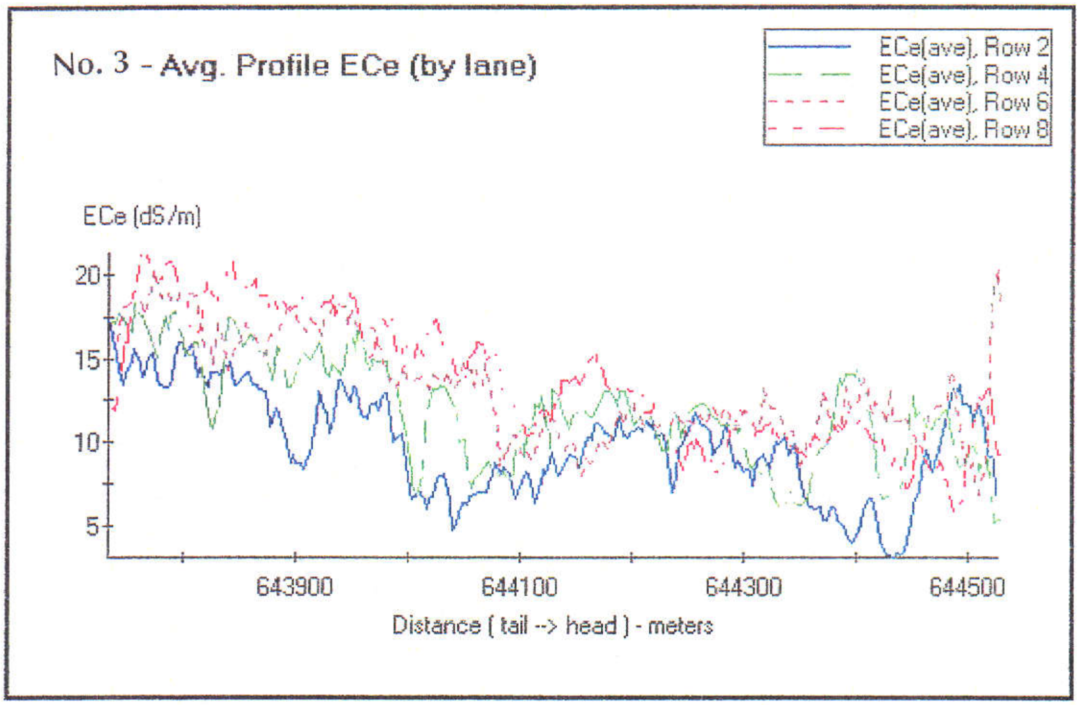
X: min & max
643724.35
644541.68

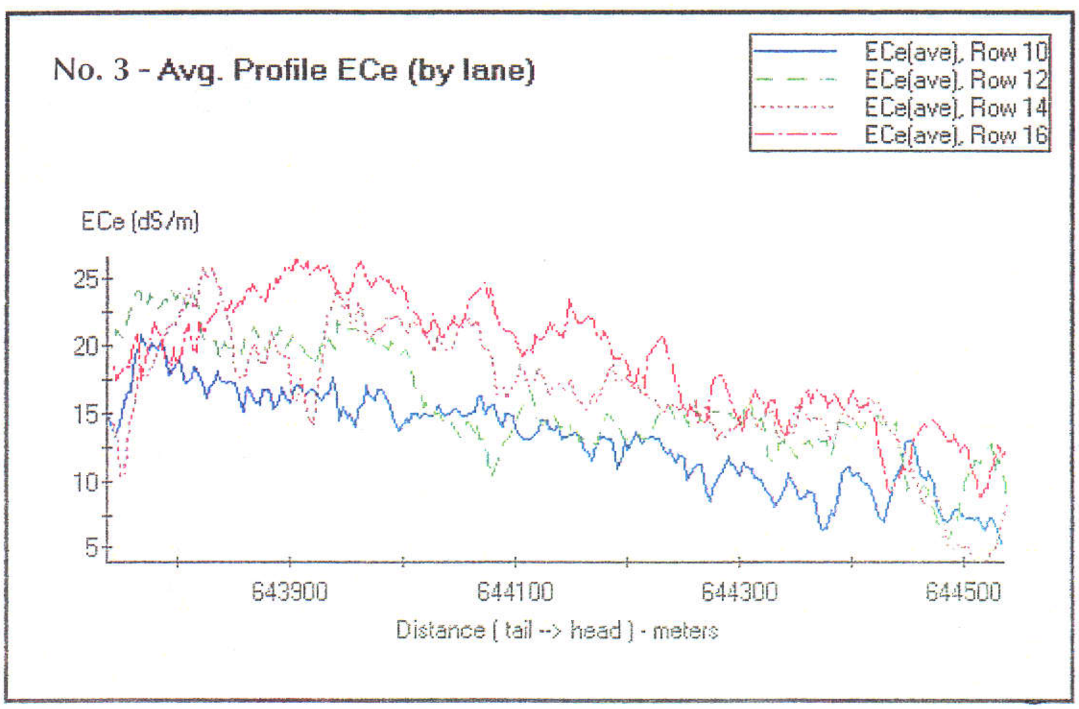
Y: min & max
3670331.97
3671093.8

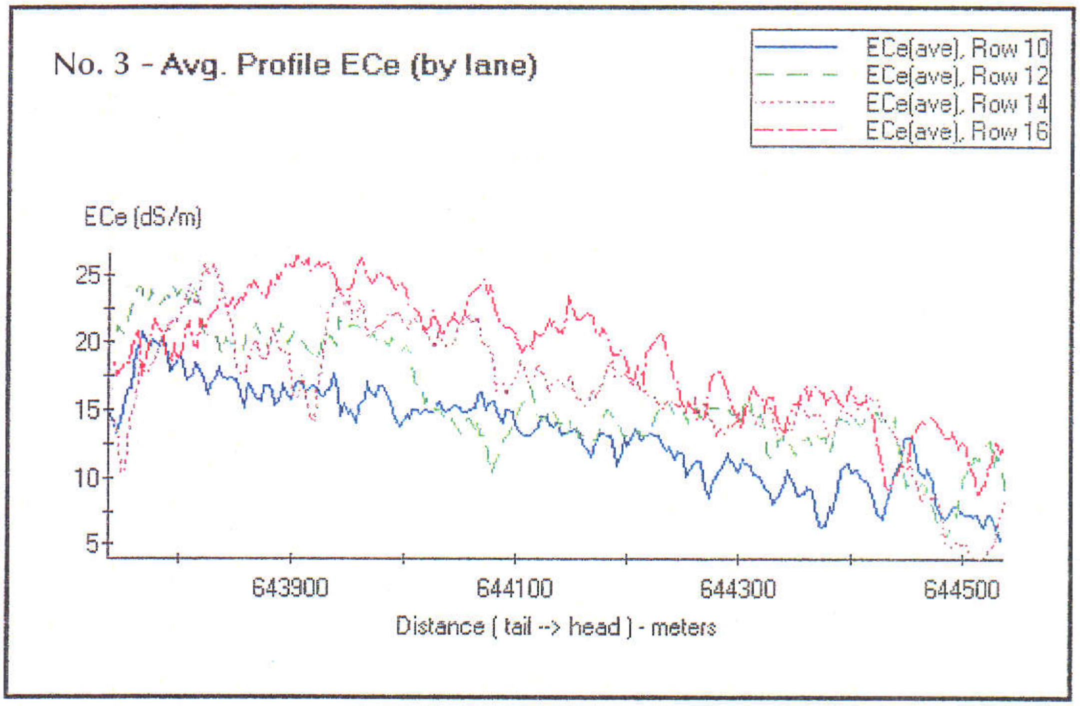


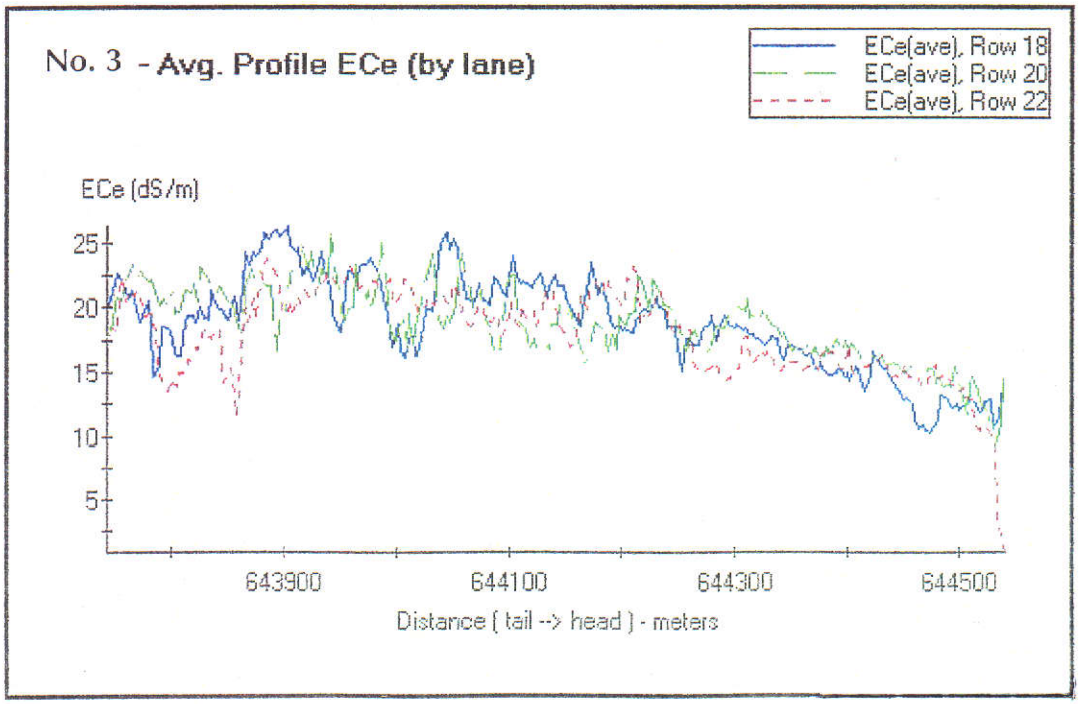
Field No. 3 - Avg. ECe in 4 ft. Profile (autoscale)




No. 3 - Avg. Profile ECe (by lane)
ECe(ave), Row 2
ECe(ave), Row 4
ECe(ave), Row 6
ECe(ave), Row 8
ECe (dS/m)
20
15
10
5
643900
644100
644300
644500
Distance (tail --> head) - meters


No. 3 - Avg. Profile ECe (by lane)
ECe(ave), Row 10
ECe(ave), Row 12
ECe(ave), Row 14
ECe(ave), Row 16
ECe (dS/m)
25
20
15
10
5
643900
644100
644300
644500
Distance (tail --> head) - meters


No. 3 - Avg. Profile ECe (by lane)
ECe(ave), Row 10
ECe(ave), Row 12
ECe(ave), Row 14
ECe(ave), Row 16
ECe (dS/m)
25
20
15
10
5
643900
644100
644300
644500
Distance (tail --> head) - meters


No. 3 - Avg. Profile ECe (by lane)
ECe(ave), Row 18
ECe(ave), Row 20
ECe(ave), Row 22
ECe (dS/m)
25
20
15
10
5
643900
644100
644300
644500
Distance (tail --> head) - meters

Field No. 4

Field Irrigation Evaluation

Data Summary

FIELD IRRIGATION EVALUATION FOR
IMPERIAL IRRIGATION DISTRICT
IMPERIAL VALLEY, CALIFORNIA.
FIELD NO. 4

FIELD DATA

Irrigated Acreage: 75 acres (ac) (second field served by the same turnout also about 75 acres).
Border Length: 1330 feet (ft)
Border Width: 150 ft
Border Slope: Average, 0.002641 ft/ft

CROP DATA

Crop: Second year Alfalfa, planted November of 1998.
Crop Growth Stage: 15 inches (in) in height
Crop Condition: Good

SOILS DATA

Soil Texture: Rositas fine sand (80%); Vint loamy very fine sand (18%); Indio loam (2%).
Soil Depth: > 4ft
Soil Uniformity: All sandy.
Effective Crop Rooting Depth: 4 ft
Available Water Capacity: 0.05 – 0.11 in/in.
Estimated Allowable Depletion: Not determined.

SOIL CONDITION

Estimated Soil Water Deficit at Beginning of Irrigation:
Average: 3.9 in.
Estimated Irrigation Water Stored in Root Zone:
Average: 3.7 in.

IRRIGATION DATA

Irrigation Method: Borders with gated outlets from concrete-lined head ditch.
Field and Soil Condition: Very little salinity in the field. Previous irrigation on June 20, 2000.

Beginning Irrigation Time: June 29, 2000, 9:30 a.m.
Ending Irrigation Time: June 30, 2000, 8:15 a.m.
Beginning Outflow Time: No outflow.
Ending Outflow Time: No outflow.
Average Inflow: 15.3 cubic feet per second (cfs).
Average Outflow: None

Number of Sets: 8
Set Time: 2.5 to 3.5 hours.
Advance Time: 4.6 to 5.3 hours.
Uniformity of Advance: There was no tailwater. The irrigation was not long enough or the flow rate was too low.
Number of Borders per Set: 2

Irrigation Observations:
Uniformity: Under irrigation at bottom of field and excess irrigation at top end.
Ponding: None.
Erosion: None
Estimated Irrigation Efficiency: 85 %.

Irrigation Summary		
	Average Depth[1], in	Percent of Applied Water, %
Total Water Applied	4.60	
Total Water Stored in Root Zone	3.70	80
Total Runoff	0.00	0
Total Deep Percolation	0.90	20

[1]Depth based on field irrigated acreage.

Field No.4 - Irrigation and Cropping History

Cropped Area: 150 ac

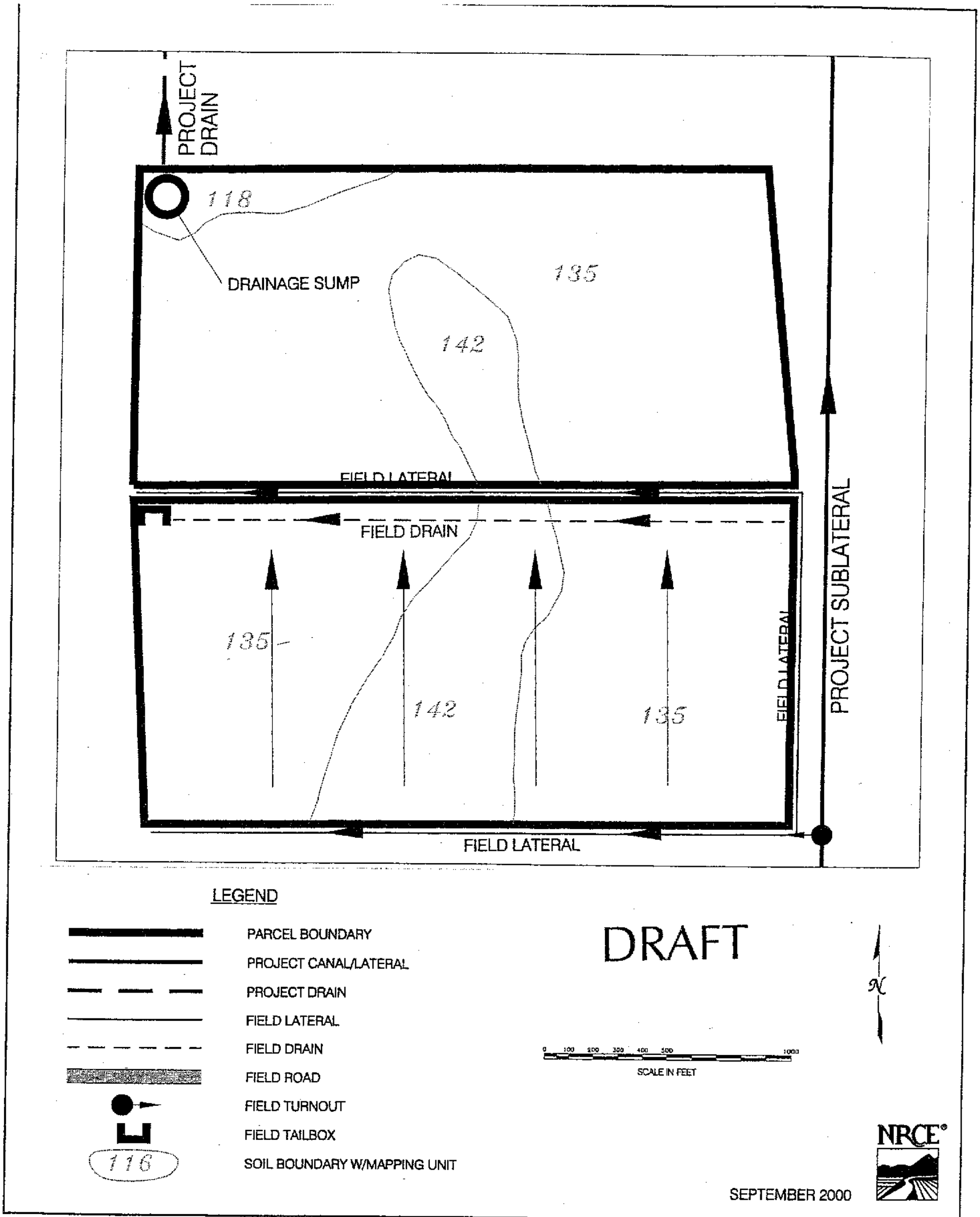
Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Flooding, row	1/27/97		12	11.9	11.9	1.89	
Flooding, row	1/28/97	1	13	13.7	13.7	2.17	
Flooding, row	1/29/97	1	13	13.4	13.4	2.13	**6.19**
Flooding, row	2/11/97	13	13	14.5	14.5	2.30	
Flooding, row	2/12/97	1	13	14.5	14.5	2.30	
Flooding, row	2/13/97	1	13	13.3	13.3	2.11	**6.71**
Flooding, row	2/24/97	11	13	13.9	13.9	2.21	
Flooding, row	2/25/97	1	13	12.8	12.8	2.03	
Flooding, row	2/26/97	1	13	12.8	12.8	2.03	**6.27**
Flooding, row	3/6/97	8	9	9.5	9.5	1.51	
Flooding, row	3/7/97	1	9	9.5	9.5	1.51	**3.01**
Flooding, row	3/12/97	5	10	9.7	9.7	1.54	**1.54**
Flooding, row	3/21/97	9	11	11	11	1.75	**1.75**
Flooding, row	3/31/97	10	11	10.6	10.6	1.68	**1.68**
Flooding, row	4/20/97	20	10	9.5	9.5	1.51	
Flooding, row	4/21/97	1	15	15.2	15.2	2.41	
Flooding, row	4/22/97	1	15	15	15	2.38	
Flooding, row	4/23/97	1	8	9	9	1.43	**7.73**
Flooding, row	8/10/97	109	13	12.5	12.5	1.98	
Flooding, row	8/11/97	1	13	12.7	12.7	2.02	
Flooding, row	8/12/97	1	13	12.7	12.7	2.02	
Flooding, row	8/13/97	1	13	13.1	13.1	2.08	
Flooding, row	8/14/97	1	13	9.4	9.4	1.49	
Flooding, row	8/15/97	1	6	0	3.5	0.56	**10.14**
Carrots	10/14/97	60	4.5	4.6	4.6	0.73	0.73
Carrots	10/15/97	1	4.5	4.5	4.5	0.71	0.71
Carrots	10/16/97	1	4.5	4.5	4.5	0.71	0.71
Carrots	10/17/97	1	4.5	4.5	4.5	0.71	0.71
Carrots	10/18/97	1	4.5	2.4	2.4	0.38	0.38
Carrots	10/20/97	2	5	2.6	2.6	0.41	0.41
Carrots	10/21/97	1	5	2.5	2.5	0.40	0.40
Carrots	10/22/97	1	5	2.3	2.5	0.40	0.40
Carrots	10/23/97	1	5	2.2	2.5	0.40	0.40
Carrots	10/24/97	1	5	2.5	2.5	0.40	0.40
Carrots	10/25/97	1	5	5	5	0.79	0.79
Carrots	10/28/97	3	5	5.2	5.2	0.83	0.83
Carrots	10/29/97	1	5	5.1	5.1	0.81	0.81
Carrots	10/30/97	1	5	5.1	5.1	0.81	0.81
Carrots	10/31/97	1	5	5.1	5.1	0.81	0.81
Carrots	11/1/97	1	5	2.5	2.5	0.40	0.40
Carrots	11/3/97	2	5	2.4	2.5	0.40	0.40
Carrots	11/5/97	2	5	2.3	2.3	0.36	
Carrots	11/6/97	1	5	4.7	4.7	0.75	1.11

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Carrots	11/28/97	22	7	7	7	1.11	
Carrots	11/29/97	1	7	6.9	6.9	1.09	
Carrots	11/30/97	1	7	7.4	7.4	1.17	
Carrots	12/1/97	1	5	2.6	2.6	0.41	3.79
Carrots	12/17/97	16	9	8.8	8.8	1.40	
Carrots	12/18/97	1	9	8.8	8.8	1.40	
Carrots	12/19/97	1	11	11.1	11.1	1.76	
Carrots	12/20/97	1	11	11.1	11.1	1.76	6.32
Carrots	1/7/98	18	12	12.1	12.1	1.92	
Carrots	1/8/98	1	12	12.1	12.1	1.92	
Carrots	1/9/98	1	12	12.1	12.1	1.92	5.76
Carrots	1/22/98	13	12	12.1	12.1	1.92	
Carrots	1/23/98	1	12	12.1	12.1	1.92	
Carrots	1/24/98	1	12	12.4	12.4	1.97	5.81
Carrots	2/11/98	18	11	11	11	1.75	
Carrots	2/12/98	1	11	11.1	11.1	1.76	
Carrots	2/13/98	1	11	11.1	11.1	1.76	5.27
Carrots	3/1/98	16	11	11.4	11.4	1.81	
Carrots	3/2/98	1	11	11.7	11.7	1.86	
Carrots	3/3/98	1	11	11.1	11.1	1.76	5.43
Carrots	3/10/98	7	9	9	9	1.43	
Carrots	3/11/98	1	9	9.3	9.3	1.48	
Carrots	3/12/98	1	7	7.1	7.1	1.13	
Carrots	3/13/98	1	7	7.1	7.1	1.13	5.16
Carrots	3/23/98	10	7	7.1	7.1	1.13	
Carrots	3/24/98	1	7	7.3	7.3	1.16	2.28
Carrots	4/1/98	8	7	7.1	7.1	1.13	
Carrots	4/2/98	1	7	7	7	1.11	
Carrots	4/3/98	1	10	10.2	10.2	1.62	
Carrots	4/4/98	1	10	10.2	10.2	1.62	
Carrots	4/5/98	1	7	2.1	2.1	0.33	5.81
Sudan Grass	4/18/98	13	9	9.1	9.1	1.44	
Sudan Grass	4/19/98	1	9	9.1	9.1	1.44	2.89
Sudan Grass	4/30/98	11	11	11.2	11.2	1.78	
Sudan Grass	5/1/98	1	11	11.4	11.4	1.81	3.59
Sudan Grass	5/6/98	5	9	9.4	9.4	1.49	
Sudan Grass	5/7/98	1	9	9.1	9.1	1.44	2.94
Sudan Grass	5/10/98	3	10	10.2	10.2	1.62	
Sudan Grass	5/11/98	1	10	10.2	10.2	1.62	3.24
Sudan Grass	5/17/98	6	9	9.9	9.9	1.57	
Sudan Grass	5/18/98	1	9	9.7	9.7	1.54	3.11
Sudan Grass	5/22/98	4	15	15.2	15.2	2.41	2.41
Sudan Grass	5/31/98	9	14	14.4	14.4	2.28	
Sudan Grass	6/1/98	1	14	14.9	14.9	2.36	
Sudan Grass	6/2/98	1	7	3.2	3.2	0.51	5.16
Sudan Grass	6/22/98	20	15	15.2	15.2	2.41	
Sudan Grass	6/23/98	1	15	16.2	16.2	2.57	

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Sudan Grass	6/24/98	1	15	15.2	15.2	2.41	
Sudan Grass	6/25/98	1	15	11.1	11.8	1.87	9.27
Sudan Grass	7/6/98	11	15	15.7	15.7	2.49	
Sudan Grass	7/7/98	1	15	15.6	15.6	2.48	
Sudan Grass	7/8/98	1	15	15.2	15.2	2.41	
Sudan Grass	7/9/98	1	15	3.8	3.8	0.60	7.98
Sudan Grass	7/14/98	5	15	15.5	15.5	2.46	
Sudan Grass	7/15/98	1	15	15.5	15.5	2.46	
Sudan Grass	7/16/98	1	15	7.7	7.7	1.22	6.14
Flooding, flat	9/19/98	65	12	12.1	12.1	1.92	
Flooding, flat	9/20/98	1	12	12.1	12.1	1.92	
Flooding, flat	9/21/98	1	12	12.1	12.1	1.92	
Flooding, flat	9/22/98	1	12	12.1	12.1	1.92	
Flooding, flat	9/23/98	1	12	12.1	12.1	1.92	
Flooding, flat	9/24/98	1	8	5	5	0.79	**10.39**
Alfalfa, flat	10/10/98	16	4.5	5.2	5.2	0.83	
Alfalfa, flat	10/11/98	1	4.5	4.8	4.8	0.76	
Alfalfa, flat	10/12/98	1	4.5	4.7	4.7	0.75	
Alfalfa, flat	10/13/98	1	4.5	4.7	4.7	0.75	3.08
Alfalfa, flat	10/16/98	3	4.5	2.3	2.3	0.36	
Alfalfa, flat	10/17/98	1	4.5	2.4	2.4	0.38	
Alfalfa, flat	10/18/98	1	4.5	1.9	1.9	0.30	1.05
Alfalfa, flat	10/20/98	2	4.5	4.7	4.7	0.75	0.75
Alfalfa, flat	11/12/98	23	4.5	2.4	2.4	0.38	
Alfalfa, flat	11/13/98	1	4.5	2.4	4.5	0.71	
Alfalfa, flat	11/14/98	1	4.5	2.4	2.4	0.38	
Alfalfa, flat	11/15/98	1	4.5	2.7	2.7	0.43	1.90
Alfalfa, flat	12/6/98	21	12	12.1	12.1	1.92	
Alfalfa, flat	12/7/98	1	14	13	13	2.06	
Alfalfa, flat	12/8/98	1	8	8	8	1.27	5.25
Alfalfa, flat	1/4/99	27	16	16	16	2.54	
Alfalfa, flat	1/5/99	1	13	13	13	2.06	4.60
Alfalfa, flat	2/1/99	27	13	13.3	13.3	2.11	
Alfalfa, flat	2/2/99	1	10	10.2	10.2	1.62	3.73
Alfalfa, flat	3/11/99	37	11	11.7	11.7	1.86	
Alfalfa, flat	3/12/99	1	14	14.1	14.1	2.24	
Alfalfa, flat	3/13/99	1	8	4.7	4.7	0.75	4.84
Alfalfa, flat	3/24/99	11	16	14.9	14.9	2.36	2.36
Alfalfa, flat	4/23/99	30	15	15.2	15.2	2.41	
Alfalfa, flat	4/24/99	1	15	15.2	15.2	2.41	
Alfalfa, flat	4/25/99	1	13	13.4	13.4	2.13	6.95
Alfalfa, flat	5/1/99	6	10	10.5	10.5	1.67	
Alfalfa, flat	5/2/99	1	10	11.9	11.9	1.89	
Alfalfa, flat	5/3/99	1	15	15.2	15.2	2.41	5.97
Alfalfa, flat	5/11/99	8	14	14.6	14.6	2.32	
Alfalfa, flat	5/12/99	1	14	14.2	14.2	2.25	4.57
Alfalfa, flat	5/29/99	17	16	16.5	16.5	2.62	

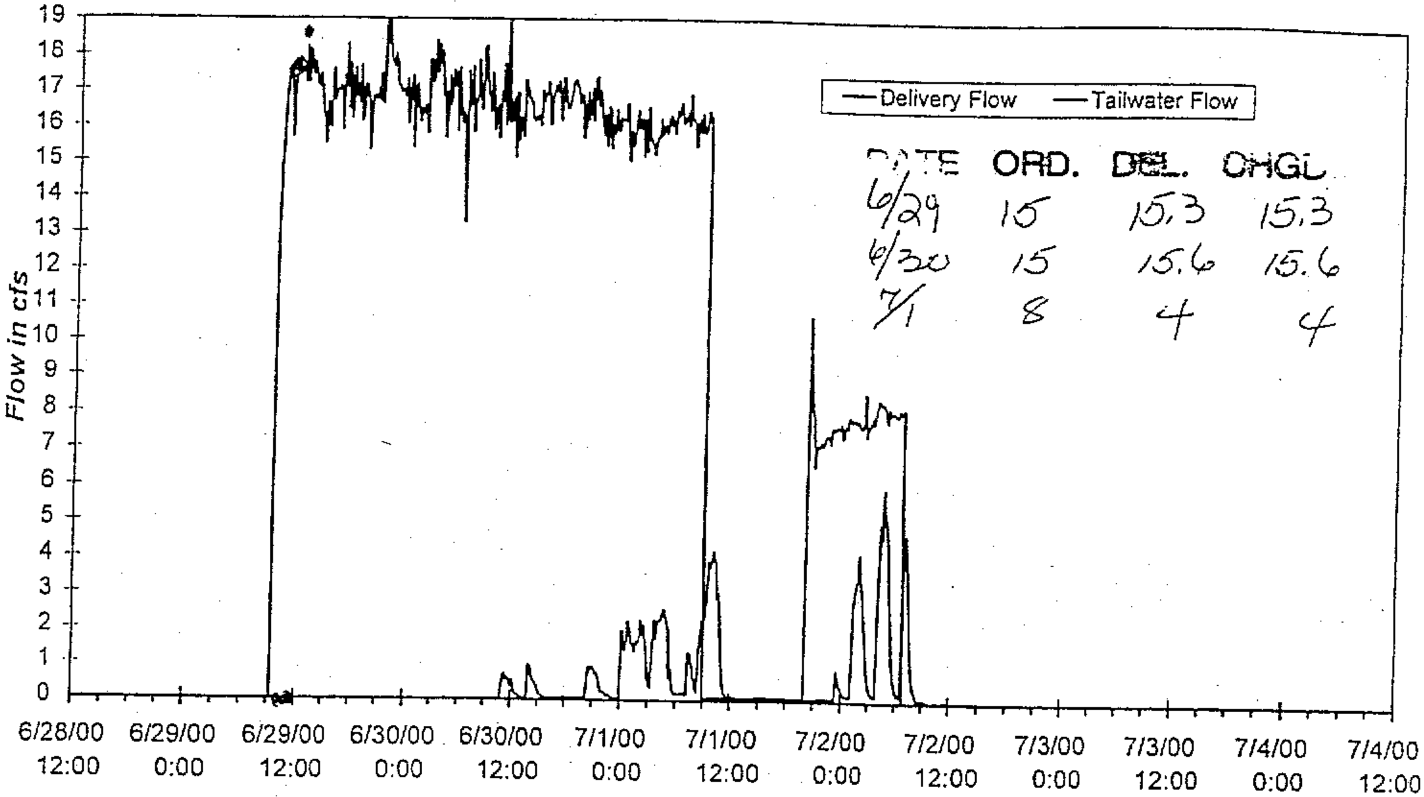
Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Alfalfa, flat	5/30/99	1	16	16.2	16.2	2.57	5.19
Alfalfa, flat	6/1/99	2	7	3.9	3.9	0.62	0.62
Alfalfa, flat	6/10/99	9	14	14.5	14.5	2.30	
Alfalfa, flat	6/11/99	1	14	14.6	14.6	2.32	4.62
Alfalfa, flat	6/13/99	2	7	7.3	7.3	1.16	
Alfalfa, flat	6/30/99	17	16	15.9	15.9	2.52	
Alfalfa, flat	7/1/99	1	16	18.9	18.9	3.00	
Alfalfa, flat	7/2/99	1	7	3.5	3.5	0.56	6.08
Alfalfa, flat	7/9/99	7	14	14.6	14.6	2.32	
Alfalfa, flat	7/10/99	1	14	16.5	16.5	2.62	4.93
Alfalfa, flat	7/28/99	18	18	17.9	17.9	2.84	
Alfalfa, flat	7/29/99	1	18	18.1	18.1	2.87	5.71
Alfalfa, flat	8/7/99	9	14	15.9	15.9	2.52	
Alfalfa, flat	8/8/99	1	14	16.5	16.5	2.62	5.14
Alfalfa, flat	8/27/99	19	18	17.9	17.9	2.84	
Alfalfa, flat	8/28/99	1	18	17.9	17.9	2.84	5.68
Alfalfa, flat	9/6/99	9	14	14.4	14.4	2.28	
Alfalfa, flat	9/7/99	1	14	14.4	14.4	2.28	4.57
Alfalfa, flat	9/28/99	21	18	18.6	18.6	2.95	
Alfalfa, flat	9/29/99	1	18	18.4	18.4	2.92	5.87
Alfalfa, flat	10/11/99	12	14	14.9	14.9	2.36	
Alfalfa, flat	10/12/99	1	14	14.1	14.1	2.24	
Alfalfa, flat	10/13/99	1	7	2.4	2.4	0.38	4.98
Alfalfa, flat	11/12/99	30	18	18.9	18.9	3.00	
Alfalfa, flat	11/13/99	1	18	18.9	18.9	3.00	6.00
Alfalfa, flat	1/4/00	52	18	18.1	18.1	2.87	2.87
Alfalfa, flat	1/11/00	7	13	12.9	12.9	2.05	2.05
Alfalfa, flat	1/29/00	18	14	14	14	2.22	
Alfalfa, flat	1/30/00	1	12	11.9	11.9	1.89	4.11
Alfalfa, flat	3/4/00	34	18	18.1	18.1	2.87	
Alfalfa, flat	3/5/00	1	18	18.1	18.1	2.87	5.74
Alfalfa, flat	3/20/00	15	14	14.2	14.1	2.24	
Alfalfa, flat	3/21/00	1	14	13	13	2.06	4.30
Alfalfa, flat	4/15/00	25	18	18	18	2.86	
Alfalfa, flat	4/16/00	1	18	18.2	18.2	2.89	5.74
Alfalfa, flat	4/26/00	10	14	14.6	14.6	2.32	
Alfalfa, flat	4/27/00	1	14	14.6	14.6	2.32	4.63
Alfalfa, flat	5/20/00	23	18	18.1	18.1	2.87	
Alfalfa, flat	5/21/00	1	18	18.1	18.1	2.87	5.74
Alfalfa, flat	5/30/00	9	14	14.1	14.1	2.24	
Alfalfa, flat	5/31/00	1	14	14	14	2.22	4.46
Alfalfa, flat	6/17/00	17	18	18	18	2.86	
Alfalfa, flat	6/18/00	1	18	18.1	18.1	2.87	5.73
Alfalfa, flat	6/20/00	2	7	7.1	7	1.11	1.11
Alfalfa, flat	6/29/00	9	15	15.3	15.3	2.43	
Alfalfa, flat	6/30/00	1	15	15.6	15.6	2.48	
Alfalfa, flat	7/1/00	1	8	4	4	0.63	5.54

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Alfalfa, flat	7/15/00	14	18	18.2	18.1	2.87	
Alfalfa, flat	7/16/00	1	14	14.2	14.2	2.25	5.13
Alfalfa, flat	7/18/00	2	5	1.9	1.9	0.30	0.30
Alfalfa, flat	7/25/00	7	14	14.2	14.2	2.25	
Alfalfa, flat	7/26/00	1	14	14.6	14.6	2.32	4.57
Alfalfa, flat	7/28/00	2	7	7.4	7.4	1.17	

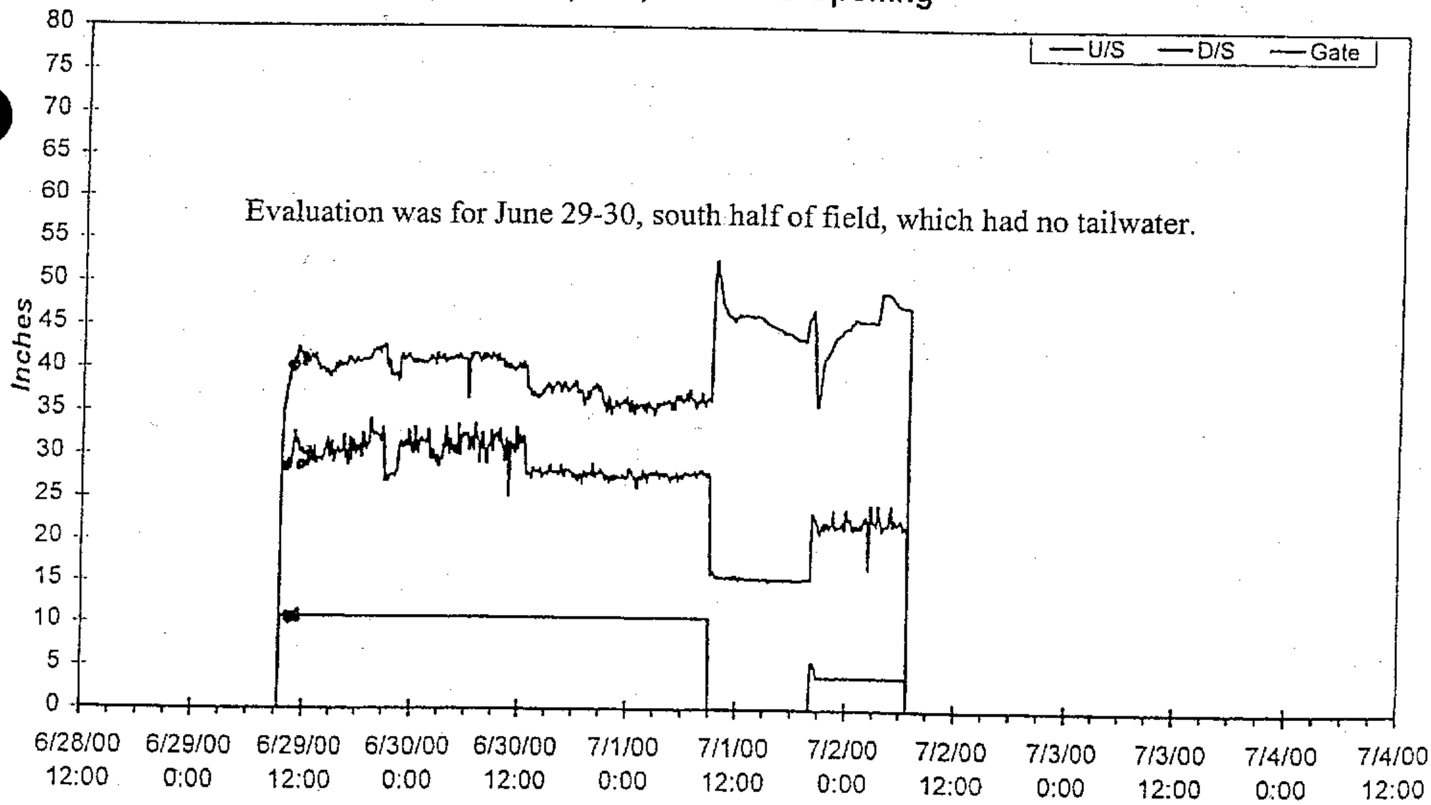


Field No. 4 Layout

Delivery and Tailwater Flow for Parcel No.4



U/S, D/S, and Gate Opening



Order = **2d-15', 1d-8'**	Delivery Volume (AF) = **72.4**	% Tailwater= **5%**	Acres = **150**
Type = **142, 132**	Tailwater Volume (AF)= **3.3**	Crop = **Flat alfalfa**	Inches Applied= **5.8**

Field No. 4 - 0 to 1 ft. (auto scale)

ECe(0.5)
dS/m

< .557

.557 - .611

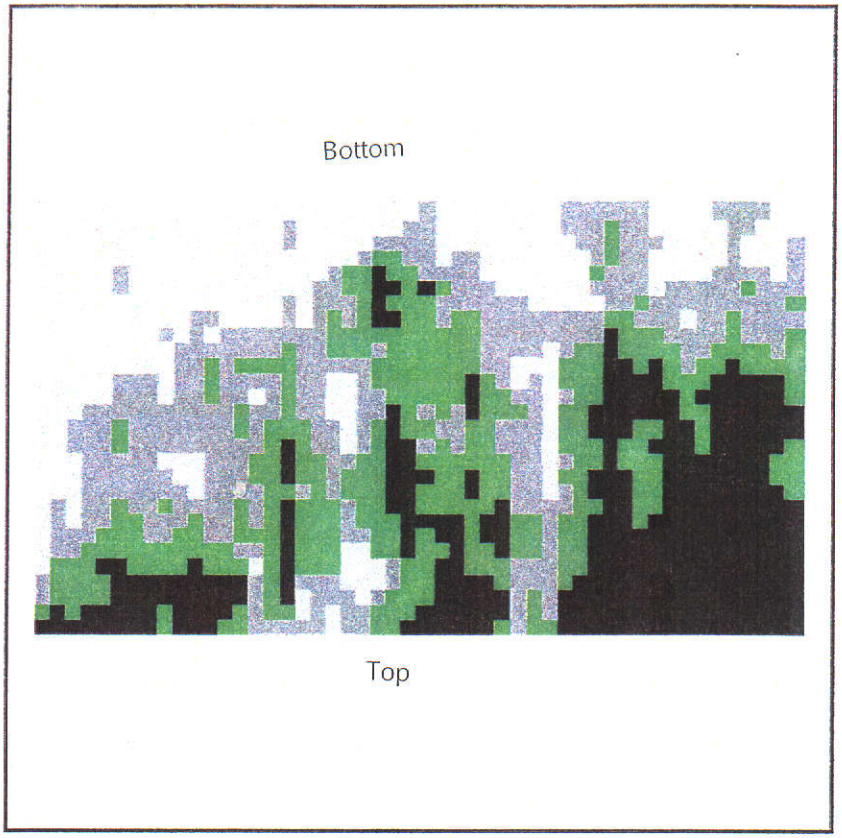
.611 - .666

> .666

Data Bounds

X: min & max
622056.53
622832.74

Y: min & max
3661180.24
3661585.34



1 to 2 ft.

ECe(1.5)
dS/m

< .696

.696 - 1.082

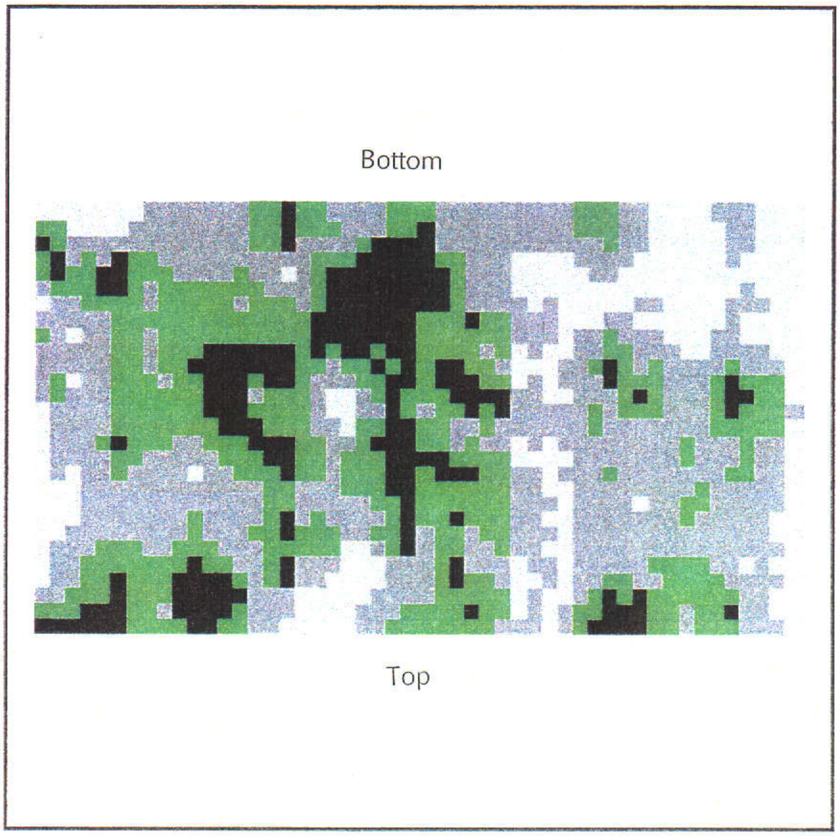
1.082 - 1.468

> 1.468

Data Bounds

X: min & max
622056.53
622832.74

Y: min & max
3661180.24
3661585.34



Field No. 4 - 2 to 3 ft. (auto scale)

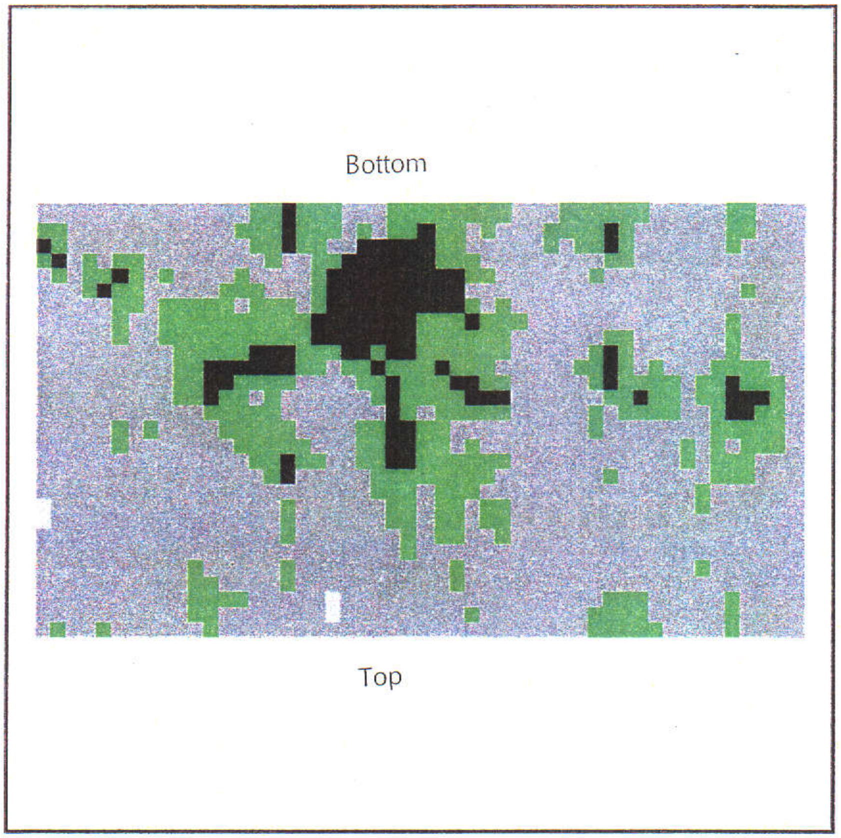
ECe(2.5)
dS/m

< .33
.33 - 2.457
2.457 - 4.583
> 4.583

Data Bounds

X: min & max
622056.53
622832.74

Y: min & max
3661180.24
3661585.34



3 to 4 ft.

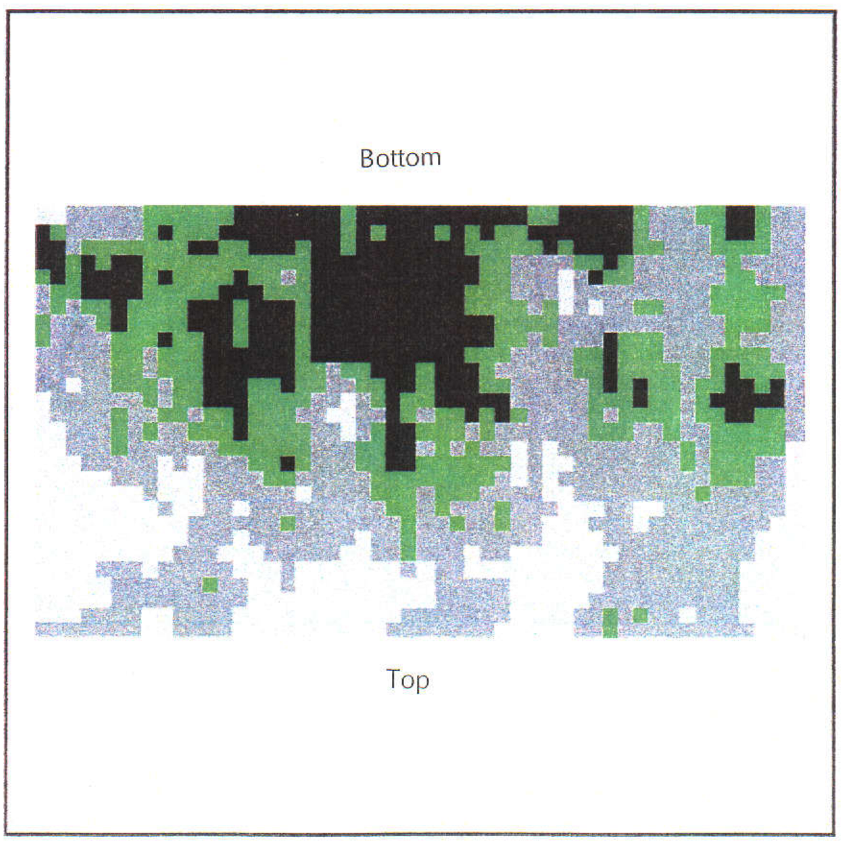
ECe(3.5)
dS/m

< 1.864
1.864 - 2.532
2.532 - 3.201
> 3.201

Data Bounds

X: min & max
622056.53
622832.74

Y: min & max
3661180.24
3661585.34



Field No. 4 - 4 ft. Profile Avg. (auto scale)

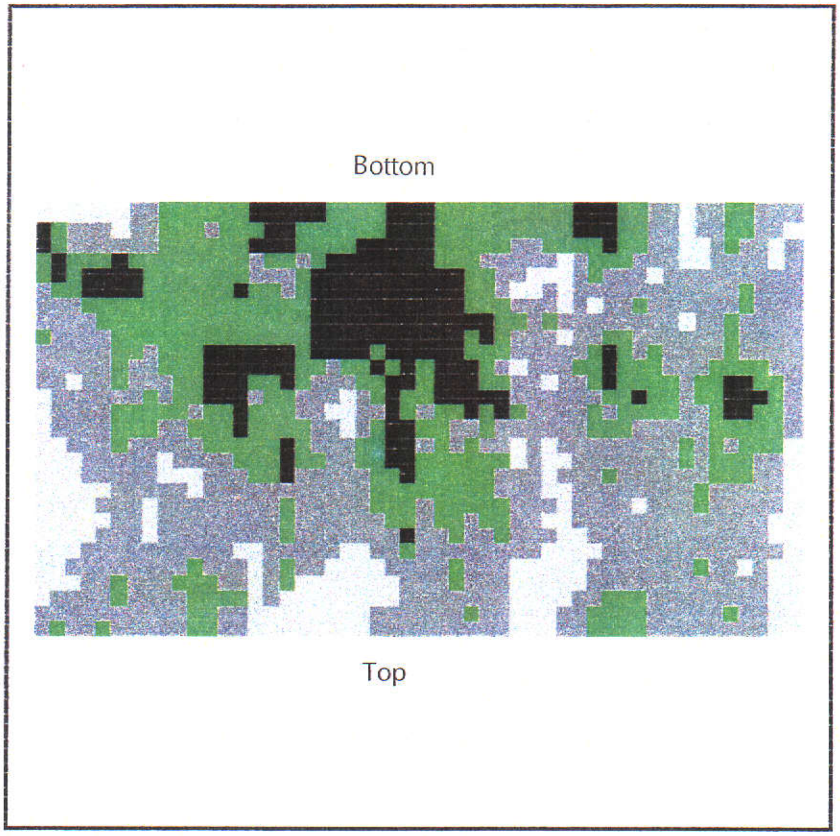
ECe(ave)
dS/m

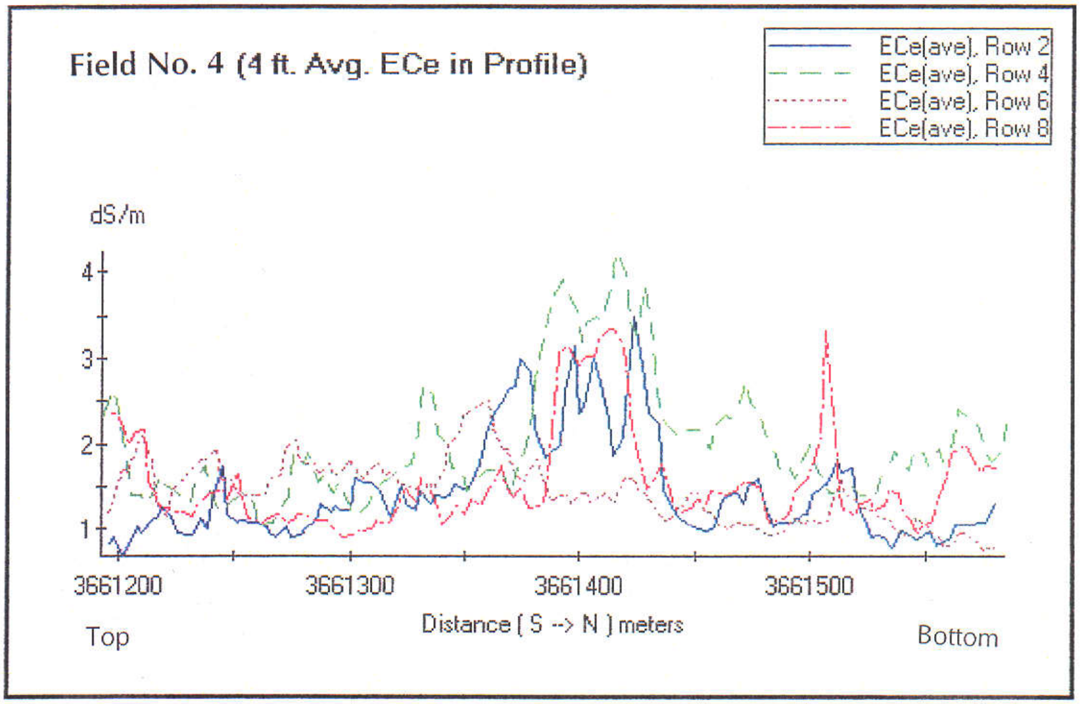
< 1.061
1.061 - 1.733
1.733 - 2.404
> 2.404

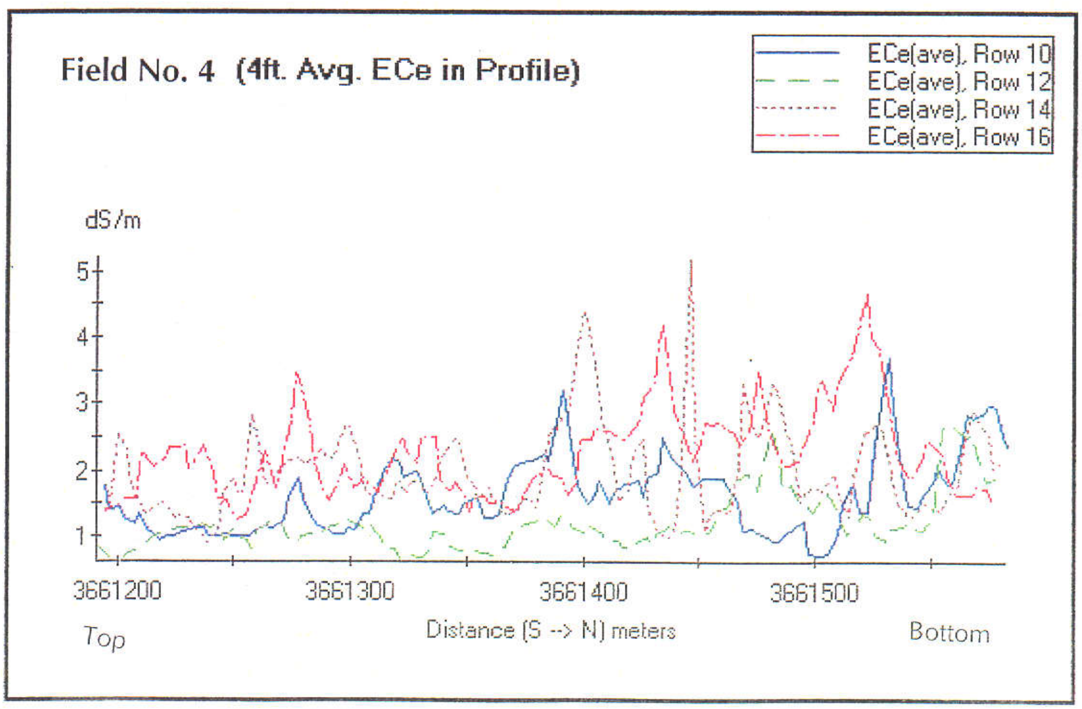
Data Bounds

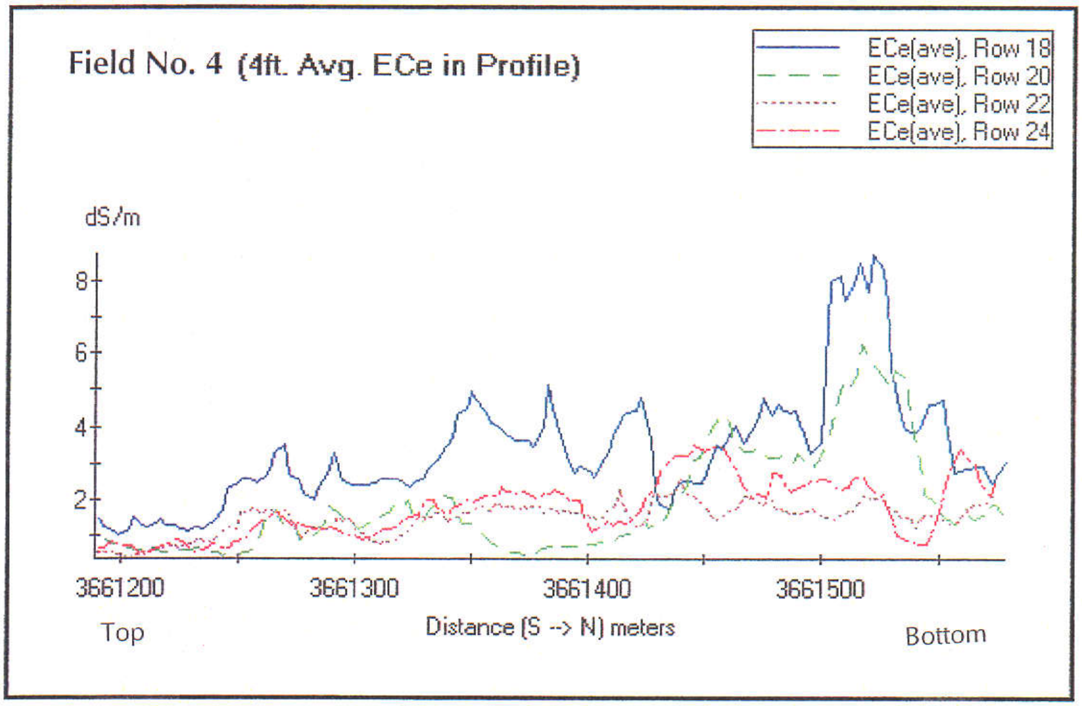
X: min & max
622056.53
622832.74

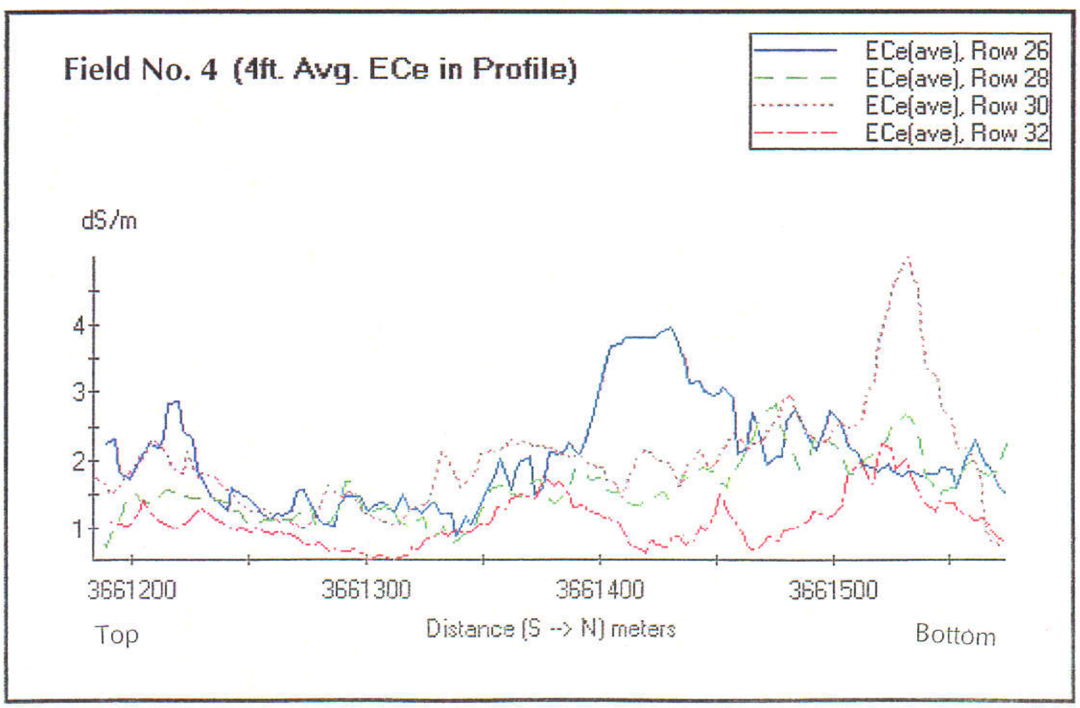
Y: min & max
3661180.24
3661585.34




Field No. 4 (4 ft. Avg. ECe in Profile)
ECe(ave), Row 2
ECe(ave), Row 4
ECe(ave), Row 6
ECe(ave), Row 8
dS/m
4
3
2
1
3661200
3661300
3661400
3661500
Distance (S --> N) meters
Top
Bottom


Field No. 4 (4ft. Avg. ECe in Profile)
ECe(ave), Row 10
ECe(ave), Row 12
ECe(ave), Row 14
ECe(ave), Row 16
dS/m
5
4
3
2
1
3661200
3661300
3661400
3661500
Distance (S --> N) meters
Top
Bottom


Field No. 4 (4ft. Avg. ECe in Profile)
ECe(ave), Row 18
ECe(ave), Row 20
ECe(ave), Row 22
ECe(ave), Row 24
dS/m
8
6
4
2
3661200
3661300
3661400
3661500
Top
Distance (S --> N) meters
Bottom


Field No. 4 (4ft. Avg. ECe in Profile)
ECe(ave), Row 26
ECe(ave), Row 28
ECe(ave), Row 30
ECe(ave), Row 32
dS/m
4
3
2
1
3661200
3661300
3661400
3661500
Top
Distance (S --> N) meters
Bottom

Field No. 5

Field Irrigation Evaluation

Data Summary

FIELD IRRIGATION EVALUATION FOR
IMPERIAL IRRIGATION DISTRICT
IMPERIAL VALLEY, CALIFORNIA.
FIELD NO. 5

FIELD DATA

Irrigated Acreage: 52 acres (ac) (second field served by same turnout about 78 acres).
Border Length: 2460 feet (ft)
Border Width: 130 ft
Border Slope: Average, 0.001665 ft/ft

CROP DATA

Crop: First year Bermuda Grass following leaching, planted September 1999.
Crop Growth Stage: 10 inches (in) in height
Crop Condition: Good

SOILS DATA

Soil Texture: Imperial silty clay (100%).
Soil Depth: > 4 ft.
Soil Uniformity: Average to good
Effective Crop Rooting Depth: 3 ft
Available Water Capacity: 0.17 – 0.35 in/in.
Estimated Allowable Depletion: Not determined.

SOIL CONDITION

Estimated Soil Water Deficit at Beginning of Irrigation:
Average: 3.95 in.
Estimated Irrigation Water Stored in Root Zone:
Average: 3.95 in.

IRRIGATION DATA

Irrigation Method: Borders with gated outlets from concrete-lined head ditch.
Field and Soil Condition: Slight cracking. Previous irrigation on June 29, 2000.

Beginning Irrigation Time: July 11, 2000, 8:30 a.m.
Ending Irrigation Time: July 12, 2000, 8:45 a.m
Beginning Outflow Time: July 12, about 9 p.m.
Ending Outflow Time: July 15, about 1 p.m.
Average Inflow: 11.0 cubic feet per second (cfs)
Average Outflow: 0.23 cfs.

Number of Sets: 1
Set Time: Average, 24 hours
Advance Time: 33.5 to 35 hours
Uniformity of Advance: Near constant rate of advance. Quite uniform.
Number of Borders per Set: 7

Irrigation Observations: The irrigation set time of 24 hours is not typical for irrigations during cropping. Water had advanced about 70 % of the field when it was shut off.
Uniformity: Good
Ponding: Some at the bottom of the field.
Erosion: None.
Estimated Irrigation Efficiency: 87 %.

Irrigation Summary		
	Average Depth[1], in	Percent of Applied Water, %
Total Water Applied	5.08	
Total Water Stored in Root Zone	3.95	77
Total Runoff	0.28	6
Total Deep Percolation	0.85	17

[1]Depth based on field irrigated acreage.

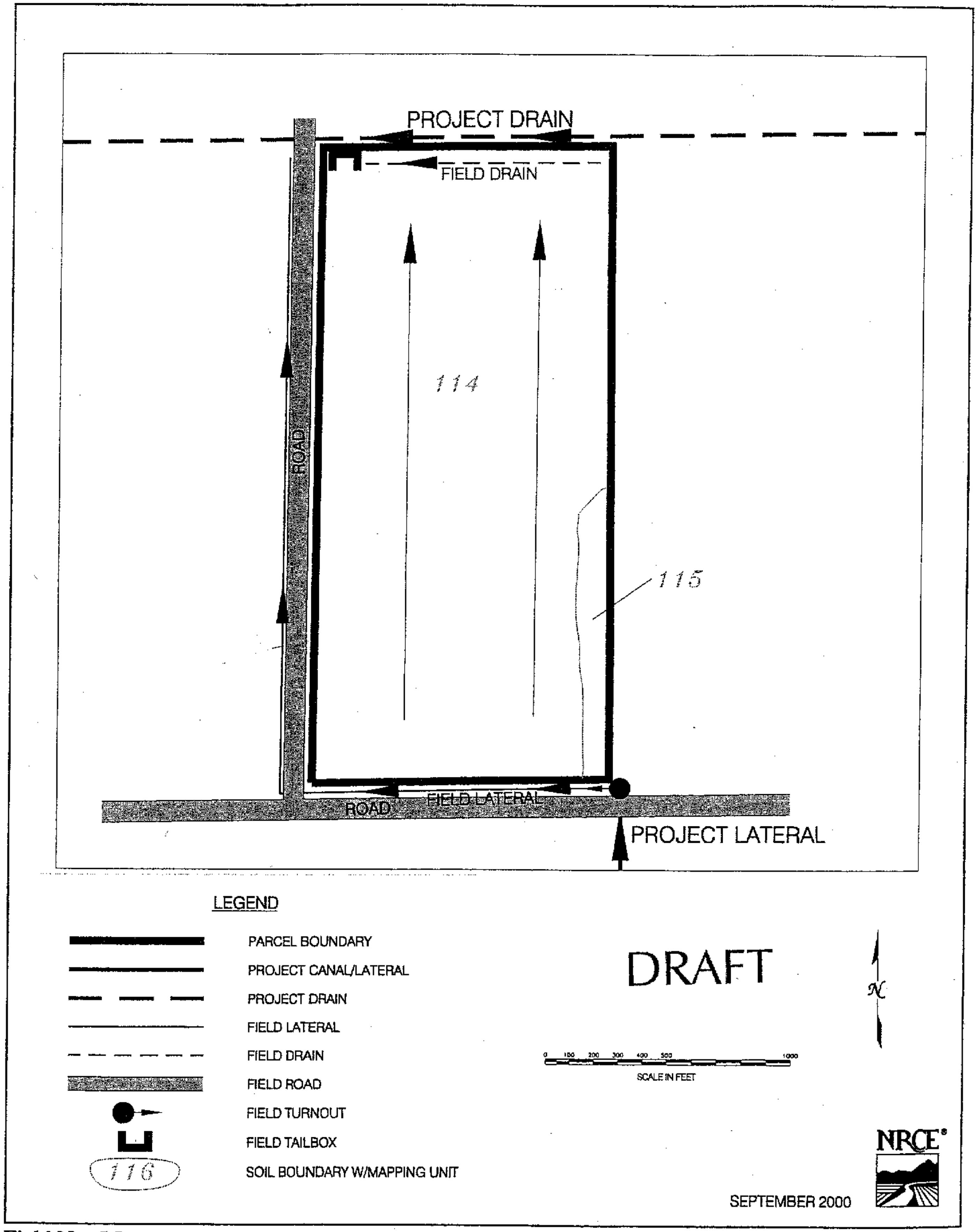
Field No.5 - Irrigation and Cropping History

Cropped Area: **130 ac**

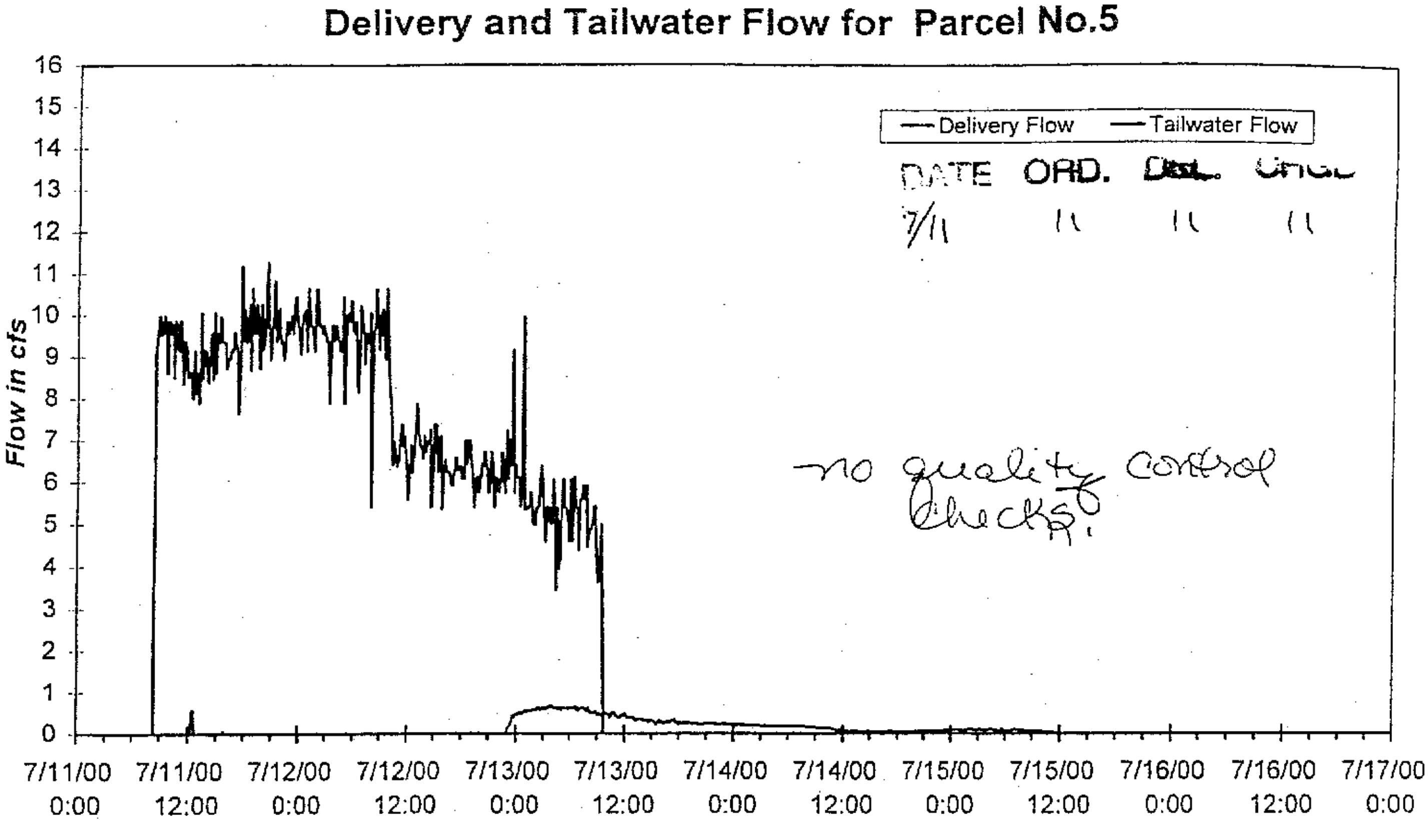
Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Flooding, flat							
Wheat	1/21/97		8	8	8	1.46	
Wheat	1/22/97	1	8	8	8	1.46	2.93
Wheat	2/7/97	16	14	14.2	14.2	2.60	2.60
Wheat	2/13/97	6	14	12.5	14	2.56	2.56
Wheat	3/6/97	21	9.5	9.5	9.5	1.74	1.74
Wheat	3/20/97	14	10	10	10	1.83	1.83
Wheat	3/29/97	9	18	18	18	3.30	3.30
Wheat	3/31/97	2	4	4	4	0.73	
Wheat	4/1/97	1	9	9	9	1.65	2.38
Wheat	4/14/97	13	9.5	9.6	9.6	1.76	1.76
Wheat	4/19/97	5	19	19	19	3.48	3.48
Wheat	4/25/97	6	10	10	10	1.83	1.83
Wheat	5/2/97	7	17	17	17	3.11	3.11
Idle	5/15/97	13	17	17	17	3.11	3.11
Idle	5/25/97	10	16	16	16	2.93	2.93
Idle	6/20/97	26	19	19	19	3.48	3.48
Idle	6/30/97	10	16	16	16	2.93	2.93
Idle	7/10/97	10	16	16	16	2.93	2.93
Idle	7/21/97	11	16	16	16	2.93	2.93
Idle	8/5/97	15	17.5	17.5	17.5	3.20	3.20
Idle	8/8/97	3	8	8.1	8.1	1.48	
Idle	8/9/97	1	8	8.1	8.1	1.48	
Idle	8/10/97	1	6	5.7	6	1.10	4.06
Idle	8/16/97	6	15.5	15.5	15.5	2.84	**2.84**
Flooding, flat	8/28/97	12	15.5	15.4	15.4	2.82	**2.82**
Flooding, flat	9/18/97	21	16	12.2	16	2.93	**2.93**
Flooding, flat	10/11/97	23	16	16	16	2.93	**2.93**
Flooding, flat	11/13/97	33	5	5.2	5.2	0.95	
Flooding, flat	11/14/97	1	5	1.5	2.5	0.46	**1.41**
Wheat	1/14/98	61	9	9	9	1.65	1.65
Wheat	3/3/98	48	18	18.6	18.6	3.41	3.41
Wheat	3/5/98	2	9	8.9	8.9	1.63	1.63
Wheat	3/9/98	4	10	10	10	1.83	1.83
Wheat	3/24/98	15	16	16	16	2.93	
Wheat	3/25/98	1	10	10	10	1.83	4.76
Wheat	4/7/98	13	9	9	9	1.65	1.65
Wheat	4/11/98	4	16	16	16	2.93	2.93
Wheat	4/19/98	8	9	9	9	1.65	1.65
Wheat	4/28/98	9	17	18.1	18.1	3.31	
Wheat	4/29/98	1	9	8.9	8.9	1.63	4.94
Wheat	5/7/98	8	7	7	7	1.28	1.28
Wheat	5/11/98	4	17	17	17	3.11	3.11

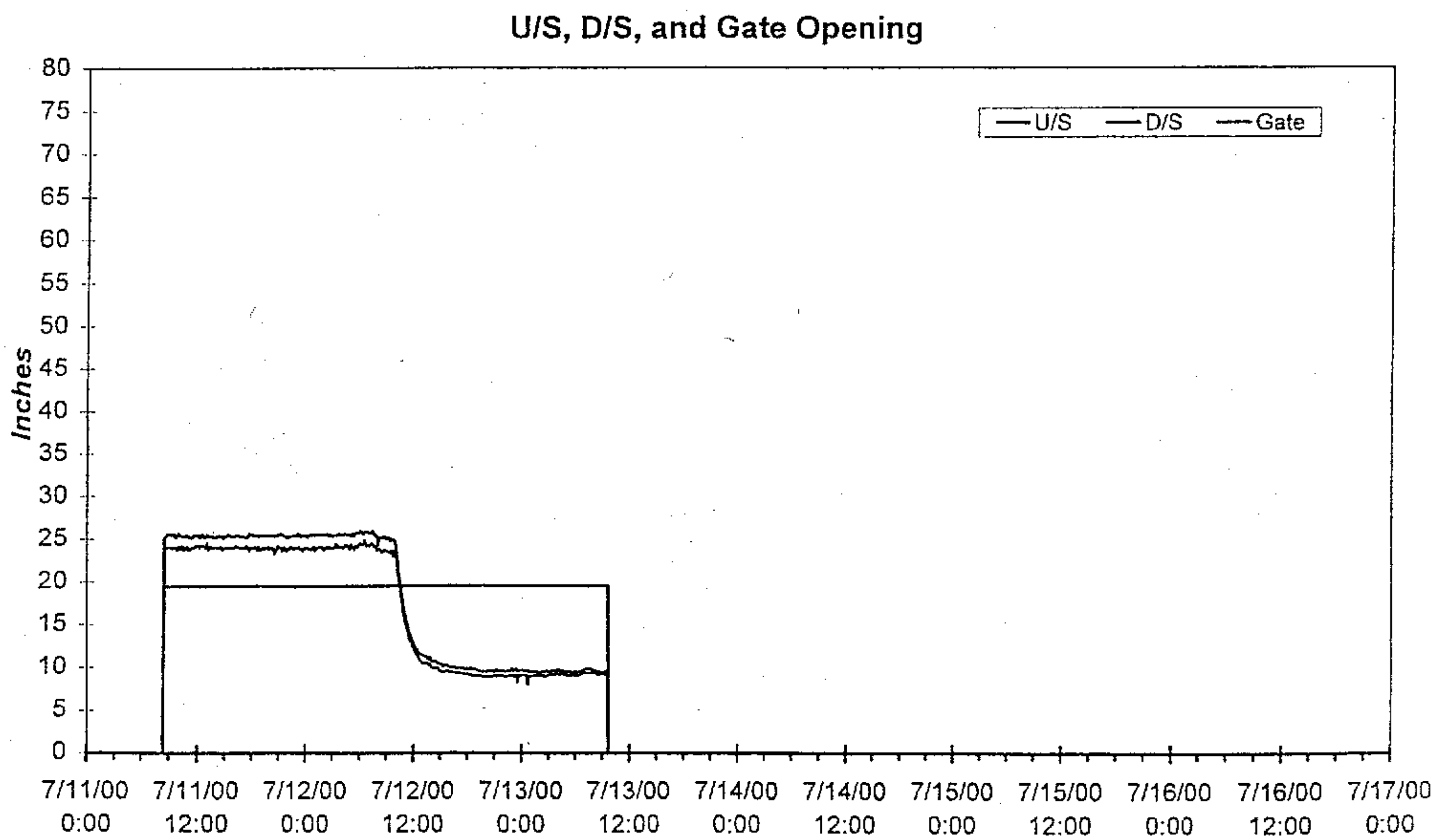
Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Wheat	5/21/98	10	16	16	16	2.93	2.93
Idle	5/31/98	10	15	15	15	2.75	2.75
Idle	6/12/98	12	16	16	16	2.93	2.93
Idle	7/1/98	19	18	18	18	3.30	3.30
Idle	7/10/98	9	14	14	14	2.56	2.56
Idle	7/20/98	10	15	15.2	15.2	2.78	2.78
Idle	7/31/98	11	15	15.2	15.2	2.78	2.78
Idle	8/15/98	15	17	16.8	16.8	3.08	
Flooding, flat	8/20/98	5	8	8	8	1.46	
Flooding, flat	8/21/98	1	8	8	8	1.46	
Flooding, flat	8/22/98	1	8	8.3	8.3	1.52	**4.45**
Flooding, flat	8/27/98	5	16	16	16	2.93	**2.93**
Flooding, flat	9/9/98	13	15	15	15	2.75	**2.75**
Flooding, flat	9/23/98	14	15	15	15	2.75	**2.75**
Flooding, flat	10/7/98	14	15	15	15	2.75	**2.75**
Flooding, flat	11/12/98	36	5	4.3	4.3	0.79	**0.79**
Wheat	1/8/99	57	8	7.5	8	1.46	1.46
Wheat	2/6/99	29	5.5	5.5	5.5	1.01	1.01
Wheat	2/23/99	17	11	11	11	2.01	
Wheat	2/24/99	1	11	10.9	10.9	2.00	4.01
Wheat	2/28/99	4	7.5	7.5	7.5	1.37	
Wheat	3/1/99	1	4.5	2.4	2.4	0.44	1.81
Wheat	3/14/99	13	8.5	8.6	8.6	1.57	1.57
Wheat	3/20/99	6	12.5	12.5	12.5	2.29	
Wheat	3/21/99	1	3	2.5	2.5	0.46	2.75
Wheat	3/27/99	6	9	9	9	1.65	1.65
Wheat	4/6/99	10	15	15	15	2.75	2.75
Wheat	4/8/99	2	7	7.1	7.1	1.30	
Wheat	4/20/99	12	8.5	8.4	8.4	1.54	
Wheat	4/21/99	1	13.5	15.3	15.3	2.80	4.34
Wheat	4/23/99	2	4	3.8	3.8	0.70	0.70
Wheat	5/1/99	8	9	9.1	9.1	1.67	
Wheat	5/2/99	1	4	2.4	2.4	0.44	2.11
Wheat	5/4/99	2	16	15.9	15.9	2.91	2.91
Wheat	5/23/99	19	18	17.9	17.9	3.28	3.28
Idle	6/3/99	11	16	16.1	16.1	2.95	2.95
Idle	6/14/99	11	15	15	15	2.75	
Idle	6/15/99	1	3	1.9	1.9	0.35	3.09
Idle	6/23/99	8	16	16	16	2.93	2.93
Idle	7/2/99	9	15.5	15.5	15.5	2.84	2.84
Idle	7/12/99	10	15.5	15.5	15.5	2.84	2.84
Idle	8/1/99	20	18	19	19	3.48	3.48
Idle	8/12/99	11	15	15	15	2.75	2.75
Flooding, flat	8/14/99	2	10	10	10	1.83	
Flooding, flat	8/15/99	1	10	10	10	1.83	
Flooding, flat	8/16/99	1	7	7	7	1.28	**4.94**
Flooding, flat	8/22/99	6	15	15	15	2.75	**2.75**

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Flooding, flat	9/8/99	17	17	16.9	16.9	3.09	**3.09**
Bermuda Grass	9/10/99	2	9	9.1	9.1	1.67	
Bermuda Grass	9/11/99	1	7	3.8	3.8	0.70	2.36
Bermuda Grass	9/13/99	2	7	3.4	7	1.28	1.28
Bermuda Grass	9/16/99	3	7	4.9	4.9	0.90	0.90
Bermuda Grass	9/23/99	7	14	14	14	2.56	2.56
Bermuda Grass	9/27/99	4	7	6.5	7	1.28	1.28
Bermuda Grass	10/8/99	11	15	15	15	2.75	
Bermuda Grass	10/9/99	1	10	9.9	15	2.75	5.49
Bermuda Grass	2/8/00	122	12	12	12	2.20	
Bermuda Grass	2/9/00	1	12	12	12	2.20	
Bermuda Grass	2/10/00	1	12	12	12	2.20	
Bermuda Grass	2/11/00	1	9	9	9	1.65	8.24
Bermuda Grass	3/6/00	24	12	10	12	2.20	2.20
Bermuda Grass	3/13/00	7	16	16	16	2.93	2.93
Bermuda Grass	3/29/00	16	14	14	14	2.56	
Bermuda Grass	3/30/00	1	13	12.9	12.9	2.36	
Bermuda Grass	3/31/00	1	2	2	2	0.37	5.29
Bermuda Grass	4/12/00	12	16	16.2	16.2	2.97	2.97
Bermuda Grass	4/17/00	5	13	13	13	2.38	2.38
Bermuda Grass	4/26/00	9	15	16.3	16.2	2.97	2.97
Bermuda Grass	5/6/00	10	13	13	13	2.38	2.38
Bermuda Grass	5/9/00	3	16	15.8	15.8	2.89	2.89
Bermuda Grass	5/19/00	10	15	15.4	15.4	2.82	2.82
Bermuda Grass	5/22/00	3	13	13.3	13.3	2.44	2.44
Bermuda Grass	5/29/00	7	15	15	15	2.75	2.75
Bermuda Grass	6/18/00	20	16	16	16	2.93	2.93
Bermuda Grass	6/24/00	6	20	20	20	3.66	3.66
Bermuda Grass	6/26/00	2	5	3.7	3.7	0.68	0.68
Bermuda Grass	6/29/00	3	10	10	10	1.83	1.83
Bermuda Grass	7/5/00	6	15	14.8	14.8	2.71	2.71
Bermuda Grass	7/11/00	6	11	11	11	2.01	2.01
Bermuda Grass	7/15/00	4	15	15	15	2.75	2.75
Bermuda Grass	7/24/00	9	15	15	15	2.75	2.75
Bermuda Grass	7/30/00	6	14	14	14	2.56	2.56



Field No. 5 Layout





Order = **1d-11', 1d-15'** Delivery Volume (AF) = **31.7** % Tailwater= **4%** Acres = **95**
Soil Type = **114** Tailwater Volume (AF)= **1.2** Crop = **Bermudagrass** Inches Applied= **4.0**

Field No. 5 - 0 to 1 ft.

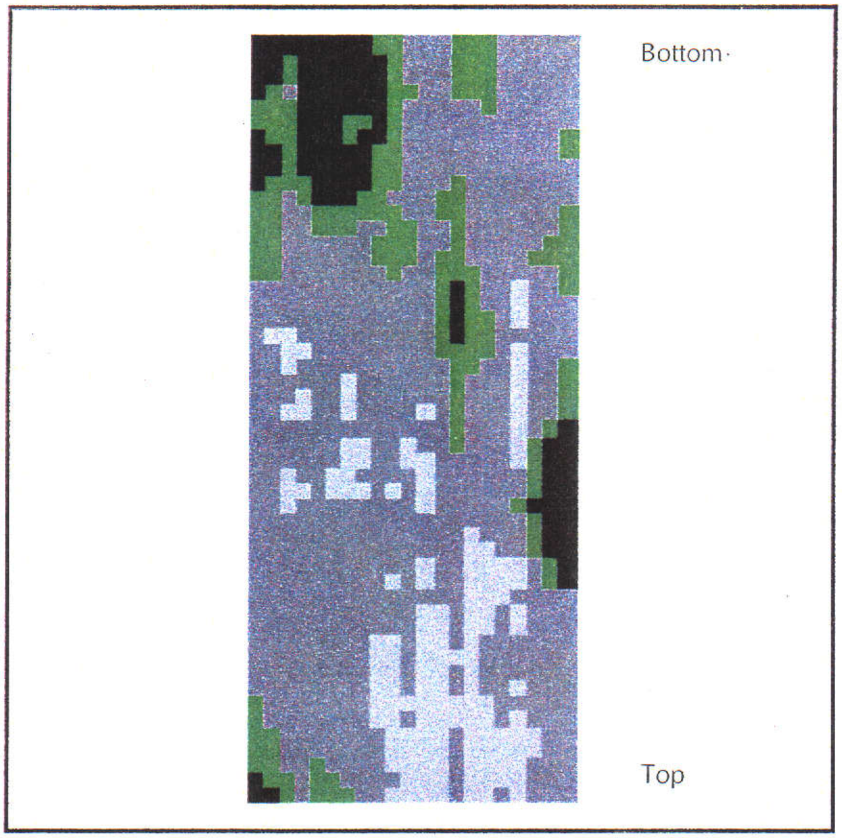
ECe(0.5)
dS/m

- < 3
- 3 - 8
- 8 - 13
- > 13

Data Bounds

X: min & max
642438.19
642724.78

Y: min & max
3635414.88
3636157.68



1 to 2 ft.

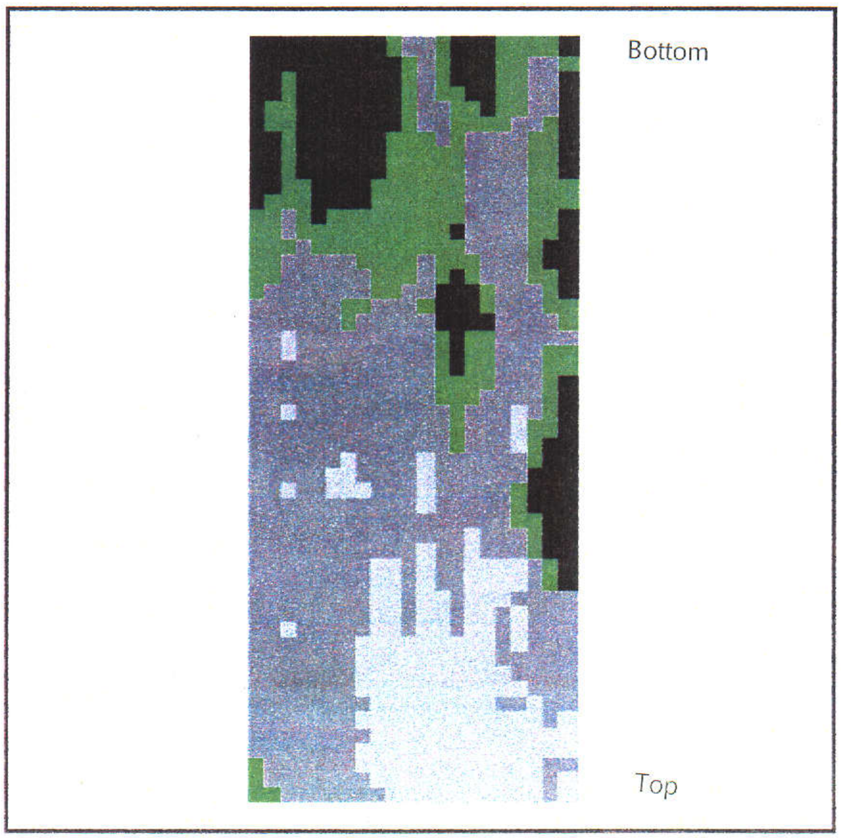
ECe(1.5)
dS/m

- < 3
- 3 - 8
- 8 - 13
- > 13

Data Bounds

X: min & max
642438.19
642724.78

Y: min & max
3635414.88
3636157.68



Field No. 5 - 2 to 3 ft.

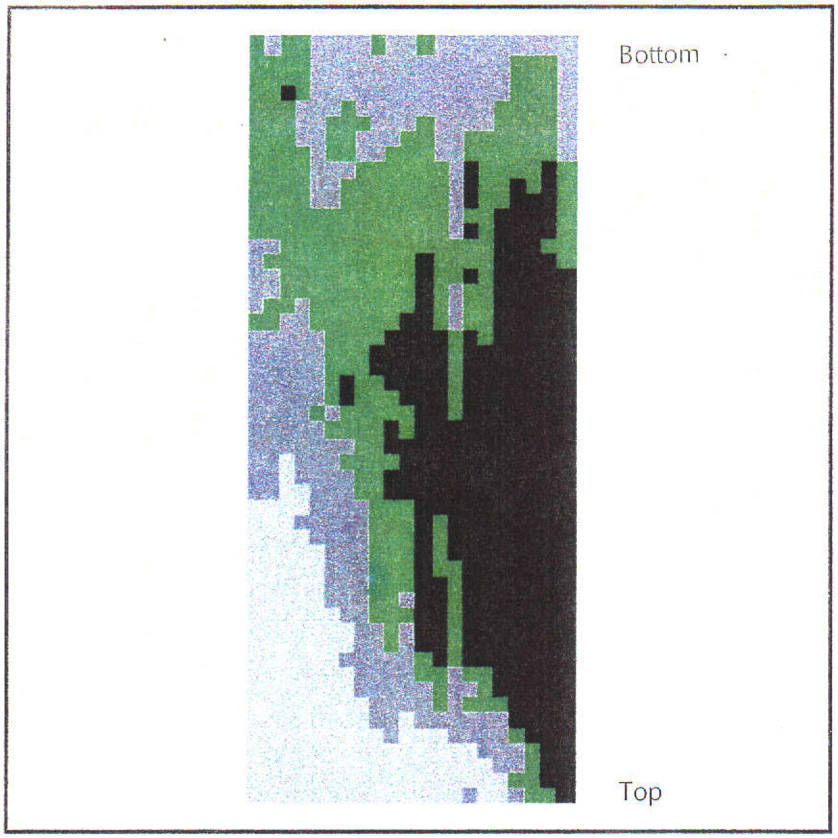
ECe(2.5)
dS/m

< 3
3 - 8
8 - 13
> 13

Data Bounds

X: min & max
642438.19
642724.78

Y: min & max
3635414.88
3636157.68



3 to 4 ft.

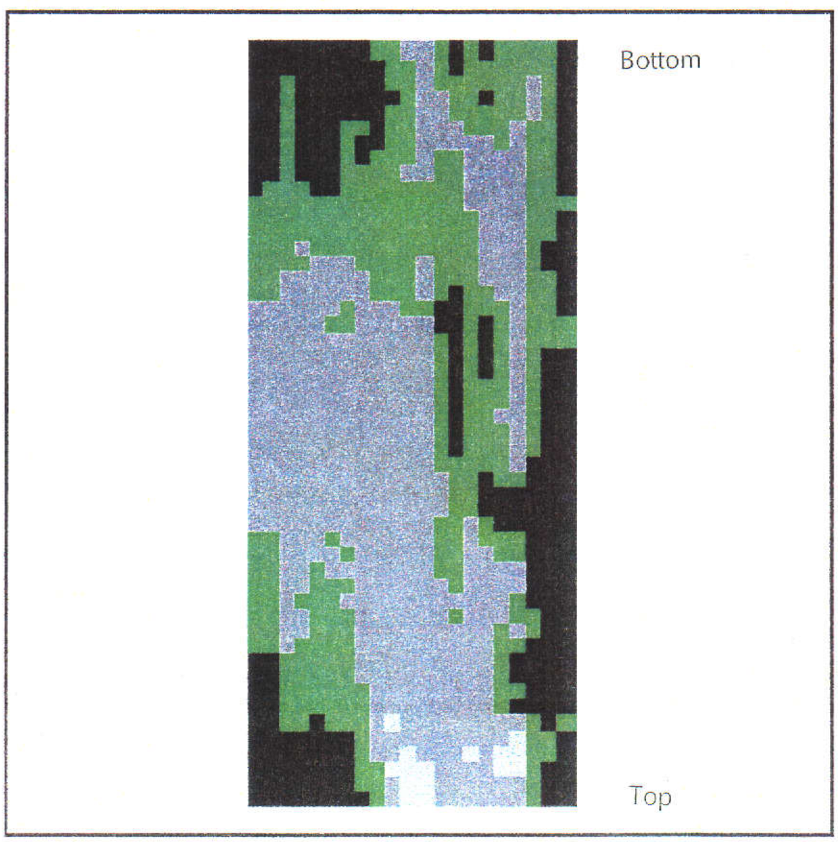
ECe(3.5)
dS/m

< 3
3 - 8
8 - 13
> 13

Data Bounds

X: min & max
642438.19
642724.78

Y: min & max
3635414.88
3636157.68



Field No. 5 - Avg. ECe in 4 ft. Profile

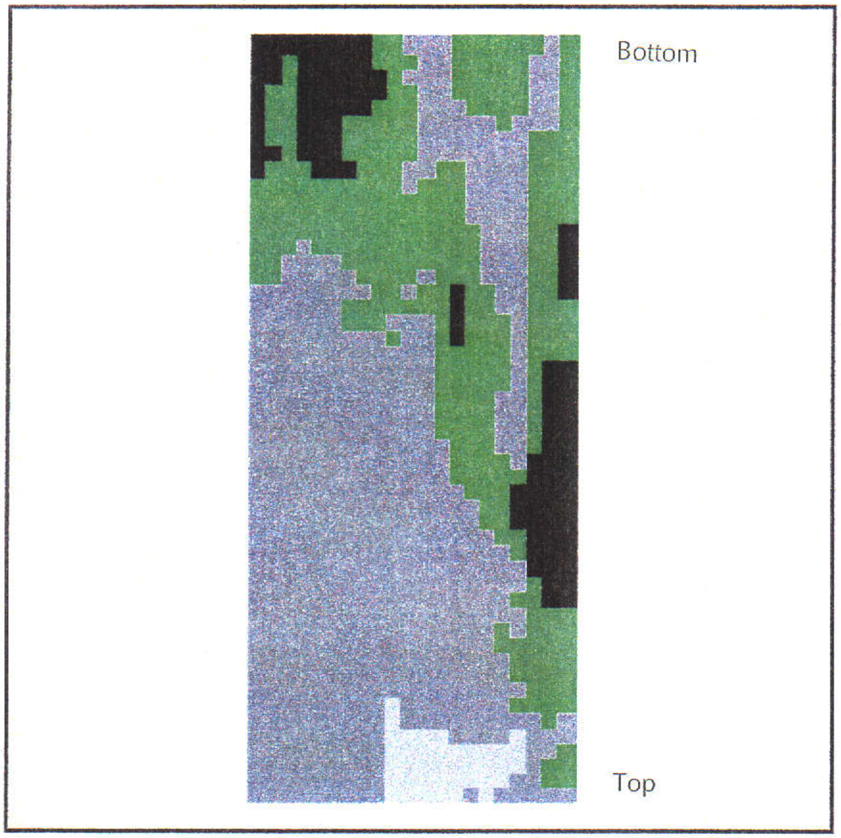
ECe(ave)
dS/m

- < 3
- 3 - 8
- 8 - 13
- > 13

Data Bounds

X: min & max
642438.19
642724.78

Y: min & max
3635414.88
3636157.68



Field No. 5 - 0 to 1 ft. (autoscale)

ECe(0.5)
dS/m

< 2.98

2.98 - 6.6

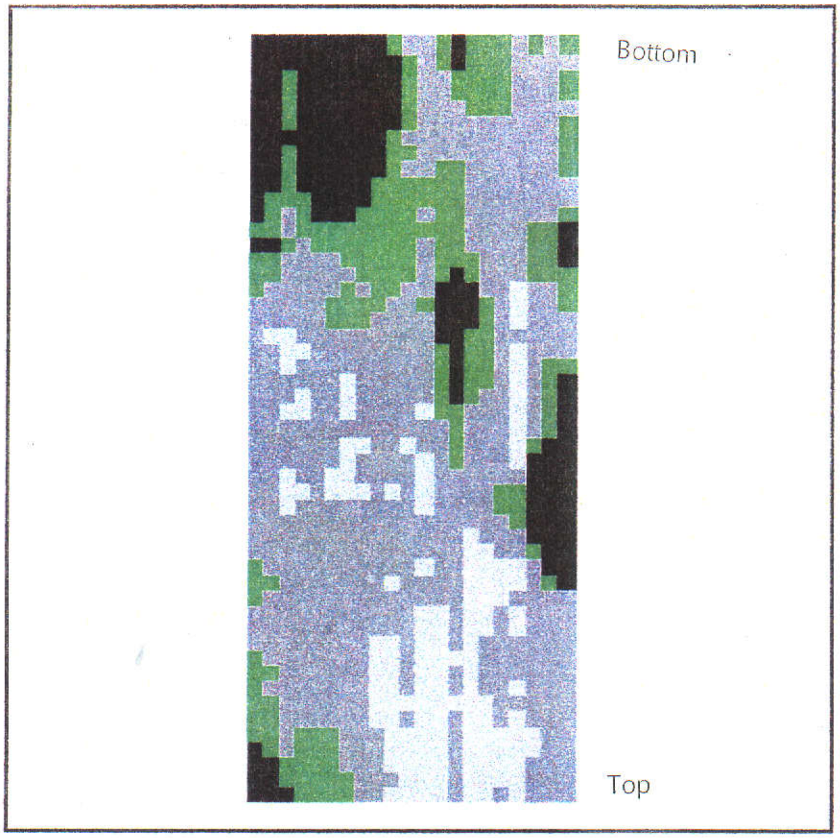
6.6 - 10.23

> 10.23

Data Bounds

X: min & max
642438.19
642724.78

Y: min & max
3635414.88
3636157.68



1 to 2 ft. (autoscale)

ECe(1.5)
dS/m

< 3.28

3.28 - 7.67

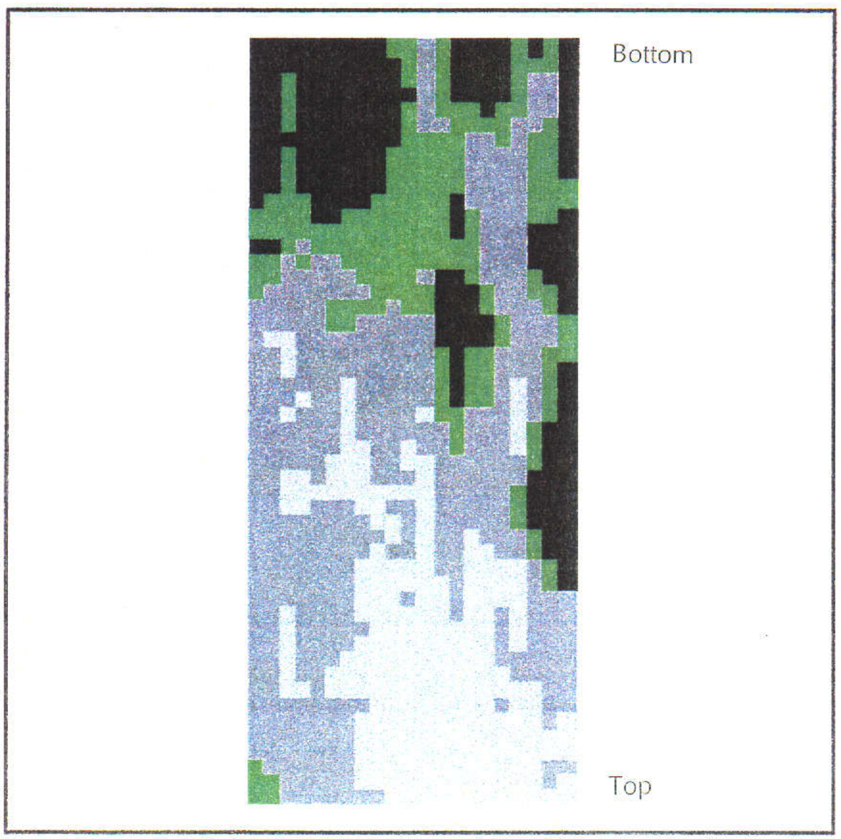
7.67 - 12.05

> 12.05

Data Bounds

X: min & max
642438.19
642724.78

Y: min & max
3635414.88
3636157.68



Field No. 5 - 2 to 3 ft. (autoscale)

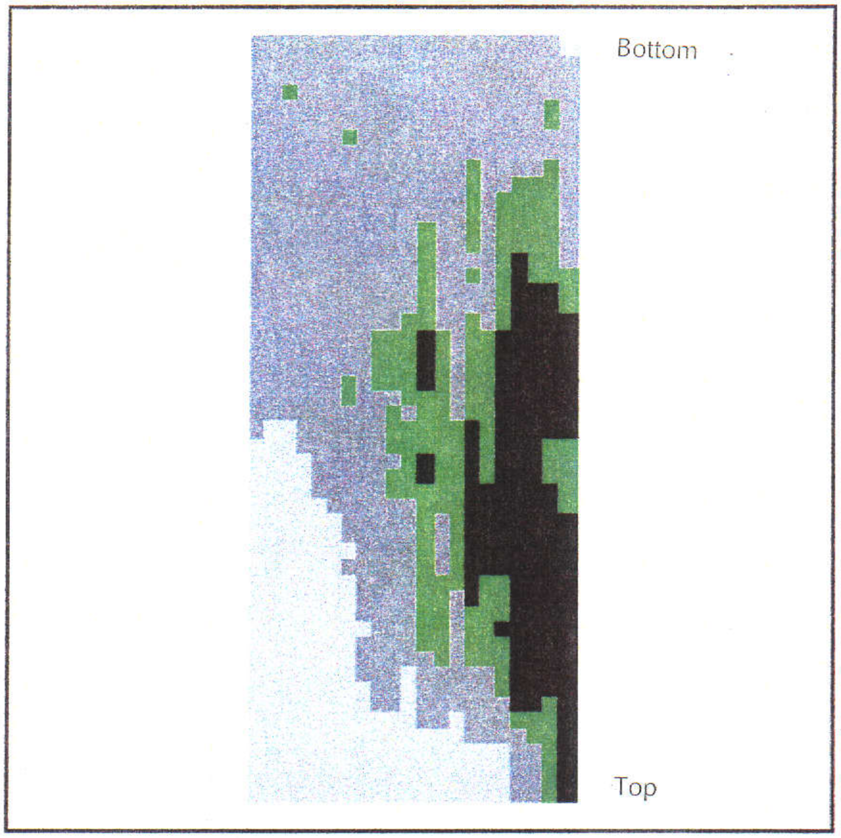
ECe(2.5)
dS/m

< 4.24
4.24 - 12.57
12.57 - 20.89
> 20.89

Data Bounds

X: min & max
642438.19
642724.78

Y: min & max
3635414.88
3636157.68



3 to 4 ft. (autoscale)

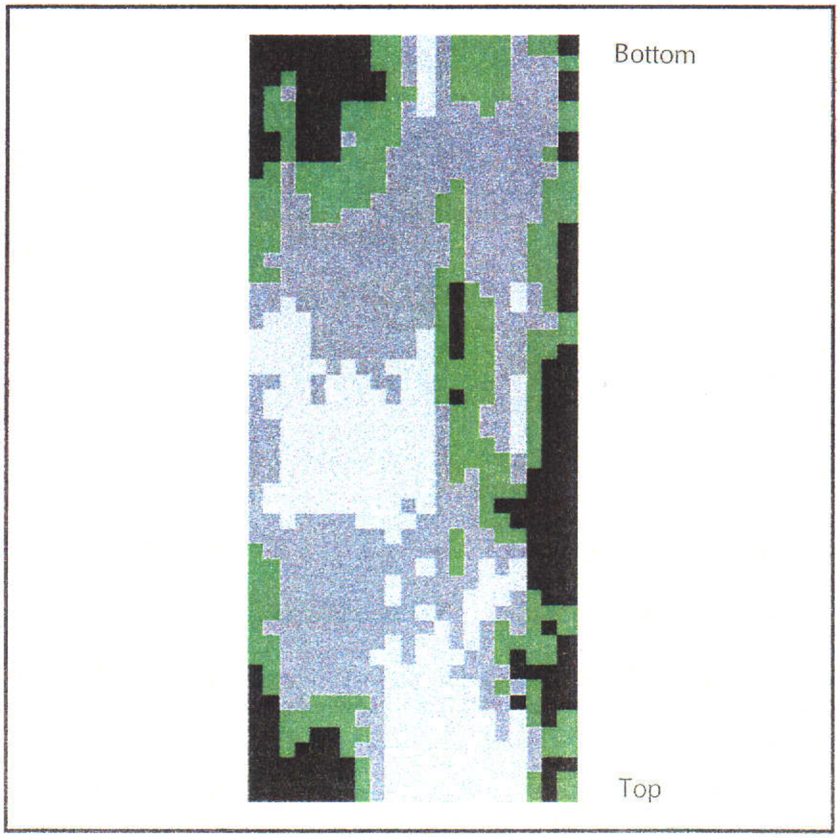
ECe(3.5)
dS/m

< 5.95
5.95 - 10.38
10.38 - 14.82
> 14.82

Data Bounds

X: min & max
642438.19
642724.78

Y: min & max
3635414.88
3636157.68



Field No. 5 - Avg. ECe in 4 ft. Profile (autoscale)

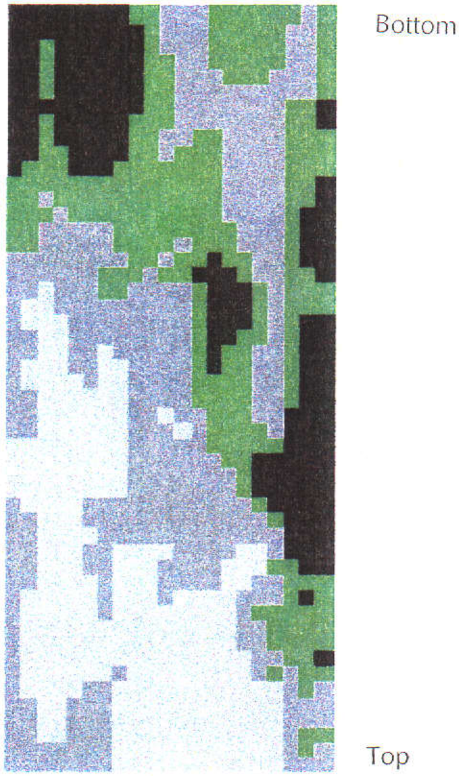
ECe(ave)
dS/m

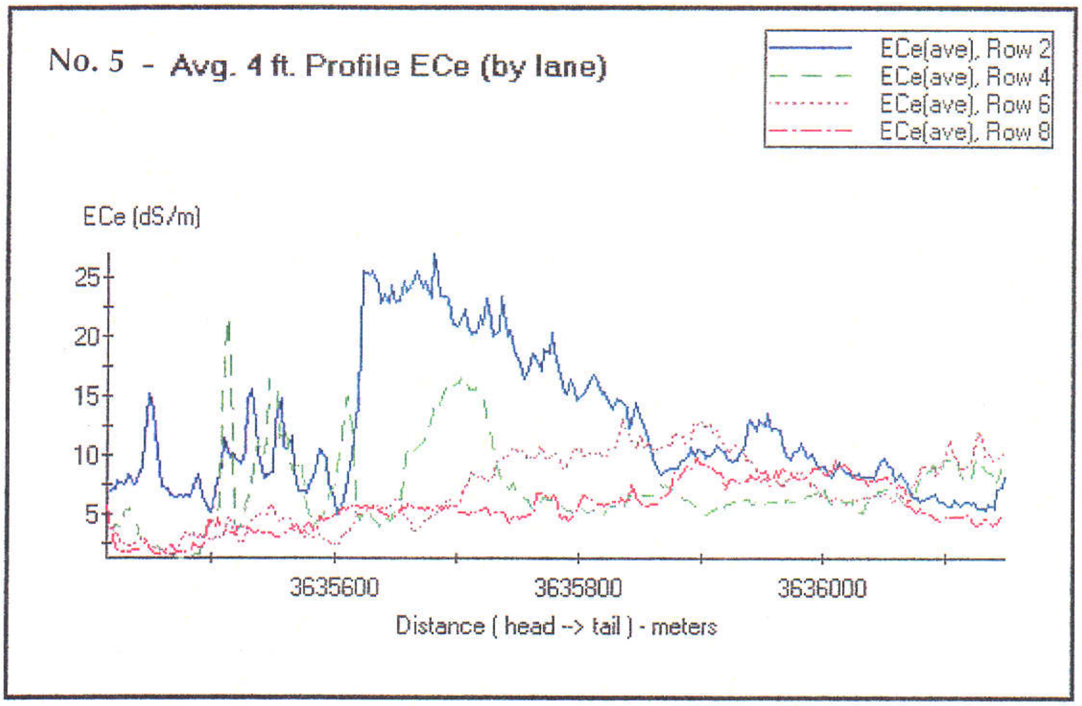
- < 4.91
- 4.91 - 8.14
- 8.14 - 11.38
- > 11.38

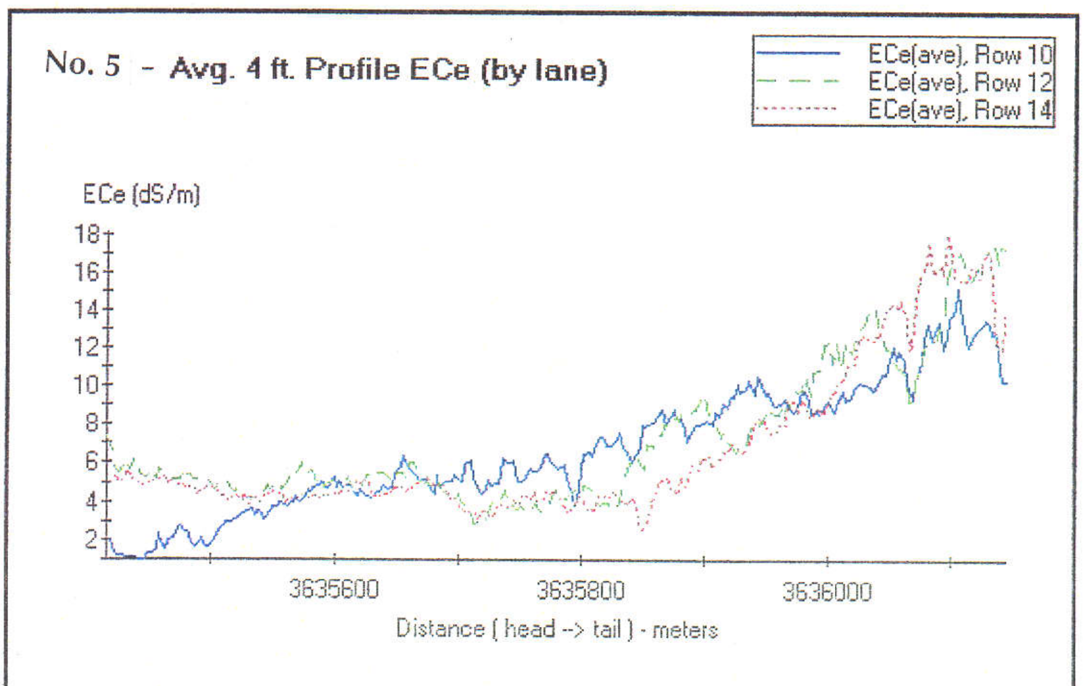
Data Bounds

X: min & max
642438.19
642724.78

Y: min & max
3635414.88
3636157.68




No. 5 - Avg. 4 ft. Profile ECe (by lane)
ECe(ave), Row 2
ECe(ave), Row 4
ECe(ave), Row 6
ECe(ave), Row 8
ECe (dS/m)
25
20
15
10
5
3635600
3635800
3636000
Distance (head --> tail) - meters


No. 5 - Avg. 4 ft. Profile ECe (by lane)
ECe(ave), Row 10
ECe(ave), Row 12
ECe(ave), Row 14
ECe (dS/m)
18
16
14
12
10
8
6
4
2
3635600
3635800
3636000
Distance (head --> tail) - meters

Field No. 6

Field Irrigation Evaluation

Data Summary

FIELD IRRIGATION EVALUATION FOR
IMPERIAL IRRIGATION DISTRICT
IMPERIAL VALLEY, CALIFORNIA.
FIELD NO. 6

FIELD DATA

Irrigated Acreage: 76 acres (ac)
Border Length: 2450 feet (ft)
Border Width: 130 ft
Border Slope: Average, 0.002533 ft/ft

CROP DATA

Crop: Sudan Grass, planted in February 2000 following Carrots.
Crop Growth Stage: 34 inches (in) in height
Crop Condition: Good

SOILS DATA

Soil Texture: Holtville silty clay (40%); Imperial silty clay (40%); Meloland very fine sandy loam (20%).
Soil Depth: > 4ft
Soil Uniformity: Average to good
Effective Crop Rooting Depth: 4 ft
Available Water Capacity: 0.17 – 0.35 in/in.
Estimated Allowable Depletion: Not determined.

SOIL CONDITION

Estimated Soil Water Deficit at Beginning of Irrigation:
Average: 4.20 in.
Estimated Irrigation Water Stored in Root Zone:
Average: 4.15 in.

IRRIGATION DATA

Irrigation Method: Borders with gated outlets from concrete-lined head ditch.
Field and Soil Condition: There is a lot of variability in the field soils. Previous irrigation on June 30, 2000.

Beginning Irrigation Time: July 13, 2000, 8:30 a.m.
Ending Irrigation Time: July 15, 2000, 8:30 a.m
Beginning Outflow Time: July 13, about 4 p.m.
Ending Outflow Time: July 15, about 3 p.m.
Average Inflow: 8.3 cubic feet per second (cfs)
Average Outflow: 0.97 cfs.
Data logger was not installed at beginning of irrigation

Number of Sets: 5
Set Time: 4.5 hours.
Advance Time: 6.8 to 7.4 hours
Uniformity of Advance: Near constant rate of advance. Quite uniform
Number of Borders per Set: 1 or 2

Irrigation Observations: Water did not make it to the bottom of a few borders.
Uniformity: Below average.
Ponding: At the bottom of the field, near the tailwater box.
Erosion: None
Estimated Irrigation Efficiency: 88 %.

Irrigation Summary		
	Average Depth[1], in	Percent of Applied Water, %
Total Water Applied	5.20	
Total Water Stored in Root Zone	4.15	79
Total Runoff	0.60	12
Total Deep Percolation	0.45	9

[1]Depth based on field irrigated acreage.

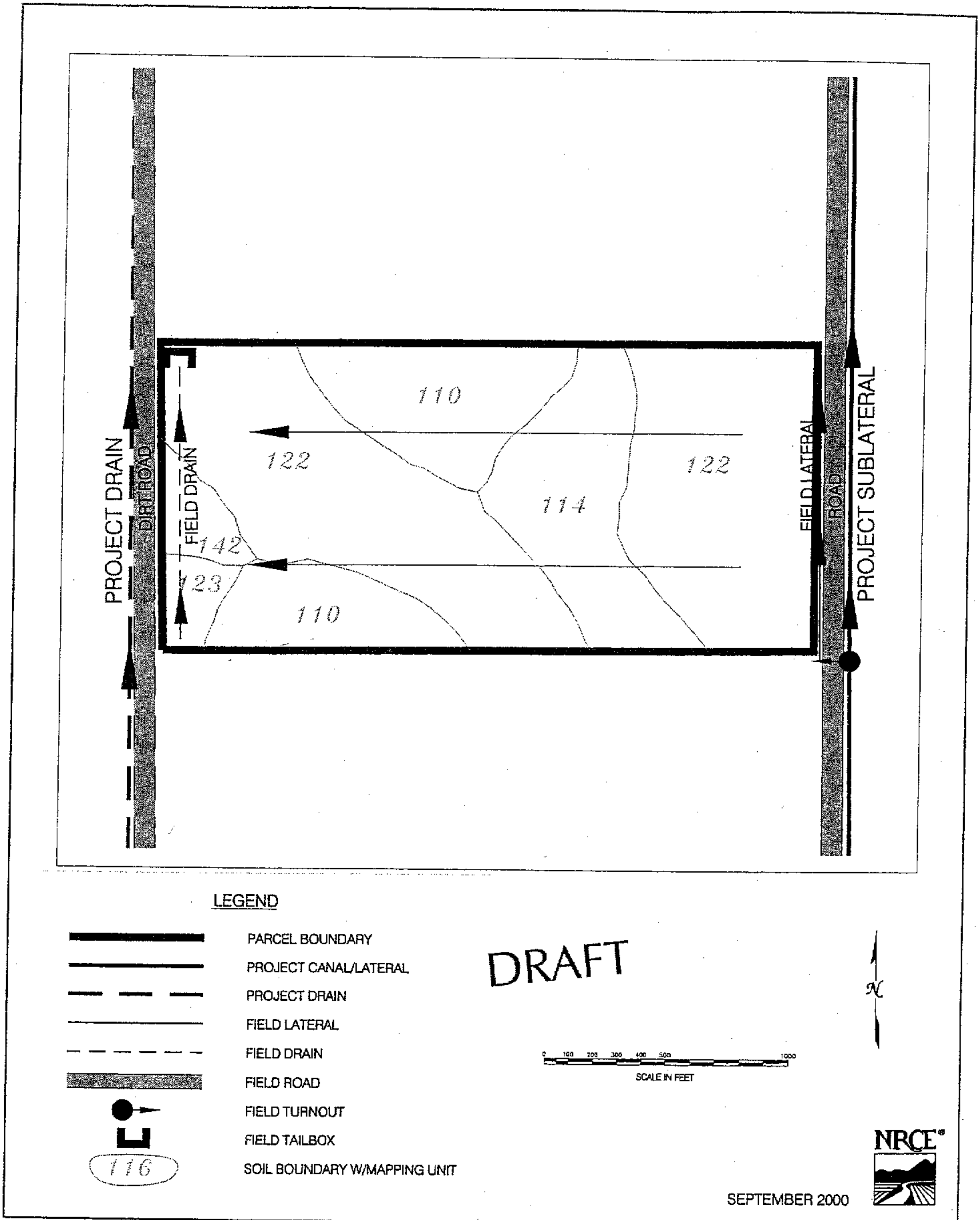
Field No.6 - Irrigation and Cropping History

Cropped Area: **76 ac**

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Alfalfa, flat	1/11/97		12	11.9	11.9	3.73	3.73
Alfalfa, flat	2/8/97	28	10	9.7	9.7	3.04	3.04
Alfalfa, flat	2/25/97	17	11	10.9	10.9	3.41	3.41
Alfalfa, flat	3/22/97	25	12	11.8	11.8	3.70	3.70
Alfalfa, flat	4/2/97	11	11	9.7	9.7	3.04	3.04
Alfalfa, flat	4/20/97	18	12	11.2	11.2	3.51	3.51
Alfalfa, flat	4/30/97	10	12	11.9	11.9	3.73	3.73
Alfalfa, flat	5/17/97	17	6	6.1	6.1	1.91	1.91
Alfalfa, flat	5/28/97	11	12	11.2	11.2	3.51	
Alfalfa, flat	5/29/97	1	12	12.8	12.8	4.01	7.52
Alfalfa, flat	6/16/97	18	13	11.9	11.9	3.73	3.73
Alfalfa, seed	7/20/97	34	13	12.9	12.9	4.04	4.04
Alfalfa, flat	10/31/97	103	13	14.8	14.8	4.64	4.64
Alfalfa, flat	11/20/97	20	10	10	10	3.13	3.13
Alfalfa, flat	1/17/98	58	10	11.5	11.5	3.60	3.60
Alfalfa, flat	2/14/98	28	11	10.6	10.6	3.32	3.32
Alfalfa, flat	3/15/98	29	12	11.9	11.9	3.73	3.73
Alfalfa, flat	3/26/98	11	12	12.2	12.2	3.82	3.82
Alfalfa, flat	4/19/98	24	12	11.8	11.8	3.70	
Alfalfa, flat	4/20/98	1	5	5	5	1.57	5.26
Alfalfa, flat	4/29/98	9	12	12.2	12.2	3.82	3.82
Alfalfa, flat	5/9/98	10	12	11.9	11.9	3.73	3.73
Alfalfa, flat	5/27/98	18	14	14	14	4.38	
Alfalfa, flat	5/28/98	1	5	5.1	5.1	1.60	5.98
Alfalfa, flat	6/15/98	18	13	13.1	13.1	4.10	4.10
Alfalfa, flat	7/4/98	19	8	6.5	8	2.51	2.51
Alfalfa, seed	7/19/98	15	14	12.9	12.9	4.04	
Alfalfa, seed	7/20/98	1	1.5	1.8	1.8	0.56	4.60
Flooding, Flat	9/4/98	46	12	12.2	12.2	3.82	
Flooding, Flat	9/5/98	1	12	12.2	12.2	3.82	
Flooding, Flat	9/6/98	1	12	12.2	12.2	3.82	**11.46**
Carrots	10/11/98	35	5	4.6	4.6	1.44	
Carrots	10/12/98	1	5	3.9	5	1.57	
Carrots	10/13/98	1	5	4.5	5	1.57	4.57
Carrots	10/15/98	2	5	5.1	5.1	1.60	1.60
Carrots	10/17/98	2	5	2.5	2.5	0.78	0.78
Carrots	10/19/98	2	5	1.7	2.5	0.78	0.78
Carrots	10/21/98	2	5	2.1	2.5	0.78	0.78
Carrots	10/23/98	2	5	1.3	2.5	0.78	0.78
Carrots	11/9/98	17	7	7	7	2.19	
Carrots	11/10/98	1	7	7.3	7.3	2.29	
Carrots	11/11/98	1	7	6.9	6.9	2.16	6.64
Carrots	12/17/98	36	7	7	7	2.19	

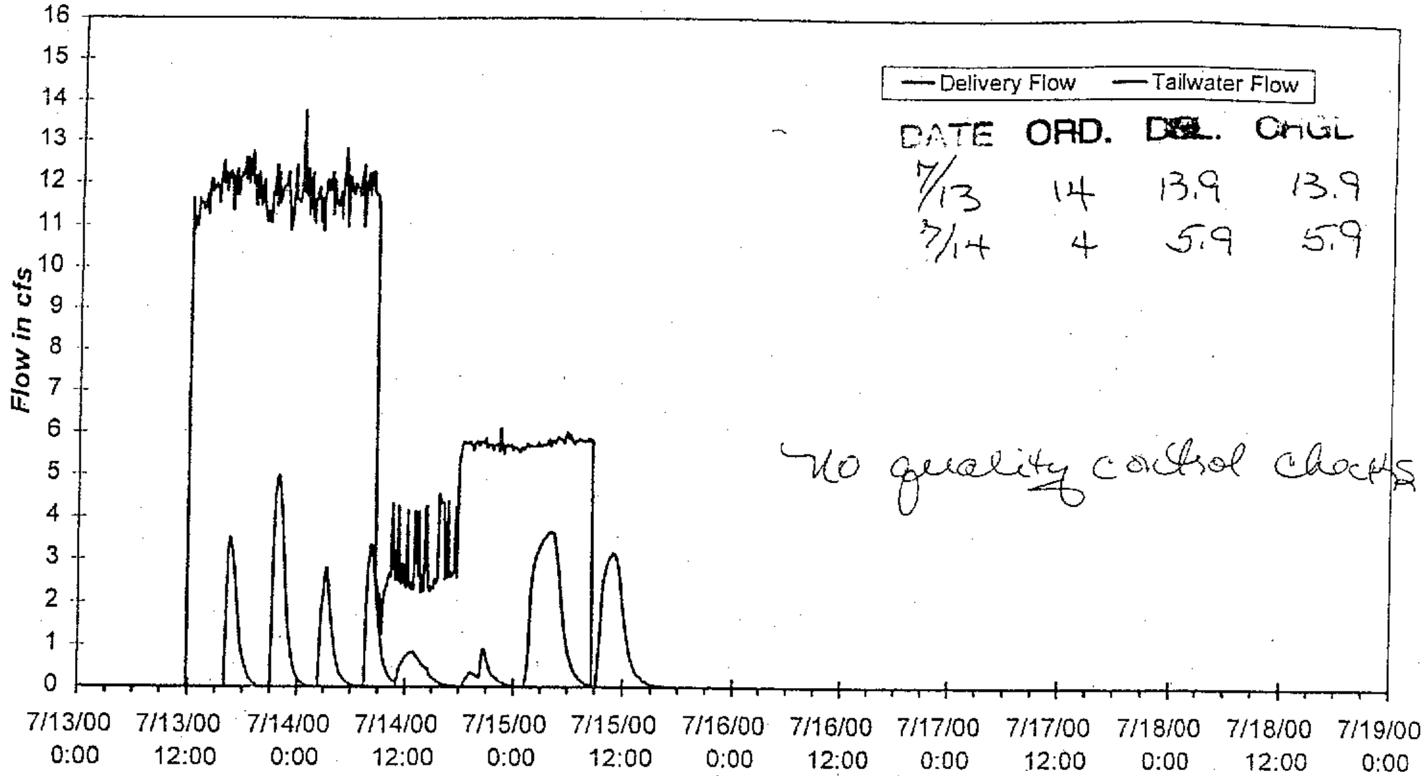
Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Carrots	12/18/98	1	7	7.1	7.1	2.22	4.42
Carrots	1/15/99	28	6	6.3	6.3	1.97	
Carrots	1/16/99	1	6	6	6	1.88	3.85
Carrots	2/11/99	26	5	5.1	5.1	1.60	
Carrots	2/12/99	1	5	4.9	4.9	1.53	3.13
Sudan Grass	3/26/99	42	12	10.5	10.5	3.29	
Sudan Grass	3/27/99	1	12	12.4	12.4	3.88	7.17
Sudan Grass	4/18/99	22	12	12.1	12.1	3.79	3.79
Sudan Grass	5/2/99	14	8	9.6	9.6	3.01	
Sudan Grass	5/3/99	1	12	11.9	11.9	3.73	6.73
Sudan Grass	5/17/99	14	5	3.3	3.3	1.03	
Sudan Grass	5/18/99	1	12	12.1	12.1	3.79	
Sudan Grass	5/19/99	1	2	0.9	0.9	0.28	5.10
Sudan Grass	6/9/99	21	12	11.9	11.9	3.73	
Sudan Grass	6/10/99	1	12	12.2	12.2	3.82	7.55
Sudan Grass	6/20/99	10	14	13.9	13.9	4.35	4.35
Flooding, Flat	8/6/99	47	12	12.3	12.3	3.85	
Flooding, Flat	8/7/99	1	12	10.9	10.9	3.41	
Flooding, Flat	8/8/99	1	12	4.4	12	3.76	**11.02**
Idle	10/17/99	70	5	4.5	5	1.57	
Carrots	10/18/99	1	5	4.2	5	1.57	
Carrots	10/19/99	1	5	4	5	1.57	4.70
Carrots	10/21/99	2	5	1.9	2.5	0.78	0.78
Carrots	10/23/99	2	5	2.1	2.5	0.78	0.78
Carrots	10/25/99	2	5	1.9	1.9	0.60	0.60
Carrots	10/27/99	2	5	1.9	1.9	0.60	0.60
Carrots	11/11/99	15	7	7	7	2.19	2.19
Carrots	11/12/99	1	7	7	7	2.19	2.19
Carrots	11/13/99	1	7	7	7	2.19	2.19
Carrots	11/14/99	1	5	5.1	5.1	1.60	1.60
Carrots	1/2/00	49	7	7	7	2.19	
Carrots	1/3/00	1	7	7	7	2.19	
Carrots	1/4/00	1	7	7	7	2.19	6.58
Sudan Grass	2/13/00	40	6	5.9	5.9	1.85	
Sudan Grass	2/14/00	1	6	5.9	5.9	1.85	
Sudan Grass	2/15/00	1	5	4.9	4.9	1.53	5.23
Sudan Grass	3/3/00	17	6	5.9	5.9	1.85	
Sudan Grass	3/4/00	1	7	6.9	6.9	2.16	
Sudan Grass	3/5/00	1	5	1	2.5	0.78	4.79
Sudan Grass	3/21/00	16	6	6.1	6	1.88	
Sudan Grass	3/22/00	1	7	7.4	7.4	2.32	4.20
Sudan Grass	4/5/00	14	7	7	7	2.19	
Sudan Grass	4/6/00	1	7	7	7	2.19	
Sudan Grass	4/7/00	1	5	5	5	1.57	5.95
Sudan Grass	4/24/00	17	13	13.1	13.1	4.10	4.10
Sudan Grass	5/3/00	9	12	12	12	3.76	
Sudan Grass	5/4/00	1	12	6.2	6.2	1.94	5.70

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Sudan Grass	5/18/00	14	14	15	15	4.70	4.70
Sudan Grass	5/29/00	11	14	13.9	13.9	4.35	4.35
Sudan Grass	6/8/00	10	4	10.5	10.5	3.29	
Sudan Grass	6/9/00	1	10	10.2	14	4.38	7.67
Sudan Grass	6/29/00	20	15	16.1	16.1	5.04	
Sudan Grass	6/30/00	1	5	6	6	1.88	6.92
Sudan Grass	7/13/00	13	14	13.9	13.9	4.35	
Sudan Grass	7/14/00	1	4	5.9	5.9	1.85	6.20
Sudan Grass	7/23/00	9	14	14	14	4.38	

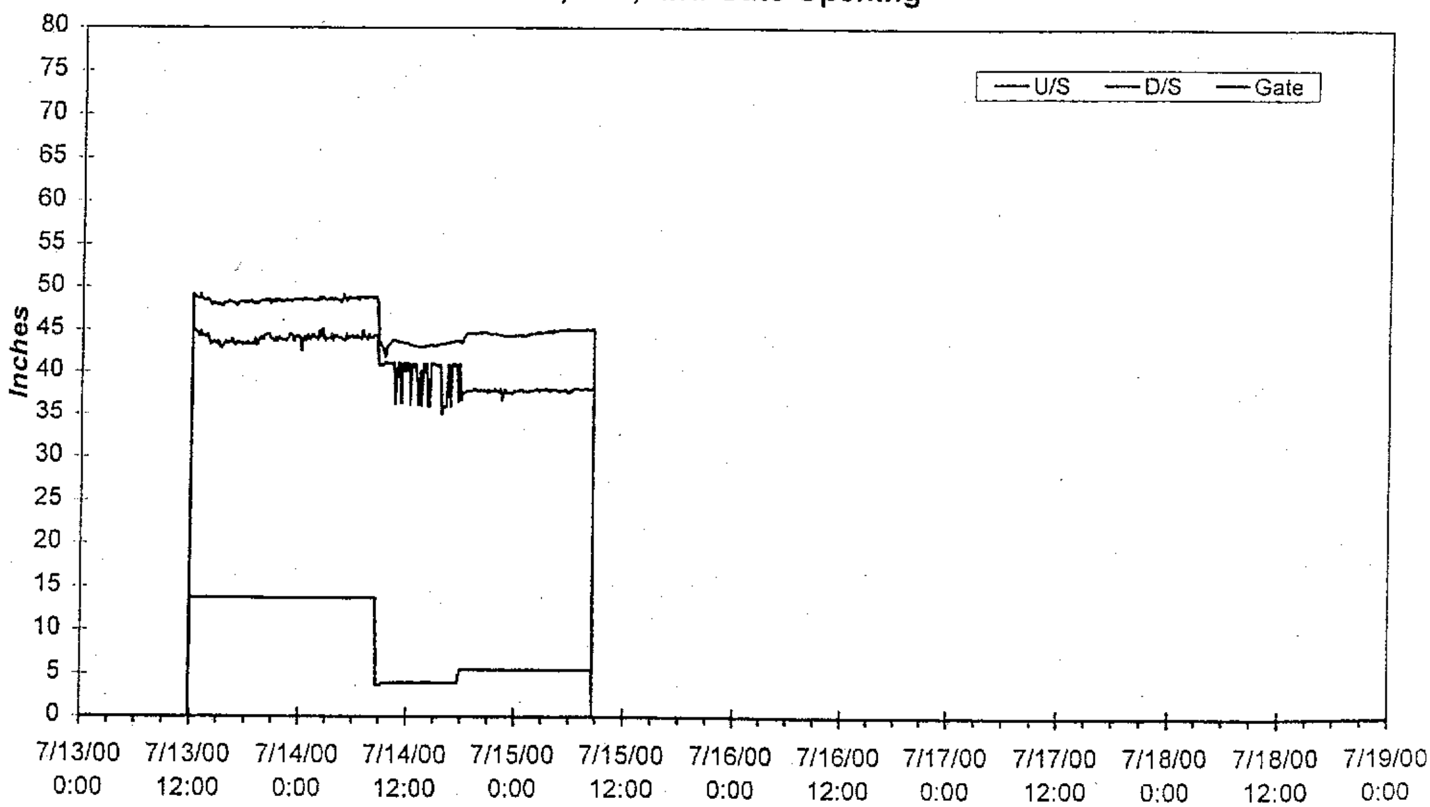


Field No. 6 Layout

Delivery and Tailwater Flow for Parcel No.6



U/S, D/S, and Gate Opening



Order = **1d-14', 1d-4'** Delivery Volume (AF) = **29.4** % Tailwater= **13%** Acres = **76**
Soil Type = **0** Tailwater Volume (AF)= **3.8** Crop = **Sudangrass** Inches Applied= **4.6**

Field No. 6 - 0 to 1 ft.

ECe(0.5)
dS/m

< 2

2 - 4

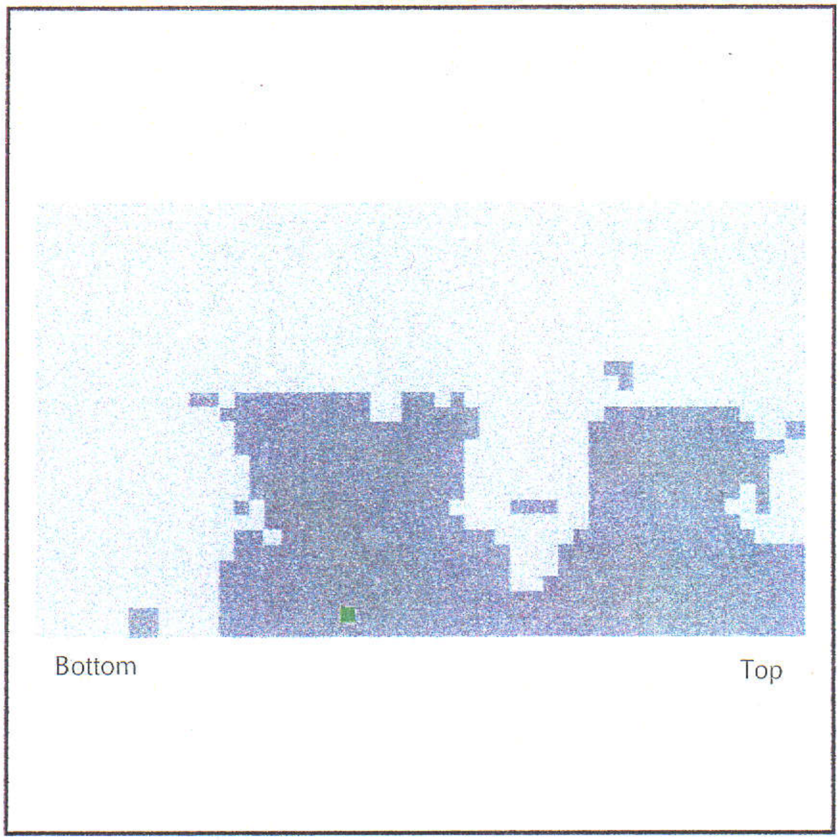
4 - 6

> 6

Data Bounds

X: min & max
642124.5
642870.35

Y: min & max
3628899.86
3629263.81



1 to 2 ft.

ECe(1.5)
dS/m

< 2

2 - 4

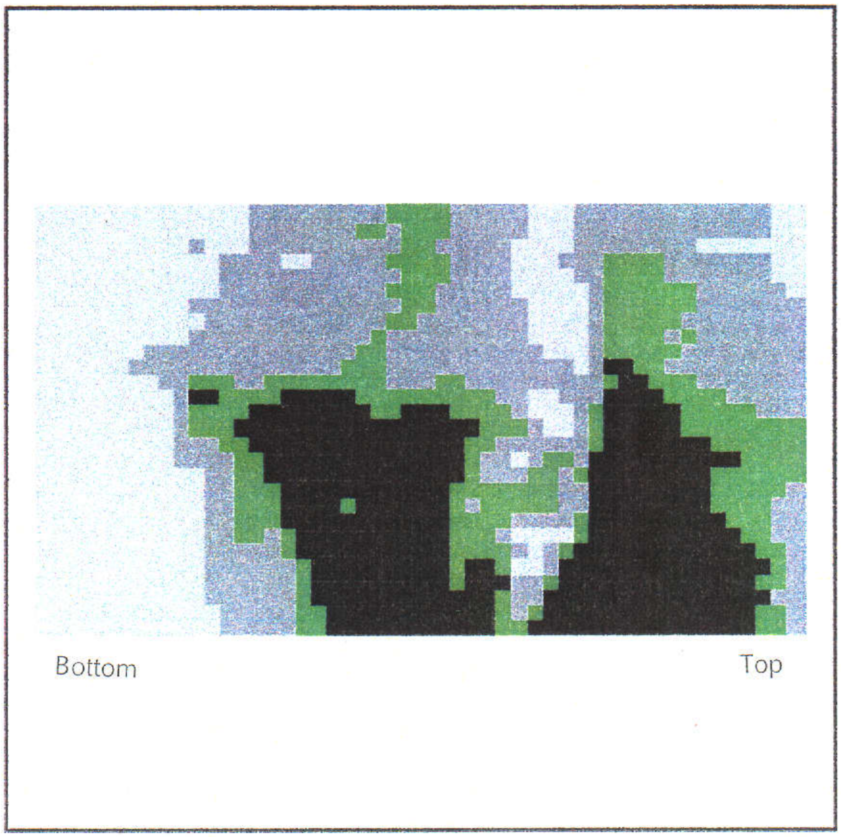
4 - 6

> 6

Data Bounds

X: min & max
642124.5
642870.35

Y: min & max
3628899.86
3629263.81



Field No. 6 – 2 to 3 ft.

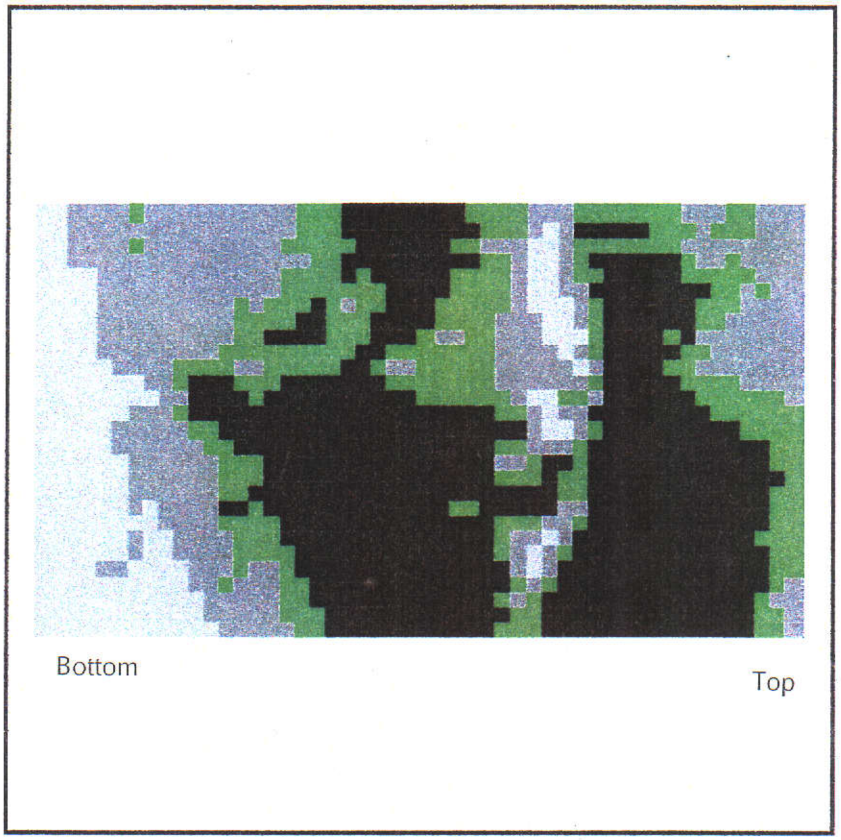
ECe(2.5)
dS/m

- < 2
- 2 - 4
- 4 - 6
- > 6

Data Bounds

X: min & max
642124.5
642870.35

Y: min & max
3628899.86
3629263.81



3 to 4 ft.

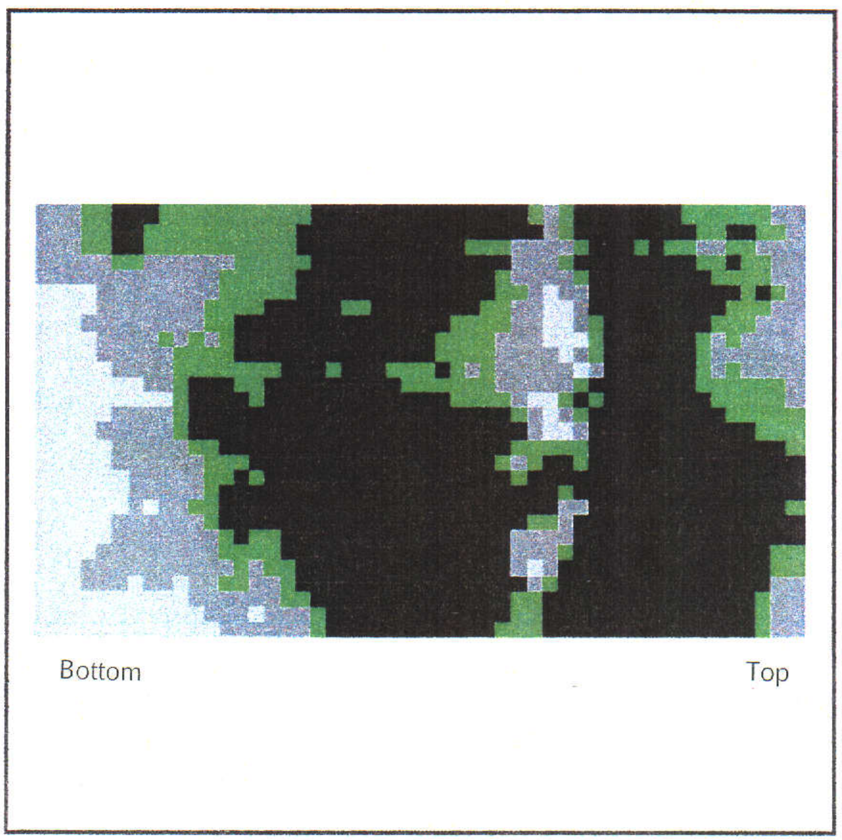
ECe(3.5)
dS/m

- < 2
- 2 - 4
- 4 - 6
- > 6

Data Bounds

X: min & max
642124.5
642870.35

Y: min & max
3628899.86
3629263.81



Field No. 6 - Avg. EC in 4 ft. Profile

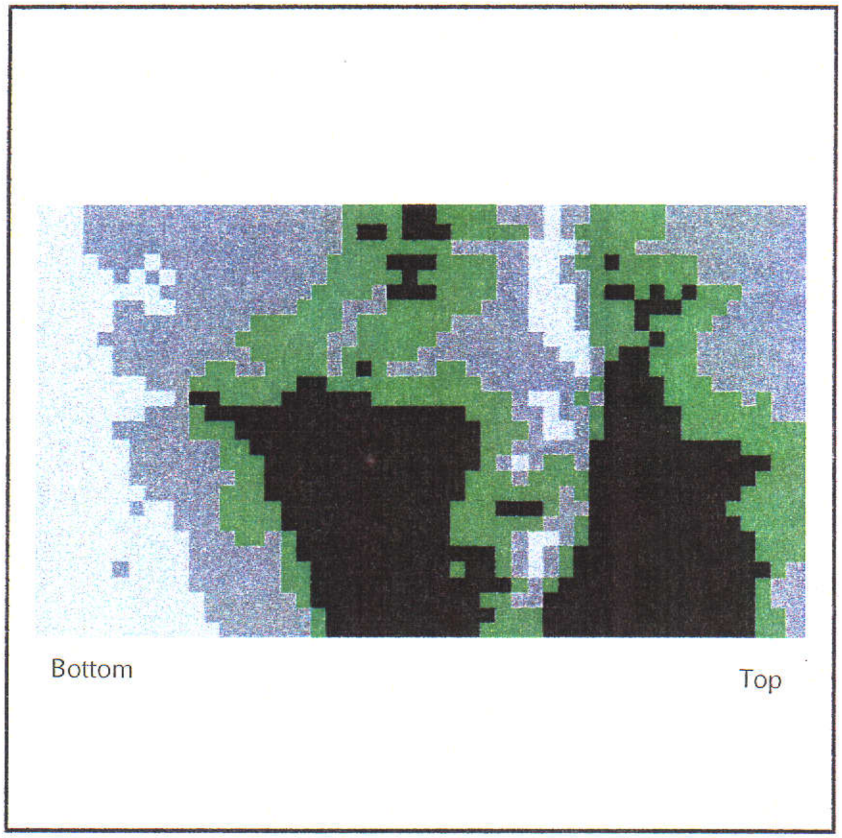
ECe(ave)
dS/m

- < 2
- 2 - 4
- 4 - 6
- > 6

Data Bounds

X: min & max
642124.5
642870.35

Y: min & max
3628899.86
3629263.81



Field No. 6 - 0 to 1 ft. (autoscale)

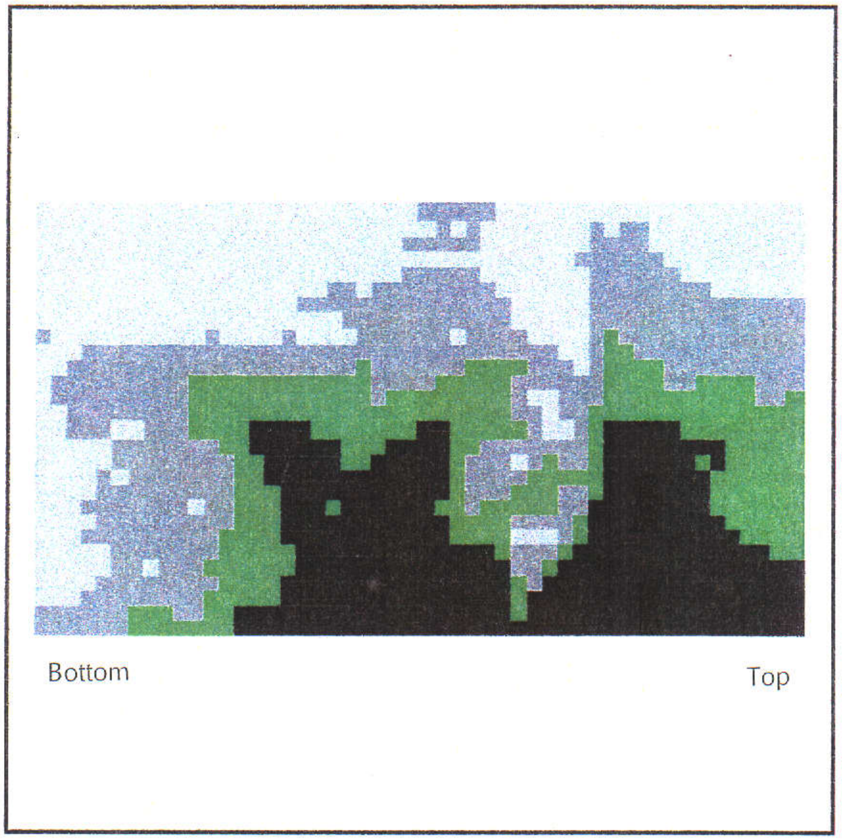
ECe(0.5)
dS/m

- < 1.187
- 1.187 - 1.742
- 1.742 - 2.298
- > 2.298

Data Bounds

X: min & max
642124.5
642870.35

Y: min & max
3628899.86
3629263.81



1 to 2 ft. (autoscale)

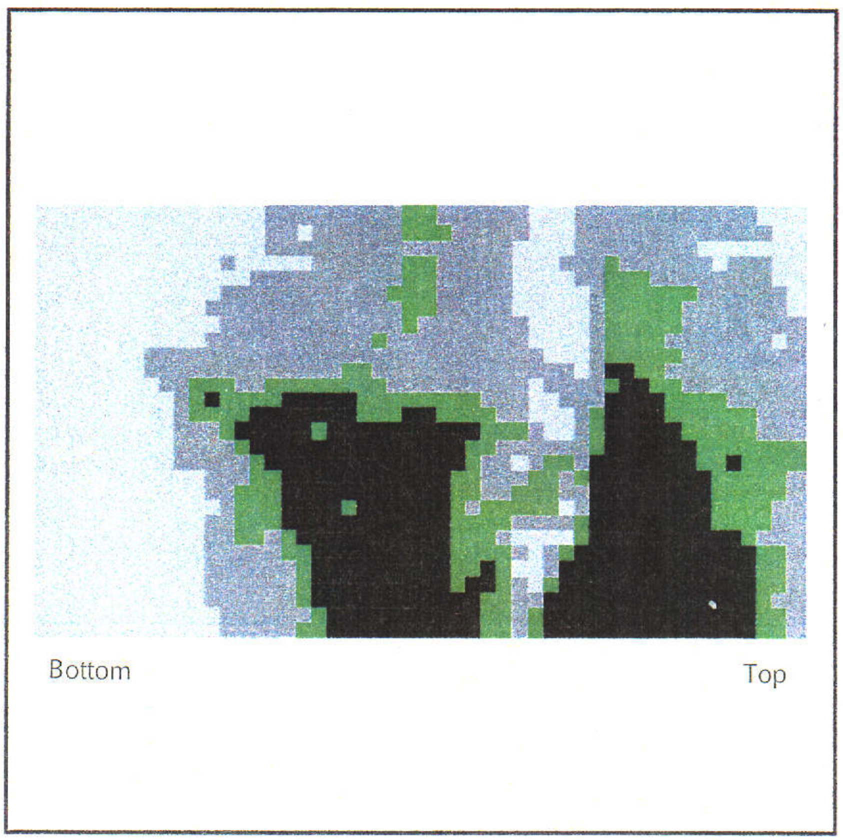
ECe(1.5)
dS/m

- < 2.105
- 2.105 - 4.175
- 4.175 - 6.244
- > 6.244

Data Bounds

X: min & max
642124.5
642870.35

Y: min & max
3628899.86
3629263.81



Field No. 6 - 2 to 3 ft. (autoscale)

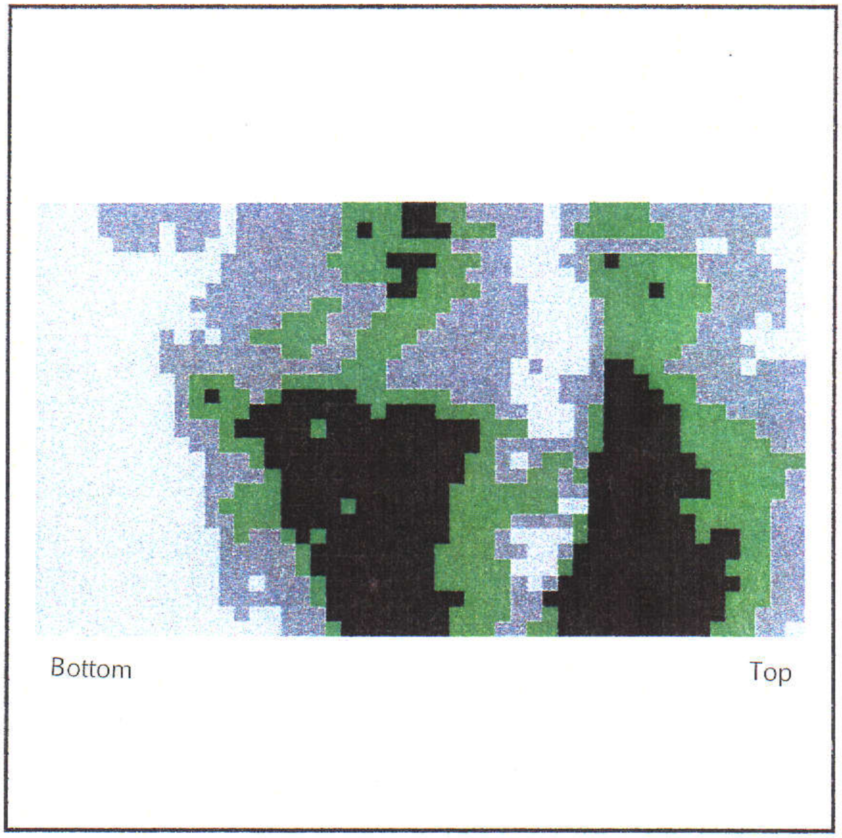
ECe(2.5)
dS/m

< 3.069
3.069 - 5.595
5.595 - 8.12
> 8.12

Data Bounds

X: min & max
642124.5
642870.35

Y: min & max
3628899.86
3629263.81



3 to 4 ft. (autoscale)

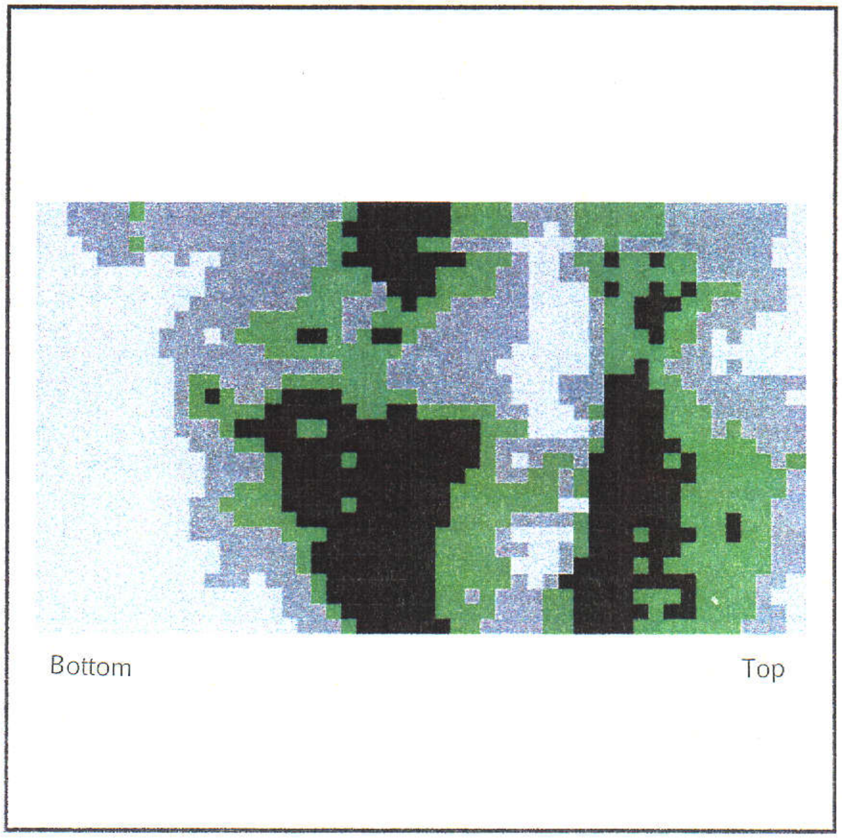
ECe(3.5)
dS/m

< 3.59
3.59 - 6.92
6.92 - 10.25
> 10.25

Data Bounds

X: min & max
642124.5
642870.35

Y: min & max
3628899.86
3629263.81



Field No. 6 - Avg. EC in 4 ft. Profile (autoscale)

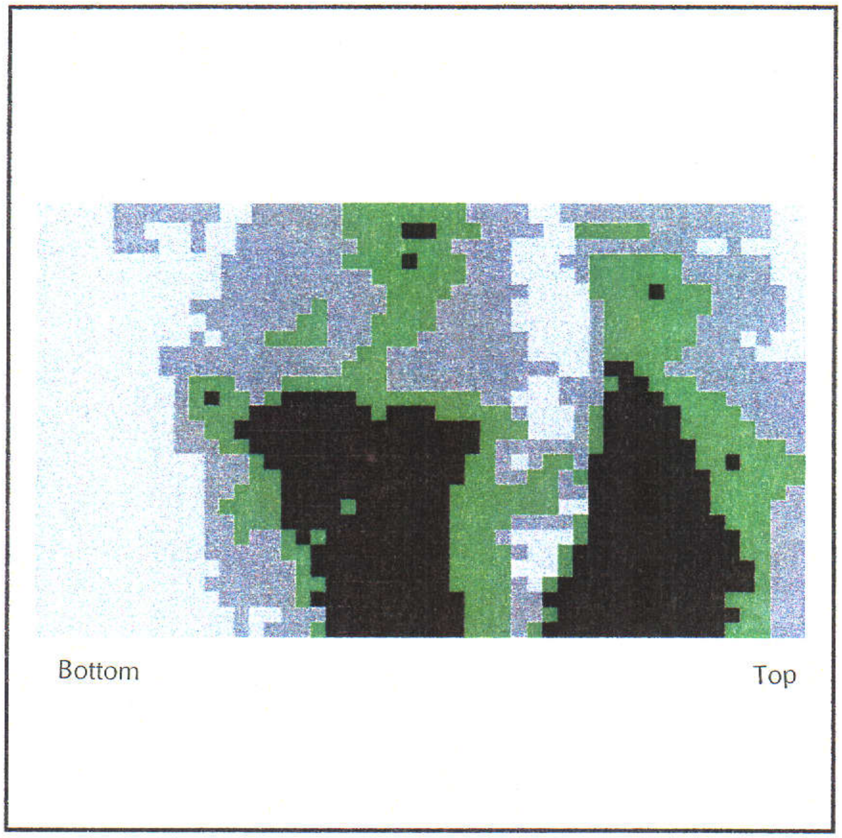
ECe(ave)
dS/m

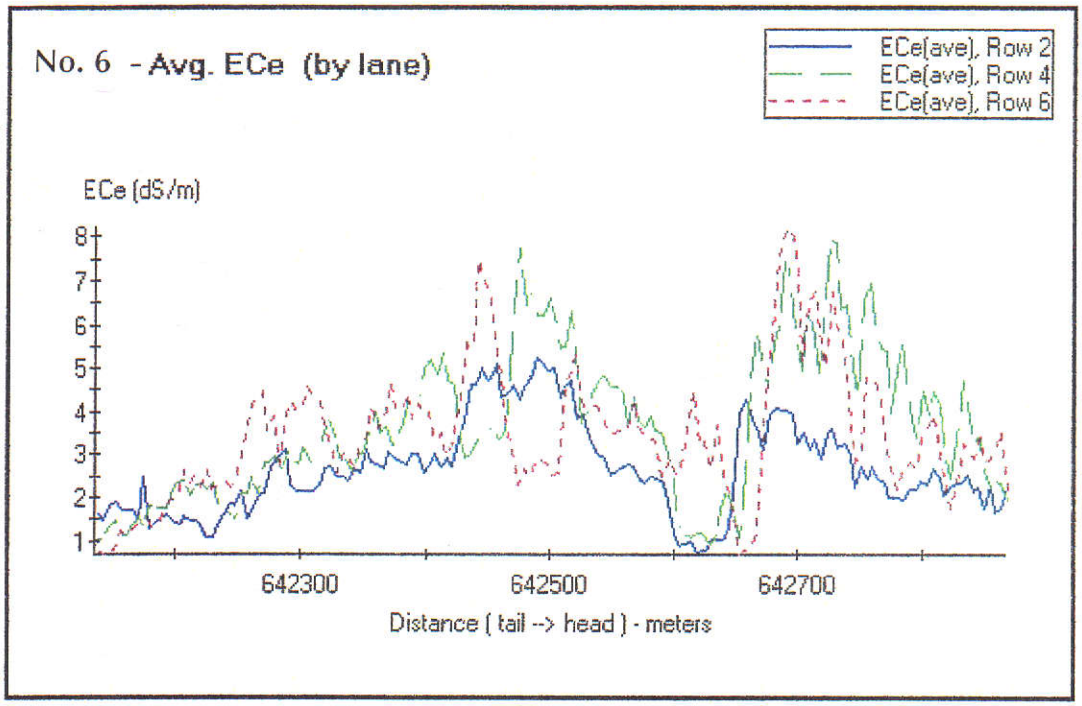
- < 2.715
- 2.715 - 4.714
- 4.714 - 6.714
- > 6.714

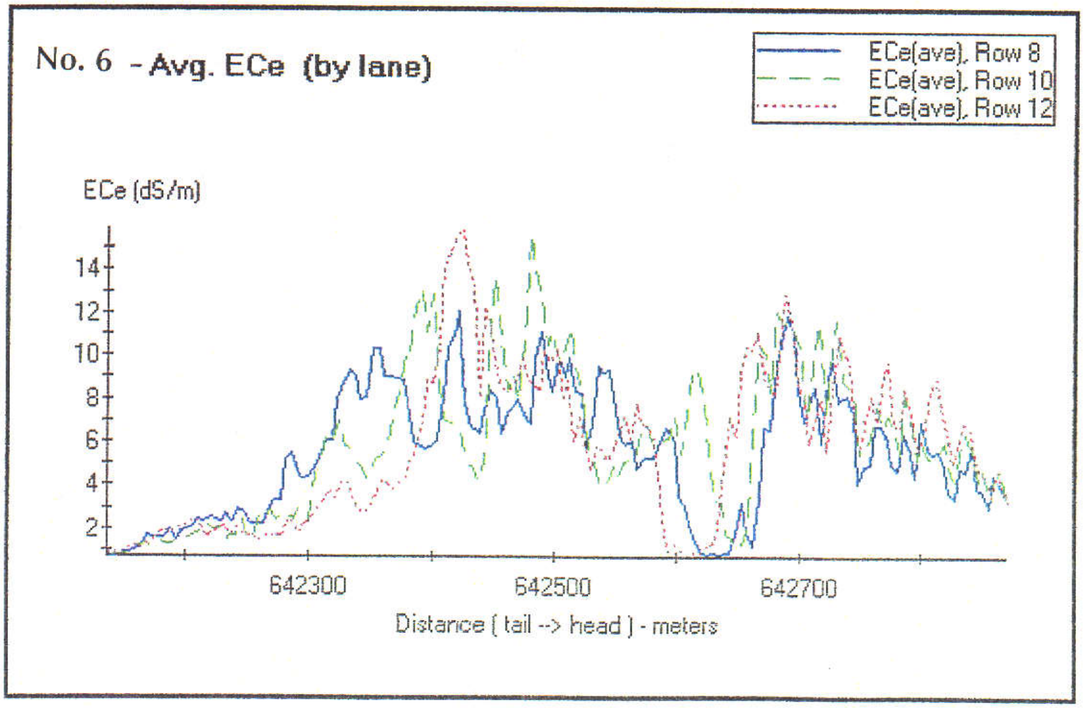
Data Bounds

X: min & max
642124.5
642870.35

Y: min & max
3628899.86
3629263.81




No. 6 - Avg. ECe (by lane)
ECe(ave), Row 2
ECe(ave), Row 4
ECe(ave), Row 6
ECe (dS/m)
8
7
6
5
4
3
2
1
642300
642500
642700
Distance (tail --> head) - meters


No. 6 - Avg. ECe (by lane)
ECe(ave), Row 8
ECe(ave), Row 10
ECe(ave), Row 12
ECe (dS/m)
14
12
10
8
6
4
2
642300
642500
642700
Distance (tail --> head) - meters

Field No. 7

Field Irrigation Evaluation

Data Summary

FIELD IRRIGATION EVALUATION FOR
IMPERIAL IRRIGATION DISTRICT
IMPERIAL VALLEY, CALIFORNIA.
FIELD NO. 7

FIELD DATA

Irrigated Acreage: 73 acres (ac)
Border Length: 2580 feet (ft)
Border Width: 120 ft
Border Slope: Average, 0.002683 ft/ft

CROP DATA

Crop: Third or forth year seed alfalfa crop, planted prior to January 1997.
Crop Growth Stage: 24 inches (in) in height with a heavy bloom.
Crop Condition: Good

SOILS DATA

Soil Texture: Imperial-Glenbar silty clay loam (80%); Holtville silty clay (20%).
Soil Depth: > 4ft
Soil Uniformity: Average to good
Effective Crop Rooting Depth: 4 ft
Available Water Capacity: 0.17 – 0.25 in/in.
Estimated Allowable Depletion: [ ] in

SOIL CONDITION

Estimated Soil Water Deficit at Beginning of Irrigation:
Average: 5.0 in.
Estimated Irrigation Water Stored in Root Zone:
Average: 4.85 in

IRRIGATION DATA

Irrigation Method: Borders with gated outlets from concrete-lined head ditch.
Field and Soil Condition: Significant cracking in soil. Soil was quite dry before the irrigation. Previous irrigation on July 2, 2000

Beginning Irrigation Time: July 14, 2000, 8:10 a.m.
Ending Irrigation Time: July 16, 2000, 8:10 a.m
Beginning Outflow Time: July 14, about 4 p.m.
Ending Outflow Time: July 16, about 8 a.m.
Average Inflow: 9.7 cubic feet per second (cfs)
Average Outflow: 2.45 cfs.
The data logger recorded inflow was split between two fields, but the data logger data for outflow is for the correct field.

Number of Sets: 4
Set Time: 9.0 to 14.0 hours.
Advance Time: 7.9 to 8.0 hours
Uniformity of Advance: Near constant rate of advance. Good.
Number of Borders per Set: Varied, 2 or 3.

Irrigation Observations:
Uniformity: The bottom of the field appeared to be under-irrigated, based on observed crop heights.
Ponding: Some at the bottom of the field, near the tailwater box..
Erosion: None
Estimated Irrigation Efficiency: 80 %.

Irrigation Summary		
	Average Depth[1], in	Percent of Applied Water, %
Total Water Applied	6.35	
Total Water Stored in Root Zone	4.85	76
Total Runoff	1.20	20
Total Deep Percolation	0.30	4

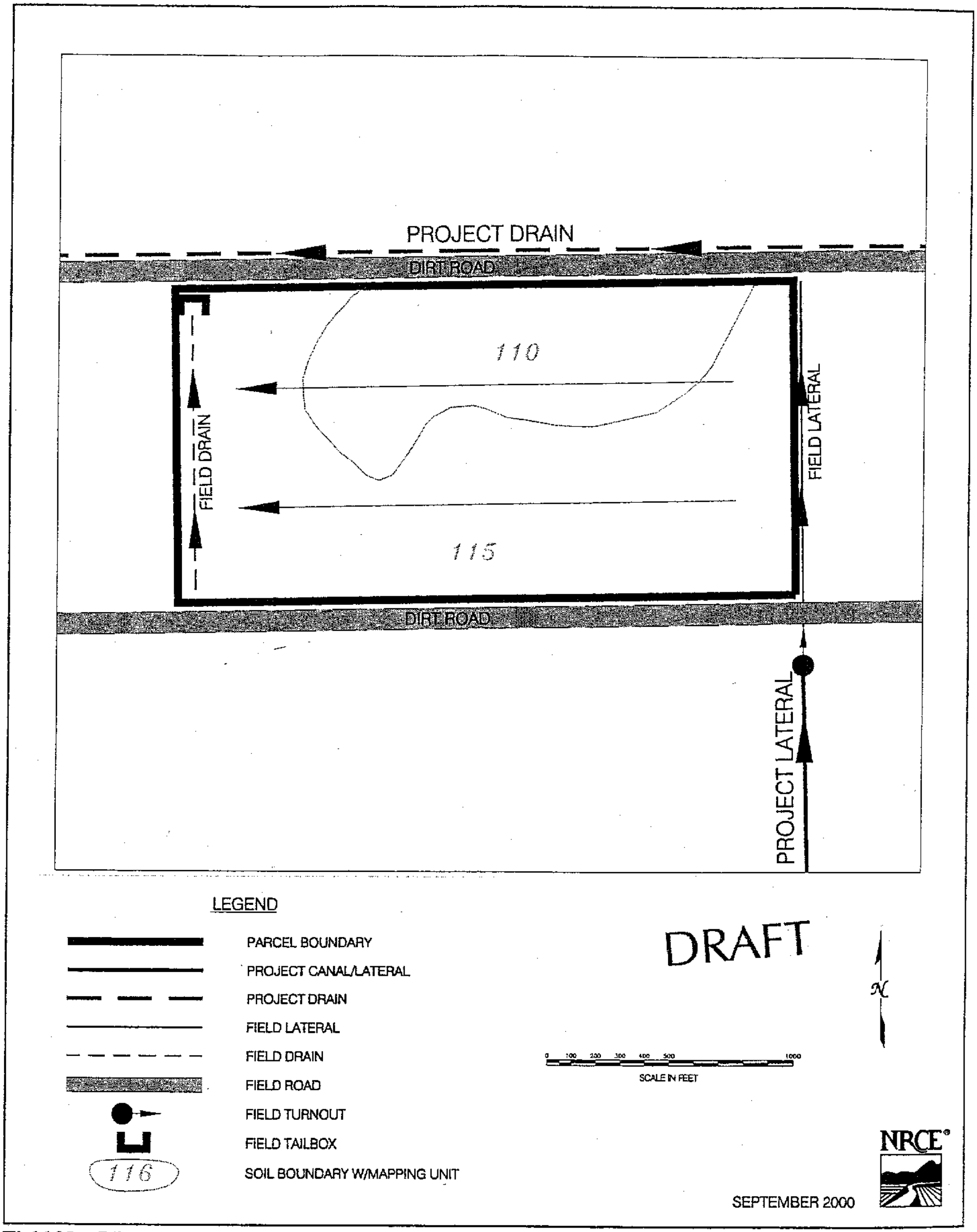
[1]Depth based on field irrigated acreage.

Field No.7 - Irrigation and Cropping History

Cropped Area: 73 ac

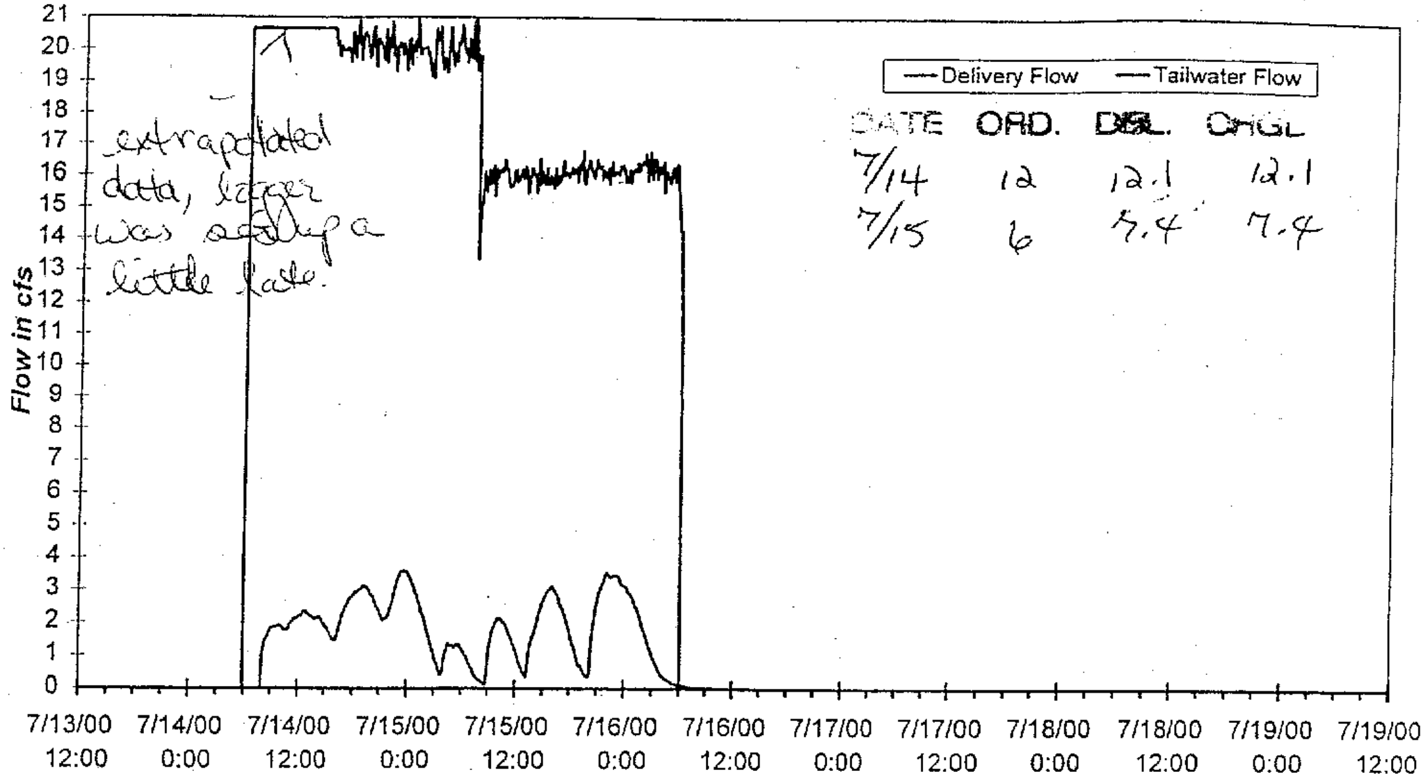
Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Alfalfa, flat	1/28/97		11	11.5	11.5	3.75	3.75
Alfalfa, flat	2/11/97	14	11	6.4	6.4	2.09	2.09
Alfalfa, flat	3/7/97	24	7	5.5	5.5	1.79	1.79
Alfalfa, flat	3/22/97	15	12	12.2	12.2	3.98	3.98
Alfalfa, flat	4/14/97	23	9	9.5	9.5	3.10	3.10
Alfalfa, flat	4/26/97	12	12	12.2	12.2	3.98	3.98
Alfalfa, flat	5/10/97	14	12	14	14	4.56	4.56
Alfalfa, flat	5/21/97	11	12	12.4	12.4	4.04	
Alfalfa, flat	5/22/97	1	5	1.9	1.9	0.62	4.66
Alfalfa, flat	6/5/97	14	12	12.2	12.2	3.98	
Alfalfa, flat	6/6/97	1	5	4.9	4.9	1.60	5.58
Alfalfa, flat	6/15/97	9	12	11.9	11.9	3.88	3.88
Alfalfa, flat	7/6/97	21	12	11.4	11.4	3.72	
Alfalfa, flat	7/7/97	1	7	8.5	8.5	2.77	6.49
Alfalfa, flat	7/17/97	10	12	12	12.1	3.95	3.95
Alfalfa, flat	8/1/97	15	12	11.8	11.8	3.85	
Alfalfa, flat	8/2/97	1	7	4.9	4.9	1.60	5.45
Alfalfa, flat	8/23/97	21	12	12.6	12.6	4.11	4.11
Alfalfa, flat	9/22/97	30	12	12.6	12.6	4.11	
Alfalfa, flat	9/23/97	1	8	8	8	2.61	6.72
Alfalfa, flat	10/13/97	20	12	12	12	3.91	
Alfalfa, flat	10/14/97	1	7	3.5	3.5	1.14	5.05
Alfalfa, flat	11/17/97	34	12	12.2	12.2	3.98	3.98
Alfalfa, flat	12/17/97	30	10	10.3	10.3	3.36	3.36
Alfalfa, flat	2/25/98	70	12	10.2	10.1	3.29	3.29
Alfalfa, flat	3/9/98	12	12	12.1	12.1	3.95	3.95
Alfalfa, flat	4/5/98	27	12	12.2	12.2	3.98	3.98
Alfalfa, flat	4/18/98	13	12	13.2	13.2	4.30	4.30
Alfalfa, flat	5/6/98	18	12	12.9	12.9	4.21	4.21
Alfalfa, flat	5/19/98	13	12	11.9	11.9	3.88	3.88
Alfalfa, flat	6/6/98	18	12	11.9	11.9	3.88	3.88
Alfalfa, flat	6/15/98	9	12	12.2	12.2	3.98	3.98
Alfalfa, flat	6/28/98	13	12	12.2	12.2	3.98	3.98
Alfalfa, flat	7/10/98	12	12	11.8	11.8	3.85	
Alfalfa, flat	7/11/98	1	4	0	0.3	0.10	3.95
Alfalfa, flat	8/4/98	24	12	1.5	9.5	3.10	3.10
Alfalfa, flat	8/9/98	5	13	13.1	13.2	4.30	
Alfalfa, flat	8/10/98	1	13	10.4	10.3	3.36	7.66
Alfalfa, flat	9/15/98	36	12	10.9	10.9	3.55	
Alfalfa, flat	9/16/98	1	12	11.9	11.9	3.88	7.43
Alfalfa, flat	9/30/98	14	12	11.9	11.9	3.88	3.88
Alfalfa, flat	10/27/98	27	12	12.2	12.2	3.98	3.98
Alfalfa, flat	12/4/98	38	12	11.9	11.9	3.88	3.88

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Alfalfa, flat	12/21/98	17	12	12.2	12.2	3.98	3.98
Alfalfa, flat	1/22/99	32	12	12.2	12.2	3.98	3.98
Alfalfa, flat	2/25/99	34	11	11.4	11.3	3.68	
Alfalfa, flat	2/26/99	1	4	0.5	0.5	0.16	3.85
Alfalfa, flat	3/12/99	14	12	11.9	11.9	3.88	3.88
Alfalfa, flat	4/2/99	21	12	5.6	9.5	3.10	3.10
Alfalfa, flat	4/18/99	16	12	11.9	11.9	3.88	3.88
Alfalfa, flat	5/7/99	19	12	11.5	11.5	3.75	3.75
Alfalfa, flat	5/16/99	9	12	12.2	12.2	3.98	3.98
Alfalfa, flat	6/9/99	24	12	12.2	12.2	3.98	3.98
Alfalfa, flat	7/2/99	23	12	12.2	12.2	3.98	3.98
Alfalfa, flat	7/28/99	26	12	12.6	12.6	4.11	
Alfalfa, flat	7/29/99	1	12	12.2	12.2	3.98	8.09
Alfalfa, flat	9/6/99	39	12	11.9	11.9	3.88	
Alfalfa, flat	9/7/99	1	4	5.3	5.3	1.73	5.61
Alfalfa, flat	9/21/99	14	10	10.3	10.3	3.36	
Alfalfa, flat	9/22/99	1	3	1.3	1.3	0.42	3.78
Alfalfa, flat	10/17/99	25	10	10.3	10.3	3.36	3.36
Alfalfa, flat	11/5/99	19	12	12	12	3.91	
Alfalfa, flat	11/6/99	1	4	2.2	2.2	0.72	4.63
Alfalfa, flat	12/10/99	34	12	11.8	11.7	3.81	
Alfalfa, flat	12/11/99	1	4	1.4	1.4	0.46	4.27
Alfalfa, flat	12/30/99	19	4	3.3	3.3	1.08	1.08
Alfalfa, flat	1/19/00	20	12	11.9	11.9	3.88	
Alfalfa, flat	1/20/00	1	6	0.8	0.8	0.26	4.14
Alfalfa, flat	3/8/00	48	8	7.9	7.9	2.58	2.58
Alfalfa, flat	3/31/00	23	12	11.9	11.9	3.88	
Alfalfa, flat	4/1/00	1	4	2	2	0.65	4.53
Alfalfa, flat	4/17/00	16	12	11.9	11.9	3.88	
Alfalfa, flat	4/18/00	1	5	2.3	2.5	0.82	4.70
Alfalfa, flat	5/1/00	13	12	12.1	12.1	3.95	
Alfalfa, flat	5/2/00	1	4	4	4	1.30	5.25
Alfalfa, flat	5/8/00	6	12	12	12	3.91	3.91
Alfalfa, flat	5/31/00	23	12	12.2	12.2	3.98	
Alfalfa, flat	6/1/00	1	8	4	4	1.30	5.28
Alfalfa, flat	6/17/00	16	12	11.9	11.9	3.88	
Alfalfa, flat	6/18/00	1	8	8	8	2.61	6.49
Alfalfa, flat	7/2/00	14	12	11.9	11.9	3.88	3.88
Alfalfa, flat	7/14/00	12	12	12.1	12.1	3.95	
Alfalfa, flat	7/15/00	1	6	7.4	7.4	2.41	6.36

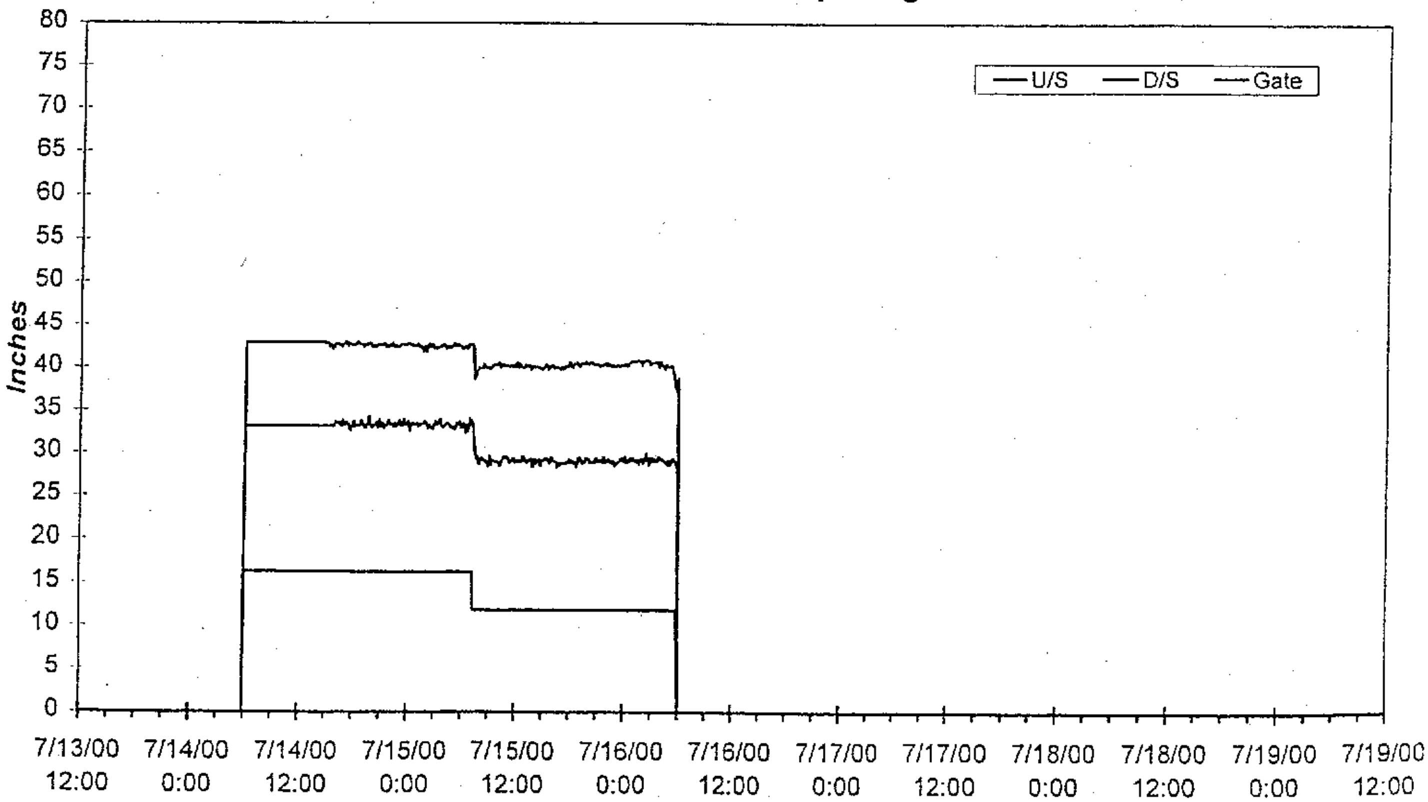


Field No. 7 Layout

Delivery and Tailwater Flow for Parcel No.7



U/S, D/S, and Gate Opening



Order = **1d-12, 1d-6'** Delivery Volume (AF) = **72.3** % Tailwater= **10%** Acres = **73**

Soil Type = **110, 115** Tailwater Volume (AF)= **7.2** Crop = **Flat alfalfa** Inches Applied= **11.9**

Field No. 8

Field Irrigation Evaluation

Data Summary

FIELD IRRIGATION EVALUATION FOR IMPERIAL IRRIGATION DISTRICT IMPERIAL VALLEY, CALIFORNIA. FIELD NO. 8

FIELD DATA

Irrigated Acreage: 72 acres (ac)
Furrow Length: 1320 feet (ft)
Furrow Spacing: 40 inches (in)
Furrow Slope: Average, 0.002567 ft/ft

CROP DATA

Crop: First year alfalfa, planted June 1999 following onions.
Crop Growth Stage: 20 inches (in) in height
Crop Condition: Good

SOILS DATA

Soil Texture: Imperial silty clay (50%); Imperial-Glenbar silty clay loam (50%).
Soil Depth: > 4ft
Soil Uniformity: Average to good
Effective Crop Rooting Depth: 4 ft
Available Water Capacity: 0.17 – 0.35 in/in.
Estimated Allowable Depletion: Not determined.

SOIL CONDITION

Estimated Soil Water Deficit at Beginning of Irrigation:
 Average: 3.0 in.
Estimated Irrigation Water Stored in Root Zone:
 Average: 2.9 in.
NOTES: Soil was quite moist below 2 ft.

IRRIGATION DATA

Irrigation Method: Furrows with gated outlets from concrete-lined head ditch.
Field and Soil Condition: Some cracking of the soil. Previous irrigation on July 7, 2000.

Beginning Irrigation Time: July 15, 2000, 6:30 a.m.
Ending Irrigation Time: July 16, 2000, 12:45 p m
Beginning Outflow Time: July 15, about 3:30 p.m.
Ending Outflow Time: July 16, about 5:30 p.m.
Average Inflow: 9.2 cubic feet per second (cfs)
Average Outflow: 2.2 cfs.

Number of Sets: 9
Set Time: 2.4 to 3.5 hours.
Advance Time: 3.0 to 3.3 hours
Uniformity of Advance: Some furows advanced much faster than others.
Number of Furrows per Set: 80

Irrigation Observations: The advance was quite fast and runoff quite high.
Uniformity:
Ponding: None.
Erosion: None.
Estimated Irrigation Efficiency: 80 %.

Irrigation Summary		
	Average Depth[1], in	Percent of Applied Water, %
Total Water Applied	3.84	
Total Water Stored in Root Zone	2.90	76
Total Runoff	0.78	20
Total Deep Percolation	0.16	4

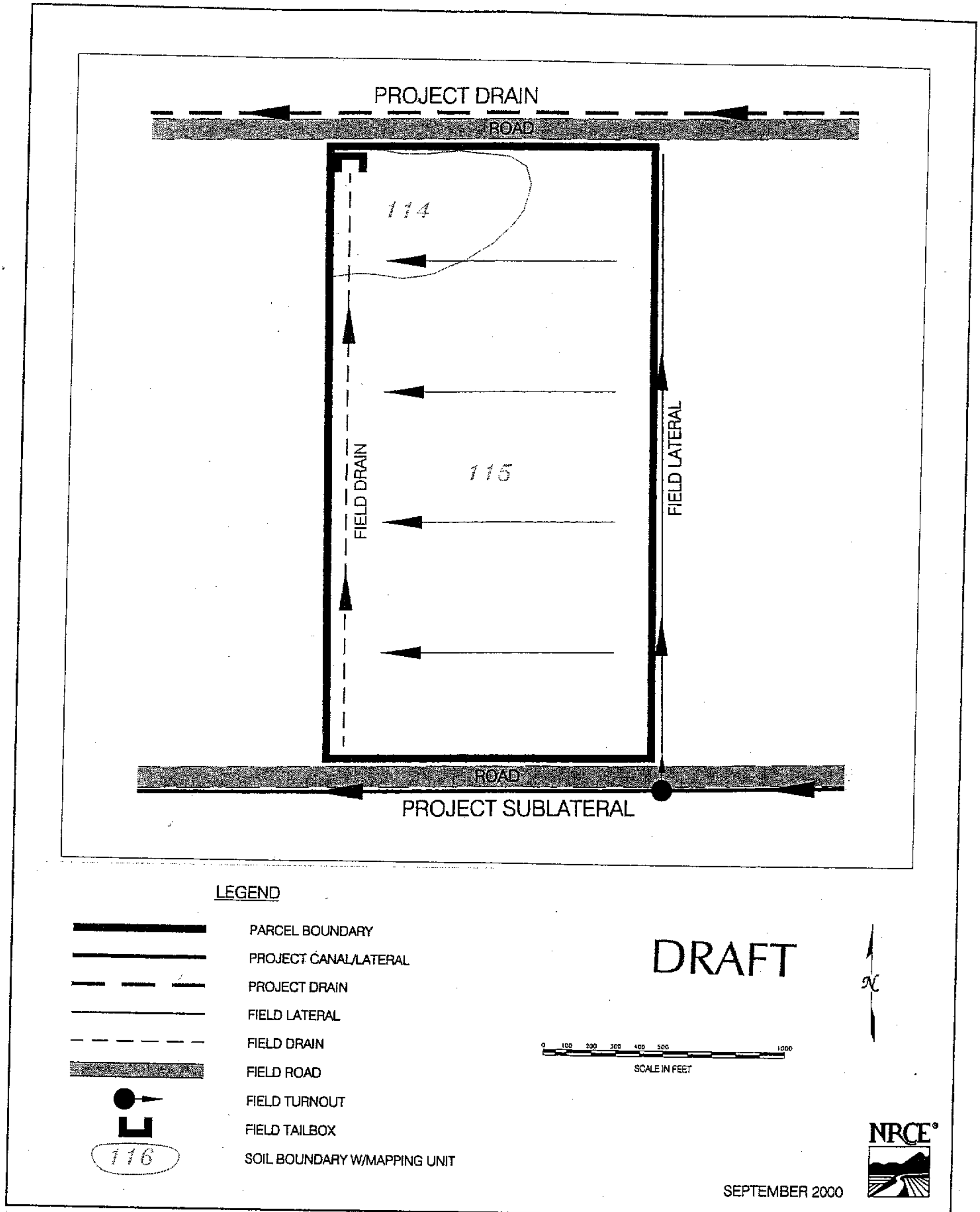
[1]Depth based on field irrigated acreage.

Field No.8 - Irrigation and Cropping History

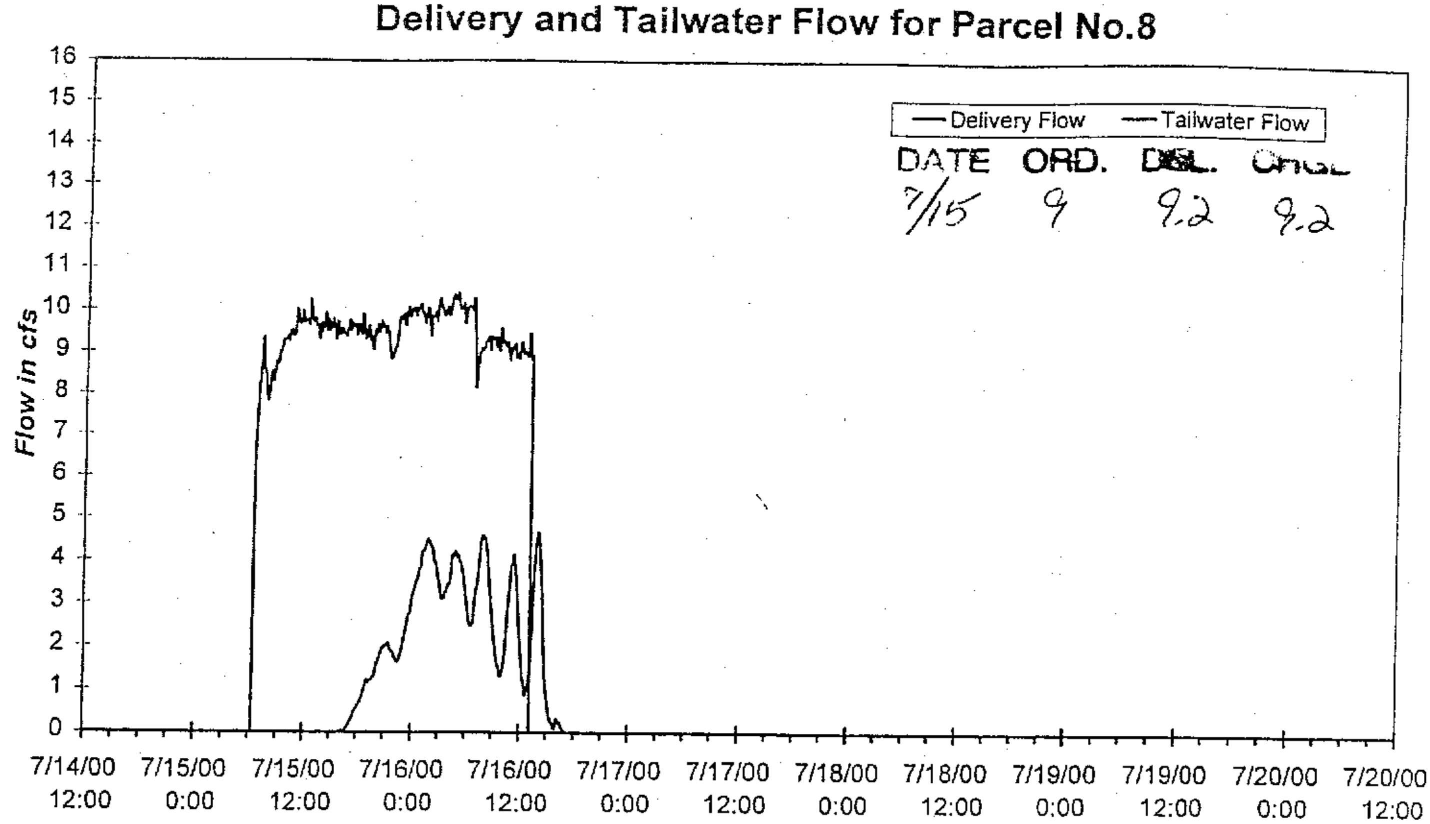
Cropped Area: **72 ac**

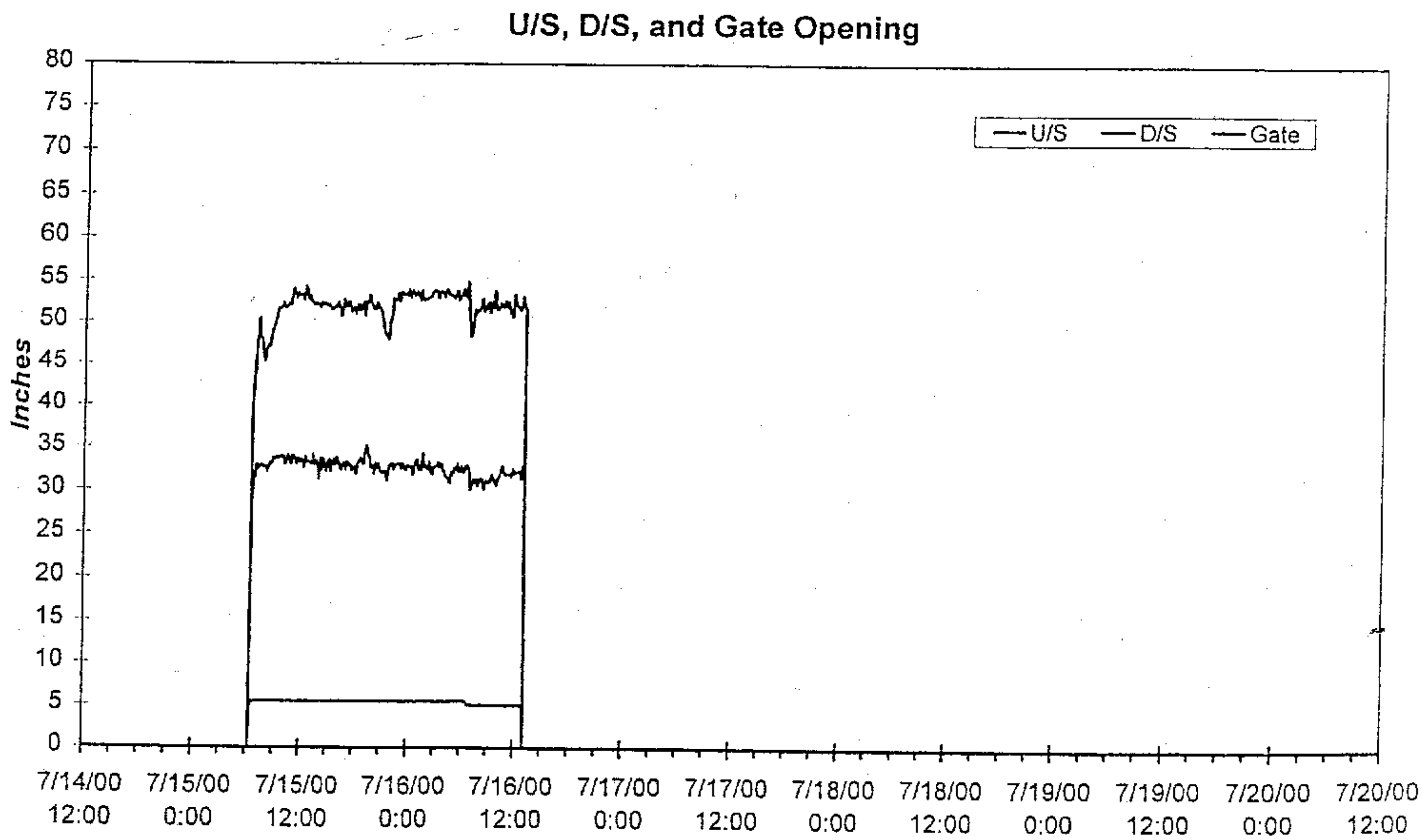
Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Sugar Beets	1/13/97		9	4.9	4.9	1.62	
Sugar Beets	1/14/97	1	7	1.5	3.5	1.16	2.78
Sugar Beets	2/6/97	23	6	4.3	4.3	1.42	
Sugar Beets	2/7/97	1	6	6	6	1.98	3.41
Sugar Beets	2/26/97	19	3	3	3	0.99	0.99
Sugar Beets	3/13/97	15	7	7.3	7.3	2.41	
Sugar Beets	3/14/97	1	7	3.5	3.5	1.16	3.57
Sugar Beets	3/27/97	13	8	8.3	8.3	2.74	2.74
Sugar Beets	4/6/97	10	8	7.1	8	2.64	2.64
Idle	5/16/97	40	8	8.6	8.6	2.84	
Flooding, flat	5/17/97	1	8	8.3	8.3	2.74	
Flooding, flat	5/18/97	1	8	4.2	8	2.64	**8.23**
Sugar Beets	9/10/97	115	7	7.1	7.1	2.35	
Sugar Beets	9/11/97	1	7	7.3	7.3	2.41	
Sugar Beets	9/12/97	1	7	7.1	7.1	2.35	
Sugar Beets	9/13/97	1	5	5.2	7	2.31	9.42
Sugar Beets	9/17/97	4	8	8.2	8.2	2.71	2.71
Sugar Beets	10/18/97	31	9	7.9	9	2.98	2.98
Sugar Beets	11/7/97	20	9	9	9	2.98	
Sugar Beets	11/8/97	1	5	5.2	5.2	1.72	4.69
Sugar Beets	12/7/97	29	9	8.9	9	2.98	
Sugar Beets	12/8/97	1	7	7	7	2.31	5.29
Sugar Beets	1/13/98	36	9	6.5	9	2.98	2.98
Sugar Beets	3/2/98	48	8	6.4	8	2.64	2.64
Sugar Beets	3/18/98	16	7	6.3	7	2.31	2.31
Idle	5/6/98	49	8	8.4	8.4	2.78	
Idle	5/7/98	1	8	8.4	8.4	2.78	2.78
Flooding, flat	5/9/98	2	8	3.8	8	2.64	
Flooding, flat	5/15/98	6	8	8.3	8.3	2.74	
Flooding, flat	5/24/98	9	8	8.6	8.6	2.84	
Flooding, flat	6/1/98	8	8	8	8	2.64	
Flooding, flat	6/10/98	9	8	8.4	8.4	2.78	
Flooding, flat	6/18/98	8	8	3.8	4	1.32	
Flooding, flat	6/25/98	7	8	8.3	8.3	2.74	
Flooding, flat	7/7/98	12	8	8.2	8.2	2.71	**23.21**
Onions	10/27/98	112	8	8.6	8.6	2.84	
Onions	10/28/98	1	8	8.3	8.3	2.74	5.59
Onions	11/1/98	4	8	3.8	4	1.32	1.32
Onions	11/10/98	9	8	3.3	4	1.32	1.32
Onions	11/21/98	11	8	4.2	4.2	1.39	1.39
Onions	12/2/98	11	8	3.5	4	1.32	1.32
Onions	12/11/98	9	8	3.3	4	1.32	1.32
Onions	1/11/99	31	5	5.1	6	1.98	

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Onions	1/12/99	1	1	0.1	0.5	0.17	2.15
Onions	1/26/99	14	4	3.9	4	1.32	1.32
Onions	2/7/99	12	4	1.5	2	0.66	0.66
Onions	2/15/99	8	4	1.7	2	0.66	0.66
Onions	2/23/99	8	4	2.7	4	1.32	1.32
Onions	3/2/99	7	5	3	3	0.99	
Onions	3/3/99	1	1	0.5	0.5	0.17	1.16
Onions	3/9/99	6	5	2.6	5	1.65	1.65
Onions	3/16/99	7	5	2.9	3	0.99	0.99
Onions	3/22/99	6	6	3.7	6	1.98	1.98
Onions	3/28/99	6	5	3.7	5	1.65	1.65
Onions	4/9/99	12	5	3.1	5	1.65	1.65
Onions	4/15/99	6	5	5	5	1.65	1.65
Onions	4/21/99	6	5	3.1	5	1.65	1.65
Onions	4/27/99	6	6	6	6	1.98	1.98
Onions	5/3/99	6	6	6.1	6.1	2.02	2.02
Onions	5/10/99	7	6	3.8	6	1.98	1.98
Alfalfa, row	9/6/99	119	9	9	9	2.98	
Alfalfa, row	9/7/99	1	9	8.6	8.6	2.84	5.82
Alfalfa, row	9/14/99	7	9	9.1	9.1	3.01	3.01
Alfalfa, row	10/5/99	21	7	7	7	2.31	
Alfalfa, row	10/6/99	1	7	5.8	7	2.31	4.63
Alfalfa, row	10/25/99	19	10	10	10	3.31	3.31
Alfalfa, row	11/28/99	34	7	7	7	2.31	2.31
Alfalfa, row	12/16/99	18	7	7	6.9	2.28	2.28
Alfalfa, row	1/29/00	44	7	1.4	1.4	0.46	0.46
Alfalfa, row	2/14/00	16	7	6.9	6.9	2.28	
Alfalfa, row	2/15/00	1	7	7.3	7.3	2.41	4.69
Alfalfa, row	4/1/00	46	7	7	7	2.31	
Alfalfa, row	4/2/00	1	7	7	7	2.31	4.63
Alfalfa, row	4/14/00	12	7	7.2	7.2	2.38	
Alfalfa, row	4/15/00	1	3	0	1.5	0.50	2.88
Alfalfa, row	4/23/00	8	6	6.3	6.3	2.08	2.08
Alfalfa, row	5/8/00	15	8	8.2	8.2	2.71	2.71
Alfalfa, row	5/16/00	8	6	7.6	7.6	2.51	2.51
Alfalfa, row	6/6/00	21	8	8.1	8.1	2.68	
Alfalfa, row	6/7/00	1	8	8.1	8.1	2.68	5.36
Alfalfa, row	6/15/00	8	9	9.1	9.1	3.01	3.01
Alfalfa, row	6/22/00	7	8	8.1	8.1	2.68	2.68
Alfalfa, row	7/6/00	14	8	8.3	8.3	2.74	
Alfalfa, row	7/7/00	1	8	7.9	7.9	2.61	5.36
Alfalfa, row	7/15/00	8	9	9.2	9.2	3.04	3.04
Alfalfa, row	7/23/00	8	9	9.1	9.1	3.01	3.01



Field No. 8 Layout





Order = **1d-9'**	Delivery Volume (AF) = **24.0**	% Tailwater= **20%**	Acres = **0**
Soil Type = **0**	Tailwater Volume (AF)= **4.9**	Crop = **Row alfalfa**	Inches Applied= **#DIV/0!**

Field No. 8 - 0 to 1 ft.

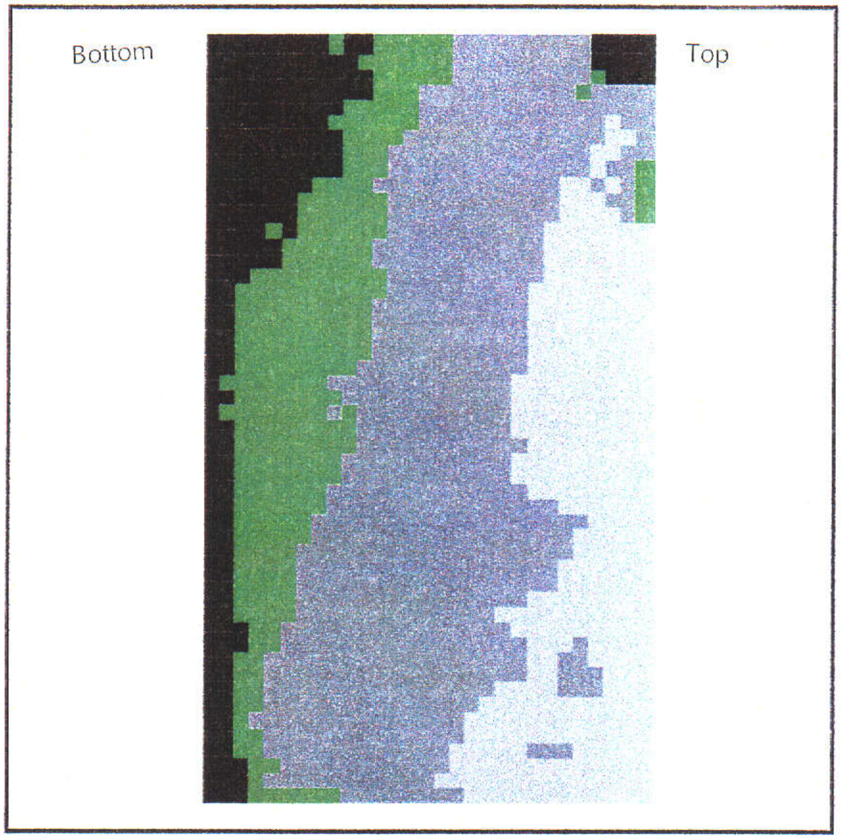
ECe(0.5)
dS/m

- < 4
- 4 - 6
- 6 - 8
- > 8

Data Bounds

X: min & max
653782.03
654206.88

Y: min & max
3648108.53
3648852.65



1 to 2 ft.

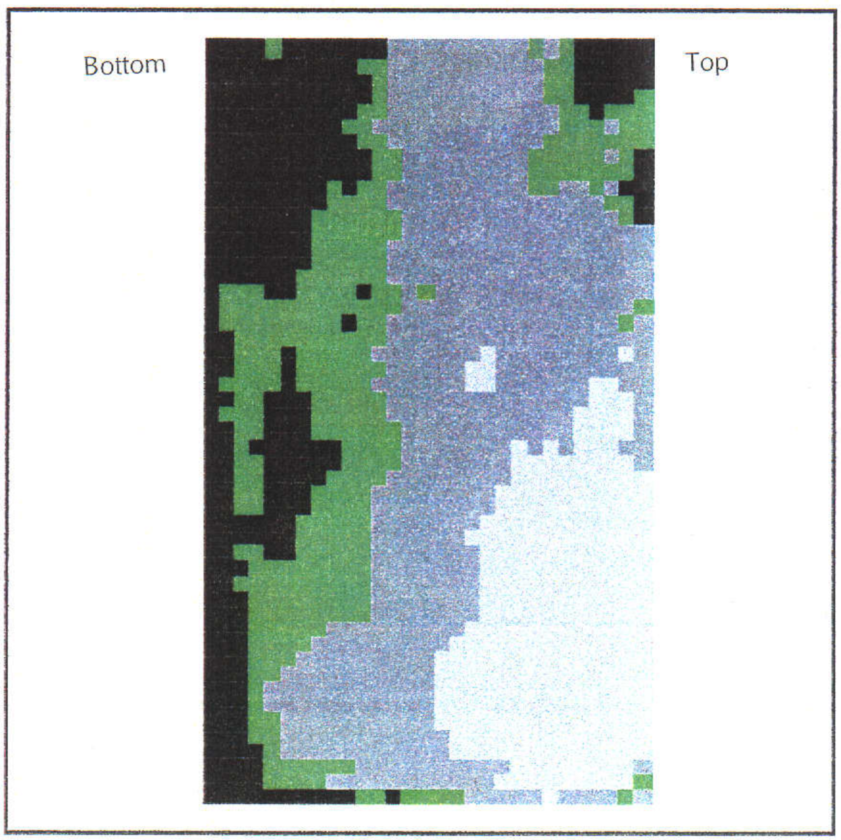
ECe(1.5)
dS/m

- < 7
- 7 - 9
- 9 - 11
- > 11

Data Bounds

X: min & max
653782.03
654206.88

Y: min & max
3648108.53
3648852.65



Field No. 8 - 2 to 3 ft.

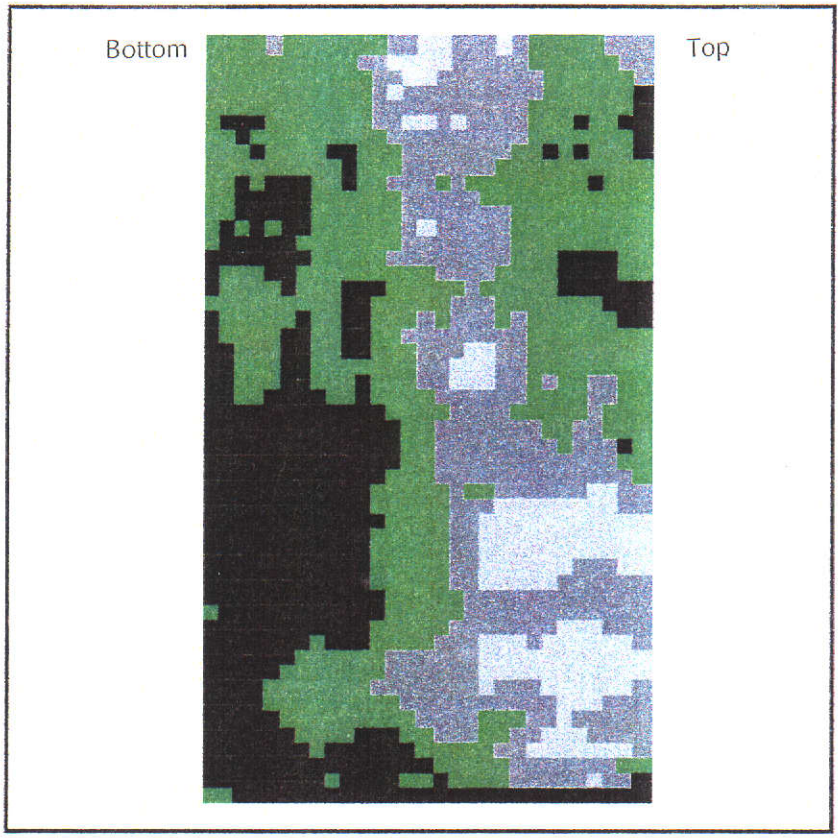
ECe(2.5)
dS/m

- < 7
- 7 - 9
- 9 - 11
- > 11

Data Bounds

X: min & max
653782.03
654206.88

Y: min & max
3648108.53
3648852.65



3 to 4 ft.

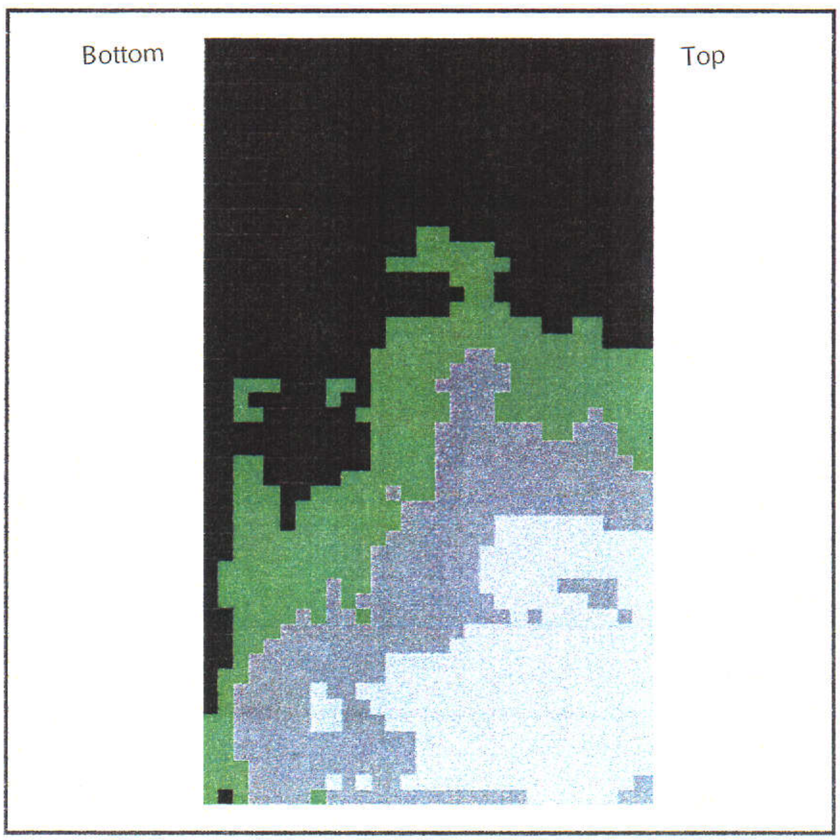
ECe(3.5)
dS/m

- < 7
- 7 - 9
- 9 - 11
- > 11

Data Bounds

X: min & max
653782.03
654206.88

Y: min & max
3648108.53
3648852.65



Field No. 8 - Avg. ECe in 4 ft. Profile

ECe(ave)
dS/m

< 7

7 - 9

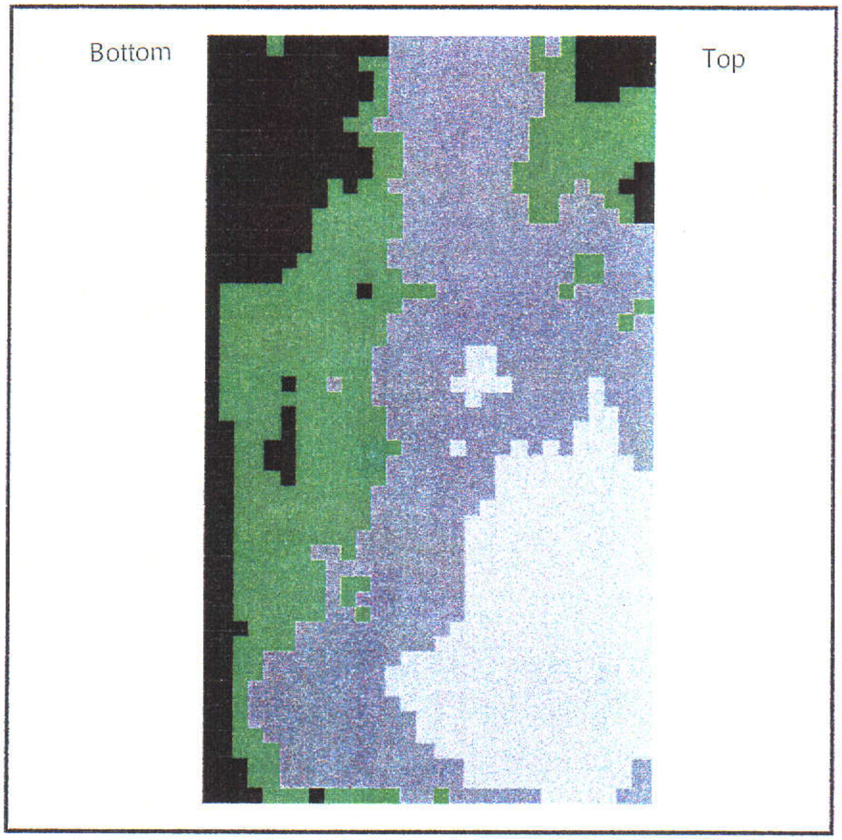
9 - 11

> 11

Data Bounds

X: min & max
653782.03
654206.88

Y: min & max
3648108.53
3648852.65



Field No. 8 - 0 to 1 ft. (autoscale)

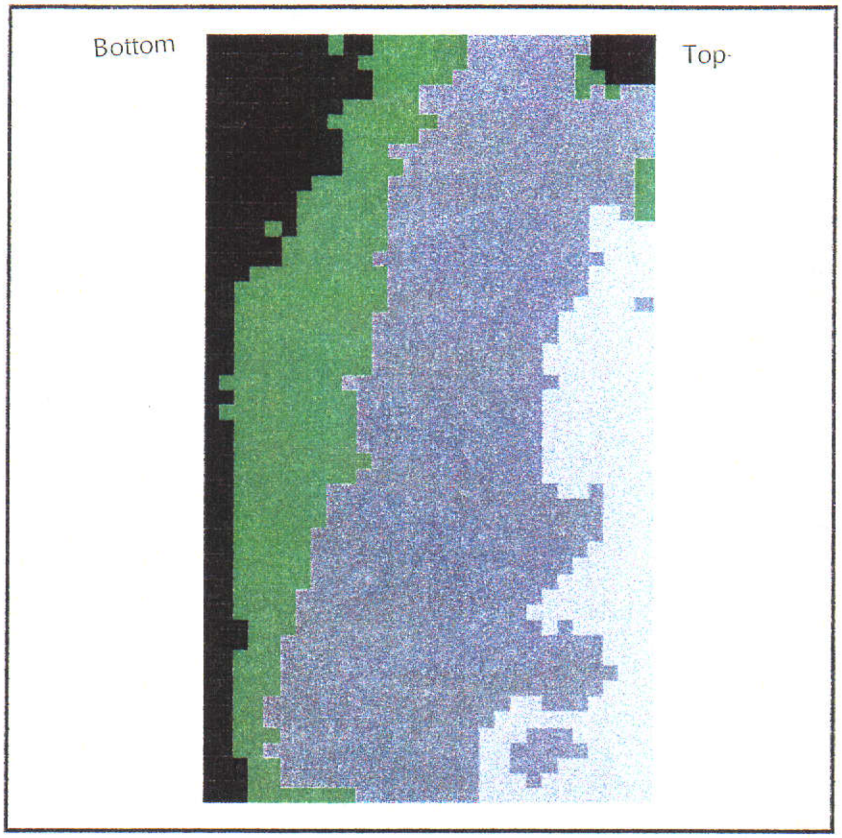
ECe(0.5)
dS/m

- < 3.689
- 3.689 - 5.828
- 5.828 - 7.968
- > 7.968

Data Bounds

X: min & max
653782.03
654206.88

Y: min & max
3648108.53
3648852.65



1 to 2 ft. (autoscale)

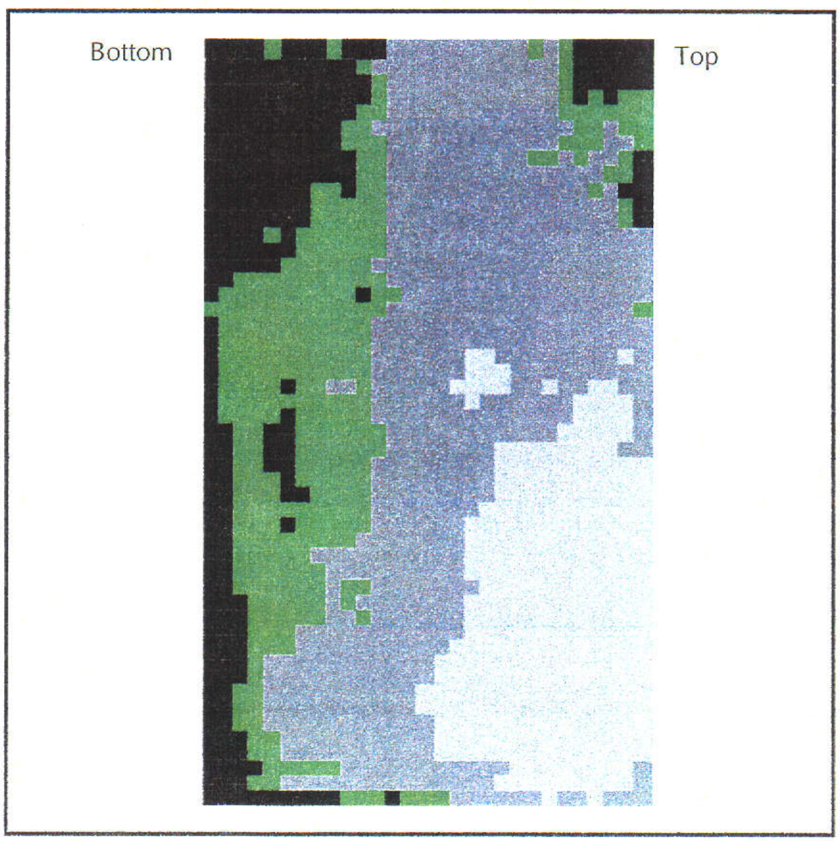
ECe(1.5)
dS/m

- < 7.1
- 7.1 - 9.38
- 9.38 - 11.66
- > 11.66

Data Bounds

X: min & max
653782.03
654206.88

Y: min & max
3648108.53
3648852.65



Field No. 8 - 2 to 3 ft. (autoscale)

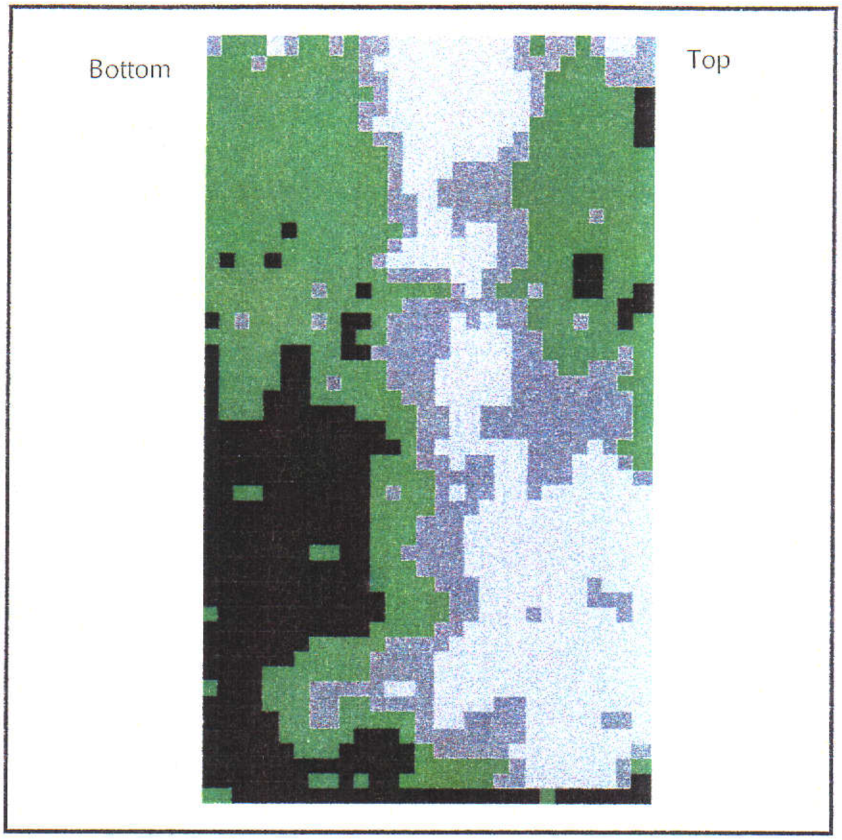
ECe(2.5)
dS/m

- < 8.26
- 8.26 - 9.8
- 9.8 - 11.34
- > 11.34

Data Bounds

X: min & max
653782.03
654206.88

Y: min & max
3648108.53
3648852.65



3 to 4 ft. (autoscale)

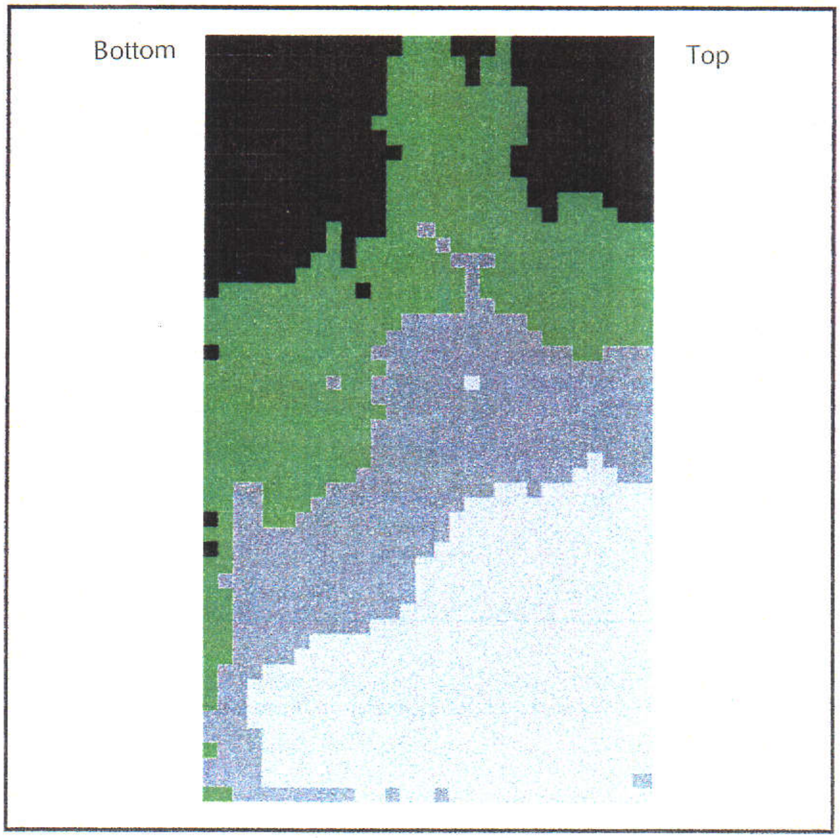
ECe(3.5)
dS/m

- < 8.16
- 8.16 - 10.66
- 10.66 - 13.17
- > 13.17

Data Bounds

X: min & max
653782.03
654206.88

Y: min & max
3648108.53
3648852.65



Field No. 8 - Avg. ECe in 4 ft. Profile (autoscale)

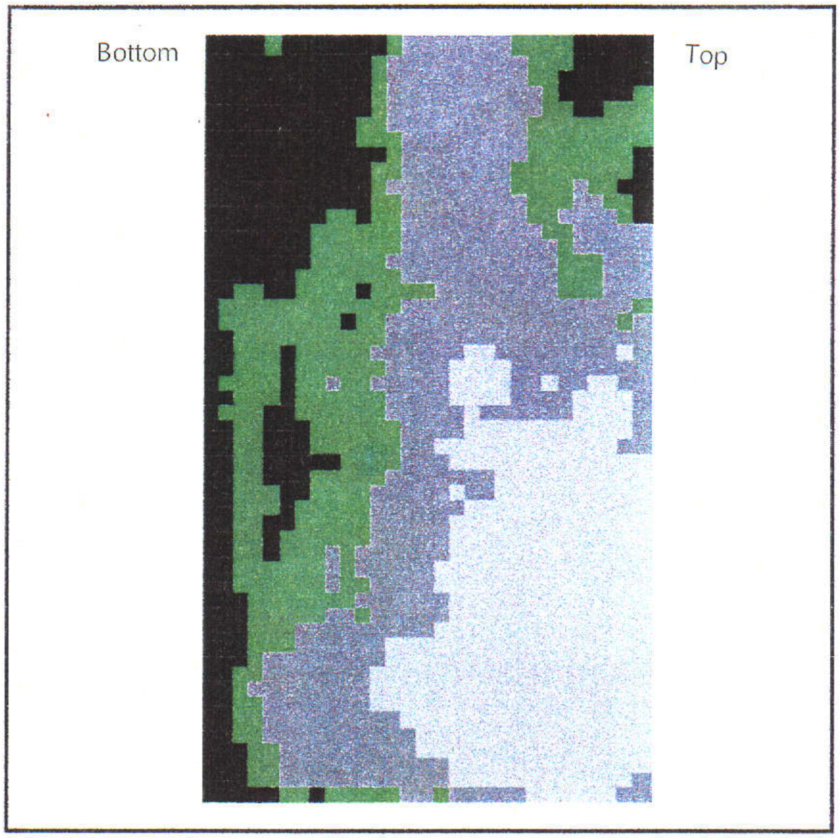
ECe(ave) dS/m

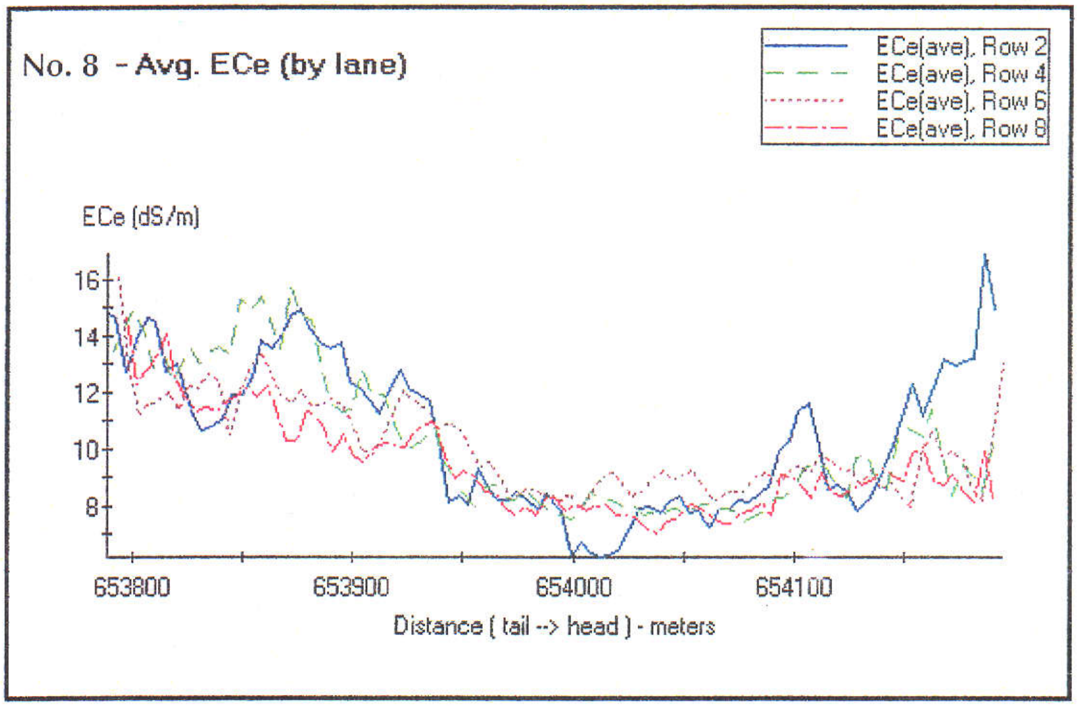
- < 7.27
- 7.27 - 8.91
- 8.91 - 10.56
- > 10.56

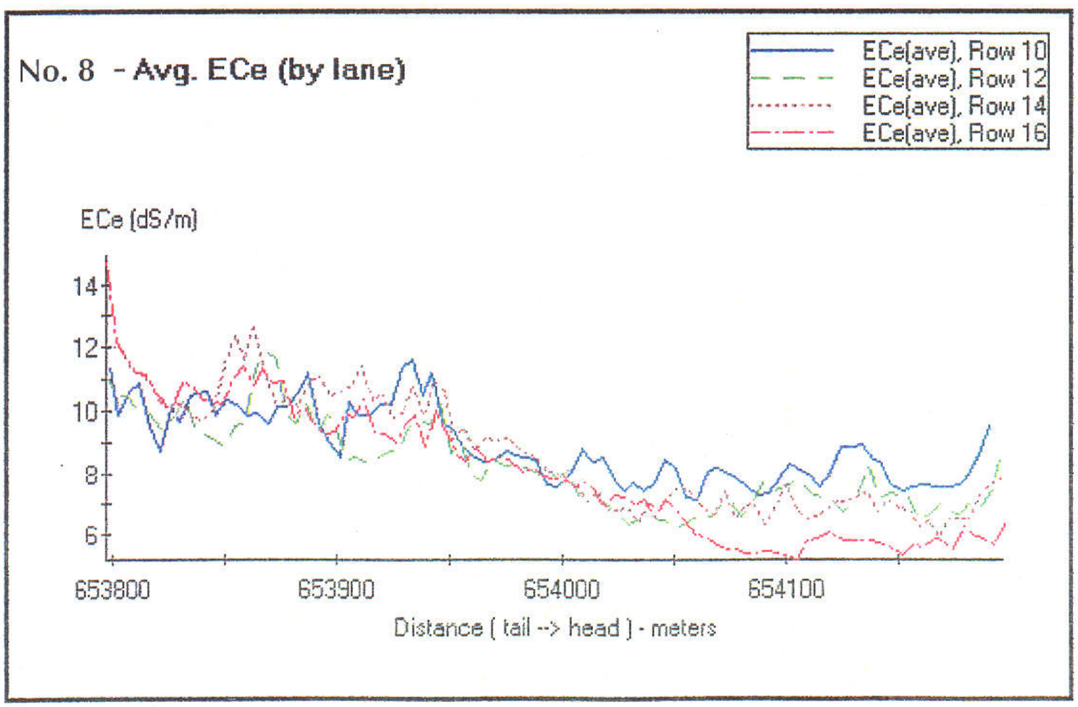
Data Bounds

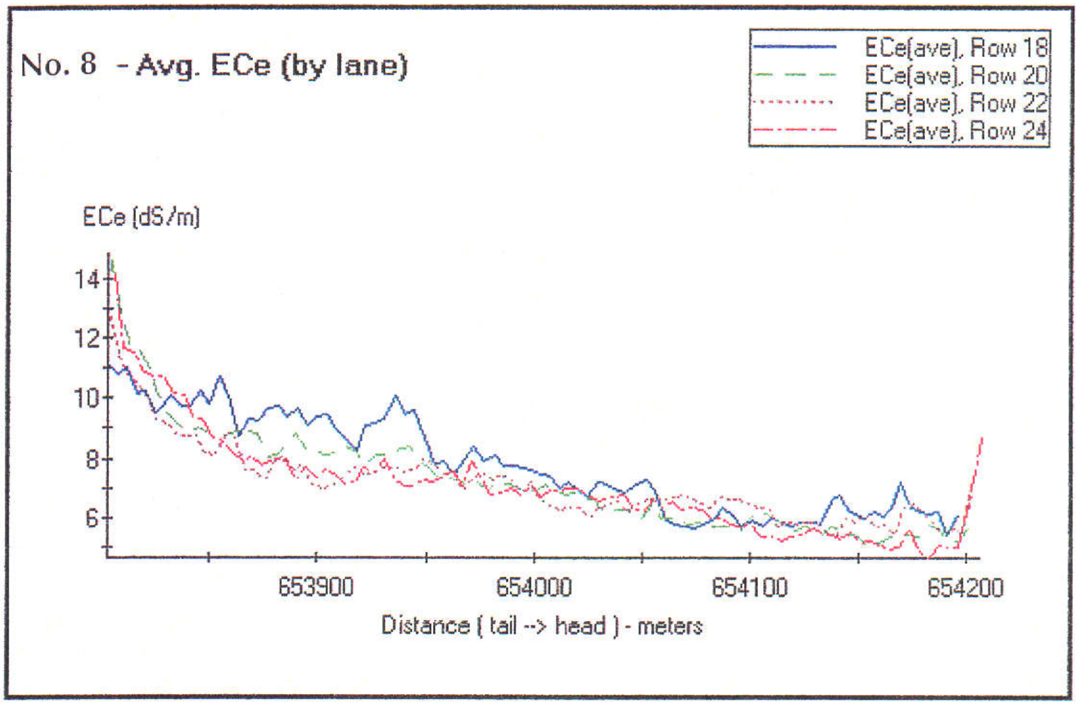
X: min & max
653782.03
654206.88

Y: min & max
3648108.53
3648852.65




No. 8 - Avg. ECe (by lane)
ECe(ave), Row 2
ECe(ave), Row 4
ECe(ave), Row 6
ECe(ave), Row 8
ECe (dS/m)
16
14
12
10
8
653800
653900
654000
654100
Distance (tail --> head) - meters


No. 8 - Avg. ECe (by lane)
ECe(ave), Row 10
ECe(ave), Row 12
ECe(ave), Row 14
ECe(ave), Row 16
ECe (dS/m)
14
12
10
8
6
653800
653900
654000
654100
Distance (tail --> head) - meters



No. 8 - Avg. ECe (by lane)
ECe(ave), Row 18
ECe(ave), Row 20
ECe(ave), Row 22
ECe(ave), Row 24
ECe (dS/m)
14
12
10
8
6
653900
654000
654100
654200
Distance (tail --> head) - meters

Field No. 9

Field Irrigation Evaluation

Data Summary

FIELD IRRIGATION EVALUATION FOR
IMPERIAL IRRIGATION DISTRICT
IMPERIAL VALLEY, CALIFORNIA.
FIELD NO. 9

FIELD DATA

Irrigated Acreage: 78 acres (ac) (second field served by same turnout about 67 acres).
Border Length: 1200 feet (ft)
Border Spacing: 75 Feet (ft)
Border Slope: Average, 0.001558 ft/ft

CROP DATA

Crop: Third year Bermuda Grass.
Crop Growth Stage: 18 inches (in) in height
Crop Condition: Good

SOILS DATA

Soil Texture: Imperial-Glenbar silty clay loam (100%).
Soil Depth: > 4ft
Soil Uniformity: Good.
Effective Crop Rooting Depth: 4 ft
Available Water Capacity: 0.17 – 0.35 in/in.
Estimated Allowable Depletion: Not determined.

SOIL CONDITION

Estimated Soil Water Deficit at Beginning of Irrigation:
Average: 2.6 in.
Estimated Irrigation Water Stored in Root Zone:
Average: 2.57 in.

IRRIGATION DATA

Irrigation Method: Borders with gated outlets from concrete-lined head ditch.
Field and Soil Condition: Some cracking. Previous irrigation on July 9, 2000.

Beginning Irrigation Time: July 18, 2000, 6:30 a.m.
Ending Irrigation Time: July 19, 2000, 8:15 a.m.
Beginning Outflow Time: Not determined
Ending Outflow Time: Not determined
Average Inflow: 10 cubic feet per second (cfs)
Average Outflow: Not determined.

Number of Sets: 4
Set Time: 6.0 to 7.0 hours.
Advance Time: 9.8 to 10.0 hours
Uniformity of Advance: Near constant rate of advance. Good.
Number of Borders per Set: 8 to 10

Irrigation Observations: Data logger was not installed on head gate or tailwater box. Tailwater was estimated with a limited number of hand-made measurements.
Uniformity: Good
Ponding: None.
Erosion: None
Estimated Irrigation Efficiency: 80 %.

Irrigation Summary		
	Average Depth[1], in	Percent of Applied Water, %
Total Water Applied	3.28	
Total Water Stored in Root Zone	2.57	77
Total Runoff	0.60	20
Total Deep Percolation	0.11	3

[1]Depth based on field irrigated acreage.

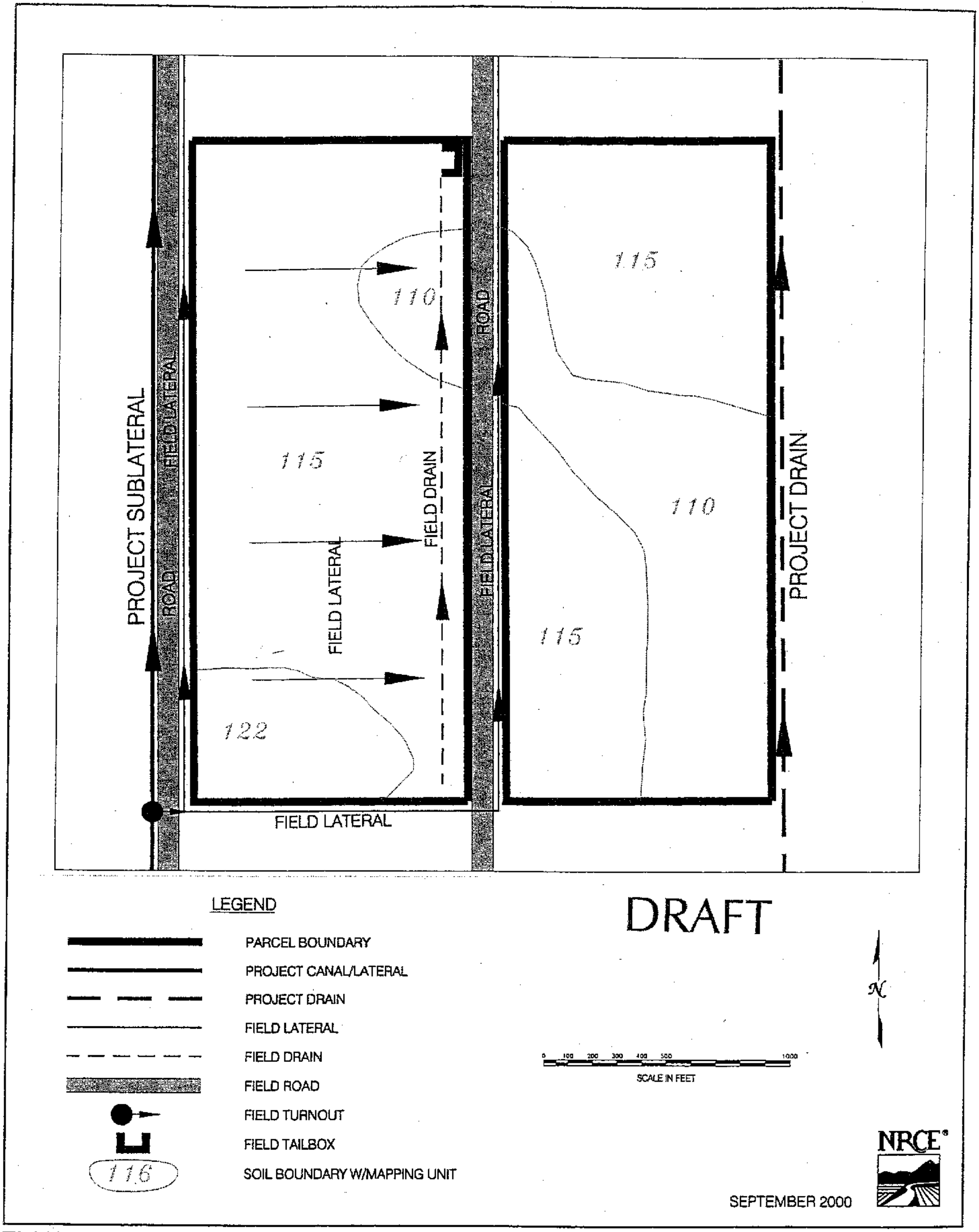
Field No.9 - Irrigation and Cropping History

Cropped Area: **145 ac**

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Sugar Beets	1/23/97		7	7.3	7.3	1.20	
Sugar Beets	1/24/97	1	7	7.1	7.1	1.17	2.36
Sugar Beets	2/19/97	26	7	7.1	7.1	1.17	
Sugar Beets	2/20/97	1	7	7.3	7.3	1.20	2.36
Sugar Beets	3/10/97	18	6	6	6	0.98	
Sugar Beets	3/11/97	1	6	6	6	0.98	1.97
Sugar Beets	3/27/97	16	7	7	7	1.15	
Sugar Beets	3/28/97	1	7	7	7	1.15	
Sugar Beets	3/29/97	1	7	7	7	1.15	3.45
Sugar Beets	4/16/97	18	6	6.2	6.2	1.02	
Sugar Beets	4/17/97	1	6	6	6	0.98	2.00
Sugar Beets	5/3/97	16	8	7.9	7.9	1.30	
Sugar Beets	5/4/97	1	8	7.9	7.9	1.30	
Sugar Beets	5/5/97	1	8	7.9	7.9	1.30	3.89
Sugar Beets	6/17/97	43	8	7.9	7.9	1.30	
Bermuda Grass	6/18/97	1	8	7.9	7.9	1.30	
Bermuda Grass	6/19/97	1	8	4	8	1.31	3.91
Bermuda Grass	6/22/97	3	8	8.1	8.1	1.33	1.33
Bermuda Grass	6/25/97	3	4	4.1	4.1	0.67	
Bermuda Grass	6/26/97	1	4	4.1	4.1	0.67	1.35
Bermuda Grass	6/29/97	3	4	4.1	4.1	0.67	0.67
Bermuda Grass	7/1/97	2	4	4.1	4.1	0.67	
Bermuda Grass	7/2/97	1	4	4.1	4.1	0.67	1.35
Bermuda Grass	7/4/97	2	4	4.1	4.1	0.67	
Bermuda Grass	7/5/97	1	4	4.1	4.1	0.67	1.35
Bermuda Grass	7/14/97	9	8	7.9	7.9	1.30	
Bermuda Grass	7/15/97	1	8	7.9	7.9	1.30	2.59
Bermuda Grass	7/24/97	9	10	9.9	9.9	1.63	
Bermuda Grass	7/25/97	1	7	3.5	3.5	0.57	2.20
Bermuda Grass	8/5/97	11	13	12.9	12.9	2.12	
Bermuda Grass	8/6/97	1	12	11.9	11.9	1.95	4.07
Bermuda Grass	8/29/97	23	14	14.2	14.2	2.33	
Bermuda Grass	8/30/97	1	7	7.1	7.1	1.17	3.50
Bermuda Grass	9/15/97	16	12	11.9	11.9	1.95	1.95
Bermuda Grass	10/8/97	23	6	6.1	6.1	1.00	1.00
Bermuda Grass	2/21/98	136	10	10.1	10.1	1.66	
Bermuda Grass	2/22/98	1	9	9.1	9.1	1.49	3.15
Bermuda Grass	3/16/98	22	12	12.2	12.2	2.00	2.00
Bermuda Grass	4/5/98	20	12	11.9	11.9	1.95	
Bermuda Grass	4/6/98	1	12	5.6	12	1.97	3.92
Bermuda Grass	4/25/98	19	12	11.9	11.9	1.95	
Bermuda Grass	4/26/98	1	5	5	5	0.82	
Bermuda Grass	4/27/98	1	5	5	5	0.82	3.59

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Bermuda Grass	5/19/98	22	12	12.2	12.2	2.00	
Bermuda Grass	5/20/98	1	6	6.1	6.1	1.00	
Bermuda Grass	5/21/98	1	5	5	5	0.82	3.82
Bermuda Grass	6/4/98	14	10	9.9	9.9	1.63	
Bermuda Grass	6/5/98	1	10	9.9	9.9	1.63	3.25
Bermuda Grass	7/6/98	31	12	11.9	11.9	1.95	
Bermuda Grass	7/7/98	1	12	11.9	11.9	1.95	3.91
Bermuda Grass	7/24/98	17	12	12.2	12.2	2.00	
Bermuda Grass	7/25/98	1	12	12.2	12.2	2.00	
Bermuda Grass	7/26/98	1	6	2.8	3	0.49	4.50
Bermuda Grass	8/20/98	25	10	9.9	9.9	1.63	
Bermuda Grass	8/21/98	1	10	10.1	10.1	1.66	3.28
Bermuda Grass	9/5/98	15	12	8.6	8.6	1.41	1.41
Bermuda Grass	9/18/98	13	10	10.1	10.1	1.66	1.66
Bermuda Grass	2/24/99	159	12	11.9	11.9	1.95	1.95
Bermuda Grass	2/26/99	2	7	7	7	1.15	1.15
Bermuda Grass	3/19/99	21	12	12.1	12.1	1.99	
Bermuda Grass	3/20/99	1	5	5	5	0.82	2.81
Bermuda Grass	4/9/99	20	12	11.9	11.9	1.95	
Bermuda Grass	4/10/99	1	5	2.5	2.5	0.41	2.36
Bermuda Grass	4/28/99	18	10	10.1	10.1	1.66	1.66
Bermuda Grass	5/15/99	17	11	10.9	10.9	1.79	1.79
Bermuda Grass	6/10/99	26	10	10	10	1.64	
Bermuda Grass	6/11/99	1	10	9.9	9.9	1.63	
Bermuda Grass	6/12/99	1	7	3.5	3.5	0.57	3.84
Bermuda Grass	7/20/99	38	10	10.1	10.1	1.66	
Bermuda Grass	7/21/99	1	10	10.1	10.1	1.66	
Bermuda Grass	7/22/99	1	8	8.1	8.1	1.33	4.65
Bermuda Grass	8/7/99	16	12	11.8	11.8	1.94	
Bermuda Grass	8/8/99	1	7	7	7	1.15	3.09
Bermuda Grass	8/25/99	17	7	7	7	1.15	1.15
Bermuda Grass	9/6/99	12	10	9.9	9.9	1.63	
Bermuda Grass	9/7/99	1	10	9.9	9.9	1.63	3.25
Bermuda Grass	9/20/99	13	10	9.9	9.9	1.63	
Bermuda Grass	9/21/99	1	6	3.5	6	0.98	2.61
Bermuda Grass	10/5/99	14	12	11.9	11.9	1.95	
Bermuda Grass	10/6/99	1	7	6	7	1.15	3.10
Bermuda Grass	3/2/00	148	12	11.9	11.9	1.95	
Bermuda Grass	3/3/00	1	12	11.9	11.8	1.94	3.89
Bermuda Grass	3/24/00	21	12	12.1	12.1	1.99	
Bermuda Grass	3/25/00	1	4	4	4	0.66	2.64
Bermuda Grass	4/11/00	17	10	10	10	1.64	
Bermuda Grass	4/12/00	1	10	10	10	1.64	3.28
Bermuda Grass	4/25/00	13	12	11.9	11.9	1.95	1.95
Bermuda Grass	5/8/00	13	12	11.9	11.9	1.95	1.95
Bermuda Grass	5/23/00	15	10	11.9	11.9	1.95	
Bermuda Grass	5/24/00	1	12	6.4	12	1.97	3.92

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Bermuda Grass	6/3/00	10	10	9.9	9.9	1.63	
Bermuda Grass	6/4/00	1	10	9.9	9.9	1.63	3.25
Bermuda Grass	7/7/00	33	12	11.9	11.9	1.95	
Bermuda Grass	7/8/00	1	12	11.9	11.9	1.95	
Bermuda Grass	7/9/00	1	10	9.9	9.9	1.63	5.53
Bermuda Grass	7/18/00	9	10	10	10	1.64	
Bermuda Grass	7/19/00	1	10	5.8	10	1.64	3.28



Field No. 9 Layout

Field No. 10

Field Irrigation Evaluation

Data Summary

FIELD IRRIGATION EVALUATION FOR IMPERIAL IRRIGATION DISTRICT IMPERIAL VALLEY, CALIFORNIA. FIELD NO. 10

FIELD DATA

Irrigated Acreage: 81 acres (ac)
Border Length: 1200 feet (ft)
Border Spacing: Not determined
Border Slope: Not determined.

CROP DATA

Crop: None, leaching following Sugar Beets.
Crop Growth Stage: N/A
Crop Condition: N/A

SOILS DATA

Soil Texture: Imperial-Glenbar silty clay loam (55%); Meloland very fine Sandy loam (20%); Holtville silty clay (15%).
Soil Depth: > 4ft
Soil Uniformity: Not determined.
Effective Crop Rooting Depth: Not determined.
Available Water Capacity: 0.15 - .35 in/in.
Estimated Allowable Depletion: Not determined.

SOIL CONDITION

Estimated Soil Water Deficit at Beginning of Irrigation:
Average: Not determined
Estimated Irrigation Water Stored in Root Zone:
Average: Not determined

IRRIGATION DATA

Irrigation Method: Borders with gated outlets from concrete-lined head ditch.
Field and Soil Condition: Field had been prepared for a leaching irrigation.
Border Condition: Previous irrigation on May 19, 2000.

Beginning Irrigation Time: June 24, 2000, 6:30 a.m.
Ending Irrigation Time: July 3, 2000, 6:30 a.m.
Beginning Outflow Time: None
Ending Outflow Time: None
Average Inflow: 4.16 cubic feet per second (cfs)
Average Outflow: No tailwater was allowed during the leaching irrigation.

Number of Sets: 1
Set Time: 8 days.
Advance Time: Approximately 3 days.
Uniformity of Advance: Fair
Number of Borders per Set: Entire field.

Irrigation Observations: Tailwater was being pumped back to the head ditch.
Uniformity:
Ponding: Yes.
Erosion: None
Estimated Irrigation Efficiency: Non-applicable, all water was used for leaching, soil moisture storage, and evaporation.

Irrigation Summary		
	Average Depth[1], in	Percent of Water Applied, %
Total Water Applied	9.8	
Total Water Stored in Root Zone	3.8	39
Total Runoff	0	0
Total Deep Percolation	3.6	37

[1]Depth based on field irrigated acreage.

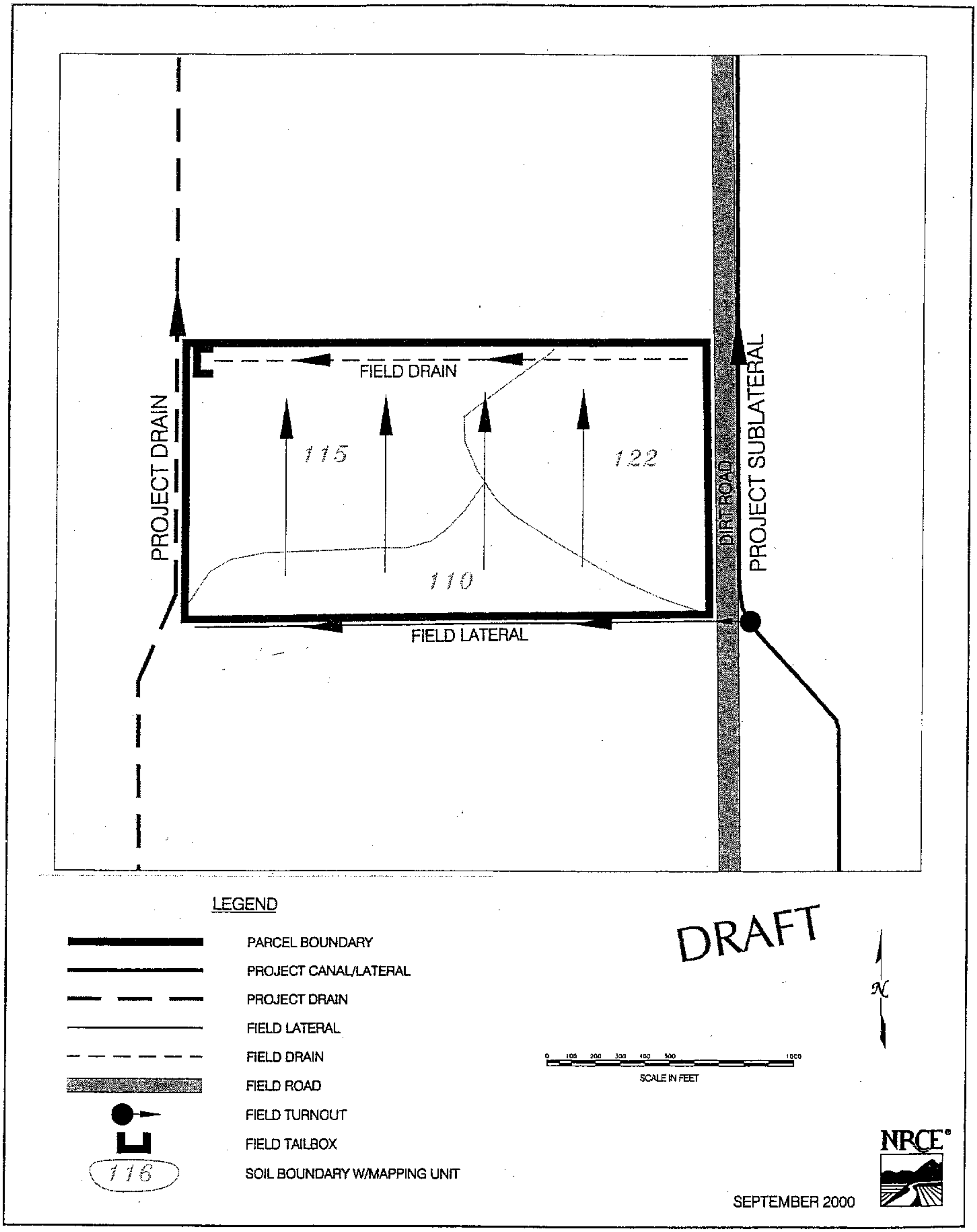
Field No.10 - Irrigation and Cropping History

Cropped Area: **81 ac**

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Alfalfa, row	2/12/97		8	8.6	8.6	2.53	2.53
Alfalfa, row	2/28/97	16	9	10	10	2.94	2.94
Alfalfa, row	3/12/97	12	8	8	8	2.35	2.35
Alfalfa, row	4/2/97	21	10	10.3	10.3	3.03	
Alfalfa, row	4/3/97	1	10	3.8	3.8	1.12	4.14
Alfalfa, row	4/15/97	12	9	8.9	8.9	2.62	2.62
Alfalfa, row	4/25/97	10	8	9	9	2.64	2.64
Alfalfa, row	5/9/97	14	11	11.4	11.4	3.35	
Alfalfa, row	5/10/97	1	11	11.4	11.4	3.35	6.70
Alfalfa, row	5/17/97	7	5	5	5	1.47	1.47
Alfalfa, row	5/25/97	8	10	10.9	10.9	3.20	3.20
Alfalfa, row	6/7/97	13	11	10.7	10.7	3.14	
Alfalfa, row	6/8/97	1	7	3.5	3.5	1.03	4.17
Alfalfa, row	6/16/97	8	7	9.8	9.8	2.88	2.88
Alfalfa, row	6/23/97	7	10	9.9	9.9	2.91	
Alfalfa, row	6/24/97	1	10	11.3	11.3	3.32	6.23
Alfalfa, row	7/1/97	7	10	10.9	10.9	3.20	3.20
Alfalfa, row	7/13/97	12	10	10.3	10.3	3.03	
Alfalfa, row	7/14/97	1	7	8.3	8.3	2.44	5.47
Alfalfa, row	7/22/97	8	10	10.9	10.9	3.20	3.20
Alfalfa, row	7/31/97	9	10	11.8	11.8	3.47	3.47
Alfalfa, row	8/12/97	12	11	11	11	3.23	
Alfalfa, row	8/13/97	1	5	1.6	2.5	0.73	3.97
Alfalfa, row	8/22/97	9	9	9.1	9.1	2.67	2.67
Alfalfa, row	9/2/97	11	12	10.9	10.9	3.20	3.20
Alfalfa, row	9/16/97	14	10	10.6	10.6	3.11	
Alfalfa, row	9/17/97	1	6	4.5	6	1.76	4.88
Alfalfa, row	10/6/97	19	10	9.9	9.9	2.91	2.91
Alfalfa, row	10/27/97	21	10	10.7	10.7	3.14	
Alfalfa, row	10/28/97	1	8	8	8	2.35	5.50
Alfalfa, row	11/20/97	23	10	9.9	9.9	2.91	2.91
Alfalfa, row	12/23/97	33	10	10.3	10.3	3.03	3.03
Alfalfa, row	3/6/98	73	11	11.5	11.5	3.38	3.38
Alfalfa, row	3/22/98	16	9	9.5	9.5	2.79	2.79
Alfalfa, row	4/15/98	24	12	12.2	12.2	3.58	3.58
Alfalfa, row	4/29/98	14	12	12.4	12.4	3.64	3.64
Alfalfa, row	5/15/98	16	12	12	12	3.53	3.53
Alfalfa, row	5/27/98	12	12	13.2	13.2	3.88	
Alfalfa, row	5/28/98	1	12	11.9	11.9	3.50	7.38
Alfalfa, row	6/10/98	13	12	12.8	12.8	3.76	3.76
Alfalfa, row	6/19/98	9	9	8.9	8.9	2.62	2.62
Alfalfa, row	6/27/98	8	10	10.2	10.2	3.00	3.00
Alfalfa, row	7/11/98	14	9	8.9	8.9	2.62	2.62

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Alfalfa, row	7/22/98	11	10	13.4	13.4	3.94	3.94
Alfalfa, row	8/1/98	10	11	11.7	11.7	3.44	3.44
Alfalfa, row	8/14/98	13	12	12.6	12.6	3.70	3.70
Alfalfa, row	8/24/98	10	7	7.6	7.6	2.23	2.23
Alfalfa, row	9/4/98	11	8	8.8	8.8	2.59	
Alfalfa, row	9/5/98	1	8	9.5	9.5	2.79	5.38
Alfalfa, row	9/19/98	14	11	11.1	11.1	3.26	3.26
Alfalfa, row	10/6/98	17	12	12.8	12.8	3.76	3.76
Alfalfa, row	10/27/98	21	11	10.9	10.9	3.20	
Alfalfa, row	10/28/98	1	11	12.8	12.8	3.76	6.96
Alfalfa, row	11/23/98	26	11	11.9	11.9	3.50	3.50
Alfalfa, row	1/5/99	43	9	9.1	9.1	2.67	2.67
Alfalfa, row	2/4/99	30	10	11.5	11.5	3.38	3.38
Alfalfa, row	3/4/99	28	8	8.6	8.6	2.53	
Alfalfa, row	3/5/99	1	7	7.8	7.8	2.29	4.82
Alfalfa, row	3/22/99	17	8	8.1	8.1	2.38	
Alfalfa, row	3/23/99	1	8	2.7	2.7	0.79	3.17
Alfalfa, row	4/17/99	25	12	12.1	12.1	3.56	3.56
Alfalfa, row	5/2/99	15	13	13.9	13.9	4.08	
Alfalfa, row	5/3/99	1	13	14	14	4.11	8.20
Alfalfa, row	5/18/99	15	11	12.4	12.4	3.64	3.64
Alfalfa, row	5/28/99	10	9	10.2	10.2	3.00	3.00
Flooding, flat	7/9/99	42	8	8.7	8.7	2.56	
Flooding, flat	7/10/99	1	8	8.9	8.9	2.62	
Flooding, flat	7/11/99	1	8	8.6	8.6	2.53	
Flooding, flat	7/12/99	1	7	8.4	8.4	2.47	**10.17**
Sugar Beets	9/24/99	74	10	11.9	11.9	3.50	3.50
Sugar Beets	9/25/99	1	10	11.7	11.7	3.44	3.44
Sugar Beets	9/26/99	1	8	8.1	8.1	2.38	2.38
Sugar Beets	9/27/99	1	7	7.5	7.5	2.20	2.20
Sugar Beets	9/28/99	1	6	1.8	1.8	0.53	0.53
Sugar Beets	10/2/99	4	7	6.9	6.9	2.03	2.03
Sugar Beets	11/2/99	31	9	8.9	8.9	2.62	
Sugar Beets	11/3/99	1	9	11.5	11.5	3.38	5.99
Sugar Beets	11/30/99	27	8	7.8	7.8	2.29	2.29
Sugar Beets	12/27/99	27	7	7.3	7.3	2.15	
Sugar Beets	12/28/99	1	7	7.2	7.2	2.12	4.26
Sugar Beets	1/25/00	28	7	7.2	7.2	2.12	2.12
Sugar Beets	2/18/00	24	7	8.3	8.3	2.44	
Sugar Beets	2/19/00	1	7	7.2	7.2	2.12	4.55
Sugar Beets	3/8/00	18	7	7.2	7.2	2.12	
Sugar Beets	3/9/00	1	7	7.7	7.7	2.26	4.38
Sugar Beets	3/24/00	15	7	7.8	7.8	2.29	
Sugar Beets	3/25/00	1	7	6.6	6.6	1.94	4.23
Sugar Beets	4/8/00	14	8	8.3	8.3	2.44	
Sugar Beets	4/9/00	1	8	8.1	8.1	2.38	4.82
Sugar Beets	4/18/00	9	7	7.1	7	2.06	

Crop	Delivery Date	Interval (days)	Order (cfs)	Delivered (cfs)	Charged (cfs)	Water Applied (in)	Total Irrigation Applied (in)
Sugar Beets	4/19/00	1	9	8.3	8.3	2.44	4.50
Sugar Beets	4/30/00	11	7	7.7	7.7	2.26	
Sugar Beets	5/1/00	1	7	5.6	5.6	1.65	3.91
Sugar Beets	5/10/00	9	7	8.4	8.4	2.47	
Sugar Beets	5/11/00	1	7	5.6	5.6	1.65	4.11
Sugar Beets	5/19/00	8	7	8.4	8.4	2.47	
Sugar Beets	5/20/00	1	7	1.5	1.5	0.44	2.91
Flooding, flat	6/24/00	35	7	7.1	7	2.06	
Flooding, flat	6/25/00	1	5	5.6	5.6	1.65	
Flooding, flat	6/26/00	1	4	3.8	3.8	1.12	
Flooding, flat	6/27/00	1	4	4.7	4.7	1.38	
Flooding, flat	6/28/00	1	2.5	2.8	2.8	0.82	
Flooding, flat	6/29/00	1	2.5	2.4	2.4	0.71	
Flooding, flat	6/30/00	1	2.5	2.3	2.3	0.68	
Flooding, flat	7/1/00	1	2.5	2.3	2.3	0.68	
Flooding, flat	7/2/00	1	2.5	2.4	2.4	0.71	9.79



Field No. 10 Layout

Tam , - 0 to 1 ft. (autoscale)

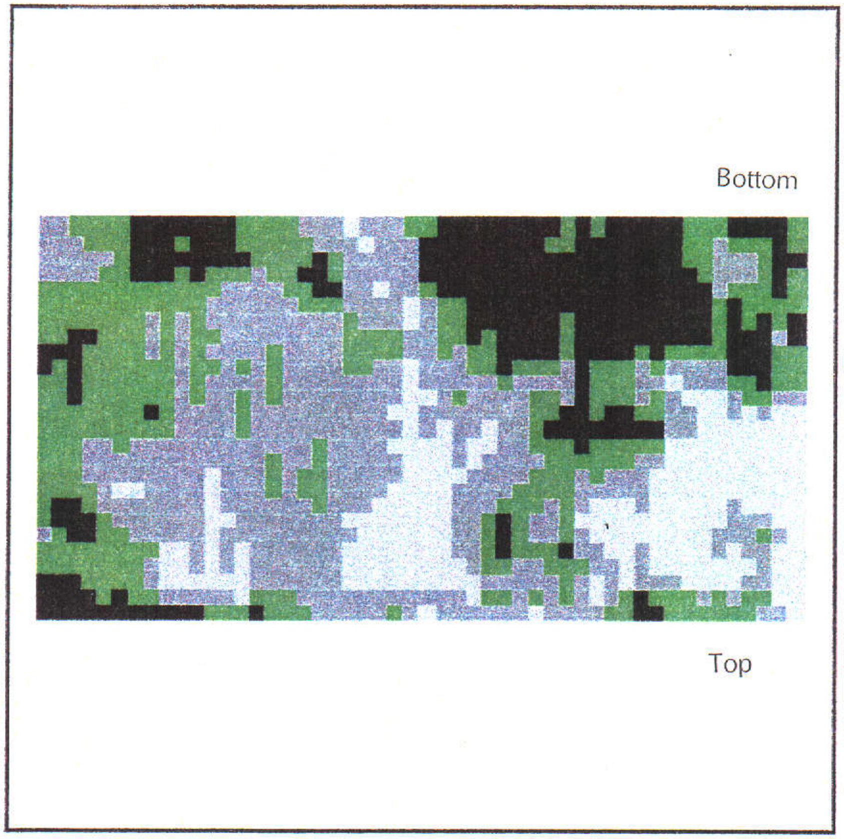
ECe(0.5)
dS/m

- < 3.318
- 3.318 - 3.896
- 3.896 - 4.473
- \> 4.473

Data Bounds

X: min & max
631967.5
632691.34

Y: min & max
3655520.35
3655886.52



1 to 2 ft. (autoscale)

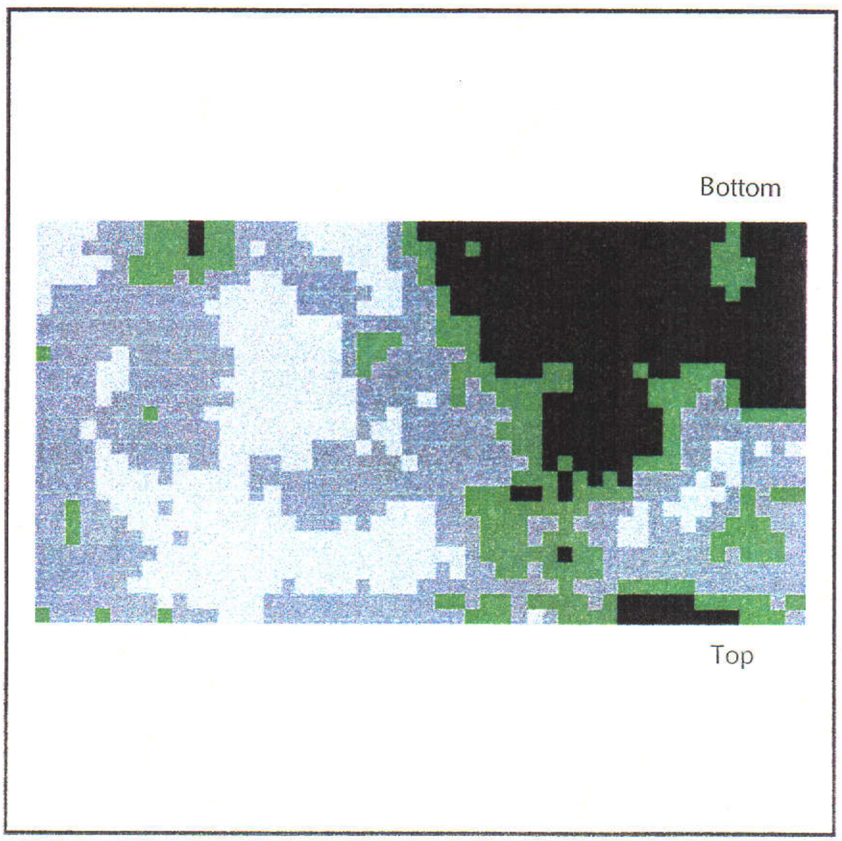
ECe(1.5)
dS/m

- < 3.667
- 3.667 - 5.072
- 5.072 - 6.478
- \> 6.478

Data Bounds

X: min & max
631967.5
632691.34

Y: min & max
3655520.35
3655886.52



Tam - 2 to 3 ft. (autoscale)

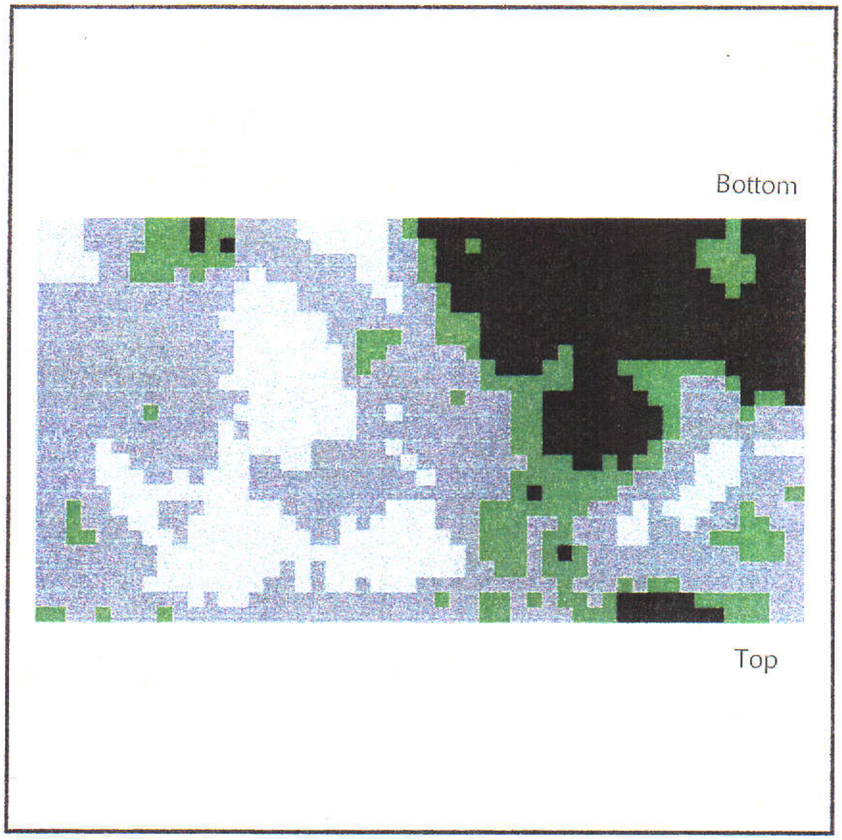
ECe(2.5)
dS/m

- < 5
- 5 - 8.88
- 8.88 - 12.76
- > 12.76

Data Bounds

X: min & max
631967.5
632691.34

Y: min & max
3655520.35
3655886.52



3 to 4 ft. (autoscale)

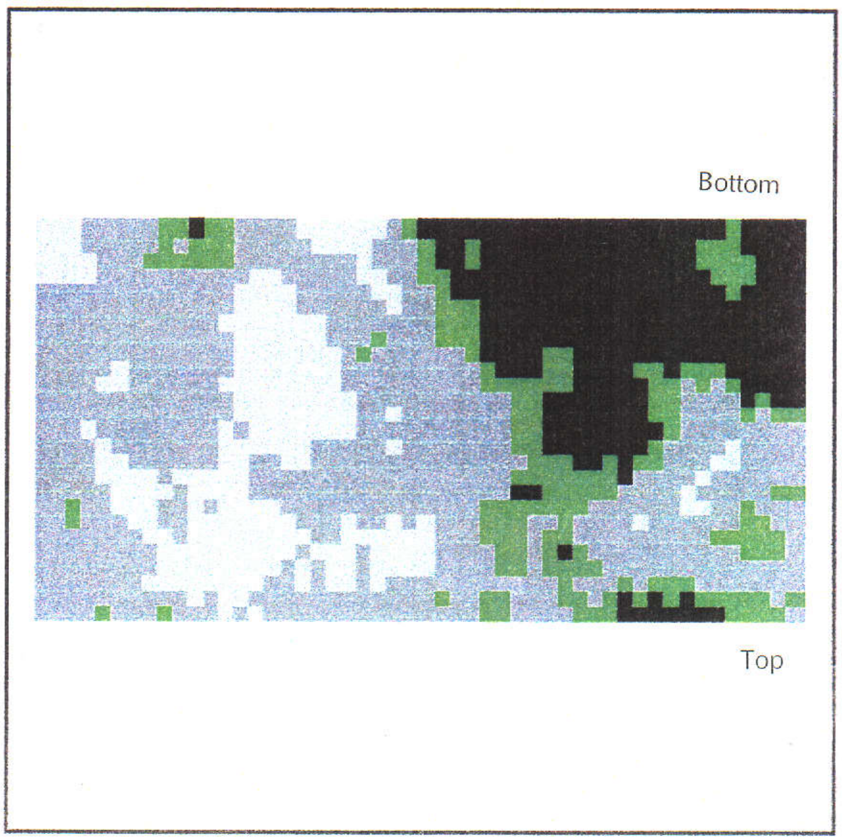
ECe(3.5)
dS/m

- < 5.4
- 5.4 - 11.39
- 11.39 - 17.37
- > 17.37

Data Bounds

X: min & max
631967.5
632691.34

Y: min & max
3655520.35
3655886.52



Tam - 4 ft. Profile Avg. (autoscale)

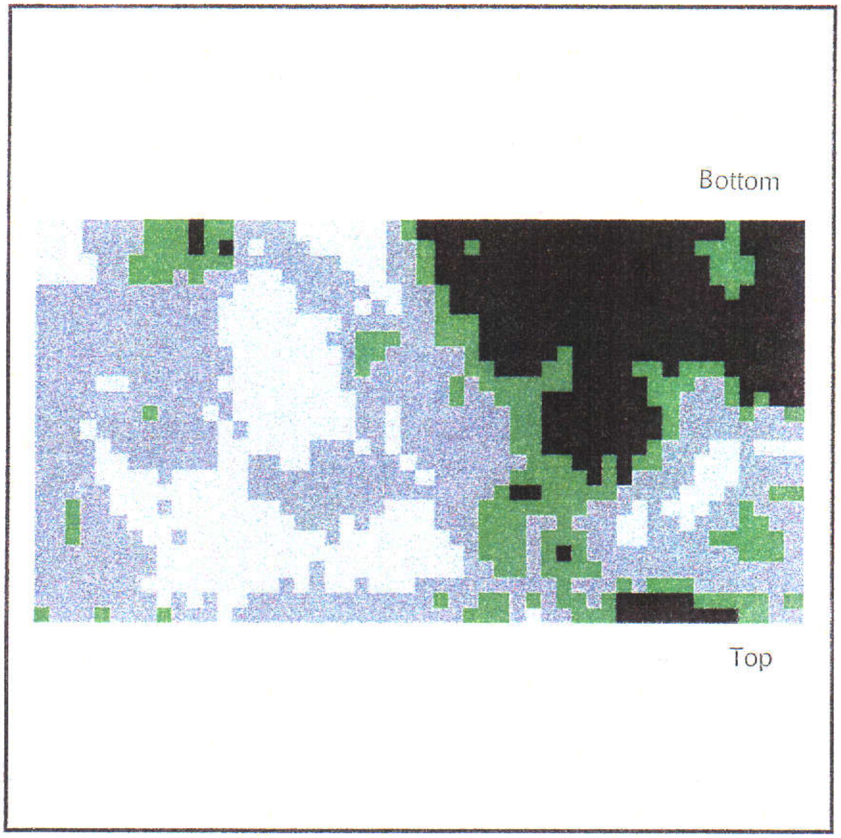
ECe(ave)
dS/m

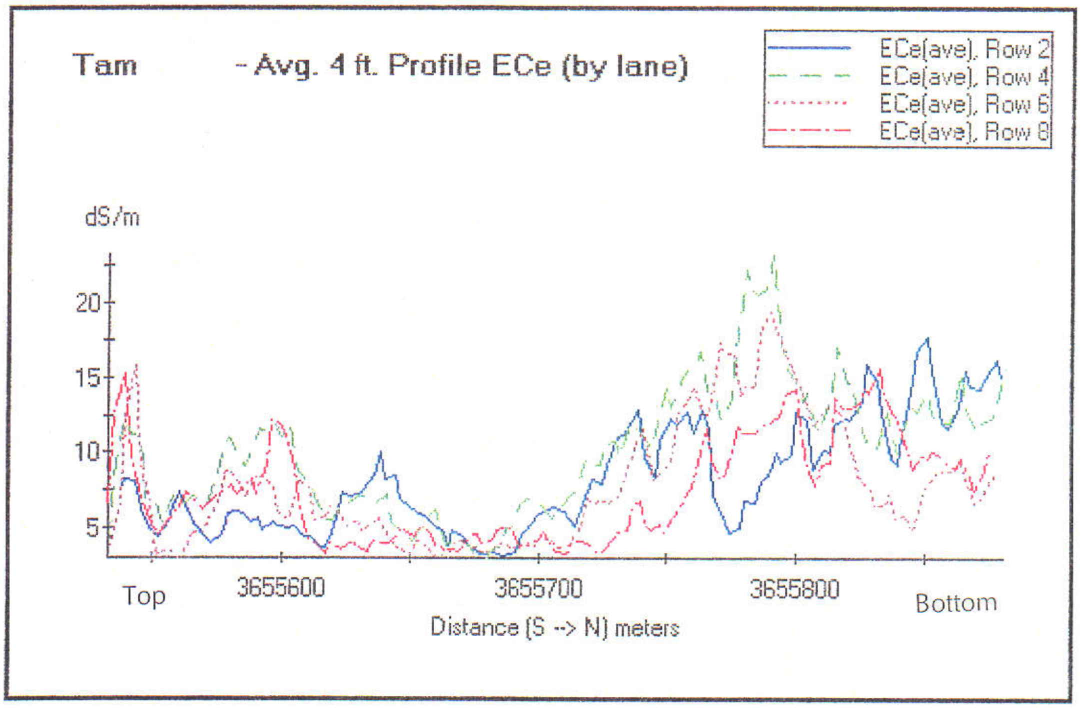
- < 4.61
- 4.61 - 7.35
- 7.35 - 10.08
- > 10.08

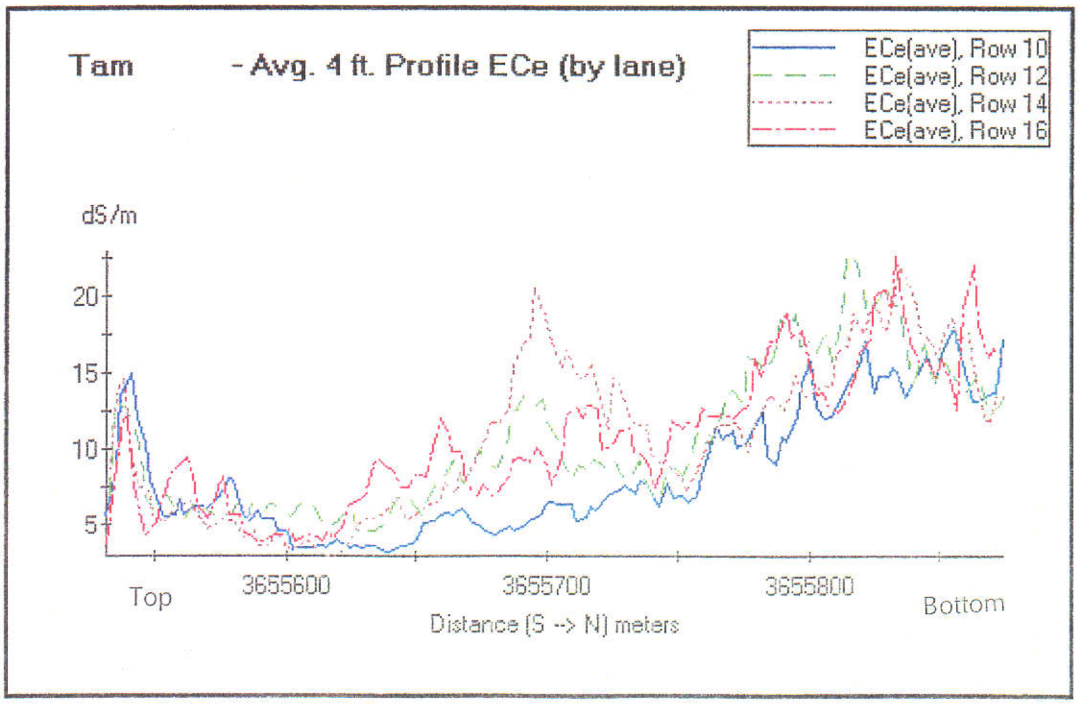
Data Bounds

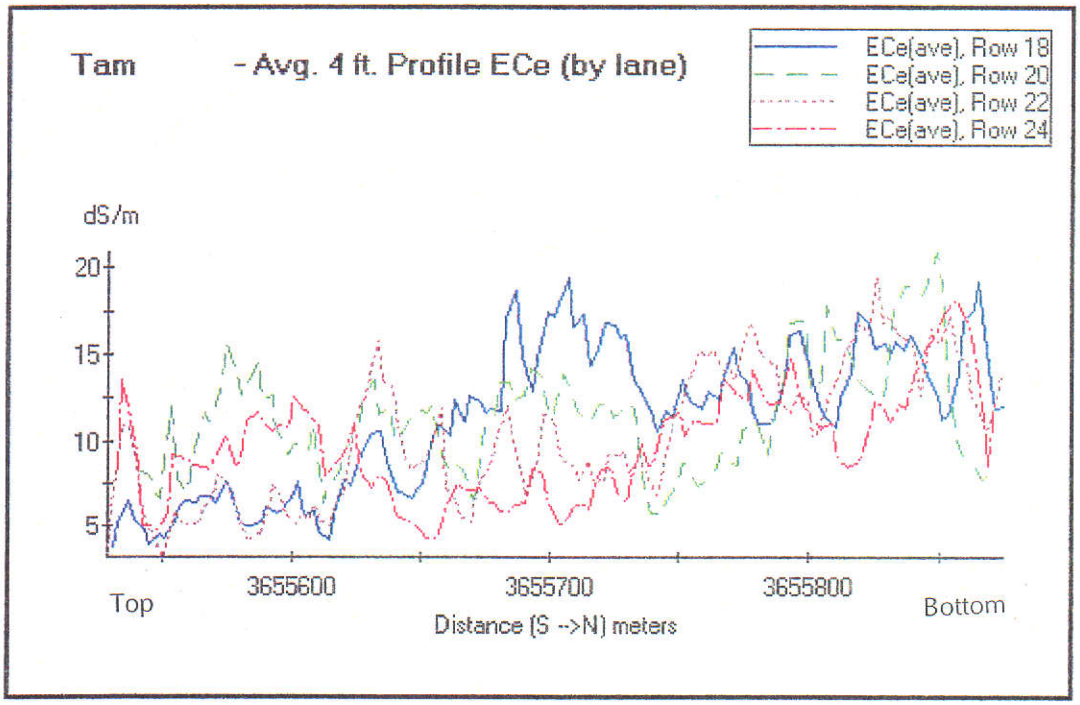
X: min & max
631967.5
632691.34

Y: min & max
3655520.35
3655886.52

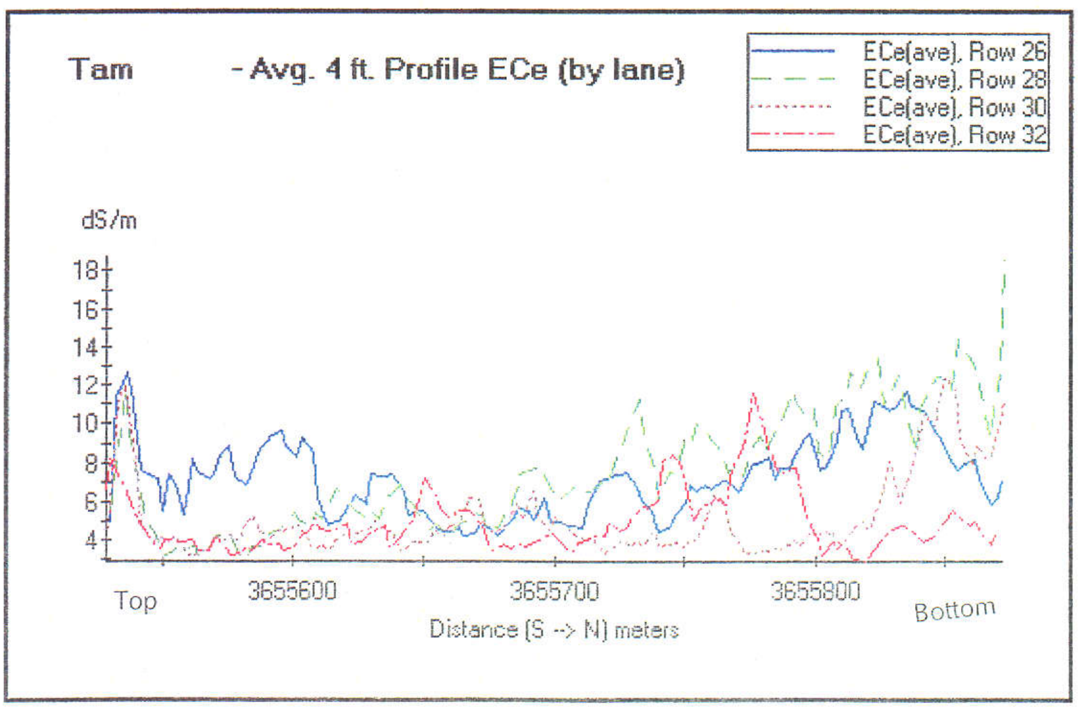



Tam - Avg. 4 ft. Profile ECe (by lane)
ECe(ave), Row 2
ECe(ave), Row 4
ECe(ave), Row 6
ECe(ave), Row 8
dS/m
20
15
10
5
Top
3655600
3655700
3655800
Bottom
Distance (S --> N) meters

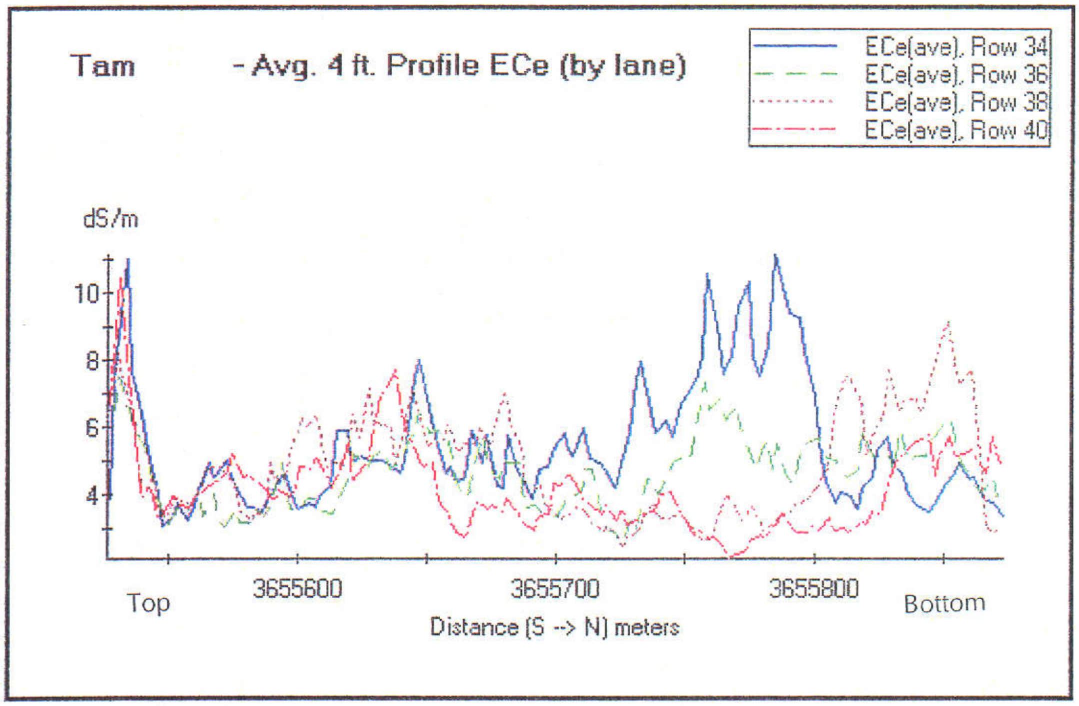

Tam - Avg. 4 ft. Profile ECe (by lane)
ECe(ave), Row 10
ECe(ave), Row 12
ECe(ave), Row 14
ECe(ave), Row 16
dS/m
20
15
10
5
Top
3655600
3655700
3655800
Bottom
Distance (S --> N) meters

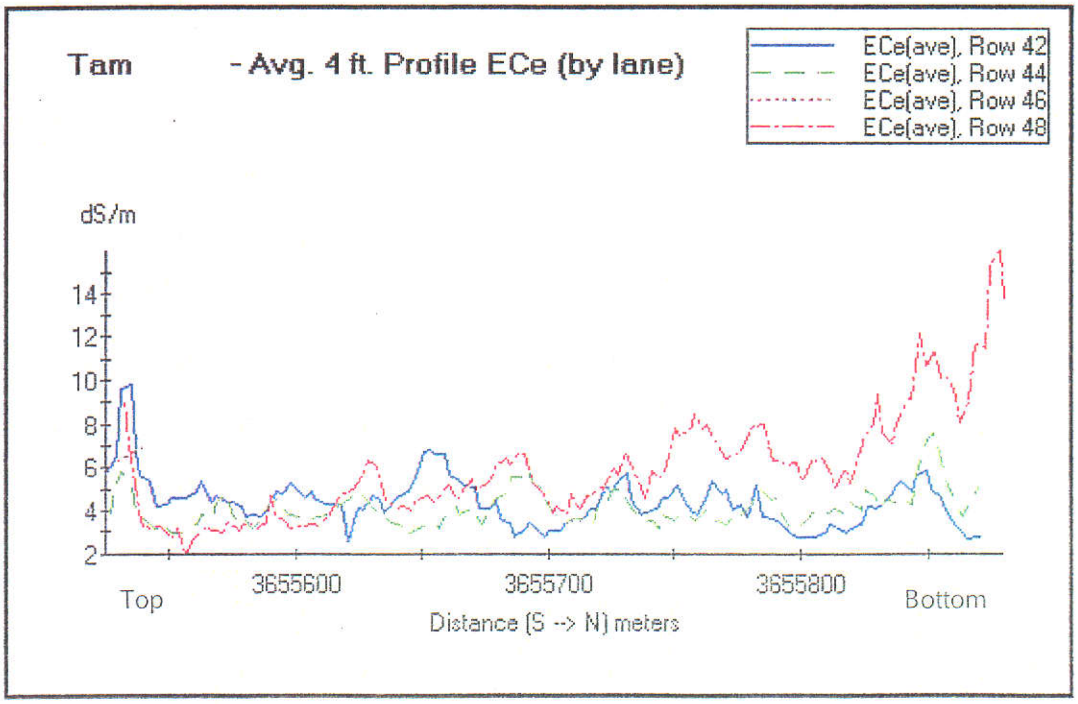


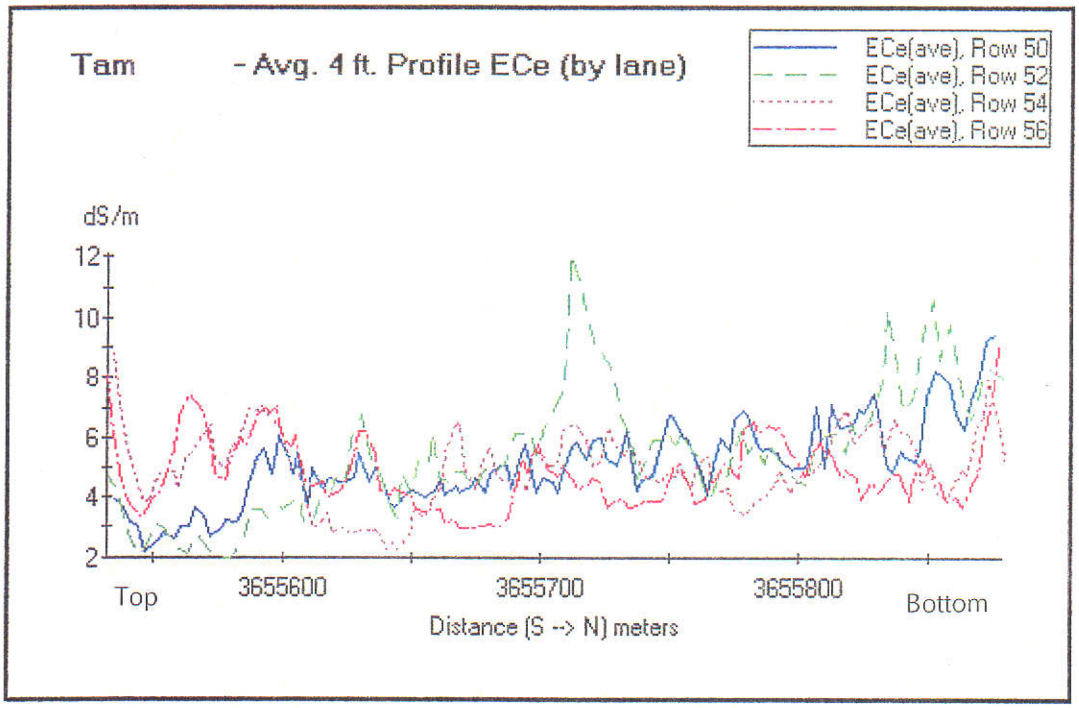
Tam - Avg. 4 ft. Profile ECe (by lane)
ECe(ave), Row 18
ECe(ave), Row 20
ECe(ave), Row 22
ECe(ave), Row 24
dS/m
20
15
10
5
Top
3655600
3655700
3655800
Bottom
Distance (S --> N) meters

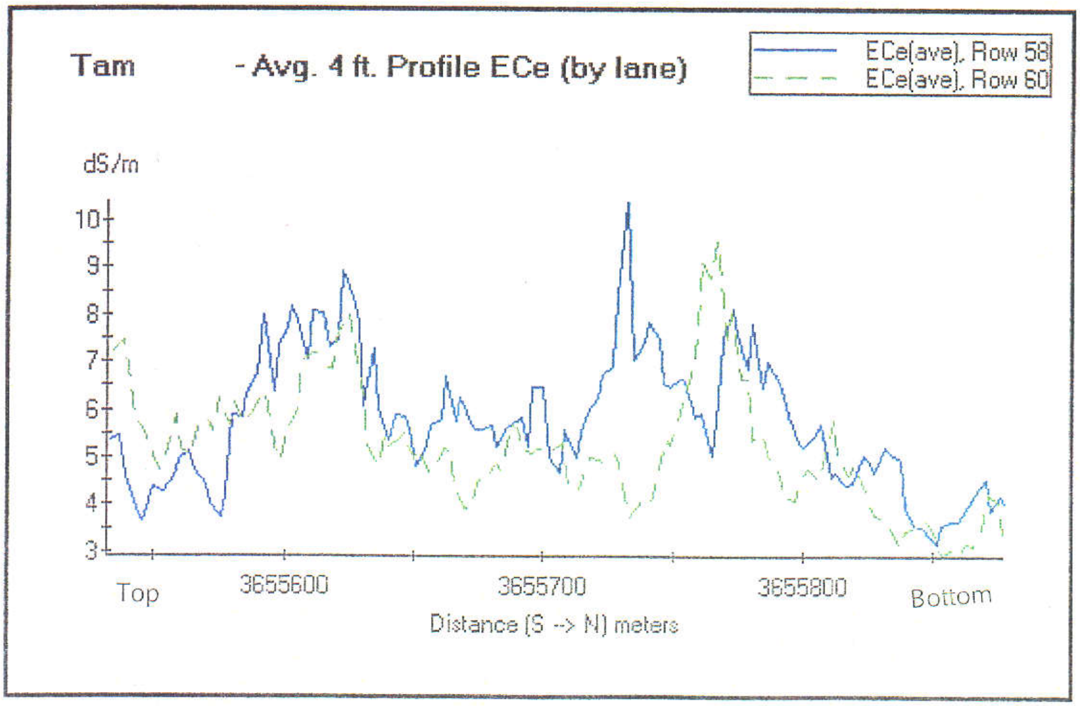


Tam - Avg. 4 ft. Profile ECe (by lane)
ECe(ave), Row 26
ECe(ave), Row 28
ECe(ave), Row 30
ECe(ave), Row 32
dS/m
18
16
14
12
10
8
6
4
Top
3655600
3655700
3655800
Bottom
Distance (S --> N) meters


Tam - Avg. 4 ft. Profile ECe (by lane)
ECe(ave), Row 34
ECe(ave), Row 36
ECe(ave), Row 38
ECe(ave), Row 40
dS/m
10
8
6
4
Top
3655600
3655700
3655800
Bottom
Distance (S --> N) meters


Tam - Avg. 4 ft. Profile ECe (by lane)
ECe(ave), Row 42
ECe(ave), Row 44
ECe(ave), Row 46
ECe(ave), Row 48
dS/m
14
12
10
8
6
4
2
Top
3655600
3655700
3655800
Bottom
Distance (S --> N) meters


Tam - Avg. 4 ft. Profile ECe (by lane)
ECe(ave), Row 50
ECe(ave), Row 52
ECe(ave), Row 54
ECe(ave), Row 56
dS/m
12
10
8
6
4
2
Top
3655600
3655700
3655800
Bottom
Distance (S --> N) meters


Tam - Avg. 4 ft. Profile ECe (by lane)
ECe(ave), Row 58
ECe(ave), Row 60
dS/m
10
9
8
7
6
5
4
3
Top
3655600
3655700
3655800
Bottom
Distance (S --> N) meters

Random Tailwater Data

Tailwater Box ID	Date	Time	Box Width (ft)	Flow Depth (ft)	EC (dS/m)	Temp (C)	Flowrate (cfs)
E33	6/27/00	12:25	1.04	0.29	2.115	36.4	0.55
E33	6/27/00	18:42	1.04	0.54	1.975	30.3	1.38
F14	6/28/00	11:50	1.67	1.58	1.31	28.5	Submerged
H12	6/24/00	12:54	2.25	1.00			Submerged
H12	6/24/00	13:25	2.25	0.26	1.775	40.9	0.98
H12	6/24/00	17:14	2.25	0.63	1.185	38	3.78
H12	6/24/00	20:00	2.25	0.83	1.15	31.9	5.70
H12	6/25/00	10:50	2.25	1.53	1.285	29.3	Submerged
H12	6/25/00	11:10	2.25	1.25	1.315	29.4	Submerged
H12	6/25/00	11:25	2.25	0.71	1.359	29.3	4.47
H12	6/25/00	12:00	2.25	0.19	1.491	28.5	0.63
H12	6/25/00	12:45	2.25	0.35	1.61	28	1.58
H12	6/25/00	12:55	2.25	0.08	1.735	28.5	0.18
H12	6/25/00	13:38	2.25	0.33	1.87	27.8	1.44
H12	6/25/00	14:10	2.25	0.02	1.975	27.2	0.02
H14	6/25/00	7:00	1.63	0.13	1.295	25.8	0.24
H14	6/25/00	10:55	1.63	0.08	1.43	29.6	0.13
H14	6/25/00	11:30	1.63	1.00	1.509	29.2	Submerged
H14	6/25/00	11:55	1.63	0.67	1.559	29.1	2.95
H14	6/25/00	12:20	1.63	0.50	1.573	28.5	1.91
H14	6/25/00	13:10	1.63	0.27	1.66	28.3	0.76
H14	6/25/00	13:30	1.63	0.22	1.776	26.8	0.55
H14	6/25/00	14:05	1.63	0.13	2.033	26.7	0.24
H16	6/27/00	12:10	1.67	1.25	2.425	36.3	Submerged
H22	6/27/00	12:20	1.75	1.08	1.78	33.9	Submerged
H22	6/27/00	19:21	1.75	0.83	1.952	31.8	4.43
I8	6/24/00	13:10	1.67	0.25	1.213	40.3	0.69
J12	6/27/00	9:30	2.08	1.04	2.32	33.1	Submerged
J12	6/27/00	11:55	2.08	0.34	3.56	37	1.39
J14	6/27/00	9:36	2.00	0.42	2.1	32.5	1.79
J14	6/27/00	11:55	2.00	0.75	2.505	35.9	4.33
J14	6/27/00	19:00	2.00	1.08	1.551	30.3	Submerged
MH203A	6/28/00	8:55	2.00	0.17	1.306	27.4	0.45
T6_109	6/28/00	16:50	1.50	0.13	1.946	34.8	0.22

If depth of water over weir is one foot or more it was assumed that the weir was submerged. At these depths the tailwater boxes have a tendency to backup submerging the weir.

Nec. - 0 to 1 ft

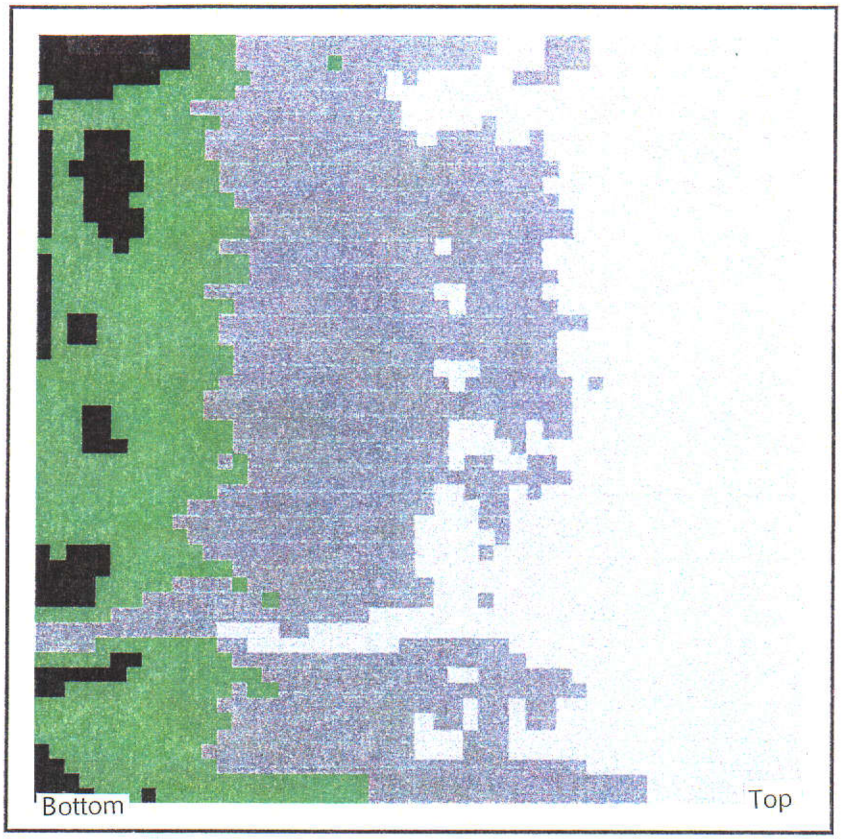
ECe(0.5)
dS/m

- < 10
- 10 - 14
- 14 - 18
- > 18

Data Bounds

X: min & max
642213.47
643003

Y: min & max
3663875.34
3664633.63



1 to 2 ft.

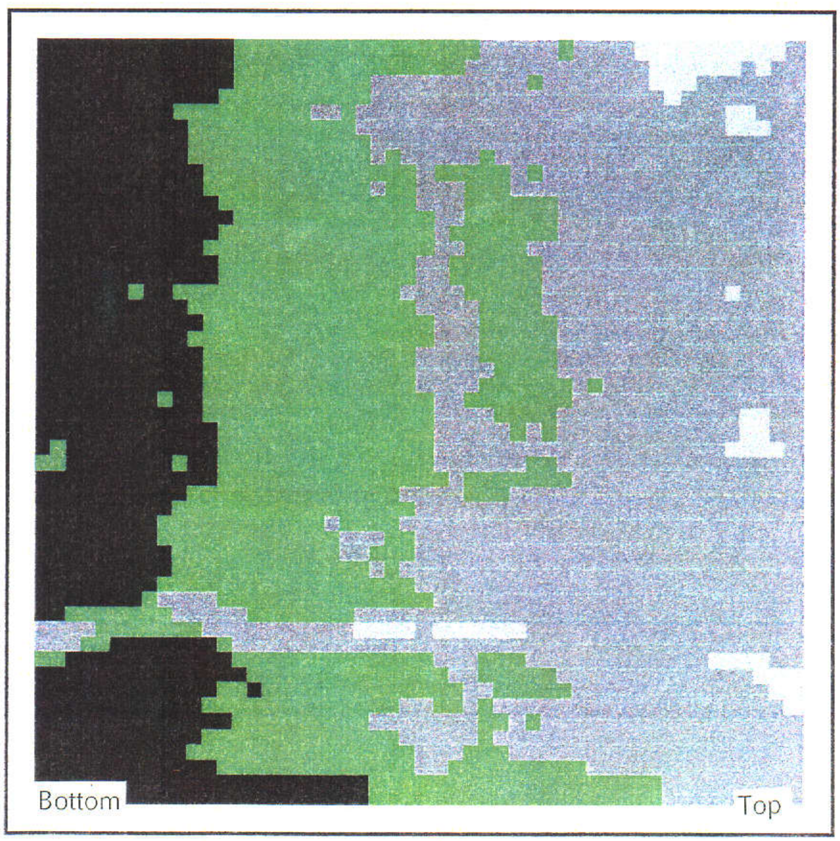
ECe(1.5)
dS/m

- < 10
- 10 - 14
- 14 - 18
- > 18

Data Bounds

X: min & max
642213.47
643003

Y: min & max
3663875.34
3664633.63



Nec. - 2 to 3 ft.

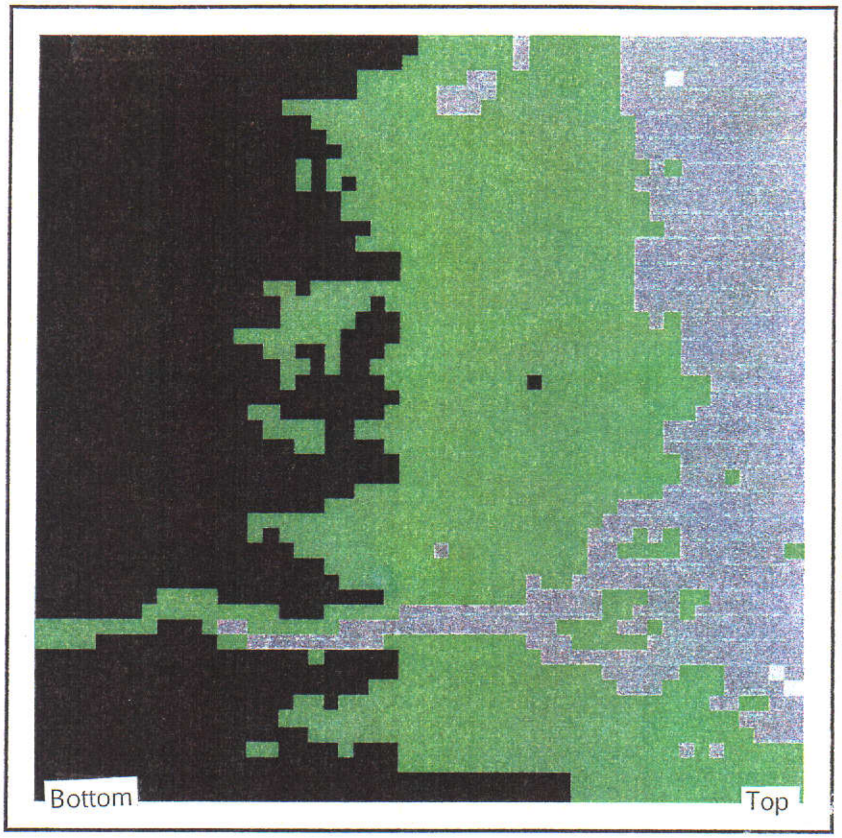
ECe(2.5)
dS/m

< 10
10 - 14
14 - 18
> 18

Data Bounds

X: min & max
642213.47
643003

Y: min & max
3663875.34
3664633.63



3 to 4 ft.

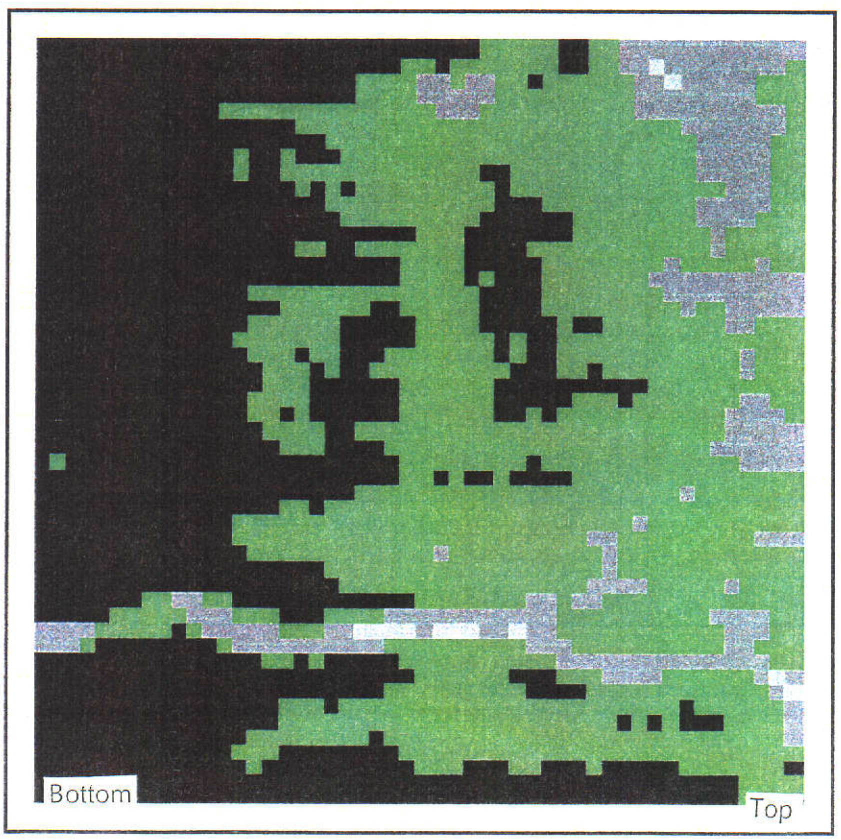
ECe(3.5)
dS/m

< 10
10 - 14
14 - 18
> 18

Data Bounds

X: min & max
642213.47
643003

Y: min & max
3663875.34
3664633.63



Nec. - Avg. EC in 4 ft. Profile

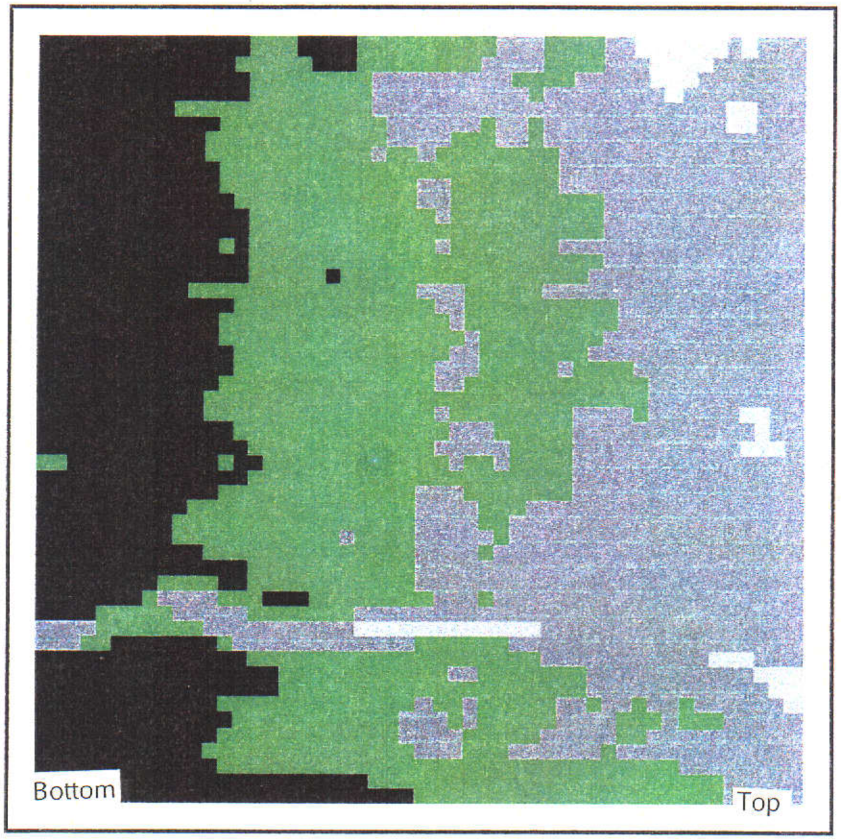
ECe(ave)
dS/m

- < 10
- 10 - 14
- 14 - 18
- > 18

Data Bounds

X: min & max
642213.47
643003

Y: min & max
3663875.34
3664633.63



Nec. - 0 to 1 ft. (autoscale)

ECe(0.5)
dS/m

< 9.22

9.22 - 11.58

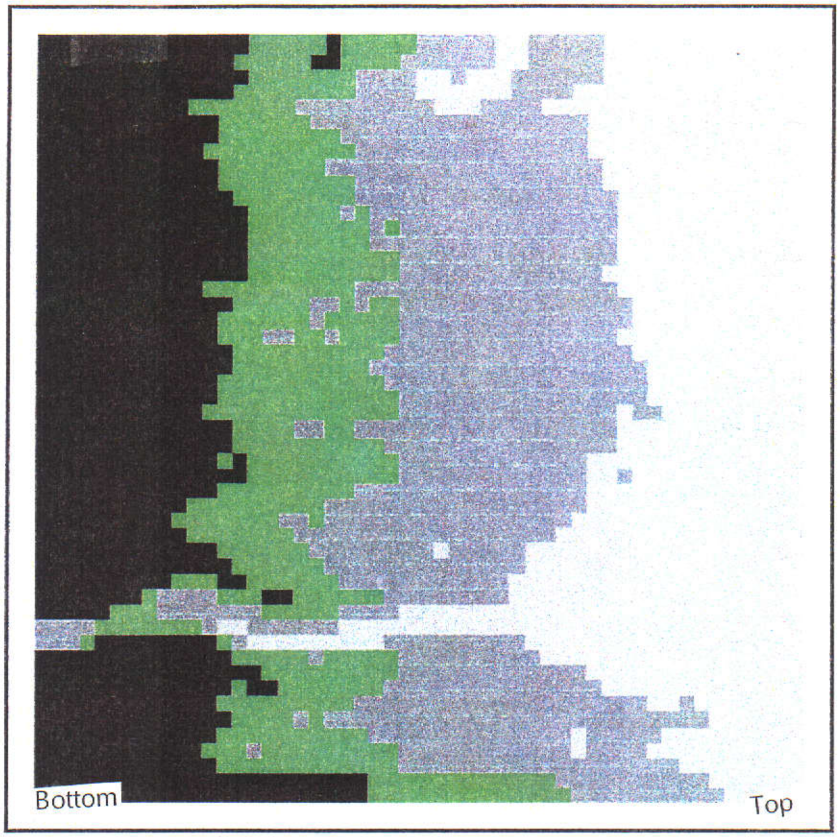
11.58 - 13.94

> 13.94

Data Bounds

X: min & max
642213.47
643003

Y: min & max
3663875.34
3664633.63



1 to 2 ft. (autoscale)

ECe(1.5)
dS/m

< 12.74

12.74 - 15.05

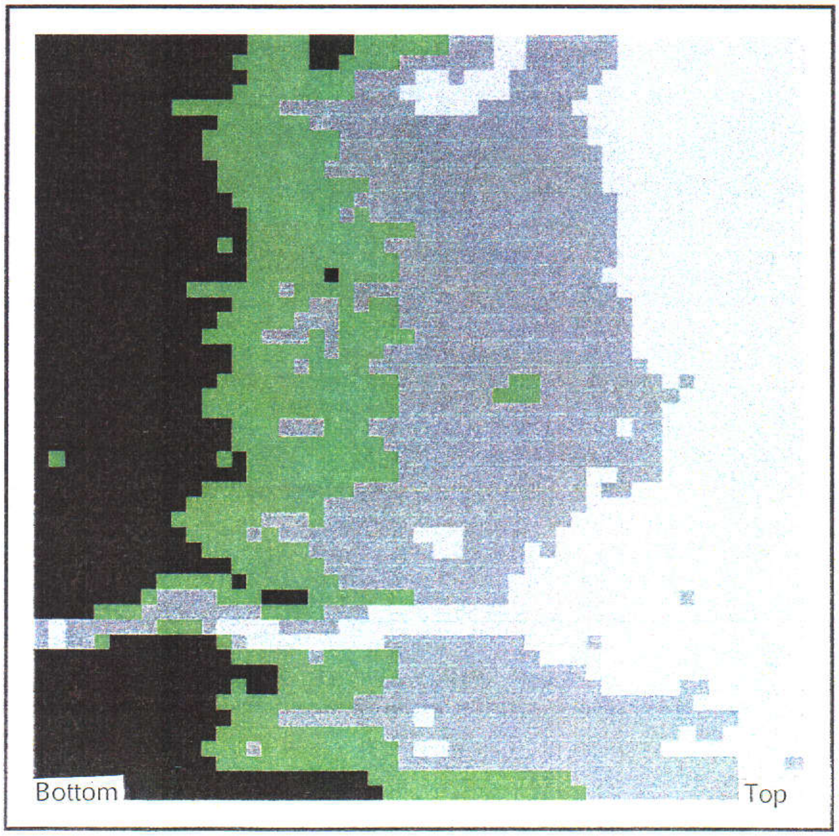
15.05 - 17.37

> 17.37

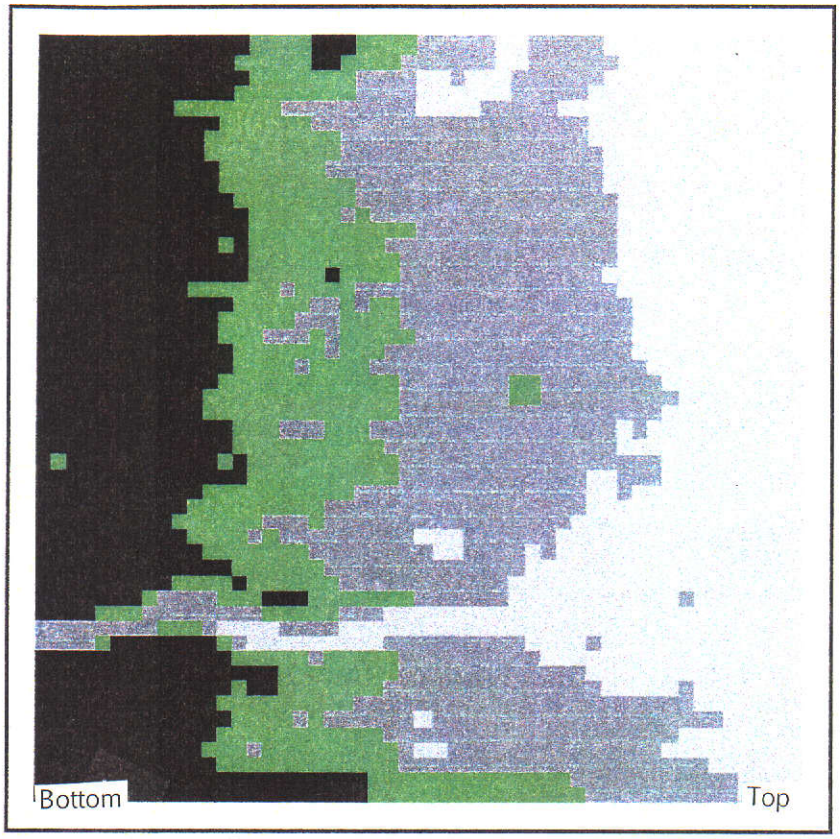
Data Bounds

X: min & max
642213.47
643003

Y: min & max
3663875.34
3664633.63



Nec. - 2 to 3 ft. (autoscale)



ECe(2.5)
dS/m

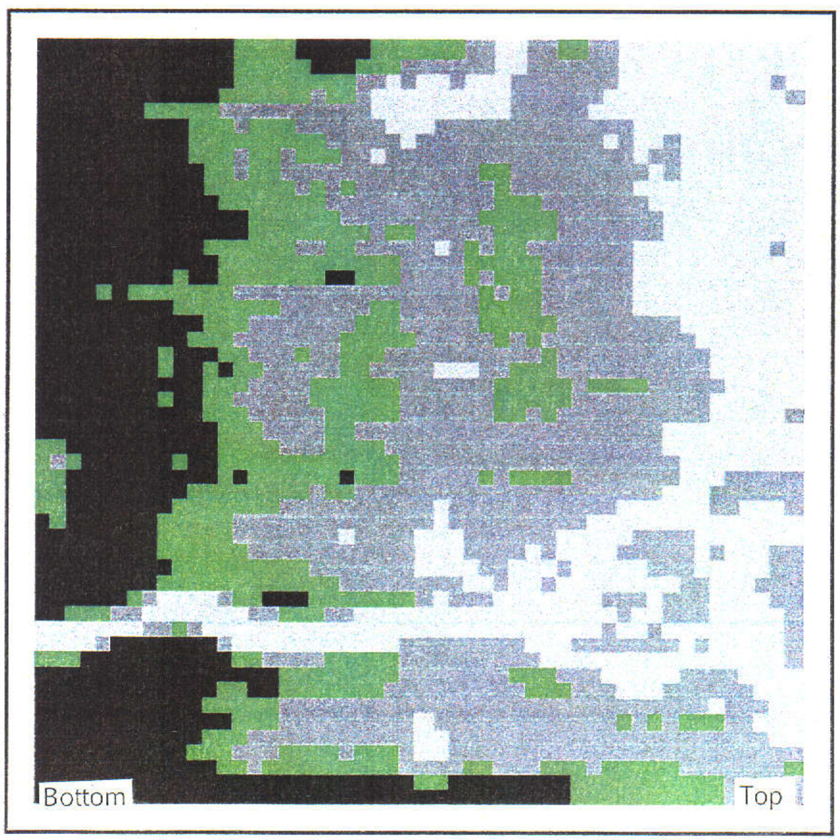
- < 14.77
- 14.77 - 17.65
- 17.65 - 20.54
- > 20.54

Data Bounds

X: min & max
642213.47
643003

Y: min & max
3663875.34
3664633.63

3 to 4 ft. (autoscale)



ECe(3.5)
dS/m

- < 15.38
- 15.38 - 18.12
- 18.12 - 20.85
- > 20.85

Data Bounds

X: min & max
642213.47
643003

Y: min & max
3663875.34
3664633.63

Nec.   - 4 ft. Profile Avg. (autoscale)

ECe(ave)
dS/m

< 13.08

13.08 - 15.64

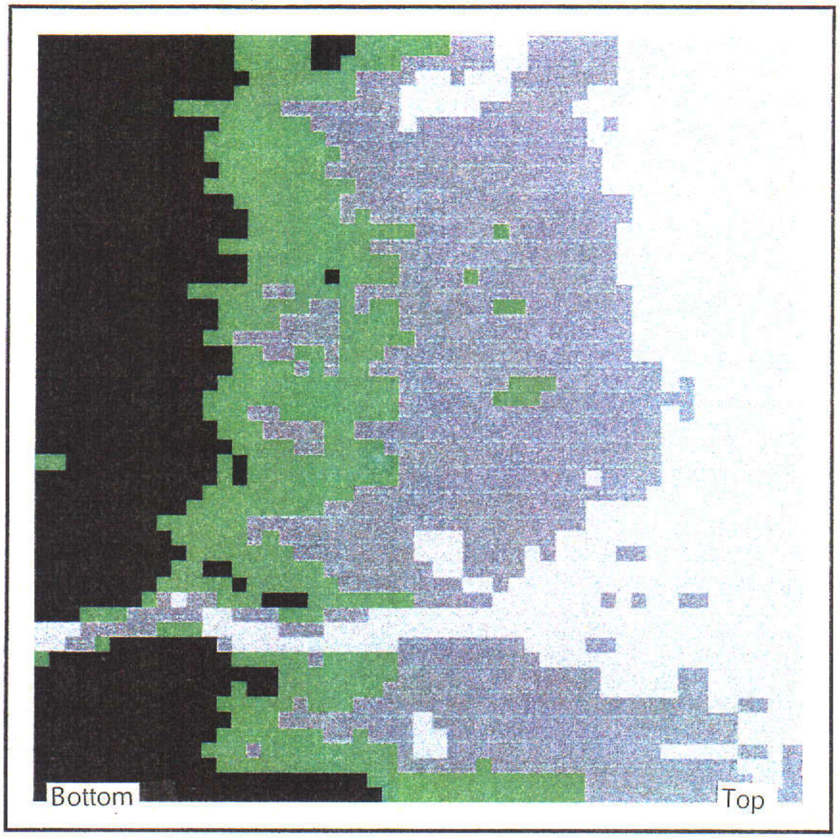
15.64 - 18.21

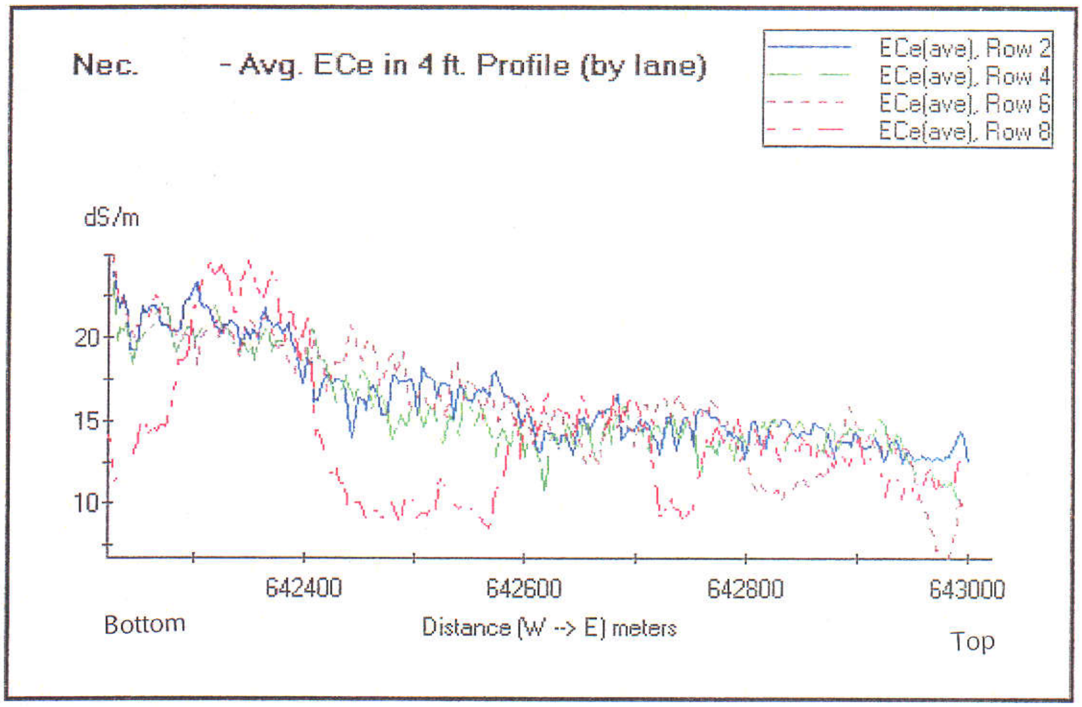
> 18.21

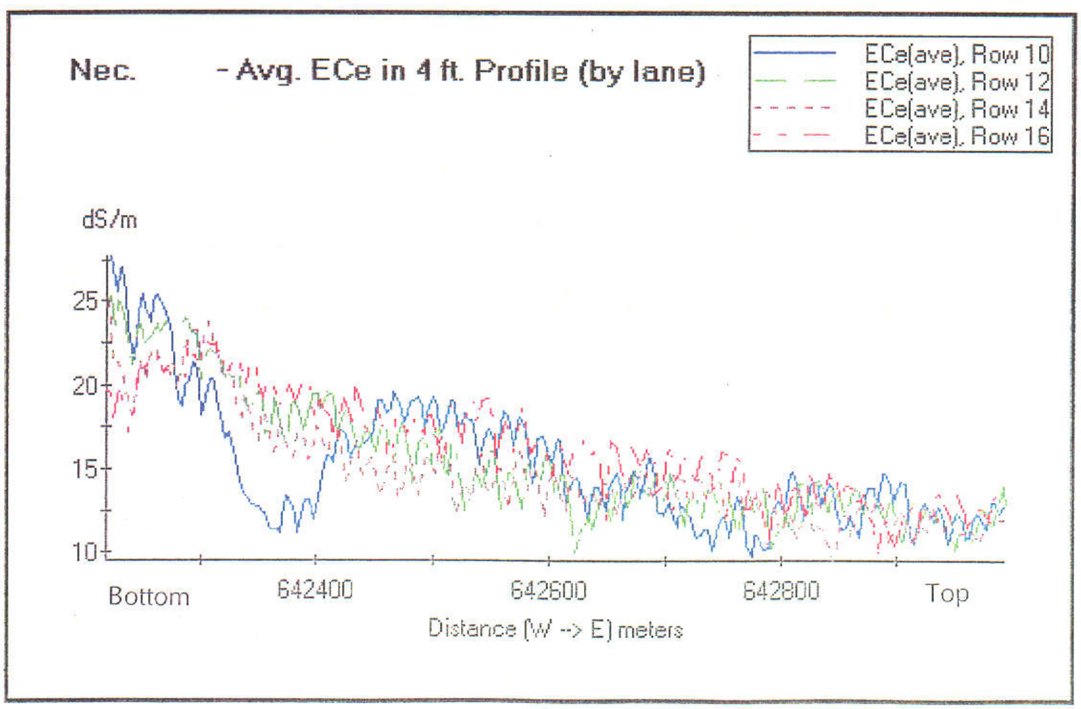
Data Bounds

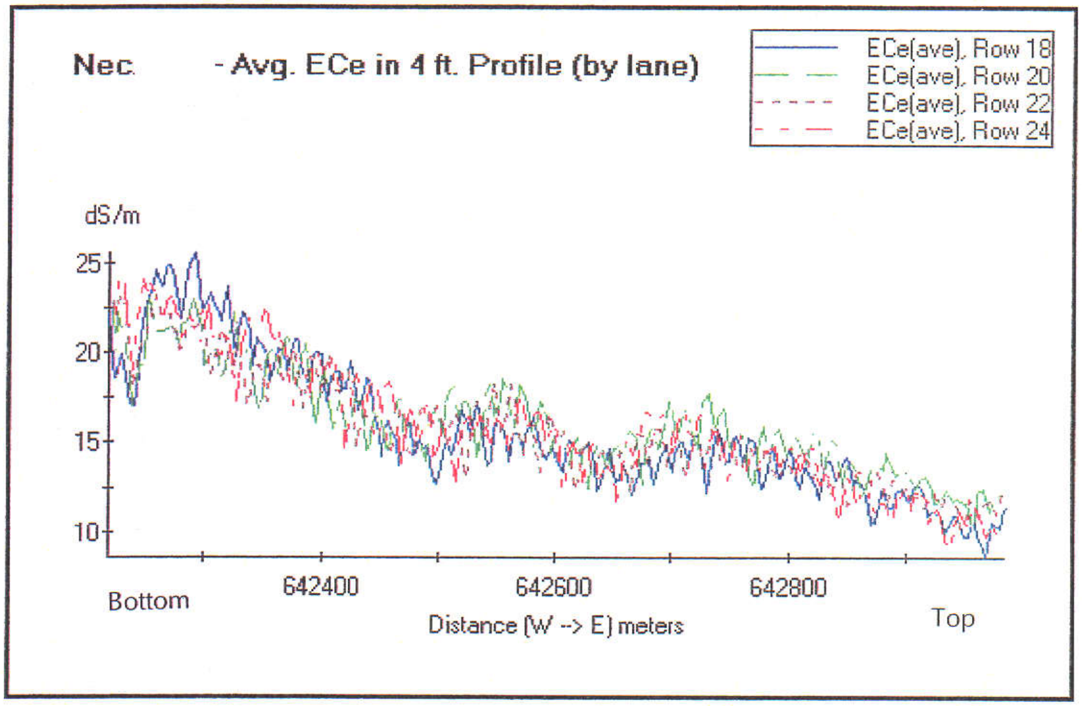
X: min & max
642213.47
643003

Y: min & max
3663875.34
3664633.63

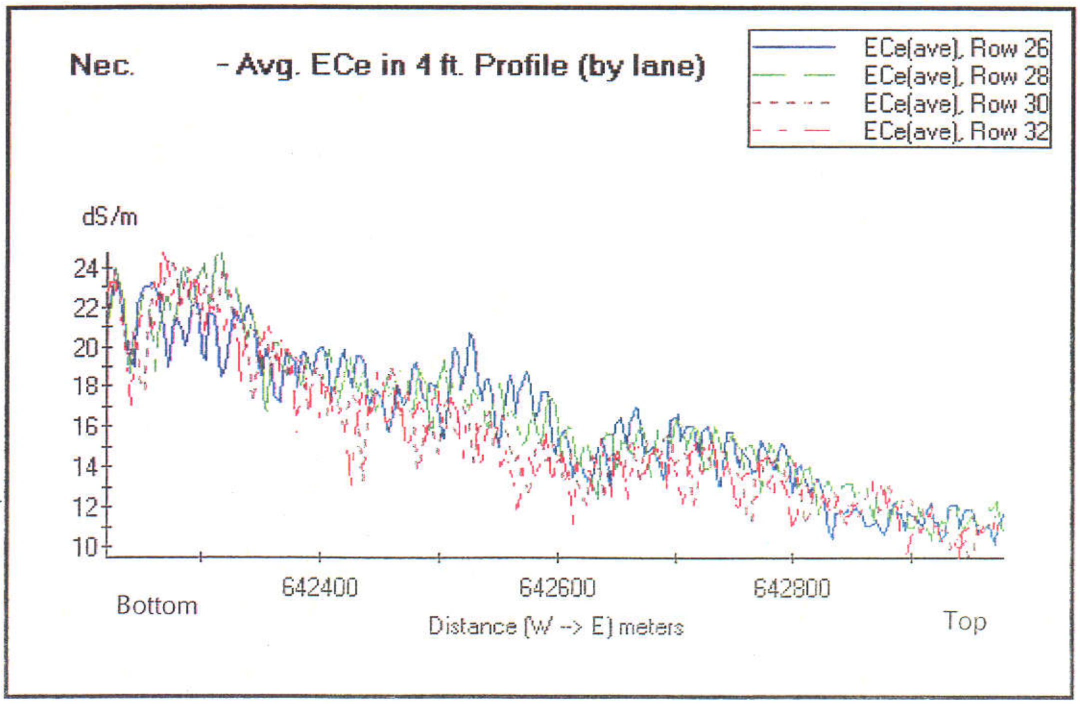



Nec. - Avg. ECe in 4 ft. Profile (by lane)
ECe(ave), Row 2
ECe(ave), Row 4
ECe(ave), Row 6
ECe(ave), Row 8
dS/m
20
15
10
642400
642600
642800
643000
Bottom
Distance (W --> E) meters
Top

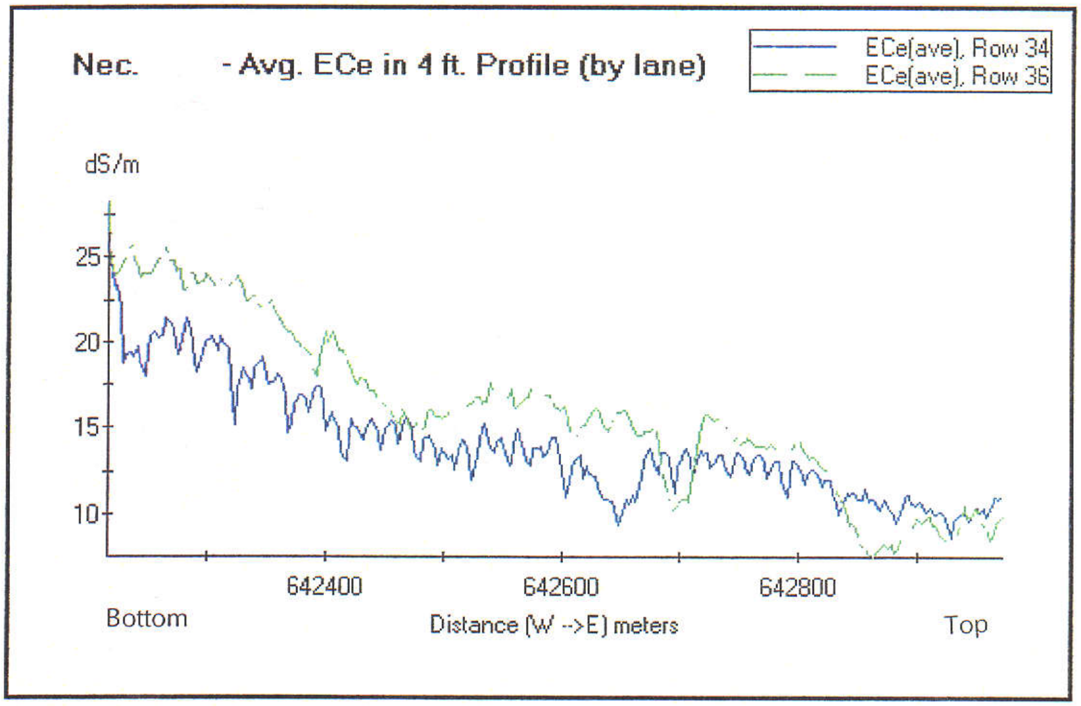

Nec. - Avg. ECe in 4 ft. Profile (by lane)
ECe(ave), Row 10
ECe(ave), Row 12
ECe(ave), Row 14
ECe(ave), Row 16
dS/m
25
20
15
10
Bottom
642400
642600
642800
Top
Distance (W --> E) meters



Nec. - Avg. ECe in 4 ft. Profile (by lane)
ECe(ave), Row 18
ECe(ave), Row 20
ECe(ave), Row 22
ECe(ave), Row 24
dS/m
25
20
15
10
Bottom
642400
642600
642800
Top
Distance (W --> E) meters



Nec. - Avg. ECe in 4 ft. Profile (by lane)
ECe(ave), Row 26
ECe(ave), Row 28
ECe(ave), Row 30
ECe(ave), Row 32
dS/m
24
22
20
18
16
14
12
10
Bottom
642400
642600
642800
Top
Distance (W --> E) meters



Nec. - Avg. ECe in 4 ft. Profile (by lane)
ECe(ave), Row 34
ECe(ave), Row 36
dS/m
25
20
15
10
642400
642600
642800
Bottom
Distance (W -->E) meters
Top

APPENDIX 8

Imperial Irrigation District Water Volume Balance Data and Calculations

Raw Data for the IID Water Budget

Water balance component	Units	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
Delivery to AAC at Pilot Knob	1000 ac-ft	3278.63	3376.80	3419.70	3211.12	2876.37	3084.86	3368.61	3391.42	3485.72	3492.00	3298.52
Water Delivered to Coachella Canal	1000 ac-ft	324.75	351.26	359.40	307.83	297.48	307.03	318.85	320.78	327.46	324.03	323.89
Deliveries to IID Farms above EHL	1000 ac-ft	3.13	3.13	3.46	6.05	4.49	2.77	1.81	1.77	1.55	0.57	2.87
M&I Deliveries	1000 ac-ft	62.25	65.89	69.83	72.12	72.71	75.11	76.11	78.68	78.72	78.19	72.96
M&I Returnflows	1000 ac-ft	13.57	14.55	15.79	16.08	16.70	17.31	17.61	18.38	18.39	18.36	16.67
Alamo River outflow to Sea	1000 ac-ft	558.69	593.66	617.87	594.13	546.04	617.03	641.07	646.17	640.97	636.81	609.24
New River outflow to Sea	1000 ac-ft	488.94	431.43	430.51	410.63	396.60	460.30	443.06	472.69	436.59	487.22	445.80
Direct outflow to Sea	1000 ac-ft	100.05	96.11	91.09	88.34	80.73	88.59	108.81	115.13	114.00	107.09	98.99
Mesa Storm inflows	1000 ac-ft	2.40	1.97	2.38	4.61	8.07	7.07	3.36	2.78	1.06	4.29	3.80
Subsurface inflow to drains (external sources)	1000 ac-ft	20	20	20	20	20	20	20	20	20	20	20
Subsurface outflow to Salton sea	1000 ac-ft	1	1	1	1	1	1	1	1	1	1	1.00
Surface Inflow from Mexico	1000 ac-ft	228.95	155.32	135.08	132.73	144.89	192.10	147.00	150.00	119.76	162.42	156.82
Reference ET	ft	7.1	7.44	6.85	5.87	5.89	6.52	6.67	6.8	7.23	6.75	6.71
Rainfall	ft	0.152	0.125	0.151	0.292	0.511	0.448	0.213	0.176	0.067	0.272	0.24
Non-Ag land rainfall E and ET (fraction)		0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Agricultural land	ac	486,476	486,565	485,863	482,833	480,567	480,270	477,705	478,515	477,615	478,158	481,457
Phreatophyte acerage	ac	11,424	11,424	11,424	11,424	11,424	11,424	11,424	11,424	11,424	11,424	11,424
Water surface area - canals & reservoirs	ac	3,401	3,401	3,401	3,401	3,401	3,401	3,401	3,401	3,401	3,401	3,401
Water surface area of drains and rivers	ac	2,357	2,357	2,357	2,357	2,357	2,357	2,357	2,357	2,357	2,357	2,357
Other Non-ag land area	ac	152,648	152,559	153,261	156,291	158,557	158,854	161,419	160,609	161,509	160,966	157,667
Total Area	ac	656,306	656,306	656,306	656,306	656,306	656,306	656,306	656,306	656,306	656,306	656,306
ET factor for canals		1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
ET factor for reservoirs and ponds		1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
ET factor for phreatophytes		1	1	1	1	1	1	1	1	1	1	1
ET fractor for drains & rivers		1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Seepage (PK to EHL)	1000 ac-ft	94.2	94.2	94.2	94.2	94.2	94.2	94.2	94.2	94.2	94.2	94.20
Water surface area (PK to EHL)	ac	756	756	756	756	756	756	756	756	756	756	756.00
District storage change	1000 ac-ft	0	0	0	0	0	0	0	0	0	0	0.00
rainfall consumption fraction on Ag-land		0.92	0.97	1.00	0.96	0.85	0.88	0.89	0.94	0.89	0.92	0.92
Colorado Water Delivered to Farms	1000 ac-ft	2,481.95	2,565.16	2,611.09	2,448.04	2,106.06	2,329.34	2,576.67	2,581.03	2,715.16	2,689.84	2,510.43
Delivery to IID farms from Coachella Canal	1000 ac-ft	4.03	4.03	3.35	3.58	3.85	4.24	4.43	4.44	4.29	5.19	4.14
Total Internal canal seepage	1000 ac-ft	103.92	103.92	99.72	93.58	88.68	80.97	77.02	76.13	76.13	76.00	87.61
Main canal seepage	1000 ac-ft	66.60	66.60	65.67	65.09	65.09	63.05	63.05	63.05	63.05	63.00	64.43
Main canal spills to drains	1000 ac-ft	6.65	5.81	7.18	7.48	4.24	3.34	3.20	3.92	3.92	1.49	4.72
Lateral canal spills	%	0.031	0.029	0.031	0.031	0.037	0.036	0.037	0.038	0.038	0.031	0.03
Delivered to Interceptor canals	1000 ac-ft	0	0	0	0	0	0	131.191	130.008	298.379	304.832	86.44
Interceptor Volume spilled	1000 ac-ft	0	0	0	0	0	0	0.965	1.223	3.937	4.127	1.03

IID System-Wide Water Budget

		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
All American Canal inflow		Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	
		(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)
Delivery to AAC at Pilot Knob		3,278.6	3,376.8	3,419.7	3,211.1	2,876.4	3,084.9	3,368.6	3,391.4	3,485.7	3,492.0	3,298.5
Water Delivered to Coachella Canal		-324.8	-351.3	-359.4	-307.8	-297.5	-307.0	-318.9	-320.8	-327.5	-324.0	-323.9
Deliveries to IID Farms above EHL		-3.1	-3.1	-3.5	-6.1	-4.5	-2.8	-1.8	-1.8	-1.5	-0.6	-2.9
Seepage (PK to EHL)		-94.2	-94.2	-94.2	-94.2	-94.2	-94.2	-94.2	-94.2	-94.2	-94.2	-94.2
Evaporation between PK and EHL		-5.9	-6.2	-5.7	-4.9	-4.9	-5.4	-5.5	-5.7	-6.0	-5.6	-5.6
All American Canal inflow	Sum =	2,850.6	2,922.0	2,956.9	2,798.2	2,475.3	2,675.4	2,948.2	2,969.0	3,056.5	3,067.6	2,872.0
Surface and subsurface inflows		Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	
		(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)
All American Canal inflow		2,850.6	2,922.0	2,956.9	2,798.2	2,475.3	2,675.4	2,948.2	2,969.0	3,056.5	3,067.6	2,872.0
Surface Inflow from Mexico		229.0	155.3	135.1	132.7	144.9	192.1	147.0	150.0	119.8	162.4	156.8
Rainfall Volume		99.8	82.0	99.1	191.6	335.4	294.0	139.8	115.5	44.0	178.5	158.0
Other surface inflows		2.4	2.0	2.4	4.6	8.1	7.1	3.4	2.8	1.1	4.3	3.8
Subsurface inflows		20	20	20	20	20	20	20	20	20	20	20.0
Total Inflow	Sum =	3,201.8	3,181.4	3,213.5	3,147.1	2,983.6	3,188.6	3,258.4	3,257.3	3,241.3	3,432.8	3,210.6
Surface and subsurface outflows		Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	
		(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)
Alamo River outflow to Sea		558.7	593.7	617.9	594.1	546.0	617.0	641.1	646.2	641.0	636.8	609.2
New River outflow to Sea		488.9	431.4	430.5	410.6	396.6	460.3	443.1	472.7	436.6	487.2	445.8
Direct outflow to Sea		100.1	96.1	91.1	88.3	80.7	88.6	108.8	115.1	114.0	107.1	99.0
Subsurface outflow to Salton sea		1	1	1	1	1	1	1	1	1	1	1.0
Total outflow	Sum =	1,148.7	1,122.2	1,140.5	1,094.1	1,024.4	1,166.9	1,193.9	1,235.0	1,192.6	1,232.1	1,155.0
Total water consumption		Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	
		(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)
Total inflow		3,201.8	3,181.4	3,213.5	3,147.1	2,983.6	3,188.6	3,258.4	3,257.3	3,241.3	3,432.8	3,210.6
Total outflow		-1,148.7	-1,122.2	-1,140.5	-1,094.1	-1,024.4	-1,166.9	-1,193.9	-1,235.0	-1,192.6	-1,232.1	-1,155.0
Change in storage		0	0	0	0	0	0	0	0	0	0	0.0
Total water consumption	Sum =	2,053.1	2,059.2	2,073.0	2,053.0	1,959.2	2,021.7	2,064.4	2,022.3	2,048.7	2,200.7	2,055.5
Total water consumption on Ag. land		Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	
		(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)
Total water consumption		2,053.1	2,059.2	2,073.0	2,053.0	1,959.2	2,021.7	2,064.4	2,022.3	2,048.7	2,200.7	2,055.5
Canal and Reservoir Evap.		-26.6	-27.8	-25.6	-22.0	-22.0	-24.4	-25.0	-25.4	-27.0	-25.3	-25.1
M & I consumption		-48.7	-51.3	-54.0	-56.0	-56.0	-57.8	-58.5	-60.3	-60.3	-59.8	-56.3
ET - drains, rivers, phreatophytes		-99.5	-104.3	-96.0	-82.3	-82.6	-91.4	-93.5	-95.3	-101.3	-94.6	-94.1
ET - rainfall on non-Ag land		-17.4	-14.3	-17.4	-34.2	-60.8	-53.4	-25.8	-21.2	-8.1	-32.8	-28.5
Total water consumption on Ag. land		1,860.9	1,861.4	1,880.0	1,858.5	1,737.9	1,794.8	1,861.7	1,820.1	1,851.9	1,988.1	1,851.5
Irrigation Water consum. on Ag. land		Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	
		(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)
Total water consumption on Ag. land		1,860.9	1,861.4	1,880.0	1,858.5	1,737.9	1,794.8	1,861.7	1,820.1	1,851.9	1,988.1	1,851.5
Rainfall consumption on Ag-land		-68.4	-59.0	-73.4	-135.1	-209.7	-190.4	-90.9	-79.3	-28.6	-119.7	-105.4
Irrigation Water consum. on Ag. land	Sum =	1,792.6	1,802.3	1,806.7	1,723.5	1,528.2	1,604.4	1,770.8	1,740.8	1,823.3	1,868.5	1,746.1

Canal Subsystem Water Budget

		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
Canal deliveries as remainder		Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	
		(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)
Net Irrigation Water Supply		2,788.4	2,856.1	2,887.1	2,726.0	2,402.6	2,600.3	2,872.1	2,890.3	2,977.8	2,989.4	2,799.0
Canal and Reservoir Evap.		-26.0	-27.4	-25.1	-21.0	-20.3	-22.9	-24.2	-24.8	-26.8	-24.3	-24.3
Canal seepage		-103.9	-103.9	-99.7	-93.6	-88.7	-81.0	-77.0	-76.1	-76.1	-76.0	-87.6
Main canal spills		-6.6	-5.8	-7.2	-7.5	-4.2	-3.3	-3.2	-3.9	-3.9	-1.5	-4.7
Lateral spills		-83.8	-80.3	-86.8	-81.9	-85.9	-90.8	-99.5	-103.1	-102.7	-85.0	-90.0
change in storage		0	0	0	0	0	0	0	0	0	0	0.0
Delivered to Farms	Sum =	2,568.0	2,638.7	2,668.3	2,522.1	2,203.4	2,402.4	2,668.2	2,682.4	2,768.2	2,802.6	2,592.4

On-farm Subsystem Water Budget

		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
Farm irrigation water outflow to drains (tailwater an		Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	Vol Bal	
		(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)	(1,000 ac-ft)
Delivered to Farms		2,568.0	2,638.7	2,668.3	2,522.1	2,203.4	2,402.4	2,668.2	2,682.4	2,768.2	2,802.6	2,592.4
Irrigation Water consum. on Ag. land		-1,792.6	-1,802.3	-1,806.7	-1,723.5	-1,528.2	-1,604.4	-1,770.8	-1,740.8	-1,823.3	-1,868.5	-1,746.1
Farm irrigation water outflow to drains (tailwater and deep percolation)	Sum =	775.5	836.3	861.6	798.6	675.3	798.0	897.3	941.6	944.9	934.1	846.3

APPENDIX 9

Review of Water Use Assessment Reports Prepared by Marvin E. Jensen in 1995 and 1997

NRCE

REVIEW OF WATER USE ASSESSMENT REPORTS PREPARED BY MARVIN E. JENSEN IN 1995 AND 1997

March 12, 2002

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SECTION 1 WATER USE ASSESSMENT OF THE IMPERIAL IRRIGATION DISTRICT (JENSEN, 1995)

I. INTRODUCTION

In 1995, the U.S. Bureau of Reclamation (USBR) expressed concern that diversions from the Colorado River to Imperial Irrigation District (IID) did not decrease as the USBR expected after IID implemented the water conservation measures as part of an agreement with Metropolitan Water District of Southern California (IID/MWD Agreement). Apparently due to this concern, the USBR commissioned a study by Marvin E. Jensen to assess the water use of IID. In his report, *Water Use Assessment of the Imperial Irrigation District* (Jensen, 1995), Jensen concluded that on-farm system improvements and irrigation scheduling improvements should be implemented within IID. This section contains an overview, evaluation, and summary of the 1995 Jensen Report.

II. OVERVIEW OF REPORT

The overview of the 1995 Jensen Report summarizes the report's purpose, methodology, and conclusions.

1. Purpose

The introduction of the 1995 Jensen Report states:

- *The purpose of the study was to assess the use of Colorado River water by IID to determine why diversions have not decreased as conservation measures have been implemented. A secondary purpose was to identify alternative mechanisms for Reclamation and IID to consider in implementing more effective conservation measures. Another purpose was to develop procedures for use by Reclamation in taking a more proactive role in estimating diversions required for beneficial use of water in the IID (page 1).*

The purpose of the 1995 Jensen Report is stated in the following six objectives (page 5):

1. *Update the water balance for 1993 and 1994 following the format used in the "Water Use Assessment at CVWD and IID" January 31, 1994 Phase I Report (TWG Report).*
2. *Develop water balances and projections of water use for the years 1995 and 1996*

3. *Formulate recommendations relating to water conservation measures and operating practices as required in Section 417.2 and discussed in 417.3 of Title 43 (Code of Federal Regulation, 1993).*

4. *Develop statements to assist Reclamation in responding to the trends in water use by IID.*

5. *Develop a working spreadsheet program for use by Reclamation in updating IID's annual water balance with associated confidence intervals.*

6. *Develop a working spreadsheet program for use by Reclamation to evaluate water use by any district considering* [water supplies and water uses], *but not limited to items listed in Appendix B, and including confidence intervals.*

2. Methodology

This section describes the methodology used in the 1995 Jensen Report in order to determine crop evapotranspiration (ET), irrigation water use, efficiencies, and Salton Sea inflows. The water balance is formulated into the *Spreadsheet Program for Estimating Water Use by IID*, which is presented in Appendix C of the 1995 Jensen Report.

Irrigation Water Requirement

The methodology used in the 1995 Jensen Report to estimate crop ET is from crop coefficients (Kc) and reference ET (ET_o), based on CIMIS ET_o data. Major crops were evaluated individually and minor crops were grouped in categories. The spreadsheet model includes ET to account for preplant irrigation and crop establishment by setting Kc=1.0 for five to ten days after planting. Estimated alfalfa ET is reduced to help match calculated water use to results of the overall District water balance. Leaching requirements are based on a fixed fraction of 12.35 percent of estimated crop ET. Table 1-1 summarizes the methodology and data sources.

Table 1-1 Summary of Water Use Assessment Methodology Used in the 1995 Jensen Report

Modeling Data/Methodology	Data Source/Comments
Climatic Data	Average of three CIMIS weather stations within IID.
ET_o Calculations	Modified Penman method as described in University of California Publication 21454 (1989) referred to as CIMIS ET_o.
Crop Coefficients	Obtained from the Technical Working Group (TWG) Report (1994). Alfalfa crop coefficient is adjusted to achieve agreement of water balance terms during study period.
Crop Acreage	Acreage for 1987-1991 (Boyle, 1993), acreage for 1992-1994 (USBR Annual Reports).
Cropping Dates	Obtained from TWG Report (1994) and University of California Leaflet 21427 (1989). The 1995 Jensen Report acknowledges cropping date data needs refinement.
Effective Precipitation	Frequency and magnitude of rain events are used to determine effective precipitation (no details are provided discussing how the information was used).
Leaching Requirement	Constant each year at crop ET multiplied by 0.1235. Annual changes in irrigation water salinity are not taken into consideration.
Water Requirement for Land Preparation, Seed Germination, and Crop Establishment	Determined for some crops by setting Kc = 1.0 for five to ten days after planting. Soil evaporation was not estimated during non-cropped periods.
Evaporation from Drains, Canals, and Non-crop Vegetation	Calculated from ET_o of drains, canals, and non-crop areas. The values are constant for all years of the study.

Efficiencies

Evaluation of irrigation efficiencies is not an official objective of the 1995 Jensen Report (1995), although calculated efficiencies are presented. Irrigation efficiency (also referred to as "operating efficiency" in the 1995 Jensen Report) is defined as the fraction of water delivered to the farms that is beneficially used. Irrigation efficiency is reported to have dropped from about 78 percent for the period 1990-1991 to 72 percent for the period 1994-1995.

The 1995 Jensen Report concludes that, although operating (on-farm) efficiencies were expected to increase, efficiencies had declined in spite of improvements made in previous years. The report also concludes that significant changes in on-farm irrigation systems and water management practices are needed in order to increase efficiencies to the levels achieved during the period 1990-1991 or greater. Finally, the 1995 Jensen Report concludes that irrigation technology has improved greatly in recent years, that such improvements are not being applied in IID, and that greater effort is needed to improve on-farm systems and practices, including the adoption of modern irrigation scheduling technology.

Salton Sea Inflow

In the 1995 Jensen Report, net drainage from IID is evaluated with respect to the level of the Salton

Sea. The net drainage is reported to provide approximately 60 percent of the inflow annually evaporating from the sea. Trends in the Salton Sea elevation are presented, indicating that levels had decreased from 1988 through 1991 and had increased since 1991. The rise (1992-1994) in the level of the Salton Sea, as Jensen reports, indicates that the increase in water diverted by IID during that period was not offset by increased crop consumptive use.

3. Jensen's Conclusions

The 1995 Jensen Report conclusions focus on an increase in Colorado River diversions by IID and offer reasons for the increased diversions. Primary findings of the 1995 Jensen Report, presented in the Executive Summary (page 2) and in the Summary and Conclusions (page 38) of the report, include the following:

- *...IID entered into an agreement with MWD to finance a conservation program and has implemented other water conservation measures. ...However, diversions in 1994 were essentially the same as in 1990* (summarized from page 38).

- *The ratios of beneficial use to farm deliveries, or irrigation efficiencies, have been decreasing indicating that major changes are needed in farm irrigation systems and practices.*

- *The largest potential for reducing diversions to the IID and reducing inflows to the Salton Sea from IID is to improve on-farm irrigation systems and practices.*

- *Estimates of ET and soil water depletion to schedule irrigations* [in order to] *limit water application amounts to that which can be retained or infiltrated in the soil* [to] *reduce surface runoff and/or deep percolation.*

- *The net water supply to IID has increased from 1991 to 1994.*

- *Since 1991, the ratios of drainage to water delivered to the farms, or drainage to net water supply, have increased indicating a reduction in irrigation efficiencies.*

- *A spreadsheet model was developed for estimating mean monthly crop ET in the IID ... Estimated monthly diversions requirements ... based on CIMIS ETo and crop and water surface coefficients agree well with actual diversions except for the months of December through March.... Results indicate that the spreadsheet program estimates E, ET and net drainage reasonably well. The results also support other data, which show that net supply has increased more than that required for crop ET and other consumptive water uses.*

Many of these conclusions are discussed later in this section.

III. EVALUATION OF REPORT

This section contains an evaluation of the purpose, methodology, and conclusions contained in the 1995 Jensen Report.

1. Purpose

While the stated purposes of the 1995 Jensen Report are addressed in the report, the applicability and usefulness of the information and conclusions concerning water diversions are limited due to inadequate assessment of water use. Specific water use components that are inadequately addressed include: (1) the spreadsheet model, which inaccurately predicts water use, and (2) the on-farm recommendations, which are not supported by the water use assessment.

2. Methodology

Irrigation Water Requirement

The 1995 Jensen Report assesses water use within IID for a five-year period, 1990-1994, and draws conclusions concerning water use trends. NRCE used a longer period to include the period analyzed by Jensen and Walters in 1997 and is the same period used in the main report. The trends and conclusions are not supported by accurate and appropriate analysis. Furthermore, the shortness of the period of evaluation is coupled with unique crop production problems such as the white fly infestation of 1992, making the period inadequate to establish trends. Due to the complex nature of crop production and irrigation within IID, the spreadsheet model described in the 1995 Jensen Report is inadequate in determining water use within IID. Hence, the results of the water use assessment fail to provide sufficient information to determine why changes in Colorado River diversions have occurred. Factors not considered or deficient in the analysis include:

- Increasing salinity in IID's Colorado River irrigation water supply during the study period.
- Constraints due to soil and salt conditions.
- The period of analysis is too short to establish trends.
- Market demands, insect pressures, and economic considerations.
- Water use not only includes crop ET and leaching, but acceptable levels of tailwater runoff for horizontal leaching, deep percolation, and consumptive use during leaching and soil preparation irrigations.

- The use of a constant multiplying factor (0.1235) to determine leaching based on ET does not take into account the heavy cracking nature of the soil and the leaching practices in IID.

Efficiencies

The irrigation (on-farm) efficiencies discussed in the 1995 Jensen Report are calculated by dividing the estimated on-farm beneficial use requirement by the farm headgate deliveries. Primary components of beneficial use on-farm requirements are (1) consumptive use from crop ET and soil evaporation resulting from special irrigations for land preparation, seed germination, and crop establishment, and (2) leaching to maintain the salinity balance in the soil. Headgate deliveries include tailwater (necessary for the irrigation of the entire field and for horizontal leaching) and deep percolation (necessary for the vertical leaching of salts) in addition to the consumptive irrigation requirements.

The 1995 Jensen Report bases the irrigation efficiency calculations on headgate delivery reported by IID (IID All-American Canal Worksheet). The consumptive use portion of headgate deliveries can be obtained from either a water balance or from estimated crop ET and soil evaporation associated with special irrigations. The 1995 Jensen Report uses estimated consumptive use by utilizing CIMIS ET_0 and rainfall data, and independently developed Kc values to estimate crop ET. That portion of headgate deliveries which is not irrigation consumptive use is composed of tailwater, deep percolation, and leaching components. The 1995 Jensen Report calculated leaching as a fixed amount of 12.35 percent of the estimated crop ET. Therefore, the on-farm efficiency, as presented in the 1995 Jensen Report, is equal to crop ET multiplied by 1.1235 divided by headgate deliveries. This approach to estimating leaching water requirements used by Jensen does not account for annual changes in leaching requirements resulting from cropping pattern changes, crop sensitivity to salinity, or the behavior of irrigation water flows due to the unique nature of most of IID's soils and irrigation water quality. Adequate salinity management is a critical component of sustainable crop production in the Imperial Valley.

Another commonly used method of estimating on-farm water use and efficiencies is the water balance method. Most components of the water balance data are available from IID water measurement records. Table 1-2 contains recorded data and data estimated by Natural Resources Consulting Engineers, Inc. (NRCE) (Chapters IV and V of the main report) that are derived from the water balance of 1988-1997.

Total consumptive use equals all inflows to the Imperial Valley minus all outflows to the Salton Sea. Consumption use from irrigation equals total consumptive use minus evaporation from canals and reservoirs; evaporation; ET from drains, rivers, and pheatorphytes; ET of the rainfall; and consumptive use of M&I deliveries. Irrigation deliveries minus on-farm irrigation water beneficially used equals other tailwater and deep percolation. It should be noted that a portion of the tailwater is regarded as horizontal leaching.

Table 1-2 Water Balance for Irrigation Water Within IID (1988-1997) (1,000 acre-feet).

Year	Irrigation Deliveries	On-farm Irrigation CU	Vertical and Horizontal Leaching	On-farm Irrigation Water Beneficially Used	On-farm Efficiency (%)
1988	2,475	1,793	309	2,102	84.9
1989	2,558	1,802	331	2,133	83.4
1990	2,604	1,807	340	2,147	82.4
1991	2,438	1,723	345	2,068	84.8
1992	2,098	1,528	301	1,826	87.2
1993	2,322	1,604	317	1,921	82.7
1994	2,570	1,771	365	2,136	83.1
1995	2,575	1,741	353	2,094	81.3
1996	2,709	1,823	372	2,195	81.0
1997	2,684	1,868	345	2,213	82.4
Average	2,503	1,746	338	2,084	83.3

See main report Chapters IV and V.

On-farm leaching requirements were estimated based on field irrigation evaluations and the salinity of the irrigation water as described in Chapters IV and V of NRCE's main report. It was determined that the traditional method for estimating leaching requirements is only valid for the non-cracking light soils in IID (13 percent of IID's soils), but most of the soils in IID are heavy and medium cracking soils (87 percent of IID's soils). In addition to vertical leaching in the heavier soils, leaching also occurs horizontally as water flows through the cracks in the soil. It was also determined that the low infiltration rate of the heavy and medium soils prohibits adequate leaching during crop irrigation, thus adequate leaching requires leaching irrigation between crops. A complete discussion concerning leaching requirements is in NRCE's main report.

In addition to NRCE's analysis of water use in IID, two other water balance studies by Boyle Engineering (1993) which was updated by Jensen and Walter in 1997, and the Water Study Team (WST, 1998) are used for comparison. Information from these studies is presented in Figures 1-1 through 1-4. Figure 1-1 is the irrigation deliveries reported by IID. The Water Study Team headgate deliveries are not presented because they are estimated rather than reported values. Figure 1-2 is the estimated irrigation consumptive use. The estimated consumptive use values are nearly the same for the three studies using the water balance method (NRCE, Boyle, and the Water Study Team) and significantly different than the 1995 Jensen estimates. Jensen calculated irrigation consumptive use as crop ET and other irrigation consumptive use. Because of the Imperial Valley's unique hydrogeologic conditions and physical setting as a closed basin, the water balance provides a better method to estimate irrigation consumptive use than crop ET based on climatic data, crop acreage, and cropping patterns. Many of the variables that influence crop ET, such as pest and crop production decisions based on economics, are difficult to properly estimate. Figure 1-3 is the estimated leaching for the studies. Each of the analyses estimated leaching in a different manner.

The following are brief descriptions of the methods use to calculate leaching:

- Jensen estimated leaching as 12.35 percent of the calculated crop ET for all years regardless of changes in irrigation water salinity. Tailwater was estimated as a closure term.

- Boyle estimated tailwater as approximately 16.8 percent of irrigation deliveries. The deep percolation was the closure term for the water flowing into the Salton Sea. The leaching used to estimate irrigation efficiency was 90 percent of the estimated deep percolation and 5 percent of the tailwater.

- The Water Study Team estimated leaching based on soils, cropping patterns, and irrigation water salinity. The leaching requirement was calculated using the traditional method for light soils (different classification than used by NRCE). For heavy soils, the leaching requirement equation used a multiplier of 2.0. The computations of leaching for heavy soils were based on an average soil salinity of 3.75 dS/m and include an adjustment for miles of tile drainage pipe.

- NRCE's estimation of leaching was based on soils, irrigation water salinity, irrigation consumptive use, and results of on-farm irrigation evaluations. The estimated leaching include a horizontal leaching component for the heavy soils. A detailed description of the methodology is found in Chapters IV and V of the main report.

As illustrated in Figure 1-3, the leaching estimates from the 1995 Jensen Report are lower than the estimates in the other studies. Leaching is to remove salts applied by irrigation water and it is proper for leaching to increase when the salinity of the irrigation water increases.

Figure 1-4 shows the on-farm irrigation efficiencies. Again, the Water Study Team's on-farm irrigation efficiencies are not presented because the impacts of the estimated headgate deliveries result in efficiencies that are not comparable. The differences in irrigation consumptive use and leaching result in the irrigation efficiencies estimated by Jensen being lower than Boyle's and NRCE's estimates. A small fluctuation in irrigation efficiencies is expected due to the dynamics of crop production and economic conditions. This is in contrast to the 1995 Jensen Report, which shows significant annual changes and generally declining efficiencies from 82% down to 72%. The water balance approach demonstrates that the efficiencies average around 83%. The high irrigation efficiency of 87% in 1992 is unusual (due to a white fly infestation), and is likely a very non-typical year. The primary reason for NRCE's and Boyle's on-farm efficiencies being higher than Jensen is higher on-farm beneficial irrigation water use due to higher estimates of irrigation consumptive use plus leaching.

Figure 1-1
Irrigation Delivery Estimates Based on 1995 Jensen, Boyle, and NRCE.

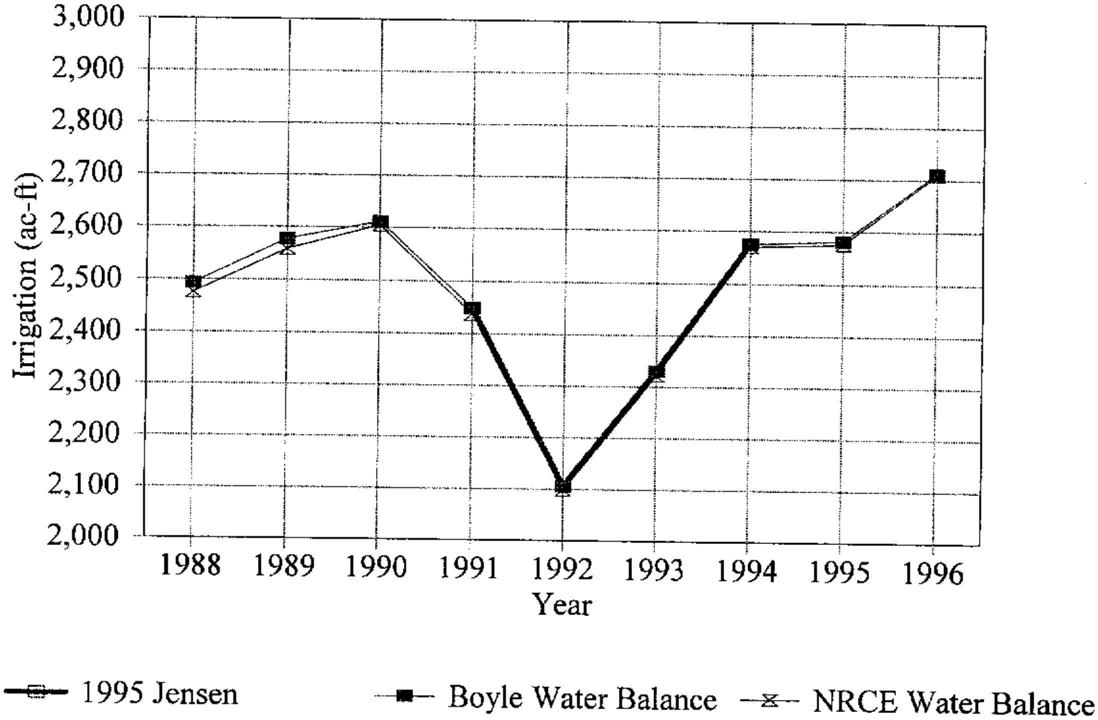


Figure 1-2
Irrigation On-farm Consumptive Use Estimates Based on 1995 Jensen, Boyle, Water Study Team, and NRCE

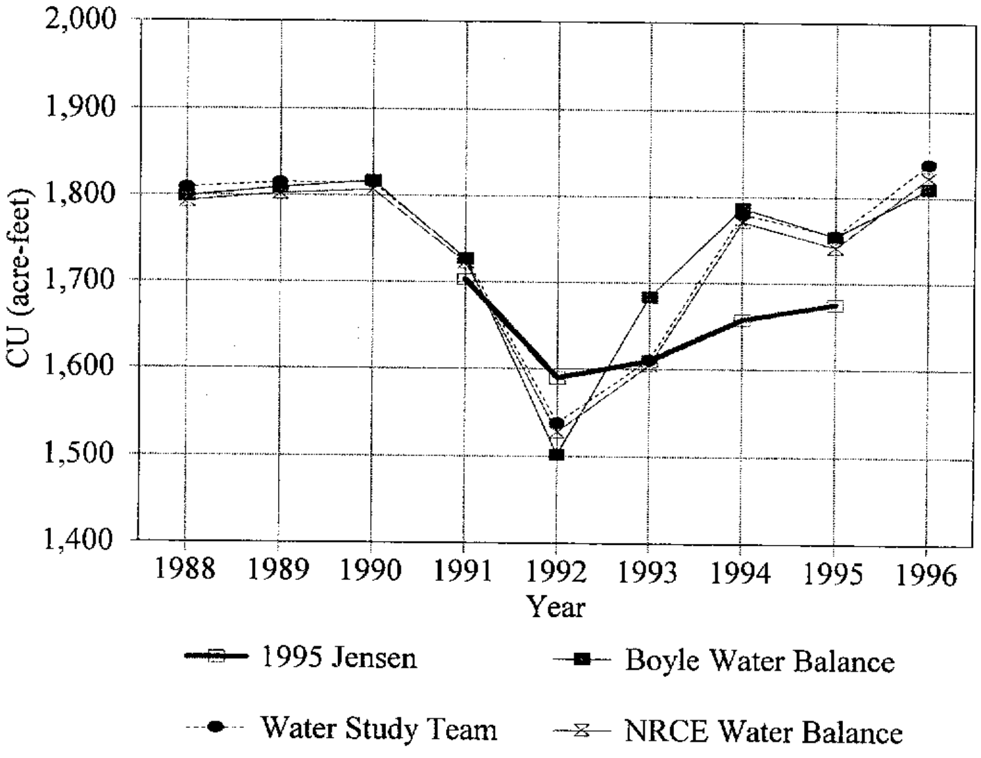


Figure 1-3
Estimated Leaching Based on 1995 Jensen, Boyle,
Water Study Team, and NRCE.

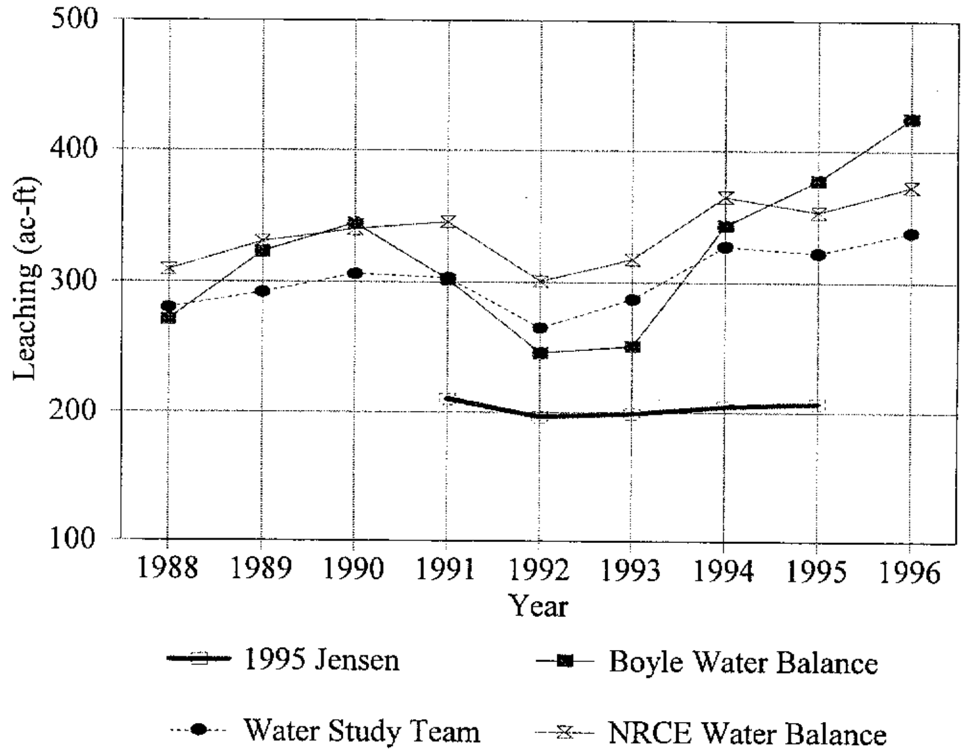
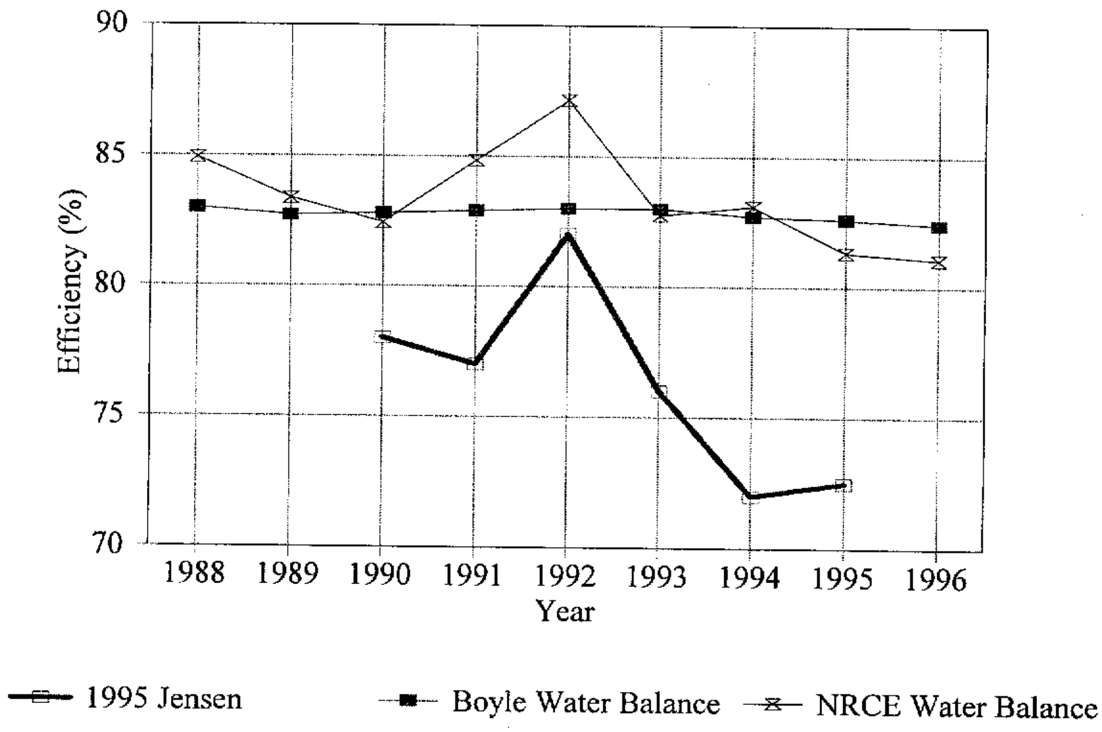


Figure 1-4
On-farm Irrigation Efficiency Estimates Based on
1995 Jensen, Boyle, and NRCE.



3. Conclusions

Of primary concern are the 1995 Jensen Report conclusions concerning on-farm water use and the effectiveness of water conservation measures implemented as part of the IID/MWD Agreement. Summary and conclusion statements from the 1995 Jensen Report are listed below, followed by review comments:

- 1995 Jensen Report Statement-...*IID entered into an agreement with MWD to finance a conservation program and has implemented other water conservation measures. ...However, diversions in 1994 were essentially the same as in 1990* (summarized from page 38).

  Comment - Diversions from the Colorado River alone are an ineffective way to measure water conservation within IID. Water savings from conservation do not necessarily reflect reductions of IID diversions from the Colorado River because changes in water diversions result from changes in cropping patterns, acreage, economic factors, salinity of irrigation water, and insect problems. The changes in irrigation consumptive use in Figure 1-2 show the annual variations.

- 1995 Jensen Report Statement- *The ratios of beneficial use to farm deliveries, or irrigation efficiencies, have been decreasing indicating that major changes are needed in farm irrigation systems and practices* (page 38).

  Comment- Changes in on-farm irrigation system efficiencies do not necessarily indicate that major changes are needed in farm irrigation systems and practices. The profitable production of crops is the critical factor in determining the appropriate on-farm irrigation efficiency. Irrigation efficiencies can be inappropriately high, resulting in deficit irrigation (irrigation that does not satisfy potential crop ET) and inadequate leaching. For example, it is very likely that the higher on-farm irrigation efficiency estimated in 1992 is not the appropriate efficiency for IID and is due to deficit irrigation for pest control and inadequate leaching.

  The 1995 Jensen Report fails to consider changes in the salinity of the irrigation water supply and its effect on leaching requirements. The weighted average annual salinity of the water delivered to IID was 749, 800, 780, 787, and 819 ppm for 1990 through 1994, respectively (annual IID records). The increase in salinity from 1990 to 1994 was about 9%, which increased the leaching requirement. NRCE's and Boyle's estimates of irrigation efficiencies are about 83% in both 1990 and 1994.

  The on-farm irrigation efficiencies calculated from the water balance show smaller changes in on-farm efficiencies and not a definite trend in the direction of decreased efficiencies. The water balance clearly demonstrates that the variation in diversions from the Colorado River to IID are in response to irrigation demands and salinity of water.

- 1995 Jensen Report Statement- *The largest potential for reducing diversions to the IID and reducing inflows to the Salton Sea from IID is to improve on-farm irrigation systems and practices* (page 38).

Comment- The primary reason for increased diversions during the study period was due to increased irrigation water salinity. The only significant potential to increase IID's current on-farm efficiency of about 83% (NRCE's and Boyle's estimates) would be through major changes in irrigation systems, requiring large capital investments. The estimated high efficiency of IID is at the expense of decreased crop yields and higher salinity in the soils due to inadequate leaching. Hence, it would be very difficult to increase the already very high efficiency without crop irrigation deficit and higher salinity build-up in the soil root zone.

- 1995 Jensen Report Statement- *Continued irrigation for fixed time periods appears to be a major factor affecting irrigation efficiencies* (page 38).

  Comment- The information in the 1995 Jensen Report does not support this conclusion. While there may be some excess irrigation due to water application by irrigators for fixed time periods, there are also a number of irrigators who terminate their irrigations before the fields are adequately irrigated. IID has instituted a more flexible water delivery system where growers are allowed to order additional water by giving just a few hours of advance time and also have the ability to stop irrigation before the allotted time is over. However, this flexibility is subject to IID system constraints.

- 1995 Jensen Report Statement- *Estimates of ET and soil water depletion to schedule irrigations and limit water application amounts to that which can be retained or infiltrated in the soil can reduce surface runoff and/or deep percolation* (page 38).

  Comment- The statement is correct in that it uses the term "can"; however, if the statement implies that different irrigation scheduling within IID "will" reduce runoff and/or deep percolation, it may not be correct. This conclusion is not supported by information in the 1995 Jensen Report. There is no information that indicates growers within IID are collectively applying excess irrigation water; to the contrary, there is evidence of deficit irrigation within IID.

- 1995 Jensen Report Statement- *The net water supply to IID has increased from 1991 to 1994,* ... (page 38).

  Comment- The net IID irrigation supply in 1992 and 1993 was lower than that of 1991. However, the net IID irrigation supply was higher in 1994 than 1991, but the irrigation consumptive use and the leaching water requirements were higher due to higher salinity content of the irrigation water in 1994.

- 1995 Jensen Report Statement- *Since 1991, the ratios of drainage to water delivered to the farms,* or *drainage to net* water *supply, have increased indicating a reduction in irrigation efficiencies* (page 38).

  Comment- A portion of the drainage water used to leach salinity is a beneficial use; hence, the ratio of drainage to water delivered to the farms does not indicate a reduction in irrigation efficiencies. When the change in irrigation water salinity and its effect on leaching requirements are taken into consideration, the calculated irrigation efficiency has not changed significantly.

- 1995 Jensen Report Statement- *Expressed as a fraction of water delivered to farms that is used beneficially, or irrigation efficiency, the fraction of water delivered that was used beneficially has decreased from about 78 percent in 1990-91 to 72 percent in 1994-95. This trend indicates that significant changes are needed in on-farm irrigation systems and water management practices to reduce the spread between net supply and beneficial use to increase irrigation efficiency to at least back to what was being achieved in 1990-91. Irrigation technology, including irrigation scheduling has improved greatly in recent years. The data presented in this study show that such improvements are not being applied adequately in the IID. Greater effort is needed to improve on-farm systems and practices including adaption of modern irrigation scheduling technology* (page 30).

Comment- As stated previously, the calculation of irrigation efficiencies in the 1995 Jensen Report fails to properly account for the change in salinity in the irrigation water, which increased from 749 ppm in 1990 to 819 ppm in 1994 (Colorado River Records). The appropriate irrigation efficiency can change over time based on factors such as economic conditions, irrigation methods, and crop selection. The IID on-farm irrigation efficiency of 83%, based on the water balance, is a reflection of good farming practices, and may also reflect deficit irrigation and inadequate leaching. The on-farm irrigation efficiency has not decreased dramatically, as claimed by Jensen. The on-farm irrigation efficiency in IID is among the highest in the southwest United States and is clearly within the acceptable irrigation efficiencies for furrow and border irrigation. In most cases there is no one better qualified to schedule and manage irrigations than the grower or irrigator who is intimately familiar with each field. The experience required to make such complicated surface irrigation decisions as when to irrigate, how much water to order, how to determine proper furrow or border inflow rates, and how long to allow the water to inflow, is only obtained with time and experience.

SECTION 2 ASSESSMENT OF 1987-1996 WATER USE BY THE IMPERIAL IRRIGATION DISTRICT USING WATER BALANCE AND CROPPING DATA (DRAFT JENSEN-WALTER, 1997)

I. INTRODUCTION

A special report, the *Assessment of 1987-1996 Water Use by the Imperial Irrigation District Using Water Balance and Cropping Data* (Draft Jensen-Walter Report, 1997), prepared by Marvin E. Jensen and Ivan A. Walter for the USBR, Boulder City, Nevada, was issued in June 1997. The status of the report is indefinite draft, pending further authorization from the USBR. The Draft Jensen-Walter Report was developed to update the water use assessment presented in the 1995 Jensen Report. Additionally, following completion of the 1995 Jensen Report and subsequent review by IID, a number of issues requiring clarification or additional analysis were identified. The 1997 Draft Jensen-Walter Report also addresses these issues. This section contains an overview, evaluation, and summary of the 1997 Draft Jensen-Walter Report.

II. OVERVIEW OF REPORT

The 1997 Draft Jensen-Walter Report was reviewed in its draft status format. As such, the Jensen-Walter findings, conclusions, and recommendations are considered preliminary, subject to refinement based on additional information and further evaluation.

1. Purpose

The purpose of the 1997 Draft Jensen-Walter Report is to cover the following 3 points (page 4):

1. *Review recent trends in IID water use based mainly on IID water balance.*
2. *Update the evaluation of IID water use for the years 1995 and 1996.*
3. *Develop a water balance and projections for 1997.*

Additionally, four specific objectives are identified (page 5):

1. *Evaluate the water balance to update assessments of water use for the years 1995 and 1996.*
2. *Develop water balance estimates and projected diversions for the year 1997.*
3. *Formulate recommendations relating to water conservation measures and operating practices as required in Section 417.3 of Title 43 CFR.*
4. *Update the spreadsheet program for use by Reclamation in updating IID's annual water balance and associated confidence intervals.*

2. Methodology and Findings

Irrigation Water Requirement

The methodology used in the 1997 Draft Jensen-Walter Report is an extension of the water balance approach developed for IID by Boyle Engineering in the *On-farm Irrigation Efficiency Special Technical Report* (Boyle, 1993). Jensen and Walter updated Boyle's water balance spreadsheet with current cropping and water use information in 1997. The spreadsheet approach, described in the 1995 Jensen Report for estimating diversions by IID has been updated in the 1997 Draft Jensen-Walter Report and is used to estimate 1997 Colorado River diversions.

Crop water use estimates in the 1997 Draft Jensen-Walter Report are primarily based on results from the IID water balance developed by Boyle (1993). The IID water balance has been revised by Jensen-Walter to obtain a second summary in which agricultural tailwater is used as the closure term rather than crop leaching. In Boyle's water balance, the tailwater component of water use is estimated as a constant fraction of the on-farm irrigation deliveries (Boyle, 1993). The rationale Jensen-Walter present for this modification is that, for small changes in cropped acreage, the leaching requirement should remain relatively constant. Further, it is stated that the leaching requirement is a "credit" allowed in computing beneficial use, and the amount of water actually used depends upon the effectiveness of the leaching practice. Finally, since the leaching water volume is less than the tailwater volume, and the leaching fraction allegedly should be relatively constant from year to year, Jensen-Walter concluded it is more logical to use tailwater as the closure term.

Efficiencies

On-farm irrigation efficiencies are not specifically discussed in the main body of the 1997 Draft Jensen-Walter Report; however, they are listed in the water balance spreadsheet printout. The listed on-farm irrigation efficiencies, using the water balance approach, range from a high of 83.1 percent in 1987 to a low of 76.5 percent in 1996. The primary reason for the decrease in on-farm irrigation efficiency is that the estimated tailwater (closure term) increased from 387,000 acre-feet in 1987 to 645,000 acre-feet in 1996.

The report discusses consumptive use coefficient trends from 1987 to 1996 (fraction of water delivered to IID that is consumed by ET and evaporation). The results of the Jensen-Walter analysis show that the consumptive use coefficient decreased from 1987 to 1996.

On-farm irrigation efficiencies are not presented in the main text of the 1997 Draft Jensen-Walter Report but are displayed in Appendix B. The focus of much discussion in the report is, however, directed at the increasing fraction of tailwater in IID, based on results of the Jensen-Walter modified water balance. The estimated increase in the tailwater fraction implies an increasing fraction of the irrigation water supply not used for crop ET and leaching. Such an increase would result in lower on-farm irrigation efficiencies.

Salton Sea Inflows

The Salton Sea inflow values used by Jensen-Walter were obtained from IID and are the same as those used in the Boyle analysis (Boyle, 1993). An equation was developed to predict the change in the water level elevation of the Salton Sea based on inflow from IID, Mexico, the Coachella Valley, rainfall, and loss due to evaporation.

The report states that the Salton Sea has risen due, in part, to increased drainage from IID. The 1997 Draft Jensen-Walter Report uses inflow values measured by IID or the United States Geological Survey as input to the analysis.

3. Jensen's Conclusions

The water balance analysis for 1987-1996 was used to identify trends in IID's water balance components, as shown in Table 2-1.

Table 2-1 Summary of Trends Identified in the 1997 Draft Jensen-Walter Report

Component	Trend
No Trend or Slight Trend	
Volume at Pilot Knob	Slight Increase
Volume at EHL	Slight Increase
Deliveries to Agricultural Users	Slight Increase
Tailwater (closure)	Increasing
Consumptive Use of Irrigation Water	No Trend
Surface Flow to Salton Sea	Increasing
Significant Trends	
Deliveries to Non-agricultural Users	Increasing
Seepage, Earthen Laterals	Decreasing
Main Canal Spills	Decreasing
Canal and Reservoir Evaporation	No Trend
Lateral Canal Spills	Increasing

Source: 1997 Draft Jensen-Walter Report, page 14.

A summary of the trends presented in the 1997 Draft Jensen-Walter Report are listed below (pages 5-6):

- Colorado River diversions have gradually increased since 1987. Total crop acreage has remained constant from 1990 to 1995, and there has been an increase in field crops and a decrease in garden crops.

- Water conservation programs involving seepage and system improvements have not translated into reduced Colorado River diversions. The net effect has been an increase in operational wastes that contribute to surface flow to the Salton Sea.

- Tailwater and tailwater plus crop leaching increased from 1987 to 1996.

- Salton Sea levels have been rising, due, in part, to increasing net drainage from IID. The consumptive use fraction of diverted water has been decreasing. The increase in net drainage is due to the large increase in tailwater, as computed in the Jensen-Walter modified water balance.

III. EVALUATION OF REPORT

1. Purpose

The 1997 Draft Jensen-Walter Report employs a water balance approach as a result of feedback from IID on the 1995 Jensen Report. The water balance approach is a substantial improvement over the 1995 Jensen Report procedures. However, of particular concern is the method that Jensen-Walter used to estimate tailwater, as well as the conclusion that the annual tailwater flow increased about 245,600 acre-feet from 1987 to 1996. The conclusion determined by the 1997 Draft Jensen-Walter Report is that the large increase in tailwater implies that IID farmers are not using water as efficiently as in the past.

2. Methodology and Findings

The 1997 Draft Jensen-Walter Report uses a modification of the water-balance approach developed by Boyle (1993) to determine trends in water use. The differences between data analyses by Jensen-Walter, Boyle, the Water Study Team, and NRCE are presented in Tables 2-2 through 2-7 and Figures 2-1 through 2-3. At the fundamental level, on-farm irrigation deliveries, irrigation consumptive use, and leaching are needed to estimate on-farm irrigation efficiencies.

Factors Influencing IID Diversions

IID's annual inflow, deliveries, and irrigation consumptive use varied during the 1988 to 1996 period. Table 2-2 shows reference ET, precipitation, salinity, and M&I deliveries. During the 1988 to 1996 period, the following occurred:

- Penman-Montieth reference ET ranged from 70.4 to 89.3 inches.
- Salinity (electrical conductivity) of IID's inflow ranged from 1.072 to 1.280 dS/m resulting in varying leaching requirements.
- Annual precipitation ranged from 6.13 to 0.80 inches.
- In 1992 and 1993, many farmers altered their normal irrigation and cropping practices to combat the white fly infestation problem.

- Annual M&I deliveries increased by about 15,000 acre-feet from 1988 to 1996.

Table 2-2 Summary of Annual Reference ET, Precipitation, Salinity, and M&I Deliveries.

Year	Reference ET (in)	Precipitation (in)	Inflow Salinity (EC) (dS/m)	M&I Deliveries (Kaf)
1988	85.2	1.82	1.072	63
1989	89.3	1.5	1.140	65
1990	82.2	1.81	1.168	69
1991	70.4	3.5	1.243	72
1992	70.7	6.13	1.223	72
1993	78.2	5.37	1.230	74
1994	80.0	2.56	1.280	75
1995	81.6	2.11	1.260	78
1996	86.8	0.8	1.270	78

These factors provide explanations as to why IID's Colorado River diversion change from year-to-year. IID's Colorado River diversions are to fill water user's orders and increased diversions are not due to waste or inefficiencies. Major factors impacting headgate deliveries are climatic conditions and irrigation water salinity. Climatic conditions are reflected in reference evapotranspiration (ETo) and precipitation. ET_o was calculated using the Penman-Montieth equation and was used as an indicator of climatic conditions, such as temperature, humidity, solar radiation, and wind.

Irrigation Deliveries

IID records were used to estimate irrigation deliveries. The annual irrigation delivery values are summarized in Table 2-3. There are some minor differences based on assumptions. Jensen-Walter used the Boyle methodology, so their values are very similar to NRCE's estimates. The Water Study Team's estimated irrigation deliveries rather than using recorded headgate deliveries, which results in irrigation deliveries about 3.5 percent higher than reported values. Therefore, the Water Study Team's estimates of irrigation deliveries are not comparable to the other values and are not listed in Table 2-3.

Table 2-3. Estimated Irrigation Deliveries Based on IID Reported Values.

Year	1997 Jensen-Walter (Kaf)	Boyle Updated 1997 (Kaf)	NRCE (Kaf)
1988	2,493	2,493	2,475
1989	2,577	2,577	2,558
1990	2,611	2,611	2,604
1991	2,449	2,449	2,438
1992	2,106	2,106	2,098
1993	2,331	2,331	2,322
1994	2,575	2,575	2,570
1995	2,581	2,581	2,575
1996	2,712	2,712	2,709
Average	2,493	2,493	2,483

Consumptive Irrigation Use

The water balance approach used in the 1997 Draft Jensen-Walter Report is an improvement over the approach used in the 1995 Jensen Report. All of the four analyses use water balances to estimate consumptive irrigation use. The water balance methodology does not rely on crop acreage, cropping dates or patterns to determine irrigation consumptive use. The estimated annual irrigation consumptive use values are summarized in Table 2-4 and shown in Figure 2-1. The differences in results are relatively small and result in minor differences in assumptions. Jensen-Walter used the Boyle methodology, so these values are equal.

Table 2-4. Estimated Irrigation Consumptive Use from Water Balance

Year	1997 Jensen-Walter (Kaf)	Boyle Updated 1997 (Kaf)	Water Study Team (Kaf)	NRCE (Kaf)
1988	1,799	1,799	1,809	1,793
1989	1,809	1,809	1,815	1,802
1990	1,817	1,817	1,815	1,807
1991	1,727	1,727	1,728	1,723
1992	1,502	1,502	1,538	1,528
1993	1,683	1,683	1,610	1,604
1994	1,787	1,787	1,780	1,771
1995	1,754	1,754	1,755	1,741
1996	1,810	1,810	1,839	1,823
Average	1,743	1,743	1,743	1,732

Leaching

Leaching is the third primary component used to calculate on-farm irrigation efficiency. Each of the analyses estimated leaching in a different manner resulting in different irrigation efficiencies. The estimated annual leaching values are summarized in Table 2-5 and are shown in Figure 2-2. Jensen-Walter estimated deep percolation as 14.1 percent of irrigation consumptive use for all years regardless of changes in irrigation water salinity. Tailwater as a closure term was estimated as irrigation deliveries minus irrigation consumptive use minus estimated deep percolation. The leaching used to estimate irrigation efficiency was 90 percent of the estimated deep percolation and 5 percent of tailwater plus reclamation leaching as provided by IID Water Control. The other methods of estimating leaching were described in Section 1.

Figure 2-1
Irrigation On-Farm Consumptive Use Estimates Based on 1997 Jensen-Watler, Boyle, Water Study Team, and NRCE Water Balances

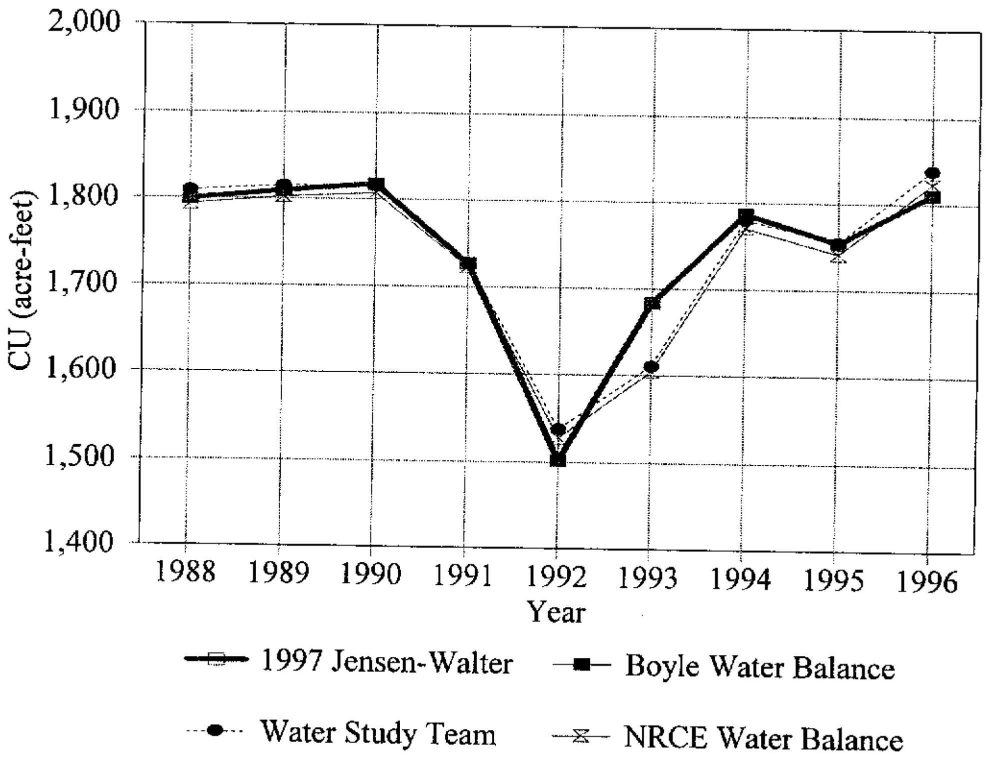


Figure 2-2
Estimate Leaching Based on 1997 Jensen-Walter, Boyle,
Water Study Team, and NRCE Water Balances

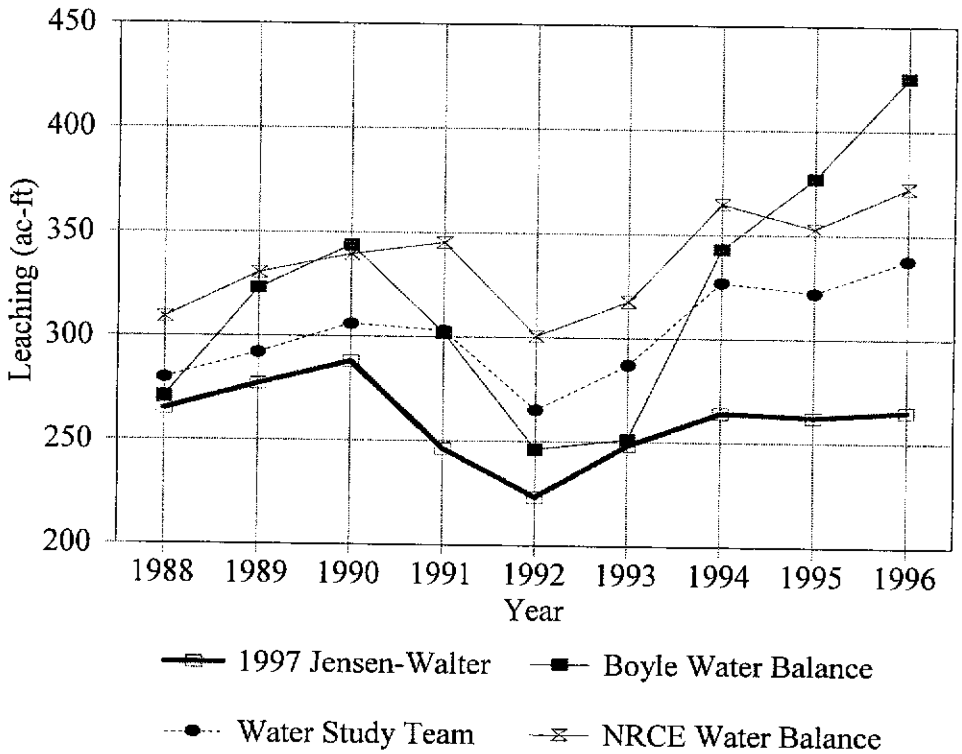


Table 2-5. Estimated Annual Leaching.

Year	1997 Jensen-Walter (Kaf)	Boyle Updated 1997 (Kaf)	Water Study Team (Kaf)	NRCE (Kaf)
1988	265	271	280	309
1989	277	323	292	331
1990	288	344	306	340
1991	246	302	303	345
1992	223	246	265	301
1993	248	251	287	317
1994	264	343	327	365
1995	262	377	322	353
1996	265	425	338	372
Average	260	320	302	337

The comparison of estimated leaching shows that the Jensen-Walter values do not increase at the same rate as the others. The 1988 and 1996 estimated leaching for Jensen-Walter are the same, while Boyle's estimate increased by 154 Kaf (39 percent), the Water Study Team's estimate increased by 58 Kaf (21 percent), and NRCE's estimate increased by 63 Kaf (20 percent). From 1988 to 1996, the salinity of the Colorado River water supplied to IID increased by 19 percent. The leaching fraction of headgate deliveries based on the Jensen-Walter water balance decreased by 9 percent. The leaching fraction of headgate deliveries estimated by NRCE increased by 10 percent. The leaching requirement as a percentage of headgate or irrigation consumptive use should follow the irrigation water salinity trend.

The 1997 Draft Jensen-Walter approach to leaching water requirements represents a fundamental deviation from recommended approaches in which leaching water requirements are dynamically dependent on crop sensitivity to salinity and irrigation water quality. The method used by NRCE includes horizontal and vertical leaching in the heavy cracking soils. Adequate salinity management is a key component to sustainable crop production in IID.

Deep Percolation and Tailwater

The estimated deep percolation and tailwater not used for leaching is the irrigation deliveries minus the irrigation consumptive use and the leaching. Table 2-6 lists the estimated deep percolation and tailwater values for the 1997 Jensen-Walter, Boyle updated by Jensen-Walter, and NRCE studies. The average for the 1997 Jensen-Walter analysis is much higher than the other two studies. The largest difference occurred in 1996 where the 1997 Jensen-Walter estimate shows 637 Kaf resulting in 160 and 123 Kaf more than Boyle's and NRCE's estimates, respectively. These difference result primarily from the differences in estimated leaching.

Table 2-6. Estimated Deep Percolation and Tailwater.

Year	1997 Jensen-Walter (Kaf)	Boyle Updated 1997 (Kaf)	NRCE (Kaf)
1988	429	423	373
1989	491	445	425
1990	506	450	457
1991	476	420	370
1992	381	358	269
1993	400	397	401
1994	524	445	434
1995	565	450	481
1996	637	477	514
Average	490	429	414

On-Farm Irrigation Efficiencies

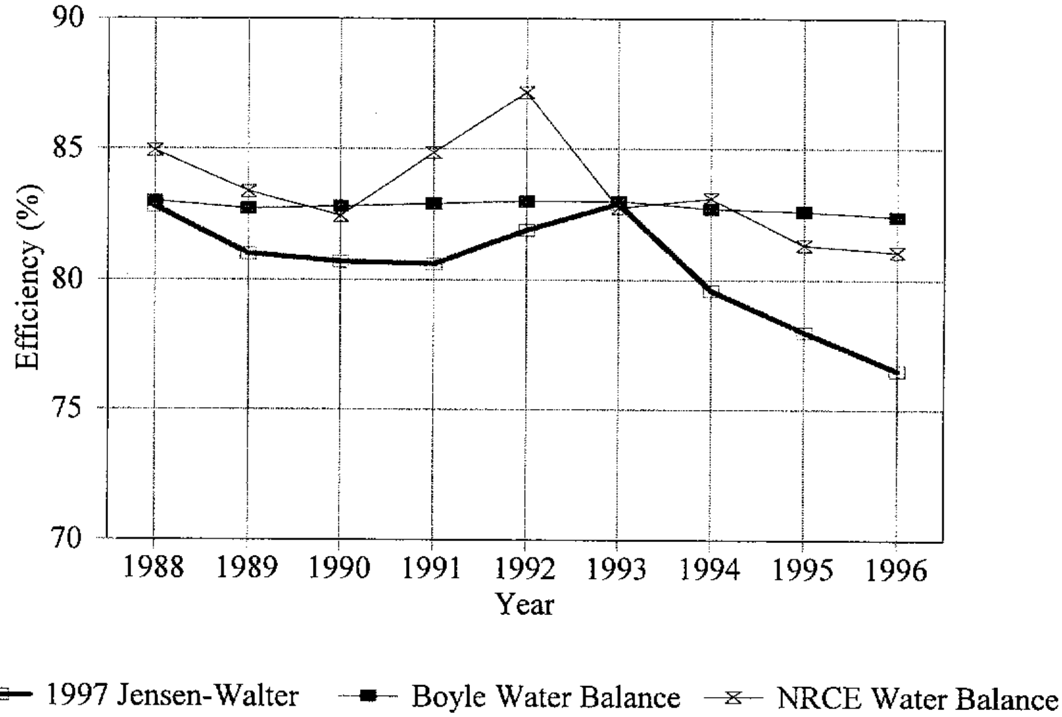
On-farm irrigation efficiencies are listed in Table 2-7. Although the 1997 Draft Jensen-Walter and Boyle updated by Jensen-Walter (1997) analyses use the same general water balance approach, different procedures are used to subdivide some components including leaching water, tailwater, and deep percolation. The procedure for subdividing the non-consumptive use components adopted by Jensen-Walter directly influences the on-farm efficiency because leaching is part of the net crop irrigation requirement.

Table 2-7. On-farm Irrigation Efficiencies.

Year	1997 Jensen-Walter (%)	Boyle Updated 1997 (%)	NRCE (%)
1988	82.8	83.0	84.9
1989	81.0	82.7	83.4
1990	80.7	82.8	82.4
1991	80.6	82.9	84.8
1992	81.9	83.0	87.2
1993	82.9	83.0	82.7
1994	79.6	82.7	83.1
1995	78.0	82.6	81.3
1996	76.5	82.4	81.0
Average	80.4	82.8	83.4

The annual on-farm efficiencies (1988-1996) estimated by Jensen-Walter (1997), Boyle updated by Jensen-Walter (1997), and NRCE, are presented in Figure 2-3. The irrigation efficiency resulting from the Jensen-Walter (1997) water balance decreased from 83.1 percent in 1987 to 76.5 percent in 1996, while the irrigation efficiencies from the Boyle Report updated by Jensen-Walter (1997) remained at about 83 percent throughout the entire period. The irrigation efficiencies estimated by NRCE change annually and are low in 1996. However, NRCE's analysis also includes 1997 when the irrigation increased to 82.4 percent. Since all methods use the same headgate deliveries and have similar on-farm consumptive use, the leaching volume in the analyses described is the primary factor that results in different on-farm irrigation efficiencies.

Figure 2-3
On-Farm Irrigation Efficiency Estimates Based on
1997 Jensen-Walter, Boyle, and NRCE Water Balances



3. Conclusions

The primary concerns with the results of the 1997 Draft Jensen-Walter Report are in the areas of modification of the water balance approach and suggested trends. The major trends indicated in the 1997 Draft Jensen-Walter Report are presented in Table 2-1. The findings of the 1997 Draft Jensen-Walter Report include stated and inferred conclusions based on the analysis conducted. Following are statements from the 1997 Draft Jensen-Walter Report, followed by review comments:

- 1997 Draft Jensen-Walter Report Statement-*Agricultural tailwater, computed as a closure term instead of the leaching requirement, increased about 16,200 acre-feet per year, or 3.3% per year. This is the main trend in the IID water balance components* (page 2).

  Comment-Tailwater was computed as a closure term by calculating leaching as a fixed fraction of estimated crop ET. Using a fixed fraction for leaching does not adequately account for crop salinity tolerance differences and variable irrigation water quality over time. The stated increase in tailwater is higher than would reasonably be expected, considering there were no large scale changes in the types of irrigation systems used in the Imperial Valley during the period evaluated. NRCE's, Boyle updated by Jensen-Walter, and the Water Study Team's assessments of IID data shows that the majority of the increasing tailwater trend identified in the 1997 Draft Jensen-Walter Report can be accounted for by increased leaching requirements.

- 1997 Draft Jensen-Walter Report Statement-*IID has initiated a number of water conservation efforts which have reduced losses in the distribution system. However, diversions to IID were not decreased as a result of the conservation effort* (page 4).

  Comment-If IID had not implemented conservation measures, diversions would have increased even more. The water savings from the IID/MWD water conservation measures have been verified. Total diversions are dependent upon all water use factors and have changed due to crop water use, M&I demands, and leaching requirements. Total diversion is not the measure of whether or not conservation efforts have been successful.

- 1997 Draft Jensen-Walter Report Statement-*The increase in net drainage is due mainly to the large increase in tailwater whether computed as a closure term or the combination of calculated tailwater and crop leaching calculated as a closure term in the water balance for IID* (page 6).

  The increasing ratio of tailwater plus crop leaching to farm deliveries from 1987 to 1996 indicates that significant improvements have not been made in on-farm irrigation systems and practices (page 6).

  The effect of increasing deliveries with essentially no increase in CU is an increase in tailwater (when calculated as a closure term), or a large increase in computed tailwater plus crop leaching calculated as a closing term....The data....clearly show that improvements in *water delivery policies and on-farm irrigation systems and practices have not been made concurrent with improvements in the distribution system* (page 16).

Comment- It is incorrect to combine all tailwater and leaching, because leaching is a beneficial use in calculating irrigation efficiencies. Based on NRCE's and the Water Study Team's analyses, leaching has increased due to an increase in salinity over the period of analysis.

Small changes in estimated irrigation system efficiencies do not indicate that major changes are needed in farm irrigation systems and practices. Profitable production of crops is a critical factor in the determination of the appropriate on-farm irrigation efficiency. Irrigation efficiencies can be inappropriately high, resulting from deficit irrigation (irrigation that is less than potential crop ET) and inadequate leaching, as was likely the case in 1992. The on-farm irrigation efficiencies previously calculated from the water balance show very little change in on-farm efficiencies and certainly no trends. The water balance shows that the changes in diversions to IID are in response to crop and leaching requirements, as previously described.

The 1997 Draft Jensen-Walter Report fails to consider changes in salinity of the irrigation water supply and the effect on leaching requirements. The average annual salinity of the water delivered to IID increased by 27 percent from 1987 to 1996 (Electrical Conductivity of 0.999 ds/m in 1987 and 1.270 ds/m in 1996). This increase in salinity increases the leaching requirement.

- 1997 Draft Jensen-Walter Report Statement-*The net effect of changes that have been occurring in the IID -a slight increase in diversions, a slight increase in operational waste (except in 1996), and essentially a constant irrigation water CU is that there has been a general increase in net drainage from the IID.....* (page 16).

Comment-The net drainage volume has increased primarily due to increased leaching requirements. The on-farm consumptive use varies substantially from year to year, as was illustrated in Figure 2-1. Other irrigation parameters, such as leaching and net drainage also vary from year to year.

- 1997 Draft Jensen-Walter Report Statement-*The trends show that the CUc [Consumptive Use Coefficient] values for each of the six months* [April-September for the years 1987-1996] *have been decreasing which indicates that the fraction of the water delivered to the EHL canal that is consumed has been decreasing* (page 20).

Comment- The fraction of the total water consumed has decreased primarily due to the increased leaching requirements. This increase in leaching requirements is due to increasing salinity of the Colorado River water. Additional leaching is required to maintain sustainable crop production.

IV. SUMMARY

The 1997 Draft Jensen-Walter analysis, using a modified water balance approach, provides results that are more accurate than the crop ET estimate method used in the 1995 Jensen Report. However, a major concern with the 1997 Draft Jensen-Walter Report is that the tailwater volume is the closure term in the water balance, which results in a smaller amount of water being used for leaching and a decrease in the on-farm irrigation efficiency. The results of the 1997 Draft Jensen-Walter Report have the tailwater increasing from 16.7 to 23.8 percent of headgate deliveries from 1987 to 1996 (387,000 acre-feet in 1987 to 645,000 acre-feet in 1996). This allegedly large increase in tailwater is an unsound conclusion because there has not been a major shift in irrigation methods in IID. A second major concern is using a fixed fraction for the leaching requirements. Leaching requirements vary with cropping patterns, soil characteristics, and irrigation water quality. An acceptable approach to estimating leaching requirements must include consideration of all these parameters.

As a result of the methodology used by Jensen-Walter, some conclusions stated in the 1997 Draft Jensen-Walter Report are invalid. Of particular concern is the following statement in the 1997 Draft Jensen-Walter Report:

- *...improvements in water delivery policies and on-farm irrigation systems and practices have not been made concurrent with improvements in the distribution system* (page 16).

There is no evidence that improvements in delivery system policies and on-farm irrigation systems have not occurred, and no attempt was made to substantiate this assertion in the 1997 Draft Jensen-Walter Report. As shown in this review, the on-farm irrigation efficiencies have remained relatively constant during the period of analysis. Additionally, the appropriate irrigation efficiency is based on cropping patterns and economic conditions that change annually.

REFERENCES

Conservation Verification Consultants. (1997). "Imperial Irrigation District-Metropolitan Water District of Southern California, Water Conservation Agreement. Projected 1997 Water Conservation Agreement. Projected 1997 Water Conservation Savings with Supporting Documentation in Tabular Summaries."

Boyle Engineering Corporation. (1993). "On-Farm Irrigation Efficiency, Special Technical Report for Imperial Irrigation District."

Imperial Irrigation District. (IID) and Metropolitan Water District of Southern California (MWD). (1989). "Agreement for the Implementation of a Water Conservation Program and Use of Conserved Water."

Jensen, Marvin E. (1995). "Water Use Assessment of the Imperial Irrigation District. Special Report prepared for the U.S. Bureau of Reclamation. Boulder City, NV."

Jensen, Marvin E. and Ivan A. Walter. (1997). "Assessment of 1987-1996 Water Use by the Imperial Irrigation District using Water Balance and Cropping Data. Special Report prepared for the U.S. Bureau of Reclamation. Boulder City, NV."

Technical Working Group. (1994). "Water Use Assessment. Coachella Valley Water District and Imperial Irrigation District. Phase I Report. Draft."

Water Study Team. (1998). "Imperial Irrigation District Water Use Assessment for the Years 1987-1996. Prepared for Imperial Irrigation District by the Water Study Team (Drs. Richard Allen, Charles Burt, Albert Clemmens, and Kenneth Solomon, and Mr. Ed Craddock). March 1998.

APPENDIX A

SUMMARY OF CONSERVATION VERIFICATION CONSULTANTS ESTIMATED IID/MWD AGREEMENT WATER SAVINGS

January 31, 1997

TO: Mike Clinton
FROM: Elston Grubaugh

RE: IID/MWD Water Conservation estimates

Per your request –

Date:		Estimate
December, 1990	(Water available in Calendar Year 1991)	26,700 Ac.-Ft.
December, 1991	(Water available in Calendar Year 1992)	33,929 Ac.-Ft.
December, 1992	(Water available in Calendar Year 1993)	54,830 Ac.-Ft.
December, 1994	(Water available in Calendar Year 1995)	74,570 Ac.-Ft.
December, 1995	(Water available in Calendar Year 1996)	90,880 Ac.-Ft.
December, 1996	(Water available in Calendar Year 1997)	97,740 Ac.-ht.

Please call if you have any questions or need additional information.

Imperial Irrigation District

Metropolitan Water District of
Southern California

Water Conservation Agreement

Projected 1997
Water Conservation Savings
with Supporting Documentation
In Tabular Summaries

Conservation Verification Consultants

April 1997

Conservation Verification Consultants

April 24, 1997

To: Water Conservation Measurement Committee Members

Mr. Gerald Davisson
Palo Verde Irrigation District
180 West 14th Avenue
Blythe, California 92225

Mr. Robert Krieger
Krieger and Stewart
3602 University Avenue, Suite 201
Riverside, California 92501

Mr. Joseph Summers
WCMC Chairman
Summers Engineering
P.O. Box 1122
Hanford, California 93232

Mr. Kirk Dimmitt
Metropolitan Water District
107 South 5th Street, Suit 200
El Centro, California 92243

Mr. Jesse Silva
Imperial Irrigation District
P.O. Box 937
Imperial, California 92251

Dear Sirs,

Transmitted herewith is the Conservation Verification Consultants' final report "Projected 1997 Water Conservation Savings with Supporting Documentation in Tabular Summaries".

Conservation Verification Consultants

Jack Keller, PhD, PE

Grant G. Davids, PE

Joseph I. Burns, ENG, PE

cc: Mr. Mike King
IID/Project Management

EXECUTIVE SUMMARY

This report contains the projected 1997 water conservation savings with the supporting documentation in the form of summary tables for most of the projects in the Imperial Irrigation District/Metropolitan Water District Water Conservation Agreement. The projected savings for the projects are summarized in Table ES-1. These projections have been prepared by the Conservation Verification Consultants (CVC) under the direction of the Water Conservation Measurement Committee. The savings projections represent the CVC's estimate of the amount of water that will be saved in calendar year 1997 given the status of project completion and level of project use at the end of 1996.

Table ES-1

Summary of 1997 Conservation Projections

Project Number	Title	1997 Conservation Projection (AF)
1	Robert F. Carter Reservoir	4,450
2, 5, 10, 11 & 16	Main Canal Lining	1,810
3	Plum-Oasis Lateral Interceptor	10,000
4	Bernard Galleano ("Z") Reservoir	5,010
7	Lateral Canal Lining	24,250
9	12-Hour Delivery (12-HD) Program	34,200
12	Non-Leak Gates	630
14	Lateral Move Sprinkler Irrigation Systems	410
14 & 18	Drip Irrigation Systems	230
15	System Automation	4,620
17	Mulberry-D Lateral Interceptor	7,650
18	Tailwater Recovery Systems	4,480
	Total	97,740

PROGRAM COORDINATING COMMITTEE
The Metropolitan Water District of Southern California
and
Imperial Irrigation District
P. O. Box 937
Imperial, CA 92251

JOSEPH B. SUMMERS - CHAIRMAN
KIRK DIMMITT - MWD
JESSE SILVA - IID

Telephone
(760) 339-9263

Telecopier
(760) 339-9262

December 22, 1997

Mr. Michael J. Clinton, General Manager
Imperial Irrigation District
P. O. Box 937
Imperial, CA 92251

Mr. John R. Wodraska, General Manager
Metropolitan Water District of Southern California
P. O. Box 54153 - Terminal Annex
2 California Plaza, 350 South Grand Avenue
Los Angeles, California 90071

Gentlemen:

The Program Coordinating Committee hereby submits, based on the Water Conservation Measurement Committee's recommendation, the water availability schedule for 1998. This submittal is consistent with the Water Conservation Agreement between Imperial Irrigation District and the Metropolitan Water District of Southern California.

The amount of water available under the agreement for calendar year 1998 is 107,160 acre feet.

Very truly yours,

Joseph B. Summers
Chairman

JBS/p
Enclosure
cc w/encl: Members of the Water Conservation Measurement Committee

PROJECTS OF CONSERVATION AND AUGMENTATION PROGRAM[1]
1997 PROVISIONAL AND VERIFIED ANNUAL AMOUNT OF WATER CONSERVED
(In Acre Feet)

Project No.	Project	Water Conserved Acre Feet		
		1988 Agreement	Provisional[2]	Verified[3]
1	Trifolium (Carter) Reservoir	4,600		4,470
2	South Alamo Canal Lining, Phase 1	1,510		510
3	Lateral (Plum-Oasis) Interceptor	5,700		6,650
4	Z (Galleano) Reservoir	3,850		5,230
5	South Alamo Canal Lining, Phase II	2,400		900
6	Sperber Outlet (Deleted)	465	---	---
7	Lateral Canal Lining	29,150		24,250
8	Trifolium Interceptor	10,700	14,700	
9	12 Hour Delivery	12,000	22,290	
10	Vail Supply Canal Lining	2,000		10
11	Rositas Supply Canal Lining	2,000		130
12	Non-Leak Gates	3,550		630
13	Tailwater Assessment (Deleted in Approval Agreement)	0	0	0
14	Irrigation Water Management	3,400	510	
15	System Automation	9,075	13,490	
16	Westside Main Canal Lining, North	4,600		260
17	Modified East Lowline (Mulberry - D) Interceptor	7,390		8,460
18	Additional Irrigation Water Management	3,720		4,670
	Totals	106,110	50,990	56,170
	Current Provisional and Verified Totals		107,160	

[1] Trifolium (Carter) Reservoir and South Alamo Canal Lining, Phase 1, constitute the Augmentation Projects. All the remaining projects, excluding the Tailwater Assessment, constitute the Conservation Program.

[2] "Provisional" values are based on information/analysis completed to date and is subject to change based on further study.

[3] The "Verified" conservation values for projects 2, 5, 7, 10, 11, 12, and 16 are based on information/analysis which are considered final and are not expected to change.

APPENDIX 10

Evaluation of IID Grower Market Power

Evaluation of IID Grower Market Power

By:

Jason Bass
And
Jim Merchant
of

DORNBUSCH ASSOCIATES
Berkeley, California

February 20, 2002

TABLE OF CONTENTS

I. INTRODUCTION AND SUMMARY

The Imperial Irrigation District (IID) has negotiated a Water Conservation and Transfer Agreement (Agreement) with the San Diego County Water Authority (SDCWA). Among other terms, the Agreement stipulates that IID would conserve 200,000 acre-feet of water per year (afy) and subsequently transfer that conserved water to SDCWA. In exchange, SDCWA would compensate IID growers for the transferred water to defray any grower conservation-related costs.

As the legal and institutional process to implement the transfer agreement has unfolded, a number of issues regarding IID's water resource management have been the focus of debate. One of these issues relates to how IID growers would be financially impacted if they were mandated to conserve water without receiving any offsetting third-party compensation such as that from SDCWA stipulated in the transfer agreement proposal.

This report evaluates the extent to which IID growers could realistically pass on conservation-related increases in their cost of water by unilaterally increasing their crop prices. To answer this question, we qualitatively and quantitatively analyzed the markets in which IID growers sell their crops, and for IID's most prevalent crop, alfalfa hay, also used a modified version of the Central Valley Production Model (CVPM) that the California Department of Water Resources developed to evaluate the impacts of water shortages and water price increases on California agriculture.

As discussed below, the analysis indicates that IID growers do not have power in their respective crop markets due to a range of competitive marketplace dynamics, including packer/shipper concentration, geographic scope, and falling trade barriers, among other factors. Consequently, IID growers cannot be expected to pay for the cost of water conservation by unilaterally increasing the prices they receive for their crops. Crop costs of production have continued to increase, while in most cases crop prices have remained stagnant or declined. Accordingly, any continued escalation in crop production costs, including any costs to implement water conservation measures, is likely to further erode IID grower profitability leading to a decline in farm property values, and adversely impacting the overall regional economy.

II. INABILITY OF IID GROWERS TO PASS THROUGH WATER RATE INCREASES

Regardless of the water conservation measure(s) IID growers and/or the District itself adopt to achieve their annual water conservation target of 200,000 acre-feet, conservation of this magnitude could result in a substantial and meaningful increase in the cost of water for the District's growers. This cost may derive directly from the capital investment and on-going O&M-expenses to implement specific on-farm or system-level water conservation measures, or indirectly from lost revenue due to deficit irrigation-and/or land fallowing. Irrespective of the method, water-conservation in IID will have financial impacts on District growers. Absent offsetting third-part compensation, the severity of those impacts, and associated regional economic effects, will depend largely on the extent to which IID growers have the market power to pass any conservation-related costs through to their customers by increasing crop prices. Ultimately, the less IID growers are able to mitigate water conservation-related costs with crop price increases, the greater the potential impacts of that conservation on grower income and subsequently, regional property values and local tax revenues.

Imperial Irrigation District is one of the largest irrigation districts in the western United States. In California, it is second only to the Westlands Irrigation District in terms of acreage under crop production (Westlands is located in the Southern San Joaquin Valley west of Fresno).[1] In 1998, 461,061 acres within IID were cropped.[2] IID growers enjoy climate conditions suitable to the production of many different field, melon & vegetable and fruit crops on a year-round basis. Over 100 crops are grown commercially within the District. However, a majority of the District's land under production, about 71% in 2000, is consistently planted to relatively lower margin forage and grain crops, primarily alfalfa hay, Sudan grass hay, Bermuda grass hay, and wheat. (In 1998, 11% and 8% of the acreage in the Westlands and Coachella irrigation districts were planted to these types of crops, respectively.)

A. Study Approach

IID growers market their crops through many channels, including growers associations and brokers. The prices IID growers receive for their crops at a given time reflect

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[1] Westlands covers about 600,000 acres along the west side of the San Joaquin Valley within Fresno and Kings Counties. In 1998, the district reported a net cropped acreage of 530,371 acres (net of double-cropped and fallowed parcels as well as lands dedicated to wildlife purposes).

[2] Understates actual acreage harvested due to multi-cropping. In 1998, 541,652 acres of crops were reported, including 82,090 acres multi-cropped (i.e., more than one planting and harvesting of a crop in a single year).

numerous supply and demand factors that differ from crop to crop and season to season. These include the volume and harvest timing of the crop in other growing regions, the price and availability of substitutes[3] and complements[4] for that crop, the concentration of buyers, the relative quality of the crop, the crop's suitability for storage, the cost of transportation and storage for the crop, general economic conditions and even market perceptions, among other factors.

IID farmers do not just compete against growers from other regions in the markets for the crops they grow, but they also compete with each another. While the level of marketing competition within the District may be tempered by local cooperation through crop associations and other marketing coordination vehicles, the consensus among extension agents, brokers and growers with whom we spoke is that market competition within IID has an important influence on the crop prices realized by individual District growers.

Nonetheless, the central concept at issue is market power. Specifically, are IID growers:

- Price-takers for the crops they produce? This would mean they have no market power, and thus cannot influence the prevailing market price; they must sell their crop at prices determined purely by market forces or risk competition entering the market and undercutting their prices.
- Price-makers for a given crop? This would mean they have substantial market power, and thus can directly influence the prevailing price; absent are alternative sources of the subject crop or adequate substitutes for the crop that might constrain IID price escalation.
- Or, are they somewhere in the middle? They would then have some influence on price that might allow at least a partial mitigation of increased costs of production resulting from conservation.

We approached this assessment in three steps.

In the first step, we identified the primary crops produced in IID. While it is true that IID produces many different crops, ten crops account for about 80% of the total acreage under

[3] An example of a substitute might be grain corn for alfalfa hay. If the price of grain corn drops relative to alfalfa hay due to an unanticipated bumper corn crop, livestock and dairy operators may increase the quantity demanded for grain corn as a substitute for alfalfa hay. This buyer response might decrease the demand for alfalfa hay and force alfalfa hay prices down if producers wish to sell all their production.

[4] The often-used example of complementary products is peanut butter and jelly. If the supply of peanut butter drops due to lower production of peanuts, people may buy less jelly as well, having a negative impact on growers supplying jelly producers with grapes and other fruit.

irrigation and about 85%, if we exclude field crop seed crops.[5] Accordingly, we believe that an analysis of IID crop pricing and market power that focuses on these ten crops alone should adequately characterize the overall extent to which IID growers control the prices they receive for their crops.

In the second step, we defined the market for each of the crops selected for the analysis. Towards this end, we emphasized three separate market delineators:

- Geographic Region
  What other geographic areas produce the crops grown in IID and deliver those crops to the same markets as IID?
- Crop Substitutes
  What crops serve as good substitutes for the crops grown in IID and therefore influence the competitive landscape faced by IID growers?
- Temporal Influences
  To what extent does the seasonal timing of IID's harvest of the crop limit the competition faced by District growers in the production of that crop? This relates to the concept of market windows and is most important when examining the market for highly perishable crops such as lettuce. IID enjoys year-round conditions suitable to crop production that afford District growers with market window opportunities, specifically, in the production of vegetable crops during the winter and early Spring when many growing regions are idle.

In the third step, we examine the market for each crop as defined under step 2 to determine, as much as possible, the relative contribution and influence of IID growers, the ability of other producers to increase their production of the crop in response to increased prices from IID growers (supply response) and finally, the potential response of buyers of the subject crop to increased IID prices (demand response). All of this information was pooled to draw conclusions about the market power of IID growers within the respective market for each crop.

[5] Most of the seed grown in the district is alfalfa and Bermuda grass. These seed crops are harvested largely on stands previously used for the production of hay and allowed to go to seed in their last year of production.

B. IID Cropping Pattern

Table 1 summarizes the IID cropping pattern in 2000 itemizing the ten most important non-seed crops in terms of acreage.[6]

Table 1
Cropping Pattern Summary – 2000
Imperial Irrigation District

Garden Crops	Acres	% of Total	Field Crops	Acres	% of Total
Broccoli	10,916	2%	Alfalfa Hay	177,854	33%
Carrots	18,167	3%	Bermuda Grass Hay	41,918	8%
Lettuce	18,089	3%	Sudan Grass Hay	53,446	10%
Cantaloupes	11,270	2%	Sugar Beets	31,475	6%
Onions (dry)	12,377	2%	Wheat	49,868	9%
Other	27,615	5%	Other	59,647	11%
Total Garden Crops	98,434	18%	Total Field Crops	414,208	77%
Permanent Crops	24,434	5%			
Total Acres of Crops (Includes Multi-Cropping)				537,076	

Source: Imperial Irrigation District Annual Inventory of Areas Receiving Water, Years 2000,1999, 1998.

The table reveals that field crops account for approximately 77% of IID's cropping pattern, while permanent crops such as citrus account for only about 5%. In addition, the table indicates that alfalfa hay is planted to approximately one-third of IID lands under production. For this reason we focused a significant amount of our market analysis research on alfalfa hay.

C. Crop-Specific IID Market Power Assessment

Before examining IID grower market power on a crop-specific basis, it is appropriate to briefly discuss the North American Free Trade Agreement (NAFTA), as NAFTA has had a substantial recent influence on the dynamics of the crop markets in which IID growers participate. The U.S., Mexico and Canada entered into NAFTA on January 1, 1994. The primary objective of NAFTA, by design, was to increase North American trade and

[6] Excluding Sudan Grass and Bermuda Grass Hay, the remaining eight crops are also the most important non-livestock commodities produced in the District in terms of gross value of production.

economic efficiency, particularly in the manufacturing and natural resource sectors (including agriculture), by dismantling import tariffs and quotas, facilitating trade and environmental dispute resolution, and improving labor mobility among the three signatory countries.

Free trade has always been a politically charged issue, and the debate on NAFTA has proven no exception. Now, as the U.S. enters a new phase in international trade liberalization and trading partnerships, highlighted by the recent admission of China to the World Trade Organization (WTO) and attempts to fast track the expansion of NAFTA to include Central and South America, the socio-economic and environmental impacts of NAFTA during its brief history have become the focus of intense public and governmental scrutiny. While the conclusions presented in the associated literature tend to reflect public policy biases as much as hard analysis, the general consensus appears to be that since NAFTA's inception farmers in all three countries have experienced stagnant to declining prices for most crops and a subsequent erosion of incomes. Though many correctly point out that non-NAFTA factors, including recent currency exchange shocks, broad macro-economic trends, agricultural consolidation, weather problems (i.e., el nino and la nina) and government domestic agricultural policy changes have adversely affected U.S. farmers to varying degrees, NAFTA appears to have had, and continues to have, an important influence on the U.S. farm sector.

Within the NAFTA blueprint, U.S. policy makers expected anticipated increases in U.S. agricultural commodity imports from Mexico and Canada to be approximately offset with increases in U.S. agricultural commodity exports to those countries; an outcome that according to the USDA Economic Research Service has, in aggregate, by and large materialized. When one narrows the focus, however, to trade patterns for many of the non-hay crops produced in IID, particularly higher-valued crops of particular importance to District incomes, such as lettuce and melons, indications are that the NAFTA experience has been fairly one-sided in terms of trade flows. Aided by the Mexican Peso's devaluation in 1994/95, U.S. imports of Mexican produce have increased substantially under NAFTA. These imports compete directly with IID and other Southwestern growers, particularly during periods that have traditionally provided those growers with valuable seasonal market windows for their crops. For example, the Economic Research Service found that U.S. net imports of Mexican cantaloupe are 17% to 25% higher than they would be absent NAFTA-associated tariff cuts. This has had a clear negative affect on IID melon grower incomes. Another study of NAFTA by the University of Texas A&M's Center for North American Studies reports that the NAFTA-related elimination of U.S. vegetable import duties has contributed significantly to the near doubling of U.S. imports of broccoli, cucumbers and onions during the 1990s.

Furthermore, and referring to the period since NAFTA's inception, a recent study by the Public Citizen's Global Trade Watch concludes that "...North America's farmers and consumers have not benefited from the pact..." The report also indicates that the U.S.'s trade surplus with Canada and Mexico fell by $1.5 billion during the first seven years since NAFTA's inception. In contrast, the U.S.'s trade surplus with Canada and Mexico grew approximately $203 million between 1991 and 1994.

Our research indicates that while all of IID farmers have been financially squeezed by NAFTA, those most impacted are farmers producing relatively labor-intensive crops such as asparagus and melons. A primary cause is the substantial labor cost disparity between California and Mexico. In some situations, for example, what IID growers are paying laborers for an hour of work is approximately equal to what Mexican growers across the border pay for a full day of labor. With such a disparity in the cost of so essential a crop production input as labor, IID growers are at a disadvantage in competing with Mexico in the marketplaces for many fruit and vegetable crops. Prior to NAFTA, import tariffs allowed IID growers to compete effectively with Mexico despite relatively expensive labor associated with California's high (and ever increasing) minimum wage rate, and strict time-and-a-half requirements for overtime, among other labor cost factors. The situation is likely to deteriorate further as most of the remaining tariffs that now partially insulate IID growers are completely phased out per NAFTA's terms.

1. Alfalfa Hay

a. Market Definition

According to the State of California Agricultural Statistics Service, in 2000 alfalfa hay was grown on 1.35 million acres in California producing about 7.6 million tons of hay. Alfalfa hay growers within IID are relatively high-yield producers, accounting collectively for approximately 13.2% of the State's 2000 alfalfa hay acreage and almost 18.9% (1.44 million tons) of the State's total alfalfa hay production in that year. According to the 1997 Census of Agriculture, there were 557 farms in Imperial County in 1997 of which about 57% (320) produced hay.

Alfalfa hay produced in IID is generally considered good to premium quality hay with high protein and nutrient levels and, for this reason, is sold primarily to dairies. According to Juan Guerrero, an Imperial County agricultural extension agent, in excess of 70% of IID's alfalfa hay is shipped to dairies in the Chino Basin near Interstate 10 East of Los Angeles. The Chino Basin area has the largest concentration of dairies in the State and produces a large share of the State's milk and other dairy products. The remainder of IID's alfalfa hay is sold for use in feed-lots (much of it local) and for horses, with about 15% exported mostly to Asian feed markets.

Discussions with representatives of several dairies in the Chino Basin, including Excelsior Farms, Syann Dairy and Three Brothers Dairy, revealed that while IID is their primary source of alfalfa hay, they also buy large amounts of hay from growers in the Yuma area of South-Western Arizona, growers around Blythe in Eastern Riverside County as well as growers in the Southern San-Joaquin Valley near Lancaster. All of these areas are large agricultural regions. Conversations with a number of alfalfa hay brokers working with IID growers and dairies in the Chino Basin confirmed that IID competes primarily with hay producers in these areas. Clark Seybert, principal of Clark Company, a hay broker operating out of Brawley in the Imperial Valley indicated that IID alfalfa hay growers compete in a marketplace that extends largely from the Southern San Joaquin Valley south and into Western Arizona.

Alfalfa hay is bulky and costly to transport and therefore is usually marketed fairly close to where it is grown. However, Mr. Seybert said that it is not uncommon for premium quality hay to be shipped long distances if the quality merits the added transportation costs. For example, some alfalfa hay grown as far away as Utah and considered to be of extraordinary quality is shipped to dairies in Southern California. Bill Sandig, California's border station supervisor for the state's Department of Food and Agriculture, believes that Utah hay is an important factor in the Southern California Dairy industry. According to Mr. Sandig, the Southern California market for alfalfa hay is very price sensitive. This would suggest that if the price of IID hay were to increase relative to other growers outside the area, IID's competition in the Chino Basin dairy market would increase because the cost to transport hay to the Chino Basin from producing areas further away would become relatively more economical.

Our own survey of approximately ten trucking companies in California, Arizona and Nevada that transport hay revealed that haul rates are as much a function of back haul opportunities available to the particular trucking company as they are of mileage. For example, the Lanting Hay Company in Chino quoted a cost to ship hay from the Phoenix Area (Maricopa County) Arizona, of $25 per ton, the same rate that many truckers, including Lanting, would charge to haul to the Chino Basin area from El Centro in the Imperial Irrigation District: a much shorter distance in road miles. This pricing reflects the fact that Lanting already hauls a variety of goods between Los Angeles and Phoenix along Interstate 10 and could absorb additional hay hauling on that route at relatively little cost. Frank Delpapa of Be and Me Trucking out of Bakersfield quoted the same price, $25, to haul hay from Sacramento to the Chino Basin.

According to Michael Rethwisch of the Riverside County Palo Verde Cooperative Extension office, alfalfa hay markets are defined based on quality. Blythe, El Centro, and Yuma produce premium quality hay during the winter. In the summer, Chino Basin dairies buy some of their hay from Nevada and Utah because summer hay from those areas is of a better quality than IID's. During the summer the price of hay drops in the Imperial and Palo Verde valleys because production increases result in reduced quality.

Alfalfa hay is considered the feed of choice among dairy farmers due to its high protein content, nutrient levels and palatability. Nonetheless, the dairy industry is extremely sensitive to feed expenses because feed accounts for over 50% of the cost to produce milk. Also, the dairy sector, perhaps more than any other agricultural sector, is very sophisticated in its cost management, applying linear programming and other quantitative techniques to maximize feed nutrition at a minimum of cost. Therefore, since alfalfa hay is a relatively high-priced feed source, many dairies proactively seek to reduce their purchases of alfalfa hay by substituting a wide range of alternative and lower cost feeds including grain, corn silage, oat and barley hay, even beet pulp and tomato pumice (waste from processing). For example, Seth Hoyt, a senior agricultural economist with the California Agricultural Statistics Service, believes that while recent alfalfa hay prices may face upward pressures due to a decline in acreage and strong dairy and export demand for hay, any price inflation may be tempered by lower grain and feedstuff prices.

While Imperial County does produce alfalfa year round, including during the winter and early spring months when many growers to the north are idle, alfalfa hay can be stored for long periods of time with little quality deterioration if properly stored. Nonetheless, Imperial growers do gain some competitive advantage in their winter season production of hay from avoided storage, shrinkage and general carrying-related costs incurred by growers targeting those markets with stored hay.

b. Market Power

Based on our research, we concluded that IID's primary market competition for alfalfa hay comes from other Southern California growers extending north to include the Southern San Joaquin Valley (i.e., Fresno, Kern, King counties, etc.) and extending east into Arizona including Yuma, La Paz, Pinal and Maricopa counties. This is not to suggest that the alfalfa hay market in which IID producers compete is not influenced by producers further afield (such as Utah), only that IID's primary competition is located within this area. In 1999, IID produced 15% of the alfalfa hay grown within this market region. However, according to Mr. Seybert and other brokers with whom we spoke, IID growers have little ability to dictate their hay prices because of significant competition within and from outside the District as well as the availability of low cost substitutes.

In addition, we sought to assess IID alfalfa hay grower market power by examining and analyzing historical IID alfalfa hay price, acreage and production data. Figure 1 provides a graphic summary of the average price received by alfalfa growers in Imperial County between 1980 and 2000. During this period, grower costs of production steadily rose, yet as the graph shows, alfalfa hay prices fluctuated significantly. In fact, the average price of alfalfa hay in 2000 for the county was actually lower than the 1980 price. It should be noted that the prices presented here are average prices. Individual growers realize a range of prices on their hay based primarily on quality, time to market and seasonal demand.

Figure 1
AVERAGE ALFALFA HAY PRICES
IMPERIAL COUNTY
1980-2000

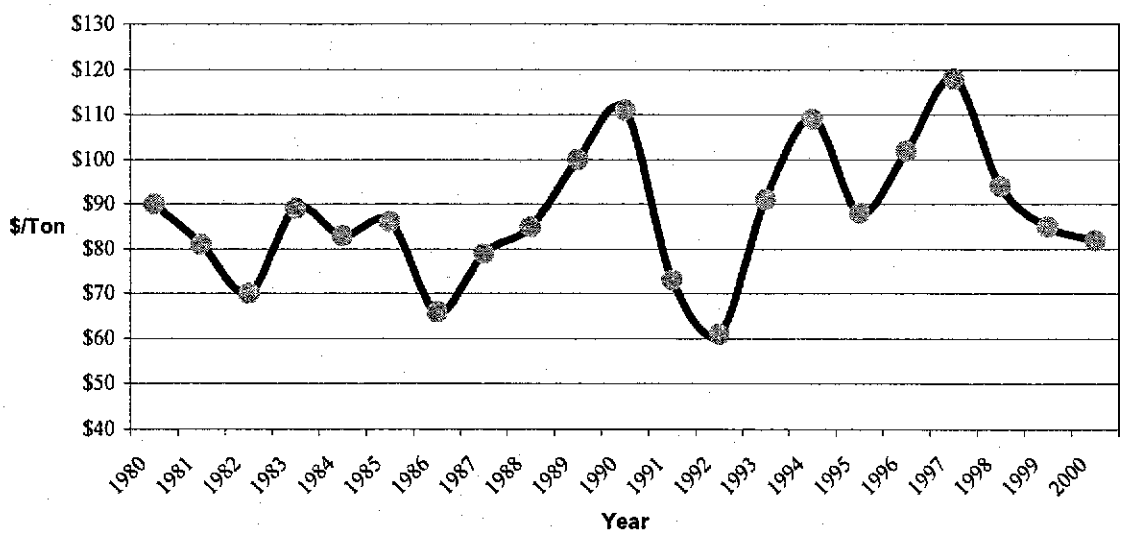


Figure 2 summarizes reported acreage of alfalfa in IID for the same 21-year period. The figure reveals fairly significant inter-year variation in the District's alfalfa hay acreage and total production. We compared the historical trend in IID alfalfa acreage and production with alfalfa hay prices, assuming different lags in production and price. This analysis suggests that the amount of total IID hay production does little to explain the prices received by growers for that hay (suggesting the hay market in which IID operates is larger than IID itself). For example, covering the period 1980 through 2000, the coefficients of determination comparing estimated total IID alfalfa hay production in a given year to, (1) the IID grower average price received for hay in that year, and (2) the

IID grower average price received for alfalfa hay in the previous year, are near zero. Therefore, very little of the variation in IID alfalfa hay production appears to explain variation in the average price received by growers for that hay. This serves as one indication that IID alfalfa growers are operating in a market substantially larger than that represented by their production and have little unilateral influence on prices.

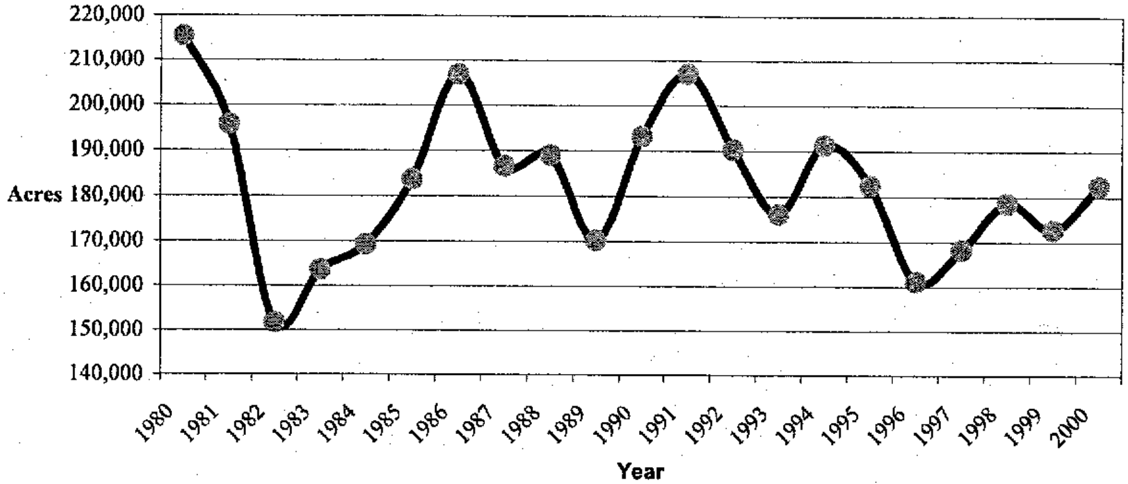
At the same time, our analysis suggested little or no relationship between the lagged price for IID hay and the production of alfalfa hay, indicating that growers collectively are not making their alfalfa production decisions based on recent average prices received for their alfalfa.

We also conducted a similar correlation analysis by comparing historical IID average alfalfa hay prices and an index of farmer production costs. The purpose of this analysis was to evaluate the extent to which IID growers have been able to recoup unavoidable inflation in their costs of production through increases in the prices received for their crops. The farmer production cost index used was the Prices Paid by Farmers for Production, Interest, Taxes and Wages published by the USDA's Economic Research Service (PPITW). We believe that this index, though national in its coverage, reasonably characterizes the general trend and variability in overall crop production costs incurred by IID growers. (No appropriate State-level or regional farmer cost-of-production index is available.[7,8])

[7] To test the reasonableness of using a national farmer cost of production index (the PPITW) to characterize the trend and variability in overall Imperial Valley farmer production costs (absent a more geographically-specific production cost index), we compared the historical PPITW index to available consumer price indices (CPI) for the State of California as a whole as well as the Los Angeles (including Riverside) and San Diego areas individually. (These CPI indices are reported by the State of California's Division of Labor Statistics and Research.) The comparisons revealed that a significant amount, almost 90%, of the observed variation in the PPITW can be explained (is mirrored) by variation in the CPI indices. We believe this validates the use of the PPITW as a proxy for farmer cost of production trends and variability in IID since our own past analyses of consumer and producer price indices where available for specific geographic areas would suggest that the indices tend to track quite closely.

[8] An examination of available data on the cost in California of important farm inputs such as labor, chemicals and particularly energy reveals fairly substantial recent cost inflation that has eroded farmer income due to stagnant or falling crop prices.

Figure 2
AVERAGE ALFALFA HAY ACREAGE
IMPERIAL COUNTY
1980-2000



The correlation analysis indicates that only about 20% of the observed historical variation in IID alfalfa hay prices can be statistically explained by cost of production inflation, suggesting that while cost is certainly one factor driving hay prices, many other factors influence price as well, and IID growers could not expect to recoup increased water costs by unilaterally increasing the price of their hay. Thus, while a higher correlation would not necessarily imply market power as it could just relate to a general upward trend related to increased price levels throughout the economy, the low level of correlation found does imply that alfalfa hay growers are unable to control income erosion due to increasing costs through crop pricing. To further validate this conclusion, we performed an additional correlation analysis between IID historical alfalfa hay prices and a time series of farmer hourly wage rates for California reported by the USDA in the Department's Farm Labor Bulletin. The period of the analysis again covered 1980 through 2000. We believe this to be a meaningful analysis since labor is a major cost of crop production and the labor rate series used is specific to California. The analysis indicates a similar, though smaller statistical relationship between cost of production and price for alfalfa hay in IID.[9]

According to Steve Blank, an extension economist with the University of California Department of Agriculture, the factors most affecting the prices received by IID growers for their crops include the amount of hay in storage, cost of alternate feed sources,

[9] This would be expected since the PPITW and the farmer wage rate series for California are highly correlated.

government programs, conditions in other alfalfa producing areas, past prices and beef and dairy cattle numbers. All of these factors are outside the control of IID growers and therefore, severely constrain grower ability to influence the price they receive for alfalfa hay.

Finally, given the importance of alfalfa hay to the IID cropping pattern, we used a modified version of the Central Valley Production Model (CVPM) to project the impact on prices paid by Southern California dairies following an increase in IID grower cost of water. The CVPM model was developed by the California Department of Water Resources (DWR) in collaboration with private sector consultants, including CH2M Hill and a number of agricultural economists from the University of California. The model is used frequently by DWR and also the Bureau of Reclamation to evaluate the potential effects on California farming from changes in the cost and availability of production inputs, particularly water. The model uses sophisticated quantitative methods termed "positive quadratic programming" to relate farmer crop production decision-making to the relative cost, availability and efficiencies of different crop production inputs and technologies. For the purposes of our analysis of the alfalfa hay market in which IID competes, we expanded the model to include Yuma, La Paz, Pinal and Maricopa counties in Arizona. We also incorporated a model of the Southern California demand for alfalfa hay based on the work of Konyar and Knapp. This analysis indicates that even with conservation-induced increases in the cost of IID water, there would be no resulting increase in farm-gate alfalfa hay prices in the Southern California/Arizona marketplace

2. Sudan Grass Hay and Bermuda Grass Hay

a. Market Definition

According to the State of California Agricultural Statistics Service, in 2000 Sudan grass hay was grown on approximately 77,500 acres in California, over 70% of which was in IID. The State does not separately monitor the production of Bermuda Grass Hay, but instead adds that production into a broader category, "Hay Unspecified," that includes Bermuda Grass, Timothy and other hay varieties. However, a review of Agricultural Commissioner reports for California's southern counties indicated that almost all the Bermuda grass hay grown in the State is produced by IID. In 2000, Imperial growers produced Bermuda grass hay on 41,918 acres, almost the same number of acres the state reported for "Hay Unspecified" in Imperial County. This hay production accounted for almost 20% of the State's total reported "Hay Unspecified," acreage in that year.

Unfortunately, the amount of market information available for Sudan and Bermuda grass hay is limited. However, based on our research, including conversations with hay brokers and exporters in the region, most of these hay products are exported to Asia, particularly Japan. In 1997, the U.S. exported 2.9 million metric tons of hay, 2.7 million of which went to Japan. Half of this hay was alfalfa. Since only about 15% of IID's alfalfa hay (or about 150,000 to 200,000 tons) is exported, much of the hay exported from the U.S. to Japan and Asia is coming from other hay-growing regions. Other countries exporting significant amounts of hay to Asia include Australia/New Zealand and Canada. Accordingly, IID Sudan grass hay and Bermuda grass hay production competes with other hay produced throughout the Western states as well as from different Pacific Rim countries.

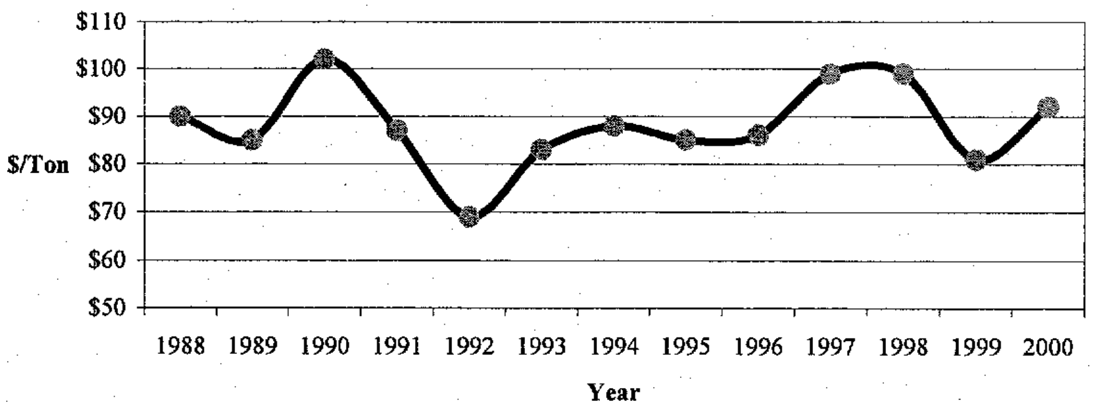
Direct hay export statistics for Canada and Australia/New Zealand were unavailable. However, according to Terry Hansen with ACX Trading, a large hay exporter in Long Beach, California, the Asian hay markets are extremely price competitive and that IID-baled Sudan grass and Bermuda grass face strong competition, particularly from Australian oat hay and Canadian Timothy hay. He also indicated that IID Sudan grass hay competes with rye hay produced in the Wilamette Valley in Oregon. According to Mr. Hansen, Australia is exporting about 400,000 tons of oat hay annually into Asian markets, and that amount is steadily increasing. He also told us that Asian markets are tough to compete in because of the exacting and ever-changing requirements of buyers with respect to quality and appearance. This opinion is corroborated by James Kuhn with Kuhn Farms, a hay grower in Imperial. On the overall hay export market, Mr. Kuhn believes that an abundance of hay supply and production capacity in overseas markets is placing downward pressure on prices that is exacerbated by weakness in the Japanese and other Asian economies.

b. Market Power

Based on the above characterization of the "other" hay marketplace, it appears that IID growers cannot unilaterally respond to crop cost of production increases by increasing the price they receive for Sudan grass and Bermuda grass hay.

To validate this finding, we sought to assess IID Sudan and Bermuda grass hay grower market power, by analyzing historical price, acreage and production data for those crops. Figure 3 below provides a graphic summary of the average price received by Sudan Grass hay growers in Imperial County between 1988 and 2000 (price data before 1988 was not available, as Sudan grass hay was not previously reported as a separate hay crop from the County Commissioner's "Other Hay" category). During this period, while grower costs of production steadily rose, average Sudan grass hay prices, despite some significant inter-year variation, did not. In fact, the Imperial County average price received for Sudan grass hay in 2000 was about the same as the 1988 average price.

Figure 3
AVERAGE SUDAN GRASS HAY PRICES
IMPERIAL COUNTY
1988 - 2000



We also conducted correlation analyses between historical IID average Sudan grass hay prices, and (1) the index of Prices Paid by Farmers for Production, Interest, Taxes and Wages (again lacking a comprehensive state-level or regional cost of production index) and (2) average farm hourly wage rates for California reported by the USDA. These analyses indicate almost no relationship between the farmer cost of production and the prices received by IID growers for their Sudan grass hay. This would support the opinion that production costs don't have a strong influence on prices and accordingly, IID growers have no real power to pay for higher water costs by correspondingly increasing the price they charge for Sudan grass increases. Market supply and demand factors appear to dictate the prices that IID farmers can receive for their hay in a given year irrespective of IID grower production costs.

Unfortunately, Imperial Valley Bermuda grass hay prices have not been tracked for more than the last several years. Accordingly, we were unable to perform a similar analysis for Bermuda grass. However, we believe that IID Bermuda grass hay growers also have little control over the price they receive for their hay as this hay is subject to similar competitive forces in the export market as Sudan grass hay.

3. Sugar Beets

a. Market Definition

According to the State of California Agricultural Statistics Service, in 2000 sugar beets were grown on a little less than 100,000 acres in California producing almost 3.3 million tons of beets. IID accounted for over 31% of this acreage, 31,475 acres. California produces about 10% of the U.S.'s sugar beets. The majority of the country's sugar beets are grown and processed in the northern states, particularly the Red River Valley extending from Minnesota into eastern North Dakota.

Until quite recently, there were four factories that processed all of the sugar beets grown in California. They were located in Woodland, Tracy, Mendota and Brawley. A short time ago the Woodland and Tracy plants closed due to financial troubles. According to the USDA's current assessment of the U.S. sugar sector, it is anticipated that these plant closures will result in a sizeable reduction in the future acreages of sugar beets in the State. This is largely due to the high cost to transport beets. Due to transportation costs most processing facilities purchase beets from nearby growers.

The Brawley plant is operated by Imperial Sugar. All of the beets processed at Brawley are produced in IID. And, all of IID's beets are processed at the Brawley plant.[10] Accordingly, IID growers currently face no outside competition in supplying Imperial Sugar's Brawley processing facility with beets. However, the true market in which IID sugar beet growers compete is not limited to the Imperial Sugar's Brawley facility, but is really international in scope, since this is the geographic market in which sugar processors such as Imperial Sugar compete. According to representatives of the California Sugar Beet Association, IID is considered a relatively low-cost sugar beet producer due to its relatively high yields compared to other growing regions. This finding is supported by sugar beet cost of production analyses conducted by the USDA's Economic Research Service. At the same time, Imperial Sugar faces relatively high production cost conditions, largely due to the high cost of labor and power in Southern California.

According to Steve Kaffka, with the U.C. Davis Department of Agronomy and Range Science, the Tracy and Woodland sugar beet processing plants closed because their operator got into financial trouble when the price of sugar dropped 20% due to a

[10] Historically, Imperial shipped some of its beets to Tracy for processing prior to that plant's closure.

combination of factors, including increased production in North Dakota and Minnesota, oversupply and shortfalls in the USDA-administered U.S. sugar program.

Keith Mayberry, an Imperial County Cooperative Extension agent, informed us that even though IID is perhaps the highest sugar and highest yield sugar beet producer in the world, there is some talk of closing down the Brawley plant. The reason; an abundance of sugar supply (imported and domestically produced) has driven prices so low that US processors, no matter how efficient, are unable to compete. According to the USDA's Economic Research Service, while USDA intervention has helped to reduce supplies and support the prices received by some processors, the Department's legislated maximum intervention in the sugar marketplace has done little to keep prices up. It should be noted that the USDA participates in the sugar market by setting annual quotas on certain raw and refined sugar commodities and by providing loans to sugar processors that use sugar as collateral. In terms of the latter, if the price of sugar falls below the legislated loan rate per pound of sugar, the USDA takes delivery on the sugar in lieu of loan repayment. In this manner the loan rate serves as a price support on the affected sugar. Traditionally, beet and sugar cane growers themselves have not had direct access to any meaningful government support programs.[11]

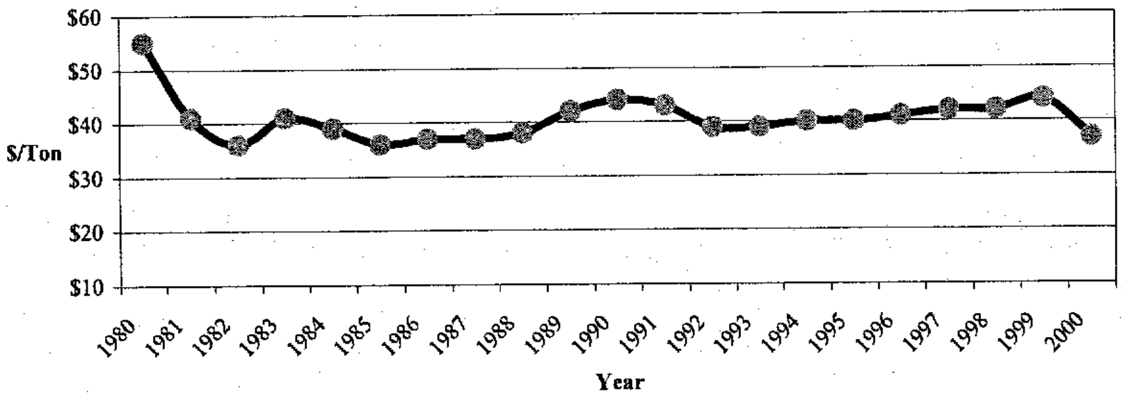
b. Market Power

IID's sugar beet processors depend on the continued operation of Imperial Sugar's Brawley processor. Accordingly, those growers are forced to price their beets at a level that keeps Imperial Sugar competitive in the overall highly competitive sugar marketplace. Accordingly, IID sugar beet growers have little ability to raise their prices if they do not want to jeopardize the continued operation of the only outlet for their crop.

We sought to further assess IID sugar beet grower market power by examining and analyzing historical IID sugar beet price, acreage and production data. Figure 4 provides a graphic summary of the average price received by sugar beet growers in Imperial County between 1980 and 2000. During this period, grower costs of production steadily rose, yet as the graph shows, sugar beet prices were little changed. In fact, the average price received for sugar beets by Imperial County growers was $41 dollars per ton in 1981, and 15 years later in 1996, it was still only $41 dollars per ton, thus showing a significant real decline over the period when one factors in inflation.

[11] The USDA, in an effort to improve the sugar market and reduce its stocks of sugar obtained from processor loan forfeitures (and ongoing related storage costs), has proposed to offer sugar beet growers sugar in exchange for not harvesting their crop. Unfortunately, this payment-in-kind program will be limited in 2001 to $20,000 per farmer, and such compensation reflects already depressed sugar prices.

Figure 4
AVERAGE SUGAR BEET PRICES
IMPERIAL COUNTY
1980-2000



We also conducted correlation analyses between historical IID average sugar beet prices and both the PPITW index and average farm wage rates. These analyses indicate almost no relationship between the trend in crop cost of production and the prices received by IID growers for their sugar beet production over the period 1980 through 2000. This would support the opinion that IID growers have no real power to recoup increased production costs for their sugar beets by increasing the prices they charge for that crop.

We also compared wholesale sugar prices in the U.S. to the average prices received by IID growers for their sugar beets for the period 1990 through 2000. This analysis indicated a moderate relationship between these two variables suggesting that IID sugar beet prices move somewhat in line with the national wholesale price of sugar over which IID growers have no control.

4. Wheat

a. Market Definition

According to the State of California Agricultural Statistics Service, in 2000 wheat was grown on approximately 577,000 acres in California producing about 1.5 million tons of wheat. In that year, IID accounted for about 8.6% of this acreage, almost 50,000 acres. California produces only a small portion of the U.S.'s wheat. The U.S. is a net exporter of wheat but does import significant amounts, particularly from Canada. Wheat is highly storable and easily shipped. The geographic market for wheat is international in scope.

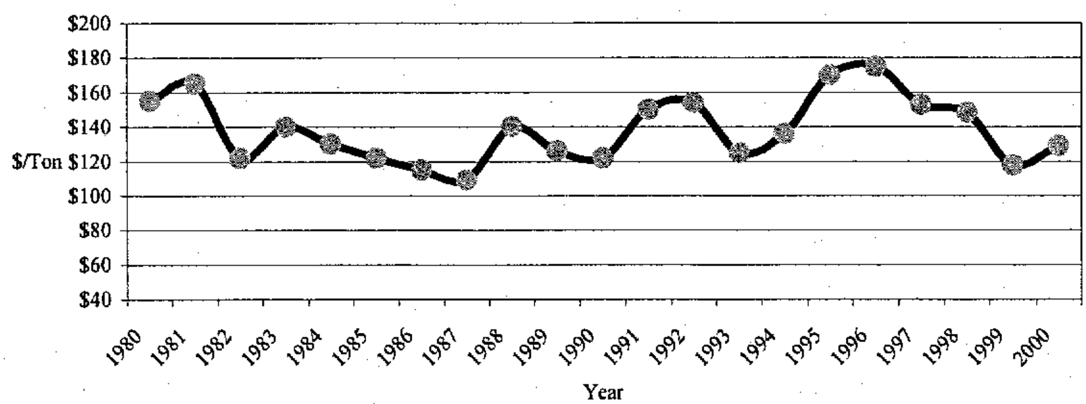
b. Market Power

IID has no power to influence the prices its growers receive for wheat given the relatively low cost to ship wheat, the international scope of the market and the overall continued glut of wheat in the marketplace.

We sought to validate this conclusion by examining and analyzing historical IID wheat prices, acreage and production data. Figure 5 provides a graphic summary of the average price received by wheat growers in Imperial County between 1980 and 2000. During this period, grower costs of production steadily rose, yet as the graph shows, the prices received for wheat did not. In fact the average price received for wheat by Imperial County growers was lower in 1999 and 2000 than in 1980 and 1981. From 1980 through 2000 the average cost to produce crops according to the PPITW Index increased by about 67%.

We conducted correlation analyses between historical IID average wheat prices and both the PPITW index and USDA farmer wage rate data. These analyses indicates almost no relationship between the variation and trend in crop cost of production and the variation and trend in average prices received by IID growers for their wheat over the period 1980 through 2000. This would support the opinion that IID growers have no real power to increase the prices they receive for their wheat to recoup increased production costs.

Figure 5
WHEAT PRICES
IMPERIAL COUNTY
1980-2000



5. Lettuce

a. Market Definition

According to the State of California Agricultural Statistics Service, in 2000 lettuce was grown on about 204,000 acres in California. IID accounted for approximately 8.8% of this acreage, about 18,000 acres. California is the country's largest lettuce producer, followed by Arizona. Almost 70% of California's lettuce is grown in Monterey and other Central Coast counties. However, lettuce produced in this region is harvested in the late spring and summer months. Lettuce grown in IID, the majority of which is head lettuce, is harvested in late fall and early winter and therefore, does not directly compete with Monterey production. In fact, IID accounts for almost all of the late fall and winter lettuce harvest in California. According to Keith Mayberry with U.C. extension, IID's only competition in California comes from some production in Santa Maria, Ventura and the western San Joaquin Valley. IID's primary competition in the lettuce market, however, derives from growers in western Arizona, particularly the Yuma area. IID and Yuma together supply 85% of the US's supply of winter lettuce. In 2000, Yuma County reported over 50,000 acres planted to head lettuce, compared to IID's approximately 15,300 acres.

b. Market Power

According to Keith Mayberry with U.C. extension, Yuma's vegetable season starts earlier but also runs concurrent and even a little past IID's. This provides Yuma growers access to a particularly lucrative market window for lettuce between the end of the Salinas harvest (Monterey County) and the start of the IID harvest (when any competition is virtually non-existent). Then when IID lettuce starts coming off the fields Yuma's ongoing production competes directly with IID's. Mr. Mayberry has also found that Yuma lettuce tends to get higher prices than IID lettuce, not because of actual quality differences, but perceived differences in quality. Many of Salinas' well-known shippers also operate out of Yuma and IID during the winter season. However, more chose to set up shop in the Yuma area. Accordingly, much of Yuma's lettuce is labeled from Salinas, even though it is grown in, and shipped from, Yuma. This lettuce generally receives a premium price in the marketplace because of the image of quality maintained by Salinas's shippers.

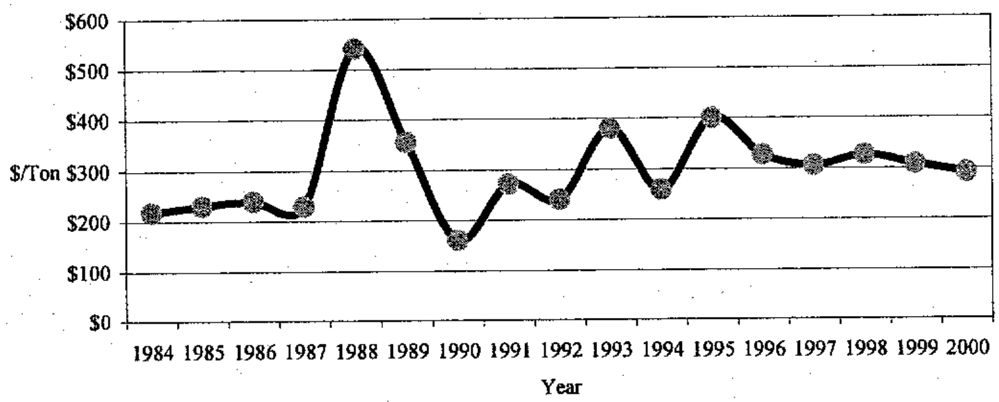
Overall, Mr. Mayberry believes that even though IID is an important player in the winter lettuce market, it would be impossible for IID growers to dictate the price of their lettuce.

Much of the lettuce produced in IID and Yuma is sold in bulk to fast food chains. In this market even very small price increases ($.01 per pound) will cause buyers to seek lettuce from other growers. Furthermore, the lettuce marketplace, like many other crop markets in which IID operates, is characterized by a highly concentrated and coordinated processing and transportation infrastructure that effectively limits the ability of growers to unilaterally dictate prices and other terms of sale.

In addition to anecdotal information, we sought to assess IID lettuce grower market power by examining and analyzing historical IID lettuce prices, acreage and production data. The focus of this analysis is on head lettuce since it comprises the majority of IID lettuce production. Figure 6 provides a graphic summary of the average price received by head lettuce growers in Imperial County between 1984 and 2000 (average head lettuce prices for IID were not published before 1984). During this period, grower costs of production steadily rose, yet as the graph shows, average head lettuce prices did not. In fact the average price of head lettuce in 2000 for the County was below the average price recorded from 1988 through 1990.

The volatility in the price of lettuce observed in the figure can be partially explained by the highly perishable nature of lettuce and subsequent influence of harvest timing on lettuce supply. The demand for lettuce is relatively inflexible—i.e., changes in production in a given period tend to have very large impacts seasonal and average annual prices. While a number of factors influence harvest timing, the weather and pests/disease play a significant and highly uncertain role. To mitigate as much as possible the impact of natural factors, shippers and handlers proactively manage the sequence of planting and harvesting within the different lettuce producing areas of California and Arizona through formal and informal production agreements with growers.

Figure 6
AVERAGE HEAD LETTUCE PRICES
IMPERIAL COUNTY
1984 - 2000



We also conducted correlation analyses between historical IID average head lettuce prices and both the PPITW index and farmer wage rates. From examining Figure 6, these analyses indicate trends in crop cost of production do little to explain the prices received by IID growers for their head lettuce production. This would support the opinion that IID growers have no real power to recoup increased lettuce production costs associated with water conservation by unilaterally increasing the price they charge for lettuce. This is particularly true since Yuma growers would not incur the same cost of production increases.

6. Carrots

a. Market Definition

According to the State of California Agricultural Statistics Service, in 2000 carrots were grown on about 90,000 acres in California. In that same year, IID accounted for about 20% of this acreage, approximately 18,160 acres. About two-thirds of IID's carrot production is sold into the processing market. Kern County is the State's leading producer of carrots, accounting for more than half the State's production. Almost all of Kern County's production is sold into the fresh market.

California's largest competitor in the processing carrot market is Washington. In 2000, Washington growers produced processing carrots on about 5,000 acres. However, Washington carrots are harvested during the summer months, while IID growers harvest carrots during the late fall and winter (though seasonal harvest timing with processing carrots is much less a market factor than for fresh carrots).

A review of 1999 monthly arrivals of carrot shipments by terminal market tabulated by the USDA (including Chicago, Dallas, San Francisco, St. Louis, and Los Angeles), indicates that during the winter months most of the U.S.'s carrots are produced in California, with some competition from Mexico. Mexican carrots compete with California carrots primarily in Dallas and other southern terminal markets.

According to Keith Mayberry, carrots are grown in Imperial as a winter crop while very few carrots are grown in Arizona. There is limited processing available in Imperial. Historically, it has been more cost-effective to ship carrots up to Bakersfield (Kern County) for processing/packaging.

b. Market Power

Our research indicates that IID fresh carrot growers as a group face little competition in the fresh carrot marketplace during the late winter months (January through March). However, carrot production in the Imperial Valley has declined because of the rising cost of transportation up to the Bakersfield processing plants that would otherwise be mostly idle during the primary IID carrot harvest. The volume of carrot production in IID is not high enough to attract investment in local processing/packing.

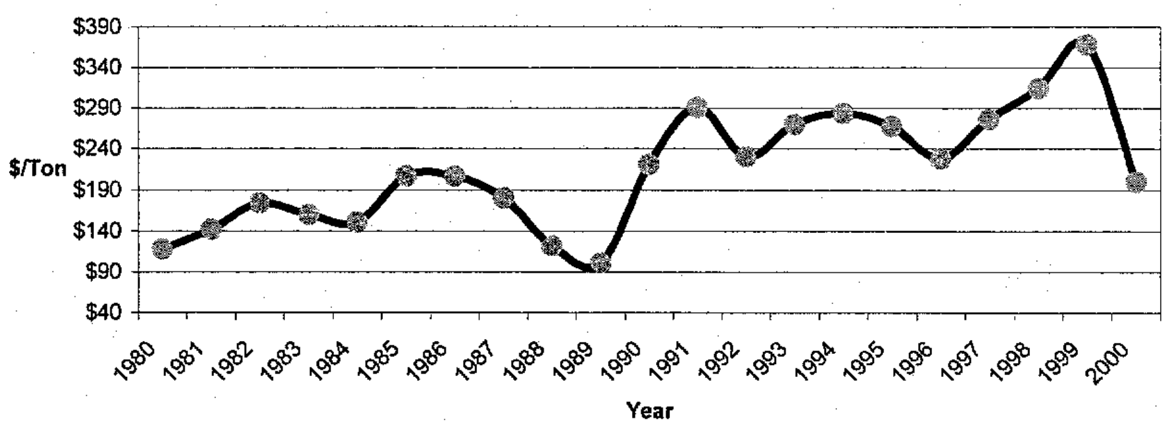
While most fresh market carrots are shipped soon after packing, they can be stored for extended periods. This limits the advantages IID growers have in the market as the only major fresh carrot producers in the U.S. during the late winter. This, combined with the fact that Imperial carrot farmers grow all their carrots under contract to a small group of packer/shippers, basically eliminates any market power of individual IID carrot growers. These contracts are inked prior to planting. The shippers themselves do the harvesting of the crop. There are eight primary shippers in California and the two largest control 90% of the market.

Figure 7 presents Imperial County fresh carrot prices for the period 1980 through 2000.[12] The figure clearly shows prices trending upwards over time, despite some inter-year variation (and a very sharp year-over decline in 2000 which Keith Mayberry with

[12] While processing carrots have recently comprised a larger share of IID's overall cropping pattern than fresh carrots, IID grower's only began farming significant acres of carrots specifically for the processing marketplace beginning in the mid to late 1990s. Accordingly, little IID-specific processing carrot price data is available for analysis.

Imperial County Agricultural Extension attributes to over-planting and subsequent production). The coefficient of determination between average Imperial County carrot prices and the USDA's farmer producer price index for the period is quite high, about 0.53. The coefficient of determination between average Imperial County carrot prices and the USDA's reported average farmer wage rates for California for the period is lower at about 0.48, but still quite high. However, given the apparent limits on IID carrot grower market power, this trend would appear to be more the result of supply and demand trends (particularly strong growth in consumer demand during the 1990s and associated upward price pressures) than an indication that IID growers have the ability to unilaterally pass on to packer/shippers a portion of any water-conservation-related increases in their costs of production. It should also be noted that in the middle of the 1990s, the U.S. for the first time became a net importer of fresh carrots, as producers in Mexico and Canada established a larger presence in the American marketplace. As these and other countries continue to adopt newer carrot production technologies already widely employed in the U.S., and remaining constraints to trade are eliminated under NAFTA and other agreements, competition faced by IID carrot growers is only expected to increase, constraining carrot price escalation and further limiting IID market power.

Figure 7
FRESH CARROT PRICES
IMPERIAL COUNTY
1980-2000



7. Broccoli

a. Market Definition

According to the State of California Agricultural Statistics Service, in 2000 broccoli was grown on about 132,000 acres in California, including almost 90,000 acres of fresh market production.[13] In that same year, IID growers planted almost 11,000 acres of broccoli. All of IID's broccoli production is sold into the fresh market. Accordingly, in the year 2000 IID accounted for about 12% of California's fresh broccoli acreage. The largest source of broccoli in the State is Monterey County, accounting for over half the State's production of fresh broccoli.

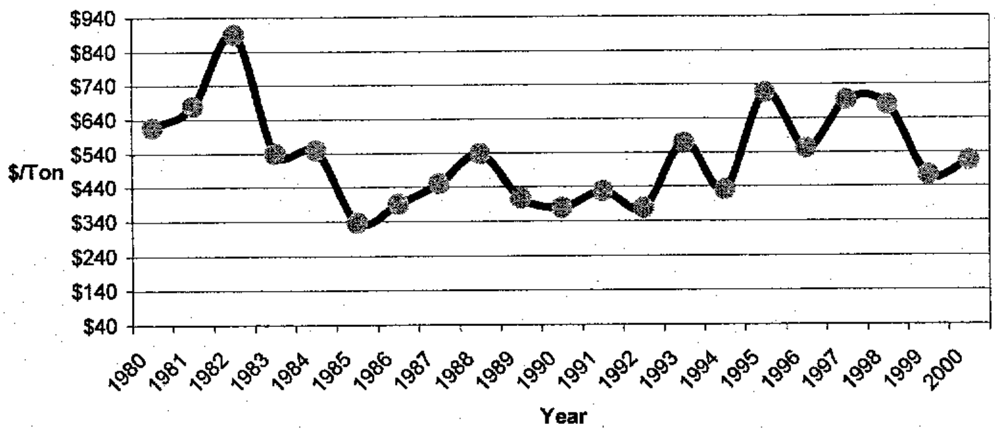
Growers in Monterey and Salinas ship broccoli year-round, though the production from these areas drops off during the winter months. IID's broccoli is harvested from October through March. During this time, the District's primary domestic competition comes from Arizona producers in Yuma and Maricopa counties. In 1999, these two counties together produced broccoli on approximately 12,000 acres (nearly the same acreage as IID in that year, though average per-acre yields were higher in IID). Texas also has small acreages of broccoli that are harvested during the winter months. Furthermore, an increasing share of the fresh broccoli consumed in the U.S., particularly during the fall and winter months, is imported from Mexico. Historically, Mexican exports of broccoli to the U.S. were constrained by high U.S. import tariffs; however, the NAFTA-driven phase-out of those tariffs, combined with a precipitous drop in the dollar to peso exchange rate during the mid-90's, has stimulated Mexican broccoli imports.

b. Market Power

A 1999 USDA Economic Research Service report concluded that the general upward trend in retail broccoli prices during the 1990's (inter-year variation aside), following a decline in those prices during the 1980's, has been driven by renewed consumer demand for broccoli and the successful marketing of value-added products such as specialty wrapped and cut fresh broccoli. As a result, broccoli packer/shippers have seen their marketing price spread on broccoli, the difference between farm-gate and retail prices for the crop, increase substantially. Concurrently, average prices received by IID growers for their broccoli also declined during the 1980's followed by a general upward trend in the 1990's (see Figure 8). In fact, the average broccoli price received by IID growers in the late 1990's was within the range, though still below the peak, of prices received about twenty years prior during the early 1980's. It would thus appear that like many crops, consumer demand trends are largely driving the prices received by IID growers for their broccoli, a factor over which IID growers have no control.

[13] A significant majority of all broccoli grown in the U.S. is sold into the fresh market.

Figure 8
BROCCOLI PRICES
IMPERIAL COUNTY
1980-2000



At the same time, crop production-cost trends do not appear to have a meaningful impact on IID grower broccoli prices since those costs generally trended upward over the entire twenty-one-year period of study. Examining the relationship between historical farm production costs and IID average broccoli prices validates this conclusion. Specifically, the coefficient of determination between IID average broccoli prices and both the PPITW and the USDA's reported average farm wage rates for California during the period 1980 through 2000 are near zero. Accordingly, broccoli growers in IID cannot expect to recoup increases in the cost of crop production (including the cost of water) by unilaterally increasing the farm-gate prices charged for broccoli; instead they must accept the market price for broccoli irrespective of their production cost situation.

8. Dry Onions

a. Market Definition

According to the State of California Agricultural Statistics Service, in 2000 dry onions were grown on about 46,000 acres in California. In that same year, IID accounted for about 27% of this acreage, about 12,400 acres. IID growers harvest their dehydrator onions during the first three months of the year and onions for fresh market from April through June. The onion harvest begins in June in Fresno and Kern counties where half of California's acreage of dry onions is located.

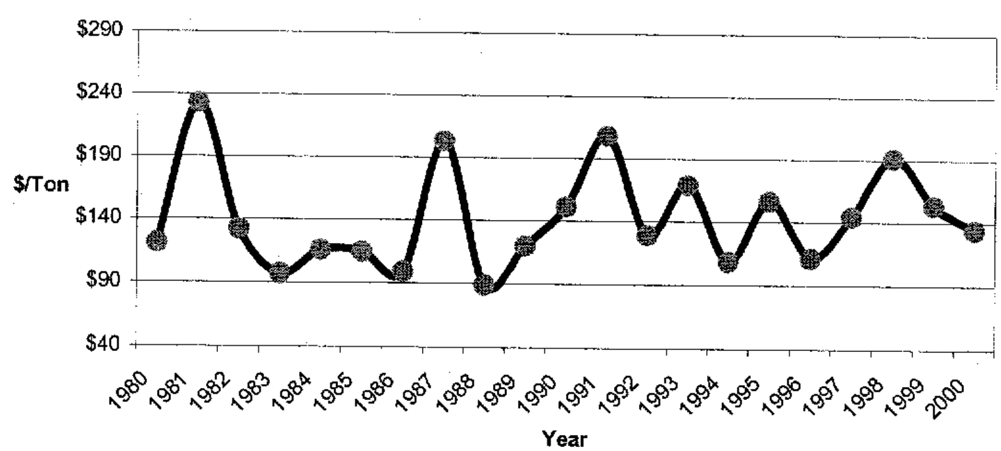
Dry onions are produced in many states, and advances in storage technologies have limited the significance of market windows, particularly during the late winter and early spring when IID (along with Arizona and Texas) is harvesting its onion crop.

We reviewed 1999 monthly arrivals of onion shipments by terminal market tabulated by the USDA (including Chicago, Dallas, San Francisco, St. Louis, and Los Angeles). This data indicates that California onion growers compete nationally in the market for onions, as significant amounts of onions from Oregon, California, Texas, and many U.S. and international origins arrived at all the terminal markets throughout the year.

b. Market Power

Given the competitive landscape of the dry onion market, particularly the diversification of production throughout the country, we believe that IID growers would be unable to pass on additional costs of water by unilaterally increasing the prices for their dry onions. This finding was corroborated by an analysis of historical costs of farm production, farmer wage rates and IID average dry onion prices. Figure 9 presents those prices for the period 1980 through 2000. The figure shows prices remaining relatively flat, despite some fairly significant inter-year variation. The coefficient of determination between IID average dry onion prices and both farmer producer prices for the period and farmer wage rates is negligible, indicating that trends in the cost of production have little direct influence on prices received by IID farmers for their onions.

Figure 9
DRY ONION PRICES
IMPERIAL COUNTY
1980-2000



9. Cantaloupes

a. Market Definition

According to the State of California Agricultural Statistics Service, in 2000 cantaloupes were grown on approximately 58,000 acres in California. In that same year, IID accounted for almost 20% of this acreage, about 11,300 acres. Fresno County is the State's largest producer of cantaloupes, reporting about 28,700 acres in 2000.

Most of the State's cantaloupes are produced in the San Joaquin Valley and are harvested in the summer. In 2000, approximately 90% of IID's cantaloupes were harvested in the spring, April through June. IID's primary California competition during these months comes from nearby growing areas in the Southern part of the State, primarily Riverside County (Coachella Valley).

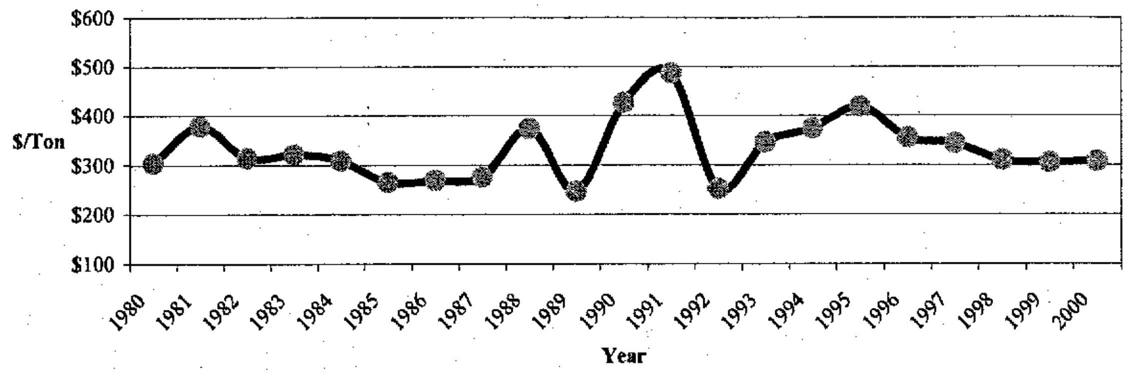
Other primary cantaloupe-producing states that compete directly with IID's spring production are Arizona and Texas. In 1999, Arizona produced over 12,000 acres of spring cantaloupes (primarily in Maricopa and Yuma Counties). However, IID's principal competitor in the spring cantaloupe marketplace is Mexico. IID's primary competition in the market for fall cantaloupes derives from Arizona and Mexico.

We reviewed 1999 monthly arrivals of cantaloupe shipments by terminal market tabulated by the USDA (including Chicago, Dallas, San Francisco, St. Louis, and Los Angeles). This data indicates that about 40% overall, and a clear majority of cantaloupes shipped in May and June to the Los Angeles and Chicago terminal markets, respectively, have an international point of origin (primarily Mexico).

b. Market Power

Given the competitive landscape of the cantaloupe market and particularly the growing significance of Mexico's exports to the U.S. (as noted previously), it appears that IID growers have little control over the prices they receive for cantaloupes. Accordingly, IID growers would be unable to pass on additional costs of water by unilaterally increasing the prices for their cantaloupes. This finding was corroborated by an analysis of historical costs of farm production and IID average cantaloupe prices. Figure 10 presents those prices for the period 1980 through 2000.

Figure 10
CANTALOUPE PRICES
IMPERIAL COUNTY
1980-2000



The figure shows prices remaining relatively flat, despite some fairly significant inter-year variation. The coefficient of determination between IID average cantaloupe prices and both farmer producer prices and California farmer wage rates for the period is near zero, suggesting that trends in the cost of production have no meaningful influence on prices received by IID farmers for their cantaloupes.

III. CONCLUSION

To the extent that growers cannot pass on any increase in their cost of water, they will be adversely impacted financially. Individual growers will be affected differently, depending on their profitability prior to water cost increases and their ability to restructure operations to minimize the impact of higher water costs. Water rates aside, grower profit margins depend on a variety of factors, including crop mix, soil quality, terrain, debt structure and management capabilities. Some of these factors impact profitability by affecting yields and/or production costs.

It is our opinion that IID growers could not recoup increases in their cost of water by unilaterally raising crop prices. Generally, IID growers have little influence over the prices they receive for their crops. In many crop markets, IID is too small a player to exercise market power. For crops that IID growers collectively have a relatively large overall or temporal share of the marketplace, our research discussed above suggests that they still do not have sufficient market power to unilaterally raise their crop prices. With many of these crops, commodity prices are constrained by a highly concentrated packing/shipping infrastructure. Furthermore, NAFTA and continued trade liberalization within the Western Hemisphere have proven significant additional constraints to IID grower market power.

Bibliography

Adock, F. and Rosson, P., *The North American Free Trade Agreement and Horticultural Products*, The Texas A&M University System, Center for North American Studies, September 1999.

Burnham, T.J., *Sour Sugar*, in California Farmer, March 2001.

Cline, H., *Alfalfa hay price likely to improve this season*, www.homefarm.com/archives/2000, Western Farm Press, Volume 22, No. 2, January 15, 2000.

Cook, R., Nuckton, C. and Johnston, W., *California Vegetable Crops: Production and Markets*, for Giannini Foundation Information Series No. 94-3, April 1994.

Glaser, L. and Thompson, G., for USDA Economic Research Service, *The U.S. Lettuce and Fresh-Cut Vegetable Industries: Marketing Channels, Sales Arrangements, Fees and Services*, April 2001.

Glaser, L., Thompson, G. and Handy, C., for USDA Economic Research Service, *Recent Changes in Marketing and Trade Practices in the U.S. Lettuce and Fresh-Cut Vegetable Industries*, May 2001.

Hilsenrath, J. and Rundle, R., *Will Economy Feel California's Tremors?*, in Wall Street Journal – under "The Outlook" column, January 8, 2001.

Howitt, R.E., Ward, K. and Msangi, S., *Statewide Water and Agricultural Production Model*, 1999

Imperial Irrigation District, *Imperial Irrigation District Annual Inventory of Areas Receiving Water – Years 1999, 1998, 1997*. 2000 release.

Klonsky, K. and Livingston, P., *Variations in Regional Alfalfa Production Practices and Costs,"* 1991.

Knapp, K. and Konyar, K., *A dynamic spatial equilibrium model of the California alfalfa market*, Giannini Foundation of Agricultural Economics, University of California : Division of Agriculture and Natural Resources, California Agricultural Experiment Station, January 1990

Knowles, T. and Ottman, M., *Sudangrass Hay Production in the Irrigated Deserts of Arizona and California*, Arizona Cooperative Extension publication 197002, December 1997.

Kuhn, J., *History of Imperial Valley Forage Exports*, http://agronomy.ucdavis.edu.alfalfa.wg, 1998.

Morgan Consulting Group, *U.S. Hay Exports Increase Dramatically*, http://www.forage.com/hay/articles, August 1997.

Public Citizen's Global Trade Watch, *Down on the Farm: NAFTA's Seven-Years War on Farmers and Ranchers in the U.S., Canada and Mexico*, August, 2001 -- http://www.citizen.org/trade/nafta/agriculture/.

State of California Agricultural Commissioner, *Agricultural Crop and Livestock Report – Imperial County*, various years.

State of Utah, Department of Agriculture and Food, *Utah Praised for Its Quality and Safety Standards*, February 1997 – http://www.ag.state.ut.us/pressrel/hay2ca.htm

USDA Economic Research Service, *The U.S. Hay Market: Higher Prices in 1996/97*, Agricultural Outlook, December 1996.

USDA Economic Research Service, *What's Up, Doc?—Carrots!*, Agricultural Outlook, October/November 1997.

USDA Economic Research Service, *Broccoli: Super Food for All Seasons*, Agricultural Outlook, April 1999.

USDA Agricultural Marketing Service, *Fresh Fruit and Vegetable Shipments by Commodities, States and Months*, FVAS-4 Calendar Year 1999 issued March 2000.

USDA Economic Research Service, *Forces Shaping the U.S. Wheat Economy*, Agricultural Outlook, August 2000.

USDA Economic Research Service, *Weak Prices Test U.S. Sugar Policy*, Agricultural Outlook, September 2000.

USDA Economic Research Service, Briefing Room, *North American Free Trade Agreement (NAFTA): Impact on U.S. Agriculture*, December 2000.

Westlands Water District, *Westlands Water District 1998 Crop Acreage Report,* 1999

APPENDIX A
Price and Cost of Production Data Supporting Dornbusch Associates Analysis

Year	Crop Price									Production Cost Measures	
	Alfalfa Hay ($/ton)	Sudan Grass Hay ($/ton)	Sugar Beets ($/ton)	Wheat ($/ton)	Head Lettuce ($/ton)	Fresh Carrots ($/ton)	Broccoli ($/ton)	Dry Onions ($/ton)	Cantaloupes ($/ton)	PPITW Index	USDA California Avg. Farm Labor Rate ($/hr)
1980	$90.0		$55.0	$155.0		$118.0	$615.0	$121.0	$304.0	949	4.51
1981	$81.0		$41.0	$165.0		$142.0	$680.0	$233.0	$378.0	1035	4.84
1982	$70.0		$36.0	$122.0		$174.0	$889.0	$132.0	$314.0	1090	4.89
1983	$89.0		$41.0	$140.0		$160.0	$540.0	$97.0	$321.0	1104	4.85
1984	$83.0		$39.0	$130.0	$218.0	$151.0	$548.0	$116.0	$308.0	1129	5.32
1985	$86.0		$36.0	$122.0	$230.0	$207.0	$336.0	$114.0	$264.0	1131	5.47
1986	$66.0		$37.0	$115.0	$239.0	$207.0	$390.0	$99.0	$268.0	1109	5.64
1987	$79.0		$37.0	$109.0	$229.0	$180.0	$450.0	$203.0	$275.0	1139	5.90
1988	$85.0	$90.0	$38.0	$140.0	$541.0	$122.0	$538.0	$89.0	$373.0	1191	6.02
1989	$100.0	$85.0	$42.0	$126.0	$355.0	$101.0	$408.0	$120.0	$247.0	1261	6.39
1990	$111.0	$102.0	$44.0	$122.0	$161.0	$221.0	$380.0	$151.0	$427.0	1310	6.34
1991	$73.0	$87.0	$43.0	$150.0	$271.0	$291.0	$427.0	$208.0	$487.0	1334	6.41
1992	$61.0	$69.0	$39.0	$154.0	$241.0	$230.0	$378.0	$129.0	$251.0	1348	6.66
1993	$91.0	$83.0	$39.0	$125.0	$379.0	$270.0	$568.0	$169.0	$346.0	1381	6.56
1994	$109.0	$88.0	$40.0	$136.0	$258.0	$284.0	$431.0	$108.0	$374.0	1416	6.78
1995	$88.0	$85.0	$40.0	$170.0	$400.0	$268.0	$716.0	$156.0	$419.0	1454	6.83
1996	$102.0	$86.0	$41.0	$175.0	$327.0	$228.0	$553.0	$111.0	$355.0	1531	7.01
1997	$118.0	$99.0	$42.0	$153.0	$306.0	$276.0	$694.0	$144.0	$344.0	1574	7.32
1998	$94.0	$99.0	$42.0	$148.0	$326.0	$314.0	$680.0	$191.0	$310.0	1532	7.71
1999	$85.0	$81.0	$44.0	$118.0	$308.0	$368.0	$472.0	$153.0	$305.0	1531	7.88
2000	$82.0	$92.0	$37.0	$129.0	$292.0	$200.0	$515.0	$134.0	$307.0	1594	8.21

Sources: Imperial Irrigation District, Imperial County Agricultural Commissioner's Office and United States Department of Agriculture insert oversized map here