The U.S. Department of Agriculture (USDA) prohibits discrimination in its programs on the basis of race, color, national origin, sex, religion, age, disability, political beliefs, and marital or familial status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audio tape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint, write the Secretary of Agriculture, U.S. Department of Agriculture, Washington, DC 20250, or call 1-800-245-6340 (voice) or (202) 720-1127 TDD). USDA is an equal employment opportunity employer.

Revised August 1997

Irrigating with Furrow, Border, and Sprinkler Systems

When and How Much?

U.S. Department of Agriculture
Natural Resources Conservation Service

California Department of Water Resources
Water Conservation Office

University of California
Cooperative Extension

Irrigation...When and How Much?

Conservation irrigation water management means controlling or regulating irrigation water applications in a way that will satisfy crop water requirements without wasting water, eroding soil, or degrading water quality. It involves applying water in accordance with specific crop needs in amounts that can be retained in the soil for crop use and at rates and times that are consistent with soil intake characteristics and erosion hazard.

Soil

The amount of water a soil can hold, and that is available for plant use, is determined by the soil's physical properties. Soil texture and depth are the most influential factors in determining the Available Waterholding Capacity (AWC) of a soil. Many soils have varying textures at different depths. Table 1 gives the general range of AWC per foot of depth for several soil textures.

TABLE 1 **Available Waterholding Capacity for Various Soil Textures**

	Available Moisture	
Soil Texture	Range *(in./ft.)*	Average *(in./ft.)*
Very coarse to coarse-textured sand	0.5-1.25	0.90
Moderately coarse-textured sandy loams and fine sandy loams	1.25-1.75	1.50
Medium texture—very fine sandy loams to silty clay loams	1.50-2.30	1.90
Fine and very fine texture—silty clay to clay	1.60-2.50	2.10
Peats and mucks	2.00-3.00	2.50

Rooting Depth

The depth of soil from which a crop can extract water is the effective crop rooting depth. This depth will vary with the stage of crop growth. Rooting depth may be restricted to a depth considerably less than the normal root depth by soil limitations (i.e., hardpan, high water table, and so forth). Irrigation design rooting depths for several mature irrigated crops, grown on deep, permeable well-drained soil, are given below.

TABLE 2 **Rooting Depth for Irrigation**

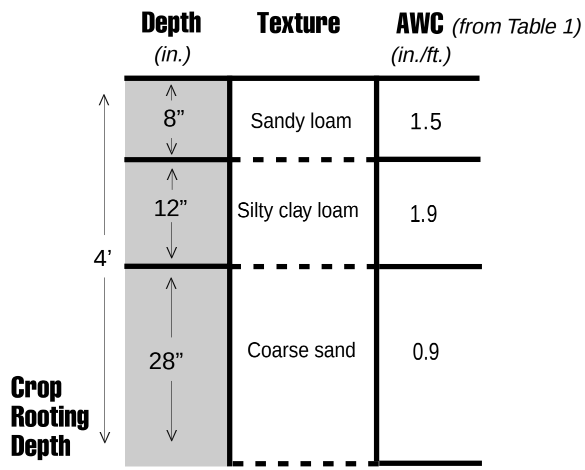
Crop	**Feet**
Alfalfa	3.0-6.0
Almond, apple, apricot	4.0-5.0
Asparagus	3.0-6.0
Barley	2.0-3.0
Beans	2.0-4.0
Citrus	3.0-5.0
Corn	2.0-4.0
Cotton	4.0-5.0
Grape	3.0-4.0
Ladino Clover	2.0-3.0
Lettuce	1.0-2.0
Melons	3.0-4.0
Oats	2.0-3.0
Olives	4.0-5.0
Onions	1.0-3.0
Pasture (perennial)	2.0-4.0
Peach, pear, plum	4.0-5.0
Safflower	3.0-5.0
Sorghum	3.0-4.0
Squash	3.0-4.0
Sugar beets	4.0-6.0
Tomato	3.0-4.0
Walnut	5.0-7.0
Wheat	2.0-3.0

Total Available Moisture

The total amount of water available for plant use in the root zone is the sum of the AWC per foot for the various soil types within the effective rooting depth. See the example below.

Example 1. Calculation of Total Available Moisture in the Root Zone

Assume the crop is beans with a 4-foot rooting depth (Table 2) and is grown in a soil with the following characteristics:



Depth (in.)	Layer thickness (ft.)		AWC per foot (in./ft.)		Available moisture (in.)
0-8	$\frac{8}{12}$	x	1.5	=	1.0
8-20	$\frac{12}{12}$	x	1.9	=	1.9
20-48	$\frac{28}{12}$	x	0.9	=	2.1
	Total available moisture			=	5.0

When To Irrigate

Most surface- or spring-irrigated crops are normally irrigated when about 50 percent of the available moisture has been removed. Exceptions would be specialty crops needing certain conditions for product quality.

One method of estimating the amount of water depleted from the soil is the “feel” method, using Table 3. The depletion level estimates can be made by taking soil samples at various locations in the field with an auger, soil tube, or shovel at approximately 1-foot increments for the entire crop root zone. The total amount of moisture depleted at each location is the sum of the 1-foot increments for the crop rooting depth. This is also the new amount to be replaced by irrigation in order to refill the soil profile to its capacity. Additional allowance must be made for deep percolation, runoff losses, salinity leaching, and application efficiency.

Example 2. Estimating When To Irrigate

Assume the following:

- The same soil and crop as in Example 1.
- An allowable moisture depletion of 60 percent of the total available in the 4-foot root zone.
- Allowable depletion level = 0.60 x 5.0 inches = 3.0 inches

This means that irrigation should begin when about 3 inches of moisture have been lost by this calculation.

TABLE 3

Guide for Estimating Available Soil Moisture Depleted by the "Feel" Method

Moisture Deficiency *(in./ft.)*	SOIL TEXTURE CLASSIFICATION Coarse (loamy sand)	Sandy (loamy sand)	Medium (loam)	Fine (clay loam)	**Moisture Deficiency** *(in./ft.)*
	(field capacity)	(field capacity)	(field capacity)	(field capacity)	
.0		Appears very dark, leaves wet outline on hand, makes a short ribbon	Appears very dark, leaves wet outline on hand, will ribbon about 1 inch		**.0**
.2				Appears very dark, leaves leaves slight moisture on hand when squeezed, will ribbon about 2 inches	**.2**
.4	Appears moist, makes a weak ball	Quite dark color, makes a hard ball	Dark color, forms a plastic ball, slicks when rubbed	Dark color, will slick, ribbons easily	**.4**
.6	Appears slightly moist, sticks together slightly	Fairly dark color, makes a good ball	Quite dark, forms a hard ball	Quite dark, will make thick ribbon, may slick when rubbed	**.6**
.8	Dry, loose, flows through fingers **(wilting point)**	Slightly dark color, makes a weak ball	Fairly dark, forms a good ball		**.8**
1.0		Lightly colored by moisture, will not ball		Fairly dark, makes a good ball	**1.0**
1.2			Slightly dark, forms a weak ball	Will ball, small clods will flatten out rather than crumble	**1.2**
1.4		Very slight color due to moisture **(wilting point)**	Lightly colored, small clods crumble fairly easily	Slightly dark, clods crumble	**1.4**
1.6					**1.6**
1.8			Slight color due to moisture, small clods are hard **(wilting point)**	Some darkness due to unavailable moisture, clods are hard and cracked **(wilting point)**	**1.8**
2.0					**2.0**

Application Efficiency

Application efficiency is a measure of irrigation performance. It involves the total amount of water applied, the uniformity of the distribution, losses (such as runoff, evaporation, and deep percolation) and the net amount of water needed to meet plant growth requirements and leaching. Common application efficiencies for various types of irrigation systems, under good-to-excellent management, are listed below in Table 4.

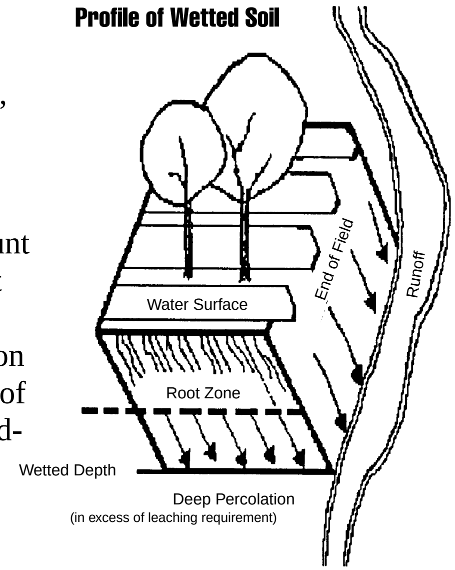


TABLE 4 **Irrigation Application Efficiencies Under Good-to-Excellent Management**

System	**Approximate Range of Application Efficiencies** *(in percentage)*
Furrow	70-85
Basin	75-90
Sprinklers	70-85
Graded Border	70-85
Drip (Trickle)	80-90

TABLE 5

Procedure for Calculating Depth of Water Applied

Step One

	Furrows	Borders/Basins	Sprinklers	Center Pivot
Area irrigated *(acres)*	Area = $\frac{(\text{Number of furrows}) \times (\text{Spacing in feet}) \times (\text{Length in feet})}{(43{,}560)}$	(A) Area per border = $\frac{(\text{Length in feet}) \times (\text{Width in feet})}{(43{,}560)}$ (B) Total area acres = $(\text{Number of borders}) \times (\text{Area per border})$	Area = $\frac{(\text{Lateral length in feet}) \times (\text{Move in feet})}{(43{,}560)}$	Area per center pivot $\frac{(.0314) \times \left[\text{Lateral length in feet}\right]^2 \times (P)}{(43{,}560)}$ Where: P = Percent of full circle

Step Two

	Siphons	Pumps	Sprinklers	
Flow *(in gallons per minute (GPM))*	(A) See Table 7 for GPM per siphon (B) Total flow = $\left[\text{Number of siphons}\right] \times \left[\text{GPM per siphon}\right]$	If a flow meter is not available, see Tables 9, 10, and 11 for GPM flow from pump with free discharge.	(A) See Table 6 for GPM per sprinkler (B) Total flow = $\left[\text{Number of sprinklers}\right] \times \left[\text{GPM per sprinkler}\right]$	

Step Three

Depth of Water Applied *(inches)*	Use total flow from Step Two with Table 8 and your set time to get acre inches of water applied. Depth applied (inches) = $\frac{(\text{Acre inches of water applied})}{(\text{Area irrigated from Step One})}$

How Much To Apply

The gross amount of water to be applied is the net amount required to refill the crop root zone (to meet plant requirements), divided by the application efficiency.

$$\text{Gross application required} = \frac{\text{Depleted moisture to be replaced}}{\text{Application efficiency (decimal)}}$$

Management

So far, the discussion has assumed flexibility in the scheduling of irrigation and the total amount applied. An irrigation is scheduled when the amount of soil moisture depleted from the root zone approaches the allowable depletion level. The amount of water applied is based on replacing the depleted soil moisture. This involves decisions for when to irrigate and how much to apply in order to optimize moisture conditions for crop production and minimize irrigation costs.

Occasionally, water deliveries are on a fixed schedule when deliveries are made every 10 to 15 days. Under these conditions, it is not necessary to decide when to irrigate, but only how much to apply. The amount applied then should be based only on the soil moisture depleted since the last irrigation.

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 = Cross application depth (inches)
A = Area irrigated (acres)
Q = Flow rate (cublic feet per second)
T = Set time (hours)

*This equation can be used to calculate gross application **depth** applied, the **area** to be irrigated, the **flow** rate required, and 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 by:

$$D = \frac{Q \times T}{A}$$

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

$$A = \frac{Q \times T}{D}$$

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

$$Q = \frac{D \times A}{T}$$

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

$$T = \frac{D \times A}{Q}$$

TABLE 6 **Sprinkler Nozzle Discharge** *(in GPM)*

Nozzle Size (in.)	Nozzle Pressure (#/sq. in.) 25	30	35	40	45	50	55	60	65	70	75	Wetted Diameter[1] (ft.)
												60
3/32	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0				70
7/64	1.7	1.9	2.0	2.2	2.3	2.4	2.6	2.7				80
1/8	2.2	2.4	2.6	2.8	3.0	3.2	3.3	3.5	3.6			
9/64	2.9	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6			
5/32	3.5	3.9	4.2	4.5	4.7	5.0	5.2	5.5	5.7	5.9		90
11/64	4.3	4.7	5.1	5.4	5.7	6.0	6.3	6.6	6.8	7.1		
3/16	5.0	5.5	6.0	6.4	6.8	7.2	7.5	7.8	8.1	8.4	8.7	
13/64	5.9	6.5	7.1	7.6	8.1	8.5	8.9	9.2	9.5	9.8	10.2	100
7/32	6.8	7.6	8.3	8.9	9.4	9.9	10.3	10.7	11.2	11.6	12.0	110
1/4		9.9	10.7	11.4	12.1	12.8	13.5	14.1	14.8	15.4	16.0	125
9/32		12.4	13.4	14.3	15.2	16.1	17.0	17.9	18.7	19.5	20.3	
5/16		15.2	16.5	17.7	18.9	20.0	21.0	22.0	23.0	23.9	24.8	
11/32			19.7	21.1	22.4	23.6	24.8	25.9	27.0	28.1	29.2	145
3/8			22.8	24.4	26.0	27.6	29.2	30.6	32.0	33.3	34.5	
13/32			27.2	29.1	30.9	32.7	34.3	35.9	37.4	38.9	40.3	165
7/16				33.9	35.9	37.8	39.7	41.5	43.3	45.1	46.8	
15/32				38.9	41.1	43.3	45.4	47.4	49.4	51.4	53.3	185
1/2				43.6	46.0	48.4	50.7	53.0	55.3	57.2	59.6	
17/32					51.6	54.0	56.4	58.8	61.2	63.5	65.8	
9/16					57.5	60.6	63.6	66.5	69.4	72.2	74.9	205
5/8					70.0	73.6	77.2	80.8	84.4	87.8	91.0	

[1] Approximate diameter of coverage. For sprinkler with two different nozzles, the wetted diameter is coverage of the larger nozzle.

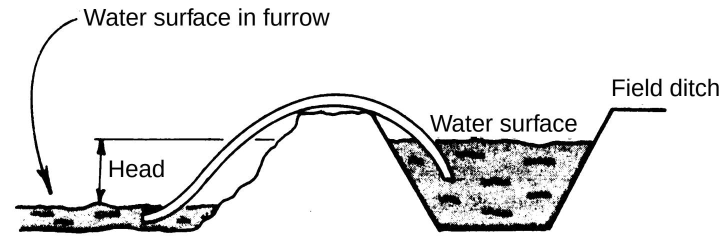


TABLE 7 **Siphon Tube Discharge** *(in GPM)*

Diameter of Siphon (inches)	2″ head*	3″ head	4″ head	6″ head	9″ head
3/8	.7	1.0	1.2	1.5	1.7
1/2	1.3	1.6	1.8	2.1	2.7
3/4	3	4	5	6	7
1	5	6	7	9	11
1-1/4	8	10	12	15	18
1-3/8	10	13	15	19	23
1-1/2	13	16	18	24	28
2	21	27	32	41	50
2-1/2	32	40	48	54	65
3	46	57	65	82	100
4	86	106	122	153	200

* Head is difference in height of water in supply ditch and center of discharge end of tube or water surface to water surface if tube outlet is submerged.

$$\text{Number of furrows} = \frac{\text{Q - GPM stream}}{\text{q - GPM of siphon tubes}}$$

TABLE 8
Conversion Table—Gallons Per Minute *(GPM)* and Cubic Feet Per Second *(CFS)* to Acre Inches of Water Applied

GPM	CFS	Set Time—Hours 6	7	8	9	10	11	12	14	16	18	20	24	36	48
45	.1	.6	.7	.8	.9	1.0	1.1	1.2	1.4	1.6	1.8	2.0	2.4	3.6	4.8
90	.2	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.8	3.2	3.6	4.0	4.8	7.2	9.6
135	.3	1.8	2.1	2.4	2.7	3.0	3.3	3.6	4.2	4.8	5.4	6.0	7.2	10.8	14.4
180	.4	2.4	2.8	3.2	3.6	4.0	4.4	4.8	5.6	6.4	7.2	8.0	9.6	14.4	19.2
225	.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0	8.0	9.0	10.0	12.0	18.0	24.0
270	.6	3.6	4.2	4.8	5.4	6.0	6.6	7.2	8.4	9.6	10.8	12.0	14.4	21.6	28.8
315	.7	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.8	11.2	12.6	14.0	16.8	25.2	33.6
360	.8	4.8	5.6	6.4	7.2	8.0	8.8	9.6	11.2	12.8	14.4	16.0	19.2	28.8	38.4
405	.9	5.4	6.3	7.2	8.1	9.0	9.9	10.8	12.6	14.4	16.2	18.0	21.6	32.4	43.2
450	1.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	16.0	18.0	20.0	24.0	36.0	48.0
495	1.1	6.6	7.7	8.8	9.9	11.0	12.1	13.2	15.4	17.6	19.8	22.0	26.4	39.6	52.8
540	1.2	7.2	8.4	9.6	10.8	12.0	13.2	14.4	16.8	19.2	21.6	24.0	28.8	43.2	57.6
585	1.3	7.8	9.1	10.4	11.7	13.0	14.3	15.6	18.2	20.8	23.4	26.0	31.2	46.8	62.4
630	1.4	8.4	9.8	11.2	12.6	14.0	15.4	16.8	19.6	22.4	25.2	28.0	33.6	50.4	67.2
675	1.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	21.0	24.0	27.0	30.0	36.0	54.0	72.0
720	1.6	9.6	11.2	13.0	14.4	16.0	17.6	19.2	22.4	25.6	28.8	32.0	38.4	57.6	76.8
765	1.7	10.2	11.9	13.6	15.3	17.0	18.7	20.4	23.8	27.2	30.6	34.0	40.8	61.2	81.6
810	1.8	10.8	12.6	14.4	16.2	18.0	19.8	21.6	25.2	28.8	32.4	36.0	43.2	64.8	86.4
855	1.9	11.4	13.3	15.2	17.1	19.0	20.9	22.8	26.6	30.4	34.2	38.0	45.6	68.4	91.2
900	2.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	28.0	32.0	36.0	40.0	48.0	72.0	96.0
990	2.2	13.2	15.4	17.6	19.8	22.0	24.2	26.4	30.8	35.2	39.6	44.0	52.8	79.2	105.6
1080	2.4	14.4	16.8	19.2	21.6	24.0	26.4	28.8	33.6	38.4	43.2	48.0	57.6	86.4	115.2
1170	2.6	15.6	18.2	20.8	23.4	26.0	28.6	31.2	36.4	41.6	46.8	52.0	62.4	93.6	124.8
1260	2.8	16.8	19.6	22.4	26.2	28.0	30.8	33.2	39.2	44.8	50.4	56.0	67.2	100.4	134.4
1350	3.0	18.0	21.0	24.0	27.0	30.0	33.0	36.0	42.0	48.0	54.0	60.0	72.0	108.0	144.0

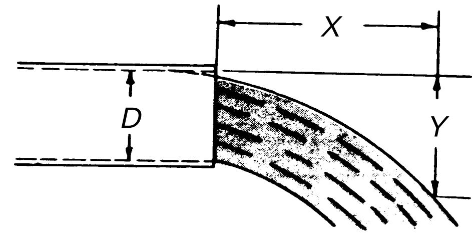


TABLE 9 **When *X*=12 inches**

Y (in.)	4-inch	6-inch	8-inch	10-inch	12-inch	14-inch	16-inch
	D=Inside diameter of pipe						
2	419	1044	2005	3312	4969	6977	9339
4	294	724	1386	2288	3435	4829	6471
6	238	580	1106	1826	2742	3859	5177
8	204	493	937	1545	2322	3271	4394
10	1181	433	819	1350	2031	2864	3851
12	164	387	731	1204	1812	2559	3445
14	150	352	662	1089	1641	2319	3126
16	139	323	605	996	1500	2123	2865
18	130	299	558	917	1383	1959	2647
20	122	278	517	850	1283	1819	2461

TABLE 10 **When *X*=18 inches**

Y (in.)	4-inch	6-inch	8-inch	10-inch	12-inch	14-inch	16-inch
	D=Inside diameter of pipe						
2	601	1421	2713	4508	6819	9652	13011
4	423	999	1897	3144	4750	6721	9060
6	345	811	1532	2532	3820	5403	7285
8	298	698	1313	2163	3259	4608	6213
10	265	621	1161	1908	2871	4058	5472
12	242	563	1049	1718	2582	3648	4919
14	223	519	960	1569	2355	3325	4485
16	208	482	888	1447	2170	3063	4132
18	196	452	829	1346	2015	2844	3836
20	185	426	777	1259	1883	2656	3584

TABLE 11 **When *X*=24 inches**

Y (in.)	4-inch	6-inch	8-inch	10-inch	12-inch	14-inch	16-inch
	D=Inside diameter of pipe						
2	806	1815	3373	5569	8434	11983	16226
4	565	1281	2375	3909	5907	8384	11345
6	458	1044	1931	3168	4778	6773	9159
8	393	903	1665	2723	4099	5803	7843
10	348	806	1483	2418	3632	5135	6936
12	315	735	1348	2191	3284	4638	6261
14	290	679	1242	2041	3012	4249	5731
16	269	634	1157	1870	2791	3932	5301
18	251	597	1086	1750	2607	3668	4942
20	236	565	1026	1648	2450	3443	4635