Irrigation Training Toolbox
Irrigation Water Management

Lesson Plan
Efficiencies

National Employee Development Center
Natural Resources Conservation Service
Fort Worth, TX
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LESSON PLAN

COURSE:	IRRIGATION WATER MANAGEMENT
LESSON TITLE:	EFFICIENCIES
DEVELOPED BY:	Charles Schmitt
OBJECTIVES:	Understand the effect of systems efficiencies on the volume of water delivered to the crop
REFERENCES:	NebGuide, "Management of Farm Irrigation Systems"
TRAINING AIDS:	Overheads
ARRANGEMENTS:	
TIME REQUIRED:	1.0-2.0 Hours

EFFICIENCIES

1. Introduction

The relationship, QT=DA discussed above, can be related to net application if efficiency is considered. The relationship is expressed as $QTe=d_nA$, in which "e" is equal to efficiency, either seasonal or application, depending upon usage and d_n equals the net application depth. To understand this relationship we must first define the efficiency term used.

2. Definitions

Irrigation efficiencies can be defined by several different relationships. Two of the commonly used irrigation efficiencies are application and seasonal efficiencies. Also the delivery and distribution system can be defined by the conveyance efficiency.

a. Application Efficiency

Application efficiency is related to an individual irrigation application. It is defined as follows:

Overhead #1
Ref. "Management of Farm Irrigation Systems" by Hoffman, Howell and Solomon

$$e_a = \frac{V_s}{V_f}$$

where:

e_a = application efficiency

V_s = the volume of water stored in the root zone usable by the plant for evapotranspiration.

V_f = the gross volume of water delivered to the field for the individual irrigation.

The difference between Vs and Vf are the irrigation losses. These losses result from deep percolation or runoff.

In general, the higher the application efficiency, the better the job of irrigation. However, the application efficiency can be 1.0 (100%), if the soil profile is not filled from an irrigation and all the water delivered to the field is available for use by the crop (ie. no deep percolation and no runoff) The available water may not be sufficient to satisfy crop water requirements which could result in yield reduction. A high application efficiency may therefore be a result of an inadequate irrigation.

When trying to maximize the application efficiency it is important to remember that the applied irrigation depth and its uniformity must be adequate to provide reasonable crop growth throughout the field. Computation of the applied depth and uniformity will be further discussed in this section as well as the furrow uniformity and sprinkler sections.

Ref NebGuide G85-753

Average values for application efficiency for different types of irrigation systems can be found in various publications. The value from NebGuide "Irrigation Scheduling Using Crop Water Use Data" is listed below in the table.

Overhead #2

Irrigation System Type	Efficiency (percent)
SPRINKLER	
Center pivot and lateral move	80
Skid tow	75
Solid set	75
Side roll	75
Big gun traveler	70
SURFACE	
Gated pipe with reuse	70
Gated pipe without reuse	50
Siphon tube with reuse	65
Siphon tube without reuse	45
Auto-Surface with reuse	80

b. Seasonal Efficiency

Seasonal efficiency, as the name applies, relates crop water use and irrigation for the entire season. It is defined as follows:

$$e_s = \frac{V_b}{V_f}$$

Overhead #3
Ref. "Management of Farm Irrigation Systems" by Hoffman, Howell and Solomon

For Effective Rainfall see NebGuide G92-1099-A "Estimating Effective Rainfall"

where:
e_s = seasonal efficiency

V_b = the volume of water beneficially used over a season. It is defined as the net irrigation required for the season and derived as: consumptive use + leaching required + other beneficial uses + ending stored water in effective root zone - effective precipitation - starting stored water in effective root zone.

V_f = the gross volume of irrigation water delivered to the field.

Like the application efficiency, the differences between the gross volume delivered and the volume of water beneficially used are the irrigation losses. These losses result from deep percolation and runoff

In determining the seasonal efficiency the effects of application efficiency of each individual irrigation would be included on a seasonal basis. Seasonal efficiency also accounts for management efficiency. For example, do the number of irrigations match the required crop water needs (scheduling), or are extra irrigations performed which cause excess deep percolation and runoff.

Seasonal efficiency may or may not give a realistic picture of the adequacy of the actual irrigation for the season. For example, if a landowner irrigates two times over the season, on the first irrigation the landowner over irrigates and causes excessive deep percolation and on the second irrigation he/she under irrigates and causes severe stress to the crop. The seasonal efficiency would average out the two irrigations and show a good job of irrigation, even though a poor job actually occurred. This illustrates the importance of using both seasonal and application efficiency when defining and evaluating the irrigation application and/or system.

c. Conveyance Efficiency

The water actually delivered to the field for direct application is less than that diverted by the amount lost in the conveyance and distribution system. The efficiency of a conveyance system is defined as follows:

Overhead #4
Ref. "Management of Farm Irrigation Systems" by Hoffman, Howell and Solomon

$$e_c = \frac{V_f}{V_t}$$

where:

e_c = conveyance efficiency

V_f = volume of water delivered to the field

V_t = volume of water diverted from the source.

d. Farm Irrigation Efficiency

When evaluating an irrigation system, the total efficiency also called farm irrigation efficiency, must be used. This efficiency is the product of the conveyance and irrigation efficiencies (either application or seasonal) expressed as ratios.

Overhead #5

For Example:

$$e_i = e_s \times e_c$$

or

$$e_i = e_a \times e_c$$

Where:

e_i = the farm irrigation efficiency
All other variables are as defined above.

3. Net Irrigation Application Depth

The formula QT=DA relates the volume of water delivered to the field to the application depth for the irrigated area. The above relationship is true using gross application. To determine net application depth efficiency must be accounted for in the formula. The basic relationship is as follows:

$$QTe = d_n A$$

Overhead #6

Where:

d_n = gross depth of water applied in inches
A = area to be irrigated in acres
Q = flow in cfs
T = time in hours
e = efficiency (application or seasonal)

With this formula a comparison between the water needed (required irrigation) and the water applied d_n can be made. This formula can also be to evaluate the application efficiency when the other variables are determined in an on-site observation and should provide guidance as to where improvements might be made.

EXAMPLE

1. How long will it take apply a 4 inch net irrigation to a 35 acre field with a 900 gpm water supply and a irrigation application efficiency of 45%.

Blackboard

$$Q \times T \times e = d_n \times A$$

$$T = (d_n \times A) \div (Q \times e)$$

$$T = (4.0 \text{ in} \times 35 \text{ ac}) \div (900 \text{ gpm} \times \frac{1 \text{ cfs}}{449 \text{ gpm}} \times \frac{1 \text{ ac-in}}{\text{hr}} \div 1 \text{ cfs} \times .45)$$

$$T = 155.2 \text{ hours} = 6.5 \text{ days}$$

CLASS PROBLEM

Problem No. 1

A twelve acre corn field is furrow irrigated and has an irrigation slope of 2%. The soil intake rate is 1.0 in/hr and the available water holding capacity (AWC) is 2" per foot throughout the root zone. The maximum allowed depletion is 50%. The well capacity supplying the field is 900 gpm.

Assuming a system application efficiency of 50% and the corn root depth is 4 feet, determine how long it will take to replenish the root zone with the depletion rate as shown below.

SOIL DEPTH (FEET)	AWC (INCHES)	MOISTURE DEFICIENT(%)	NEEDED TO BRING TO FIELD CAPACITY
0'- 1'	2.0"	50%	"
1'- 2'	2.0"	50%	"
2'- 3'	2.0"	25%	"
3'- 4'	2.0"	25%	"

What would the application efficiency be if the above field was irrigated in two 24 hr. sets with all other variables remaining constant?

CLASS PROBLEM

Problem No. 2

Sugar beets are being raised in Scottsbluff and being irrigated with a 900 gpm well. How many acres can be grown assuming no rainfall and the profile is completely maintained? Compute for furrow with siphon tubes, furrow with gated pipe and reuse, and center pivot sprinkler irrigation systems assuming 45%, 70% and 80% application efficiencies respectively.

Maximum ET rate = 0.32 in/day for a 44 day period (see graph). Compute on a per day basis.

Blackboard

EXAMPLE

2. Determine the seasonal efficiency for the given situation.

A furrow irrigated corn field is 40 acres size. The farmer applied 6 irrigations, 8, 7, 6, 6, 6 and 6 inches gross depth of application, respectively. The available water holding capacity in the root zone was 6.4 inches and was 75% full when the irrigation season started and 90% full at the end. The effective rainfall for the season was 5.4inches and the consumptive use was 24.9 inches.

$$e_s = \frac{V_b}{Vf}$$

Vb = volume beneficially used = Consumptive Use + Available moisture end of season - effective rainfall - available moisture start of season.

Since the values are all in inches solve this on a per acre basis.

$$V_b = 24.9+(.9)(6.4)-(.75)(6.4)-5.4$$

$$V_b = 20.46 \text{ inches}$$

$$V_f = \text{gross water delivered to the field}$$

$$V_f = 8+7+6+6+6+6$$

$$V_f = 39 \text{ inches}$$

$$e_s = \frac{20.46 \text{ inches}}{39 \text{ inches}}$$

$$e_s = .525 = 52.5\%$$

CLASS PROBLEM

Problem No. 3

From the previous example (example 2), what would the seasonal efficiency be if better scheduling is performed and one of the 6 inch irrigations is not performed?

What would be the seasonal efficiency if each of the original irrigations (six irrigations total) are reduces by one inch each due to better management or system improvement (ie. surge, reuse)?

What would be the seasonal efficiency if both of the scenarios mentioned above (reduce 1 irrigation and reduce gross of each irrigation by 1 inch)?

4. System Capacity

The volume, depth, area relationship (QTe=dnA) can also be used to evaluate the adequacy of the water supply and distribution system for a given crop and soil texture.

If the water supply and distribution system is unable to supply the water required to meet peak consumptive use, then a potential deficit situation exists (we cannot supply as much water as is being used.)

Overhead #7

The evaluation of the potential deficit or surplus situation should be analyzed at the time of the system design. The design goals for a surplus or deficit system may be different and should be addressed accordingly (ie. surplus goal - reduce deep percolation; deficit goal - maximize efficiency).

Several opportunities exist for the correction of a deficit situation:
- -Store enough water in the soil profile to cover the deficit.
- -Increase application efficiency through management or system improvement.
- -Plant crop with a smaller consumptive use.
- -Accept reduced crop yields.
- -Reduce the irrigated acres.
- -Combination of all the above.

When evaluating the system the time required should represent the actual time the system would be operating. Sufficient time must be allowed for shut-down time for well systems (ie. operation 6 out of 7 days) . For canal system the actual time water delivery is expected to occur should be used.

CLASS PROBLEM

Problem No. 4

Corn is to be planted on a 80 acre field and irrigated with a 900 gpm well in Scotts Bluff County.
The well is expected to operate 6 out of 7 days or 20.6 hours out of a day. The application efficiency of the furrow irrigation system is 50%.Is this system potentially surplus or deficit?
Maximum ET rate = .32 in/day for 38 days (see graph)?

What maximum ET rate can the system supply?

Can our system meet the Maximum ET rate of field beans?

How much water would we have to store in the soil profile to offset the potential deficit? Assuming no rain.

How much would we need to store in the soil profile if we account for **average** rainfall? The effective average rainfall for with a CN of 81 are; June 1.8 inches, July 1.4 inches and August 1.0 inches. Note, only a portion of beginning and ending month effective rainfall occurs during the peak consumptive use period.

CLASS PROBLEM

Problem No. 1

A twelve acre corn field is furrow irrigated and has an irrigation slope of 2%. The soil intake rate is 1.0 in/hr and the available water holding capacity (AWC) is 2" per foot throughout the root zone. The maximum allowed depletion is 50%. The well capacity supplying the field is 900 gpm.

Assuming a system application efficiency of 50% and the corn root depth is 4 feet, determine how long it will take to replenish the root zone with the depletion rate as shown below.

SOIL DEPTH (FEET)	AWC (INCHES)	MOISTURE DEFICIENT(%)	NEEDED TO BRING TO FIELD CAPACITY
0'- 1'	2.0"	50%	1 "
1'- 2'	2.0"	50%	1 "
2'- 3'	2.0"	25%	.5 "
3'- 4'	2.0"	25%	.5 "
			3.0 inches = d_n

$QTe = d_n A$

$T = \frac{d_n A}{Qe}$

$$T = \frac{(3.0 \text{ inches})(12 \text{ acres})}{\left(900 \text{ gpm} \times \frac{1 \text{ cfs}}{449 \text{ gpm}} \times \frac{1 \text{ ac-in}/\text{hr}}{1 \text{ cfs}}\right)(.5)}$$

$T = 35.9$ hours

What would the application efficiency be if the above field was irrigated in two 24 hr. sets with all other variables remaining constant?

$QTe = d_n A \qquad e = \frac{d_n A}{QT}$

$$e = \frac{(3.0 \text{ inches})(12 \text{ acres})}{\left(900 \text{ gpm} \times \frac{1 \text{ cfs}}{449 \text{ gpm}} \times \frac{1 \text{ ac-in}/\text{hr}}{1 \text{ cfs}}\right)(48 \text{ hr})}$$

$e = .374 = 37.4\%$

CLASS PROBLEM

Problem No. 2

Sugar beets are being raised in Scottsbluff and being irrigated with a 900 gpm well. How many acres can be grown assuming no rainfall and the profile is completely maintained? Compute for furrow with siphon tubes, furrow with gated pipe and reuse, and center pivot sprinkler irrigation systems assuming 45%, 70% and 80% application efficiencies respectively.

Maximum ET rate = 0.32 in/day for a 44 day period (see graph). Compute on a per day basis.

$$QTe = d_n A$$

$$\left(900\text{ gpm} \times \frac{1\text{ cfs}}{449\text{ gpm}} \times \frac{1\ \frac{\text{ac-in}}{\text{hr}}}{1\text{ cfs}}\right)\left(\frac{24\text{ hr}}{\text{day}}\right)(e) = \left(.32\ \frac{\text{in}}{\text{day}}\right)(A)$$

$$A = (150)(e)$$

For Furrow with Siphon Tubes $e = .45$

$A = (150)(.45) =$ 67.5 acres

For Furrow with gated pipe and reuse $e = .70$

$A = (150)(.7) =$ 105 acres

For center pivot sprinkler $e = .80$

$A = (150)(.8) =$ 120 acres

CLASS PROBLEM

Problem No. 3

From the previous example (example 2), what would the seasonal efficiency be if better scheduling is performed and one of the 6 inch irrigations is not performed?

$e_s = V_b / V_f \qquad V_b = 20.46$ in. (from example no change)

$V_f = (8 + 7 + 6 + 6 + 6)$ in $= 33$ in.

$e_s = \dfrac{20.46 \text{ in}}{33 \text{ in}} = .62 = 62\%$

What would be the seasonal efficiency if each of the original irrigations (six irrigations total) are reduces by one inch each due to better management or system improvement (ie. surge, reuse)?

$V_f = (7 + 6 + 5 + 5 + 5 + 5)$ in $= 33$ in.

$e_s = \dfrac{20.46 \text{ in}}{33 \text{ in}}$

$e_s = .62 = 62\%$

What would be the seasonal efficiency if both of the scenarios mentioned above (reduce 1 irrigation and reduce gross of each irrigation by 1 inch)?

$V_f = (7 + 6 + 5 + 5 + 5)$ in $= 28$ in.

$e_s = \dfrac{20.46 \text{ in.}}{28 \text{ in}}$

$e_s = .731 = 73.1\%$

CLASS PROBLEM

Problem No. 4

Corn is to be planted on a 80 acre field and irrigated with a 900 gpm well in Scotts Bluff County. The well is expected to operate 6 out of 7 days or 20.6 hours out of a day. The application efficiency of the furrow irrigation system is 50%. Is this system potentially surplus or deficit?
Maximum ET rate = .32 in/day for 38 days (see graph)?

$QTe = d_n A$

$$\left(900\ gpm \times \frac{1\ cfs}{449\ gpm} \times \frac{1\ ac\text{-}in/hr}{1\ cfs}\right)\left(20.6\ \frac{hrs}{day}\right)(.5) = \left(.32\ \frac{in}{day}\right)(A)$$

A = 64.5 < 80 acres potential deficit

What maximum ET rate can the system supply?

$QTe = d_n A$

$$\left(900\ gpm \times \frac{1\ cfs}{449\ gpm} \times \frac{1\ ac\text{-}in/hr}{1\ cfs}\right)\left(20.6\ \frac{hrs}{day}\right)(.5) = d_n\,(80\ ac)$$

$d_n = .26$ in/day

Can our system meet the Maximum ET rate of field beans?
Yes, maximum ET for field beans equals .26 in/day.

How much water would we have to store in the soil profile to offset the potential deficit? Assuming no rain.

Depth per acre = (max ET − water supplied)(Ave. No. of days)

$$Depth = \left(.32\ \frac{in}{day} - .26\ \frac{in}{day}\right)\left(\frac{38+53}{2}\right) days$$

Depth = 2.7 in per acre (see graph)

How much would we need to store in the soil profile if we account for **average** rainfall? The effective average rainfall for with a CN of 81 are; June 1.8 inches, July 1.4 inches and August 1.0 inches. Note, only a portion of beginning and ending month effective rainfall occurs during the peak consumptive use period.

Depth per acre req = Potential deficit − effective rainfall

$Depth = 2.7\ in - (3/30)(1.8\ in) - 1.4\ in - 19/31\,(1.0\ in)$

Depth = .6 inches per acre

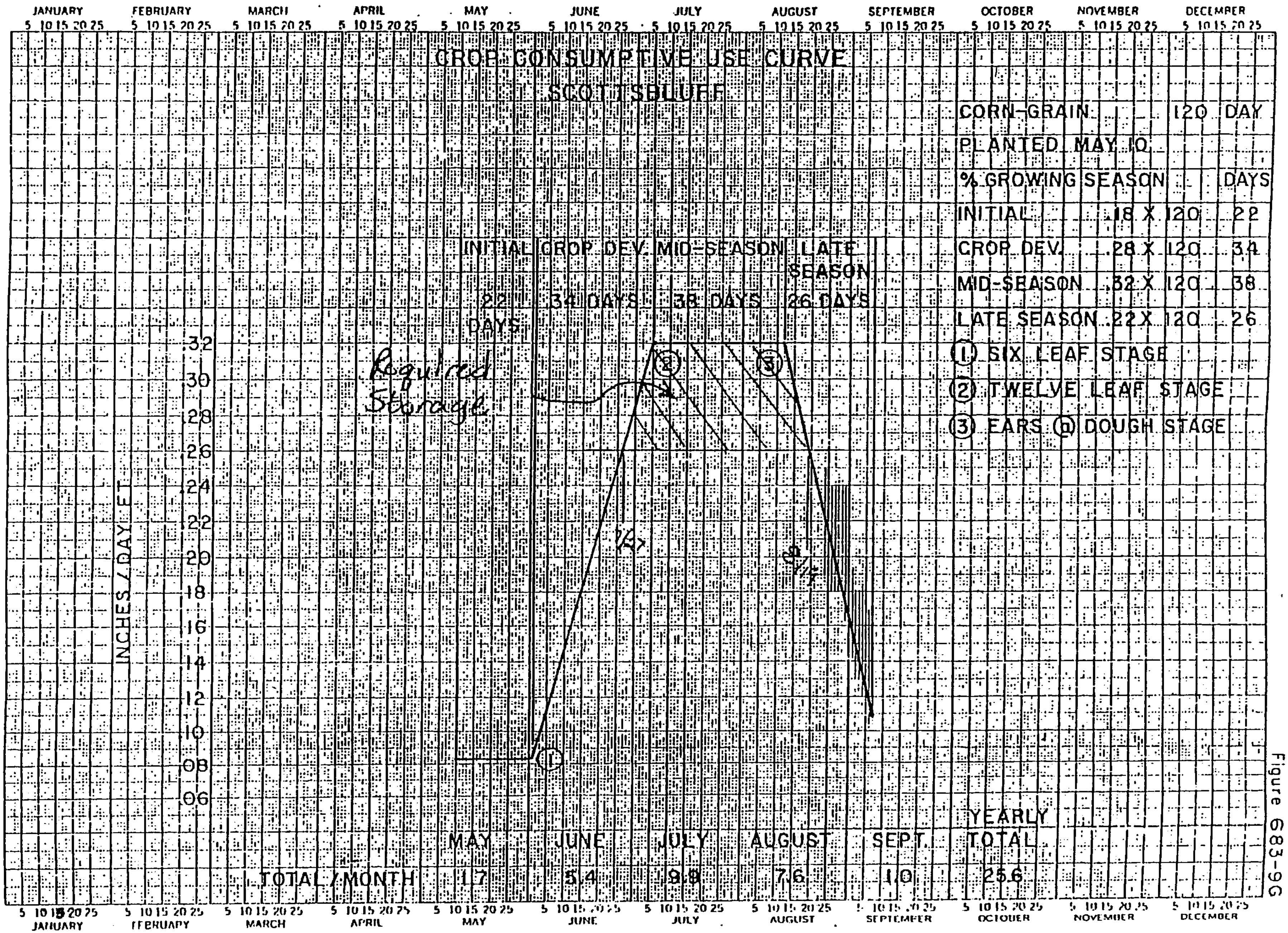

Figure 683-9G