GRASSLAND BASIN IRRIGATION AND DRAINAGE STUDY

by

Dennis Westcot
Regional Water Quality Control Board
Central Valley District
Sacramento, California

Ross Steenssen
Regional Water Quality Control Board
Central Valley District
Sacramento, California

Stuart Styles
Irrigation Training & Research Center
California Polytechnic State University
San Luis Obispo, California

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Summary:

This paper summarizes a project that analyzed the district irrigation efficiency for six subareas of the Grassland Basin roughly representing 80,000 acres on the west side of the San Joaquin Valley near Firebaugh, California. The objectives of this project were to:

• Determine the district irrigation efficiency for the six subareas.
• Update district drainage policies and water reuse.
• Update the geographical information system (GIS).
• Perform a pre-plant irrigation efficiency analysis.
• Establish a relationship between the drainage volumes and the district irrigation efficiency.
• Determine the maximum district irrigation efficiency attainable.
• Determine the impact of optimizing district irrigation efficiency on loads and concentrations leaving the districts.

Keywords:

Irrigation efficiency  Drainage
GIS systems    Selenium

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GRASSLAND BASIN IRRIGATION AND DRAINAGE STUDY

Stuart Styles, Charles Burt, Dennis Westcot, Ross Steensen

INTRODUCTION

This project analyzed six subareas of the Grassland Basin roughly representing 80,000 acres on the west side of the San Joaquin Valley near Firebaugh, California. The study area shown in Figure 1 is located approximately 50 miles west of Fresno, California. The subareas are identified in this report as: Broadview Water District (BWD), Central California Irrigation District (CCID-Camp 13), Charleston Drainage District (CDD), Firebaugh Canal Water District (FCWD), Pacheco Water District (PoWD), and Panoche Drainage District (PDD). The time span was from 1981 through 1992.

![Figure 1. Project location map.](image)

The basic problem facing these districts is that their drainage outflows have high concentrations of total salinity and specific elements such as selenium and boron. These discharges, when added to the low flow rates in various sloughs and streams, exceed the maximum concentration limits which have been set or suggested by a variety of regulatory agencies.

The drainage outflows consist of both tailwater (surface runoff from sprinkler and furrow fields) and tilewater (from deep percolation or inflows from neighboring irrigation district lands). The districts are struggling with ways to reduce the drainage flows and also increase the drainage quality; these options, of course, are contradictory. An increase in tailwater discharge will dilute the high salinities in the tilewater flows. However, the salt loading is not decreased.

There are many difficulties associated with establishing a good drainage plan, and with time it is being learned that some water quality objectives for rivers and sloughs cannot be met while simultaneously farming in some areas. The inter-relationships between irrigation efficiency, drainage water recycling (both tail and tile waters), volumes and quantities of
water leaving the districts as drainage water, and groundwater contributions into and out of the district boundaries are quite complex and are still being learned.

One of the first steps in achieving a reasonable drainage water management plan, and in discussing the various benefits/disbenefits of certain on-farm and district-level practices, is to establish a set of baseline data regarding water inflows, ET, drainage outflows, and drainage water qualities in an area. To do this well is quite a formidable challenge, especially when data collection by districts has historically been for operational purposes, and often does not have the frequency or quality controls required for regulatory-type studies. In addition, there always problems with defining subsurface flow rates.

The study collected and organized baseline data to constructed water balances using two techniques. The first technique assumed certain crop ET rates based upon daily crop ETo and crop coefficients, plus cropped acreages and planting/harvest dates. That technique also utilized a "de-rating" of ET values due to non-uniform crop stands and vigor throughout average fields. The second technique utilized actual data of district surface drainage outflows, plus estimated subsurface outflows to estimate the crop ET.

Once baseline data is obtained regarding district-level Irrigation Efficiencies, one must also make judgment regarding the reasonableness of those efficiencies; ie, one must assign some value to "Irrigation Sagacity" which combines both beneficial and reasonable irrigation water uses. In this regard, the study interviewed farmers and district personnel to determine what types of successes and failures had occurred with various on-farm and district-level drainage practices. It was found, for example, that farmers in the irrigation districts with very high (close to 90%) district-level irrigation efficiencies were beginning to experience crop reductions due to salinity buildup in the soil.

DRAINAGE RECYCLING

The districts in the study area have different options available for handling surface runoff and subsurface drainage. The drainage strategy is made up of five different policy levels: Acceptance, Separation, District Level Recycling, Holding, and Assimilation Water. Each of these levels was analyzed for each district. Table 1 is a listing of these drainage policies and a brief description of the policy.

<table>
<thead>
<tr>
<th>Policy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance</td>
<td>Decision by districts to accept or deny drainage or surface water into district surface drains.</td>
</tr>
<tr>
<td>Separation</td>
<td>If a district accepts both tile water and tailwater, the next policy decision is whether or not to keep them separate.</td>
</tr>
<tr>
<td>Recycling</td>
<td>The next policy decision is whether or not a district will recycle any of the water back into the supply.</td>
</tr>
<tr>
<td>Holding</td>
<td>Storage of drainage water could be required to meet water quality standards.</td>
</tr>
<tr>
<td>Assimilation</td>
<td>Blending of the drain water with better quality water to meet water quality standards.</td>
</tr>
</tbody>
</table>
• **Acceptance Of Tailwater and Tilewater.** All districts are currently accepting both tilewater and tailwater. However, PDD's formal policy is to not accept tailwater and that policy will soon be completely enforced. BWD has plans for installing a new turnout on the San Luis Canal. If this installation is completed, BWD will no longer accept tailwater either. Although this report does not include detailed information about on-farm recycling, there is already considerable on-farm recycling of tailwater in the study region especially within PDD and PoWD.

• **Separation Of Tailwater And Tilewater.** COD's drainage system keeps tile water separate from tailwater on the upslope side of the DMC. Once pumped across the DMC, tile water and tailwater are commingled in the open drains. PoWD is attempting to keep tile water and tailwater separated. All other districts commingle tile water and tailwater.

• **District Level Recycling.** COD does not recycle any drainage water at the district level. CCID, while recycling substantial amounts of drainage water in other parts of their system, is recycling only one tile sump of ten in the 6,000 acre Camp 13 Study Area. PeWD has only recycled drainage water in the past two years. PoWD, and BWD recycle substantial amounts of drainage water. FCWD recycles a significant portion of their drainage water.

• **Holding Facilities.** Only Panoche Water District (PeWD) has an external holding facility, and this is only a pilot project.

• **Assimilation.** CCID has indicated that it can blend its problem drainage water with its own irrigation water. FCWD and BWD have not indicated what their formal policies will be in the future. CDD, PDD, and PoWD have indicated that they will maximize their use of the San Joaquin River's assimulative capacity. Formal policies are lacking at all districts that would govern the extent of recycling, the allowable water quality limits for blended irrigation water, and division of the assimilative capacity of the San Joaquin River among the area drainers.

Obviously the on-going drought has had an impact on the amount of recycling and drainage. It is impossible to accurately predict district operations in a normal year. Looking at pre-drought years would probably not be appropriate due to the change in the political/regulatory climate regarding agricultural drainage in the area.

**GEOGRAPHICAL INFORMATION SYSTEM (GIS)**

The GIS database was updated and utilized several times throughout the course of this project. The database has been transmitted to the USBR (through Internet), USSL in Riverside (tape file), and to the USGS in Sacramento (tape file). Copies of the file can be made for other entities wishing to perform analysis of the study area using GIS.

An ARC/INFO database has been developed for this project to manage all of the map data. Although initial maps were down-loaded from the Bureau of Reclamation's computer in Sacramento at the start of the project, many changes to the existing data were found to be necessary. Therefore, data was re-digitized from existing map sources and field checking using a USGS 7.5 minute quad series as the base. The quads are as follows:

<table>
<thead>
<tr>
<th>Charleston School</th>
<th>Mendota Dam</th>
<th>Laguna Seca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dos Palos</td>
<td>Firebaugh</td>
<td>Hammonds Ranch</td>
</tr>
<tr>
<td>Oxalis</td>
<td>Broadview Farms</td>
<td>Poso Farm</td>
</tr>
</tbody>
</table>
SUBSURFACE FLOWS

John Fio, with the USGS in Sacramento, used the GIS to perform an analysis of the base flow for the study area. The sump discharge data for all of the sumps in the study area was analyzed for the study period. Low flows have been assumed to approximate the most accurate determination of the base flow. The base flow was defined for this study as the net groundwater inflow to the region from outside of the study area boundaries measured in the surface discharge measurements during the nonirrigated periods.

Sump discharge data from Broadview, CCID-Camp 13, Charleston, Firebaugh, Pacheco, and Panoche districts was obtained and formatted to a single spreadsheet application. High flows (January through September - in general) were separated from low flows during the non-irrigated time of the year (October-December).

The data collection effort uncovered an important recommendation for future activities for the districts. All data should be reported in a consistent format with well-defined protocols for data storage and retrieval. For example, all data could be provided in ASCII format. Retrieval of the raw data was a significant amount of the expense for this portion of the study due to differences in reporting formats, embedded graphs, and programmed cell formulas.

The estimated drainflow for this study in 1992 (most complete data set) was as follows; Broadview-52 AF, CCID C13-No Estimate, Charleston-30 AF, Firebaugh-409 AF, Pacheco-575 AF, Panoche-970 AF. The total low flow volume was 2,036 AF for the entire study area. The total sump flow was estimated at 15,165 AF. The low flow represents about 13% of the total sump flow for the study area. The low flow total would represent a minimum base flow since it does not account for baseflow during the irrigation months.

An estimate of incidental recharge below the Corcoran Clay was also required for the water balance in this study. Preliminary results from a steady-state groundwater-flow model constricted by Fio (in review) indicate the following simulated incidental recharge to the aquifer below the Corcoran Clay; Panoche-0.54 AF/yr, Broadview-0.31 AF/yr, Firebaugh-0.26 AF/yr.

Well pumping estimates were made by contacting individual growers in the study area. It was not possible to obtain values that were reasonable. Estimates of groundwater pumping were made by evaluating the ETc requirements. This was significant for Panoche Drainage District in 1991 and 1992 where groundwater pumping represented about 30% of the water supply.
DISTRICT IRRIGATION EFFICIENCY (DIE) - CROP ET (ETC) APPROACH

The District Irrigation Efficiency (DIE) is computed using the irrigation district boundaries as entrance/exit points for water movement. The irrigation efficiency is calculated with the following equation:

\[
\text{DIE} = \frac{(\text{ETc} + \text{Leaching} - \text{Effective Rain} - \text{Ext. groundwater contrib. to ETc})}{\text{Irrigation Water Applied}} \times 100
\]

where:
- \( \text{DIE} \) = District Irrigation Efficiency (%)
- \( \text{ETc} \) = Adj. ETc values (reduction for poor stands and bare spots)
- \( \text{Leaching} \) = Irrig. water necessary to satisfy the Leaching Requirement (LR)
- \( \text{Effective Rain} \) = Rain used by crops or for salt control

Table 2 summarizes the calculated values. The low irrigation efficiency values in 1983 and 1986 occurred during years that were high rainfall amount years. Broadview Water District had high values in 1981 and 1982 which then decreased in 1983 when BWD obtained an outlet to the San Joaquin River. The 80% efficiency occurred with 100% internal recycling of both tailwater and tilewater. Since the water quality degraded to an unsatisfactory value, the 80% may well represent the range of maximum sustainable irrigation efficiency with this type of hydrology. Note that after several years of high irrigation efficiency, the DIE drops in value significantly in Broadview. This can be partially explained by the result of leaching done in subsequent years to make up for short water years. This means that the highest values on the table may reflect levels that are not maintainable. A more detailed discussion of the 80% DIE value is found later in this paper.

Figure 2 shows the irrigation efficiency (DIE) using the ETc approach graphically. The trend is definitely one of increasing irrigation efficiency over the 12 years of the study. This reflects a necessary reaction by growers and districts to respond to decreasing water supplies and increasing environmental, political, and social concerns of drainage.

Table 2. District Irrigation Efficiency - ETc Approach.

<table>
<thead>
<tr>
<th>Year</th>
<th>Broadview</th>
<th>CCID</th>
<th>Charleston</th>
<th>Firebaugh</th>
<th>Pacheco</th>
<th>Panoche</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>81%</td>
<td>48%</td>
<td>59%</td>
<td>55%</td>
<td>67%</td>
<td>58%</td>
</tr>
<tr>
<td>1982</td>
<td>81%</td>
<td>48%</td>
<td>62%</td>
<td>55%</td>
<td>40%</td>
<td>40%</td>
</tr>
<tr>
<td>1983</td>
<td>58%</td>
<td>44%</td>
<td>62%</td>
<td>61%</td>
<td>72%</td>
<td>62%</td>
</tr>
<tr>
<td>1984</td>
<td>57%</td>
<td>43%</td>
<td>43%</td>
<td>53%</td>
<td>77%</td>
<td>54%</td>
</tr>
<tr>
<td>1985</td>
<td>55%</td>
<td>61%</td>
<td>42%</td>
<td>51%</td>
<td>7%</td>
<td>61%</td>
</tr>
<tr>
<td>1986</td>
<td>51%</td>
<td>63%</td>
<td>47%</td>
<td>52%</td>
<td>6%</td>
<td>61%</td>
</tr>
<tr>
<td>1987</td>
<td>56%</td>
<td>71%</td>
<td>45%</td>
<td>53%</td>
<td>7%</td>
<td>61%</td>
</tr>
<tr>
<td>1988</td>
<td>58%</td>
<td>73%</td>
<td>55%</td>
<td>61%</td>
<td>7%</td>
<td>61%</td>
</tr>
<tr>
<td>1989</td>
<td>62%</td>
<td>87%</td>
<td>68%</td>
<td>68%</td>
<td>7%</td>
<td>61%</td>
</tr>
<tr>
<td>1990</td>
<td>73%</td>
<td>77%</td>
<td>68%</td>
<td>68%</td>
<td>7%</td>
<td>61%</td>
</tr>
<tr>
<td>1991</td>
<td>87%</td>
<td>66%</td>
<td>71%</td>
<td>71%</td>
<td>7%</td>
<td>61%</td>
</tr>
<tr>
<td>1992</td>
<td>94%</td>
<td>71%</td>
<td>73%</td>
<td>73%</td>
<td>7%</td>
<td>61%</td>
</tr>
</tbody>
</table>

PRE-PLANT IRRIGATION EFFICIENCY

Examination of pre-plant irrigation efficiencies for five of the Grassland Basin districts was completed in order to determine the potential for reduction of drainage water from the area during the period of time when pre-plant irrigation events occur (December through March). In theory, the time frame for the poorest irrigation efficiencies occurs during the pre-plant irrigations since irrigations are required for germination, but the soil moisture deficit may not warrant the quantity of water applied.
Figure 2
Grassland Basin Irrigation and Drainage Study
District Irrigation Efficiencies (ETc Approach)
The study of the pre-plant irrigation efficiencies depends on the application of broad-based and theoretical assumptions about agricultural practices to highly variable and site specific cropping and irrigation patterns. Furthermore, the information available from the water districts involved is general in nature. Given these limitations, quantifying the data and arriving at specific numbers for district-wide pre-plant irrigation efficiencies for a certain portion of the cropping season is a task which requires a certain amount of professional skill to evaluate the results.

The intention in this portion of the study was to obtain numbers which would reflect trends in pre-plant irrigation efficiencies and indicate the degree of need for modifying irrigation practices during the time of year when pre-plant irrigation occurs. Figure 3 shows the irrigation efficiency using the Pre-Plant Irrigation Efficiency approach graphically. Results indicated overirrigation (low irrigation efficiencies) prior to 1990. Results also indicated poor irrigation efficiencies during high rainfall years. Rainfall in the pre-plant months tended to decrease the irrigation efficiency in this analysis. However, the rainfall may not have been beneficial to the individual farmer depending on several factors. Results for 1990 through 1992 generally indicated underirrigation during the pre-plant months (high irrigation efficiencies). The following main conclusions were drawn from the data:

- The data indicate that growers are adjusting water deliveries in response to the quantity of effective rainfall.
- Low PIE values can generally be explained where growers are applying excess water in one year to satisfy leaching requirements from previous years.
- High PIE values from 1990-1992 in some of the districts reflect inadequate water supplied for leaching.
- 1993 can be expected to be a low PIE year if water was available.

REGIONAL IRRIGATION EFFICIENCY - WATER BALANCE APPROACH

This section of the study was designed to be a check against the DIE which was computed with the ETc approach. The Water Balance approach used the reported district drainage (and its quality) to determine the DIE. If a district acts hydrologically as a "bathtub", this is a reasonable approach. Because there are difficulties in determining drainage outflows from individual districts, the data was eventually grouped to estimate a regional IE.

Since 1985, additional data has been collected and reported for the drainage volumes discharged by the districts. Using this data and some assumptions regarding subsurface water flows, an estimate of the irrigation efficiency using a "bathtub" or water balance approach was completed in order to verify the validity of the values generated by the theoretical ETc approach.

The Regional Irrigation Efficiency values were determined for water years 1986 to 1992 depending on what information was available. In this report, 1986 refers to the water year October 1, 1985 through September 30, 1986. The goal was to verify the relative values of the DIE estimates using the ETc approach. Note on this table that Broadview Water District, CCID-Camp 13, and Firebaugh Canal Water District are referred to as the Eastside Districts. This was done since they all drain through one, common drainage point (FC-5).

Table 3 shows the calculation of the district irrigation efficiency based using a water balance approach and using the following equation:
Figure 3
Grassland Basin Irrigation and Drainage Study
Pre-Plant Irrigation Efficiency

YEAR

PERCENT


PANOQUE
BROADVIEW
FIREBAUGH
PACHECO
CHARLESTON
IE = \frac{\text{Irrigation Water Beneficially Used}}{\text{Irrigation Water Applied}} \times 100

Also shown on this table is the comparison to the Regional IE estimate from the ETc approach. The data for the regional irrigation efficiency for both approaches is shown in Figure 4. The values trend similar to each other indicating increasing irrigation efficiencies as the drought continued into the 6th year (1992). The values are 5% or less difference starting in 1987. The values are within 3% in the years 1989 through 1992. This close comparison of results of two entirely different calculation procedures validates the assumptions used in the ETc Irrigation Efficiency approach.

<table>
<thead>
<tr>
<th>Year</th>
<th>Panoche (DIE)</th>
<th>Pacheco (DIE)</th>
<th>Charleston (DIE)</th>
<th>Eastside Districts (BWD, FCWD, CCID-Camp 13)</th>
<th>Regional IE (Water Balance Approach-Weighted)</th>
<th>Regional IE (ETc Approach)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>64%</td>
<td>59%</td>
<td>59%</td>
<td>66%</td>
<td>64%</td>
<td>56%</td>
</tr>
<tr>
<td>1987</td>
<td>61%</td>
<td>45%</td>
<td>59%</td>
<td>68%</td>
<td>64%</td>
<td>59%</td>
</tr>
<tr>
<td>1988</td>
<td>64%</td>
<td>52%</td>
<td>74%</td>
<td>52%</td>
<td>64%</td>
<td>64%</td>
</tr>
<tr>
<td>1989</td>
<td>69%</td>
<td>69%</td>
<td>75%</td>
<td>75%</td>
<td>69%</td>
<td>73%</td>
</tr>
<tr>
<td>1990</td>
<td>69%</td>
<td>69%</td>
<td>78%</td>
<td>78%</td>
<td>72%</td>
<td>75%</td>
</tr>
<tr>
<td>1991</td>
<td>72%</td>
<td>72%</td>
<td>77%</td>
<td>77%</td>
<td>76%</td>
<td>78%</td>
</tr>
<tr>
<td>1992</td>
<td>69%</td>
<td>72%</td>
<td>79%</td>
<td>82%</td>
<td>74%</td>
<td>77%</td>
</tr>
</tbody>
</table>

CONCLUSIONS

One effect of the drought may well be a reduction in the ETc adjustment factor as farmers stress crops. Another factor might be farmers planting more acreage than prudent; hoping for extra water to appear in mid-season. Without the additional water, some acreages would have to be considered separately if performing further analyses in the same manner as this study.

The results of this study indicate that most of the districts were able to improve DIE. The main problem is whether they can maintain the high levels of irrigation efficiency without being impacted by increasing salinity in the rootzones. Based on the pre-plant analysis, the data indicated that significant underirrigation was being practiced due to the limited irrigation water supplies. If the trend were to continue, excessive levels of salts in the rootzone would be expected.

The results also indicate a basic need for better coordination among the districts in the data collection and recording efforts. The districts might invest in a common spreadsheet and word processing format to aid in information transfer. There has been much data collected for this study area. However, most of the data is not readily accessible for data analysis. Some of the data monitoring sites need to be improved. For example, wells and drainage sumps must be fitted with flowmeters. Other suggestions include standardized procedures for the collection of water quality data, improved drainage discharge point measuring stations, and standardized format for reporting irrigated acreage and water delivery data (suggest the September through October format).
Figure 4
Grassland Basin Irrigation and Drainage Study
District Irrigation Efficiencies (Water Balance Method)

![Graph showing district irrigation efficiencies over the years 1981 to 1992. The graph includes lines for Panoche (PE-14), Pacheco (PO-1), Charleston (CH-1), and Eastside (FC-5). The x-axis represents the years 1981 to 1992, and the y-axis represents irrigation efficiencies ranging from 30% to 100%. The graph indicates varying efficiency levels across different years for each district.]
An important assumption made in this study was adjusting the ETc downwards to account for nonuniformity and bare spots (about 15%). This tended to decrease DIE using the ETc approach because it decreases beneficial use for the same amount of applied irrigation water. This assumption appeared to be verified by comparing the ETc approach results of DIE with the water balance approach.

**Other Significant Results:**

- The water balance approach has identified several destinations of water that have not been used in previous reports. These include an estimate of the amount of rainfall runoff that enters the drains. The total amount ranged from about 4,500 AF to 10,000 AF for the entire study area based on 50% of the total rainfall between October and March. Another estimated value was the amount of deep percolation losses below the Corcoran Clay layer. This report estimated losses of about 23,100 AF per year for the study area. This is compared to the measured drainage volume in 1992 of 30,500 AF. This is significant because a salt balance of this region needs to include an estimate of the salt removed with the water passing through the Corcoran Clay.

- Due to the fluctuating characteristics of the water quality data from the sumps and the district drains, it was felt it was not possible to draw conclusions regarding the expected selenium, salinity, or boron levels with additional recycling. Future data collection efforts need to focus on consistent water quality measurements and accurate flow measurement devices. Reported water quality measurements appear to use averaging techniques that may not accurately reflect the water quality in the drains. Some of the drainage discharge measurement sites need improvements to ensure accurate water measurement.

- In addition, special analyses were made of the sumps in Panoche Drainage District. It was found that 50% of the reported load of Se into the discharge of the district comes from 5 of 61 sumps. 80% of the loading comes from 10 of the sumps. These sumps are located close to each other on the eastern side of the district. If flows from these sumps could be minimized, the impact on the drain Se loading would be significant. Future studies may want to focus on water table control in these areas to minimize drainage volumes. For example, maintaining higher water tables could force additional upflux from the shallow water table. It is recognized that these regions may be draining significant flows from upslope water users. PDD has also been at the forefront in researching methods to remove harmful salts from the drainage water.

- It was found that the water quality from individual sumps varies significantly and that this is due to variations in the timing of the water quality samples. Apparently, water samples are drawn when convenient and costs do not allow consideration for the timing of irrigation events. However, the data indicates that reductions in the drainage volumes will definitely reduce the EC, Se, and B loadings in the drains with the tradeoff of some increase in the concentrations.

**FUTURE OF THE GRASSLAND BASIN**

Long-term success for farmers in the Grassland Drainage Basin might be defined as "maintaining acceptable agricultural profitability while meeting the water quality standards in the San Joaquin River". This success will depend on the drainers' ability, in the Grassland Area, to control the timing and amount of salt movement to the San Joaquin River. This ability will be affected by:
• Modifications to on-farm tile drain systems and irrigation practices that could possibly reduce the pickup of salts, especially selenium (i.e., closer tile line spacings, maintenance of higher water table, and water table control for maximum crop use).

• Individual district strategies for disposal of drainage water (increase DIE).

• Cooperation among the districts in jointly meeting water quality standards.

Unblended agricultural drainage that leaves a district's boundaries will almost always be of worse quality than the water quality standards of the San Joaquin River. Thus, drainage water must be blended with better-quality water. There are two possible sources for blending water:

1. The natural flows of the San Joaquin River
2. High quality drainage water which leaves a district

Future actions by various regulatory agencies may restrict the amount of San Joaquin River water which can be used by districts to blend with their drainage water. If this occurs, districts will have to use their own irrigation water supply. In either case, districts can develop a management strategy if they have internal control of drainage amounts, qualities, and destinations.

Increasing the DIE will result in reduced drain water volumes and lower loads. Reduced drain water volumes and loads will result in higher concentrations of boron and selenium at district discharge outlets. Thus, while the probability of achieving water quality objectives in the San Joaquin River will be increased, the concentrations of boron and selenium in Mud Slough (North) and Salt Slough will also be increased.

There are two reasonable approaches available towards increasing the DIE in this area:

• The first is the classical approach of improved water management on both district and on-farm levels.

• The second path is a relatively new idea. This approach is an integrated approach which attempts to maximize the ratio of crop yield to the unit-water applied. Through improved management of the soil fertility, planting, irrigation, and other agronomic factors, the zones in a field which have weak or bare crop growth will be eliminated or minimized. Therefore, with a stronger crop, the field ET will increase because there are more and healthier plants. The applied water would remain about the same. The net result is less deep percolation and a higher IE.

SUSTAINABLE DISTRICT IRRIGATION EFFICIENCIES

There are two important and related questions which the ITRC has addressed in this study:

• What is the highest District Irrigation Efficiency (DIE) which can be sustained in this
• How much tile water recycling can be done?

The evidence to date indicates that the answers are three-fold:

• If there is under-irrigation on fields (caused by a combination of short durations and non-uniformity), any tile water recycling appears to be unsustainable in that some portions of the fields will accumulate unacceptably high and toxic salt levels.
• If there is no under-irrigation on fields (i.e., all non-uniformity is compensated for with extra water application, and irrigation scheduling is sufficient to have no stress anywhere), about 30% of the deep percolation through the root zone can be recycled without raising the average root zone ECe to more than about 2.5 dS/m. The remaining 70% of the root zone deep percolation will either exit through the Corcoran Clay layer or be discharged (via tiles and then surface drains) from the district. Because of the uncertainties of the magnitude of the flow rate downward through the Corcoran Clay layer, it is impossible to predict the precise amount of tile water that must be discharged from the district via surface drains.

• The maximum sustainable DIE is about 80% in this region.

These conclusions are based upon the following:

1. All on-farm irrigation has non-uniformity (Distribution Uniformity, DU, of less than 100%) of water distribution across a field. Typical well-managed and well-designed irrigation systems have a DU of about 75-85%.

2. Assuming no under-irrigation at any point in a field, with a DU of 75% and about 5% non-beneficial evaporation loss, the Irrigation Efficiency (IE) of a farm with no recycling is about 71%:

\[
IE = DU \times (1 - \frac{\% \text{ evap. loss}}{100})
\]

\[
= 75 \times (1 - \frac{5}{100})
\]

\[
= 71\%
\]

3. A simple spreadsheet was developed to examine soil salinities across a field with a linear DU pattern and varying percentages of tile recycling. A 30% recycling of root zone deep percolation, accomplished through blending tile water with supply water, indicated that the drainwater EC and blended water EC stabilize within a couple of years. This assumes **no under-irrigation** (a key assumption, as explained below). Estimated stabilized values were:

- EC of source water = 0.6 dS/m (assumed)
- ECe at "worst spot" in the field = 2.6 dS/m
- ECe at "best spot" in the field = 0.5 dS/m
- ECw (blended) = 0.8 dS/m
- ECdw = 2.5 dS/m

4. The numbers in item (3) above do not match what is actually seen in field. In particular, Broadview Water District has excellent data since about 1980. That data shows the following:

- Before BWD had an outlet for its tile drain water, the EC of the blended irrigation water was about 3.0 dS/m, higher than predicted in (3).
- This report has estimated that the present annual DIE values and pre-irrigation DIE values are in the range of 90%.
- Soil salinities measured throughout BWD by Lesch and Rhoades in 1991 are much higher than the ECe's predicted.
- The high DIE values in BWD are indicative of under-irrigation on parts of fields. That under-irrigation leads to salt build-up (due to no leaching) in some parts of
fields, and very concentrated tile drain water in the areas with some leaching. That concentrated tile drain water is then recirculated on all the field, compounding the problem.

5. The district farmers see processing tomatoes as a key crop in their economic rotation. Tomatoes have a threshold (critical maximum) ECe of about 2.5 dS/m for soil salinity. Therefore, this discussion of sustainability revolves around the objective of maintaining a soil salinity distribution such that there is no yield decline of tomatoes anywhere in the field due to salt buildup.

In summary, the evidence indicates that the best strategy for soil productivity sustainability requires all three of the following:

- Have high irrigation DU's
- Have excellent irrigation scheduling and water depth control, and avoid under-irrigation
- Recycle no more than about 30% of the root zone deep percolation, which may be equivalent to 40-60% of the tile water

REFERENCE