Irrigated area:

California has more irrigated area than any other State in the U.S. It accounts for almost 20 percent of the irrigated area in the nation.

Alfalfa and cotton are the leading irrigated crops in the state, each with over 1.3 million acres irrigated annually.

Water use:

Average annual water use of alfalfa varied from 3.8 to 6.2 acre feet per acre per year with a statewide average of about 5.0 acre feet per acre.

About 60 percent of the alfalfa is grown in the San Joaquin Valley, 14 percent in the Imperial Valley, 8 percent in the Sacramento Valley and 18 percent throughout the rest of the state. Alfalfa production is expected to increase by about 19 percent by the year 2020 (1).

Irrigation methods:

Alfalfa accounts for about 20 percent of the irrigated area in the state and uses about 22 percent of the irrigation water. About 87 percent of the alfalfa is irrigated by the border method and 13 percent by sprinklers.

Average irrigation application efficiency:

Since alfalfa is one of the major crops in California, an improvement in irrigation methods and efficiency could have a significant impact on production, water conservation, energy conservation and water quality. The average irrigation efficiency for all crops in California is 66 percent with a potential efficiency, weighted by irrigation method, of 81 percent (2). The increase in efficiency of 15 percent could significantly reduce groundwater pumping (about 45 percent of the water is pumped from deep wells) which would result in an energy savings and a reduction of groundwater overdraft.

Improved irrigation efficiencies would result in less leaching of nutrients below the root zone and into the groundwater. Savings in fertilizer application may also be significant because the same results could be accomplished with a reduced application rate.

For these and other reasons, the USDA, Soil Conservation Service has given irrigation water management a high priority in California and has increased its technical assistance to farmers through the Resource Conservation District Program. Staffing and budget limitations have limited expansion of the program, but we are hopeful that future budgets will give proper consideration to this program.

Irrigation theory:

Since about 80 percent of the alfalfa is irrigated by the border method, let's briefly review the theory behind border irrigation.

There are two basic types of border systems, 1) level borders or basins and 2) graded borders.

The basic difference is that level basins are leveled to zero slope and surrounded by a border to retain the water on the area until it is infiltrated into the soil. No tailwater runoff is produced.
In graded border systems, the area between the borders is sloped, usually with a constant grade. Water is applied at the upper end and shut off when the advancing wetted front reaches about three-quarters of the length of run. The water then advances to the end of the border providing the proper irrigation. If the shut off time is too soon, the water doesn’t reach the end of the border. If the shut off time is too late, excess water is applied to the lower end of the border and produces ponding or tailwater runoff.

**Level basins:**

Water may be applied at one or several points within level basins until the desired amount of water is applied. The water is retained until it infiltrates into the soil. This method requires relatively large flow rates since efficiency is directly related to the time required to wet the farthest point in the basin. This is referred to as the "advance time" across the basin. The water recedes at the same time (recession curve) over the entire area since the area is level. Figure 1 depicts the typical components of a normal irrigation application in level basins. The advancing distance of the wetted front across the basin (horizontal axis) is plotted against time (vertical axis).

![FIGURE 1]

Normal application at far side of basins, slight over irrigation near inlet. Proper amount applied to border area. Application efficiency high.

The desired depth of application is based on the amount of moisture depleted from the root zone of the crop and is measured at the far side of the basin. The desired application line is based on the intake opportunity time required to infiltrate the desired amount into the soil and is always plotted parallel to the advance curve. When the recession line is above the "desired application" line, deep percolation occurs. When the recession line is below the "desired application" line, under irrigation occurs.

If the advance rate is fast, the application efficiency can exceed 90 percent. Level basins are easily automated since a specific amount of water is applied in a short time and runoff is not a problem.

Figures 2 through 4 depict some of the management problems encountered with level basin irrigation. The maximum stream size is limited only by the erosion hazard of the soil. Large stream sizes may require special structures to spread the water without causing erosion.

![FIGURE 2]

Normal irrigation at inlet, under irrigation on remainder of the basin area. Set time too short.

![FIGURE 3]

Over irrigation of the entire area. Set time too long.
For both level basins and graded borders, the relationship between the total amount delivered, delivery flow rate, set time, gross application and the area to be irrigated is as follows:

\[
\text{Total Amount Delivered} = D \times A = Q \times T
\]

Where,

- \(D\) = Average Gross Application Depth (inches)
- \(A\) = Area Irrigated (acres)
- \(Q\) = Flow Rate (cubic feet per second)
- \(T\) = Set Time (hours)

This equation can be used to calculate 1) gross application depth applied, 2) the area to be irrigated, 3) the flow rate \((Q)\) required, and 4) the set or delivery time.

When the flow rate, time of set and area irrigated are known, the gross application depth \((D)\) can be calculated:

\[
D = \frac{Q \times T}{A}
\]

The depth infiltrated at any point in the field depends on the intake opportunity time at that point. It can be calculated from the advance and recession curves and an infiltration curve for the site (3).

When the flow rate, the set time and the gross application depth are known, the area that can be irrigated \((A)\) can be calculated:

\[
A = \frac{Q \times T}{D}
\]

When the gross application depth, the set time and the area irrigated are known, the flow rate \((Q)\) needed can be calculated:

\[
Q = \frac{D \times A}{T}
\]

When the gross application depth, the flow rate and the area to be irrigated are known, the set time \((T)\) can be calculated:

\[
T = \frac{D \times A}{Q}
\]
Graded borders:

Graded borders are commonly used where it is not feasible to level fields to zero slope and drainage from rainfall is desirable. Grades in the direction of irrigation are selected based on soil intake rate, available stream size and irrigation application depth desired (4). Border strip widths are selected which are compatible with the available stream size, soil intake rate and farm machinery width.

Water is applied at the upper end of the border and advances down the strip at a decreasing rate. When the wetted front reaches a point about 3/4 of the way down the strip, the water is shut off and the water in storage in the border continues to advance and wet the remaining area.

The recession or drying up of the ponded water in the border strip begins at the upper end and progresses down the strip. The advancing front and receding water can be measured and plotted to analyze the water application. The basic components of the analysis are shown in Figure 5. Cutoff was made when the water reached about 80 percent of the length of the run. If the water is cut off too soon, the lower end of the border will not receive any water and the adjacent border strip must be over irrigated and the ponded water cut across to the lower end of the deficient border. If the cutoff time is delayed, water will be ponded at the lower end of the border and must be drained into the next border to be irrigated and that cutoff time adjusted to compensate for the extra water. Many farmers can completely irrigate an 80-acre field, adjusting the cutoff times in each border, and not have any ponded water or dry borders when they finish. Others find it much easier to rely on a tailwater return system to take care of the runoff water. Return systems will be discussed later. Figures 6 through 8 depict some of the problems encountered in managing a graded border system with dikes at the end of the border to prevent runoff. The "desired application" curve is parallel to the advance curve and represents the time required to infiltrate the desired application depth at each point in the border strip. Uniform soil intake down the border strip is assumed. With proper management, application efficiencies of 90 percent can be obtained.

**FIGURE 5**
Normal or desirable cutoff time allowed water to advance to end of field with adequate water to irrigate lower end. No ponding. Irrigation same at upper and lower end.

**FIGURE 6**
Over irrigation & ponding on lower end of border. Set time too long.
FIGURE 7
Ponding & over irrigation on lower end, under irrigation on upper end. Stream size too large & set time too long.

FIGURE 8
Normal irrigation at lower end, over irrigation on rest of border. Stream size too small.

Tailwater return systems:

Tailwater return systems consist of a facility to collect (drainage channel), store (sump), and return (pump & return line) the excess water to the irrigation distribution system for reuse on the field or on other fields within the system.

Return system design must be based on specific site and management needs. They can improve irrigation application efficiencies by 5 to 20 percent depending on management and save a significant amount of labor (5). Where irrigation water is pumped from groundwater, the amount pumped can be reduced by the amount reclaimed by the tailwater recovery system, thus reducing both groundwater pumpage and energy consumption. Figure 9 depicts the amount of water reclaimed by a tailwater return system that would normally be lost to runoff where the lower end of the border is open to allow for drainage.

Return systems are basically of two types, 1) a small sump, usually of concrete, with a small fast cycling pump with automatic control and, 2) large earth sumps with larger pumps that may be either automatically or manually controlled.

FIGURE 9
Tailwater normally lost is recovered for reuse with a return system. Irrigation efficiency is increased, ponding at the lower end of the border is eliminated and energy required for deep well pumping is reduced.
Small automatic systems:

The small sumps are used in citrus or other crops where a high degree of control is exercised over the irrigation water and small flow rates are involved. The sump capacity is designed based on inflow and outflow (pump) rates so that the pump will not cycle more than 15 times per hour to prevent overheating (6). Return is usually directly to the irrigation supply for reuse on the same field.

It was shown by Dickey (7) that small sumps can be designed on the basis of the formula:

\[ S = P \]

Where: \( S \) = Sump volume in gallons between the "on" and "off" water levels.

\( P \) = Pumping rate of return pump in gallons per minute.

Table 1 gives the minimum diameter required for small concrete sumps (see Figure 10) for various changes in depth of storage (\( H \)) based on the above formula for various inflow rates.

<table>
<thead>
<tr>
<th>Tailwater inflow in gpm</th>
<th>Inside Diameter of Circular Sump, in Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( H^* = 2 )</td>
</tr>
<tr>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>100</td>
<td>35</td>
</tr>
<tr>
<td>150</td>
<td>43</td>
</tr>
<tr>
<td>200</td>
<td>50</td>
</tr>
<tr>
<td>250</td>
<td>56</td>
</tr>
<tr>
<td>300</td>
<td>61</td>
</tr>
<tr>
<td>350</td>
<td>66</td>
</tr>
<tr>
<td>400</td>
<td>70</td>
</tr>
<tr>
<td>450</td>
<td>75</td>
</tr>
<tr>
<td>500</td>
<td>79</td>
</tr>
<tr>
<td>550</td>
<td>83</td>
</tr>
<tr>
<td>600</td>
<td>86</td>
</tr>
</tbody>
</table>

* \( H \) is the depth of storage in the sump, between on and off float levels, in feet (See Figure 10).
Large earth sumps:

Design of large earth sumps is usually based on management's decision on how the reclaimed water is used. Enough storage may be required to irrigate one complete set. In this case, it is just a matter of calculating the irrigation volume required. The equation on page 3 may be used for this purpose.

Another system of management is to use the reclaimed water to supplement the irrigation flow at the beginning of each set. This produces a larger initial stream size and reduces the time required to get the water down the border and empties the sump for the next cycle. This method is more important in furrow irrigation systems than border systems.

Table 2 lists several sump capacities and dimensions for earth sumps based on a runoff rate of 15% of the irrigation supply. They have been used over a period of years by SCS technicians and have proven satisfactory.

Table 2 - Design of large earth sumps

<table>
<thead>
<tr>
<th>Field Size (Acres)</th>
<th>Water Available (Cfs.)</th>
<th>Average Acres Irrigated Per Day</th>
<th>Sump Capacity Cu. Yd.</th>
<th>Recommended Dimensions Depth L or W</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 to 35</td>
<td>3</td>
<td>10</td>
<td>250 to 450</td>
<td>4' 40' x 45'</td>
</tr>
<tr>
<td>35 to 55</td>
<td>5</td>
<td>13</td>
<td>450 to 600</td>
<td>4' 40' x 100'</td>
</tr>
<tr>
<td>55 to 80</td>
<td>7+</td>
<td>19</td>
<td>750 to 900</td>
<td>5' 50' x 100'</td>
</tr>
</tbody>
</table>

Note: A smaller sump may be used providing the pump is large enough to return 15% of the irrigation supply and storage volume is adequate for management's proposed reuse method.
Sumps should be at least 5 feet deep to discourage weed growth. Side slopes depend on soil stability. Drop inlets with pipelines should be provided to prevent erosion from water entering the sump.

Figure 11 shows a typical earth sump with structures for erosion control.

**SUMP LAYOUT**

FIGURE 11 - Typical components of a large earth sump return system.

Changing irrigation methods:

Irrigation methods should be selected based on the soil, crop to be grown, climate, topography, water supply, water quality, available labor and management. All methods have advantages and disadvantages. Your irrigation method and system should meet your requirements and function efficiently under your management conditions. Remember that the best designed system will not function efficiently without proper management.
Careful consideration should be given to all factors involved before changing from one method to another. Labor could be reduced while capital and energy requirements increase considerably without an increase in efficiency.

Table 3 lists some of the factors to consider when selecting an irrigation method or when changing from one method to another. More detailed information and assistance is available from your local Soil Conservation Service Office, Resource Conservation District, University of California Cooperative Extension Service or private irrigation consultant.

### Table 3 - Factors to Consider in Selecting an Irrigation System (8)

**Slope Limitations:**

<table>
<thead>
<tr>
<th>FACTORS TO CONSIDER</th>
<th>SPRINKLER SYSTEMS</th>
<th>SURFACE FLOOD SYSTEMS</th>
<th>DRIP SYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Portable</td>
<td>Wheel Roll</td>
<td>Solid Set</td>
</tr>
<tr>
<td>Direction of Irrigation</td>
<td>20%</td>
<td>15%</td>
<td>None</td>
</tr>
<tr>
<td>Cross-Slope</td>
<td>20%</td>
<td>15%</td>
<td>None</td>
</tr>
</tbody>
</table>

**Soil Limitations:**

<table>
<thead>
<tr>
<th></th>
<th>Minimum (in./hr.)</th>
<th>Maximum (in./hr.)</th>
<th>Minimum (in./hr.)</th>
<th>Maximum (in./hr.)</th>
<th>Minimum (in./hr.)</th>
<th>Maximum (in./hr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake Rate</td>
<td>0.10</td>
<td>6.0</td>
<td>0.90</td>
<td>6.0</td>
<td>0.30</td>
<td>6.0</td>
</tr>
<tr>
<td>Water Holding Capacity in Root Zone</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
<td>2.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

**Erosion Hazard**

<table>
<thead>
<tr>
<th></th>
<th>Slight</th>
<th>Slight</th>
<th>Slight</th>
<th>Moderate</th>
<th>Severe</th>
<th>Moderate</th>
<th>Slight</th>
<th>Severe</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saline-Alkali Soils</td>
<td>Slight</td>
<td>Slight</td>
<td>Slight</td>
<td>Slight</td>
<td>Slight</td>
<td>Slight</td>
<td>Slight</td>
<td>Slight</td>
<td>None</td>
</tr>
</tbody>
</table>

**Water Limitations:**

<table>
<thead>
<tr>
<th></th>
<th>Moderate</th>
<th>Moderate</th>
<th>Moderate</th>
<th>Moderate</th>
<th>None</th>
<th>None</th>
<th>None</th>
<th>None</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids (TDS)</td>
<td>Severe</td>
<td>Severe</td>
<td>Severe</td>
<td>Severe</td>
<td>Moderate</td>
<td>Slight</td>
<td>Slight</td>
<td>Moderate</td>
<td>Slight</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Severe</td>
</tr>
<tr>
<td>Rate of Flow</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
</tr>
</tbody>
</table>

**Climatic Factors:**

<table>
<thead>
<tr>
<th></th>
<th>No</th>
<th>No</th>
<th>Yes</th>
<th>Yes</th>
<th>No</th>
<th>Yes</th>
<th>Yes</th>
<th>No</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Control</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Fair</td>
<td>Limited</td>
<td>Very Good</td>
<td>Very Good</td>
<td>Very Good</td>
<td>Good</td>
</tr>
<tr>
<td>Wind Affected</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

**Adaptability to All Crops**

<table>
<thead>
<tr>
<th></th>
<th>400-600</th>
<th>400-400</th>
<th>700-1200</th>
<th>700-1000</th>
<th>600-700</th>
<th>500-600</th>
<th>500-600</th>
<th>400-500</th>
<th>300-400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost ($)</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Labor Cost ($)</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Power Cost ($)</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Average Annual Cost ($)</td>
<td>100-200</td>
<td>100-200</td>
<td>200-400</td>
<td>200-400</td>
<td>100-100</td>
<td>100-100</td>
<td>100-100</td>
<td>200-300</td>
<td>200-300</td>
</tr>
</tbody>
</table>

**Application Efficiency [%]**

<table>
<thead>
<tr>
<th></th>
<th>70-85</th>
<th>70-85</th>
<th>75-90</th>
<th>70-85</th>
<th>65-80</th>
<th>70-85</th>
<th>75-90</th>
<th>70-85</th>
<th>80-90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost less than $20/ac/yr.</td>
<td>Moderate</td>
<td>$20-50/ac/yr.</td>
<td>High</td>
<td>over $50/ac/yr.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>0-5/ac/yr.</td>
<td>Moderate</td>
<td>$5-15/ac/yr.</td>
<td>High</td>
<td>over $15/ac/yr.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Assisting capital cost plus operation and maintenance cost. | Assuring good to excellent management.
Irrigation scheduling:

Much time and effort has been expended on relating crop production to water application. Results are very difficult to apply to other locations because of the variations in soils and climate.

More recent work done by Hsiao, O'Tode, Tomar and others show that a more direct relationship exists between plant stress and yield. The Soil Conservation Service has been using this relationship as the basis for scheduling irrigations for over 30 years, but recent developments allowing rapid and accurate monitoring of soil moisture have allowed an improvement in the program.

For every crop there is a maximum allowable plant stress that varies with stage of growth that if exceeded will result in reduced yield or lower crop quality. These limits are known for some crops but relatively unknown for many. We need more data on alfalfa.

If these values can be determined for a crop, an irrigations schedule can be prepared by converting maximum allowable plant stress to allowable soil moisture depletion which is much easier to monitor than plant stress.

Using this technique, the irrigation schedule is site specific for the crop and soil. Monitoring the soil moisture in the root zone allows one to predict irrigations at any time and determine the amount of water to apply to bring the soil back to the field capacity or full condition.

Figure 12 is an example of the allowable plant stress by stage of growth for a crop. Similar curves can be developed for all crops including alfalfa that would incorporate cultural practices (mowing & baling), labor and other economic factors to produce the desired quality results. Once determined this would be directly applicable to other areas since it is based strictly on allowable plant stress.

Figure 13 can be used to adapt the allowable plant stress to allowable soil moisture depletion compatible with the allowable plant stress. This can be tailored directly to the field on which the crop is planted and is usually based on actual soil laboratory data.

Figure 14 depicts the irrigation schedule that is crop and soil specific. Soil moisture in the crop root zone is monitored periodically and plotted on the chart. Irrigations can be predicted at any time by drawing a straight line through the last two soil moisture points and extending it to the allowable depletion line to get the date of the next irrigation. The net amount to be applied is determined from the available moisture depleted from the root zone as shown on the left index. The schedule can be adjusted for salinity and other factors by applying the needed correction to the allowable soil moisture depletion line. The results can be checked external to the system by taking pressure chamber readings from the crop leaves to determine the actual plant stress. This allows the allowable soil moisture depletion to be further adjusted to make it compatible with the desired allowable plant stress. Farmers can make their own adjustments in the allowable plant stress curve and compare the changes to results in yields to optimize their production.
FIGURE 12 - An example of allowable plant tension by stage of growth incorporating economics, cultural practices and type of irrigation system.

FIGURE 13 - Soil moisture release curve for converting from maximum allowable plant stress to available moisture depletion (3).
Conclusion:

Improved system management should be considered to optimize the present system efficiency before considering a change of irrigation methods (for instance from border to sprinklers).

Considerable opportunities exist for irrigation application efficiency improvement in the state to have a significant impact on reduced energy requirements, water conservation and reduced groundwater pumpage.

An irrigation scheduling method now exists that allows a farmer to improve his production from year to year and optimize production, water conservation, energy conservation or other results compatible with his farming methods and irrigation system.

If this valuable tool of scheduling irrigations, which is crop specific, site specific and management specific, is used by the alfalfa growers of California, the 19 percent increase in irrigated area by the year 2020 can quite possibly be accomplished without and increase in water consumption above the present level.
References cited


4. USDA-Soil Conservation Service National Engineering Handbook Section 15, Irrigation, Chapter 4, Border Irrigation, August 1974.


