Purpose

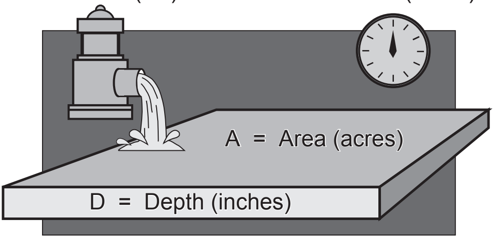
The purpose of this book is to help you manage one of your operation's most valuable resources, water. This book includes:

- calculations to determine irrigation depth (p. 5)
- descriptions to estimate soil moisture (p. 13)
- irrigation scheduling information (p. 21)
- irrigation system information (p. 28)
- conversion factors (p. 34)
- tables for recording irrigation events (p. 42)
- a five-year calendar (p. 62)
- a section for field notes (p. 68)

We encourage farms of all sizes to utilize these tools for irrigation management.

Estimating application amounts using the irrigator's equation

This section provides equations, tables and figures to help irrigators determine application amounts. Obtaining accurate irrigation application amounts is helpful for understanding water right and allocation limitations, determining irrigation system efficiency, monitoring system performance, detecting well and pump problems, and can improve irrigation scheduling.



Area (A) x Depth (D) = Flow (Q) x Time (T)

Rearrange AD=QT to calculate the average irrigation depth:

$$D = \frac{QT}{A}$$

* 450 gallons per minute = 1cfs = 1 acre inch/hr (see page 9)

Finding depth (D) of applied water

Example: Using the irrigator's equation to find depth.

Solve for depth: $D = \frac{QT}{A}$

Q- flow rate: 4 cfs
T - set time: 8 hours
A - area: 20 acres
D - depth for applied water: unknown inches.

$$D = \frac{4 \text{ cfs} \times 8 \text{ hours}}{20 \text{ acres}} = 1.6 \text{ inches}$$

Finding time (T) of irrigation

Example: Given a desired application depth, use the irrigator's equation to estimate irrigation time in hours.

$$\text{Time (hours)} = \frac{\text{D (inches)} \times \text{acres}}{\text{flow (cfs)}}$$

$$\text{hours} = \frac{\text{2 inches (gross*)} \times \text{80 A (acres)}}{\text{3 cfs}} = 53 \text{ hrs}$$

*gross amount = net/irrigation efficiency

Using 3 cfs of flow it will require at least 53 hours to apply 2 inches (gross) of water to an 80 acre field.

Determining Irrigation Time with Drip Tape

Two variables are required to estimate the correct time for application for drip tape:

1) flowrate of drip tape used – measured in gallons/ minute (gpm) per 100 ft of tape (if in gallons/hour divide by 60 to get gal/min)

2) tape spacing – inches between tapes on or between beds

Table 1. Application rate (inches/hour) of drip tapes and tubing for various flowrates and spacings

Drip Tape Flow Rate (gpm per 100ft)	**Tape Spacing (inches)**						
	12	14	16	18	24	30	60
0.20	0.19	0.17	0.14	0.13	0.10	0.08	0.04
0.25	0.24	0.21	0.18	0.16	0.12	0.10	0.05
0.30	0.29	0.25	0.22	0.19	0.14	0.12	0.06
0.35	0.34	0.29	0.25	0.22	0.17	0.13	0.07
0.40	0.39	0.33	0.29	0.26	0.19	0.15	0.08
0.45	0.43	0.37	0.32	0.29	0.22	0.17	0.09
0.50	0.48	0.41	0.36	0.32	0.24	0.19	0.10
0.55	0.53	0.46	0.4	0.35	0.27	0.21	0.11
0.60	0.58	0.5	0.44	0.38	0.29	0.23	0.12
0.65	0.63	0.54	0.48	0.41	0.32	0.25	0.13
0.70	0.68	0.58	0.52	0.44	0.34	0.27	0.14
0.75	0.73	0.62	0.56	0.47	0.37	0.29	0.15

Adapted with permission from “Drip Irrigation for Row Crops”, Blaine Hansen, et al., UC Davis, 1997

Example:

- 1.0 inches of irrigation (net) required
- Drip tape has flow rate = 0.35 gpm per 100 feet of tape
- Drip tapes spacing = 12 inches
- Irrigation rate = 0.34 inch of water per hour. (table 1)

$$\frac{1.0 \text{ inch of irrigation}}{0.34 \text{ inches of water per hour}} \approx 2.9 \text{ hours or } 174 \text{ minutes}$$

Finding irrigated area (A)

Furrow systems

Table 2. Use this table to find irrigated acres from irrigated 30 inch rows.

	Number of Rows per Set-30-inch* rows								
Run length	10	20	30	40	50	60	70	80	100
	Acres/set								
5200	3.0	6.0	9.0	11.9	14.9	17.9	20.9	23.9	29.8
2600	1.5	3.0	4.5	6.0	7.5	9.0	10.4	11.9	14.9
2000	1.15	2.3	3.4	4.6	5.7	6.9	8.0	9.2	11.5
1320	0.76	1.5	2.3	3.0	3.8	4.5	5.3	6.1	7.6
1000	0.57	1.1	1.7	2.3	2.9	3.4	4.0	4.6	5.7
750	0.43	0.86	1.3	1.7	2.2	2.6	3.0	3.4	4.3
600	0.34	0.69	1.0	1.4	1.7	2.1	2.4	2.8	3.4
300	0.17	0.34	0.52	0.69	0.86	1.03	1.21	1.38	1.72

* Set size (acres) is computed by the formula:

$$\frac{\text{\# of rows x row width (feet) x run length (feet)}}{43{,}560 \text{ feet}^2\text{/acre}}$$

Table 3. Rows per acre at given row spacings and lengths. *

	------- Row spacing (inches)-------			
row length	12	30	36	40
	------------ Rows per acre ------------			
5280	8	3	3	2
3690	12	5	4	4
2600	17	7	6	5
1320	33	13	11	10
600	73	29	24	22
300	145	58	48	44
100	436	174	145	131

* To find row/acre with other spacings or lengths use this formula:

$$\text{Rows/acre} = \frac{43{,}560}{\text{row spacing (ft)} \times \text{row length (ft)}}$$

Center Pivot

Table 4. Irrigated area by pivot size.

Radius* (ft)	Irrigated area (acres)
2600	487.3
1300	121.8
600	25.9
300	6.5

*Radius of wetted area

$$\text{Acres covered**} = \frac{(\text{radius of wetted area})^2 \times 3.1416}{43{,}560 \text{ feet}}$$

**When end guns operate continuously

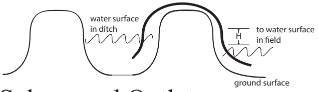
Finding Flow (Q)

Approximate flow rates for various tube sizes

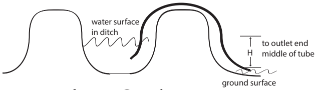
Table 5. Flow per tube in gpm at a given head.

Tube diameter (inches)	Height difference (H)* inches 2	4	6	8
	gpm			
1/2	1.3	1.8	2.2	2.5
3/4	2.9	4.1	5.0	5.8
1	5.1	7.3	9.0	10.5
1 1/4	8.1	11.5	13.7	16.3
1 1/2	11.7	16.5	20.2	23.0
2	2.0	29.0	35.0	41.0
3		66.0	81.0	92.0
4		117.0	142.0	166.0
5		176.0	220.0	255.0
6		260.0	320.0	370.0

* Measure H by raising downstream end of the tube alongside a measuring stick until flow just stops.



Submerged Outlet



Free Flow Outlet

Flow (Q) equations for flumes and weirs

Cutthroat flumes

$Q = CH^{n_1}$

Where Q = flow in cfs
C = coefficient
n_1 = coefficient
H = height of water in feet

Table 6. Cutthroat flume. Table for free flow (not submerged) conditions.

Length, L	Width, W	Free Flow	
Ft.	Ft.	C	n
9.00	1.000	3.500	1.560
9.00	2.000	7.110	1.560
9.00	4.000	14.490	1.560
9.00	6.000	22.000	1.560
4.50	0.250	0.960	1.720
4.50	0.500	1.960	1.720
4.50	1.000	3.980	1.720
4.50	2.000	8.010	1.720
3.00	0.167	0.719	1.840
3.00	0.333	1.459	1.840
3.00	0.667	2.970	1.840
3.00	1.333	6.040	1.840
1.50	0.083	0.494	2.150
1.50	0.167	0.974	2.150
1.50	0.333	1.975	2.150
1.50	0.667	4.030	2.150

Parshall Flumes

Free flow discharge, height (H) of water is in feet

width=	cfs=
6”	$2.06H^{1.58}$
9”	$3.07H^{1.53}$
1’	$4H^{1.522}$
2’	$8H^{1.55}$
3’	$12H^{1.566}$
4’	$16H^{1.578}$

Weirs

V-notch

	cfs=
22.5°	$0.497H^{2.5}$
30°	$0.676H^{2.5}$
45°	$1.035H^{2.5}$
60°	$1.43H^{2.5}$
90°	$2.500H^{2.5}$

Rectangular (with end contractions) (1’, 1.5’, 2’, 2.5’, 3’ weirs)

cfs= $3.33\ (L-0.2H)H^{1.5}$

Without end contractions

	cfs=
1’	$3.33H^{1.5}$
1.5’	$4.995H^{1.5}$
2’	$6.66H^{1.5}$
2.5’	$8.325H^{1.5}$
3’	$9.99H^{1.5}$

Cipolletti (trapezoidal)

	cfs=
1’	$3.367H^{1.5}$
1.5’	$5.050H^{1.5}$
2’	$6.734H^{1.5}$
2.5’	$8.417H^{1.5}$
3’	$10.101H^{1.5}$

Table 7. Flow equivalents

Cubic feet/second (cfs)	Gallons/minute (gpm)*	Colorado Miner’s inches
0.5	224	19.25
2	898	76.9
4	1795	153.8
6	2693	230.8
8	3590	307.7
10	4488	384.6

*1 acre-inch/hour ≈ 450 gallons per minute (gpm) ≈ 1 cubic foot per second (cfs)
1 cfs for 1 hours ≈ 1 acre-inch
1 cfs for 24 hours ≈ 2 acre-feet
1 cfs for 30 days ≈ 60 acre feet

For additional resources on water measurement, see the USBR Water Measurement Manual at www.usbr.gov/pmts/hydraulics_lab/pubs/wmm

Soil Moisture

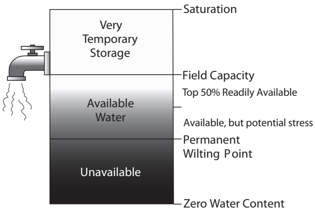
Soil texture is the most important factor for soil water holding capacity, however, it can also vary with organic matter content, coarse fragments (rocks, gravel) and salinity. Refer to a soil survey for more localized estimates of soil water holding capacity.

Table 8. Soil texture and plant available water.

Soil Texture	**Total Plant Available Water**		
	low	high	average
	--- inches / foot soil ---		
Coarse sands	0.6	0.8	0.7
Fine sands	0.8	1.0	0.9
Loamy sands	0.8	1.2	1.0
Sandy loams	1.2	1.5	1.4
Fine sandy loams	1.5	2.0	1.8
Sandy clay loams	1.6	2.1	1.9
Loams	2.2	2.5	2.4
Silt loams	2.0	2.5	2.3
Silty clay loams	1.6	2.0	1.8
Clay loam	1.6	2.0	1.8
Silty clay	1.5	1.7	1.6
Clay	1.3	1.5	1.4

Plant Available Water

Plant available water is the water held in soils between field capacity and permanent wilting point. Soil retains water below wilting point, but it is unavailable to plants. Generally speaking, the top 50% of plant available water is readily available to plant roots. As water depletes below 50%, it becomes harder for the plant to extract and the plant undergoes increasing stress as the soil dries, especially during conditions of high ET.



Management Allowable Depletion (MAD)

The term Management Allowable Depletion (MAD) is simply the amount of plant available water that can be depleted in the soil without yield-reducing water stress. It can be expressed as a percent or as inches of plant available water in the soil. MAD will vary between crops based upon their sensitivity to water stress. The most common MAD that is typically used is 50%, but it can vary according to crop growth stage through-out the growing season (Table 14).

Estimating soil moisture by feel (see next two pages)

When estimating soil moisture by feel, use a handful of soil and form a ball by squeezing a handful of soil firmly with fingers. Take soil samples from plant rows or on the side of the beds in bedded fields.

Soil moisture is rarely uniform within fields, especially with surface irrigation. In surface irrigated fields, check soil moisture at distances of 1/3 and 2/3 down from the top of the field. With sprinkler irrigation take samples between sprinkler nozzles. Take samples in 1-foot increments from the active root zone.

Use Table 9 for guidelines on using the hand-feel method. The far right columns are soil moisture available to plants and the number in parenthesis above each description is the inches of depleted plant available water, based upon the description of soil conditions. Use a soil survey or have your soil analyzed to determine texture.

Table 9. Estimating soil moisture by feel

	Coarse Texture-Fine Sand and Loamy Fine Sand	Moderately Coarse Texture- Sandy Loam and Fine Sandy Loam
	Available Water Capacity (inches/foot)	
	0.6-1.2	1.3-1.7
Available Soil Moisture %	**Soil Moisture Deficit (SMD) in inches per foot**	
0-25	**(1.2-0.5)** Dry, loose, holds together un-disturbed, loose sand grains on fingers with applied pressure	**(1.7-1.0)** Dry, forms a very weak ball[1], aggregated soil grains break away easily from ball.
25-50	**(0.9-0.3)** Slightly moist, forms a very weak ball with well-defined finger marks, light coating of loose and aggregated sand grains remain on fingers.	**(1.3-0.7)** Slightly moist, forms a weak ball with defined finger marks, darkened color, no water staining on fingers, grains break away.
50-75	**(0.6-0.2)** Moist, forms a weak ball with loose and aggregated sand grains on fingers, darkened color, moderate water staining on fingers, will not ribbon[2].	**(0.9-0.3)** Moist, forms a ball with defined finger marks, very light soil/water staining on fingers, darkened color, will not slick.
75-100	**(0.3-0.0)** Wet, forms a weak ball, loose and aggregated sand grains remain on fingers, darkened color, leaving water staining on fingers, will not ribbon.	**(0.4-0.0)** Wet, forms a ball with wet outline left on hand, light to medium water staining on fingers, makes a weak ribbon between thumb and forefinger.
Field Capacity (100 %)	**(0.0)** Wet, forms a weak ball, moderate to heavy soil/water coating on fingers, wet outline of soft ball remains on hand.	**(0.0)** Wet, forms a soft ball, free water appears briefly on soil surface after squeezing or shaking, medium to heavy soil/water coating on fingers.

[1] Ball is formed by squeezing a hand full of soil very firmly with one hand.

[2] Ribbon is formed when soil is squeezed out of hand between thumb and forefinger

	Medium Texture- Sandy Clay Loam, Loam, and Silt Loam	Fine Texture-Clay, Clay Loam, or Silty Clay Loam
	Available Water Capacity (inches/foot)	
	1.5-2.1	1.6-2.4
Available Soil Moisture %	**Soil Moisture Deficit (SMD) in inches per foot.**	
0-25	**(2.1-1.1)** Dry, soil aggregations break away easily, no moisture staining on fingers, clods crumble with applied pressure.	**(2.4-1.2)** Dry, soil aggregations easily separate, clods are hard to crumble with applied pressure.
25-50	**(1.6-0.8)** Slightly moist, forms a weak ball with rough surfaces, no water staining on fingers, few aggregated soil grains break away.	**(1.8-0.8)** Slightly moist, forms a weak ball, very few soil aggregations break away, no water stains, clods flatten with applied pressure.
50-75	**(1.1-0.4)** Moist, forms a ball, very light water staining on gingers, darkened color, pliable, forms a weak ribbon between thumb and forefinger.	**(1.2-0.4)** Moist, forms a smooth ball with defined finger marks, light soil/water staining on fingers, ribbons between thumb and forefinger.
75-100	**(0.5-0.0)** Wet, forms a ball with well-defined finger marks, light to heavy soil/water coating on fingers, ribbons between thumb and forefinger.	**(0.6-0.0)** Wet, forms a ball, uneven medium to heavy soil/water coating on fingers, ribbons easily between thumb and forefinger.
Field Capacity (100 %)	**(0.0)** Wet, forms a soft ball, free water appears briefly on soil surface after squeezing or shaking, medium to heavy soil/water coating on fingers.	**(0.0)** Wet, forms a soft ball, fee water appears on soil surface after squeezing or shaking, thick soil/water coating on fingers, slick and sticky.

Soil moisture and tension

Soil moisture tension, often referred to as matric potential, is used to estimate plant available water by tensionmeters and granular matrix block such as WaterMark sensors. The following tables provide information to interpret these readings.

General guide for interpreting WaterMark readings*

"- -"	= Dry or non-conditioned sensor
0-10 cbars	= Saturated soil
10-30 cbars	= Soil is adequately wet (except for coarse sands which are beginning to lose water.)
30-60 cbars	= Usual range for irrigation (except heavy clay soils)
60-100 cbars	= Usual range for irrigation in heavy clay soils
100-200 cbars	= Soil becoming dangerously dry for maximum production

* from Irrometer.com

Table 10. Approximate soil moisture tension and available water for sandy soils. Tension readings can be used for WaterMark® sensors. Readings within the shaded areas are usual range for irrigation. Begin irrigation at a higher soil moisture for shallow or gravelly soils.

Soil Moisture Tension		Soil Texture: Fine sands	Loamy sand	Sandy loam	Fine sandy loam
cb		Inches of water per foot of soil			
0	Wet	1.00	1.10	1.40	1.80
10		1.00	1.10	1.40	1.80
15		0.90	1.10	1.40	1.80
20		0.80	0.90	1.20	1.80
25		0.70	0.80	1.10	1.60
30		0.60	0.70	1.00	1.50
35		0.50	0.70	0.90	1.30
40		0.40	0.60	0.90	1.20
45		0.40	0.60	0.80	1.10
50		0.40	0.50	0.80	1.00
55		0.30	0.50	0.70	1.00
60		0.30	0.40	0.70	0.90
65		0.30	0.40	0.60	0.80
70		0.20	0.40	0.60	0.80
75		0.20	0.30	0.60	0.70
80	Drier	0.20	0.30	0.50	0.70

Soil Moisture

Soil moisture and tension- loam soils

Table 11. Approximate soil moisture tension and available water for silty, clay loam, and loam soils. Tension readings can be used for tensiometers and WaterMark® sensors. Readings within the shaded areas are usual range for beginning irrigation.

		Soil Texture			
		Sandy clay loam	Clay loam	Silt loams	Loams
cb		Available Soil Water			
	Wet	Inches per foot of soil			
0		1.8	1.8	2.2	2.4
10		1.8	1.7	2.0	2.4
20		1.7	1.6	1.9	2.3
25		1.6	1.4	1.8	2.1
30		1.5	1.3	1.7	2
35		1.4	1.3	1.6	1.9
40		1.3	1.2	1.5	1.8
45		1.2	1.1	1.5	1.7
50		1.1	1.1	1.4	1.6
55		1.0	1.0	1.3	1.5
60		0.90	1.0	1.2	1.4
70		0.80	0.90	1.1	1.3
75		0.70	0.85	1.0	1.2
80	Drier	0.60	0.80	0.95	1.1

Scheduling irrigations

This booklet contains information that can be useful for estimating the next irrigation date. The following example shows how this information can be used.

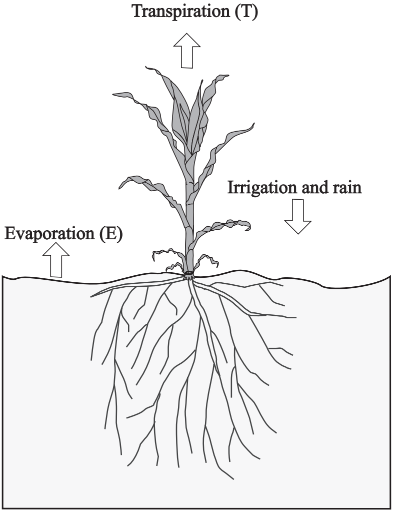
	----------------Example------------	
1. Soil type:	sandy loam – 1.3” H_2O/ft	
2. Corn growth stage:	V8	
3. Rooting depth:	2 ft	2’ x 1.3” = 2.60”
4. Current soil moisture: (% of available):	80%	0.80 x 2.60” = 2.10”
5. Maximum allowable depletion for growth stage (60% available) 40% remains:		0.40 x 2.60” = 1.00”
6. Useable water (before stress):		2.10”-1.00” = 1.10”
7. Estimated crop ET:		0.20”/day
8. Days to next irrigation:	1.10” usable water / 0.20”/day = 5 days	

Information on the lines is available in:
1. Table 8, page 13
3. Table 15, page 27
4. Tables 8, 10, 11, pages 13, 19-20
5. Table 14, page 26
7. Obtain from www.coagmet.colostate.edu

Using crop ET (evapotranspiration) information

ET information can help balance crop water use with irrigation and rainfall.

Daily ET rates are based upon current weather data and can be obtained from the Colorado Agricultural Meteorological Network (CoAgMet) at www.coagmet.colostate.edu.



Reference ET, (ET_r) is calculated from weather parameters using equations that are calibrated to well-watered alfalfa. Referenced ET is multiplied (ET_r) by a crop coefficient to get actual crop ET for a given crop and growth stage.

Table 12. Weather station list for CoAgMet. ET reports are available from this network at www.coagmet.colostate.edu.

Station ID	Station Name	Location	Station Environment
ALT01	Ault	1 mi SE Ault	Fully Irrigated
AVN01	Avondale	1 mi SE Avondale	Partially Irrigated
BNV01	Buena Vista	CDW Area SW of Buena Vista	Partially Irrigated
BRL03	Burlington 3	4 mi NE of Burlington	Fully Irrigated
CDG01	Cedaredge	1 mi N of Cedaredge	Fully Irrigated
CNN01	Canon City	2 mi E of Canon City	Partially Irrigated
COW01	Cowdrey	9 miles north of Walden	Fully Irrigated
CTR01	Center	CSU San Luis Valley Expt Sta	Partially Irrigated
CTR02	Center #2	Coors Research Farm	Partially Irrigated
CTZ01	Cortez	9 mi SW Cortez	Fully Irrigated
DLT01	Delta	3 mi W Delta	Partially Irrigated
FRT02	CSU Fruita Expt Station	2 mi ENE Fruita	Fully Irrigated
FTC03	CSU - ARDEC	6 mi NE Fort Collins	Fully Irrigated
FTL01	Fort Lupton	6 mi SSW Fort Lupton	Fully Irrigated
FWL01	Fowler	Fowler Golf Course	Fully Irrigated
GLY04	Greeley 4	1.5 mi N of Greeley Airport	Fully Irrigated
HEB01	Hebron	13 miles SW of Walden	Fully Irrigated
HLY02	Holly #2	8.5 mi NW Holly	Fully Irrigated
HNE01	Hoehne	NE Trinidad	Partially Irrigated
HOT01	CSU Rogers Mesa Expt Sta	4 mi W Hotchkiss	Partially Irrigated
HXT01	Haxtun	2.5 mi NW Haxtun	Partially Irrigated
HYD01	Hayden	4 mi E of Hayden	Fully Irrigated
HYK02	Holyoke	12 mi SE Holyoke	Dryland

Scheduling Information

Table 12. Continued

IDL01	Idalia	2 mi N Idalia	Fully Irrigated
ILF01	Iliff	1.5 mi NE of Iliff	Fully Irrigated
KRK01	Kirk	3 mi W Joes	Partially Irrigated
KSY01	Kersey	2 mi SE Kersey	Partially Irrigated
LAM04	Lamar #4	4.5 mi NNE Lamar	Fully Irrigated
LAR01	Larand	8 miles south of Walden	Fully Irrigated
LCN01	Lucerne	1/4 mi SW Lucerne	Partially Irrigated
LJR01	LaJara	2 mi S LaJara	Partially Irrigated
LJT01	LaJunta	11 mi NE LaJunta	Fully Irrigated
LMS01	Las Animas	1 mi NW McClave	Fully Irrigated
LSL01	La Salle	4 mi SE of La Salle	Partially Irrigated
MNC01	Mancos	3.5 Mi SW Mancos	Fully Irrigated
MTR01	Montrose	3 mi NW of Montrose	Fully Irrigated
ORM01	Orchard Mesa	Orchard Mesa Expt. Station	Partially Irrigated
OTH01	Olathe	3 mi NE Olathe	Partially Irrigated
OTH02	Olathe 2	4 mi W Olathe	Fully Irrigated
PKH01	Peckham	3 mi ENE Peckham	Partially Irrigated
PNR01	Penrose	near L and 13th Sts.	Fully Irrigated
RFD01	CSU Expt Stn Rocky Ford	2.5 mi SE Rocky Ford	Fully Irrigated
SLD01	Salida	Near Salida	Fully Irrigated
TWC01	Towaoc	Ute Mtn Ute Farm	Partially Irrigated
WCF01	Westcliffe	2 mi NW Westcliffe	Fully Irrigated
WRY01	Wray	10 mi N Wray	Fully Irrigated
YJK01	Yellow Jacket	2.5 mi NW Yellow Jacket	Fully Irrigated
YUM02	Yuma	2 mi N Yuma	Fully Irrigated

W.I.S.E Irrigation Scheduling

The Water Irrigation Scheduler for Efficiency (WISE) has been developed at Colorado State University to help irrigators accurately match water applications in timing and amount to actual crop needs.

Benefits of using WISE:

- An online ET-based program with accompanying phone Apps
- No software or downloads are required to use the program since it utilizes existing internet browsers
- Provides an easy to use interface where users can quickly map their fields and set up cropping situations (planting date, etc.)
- Soil properties are automatically downloaded from an NRCS database
- Weather data from nearby stations in the CoAgMet and Northern Colorado Water Conservancy District networks are gathered and used to calculate crop ET
- Phone Apps allow users to view soil water balance, weather data and enter irrigations and rainfall from the field
- Users can enter irrigation events from a computer or their phone
- An excellent irrigation water management record keeping tool with a variety of reporting functions

The program, Water Irrigation Scheduler for Efficiency (W.I.S.E), can be accessed at http://wise.colostate.edu.

Critical Growth Stages

Crops vary in their response to water stress depending upon their growth stage. In general, crops will suffer the most yield loss when water stress occurs during reproductive growth such as tasseling and flowering. Germination and plant establishment are also important to ensure an adequate number healthy plants.

Table 13. Critical growth stages for major crops.

Crop	Critical period
Alfalfa	Early spring and immediately after cuttings
Corn	Tasseling, silk, and early grain fill
Sorghum	Boot, bloom and dough stages
Sugar Beets	Germination and early plant development
Dry Beans	Flowering and pod set
Small grain	Boot and bloom stages
Potatoes	Tuber set and early bulking
Onions	Bulb formation
Tomatoes	After fruit set
Cool Season grass	Early spring, early fall

Table 14. Growth stages and management allowable depletion (MAD) of soil water in the root zone of selected crops at different growth stages. MAD is the percent of plant available water (Table 8) that can be depleted without yield-reducing stress.

Crop	Growth stages	MAD(%) in root zone
Alfalfa	emergence - 1st cut	65
	1st cut - 2nd cut	50
	2nd cut - 3rd cut	40
	3rd cut - 4th cut	60-70
Pinto beans	emergence - aux, budding	60-70
	flower - bud filling	55
	bud filling - maturity	60-70
Potatoes	early vegetation period	40-60
	tuber bulking period	30-40
	ripening period	65
Corn	emergence - V4	50
	V4 - V16	60-70
	V16 - dough	50
	dough-maturity	60-70
Small grains	emergence - first node	65-70
	first node - flowering	40-60
	mild ripe - maturity	50-70

Source: CSU Extension Fact Sheet No. 4.715

Crop irrigation factors

Table 15. Irrigation management depths for selected crops. Assumes rooting is not restricted by compaction or shallow soils.

	Irrigation management depths			
Annual crop	Establishment	Vegetative	Flowering/ Yield Formation	Mature
	------------------ Soil depth (inches) ------------------			
Corn	12	24	30	36 to 48
Potatoes	12	18	24	24 to 48
Small grain	12	18	24	36 to 48
Dry beans	12	18	18	18 to 24
Sugarbeets	12	18	30	36 to 48
Vegetables	6 to 12	18	18	18 to 24

Perennial crop	Seedling	Establishment	Mature
Alfalfa	6 to 12	24 to 36	48 to 72
Turf and lawns	6	12	12
Grass and pasture	6	12	24

Crop irrigation factors

The final irrigation should be properly timed to prevent unused soil moisture that causes harvest difficulties and increases soil compaction potential. Under-irrigating may reduce test weight and yield. The tables below are provided to help growers time the last irrigation event for corn. The amount of ET to maturity for several crop growth stages is provided in Table 16. These numbers are a good reference for predicting the amount of water needed to reach maturity. Producers can estimate the final irrigation by comparing the water use to maturity in Table 16 to the allowable soil moisture in Table 17. If soil moisture exceeds the water requirement to maturity, then additional irrigation is not required.

Table 16. Average water use for given corn growth stages to maturity.

Growth Stage	Approximate Days to Maturity	Approximate GDUs to Maturity	Water Use to Maturity
Blister (R2)	45	1050	11.5
Dough (R4)	35	700	8.5
Beginning Dent	24	600	5.5
Full Dent (R5)	14	400	3
Maturity (R6)	0	0	0

Scheduling Information

Table 17. Allowable soil water depletion for corn at maturity.

Soil Texture	Available Water		Allowable soil water depletion	Available water in 4’	Minium allowable soil water balance
	Low	High	-- inches water/root zone --		
	inches/foot				
Fine Sands	0.8	1.0	2.2	3.6	1.4
Loamy Sands	0.8	1.2	2.4	4.0	1.6
Sandy Loams	1.2	1.5	3.2	5.4	2.2
Loam	1.7	2.5	5.0	8.4	3.4
Silty Loams	2.0	2.5	5.4	9.0	3.6
Clay Loam	1.6	2.0	4.3	7.2	2.9

Estimating the final irrigation

	-----------Example---------
Corn growth stage:	full dent (R5)
Current soil moisture in 4’ root zone in silt loam, 80% of available (2.25” x 4 x .80)	= 7.2”
Minimum allowable soil water balance (Table 17):	3.6’
Usable available water:	7.2” - 3.6” = 3.6”
ET, full dent to maturity (Table 16)	3.0”

No additional irrigation needed

Irrigation systems information

Use Table 18 to estimate whether a water supply can meet crop ET demand for various field sizes and adjust irrigation schedules accordingly. Fields with more capacity per day can keep tighter irrigation schedules than those closer to, or below crop ET demand. For example, a 500 gpm well might irrigate a 140 acre pivot in three days. In one day it applies 0.57 inches over the area traveled, but the average application rate is only 0.19 inches per day over the whole field, which is not adequate to supply peak ET demand for most crops.

Table 18. Water supply (gpm or cfs) converted to average inches per day (gross*). Table assumes the water supply runs for 24 hours.

	---------------Field size (acres)---------------							
gpm	20	40	80	120	140	160	240	cfs
	-------------------- inches per day ------------------							
200	0.53	0.27	0.13	0.09	0.08	0.07	0.04	0.4
300	0.80	0.40	0.20	0.13	0.11	0.10	0.07	0.7
400	1.06	0.53	0.27	0.18	0.15	0.13	0.09	0.9
500	1.33	0.66	0.33	0.22	0.19	0.17	0.11	1.1
600	1.59	0.80	0.40	0.27	0.23	0.20	0.13	1.3
700	1.86	0.93	0.46	0.31	0.27	0.23	0.15	1.5
800	2.12	1.06	0.53	0.35	0.30	0.27	0.18	1.8
900	2.39	1.19	0.60	0.40	0.34	0.30	0.20	2.0
1000	2.65	1.33	0.66	0.44	0.38	0.33	0.22	2.2
1200	3.18	1.59	0.80	0.53	0.45	0.40	0.27	2.6
1400	3.71	1.86	0.93	0.62	0.53	0.46	0.31	3.1
1600	4.24	2.12	1.06	0.71	0.61	0.53	0.35	3.5
1800	4.77	2.39	1.19	0.80	0.68	0.60	0.40	4.0
2000	5.30	2.65	1.33	0.88	0.76	0.66	0.44	4.4
2500	6.63	3.31	1.66	1.10	0.95	0.83	0.55	5.5
3000	7.95	3.98	1.99	1.33	1.14	0.99	0.66	6.6

*Gross application rate. Multiply by irrigation efficiency to obtain net application amount.

Flow rates

Erosion from furrow irrigation may cause excessive sediment loss and harms long term soil productivity. Utilizing appropriate flow rates can minimize soil losses.

Table 19. Furrow irrigation recommendations for different soil types.

	Basic intake rate (in/hr)	Basic intake rate (gpm/100 ft)	Maximum furrow length (ft)	Stream size* (gpm/100 ft)
Loamy sand	2.0-5.0	2.4	600	4.8
Sandy loam	0.5-4.0	1.9	800	3.8
Fine sandy loam	0.2-2.0	1.7	1000	3.4
Silt loam	0.2-1.5	1.1	1100	2.2
Silty clay loam	0.05-0.25	0.1	1300	1.4

*Recommended stream size, actual stream size must be less than maximum nonerosive stream size.

Source: D. Eisenhauer, D. Martin, and G. Hoffman. Irrigation Systems Management, U of N, Lincoln

Table 20. Recommended maxium furrow stream size for various slopes and soil types to prevent erosion. Use higher flow rates when using polyacrylamide (PAM).

Slope	Erosion Resistant	Average	Moderately Erodible	Highly Erodible
(%)	Stream size (gpm)			
0.25	50	50	40	20
0.50	30	25	20	10
0.75	20	17	13	7
1.25	12	10	8	5

Source: NRCS National Irrigation Guide. Varies with soil type and condition.

Irrigation Systems

Calibration for center-pivot chemigation

Only products specifically labeled for chemigation may be applied through any irrigation system. The label may also contain specific chemigation requirements that must be followed. The following calculations will help you determine the injection pump settings for the proper application rate.

a. Acres to be treated

$$\text{Acres} = \frac{\Pi R^2}{43{,}560}$$

(∏ =3.1416; R= wetted radius in feet)

Chemigation Calibration

b. Acres treated per hour or per minute

Acres/hour = <u>acres to be treated</u>
revolution time (fr)
@ desired inches of water

or

$$\text{Acres/min} = \frac{\text{acres/hour}}{60}$$

c. Pump setting

Depending upon the manufacturer of your injection pump, you will initially need to set the pump in either gallons per hour (gal/hr) or percent. The following calculations will help you make the correct setting.

gal/hr = acres treated per hours x gallons per acre (labeled rate of product to be applied)

% dial setting on pump = gallons per hour
max injection pump rating (GPH)

(continued on next page)

Chemigation Calibraiton

d. After initially setting the pump, it is a good idea to fin-tune the pump output. Systems should have a calibration tube (graduated in ounces or milliliter) located between the nurse tank and the pump. Adjust the pump while monitoring the sight tube until the proper rate is achieved. Use the following conversions to convert gallons per hour to ounces or milliliter per minute.

ounces (oz) per minute = (gallons per hour) x 2.13

milliliters (ml) per minute = (gallons per hour) x 63.1

The Colorado Chemigation Act requires a chemigation permit and the appropriate anti-siphoning and automatic injection pump shut off devices to be used when applying pesticides and fertilizers in closed irrigation systems. Chemigation units are subject to inspection by the Colorado Department of Agriculture (CDA). Contact the CDA at (303) 239-4149 for updated information on these requirements.

Equivalents

Volume equivalents

1 acre-foot covers 1 acre of land 1 foot deep;

1 acre-foot
= 43,560 cubic feet
= 325,851 gallons
= 12 acre-inches
= 2,718,000 pounds

1 acre-inch = 27,154 gallons

1 cubic foot
= 7.481 gallons
= 62.4 pounds water

1 cubic meter
= 1,000 liters
= 264.2 gallons

1 gallon
= 128 ounces
= 8.35 pounds
= 3.785 liters
= 3,785 milliliters

1 quart of water
= 0.947 liters

Flow equivalents

1acre-inch/hour
≈ 450 gallons per minute (gpm)
≈ 1 cubic foot per second (cfs)

1 cfs for 1 hour ≈ 1 acre-inch

1 cfs for 24 hours ≈ 2 acre-feet

1 cfs for 30 days ≈ 60 acre feet

Table 21. Flow equivalents

Cubic feet/second (cfs)	Gallons/minute (gpm)*	Colorado Miner's inches
1	449	35.8
2	898	76.9
4	1795	153.8
6	2693	230.8
8	3590	307.7
10	4488	384.6

*Rounded to nearest gpm.

Table 22. Maximum flow capacities (full pipe) for coupled and gated pipe.

Pipe ID (inches)	Flow (gpm)
6	400
8	800
10	1,200
12	1,700

Volume

Convert from:
Acre feet

Into:	**Multiply by:**
cubic feet	43,560
cubic meters	1,233
gallons	325,851
million gallons	0.326

Cubic feet

Into:	**Multiply by:**
acre feet	0.000023
cubic meters	0.2832
gallons	7.481

Gallons

Into:	**Multiply by:**
acre feet	0.000003069
cubic feet	0.1337
cubic meters	0.00379
liters	3.785
million gallons	0.000001

Volume

Convert from:
Million Gallons

Into:	**Multiply by:**
acre feet	3.068
cubic feet	133,680
cubic meters	3,785

Flow

Acre foot per day

Into:	**Multiply by:**
cubic foot per day	43,560
cubic foot per second	0.5042
cubic meters per second	0.014
gallons per second	3.771
gallons per minute	226.3

Cubic foot per day

Into:	**Multiply by:**
acre foot per day	0.00002296
cubic foot per second	0.00001157
gallons per second	0.00008656
gallons per minute	0.005195

Cubic foot per second

Into:	**Multiply by:**
acre foot per day	1.984
gallons per second	7.481
gallons per minute	448.8

Flow

Convert from:
Gallons per second

Into:	**Multiply by:**
acre foot per day	0.265
cubic foot per day	11,550
cubic foot per second	0.1337
gallons per minute	60
liters per second	3.785

Gallons per minute

Into:	**Multiply by:**
acre foot per day	0.00442
cubic foot per day	192.5
cubic foot per second	0.00223
cubic meters per day	5.451
cubic meters per second	0.00006309
gallons per second	0.01667

Other

Horse power

Into:	**Multiply by:**
Kilowatt	0.746

PSI

Into:	**Multiply by:**
foot of head	2.31*

*A column of water 2.31 feet deep exerts pressure of 1 psi

Conversions