Chapter 9 Irrigation Water Management

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Chapter 9 Irrigation Water Management

652.0900 General

Irrigation water management (IWM) is the act of timing and regulating irrigation water application in a way that will satisfy the water requirement of the crop without wasting water, soil, and plant nutrients and degrading the soil resource. This involves applying water:

- According to crop needs
- In amounts that can be held in the soil and be available to crops
- At rates consistent with the intake characteristics of the soil and the erosion hazard of the site
- So that water quality is maintained or improved

A primary objective in the field of irrigation water management is to give irrigation decisionmakers an understanding of conservation irrigation principles by showing them how they can judge the effectiveness of their own irrigation practices, make good water management decisions, recognize the need to make minor adjustments in existing systems, and recognize the need to make major improvements in existing systems or to install new systems. The net results of proper irrigation water management typically:

- Prevent excessive use of water for irrigation purposes.
- Prevent excessive soil erosion
- Reduce labor
- Minimize pumping costs
- Maintain or improve quality of ground water and downstream surface water
- Increase crop biomass yield and product quality

Tools, aids, practices, and programs to assist the irrigation decisionmaker in applying proper irrigation water management include:

- Applying the use of water budgets, water balances, or both, to identify potential water application improvements
- Applying the knowledge of soil characteristics for water release, allowable irrigation application rates, available water capacity, and water table depths
- Applying the knowledge of crop characteristics for water use rates, growth characteristics, yield and quality, rooting depths, and allowable plant moisture stress levels
- Water delivery schedule effects
- Water flow measurement for onfield water management
- Irrigation scheduling techniques
- Irrigation system evaluation techniques

See Chapter 15 for resource planning and evaluation tools and for applicable worksheets.

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652.0901 Irrigation water management concepts

(a) Irrigation water management concepts

Field monitoring techniques can be used to establish when and how much to irrigate. The long existing rule of thumb for loamy soils has been that most crops should be irrigated before more than half of the available soil water in the crop root zone has been used. It has also been demonstrated that certain crops respond with higher yields and product quality by maintaining a higher available soil-water content, especially with clay soils. Desired or allowable soil moisture depletion levels, referred to as Management Allowable Depletion (MAD), are described in Chapter 2, Soils, and Chapter 3, Crops. If the Available Water Capacity (AWC) of the soil, the crop rooting depth for the specific stage of growth, and the MAD level are known, then *how much water to apply* per irrigation can be determined. Part 652.0903 reviews measurement of soil-water content and describes tools, techniques, and irrigation scheduling. Part 652.0908, Water management, addresses the importance of measuring a predetermined quantity of water onto the field.

(1) Concepts of irrigation water management

The simplest and basic irrigation water management tool is the equation:

$$Q\,T = D\,A$$

where:
Q = flow rate (ft^3/s)
T = time (hr)
D = depth (in)
A = area (acres)

For example, a flow rate of 1 cubic foot per second for 1 hour = 1-inch depth over 1 acre. This simple equation, modified by an overall irrigation efficiency, can be used to calculate daily water supply needs by plants, number of acres irrigable from a source, or the time required to apply a given depth of water from an irrigation well or diversion. Typically, over 80 percent of IWM concerns can be at least partly clarified by the application of this equation.

Quantity of water to be applied is often determined by available water capacity of the soil, planned management allowable depletion, and estimated crop evapotranspiration (ET_c). When rainfall provides a significant part of seasonal plant water requirements, irrigation can be used to supplement plant water needs during dry periods resulting from untimely rainfall events.

Water should be applied at a rate or quantity and in such a manner to have sufficient soil-water storage, be nonerosive, have minimal waste, and be nondegrading to public water quality. Irrigations are timed to replace the planned depleted soil moisture used by the crop. Effective rainfall during the growing season should be taken into consideration.

(2) When to irrigate

When to irrigate is dependent on the crop water use rate, sometimes referred to as irrigation frequency. This rate can be determined by calculation of ET_c rate for specific crop stage of growth, monitoring plant moisture stress levels, monitoring soil-water depletion, or a combination if these. Too frequently, crop condition is observed to determine when to irrigate. When plants show stress from lack of moisture, it is typically too late. Generally, crop yield and product quality have already been adversely affected. The over-stress appearance may also be from shallow roots resulting from overirriga-tion or from disease, insect damage, or lack of trace elements. Certain plants can be excessively stressed during parts of their growth stage and have little effect on yield. Part 652.0903 reviews measurement of plant moisture stress levels and describes tools, techniques and irrigation scheduling.

(3) Rainfall management

In moderate to high rainfall areas, managing the timing of irrigations to allow effective use of rainfall during the irrigation season is a common practice. The irrigation decisionmaker can attempt to predict rainfall events and amounts (which too often does not work), or the depleted soil water is never fully replaced with each irrigation. Instead, between 0.5 and 1.0 inch of available water capacity in the soil profile can be left unfilled for storage of potential rainfall. Rainfall probability during a specific crop growing period and the level of risk to be taken must be carefully considered by the irrigation decisionmaker. Applied irrigation water should always be considered supplemental to rainfall events.

(4) Water supply limitations

Where water supply is limiting, deficit or partial year irrigation is often practiced. Partial irrigation works well with lower value field crops. It does not work well with high value crops where quality determines market price, especially the fresh vegetable and fruit market. Typically, water is applied at times of critical plant stress (see Chapter 3, Crops) or until the water is no longer available for the season. Yields are generally reduced from their potential, but net benefit to the farmer may be highest, especially when using high cost water or a declining water source, such as pumping from a declining aquifer. An economic evaluation may be beneficial.

(5) Water delivery

Water supply and delivery schedules are key to proper irrigation water management. When water users pump from a well or an adjacent stream or maintain a diversion or storage reservoir, they control their own delivery. In some areas delivery is controlled by an irrigation district or company. Delivery by an irrigation district may be controlled by its own institutional constraints (management) or by canal supply and structure capacity limitations.

Flexibility in delivery generally is controlled by institutional restraints or capacity limitations on the downstream ends of irrigation laterals. Capacity limitations are primarily because required storage is not within or very close to farm delivery locations. Where water supplies are not limited and delivery is in open canal systems, irrigation districts often carry from 10 to 30 percent additional water through the system as *management water* to reduce district water management requirements. Low cost semi or fully automated controllers are available for water control structures that accomplish the same purpose with less water. (One large irrigation district discovered they had over 20 percent more water available to users when water measuring devices and semiautomatic gate controls were installed at each major lateral division.) The following schedules are widely used.

(i) Fixed and rotation**—**With fixed delivery time at fixed delivery rates, irrigation districts provide a single delivery point to an individual water user or to a group of neighbors that rotate the delivery among themselves. Generally the delivery schedule is the easiest to use and the least costly. Turnout gates are adjusted to deliver a given share of water on a continual basis. This delivery schedule however, generally promotes the philosophy of **use the water (whether the crop needs it or not) or lose it.** This practice is not conducive to proper irrigation scheduling. Many project delivery systems have been designed based on this delivery schedule method because of the perception it allows minimum capacity sizing of all components. When in fact, only the lower end of laterals (± 5 water users) is affected.

(ii) Arranged**—**The water user requests or orders water delivery at a rate, start time, and duration in advance. Most arranged schedules require a minimum of 24 to 48 hours advance notice for water to be turned on or turned off. Arranged schedules often require water be turned on or off at specific times; i.e., 7 to 9 a.m., to correspond to ditch riders' schedules. This delivery schedule requires good, advance communication between water user and irrigation company. Irrigation districts need to have flexibility in their delivery with this method. Temporary storage facilities are typically needed because water spills out the end of the delivery system.

(iii) Demand**—**A demand schedule is one that allows users to have flexibility of frequency, rate, and duration of delivery. A municipal water system meets this type of delivery schedule system. It also works best where the water user owns and maintains the water supply; i.e., well, storage reservoir, and stream diversion. On-demand schedules are technically feasible for most moderate to large irrigation districts. Except for downstream ends of supply laterals, canal and lateral sizes are the same whether demand, rotation, or arranged deliveries are used. Temporary storage is provided by main canals and laterals; however, canal appurtenances (diversions, turnouts, and flow measuring devices) must be sized accordingly. With smaller delivery systems, slight oversizing of main canals and temporary storage facilities can often be provided at a small increase in delivery system cost. Modifications to on-demand schedule can work well. For example, the rate may be limited, but frequency and duration made flexible. This method works quite well in many projects if the main canal capacity is increased slightly and if temporary storage facilities are provided within the delivery system.

Most onfarm irrigation delivery and distribution facilities are limited by their capacity. Therefore, variable frequency and duration are typically the best delivery schedule reasonably available. A good irrigation scheduling program can be developed around this type of delivery schedule.

(6) Water measurement

A key factor in proper irrigation water management is knowing how much water is available to apply or is applied to a field through an irrigation application system. Many devices are available to measure open channel or pipeline flows. See Chapter 7, Farm Distribution Systems, for more details. Too many irrigators consider water measurement a regulation issue and an inconvenience. The importance of flow measurement for proper irrigation water management cannot be overstressed. Typically, less water is used where adequate flow measurement is a part of the water delivery system and a unit cost billing mechanism is used. In addition to chapter 7, the joint USBR, ARS, and NRCS water measurement publication should be consulted.

652.0902 Soil-plant-water balance

Detailed soil and crop characteristics were described in chapters 2 and 3 of this guide. Applying those characteristics and monitoring changes in soil-water content, plant moisture tension levels, canopy cover, root development, and water use rates provide valuable factors to implement proper irrigation water management. Generally, water budgets are a planning tool, water balance is the daily accounting of water availability. Both can be important irrigation water management tools.

(a) Soil

Soil intake characteristics, field capacity, wilting point, available water capacity, water holding capacity, management allowed depletion, and bulk density are soil characteristics that irrigation consultants and decisionmakers must take into account to implement proper irrigation water management. Also see Chapter 2, Soils, and Chapter 17, Glossary.

Field capacity (FC) is the amount of water remaining in the soil when the downward water flow from gravity becomes negligible. It occurs soon after an irrigation or rainfall event fills the soil. Field capacity is generally assumed to be 1/10 atmosphere (bar) soil-water tension for sandy soils and 1/3 atmosphere (bar) tension for medium to fine textured soils. For accurate results these points should be measured in the laboratory, but can be measured (reasonably close) in the field if done soon after an irrigation and before plants start using soil moisture.

Free or excess water is available for plant use for the short time it is in the soil. With coarse textured soil, excess water can be available for a few hours because free water drains rapidly, but with fine textured soil it can be up to 2 days because free water drains more slowly. Laboratory results are typically good for homogenous soils, but results may be inaccurate for stratified soils because of free water movement being restricted by fine textured layers. In stratified soils, proper field tests can provide more representative data.

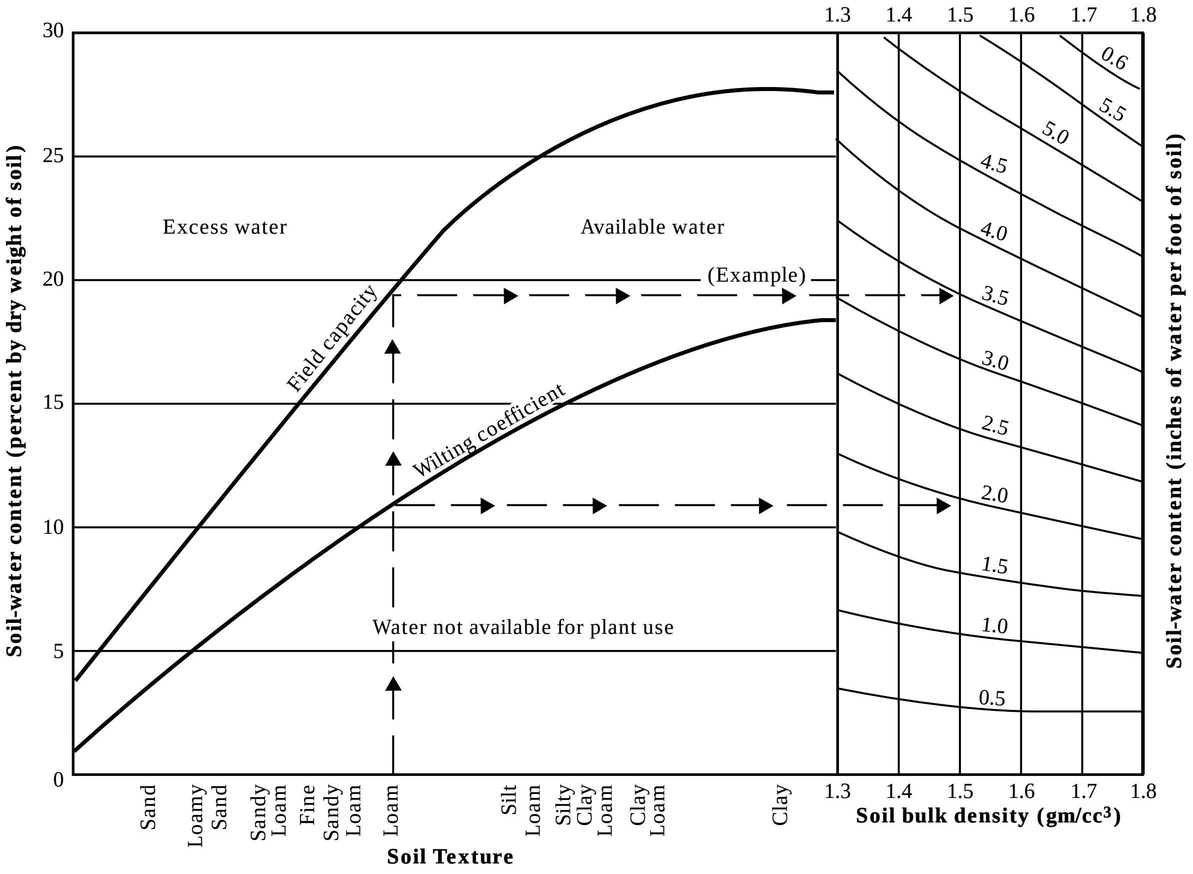
In stratified soils, a common perception that downward water movement is held up by fine textured soil layers is not entirely true. In fact, water enters fine textured soil layers almost immediately. However, because the fine textured soil has greater soil-water tension, downward water movement into a coarse textured soil below is restricted. A recently published NRCS video, *How Water Moves Through Soil,* demonstrates water movement in various soil profiles.

Wilting point (WP), sometimes called wilting coefficient, is the soil-water content below which plants cannot obtain sufficient water to maintain plant growth and never totally recover. Generally, wilting point is assumed to be 15 atmospheres (bar) tension. It is measured only in the laboratory using a pressure plate apparatus and is difficult to determine in the field.

Available water capacity (AWC) is that portion of water in the soil (plant root zone) that can be absorbed by plant roots. It is the amount of water released between field capacity and permanent wilting point, also called available water holding capacity. Average available water capacities are displayed in table 9–1, based on texture in the profile. A specific soil series (i.e., Warden) can have different surface textures. Average soil-water content based on various textures and varying bulk density is displayed in figure 9–1.

Soil-water content (SWC) is the water content of a given volume of soil at any specific time. This is the water content that is measured by most soil-water content measuring devices. Amount available to plants then is SWC – WP.

Figure 9–1 Total soil-water content for various soil textures with adjustment for changes in bulk density



Management allowable depletion (MAD) is the desired soil-water deficit at the time of irrigation. It can be expressed as the percentage of available soil-water capacity or as the depth of water that has been depleted in the root zone. Providing irrigation water at this time minimizes plant water stresses that could reduce yield and quality.

Bulk density is the mass of dry soil per unit bulk volume. It is the oven dried weight of total material per unit volume of soil, exclusive of rock fragments 2 mm or larger. The volume applies to the soil near field capacity water content. To convert soil-water content on a dry weight basis to volumetric basis, soil bulk density must be used. Bulk density is an indicator of how well plant roots are able to extend into the soil. See Chapter 2, Soils, for example of conversion procedure. Core soil samplers are most commonly used to collect inplace density samples. Commercial samplers available include the Madera sampler in which a 60 cc sample is collected. This sampler was developed for use with a neutron probe. The Eley Volumeter and the AMS core sampler are other examples. Other commercial push type core samplers use known volume removable retaining cylinders. These cylinders contain the core samples. NRCS soil scientists use liquid saran to coat soil clods, and the volume of the clod is determined in a soils laboratory using a water displacement technique. This process provides the least disturbance to a soil sample; however, obtaining clods from sandy soils can be difficult. Techniques to determine density used in construction, such as using a sand cone, and balloon methods can also be used in soils with coarse rock fragments or with coarse sandy soils. Rock fragments cause disturbance of core samples when using a push type core sampler.

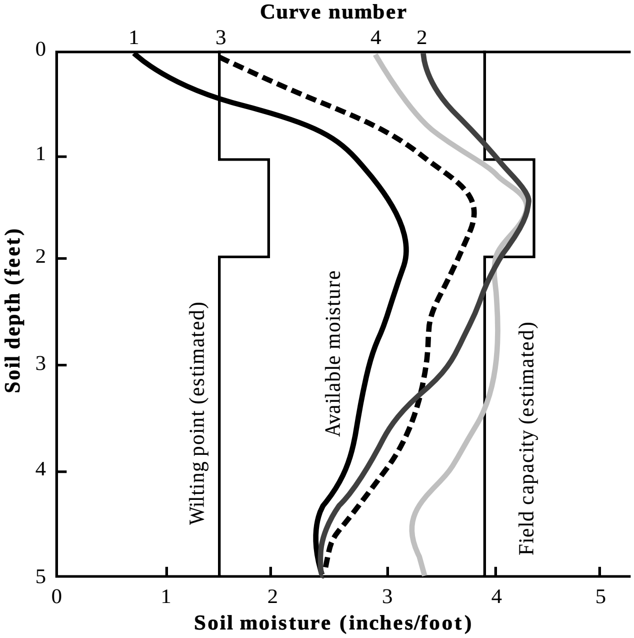
Soil-water profiles are a plot of soil-water content versus soil root zone depth. As a water management tool, this plot visually displays available water, total water content, or water content at the time to irrigate level (fig. 9–2).

The rate of decrease in soil-water content is an indication of plant water use and evaporation, which can be used to determine **when to irrigate and how much to apply**. This is the basic concept in scheduling irrigations.

Table 9–1 Available water capacity for various soil textures

Soil texture	Estimated AWC in/in	 in/ft
Sand to fine sand	0.04	0.5
Loamy sand to loamy fine sand	0.08	1.0
Loamy fine sands, loamy very fine sands, fine sands, very fine sands	0.10	1.2
Sandy loam, fine sandy loam	0.13	1.6
Very fine sandy loam, silt loam, silt	0.17	2.0
Clay loam, sandy clay loam, silty clay loam	0.18	2.2
Sandy clay, silty clay, clay	0.17	2.0

Figure 9–2 Soil-water content versus depth



An interpretation of data that soil moisture curves 1 through 4 on figure 9–2 represent includes:

- Curve #1—This curve shows the upper 6 inches of the soil profile is below wilting point. Shallow rooted plants are excessively stressed. Below a depth of 12 inches, soil moisture is still ample at 50 percent. If it is desirable to maintain soil moisture at 50 percent of total available moisture or higher (i.e., for plants with less than 10 inches rooting depth), it is time to irrigate, maybe even a little late to maintain optimum growth conditions. Deeper rooted plants are still drawing moisture from below a depth of 12 inches.
- Curve #2—This curve represents what soil moisture may be a day or two after an irrigation. The lower part of the soil profile did not reach field capacity. However, this situation may be desirable for crops with less than 25-inch rooting depth. For deeper rooted crops, additional water should have been applied.
- Curve #3—This curve represents moisture withdrawal from shallow rooted plants. There is ample moisture below 12 inches. A light application of water, to 12 inches depth, is needed for shallow rooted plants. A heavy application of water could put excess water below the crop root zone.
- Curve #4—This curve represents what soil moisture may be a day or two after an irrigation. The soil profile below a depth of 12 inches is nearly at field capacity, indicating a good irrigation application to approximately a 4-foot depth. Water is probably still moving downward.

(b) Measuring soil-water content

To measure soil-water content change for the purpose of scheduling irrigation, several site locations in each field and each horizon (or if homogenous at 6 inch depth increments) at the site (test hole) should be sampled. Quite often, the experienced irrigation decisionmaker calibrates available soil water in the soil profile relative to one sample at a specific depth. Multiple sites in a field are used to improve confidence in determining when and how much water to apply.

Most commercial soil-water content measuring devices provide a numerical measurement range. This measurement range is an indication of relative water content. The range might be 0 to 100 percent AWC or 0 to 10. Readings represent different specific soil-water content depending on soil type. Most devices that indicate relative values are difficult to calibrate to relate to specific quantitative values. A calibration curve for each specific kind of soil and soil-water content (tension) should be available with the device or needs to be developed.

If the irrigator is only interested in knowing when to irrigate, a specific indicated value on the gauge or meter may be sufficient. The manufacturer may provide this information either prebuilt into the device or with separate calibration curves. Irrigators must know what number (value) on the meter represents what approximate soil-water content level for their field and soils. They then must associate a specific number on the gauge to when irrigation is needed for each soil texture. Irrigation system design and water management planning provide the **how much to apply**. Example worksheets are provided in Chapter 15, Planning and Evaluation Tools.

(1) Methods and devices to measure or estimate soil-water content

(i) Soil feel and appearance method—This method is easy to implement and with experience can be accurate. Soil samples are collected in the field at desired depths, typically at 6 inch increments. Samples are compared to tables or pictures that give moisture characteristics of different soil textures in terms of feel and appearance. With practice, estimates can be obtained within 10 percent of actual. Typically the irrigation decisionmaker needs to learn only a few soils and textures.

Exhibit 9–1 displays the identification of soils and corresponding available water content when using feel and appearance method for determining soil-water content. The NRCS color publication, *Estimating Soil Moisture by Feel and Appearance,* is reproduced in chapter 15. Figure 9–3 is an example worksheet for determining soil-water deficient (SWD) in the soil profile.

Every operation can afford tools necessary to use this method of soil-water determination. Tools required are a push type core sampler, auger, or shovel. Care should be taken to not mix soil layers when sampling. Example forms for recording field data and calculating depleted or available soil-water content are in chapter 15.

Exhibit 9–1 Guide for estimating soil moisture conditions using the feel and appearance method

Available soil moisture (%)	Coarse texture fine sand, loamy fine sand	Moderately coarse texture sandy loam, fine sandy loam	Medium texture sandy clay loam, loam, silt loam	Fine texture clay loam, silty clay loam
	Available water capacity (in/ft)			
	0.6 – 1.2	1.3 – 1.7	1.5 – 2.1	1.6 – 2.4
0 – 25	Dry, loose, will hold together if not disturbed, loose sand grains on fingers with applied pressure	Dry, forms a very weak ball [1], aggregated soil grains break away easily from ball	Dry, soil aggregations break away easily, no moisture staining on fingers, clods crumble	Dry, soil aggregations easily separate, clods are hard to crumble with applied pressure
25 – 50	Slightly moist, forms a very weak ball with well defined finger marks, light coating of loose and aggregated sand grains remain on fingers	Slightly moist, forms a weak ball with defined finger marks, darkened color, no water staining on fingers grains break away	Slightly moist, forms a weak ball with rough surfaces, no water staining on fingers few aggregated soil pressure	Slightly moist, forms a weak ball, very few soil aggregations break away, no water stains, clods flatten with applied
50 – 75	Moist, forms a weak ball with loose and aggregated sand grains remain on fingers, darkened color, heavy water staining on fingers, will not ribbon [2]	Moist, forms a ball with defined finger marks, very light soil water staining on fingers, darkened color, will not slick	Moist, forms a ball, very light water staining on fingers, darkened color, pliable, forms a weak ribbon between thumb and forefinger	Moist, forms a smooth ball with defined finger marks, light soil water staining on fingers, ribbons between thumb and forefinger
75 – 100	Wet, forms a weak ball, loose and aggregated sand grains remain on fingers, darkened color, heavy water staining on fingers, will not ribbon	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	Wet, forms a ball with well defined finger marks, light to heavy soil water coating on fingers, ribbons between thumb and forefinger	Wet, forms a ball, uneven medium to heavy soil water coating on fingers, ribbons easily between thumb and forefinger
Field capacity (100%)	Wet, forms a weak ball, light to heavy soil water coating on fingers, wet outline of soft ball remains on hand	Wet, forms a soft ball, free water appears briefly on soil surface after squeezing or shaking, medium to heavy soil water coating on fingers	Wet, forms a soft ball, free water appears briefly on soil surface after squeezing or shaking, medium to heavy soil water coating on fingers	Wet, forms a soft ball, free water appears on soil surface after squeezing or shaking, thick soil water coating on fingers, slick and sticky

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[1] Ball is formed by squeezing a hand full of soil very firmly with one hand.
[2] Ribbon is formed by when soil is squeezed out of hand between thumb and forefinger.

Figure 9–3 Available soil-water holding worksheet (feel and appearance)

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Soil Water Holding Worksheet

Field ________________________________ Location in field _____________________________________
Year _________________________ By ___________________________________
Crop ____
Planting data _________________________________ Emergence data _________________________
Soil name if available ____
____
____

Factor	Season	
	1st 30 days	Remainder of season
Root zone depth or max soil depth - ft		
Available water capacity AWC - in		
Management allowed deficit MAD - %		
Management allowed deficit MAD - in		

(Note: Irrigate prior to the time that SWD is equal to or greater than MAD - in)

Estimated irrigation system application efficiency ___________________ percent

Data obtained during first field check

(1) Depth range (in)	(2) Soil layer thickness (in)	(3) Soil texture	(4) Available water capacity (AWC) (in/in)	(5) AWC in soil layer (in)

Total AWC for root zone depth of ________ ft= ________
Total AWC for root zone depth of ________ ft= ________

Data obtained each check

(6) Field check number	(7) Soil water deficit (SWD) (%)	(8) Soil water deficit (SWD) (in)
1		
2		
3		
4		
5		
6		
7		
8		
1		
2		
3		
4		
5		
6		
7		
8		
1		
2		
3		
4		
5		
6		
7		
8		

SWD summary

Check number	Check date	SWD totals
1		
2		
3		
4		
5		
6		
7		
8		

AWC(5) = layer thickness(2) x AWC(4)

$$SWD(8) = \frac{AWC(5) \times SWD(7)}{100}$$

(ii) Gravimetric or oven dry method**—**Soil samples are collected in the field at desired depths using a core sampler or auger. Care must be taken to protect soil samples from drying before they are weighed. Samples are taken to the office work room, weighed (wet weight), ovendried, and weighed again (dry weight). An electric oven takes 24 hours at 105 degrees Celsius to adequately remove soil water. A microwave oven takes a few minutes. Excessive high temperatures can degrade the soil sample by burning organic material. The drying oven can exhaust moisture from several samples at one time, but the microwave typically dries only one or two samples at a time. Percentage of total soil-water content on a dry weight basis is computed. To convert to a volumetric basis, the percentage water content is multiplied by the soil bulk density. Available soil water is calculated by subtracting percent total soil water at wilting point.

Tools required to use this method are a core sampler or auger, soil sample containers (airtight plastic bags or soil sample tins with tight lids), weighing scales, and a drying oven. Soil moisture will condense inside plastic bags, when used. This is part of the total soil moisture in the sample and must be accounted for in the weighing and drying operation. Standard electric soils drying ovens are commercially available. A much shorter drying time can be used with a microwave oven or infrared heat lamp, but samples need to be turned and weighed several times during drying to check water loss. Samples should be allowed to cool before weighing. These drying procedures are more labor intensive than using a standard drying oven at 105 degrees Celsius. Figure 9–4 displays an example worksheet for determining soil-water content of the soil profile.

(iii) Carbide soil moisture tester**—**A carbide soil moisture tester (sometimes called Speedy Moisture Tester) can provide percent water content of soil samples in the field; however, practice is necessary to provide satisfactory and consistent results. The tester is commercially available. Typically, a 26-gram soil sample and a measure of calcium carbide are placed in the air tight container. Some models use a 13-gram sample. When calcium carbide comes in contact with water in the soil, a gas (oxy-acetylene, C_2H_2) develops. As the reaction takes place, the gas develops a pressure in the small air tight container. The amount of gas developed is related to amount of water in the soil sample (providing excess carbide is present).

Caution: If inadequate carbide is available to react with all of the water, indicated moisture content is low. The higher the water content, the higher the pressure. The tester provides a gauge that reads percent soil-water content on a wet-weight basis. A standard chart is available to convert percent soil-water content from wet weight basis to dry weight basis. Figure 9–4 displays an example worksheet for determining soil-water content of the soil profile. The worksheet shown in figure 9–5 can help determine soil moisture and bulk density using the Eley volumeter and carbide moisture tester. Table 9–2 displays oven dry moisture content, P_d, based on meter gauge reading, W_P. This instrument measures total water held in the soil sample. To obtain AWC, subtract water held at W_P.

Figure 9–4 Soil-water content worksheet (gravimetric method)

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Worksheet
Soil-Water Content
(Gravimetric Method)

Land user____ Date _________________ Field office ____

Taken by ____ Field name/number ____

Soil name (if available) ____ Crop ___________________________ Maximum effective root depth _____________ ft

Depth range inches	Soil layer thickness inches d	Soil texture	Sample			Tare weight g Tw	Net dry weight g Dw	Volume of sample cc Vol	Moisture per-centage % Pd	Bulk density g/cc Dbd	Soil-water content in/in SWC	Layer water content inches TSWC
			Wet weight g WW	Dry weight g DW	Water loss g Ww							

Dry weight (Dw) of soil = DW - TW = ________g

Weight of water lost (Ww) = WW - DW = ________g

Bulk density (Dbd) = $\frac{\text{Dw(g)}}{\text{Vol (cc)}}$ = ________g/cc

Percent water content, dry weight Pd = $\frac{\text{Ww x 100}}{\text{Dw}}$ = ________%

Soil-water content (SWC) = $\frac{\text{Dbd x Pd}}{\text{100 x 1}}$ = ________in/in

Total soil-water content in the layer (TSWC) = SWC x d = ________inches

Figure 9–5 Determination of soil moisture and bulk density using Eley volumeter and Speedy moisture tester

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Determination of Soil Moisture and Bulk Density (dry) Using Eley Volumeter and Carbide Moisture Tester

Farm ________________________ Location ________________________ SWCD ________________________

Crop ________________________ Soil type ________________ Date __________ Tested by ________________________

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Texture	Thickness of layer	Volumeter							Bulk density (g/cc)	Soil-water content (in)	Soil-water content at field capacity	Soil-water deficit (in)
		Reading before (cc)	Reading after (cc)	Volume (cc)	% Wet wt.	% Dry wt.	% Wilting point	% Soil-water				
	d			V	W_p	P_d	P_w	SWC_p	Db_d	SWC	AWC	SWD
									Totals			

Wet weight of all samples in grams unless otherwise shown.

$$Db_d = \frac{26}{\frac{V(1 + P_d)}{100}}$$

$$SWC = \frac{Db_d \times SWC_p \times d}{100 \times 1}$$

$$SWC_p = P_d - P_w$$

Table 9–2 Oven dry moisture content based on 3-minute carbide moisture tester readings

Gauge reading 1/	Oven dry moisture, P_d (%) 0	.1	.2	.3	.4	.5	.6	.7	.8	.9
2	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
3	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
4	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9
5	5.1	5.2	5.3	5.4	5.5	5.7	5.8	5.9	6.0	6.1
6	6.2	6.3	6.4	6.5	6.6	6.8	6.9	7.0	7.1	7.2
7	7.3	7.4	7.5	7.6	7.7	7.9	8.0	8.1	8.2	8.3
8	8.4	8.5	8.6	8.7	8.8	9.0	9.1	9.2	9.3	9.4
9	9.5	9.6	9.7	9.8	9.9	10.1	10.2	10.3	10.4	10.5
10	10.6	10.7	10.8	11.0	11.1	11.2	11.3	11.4	11.6	11.7
11	11.8	11.9	12.0	12.2	12.3	12.4	12.5	12.6	12.8	12.9
12	13.0	13.1	13.3	13.4	13.5	13.7	13.8	13.9	14.0	14.2
13	14.3	14.4	14.6	14.7	14.8	15.0	15.1	15.2	15.3	15.5
14	15.6	15.7	15.9	16.0	16.2	16.3	16.4	16.6	16.7	16.9
15	17.0	17.1	17.3	17.4	17.5	17.7	17.8	17.9	18.0	18.2
16	18.3	18.4	18.6	18.7	18.9	19.0	19.1	19.3	19.4	19.6
17	19.7	19.8	20.0	20.1	20.3	20.4	20.5	20.7	20.8	21.0
18	21.1	21.3	21.4	21.6	21.7	21.9	22.0	22.2	22.3	22.5
19	22.6	22.8	22.9	23.1	23.2	23.4	23.5	23.7	23.8	24.0
20	24.1	24.3	24.4	24.6	24.7	24.9	25.0	25.2	25.3	25.5
21	25.6	25.8	25.9	26.1	26.2	26.4	26.5	26.7	26.8	27.0
22	27.1	27.3	27.4	27.6	27.7	27.9	28.1	28.2	28.3	28.5
23	28.6	28.8	28.9	29.1	29.2	29.4	29.6	29.7	29.9	30.0
24	30.2	30.4	30.5	30.7	30.8	31.0	31.1	31.3	31.4	31.6
25	31.7	31.9	32.0	32.2	32.3	32.5	32.7	32.8	33.0	33.1
26	33.3	33.5	33.6	33.8	33.9	34.1	34.3	34.4	34.6	34.7
27	34.9	35.1	35.2	35.4	35.5	35.7	35.9	36.0	36.2	36.3
28	36.5	36.7	36.8	37.0	37.1	37.3	34.5	37.6	37.8	37.9
29	38.1	38.3	38.4	38.6	38.8	39.0	39.1	39.3	39.5	39.6
30	39.8	40.0	40.1	40.3	40.5	40.7	40.8	41.0	41.2	41.3
31	41.5	41.7	41.8	42.0	42.2	42.4	42.5	42.7	42.9	43.0
32	43.2	43.4	43.5	43.7	43.8	44.0	44.2	44.3	44.5	44.6
33	44.8	45.0	45.1	45.3	45.5	45.7	45.8	46.0	46.2	46.3

1/ Carbide moisture tester—3-minute readings = W_p

(iv) Tensiometers (moisture stake)—Soil-water potential (tension) is a measure of the amount of energy with which water is held in the soil. Tensiometers are water filled tubes with hollow ceramic tips attached on the lower end and a vacuum gauge on the upper end. The container is air tight at the upper end. The device is installed in the soil with the ceramic tip in contact with the soil at the desired depth. The water in the tensiometer comes to equilibrium with soil water surrounding the ceramic tip. Water is pulled out of the ceramic tip by soil-water potential (tension) as soil water is used by plants. This creates a negative pressure (vacuum) in the tube that is indicated on the vacuum gauge. When the soil is rewetted, the tension gradient reduces, causing water to flow from the soil into the ceramic tip.

The range of tension created by this devise is 0 to 100 centibars (0 to 1 atmospheres). Near 0 centibars is considered field capacity, or near 0 soil water tension. Practical operating range is 0 to 80 centibars. The upper limit of 80 centibars corresponds to about: 90 percent AWC depletion for a sandy soil and about 30 percent AWC depletion for medium to fine textured soils. This limits the practical use of tensiometers to medium to fine textured soils with high frequency irrigation or where soil-water content is maintained at high levels. Tensiometers break suction if improperly installed and if the soil-water tension exceeds practical operating limits, typically 80 to 85 centibars. Once vacuum is broken, the tube must be refilled with water and the air removed by using a small hand-operated vacuum pump. A period to establish tensiometer-soil-water stability follows.

Tensiometers require careful installation, and maintenance is required for reliable results. They must also be protected against freeze damage. Maintenance kits that include a hand vacuum pump are required for servicing tensiometers. The hand pump is used to draw out air bubbles from the tensiometer and provide an equilibrium in tension. Tensiometers should be installed in pairs at each site, at one-third and two-thirds of the crop rooting depth. A small diameter auger (or half-inch steel water pipe) is required for making a hole to insert the tensiometer. Figure 9–6 shows a tensiometer and gauge and illustrates installation and vacuum pump servicing. Tensiometers are commercially and readily available at a reasonable cost.

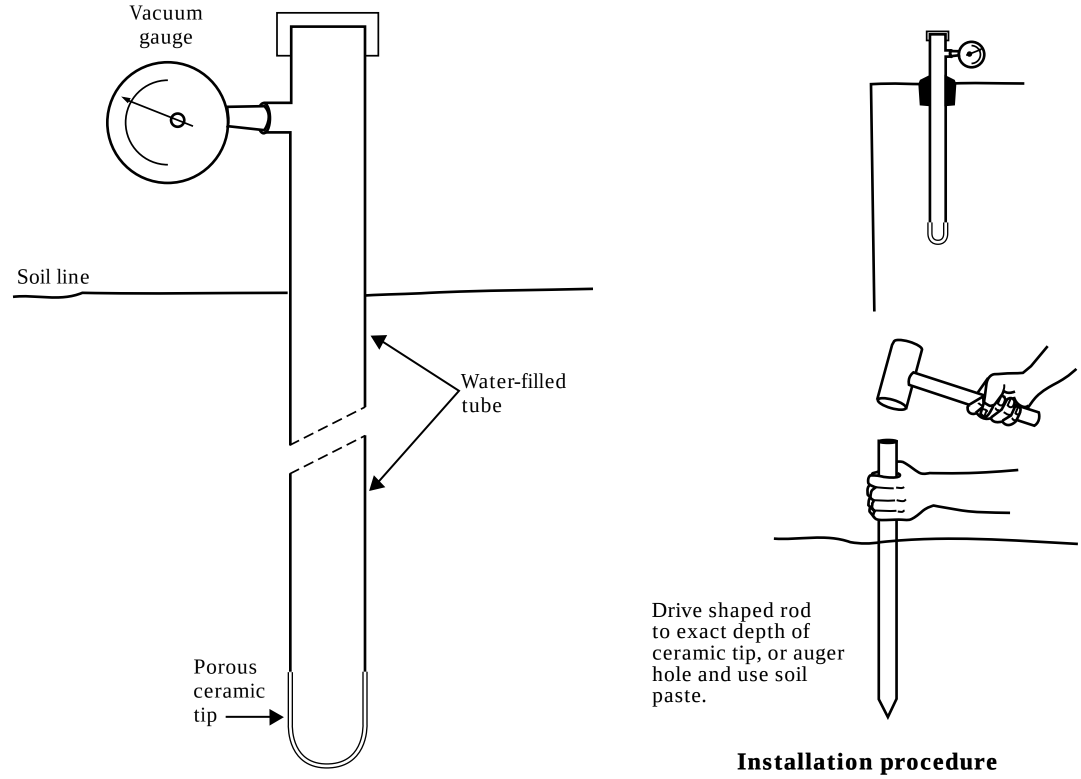
When installing tensiometers, make a heavy paste from part of the soil removed at the depth the ceramic tip is to be placed. When the hole has been augured about 2 inches below the desired depth of the ceramic tip, the paste is placed in the hole. As you install the tensiometer tube, move the tube up and down a few times to help assure good soil paste contact with the ceramic tip. Do not handle or touch the ceramic tip as contamination from material and body oil on the hands affects water tension on the tip. If the soil is wet at the desired ceramic tip depth, tensiometers can be installed by driving a rod or 0.5-inch diameter galvanized iron pipe to the desired depth. The end of the driving rod should be shaped the same as, but slightly smaller than the tensiometer tip. Pour a little water in the hole, move the driving rod up and down a few times to develop a soil paste at the bottom of the hole. Insert tensiometer tube, move the tube up and down a few times to help assure good soil paste contact with the ceramic tip.

Tensiometers installed at different rooting depths have different gauge readings because of soil water potential change in rooting depths. With uniform deep soil, about 70 to 80 percent of soil moisture withdrawal by plant roots is in the upper half of the rooting depth. Recommended depths for setting tensiometers are given in table 9–3.

Table 9–3 Recommended depths for setting tensiometers

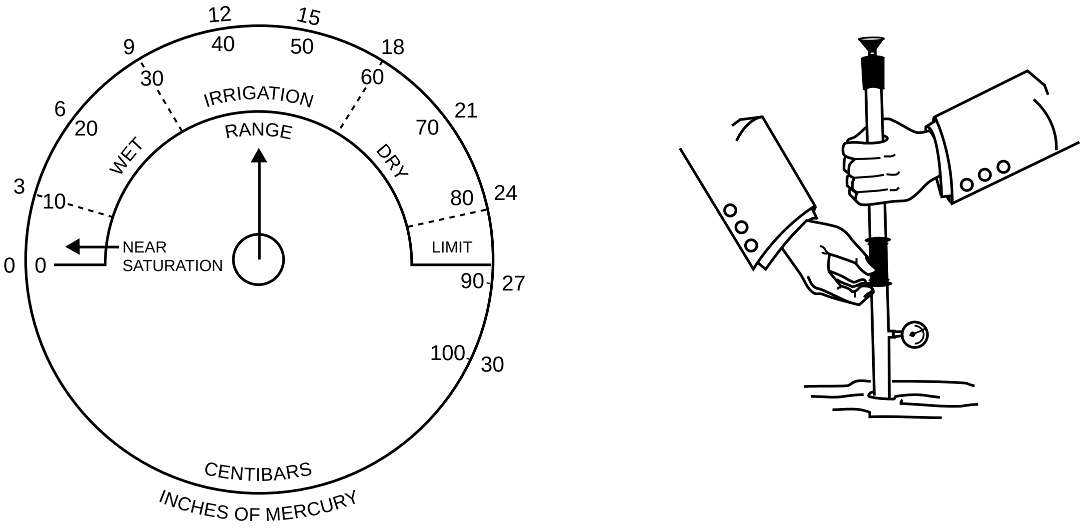
Plant root zone depth (in)	Shallow tensiometer (in)	Deep tensiometer (in)
18	8	12
24	12	18
36	12	24
> 48	18	36

Figure 9–6 Tensiometer, installation, gauge, and servicing



Drive shaped rod to exact depth of ceramic tip, or auger hole and use soil paste.

Installation procedure



Vacuum gauge

Servicing tensiometer using a vacuum pump

(v) Electrical resistance (porous) blocks— Electrical resistance blocks are made of material where water moves readily into and out of the block. Materials are typically gypsum, ceramic, nylon, plastic, or fiberglass. When buried and in close contact with the surrounding soil, water in the block comes to water tension equilibrium with the surrounding soil. Once equilibrium is reached, different properties of the block affected by its water content can be measured. Electrical resistance blocks work best between 0 and 2 atmospheres (bars). Thus, they have a wider operating range than do tensiometers, but are still limited to medium to coarse textured soils.

Electrical resistance blocks are buried in the soil at desired depths. Intimate contact by the soil is essential. With porous blocks, electrical resistance is measured across the block using electrodes encased in the block. Electrical resistance is affected by the water content of the block, which is a function of the soil-water tension. Electrical resistance is measured with an ohm meter calibrated to provide numerical readings for the specific type of block. Higher resistance readings mean lower water content, thus higher soil-water tension. Lower resistance readings indicate higher water content and lower soil-water tension.

Gypsum blocks are affected by soil salinity, which cause misleading readings, and are prone to breakdown in sodic soils. They are best suited to medium and fine texture soils. Being made of gypsum, the blocks slowly dissolve with time in any soil. The rate is dependent upon pH and soil-water quality. Freezing does not seem to affect them. Blocks made from other material do not dissolve; therefore, have a longer life. Electrical resistance blocks are relatively low cost and with reasonable care are easy to install. Close contact with soil is important.

Installation tools required are a small diameter auger for making a hole for inserting blocks, a wooden dowel to insert blocks, and water and a container for mixing soil paste. (Multiple electrical resistance blocks can be installed in the same auger hole.) After the hole has been augured to about 2 inches below the deepest block installation depth, a soil paste is made from removed soil and placed about 6 inches deep in the bottom of the hole. Wet resistance block with clean water. Handling or touching the electrical resistance block may affect soil moisture readings. With the electrical resistance block carefully held on the end of the dowel by the wires, place the block in the hole at the desired depth with a slight up and down movement to help assure soil paste contact with the block. Check for broken wires with an electric meter. Hold the electric wires along the side of the hole and carefully fill the hole with soil. Soil should be replaced by layers. It should be from the same layer from which it was removed. Repeat soil paste and block procedure at each electrical resistance block depth.

When electrical resistance blocks are located properly, almost anyone can obtain readings. One person with a meter can provide readings for many field test sites. Where farms are small, neighbors can share a single meter. Following each reading a report is developed and given to each farm irrigation decisionmaker. The irrigation decisionmaker must learn to interpret meter readings to decide the right time to irrigate.

Electrical resistance blocks and resistance meters (battery powered) are commercially and readily available. Table 9–4 displays interpretations of readings from a typical electrical resistance meter.

(vi) Thermal dissipation blocks—These blocks are porous ceramic materials in which a small heater and temperature sensors are imbedded. This allows measurement of the thermal dissipation of the block, or the rate at which heat is conducted away from the heater. This property is directly related to the water content of the block and thus soil-water content. Thermal dissipation blocks must be individually calibrated. They are sensitive to soil-water content across a wide range. Meter readings can be used directly, or translated using manufacturer’s charts to soil-water tension. Specific meters are to be used with specific type of blocks.

***(vii) Neutron scattering*—**A neutron gauge estimates the total amount of water in a volume of soil by measuring the amount of hydrogen molecules in the soil. Hydrogen is a key element in water (i.e., H_2O). The device is commonly called a neutron probe. The probe itself consists of a radioactive source that emits (scatters) high energy neutrons and a slow speed neutron detector housed in a unit that is lowered into a permanent access tube installed in the soil. The probe is connected by a cable to a control unit (neutron gauge) remaining at the surface. The control unit includes electronics for time control, a neutron counter, memory, and other electronics for processing readings.

Fast neutrons, emitted from the source and passing through the access tube into the surrounding soil, gradually lose their energy (and speed) through collisions with hydrogen molecules. The result is a mass of slowed or thermalized neutrons, some of which diffuse back to the detector. The detector physically counts returned neutrons. The number of slow neutrons counted in a specific interval of time is directly related to the volumetric soil-water content in a sphere ranging from 6 to 16 inches. A higher count indicates higher soil-water content, and a lower count indicates lower soil-water content.

When properly calibrated and operated, the neutron gauge can be the most accurate and most repeatable method of measuring soil-water content. When plotted, count versus soil-water content is a linear relationship. The gauge as it comes from the manufacturer is calibrated to a general kind of soil (medium texture) and to a medium soil bulk density. A microprocessor calculates soil-water content in acre-inches or percent, dry weight basis. However, the gauge must be calibrated for inplace soils and type of access tube material being used; i.e., PVC, aluminum, or steel. Calibration is done using gravimetric sampling procedures. Also, for any soil texture other than what the device was calibrated to by the manufacturer, or with widely varying bulk density, the device must be recalibrated. This is a time consuming process in layered soils on alluvial sites where the texture and bulk density vary widely. Recalibration is generally not necessary in medium textured, medium bulk density, uniform soils.

Table 9–4 Interpretations of readings on typical electrical resistance meter

Soil water condition	Meter readings 1/ (0 – 200 scale)	Interpretation
Nearly saturated	180 – 200	Near saturated soil often occurs for a few hours following an irrigation. Danger of water logged soils, a high water table, or poor soil aeration if readings persists for several days.
Field capacity	170 – 180	Excess water has mostly drained out. No need to irrigate. Any irrigation would move nutrients below irrigation depth (root zone).
Irrigation range	80 – 120	Usual range for starting irrigations. Soil aeration is assured in this range. Starting irrigations in this range generally ensures maintaining readily available soil water at all times.
Dry	< 80	This is the stress range; however, crop may not be necessarily damaged or yield reduced. Some soil water is available for plant use, but is getting dangerously low.

1/ Indicative of soil-water condition where the block is located. Judgment should be used to correlate these readings to general crop conditions throughout the field. It should be noted, the more sites measured, the more area represented by the measurements.

The total volumetric soil-water content reading (count) of the neutron gauge should be translated into available soil-water content (AWC). Field capacity and wilting point levels must be known. It is more convenient if field measurements could be taken near those soil-water content levels. The neutron gauge method is highly accurate (1 to 2 percent of actual) if properly operated and adequately calibrated except:

- in the upper 6 inches of soil profile where fast neutrons tend to escape above the soil surface;
- in high clay content soil that contain tightly bound hydrogen ions that are not reflected in the detecting process;
- in soil with high organic matter content; and
- in soil containing boron ions.

These soil conditions all require recalibration of the gauge. Chapter 15 contains example worksheets, typical calibration curves, and sample displays for soil-water content by depth relationships.

Because a neutron gauge contains a radiation source and is a potential safety hazard to a technician using a gauge, special licensing, operator training, handling, shipping, and storage are required. The wearing of a radioactive detecting film badge is required by all technicians when handling and using a neutron gauge. The use of a neutron gauge is not to be taken lightly. NRCS operates under a site license held by the USDA Agricultural Research Service. Inspections of storage facilities are made periodically. Disposal of old neutron probes (radioactive source) is strictly controlled by U.S. Nuclear Regulatory Commission (NRC).

A neutron probe is recommended for large farms or farm groups where use efficiency and accuracy can justify high initial cost, maintenance, and operating under NRC requirements.

Tools needed are:

- Approved storage facility for the probe at the workshop and in the vehicle
- Small diameter soil auger
- Soil bulk density sampler
- Watertight access tubes that fit snugly against the soil
- Gravimetric soil sampling equipment (core sampler, auger, sample bags, weighing scales, drying oven) for calibration
- Neutron gauge
- Small square of canvas
- Tool box containing a variety of tools
- Film badges for everyone involved

(vii) Diaelectric constant method**—**The diaelectric constant of material is a measure of the capacity of a nonconducting material to transmit high frequency electromagnetic waves or pulses. The diaelectric constant of a dry soil is between 2 and 5. The diaelectric constant of water is 80 at frequency range of 30 MHz – 1 GHz. Relatively small changes in the quantity of free water in the soil have large effects on the electromagnetic properties of the soil-water media. Two approaches developed for measuring the diaelectric constant of the soil-water media (water content by volume) are time domain reflectometry (TDR) and frequency domain reflectometry (FDR).

For TDR technology used in measuring soil-water content, the device propagates a high frequency transverse electromagnetic wave along a cable attached to parallel conducting probes inserted into the soil. A TDR soil measurement system measures the average volumetric soil-water percentage along the length of a wave guide. Wave guides (parallel pair) must be carefully installed in the soil with complete soil contact along their entire length, and the guides must remain parallel. Minimum soil disturbance is required when inserting probes. This is difficult when using the device as a portable device. The device must be properly installed and calibrated. Differing soil texture, bulk density, and salinity do not appear to affect the diaelectric constant.

FDR approaches to measurement of soil-water content are also known as radio frequency (RF) capacitance technique. This technique actually measures soil capacitance. A pair of electrodes is inserted into the soil. The soil acts as the diaelectric completing a capacitance circuit, which is part of a feedback loop of a high frequency transistor oscillator. The soil capacitance is related to the diaelectric constant by the geometry of the electric field established around the electrodes. Changes in soil-water content cause a shift in frequency. University and ARS comparison tests have indicated that, as soil salinity increases, sensor moisture values were positively skewed, which suggests readings were wetter than actual condition.

FDR devices commercially available include:

Portable hand-push probes—These probes allow rapid, easy, but only qualitative readings of soil-water content. Probe use is difficult in drier soil of any texture, soils with coarse fragments, or soils with hardpans. A pilot hole may need to be made using an auger. The probe provides an analog, color-coded dial gauge (for three soil types—sand, loam, and clay), or a digital readout. The volume of soil measured is relatively small (a cylinder 4 inches tall by 1 inch in diameter). Several sites in a field should be measured, and can be, because probes are rapid and easy to use. Proper soil/probe tip contact is essential for accurate and consistent readings.

Portable device that uses an access tube similar to a neutron gauge—The probe suspended on a cable is centered in an access tube at predetermined depths where the natural resonant frequency or frequency shift between the emitted and received frequency is measured by the probe. The standard access tube is 2-inch diameter schedule 40 PVC pipe. Installation of the access tube requires extreme care to ensure a snug fit between the tube and the surrounding soil. Air gaps or soil cracks between the tube and soil induce error.

The device is calibrated by the manufacturer to sand and to an average bulk density for sand. Recalibration is required for any other soil texture and differing bulk density. The volume of soil measured is not texture or water content dependent, and approximates a cylinder 4 inches tall and 10 inches in diameter. Accuracy can be good in some soils with proper installation and calibration, and there are no radioactive hazards to personnel such as when using a neutron gauge. Proper installation of the access tube is essential and can be quite time consuming. Accuracy of data is largely dependent on having a tight, complete contact between the access tube and the surrounding soil. Before making a large investment in equipment, it is highly recommended that adequate research be done on comparison evaluations that are in process by various universities and the ARS. Good sources of information are technical papers and proceedings of ASAE, ASCE, and Soil Science Society of America, as well as direct discussion with personnel doing evaluations.

Other electronic sensors—Numerous sensors are commercially available using microelectronics. Inexpensive devices sold at flower and garden shops measure the electrical voltage generated when two dissimilar metals incorporated into the tip are placed in an electrolyte solution; i.e., the soil water. Most of these devices are sensitive to salt content in the soil-water solution.

Factors to be evaluated for the selection and application of a soil-water content measuring program include:

- Initial cost of device, appurtenances, special tools, and training
- Irrigation decisionmaker's skill, personal interest, and labor availability
- Field site setup, ease of use and technical skill requirements
- Repeatable readings and calibration requirement
- Interpretations of readings—qualitative and quantitative needs
- Accuracy desired and accuracy of device
- Operation and maintenance costs
- Special considerations including licensing from NRC (private individuals do not operate under ARS licensing), storage, handling, film badge use, training required, disposal of radioactive devices, and special tools required for access tube installation

(c) Crops

Crop characteristics are important for the irrigation planner and decisionmaker to know. Those characteristics necessary for implementing a proper irrigation water management program include purpose of crop, crop evapotranspiration, critical growth periods, and root development.

(1) Crop evapotranspiration

Crop evapotranspiration (ET_c) is the amount of water used by the crop in transpiration building of plant tissue and evaporated from the soil or plant foliage surface. It is determined by using local climatic factors and stage of growth. Several equations can be used depending on climate data availability and degree of intensity of IWM program. ET_c provides one of the key ingredients in scheduling irrigations; i.e., how much water the crop uses or is projected to use.

(2) Critical growth periods

Plants generally need sufficient moisture throughout the growing season. Most crops are sensitive to water stress during one or more critical growth periods during their growing season. If adequate moisture is not available during the critical period(s), irreversible loss of yield or product quality results. With many fruit and fresh vegetable crops, lack of available water at critical growth periods can result in a product that may be partly or totally unmarketable on the fresh market because of poor quality. See Chapter 3, Crops, for critical growth stages, and chapter 15 for IWM tools.

(3) Root development

Roots develop as plants grow and mature. Major factors controlling root development are stage of plant growth, usable soil depth, soil compaction, soil condition, and amount of water in the soil. Irrigation should be planned to provide water only to the usable plant root zone unless leaching for salinity control is necessary.

Never assume a plant root zone depth. Observe and measure the actual depth roots penetrate a soil profile by digging a shallow pit and auguring. Notice the pattern of root development in the side of the pit. Check for roots in handfuls of augured soil. Generally 2 to 4 feet of total depth is adequate. If root development pattern depth is overestimated, an overirrigation recommendation is guaranteed. Plants will show unneeded stress between irrigations.

(4) Yield (quality) versus water use relationships

Most crops respond to water availability and use to provide a given biomass or yield. Limited data are available for predicting specific yield versus water use relationships except for a few crops. With most crops, yield and product quality are reduced where excess water is applied. Too much water can also be detrimental to crop yield by leaching of otherwise available plant nutrients below the root zone. Water is also wasted. Tables or curves for several crops are in Chapter 3, Crops.

The following methods and devices are commercially available to measure plant moisture tension levels. They can provide indications of plant moisture stress.

(i) Crop Water Stress Index (CWSI)—The crop water stress gun measures plant canopy (foliage), temperature, ambient air temperature, relative humidity, and a range of solar radiation. The CWSI gun is commonly mistakenly called infrared gun or IR thermometer. In the CWSI gun a microprocessor calculates plant water stress and expresses it as an index from 0 to 1.0 or 0 to 10, depending upon the manufacturer. (The latter avoids using a decimal. Overall range is the same.) Threshold stress levels are developed for each crop for determining when to irrigate. Once developed, the stress index for a specific crop appears to be usable in all climate zones and for similar crop species. When first used in an area, it is best to affirm calibration based upon local conditions. When the canopy temperature in relation with other climate factors increases to a predetermined upper target level, the plants are considered stressed. A well watered plant has relative cool foliage because of the continual plant transpiration and has an index near zero. When plant canopy temperature reaches ambient temperature, the plant is not transpiring moisture and is probably beyond permanent wilting point. When following good water management practices, the irrigator can provide irrigations before upper target threshold stress levels are reached.

Periodic soil-water content checks should be made to relate plant water stress indexes and soil-water content levels. Observe and measure the depth of plant roots. Adequate soil moisture may be present below the plant root zone. CWSI readings can be observed over several days to predict the need for irrigation 3 to 5 days in advance.

This device is relatively easy to use and can provide rapid results at varied locations in a field. Proper techniques for use are important. Readings can be taken when the sky is clear or overcast, but not clouded over. The best time is midmorning to early afternoon, and the foliage must be dry. Readings must be taken only of foliage, not bare soil, landscape, sky, or other factors. Average several readings to improve accuracy. The gun is held at least 1 meter above the crop canopy, but not more than 10 meters. Direct the device more or less down onto the crop canopy. This creates a challenge with tall crops (corn, cotton, fruit, citrus, nuts). Caution must be exercised because apparent high stress levels may be from factors other than moisture, such as insects and disease. The user should be able to observe field conditions and correctly interpret readings. Several models are commercially available. Different crops have different target stress levels.

Technology exists to provide CWSI readings from aircraft and satellite. Current limitations include getting information into the hands of the irrigation decisionmaker for timely irrigation water management decisions. Other uses of the CWSI gun include identification of plant stress before visual observation signs appear. Observing irrigation uniformity across the field and damage from crop insects, fungus (including root rot), and rodents are a few other uses.

(ii) Leaf moisture stress (pressure chamber)—This method involves encasing a part of the plant, such as a leaf, inside a pressure chamber, and checking the amount of pressure required to force the fluid stored in the sample back out the stem. Nitrogen gas is typically used. The pressure required to reverse the flow of plant moisture is interpreted to indicate plant moisture tension (stress). Target tension (stress) points must be developed for specific plants, after which it can be used as a reference for subsequent tests. Success of this method depends on standardization of the test protocol. It is desirable to take readings at predawn. Predawn plant water tension is controlled by soil-water tension, and daytime plant moisture tension is controlled by climate. Plant moisture stress can be several times higher during the heat of the day than at predawn and not be consistent at any specific time of day for each day. Sun angle, cloud cover, temperature, humidity, and wind all affect plant moisture tension levels during daylight hours.

(iii) Evaporimeter (atmometer)—An evaporimeter consists of a flat, porous ceramic disk (Bellani plate) in which water is drawn up by capillary action as water is evaporated from the disk. It is used to directly estimate crop evapotranspiration rate. Several commercial models can be easily installed near the edge of a field or on a roadway in a field. (The unit must be located far enough into the field to avoid field boundary effects.) One commercial model provides a green canvas-like material covering the ceramic disc to simulate crop leaf color. Reasonably good correlation has been found between field measurements and that calculated from Penman-type equations. Small difference in evaporation rates may be found between individual meters. Maintaining water levels and removal for freeze protection are necessary.

(iv) Evaporation pans—U.S. Weather Bureau Class A evaporation pans are standard sized, opentop metal water containers. Water is evaporated from a saturated source (water body) with solar energy. Coefficients must be applied to the evaporation rate representing pan coefficients and crop growth stage coefficients. Nonstandard pans have been tried with varying degrees of success. Materials range from galvanized metal wash tubs to PVC pipe (placed vertically). The devices are generally calibrated to a local Class A evaporation pan, and can be reasonably effective in determining when to irrigate. Coefficients are applied to the pan evaporation rate to represent crop evapotranspiration rate.

(v) Infrared photography—Aerial infrared photography can show current plant condition by the darkness of green vegetation. Red color intensity on photo prints displays dark green and lighter green patterns in the vegetation. Infrared photography is a valuable tool to visually observe local areas within an irrigation system or field(s) that receive either insufficient or excess irrigation water. Red color intensity differences can result from:

- Wrong sized or plugged nozzles or broken sprinkler heads giving poor distribution patterns
- Shallow or coarse textured soil areas (inclusions)
- Insect, fungus, or disease damage

Some skill is required to interpret color intensity on infrared photo prints. Plant canopy (foliage) temperature measured with a crop water stress gun may also be helpful.

(vi) Visual—Observation of plant condition is too often the only basis used for determining when a crop needs irrigated. By the time leaf color or degree of curl indicates the need of water, the plant generally is overstressed and yield and product quality are negatively affected. However, certain crops can be stressed at noncritical growth stages with little effect on yield. Some well-watered crops normally show visual signs of stress at or following solar noon on hot days. Overirrigation, especially early in the growing season, limits plant root development volume and depth, which limits the volume of soil containing water available for plant use. Often adequate soil water exists below existing plant root systems, but roots cannot grow rapidly enough to obtain adequate moisture to maintain plant evapotranspiration and growth.

Some irrigation decisionmakers randomly locate (or plant small areas in critical locations) a plant that shows moisture stress before the main crop. Corn is often used as a moisture stress indicator plant because it shows stress several days before many other crops. Many other indicator plants can be used. See Chapter 3, Crops.

(d) Upward water movement (upflux)

When a water table exists close to the root zone, crops extract water from the capillary fringe or water moving upward (upflux) into the crop root zone. The rate of upward flow depends primarily on the depth to the water table and soil texture. See Chapter 6, Irrigation System Design, for additional discussion.

652.0903 Irrigation scheduling

(a) General

Irrigation scheduling is that part of proper irrigation water management involving the decision, when to irrigate and how much water to apply. Scheduling tools provide information that irrigation decisionmakers can use to develop irrigation strategies for each field on the farm. Such strategies may be based on long-term data, representing average conditions, or may be developed as the season progresses, using real time information and short-time predictions. In both cases information about the crop, soil, climate, irrigation system, water deliveries, and management objectives must be considered to tailor irrigation scheduling procedures to a specific irrigation decisionmaker and field condition. An irrigation scheduling tool needs only be accurate enough to make the decision when and how much to irrigate.

The need for proper irrigation water management, including irrigation scheduling, can best be demonstrated by identifying physical effects. To be most effective, identify the physical effects the irrigation decisionmaker is most concerned about, then show how proper irrigation water management will affect the concerns. The concerns include:

- Energy cost per season (fuel or electricity)
- Irrigation labor (kind of labor, timing, and amount)
- Wear and tear on irrigation equipment
- Plant response (yield) compared to potential
- Quality of product or crop
- Amount of irrigation water used
- Soil condition
- Plant response to fertilizer used
- Water quality onsite or offsite

Modern scheduling is based on soil-water balance or crop-water balance for one or more points in the field. By measuring existing and estimating future soil-water content or monitoring crop-water stress level, irrigation water can be applied before damaging crop stress occurs. Scheduling irrigation involves forecasting of crop water use rates to anticipate future water needs.

Figure 9–7 displays a flowchart for an irrigation scheduling process that uses soil-water content monitoring as the crop-water use indicator. Other techniques used to monitor current crop condition, such as infrared photography and leaf and plant moisture stress level index typically do not include a continual monitoring of soil-water content. Periodic checking of soil moisture status is generally sufficient to validate or update scheduling model.

The producer's management objective must be considered when developing a scheduling program. Maximizing net return is a common objective; other objectives may be to minimize irrigation costs, maximize yield, use less water, minimize ground water and downstream surface water pollution, optimize production from a limited water supply, use less energy for pumping, or to improve product quality.

Several scheduling techniques and levels of sophistication can be applied to track the amount of soil water in the crop root zone and crop water use. In some locations crop water use information is made available via newspapers, telephone call-in, television, or by computer modem systems. All irrigation scheduling programs should account for rainfall measured at the field site. Because of the spatial variation in rainfall, amount recorded at the farmstead or in town often does not represent precipitation at the field site. With precipitation (usually rainfall) at the field site known, accuracy for scheduling irrigations is improved. The amount available to meet plant water needs is called *effective precipitation*.

In addition to soil water to plant relationships, other factors are important in selecting a method of scheduling irrigations and setting up the scheduling procedures. Labor skill, availability, and personal interest dictate what type and level of intensity for readings and calculations can be made to make the scheduling procedure work. Irrigation district policies and capabilities often dictate when and for how long an irrigator will get water; i.e., delivery schedule. Cultural operations, such as hay cutting, over-canopy pesticide application, or row crop cultivation, have a major impact on scheduling. Some farmers do not like to keep written records; however, most have accepted the fact that they must for other purposes. Many farmers have a personal computer system. Some prefer to hire management services to give them information needed.

All these factors must be taken into account when determining what irrigation scheduling procedure will be best suited to a water user. A good rule to follow, **keep it simple and easy to understand**, even when a computer system is used. Adaptation requires maintaining the risk perceived equal to or less than the current way irrigation water is being scheduled.

(b) Irrigation scheduling methods

Irrigations can be scheduled using methods varying from simple soil water monitoring using the feel and appearance method to sophisticated computer assisted programs that predict plant growth. Scheduling involves continual updating of field information and forecasting future irrigation dates and amounts.

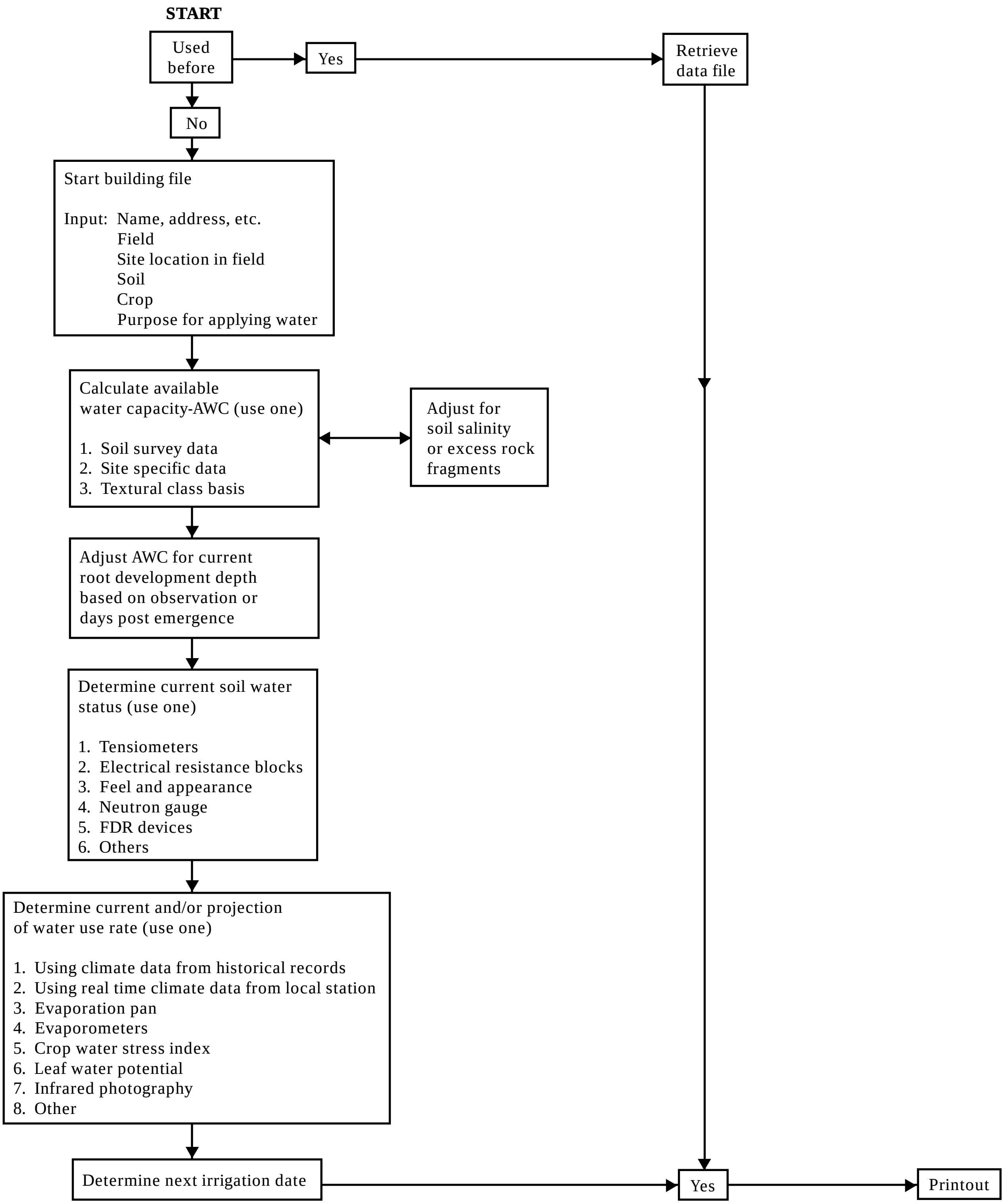
Crop yield and quality can be improved with most plants by maintaining lower soil-water tensions (higher moisture levels). Thus, it is wise to irrigate when the soil profile can hold a full irrigation. Waiting until a predetermined percent of soil AWC is used can cause unnecessary stress.

(1) Soil and crop monitoring methods

Some scheduling practices are based solely on monitoring soil-water content or crop water use. Irrigations are needed when the soil-water content or crop water use reaches predetermined critical levels. Soil-water content and plant moisture tension measuring devices and procedures are described in section 652.0902(b). Using the monitoring data is briefly described in this section.

Accurate monitoring should provide the irrigation decisionmaker information at or soon after the time of measurement. The data must be available to ensure that the field can be irrigated before moisture stress occurs. Monitored data must be displayed so that the information is easy to understand and use to predict an irrigation date. When past data are projected forward, usually the future will resemble the past. Rapidly growing crops and weather changes must be considered. Local weather forecasts can provide a guide as to when to irrigate, but frequent field measurements are often necessary.

Figure 9–7 Example irrigation scheduling program flowchart using soil water content for validation



(i) Crop water use monitoring—Monitoring crop conditions can be used to estimate when to irrigate, but it does not provide any information on how much water to apply. Crop water use can be measured, but it is usually calculated or estimated. The Crop Water Stress Index (CWSI) method measures plant condition and compares that status to a known reference for a well watered plant condition. Infrared photography indicates presence or lack of surface moisture, either on soil surface or plant leaf surface. Some skill is necessary to interpret color intensity on infrared photographs. What appears to be plant moisture stress may result from other causes, such as insect damage, lack of key nutrients, or from other toxic materials on leaf surfaces. Number of sets, days, and rotation or cycle time to get across a field should be considered when using a field monitoring method.

Some level of soil and crop monitoring is essential for efficient irrigation water management. Growing high value crops can support a sophisticated monitoring and scheduling program whether it be for optimizing water use and crop yield, maintaining desirable crop quality, minimizing use of fertilizer, or educing runoff, deep percolation, or both. Monitoring can be accurate where irrigators are adequately trained and personally interested. The monitoring schedule should fit into the pattern of irrigation. Monitoring dates before and after an irrigation should be flexible and adjustable to provide better management information.

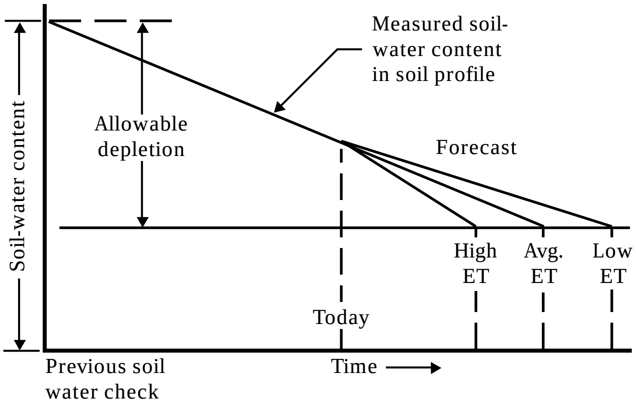
(ii) Soil moisture monitoring—Monitoring soil-water content before, during, and after the crop growing season is the primary tool to schedule irrigations or calibrate other less labor intensive irrigation scheduling tools.

Soil moisture monitoring is perhaps the most accurate irrigation scheduling tool. With experience the feel and appearance method can be used to accurately determine soil moisture available for crop use. If other methods are used to determine soil moisture, the feel and appearance method should also be used to check the other method and to *experience* the fingers in determining soil moisture. At first three to five samples are examined at four or five sample sites in a field. Again with experience and a specific crop and soil, one soil sample at a depth of 12 to 18 inches can be sufficient per sample site. At this depth soil samples can be removed with a soil probe or small auger, typically under the growing plant. Displaying moisture content at various depths may be desirable at each monitoring site. Too little or too much soil moisture in the profile becomes more apparent when displayed graphically.

Soil moisture monitoring is used to calibrate or affirm other irrigation scheduling methods that predict plant water use by measuring plant stress (crop water stress index, plant tissue monitoring) or calculate plant water use based upon climatic data. Examples are NRCS (SCS) SCHEDULER computer software or checkbook method. With these other methods, checking actual soil moisture is like receiving your bank statement from the bank. It affirms or cautions you when an error may exist or other adjustments are needed. See Section 652.0902(b), Measuring soil-water content.

Many computer scheduling programs use soil moisture measurements for updating methods based on computing the soil-water balance. Figure 9–8 provides a schematic of a basic soil-water content monitoring display to schedule irrigations. The same principal can be used regardless of units provided by a soil-water content or plant moisture tension level measuring device. Displaying may be desirable the various depths, if applicable, at each monitoring site.

Figure 9–8 Soil-water measurements used to predict day to irrigate



(2) Checkbook method

The checkbook irrigation scheduling method is similar in principle to using a checkbook to transfer money into or out of a home checking account. In this case, instead of a bank holding the money, the soil profile holds water available for plant growth in the root zone. If the amount of available water (bank balance) in the root zone at the end of day one is known and if the water losses (withdrawals) and gains (deposits) that occurred on day two are known or can be estimated, then the amount of soil water in the root zone at the end of day two can be calculated.

Deposits of water to the plant root zone are effective precipitation, irrigation, or water table contribution. Withdrawal of water from the root zone is primarily crop evapotranspiration (ET_c) and soil evaporation. Manual, adding machine, hand calculator, or computer bookkeeping methods can be used. Checkbook crop use data can be forecasted crop ET, pan evaporation, or other data. Because of spatial variability, rainfall amounts should be measured at the field. Net irrigation or precipitation application amounts can be reasonably estimated. Soil-water content measurements should be made to calibrate calculations and other measurements.

Deep percolation cannot be directly measured in a field situation, but is accounted for in field application efficiency, which also includes improper irrigation timing (too much water too late). Irrigation depths applied under sprinkler systems can be measured by using catch cans (rain gauges) to determine application amounts, flow measuring devices to measure irrigation flows to laterals or from sprinkler heads, and estimates of evaporation losses. A water balance method, such as the checkbook method, is used by the irrigator to track crop water use and soil-water deficit.

Crop evapotranspiration reporting services are sometimes available. This community wide, private, or public service calculates daily crop evapotranspiration for selected crops and provides this information to irrigators through radio, newspaper, television, or by a special telephone service. The TV Weather Channel displays maps showing ET of well-watered grass for the preceding week.

The Water Balance Irrigation Scheduling Worksheet (fig. 9–9) may be used with the checkbook method.

(3) Computer assisted methods

Computerized irrigation scheduling allows the storage and transfer of data, easy access to data, and calculations using the most advanced and complex methods for predicting crop ET. Many computer software programs are available to assist in scheduling irrigations. Most programs access data bases for soil characteristics, crop growth characteristics, climate, water supply, irrigation system, and economic data. The ability to directly access and process climate data from a regional network of local stations or an onsite weather station has greatly streamlined data entry and analysis for computerized scheduling. Scheduling programs are no better than the data used or the ability of the irrigator to interpret output data.

***(i) Daily crop evapotranspiration*—**ET_c is computed to the day of real-time climate data availability, then the method predicts crop ET for up to 10 days in the future. The data can be used by the irrigator to keep a water balance worksheet (fig. 9–9) for each field. This type program generally is used by a local agency or district, consultant, water company, or water district to provide information to local irrigators. Crop ET data are often available to the irrigation decisionmaker in local newspapers, telephone dial-up service, or television. Irrigation decisionmakers for large farms or farms growing high value crops often use onfarm weather station(s) and the farm computer to calculate daily plant water use. However, almost any size farm can support the use of a computer. The computer facilitates the management of all natural resource data as well as record keeping on the farm. The method is similar to the checkbook method.

***(ii) Local real-time climate data*—**Climate data are retrieved by computer phone modem, soils data and crop growth characteristics are accessed, current crop ET is computed, monitored soil-water content is input if available, and a complete crop-soil water balance set of records is developed by computer software for each field being scheduled. Actual onsite, field by field, irrigation system performance is used as basis to determine net irrigation application values. This type program is used directly by the irrigator (or farm consultant) using their own computer and telephone modem.

Figure 9–9 Typical water balance irrigation scheduling worksheet

U.S. Department of Agriculture
Natural Resources Conservation Service

Typical Water Balance Irrigation Scheduling Worksheet

Grower ______________________________ Field ID ______________________ Crop ________________________

Planting date ___________________________ Full cover date __________________ Harvest date ___________________

Soil water holding capacity (in/ft) ________; ________; ________; _________ Rooting depth _____________________________

Management allowable depletion _________________________ Minimum soil-water content ___________________________

Date	Daily crop ET (in)	Forecast crop ET (in)	Cum total ET (in)	Rainfall (in)	Irrigation applied (in)	Cumulative total irrigation (in)	Allowable depletion balance (in)	Soil-water content (in)	Predicted irrigation date

A good irrigation scheduling program can be updated on a regular basis with soil-water content data to improve efficiency and accuracy of determining when to irrigate and how much water to apply. Following periods of excess rainfall when soils are probably at or near field capacity is an easy calibration point. Calculated available soil water should be near field capacity. When crop ET and water costs versus crop yield data are known, a true current economic evaluation can be presented to the irrigation decisionmaker. Improved predictions from computerized irrigation scheduling allow the irrigation decisionmaker to lengthen the period between field monitoring and reduce the uncertainty of the soil-water balance. Adequate and timely water can be provided to the crop and deep percolation losses minimized when following a good irrigation scheduling program.

Some currently available computer programs are briefly described in the following paragraphs. Documentation required to run the program must be available and easy to understand.

NRCS (SCS) Scheduler (DOS Version 3.0 as of 6/96) —This irrigation scheduling program was developed for NRCS by Michigan State University. It is usable nationwide and is applicable in most climates. Using onfarm characteristics and local real time climate data, a simple accounting process is employed to:

- Determine daily and monthly evapotranspiration of the crop.
- Determine seasonal irrigation requirement.
- Account for change in soil-water content since it was last measured.
- Predict rate at which soil water will decrease over the next 10 days.

This program works with any soil and may be applied to any number of crops as crop-specific growth data become available. Currently the program includes 42 crop curves. Climatic data and crop information necessary for local irrigation scheduling should be developed or adapted from local information. Accounting for onsite rainfall is essential. Climate data may be entered manually or transferred directly from a local real-time climatic data collection station via phone modem. To update the soil-water balance, soil-water content monitoring data can be input at anytime. Figures 9–10 and 9–11 display seasonal crop ET curves and soil-water content status using NRCS (SCS) SCHEDULER computer program.

US Bureau of Reclamation Scheduling program (Agrimet)—Bureau of Reclamation has adopted and modified a computer scheduling program developed at USDA Agriculture Research Station at Kimberly, Idaho. Agrimet is the Northwest Cooperative Agricultural Weather Network. It is cooperatively sponsored by land grant universities, Cooperative Extension Service, NRCS, local soil and water conservation districts, ARS, local irrigation districts, and other state and local water resource agencies and organizations.

Sensors collect real time climate data (air temperature, relative humidity, solar radiation, precipitation, and wind run speed and direction). A data collection platform (DCP) interrogates the sensors at programmed intervals, every 15 minutes or hourly, depending on the parameter. The DCP transmits the data every 4 hours via the GOES satellite to a central receive site in Boise, Idaho. The recorded parameters are used to calculate a daily reference ET based on the 1982 Kimberly-Penman equation. Crop water use models are run daily to translate the local climatic data into daily ET information for crops at each weather station. Anyone with a computer, a modem, and an Agrimet user name can access Agrimet for weather data or site-specific daily crop water use information from throughout the Pacific Northwest Region. Other onfarm factors to considered when using the published crop ET data include water used for environmental control, salinity control, and irrigation system application efficiency and uniformity.

ARS personnel at Ft. Collins, Colorado, developed a computer assisted irrigation scheduling program. Program software uses minimum to optimum field data to predict when to irrigate. Default values replace measured data where necessary. In general, the better the field data input, the more precise the data output.

University scheduling programs—Several computer scheduling programs are available and supported by many local universities. Typically, these programs apply statewide or to more localized areas within a state. The State Supplement section at the end of this chapter gives additional information on programs available from local universities.

Figure 9–10 NRCS (SCS) SCHEDULER—seasonal crop ET

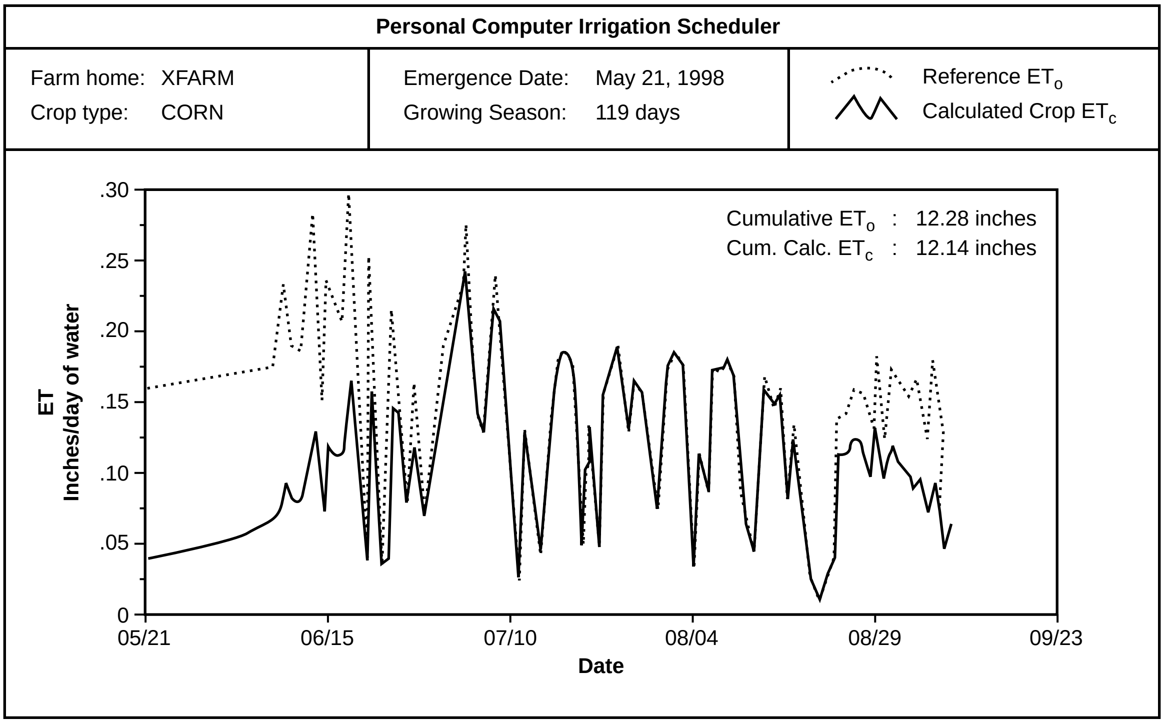
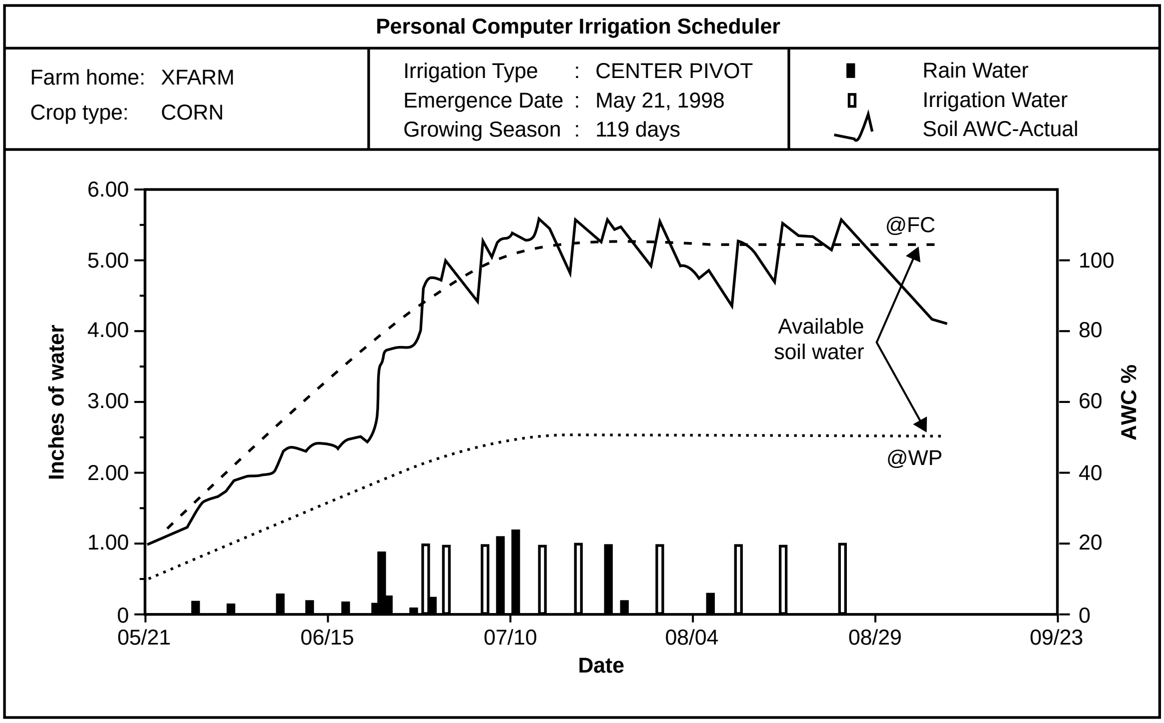


Figure 9–11 NRCS (SCS) SCHEDULER—seasonal soil moisture status



(4) Consultative irrigation scheduling services

Consultants are available who will (for a fee) provide irrigation scheduling services throughout the irrigation season. These consultants often offer other agricultural services including fertilizer and pest management programs.

The advantages of this type scheduling are:

- The consultant is generally well trained and professional.
- The latest techniques are typically used, including state-of-art soil-water content measuring devices and computers.
- Fine tuned management can be maintained.
- Water management integrated with fertilizer, pest, and other management programs can result in optimum plant growing conditions.
- The farm manager who is willing to pay for such services is probably going to follow the recommendations faithfully.
- The saving or proper timing of one irrigation often pays for the service for the entire growing season.

(5) Commercial service

Associated with crop growing contracts, many commercial companies provide field assistance to the irrigator to assure that expected crop yield and crop quality are obtained. Assistance from a field specialist, involving irrigation and fertilizer recommendations and insect control, is typically provided as part of the crop contract arrangement.

652.0904 Irrigation system evaluation procedures

(a) General

The effectiveness of irrigators' irrigation water management practices can be determined by making field observations and evaluations. The results of these observations and evaluations are used to help them improve water management techniques, upgrade their irrigation system(s), or both. Improvements to operations and management can conserve water; reduce labor, energy, and nutrient losses; generally improve crop yields, biomass, and product quality; and reduce existing or potential water pollution. The following principles apply to all irrigation methods and systems.

- Irrigation should be completed in a timely manner to maintain a favorable soil-water content for desired crop growth. An exception may be made where the water supply is limited. In this situation, water should be applied in a manner that maximizes water use benefits.
- The amount of water applied should be sufficient to bring the crop root zone to field capacity minus allowable storage for potential rainfall events.
- Water should be applied at a rate that will not cause waste, erosion, or contamination of ground water and downstream surface water.
- Improving management of the existing system is always the first increment of change for improved water management. Each irrigation evaluation should consider a change in water management decisions only, and then a change in water management decisions and irrigation system performance.

Evaluation is the analysis of any irrigation system and management based on measurements taken in the field under conditions and practices normally used. An examination of irrigation water management practices should attempt to answer the following questions:

- Is the water supply sufficient (quantity and quality) and is it reliable enough to meet the producers objective?
- Are irrigations being applied in a timely manner?

- How is the need for irrigation determined? What is the planned soil-water deficit (SWD)? Is it dry enough to irrigate, too dry, or wet enough to stop irrigating?
- How much water is being applied by each irrigation? How is this amount determined?
- Is irrigation causing erosion or sediment deposition in parts of the field? Off the field?
- How uniform is water being applied over the irrigated area?
- How much water is being infiltrated into the area being irrigated?
- Is there excessive deep percolation or runoff in parts of the field?
- How much deep percolation or runoff? Are amounts reasonable?
- Does water applied for salinity management meet salt level balance needs throughout the soil profile? meet quality of water being used? for the crop being grown? during the desirable crop growth period? over the field?
- Does water applied for climate control meet uniformity and rate objectives?
- Are pesticides or fertilizers being applied through the irrigation system? (May require a high level of management, more or less water per application, and such additional safety devices as back flow prevention devices.)
- Is there a real or potential pollution problem being caused by irrigation?
- What is the overall irrigation application efficiency (mostly affected by management decisions) and irrigation system distribution uniformity of application (highly dependent on system flow rates and configuration)?
- On a sprinkle (or micro) irrigated field, is there translocation of water from the point of application to adjacent areas? How does this affect uniformity of application?

(b) Irrigation efficiency definitions

Irrigation efficiencies are a measure of how well an irrigation system works as well as the level of management of the system. The definitions that follow are similar to standard definitions developed by ASAE and ASCE, and are used in NRCS.

(1) Conveyance efficiency

Conveyance efficiency (E_c) is the ratio of water delivered to the total water diverted or pumped into an open channel or pipeline at the upstream end, expressed as a percentage. It includes seepage losses, evaporation, and leakage inherent in the specific conveyance facility. With appropriate identification it could also include operational spills.

(2) Irrigation efficiency

Irrigation efficiency (E_i) is the ratio of the average depth of irrigation water beneficially used to the average depth applied, expressed as a percentage.

(3) Application efficiency

Application efficiency (E_a) is the ratio of the average depth of irrigation water infiltrated and stored in the plant root zone to the average depth of irrigation water applied, expressed as a percentage. Average depth stored in root zone (or intercepted by plants) cannot exceed soil-water deficit (SWD), but may be equal. If the entire root zone will be filled to field capacity during an irrigation, then average depth infiltrated and stored in the root zone is SWD.

(4) Application efficiency low quarter

Application efficiency low quarter (AELQ or E_q) is the ratio of the average of the lowest one-fourth of measurements of irrigation water infiltrated and stored in the plant root zone to the average depth of irrigation applied; it is expressed as a percentage.

(5) Application efficiency low half

Application efficiency low half (AELH or E_h) is the ratio of the average of the low one-half of measurements of irrigation water infiltrated and stored in the plant root zone to the average depth of irrigation water applied; it is expressed as a percentage.

(6) Project application efficiency

Project application efficiency (E_p) is the ratio of the average depth of irrigation water infiltrated and stored in the plant root zone to the average depth of irrigation water diverted or pumped; it is expressed as a percentage. Project application efficiency includes the combined efficiencies from conveyance and application. It can be the overall efficiency of only onfarm facilities, or for community projects, it may include both on and off-farm efficiencies.

(7) Potential or design application efficiencies

Potential or design application efficiencies are usually those recommended in the irrigation guide and in various tables and charts in NEH, Part 623 (Section 15), Irrigation. These efficiencies are typically used for designing irrigation systems. The efficiency recommendations usually assume good management and maintenance of a well designed and installed system. If it is anticipated that a specific irrigator will not meet these criteria, then a lower potential application efficiency should be used than those recommended in references. Judgment by the designer is required. Overestimating the operator's level of management can result in an inadequate irrigation system design.

(8) Uniformity of application

How uniform an irrigation system applies water across the field is important. Within a range of physical conditions and management, any irrigation method can apply water in such a manner that over 90 percent of applied water is used by the plant. However, the range of physical conditions (topography, soils, water supply) in which this level of uniformity and management can be accomplished, can be narrow. Selection of a different irrigation method and system may provide a wider, more reasonable range of conditions; thus fewer management limitations.

(9) Distribution uniformity

Distribution uniformity (DU) is a measure of the uniformity of infiltrated irrigation water distribution over a field. DU is defined as the ratio of the lowest one-fourth of measurements of irrigation water infiltrated to the average depth of irrigation water infiltrated, expressed as a percentage. For low value crops, maintenance of vegetation, or areas of partial season irrigation, DU of low one-half may be more economical than using low one-quarter.

Sprinkler systems:

$$\text{DU} = \frac{\text{Average low - quarter depth received}}{\text{Average catch can depth received}} \times 100$$

Surface systems:

$$\text{DU} = \frac{\text{Average low - quarter depth infiltrated}}{\text{Average depth infiltrated}} \times 100$$

The average low-quarter depth of water received is the average of the lowest one-quarter of the measured values where each value represents an equal area. For calculation of DU of low one-half, substitute average low half depth received or infiltrated in place of low quarter.

(10) Christiansen's uniformity

Christiansen's uniformity (CU) is another parameter that has been used to evaluate uniformity for sprinkle and micro irrigation systems. DU should be used instead of CU. Thus, sprinkler and micro irrigation application uniformity can be directly compared to other irrigation methods and systems. Christiansen's uniformity is expressed as:

$$\text{CU} = 100\left(1.0 - \frac{\sum X}{m\ n}\right)$$

where:
X = absolute deviation of the individual observations from the mean (in)
m = mean depth of observations (in)
n = number of observations

CU can be approximated by:

$$\text{CU} = \frac{\text{Average low - quarter of water received}}{m} \times 100$$

and the relationship between DU and CU can be approximated by:

$$\text{CU} = 100 - 0.63\ (100 - \text{DU})$$
$$\text{DU} = 100 - 1.59\ (100 - \text{CU})$$

Some parameters that affect uniformity tend to average out during a series of irrigation applications. Other aspects of nonuniformity tend to concentrate in the same areas, either over or under irrigation during each application. See discussion in NEH, Part 623, Chapter 11, Sprinkle Irrigation, Sprinkle Irrigation Efficiency.

(c) Irrigation system evaluations

(1) First step

Many important factors concerning how well an irrigation system is operating and how well it is being managed can be determined with a few simple observations and evaluation procedures. These procedures are used for a simple, abbreviated, or detailed evaluation and are the first step in any system evaluation.

For any irrigation method or system, equipment needed to check soil moisture and compacted layers is a soil auger, push tube sampler, or soil probe. If the soil is rocky, a shovel (sharp shooter) is also needed

A pressure gauge with pitot tube attachment, drill bits to check nozzle wear, short piece of hose, and calibrated container to check nozzle discharge are needed for sprinkler irrigation systems. For micro irrigation systems, special fittings for pressure gauge and catch containers to check the head and emitter discharge are needed. Surface irrigation systems require measuring devices to check furrow and border inflow and outflow. Flow measuring devices are needed for subirrigation systems.

(2) Evaluation procedures

Step 1—Determine basic data about the irrigation system and management from the irrigation decisionmaker. Some questions that might be asked include:

- How does the irrigation decisionmaker determine when to irrigate and how much water to apply?
- How is length of time for each irrigation set determined?
- For sprinkler and micro irrigation systems, what are the operating pressures at several locations along a selected lateral?
- How is the time to shut water off determined?
- How long does it take for water to reach the end of borders or furrows?
- What is the irrigation water supply flow rate in early season? mid season? late season?
- How is flow rate determined?
- What is the rate of flow onto each border or into a furrow? into the system?
- What problems (or concerns) have the irrigator experienced with the system?
- Are there dry spots in the field? wet spots? Are large areas of the field under irrigated? overirrigated?
- Crop production:
  - — What is the average production of each field irrigated?
  - — Does it meet or exceed county or area averages?
  - — Does production vary across the field? If so, what does the irrigation decisionmaker feel are the causes (irrigation system, field surface nonuniformity, water supply amount and location of source or delivery, soil, fertilizer, chemigation, pests)?
- How much control does the irrigator have over when and how much irrigation water is available? delivery schedule?
- What are farm manager's objectives?
- What is the skill level, timing, and amount of labor available?
- Can water be changed at night? during the middle of the day? at odd hours? If short set times are necessary, is a semiautomatic or complete automatic control system available?

Step 2—Observe the field in question. Look at other fields. Look at the supply system. Look for and ask:

- Are there erosion or sediment deposition areas?
- Are there indications of excessive runoff from part or all of the field?
- Are there problems (benefits) created by excessive irrigation tailwater or field runoff?
- Do leaky ditches and pipelines appear to have excessive water loss (seeps or leaks)? (1gpm=1 acre inch every 20 days)
- Are crops uneven or discolored? Do they show obvious stress?
- Are there water loving plants and weeds present? If so, is there an obvious wildlife benefit?
- Are there saline or swampy areas?
- Are there obvious signs of poorly maintained micro and sprinkler hardware, including leaky gaskets, weak or broken springs, plugged emitters, or worn nozzles?
- Are there poorly maintained diversion or turnout gates, leaks, uneven flows from siphon tubes or gated pipe gates, uneven irrigation heads, weeds, and trash?
- Are there measuring devices? Are they in satisfactory operating condition? Are they used to make onfield water management decisions?

Step 3—With the irrigation decisionmaker, auger or probe several holes at selected locations in the field. This is the best time to start talking to the farm manager or irrigation decisionmaker about proper irrigation water management. The feel and appearance method of moisture determination can also be demonstrated. Look for such information as:

- Is there evidence of an excessive high water table or indications of a fluctuating water table?
- Locate hard pans, compacted layers, mineral layers, or other characteristics that can restrict root growth and the movement of water in the soil. What is the apparent cause(s) of each restriction?
- Does soil texture change at various levels in the soil profile?
- Observe water content of each soil layer. Demonstrate the feel and appearance method of moisture determination to the irrigation decisionmaker. Is the location of wetted soil shallow (typically under irrigated) or deep (typically overirrigated) in the soil profile?
- Are root development patterns normal (unrestricted by soil compaction, overirrigation) for the time of year and stage of crop growth?
- Is soil condition favorable for plant growth?

Step 4—Discuss with the irrigation decisionmaker the findings and information so far obtained. Listen for management reasons. Make recommendations if enough information is available to do so. Make sure there is a true communication with the farm manager or irrigator. Use sketches and narratives, if appropriate. Are decisions based on tradition or field observations and measurements?

(d) Simplified irrigation system and water management evaluations

Some simple evaluation items can be done by irrigation system operators that will help them make management and operation of irrigation equipment decisions. They include:

Item 1—For sprinkler and micro irrigation system, they can check:

- Operating pressures at pump, mainline, sprinkler heads, upstream and downstream of filters to assure they match design.
- Application depth for the irrigation set by using a few 3- to 4-inch random placed, straight sided, vegetable or fruit tin containers for catch containers. Measure water depth in catch containers with a pocket tape. Does it match design and what is desired?
- Discharge from a few microsystem emitters using a one-quart container and a watch. Do not raise emitter more than a few inches. Compute flow in gallons per hour. Do flows match design?
- Translocation and runoff from sprinkler systems.

Item 2—For all irrigation systems, simplified field checking by the operator can include calculation of depth of irrigation for a set using the basic equation,

$$QT = DA.$$

where:

Q = flow rate (ft^3/s)
T = time of irrigation application (hr)
D = gross depth of water applied (in)
A = area irrigated (acres)

Item 3—Using a probe, shovel, soils auger, or push type core sampler, the operator can put down a few holes after an irrigation to determine depth of water penetration. Does it match plant rooting depths? Depending on the irrigation system and soil, checking on water penetration could be anywhere from an hour after the irrigation to the next day.

Item 4—Check runoff. Is it excessive? Does it contain sediment?

(e) Abbreviated water management and irrigation system evaluations

An abbreviated evaluation can determine whether a problem(s) exists in a field and how serious it may be. Frequently, a simple evaluation provides enough information to make a decision. Such an evaluation should always precede a more detailed evaluation. With some guidance the irrigation decisionmaker can perform abbreviated irrigation evaluations themselves. Abbreviated management and irrigation system evaluations can be made by onfarm managers or NRCS field staff. Many times, needed changes can be identified in less than an hour.

(1) Sprinkle irrigation

Before irrigation, randomly place calibrated catch containers (or rain gauges) at plant canopy height. Containers should be straight sided with a reasonably sharp edge. When irrigation is complete, a pocket tape or graduated cylinder may be used to measure depth of water caught in each container. This provides an indication of average depth of application only. When sufficient number of containers is used with a uniform spacing pattern within all of the sprinkler lateral application area, pattern uniformity can be calculated (see section 3 in this section).

(2) Sprinkle irrigation (center pivot or linear move)

Using the design nozzle package, source pressure, and lateral size provided by the owner or dealer, a computer evaluation can be made in a few minutes if the computer program is readily available. Field observation of an operating system can identify improper (usually plugged or wrong nozzle size) nozzle operation. A computer equipment evaluation or field inspection of irrigation equipment in use (including lateral pressures and nozzles used) should always precede a detailed system evaluation.

(3) Sprinkle, surface, and micro irrigation

A portable or permanently installed flow measuring device can be used to evaluate gross irrigation water applied. By knowing the flow rate and kilowatt hours per hour energy used with electric powered pumps, the volume of water pumped can be determined using the common electric meter. When using gas or diesel, hours of operation can be determined by knowing the cubic feet, pounds, or gallons of fuel used and the rate of fuel used per hour. Totalizing time clocks that operate from the engine ignition can also be used.

Irrigators try all too often to cover more acres than the water supply will adequately provide, or they overirrigate a large part of the field to satisfy a small area. Applying the formula QT = DA will solve four out of five IWM problems. Net irrigation depth can be calculated by multiplying gross depth by the overall irrigation efficiency expressed as a decimal.

Some irrigators estimate plant water need accurately then fail to measure flow onto the field, thus applying an unknown quantity of water. Flow measuring devices are one of the most valuable water management tools available to the irrigator. Accurate devices for pipelines and open channels may cost as little as $50 to over $1,000. Where water supply is not limited, farmers typically apply too much water, especially where plant water needs or water applied are not measured. This is also common with an irrigation delivery system where water is delivered on a rotation basis.

(4) Surface and sprinkle irrigation

The ball or tile probe is perhaps the most versatile and cheapest tool available to the irrigation decisionmaker. Following irrigation, the probe can be inserted in the soil at various points along the length of run (surface irrigation) or across the field (sprinkle irrigation) to measure the depth of water penetration. (Penetration is easy where water lubricates the soil.) By knowing the soil AWC, the effective irrigation water applied is calculated. Both management application efficiency and system distribution uniformity can be calculated. The ball or tile probe works best where there is an abrupt boundary between a wetted soil and a soil with moisture at less than field capacity. In rocky soil, a sound is emitted when the probe strikes a rock, otherwise no sound should be heard.

The ball or tile probe can also be used to detect excess moisture in lower portions of the soil profile even though soil at or near the surface appears dry, thus delaying irrigation and improving plant vigor.

(5) Surface and sprinkle irrigation

A soil auger or push type core sampling probe can be used at various locations in a field to determine depth of irrigation, extent of lateral movement, and available soil moisture. With experience the irrigation decision-maker can schedule irrigation applications based upon soil moisture at a relatively shallow depth. Application efficiency (E_a) and irrigation system distribution uniformity (DU) can be calculated using soil auger or probe observations. An advantage in using the ball probe, soil probe, or soil auger is that you observe other field crop conditions when walking through the field, thus use the multiresource planning process. Many locations in the field can be quickly checked.

(f) Water management and irrigation system evaluations

(1) Graded or level border (basin)

***(i) Equipment*—**Equipment needed for a graded or level border includes:

- Soil auger, probe, push type core sampler.
- Watch, 100-foot tape.
- Lath or wire flags for marking stations.
- Portable water measuring device, such as sharp crested weir, Replogle flume, Parshall flume, broadcrested weir, and pipe flow meter. Capacity needed depends on typical inflows used in the area.

***(ii) Procedures*—**The following procedures should be followed.

Before start of irrigation:

- Estimate the soil-water deficit (SWD) at several locations down the border being investigated. Use feel and appearance method.
- Set flags or stakes at uniform distances down the border (generally 100-foot spacing).

During irrigation:

- Observe how uniformly water spreads across the border (basin) width. The soil surface should not have excessively high or low spots, and no intermittent ponding should occur.
- Observe and record the time when the water reaches each station. These times will be used later in plotting a simple advance rate curve.
- Record the time and location of the water front when inflow is turned off.
- Record the time when 90 percent of the soil surface area is no longer covered by water at each station. These times will be used later in plotting a recession curve. No long time ponding should occur.
- Measure or estimate the volume of runoff in terms of percent of inflow volume. (Duration of runoff is determined from the records mentioned above.)
- Probe approximately 24 hours following irrigation, the soil profile down the border strip to check uniformity of water penetration. Where soil and crops are uniform, a previously irrigated border strip may be used for this purpose.
- Determine adequacy of the irrigation with an additional simple check if the rate of inflow is known or can be estimated. Use the basic equation QT = DA to calculate the gross depth of irrigation application from the known rate of inflow, duration of irrigation, and length and width of border strip. An example to determine gross application depth, D, for a border strip 100 feet wide and 1,200 feet long, with 3 cubic feet per second inflow for a set inflow time of 4.5 hours, would be:

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

$$D = \frac{(3.0\ \text{ft}^3/\text{s}) \times (4.5\ \text{hr})}{A} = 4.9\ \text{in.}$$

where:

$$A = \frac{(100\ \text{ft}) \times (1,200\ \text{ft})}{43,560\ \text{ft}^2/\text{acre}} = 2.75\ \text{acres}$$

When the gross depth of application, D = 4.9 inches, is multiplied by the estimated overall application efficiency (decimal), average net depth of irrigation can be estimated. The field technician needs to have experience in ranges of average application efficiencies for the farm or in the general area.

Ave. net depth = 4.9 x 60% = 3 inches (approx.)

(iii) Use of field data—The following steps should be used with the field data:

Step 1—Using distance down the border (stations) and elapsed time in minutes, plot advance and recession curves for the border (fig. 9–12). Show the time when water was shutoff and location of water front at that time. The opportunity time is the time water was in contact with the soil surface (the interval between the advance and recession curves) at any given point (station) along the border. With basins, the water front at various times is plotted on an area basis, similar to topographic contour lines. Advance and recession curves can be plotted at select locations radiating away from the water supply onto the field.

Step 2—Compare probe depths at various locations down the border (basin) keeping in mind that water movement through the soil may not be complete. Does it appear that parts of the border (basin) have had too short an opportunity time?

Step 3—If information on accumulated intake versus time (intake characteristic [family] curve) for the particular soil is available, compare actual opportunity times throughout the length of the border to the opportunity time required for the net application as interpolated from intake characteristic curves.

Step 4—Large variations in opportunity times along the length of the border indicate changes need to be made in the rate of flow, duration of flow, or field surface conditions. Large variations between the opportunity time determined from the intake characteristic (family) curve and the actual opportunity times indicate that changes need to be made in the application or that the estimated intake characteristic (family) curve number is wrong. If it appears that the intake characteristic (family) curve number used is wrong, then a complete system analysis, including ring infiltrometer tests, may be required if more detailed recommendations are desirable.

Step 5—If possible, check the original design. Is the system being operated in accordance with the design (hours of each set, return frequency)? Should redesign be considered?

Step 6—Are irrigation water screening facilities needed?

Step 7—Are there water, soil, or plant management changes that can be made to reduce beneficial water use, fertilizer use, or water lost?

(2) Graded or level furrows

(i) Equipment—The equipment needed includes:

- Soil auger, probe, push type core sampler, shovel.
- Portable flow measuring devices (broadcrested weir/flume, Replogle flume, Parshall flume, v-notch flume, v-notch sharpcrested weir, orifice flow plate, siphon tubes, flow meter in a short length of pipe, bucket).
- Watch with second hand or stop watch.
- Stakes or wire flags for locating stations.

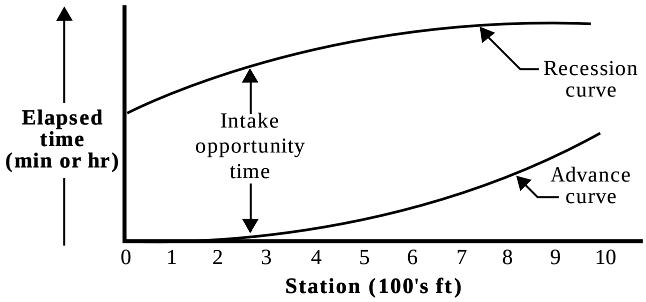
At least three furrows should be evaluated. Included should be the correct proportion of wheel rows, nonwheel rows, and guess rows. A judgment decision must be whether these few furrows adequately represent the entire field.

(ii) Procedures—The following procedures should be followed.

Before the start of irrigation:

- Estimate the soil-water deficit (SWD) at several locations down furrows being investigated (use feel and appearance method). Check soil moisture in the root zone (not necessarily in the center of the furrow). Is it dry enough to irrigate?
- Note the condition of furrows. Has there been a cultivation since the last irrigation?
- Set stakes or wire flags at 100-foot stations down the length of each furrow evaluated.

Figure 9–12 Plot of example advance and recession curves



During an irrigation:

- Measure (or estimate) the inflow rate (example 9–1). If siphon tubes are used, a siphon tube head-discharge chart can be used to estimate inflow. If total inflow is known, divide total inflow by the number of furrows being irrigated. Timing furrow flow catch in a bucket of known capacity or using a portable furrow flow measuring device are both accurate.
- Observe the time it takes water to reach each station (lath or wire flag) and to reach the lower end of each furrow evaluated.
- Measure furrow outflow with a portable flow measuring device periodically during the runoff phase to get an average outflow rate in gallons per minute, or estimate runoff rate in terms of percent of inflow rate (example 9–1).
- Check for erosion and sedimentation in the furrow or tailwater collection facilities.
- Dig a trench across a furrow (plant stem to plant stem) to be irrigated by the next set. The wetted bulb can also be observed following an irrigation. Observe conditions, such as:
  - — Actual root development, location, and pattern
  - — Compaction layers—identify cause (cultivation, wheel type equipment, plowing, disking)
  - — Soil textural changes
  - — Salt accumulation and location
- About 24 hours following irrigation, probe the length of a representative furrow to check uniformity of water penetration. Where soil and crops are uniform, a previously irrigated furrow set can be used for this purpose.

(iii) Use of field data—The following steps should be used with the field data:

Step 1—Was the soil dry enough to start irrigating? What was the soil-water deficit in the root zone at various points along the furrow before irrigating?

Step 2—Did water penetrate uniformly along the length of furrow? Good uniformity usually is achieved if the stream progresses uniformly and reaches the lower end of the furrow without erosion in about a quarter to a third of the total inflow time. Should furrow length be reduced? increased? Should inflow rate be changed?

Plot the advance curve for the furrow (see fig. 9–12). Plotting of the furrow advance curve is basically the same as the plot of the border advance curve. Shape of advance curve can indicate adequacy of inflow rates in relation to soil intake characteristics for that specific length of furrow. Estimates for adjustments in furrow irrigation operation values can be made using inflow and advance rate estimates.

Step 3—Was there runoff? How much? Water ponding with blocked end nearly level furrows or running off at the lower end of nonblocked furrows is essential for practical operation and a full, uniform irrigation. Runoff water can be collected and reused by using a tailwater collection and return-flow facility.

Step 4—Are the water supply and conveyance systems capable of delivering enough water for efficient and convenient use of both water and labor? Supplies should be large enough and flexible in both rate and duration. Furrow streams should be adjustable to the degree that flow will reach the end of most furrows in about a quarter to a third of the total inflow time. If appropriate, tailwater reuse, cablegation, cutback, or surge irrigation techniques can significantly increase distribution uniformity (see chapter 5).

(iv) Observations—Did soil in the crop root zone contain all of the irrigation water applied? Is there still a soil-water deficit in the root zone or is deep percolation below the root zone occurring? A simple before and after soil-water content check can provide data to estimate amounts before and after irrigation. However, this does not account for uniformity or nonuniformity in application depths throughout the length of the furrow. By simple soil probing or push core sampling throughout the length of the furrow the next day following an irrigation (or on a previous set), depth of water penetration along the furrow can be observed.

With some field experience, inflow rate and set time adjustments can be recommended to improve depth of water penetration and uniformity of water penetration along the furrow length. A detailed field evaluation is necessary for fine tuning recommendations. Often these measurements can be observed by the farm irrigation decisionmaker or irrigator. Until a field technician is experienced with furrow irrigation, a complete evaluation process with data should be used.

Was the soil dry enough to start irrigating? Was it too dry? Compare the SWD to application. How does the crop look? Is there evidence of under irrigation, salinity problems, overirrigation? Are there obvious dry spots? dry strips?

Is there soil erosion? water translocation? or runoff? Is it general or only at specific locations? A solution may be to improve irrigation water or tillage management.

Example 9–1 Estimating furrow inflow and outflow depths

Use the basic equation QT = DA (altered to use common field units; i.e., conversion factor of 96.3 so flow can be shown in gallons per minute and furrow spacing and length in feet)

Inflow:

$$\text{Depth, } D = \frac{(\text{furrow flow, gpm}) \times (\text{set time, hr}) \times (96.3)}{(\text{furrow spacing, ft}) \times (\text{furrow length, ft})}$$

Field data: 10 gpm per furrow inflow
12 hours set time
30-inch furrow spacing (with flow every furrow)
1,000-foot furrow length, gives:

$$D = \frac{(10\text{ gpm}) \times (12\text{ hr}) \times (96.3)}{(2.5\text{ ft}) \times (1{,}000\text{ ft})}$$

Outflow:

$$RO = \frac{(\text{average furrow outflow, gpm}) \times (\text{outflow time, hrs}) \times 96.3}{(\text{furrow spacing, ft}) \times (\text{furrow length, ft})}$$

Field data: 3.5 gpm average outflow and 9.5 hours outflow time, gives:

$$RO = \frac{(3.5\text{ gpm}) \times (9.5\text{ hr}) \times (96.3)}{(2.5\text{ ft}) \times (1{,}000\text{ ft})} = 1.3\text{ inches}$$

Summary: Infiltration = 4.6 inches – 1.3 inches = 3.3 inches, or 72 percent

$$RO = \frac{1.3\text{ inches}}{4.6\text{ inches}} = 28\%$$

(3) Sprinkler systems

***(i) Periodic move laterals*—**This type sprinkler systems include sideroll wheel lines, handmove, end tow, and fixed or solid set operations.

Equipment—The equipment needed includes:

- Soil auger, probe, push type core sampler.
- Bucket calibrated in gallons (2 to 5 gal).
- 5-foot piece of 3/4-inch garden hose.
- Set of new twist drill bits (1/8 to 1/4 inch by 64ths).
- Watch with second hand or stop watch.
- Pressure gauge with pitot tube attachment. Suggest using liquid filled pressure gauges for increased durability, plus the indicator needle does not flutter when making a reading.

Procedures—The following procedures should be used in the evaluation.

Step 1—Estimate the soil-water deficit (SWD) at several locations ahead of the sprinkler lateral. Check irrigation adequacy behind the sprinkler. Use the feel and appearance method.

Check uniformity of water penetration into the soil between sprinkler heads and laterals on the previous irrigation set using a probe or push core sampler. Properly overlapping sprinkler-wetted areas (pressure, discharge, sprinkler head, and lateral spacing) provides nearly uniform application. A detailed evaluation using a complete grid of catch devices can accurately determine application pattern uniformity.

Step 2—Using the IWM formula, QT = DA, determine depth of water applied by an irrigation. This is accomplished by first measuring nozzle discharge by placing the hose over the nozzle and then timing the flow into the calibrated container.

Step 3—To check nozzle discharge, fit hose over sprinkler head nozzle (two hoses for double nozzle sprinkler heads). A loose fit is desirable. Direct water into a calibrated bucket. Using a watch or timer, determine the time period it takes to fill the calibrated bucket. Check several sprinkler heads on the lateral. Calculate nozzle flow rate in gallons per minute. Calculate the precipitation rate from manufacturer tables or charts, or use the IWM equation (96.3 is units conversion factor when using gallons per minute and sprinkler head spacing in feet):

$$I = \frac{(96.3)\times(q)}{S_l \times S_m}$$

and

$$\text{Depth of water applied} = I \times H$$

where:

I = precipitation (application) rate, in/hr
q = nozzle flow, gpm
H = set time, hr
S_l = spacing of heads along lateral, ft
S_m = lateral spacing along main, ft

Step 4—Take pressure readings at several locations along the lateral(s) using the pitot tube pressure gauge. If not in the critical position, measure elevations and calculate pressure differences if the lateral was moved to that location. Critical location is usually determined by elevation and distance from the mainline or pump. Pressure differences should not exceed 20 percent between any two sprinkler heads on the same lateral. This provides for less than 10 percent difference in discharge between heads on the lateral.

Desirable and design operating pressure should occur in the area that affects most sprinklers; i.e., about a third the distance from upstream end, on uniform diameter, level laterals. Excessive operating pressure produces small droplets, or fogging, and irregular turning of sprinkler heads. Small droplets are subject to wind drift and result in increased application close to the sprinkler head. Too low of a pressure causes improper jet breakup giving large droplet sizes. This typically produces a doughnut-shaped spray pattern, which if not corrected, results in a similar plant growth pattern. Larger droplets are less affected by wind. Very little water is applied close to the sprinkler head. Both conditions, excessive and too little pressure, result in poor distribution patterns.

Step 5—Using the shank end of a new, same size twist drill bit, check the orifice diameter of several sprinkler nozzles for appropriate size and wear. The twist drill shank should just fit into the orifice without wiggle. Excess wiggle indicates excessive wear (or too large nozzle diameter), which indicates nonuniform discharge from nozzles and poor distribution pattern between heads. Nozzles are considered worn if the next diameter bit fits into the orifice or the drill bit can be moved sideways more than 5 degrees. Wear is typically caused from abrasive sediment in the water. Often excessive wear creates an oblong opening and is readily apparent.

Utilization of field data—The following steps should be used with field data:

Step 1—Was the soil dry enough to start irrigating? Was it too dry? What was the soil-water deficit at various locations in the field ahead of the sprinkler?

Step 2—Compare the SWD to application. How does the crop look? Is there evidence of under irrigation, salinity problems, overirrigation? Are there obvious sprinkler application pattern problems? dry spots? dry strips? donut-shaped patterns?

Step 3—Is there soil erosion, water translocation, or runoff? Is it general or only at specific locations? This indicates whether the application rate is too great. A solution may be to improve irrigation water or tillage management rather than changing hardware.

Step 4—Are sprinkler heads vertical and are self leveling risers on wheel lines operating properly? Are sprinkler heads rotating evenly and timely? (They should rotate at 1 to 2 revolutions per minute.) Do sprinkler head type, nozzle size, and pressure match spacing on lateral and along mainline and design? If it is apparent that sprinkler heads along the wheel line are not plumb, installation of self leveling heads should be recommended. Installing new, proper sized nozzles can be one of the most cost effective operational inprovements.

Step 5—If possible, check the original design. Is the system being operated in accordance with the design (pressure, hours of each set, return frequency)? Should redesign be considered?

Step 6—Are gaskets in good condition with no excessive leaks? Are nozzles plugged or partly plugged? Are return springs broken? Is a screening system needed? If the nozzles are oversize, of varying size, or worn, they should be replaced. Replacement with new nozzles of uniform size generally is one of the most cost effective actions an irrigator can take.

***(ii) Continuous (self) move*—**This type sprinkler system includes center pivot, linear, or lateral move.

Equipment—The equipment needed includes:

- Soil auger, probe, small diameter (1 inch) push type core sampler.
- Calibrated catch containers or rain gauges.
- Measuring tape (50 ft).
- Pressure gauge with pitot tube attachment. Suggest using liquid filled pressure gauges for increased durability, plus the indicator needle does not flutter when making a reading.
- Electrical resistance meter (tick meter) to check for stray voltage.
- Stakes to set containers or rain gauges above crop canopy.

Procedures—The following procedures should be used in the evaluation.

Step 1—Safety precautions should be followed before touching or climbing upon an electric powered self moving lateral system. Check for stray electric currents with a properly grounded tick meter or other approved equipment or methods, then use the back of the hand to briefly touch metal lateral components the first time. Don't grab any part of the system until it is checked. Muscles in the hand and fingers contract when subjected to electrical currents, causing the fingers to close and stay closed. If portable ladders are used to reach any of the sprinkler heads, it is advisable to use ladders made from OSHA approved nonconductive material. Hooks should be installed on the upper end of the ladder because the system moves during the evaluation.

Step 2—Uniformly place catch containers or rain gauges at or slightly above the crop canopy equidistant apart (the closer the spacing the more accurate the results, generally not greater than 30 feet apart) and ahead of the moving lateral so the lateral will cross perpendicular over them. For best accuracy, two rows of catch containers are set out and catch is averaged. However, one row is typically used to provide information needed to make general decisions. For center pivot systems, select representative spans near the middle and end of the lateral.

Catch containers or rain gauges are often omitted within 400 feet of the pivot point, as containers represent a small area (less than 3 acres). Uniformly space containers or rain gauges within each test section. The nearer to the outer end of the lateral, the shorter time period required for the lateral to pass over the catch containers. Let the lateral completely cross the containers. The start-stop operation of self move systems, evaporation losses between night and day operation, and changing wind speeds and direction can cause nonuniformity in catch volume for a single spot. If this appears to be a problem, use two lines of containers or rain gauges at different lateral positions. Use the same container spacing and start distance from pivot point for both rows of catch containers. Water caught in containers positioned at the same distance from the pivot point represent the same area on the lateral. Averages should be used. Identify tower positions when laying out catch containers for later reference when presenting results to the irrigation decision-maker.

If containers are left for an extended time, a small amount of mineral oil placed in them will reduce evaporation effects.

Step 3—Calculate the average depth of water caught in all containers to find average application depth for the length of lateral tested. The longer the lateral length tested, the more representative the average depth of application. Testing the full length of the lateral would represent the total area, but requires more time. Operating pressure should be measured at several points along the lateral.

Special and unique field catch devices and evaluation procedures must be used for low energy precision application (LEPA), low pressure in-canopy (LPIC), and low pressure systems using specialty heads.

(iii) Continuous (self) move—This type sprinkler system includes the traveling gun sprinkler.

Equipment—The equipment needed includes:

- Soil auger, probe, push type core sampler.
- Calibrated catch containers or rain gauges.
- Pressure gauge with pitot tube attachment. Suggest using liquid filled pressure gauges for increased durability plus the indicator needle does not flutter when making a reading.

Procedures—The following procedures should be used in the evaluation.

Step 1—Uniformly space catch containers or rain gauges across the path of the traveling sprinkler. Catch should represent a cross section of the total application. When the sprinkler has completely passed over the catch containers, measure the depth of water in each can and record the distance from the sprinkler travel path. Combine sprinkler catch where lap would have occurred. Calculate the average irrigation application.

Step 2—With water shut off, use calipers (for improved accuracy) to check inside diameter of nozzles on big gun sprinkler heads. It is rather difficult and hazardous to check nozzle discharge with a hose and bucket or use nozzle pressure with a pitot tube on a pressure gauge. If attempted, hold the driving arm down to prevent sprinkler head rotation. An access plug that is often near the base of the big gun can be used to temporarily install a pressure gauge. Line pressure should be corrected for elevation of the nozzle. Manufacturer charts and tables should be referenced.

Utilization of field data—The following steps should be used with the field data:

Step 1—Was the soil dry enough to start irrigating? Was it too dry? What was the soil-water deficit (SWD) at various locations in the field ahead of the sprinkler? following the sprinkler?

Step 2—Compare the soil-water deficit (SWD) to the water application. How does the crop look? Is there evidence of under irrigation? salinity problems? overirrigation? Are there obvious sprinkler application pattern problems? dry spots? dry strips? donut shaped patterns? wet areas?

Step 3—Is there soil erosion, water translocation, or field runoff? Is it general or only at specific locations? These items indicate whether application rate is too great. A solution may be to improve irrigation water or tillage management rather than changing hardware. Increasing traveler speed to apply less water or changing tillage to increase soil surface storage are examples of low cost management changes.

Step 4—Are sprinkler heads positioned vertically? Are sprinkler heads rotating evenly and timely? Do sprinkler head type, nozzle size, pressure, and lane spacing match the design?

Step 5—If possible, check the original design. Is the system being operated in accordance with the design (pressure, speed, return frequency)? Should redesign be considered?

Step 6—Are gaskets in good condition with no excessive leaks? Are nozzles and equipment worn? Is a screening system needed? Should nozzles be replaced?

Step 7—Are there water, soil, or plant management changes that can be made to reduce beneficial water use, fertilizer use, or water loss?

(4) Micro systems

***(i) Equipment*—**The equipment needed includes:

- Soil auger, probe, or small diameter (1 inch) push core sampler.
- Catch devices, graduated cylinder with 250 mL capacity. Devices used for catching discharge are generally home crafted so the catch device is fitted to the specific type of emitter device(s). Examples of catch devices are:
    - Troughs made from rain gutter (preferably plastic) or rigid plastic pipe (cut in half longitudinally) for line source emitters.
    - Single catch container for single emitters.
    - Cut and fit 2-liter plastic soda bottles for minispray heads (fig. 9–13)
- Watch with second hand or stop watch.
- Pressure gauge with special adapters to fit polyethylene pipe microsystem fittings.
- Manufacturer emitter performance charts.
- Measuring tape.

***(ii) Procedures*—**The following procedures should be used for the evaluation.

Step 1—Set catch devices under selected drippers or over minispray heads and sprinklers, or both. Checking a few emitters can give an idea if a detail evaluation is necessary. Figure 9–13 shows a home fabricated catch device made from a 2-liter plastic soda bottle that can be used to catch flow from minispray heads and sprinklers. Check operating pressure at head and end of lateral or wherever possible and practical. Fittings may need to be installed. A low range reading pressure gauge (0 to 20 psi) may be necessary to obtain reasonably accurate pressure readings. Do not raise a micro irrigation emitter device more than a few inches. Raising the emitter reduces the operating pressure and discharge.

Step 2—Use a probe or push core sampler to determine wetted area and depth of water penetration for all types of emitter devices, including single and line-source emitters for both surface installed and buried laterals. Wetted width should reach the drip line of plants (perennials). Wetted depth should reach potential root zone depth. For annual plants, such as row crops, wetted width should be at a planned width, but generally not less than 50 to 65 percent of the total surface area.

***(iii) Utilization of field data*—**The following steps should be used with the field data:

Step 1—Was the soil dry enough to start irrigating? Was it too dry? What was the soil-water deficit (SWD) at various locations in the field ahead of the emitter system? following irrigation? If soils are uniform, a previous irrigation can be used.

Step 2—Compare the soil-water deficit to application. How does the crop look? Is there evidence of under irrigation, salinity problems, or overirrigation? Are there obvious pattern or distribution problems?

Step 3—Are visible emitters operating properly? Are minispray heads and sprinklers rotating evenly and timely?

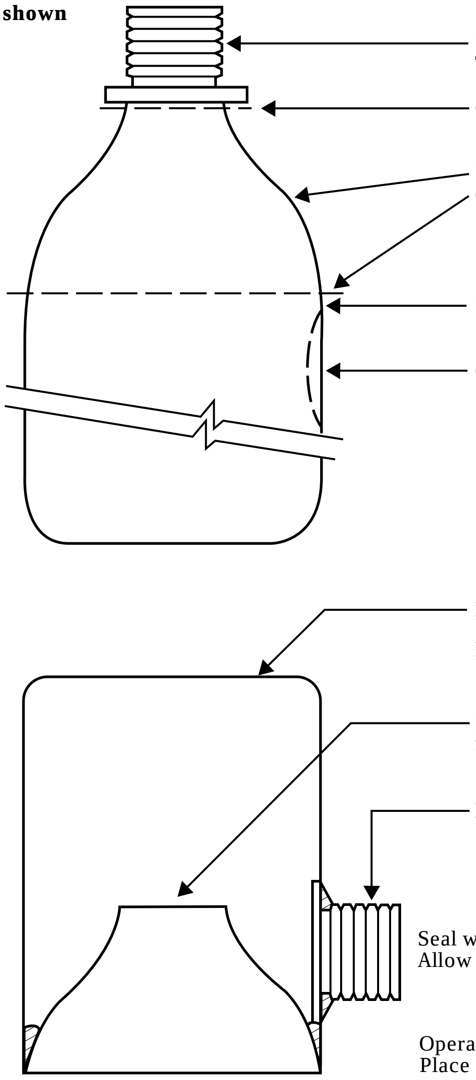
Step 4—If possible, check the original design. Is the system being operated in accordance with the design (pressure, hours of each set, return frequency)? Should redesign be considered?

Step 5—Are there excessive leaks? Are emitters or nozzles plugged? Is the filter system appropriate and being operated satisfactory?

Step 6—Compare catch against manufacturer’s flow rate chart. Discharge variation could be because of plugging, inadequate or excessive pressure, excessive main, submain and lateral head loss, or manufacturing discharge variation.

Step 7—Are there water, soil, or plant management changes that can be made to reduce water use, water lost to nonbeneficial uses, and fertilizer use?

Figure 9–13 Minispray head catch device (made from a 2-liter plastic soft drink bottle)



Step 1. Make cuts as shown

Part 1
To be the new spout.

Cut just below stiffener ring.

Part 2
Cut just below shoulder.

Part 3

Cut hole same diameter as threaded neck.

Step 2.

Invert part 3

Insert part 2 into part 3 as shown.

Step 3.

Enlarge hole in part 2 as needed so it fits over minispray heads.

Insert part 1 through hole from inside of part 3. Seal with silicone caulking compound.

Seal with silicone caulking compound.
Allow silicone caulking compound to cure before using.

Operation:
Place device over minispray head, allow flow from spout to stabilize, check for splash losses, and make field adjustments as necessary.

(g) Detailed irrigation system evaluation procedures

More detailed irrigation system evaluations are occasionally needed when complete field data, including pattern uniformity and distribution efficiency, are needed at a particular site. The first-step procedures described in 652.0904(c) should always be completed before deciding to expend the considerable time and effort required to do a complete irrigation system and management evaluation. Each detailed system evaluation consumes from one to five staff person days, depending on type of irrigation system. The objective of any evaluation is to improve irrigation system operation and water management.

The product for the irrigation decisionmaker would be an evaluation report and a comprehensive irrigation system operation and management plan. Depending on local concerns and priorities (i.e., water quantity or quality), it may be desirable to set up multi-agency sponsored IWM teams that have the necessary full-time staff and equipment to provide assistance to farm managers and irrigation decisionmakers. Irrigation decisionmakers should be present during the evaluation so they can observe measurements being taken. The weighted importance (or effect) of measured observations can also be discussed.

In addition to site specific benefits derived from a complete evaluation for the irrigation decisionmaker, collected field data can support or modify estimated values in the local irrigation guide. The data can be used as a basis for future irrigation system planning and design. Another benefit is local on-the-job training opportunities for NRCS irrigation personnel. The best way to learn about planning, designing, and operating irrigation systems is to closely observe and evaluate irrigation system(s) operation and management as they are taking place. Every person performing irrigation planning and design should occasionally go through a complete evaluation on each type of system being used in the area. It is a fantastic learning opportunity. To become adequately experienced in irrigation to where sound knowledgeable and practical recommendations can be made, typically is a long-term process. True communication takes place when the irrigation decisionmaker perceives the consultant's knowledge being equal to or expanded beyond their own.

Providing detailed field evaluations is time consuming and must be comprehensive enough to provide detailed recommendations for improvements to both management and system operations.

This part of chapter 9 describes procedures for performing detailed irrigation system evaluations. Included are detailed procedures for performing irrigation system evaluations for surface, sprinkle, micro, and subirrigation systems and for pumps. Examples and blank worksheets are included in chapter 15 of this guide.

(1) Graded border irrigation systems

Improving water use efficiency of border irrigation has great potential for conserving irrigation water and improving downstream water quality. A detailed evaluation can provide the information for design or help to properly operate and manage a graded border irrigation system. It can help the irrigation decisionmaker determine proper border inflows, lengths of run, and time of inflow for specific field and crop conditions. It should also be recognized that soil intake characteristics have the biggest influence on application uniformity. Intake rate for a specific soil series and surface texture varies from farm to farm, field to field, and throughout the growing season; typically because of the field preparation, cultivation and harvest equipment, and other field traffic.

To approximate the infiltration amount (intake rate) based upon advance and opportunity time for a border, a correlation is made using cylinder infiltration test data. A detailed irrigation system evaluation can identify soil intake characteristics for site conditions within that particular field. It can also provide valuable data to support local irrigation guides for planning graded border irrigation systems on other farms on similar soils.

***(i) Equipment*—**The equipment needed for a graded border irrigation system includes:

- Engineers level and rod, 100 foot tape
- Pocket tape marked in inches and tenths/hundredths of feet
- Stakes or flags, marker for stakes or flags
- Measuring devises for measuring inflow and outflow
- Carpenters level for setting flumes or weirs.
- Cylinder infiltrometer (minimum of 4 rings) set with hook gauge and driving hammer and plate

- Equipment for determining soil moisture amounts (feel and appearance charts, Speedy moisture meter and Eley Volumeter, or Madera sampler and soil moisture sample cans)
- Water supply and buckets to provide infiltrometers with water
- Soil auger, push tube sampler, probe, shovel
- Graded border evaluation worksheet, clipboard, and pencil
- Soils data for field
- Stop watch, camera
- Boots

(ii) Procedures—The field procedures needed for this system are in two main categories: General and inventory and data collection.

General

Choose a typical location in the field to be irrigated. The typical location should be representative of the type of soil for which the entire field is managed. Use standard soil surveys, where available, to locate border evaluation sites. Then have a qualified person determine the actual surface texture, restricted layers, depth, and other soil characteristics that affect irrigation. Soil surveys are generally inadequate for this level of detail. Almost all mapping units have inclusions of other soil. Extension of results to other areas also has more reliability. The site selected should allow measurement of runoff if it occurs. The evaluation should be run at a time when soil moisture conditions are similar to conditions when irrigation would normally be initiated. This procedure is described in the following steps.

Step 1—Obtain information from the irrigation decisionmaker about the field and how it is irrigated; i.e., irrigation set time; borders irrigated per set with typical inflow rates, advance rates (times), adjustments made during irrigation set time, and number of irrigations per season; and tillage and harvesting equipment.

Step 2—Record field observations, such as crops grown, crop color differences in different parts of the border or field, crop uniformity, salinity, and wet areas. Also make field observations concerning erosion and sediment deposition areas. The border to be evaluated should have uniform cross slope grade and uniform downslope grade.

Set stakes or flags at 50- to 100-foot stations down the center of the border to be evaluated. Mark stations so readings can be observed from at least 50 feet; i.e., border dike or adjacent border. Determine field elevation at each station and for a typical cross section of the border.

Record border width (center to center of border dike), strip width (distance between toes of border dikes), and wetted width (width to which water soaks or spreads beyond the edge of dike).

Set flumes, weirs, or other measuring devices at the upper end of the border and at the lower end if runoff is to be measured. Continuous water level recorders in the measuring devices may be convenient to use.

Part of the objective during a detail evaluation is to determine infiltration rate under actual field conditions using cylinder infiltrometers. Set three to five cylinder infiltrometers in carefully chosen typical locations within the border strip. Generally the most convenient location is a couple of hundred feet from the upper end of the strip (close to the water supply). Continuous water level recorders are convenient to use in the infiltrometers. USDA publications reviewing the installation of the cylinders are nearly nonexistent. See Part 652.0905(b) for additional information on installation and operation of cylinders.

Step 3—Estimate soil water deficit at several locations along the border. Use the feel and appearance method, Eley Volumeter/Speedy Moisture Meter, push type core sampler and gravimetric, or some other portable method. Pick one location as being typical for the border strip and record the data for that location on the worksheet.

Step 4—At the same time make note of soil profile conditions. With uniform soils, this can be done in an adjacent border during a later portion of the test when infiltration rates are typically slower. Soil conditions to consider include:

- Depth to water table
- Apparent root depth of existing or previous crop (to determine effective plant root zone)
- Restrictive (compacted) soil layers to root development and water movement; i.e., tillage pans
- Mineral layers
- Hard pans or bedrock
- Soil textural changes

Inventory and data collection

Steps to following during irrigation are:

Step 1—Irrigate with inflow rates normally used by the irrigator, and record starting time.

Step 2—Measure and record the inflow rate at 5- to 10-minute intervals until it reaches a constant rate. During the trial, periodically check inflow rate and record the values. More frequent checks are needed if the inflow rate fluctuates considerably.

Step 3—Observe and record how well water spreads across as water advances down the border strip.

Step 4—Record the time when the leading edge of the water reaches each station. If the leading edge is an irregular line across the border strip, average the time as different parts of the leading edge reach the station.

Step 5—Fill cylinder infiltrometers (rings) as the leading edge of the water flow in the border passes through the test site. An alternative to measuring infiltration while the border is being irrigated is to build berms (or install a larger ring) around infiltrometers being measured. Maintain water between the berm and infiltrometer ring at the same time water is poured into and measured inside infiltrometer rings. Using a hook gauge or other water level recording device, record water levels in each infiltrometer at times shown on the infiltrometer worksheet. See procedure and worksheets in section 652.0905, Soil intake determination procedure.

Step 6—If there is runoff, record the time when it starts. If outflow is being measured, periodically measure the flow rate and record the rate and time of measurement until it ceases.

Step 7—Record the time when water is turned off at the head of the border and the time water recedes past each station. This requires good judgment. On slopes of 0.5 percent or greater, a large part of the water remaining in the border strip when the supply is shut off may move downslope in a fairly uniform manner. On these fields, record recession time at each station when the water has disappeared from the area above it. If the recession line across the border strip is irregular, record the time when less than 10 to 20 percent of the area is covered by water. Another method is to judge when there is about as much cleared area below the station as there is above the station.

Step 8—On slopes of less than 0.5 percent, a smaller proportion of the water moves down the strip. Some water may be trapped in small depressions and may not be absorbed for some time after surrounding areas are clear. The important thing is to determine when the intake opportunity time has essentially ceased. The recession time may be recorded for a station when 80 to 90 percent of the area between it and the next upstream station has no water on the surface.

Step 9—Immediately after recession, use a probe or auger to check depth of water penetration at several locations down the border. A check at this time will indicate the depth to which water has already percolated. A ball type probe (a 1/2-inch diameter ball welded onto the end of a 3/8-inch diameter push probe) is handy for this task. In the absence of rock, the probe inserts easily where soil has been lubricated by water, and stops abruptly when the wetted front (dry soil) is encountered.

Step 10—If possible, check for adequacy and uniformity of irrigation time when the soil profile has reached field capacity. Sandy soils can be checked 4 to 24 hours after irrigation. Clayey soils typically are checked about 48 hours after irrigation when most gravitational water has drained.

Step 11—If field capacity must be established, determine the soil water content when checking the adequacy of irrigation. With uniform soils, a previously irrigated border strip can be used for this purpose at the same time cylinder infiltrometer rings are being observed.

(iii) Evaluation computations—Information gathered in the field procedures is used in the detailed system evaluation computations. Example 9–2 outlines computations used to complete the Surface Irrigation System Detailed Evaluation Graded Border Worksheet (exhibit 9–2)

Exhibit 9–2 Completed worksheet—Surface irrigation system, detailed evaluation of graded border system

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Sheet 1 of 8

Example - Surface Irrigation System Detailed Evaluation
Graded Border Worksheet

Land user Joe Example Field office ____
Field name/number West 40
Observer ____ Date ____ Checked by ____ Date ____

Field Data Inventory:
Field area 40 acres
Border number 5 as counted from the North side of field
Crop Alfalfa Root zone depth ____ ft MAD 3.6 %
Stage of crop ____

Soil-water data for controlling soil:
Station 2+00 Moisture determination method Feel & appearance
Soil series name Glenberg loam

Depth	**Texture**	**AWC (in)***	**SWD (%)***	**SWD (in)***
0 - 1'	L	2.0	50	1.0
1 - 2'	LFS	1.5	40	0.7
2 - 3.5'	VFLS	2.2	40	0.9
3.5 - 5.0'	GLS	1.5	20	0.3
	Total	7.2		2.9

MAD, in = $\frac{\text{MAD, \% x total AWC, in}}{100}$ = $\frac{50 \text{ X } 7.2}{100}$ = 3.6 in

Comments about soils: Compact layer @ 10 - 14 inches

Typical irrigation duration 1.5 hr, irrigation frequency 14 days
Typical number of irrigation's per year 12 +/-
Annual net irrigation requirement, NIR (from irrigation guide) 22.1 in
Type of delivery system (gated pipe, turnouts, siphon tubes) Siphon tubes from concrete lined head ditch

Delivery system size data (pipe size & gate spacing, tube size & length, turnout size) 5 - 4" siphon tubes per border

Border spacing 30', Strip width 28', Wetted width 29', Length 700'

Field Observations:
Evenness of water spread across border Notes

Crop uniformity Notes

Other observations Notes

NOTE: MAD = Management allowed deficit AWC = Available water capacity SWD = Soil water deficit

Exhibit 9–2 Completed worksheet—Surface irrigation system, detailed evaluation of graded border system—Continued

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Sheet 2 of 8

Example - Surface Irrigation System Detailed Evaluation
Graded Border Worksheet

Data: Inflow X Outflow ___________

Type of measuring device 5– 4"x10' Al. siphon tubes

Clock [1] time	Elapsed time (min)	Δ T (min)	Gage H (ft)	Flow rate (gpm)	Average flow rate (gpm)	Volume [2] (ac-in)	Cum. volume (ac-in)
Turn on (1051)	0		.25	490			
		9			525	.1740	.1740
1100	9		.33	560			
		10			625	.2302	.4042
1110	19		.50	690			
		10			657	.2402	.6462
1120	29		.41	625			
		15			627	.3464	.9926
1135	44		.42	630			
		15			632	.3491	1.3417
1150	59		.43	635			
		38			635	.8887	2.2304
1228	97		.43	635			
Turn off (1228)							

Total volume (ac-in) 2.23

Average flow rate =

$$\frac{\text{Total irrigation volume (ac-in)} \times 60.5}{\text{Inflow time (min)}} = \frac{2.23 \times 60.5}{97} = 1.4 \text{ ft}^3\text{/s}$$

Unit flow:

$$q_u = \frac{\text{Average flow rate}}{\text{Border strip spacing}} = \frac{1.4}{30} = 0.047 \text{ ft}^3\text{/s/ft}$$

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. should be recorded as 1330 hours.

2/ Flow rate to volume factors:

Find volume using ft^3/s: Volume (ac-in) = .01653 x time (min) x flow (ft^3/s)

Find volume using gpm: Volume (ac-in) = .00003683 x time (min) x flow (gpm)

Exhibit 9–2 Completed worksheet—Surface irrigation system, detailed evaluation of graded border system—Continued

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Sheet 3 of 8

Example - Surface Irrigation System Detailed Evaluation
Graded Border Worksheet

Graded border advance recession data

	Advance time			Recession time			
Station (ft)	Clock* time	Δ T (min)	Elapsed time (min)	Clock* time	T (min)	Elapsed time 1/ (min)	Opportunity time (T_o)
0+00				Turn off (1228)	Lag (13)		Inflow T 2/ (97)
0+00	Turn on (1051)		0	1241		110	110
1+00	1101	10	10	1316	35	145	135
2+00	1115	14	24	1332	16	161	137
3+00	1127	12	36	1348	16	177	141
4+00	1141	14	50	1356	8	185	135
5+00	1156	15	65	1401	5	190	125
6+00	1215	19	84	1404	3	193	109
7+00	1241	26	110	1407	3	196	86

*Use a 24 -hour clock reading; i.e., 1:30 p.m. would be recorded as 1330 hours.

1/ Time since water was turned on.
2/ Inflow time = turn off time - turn on time.

Exhibit 9–2 Completed worksheet—Surface irrigation system, detailed evaluation of graded border system—Continued

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Example - Surface Irrigation System
Detailed Evaluation Graded Border Worksheet

Depth infiltrated

		Typical intake curve		Adjusted intake curve	
Station	Opportunity time [1/] T_Q (min)	Depth [2/] infiltrated (in)	Ave. depth infiltrated (in)	Depth [3/] infiltrated (in)	Ave. depth infiltrated (in)
0+00	110	3.6	▨	4.0	▨
1+00	135	4.1	3.9	4.5	4.3
2+00	137	4.1	4.1	4.5	4.5
3+00	141	4.2	4.2	4.7	4.6
4+00	135	4.1	4.1	4.5	4.6
5+00	125	3.9	4.0	4.3	4.4
6+00	109	3.6	3.8	4.0	4.1
7+00	86	3.1	3.3	3.4	3.7
Border extension					
8+00		2.3			
9+00		0			
		Sum of ave. depths	31.3		34.5

1/ Difference in time between advance and recession curve.
2/ From "typical" cumulative intake curve.
3/ From "adjusted" cumulative intake curve.

Average depth infiltrated (typical)

$$= \frac{\text{Sum of depths (typical)}}{\text{Length (hundreds of feet-extended)}} = \frac{31.3}{9} = 34.5 \text{ in}$$

Extended border area (acres)

$$= \frac{\text{Extended border length x wetted width}}{43{,}560} = \frac{900 \text{ x } 29}{43{,}560} = 0.60 \text{ acres}$$

Actual average depth applied to extended border length

$$= \frac{\text{Ave inflow (ft}^3\text{/s) x duration (hr)}}{\text{Extended border area (acres)}} = \frac{1.4 \text{ x } 97/60}{0.60} = 3.8 \text{ in}$$

Average depth infiltrated (adjusted)

$$= \frac{\text{Sum of depths (adjusted)}}{\text{Length (hundreds of feet - extended)}} = \frac{34.5}{9} = 3.8 \text{ in}$$

Note: Should be close to actual depth applied.

Exhibit 9–2 Completed worksheet—Surface irrigation system, detailed evaluation of graded border system—Continued

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Example - Surface Irrigation System Detailed Evaluation
Graded Border Worksheet

Average depth infiltrated low 1/4 (LQ):

$$\text{Low 1/4 strip length} = \frac{\text{Actual strip length}}{4} = \frac{700}{4} = 175 \text{ ft}$$

$$\text{LQ} = \frac{\text{(Depth infiltrated at begin of L1/4 strip) + (Depth infiltrated at the end of L1/4 strip)}}{2}$$

$$= \frac{4.2 + 3.4}{2} = 3.8 \text{ in}$$

Areas under depth curve:

1. Whole curve 33.9 sq in
2. Runoff 4.4 sq in
3. Deep percolation 9.2 sq in
4. Low quarter infiltration 26.6 sq in

Actual border strip area:

$$= \frac{\text{(Actual border length, ft) x (Wetted width, ft)}}{43{,}560} = \frac{700 + 29}{43{,}560} = .47 \text{ acres}$$

Distribution uniformity low 1/4 (DU):

$$\text{DU} = \frac{\text{Low quarter infiltration area x 100}}{\text{(Whole curve area - runoff area)}} = \frac{26.6 \times 100}{33.4 - 4.4} = 92\ \%$$

Runoff (RO):

$$\text{RO, \%} = \frac{\text{Runoff area x 100}}{\text{Whole curve area}} = \frac{4.4 \times 100}{33.9} = 13\ \%$$

$$\text{RO} = \frac{\text{Total irrigation volume, ac-in x RO, \%}}{\text{Actual strip area, ac x 100}} = \frac{2.23 \times 13}{.47 \times 100} = 0.62 \text{ in}$$

Deep percolation, DP:

$$\text{DP} = \frac{\text{Deep percolation area x 100}}{} = \frac{9.2 \times 100}{33.9} = 28\ \%$$

$$\text{DP} = \frac{\text{Total irrigation volume, ac-in x DP, \%}}{\text{Actual strip area, ac x 100}} = \frac{2.23 \times 28}{.47 \times 100} = 1.33 \text{ in}$$

Exhibit 9–2 Completed worksheet—Surface irrigation system, detailed evaluation of graded border system—Continued

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Sheet 6 of 8

Example - Surface Irrigation System Detailed Evaluation
Graded Border Worksheet

Evaluation computations, cont:

Gross application, F_g:

$$F_g = \frac{\text{Total irrigation volume, ac-in}}{\text{Actual strip area, ac}} = \frac{2.23}{.47} = 4.7 \text{ in}$$

Application efficiency, E_a:

(Average depth stored in root zone = Soil water deficit (SWD) if entire root zone depth will be filled to field capacity by this irrigation, otherwise use F_g, in - RO, in)

$$E_a = \frac{\text{Average depth stored in root zone} \times 100}{\text{Gross application, in}} = \frac{2.9 \times 100}{4.7} = 62\ \%$$

Application efficiency low 1/4, E_q:

$$E_q = \frac{DU \times E_a, \%}{100} = \frac{92 \times 62}{100} = 56.8\ \%$$

Average net application, F_n

$$F_n = \frac{\text{Total irrigated volume, ac-in} \times E_a, \%}{\text{Actual strip area, ac} \times 100} = \frac{2.23 \times 56.8}{.47 \times 100} = 2.7\ \%$$

Time factors:

Required opportunity time to infiltrate soil water deficit of 3.0 in

T_o = 70 min (1 hr - 10 min)

Estimated required irrigation inflow time from adv.-recession curves;

T_{in} = 81 min (1 hr - 21 min)

At inflow rate of:

Q = 1.4 ft^3/s per border strip

Exhibit 9–2 Completed worksheet—Surface irrigation system, detailed evaluation of graded border system—Continued

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Sheet 7 of 8

Example - Surface Irrigation System Detailed Evaluation
Graded Border Worksheet

Present management:

Estimated present average net application per irrigation 3.0 inches

Present gross applied per year = $\dfrac{\text{Net applied per irrigation x number of irrigations x 100}}{\text{Application efficiency } (E_a)^{1/}}$

= $\dfrac{3.0 \times 12 \times 100}{62}$ = 58 in

1/ Use the best estimate of what the application efficiency of a typical irrigation during the season may be. The application efficiency from irrigation to irrigation can vary depending on the SWD, set times, etc. If the irrigator measures flow during the season, use that information.

Potential management:

Annual net irrigation requirement 22.1 inches, for alfalfa (crop)

Potential application efficiency (E_{pa}) 70 percent (from irrigation guide, NEH or other source)

Potential annual gross applied = $\dfrac{\text{Annual net irrigation requirement x 100}}{\text{Potential application efficiency } (E_{pa})}$

= $\dfrac{22.1 \times 100}{70}$ = 31.6 in

Total annual water conserved

= $\dfrac{\text{(Present gross applied - potential gross applied) x area irrigation (ac)}}{12}$

= $\dfrac{(58 - 31.6) \times 40}{12}$ = 91 acre feet

Annual cost savings:

Pumping plant efficiency 55 Kind of fuel electric

Cost per unit of fuel 7¢/kwh Fuel cost per acre foot $ 14.33

Cost savings = Fuel cost per acre foot x acre feet conserved per year

= 14.33 x 91 = $ 1304

Exhibit 9–2 Completed worksheet—Surface irrigation system, detailed evaluation of graded border system—Continued

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Example - Surface Irrigation System Detailed Evaluation
Graded Border Worksheet

Potential water and cost savings, cont.

Water purchase cost

= Cost per acre foot x acre feet saved per year = 12 x 91

= $ 1092

Cost savings = pumping cost + water cost = 1304 + 1092 = $ 2396

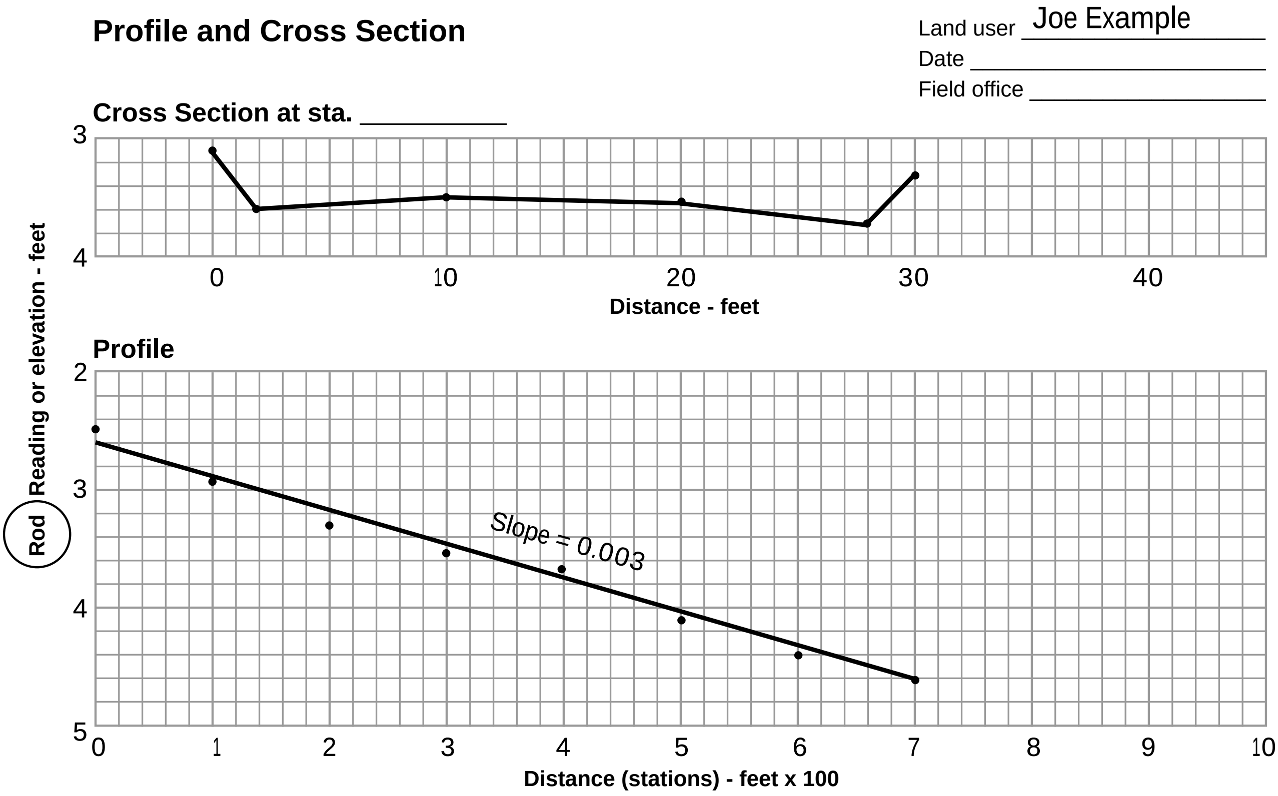
Recommendations

Notes

Example 9–2 Evaluation computation steps

1. **Plot the border downslope profile and cross section.**
The plot displayed in figure 9–14 shows uniformity of downslope and cross slope. Average downslope gradient is determined.

Figure 9–14 Border downslope profile and cross-section

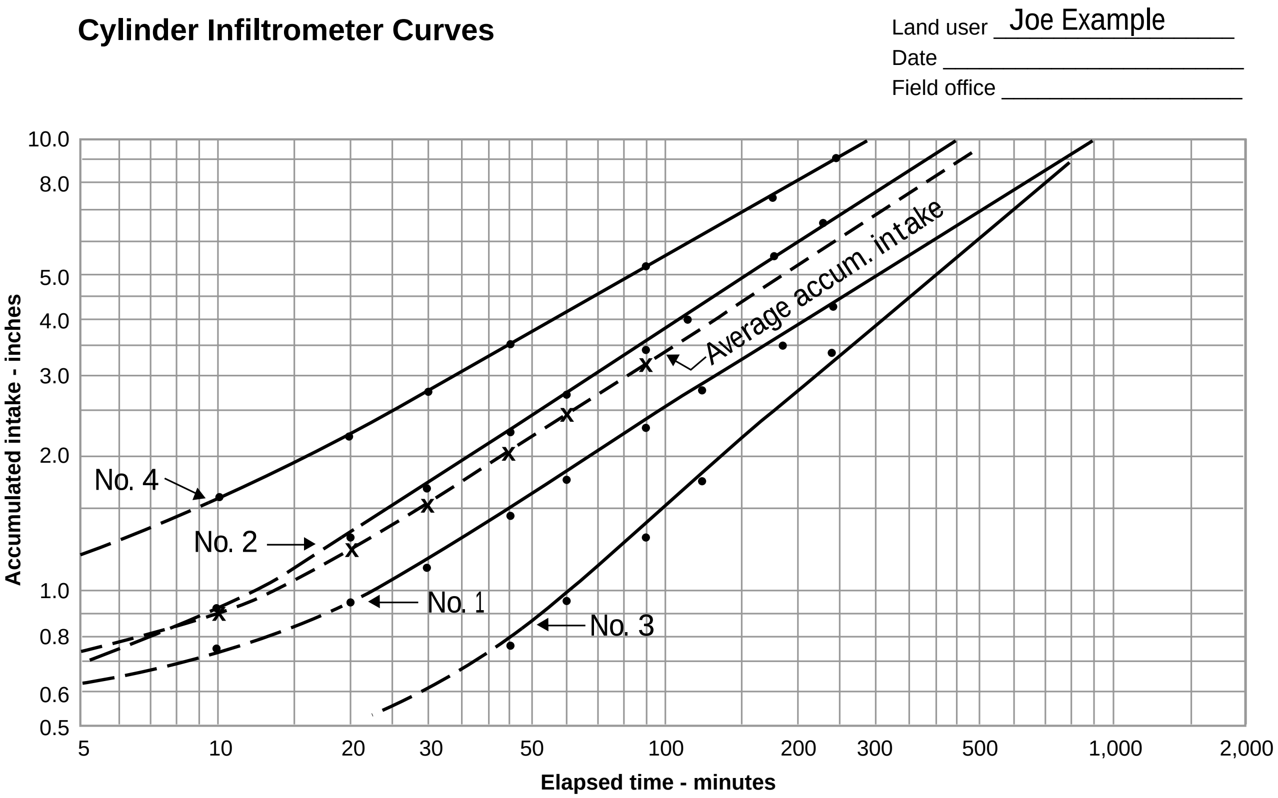


Example 9–2 Evaluation computation steps—Continued

2. **Compute the soil water deficit (SWD).** Compute SWD as shown on worksheet at the test location. This is the net depth of application (F_n) needed for the evaluated irrigation.

3. **Plot a cumulative intake curve for each infiltrometer.** Using log-log paper (fig. 9–15), plot the cumulative intake curve for each infiltrometer and the average of all infiltrometers used. Example field cylinder infiltrometer data are shown in figure 9–16. After all curves have been plotted on the same sheet and deviations have been considered, a typical straight line can be drawn for use in the evaluation. The typical position is later adjusted to represent the duration of irrigation used by the irrigator.

Figure 9–15 Cylinder infiltrometer curves



Example 9–2 Evaluation computation steps—Continued

Figure 9–16 Cylinder infiltrometer test data

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Cylinder Infiltrometer Test Data

NRCS-ENG-322
02-96

FARM Joe Example	COUNTY	STATE	LEGAL DESCRIPTION NW 1/4 S27, T3N, R28E	DATE
SOIL MAPPING SYMBOL	SOIL TYPE Glenberg Loam	SOIL MOISTURE: 0' - 1' - % of available 40% 1' - 2' - % of available 50%		
CROP Alfalfa	STAGE OF GROWTH 1 week after cutting			

GENERAL COMMENTS
Compacted layer between 10 & 14 inches

Elapsed time	Cylinder No. 1			Cylinder No. 2			Cylinder No. 3			Cylinder No. 4			Cylinder No. 5			Average accum. intake
	Time of reading	Hook gage reading	Accum. intake	Time of reading	Hook gage reading	Accum. intake	Time of reading	Hook gage reading	Accum. intake	Time of reading	Hook gage reading	Accum. intake	Time of reading	Hook gage reading	Accum. intake	
Min.		Inches			Inches			Inches			Inches			Inches		
0	11:15	1.80	0	11:16	2.10	0	11:18	3.21	0	11.19	4.10	0				0
5	11:20	2.44	.64	11:22	2.80	.70	11:23	3.56	.35	11:24	5.30	1.20				.72
10	11:25	2.57	.77	11:26	3.05	.95	11:27	3.64	.43	11:28	5.75	1.65				.95
20	11:35	2.76	.96	11:37	3.45	1.35	11:38	3.72	.51	11:39	6.30	2.20				1.26
30	11:45	2.95	1.15	11:46	3.80	1.70	11:47	3.82	.61	11:48	6.85	2.75				1.55
45	12:00	3.25	1.45	12:01	4.35	2.25	12:03	3.97	.76	12:04	7.60	3.50				1.99
60	12:15	3.58	1.78	12:17	4.80	2.70	12:18	4.15	.94	12:19	8.20	4.10				2.38
90	12:45	4.05	2.25	12:46	5.50	3.40	12:47	4.51	1.30	12:47	9.20	5.10				3.01
120	13:15	4.50	2.70	13:16	6.10	4.00	13.17	4.91	1.70	13.18	10.10/ 3.90	6.00				3.60
180	14:15	5.30	3.50	14:17	7.50	5.40	14:18	5.71	2.50	14:19	5.6	7.70				4.78
240	15:15	6.20	4.40	15:16	8.80	6.70	15:18	6.61	3.40	15:19	6.9	9.00				5.88

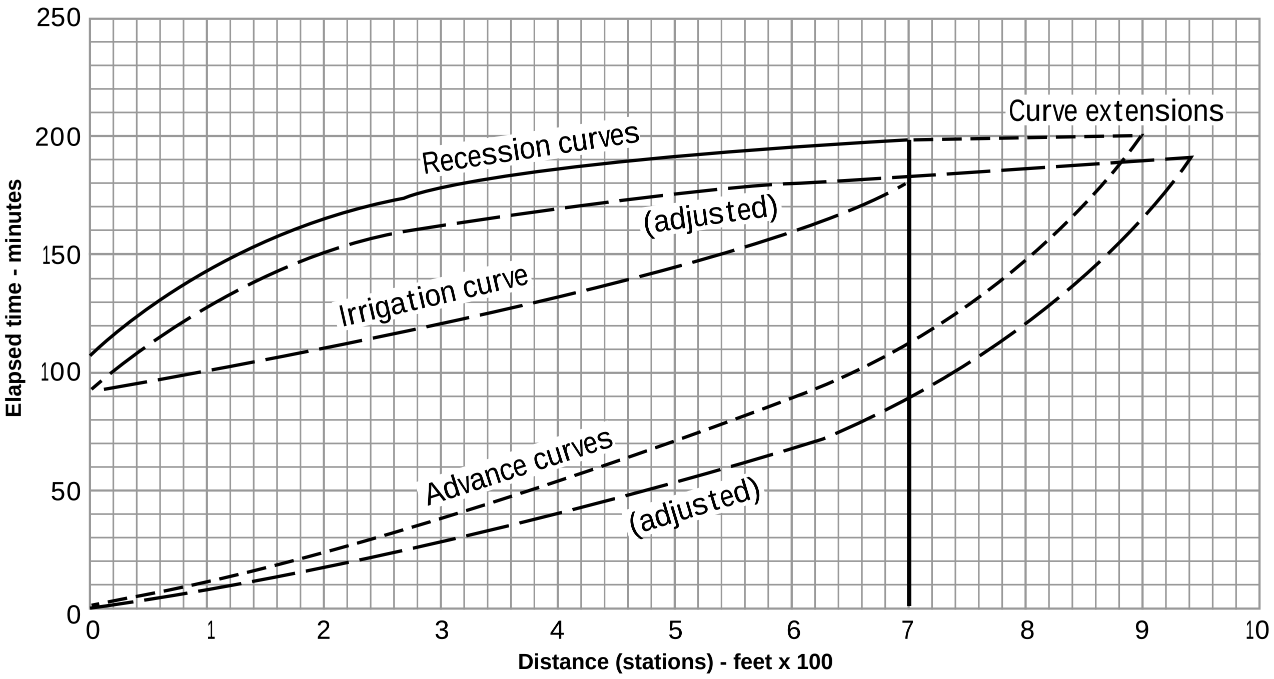
Example 9–2 Evaluation computation steps—Continued

4. **Plot advance and recession curves (time versus distance) using figure 9–17.** If runoff was not measured, extend the advance and recession curves where the lines intersect (close the ends off). This extended area represents an estimate of border runoff.

Figure 9–17 Advance and recession curves

Advance and recession curves

Land user Joe Example
Date ______
Field office ______



Example 9–2 Evaluation computation steps—Continued

5. Plot the adjusted cumulative intake curve:

- Determine and record opportunity time for each station, including extended curves on the worksheet. At each station on the border, the opportunity time (time water was on the ground) is determined by measuring the vertical interval (time) between the advance and recession curves.
- Determine and record the depth infiltrated for each station using the opportunity times from the typical cumulative intake curve. Do this for all stations to the extended end of the plotted advance and recession curves. Plotted points beyond the end of the field represent field runoff.
- Compute the average depth of water infiltrated for each station on the worksheet. The depth for a partial station at the end should be proportional to the station length. Total these average depths.
- Determine average typical depth:

$$\text{Ave. typical depth} = \frac{\text{Sum of ave. depths (typical)}}{\text{Length (hundreds of ft)}^{1/}}$$

To check if the location of the typical curve is correct, the actual average depth of water applied is computed:

$$\text{Ave. depth of water applied} = \frac{(\text{Average inflow, in ft}^3/\text{s}) \times \left(\text{Duration, in hr}\right)}{(\text{Extended border strip area, in acres})}$$

(Use the wetted border width and extended border length to compute the area of the border)

- Correct curve, if needed. A correction is often needed because the infiltrometers check the infiltration at only one spot in the border strip. However, the slope of that curve is probably typical of the average curve for the strip. An adjusted curve, since it is based on the infiltrometer curve slope and actual average depth infiltrated, closely represents the average cumulative intake curve for the border strip and the field.
- Draw an adjusted cumulative intake curve parallel to the typical intake curve prepared from plotted points. The adjusted curve is located as follows:

> Using the average intake curve and the average depth infiltrated (3.48 inches), find the corresponding average opportunity time (100 minutes). Then plot a point on 100 minutes and the actual depth applied (3.8 inches). Now draw a line parallel to the average intake curve and through the point at 100 minutes and 3.8 inches. This is the adjusted intake curve. This curve can be plotted on the same worksheet as the field curves or on a separate worksheet. See figure 9–18.

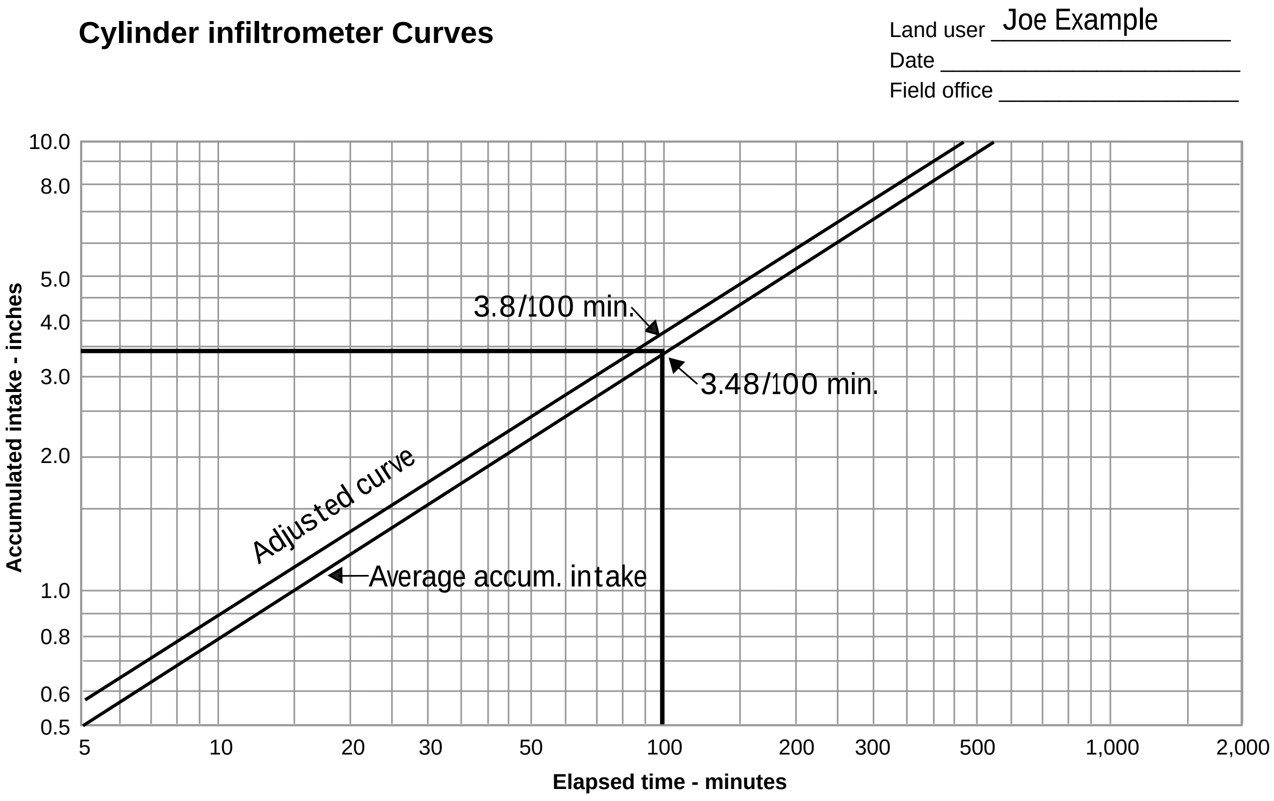
- As a check, the adjusted depths at each station are determined and recorded on page 5 of the worksheet. The averages of these depths are computed and their total is used to compute the adjusted average depth, which should compare closely to the computed actual depth for extended border length:

$$\text{Adjusted ave. depth} = \frac{\text{Sum of average depths (adjusted)}}{(\text{Length, hundreds of ft})^{1/}}$$

1/ Would be 50 feet, if 50-foot stations are used.

Example 9–2 Evaluation computation steps—Continued

Figure 9–18 Cylinder infiltrometer curve



Example 9–2 Evaluation computation steps—Continued

6. Plot a depth infiltrated curve (fig. 9–19) as follows:

- Plot a cumulative depth infiltrated versus distance curve using depths read from the adjusted intake curve recorded in the previous step.
- Draw a horizontal line at a depth equal to the soil water deficit (SWD).
- Draw a vertical line at the end of border.
- Determine location and length of the low quarter segment of the actual border length. In most cases, this is located at the lower end of the border if blocked ends are not used. On steeply sloping borders, it can occur at the upper end.

$$\text{Low 1/4 length} = \frac{\text{Actual border length, ft}}{4}$$

- Compute average depth infiltrated for low quarter:

$$\text{LQ depth} = \frac{\left(\text{Depth infiltrated begin of low } \frac{1}{4}\right) + \left(\text{depth infiltrated end of low } \frac{1}{4}\right)}{2}$$

- Using a planimeter (or by counting squares), determine the areas under the curve at each border station (see fig. 9–19).

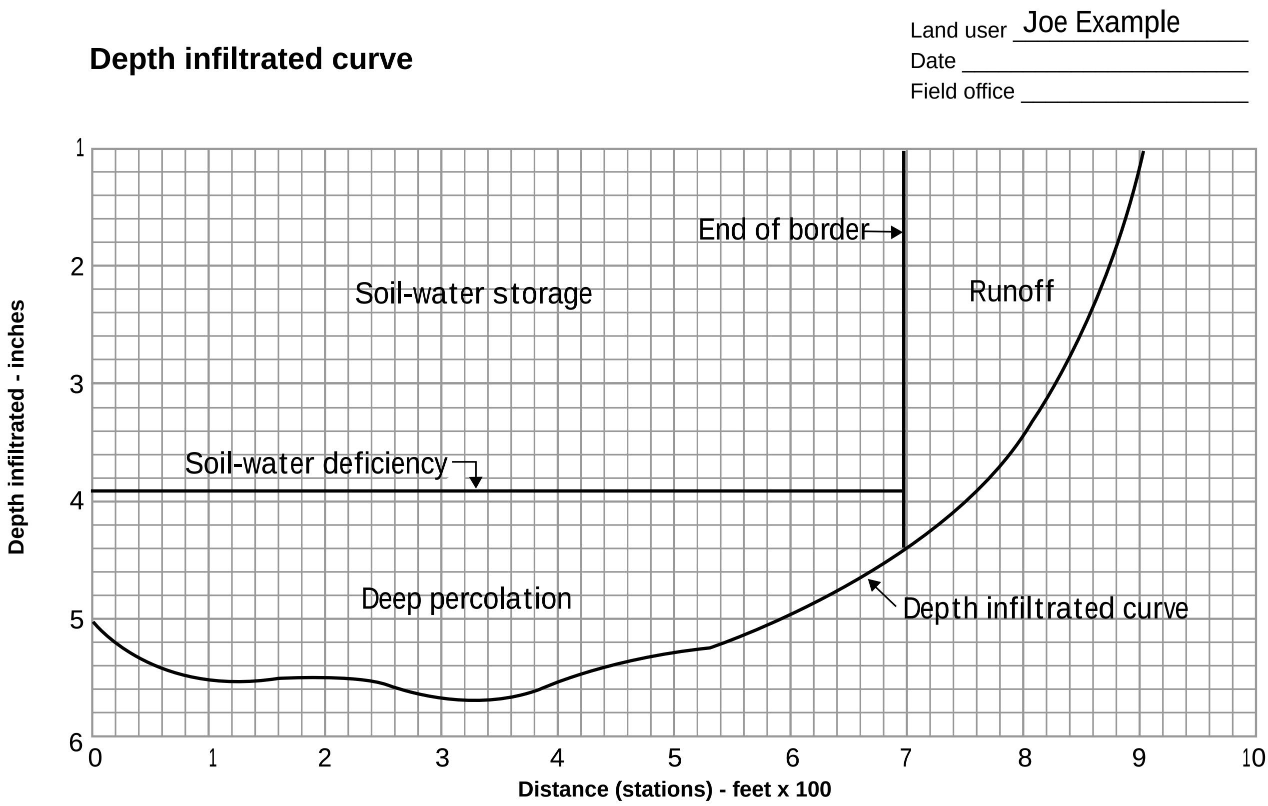
  Plot the LQ distance on the infiltration curve. Measure the area below the curve between this distance and to the left of the downstream end of the border. This is the low quarter infiltration.

  Measure the runoff from the border. This is the area below the curve to the right of the end of the border strip. If runoff was measured, this can be checked by computing total actual runoff volume.

  Measure deep percolation. This is the area to the left of the end of the border and above the SWD line.

Example 9–2 Evaluation computation steps—Continued

Figure 9–19 Depth infiltrated curve



Example 9–2 Evaluation computation steps—Continued

7. Compute irrigation characteristics:

$$\text{Actual border strip area, acres} = \frac{(\text{actual border length, ft}) \times (\text{wetted width, ft})}{43{,}560\ \text{ft}^2/\text{acre}}$$

$$\text{Distribution uniformity low } \frac{1}{4} \text{ DU} = \frac{(\text{Low quarter infiltration area})}{(\text{whole curve area} - \text{runoff area})}$$

where:
DU= distribution uniformity of low quarter

- Total irrigation volume (in acre inches) from the inflow data tabulation:

$$\text{RO} = \frac{(\text{runoff area}) \times 100}{\text{whole curve area}}$$

where:
RO = runoff, %

$$\text{RO depth} = \frac{(\text{total irrigation volume, ac-in}) \times \text{RO\%}}{(\text{actual border strip area, ac}) \times 100}$$

$$\text{DP} = \frac{(\text{deep percolation area}) \times 100}{(\text{whole curve area})}$$

where:
DP = deep percolation depth, %

$$\text{DP depth, inches} = \frac{(\text{total irrigation volume, ac-in}) \times \text{DP\%}}{(\text{actual border strip area, ac}) \times 100}$$

$$F_g \text{ depth, inches} = \frac{(\text{total irrigation volume, ac-in})}{(\text{actual border strip area, ac})}$$

where:
F_g = gross application depth, in

Example 9–2 Evaluation computation steps—Continued

- Application efficiency (E_a) is the ratio of average depth of water stored in the root zone to gross application depth. In most cases for graded border irrigation, the entire root zone is filled to field capacity by the irrigation. If this is the case, E_a is the ratio of soil water deficit to gross application. Otherwise, it is the ratio of gross application, less runoff to gross application.

$$E_a = \frac{(\text{Ave. depth in root zone, in inches}) \times 100}{(\text{Gross application depth, in inches})}$$

$$E_q = (\text{DU}) \times E_a$$

where:
E_q = application efficiency low quarter, %

8. **Determine the opportunity time required to infiltrate the SWD.** Use the adjusted cumulative intake curve to make your determination.

9. **Estimate the inflow time required to infiltrate the SWD using the evaluation inflow.** Use an analysis of advance and recession curves and the required irrigation curve to make your estimate.

Potential water conservation and pumping costs savings

1. **Make a best estimate of the present average net application per irrigation.** This is based on information from the farmer about present irrigation scheduling and application practices and on data generated during the evaluation.

2. **Compute an estimate of the gross amount of irrigation water used per year.** Use the estimated average net application, average number of annual irrigations (from farmer), and application efficiency determined by the evaluation to compute annual gross:

$$\text{Annual gross water applied} = \frac{(\text{Net applied per irrigation, in}) \times (\text{number of irrigations}) \times 100}{E_a}$$

3. **Determine annual net irrigation requirements for the crop to be managed.** Use the information in chapter 4 of this guide.

4. **Determine potential application efficiency (E_{pa}).** Make your determination using information in this guide or from table 4–12, Design efficiency for graded borders, National Engineering Handbook, section 15, chapter 4.

Example 9–2 Evaluation computation steps—Continued

5. **Compute potential gross amount to be applied per year:**

$$F_g = \frac{\left(\text{Annual net irrigation requirement}\right) \times 100}{E_{pa}}$$

where:
F_g = gross application for year, in
E_{pa} = potential application efficiency, %

6. **Compute total annual water conserved (ac-in):**

Total annual water conserved:
[(Potential gross applied, in) – (Present gross applied, in)] x (Area irrigated, ac)

7. **If pumping cost is a factor, compute cost savings:**
   - Pumping cost savings: From a separate pumping plant evaluation, determine pumping plant efficiency, kind of fuel, cost per unit of fuel, and fuel cost per acre-inch. Compute fuel cost savings:

     Fuel Savings = (Fuel cost per acre inch) x (Acre-inches conserved per year)

   - Water purchase cost savings: Obtain purchase cost data from farmer or water company. Compute as follows:

$$\text{Water cost savings} = \frac{\left(\text{Cost per acre-foot}\right) \times \left(\text{Acre-inches saved per year}\right)}{12}$$

   - Compute total potential cost savings:

     Total potential savings = Pumping cost savings + Water cost savings

Analysis of data and preparation of recommendations:

1. **Compare soil water deficit (SWD) with management allowable depletion (MAD).** This indicates whether the irrigation was correctly timed, too early, or too late.

2. **Analyze the advance and recession curves and identify management or system changes that might be made.**
   - Use the required net application (F_n) from the adjusted cumulative intake curve to determine required opportunity time (T_o).
   - Using T_o, draw an ideal recession curve equal to T_o above the advance curve (see example).
   - The shape and slope of the recession curve should not change significantly with changes in inflow or duration of flow. By moving the recession curve up or down (changing the time water is applied onto the border strip), required opportunity time can be met at least one point on the curve. To conserve water, minimize runoff, and optimize irrigation efficiency, many irrigators select the point of intersection to be 80 percent of the border length. The lower 20 percent will be under irrigated. If runoff is not a concern, this point of intersection, or management point, can be at the lower end of the border strip.

Example 9–2 Evaluation computation steps—Continued

- Changing inflow rate changes the slope of the advance curve. An estimate of the most efficient flow rate and inflow time can be made as follows:
  - Subtract the required opportunity time (T_o) from the recession time at 0+00. This provides an estimate of the time by which to reduce (or increase) the recession time at the station with the minimum opportunity time.
  - Draw an estimated recession curve parallel to the actual recession curve, equal to the time difference found in the last step.
  - At the downstream end of the border, mark a time, T_o, minutes below the estimated recession curve.
  - Draw an estimated advance curve between 0+00 and the mark made in the last step. This curve should be in about the same shape as the actual advance curve.
  - The actual inflow rate must be determined by trial and error in the field. The amount of change between the actual advance curve and the estimated curve gives some idea of the magnitude of the flow rate change required.
  - To determine required inflow time (T_{in}), subtract the lag time (time between shut off and recession at 0+00) from the required total opportunity time at station 0+00.

Recommendations:

Use field observations, data obtained by discussions with the irrigation decisionmaker, study of the advance recession curves, and data obtained by computations to make practical recommendations. Remember that the data are not exact because of the many variables in soils, crop resistance, slope, and other features. Most effective changes result from a field trial and error procedure based on measured or calculated values. After each new trial, the field should be probed to determine penetration uniformity. Observations can be made to determine the amount of runoff and distribution uniformity. Enough instruction should be given to irrigation decisionmakers so they can observe and take measurements to make necessary adjustments throughout the irrigation season.

Making management changes is always the first increment of change. Recommending irrigation system changes along with appropriate management changes is secondary.

(2) Level borders and basins detailed evaluation

Improving water use efficiency of level border and basin irrigation has great potential for conserving irrigation water and improving downstream water quality. A detailed evaluation provides information for design or to help properly operate and manage a level border irrigation system. It can help the irrigation decisionmaker use proper level border (basin) inflows, lengths of run, and time of inflow for the specific field and crop conditions. Soil intake characteristic has the biggest influence on application uniformity. Intake rate for a specific soil series and surface texture varies from farm to farm, field to field, and throughout the growing season; typically because of the field preparation, cultivation, and harvest equipment. A detailed irrigation system evaluation can tell us the soil intake characteristic for site conditions within a particular field. It can also provide valuable data to support local irrigation guides for planning level border irrigation systems on other farms on similar soils.

(i) Equipment—The equipment for this evaluation includes:

- Engineers level and level rod, 100-foot tape
- Pocket tape marked in inches and tenths/hundredths of feet
- Stakes or flags, marker for stakes or flags
- Flume, weir, or other measuring device to measure inflow
- Carpenters level for setting flume or weir
- Gauge for measuring depth of flow in flow measuring device
- Gallon can(s) or larger for basin stilling well (for windy conditions)
- Soil auger, probe, push type sampler, shovel
- Feel and Appearance Soil Moisture charts, Speedy Moisture Meter/Eley Volumeter, Madera sampler with sample cans, or some other method of determining soil moisture condition
- Level border evaluation worksheets, clipboard, and pencil
- Soils data for field
- Stop watch, camera
- Boots

(ii) Procedures—The field procedures needed to evaluate this system are in two main categories: general and inventory and data collection.

General

Choose a typical basin in the field to be irrigated. The typical location should be representative of the type of soil for which the field is being managed, from an irrigation scheduling standpoint. Use standard soil surveys, where available, to locate border evaluation sites. Then have a qualified person determine the actual surface texture, restricted layers, depth, and other soil characteristics that affect irrigation. Soil surveys are generally inadequate for this level of detail. Almost all mapping units contain inclusions of other soil. Extension of results to other areas also has more reliability. Basin size and configuration should be typical of those in the field. The evaluation should be run at a time when soil moisture conditions are as they will be when irrigation would normally take place.

The field evaluation procedure for basins and level borders uses the whole basin as if it were one large infiltrometer. Inflow volume and volume of water in the basin are measured. Because a small difference in water level in the basin can represent a rather large volume of water, water level changes must be measured accurately.

The field evaluation procedure yields a two-point average intake curve for the basin. The first point on the curve is plotted at the time water is turned off. The second point is defined by plotting the gross application at the average opportunity time. If a more detailed curve is desired or if plot points are desired at earlier times, a cylinder infiltrometer test can be run and plotted (see section 652.0904(g)(1) for procedure). The plotted curve is then adjusted in accordance with the methods described in the procedures for graded border evaluations.

This procedure will use a line of stakes in the direction of water flow; for example, down the center of the level border, to sample opportunity times. In most cases this gives adequate detail for analysis. Water flow in a square basin can be from corner to corner if water enters at a corner.

Typically, values of distribution uniformity and application efficiency of the low quarter cannot be determined exactly because small variations in soil infiltration rate in various parts of the basin and low spots cause appreciable differences in the depth infiltrated. This procedure uses one line of stakes down the basin, which gives an approximation of distribution uniformity. A more refined method of determining distribution uniformity is to stake a complete grid in the basin and determine advance and recession times (and thus time of opportunity) at each grid point. The additional points give more measurements from which to work.

The procedure discussed should be sufficient to provide data for making useful recommendations for modifications in management or the irrigation system. The graded border procedure for evaluation should be used when advance time exceeds half of the opportunity time required to fill the basin. You may be able to roughly determine these times before the evaluation by talking to the irrigator or by observing other basins that have similar soils and inflow. The graded border procedure involves taking cylinder infiltrometer tests and plotting and analyzing advance and recession curves.

Inventory and data collection

Before irrigation starts:

- Get basic information about existing irrigation procedures, concerns, and problems from the irrigation decisionmaker.
- Set stakes or flags at 50- or 100-foot stations down the border. Mark stations on each.
- Take rod readings on the average ground level at each station. Readings should be taken to the nearest 0.05 or 0.01 foot. Take readings at average elevations at each measurement point.
- Set several stilling wells within the level border (basin) for windy conditions.
- Set the measuring device(s) to measure inflow.
- Check the soil water deficit (SWD) at several points in the basin. Use the feel and appearance method, Eley Volumeter/Speedy Moisture Meter, push tube/oven dry, or other acceptable method. For the location chosen as the controlling typical soil, record the SWD data on the evaluation worksheet.
- Make note of soil profile conditions, such as:
  - Depth to water table
  - Apparent root depth of existing or previous crops (for determining effective plant root zone)
  - Soil restrictions to root development; i.e., tillage pans and other compaction layers
  - Mineral layers
  - Hard pans and bedrock
  - Soil textural changes
- Record information about type of delivery system, type and size of turnout(s), width and length of level border or basin.
- Make visual observations of the field including crop uniformity, weeds, erosion problems, crop condition or color changes, and salinity problems. Are there areas receiving too much or not enough water?

During the irrigation:

- Irrigate with the inflow rate normally used by the irrigator and record the start time.
- Check and record the inflow rate several times during irrigation. Record when irrigation ceases (turn-off time).
- Observe advance of the water front across the basin. Record the time water reaches each station. Record the time in 24-hour clock readings. Make this reading as accurately as possible. A small error can make a large difference in water volume. Record readings on the worksheet.
- As soon as water into the basin is turned off, an accurate measurement of water surface elevation in the basin must be determined. This should be done with rod readings to the nearest 0.01 foot. If there is wind or other disturbance in the basin, a stilling well(s) should be set up in the basin to observe water surface elevations. The well can be constructed from a gallon or larger bucket, with the bottom cut out and small holes punched or drilled in the sides below water level. This will buffer wave action. Make sure the measurement location is far enough away from the turnout to not be affected by flow from the turnout. Also, water levels in large basins can vary 0.1 foot or more. Be sure an average water level is used.

- Observe the recession of water in the basin. Record the time when water has receded at each of the stations where advance was recorded. Recession should be determined as that time when no more than 10 percent of the water around the station point is still visible on the surface. Some low spots will most likely be in the basin if laser controlled equipment was not used. Sketch the basin showing an outline of areas still containing surface water at the time that 10 percent of the basin still has water on it. This will indicate the leveling uniformity in the basin.
- Immediately after recession use a probe or auger to check depth of water penetration at several locations in the field. A check at this time will indicate whether water has already percolated too deeply. Typically, the probe penetrates easily where water lubricates the rod and stops abruptly at the wetted front (dry soil). A 3/8-inch diameter steel ball welded onto the point of a 1/4-inch diameter steel rod makes an effective probe.
- If possible, check for adequacy and uniformity of irrigation at a time when the soil profile has reached the field capacity moisture level. Sandy soils can be checked 4 to 24 hours after irrigation. Clayey soils should be checked about 48 hours after irrigation when most gravitational water has drained. Often a previously irrigated basin with similar conditions can be used.
- Field capacity must be established. Determine the soil water content when checking for adequacy and uniformity of irrigation.

Exhibit 9–3 shows a completed worksheet for a level border and basin system evaluation. Example 9–3 outlines the steps taken to complete this exhibit.

Exhibit 9–3 Completed worksheet—Surface irrigation system, detailed evaluation of level border and basins

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Example - Surface Irrigation System Detailed Evaluation
Level Border and Basins Worksheet

Land user Joe Example Field office ____
Field name/number West 40
Observer ____ Date ____ Checked by ____ Date ____

Field Data Inventory:
Border number 3rd border from west side
Crop Alfalfa Actual root zone depth 1/ 5 ft MAD 50 %2/
Stage of crop One week after harvest - 2nd cutting

Soil-water data for controlling soil:
Soil name Lohmiller silty clay
Location of sample Sta. 2+00
Moisture determination method Feel & appearance

Depth	**Texture**	**AWC (in)3/**	**SWD (%)4/**	**SWD (in)**
0-1'	SiC	1.6	60	.96
1-2'	SiC	1.6	50	.80
2-3'	L	2.0	40	.80
3-4'	CL	1.6	40	.64
4-5'	GS	0.5	20	.10
	Total	7.3		3.30

$$\text{MAD} = \frac{(\text{MAD, \%}) \times (\text{total AWC, in inches})}{100} = \frac{50 \times 7.3}{100} = 3.65 \text{ in}$$

Comments about soils: Compost layer at 10 - 14 inches

Typical irrigation duration 2.5 hours, Irrigation frequency 12 days
Annual net irrigation requirements 22 inches, for Alfalfa crop
Typical number of irrigations per year 10
Type of delivery system, describe (earth ditch, concrete ditch, pipeline) Earth ditch

Type and size of turnouts (automated turnout, manual screw gate, alfalfa valve, etc.)
Short 24" dia. pipe w/slide gate

Size of basin: Width 250 ft, Length 800 ft

Field Observations:
Crop uniformity Notes

Salinity problems Notes

Other observations Notes

1/ Measure depth of roots of existing or previous crop
2/ MAD = Management allowed depletion
3/ AWC = Available water capacity
4/ SWD Soil water deficit

Exhibit 9–3 Completed worksheet—Surface irrigation system, detailed evaluation of level border and basins—Continued

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Sheet 2 of 6

Example - Surface Irrigation System Detailed Evaluation
Level Border and Basins Worksheet

1. Basin area (A):

$$A = \frac{\text{Length} \times \text{Width}}{43{,}560} = \frac{250 \times 800}{46{,}560} = 4.6 \text{ acres}$$

2. Gross application, F_g, in inches:

$$F_g = \frac{\text{Total irrigation volume, in ac-in}}{\text{A, ac}} = \frac{18.9}{4.6} = 4.1 \text{ in}$$

3. Amount infiltrated during water inflow, V_i:

V_i = Gross application - Depth infiltrated after turnoff = 4.1 - 1.68 = 2.43 in

4. Deep percolation, DP, in inches:

DP = Gross application - Soil water deficit, SWD = 4.1 - 3.3 = 0.8 in

$$\text{DP, in \%} = \frac{(\text{Soil water depletion, DP in inches}) \times 100}{\text{Gross application, } F_g} = \frac{0.81 \times 100}{4.1} = 19.8 \ \%$$

5. Application efficiency, E_a:

Average depth of water stored in root zone = Soil water deficit, SWD, if the entire root zone average depth will be filled to field capacity by this irrigation.

$$E_a = \frac{(\text{Average depth stored in root zone, } F_n) \times 100}{\text{Gross application, } F_g} = \frac{3.3 \times 100}{4.1} = 80.1 \ \%$$

6. Distribution uniformity, DU:

$$\text{Depth infiltrated low 1/4} = \frac{(\text{max intake - min intake})}{8} + \text{min intake}$$

$$= \frac{4.5 - 3.75}{8} + 3.75 = 3.84$$

$$\text{DU} = \frac{\text{Depth infiltrated low 1/4}}{\text{Gross application, } F_g} = \frac{3.84 \times 100}{4.1} = 93.4$$

7. Application efficiency, low 1/4, E_q:

$$E_q = \frac{\text{DU} \times E_a}{100} = \frac{93.4 \times 80.1}{100} = 74.8 \ \%$$

Exhibit 9–3 Completed worksheet—Surface irrigation system, detailed evaluation of level border and basins—Continued

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Sheet 3 of 6

Example - Surface Irrigation System Detailed Evaluation
Level Border and Basins Worksheet

1. Present management

   Estimated present average net application per irrigation = 3.3 inches

   Present annual gross applied = $\dfrac{\text{(net applied per irrigation) x (number of irrigations) x 100}}{\text{Application efficiency, low 1/4, } E_q}$

   $$= \frac{3.3 \text{ x } 10 \text{ x } 100}{74.8} \text{ x } 100 = 44.1 \text{ in}$$

2. Potential management

   Recommended overall irrigation efficiency, E_{des} 80 %

   Potential annual gross applied = $\dfrac{\text{Annual net irrigation requirements x 100}}{E_{des}}$

   $$= \frac{22.1 \text{ x } 100}{80} = 27.6 \text{ in}$$

3. Total annual water conserved:

   = $\dfrac{\text{(resent gross applied, in - potential gross applied, in) x area irrigated, acres}}{12}$

   + __________ = __________ ac-ft

4. Annual potential cost savings

   From pumping plant evaluation: - NA

   Pumping plant efficiency __________ Kind of fuel __________

   Cost per unit of fuel __________ Fuel cost per acre-foot $ __________

   Cost savings = (fuel cost per acre foot) x (water conserved per year, in ac-ft)

   = __________ x __________ = $ __________

Water purchase cost per acre-foot, per irrigation season $12.00

Water purchase cost savings = (Cost per acre-foot) x (water saved per year, in acre-feet)

= 12.00 x 83 = $ 996

Potential cost savings = pumping cost + water purchase cost = 0 + 996 = $ 996

Exhibit 9–3 Completed worksheet—Surface irrigation system, detailed evaluation of level border and basins—Continued

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Example - Surface Irrigation System Detailed Evaluation Level Border and Basins Worksheet

Recommendations:

Notes

Exhibit 9–3 Completed worksheet—Surface irrigation system, detailed evaluation of level border and basins—Continued

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Example - Surface System
Detailed Evaluation Level Border and Basins Worksheet

Inflow Data

Type of measuring device 36" Trapezoidal sharp crested weir

Clock 1/ time	Elapsed time (min)	Δ T (min)	Gage H (ft^3/s)	Flow rate (ft^3/s)	Average flow rate (ft^3/s)	Volume (ac-in)2/	Cum. volume (ac-in)
Turn on (0705)			.78	6.90			
		5			6.97	.5703	.5703
0710	5		.79	7.04			
		8			7.11	.9402	1.5105
0718	13		.80	7.18			
		18			7.46	2.2196	3.7301
0736	31		.84	7.73			
		29			7.80	3.7391	7.4692
0805	60		.85	7.87			
		30			7.80	3.8680	11.3372
0835	90		.84	7.73			
		31			7.66	3.9252	15.2624
0906	121		.83	7.59			
		29			7.59	3.6384	18.9008
	150						

Turn off (0935)			.83	7.59

Total volume (ac-in) 18.901

Average flow:

Average flow = $\frac{\text{(Total irrigation volume, in ac-in)}}{\text{Inflow time, in minutes}} \times 60.5 = \frac{18.901 \times 60.5}{150} = 7.62$ ft^3/s

Unit:

$q_u = \frac{\text{Average inflow rate, in } ft^3/s}{\text{Border spacing}} = \frac{7.62}{250} = 0.03$ ft^3/s

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. is recorded as 1330 hours.
2/ Flow rate to volume factors:

To find volume using ft^3/s: volume (ac-in) = .01653 x time (min) x flow (ft^3/s)
To find volume using gpm: volume (ac-in) = .00003683 x time (min) x flow (gpm)

Exhibit 9–3 Completed worksheet—Surface irrigation system, detailed evaluation of level border and basins—Continued

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Sheet 6 of 6

Example - Surface System Detailed Evaluation Level Border and Basins Worksheet

Advance - Recession Data

Station (ft)	Elevation (ft)	Advance time 1/ (hr: min)	Recession time 1/ (hr: min)	Opportunity time To (min)	Intake 2/ (in)	Minimum maximum intake (in)
0+00	49.51	0705	1315	370	4.50	4.50 max.
1+00	49.44	0709	1311	362	4.40	
2+00	49.46	0714	1307	353	4.30	
3+00	49.45	0719	1304	345	4.25	
4+00	49.43	0726	1300	324	4.12	
5+00	49.38	0732	1255	323	4.10	
6+00	49.42	0739	1252	313	3.95	
7+00	49.39	0747	1249	302	3.90	
8+00	49.38	0756	1245	289	3.75	3.75 min.
Total	444.86			2991		

Water surface elevation at water turnoff 49.57 ft 3/

Average field elevation = $\frac{\text{elevation total}}{\text{no. of elevations}} = \frac{444.86}{9} = 49.43$ ft

Depth infiltrated after water turnoff
= (water surface at turnoff - average field elev) x 12

= (49.57 - 49.43 x 12 = 1.68 in

Average opportunity time = $\frac{\text{total opportunity time}}{\text{no. of sample locations}} = \frac{2991}{9} = 332$ min

1/ Use 24-hour clock time. As a minimum, record times at upper end, mid point.
2/ Obtain intake from plotted intake curve.
3/ Water surface elevation should be read to nearest 0.01 ft.

Example 9–3 Evaluation computation steps for level border and basin irrigation systems

1. **Determine average field elevations to nearest 0.01 foot.**

2. **Compute average flow rate data.** Use the Inflow Data part of the worksheet to compute the average flow rate based on the flow rate charts for the particular measuring device.

3. **Compute the volume in acre-inches for each measurement time interval.** Use the equations at the bottom of the inflow data sheets to calculate these values.

4. **Determine the total irrigation volume in acre-inches.**

5. **Calculate the average inflow rate:**

$$\frac{(\text{Total irrigation volume, ac-in})\times 60.5}{\text{Inflow time}}$$

6. **Calculate unit flow rate (q_u):**

$$q_u = \frac{(\text{Average flow rate, ft}^3/\text{s})}{(\text{Border spacing, ft})}$$

7. **Compute time period between recorded advance and recession times, in minutes.** This time is the actual opportunity time (T_o) at each station. Record T_o on the worksheet.

8. **Compute the depth infiltrated after water turn-off:**

   (Average water surface elevation at turn-off – Average field elevation) x 12

9. **Find the average opportunity time for the basin.** Average the T_o values for all stations.

10. **Compute the area covered by the basin in acres.**

11. **Compute gross depth of water applied:**

$$\frac{(\text{Total irrigation volume, ac-in})}{(\text{Area of basin, acre})}$$

12. **Compute amount infiltrated during water inflow:**

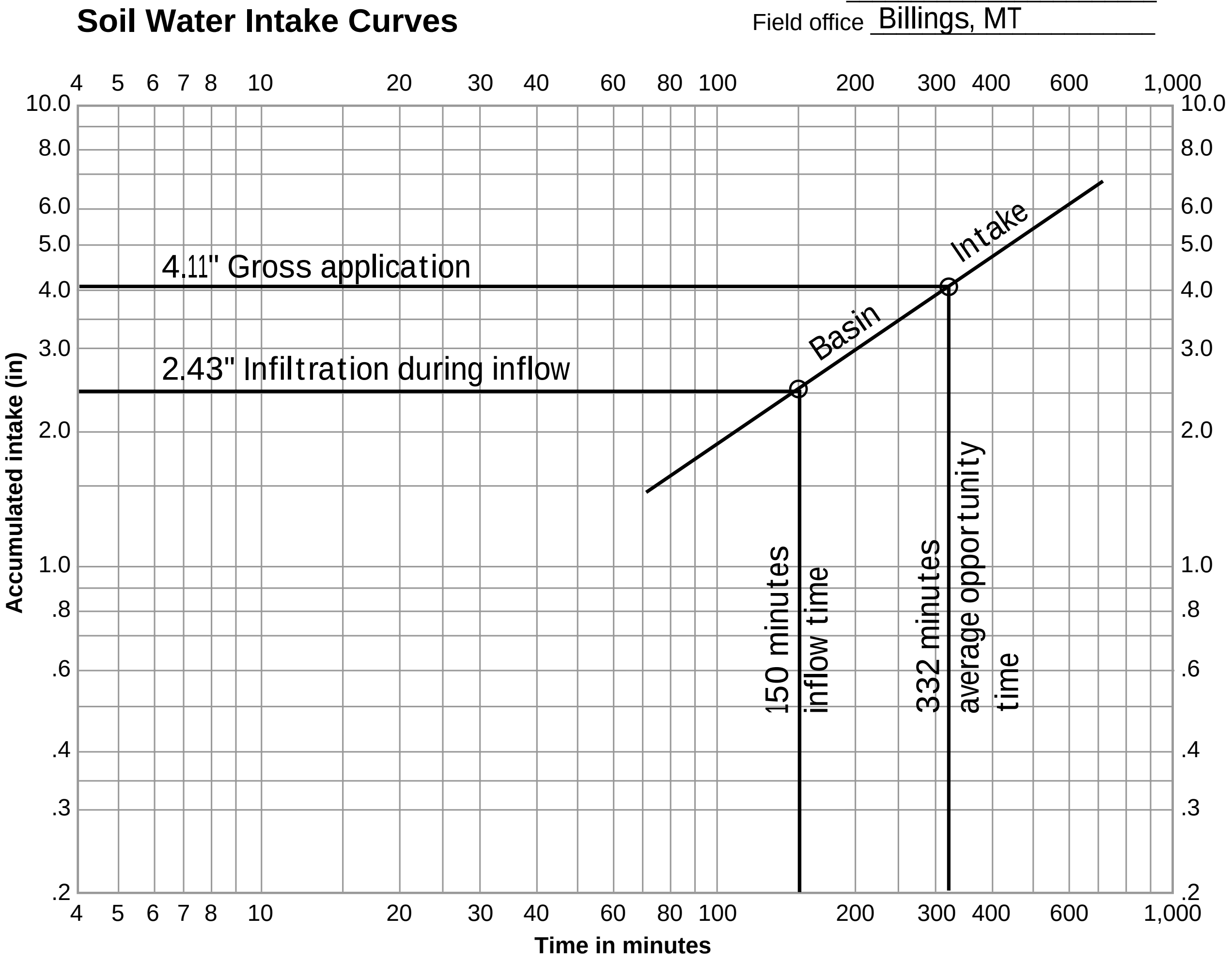
    Gross depth of water applied, inches – Depth infiltration after turnoff, inches

13. **Plot a cumulative intake curve on log-log paper (fig. 9–20).** The first point is the intersection of inflow time and the amount infiltrated during water inflow. The second point is the intersection of the average opportunity time and the gross application. Draw a straight line through the two points to get the average intake curve for the basin.

Example 9–3 Evaluation computation steps for level border and basin irrigation systems—Continued

Figure 9–20 Soil-water intake curve

Land user Joe Example
Date 7/25/84
Locaiton NW1/4,S15,R28E,T2N
Field office Billings, MT



Example 9–3 Evaluation computation steps for level border and basin irrigation systems—Continued

14. Compute deep percolation (DP):

DP = (Average gross application depth, in inches) – (Soil water deficit, SWD, in inches)

$$\text{DP, \%} = \frac{(\text{Deep percolation depth, inches}) \times 100}{(\text{Gross application, inches})}$$

15. Compute application efficiency (E_a). Application efficiency is the ratio of average depth of water stored in the root zone to the gross depth applied. If the entire soil water deficit (SWD) is replaced by the irrigation, then average depth stored in the root zone is equal to the SWD, and the SWD can be used in the calculations. This is often the case with level basin or border irrigation.

$$E_a, \% = \frac{(\text{Ave depth stored in root zone, inches}) \times 100}{(\text{Gross application, inches})}$$

16. Determine the intake amounts, in inches. Using the values of opportunity time (T_o) computed on the Advance-Recession part of the worksheet, determine intake amounts from the intake curve previously plotted. Record these values on the worksheet. Record the maximum and minimum intake amount on the worksheet.

17. Compute the net depth infiltrated (d_n) in the low quarter:

$$\text{Net depth infiltrated, } d_{n,}\text{, inches} = \frac{(\text{max intake, inches}) - (\text{min intake, inches})}{8} + (\text{min intake, inches})$$

Because of the limited number of sample points, this is a rather rough estimate of net depth infiltrated. A more detailed analysis would involve setting a grid of measured points in the basin.

18. Compute distribution uniformity (DU):

$$\text{DU} = \frac{\left(\text{Depth infiltrated low } \frac{1}{4}, \text{inches}\right)}{(\text{Gross application, inches})}$$

Example 9–3 Evaluation computation steps for level border and basin irrigation systems—Continued

Potential water and cost savings:

1. **Make a best estimate of the present average net application per irrigation.** Base your estimate on present irrigation scheduling information, application practices obtained from the irrigation decision-maker, and data derived from the evaluation,

2. **Compute an estimate of the gross amount of irrigation water used per year.** Use the estimated average net application, average number of annual irrigations (from irrigation decisionmaker), and application efficiency found by this evaluation. Compute as follows:

$$\frac{(\text{Net applied per irrigation, inches}) \times (\text{number of irrigations})}{(\text{Application efficiency, } E_a \text{, \%})} \times 100$$

3. **Using the irrigation guide, determine annual net irrigation requirements for the crop to be managed.**

4. **Determine potential application efficiency (E_{pa}).** Use the information in this guide or the chart for estimating efficiency, National Engineering Handbook, section 15, chapter 4 to make your determination.

5. **Compute potential gross amount to be applied per year.** Gross amount applied, in inches:

$$\frac{(\text{Annual net irrigation requirement, inches}) \times 100}{(\text{Potential application efficiency, } E_{pa} \text{, \%})}$$

6. **Compute total annual water conserved.** Acre-feet conserved:

$$\frac{(\text{Present gross applied, inches} - \text{Potential gross applied, inches}) \times (\text{Area irrigated, acres})}{12}$$

7. **If cost is a factor, compute cost savings:**

Pumping cost savings:	From a separate pumping plant evaluation, determine pumping plant efficiency, kind of fuel, cost per unit of fuel, and fuel cost per acre-inch. Compute fuel cost savings: (Fuel cost per acre foot) x (Acre feet conserved per year)
Water purchase cost savings:	Obtain purchase cost data from irrigation decisionmaker or water company. Compute as follows: (Cost per acre foot) x (Acre feet saved per year)
Total potential cost savings:	Pumping cost + water cost = Total potential savings.

Example 9–3 Evaluation computation steps for level border and basin irrigation systems—Continued

Analysis of data and preparation of recommendations:

1. Compare soil water deficit (SWD) with Management allowed deficit (MAD). This indicates whether the irrigation was correctly timed, too early, or too late, and if the correct amount of water was applied.

2. If the basin can be covered in about a fourth of the time needed to irrigate it fully, the adverse effect of unequal opportunity time (T_o) values at various locations within the border will be minimum. If inflow time to cover the basin exceeded a fourth of the opportunity time, determine if there are ways to decrease the inflow time, such as to increase flow rate or decrease basin size.

3. Consider changes that should be made in set time and irrigation scheduling.

4. Consider the need for releveling or changing the basin's size or shape, or both. Experience has shown laser controlled equipment to be superior, especially during final grading. Also with annual crops, annual laser leveling touch up helps maintain the field in an as designed condition and costs no more than releveling every 3 to 4 years.

Use field observations, data obtained by discussion with the irrigation decisionmaker, and data obtained by computations to make some practical recommendations. Remember that the data are not exact. There are many variables. Flow rate changes and other changes result from a trial-and-error procedure. After each new trial the field should be probed to determine water penetration. Enough instruction should be given to operators so they can make these observations and adjustments.

Making management changes is always the first increment of change. Recommending irrigation system changes along with appropriate management changes is secondary.

(3) Graded furrow detailed evaluation

Improving water use efficiency of furrow irrigation has great potential for conserving irrigation water and improving downstream water quality. An abbreviated method of evaluation was presented earlier in this section. A detailed evaluation can determine onsite intake characteristics and provide information for design or to help operate and manage (fine tune) a graded furrow irrigation system. It can help the irrigation decisionmaker use proper furrow inflows, lengths of run, and time of inflow for the specific field and crop conditions.

Soil intake characteristics have the biggest influence on application uniformity. Soil intake rate for a specific soil series and surface texture varies from farm to farm, field to field, within each field, and throughout the irrigation season because of tillage, harvest, and the equipment used. A detailed irrigation system evaluation can identify what the soil intake characteristics are for the site conditions at a particular field. It can also provide valuable data to support local irrigation guides for planning graded furrow irrigation systems on other farms on similar soils.

See American Society of Agricultural Engineer Standard ASAE EP419.1, Evaluation of Irrigation Furrows, for an overall volume balance approach to furrow evaluation.

Observations of the operating condition of delivery system and furrows should be made and recommendations provided for solving any problems. The observation should include:

- Is erosion occurring? head cutting at lower end of furrow? at outlet of siphon or gated pipe? at grade changes? Can erosion problems be solved with conservation treatment measures, such as reduced tillage, no-till, mulching, vegetative strips, crop rotation, or incorporating PAM in the water supply?
- Is sedimentation occurring as a result of furrow erosion? If so, is it occurring in furrow or in tailwater collection ditch?
- Is suspended sediment in irrigation water causing reduced water infiltration as fine material settles out?
- Is trash or debris in water supply causing plugging of siphon tubes or gated pipe outlets, resulting in uneven flow to furrows? Are gates opened excessively wide to allow trash to pass through, resulting in excessive inflow to furrows?
- Is subsurface drainage system operating satisfactorily? Is salinity management satisfactory?
- Are facilities to control surface runoff in place and working properly?

***(i) Equipment*—**The equipment needed for a detailed graded furrow system evaluation includes:

- Engineers level and rod, 100 foot tape
- Pocket tape marked in inches and tenths/hundredths of feet
- Stakes, lath or wire flags for station identification
- Flow measuring devices for measuring furrow inflow and outflow (When measuring furrow inflow where gated pipe or siphons are used, pressure or head differential can be determined and flows calculated. A short piece of clear, small diameter tubing can be used to measure head on outlets in gated pipe. With siphons, tube length and head differential between inlet and outlet can be measured and standard discharge tables used to determine discharge.)
- Carpenters level for setting flumes or weirs
- Equipment for determining soil moisture content, such as feel and appearance charts, Speedy moisture meter and Eley Volumeter, or Madera sampler and soil moisture sample cans)
- Calibrated container for measuring flow if siphon tubes are used
- Soil auger or push tube probe and shovel
- Clipboard, worksheets or evaluation forms, pencil
- Soils data for field
- Watch
- Rubber boots

(ii) Procedure—The field procedures needed for an evaluation of this type system include:

Site location— Choose a site location in the field to be irrigated. The typical location should be representative of the kind of soil for which the entire field is managed. The site should allow measurement of runoff. The evaluation should be run at a time when soil moisture conditions are similar to conditions when irrigation would normally be accomplished.

Furrows— Furrows to be evaluated should have a uniform cross section and a uniform grade between the inflow and outflow measuring points. Inflow and outflow points can be anywhere within the field where it is convenient to obtain flow measurements. At least three adjacent furrows or furrow groups should be measured at each test site. Adjacent furrows on each side of the test area should be irrigated simultaneously for a total of five furrows irrigated. Evaluate wheel rows as well as nonwheel rows. This generally occurs where three adjacent rows are selected; however, there may be two wheel rows and one nonwheel row or two nonwheel rows and one wheel row.

The entire furrow length should be evaluated; however, if time for a full length of run evaluation is not available, partial length rows can be evaluated. The minimum evaluation length for field evaluations should be 200 to 300 feet for high intake soils and 500 to 600 feet for low intake soils. Because of soil variability, shorter lengths, typically 100 to 200 feet, are used to derive values for preparing local irrigation guides. Lengths of 30 to 50 feet are used when using the flowing furrow infiltrometer method.

The steps to follow during the detailed evaluation are:

Step 1—Obtain information from the irrigation decisionmaker about the field and how it is irrigated; i.e., irrigation set time, how many rows set, typical flow advance rate and total time, adjustments made to furrow inflow during irrigation set time, number of irrigations per season, tillage pattern, and equipment. Field observations include identifying furrow erosion and sediment deposition areas, crop color differences in different parts of the field, crop uniformity, salinity and wet areas, and drainage system operation.

Step 2—Set flags or lath stakes at 100-foot stations down the selected furrows (set flags only in the middle furrow). Identify stations on each flag, lath, or stake. Do not walk in the furrows to be evaluated. Determine field elevations at each station, and plot furrow profile. Record furrow spacing (center of ridge to center of ridge) and furrow cross section. Measure the cross section with a straightedge and pocket tape or cross section board.

Step 3—Set measuring flumes, orifice plates, or other flow measuring devices at the upper and lower end of each furrow or reach to be evaluated. If there is ponded water at the lower end of the field, locate the lower measuring station upstream of the backwater.

Step 4—Estimate soil water deficit using incremental depths throughout the root zone at several locations along the furrow. Use the feel and appearance charts, Speedy Moisture Meter, or some other highly portable method. Select one location as being typical of furrows irrigated and record data for that location on the worksheet.

Step 5—Note soil profile conditions as you are recording soil water deficit data (step 4). Conditions to consider include:

- Depth to water table (if within 5 feet of soil surface)
- Actual plant root depth, root development pattern of existing or previous crop, and restrictions to normal root development
- Compacted layers and mineral layers
- Mineral layers
- Hardpans or bedrock
- Soil textures including textural change boundaries (abrupt or gradual)
- Salinity levels and soil layers of salt accumulation

Field procedure for inventory and data collection:

Step 1—Start furrow inflow with the flow rate normally used by the irrigator and record start time. Time permitting, three different flow levels (high, medium, and low inflow rates) should be used in different test sections to determine effect of using higher or lower furrow inflows.

Step 2—At 5- to 10- minute intervals, check the inflow rate of the test section until it reaches a constant rate. Record the flow rate and time of measurement each time the flow is checked, Periodically during the evaluation check the flow rate and record it. Frequent checks should be made if the flow rate fluctuates considerably.

Step 3—Observe the furrow for erosion or overtopping. Estimate the maximum usable stream size. For new furrows, loose soil often muddies the water at first, but is not considered to be erosion. Also, some erosion often occurs at each turnout, but the furrow stream becomes stable after a short time. Looking closely at the bottom of the furrow when water is flowing will indicate if movement of soil particles is causing rilling to occur or is just reshaping of the furrow cross section. If erosion is occurring, is there an opportunity to use PAM?

Step 4—Record the time water reaches each station. Record the time runoff starts at each outflow measuring location. Periodically measure the flow rate and record the rate and time of measurement until it ceases.

Step 5—Record the time when water is turned off at the head end of the field. In many cases the water disappears from the furrow relatively uniformly throughout the length of the furrow. In these cases only the time water is shut off and the time water disappears at each furrow station need to be recorded. Nonuniform soil infiltration causes recession timing to be erratic, so use your best estimate.

Step 6—Before leaving the field, use a ball probe or auger to check depth of water penetration at several locations along the length of the furrows. Suggested locations are 1/3 and 2/3 points and at 80 percent of the total furrow length. A check at this time indicates the depth that the water has already penetrated. Another check 24 to 36 hours later will indicate the final depth of water movement. An estimate of final depth can be made using a previous irrigation set on the same soil. Check for adequacy and uniformity of irrigation when the soil profile is at or near field capacity moisture level. A visit the next day may be necessary to observe wetted depth(s) in the soil profile within the area evaluated. Time for free drainage of most gravitational water should be allowed. Sandy soils can be checked a few hours after irrigation. Medium textured soils usually take about 24 hours after irrigation, and clayey soils take about 48 hours.

Step 7—Check the wetted soil bulb for a recently irrigated furrow and record the information. A trench dug across the furrow (stem to stem) is recommended. Also, it is very productive to have the irrigation decisionmaker present when viewing the trench. This is a good time to discuss what is happening in the soil profile, especially if there are restrictive layers (which there usually are).You need to observe the following:

- Location and shape of wetted bulb
- Actual root development pattern and location
- Restrictive layers to root development and water movement penetration; i.e., tillage pans

If it is desirable to establish or check soil moisture at field capacity condition, determine the soil water content or collect samples when checking for adequacy of the irrigation.

***(iii) Evaluation computations*—**The information gathered in the field procedures is used in the detailed system evaluation computations. Example 9–4 outlines the computations used to completed the Surface Irrigation System Detailed Evaluation Graded Furrow Worksheet (exhibit 9–4).

Exhibit 9–4 Completed worksheet—Surface irrigation system, detailed evaluation of graded furrow system

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Example - Surface Irrigation System Detailed Evaluation
Graded Furrow Worksheet 1

Land user Joe Example Field office ____
Field name/number ____
Observer ____ Date ____ Checked by ____ Date ____

Field Data Inventory:

Show location on evaluation furrows on sketch or photo of field.
Crop Corn Actual root zone depth 4 MAD 1/ 50 % MAD 3.9 in
Stage of crop 24" Planting date (or age of planting) ____
Field acres 100

Soil-water data:

(Show location of sample on soil map or sketch of field)
Soil moisture determination method Feel and appearance
Soil mapping unit Haverson loam Surface texture Loam

Depth	Texture	AWC (in)1/	SWD (%)1/	SWD (in)1/
0-8"	L	1.4	60	.84
8-48"	FSL	6.4	40	2.56
	Total	7.8		3.4

Comments about soils: Notes

Typical irrigation duration 11 hours, Irrigation frequency 14 days
Typical number of irrigations per year 8
Crop rotation Notes

Field uniformity condition (smoothed, leveled, laser leveled, etc., and when) Notes

1/ MAD = Management allowable depletion AWC = Available water capacity SWD = Soil water deficit

Exhibit 9–4 Completed worksheet—Surface irrigation system, detailed evaluation of graded furrow system—Continued

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Example - Surface Irrigation System Detailed Evaluation
Graded Furrow Worksheet 2

Cultivation no.	Date	Crop stage	Irrigate?
1	6/25	12"	No
2	7/25	24"	Yes
3			
4			
5			

Delivery system size (pipe diameters, gate spacing, siphon tube size, etc.) 10" diameter gated pipe w/30" spacing on outlet

Field observations

Evenness of advance across field Notes

Crop uniformity ____

Soil condition ____

Soil compaction (surface, layers, etc.) ____

Furrow condition ____

Erosion and/or sedimentation: in furrows ____

head or end of field ____

Other observations (OM, cloddiness, residue, plant row spacing, problems noted, etc.) ____

Furrow spacing 30 inches

Furrow length 1300 feet

Irrigations since last cultivation None

Furrow profile (rod readings or elevations at each 100 foot. station):

5.4	6.9	7.9	8.9	9.2	9.7	10.4	11.4	12.0	12.6	13.1	14.0
0	1	2	3	4	5	6	7	8	9	10	11
15.6	16.6	17.0									
12	13	14									

Furrow cross section:

Station: ______ Station: ______

Exhibit 9–4 Completed worksheet—Surface irrigation system, detailed evaluation of graded furrow system—Continued

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Sheet 3 of 10

Example - Surface Irrigation System Detailed Evaluation
Graded Furrow Worksheet 3

Furrow data summary:

Evaluation length 1300 Slope .005 to .016 ft/ft Average .0.0127

Section through plant root zone:

Evaluation computations

Furrow area, $A = \frac{(\text{furrow evaluation length, L, ft}) \times (\text{furrow spacing, W, ft})}{43{,}560 \text{ ft}^2/\text{acre}}$

$A = \frac{1300 \times 2.5}{43{,}560} = .0746$ acre

Present gross depth applied, $F_g = \frac{\text{Total inflow volume, gal.} \times .0000368}{\text{Furrow area, A, in acres}}$ (Total inflow from worksheet 7)

$F_g = \frac{13{,}762 \times .0000368}{0.0746} = 6.8$ inches

Minimum opportunity time, T_{ox} = 474 min at station 13+00 (from field worksheet 10)

Minimum depth infiltrated, F_{min} = 3.4 inches (from worksheet 10)

Average depth infiltrated, $F_{(0\text{-}1)}$ = 3.8 (from calculations on worksheet 10)

Distribution uniformity, $DU = \frac{\text{Minimum depth infiltrated, inches}}{\text{Average depth infiltrated, inches}} \times 100 = \frac{\text{F min}}{\text{F ave}} \times 100$

$= \frac{3.4 \times 100}{3.8} = 89.5$ %

Exhibit 9–4 Completed worksheet—Surface irrigation system, detailed evaluation of graded furrow system—Continued

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Example - Surface Irrigation System Detailed Evaluation
Graded Furrow Worksheet 4

Runoff, RO% = $\frac{\text{Total outflow volume, gal}}{\text{Total inflow volume, gal}}$ x 100 = $\frac{6{,}248 \text{ x } 100}{13{,}762}$ = 45.4 % (Total outflow, worksheet 8) (Total inflow, worksheet 7)

RO, in = $\frac{\text{Total outflow volume, gal x .0000368}}{\text{Evaluation furrow area, A, in acres}}$ = $\frac{6{,}248}{.0746}$ x 0.0000368 = 3.1 in (Furrow area, worksheet 3)

Deep percolation, DP, in = Average depth infiltrated - Soil moisture deficit, SMD (Ave. depth worksheet 10 and SMD worksheet 1)

DP = 3.8 - 3.4 = 0.40 in

Deep percolation, DP, % = $\frac{\text{Deep percolation, DP, in x 100}}{\text{Gross depth applied, } F_g\text{, inches}}$ = $\frac{0.4 \text{ x } 100}{6.8}$ = 5.9 %

Application efficiency, E_a

E_a = $\frac{\text{Ave depth stored in root zone* x 100}}{\text{Gross application, } F_g\text{, inches}}$ = $\frac{3.4 \text{ x } 100}{6.8}$ = 50 %

*Average depth of water stored in root zone = SWD if entire root zone depth is filled to field capacity by this irrigation. If irrigation efficiency is to be used in place of application efficiency, use average depth of water beneficially used (i.e., all infiltrated depths less than or equal to SWD) plus any other beneficial uses.

Exhibit 9–4 Completed worksheet—Surface irrigation system, detailed evaluation of graded furrow system—Continued

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Example - Surface Irrigation System Detailed Evaluation
Graded Furrow Worksheet 5

Potential water and cost savings

Present management

Estimated present gross net application, F_g per irrigation = 6.8 inches (F_g from worksheet 3)

Present gross applied per year = Gross applied per irrigation, F_g x number of irrigations

= 6.8 x 8 = 54.4 inches

Potential management

Annual net irrigation requirement 20.6 inches, for corn (silage) (crop)

Potential application efficiency, E_{pa} = 70 %

$$\text{Potential annual gross applied} = \frac{\text{Annual net irrigation req. x 100}}{\text{Potential application efficiency, } E_{pa}}$$

$$= \frac{20.6 \times 100}{70} = 29.4 \text{ inches}$$

$$\text{Total annual water conserved} = \frac{\text{(present gross applied - potential gross applied) x area irrigated, ac}}{12}$$

$$= \frac{(54.4 - 29.4) \times 100}{12} = 208 \text{ acre feet}$$

Exhibit 9–4 Completed worksheet—Surface irrigation system, detailed evaluation of graded furrow system—Continued

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Surface Irrigation System
Detailed Evaluation Graded Furrow Worksheet 6

Annual cost savings

Water cost

= Cost per acre foot x acre feet saved per year = ______________________________

= $ ____________________________

Cost savings = Pumping cost + water cost = ________________________________ = $ _______________

Fuel cost savings = (fuel cost per ac-ft) x (ac-ft conserved per year) =_______________ = ______________

Recommendations Further improvement can be gained by reducing length of run by half. New inflow rate and time of irrigation would then need to be determined.

Consider automated surge valves.

Exhibit 9–4 Completed worksheet—Surface irrigation system, detailed evaluation of graded furrow system—Continued

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Example - Surface Irrigation System Detailed Evaluation
Furrow Worksheet 7

Data: Furrow number 1 Inflow X Outflow ____

Type of measuring device 1" Parshall flume

Clock 1/ time	Elapsed time (min)	Δ T (min)	Gage H (ft)	Flow rate (gpm)	Average flow rate (gpm)	Volume 2/ (gal)	Cum. volume (gal)
Turn on 0630	0		0	0			
		15			8.3	125	125
0645	15		.240	16.6			
		15			16.6	249	374
0700	30		.240	16.6			
		60			17.1	1,026	1,400
0800	90		.245	17.5			
		60			18.4	1,104	2,504
0900	150		.250	19.3			
		120			21.3	2,556	5,060
1100	270		.300	23.3			
		120			24.7	2,964	8,024
1300	390		.320	26.0			
		120			24.7	2,964	10,988
1500	510		.300	23.3			
		120			22.4	2,688	13,676
1700	630		.285	21.5			
		8			10.8	86	13,762
1708	638		0	0			

Total volume 13,762 gallon

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. is recorded as 1330 hours.
2/ Volume = Δ T x average flow rate

Average flow rate = $\frac{\text{Total irrigation volume, gallon}}{\text{Elapsed time, minute}} = \frac{13{,}762}{638} = 21.6$ gpm

Exhibit 9–4 Completed worksheet—Surface irrigation system, detailed evaluation of graded furrow system—Continued

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Example - Surface Irrigation System Detailed Evaluation
Furrow Worksheet 8

Data: Furrow number 1 Inflow ________ Outflow X

Type of measuring device 1" Parshall flume

Clock 1/ time	Elapsed time (min)	Δ T (min)	Gage H (ft)	Flow rate (gpm)	Average flow rate (gpm)	Volume 2/ (gal)	Cum. volume (gal)
0915	0		0	0			
		15			2.6	39	39
0930	15		.112	5.1			
		15			6.4	96	135
0945	30		.146	7.6			
		45			8.5	383	518
1030	75		.165	9.3			
		60			10.2	612	1,130
1130	135		.183	11.1			
		120			11.8	1,416	2,546
1330	255		.200	12.5			
		120			14.0	1,680	4,226
1530	375		.230	15.5			
		90			17.2	1,548	5,774
1700	465		.260	18.8			
		10			19.4	194	5,968
1710	475		.27	19.9			
		28			10.0	280	6,248
1718	503		0	0			

Total volume 6,248 gallon

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. is recorded as 1330 hours.
2/ Volume = Δ T x average flow rate

Average flow rate = $\frac{\text{Total irrigation volume, gallon}}{\text{Elapsed time, minute}} = \frac{6{,}248}{503} = 12.4$ gpm

Exhibit 9–4 Completed worksheet—Surface irrigation system, detailed evaluation of graded furrow system—Continued

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Example - Surface Irrigation System Detailed Evaluation
Furrow Worksheet 9

Intake Curve Plotting Data

Opportunity time at time "T"							Intake at time "T"		
Clock time		Inflow time		Outflow time		Opportunity time T_o 5/ (min)	Cumulative inflow volume 6/ V_{in} (gal)	Cumulative Outflow volume 6/ V_{out} (gal)	Intake F_{0-1} 7/ (in)
(hr-min)1/	T (hr)	Start 2/ (hr)	T1 3/ (hr)	Start 2/ (hr)	T2 4/ (hr)				
0915	9.25	6.5	2.75	9.25	0	83	2,824	0	2.0
0945	9.75	6.5	3.25	9.25	.5	113	3,463	135	2.5
1030	10.5	6.5	4.0	9.25	1.25	158	4,421	518	3.0
1130	11.5	6.5	5.0	9.25	2.25	218	5,801	1,130	3.7
1330	13.5	6.5	7.0	9.25	4.25	338	8,765	2,546	5.0
1530	15.5	6.5	9.0	9.25	6.25	458	11,660	4,226	6.1
1700	17.0	6.5	10.5	9.25	7.75	548	13,676	5,774	6.5

1/ Use a 24-hour clock reading for collection of field data; i.e., 1:30 p.m. is 1330 hours. Use decimal hours for inflow and outflow times.
2/ Time at which inflow or outflow starts in decimal hours (worksheet 7-8)
3/ Inflow time: T1 = "T" - inflow start time (worksheet 7)
4/ Outflow time: T2 = "T" - outflow start time (worksheet 8)
5/ Opportunity time (minutes): T_o - 30 (T1 + T2)
6/ Cumulative inflow and outflow volumes (worksheet 7-8). If data were not recorded for time T, interpolate the inflow or outflow.

Surface storage and wetted perimeter for length of furrow with water in it.
L = length of furrow with water in it, ft (worksheet 3) = 1300
S = average furrow slope, ft/ft (worksheet 3) = .0127
n = Mannings "n" (usually 0.04 for furrows, 0.10 for corrugations = .04
Q_{av} = average inflow rate, gpm (worksheet 7) = 21.6

Surface storage: $V_s = L\left[0.09731\left(\frac{Q_{av}\times n}{S^{.5}}\right)^{.7567} + 0.00574\right]$ = 583

Wetted perimeter: $P = 0.2686\left(\frac{Q_{av}\times n}{S^{.5}}\right)^{.4247} + 0.7462$ = 1.38

7/ Intake plotting point:

V_{in} = Cumulative inflow (gal) from worksheet 7
V_{out} = Cumulative outflow (gal) from worksheet 8
V_s = Surface storage (gal) in length of furrow with water in it

$$F_{0-1} = \frac{1.604\ (V_{in} - V_{out} - V_s)}{L \times P}$$

Exhibit 9–4 Completed worksheet—Surface irrigation system, detailed evaluation of graded furrow system—Continued

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Sheet 10 of 10

Example - Surface Irrigation System Detailed Evaluation
Furrow Worksheet 10

Furrow advance/recession data

Station (ft)	Advance time: Clock time 1/	Advance time: ΔT (min)	Advance time: Elapsed time T_t (min)	Recession time: Clock time 1/	Recession time: ΔT (min)	Recession time: Elapsed time T_r (min)	Total elapsed time 3/	Opportunity time (T_o) 2/ (min)	Intake in wetted perimeter (in) 4/	Intake in furrow width (in)
0+00				Turn off (1705)	Lag (3)	0	635	Inflow T (635)		
0+00	Turn on (0630)		0	1708		3	638	638	7.5	4.1
1+00	0635	5	5	1713	5	8	643	638	7.5	4.1
2+00	0644	9	14	1716	3	11	646	632	7.4	4.1
3+00	0658	14	28	1719	3	14	649	621	7.3	4.0
4+00	0711	13	41	1721	2	16	651	610	7.2	4.0
5+00	0724	13	54	1724	3	19	654	600	7.2	4.0
6+00	0742	18	72	1727	3	22	657	585	7.1	3.9
7+00	0755	13	85	1728	1	23	658	573	7.0	3.8
8+00	0806	11	96	1729	1	24	659	563	6.9	3.8
9+00	0821	15	111	1731	2	26	661	550	6.8	3.7
10+00	0840	19	130	1733	2	28	663	533	6.6	3.7
11+00	0900	20	150	1734	1	29	664	514	6.5	3.6
12+00	0917	17	167	1735	1	30	665	498	6.3	3.5
13+00	0944	27	194	1738	3	33	668	474	6.1	3.4
							Totals	8029	97.4	

T_i = 635 minutes

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. is 1330 hours.
2/ $T_o = T_i - T_t + T_r$
3/ Time since water was turned on.
4/ Interpolated from graph, furrows volume curve

Average opportunity time = $\frac{\text{total opportunity time}}{\text{number of stations}} = \frac{8029}{14}$ = 574 minutes

Average depth infiltrated in wetted perimeter, F_{wp}:

$F_{wp} = \frac{\text{total intake in wetted perimeter}}{\text{number of stations}} = \frac{97.4}{14}$ = 7.0 inches

Average depth infiltrated in tested length of furrow, F_{0-1}:

$F_{0-1} = \frac{F_{wp} \times P}{W} = \frac{7.0 \times 1.38}{2.5}$ = 3.8 inches

Example 9–4 Evaluation computation steps for graded furrow irrigation systems

1. Plot the furrow profile on cross section paper (fig. 9–21).

Figure 9–21 Furrow profile

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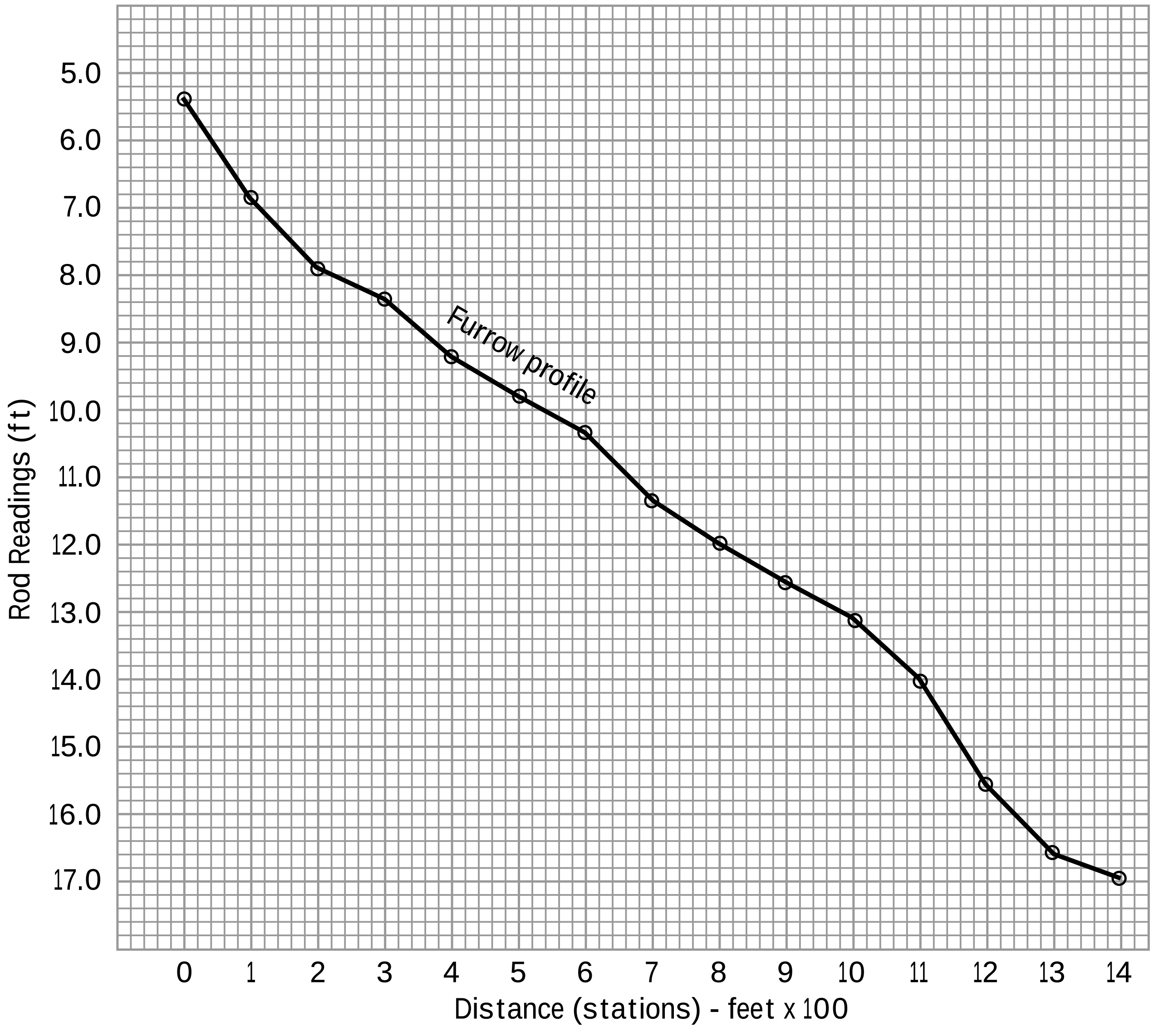
National Resources Conservation Service

Example - Surface Irrigation System Detailed Evaluation
Furrow Worksheet 11



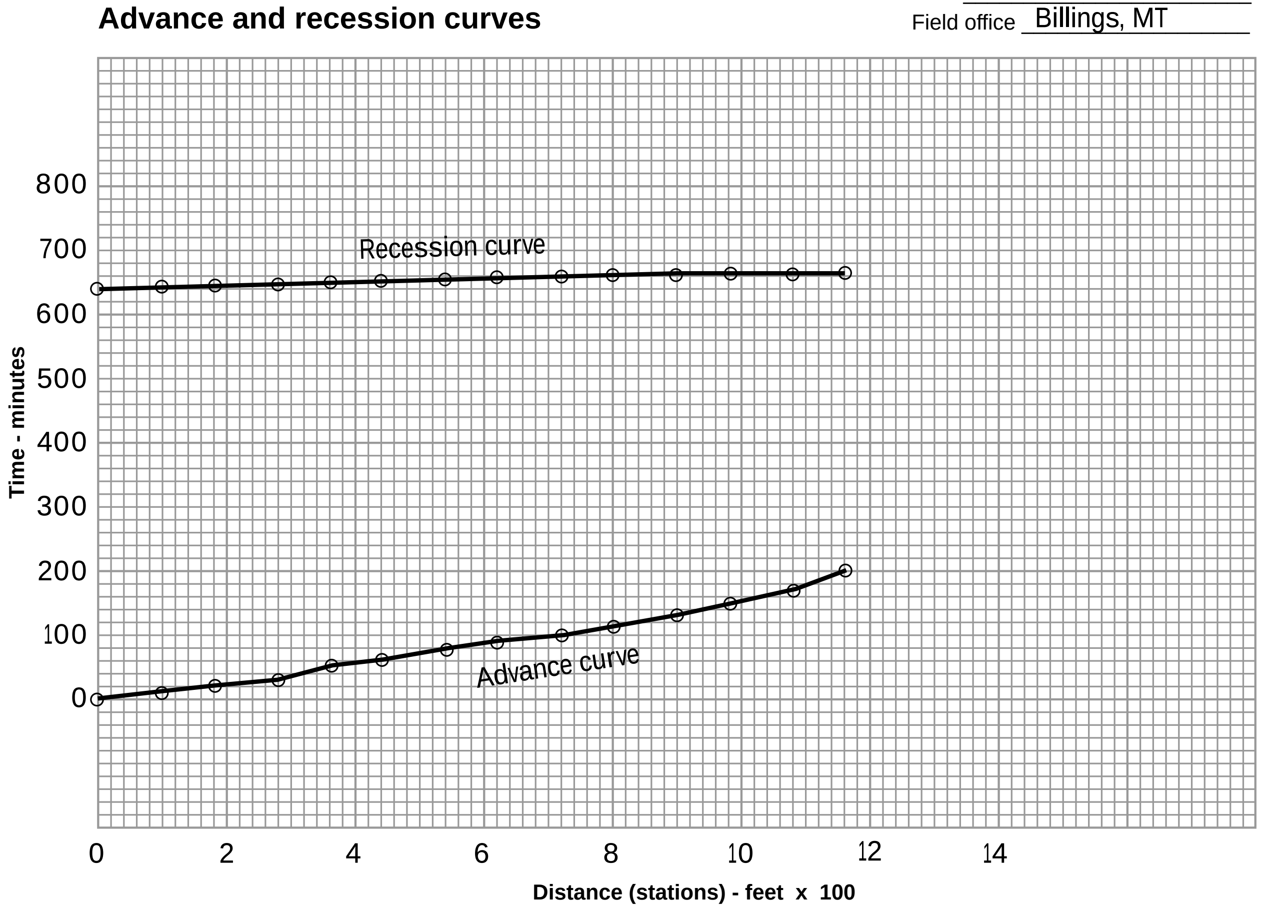
Example 9–4 Evaluation computation steps for graded furrow irrigation systems—Continued

2. **Compute the soil water deficit (SWD) at each station (worksheet 1).** This is the net depth of water required to refill the plant root zone to field capacity. In arid areas, it typically is needed for the evaluation irrigation. In humid areas, some soil water storage can be reserved for anticipated rainfall events (i.e., 1 inch).

3. **Complete the calculation of opportunity times at each station (worksheet 10).** Use the Advance Recession part of the evaluation worksheet 10. Plot (fig. 9–22).

Figure 9–22 Advance recession curve

Land user Joe Example
Date 7-10-86
Field office Billings, MT



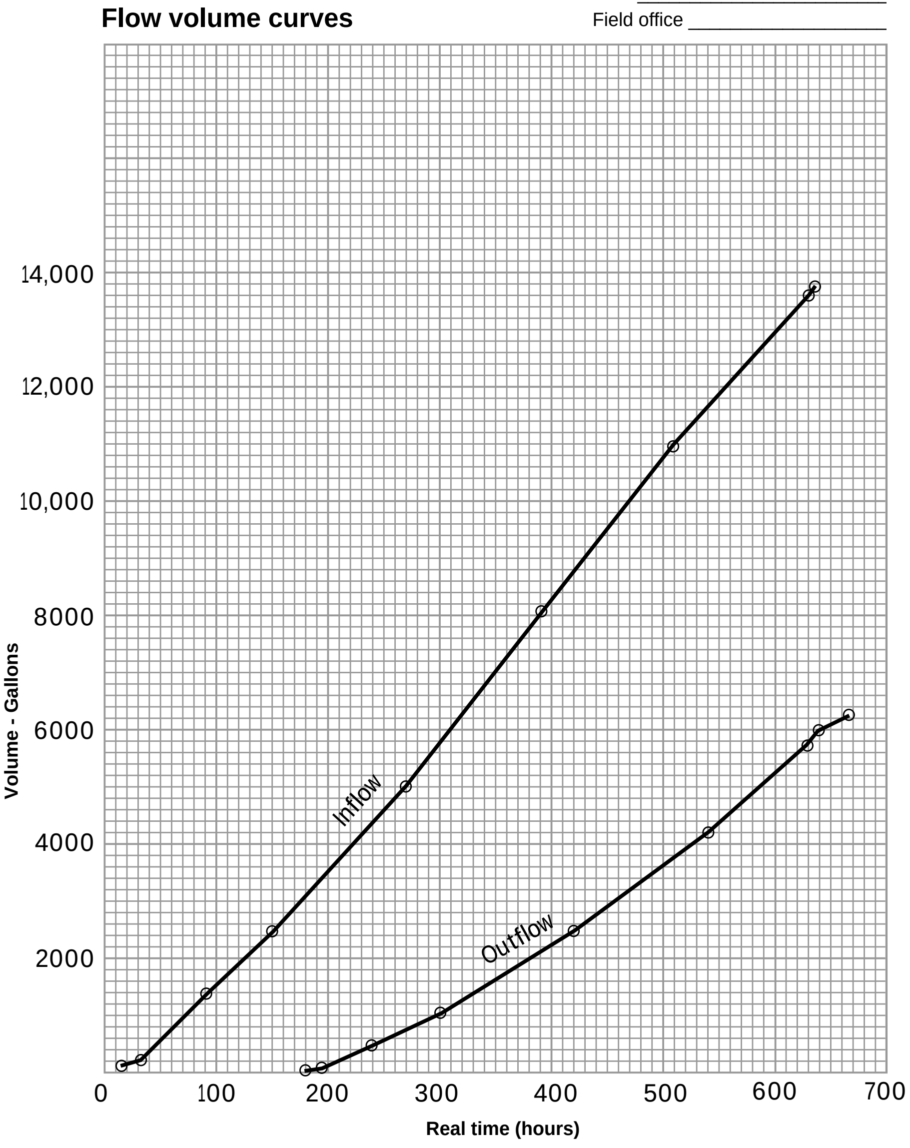
Example 9–4 Evaluation computation steps for graded furrow irrigation systems—Continued

4. **Plot both advance and recession curves from worksheet 10 on the worksheet provided or on cross section paper, figure 9-22.** If recession times for the entire length of furrow were not recorded, plot a straight horizontal line at the average elapsed time when water disappears from the furrow.

5. **Complete the computations for the inflow and outflow data worksheets 7-8.** Plot inflow and outflow volume curves (fig. 9–23) using elapsed time and cumulative volume columns. Offset outflow time by the time difference between start of inflow and outflow. Compute average flow rate for each furrow for both inflow and outflow.

Figure 9–23 Flow volume curves

Land user ___________________
Date ________________________
Field office __________________



Example 9–4 Evaluation computation steps for graded furrow irrigation systems—Continued

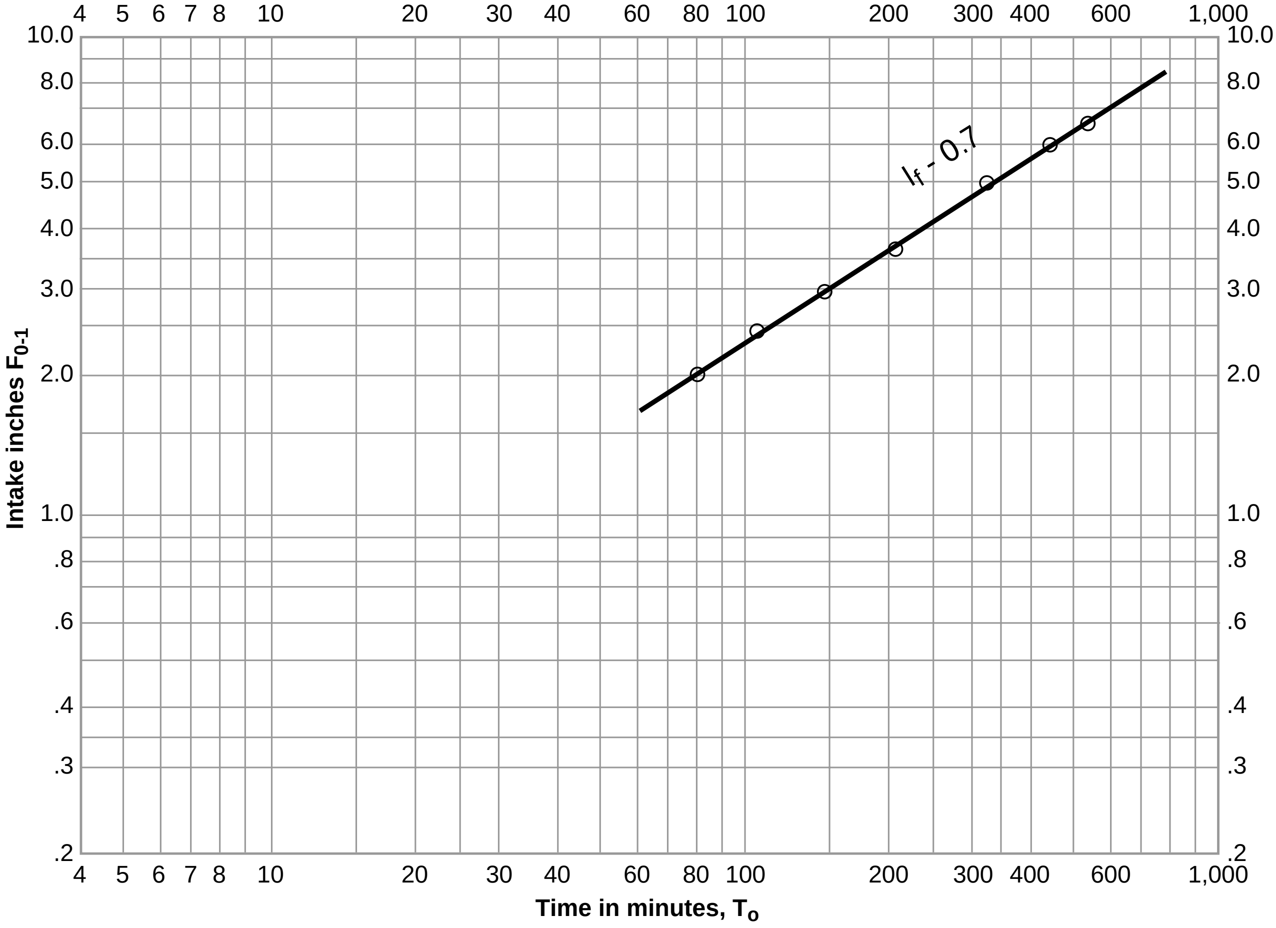
6. **Complete the Furrow Intake Characteristic Curve Input Data Worksheet 9.** Use the data on the advance-recession and the inflow-outflow data sheets. Get cumulative inflow and outflow values from plot of flow volume curves (fig. 9-23) or interpolate from data on worksheets 7-8). Follow the instructions on the sheet for doing the calculations. Computation examples are given in NEH Section 15, Chapter 5, Furrow Irrigation, for full furrow length and partial furrow length evaluations.

7. **Plot intake curve data T_o and F_{0-1} from worksheet 9 on two cycle log-log paper (fig. 9–24).** Draw a best fit line through the plotted points. Compare this line to standard furrow intake characteristic (family) curves (Chapter 2, Soils, fig. 2–4).

Figure 9–24 Soil water intake curves

Land user Joe Example
Date 7-10-86
Field office Billings, MT

Soil water intake curves



Example 9–4 Evaluation computation steps for graded furrow irrigation systems—Continued

8. **Determine water depth infiltrated at each station** (worksheet 10). Use the opportunity time at each station (computed on the advance-recession worksheet) and the cumulative intake curve to make your determination. Record the depth infiltrated in the next to the last column of the worksheet. This is the depth infiltrated within the wetted perimeter of the furrow.

9. **Correct the wetted perimeter intake at each station**(worksheet 10). The wetted perimeter intake at each station must be corrected to account for furrow spacing and representative field area. Multiply the wetted perimeter intake by the ratio of wetted perimeter (P) (worksheet 9) to furrow spacing (W) (worksheet 2). Enter the result in the last column of the advance-recession worksheet 10.

10. **Compute the average opportunity time, T_o** (worksheet 10):

$$\text{Ave. } T_o = \frac{\text{total opportunity}}{\text{number of stations}}$$

11. **Compute the average depth of water infiltrated within the wetted perimeter, F_{wp}** (worksheet 10):

$$F_{wp} = \frac{\text{total intake in wetted perimeter}}{\text{number of stations}}$$

12. **Compute the average intake for the area represented by the furrow spacing.** (worksheet 10)

$$F_{ave} = \frac{F_{wp} \times P}{W}$$

13. **Compute the furrow area for the evaluation reach (acres)** (worksheet 3):

$$A = \frac{(\text{evaluation furrow length, ft}) \times (\text{furrow spacing W, ft})}{43{,}560 \text{ ft}^2/\text{ac}}$$

14. **Compute present gross application depth, F_g, in inches** (worksheet 3):

$$\text{Present } F_g = \frac{(\text{total inflow volume, gal}) \times (.0000368)}{A\ (\text{furrow area, acres})}$$

15. **Determine the location(s) along the furrow where the minimum opportunity time (T_{ox}) occurred** (worksheet 3). Use the furrow advance and recession information (worksheet 10) to make the determinations. Record the minimum time.

16. **Determine minimum depth infiltrated, F_{min}** (worksheet 3). Use the minimum opportunity time from worksheet 10.

17. **Enter average depth infiltrated, F_{ave} on worksheet 3** (from worksheet 10).

18. **Compute furrow distribution uniformity, DU** (worksheet 3):

Example 9–4 Evaluation computation steps for graded furrow irrigation systems—Continued

Absolute minimum is often used instead of low quarter, as in other methods of irrigation. Absolute minimum is the ratio of minimum depth infiltrated to average depth infiltrated. However, to compare the furrow surface irrigation system to other irrigation systems, low quarter distribution uniformity should be used.

$$DU_{min}, \% = \frac{(\text{minimum depth infiltrated}, F_{min}, \text{ inches})}{\text{average depth infiltrated}, F_{ave}, \text{ inches}} \times 100$$

To compare irrigation methods:

$$DU\% = \frac{\text{low } \frac{1}{4} \text{ infiltrated}}{\text{average depth infiltrated, inches}}$$

19. Compute runoff, RO (worksheet 4):

$$RO, \% = \frac{\text{total outflow volume, gal}}{\text{total inflow volume, gal}} \times 100$$ (outflow from worksheet 8, inflow from worksheet 7)

$$RO, in = \frac{\text{total outflow volume, gal} \times 0.0000368}{A, (\text{furrow area, acres})}$$

20. Compute deep percolation, DP:

DP, inches = [(average depth infiltrated, inches) – (soil water deficit, inches)] (depth worksheet 10 & SMD worksheet 1)

$$DP\ \% = \frac{\text{deep percolation, inches}}{F_g, (\text{gross depth applied, inches})} \times 100$$ (F_g from worksheet 3)

21. Compute application efficiency, E_{a} (%). Average depth of water stored in root zone is equal to the soil water deficit if entire root zone depth will be filled to field capacity by this irrigation; otherwise, use F_g minus RO, in inches.

$$E_a = \frac{\text{ave depth stored in root zone, inches}}{F_g, (\text{gross depth applied, inches})} \times 100$$

If *irrigation efficiency* is to be used in place of *application efficiency*, use average depth of water beneficially used (all water infiltrated depths less than or equal to SWD plus any other beneficial uses).

Example 9–4 Evaluation computation steps for graded furrow irrigation systems—Continued

Potential water conservation and pumping costs savings

1. **Use the present gross application per irrigation (F_g, worksheet 3) and number of irrigation and enter on worksheet 5.** Base your estimation on information about present irrigation scheduling and application practices obtained from the irrigation decisionmaker and on data derived from the evaluation.

2. **Determine the annual net crop and other irrigation requirement and potential application efficiency.** Use the irrigation guide for potential efficiency and crop need. Enter on worksheet 5.

3. **Compute potential annual gross water applied on worksheet 5:**

$$\text{Potential annual gross water applied, inches} = \frac{(\text{annual net crop and other irrigation requirement, inches})}{E_{pa}(\text{potential application efficiency, \%})} \times 100$$

4. **Compute total annual water conserved (ac-ft):**

$$\text{Total annual water conserved} = \frac{(\text{present gross applied, in} - \text{potential gross applied in}) \times A(\text{area irrigated, ac})}{12}$$

5. **If cost is a factor, compute cost savings on worksheet 6:**

Pumping cost savings: From a separate pumping plant evaluation, determine pumping plant efficiency, kind of fuel, cost per unit of fuel, fuel cost per acre foot. Compute fuel cost savings:

Fuel cost savings = (fuel cost per ac-ft) x (ac-ft conserved per year)

Water purchase cost savings: Obtain purchase cost data from farmer. Compute as follows:

Water cost savings = (water cost per ac-ft) x (water conserved per year, ac-ft)

Compute total cost savings.

Example 9–4 Evaluation computation steps for graded furrow irrigation system—Continued

Analysis of data and preparation of recommendations:

1. Compare soil water deficit with management allowable depletion (MAD). This indicates whether the irrigation was correctly timed, too early, or too late.

2. Analyze the advance and recession curves and changes that might be made to improve irrigation uniformity.

Recommendations:

Use field evaluation observations, data obtained by discussion with the irrigation decisionmaker, study of advance-recession curves, and data obtained by computations to make practical recommendations. Remember that the measured and calculated data are not exact. This is mainly because soils vary and there are many other uncontrollable variables. Changes should be made with a trial-and-error procedure. After each new trial the field should be probed to determine water penetration. Observations should be made to determine furrow runoff and distribution. Enough instruction and training should be given irrigation decisionmakers so they can make observations and provide the necessary adjustments.

(4) Contour ditch irrigation detailed evaluation

Improving efficiency of contour ditch irrigation has a great potential for conserving water. Application efficiencies of 10 to 25 percent are common. Potential efficiencies with properly designed, maintained, and managed systems can be 30 to 50 percent. As an example, improving application efficiency from 10 to 40 percent where a net seasonal requirement of 17 inches is met, can conserve 10.6 acre-feet of water per irrigated acre.

Exact values for distribution uniformity and application efficiencies are impractical to determine because of difficulties in measuring depth infiltrated at representative locations in the field. The depth infiltrated varies widely throughout the irrigated area. The following procedure gives an approximation of those factors that are useful in making decisions about changes that might be made to a system or its management.

Choose a typical portion of the field to be irrigated. The site should have a representative soil type and be managed from a scheduling standpoint. If possible, the area irrigated should receive water from an individual turnout without water intermingling from other turnouts. The size and shape of the area irrigated should be typical of the size and shape of areas irrigated in the field.

If water is intermingled from adjacent turnouts during preceding and succeeding sets, estimating or making onsite determinations of the adjacent water opportunity time is necessary at each grid point. Grid point opportunity times are explained in the procedure.

The evaluation should be run at a time when soil moisture conditions are similar to those when irrigation would normally be initiated.

(i) Equipment—The equipment needed for a contour ditch irrigation system includes:

- Two 100-foot tapes (or one 100-foot tape and transit to lay out grid)
- Stakes or flags and marker for stakes or flags
- Flumes, weirs, or other measuring devices for measuring inflow and outflow
- Carpenters level for setting flumes or weirs
- Cylinder infiltrometer set with hammer and hammer plate (minimum 4 rings)
- Hook gauge and engineering scale for infiltrometer
- Equipment for determining soil moisture amounts (feel and appearance charts, Speedy Moisture Meter and Eley volumeter or Madera sampler, and soil moisture sample cans)
- Buckets to supply infiltrometer with water
- Soil auger, push tube sampler, probe, shovel
- Evaluation worksheets, aerial photo of field, clip board, and pencil
- Watch, camera, boots
- Soils data for field

(ii) Procedures—The field procedures needed for evaluation of this type system are in two categories: general, and inventory and data collection.

General

Step 1—Before irrigation is started:

- Get basic information about existing irrigation procedures, concerns, and problems from the irrigator.
- Select a turnout that irrigates an area representative of areas irrigated from turnouts in the field. If at all possible, select an area where runoff can be measured.
- Stake a grid in the basin to be irrigated. Grid spacing should be such that it defines significant undulations on the irrigated surface. The entire area irrigated from the turnout should be covered.
- Sketch the location of ditches, turnouts, location of measuring devices, and the field grid on a grid sheet as illustrated in figure 9–25.
- Set measuring devices to measure inflow and outflow.
- Set three to five cylinder infiltrometers in carefully chosen typical locations within the area to be irrigated. A location near the supply ditch will be the most convenient for providing water for infiltrometer cylinders. See discussion in section 652.0905, Determining soil intake.
- Check the soil water deficit (SWD) at several grid points in the irrigated area. Use feel and appearance, Eley volumeter/speedy moisture meter, push tube/oven (Madera sampler), or some other method. For the location chosen as the controlling typical soil, record the SWD data on the evaluation worksheet.

- At the same time, make note of soil profile conditions, such as:
  - Depth to water table
  - Apparent root depth and rooting pattern of existing or previous crop
  - Soil or compaction layers restrictive to root development and water movement
  - Mineral layers
  - Hardpans and bedrock
  - Soil textural changes

Step 2—Field observations. Make visual observations of the field including crop uniformity, weeds, erosion problems, crop condition or color changes, and wet areas.

Inventory and data collection

During the irrigation:

- Irrigate with the flow rate normally used by the irrigation decisionmaker and record the start time.
- Check and record the flow rate several times during inflow. Record the turnoff time.
- Observe advance of the water front across the irrigated area. On the map of the area, sketch the position of the water front at six or eight time intervals. Using 24-hour clock readings, record the time when the front reaches each station. An uneven advancing front line indicates location of high and low areas.
- Fill the infiltrometer cylinders when the leading edge of water reaches them. (An alternative is to build dams around the infiltrometers and pour water in the dams at the same time water is poured into the infiltrometers.) Record infiltrometer readings at times shown on the infiltrometer worksheets.
- Record when runoff starts and stops. Check and record runoff several times during the runoff period.
- Observe the recession of the water in the area. On the map of the area, sketch the position at six or eight time intervals. Record the time on each line. These lines should be of contrasting color or type to distinguish them from the advance line.
- Immediately after recession, use a probe or auger to check depth of penetration at several locations in the area. A check at this time indicates the depth that water has already percolated.
- If overlap between irrigation sets has occurred or may occur, the combined opportunity time must be determined for the adjacent sets at those points where overlap is experienced.
- If possible, check for adequacy and uniformity of irrigation at a time when the soil profile has reached field capacity. Sandy soils can be checked 4 to 24 hours after irrigation. Clayey soils should be checked about 48 hours after irrigation when most gravitational water has drained.
- If it is necessary to establish field capacity, determine the soil water content when checking for adequacy and uniformity of irrigation.

***(iii) Evaluation computations*—**The information gathered in field procedures is used in detailed system evaluation computations. Example 9–5 outlines the computations used to complete the Contour Ditch Irrigation System Detailed Evaluation Worksheet (exhibit 9–5).

Figure 9–25 Ditches, turnouts, measuring devices, and field grid for example site

Advance - recession sketch

Land user Joe Example
Date
Field office

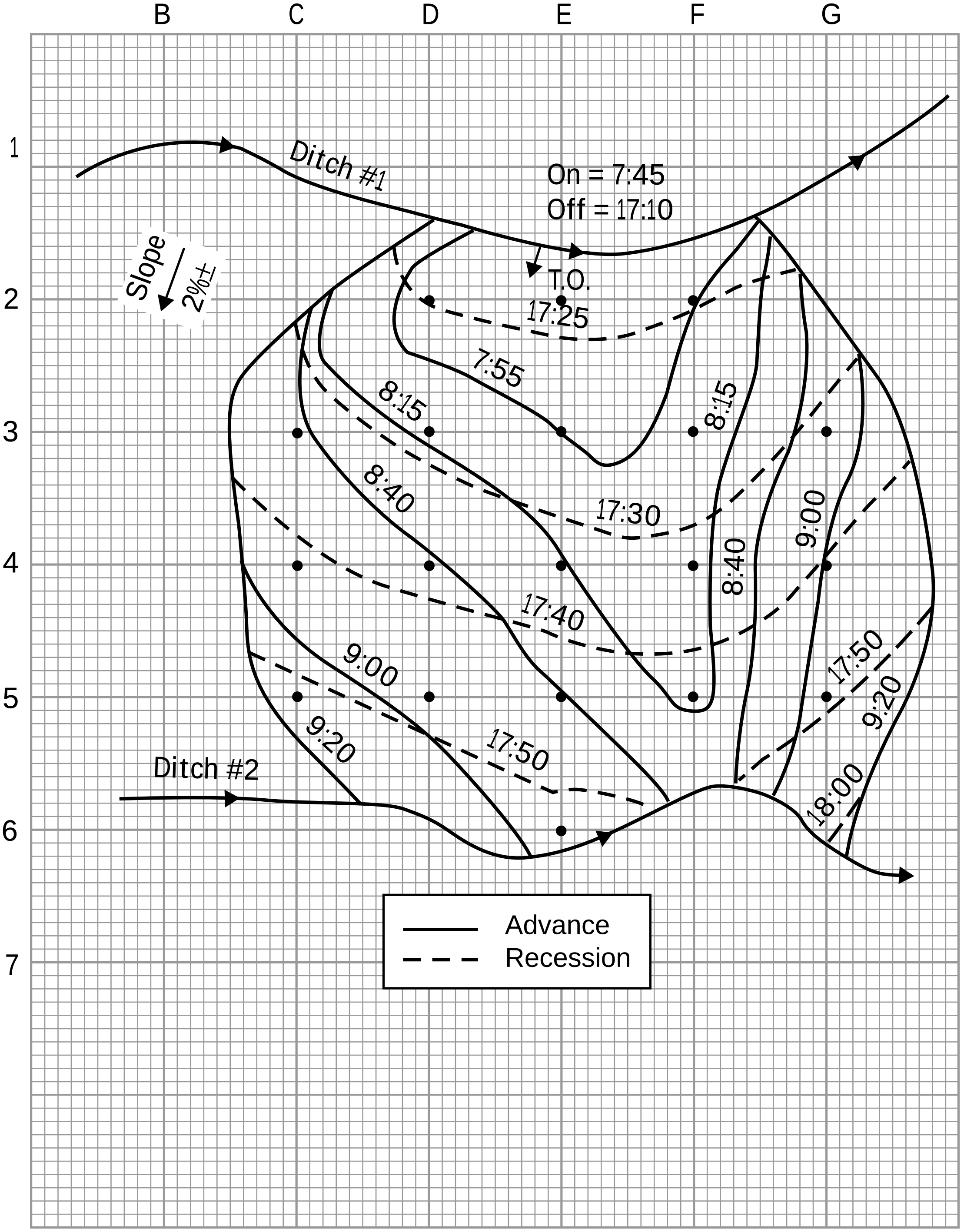


Exhibit 9–5 Completed worksheet—Surface irrigation system, detailed evaluation of contour ditch irrigation system

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Natural Resources Conservation Service

Sheet 1 of 6

Example - Surface Irrigation System
Detailed Evaluation Contour Ditch Irrigation System Worksheet

Land user Joe Example Field office ____
Field name/number #10
Observer ____ Date ____ Checked by ____ Date ____

Field Data Inventory:
Field size 50 acres
Crop ____ Root zone depth 4 ft MAD 1/ 50 % MAD 1/ 4.1 in
Stage of crop 3 weeks other harvest – very dry

Soil-water data:
(Show locacation of sample on grid map of irrigated area.)
Soil moisture determination method Feel & apperance
Soil series name Fort Collins loam

Depth	Texture	AWC 2/ (in)	SWD 3/ (%)	SWD 3/ (in)
0-4"	L	.72	100	.72
4-20"	CL	2.64	80	2.11
20-48"	CL	4.90	70	4.43
	Total	8.26		6.26

Comments about soils: Notes

Typical irrigation duration 7 hr, irrigation frequency 14-20 days
Typical number of irrigations per year 5 +/-

Type of delivery system, (earth ditch, concrete ditch, pipeline) earth head ditch

Method used to turn water out (shoveled opening, wood box turnout, siphon tubes, portable dams, concrete checks with check boards, etc.) wood turnouts

1/ MAD = Management allowable depletion
2/ AWC = Available water capacity
3/ SWD = Soil water deficit

Exhibit 9–5 Completed worksheet—Surface irrigation system, detailed evaluation of contour ditch irrigation system —Continued

U.S. Department of Agriculture
Natural Resources Conservation Service

Sheet 2 of 6

Example - Contour Ditch Irrigation System
Detailed Evaluation Worksheet

Field observations

Crop uniformity Notes

Wet and/or dry area problems Notes

Erosion problems Notes

Other observations Notes

Evaluation computations

Irrigated test area (from gird map) = (20.0 in^2) x (.2296 in^2/ac) = 4.6 ac

Actual total depth infiltrated, inches:

$$\text{Depth, inches} - \frac{(\text{Irrigated volume, ac-in}) - (\text{Runoff volume, ac-in})}{(\text{Irrigated area, acres})}$$

$$\text{Depth, inches} = \frac{49.03 - 6.32}{4.6} = 9.31 \text{ in}$$

Gross application, F_g, inches:

$$F_g = \frac{(\text{Total inflow volume, ac-in})}{(\text{Irrigated area, acres})} = \frac{49.03}{4.6} = 10.68 \text{ in}$$

Distribution uniformity low 1/4 (DU):

$$DU = \frac{(\text{Average depth infiltrated (adjusted) low 1/4, inches})}{(\text{Average depth infiltrated (adjusted), inches})}$$

$$DU = \frac{9.02 \times 100}{9.4} = 96$$

Runoff, RO, inches:

$$\text{RO, inches} = \frac{(\text{Runoff volume, ac-in})}{(\text{Irrigated area, ac})} = \frac{6.32}{4.6} = 1.38 \text{ in}$$

$$\text{RO, \%} = \frac{(\text{Runoff depth, inches})}{(\text{Gross application, } F_g\text{, inches})} \times 100 = \frac{1.38 \times 100}{10.68} = 12.9 \ \%$$

Exhibit 9–5 Completed worksheet—Surface irrigation system, detailed evaluation of contour ditch irrigation system —Continued

U.S. Department of Agriculture
Natural Resources Conservation Service

Sheet 3 of 6

Example - Contour Ditch Irrigation System
Detailed Evaluation Worksheet

Deep percolation, DP, inches:

DP, inches = (Gross applic. F_g, inches) - (Runoff depth, RO, inches) - (Soil water deficit, SWD, inches)

DP, inches = 10.68 – 1.38 – 6.26 = 3.04 inches

DP, % = $\frac{\text{(Deep percolation, DP, inches)}}{\text{(Gross application, } F_g \text{, inches)}}$ x 100 = $\frac{3.04 \times 100}{10.68}$ = 28.5 %

Application efficiency (E_a):

(Average depth replaced in root zone = Soil water deficit, SWD, inches)

E_a% = $\frac{\text{(Average depth replaced in root zone, inches)}}{\text{(Gross application, } F_g \text{, inches)}}$ x 100 = $\frac{6.26 \times 100}{10.68}$ = 58.6 %

Potential water and cost savings

Present management:

Estimated present average net application per irrigation = 5.0 inches

Present gross applied per year = $\frac{\text{(Net applied per irrigation, inches)} \times \text{(no. of irrigations)}}{\text{(Application efficiency, } E_a \text{, percent)}}$ x 100

Present gross applied per year = $\frac{5.0 \times 5 \times 100}{58.6}$ = 43.0 inches

Potential management

Annual net irrigation requirement: 13.0 inches, for alfalfa (crop)

Potential application efficiency, E_{pa}: 60 % (from irrigation guide or other source)

Potential annual gross applied = $\frac{\text{(annual net irrigation requirement, inches)}}{\text{(Potential application efficiency, } E_{pa} \text{, percent)}}$ x 100

Potential annual gross applied = $\frac{13.0 \times 100}{60}$ = 21.7 inches

Total annual water conserved:

= ($\frac{\text{(Present gross applied, inches) - (Potential gross applied, inches)}}{12}$ x Area irrigated, ac)

= ($\frac{43.0 - 21.7}{12}$) x (4.59) = 8.15 acre-feet

Exhibit 9–5 Completed worksheet—Surface irrigation system, detailed evaluation of contour ditch irrigation system —Continued

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Sheet 4 of 6

Example - Contour Ditch Irrigation System Detailed Evaluation Worksheet

Cost savings:

Pumping plant efficiency ______________ percent, Kind of energy __________________________

Cost per unit of fuel ______________________ Fuel cost per acre foot _______________________

Cost savings = (Fuel cost per acre foot) x (Acre inches conserved per year)

= ____

Water purchase cost:

= (Cost per acre foot) x (Acre feet saved per year) =

= (_____________) x (_____________) = ____

Cost savings = (Pumping cost) + (Water cost) = (_____________) + (_____________) = _________

Recommendations

Notes

Exhibit 9–5 Completed worksheet—Surface irrigation system, detailed evaluation of contour ditch irrigation system —Continued

U.S. Department of Agriculture
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Sheet 5 of 6

Example - Contour Ditch Irrigation System
Detailed Evaluation Worksheet

Inflow X Outflow _________

Type of measuring device ____

Clock 1/ time	Elapsed time (min)	Δ T (min)	Gauge H (ft)	Flow rate (ft^3/s)	Average flow rate (ft^3/s)	Volume 2/ (ac-in)	Cum. volume (ac-in)
Turn on 0745			1.33	4.75			
		10			4.84	.80	.80
0755	10		1.36	4.92			
		15			4.98	1.23	2.03
0810	25		1.38	5.03			
		80			5.09	6.73	8.76
0930	105		1.40	5.14			
		60			5.20	5.16	13.92
1030	165		1.42	5.25			
		60			5.31	5.27	19.19
1130	225		1.44	5.37			
		60			5.28	5.24	24.43
1230	285		1.41	5.19			
		60			5.22	5.18	29.61
1330	345		1.42	5.25			
		60			5.28	5.24	34.85
1430	405		1.43	5.31			
		60			5.34	5.30	40.15
1530	465		1.44	5.37			
		100			5.37	8.88	49.03
1730	565		1.44	5.37			

Total volume (ac-in) 49.03

Average flow = $\frac{\text{Total irrigation volume in (ac-in)}}{\text{Flow factor x elapsed time (min)}}$ = $\frac{49.03}{.01653 \text{ x } 565}$ = 5.25 ft^3/s

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. is recorded as 1330 hours.
2/ Flow rate to volume factors:
To find volume using ft^3/s:
Volume (ac-in) = .01653 x time (min) x flow (ft^3/s)

To find volume using gpm:
Volume (ac-in) = .00003683 x time (min) x flow (gpm)

Exhibit 9–5 Completed worksheet—Surface irrigation system, detailed evaluation of contour ditch irrigation system —Continued

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Sheet 5 of 6

Example - Contour Ditch Irrigation System
Detailed Evaluation Worksheet

Inflow ________ Outflow X

Type of measuring device 3" Parshall flume

Clock 1/ time	Elapsed time (min)	Δ T (min)	Gauge H (ft)	Flow rate (ft^3/s)	Average flow rate (ft^3/s)	Volume 2/ (ac-in)	Cum. volume (ac-in)
Turn on 0830			.20	.082			
		45			.11	.082	.082
0915	45		.28	.138			
		60			.209	.207	.289
1015	105		.44	.279			
		60			.229	.297	.586
1115	165		.48	.319			
		60			.329	.326	.912
1215	225		.50	.339			
		60			.350	.347	1.259
1315	285		.52	.361			
		60			.392	.369	1.628
1415	345		.54	.382			
		60			.388	.385	2.013
1515	405		.55	.393			
		60			.404	.401	2.414
1615	465		.57	.415			
		60			.427	.423	2.837
1715	525		.59	.438			
		35			.219	.127	2.964
1750	560		0	0			

Total volume (ac-in) 2.964

$$\text{Average flow} = \frac{\text{Total irrigation volume in (ac-in)}}{\text{Flow factor x elapsed time (min)}} = \frac{2.964}{.01653 \times 565} = 0.32 \ ft^3/s$$

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. is recorded as 1330 hours.

2/ Flow rate to volume factors:

To find volume using ft^3/s:

Volume (ac-in) = .01653 x time (min) x flow (ft^3/s)

To find volume using gpm:

Volume (ac-in) = .00003683 x time (min) x flow (gpm)

Exhibit 9–5 Completed worksheet—Surface irrigation system, detailed evaluation of contour ditch irrigation system —Continued

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Sheet 6 of 6

Example - Surface System
Detailed Evaluation Contour Ditch Irrigation Systems Worksheet

Grid Data

Grid point	Advance time 1/ (hr:min)	Recession time 1/ (hr: min)	Opportunity time " T_o" (min)	Typical depth infil. 2/ (in)	Adjusted depth infil. 2/ (in)	Low 1/4 adjusted intake 4/ (in)
D2	0752	1725	573	6.6	9.7	
E2	0749	1715	566	6.5	9.7	
F2	0755	1725	570	6.6	9.7	
C3	0841	1735	521	6.2	9.2	
D3	0814	1729	555	6.4	9.5	
E3	0755	1728	573	6.6	9.7	
F3	0813	1728	555	6.4	9.5	
G3	0850	1732	522	6.2	9.2	9.2
C4	0853	1742	529	6.3	9.3	
D4	0841	1730	537	6.3	9.4	
E4	0815	1733	558	6.4	9.5	
F4	0814	1733	559	6.4	9.6	
G4	0902	1740	518	6.1	9.2	9.2
C5	0915	1751	516	6.1	9.1	9.1
D5	0855	1748	533	6.3	9.4	
E5	0833	1743	550	6.4	9.5	
F5	0815	1742	567	6.5	9.7	
G5	0905	1750	525	6.2	9.2	9.2
E6	0857	1753	536	6.3	9.5	
G6	0920	1800	460	5.6	8.4	8.4
			Total	126.4	187.9	45.1

2/ From "typical" cumulative intake curve.
3/ From "adjusted" cumulative intake curve.
4/ Adjusted intake for lowest intake 1/4 of points (total number of points divided by 4).

Average depth infiltrated (typical):

$$= \frac{\text{Total depth typical}}{\text{Number of grid points}} = \frac{126.4}{20} = 6.32 \text{ in}$$

Average depth infliltrated (adjusted):
(Should be close to actural depth infiltrated)

$$= \frac{\text{Total depth adjusted}}{\text{Number of grid points}} = \frac{187.9}{20} = 9.395 \text{ in}$$

Average depth infiltrated (adjusted), low 1/4:

$$= \frac{\text{Total depth adjusted, low 1/4}}{\text{Number grid points, low 1/4}} = \frac{45.1}{20} = 9.02 \text{ in}$$

Example 9–5 Evaluation computation steps for contour ditch irrigation systems

1. **On the grid sheet, determine the area, in acres, covered by the irrigation.**

2. **Compute the soil water deficit (SWD).** This is the net depth of application (F_n) needed for the evaluation irrigation.

3. **Plot cumulative intake curves for each infiltrometer.** After all curves have been plotted on log-log paper and deviations have been considered and allowed for, a typical straight line can be drawn for use in evaluation (fig. 9–26). Its position should be checked later and adjusted to show the correct duration of irrigation.

Figure 9–26 Cumulative intake curve (data from figure 9–27)

Land user Joe Example
Date 6-6-94
Field office Joliet

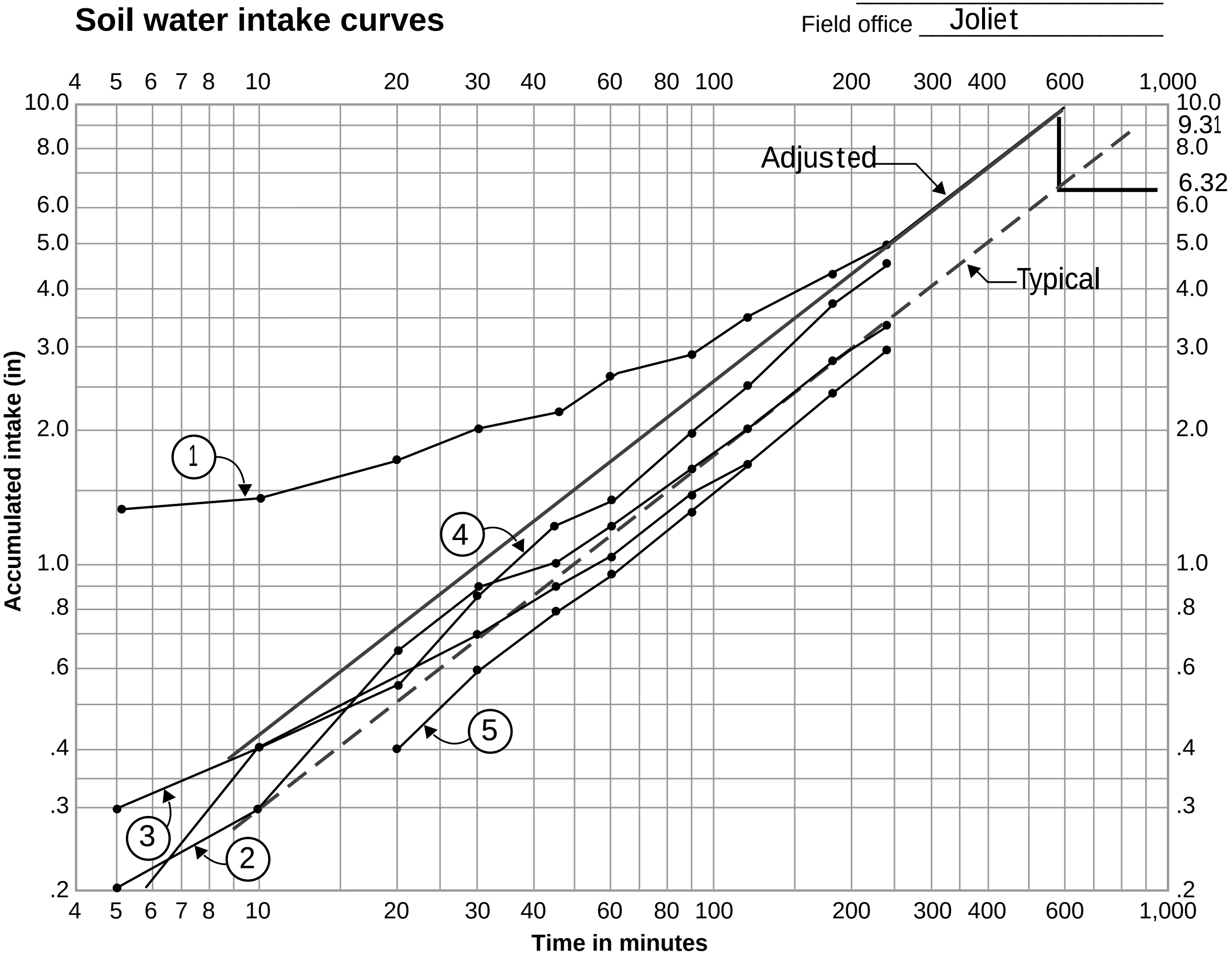

Figure 9–27 Example cylinder infiltrometer test data

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Example - Cylinder Infiltrometer Test Data

NRCS-ENG-322
02-96

FARM Joe Example	COUNTY Carbon	STATE MT	LEGAL DESCRIPTION	DATE 6-6-94
SOIL MAPPING SYMBOL	SOIL TYPE Fort Collins loam		SOIL MOISTURE: 0' - 1' - % of available 1' - 2' - % of available	
CROP Alfalfa grass	STAGE OF GROWTH			

GENERAL COMMENTS

Elapsed time	Cylinder No. 1			Cylinder No. 2			Cylinder No. 3			Cylinder No. 4			Cylinder No. 5			Average accum. intake
	Time of reading	Hook gauge reading	Accum. intake	Time of reading	Hook gauge reading	Accum. intake	Time of reading	Hook gauge reading	Accum. intake	Time of reading	Hook gauge reading	Accum. intake	Time of reading	Hook gauge reading	Accum. intake	
Min.		Inches			Inches			Inches			Inches			Inches		
0	12:01	8.5	0	12:02	7.0	0	12:03	7.2	0	12:04	6.6	0	12:05	8.0	0	
5	12:06	7.2	1.3	12:07	6.8	0.2	12:08	6.9	0.3	12:09	6.3	0.3	12:10	7.9	0.1	
10	12:11	7.1/ 8.8	1.4	12:12	6.7/ 8.2	0.3	12:13	6.8/ 7.8	0.4	12:14	6.2/ 7.2	0.4	12:15	7.6/ 8.25	0.4	
20	12:21	8.55	1.65	12:22	7.85	0.65	12:23	7.65	0.55	12:24	7.05	0.55	12:26	8.25	0.4	
30	12:31	8.2	2.0	12:32	7.6	0.9	12:33	7.4	0.7	12:34	6.75	0.85	12:35	8.05	0.6	
45	12:46	8.1	2.1	12:47	7.5	1.0	12:48	7.2	0.9	12:49	6.4/ 7.6	1.2	12:50	7.85	10.8	
60	13:01	7.7	2.5	13:02	7.3	1.2	13:03	7.05	1.05	13:04	7.4	1.4	13:05	7.7	0.95	
90	13:31	7.35	2.85	13:32	6.9	1.6	13:33	6.65	1.45	13:34	6.9	1.9	13:35	7.35	1.3	
120	14:01	6.85/ 9.05	3.35	14:02	6.55/ 9.05	1.95	14:03	6.45/ 9.2	1.65	14:04	6.4/ 9.2	2.4	14:05	7.0/ 9.2	1.65	
180	15:01	8.3	4.1	15:02	8.3	2.7	15:03	8.5	2.35	15:04	8.1	3.5	15:05	8.5	2.35	
240	16:01	7.55	4.85	16:02	7.7	3.3	16:03	7.95	2.9	16:04	7.35	4.25	16:04	7.9	2.95	

Example 9–5 Evaluation computation steps for contour ditch irrigation systems—Continued

4. **Enter the advance and recession times at each grid point on the grid data worksheet** (exhibit 9–5). This requires some interpolation of the times shown on the map. Compute difference in time between advance and recession, in minutes. This time is the actual opportunity time (T_o) at each grid point. Record T_o on the worksheet.

Find the average opportunity time for the area by averaging the T_o values for all grid points.

Using the computed opportunity times for each grid point, determine and record the typical intake depth for each point from the typical cumulative intake curve. Compute the average depth infiltrated (typical):

$$\text{Ave depth infiltrated, inches} = \frac{\text{Total depth infiltrated, typical}}{\text{Number of grid points}}$$

To check correctness of the location at which the typical curve was drawn, the actual average depth infiltrated is computed:

$$\text{Ave depth infiltrated, inches} = \frac{(\text{Irrigation volume, ac-in}) - (\text{Runoff volume, ac-in})}{(\text{Irrigated area, acres})}$$

A curve correction is needed because the infiltrometers check the infiltration at only one spot in the irrigated area. The slope of that curve is probably typical of the average curve for the area. An adjusted curve, since it is based on the infiltrometer curve slope and actual average depth infiltrated, will more nearly represent the average intake curve for the irrigated area and the field.

Draw a line parallel to the typical line passing through a point that is at the actual average depth infiltrated and at a time corresponding to the typical average depth infiltrated. This new line is the adjusted cumulative intake curve. See figure 9–26.

Using the adjusted intake curve and the opportunity time for each grid point, determine the adjusted intake depth for each grid point. Compute the average depth, adjusted:

$$\text{Ave depth} = \frac{(\text{Total depth infiltrated, adjusted})}{\text{Number of grid points}}$$

Compute the average depth infiltrated low quarter, adjusted:

$$\text{Ave depth infiltrated, inches} = \frac{\left(\text{Total depth infiltrated, adjusted, low } \frac{1}{4}\right)}{\left(\text{Number of grid points, low } \frac{1}{4}\right)}$$

Example 9–5 Evaluation computation steps for contour ditch irrigation systems—Continued

5. Compute irrigation characteristics:

Gross application (F_g):

$$F_g\text{, inches} = \frac{(\text{Total inflow volume, ac-in})}{(\text{Irrigated area, acres})}$$

Distribution uniformity – low quarter (DU)

$$DU = \frac{(\text{Total low quarter depth infiltrated})}{(\text{Total depth infiltrated})}$$

Runoff depth (RO):

$$RO\text{, inches} = \frac{(\text{Runoff volume, ac-in})}{(\text{Irrigated area, acres})}$$

$$RO\text{, \%} = \frac{(\text{Runoff depth, inches})}{(\text{Gross application, inches})} \times 100$$

Deep percolation (DP):

$$DP\text{, inches} = (\text{Gross application, inches}) - (\text{Runoff depth, inches}) - (\text{Soil water deficit, inches})$$

$$DP\text{, \%} = \frac{(\text{Deep percolation, inches})}{(\text{Gross application, inches})} \times 100$$

Application efficiency (E_a)—Application efficiency is the ratio of average depth of water stored in the root zone to gross application depth. In most cases for this type of irrigation, the entire root zone is filled to field capacity by the irrigation. If this is the case, application efficiency is the ratio of soil water deficit to gross application. Otherwise, it is the ratio of gross application less runoff to gross application.

$$E_a = \frac{(\text{Average depth stored in root zone, inches})}{(\text{Gross application, inches})} \times 100$$

6. Compute potential water conservation and pumping cost savings:

- Based on information about present irrigation scheduling and application practices obtained from the irrigation decisionmaker and on data derived from the evaluation, make a best estimate of the present net application per irrigation.

Example 9–5 Evaluation computation steps for contour ditch irrigation systems—Continued

- Compute an estimate of the gross amount of irrigation water used per year. Use the estimated average net application, average number of annual irrigations (from the irrigation decisionmaker), and application efficiency (E_a) found by this evaluation to compute annual gross:

$$\frac{(\text{Net applied per irrigation, inches}) \times (\text{Number of irrigations})}{(\text{Application efficiency, } E_a)} \times 100$$

- From the irrigation guide, determine annual net irrigation requirements for the crop to be managed.

- From the irrigation guide or other source, determine potential system efficiency (E_{pa}).

- Compute annual gross applied:

$$\frac{(\text{Annual net irrigation requirement, inches})}{(\text{Potential application efficiency, } E_{pa})} \times 100$$

- Compute total annual water conserved (ac-ft):

$$\frac{(\text{Present gross applied, inches}) - (\text{Potential gross applied, inches})}{12} \times \text{Area irrigated, acre}$$

- If cost is a factor, compute cost savings:

Pumping cost savings: From a separate pumping plant evaluation, determine pumping plant efficiency, kind of fuel, cost per unit of fuel, and fuel cost per acre foot. Compute fuel cost savings:

(Fuel cost per acre foot) x (acre feet conserved per year)

Water purchase cost savings: Obtain purchase cost data from irrigation decisionmaker. Compute as follows:

(Cost per acre foot) x (Acre feet saved per year)

Compute total cost savings.

Example 9–5 Evaluation computation steps for contour ditch irrigation systems—Continued

Analysis of data and preparation of recommendations:

1. **Compare soil water deficit (SWD) with management allowed deficit (MAD).** This indicates whether the irrigation was correctly timed, too early, or too late.
2. **Consider changes that may be made in set times and scheduling.**
3. **Consider changes that might be made in ditch location and turnout location.**
4. **Consider alternative types of turnouts.** Turnouts with better flow control may improve the ability to manage the system.
5. **Consider whether land smoothing or construction of corrugations would help distribution patterns.**

Recommendations:

Use field observations, data obtained by discussion with the irrigation decisionmaker, and data obtained by computations to make practical recommendations. Remember that the data are not exact because of the many variables. Flow rate changes and other changes are the result of a trial and error procedure. After each new trial, the field should be probed to determine penetration. Enough instruction should be given to operators so they can make these observations and adjustments.

> **Making management changes is always the first increment of change. Recommending irrigation system changes, along with appropriate management changes is secondary.**

(5) Periodic move sprinkler (sideroll wheel lines, handmove, end tow) fixed (solid) sets

The overall efficiency of sprinkler irrigation systems changes with time. Nozzles, sprinkler heads, and pumps wear (lose efficiency), and pipes and joints develop leaks. Some systems are used in ways they were not designed. A sprinkler system evaluation is designed to identify problems and develop solutions. Before a detailed evaluation is made, obvious operating and equipment deficiencies should be corrected by the water user. However, observing and evaluating a poorly designed, installed, or operated system may be a good training exercise to improve employee competence. The following evaluation procedure works satisfactorily with either impact or gear driven type sprinkler heads. Some modification to evaluation tools may be necessary to check pressure and sprinkler discharge.

(i) Equipment needed—The equipment needed to evaluate a periodic move sprinkler system includes:

- Catch containers and stakes—number of containers equals:

$$\frac{\text{lateral spacing} \times \text{sprinkler spacing}}{25}$$

- Two 50-foot tapes
- 500-mL (cc) graduated cylinder (use 250-mL graduated cylinder for light applications).
- Pocket tape (inches)
- Miscellaneous tools—pipe wrench and adjustable wrenches
- Pressure gauge with pitot tube, 0 to 100 psi pressure range (recommend liquid filled)
- Soil auger, push tube sampler, probe, shovel
- Equipment for determining soil moisture amounts—feel and appearance charts, Speedy moisture meter and Eley volumeter, or auger and oven drying cans
- Set of unused high speed twist drill bits, 1/16 to 1/4 inch (by 64ths) for measuring inside diameter of nozzles on impact type sprinkler heads
- Stop watch or watch with second hand
- Wind velocity gauge, thermometer (for air temperature)
- Calibrated bucket (2- to 5-gallon), 5-foot length of 5/8 inch diameter or larger garden hose, need two for measuring discharge from double nozzle sprinkler heads
- Manufacturer's sprinkler head performance charts
- Clipboard and pencil
- Soil data for field
- Camera, boots, rain gear
- Special adapter for measuring discharge from gear driven pop-up type sprinkler heads, if needed
- Worksheets

(ii) Field procedures—The field procedures needed to evaluate this system are in two categories: general and inventory and data collection

General

Obtain pertinent information about irrigation system hardware from the irrigation decisionmaker and from visual observation. Observe general system operating condition, crop uniformity, salinity problems, wet areas, dry areas, and wind problems. Obtain information about the field and how it is irrigated including. This information should include irrigation set time, direction of move of sprinkler laterals, number of moves per day, sprinkler head spacing and move, number of sets or irrigations per season, chemigations, and crops grown in the rotation. If at all possible, perform the evaluation on a day with no or little wind. With lateral sets involving one move per day (24-hour set), it may be desirable to leave catch can containers overnight.

Inventory and data collection

The following steps are needed to collect and inventory data:

Step 1—Estimate soil-water deficit at several locations in the field. Use the feel and appearance, Eley volumeter/Speedy moisture meter, auger or push tube sampler (Madera sampler), or some other method. Pick a typical location, and record the data on the worksheet.

Step 2—While completing step 1, also make note of soil profile conditions including:

- Depth to water table
- Apparent root development pattern and depth of existing or previous crop (for determining effective plant root zone)

- Root and water restrictions:
    - Compacted layers (tillage pans) and probable cause.
    - Mineral layers.
    - Hardpans or bedrock.
    - Soil textures including textural change boundaries (abrupt or gradual).

Step 3—If a portable flow meter is available, insert it at the beginning of the lateral before the irrigation is started and leave it throughout the irrigation. The irrigator could install and remove it when laterals or sets are changed. Clamp-on ultrasonic flowmeters can also be used effectively.

Step 4—Choose a representative location along a sprinkler lateral for the test where pressure is typical for most of the lateral. With one size of lateral pipe, about half the pressure loss resulting from pipeline friction loss in a lateral occurs in the first 20 percent of the length. Over 80 percent of pressure loss occurs in the first half of the lateral length. On a flat field the most representative pressure occurs about 30 to 40 percent of the distance from the lateral inlet to the terminal end.

Almost any container can be used. A sharp edge is desirable. The 12- or 16-ounce clear plastic drinking glass works well. For straight sided containers, the entry rim diameter is measured and the equivalent capacity in cc (mL) for 1-inch application depth is computed. For stackable tapered sided containers, a 500 cc (or 250 cc) graduated cylinder is used to volumetrically measure catch in the cans. The cross sectional area of the top of the container is used to calculate application depth, either in inches or millimeters. Large sized rain gauges can be used as catch containers and can be read directly. To get mL conversion using a circular container, measure the opening diameter in inches and the conversion from mL to inches:

$$mL = \frac{\pi D^2}{4} \times 16.387$$

Step 5—Place bags over sprinklers affecting the test area. An alternative to this is to insert a small stick or plant stem along the side or into the impact arm of impact type sprinkler heads to jam it open and prevent rotation. Make sure water does not get in the containers while they are being set out. Using a pressure gauge and pitot tube, hose, calibrated bucket, and stop watch, check pressure and flow measurement at sprinklers next to the test area. All sprinklers on the lateral need to be operating.

Note: Liquid filled pressure gauges are more durable and provide dampening of the gauge needle, allowing pressure readings more easily obtained. Gauges should be periodically checked against known pressures to determine potential errors. Purchasing a quality pressure gauge to start with is a wise investment.

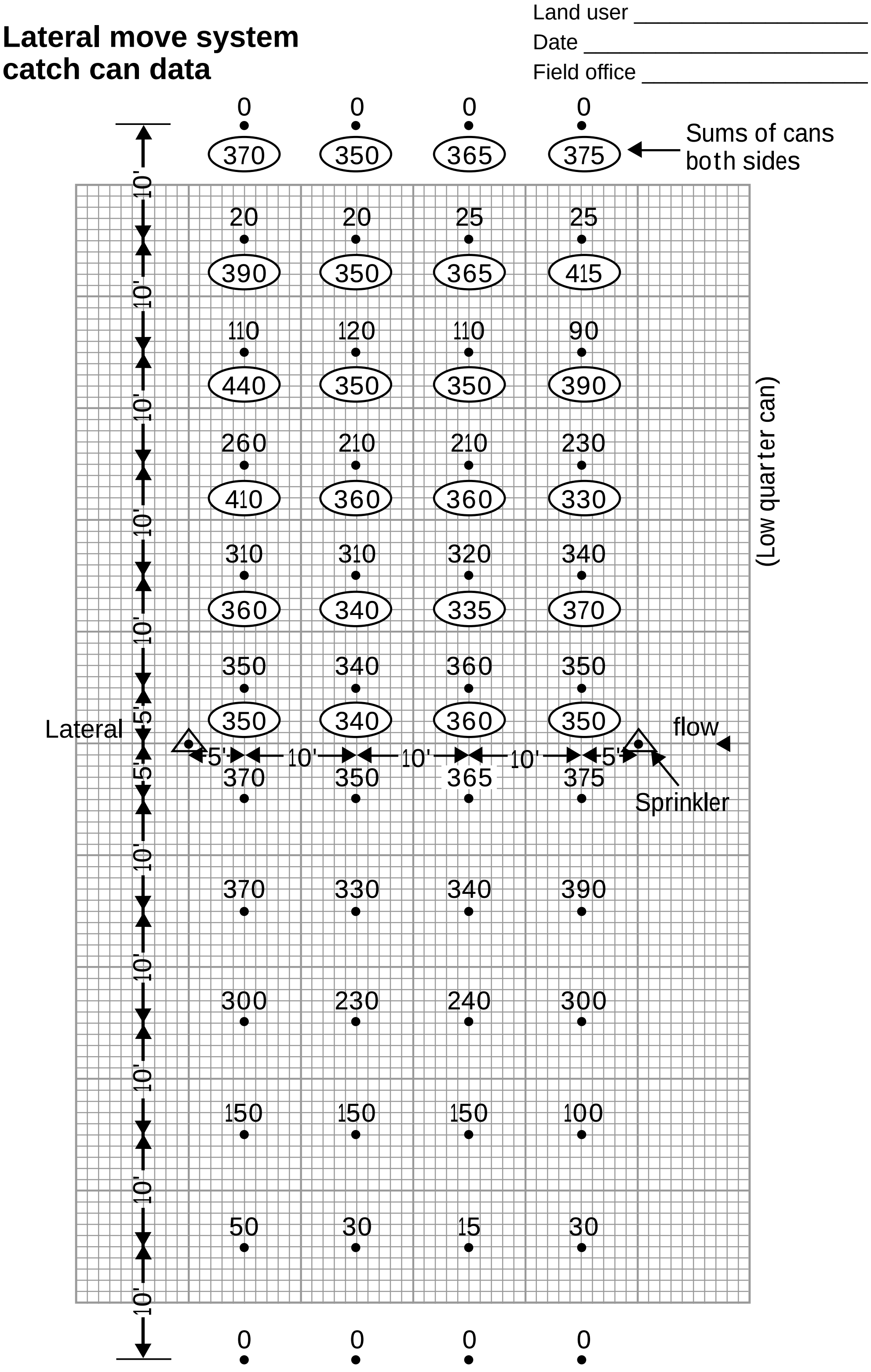
Step 6—Set out catch containers on a 10-foot by 10-foot grid on both sides of the lateral between two or more adjacent sprinkler heads. The grid pattern should be continued perpendicular to the lateral for a distance equal to the next lateral set location or just beyond sprinkler throw radius, whichever is greater. The last rows of catch containers on each side of the lateral will probably catch little water. See figure 9–28 for catch container layout and example catch data.

Each container should be located at approximate plant canopy height within a foot of its correct grid position and set carefully in an upright position with its top parallel to the ground. Any surrounding vegetation that would interfere with a container should be removed. To fasten containers to short stakes with rubber bands may be necessary. Personal ingenuity may be necessary as to shape, height, and setting of catch cans when evaluating low angle sprinkler heads installed close to the ground surface. It is necessary for water to enter the catch container nearly vertical rather than horizontal.

During hot, dry weather when long catch times are used, an evaporation container should be set upwind and away from the sprinklers. The container should be filled with water at the start of the irrigation test, and the amount of evaporation measured at the same time the rest of the containers are read. Depth of water in the evaporation container should approximate half the average catch. This measurement approximates the amount of evaporation that occurred from the catch during the test period.

Quickly remove the cloth bags or small sticks from the sprinkler heads to allow them to start rotating. Start timing the catch.

Figure 9–28 Catch can data for lateral move system



Step 7—At several locations along the lateral, use the shank end of unused high speed twist drill bits to determine nozzle diameters. Check for wear and correct nozzle size. Nozzle size generally is indicated on side of nozzle. Wear is considered excessive when the drill bit can be moved about in the nozzle over 5 to 10 degrees. Observe sprinkler heads for hang-ups, weak springs, and leaks. Impact type heads should rotate at 1 to 2 revolutions per minute. Determining the actual size of sprinkler nozzles being used with gear driven heads using noncircular orifices is difficult. The biggest cause of sprinkler irrigation application nonuniformity is mixed nozzle sizes.

Step 8—Measure and record pressure and flow rate of sprinklers at several locations along the lateral line and at both ends, preferably at the beginning and end of the test period. Pressure is most accurately measured with tip of the pitot tube in the jet stream at the orifice. Inserting the tip of the pitot tube inside the orifice restricts flow; thus, line pressure is measured rather than orifice discharge pressure. Typically the difference is 1 to 2 psi. For most evaluations line pressure is sufficient providing all measurements are line pressure or nozzle pressure.

Step 9—Record how long it takes each sprinkler tested to fill a calibrated bucket. A short length of garden hose over the sprinkler nozzle is used to collect the flow in the calibrated bucket. To avoid modifying nozzle hydraulics, the hose should fit rather loosely. Time the flow into the bucket with a stopwatch. To improve accuracy, determine the sprinkler discharge several times and compute the average. Use two hoses for double nozzle sprinkler heads. It will take personal ingenuity to develop a device to measure discharge from gear driven sprinkler heads. The head should rotate freely. A device similar to the that used when evaluating micro-irrigation systems (minispray heads) may be adopted using a larger two-piece catch container.

Step 10—Record wind speed, air temperature, and whether humidity is low, medium, or high.

Step 11—The test duration should be such that a minimum of 0.5-inch (average) depth of water is collected in catch containers. Terminate the test by replacing bags over the sprinkler heads or blocking head rotation. Record the time.

Step 12—Measure the depth of water caught in each container by pouring water into a graduated cylinder. An alternative to this is to use large commercial plastic rain gauges as catch containers as well as the evaporation container. The difference between the starting and ending depth in the evaporation container needs to be added to all catch container readings. Rain gauges can be read directly.

Step 13—Record the catch data on a grid sheet. Show location of sprinkler heads and lateral pipeline in relation to catch containers. Show north direction, direction of pipeline flow, and prevailing wind direction. Record nearby landmarks to locate the test area for discussion purposes with the water user.

(iii) Evaluation computations—The information gathered in the field procedures is used in the detailed system evaluation computations. Example 9–6 outlines the computations used to complete the Sprinkler Irrigation System Detailed Evaluation Periodic Move and Fixed Set Sprinkler System Worksheet (exhibit 9–6).

Exhibit 9–6 Completed worksheet—Sprinkler irrigation system, detailed evaluation of periodic move and fixed set sprinkler irrigation systems

U.S. Department of Agriculture Sheet 1 of 6
Natural Resources Conservation Service

Sprinkler Irrigation System
Detailed Evaluation Periodic Move and Fixed Set Sprinkler System

Land user Joe Example Prepared by ____________

District ____________ County ____________ Engineer job class ____________

Irrigation system hardware inventory:

Type of system (check one) : Side- roll ✓ Handmove ______ Lateral tow ______ Fixed set ________

Sprinkler head: make RB, model 30, nozzle size(s) 3/16 by 3/32 inches

Spacing of sprinkler heads on lateral, S_1 40 feet

Lateral spacing along mainline, S_m 60 feet, total number of laterals 1

Lateral lengths: max ________ feet, minimum ________ feet, average ________ feet

Lateral diameter: 1280 feet of 5 inches, ________ feet of ________ inches

Manufacturer rated sprinkler discharge, 8.6 gpm at 45 psi giving 96 feet wetted diameter

Total number sprinkler heads per lateral 33, lateral diameter 5 inches

Elevation difference between first and last sprinkler on lateral (=/-) –5 feet

Sprinkler riser height – feet, mainline material 6" PVC

Spray type: ✓ fine (>30psi), ________ coarse (<30psi)

Field observations:

Crop uniformity ____________

Water runoff ____________

Erosion ____________

System leaks ____________

Fouled nozzles ____________

Other observations ____________

Field data inventory & Computations:

Crop Alfalfa, root zone depth 5 feet, MAD 1/ 50 %, MAD 1/ 3.0 inches

Soil-water data (typical):

(Show locations of sample on soil map or sketch of field)

Moisture determination Feel & appearance

Soil series and surface texture Redfield loam

Depth	Texture	AWC 1/ (in)	SWD 1/ (%)	SWD 1/ (in)
0-1'	L	2.0	50	1.0
1-2'	LFS	1.5	45	0.7
2-35'	VFLS	2.25	45	1.0
3.5-5'	GLS	1.5	20	0.3
	Totals	7.25		3.0

1/ MAD = Management allowable depletion, AWC = Available water capacity, SWD = Soil water deficit

Exhibit 9–6 Completed worksheet—Sprinkler irrigation system, detailed evaluation of periodic move and fixed set sprinkler irrigation systems—Continued

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Sheet 2 of 6

Example - Sprinkler Irrigation System
Detailed Evaluation Periodic Move and Fixed Set Sprinkler System

Comments about soils (including restrictions to root development and water movement): ______

Present irrigation practices:

Typical irrigation duration 12 hr, irrigation frequency 14 days
Typical number irrigations per year 8
Distance moved per set 60 ft, Alternate sets? no

Measured nozzle diameters (using shank of high speed drill bit)

Sprinkler no.	1		13		33
Diameter	3/16 x 3/32		same		same
Size check	m		m		m

(state whether t = tight, m = medium, l = loose)

Actual sprinkler pressure and discharge data:

Sprinkler number on test lateral

	1st				end
Initial pressure (psi)	48		47		46
Final pressure (psi)	47		46		45
Catch volume (gal)	5		5		5
Catch time (sec)	33		34		34
Discharge (gpm)	9.1		8.8		8.8

Test:
Start 0924 stop 1521 duration 5:57 = 5.95 hours

Atmospheric data:
Wind: Direction: Initial from N during same final same
Speed (mph): initial 0-7 during 5-10 final 5-10

Temperature: initial 65° final 75° Humidity: ____ low __X__ med ____ high

Evaporation container: initial — final ____ loss ____ inch

Exhibit 9–6 Completed worksheet—Sprinkler irrigation system, detailed evaluation of periodic move and fixed set sprinkler irrigation systems—Continued

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Natural Resources Conservation Service

Example - Sprinkler Irrigation System
Detailed Evaluation Periodic Move and Fixed Set Sprinkler System

Lateral flow data:

Flow meter reading – gpm

Average discharge of lateral based on sprinkler head discharge

= [1st gpm - .75 times (1st gpm - last gpm)] times (number of heads)

= 9.1 - .75 (9.1 - 8.8) = 8.8 gpm (ave flow per head)

= 33 heads x 8.8 gpm/head = 290 gpm

Calculations:

Gross application per test = $\frac{\text{(flow, gpm) x (time, hr) x 96.3}}{\text{(lateral length) x (lateral spacing)}}$

= $\frac{(290\text{ gpm}) \text{ x } (12\text{ hours}) \text{ x } 96.3}{(1280\text{ feet}) \text{ x } (60\text{ feet})}$ = 2.16 inches

Gross application per irrigation = $\frac{\text{(gross application per test, in) x (set time, hour)}}{\text{(time, hour)}}$

= $\frac{(2.16\text{ inches}) \text{ x } (12\text{ hour})}{(5.95\text{ hour})}$ = 4.36 inches

Catch container type Straight sided

200 cc (mL) or in, measuring container = 1.0 inches in container

Total number of containers 48

Composite number of containers = $\frac{\text{Total number of containers}}{2}$ = $\frac{48}{2}$ = 24

Total catch, all containers = $\frac{8745}{200\text{ cc/in}}$ cc (mL)= 43.73 inches

Average total catch = $\frac{\text{Total catch}}{\text{composite no. containers}}$ = $\frac{43.73}{24}$ = 1.82 inches

Number of composite containers in low 1/4 = $\frac{\text{composite no. containers}}{4}$ = $\frac{24}{4}$ = 6

Total catch in low 1/4 composite containers = $\frac{2045}{200\text{ cc/in}}$ cc(mL) = 10.225 inches

Exhibit 9–6 Completed worksheet—Sprinkler irrigation system, detailed evaluation of periodic move and fixed set sprinkler irrigation systems—Continued

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Example - Sprinkler Irrigation System
Detailed Evaluation Periodic Move and Fixed Set Sprinkler System

Average catch of low 1/4 composite containers = $\frac{\text{total catch in low 1/4}}{\text{no. composite low 1/4 containers}}$

= $\frac{10.225}{6}$ = 1.70 inches

Average catch rate = $\frac{\text{Average total catch, inches}}{\text{Test time, hour}}$ = $\frac{1.82}{5.95\ \text{hour}}$ = 0.31 inch/hour

NOTE: Average catch rate is application rate at plant canopy height.

Distribution uniformity low 1/4 (DU):

DU = $\frac{(\text{Average catch low 1/4 composite containers})}{\text{Average total catch}}$ x 100 = $\frac{1.70 \times 100}{1.82\ \text{inches}}$ inches x 100 = 93.4 %

Approximate Christiansen Uniformity (CU):

CU = 100 - [0.63 x (100 - DU)] = 100 [0.63 x (100 - 93.4)] = 95.8 %

Effective portion of applied water (R_e):

R_e = $\frac{\text{Average total catch, inch}}{\text{Gross applications/test, inches}}$ = $\frac{1.82}{2.16\ \text{inches}}$ inches = 0.84 inches

Application efficiency of low 1/4 (E_q):

E_q = DU x (R_e) = 93.4 x .84 = 78.5 %

NOTE: Use for medium to high value crops.

Approximate application efficiency low 1/2 (E_h):

E_h = CU x (R_e) = 95.8 x .84 = 80.5 %

NOTE: Use for lower value field and forage crops.

Exhibit 9–6 Completed worksheet—Sprinkler irrigation system, detailed evaluation of periodic move and fixed set sprinkler irrigation systems—Continued

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Example - Sprinkler Irrigation System
Detailed Evaluation Periodic Move and Fixed Set Sprinkler System

Application efficiency, (E_a):

$$F_n = \frac{\text{(gross application per irrigation)} \times E_q}{100} = \frac{(\ 4.36 \text{ inches}) \times 80.5}{100} = \underline{\ 3.51\ } \text{ inches}$$

$$E_a = \frac{\text{(water stored in root zone)} \times 100}{\text{(gross application per irrigation)}} = \frac{(\ 3.0 \text{ inches}) \times 100}{(\ 4.36 \text{ inches})} = \underline{\ 68.8\ }\ \%$$

Losses = (runoff, deep percolation) = gross application per irrigation minus SWD

= (4.36 – 3.0 = 1.36 inches

Potential Water and Cost Savings:

Present management:

Gross applied per year = (gross applied per irrigation) x (number of irrigations) =

= (4.36 inches) x (8) = 34.9 inches/year

Potential management:

Annual net irrigation requirement 14.9 inches/year, for alfalfa (crop)

Potential application efficiency (E_q or E_h) 75 % (from NEH, Part 623, Ch 11)

$$\text{Potential annual gross applied} = \frac{\text{(annual net irrigation requirement)} \times 100}{\text{Potential } E_q \text{ or } E_H}$$

$$= \frac{(\ 14.87 \text{ inches}) \times 100}{75} = \underline{\ 19.8\ } \text{ inches}$$

Total annual water conserved

$$= \frac{\text{(Present gross applied - potential gross applied)} \times \text{(area irrig. (ac))}}{12} = \underline{\qquad\qquad} \text{ acre/feet}$$

$$= \frac{(\ 36.7 \text{ inches}) - (\ 19.8 \text{ inches}) \times (\ 40 \text{ acres})}{12} = \underline{\ 56.2\ } \text{acre/feet}$$

Exhibit 9–6 Completed worksheet—Sprinkler irrigation system, detailed evaluation of periodic move and fixed set sprinkler irrigation systems—Continued

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Example - Sprinkler Irrigation System
Detailed Evaluation Periodic Move and Fixed Set Sprinkler System

Cost savings:

Pumping plant efficiency NA Kind of fuel ____________

Cost per unit of fuel $ ____________ Fuel cost per acre/foot $ ____________

Cost savings = (fuel cost per acre-foot) x (acre-feet conserved per year) = $ ____________

= (____________) x (____________) = $ ____________

Water purchase cost:

= (Cost per acre-foot) x (acre-feet saved per year) = ____________ x ____________ = $ ____________

Cost Savings:

= Pumping cost + water cost = ____________ + ____________ = $ ____________

Recommendations: ____________

Example 9–6 Evaluation computation steps for periodic move and fixed set sprinkler irrigation systems

1. **Simulate sprinkler lateral overlap.** When only one lateral is operating or when operating laterals are not adjacent, simulate sprinkler lateral overlap by transposing catch from one side of the lateral and adding to catch on the other side. Note that the row of containers that would be next to the lateral during the next set must be added to the row of cans next to the test lateral. By doing this we assume that the transposed half is the same as the same side of the next set. If catch on one side has been beyond the lateral move distance, the row of cans next to the next lateral set should still be overlaid next to the test lateral location, and the extended cans added to the other side.

   Assume that the pattern for the next lateral set will have an overlap the same as the transposed half of the evaluated set. This is not always true because the next set may have significantly different patterns as a result of wind or pressure changes. If changes are significant, additional evaluations may be needed.

   The worksheet is set up for transposing catch data. Adjustments in computations are needed if data are not transposed when adjacent laterals are operating. The following description is for transposed data.

2. **Compute the gross application during the test and the gross application for the entire set time.**

3. **Compute the composite number of containers, total containers divided by 2.**

4. **Compute the total catch in all containers.**

5. **Compute the average catch in all containers.** Compute the average catch for all containers with the measure evaporation container or loss added back in (gross application minus evaporation from discharge to catch, wind drift, and system leaks).

6. **Compute the low quarter number of composite containers:** composite number of containers divided by 4.

7. **Add the lowest 25 percent composite catches to represent the low quarter.**

8. **Compute the average low one quarter catch:**

$$\frac{\text{Total catch in low } \frac{1}{4} \text{ containers}}{\text{Number of low } \frac{1}{4} \text{ containers}}$$

9. **Compute irrigation characteristics:**

   - Compute distribution uniformity low 1/4 (DU)

$$\text{DU} = \frac{\text{Average catch in low } \frac{1}{4} \text{ containers}}{\text{Average catch container depth}}$$

Example 9–6 Evaluation computation steps for periodic move and fixed set sprinkler irrigation systems—Continued

- Compute approximate Christiansen uniformity coefficient (CU) percent from:

$$\mathrm{CU} = 100 - 0.63 \times \left(100 - \mathrm{DU}\right)$$

- Compute effective portion of applied water (R_e).

  The effective portion of applied water compares the amount of water caught in containers to the amount pumped. Any difference is a loss caused by evaporation, spray drift, or leaks. It does not account for deep percolation and runoff. The effective portion of applied water can be estimated using figure 6-8 in chapter 6 by entering the chart with observed data on wind velocity, temperature, and humidity. With data from an analysis, the actual effective portion of applied water is computed as follows:

$$R_e = \frac{\text{Average total catch (in)}}{\text{Gross application (in)}}$$

The effective portion of applied water is frequently confused with application efficiency. Application efficiency is the amount of water stored in the plant root zone divided by the amount diverted or pumped. Application efficiency accounts for all losses between the pump and the plant, including system leaks, evaporation, spray drift, deep percolation, and runoff.

Application efficiency of low quarter (E_q) percentage:

$$E_q = \mathrm{DU} \times \left(R_e\right)$$

Approximate application efficiency of low half (E_h) percentage. Note it is suggested to use E_q for most conditions; however, E_h may be applicable where low value field crops are irrigated and deep medium texture soils are available.

$$E_h = \mathrm{CU} \times \left(R_e\right)$$

Application efficiency (E_a) indicates how much water has gone to deep percolation and runoff. First net irrigation application (F_n) is calculated:

$$F_n = \frac{\left(\text{Gross application per irrigation}\right)}{100} \times E_q$$

$$E_a = \frac{\left(\text{Ave depth of water stored in root zone}\right)}{\text{Ave depth of water applied}} \times 100 = \frac{F_n}{\text{Ave depth of water applied}}$$

Estimated losses for deep percolation and runoff are:

$$\text{Losses} = \frac{\left(1 - \text{Gross application}\right)}{100} \times E_a$$

Example 9–6 Evaluation computation steps for periodic move and fixed set sprinkler irrigation systems—Continued

Water and cost savings are computed as follows:

1. **Make a best estimate of present net application per irrigation.** Base the estimate on information about present irrigation scheduling and application practices obtained from the water user, and on data derived from the evaluation.

2. **Calculate the gross amount of irrigation water (F_g) applied during a typical year.** Using water user supplied information about the number of irrigations per season and the application efficiency derived as part of the evaluation, :

$$\text{Annual water applied } \left(F_g\right) = \frac{\left(\text{Net applied per irrigation}\right) \times \left(\text{Number of irrigations}\right)}{\text{Application efficiency low } \frac{1}{4}\left(E_q\right)}$$

If E_q is not available:

$$F_g = \frac{\left(\text{Net applied per irrigation}\right) \times \left(\text{Number of irrigations}\right)}{\text{Effective portion of applied water } \left(R_e\right)} \times 100$$

3. **Determine potential system application efficiency for low quarter and low half.** Use information in this irrigation guide or other sources to help make the determination. Typical ranges of potential E_q and E_h values are:

E_q	E_h
60 to 75%	70 to 85%

These values are based on full canopy crops and the assumption that the system is well designed, maintained, and managed.

E_q values are typically used for high value crops and crops that have relatively shallow roots. E_h values are often used for relatively low value field and forage crops and deep rooted crops in medium to fine texture soil.

4. **Compute potential gross applied per year:**

$$\frac{\left(\text{Annual net irrigation requirement, inches}\right) \times 100}{\text{Potential } E_q \text{ or } E_h}$$

Example 9–6 Evaluation computation steps for periodic move and fixed set sprinkler irrigation systems—Continued

Potential water conservation and pumping costs savings:

1. Compute total annual water conserved (ac-ft):

$$\frac{\left(\text{Present gross applied} - \text{Potential gross applied}\right) \times \text{Area irrigated}}{12}$$

2. If cost is a factor, compute cost savings:

Pumping cost savings: From a pumping plant evaluation, determine pumping plant efficiency, kind of fuel, cost per unit of fuel, and fuel cost per acre-foot. Compute fuel cost savings:

$$\text{Fuel cost savings} = \left(\text{Fuel cost per acre foot}\right) \times \left(\text{acre feet conserved per year}\right)$$

3. Compute water purchase cost savings (obtain purchase cost data from farmer). Compute as follows:

$$\text{Water purchase cost savings} = \left(\text{cost per acre foot}\right) \times \left(\text{acre feet saved per year}\right)$$

4. Compute total cost savings.

Analysis of data and preparation of recommendations

1. Compare soil-water deficit (SWD) with management allowable depletion (MAD). This indicates whether the irrigation was correctly timed, too early, or too late.
2. Compare test data to manufacturer's specifications for the make, model, and size of sprinkler head, nozzle(s), or flow regulator. Recommend maintenance or replacement if required.
3. Check system design. Consider changes that might be practical to make in system hardware and operation.
4. Consider changes that may be made in irrigation set times and scheduling (management).
5. Consider changes that may be made in soil, water, and plant cultural practices to improve water infiltration and use.

Recommendations:

Example 9–6 Evaluation computation steps for periodic move and fixed set sprinkler irrigation systems—Continued

Use field observations, data obtained by the water user, and data obtained by computations to make practical recommendations. Remember observed or measured data are not exact mainly because of the many variables. Irrigation system and management changes result from a calculated field trial and error procedure. The field should be probed after each new trial to determine application distribution uniformity and water penetration. Observations should be made to determine if translocation or runoff is occurring and to estimate the amount. Determine if erosion is occurring, and, if so, what may be causing the erosion. Recommend ways to reduce the erosion. If water translocation, runoff, soil erosion, or a combination of these, are occurring, adjustments in application rate set time or equipment replacement may be necessary. Changes in cultural practices may easily solve the problem. Enough instruction should be given to irrigation decisionmakers so they can make observations and adjustments themselves.

Making management changes is always the first increment of change. Recommending irrigation system changes along with appropriate management changes is secondary.

(6) Center pivot lateral—linear (lateral) move lateral

The efficiency of sprinkler systems changes with time. Nozzles and sprinkler and spray heads wear (lose efficiency), and pipes and joints develop leaks. Some systems are used in ways for which they were not designed. Sprinkler system performance evaluations are designed to identify problems and develop solutions. Before a detailed evaluation is made, obvious operating and equipment deficiencies should be corrected by the water user. However, observing and evaluating a poorly designed, installed, and operated system may be a good training exercise to improve employee competence.

The following evaluation procedure works satisfactorily with most spray heads and all impact type sprinkler heads. Modification and a bit of employee ingenuity is necessary to use this procedure with self moving systems using low pressure in-canopy (LPIC) or low energy precision application (LEPA) type discharge devices. Specially designed catch containers are needed. Using rain gutters for application catch devices is one technique that can work with in-canopy flat spray heads and bubblers. Care should be taken to not disturb foliage that would otherwise affect application uniformity. If at all possible, perform any evaluation when there is little to no wind.

(i) Equipment—The equipment needed for a moving lateral system includes:

- Catch containers and stakes: number of containers equals:

$$\frac{(\text{lateral length} + 10)}{30\ \text{ft}^{1/}}$$

  1/ (30-foot spacing is maximum recommended. Refer to ASAE Standard S436 for recommendations for more precise evaluations.)
- 100-foot tape
- 500-milliliter (cc) graduated cylinder (250 mL cylinder is sufficient for light applications.)
- Pocket tape (inches)
- Pressure gauge with pitot tube, 0 to 100 pounds per square inch pressure range
- Flow measuring device (flow meter, velocity meter)
- Ohmmeter or electric ground check meter (tick meter)
- Soil auger, push tube sampler, probe, shovel
- Equipment for determining soil moisture (fee and appearance soil moisture charts, Speedy moisture meter and Eley volumeter, soil auger and oven drying soil sample containers)
- Stopwatch, thermometer, wind velocity gauge
- Ladder with hooks on top to fit over lateral (system will be moving during evaluation)
- Raincoat, rubber boots
- Manufacturer's pivot system design information (printout)
- Clipboard and pencil
- Soil data for field
- Camera
- Worksheets

(ii) Procedures—The field procedures needed for this system are in two main categories: general and inventory and data collection.

General

Obtain all pertinent system hardware information from the irrigator and from visual observations. Observe general system operating condition, crop uniformity, salinity problems, wet areas, dry areas, translocation, runoff, and other site characteristics. The following steps should be used:

Step 1—Obtain information from the irrigation decisionmaker about the field and how it is irrigated; i.e., speed setting (%), rotation speed (hours per rotation), application depth per single pass or rotation, and passes or rotations per irrigation. Determine how many irrigations or rotations are needed per season.

Step 2—Estimate soil-water deficit at several locations in front of and behind the lateral. Observe if the full plant root zone was filled to field capacity. Use the feel and appearance, Eley Volumeasure and Speedy Moisture Meter, auger or push tube sampler (Madera sampler), or some other acceptable method. Select a typical location and record the data on the worksheet.

Step 3—At the same time, make note of such soil profile conditions as:

- Depth to water table
- Apparent root development pattern and depth of existing or previous crop (to determine effective plant root zone)

- Root and water movement restrictions
  - Restrictive or compacted layers (tillage pans) and probable cause
  - Mineral layers
  - Hardpans or bedrock
  - Soil textural changes

Step 4—An electrical safety check should be made on any electrically operated center pivot system before climbing on or working around it. **The combination of a wet condition and electrical shorts can be deadly.** An ohmmeter or ground check meter (tick meter) should be used to check for current leakage between pivot system and ground. The safety check should be made when the towers are moving to help ensure there are no electrical shorts in an individual tower drive motor. Each tower motor should have the opportunity to run during the check. **Do not proceed with the evaluation if electrical leakage is indicated.** Too often electric operated systems have faulty electrical systems. If no electrical shorts are indicated using an ohmmeter or ground check meter, briefly touch metal components with the back of the hand. Electrical current causes muscles to contract involuntary, thus tightly closing the hand on the component. Only after following the above safety checks should the evaluation proceed.

Inventory and data collection

Step 1—Select a location in the field to run test. Look at elevation change and undulations. Select a location representative of the field being irrigated. You may need to wait a few hours or schedule another day when the lateral is in a desirable location. Sometimes the extreme condition is the operating condition an evaluation is intended to display. Running more than one evaluation at different locations in the field and at different times of day is desirable because of elevation changes in the field, wind drift and evaporation losses between day time and night time, start and stop locations during a test, flow or pressure variations, plus many other variables.

A difference in application from a lateral will be noted when a pivot system's corner systems (guns or swing laterals) are either operating or not operating. The effects of the start-stop operation characteristic (to maintain alignment) and spray head patterns of self move systems are sometimes apparent if two or more catch tests are run at the same location on different days. This is most noticeable with low pressure systems where spray patterns are narrow. A minimum of two catch tests should be run before renozzling is recommended. Where differences are suspected, two rows of catch containers can be averaged to more nearly represent actual conditions.

Step 2—Determine flow into system. If a portable velocity meter (similar to Cox velocity meter) is available, insert the meter near the water source. Linear move laterals with water source in the center may require two flow measurements to obtain flow going both directions. The pitot device for this type meter can be inserted through a standard small gate valve (3/4 inch). Typically, outlet fittings available on the lateral pipe within the first span are not used. A threaded plug can be removed and replaced with a standard 3/4-inch gate valve, or the valve can be installed at the first sprinkler head before the lateral operates. A pitot tube velocity meter can then be easily installed and removed while the system is operating. Clamp-on type ultrasonic flow meters can also be used.

Velocities in the lateral pipe should be measured far enough downstream from any elbow to avoid excessive turbulence occurring just downstream of the elbow. To obtain a reliable average velocity, take several velocity readings across the diameter of the pipe to position the pitot tube to read maximum velocities. The change in velocity across the pipe diameter is readily apparent. Measure and record flow data at start and end of the catch test. Flow, velocity, and operating pressure can change when other self move systems within the same pumping system are turned on or off during the test. On center pivot systems, end guns and corner swing laterals turning on or off affect flow rate and nozzle discharge along the lateral during the test.

Without regularly scheduled maintenance and calibration, flow data accuracy from onfarm system flow meters is questionable. Poor water quality (debris, sediment, salts, manure, aquatic creatures) causes accelerated wear on impellers and bearings of flow meters. Ultrasonic meters should only be used where turbulence and excessive air movement inside the conduit are minimal. To use only flow and velocity meters that are regularly checked and calibrated is advisable. Poorly maintained flow and velocity meters often provide readings that are 10 to 40 percent in error from actual.

Step 3—Determine operating pressure. As a minimum, operating pressure should be checked at the water source point and near the far end. A pressure gauge may be permanently installed, but do not rely on the reading it displays. Use a gauge that has been recently calibrated or checked. If the evaluator does not want to get wet while checking operating pressures, gauges can be installed and removed from sprinkler or spray head fittings when the system is not running. Installing a short 1/4 inch pipe nipple and ball valve generally costs less than having personnel return to the site to remove a pressure gauge. If sprinkler heads are the impact type, a pitot tube attachment in the pressure gauge can be used to measure operating discharge pressure at the nozzle. A warm day is definitely desirable when using a pitot tube to check operating pressures. Check pressure at several locations along the lateral if possible. Record pressure and location on worksheets.

Pressures can be more easily read when using a liquid filled gauge. The liquid provides a dampening of the gauge needle and improves gauge durability.

Step 4—Determine wind speed and direction, lateral line location, air temperature, and humidity level. Record data on worksheets.

Step 5—Step catch containers. For center pivot laterals, set catch containers on a radius along and in front of the lateral so the sprinkler lateral passes perpendicularly across the row(s) of containers. For linear move laterals, set the catch containers in a straight row in front of the lateral. Any catch container can be used; however, it must be calibrated. The catch container should have a sharp edge. For straight sided containers, the entry rim area is measured and the equivalent capacity in cubic centimeters (milliliter) for 1-inch application depth computed. For stackable tapered sided containers, a graduated cylinder is used to measure catch in the containers. The cross sectional area of the top of the container is used to calculate application depth either in inches or millimeters. Large rain gauges can be used as catch containers and can be read directly.

Set containers in a straight line at any uniform interval (usually 30 feet). Start at the pivot point and extend to a point beyond the wetted area at the outer end of the lateral. The lip of each catch container should be reasonably level. Move individual containers to avoid tower wheels. On water drive systems, containers located under driver discharge will collect abnormal amounts of water. These should be relocated or discounted during calculations. If crops are too tall to permit unobstructed catches with containers on the ground, use short stakes and rubber bands to locate containers above foliage. Stakes holding catch containers should not extend above the containers.

Step 6—Allow the lateral to pass completely over the containers. With center pivot laterals, it may be desirable to omit catch containers close to pivot point (first one or two spans). The time it takes for the lateral to completely pass over these containers may be longer than is desirable to complete an evaluation, unless containers can be left for several hours or overnight. Also, the percent of field irrigated by the first one or two spans, is small on large pivots.

Step 7—Read or measure the amount of water caught in each catch container. After the lateral has passed completely over all of the containers, measure and record catch volume or water depth. Use a graduated cylinder to measure volume of catch if tapered sided containers are used. Do not measure and record volume of water or catch in containers that have tipped, partially spilled, or if it appears nearby foliage affected catch. Using a graduated cylinder for straight sided containers generally improves accuracy and can be faster.

If containers are left overnight or for long periods during hot and windy conditions, set out an evaporation can upwind of the test area. Fill the container with a known volume of water (half of the irrigation application depth is recommended) at start of test and then record volume (depth) when other containers are measured and recorded. Evaporation adjustments should be made on all readings. Use the same type of container for both evaporation check and catch. A small amount of mineral oil added to each container protects against evaporation losses.

Step 8—Catch data reduction. With center pivot lateral evaluations, volume or depth caught in each container must be weighted because the catch points represent progressively larger areas as the distance from the pivot increases. To weight the catches according to their distance from the pivot point, each container value must be multiplied by a factor related to the distance from the pivot point. This weighting factor is simplified by using uniform spacing of catch containers and using the container position number as the weighting factor. A worksheet is set up with predetermined factor values.

When evaluating linear move laterals, radial adjustment of catch values is unnecessary as sprinklers move in a straight path and each one irrigates the same area regardless of their location along the lateral.

For the weighted low quarter average application depths, the number of containers that represent the low quarter of the irrigated area must be determined. The low quarter is selected by picking progressively larger (nonweighted) catches and keeping a running total of the associated position number until the subtotal approximates a fourth of the sum of all catch position numbers.

Step 9—Determine maximum application rate. By careful observation along the lateral, an area representing maximum infiltration rate for the present site conditions can generally be observed. No surface ponding, translocation, or runoff should be occurring. Typically with medium textured soil, this location is about 75 to 85 percent of the distance from pivot on a quarter mile lateral. This location varies with soil texture, soil condition, surface storage, type of spray pattern, and pressure of discharge device. Several measurements should be taken throughout the field (representing a specific soil series and surface texture) to represent a reliable value that can be used in the local irrigation guide.

Temporary surface ponding is a reliable method to extend infiltration opportunity time, especially on the outer end of low pressure, in-canopy sprinkler heads (including LEPA). No water translocation or runoff should be occurring.

(iii) Evaluation computations—The information gathered in the field procedures is used in the detailed system evaluation computations. Example 9–7 outlines the computations used to complete the worksheet, Sprinkler Irrigation System Detailed Evaluation for Center Pivot Lateral Systems (exhibit 9–7).

Exhibit 9–7 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous/self move center pivot lateral

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Example - Sprinkler Irrigation System
Detailed Evaluation Center Pivot Lateral Worksheet

Land user Joe Example Field office ______
Observer ______ Date ______ Checked by ______ Date ______

Field name/number ______
Center pivot number 5 pivot location in field South 1/4
Acres irrigated 130

Hardware inventory:
Manufacturer: name and model Valley low pressure
Is design available? Yes (attach copy) Number of towers 7 Spacing of towers 170'
Lateral: Material AL , Inside diameter 6 inches
Nozzle: Manufacturer Senniger
Position Trailing Height above ground 12 -15 ft
Spacing 8 ft
Is pressure regulated at each nozzle? Y operating pressure range 25 - 30
Type of tower drive electric
System design capacity 800 gpm, system operating pressure 32 psi

Nozzle data, design:	Pivot				end
Sprinkler position number	5	25	90		150
Manufacturer	Senniger	same	same		same
Model					
Type (spray, impact, etc.)	spray	same	same		same
Nozzle or orifice size					
Location					
Wetted diameter (ft)	20'	20'	20'		20'
Nozzle discharge (gpm)					
Design pressure (psi)					
Operating pressure					

End gun make, model ______ (when continuously used in corners)
End gun capacity 71 gpm, Pressure 18 psi, boosted to 60 psi
End swing lateral capacity ______ gpm, pressure ______ psi

Field observations:
Crop uniformity ______
Runoff ______
Erosion ______
Tower rutting ______
System leaks ______
Elevation change between pivot and end tower 15 ft +/-

Exhibit 9–7 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous/self move center pivot lateral—Continued

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Sheet 2 of 7

Example - Sprinkler Irrigation System
Detailed Evaluation Center Pivot Lateral Worksheet

Wind: Speed 5 +/- mph Direction (from) SE
Line direction: From center to outer tower East moving ccw
Time of day 1100 , Humidity: ________ low X med _______ high, Air temp ________________
Evaporation: start depth __________ inches, end depth ___________ inches, Evaporation ___________ inches

Crop alfalfa, Root zone depth 5 foot, MAD1/ 50 %, MAD 3.6 inches

Soil-water data (typical): (show location of sample site on soil map or sketch of field)
Moisture determiniation method feel and appearance
Soil series name, surface texture unknown

Depth	Texture	*AWC (in)1/	*SWD (%)1/	*SWD (in)1/
0-1'	L	2.0	50	1.0
1-2'	LFS	1.5	45	0.7
2-3.5'	VFLS	2.25	45	1.0
3.5-5'	GLS	1.5	20	0.3
	Totals	7.25		3.0

Comments about soils:

Present irrigation practices:

Typical system application:

Crop	Stage of growth percent	Hours per 2/ revolution	Speed setting	Net application (in)
alfalfa	16"	26	50%	

Hours operated per day 24 hours
Approximate number of pivot revolutions per season 80

1/ MAD = Management allowed depletion, AWC = Available water capacity, SWD = Soil water deficit
2/ To calculate the hours per revolution around the field, first calculate the average speed the end tower moves per cycle (start to start) = distance in feet divided by time in seconds.

Then: hours per revolution = $$\frac{2\text{ (distance to end tower in feet) } \times \pi}{\text{(end tower speed in ft/s) } \times 3{,}600\text{ seconds per hour}}$$

Exhibit 9–7 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous/self move center pivot lateral—Continued

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Sheet 3 of 7

Example - Sprinkler Irrigation System
Detailed Evaluation Center Pivot Lateral Worksheet

System data:

Distance from pivot point to : end tower 1205 ft, wetted edge 1345 ft

* End tower speed: Distance between stakes 50 ft

Time at first stake 11:30:00, Time at second stake 11:40:50

Time to travel between stakes 10.8 min

* This method is satisfactory for a continuous moving system, but need to allow for moving in start-stop cycles. Recommend using end tower move distance and from start to star. Typically, percent speed setting for end tower represents, 60% = 36 seconds of each minute, 72 seconds of each 2 minutes, etc.

Measured system flow rate 850 gpm, method flow meter

Calculations: __________

Evaluation computations:

Circumference of end tower:

$$\text{Distance to end tower} \times \overset{(6.2832)}{2\pi} = 1205 \times 6.2832 = 7571 \text{ ft}$$

End tower speed:

$$\frac{\text{Distance traveled (ft)}}{\text{Time in minutes}} \times 60 = \frac{50}{10.8} \times 60 = 278 \text{ ft/hr}$$

Hours per revolution:

$$\frac{\text{Circumference at end tower (ft)}}{\text{End tower speed (ft/hr)}} = \frac{7571}{278} = 27.2 \text{ hr}$$

Area irrigated:

$$\frac{(\text{Distance to wetted edge})^2 \times \overset{(3.1416)}{\pi}}{43{,}560 \text{ square feet/acre}} = \frac{1345^2}{43{,}560} \times 3.1416 = 130.5 \text{ ac}$$

Gross application per irrigation:

$$\frac{\text{Hours per revolution} \times \text{gpm}}{435 \times \text{acres irrigated}} = \frac{27.2 \times 850}{453 \times 130.5 \text{ ac}} = 0.39 \text{ in}$$

Weighted system average application:

$$\frac{\text{Sum of: catch} \times \text{factors}}{(\text{Sum of: factors}) \times \text{number of containers}} = \frac{64155}{969} = 66.2 \text{ cc (ml)}$$

Exhibit 9–7 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous/self move center pivot lateral—Continued

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Sheet 4 of 7

Example - Sprinkler Irrigation System
Detailed Evaluation Center Pivot Lateral Worksheet

Convert cc (ml) in measuring cylinder to inches depth in catch container:

200 cc (ml) = 1 inch in catch container

Average application = $\frac{\text{Average catch (cc)}}{\text{cc/inch}} = \frac{11840}{242} = 48.9$ in

Weighted low 1/4 average application:

$\frac{\text{Sum of low 1/4 catch x factors}}{\text{(Sum of low 1/4 factors) x number of low 1/4 containers}} = \frac{11840}{242} = 48.9$ cc (ml)

Low 1/4 average application = $\frac{\text{Average low 1/4 (cc)}}{\text{cc/inch}} = \frac{48.9}{200} = 0.24$ in

Distribution uniformity low 1/4 a (DU):

DU = $\frac{\text{Weighted low 1/4 average applic.}}{\text{Weighted system average application}} = \frac{0.24}{0.33} = 72.7$ %

Approximate Christiansen uniformity (CU):

CU = 100 - [0.63 x (100 - DU)] = 100 - [0.63 x (100 - 72.7)] = 82.8 %

Effective portion of water applied (R_e):

R_e = $\frac{\text{Weighted system average application (in)}}{\text{Gross applicaiton (in)}} = \frac{0.33}{0.39} = 0.846$

Application efficiency of low 1/4 (E_q):

E_q = DU x R_e = 72.7 x 0.846 = 70 %

(Use for medium to high value crops)

Approximate application efficiency low 1/2 (E_h):

E_h = DU x R_e = 82.8 x 0.846 = 70 %

(Use for low value field and forage crops)

Exhibit 9–7 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous/self move center pivot lateral—Continued

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Sheet 5 of 7

Example - Sprinkler Irrigation System
Detailed Evaluation Center Pivot Lateral Worksheet

Application:

$$\frac{\text{Gross application x hours operated per day x } (E_q \text{ or } E_h)}{\text{Hours per revolution x 100}}$$

$$= \frac{0.39 \times 24 \times 61.5}{27.2 \times 100} = 0.21 \text{ in/day}$$

Maximum average application rate:

$$\frac{\text{Maximum catch inches x 60}}{\text{Time containers are uncovered in minutes}} = \frac{0.18 \times 60}{5} = 2.16 \text{ in/hr}$$

Pivot revolutions required t replace typical annual moisture deficit:

(Based on existing management procedures)

Annual net irrig. requirement 14.9 in, for alfalfa (crop)

Pivot revolutions required:

$$\frac{\text{Annual net irrig. requirement x 100}}{(E_q \text{ or } E_h) \text{ x gross applic. per irrig.}} = \frac{14.9 \times 100}{70 \times .39} = 55$$

Potential water and cost savings

Present management::
Gross applied per year = gross applied per irrig x number of irrig

$$= 0.39 \times 55 = 21.5 \text{ in/yr}$$

Potential management:
Potential application efficiency (E_{pq} or E_{ph}) 80 percent (from irrigation guide, NEH Sec 15, Ch 11, or other source)

$$\text{Potential annual gross applied} = \frac{\text{Annual net irrig. requirement x 100}}{\text{Potential } E_{pq} \text{ or } E_{ph}}$$

$$= \frac{14.9 \times 100}{80} = 18.6 \text{ inches}$$

Exhibit 9–7 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous/self move center pivot lateral—Continued

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Sheet 6 of 7

Example - Sprinkler Irrigation System
Detailed Evaluation Center Pivot Lateral Worksheet

Total annual water conserved:

$$= \frac{\text{(Present gross applied - potential gross applied) x area irrig. (acre)}}{12}$$

$$= \frac{(21.5 - 18.6) \times 130}{12} = \underline{\quad 31.4 \quad} \text{ acre feet}$$

Sheet 1 of 7

Cost savings:

Pumping plant efficiency ____________ kind of fuel ___________________

Cost per unit of fuel ______________ fuel cost per acre foot $ ________________

Cost savings = fuel cost per acre foot x acre foot conserved per year

= _____________________________ = $ ____________________

Water purchase cost:

= Cost per acre foot x acre feet saved per year = ______________________

= $ ___________________

Cost savings = pumping cost + water cost = _________________ = $ ________________

Recommendations:

Exhibit 9–7 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous/self move center pivot lateral—Continued

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Sheet 7 of 7

Example - Sprinkler Irrigation System
Detailed Evaluation Center Pivot Lateral Worksheet

Container spacing 30 feet

Container		Catch	Catch (cc)	Catch
No.	Factor	(cc)	x Factor	(in)
1	1	out		
2	2	out		
3	3	out		
4	4	60	240	.30
5	5	75	375	.38
6	6	75	450	.38
7	7	60	420	.30
8	8	70	560	.35
9	9	75	675	.38
10	10	70	700	.35
11	11	80	880	.40
12	12	75	900	.38
13	13	85	1,105	.43
14	14	70	980	.35
15	15	Tipped	over	–
16	16	70	1,120	.35
17	17	70	1,190	.35
18	18	85	1,530	.43
19	19	100	1,900	.50
20	20	80	1,600	.40
21	21	65	1,365	.33
22	22	65	1,430	.33
23	23	75	1,725	.38
24	24	60	1,440	.30
25	25	65	1,625	.33
26	26	80	2,080	.40
27	27	75	2,025	.38
28	28	55	1,548	.28
29	29	85	2,465	.43
30	30	70	2,100	.35
31	31	75	2,325	.38
32	32	70	2,240	.35
33	33	65	2,145	.33
34	34	65	2,210	.33
35	35	85	2,975	.43
36	36	55	1,980	.28
37	37	65	2,405	.33
38	38	55	2,090	.28
39	39	70	2,730	.35
40	40	60	2,400	.30
41	41	65	2,665	.33
42	42	55	2,310	.28
43	43	40	1,720	.20
44	44	35	1,540	.18
45	45			
46	46			
47	47			

Container		Catch	Catch (cc)	Catch
No.	Factor	(cc)	x Factor	(in)
48	48			
49	49			
50	50			
51	51			
52	52			
53	53			
54	54			
55	55			
56	56			
57	57			
58	58			
59	59			
60	60			
61	61			
62	62			
63	63			
64	64			
65	65			
66	66			
67	67			
68	68			
69	69			
70	70			

Sum 969 64,155

.25 x sum of factors 969 = 242

Low 1/4 summation:

44	44	35	1,540
43	43	40	1,720
42	42	55	2,310
38	38	55	2,090
36	36	55	1,980
28	28	55	1,540
7	7	60	420
4	4	60	240

Sum 242 11,840 (low 1/4)

Max application rate data (5 minute catch)

1		15		
2		25		
3		35		18
4		25		
5		20		

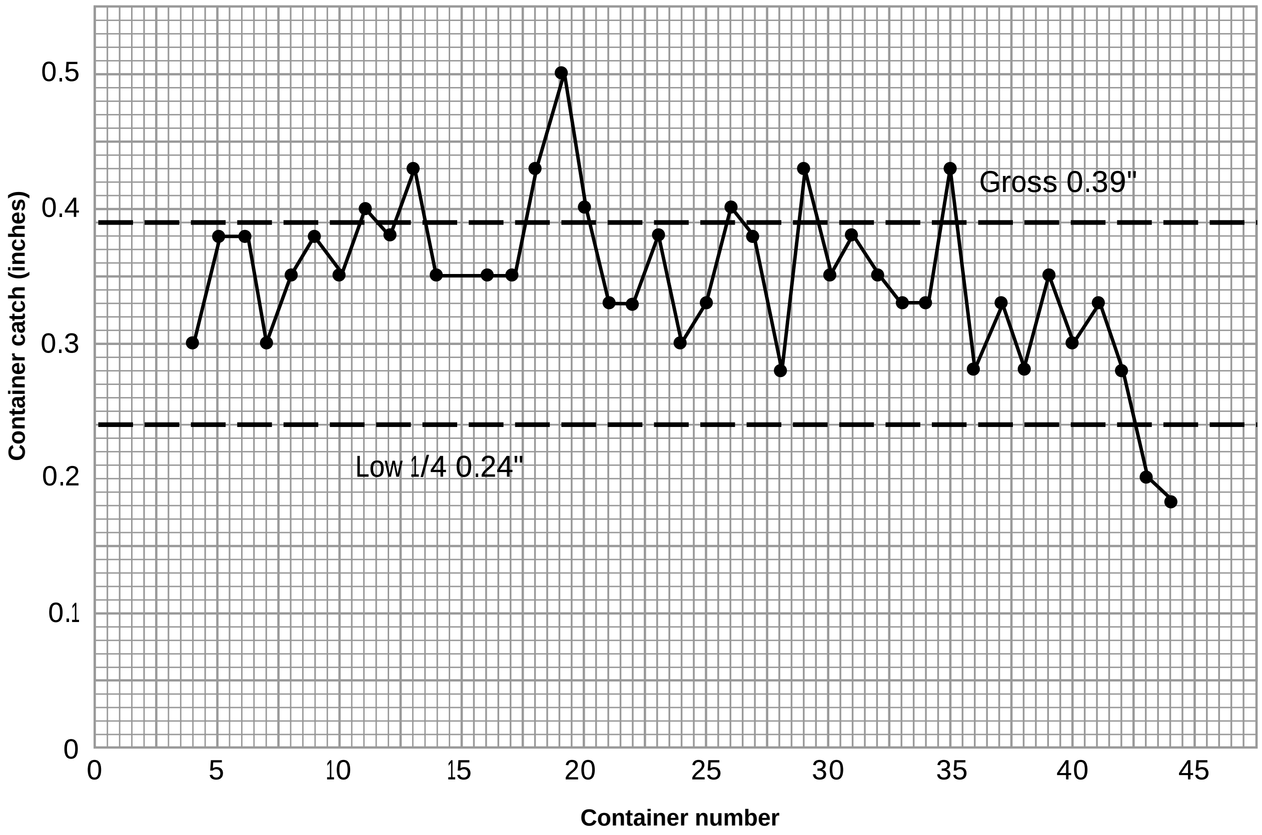
Max. rate = $\frac{\text{max. catch (in) x 60}}{\text{5 minutes}}$ = 2.16 inches/hour

Exhibit 9–7 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous/self move center pivot lateral—Continued

Center pivot lateral evaluation, distribution profile of catch

Land user Joe Example
Date ____________
Field office ____________

E_h = 61.5 %
E_q = 70.0 %



Example 9–7 Evaluation computation steps for continuous move center pivot and linear move laterals

1. **Compute maximum application rate:**

$$\text{Application rate, in/hr} = \frac{(\text{maximum catch volume, cc}) \times (60\ \text{min/hr})}{(\text{conversion factor, cc/inch}) \times (\text{time containers are uncovered, min})}$$

2. **Determine tower speed:**

For center pivot laterals, set a stake next to and in front of the end tower. Start timing when a specific part of the end tower moves past the stake. After the lateral has been in operation for at least 20 minutes, set a second stake in line with the same part of the end tower in its new position. Record time required for travel between stakes or marks, and measure the distance. Use sufficient time and distance to minimize effects of stop and start sequences during the speed check. Generally, the same procedure is used for linear move laterals except any tower can be used. Speed is determined as follows:

$$\text{Speed, ft/hr} = \frac{(\text{distance traveled, ft}) \times (60\ \text{min/hr})}{(\text{time, min})}$$

3. **Determine hours per irrigation (revolution for center pivot laterals):**

liner move lateral::

$$\text{hours/pass} = \frac{(\text{feet traveled by lateral})}{(\text{lateral speed, ft/hr})}$$

center pivot lateral::

$$\text{hours/rev} = \frac{(\text{circumference of end tower, ft})}{(\text{end tower speed, ft/hr})}$$

where:
circumference of end tower = (distance from pivot to end tower, ft) x 2π
π = 3.1416
2π = 6.2832

4. **Determine area irrigated by system:**

linear move lateral:

$$\text{area, acres} = (\text{lateral length, ft}) \times (\text{feet traveled by lateral})$$

center pivot lateral:

$$\text{area, acres} = \frac{(\text{distance from pivot to outer wetted area, ft})^2}{43{,}560\ \text{ft}^2/\text{acre}} \times \pi$$

Example 9–7 Evaluation computation steps for continuous move, center pivot linear move and lateral systems—Continued

5. Determine system capacity using flow data or pipe flow velocity data from meters:

From flow meter, read direct in gallons per minute or convert as necessary. System capacity flow is determined using velocity meter data with equation:

$$Q = A \times V$$

where:

Q = flow in system, ft^3/s
A = cross sectional area of lateral pipe, ft^2
V = average velocity in lateral pipe, ft/s

conversion units: 1 ft^3/s = 450 gpm (approximate)

6. Determine gross application per irrigation per revolution:

center pivot lateral:

$$\text{gross application, acre-inches} = \frac{(\text{hours per revolution}) \times (\text{system capacity in gpm})}{453 \times (\text{irrigated area, acre})}$$

linear move lateral:

$$\text{gross application, acre-inches} = \frac{(\text{hours per pass or set}) \times (\text{system capacity in gpm})}{453 \times (\text{irrigated area, acre})}$$

7. Determine weighted system average application:

linear move lateral:

$$\text{average application volume, cc} = \frac{\text{sum of catch, cc}}{\text{number of containers}}$$

center pivot lateral:

$$\text{average volume, cc} = \frac{\text{sum of } (\text{catch} \times \text{factors})}{\text{sum of factors}}$$

$$\text{average application, inches} = \frac{\text{average volume, cc}}{\text{conversion, cc/in}}$$

(The conversion, cc/in, is dependent on the catch container opening during the test.)

Example 9–7 Evaluation computation steps for continuous move center pivot and linear move laterals—Continued

8. Determine low quarter average application:

linear move lateral:

$$\text{low } \frac{1}{4} \text{ ave. application} = \frac{\text{sum of } \frac{1}{4} \text{ catch containers}}{\text{number of containers}}$$

center pivot lateral:

$$\text{weighted low } \frac{1}{4} \text{ ave. application} = \frac{\text{sum of} \left(\text{low } \frac{1}{4} \text{ catch} \times \text{factors}\right)}{\text{sum of low } \frac{1}{4} \text{ factors}}$$

Note: With center pivot laterals, each sprinkler irrigates a different size area. Thus a weighted low quarter average application must be used.

9. Determine distribution uniformity low quarter (DU):

linear move lateral:

$$\text{DU} = \frac{\text{low average application}}{\text{average application}}$$

center pivot laterals:

$$\text{DU} = \frac{\text{weighted low average application}}{\text{weighted system average application}}$$

10. Determine approximate Christiansen's uniformity (CU):

$$\text{CU} = 100 - [0.63 \times (100 - \text{DU})]$$

11. Determine effective portion of applied water, R_e:

Effective portion of applied water is frequently confused with and called application efficiency. Application efficiency is water stored in the plant root zone divided by gross application. Application efficiency accounts for all losses between the pump and the plant, including leaks, evaporation, spray drift, water drive use, deep percolation, and runoff. With pivot irrigation systems, the application amount per revolution generally is less than the soil-water deficit. It usually takes more than one revolution to apply the total soil-water deficit for a mature plant.

Example 9–7 Evaluation computation steps for continuous move center pivot and linear move laterals—Continued

Effective portion of applied water compares the amount of water pumped to the amount caught in catch containers. Any difference is a loss that results from evaporation, spray drift, leaks, or drive losses on water drive systems. It does not account for deep percolation and runoff. The effective portion of applied water can be estimated from figure ______, chapter ______, or figure 11–17 in chapter 11 of the National Engineering Handbook, section 15, by entering the chart with observed data on wind velocity, humidity, temperature, coarseness of spray, and potential crop ET rate. When data are available from a field evaluation, the actual effective portion of applied water is computed as follows:

linear move lateral:

$$R_e = \frac{\text{system average application, inches}}{\text{gross application, inches}}$$

center pivot lateral:

$$R_e = \frac{\text{weighted system average application, inches}}{\text{gross application, inches}}$$

12. Determine application efficiency of low quarter:

$$E_q = DU \times (R_e)$$

13. Determine net application per day:

$$\text{net application, inches} = \frac{(\text{gross application, in}) \times (\text{hours operated per day}) \times E_q}{(\text{hours per irrigation}) \times 100}$$

Note: The hours per irrigation are per revolution for center pivot laterals.

14. Determine maximum application rate:

$$\text{maximum rate, in/hr} = \frac{(\text{maximum catch, inches}) \times (60\ \text{min/hr})}{(\text{time containers are uncovered, min})}$$

15. Estimate number of irrigations (or pivot revolutions) required to replace seasonal moisture or net irrigation requirement (NIR). Obtain NIR from local irrigation guide for crop and climatic area.

linear move lateral:

$$\text{Irrigations required} = \frac{\text{NIR} \times 100}{E_q \times \text{gross application per irrigation, inches}}$$

center pivot lateral:

$$\text{Revolutions required} = \frac{\text{NIR} \times 100}{E_q \times \text{gross application per revolution, inches}}$$

Example 9–7 Evaluation computation steps for continuous move center pivot and linear move laterals—Continued

16. Prepare a plot of catch can data.

Plot the depth of water caught in containers (inches) against the location of the container with respect to the water supply (pivot) pivot point. Plot straight lines across the graph for gross application, average (weighted) application, and low quarter application. This graph can be one of the best tools for explaining the results of the evaluation to the irrigation decisionmaker.

Potential water conservation and pumping costs savings:

1. **Make a best estimate of the present gross application applied for the season.** This is based on information about present irrigation scheduling and application practices obtained from the irrigator and on data derived from the evaluation.

2. **Determine potential system application efficiency.** Use information in the local irrigation guide or other sources. Approximate range of potential E_q values is 75 to 85 percent. Range is based on full canopy crops and assumption that the system is well designed, maintained, and managed.

3. **Determine potential gross seasonal application:**

$$\text{gross seasonal application, inches} = \frac{\text{NIR} \times 100}{\text{potential } E_q}$$

where:
NIR = seasonal net irrigation requirement

4. **Determined total potential average annual water conserved in acre-feet:**

$$\frac{(\text{present gross application, inches}) - (\text{area irrigated, acres})}{12}$$

5. **If cost is a factor, compute cost savings:**

Pumping cost savings: From cost data received from irrigator or by a separate pumping plant evaluation, determine pumping plant operating costs per acre foot of water pumped.

Pumping cost savings = (energy cost per acre foot) x (acre feet conserved per year)

Water purchase cost savings: Obtain water purchase cost per year from irrigator. In water short areas, many irrigation organizations use a sliding scale for water use billings; i.e., a billing rate for a minimum volume, with increasing rates for increasing use over and above the minimum. Some organizations bill for a fixed volume of water whether used or not.

Water purchase cost savings = (water cost per acre foot) x (water saved per year in acre feet)

Determine total cost savings.

Example 9–7 Evaluation computation steps for continuous move center pivot and linear move laterals—Continued

Analysis of data and preparation of recommendations:

1. Compare soil-water deficit (SWD) with management allowed depletion (MAD). This indicates whether the existing method of irrigation scheduling is adequate and whether the right amount of water was being applied. Suggest improving irrigation scheduling techniques if needed. Determine what level of intensity of irrigation scheduling the irrigation decisionmaker can reasonably use.

2. Compare evaluation results to manufacturer's design.

3. Consider existing and potential water translocation, field runoff, and erosion problems as to irrigation system operation, including soil, water, and plant management practices. All sprinkler irrigation systems, especially low pressure in-canopy center pivot laterals, require some degree of soil, water, and plant management to prevent water translocation. Suggest those changes necessary in irrigation water management, operation speed, pressure adjustment, cultural practices, and surface storage needs. Make recommendations that are practical and can reasonably be implemented by the irrigation decisionmaker.

Making management changes is always the first increment of change. Recommending irrigation system changes, along with appropriate management changes, is secondary.

(7) Continuous move, large sprinkler gun type (travelers)

The efficiency of sprinkler irrigation systems changes with time. Nozzles, guns, and pumps wear (lose efficiency), and pipes and joints develop leaks. Some systems are used in ways they were not designed. Sprinkler system evaluations are designed to identify problems and develop solutions. Before a detailed evaluation is made, obvious operating and equipment deficiencies should be corrected by the water user. However, observing and evaluating a poorly designed, installed, or operated system may be a good training exercise to improve competence. Some ingenuity is necessary to check operating pressure of the sprinkler near the nozzle. The high sprinkler gun discharge rate and the continuous moving system make field checking of nozzle discharge unfeasible. Safety during sprinkler gun return rotation also is a factor. It is recommended a calibrated pressure gauge be installed and the nozzle measured when the system is not operating.

Typically, large traveling sprinkler guns are used on irregular shaped fields. With a flexible drag hose to convey water and either a cable and power winch or slow-moving, self-contained, tractor-powered hose reel unit, the sprinkler gun operates as it moves along a lane. Typical operating pressure is 75 to 100 pounds per square inch, and discharge from the sprinkler gun is 200 to 650 gallons per minute. Application rates near the sprinkler gun are relatively high and decrease toward the outer edge of the circle. For effectiveness, traveling large sprinkler guns should apply water in a half circle rearward of the application device. This keeps water and agricultural liquid wastes from spraying the application device, and the device is traveling on relatively dry soil.

***(i) Equipment*—**The equipment needed for a continuous move, large sprinkler gun type system includes:

- Catch containers and stakes
- 50-foot tape
- 500-milliliter (cc) graduated cylinder
- Pressure gauge, 0 to 140 pounds per square inch pressure range
- Inside diameter measurement calipers
- Soil auger, push tube sampler, probe, shovel
- Equipment for determining soil moisture amounts (feel and appearance soil moisture charts, Speedy moisture meter and Eley volumeter, or auger and oven drying soil sample containers)
- Stopwatch
- Wind velocity gauge, thermometer (for air temperature)
- Manufacturer's sprinkler head performance charts
- Clipboard and pencil
- Soil data for field
- Camera, boots, rain gear

The worksheet, Sprinkler Irrigation System Detailed Evaluation: Large Gun Type, is also needed. A copy of this worksheet is in chapter 15.

***(ii) Procedure*—**The procedures needed for this system are in two main categories: general and inventory and data collection.

General

Obtain all pertinent information about system hardware form the water user and from visual observations. What are the irrigation decisionmaker’s concerns? Observe general system operating condition, crop uniformity, salinity problems, wet areas, dry areas, translocation, runoff, and other site characteristics. The procedure is described in the following steps:

Step 1—Obtain information from the water user about crops, soils and how the field(s) is irrigated; i.e., travel speed, lane spacing, lane length, pattern overlap, application depth per irrigation. Determine the irrigations or application trips per season.

Determine sprinkler gun design specifications; i.e., operating pressure, nozzle type (taper bore or ring nozzle) and inside diameter, system speed. Actual inside diameter can be measured with inside diameter measurement calipers when system is not operating. Depending on size and height of sprinkler gun, to install a pressure gauge may also be desirable when the system is not operating. While the system is in operation, the height of the gun, configuration of the nozzle, and gun return rotations are hazards when checking pressure at the nozzle. Using a pitot tube is not recommended.

Step 2—Estimate soil-water deficit at several locations in front of and behind the traveler. Observe if the full plant root zone was filled to field capacity. Use the feel and appearance, Eley Volumeasure and Speedy Moisture Meter, auger or push tube sampler (Madera sampler), or some other acceptable method. Select a typical location and record the data on the worksheet.

Step 3—At the same time, make note of such soil profile conditions as:

- Depth to water table
- Apparent root development pattern and depth of existing or previous crop (for determining effective plant root zone)
- Root and water movement restrictions:
  - — Compacted layers
  - — Mineral layers
  - — Hardpans or bedrock
  - — Soil textures including textural change boundaries (abrupt or gradual)

Inventory and data collection

Step 1—Select a representative location in the field to conduct the evaluation. Look at elevation change and undulations. Pick a representative location ahead of sprinkler. You may need to wait a few hours or schedule another day when the sprinkler is in a desirable location. Sometimes the extreme condition is the operating condition an evaluation is intended to display. More than one evaluation may be needed at different locations in the field and at different times of the day because of the elevation changes in the field, wind drift and evaporation losses between daytime and nighttime, flow or pressure variations, plus many other variables.

Step 2—Determine system flow rate. If a portable flow meter is available, insert the meter in the flexible feed hose at or near a main line valve. Clamp-on ultrasonic flow meters can also be used if a straight section of aluminum pipe can be inserted between the riser and flexible hose. Measure and record flow data at start and end of the evaluation period. Flow, velocity, and operating pressure can change when other sprinklers within the same pumping system are turned on or off during the test.

Without regularly scheduled maintenance and calibration, accurate flow data from onfarm system flow meters is questionable. Poor water quality (debris, sediment, salts, manure, aquatic creatures) causes accelerated wear on impellers and bearings of flow meters. Ultrasonic type meters should only be used where turbulence inside the conduit is minimal. Use only flow and velocity meters that are regularly checked and calibrated. Poorly maintained flow and velocity meters often provide readings that are 10 to 40 percent in error from actual.

Step 3—Determine operating pressure. Operating pressure should be checked at the sprinkler head in the riser or near the nozzle. A pressure gauge may be permanently installed, but do not rely on the reading it displays. Use a recently calibrated or checked gauge. If the evaluator does not want to get wet while checking operating pressures, gauges can be installed and removed from sprinkler head fittings when the system is not running. A pitot tube attachment on a pressure gauge can be used to measure operating discharge pressure at the nozzle, a process that is difficult and hazardous. A warm day is the most desirable time to field check operating pressures using a pitot tube. Secure the rotating arm mechanism of a large gun type sprinkler before approaching the system. This helps to prevent unexpected rotation and possible injury. Record pressure and location on worksheet.

Pressures can be more easily read when using a liquid filled gauge. The liquid provides a dampening of the gauge needle and increased durability. Also, an adjustment for elevation must be made (2.31 ft = 1 psi) when pressure is obtained below the nozzle.

Step 4—Determine wind speed and direction, lateral line location, temperature, and humidity level. Record on worksheet.

Step 5—Set out equally spaced catch containers in a row in front of the sprinkler and slightly off the direct line of travel where the containers won’t be knocked over by the traveler or trailing hose.

Set containers in a straight line perpendicular to the sprinkler line of travel, at any uniform interval (usually 30 to 50 feet). Start at the center of the sprinkler gun lane line and set out catch containers evenly spaced to the outer end of wetted area. The lip of the container should be reasonably level and at approximate crop canopy height. Use short stakes and heavy rubber bands to locate containers above foliage. The stakes should not extend above the containers.

Any container can be used, however they must be calibrated. Use containers with a relatively sharp edge. For straight sided containers, the entry rim area is measured and the equivalent capacity in cubic centimeters (milliliters) for 1-inch application depth computed. For stackable tapered sided containers, a 500 cubic centimeter graduated cylinder is used to measure catch in the containers. The cross sectional area of the top of the container is used to calculate application depth, either in inches or millimeters. Large rain gauges can be used as catch containers and can be read directly.

Start timing when the sprinkler wetted edges begins to pass over containers. Time ceases when containers are no longer receiving water. The time it takes for the sprinkler to completely pass may be longer than is desirable to complete an evaluation, unless containers can be left for several hours or overnight.

Step 6—Read or measure amount of water caught in catch containers. After the wetted pattern has passed completely over all of the containers, measure and record catch volume or water depth. Use a graduated cylinder to measure volume of catch if tapered sided containers are used. Do not measure and record volume of water or catch in any containers that have tipped or partially spilled or if it appears nearby foliage affected the catch.

If containers are left overnight or for a long time during hot and windy conditions, an evaporation container should be set out upwind of the test area. Fill the container with a known volume (depth) of water approximating half the application depth. Record volume (depth) at beginning and end of test. Evaporation adjustments should be made on all readings. Use the same type container for both evaporation check and catch. A slight film (drop) of mineral oil can provide some evaporative protection.

Step 7—Catch data reduction. Because catch container locations for one pass do not reflect overlap from adjacent lane sprinkler gun trips, catch from one side of the wetted pattern that is in the overlap area must be added to other side. Remember, wind causes pattern distortion and influences overlap. Typically, with traveling large gun type sprinkler heads, overlap is not 100 percent. Overlap distance can be determined in the field by measuring wetted diameter and lane spacing distances. The wetted distance in the outer part of the wetted circle past the midway point between lanes is the overlap area.

Step 8—Determine the sprinkler travel speed. Set a stake next to the sprinkler. Start timing when a specific part of the sprinkler gun moves past the stake. After at least 20 minutes with the sprinkler gun in operation, set a second stake in line with the same part of the sprinkler gun in its new position. Record time required for travel between stakes or marks and measure the distance. Some stationary time at the end of each lane will provide adequate irrigation at edge of field. Speed is determined as follows:

$$\text{Speed, ft/min} = \frac{\text{distance traveled, ft}}{\text{time, min}}$$

Note: The travel speed of some hose reel sprinklers varies because of a constant hose reel velocity irrespective of the effective reel diameter the hose is being wound (or unwound).

***(iii) Evaluation calculations*—**The information gathered in the field procedures is used in the detailed system evaluation computation. Example 9–8 outlines the computations used to complete the example worksheet (exhibit 9–8).

Exhibit 9–8 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous move, large sprinkler gun type

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Natural Resources Conservation Service

Sheet 1 of 5

Example - Sprinkler Irrigation System
Detailed Evaluation Continuous Move, Large Sprinkler Gun Type

Land user ______________ Date ______________ Prepared by ______________

District ______________ County ______________ Eng job class ______________

Irrigation system hardware inventory:

Sprinkler gun make Nelson, model 201, nozzle type ring

Nozzle: size 1.5 inches, – mm

Manufacturer rated discharge, 500 gpm at 100 psi giving 510 ft wetted diameter

Hose: length, 660 ft, diameter 4 inches

Towpath: spacing 330 ft

Elevation difference between first and last location on towpath (+/-) ______________ ft or 0 % slope

Gun: height 6.5 ft

Mainline: material PVC diameter 6 inches

Field observations:

Crop uniformity Good

Water runoff None

Erosion None

System leaks None

Wind drift No serious wind drift

Other observations Crop was short midway between paths

____

____

Field data inventory and computations:

Crop Corn, root zone depth 4.0 ft, MAD 1/ 50 %, MAD 1/ ______________ inches

Soil-water data (typical):

(Show locations of sample on soil map or sketch of field)

Moisture determination method Feel

Soil series and surface texture Deschutes fine sand loam

Depth	Texture	AWC (in) 1/	SWD (%) 1/	SWD (in) 1/
	Totals			

Comments about soils and soil condition: ______________________________

____

____

____

1/ MAD = Management Allowable depletion, AWC = Available water capacity, SWD = Soil water deficit

Exhibit 9–8 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous move, large sprinkler gun type—Continued

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Example - Sprinkler Irrigation System
Detailed Evaluation Continuous Move, Large Sprinkler Gun Type

Present irrigation practices:

Typical irrigation duration ______ hr, irrigation frequency 10 days
Typical number of irrigations per year 15

Test:

Start ______, Stop ______, Duration ______ = ______ hour

Atmospheric data;
Wind: Direction: Initial ______, during ______, final ______
Speed (mph): Initial 5-10, during ______, final ______

Temperature: initial 75 final ______, humidity: ______ low ______ med ______ high
Evaporation container: initial ______, final ______, loss ______ inches

Pressure: 110 psi, at start of test
110 psi, at end of test
Measured flow into the system 520 gpm

Sprinkler travel speed:

at beginning	9.5	ft	10	min =	0.95	ft/min
at test site	10.0	ft	10	min =	1.0	ft/min
at terminal end	10.2	ft	10	min =	1.02	ft/min
average					1.0	ft/min

Calculations:

Gross average depth of water applied = $$\frac{(\text{gun discharge, gpm}) \times (1.605)}{(\text{tow path spacing, ft}) \times (\text{travel speed, ft/min})}$$

$$= \frac{(520 \text{ gpm}) \times (1.605)}{(330 \text{ ft}) \times (1.0 \text{ ft/min})} = 2.53 \text{ in}$$

Average overlapped catches

$$\text{System} = \frac{(\text{sum all catch totals } 74.87 \text{ in})}{(\text{number of totals } 33)} = 2.27 \text{ in}$$

$$\text{Low 1/4} = \frac{(\text{sum of low 1/4 catch totals } 12.91 \text{ in})}{(\text{number of low 1/4 catches } 8)} = 1.61 \text{ in}$$

Average application rate = $$\frac{(\text{Flow, gpm}) \times (13{,}624)}{(\text{tow path spacing, ft}) \times (\text{wet sector, deg.})}$$

$$= \frac{(520 \text{ gpm}) \times (13{,}624)}{(255^2 \text{ ft}) \times (290 \text{ deg})} = 0.38 \text{ in/hr}$$

Maximum application rate = (average application rate, in/hr) x (1.5)

Exhibit 9–8 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous move, large sprinkler gun type—Continued

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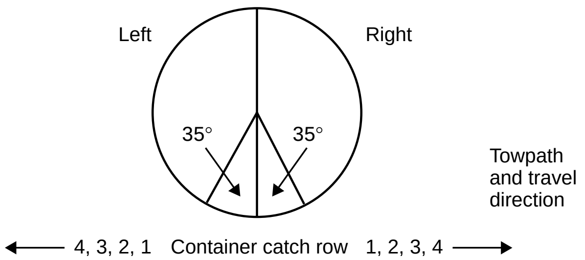
Example - Sprinkler Irrigation System
Detailed Evaluation Continuous Move, Large Sprinkler Gun Type

Container test data

Catch can type ___________, 200 cc (mL)/in

Note part circle operation
and the dry wedge size in degrees



Path spacing (ft)	Container catch volume Left side of path		Right side of path		Right plus left side catch totals	
	Catch no.	**Catch (mL)**	**Catch no.**	**Catch (mL)**	**mL**	**inches**
330	1	560	33		560	2.80
320	2	540	32		540	2.70
310	3	510	31		510	2.55
300	4	490	30		490	2.45
290	5	505	29		505	2.53
280	6	475	28		475	2.38
270	7	480	27		480	2.40
260	8	460	26		460	2.30
250	9	430	25		430	2.15
240	10	410	24		410	2.05
230	11	370	23		370	1.85
220	12	325	22		325	1.63
210	13	305	21		305	1.53
200	14	345	20		345	1.73
190	15	335	19		335	1.68
180	16	310	18		310	1.55
170	17	305	17		305	1.53
160	18	290	16	35	325	1.62
150	19	250	15	75	325	1.62
140	20	230	14	120	350	1.75
130	21	215	13	215	430	2.15
120	22	165	12	365	530	2.65
110	23	95	11	410	505	2.52
100	24	65	10	515	580	2.90
90	25	25	9	540	565	2.82
80	26	—	8	525	525	2.62
70	27		7	500	500	2.50
60	28		6	490	490	2.45
50	29		5	470	470	2.35
40	30		4	490	490	2.45
30	31		3	540	540	2.70
20	32		2	605	605	3.02
10	33		1	625	625	3.12

Sum of all catch totals 74.87

Sum of low 1/4 catch totals 12.91

Exhibit 9–8 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous move, large sprinkler gun type—Continued

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Sheet 4 of 5

Example - Sprinkler Irrigation System
Detailed Evaluation Continuous Move, Large Sprinkler Gun Type

Potential water and cost savings:

Present management:

Gross applied per year = (Gross applied per irrigation) x (number of irrigation) = 2.53 in/yr
+ (2.53 in) x (15) = 38.0 in/yr

Potential management:

Annual net irrigation requirement 18.0 in/yr, for Corn (crop)
Potential application efficiency (E_q or E_h) 60 % (estimated at 55 - 65%)
Potential annual gross applied = $\frac{\text{annual net irrigation requirement}}{\text{Potential } E_q \text{ or } E_h}$ x 100 = ______ in

= $\left(\frac{18 \text{ in}}{60}\right)$ x 100 = 30.0 inches

Total annual water conserved
= $\frac{\text{Present gross applied, inches - potential gross applied, inches}}{12}$ x (area irrigated, ac) = ______ ac/ft

= $\frac{(38.0 \text{ in}) - (30.0 \text{ in}) \times (80 \text{ ac})}{12}$ = 53.3 ac-ft

Cost savings:

Pumping plant efficiency — kind of energy Electric
Cost per unit of energy $ — energy cost per ac-ft $ 10.00
Cost savings = (energy cost per ac-ft) x (ac-ft conserved per year) = $ ______
= (10.00) x (53.3) = $ 533

Water purchase cost:

= (Cost per ac-ft) x (ac-ft saved per year) = $ 12.50 x 53.3 = $ 666

Cost savings:

= Pumping cost + water cost = 533 + 666 = $ 1199

Exhibit 9–8 Completed worksheet—Sprinkler irrigation system, detailed evaluation of continuous move, large sprinkler gun type—Continued

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Sprinkler Irrigation System
Detailed Evaluation Continuous Move, Large Sprinkler Gun Type

Recommendations:

Notes

Example 9–8 Evaluation computation steps for continuous move, large gun type sprinklers

1. **Determine gross depth of water applied:**

   The speed checked in the field should nearly match design speed. Speed is based on depth of water applied, gun discharge, and spacing between lanes. Depth of water applied is based on the equation:

$$\text{Gross Ave. depth of water applied} = \frac{1{,}605 \times (\text{sprinkler discharge, gpm})}{(\text{lane spacing, ft}) \times (\text{travel speed, ft/min})}$$

   For ease of use, table 6–10 in chapter 6, section 652.0602(e) of this guide displays this equation in table format. Depending on site conditions (soil, slope, vegetative cover) and application rate, catch containers may not reflect water actually infiltrated because of the water translocation and runoff that occurred. Water translocation and runoff are often greater with large sprinkler gun travelers because of the large water droplet size and velocity upon impact with the ground surface. To obtain net depth of application, assume an application efficiency or determine soil moisture replacement in the plant root zone. Application efficiency of the low quarter, E_q, ranges from 55 to 67 percent where there is little to no wind and with no water translocation or field runoff.

2. **Determine system capacity using flow data from a flow meter.** Read direct in gallons per minute or convert as necessary. System capacity flow container can also be determined using velocity meter data from the equation:

$$Q = A\,V$$

   where:

   Q = flow in system, ft^3/s
   A = cross sectional area of pipe, ft^2
   V = average velocity in pipe, ft/s

   Conversion units: 1.0 ft^3/s = 450 gpm (approximate)

3. **Prepare a plot of catch container data.** Plot the adjusted depth of water (include adjustment in overlap area) caught in containers (inches) against the location of the container with respect to the sprinkler gun travel path centerline. Average catch is calculated using total catch and dividing by number of containers. Plot this line on the graph. This cross section graph can be one of the best tools for explaining the results of the evaluation to the irrigation decisionmaker.

4. **Determine maximum application rate.** An approximation of maximum application rate is determined by using data from catch container(s) with maximum depth of water caught. The maximum average application rate (over entire time water was applied at the specific catch container site) is computed as catch in inches divided by time in hours of test. Since water application pattern approximates a parabola shape (from an adequately operating sprinkler head), maximum rate is about 1.5 times the maximum average rate.

$$\text{Maximum application rate, in/hr} = (\text{average application rate, in/hr}) \times 1.5$$

   See section 652.0905(f), Continuous/self move sprinkler, field procedure step 9, for a method to measure maximum application rate.

Example 9–8 Evaluation computation steps for continuous move, large gun type sprinklers—Continued

Potential water conservation and pumping costs savings:

1. **Make a best estimate of the present gross water application applied for the season.** This estimate is based on information about present irrigation scheduling and application practices obtained from the irrigator and on data derived from the evaluation.

2. **Determine potential system application efficiency of the low quarter from information in the local irrigation guide or other sources.** Approximate range of potential E_q values is:

   $E_q = 55 - 65\ \%$

   This is based on full canopy crops and assumption that the system is well designed, maintained, and managed, with little to no wind and no translocation.

3. **Determine potential gross seasonal application:**

$$\text{gross seasonal application} = \frac{\text{NIR} \times 100}{\text{potential } E_q}$$

   where:
   NIR = seasonal net irrigation requirement

4. **Determined total potential average annual water conserved in acre-feet:**

$$\frac{\left(\text{present gross application, inches} - \text{potential gross application, inches}\right) \times \left(\text{area irrigated, acres}\right)}{12}$$

5. **If cost is a factor, compute cost savings:**

Pumping cost savings:	From cost data received from irrigator or by a separate pumping plant evaluation, determine pumping plant operating costs per acre foot of water pumped. Pumping cost savings equals: (energy cost per acre foot) x (acre feet conserved per year)
Water purchase cost savings:	Obtain from irrigator the water purchase cost per year. In water short areas, many irrigation organizations use a sliding scale for water use billings; i.e., a billing rate for a minimum volume, with increased rates for increasing use over and above the minimum. Others bill for a fixed amount whether used or not. Water purchase cost savings equals: (water cost per acre foot) x (water saved per year, acre feet)

Determine total cost savings.

Example 9–8 Evaluation computation steps for continuous move, large gun type sprinklers—Continued

Analysis of data and preparation of recommendations:

1. Compare soil-water deficit (SWD) with management allowed depletion (MAD). This indicates whether the existing method of irrigation scheduling is adequate and whether the right amount of water is being applied. Suggest improving irrigation scheduling techniques if needed. Determine what level of intensity of irrigation scheduling the irrigation decisionmaker can reasonably use.

2. Compare evaluation results to manufacturer's/dealer's design.

3. Consider existing and potential runoff and erosion problems as to operation, cultural, and management practices. Suggest those changes necessary in irrigation water management, such as operation speed, pressure adjustment, cultural practices, and surface storage needs. Cultural practice changes include soil, water, and plant management. Make recommendations that are practical and can reasonably be done by the irrigation decisionmaker.

Making management changes is always the first increment of change. Recommending irrigation system changes, along with appropriate management changes, is secondary.

(8) Micro irrigation systems

Micro irrigation systems, sometimes referred to as trickle or drip systems, are described as the frequent, slow application of water to soil through mechanical devices called drippers, emitters, spray heads, or bubblers. The objective of micro irrigation is to maintain a high soil moisture content in the plant root zone at all times during the irrigation season. This can be accomplished by starting the season with high soil moisture content and replacing the amount depleted by the plant (and some to evaporation) on a 1- to 4-day basis. This is done by delivering the amount of water needed directly to the root zone of each plant through a controlled delivery system.

To accomplish this objective the system must be adequately designed and constructed. A monitoring method to determine the amount of water needed on a daily basis and a method to verify the validity of both the delivery system performance and the amount of water delivered as being adequate are also required.

(i) Components—The various components of a micro irrigation system are shown in a typical layout as in figure 9–29. An adequate filter system is necessary to ensure performance of the controlled delivery (emitters, spray heads, bubblers) at each plant without clogging. Clogged application devices cause poor distribution along the laterals.

Micro irrigation only wets a portion of the soil volume allocated to each plant or row of plants. Where the volume of soil irrigated is small, root growth can be or is restricted. The percentage of the wetted area compared to the total area for each plant depends on the emitter discharge area, discharge rate, spacing of emitters, and soil type. The preferred measure is based on the volume of soil irrigated compared to the total volume available to each plant. Where more than one emitter is used per plant, the wetted volume created by each emitter should overlap in the upper part of the plant root zone as shown in figure 9–30. Where salts are a problem, the overlap should be at the ground surface so salts are not concentrated within the root zone.

One of the objectives in evaluating a micro irrigation system is to determine the average volume of soil wetted per plant. Minimum soil wetted volume appears to be about a third for vines and orchards, and higher for close spaced row crops, such as potatoes, cotton, and tomatoes.

The total plant area does not need irrigating, but overlap should occur in the upper half of the plant root zone and be continuous along the plant row.

The successful operation of a micro irrigation system requires the frequency of irrigation and volume of water applied be carefully scheduled to meet plant

Figure 9–29 Typical split flow layouts for micro irrigation system

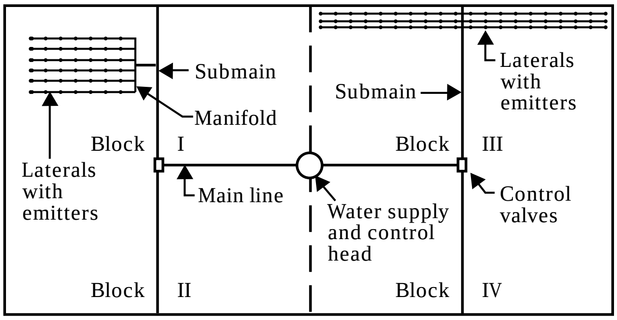
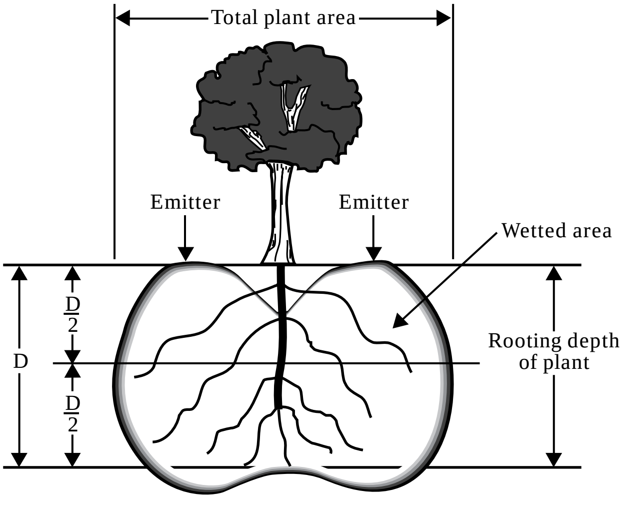


Figure 9–30 Typical wetted area under a plant with two emitters



evapotranspiration (ET). Under-irrigation is easier to detect than overirrigation. Overirrigation is lost to deep percolation and may not be apparent unless the water applied is compared to the plant ET. Properly designed, installed, and operated micro irrigation systems have the capability to place over 90 percent of applied water available for plant use. In reality 65 percent is more common because of inadequate irrigation scheduling resulting in the application of too much water.

The soil salinity level should be checked at various locations from the plant and for various depths to determine if salt buildup is becoming a problem. Where checked periodically, the change in salinity over time is noted.

Field emission uniformity, EU, must be known to properly manage the amount of water applied. Because EU can change throughout the irrigation season, periodic evaluations are needed to determine maintenance needs and irrigation scheduling changes.

(ii) Evaluation process—Use of much of the information is similar to field data and analysis for orchard sprinkler irrigation system. The data needed for evaluating a micro irrigation system can be obtained by determining:

- Duration, frequency, and sequence of operation of a normal irrigation cycle
- Soil-moisture deficit and management allowable depletion
- Rate of discharge and pressure near several emission points spaced throughout the system
- Changes in rate of discharge from emitters after cleaning or other repair
- Percent of soil volume wetted
- Spacing and size of trees, vines, or other plants being irrigated
- Location of emission points relative to trees, vines, or other plants, and uniformity of spacing of emission points.
- Pressure drop at the filter(s)
- General topography

(iii) Equipment—The equipment needed for a micro irrigation system includes:

- Pressure gauge (0 to 50 psi range) with adapters for temporary installation at either end of lateral lines
- Stopwatch
- Graduated cylinder (250 to 500 mL capacity)
- Funnel thave has a 3- to 6-inch diameter
- Shovel, soil auger, or push tube sampler, probe
- Manufacturer's emitter performance charts showing the relationships between discharge and pressure plus recommended operating pressures and filter requirements
- Shop built emitter and spray head catch containers
- Sheet metal or plastic troughs 3 feet long for measuring the discharge from several outlets in a perforated lateral simultaneously or the discharge from a 3-foot length of porous tubing (a piece of 1 1/2 or 2 inch diameter PVC pipe cut in half lengthwise works well)
- Micro Irrigation System Detailed Evaluation Worksheet (see chapter 15)

(iv) Procedure—The following field procedure is suitable for evaluating systems with individually manufactured emitters and systems that use perforated or porous laterals. Record data on evaluation worksheets while collecting the field information.

Step 1—Collect or determine soil and crop characteristics throughout the field.

Step 2—Determine from the irrigation decisionmaker the duration and frequency of irrigation and the concept of applicable MAD.

Step 3—Check and note the pressure at the inlet and outlet of the filter(s) and, if practical, inspect the screens for breaks and other possibilities for contaminants to bypass the screen(s).

Step 4—Collect emitter and lateral information.

Step 5—Locate four emitter laterals along an operating manifold; one should be near the inlet, two near the third points, and the fourth near the outer end. Sketch the system layout and note the general topography, manifold in operation and manifold where the discharge test is conducted.

Step 6—Record system discharge rate and the number of manifolds and blocks (or stations). The number of blocks is the total number of manifolds divided by the number of manifolds in operation at anyone time.

Step 7—For laterals having individual emitters, spray heads, or bubblers, measure the discharge at two adjacent emission points at each of four different tree or plant locations on each of the four selected test laterals. Collect the discharge for a number of full minutes (1, 2, 3, 4, etc.) to obtain a volume between 100 and 200 milliliters for each emission point tested. Convert each reading to milliliters per minute before entering the data on the worksheet. To convert milliliters per minute to gallons per hour, divide milliliters per minute by 63.

These steps produce 8 pressure readings and 32 discharge volumes at 16 different plant locations for individual emission points used in wide-spaced crops with two or more emission points per plant. For perforated tubing, bi-wall, or porous tubing, use a 3- to 5-foot trough and collect a discharge volume at each of the 16 locations described. These are already averages from two or more outlets, so only one reading is needed at each location. Care should be taken to avoid raising an emitter or hose more than a few inches because any raise in elevation reduces discharge pressure and volume.

For relatively wide-spaced crops, such as grapes, where a single outlet emitter or bubbler may serve one or more plants, collect a discharge reading at each of the 16 locations described. Since the plants are only served by a single emission point, only one reading should be made at each location.

Step 8—Measure and record water pressures at the inlet and downstream ends of each lateral tested, preferably under normal operations. On the inlet end, this requires disconnecting the lateral hose, installing the pressure gauge, and reconnecting the lateral before reading the pressure. On the downstream end, the pressure can be read after connecting the pressure gauge the simplest way possible. Be sure to flush the line of sediment and debris before installing the pressure gauge.

Step 9—Check the percentage of soil wetted at one of the plant locations on each test lateral. It is best to select a plant at a different relative location on each lateral. Use a push probe, soil auger, or shovel for estimating the actual extent of the wetted zone below the surface around each plant. Determine the percentage wetted by dividing the wetted area by the total surface area between four plants.

Step 10—If an interval of several days between irrigations is being used, check the SMD in the wetted volume near a few representative plants in the next block to be irrigated. This is difficult and requires averaging samples taken from several positions around each plant.

Step 11—Determine the minimum lateral inlet pressure (MLIP) along each operating manifold. For level or uphill manifolds, the MLIP is at the far end of the manifold. For downhill manifolds it is often about two-thirds the distance down the manifold. With manifolds on undulating terrain, MLIP generally is located on a knoll or high point.

Step 12—Determine the discharge correction factor (DCF) to adjust the average emission point discharges for the tested manifold. This adjustment is needed if the test manifold happened to be operating with a higher or lower MLIP than the system average MLIP. If the emitter discharge exponent, x, is known, use the second formula presented.

Step 13—Determine the average and adjusted average emission point discharges.

(v) Evaluation computations—In micro irrigation all of the system flow is delivered to individual trees, vines, shrubs, plants, rows of plants, or blocks of turf. Essentially, the only opportunity for loss of water is at the tree or plant locations. Therefore, uniformity of emission is of primary concern, assuming the crop is uniform. Locations of individual emission points, or the tree locations where several emitters are closely spaced, can be thought of in much the same manner as container positions in tests of periodic move sprinkler performance.

In exhibit 9–8, there are four single emission points (emitters) per tree in the citrus grove where data were obtained. Therefore, discharge from the two emitters at each tree can be averaged. The minimum rate of discharge (or low quarter) is then the adjusted average discharge of the lowest four (average) discharges per tree, 2.30 gallons per hour for the example evaluation. The adjusted average rate of discharge per tree for the entire system was 2.65 gallons per hour. Example 9–9 shows the computations used for a micro irrigation system evaluation.

Exhibit 9–9 Completed worksheet—Micro irrigation system detailed evaluation

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Example - Micro Irrigation System Detailed Evaluation Worksheet

Land user Joe Example Date ________ Prepared by ________

District ________ County ________

Crop: Citrus age 7 plant and row spacing 22' x 22'

Soil: mapping unit Redcliff L surface texture Loam

actual depth 4 ft AWC 2.0 inches/feet

Irrigation: duration 6 hr frequency 1 da MAD 10 % 0.8 inches/feet

Irrigation system hardware:

Filter: pressure at: inlet 60 psi, outlet 55 psi, loss 5 psi

Emitter: manufacturer SP type flushing spacing 5 ft

Rated discharge per emitter (emission point): 3.0 gph at 30 psi

Emission points per plant 4 giving 72 gallons per plant per day

Later: diameter: 0.58" material PE length 150' spacing 22'

Sketch of micro irrigation system layout:

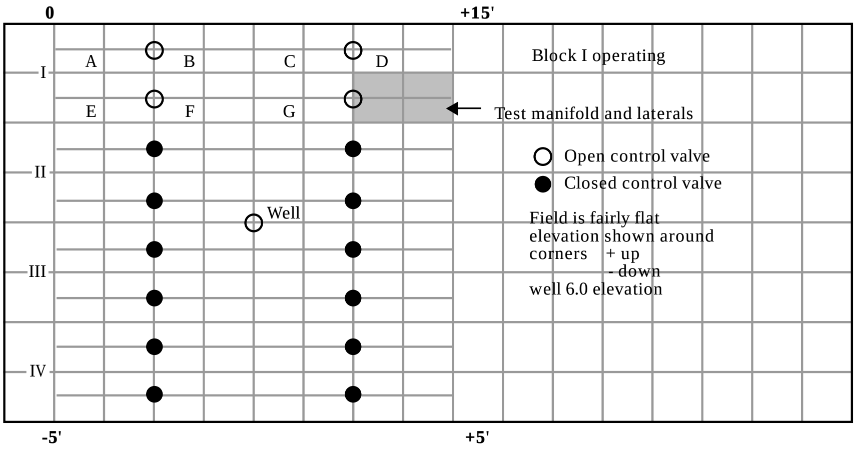

Exhibit 9–9 Completed worksheet—Micro irrigation system detailed evaluation—Continued

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Example - Micro Irrigation System
Detailed Evaluation Worksheet

System discharge: – gpm, number of manifolds 32 and blocks 4

Average test manifold emission point discharges at 45 psi

Manifold = (sum of all averages 41.94 gph) / (number of averages 16) = 2.62 gph

Low 1/4 = (sum of low 1/4 averages 9.07 gph) / (number of low 1/4 averages 4) = 2.27 gph

Adjusted average emission point discharges at 46.1 psi

System = (DCF 1.012) x (manifold average 2.62) = 2.65 gph

Low 1/4 = (DCF 1.012) x (manifold low 1/4 2.27) = 2.30 gph

Discharge test volume collected in 1.0 minutes (1.0 gph = 63 ML/min)

Outlet location on lateral		**Lateral location on the manifold**							
		inlet end		1/3 down		2/3 down		far end	
		mL	gph	mL	gph	mL	gph	mL	gph
inlet end	A	132	2.10	160	2.54	192	3.04	195	3.10
	B	160	2.54	188	2.99	140	2.23	205	3.26
	ave		2.32		2.77		2.64		3.18
1/3 down	A	160	2.54	295	3.10	175	2.78	169	2.69
	B	168	2.66	158	2.50	170	2.70	180	2.86
	ave		2.60		2.80		2.74		2.78
2/3 down	A	187	2.97	146	2.31	125	1.99	144	2.29
	B	175	2.78	155	2.46	155	2.46	175	2.78
	ave		2.88		2.38		2.23		2.54
far end	A	170	2.70	190	3.02	210	3.34	151	2.39
	B	125	1.99	135	2.15	166	2.62	130	2.07
	ave		2.34		2.58		2.98		2.18

Exhibit 9–9 Completed worksheet—Micro irrigation system detailed evaluation—Continued

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Example - Micro Irrigation System Detailed Evaluation Worksheet

Lateral:	inlet pressure	47 psi	45 psi	45 psi	45 psi
	far end pressure	46 psi	43 psi	45 psi	44 psi
Wetted area per plant		150 ft²	125 ft²	140 ft²	145 ft²
		31 %	26 %	29 %	30 %

Estimated average SMD in wetted soil volume –

Minimum lateral inlet pressures, MLIP, on all operating, manifolds:

Manifold ID:	Test	A	B	C	D	E	F	G		Ave.
pressure, psi	45	49	47	43	42	50	48	48		46.1

Discharge correction factor, DCF, for the system is:

$$\text{DCF} = \frac{2.5 \text{ x (average MLIP } 46.1 \text{ psi)}}{\text{(average MLIP } 46.1 \text{ psi + (1.5 x test MLIP } 45 \text{ psi)}} = 1.015 \text{ psi}$$

or if the emitter discharge exponent, x = 0.5 is known,

$$\text{DCF} = \left(\frac{\text{(average MLIP } 46.1 \text{ psi)}}{\text{(test MLIP } 45 \text{ psi)}}\right) \text{x} \ {}^{0.5} = 1.012 \text{ psi}$$

Comments:

Example 9–9 Evaluation computation steps for micro irrigation systems

Average application depth, D_{aw}:

The average depth applied per irrigation to the wetted area, D_{aw}, is useful for estimating management allowed depletion (MAD). The D_{aw} in inches is computed from the average gallons per hour (gph) at each emission point, the number of emission points per tree, N, the number of hours of operation per irrigation, and the wetted area per tree in square feet:

$$D_{aw} = \frac{1{,}605 \times N \times \text{gph} \times \text{hours}}{\text{ft}^2}$$

For the example evaluation:

$$D_{aw} = \frac{1{,}605 \times 4 \times 2.65 \times 6}{22 \times 22} = 0.21 \text{ inches}$$

Volume per day per tree:

The average number of gallons per day per tree or plant is computed from the average gph at each emission point, the number N of emission points per tree, the number of hours of operation per irrigation, and the irrigation interval in days:

$$\text{Average daily gallons per tree} = \frac{N \times \text{gph} \times \text{hours}}{\text{days}}$$

For the example evaluation:

$$\text{Average daily gallons per tree} = \frac{4 \times 2.65 \times 6}{1} = 63.6 \text{ gpd}$$

Emission uniformity, EU:

To determine whether system application devices are operating at an acceptable efficiency, evaluate the emission uniformity, EU:

$$EU = \frac{\text{minimum rate of discharge per plant}}{\text{average rate of discharge per plant}} \times 100$$

in which the average of the lowest quarter is used as the minimum for each of the four emitters per plant. In the example:

$$EU = \frac{4 \times 2.30}{4 \times 2.65} \times 100 = 87\%$$

General criteria for EU values for systems that have been in operation for at least one season are:

EU (%)	Efficiency
> 90 %	excellent
80 – 90 %	good
70 – 80 %	fair
< 70 %	poor

Example 9–9 Evaluation computation steps for micro irrigation systems—Continued

Potential application efficiency low quarter, PELQ:

The concept of PELQ used in other evaluation procedures must be modified when evaluating micro irrigation systems. Because micro irrigation wets only a portion of the total soil volume, the SMD must be replaced frequently. SMD is always difficult to estimate because parts of the wetted root zone often remain near field capacity even when the interval between irrigations is several days.

For the example evaluation where irrigations are applied everyday, SMD is practically impossible to estimate. For this reason, SMD must be estimated from weather data or information derived from evaporation devices even though such estimates are subject to error. Because checking for slight under-irrigation is not practical, some margin for safety should be allowed. As a rule, about 10 percent more water than the estimated SMD or evapotranspiration should be applied to the least watered areas. Thus the PELQ under full micro irrigation can be estimated by:

$$\text{PELQ} = 0.9 \text{ x EU}$$

For the example test data:

$$\text{PELQ} = 0.9 \text{ x } 87\ \% = 78\%$$

In a micro irrigation system, all field boundary effects or pressure variations along the manifold tested are taken into account in the field estimate of EU. Therefore, the estimated PELQ is an overall value for the manifold in the subunit tested except for possible minor water losses resulting from leaks, draining of lines, and flushing (unless leaks are excessive).

Some micro irrigation systems are fitted with pressure compensating emitters or have pressure (or flow) regulation at the inlet to each lateral. However, most systems are only provided with a means for pressure control or regulation at the inlets to the manifolds as was the case with the example system evaluated. If manifold inlet pressures are not properly set, the overall system PELQ is lower than the PELQ of the test manifold. An estimate of this efficiency reduction factor, ERF, can be computed from the minimum lateral inlet pressure, MLIP, along each manifold by:

$$\text{ERF} = \frac{\text{average MLIP} + (1.5 \times \text{minimum MLIP})}{2.5 \times \text{average MLIP}}$$

The ratio between the average emission point discharges in the manifold with the minimum pressure and the system is approximately equal to ERF. Therefore, the system PELQ can be approximated by:

$$\text{System PELQ} = \text{ERF x example PELQ}$$

Using the data from the example evaluation and PELQ = 78%, find ERF:

$$\text{ERF} = \frac{46.1 + (1.5 \times 42)}{2.5 \times 46.1} = 0.95$$

and,

$$\text{System PELQ} = 0.95 \text{ x } 78\ \% = 74\ \%$$

Example 9–9 Evaluation computation steps for micro irrigation systems—Continued

A more precise method for estimating the ERF can be made if the emitter discharge exponent, x, is known by

$$\mathrm{ERF} = \frac{(\text{minimum MLIP})}{(\text{average MLIP})}$$

For the example system with orifice type emitters, where x = 0.5, this alternative calculation of ERF gives:

$$\mathrm{ERF} = \frac{42^{0.5}}{46.1} = 0.14$$

In this case the two methods for computing ERF give essentially equal results; however, for larger pressure variations or x values higher or lower than 0.5, differences could be significant.

Application efficiency, low quarter (AELQ)

Like PELQ, the concept of AELQ must also be modified for micro irrigation. Effectiveness of a micro system can be estimated by how much of the applied water is stored in the root zone and is available for consumptive use by the plants. Because there are essentially no opportunities for losses by evaporation and wind drift or for inadequate irrigation in which the least watered areas are under-irrigated:

System AELQ = ERF x EU

However, if excess water is applied in the least watered areas:

$$\text{System AELQ} = \frac{\text{SMD in wetted area } \times 100}{\text{average depth applied to wetted area}}$$

For an ideal irrigation in which the SMD plus 10 percent extra water is applied to the least watered areas:

AELQ = PELQ

For the example evaluation where daily irrigations were being applied, it was impossible to estimate SMD in the wetted areas around each tree. Furthermore, the average depth applied to the total area, D_a, was only 0.21 inch per day, which is hardly sufficient to meet the expected consumptive use requirements for mature citrus trees at the example evaluation location. Therefore, it is highly probable that the trees were being under-irrigated, in which case for the example EU of 87 percent:

System AELQ = 0.95 x 87 % = 83 %

Overall minimum depth applied:

The overall average depth applied to the total area, D_a, multiplied by system PELQ (or AELQ) is useful for managing an irrigation schedule because water requirements are expressed in similar units.

Multiply D_a by the system PELQ except when there is under-irrigation and AELQ is greater than PELQ. For the example evaluation the overall minimum depth applied to the total area, D_n, is:

$$D_n = D_a \times \frac{\text{System PELQ (or AELQ)}}{100}$$

Example 9–9 Evaluation computation steps for micro irrigation systems—Continued

For the example evaluation, which is under-irrigated and has a system AELQ value of 83 percent:

$D_n = 0.21 \times 83/100 = 0.17$ inch

Analysis and recommendations

Several observations and recommendations can be based on the data collected and the calculation of EU, PELQ, and AELQ.

Pressure differences throughout the operating manifold studied were small. Pressure variations of 20 percent for orifice-type emitters and 10 percent for long tube type result in flow differences of about 10 percent. Obviously each control valve must be adjusted accurately to ensure uniform pressures throughout the field; however, this was not the case as noted by the minimum lateral inlet pressure variations between manifolds as data collected shows.

Uniformity of application throughout the operating manifold, expressed by the EU of 87 percent, was good. Because pressures were nearly constant, most of the lack of application uniformity resulted from variations in operation of the individual emitters. Discharges of emitters A and B at the same location, which would have almost identical pressures, often differed considerably.

Differences in elevation throughout the system were not extreme, so the other manifolds should have produced similar uniformities.

The percentage of wetted area ranged between 26 and 31 percent. This is less than the recommended minimum discussed in the introduction for arid areas.

For the fertilizer application program, urea was injected into the irrigation water to meet nitrogen needs. Other fertilizers were being applied directly to the soil surface and incorporated by cultivation in the fall before the rainy season. This fertilizer program should prove satisfactory and cause no problem with the irrigation equipment.

Emitters—The emitters used in the recorded test were automatic flushing type. The variations in discharge probably resulted from differences in manufacturing tolerances. These emitters, operating at pressures near 45 pounds per square inch, averaged a discharge of 2.62 gallons per hour, which is considerably less than the rated 3 gallons per hour at 30 pounds per square inch. This indicates that the orifices may be closing slowly or clogging after about one season's operation.

Variable clogging can cause large differences in flow from nonflushing emitters even though manufacturing tolerance may be close. Some emitters can be flushed manually. Systems having manually flushed emitters should be flushed monthly, and the change in flow before and after flushing determined. Some outlet emitters are pressure compensating; thus, discharge is constant over a range in pressure variations. Bubbler systems typically use 1/4 to 3/8 inch diameter tubing for outlets where clogging from suspended sediment is not a problem. Insects that build nests in small cavities can be a problem.

Example 9–9 Evaluation computation steps for micro irrigation systems—Continued

***Filters*—**In the example the filter system near the pumping plant seemed to be performing reasonably well. Pressure across it was only 5 pounds per square inch. Small safety screen filters were installed at the inlet to each lateral. This precaution is recommended. Several of these screens were checked at random. All were found reasonably clean; however, several screens had intercepted a considerable amount of coarse material that would have clogged emitters had it passed through the laterals. The operator said that each screen was routinely cleaned after every 1,000 hours of operation.

Changing to a 12-hour irrigation on alternate days instead of continuing the present 6 hours per day could improve the percentage of wetted area because longer applications wet more soil volume. No problems of infiltration were apparent, and the average depth applied to the wet area, D_a, of 0.73 inch could be doubled without exceeding the SMD at a MAD of 30 percent. For example, a total of 8 inches of moisture would be available. The depletion of 2 x 0.73 = 1.46 inches gives a MAD of less than 20 percent in the wetted area.

Manifold inlet valves should be adjusted to give the same minimum lateral inlet pressure on each manifold. This increases the system PELQ and AELQ to the PELQ and AELQ of the tested manifold, which is a 5 percent improvement.

It appears emission from laterals has been gradually decreasing, and the system was designed to yield greater flow than was observed. Thus, adding emitters could restore the systems capacity to the original 12 gallons per hour per tree at an average operating pressure of 30 pounds per square inch, while increasing the percent wetted area to almost 40 percent.

The only sure way to improve EU would be to replace the emitters. This is costly and may not be warranted at this time. Chemical treatment may clean some of the mineral deposits and partly restore discharge rate and uniformity.

Overall minimum depth applied to the total area, D_a, (only 0.17 inch per cycle) seems to be marginal for a mature citrus grove during the peak water demand period. Although emitters were rated at 3 gallons per hour when operated at 30 pounds per square inch, the test results in the field indicated an average rate of flow of 2.62 gallons per hour at 45 pounds per square inch. To meet peak demands of water, the flow rate per tree must be restored to the original design of 12 gallons per hour (four emitters at 3 gph) by cleaning or otherwise repairing the emitters, or by adding another emitter to the system at each tree.

Summary

The EU of 87 percent and estimated PELQ of 78 percent of the tested manifold are good. Main system problems are associated with a marginal amount of soil wetted (only about 30%), poor manifold control valve adjustment, and low rates of flow in the system. The irrigation decisionmaker was advised to try scheduling the irrigation to apply water for 12-hour periods on alternate days instead of continuing the current 6 hours per day cycle. He was also urged to:

- Adjust the manifold control valves to obtain equal minimum lateral inlet pressure on all manifolds (it is suggested fittings be installed to allow the use of pressure gauges).
- Clean or repair the emitters, or add an extra emitter at each tree to restore flow rates to the designed volume and to increase the percent of wetted area.

(9) Irrigation pumps

The efficiency of a pump changes with time and depends a great deal on proper maintenance and impeller diameter. Wear ring and impeller wear, corrosion, and metal erosion (cavitation) can affect the efficiency of a pump. Intake screen plugging and pipeline leaks also affect efficiency. Leaks on suction piping are often caused by pinholes in welded joints and loose couplers. Pumps are often used under conditions other than those for which they were designed. Changes in the irrigation system after pump installation often occur. Some pumps are purchased second hand and used in non-optimum situations. Another frequent problem is poor intake and outlet piping configurations. Such problems can dramatically lower pump efficiency. The purpose of a pump evaluation is to identify these problems, determine annual cost attributed to the problems, and make recommendations for modifications to improve operating efficiency and reduce energy use. A pump analysis should be considered part of a complete irrigation system analysis.

National Engineering Handbook, Section 15, Chapter 8, Irrigation Pumping Plants, should be reviewed before doing a pump test. Another useful reference is University of Nebraska's Revised Irrigation Pumping Plant Test Procedure Manual (1985).

(i) Equipment—The equipment needed to test irrigation pumps includes:

- Pressure gauges: one 0 to 100 pounds per square inch and one 0 to 200 pounds per square inch. Liquid filled or waterproof type is recommended.
- Flow meter or other method to determine flow rate.
- Collection of miscellaneous fittings used to install pressure gauges, including pipe thread compound or tape.
- Vacuum gauge: 0 inch to 30 inches Hg (optional, use to find suction head on suction side of pump).
- Electric meter: volts, amps, power factor (for electric motors).
- Hand level and survey rod.
- Pocket tape (inches and tenths of inches).
- Two pipe wrenches, two adjustable wrenches.
- For internal combustion engines:
  - Portable propane tank, hose, and fittings, and scale for weighing tank (if propane engine is analyzed).
  - Portable diesel or gasoline tank, hose, and fittings, and scale for weighing tank.
  - Method of measuring diesel or gasoline fuel (if weighing scales are not used).
- Watch with stopwatch mode, or stopwatch.
- Pump manufacturer's performance curves for pump(s) being analyzed.
  Pumping plant detailed evaluation worksheet.
- Clipboard and pencil.

Hardware inventory: Obtain the data needed to fill out the data sheet by interviewing the operator and by observing equipment name and data plates. (Use name plate data with caution as component modification(s) may render data obsolete.)

Sketch the pipeline intake assembly and discharge assembly. Show dimensions of component parts. Take pictures of these assemblies.

Safety: Use extreme caution when working around running pumps especially where live drive shafts and belts are exposed. Tie down or remove loose clothing. Use a tick meter to check for stray electrical currents. In the absence of a meter, briefly touch equipment with back of hand. If electrical equipment does not appear to be properly installed or maintained, do not proceed with the evaluation. For personnel safety, observe **no smoking** when performing pump tests where internal combustion engines are used.

The land user or a mechanic should make electrical connections, measure fuel, and make fuel line connections.

(ii) Data inventory and computations—The following steps (example 9–10) are needed to complete testing of irrigation pumps. The information is used in completing the Pumping Plant Detailed Evaluation Worksheet (exhibit 9–10).

Exhibit 9–10 Completed worksheet—Irrigation pumping plant detailed evaluation

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Sheet 1 of 5

Example - Pumping Plant Detailed Evaluation Worksheet

Land user Joe Example Field office ______
Observer ______ Date ______ Checked by ______ Date ______
Field name or number ______ Acres irrigated ______

Hardware Inventory:

Power plant:

Electric motor(s):	Main pump	Booster (if used)
Make	GE	
Model	GEPU 25	
Rated rpm	3450	
Rated hp	25	

Internal combustion engine:
Make ______
Model ______
Continuous rated hp at output shaft ______ hp at ______ rpm
Comments about condition of power plant ______

Gear or belt drive mechanism:
Type: (check one) direct drive ______ gear drive ______ belt drive ______
______ rpm at driver ______ rpm at pump

Pumps		
Type: (centrifugal, turbine, submers.)	Centrifugal	
Make	Berkeley	
Model	2 1/2 ZPBL	
Impeller diameter	8 inches	
Number of impellers	1	
Rated flow rate (gpm)	350	
at head of (ft)	175	
at rpm	3450	

Pump curves: Attached Yes (yes or no)

Comments about conditon of equipment ______

Exhibit 9–10 Completed worksheet—Irrigation pumping plant detailed evaluation—Continued

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Sheet 2 of 5

Example - Pumping Plant Detailed Evaluation Worksheet

Land user ______________ Field office ______________

Existing suction or turbine column set-up (sketch showing dimensions)

Existing discharge set-up (sketch showing dimensions)

Data and computations:

Total Dynamic Head (TDH):

Elevation difference - water surface to pump outlet 6 feet

Pressure reading at pump outlet 85 psi

Pressure at pump inlet (where supply is pressurized) — psi

Estimated friction loss in suction pipe or pump column 2 feet

Miscellaneous friction loss 5 feet

TDH = (elevation difference between water source and pump discharge) + (discharge pressure - pressure at inlet) times 2.31 + (estimated suction pipe friction loss) + miscellaneous =

6 + (85 x 2.31) + 2 + 5 = 209.4 feet

Flow rate:

Flow meter:

Flow rate = ______________ gpm

Velocity meter:

Pipe ID ______________ inches

Velocity ______________ feet/second

Flow rate, Q, in gpm = (Velocity, in feet/second) x (2.45) x (pipe ID^2) =

= ______________ = ______________ gpm

Exhibit 9–10 Completed worksheet—Irrigation pumping plant detailed evaluation—Continued

U.S. Department of Agriculture
Natural Resources Conservation Service

Sheet 3 of 5

Example - Pumping Plant Detailed Evaluation Worksheet

Land user ______________ Field office ______________

Water horsepower:

$$\text{whp} = \frac{(\text{flow rate, in gpm}) \times (\text{TDH, in feet})}{3960} = \frac{295 \times 209.4}{3960} = 15.6 \text{ hp}$$

Energy input

Electric:

Disk revolutions 10

Time: min ______ sec 53.5 = 53.5 sec

Meter constant (Kh) 28.8

PTR (power transformer ratio - usually 1.0)[1/] 1

CTR (current transformer ratio - usually 1.0)[1/] 1

$$\text{KW} = \frac{(3.6) \times (\text{disk rev}) \times (\text{Kh}) \times (\text{PTR}) \times (\text{CTR})}{(\text{time, in seconds})} = \frac{3.6 \times 10 \times 28.8 \times 1}{53.5} = 19.38 \text{ (kwh/h)}$$

Diesel or gasoline:

Evaluation time: hours ______ minutes ______ = ______ hours

Fuel use ______ gallons (a small quantity of fuel may also be weighed, at 7.05 lb/gal for diesel and 6.0 lb/gallon for gasoline)

$$\frac{(\text{fuel use, in gallons})}{(\text{time, in hours})} = \_\_\_\_\_\_ = \_\_\_\_\_\_ \text{ gallons/hour}$$

Propane:

Evaluation time: hours ______ minutes ______ = ______ hours

Fuel use ______ lb (weigh fuel used from small portable tank)

$$\frac{(\text{fuel use, in lb})}{(4.25 \text{ lb/gal}) \times (\text{time, in hr})} = \_\_\_\_\_\_ = \_\_\_\_\_\_ \text{ gallon/hours}$$

Natural gas:

Evaluation time: hours ______ minutes ______ = ______ hours

Meter reading: End ______ minus Start ______ = ______ mcf

$$\frac{(\text{fuel used, in mcf})}{(\text{time, in hr})} = \_\_\_\_\_\_ = \_\_\_\_\_\_ \text{ mcf/hr}$$

1/ Some power companies use a type of meter that requires a PTR or CTR correction factor. Check with local power company.

Exhibit 9–10 Completed worksheet—Irrigation pumping plant detailed evaluation—Continued

U.S. Department of Agriculture
Natural Resources Conservation Service

Sheet 4 of 5

Example - Pumping Plant Detailed Evaluation Worksheet

Land user ______________________ Field office ______________________

In the next step, the efficiency of the power plant and pump, as a unit, is compared to the Nebraska Standards for irrigation pumping plants. The Nebraska standard for a good condition, properly operated plant. If the comparison comes out less than 100%, there is room for improvement.

Nebraska performance rating:

Nebraska pumping plant performance criteria ______________________

	Pump and Power Plant	
Energy source	**Whp-h/unit of energy**	**Energy unit**
Diesel	12.5	gallon
Propane	6.89	gallon
Natural gas	61.7	mcf
Electricity	0.885	kW=kwh/hr
Gasoline	8.66	gallon

The Nebraska standards assume 75% pump and 88% electric motor efficiency.

Percent of Nebraska performance rating

$$= \frac{(\text{whp}) \times (100)}{(\text{energy input}) \times (\text{Nebraska criteria, in whp-h/unit})} =$$

$$= \frac{15.6 \times 100}{19.38 \times .885} = 90.9\ \%$$

Horsepower input:

Electric:

$$\frac{(\text{input kW})}{(0.746\ \text{kW/bhp})} = \frac{19.38}{0.746} = 26.0\ \text{bhp}$$

Diesel:

(16.66) x (energy input, in gal/hr) = ______________ = ________ bhp

Propane:

(9.20) x (energy input, in gal/hr) = ______________ = ________ bhp

Natural gas:

(82.20) x (energy input, in mcf/hr) = ______________ = ________ bhp

Exhibit 9–10 Completed worksheet—Irrigation pumping plant detailed evaluation—Continued

U.S. Department of Agriculture
Natural Resources Conservation Service

Sheet 5 of 5

Pumping Plant Detailed Evaluation Worksheet

Land user ______________________ Field office ______________________

Pumping plant efficiency:

$$\text{Epp} = \frac{(\text{water horsepower output, whp}) \times (100)}{(\text{brake horsepower input, bhp})} = \frac{15.6 \times 100}{26.0} = 60.0\ \%$$

Energy cost per acre-foot:

Fuel cost per unit 0.54 \$/kW-hr, or \$/gal, or \$/mcf

$$\text{Cost, in \$/ac-ft} = \frac{(5431) \times (\text{fuel cost, in \$/unit}) \times (\text{energy input, in kW, gal/hr, or mcf/hr})}{(\text{flow rate, in gpm})}$$

$$= \frac{5431 \times 0.054 \times 19.38}{295} = \$\ 19.26\ \text{/acre-foot}$$

Recommendations:

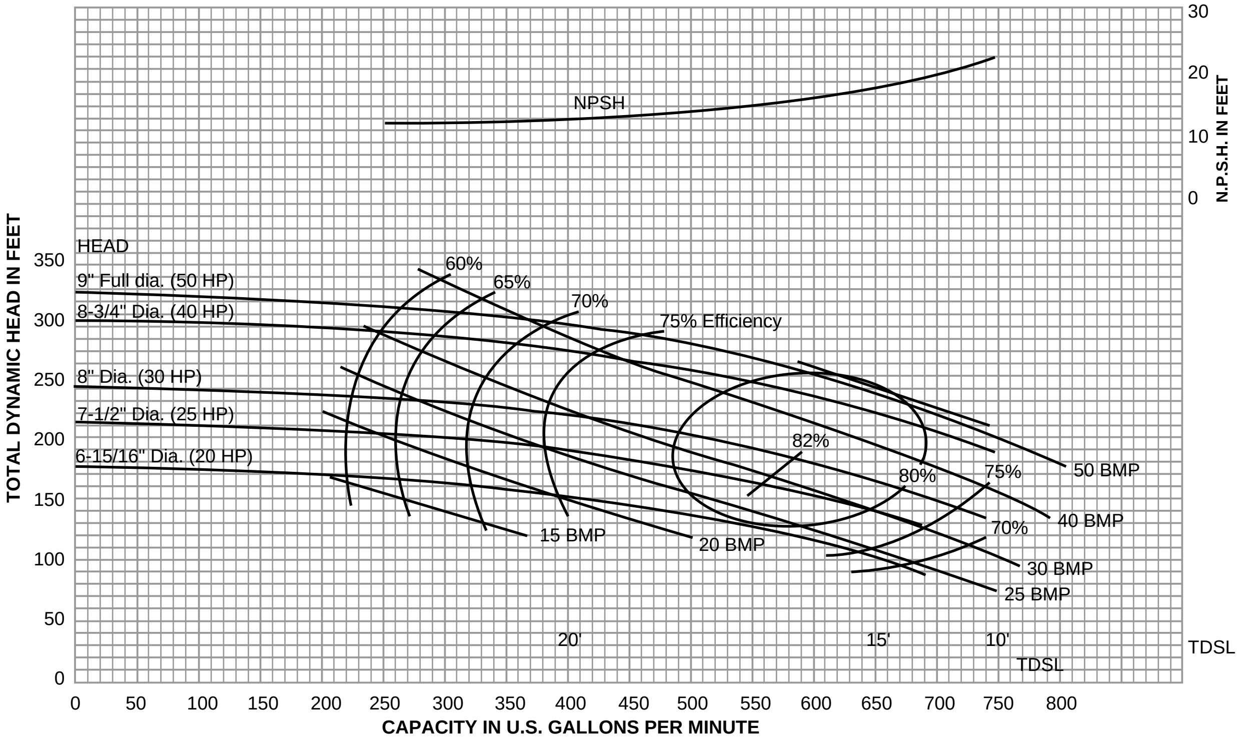
Exhibit 9–10 Completed worksheet—Irrigation pumping plant detailed evaluation—Continued

Pump performance curve example

Case: Material C.I. Patt. No. H-689 Mach. No. H-689 3600 NOMINAL R.P.M. 60 Cycles

Impeller: Material BRZ Patt. No. M-3380 Mach. No. M-3380 Dia. 9" FULL T.D.B.L. for fresh water at sea level 80° F max.

MAXIMUM WORKING PRESSURE 215 PSI M-1 ☐ M-2 ☐



C-5006 Based on T-3184 Superaades C-5006 Dated 10-30-64 Date 5-19-71 MODEL **B3ZPL**

Example 9–10 Evaluation computation steps for irrigation pumping plants

1. **Determine total dynamic head (TDH).** This is the sum of:
   - static head (elevation difference) between the supply water surface and the pump outlet at the point where pressure is read,
   - friction loss in the suction or riser pipe, and
   - discharge pressure next to the pump. (If the pressure is positive at the pump inlet, as is the case for a booster pump or gravity flow inlet, inlet pressure is subtracted from the discharge pressure.)

   Consideration should be given to operating conditions at times other than the time when the evaluation is done. Fluctuations in the supply water surface or pressure and changes in location and elevation of the irrigation outlet during the course of the irrigation should be considered. Worst cases (lowest and highest estimated TDH) should be compared to the evaluation TDH and pump performance curves.

2. **Measure flow rate using the best available method.** If a propeller flow meter is used, the most accurate flow rate is achieved by recording total flow at the beginning and end of a time period, such as a half hour, and dividing by time. This compensates for fluctuations in flow rate during that period. Flow meters or velocity meters must be installed far enough downstream of elbows, tees, valves, reducers, and enlargers to have pipeline velocity flow lines parallel to the pipeline centerline. A distance of at least five times the pipe diameter is recommended. Vanes installed in the pipeline can be used to help reduce turbulence.

3. **Compute water horsepower (whp):**

$$\text{whp} = \frac{(\text{Flow rate, in gpm}) \times (\text{TDH, in ft})}{3960}$$

4. **Determine energy input:**

   Electrical powered units—The easiest method of determining electric energy use is to count the revolutions of the electric meter disk over a period and calculate kilowatt hours.

$$\text{kWh} = \frac{(3.6) \times (\text{disk revolutions}) \times (\text{Kh}) \times (\text{PTR}) \times (\text{CTR})}{(\text{time, in sec})}$$

   where:
   kWh = kwh/hr = the kilowatt-hours used in 1 hour
   Kh = a meter constant shown on the meter
   PTR = power transformer ratio, usually equal to 1 (may need to get from power company)
   CTR = current transformer ratio, usually equal to 1 (may need to get from power company)

   Another way to determine electrical energy use is to measure voltage, amperage, and power factor (if power factor meter is available). All legs of 3-phase power must be measured. This takes proper equipment and should only be done by someone with adequate training. See Nebraska Irrigation Pumping Plant Test Procedure Manual for the procedure.

Example 9–10 Evaluation computation steps for pumping plants—Continued

Diesel or gasoline powered units—Diesel fuel use is determined by running the pump for a period and measuring the amount of fuel used. One way is to fill the fuel tank to a known point, then run the engine for several hours and then refill the tank to the known point with a measured amount of fuel.

Another way is to prepare a 5-gallon fuel can with a fitting and hose just above the bottom. Connect the fuel hose to the engine and run it for a short time. Start timing when the pump pressure has come up to operating pressure. Weigh the fuel container at the beginning and end of the timing period. Number 2 diesel weighs 7.65 pounds per gallon, and gasoline weighs 6.05 pounds per gallon. (Specific weight of diesel and gasoline varies with temperature and type.) Measure or compute gallons per hour used. This is a dangerous operation and should be done by the operator or someone with experience in working with diesel engines. If air is allowed in the fuel system, diesel fuel injectors can malfunction, requiring a diesel specialty mechanic for repair and adjustments.

Propane—The volume of fuel used is determined by running the engine for a short period and weighing the fuel used from a portable tank of propane. The tank should be of the type used on recreational vehicles. Several feet of hose and appropriate connectors are required. This hookup should be done by the operator or someone with experience in working with propane engines. Be sure to exhaust air from the hose before making carburetor connections. Measure or compute the amount of propane used per hour based on 4.25 pounds of fuel per gallon.

Natural gas—The most practical procedure for determining natural gas use is to run the pump at operating load for several hours. Read the gas meter at the beginning and end of the test to determine the number of thousand cubic feet used. Measure the evaluation time in hours and hundredths of hours.

5. **Compare the pumping plant energy usage to energy use by a well designed and operated pumping plant to measure whether improvements in the plant are warranted.** For this purpose we use a set of standards developed at the University of Nebraska. Nebraska Pump Standards are shown on the worksheet. If the comparison comes out close to or more than 100 percent, then the pumping plant (the combined power unit and pump) is considered satisfactory. If the comparison comes out significantly below 100 percent, then consideration should be given to identifying and making pumping plant changes to improve operation.

Performance of the pumping plant, including power unit and pump, can be determined as follows:

$$\text{\% of pumping plant performance criteria} = \frac{(\text{whp}) \times (100)}{(\text{energy input}) \times (\text{power plant criteria in whp-h/unit})}$$

where energy input is in terms of kW for electricity; gallons per hour for diesel, gasoline, and propane; and meters per cubit foot per hour for natural gas.

This criterion is based on 75 percent pump and 88 percent electric motor efficiency as a standard. See chapter 12 of this guide for more information on pumping plant operation.

Example 9–10 Evaluation computation steps for pumping plants—Continued

6. Compute brake horsepower input (bhp) based on fuel used.

Electric: bhp = input kW / 0.746

Diesel or gasoline: bhp = (16.66) x (energy input, in gal/hr)

Propane: bhp = (9.20) x (energy input, in gal/hr)

Natural gas: bhp = (82.20) x (energy input, in mcf/hr)

7. Compute overall pumping plant efficiency (E_{pp}):

$$\text{\% Efficiency} = \frac{(\text{water horsepower output, in whp}) \times (100)}{(\text{brake horsepower input, in bhp})}$$

8. Compute energy cost per acre foot of water delivered:

$$\text{Cost, in \$/ac-ft} = \frac{(5{,}431) \times (\text{fuel cost, \$/unit}) \times (\text{energy input, in kW, gal/hr, or mcf/hr})}{(\text{flow rate, in gpm})}$$

(iii) Analysis of data—These steps are needed to analyze the data collected.

Step 1—Analyze the pump intake and discharge plumbing to determine if unnecessary pipeline and fitting friction loss or turbulence is present. The pump discharge pipeline should expand to full diameter upstream of valves and fittings. Consult pump manufacturer's data for proper installation procedures.

Step 2—If sizes of pump inlet and discharge piping or fittings appear small, calculate friction loss and make a judgment as to whether changes should be recommended. An eccentric reducer with the flat side up should be used (where needed) to reduce the suction pipeline diameter to the inlet diameter at the pump. The inlet fitting at the pump should be the high point on the suction piping. Pump inlet and outlet diameters are based on pump design, not pipeline design. Generally, velocities in suction piping and discharge piping should be less than 5 feet per second.

Step 3—Compare the results with the design.

(iv) Recommendations

Discuss evaluation conclusions with the operator. Make recommendations based on observations, factual measurements, and experience. The data assist the operator in determining if changes are economically desirable. Use the data in completing cost saving computations in a complete irrigation system analysis. Leave sufficient written documentation for operators to review, study, and make a decision, and to provide to a pump dealer if desired.

(v) General pumping problems

Lack of maintenance is by far the greatest pumping problem. Pumps, valves, fittings, and other parts wear with use. When pumping efficiency drops more than 5 percent, maintenance needs to be performed and worn parts replaced. Excess wear in the wear ring around the eye of the impeller is a major cause of reduced pump efficiency. Removing a few bolts and using a micrometer can determine when replacement or rebuilding is needed. Air leaks in the suction piping is another major cause of pumping problems.

A practical maximum suction lift for most pumps is about 15 feet at sea level. This is because of high velocities in the suction pipeline and fittings and at the pump impeller entrance. Depending on pump elevation above sea level and hydraulic entrance conditions at the pump, cavitation can start to occur at about 8 feet of suction lift. Cavitation sounds like small gravel moving with the water through the pump. It is actually air bubbles in the water collapsing as a result of negative pressure. Excessive negative pressure accelerates metal erosion in the eye of the impeller and on the backside of impeller blades. Air leaks, primarily from fittings and welds, in the suction pipeline also cause a form of cavitation. Cavitation reduces pumping equipment efficiency and useful life.

An overheated motor or engine is an indication of excess load. An electric motor should be warm, but not hot to the touch. Check pump performance (discharge head-capacity) curves for rated power requirements. Centrifugal pump impellers can be trimmed to reduce discharge pressure without significantly reducing discharge flow. Reducing impeller rotations per minute (rpm) reduces pressure and discharge flow. Closing a valve on the pump discharge to reduce pressure does little to reduce energy required at the pump.

(vi) Changing pump performance characteristics—If the current pump performance characteristics are known, the effects of a change in diameter of impeller or pump rpm on performance characteristics can be estimated using a set of equations known as affinity laws.

With constant rpm impeller and varying impeller diameter:

- Capacity varies directly with the impeller diameter.
- Head varies as the square of the impeller diameter.
- Horsepower varies as the cube of the impeller diameter.

With constant impeller diameter and varying pump rpm:

- Pump capacity varies directly with rpm.
- Head varies as the square of the rpm.
- Horsepower input varies as the cube of the rpm.

Changing rpm on AC electric motors is typically not an option. However, under certain conditions and with higher bhp motors, use of a variable frequency drive (VFD) may be an economical option. Cost of installing a VFD versus reduced energy use must be analyzed. VFD's allow the rpm of the AC electric motor to be reduced by varying the frequency of the power into the motor, which in turn reduces the horsepower demand. The drives consist of a converter that changes AC power to DC power and an inverter that changes the DC power into adjustable frequency AC power. As the frequency of the power is decreased, the power to the motor and the motor rpm are both reduced. This decrease in motor rpm can substantially reduce the pump horsepower demand, since the pump horsepower demand is proportional to the pump rpm. The result is that a small change in rpm causes a significant change in pump horsepower demand. Review of such references as Irrigation Pumping Plants by University of California (1994) can be helpful in understanding effect of VFD's.

652.0905 Soil intake determination procedures

(a) General

Some knowledge of soil intake characteristics must be available and used to design irrigation systems. Water intake rate of soil is the most important item to be considered in the design of a surface irrigation system, and it is the most variable. Soil intake rate is also important for other irrigation methods. The two purposes for making soil intake or maximum application rate evaluations are to:

- Aid in placing a named kind of soil or group of soils in an intake characteristic (family or group) for future designs.
- Determine the intake characteristics for a specific condition on an individual field.

Table 2–6, Chapter 2, Soils, displays estimates of soil intake characteristics (for basin, border, and furrow surface irrigation) and maximum average application rate (for sprinkle irrigation). These estimates are made by interpretation of data taken from either actual field tests or estimating intake characteristics using surface soil texture by soil series. **Intake characteristic curves (intake family curves) are unitless. It is improper to use any unit, such as inches per hour.** The 1.0 intake family curve does not express an infiltration process averaging 1 inch per hour.

In the past, surface irrigation was the predominant irrigation method used to apply water to the land. Soil intake families were an attempt to group soils with similar intake characteristics for easier data manipulation and fewer digits to handle on a slide rule. Later research and field experience indicated soils were more variable and the infiltration process more complex than originally anticipated. In addition to soil surface texture, soil structure, density, organic matter content, subsurface texture, macro pores, and general soil condition are known to affect the infiltration process.

At least 30 percent of irrigated soils do not follow what was thought to be Standard Intake Curves. Especially with well graded, low organic matter soils, intake curves tend to concave downward instead of upward.

Infiltration reduces to almost zero with time. Although not technically correct, in practice a specific gross application depth and elapsed time are selected and the standard intake family curve nearest that point is used. If a different gross depth of application is selected, a new standard intake curve must be selected to represent that condition. Field measurements and a plotting of a revised accumulated intake versus time curve would work better.

Each irrigation method and system provides its own unique water infiltration process (fig. 9–31). Therefore, determining soil intake characteristics or application rate also must be unique.

Basin and border irrigation have a near uniform depth of free water on the soil surface, which creates a small hydraulic head (pressure) to force water into the soil. Water movement through the soil is primarily downward, first by gravity, then as depth increases by capillary action. With furrows (or corrugations) free water is located in open channels and typically does not cover plant beds. Flow from the furrow is downward (gravitational forces) laterally and even upward into plant rows (capillary forces). Thus, border intake characteristic (family) curves and furrow intake characteristic (family) curves are different.

With sprinkle irrigation (and precipitation), water movement into and through the soil is primarily downward (gravitational and capillary forces). Like border irrigation, the entire soil surface is wetted. However, unlike border irrigation, the small hydraulic head (pressure) on the soil surface does not exist with sprinkle irrigation. If it does, water translocation and runoff typically occur. Average maximum application rate is used for sprinkle irrigation.

Large volume short duration applications made with most low pressure in-canopy application systems require small basins or reservoirs, in-row ripping, residue, or other soil management techniques to limit water translocation and runoff.

Many field tests must be made to determine reliable averages for each soil series. Many factors affect water infiltration. Among them are soil texture, soil condition and recent cultivations, macro pore presence, organic matter content in the surface layer, tillage equipment compaction layers, soil-water content at time of irrigation, and quality of irrigation water as it affects intake (suspended sediment, electrical conductivity [EC], sodium absorption ratio [SAR], and temperature). See Chapter 13, Quality of Water Supply, for additional information.

Furthermore, intake characteristics of a given soil series vary with location, field, irrigation event, and season. Intake characteristics for furrow irrigation change as the crop growing season progresses. These changes are a result of compaction by cultivation equipment, heavy equipment compaction in furrows, worm activity, sediment in irrigation water, soil consolidation, erosion, sedimentation, and water temperature. Intake characteristics for border irrigation systems with perennial crops can decrease as a result of the operation of harvest equipment on moist soils. Under sprinkler systems having medium to large droplet sizes, intake rates can decrease because of puddling and compaction of bare soil surface and surface sealing from displaced fine soil particles. After the designer selects an intake rate or maximum sprinkler application rate from the irrigation guide, onsite investigations (followup) should be made to check actual field condition soil characteristics that affect design parameters selected.

(b) Surface irrigation systems intake

When providing an analysis of an existing surface irrigation system operation using actual field data (inflow, advance), computer software programs, such as Agricultural Research Service's SRFR program, can provide realistic results. This model uses the kinematic wave and zero-inertia theory, which more nearly simulates actual field flow conditions. The soil infiltration conditions significantly influence the achievable distribution uniformity. The relationship between cumulative infiltrated depth and infiltration opportunity time can be described by a number of empirical expressions. The most common expressions are variations of the power function shown in equation form. This equation is used in computer programs for simulating surface irrigation.

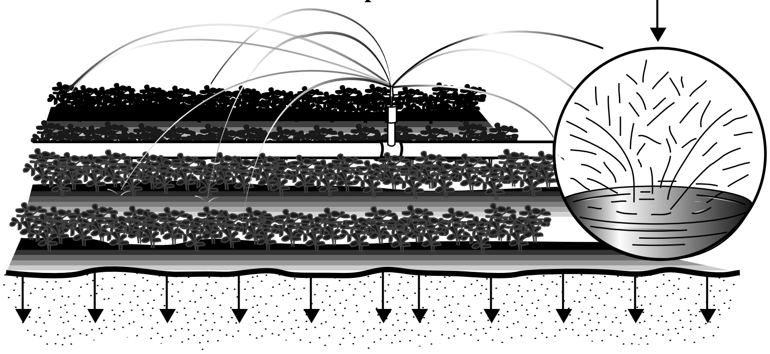
$$Z = k\,t^{a} + B^{t} + C$$

where:

Z = cumulative infiltration
t = infiltration opportunity time
a = empirical exponent
k, B, & C = empirical constants

Figure 9–31 Water infiltration characteristics for sprinkler, border, and furrow irrigation systems

Sprinkler

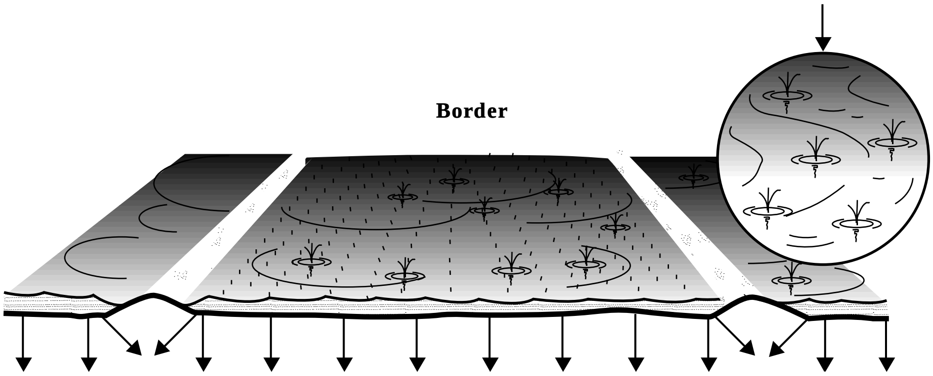


Raindrop action

Water movement vertically downward

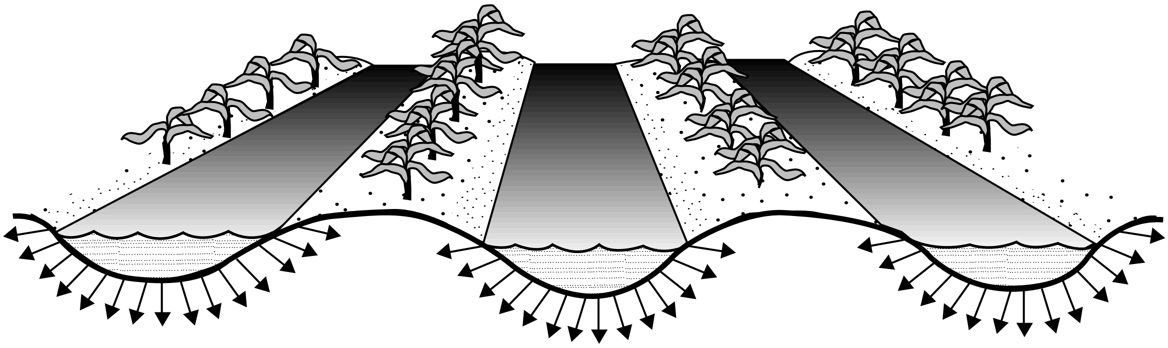
Completely flooded

Border



Water movement vertically downward

Furrow



Water movement both downward and outward from furrow

For design of border irrigation systems or to validate an intake family using known field advance and opportunity times for a border system, the concept of intake family is described in NEH, section 15, chapter 4, by the equation (NRCS modified Kostiakov equation), as follows:

$$Z = k\,t^a + C$$

where:

Z = cumulative infiltration
t = infiltration opportunity time
a = empirical exponent
k & C = empirical constants

(1) Border and basin irrigation systems

When an irrigation takes place for either level or graded border systems, water is ponded on the surface of the soil with water infiltrating vertically downward into the soil. See figure 9–31. The process to determine soil intake characteristics for borders or basins must be similar. A process using a series of cylinders (short lengths of steel pipe driven into the ground) has been developed. They are referred to as cylinder infiltrometers.

Cylinder infiltrometers are installed with buffer rings (or diked earth) around each cylinder to help maintain near vertical water movement. For the intake test, water is ponded in the cylinders and buffer rings to a depth slightly greater than the normal depth of irrigation water flow. Depth of water should be maintained within 20 percent of the normal flow depth. The rate of water level drop is measured in the inside of the cylinder(s) and recorded. With basin irrigation, the entire irrigation set can be used as an infiltrometer.

Data are plotted to display cumulative infiltration in inches versus time. The plotted curve is then compared to a standard set of border intake-family curves to determine the average border intake family for the specific soil at that specific site. See figure 2–3, Chapter 2, Soils, and NEH, Part 623, Chapter 4, Border Irrigation.

(2) Furrow irrigation systems

When an irrigation takes place for either level or graded furrow systems, water within the furrow infiltrates vertically downward, laterally, and diagonally upward into the furrow bed because of soil water tension differential. See figure 9–31. Methods developed to determine soil intake characteristics for furrows need to simulate the actual irrigation process.

Typical furrow conditions needed for determining intake characteristics would include:

- Water flowing in the furrow at a rate and depth similar to a normal irrigation,
- Water flowing at the soil water content when an irrigation is needed, and
- Water flowing in a wheel and nonwheel row or recently cultivated or noncultivated furrow.

The three methods developed to determine infiltration characteristics for furrow irrigation are the furrow inflow-outflow, flowing furrow infiltrometer, and the furrow stream-rate of advance methods. Only the flowing furrow infiltrometer and the furrow stream-rate of advance methods will be described fully in this chapter.

(i) Furrow inflow-outflow method—This method is described in NEH, Part 623, Chapter 5, Furrow Irrigation. When the furrow inflow-outflow method is used, furrow flow rate measuring flumes, weirs, or orifice plates are placed at the head end and lower end of the furrow. The actual irrigation is used for a water supply. Infiltration characteristics of enough furrows (typically four or more) should be measured to be representative of the field. Buffer furrows on each side of test furrow should be used.

(ii) Flowing furrow infiltrometer method—This method was designed by the ARS Water Conservation Lab in Phoenix, Arizona. With the flowing furrow infiltrometer, an auxiliary water supply in a vertical sided container and a return flow pump are needed. After a furrow section (typically 10 meters or 33 feet) is selected, a float controlled water sump with pump is placed at the lower end of the furrow. A flow measuring flume with return hose (from the downstream sump pump) and valve is installed at the upper end of the furrow section.

To begin the furrow intake characteristic test, water from the auxiliary supply reservoir is discharged into the downstream pump sump via the float controlled valve. The return flow pump then transfers the water to the upstream sump and flume via the return hose, where the flow rate is both controlled and measured. A constant flow rate is maintained in the furrow, with water lost by infiltration coming from the auxiliary reservoir via the float control valve in the downstream pump sump. Water surface elevation in the auxiliary reservoir versus time is recorded as soon as the furrow flow rate stabilizes, generally within 5 minutes. Furrow flow rate and soil infiltration volume determine the necessary capacity of the flowing furrow infiltrometer.

(iii) Furrow stream-rate of advance method— When this method is used, the furrow inflow stream is held constant and the rate of advance measured. The gross application calculated at the time water reaches each station (based on an area equal to the furrow spacing times length of advance) is plotted on log-log paper versus time of advance. An average cumulative intake curve results. This procedure assumes all water has been infiltrated into the soil. Thus, the test section must be long enough where surface storage is a small percentage of water infiltrated. Initial points plot as a curve on log-log paper. As the volume of water in surface storage becomes a smaller percentage of total water applied, the curve straightens. The straight line portion represents the accumulative intake curve.

Each method has its own unique field equipment and data collection process even though they provide a similar intake characteristic curve. Data are plotted to display cumulative infiltration in inches versus time. The plotted curve can be matched to a standard set of furrow intake-family curves to determine furrow intake family for that particular soil type. See figure 2–4, Chapter 2, Soils, and NEH, Section 15, Chapter 5, Furrow Irrigation.

(c) Sprinkle irrigation systems

Rotating impact type sprinkler heads apply water to the soil surface intermittently as the jet from the nozzle rotates around a riser. Spray type heads apply water to the soil surface continually. Water infiltrates vertically downward. See figure 9–31. Continuous (self) moving systems use either rotating impact type heads, rotating spray heads, or continuous spray heads. A continuous moving lateral provides an increasing and decreasing application rate pattern (assumed elliptical pattern) on a specific spot; as the lateral approaches, centers over, and moves past a specific spot on the soil surface. Short duration application rates on quarter mile center pivot laterals that have low pressure spray heads can be very high (up to 12 inches per hour). Low Energy Precision Application (LEPA) and Low Pressure In-Canopy (LPIC) systems use very narrow spray pattern discharge devices, thus providing extremely high, short duration application rates (up to 30 inches per hour). All require different processes to determine soil intake characteristics even though a maximum sprinkler application rate is the net result.

Regardless of the sprinkler application process, determining the maximum allowable application rate is a visual observation process. When application rate exceeds soil intake rate, ponding or runoff occurs. The spot or area of soil along the lateral where ponding is beginning to occur and runoff or translocation is just starting represents the area receiving the maximum allowable soil application rate. Ponding is generally not a good indicator by itself, since surface storage can contain an excessive application until sufficient time has elapsed to allow the ponded water to infiltrate. However with most sprinkler systems, some soil surface storage must be available. A small amount of wind can distort application patterns. Typically wind speed is not uniform; therefore, the test should be done during a no-wind condition.

The best judgment of maximum soil infiltration rate can be made by watching the sheen of reflected light on the soil surface as water is applied. With rotating impact sprinklers, the sheen should have just disappeared before the next sprinkler rotation. With spray heads, watch for micro runoff and ponding. Typically many tests are needed on any one soil series because of the small areas that are tested.

For periodic move or set type sprinkler systems using rotating impact type heads, a portable application evaluation device and process were developed by Rhys Tovey and Claude H. Pair, ARS, published in American Society of Agricultural Engineering, 44(12):672-673: Dec. 1963, and Transactions of the ASAE 9(3): 359-363: 1966. The Tovey Meter has a rotating impact type sprinkler head mounted inside a vertically mounted barrel having a vertical narrow discharge slot on one side. The slot allows the sprinkler head to discharge onto an area of about one-tenth of a full circle, thus conserving water and providing a dry area to work from. Water is supplied by a portable water tank. Size of the sprinkler head nozzle (discharge) is increased to where a range of application rates in the wetted pattern from below to above the maximum application rate can be observed. A set of catch containers is placed at some evenly spaced distances from the sprinkler head. Observations are made as to whether the application rate is under, equal to, or exceeds the soil maximum application rate. Catch rates are then measured in the containers in the desired area observed.

More recently, an application device and process have been developed by Michigan State University (MSU). The MSU infiltrometer is a light truss supported pipeline from which several water application devices can be suspended. The pipeline is supported on each end by A-frame style electrical conduit pipe supports. An auxiliary water supply with pump is generally used. Spray heads are typically used in this device. Several sizes of sprinkler or spray heads can provide a range of low-to-excessive application rates for the soil being tested. Sprinkler heads are cycled on and off at different frequencies to vary water application rate. A video is available from NRCS showing the use of the MSU infiltrometer.

Existing sprinkler systems can also be used. Larger than normal discharge sprinkler heads are temporarily installed on two adjacent risers on a lateral. Odd shaped areas somewhere in the sprinkler pattern will visually display ranges of low-to-excessive application rates for the soil and site being tested. Before system startup, valves are placed at least on two adjacent sprinkler heads to allow changing of nozzles without interrupting the balance of the irrigation lateral.

Existing systems are used for continuous moving center pivot and linear laterals. Excessive application rates occur somewhere along the lateral, typically in the outer quarter to one-third of the center pivot lateral. This is especially true on medium to fine textured soils. Continuous recording catch devices are almost essential to record the increasing and decreasing application rates of a moving lateral. This also is the only way to realistically record an accurate short duration maximum application rate. Where simple catch devices are used, only an average rate for the total irrigation set (lateral pass) is obtained. A method using five catch containers set perpendicular to the lateral can be used to approximate maximum application rate. The containers are kept covered until the lateral is over the first container. The cover is removed and timing is started. An elliptical shape application pattern is used to approximate maximum application rate when compared to average application rate (maximum rate = about 1.5 x average rate). See section 652.0905(g)(iii), Continuous/self move sprinkler, field procedure step 9 for a process to measure maximum soil application rate.

(d) Infiltration and application rate test procedures

(1) Border and basin

A brief description of manual procedures is presented in this part. Use reference ARS-NRCS Bulletin ARS 41-7 for additional information and details of equipment needed.

(i) Equipment needed—The equipment needed for border and basin systems include:

- Set of five cylinder infiltration rings (14- to 16-inch lengths of bare welded steel pipe at least 12 inches in diameter), driving plate, driving hammer, and coarse burlap or cotton sack material to be laid on soil surface inside rings to prevent soil puddling when pouring water into rings. See figure 9–32 for plates showing cylinder infiltrometer and hook gauge.
- Carpenter's level to level rings, hook gauge, engineer's scale, recording forms.
- 50-gallon barrel(s) for water supply, several 3-gallon buckets.
- Soil auger, push type sampler, probe, shovel.
- Buffer rings generally cut from 55-gallon barrels. Small earth dikes built around each ring can also be used. Water level is not measured inside the buffer rings.

Figure 9–32 Cylinder infiltrometer

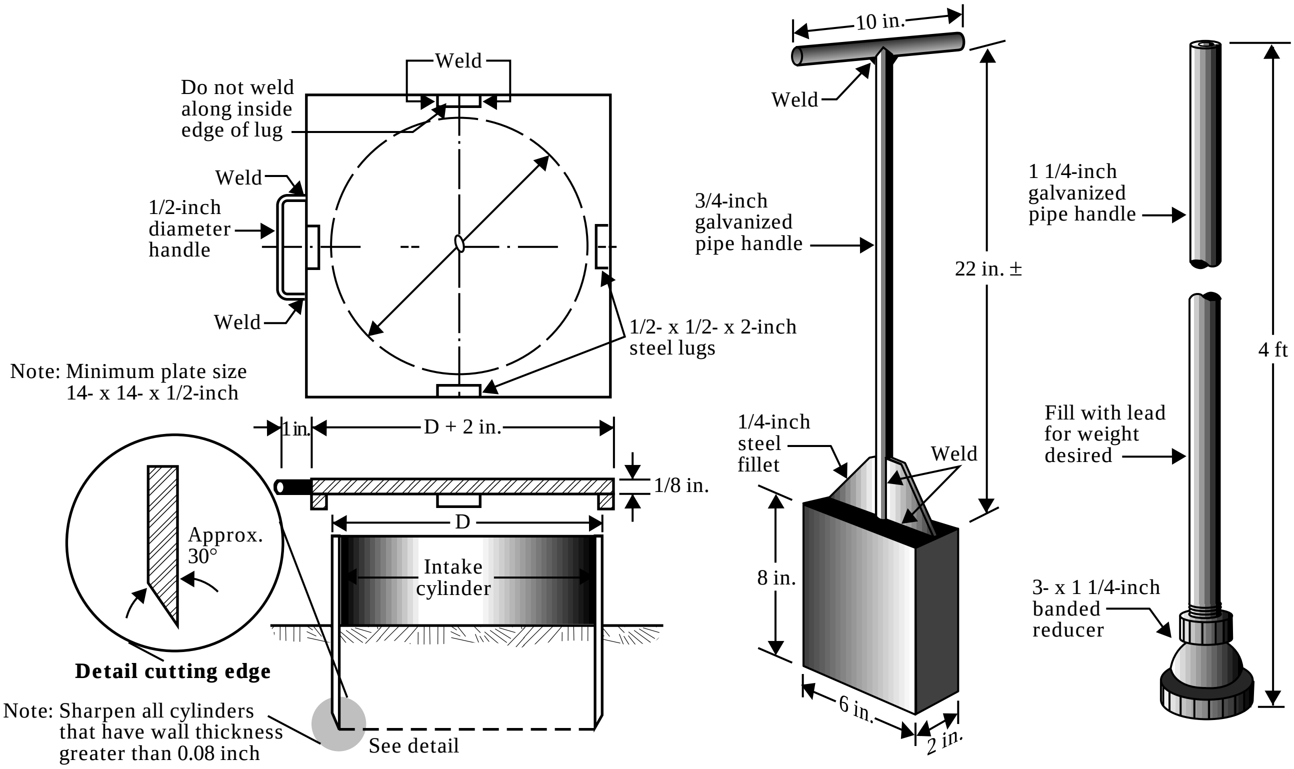
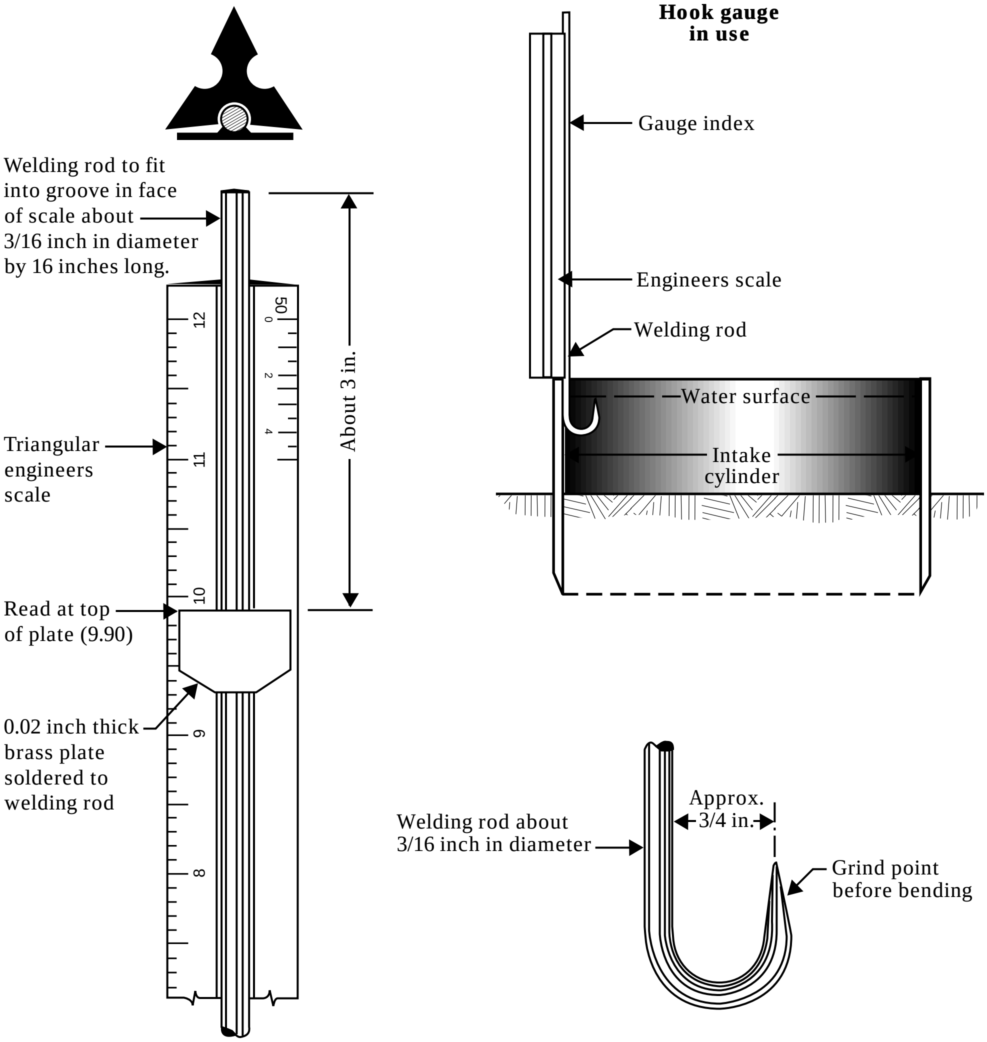


Plate 1: Intake cylinder and driving plate

Plate 2: Driving hammers for intake cylinders

Figure 9–32 Cylinder infiltrometer—Continued



Assembled gauge **Detail of hook**

***(ii) Site selection*—**Carefully preselect sites in advance that represent specific kind of soil and crops. Sites in irrigated mature alfalfa that are in need of irrigation are suggested; otherwise, use the crop and soil condition being irrigated. Replicated infiltrometer measurements on a few typical extensive kind of soil provide more reliable information than single measurements on a large number of soil types. With coarse to medium textured soils on readily accessible sites, two people can reasonably run two tests in 1 day. With medium to fine textured soil and slow intake rates, only one test can be reasonably run in a day.

Measurements made on five kinds of soil for each land resource area at carefully selected model sites for each soil are suggested. Three to five cylinder infiltrometers should be used at each site. Test data from one infiltrometer is often extreme compared to the others and is not used. Doing fewer select soils and sites should provide a basis for estimating intake rates for closely related soils.

A soil scientist should identify and correlate soil series and surface texture at each site. The sites should represent average soil conditions for the soil series. For each test site, identify and record distances to field edges or other permanent features near the site. See figure 9–33 for example soil description for test site.

***(iii) Performing tests*—**Tests are performed using the following procedure:

Step 1—Carefully drive rings into the soil keeping them vertical as possible. Avoid obvious rodent holes, rotted roots, and cracks. The soil should be reasonably moist to provide ease of driving and to provide a good seal between soil and infiltrometer walls. Identify rings and reference the point on each ring where hook gauge is to be located. Install outside buffer rings, earth dikes, or use the entire basin as a buffer.

Step 2—Have a supply of water readily available for quick filling of buckets. Open 55-gallon barrels are convenient to use. Have buckets full of water ready to put into infiltrometers. Have hook gauge, scale, and forms located at the measuring location in the infiltrometer ready to measure and record water level. Account for rapidly infiltrating water early in the test, especially with coarse textured soil where a significant amount of the irrigation can infiltrate in the first few minutes. Also, with some deep cracking fine textured soil, the initial intake can be high and dramatically slow after the cracks are filled and the soil particles swell. Worm activity can cause high initial intake because of preferential flow paths.

Step 3—Place the burlap over soil in the infiltrometers and pour water into infiltrometers. Record hook gauge readings and time. Infiltrometers should be started at successive 1-minute increments, if practical. This gives an opportunity to observe the first 5-minute reading for each infiltrometer in succession. For high intake rate soil, water may need to be added before the first 5 minutes passes. As water is added to maintain near constant levels, hook gauge readings must be made before and after water is added. Times of water addition need not be recorded if they fall between regular reading times. If buffer rings are used, water must be maintained in them also, but measurements need not be recorded. With level basin irrigation systems, the flooded basin can be used as a buffer ring.

Step 4—The first 5 to 10 minutes can be rather frantic on moderately high to high intake rate soil. Record all data on form NRCS-ENG-322. Figure 9–34 is example field data recorded on this form. When readings are taken on the suggested elapsed time intervals as indicated on the form, calculations and plotting are simplified. Soil condition, past cropping history, and tillage practices used by the farmer may be significant in interpreting results.

Step 5—A complete test requires nearly 4 hours of actual running time. Testing low to very low intake rate soil takes longer, and high intake rate soil can take as little as 1 to 2 hours. When accumulated intake is about 6 to 8 inches, the test can be stopped. Erratic data from one or more infiltrometers at a site should be discarded. On low intake soil, a complete test that allows a full irrigation may take 24 hours to complete. Quite often an intake test can be performed for an initial period of 3 to 4 hours, then by plotting on log-log paper and extending the accumulated intake versus time line, infiltration for latter parts of an irrigation is represented. If the line extension is within 10 percent of actual infiltration, performing long duration tests is not justified. Reduced test time is more practical, especially when soil variability is considered.

Figure 9–33 Soil description

U.S. Department of Agriculture
Natural Resources Conservation Service

NRCS-SOILS-2328
Rev. 5-96
File Code Soils-11

Example - Soil Description

Soil Havre Loam **File No.**

Area McCone Co. MT **Date** 7-5-85 **Stop No.**

Classification Fine-loamy, mixed (calcareous), frigid ustic torrifluvents

Location NE 18 - T26 N - R 44E

N. veg. (or crop) Alfalfa hay **Climate**

Parent material Alluvium derived from sedimentry plains and glaciated uplands

Physiography Northern rolling high plains and brown glaciated plains

Relief Smooth **Drainage** Well drained **Salt or alkali** —

Elevation 2,500 **Gr. water** Deep (>6') **Stoniness** —

Slope 0.27 **Moisture** Mod. dry

Aspect E **Root distrib.** (See column below) **% Clay***

Erosion None **% Coarse fragments*** None **% Coarser than V.F.S.***

Permeability Moderate

Additional notes Alfalfa stand is 3 years old. Last irrigated 2 weeks ago.
Cut 2 days ago.

*Control section average

Hori-zon	Depth	Color		Texture	Struc-ture	Color			Reac-tion	Boun-dary	Effer-vesc-ence	Roots	Pore	Line
		Dry	Moist			Dry	Moist	Wet						
Ap	0-5"	2.5 y 5/2	2.5 y 4/2	L	1, f, pl Parting to 1, f, gr	sh	fr	ss, sp	7.6	cs	es	3.vf & f	—	—
C1	5-18"	2.5 y 6/2	2.5 y 4/2	L with strata of VFSL	1, m, pr parting ro -1, m, sbk	sh	fr	ss, sp	8.2	gs	es	3, vf & f	3, vf & f	few threads in pores
C2	18-60"	2.5 y 6/2	2.5 y 4/2	1L with strata of FSL	m	sh	fr	ss, sp	8.2	—	es	2, vf	3, vf & f	few threads in pores

Figure 9–34 Example cylinder infiltrometer test data using form NRCS-ENG-322

U.S. Department of Agriculture
Natural Resources Conservation Service

Cylinder Infiltrometer Test Data

NRCS-ENG-322
05-96

FARM Joe Example	COUNTY Yellowstone	STATE MT	LEGAL DESCRIPTION NW 1/4 S27, T3N, R28E	DATE 7-24-84
SOIL MAPPING SYMBOL	SOIL TYPE Glenberg loam	SOIL MOISTURE: 0' - 1' - % of available 40% 1' - 2' - % of available 50%		
CROP Alfalfa	STAGE OF GROWTH 1 week after cutting			

GENERAL COMMENTS
Compacted layer between 10 and 14 inches

Elapsed time	Cylinder No. 1			Cylinder No. 2			Cylinder No. 3			Cylinder No. 4			Cylinder No. 5			Average accum. intake
	Time of reading	Hook gauge reading	Accum. intake	Time of reading	Hook gauge reading	Accum. intake	Time of reading	Hook gauge reading	Accum. intake	Time of reading	Hook gage reading	Accum. intake	Time of reading	Hook gauge reading	Accum. intake	
Min.		Inches			Inches			Inches			Inches			Inches		
0	11:15	1.80	0	11:16	2.10	0	11:18	3.21	0	11:19	4.10	0	11:19	3.56	0	0
5	11:20	2.44	.64	11:22	2.80	.70	11:23	3.56	.35	11:24	5.30	1.20	11:24	3.99	.43	0.66
10	11:25	2.57	.77	11:26	3.05	.95	11:27	3.64	.43	11:28	5.75	1.65	11:29	4.13	.57	0.87
20	11:35	2.76	.86	11:37	3.45	1.35	11:38	3.72	.51	11:39	6.30	2.20	11:40	4.41	.85	1.17
30	11:45	2.95	1.15	11:46	3.80	1.70	11:47	3.82	.61	11:48	6.85	2.75	11:49	4.71	1.15	1.47
45	12:00	3.25	1.45	12:01	4.35	2.25	12:03	3.97	.76	12:04	7.60	3.50	12:05	5.11	1.55	1.90
60	12:15	3.58	1.78	12:17	4..80	2.70	12:18	4.15	.94	12:18	8.20	4.10	12:20	5.46	1.90	2.28
90	12:45	4.05	2.25	12:46	5.50	3.40	12:47	4.51	1.30	12:47	9.20	5.10	12:48	6.26	2.70	2.95
120	13:15	4.50	2.70	13:16	6.10	4.00	13:17	4.91	1.70	13:18	10.10/ 3.90	6.00	13:19	7.26/ 3.68	3.70	3.62
180	14:15	5.30	3.50	14:17	7.50	5.40	14:18	5.71	2.50	14:19	5.6	7.70	14:20	5.88	5.90	5.00
240	15:15	6.20	4.40	15:16	8.80	6.70	15:18	6.61	3.40	15:19	6.9	9.00	15:20	7.98	8.00	6.30

Step 6—Calculate each infiltrometer and average accumulated intake for increments of elapsed time and plot on log-log paper. See example data and the resulting plot in figure 9–35. Draw best fit curve (straight line on log-log paper) through the plotted points (use 2 x 3 cycle logarithmic paper). Many soils match the standard curves. For those not matching, a regression analysis can be made to develop an equation for the curve or line. Compare to figure 9–36 for intake families for border irrigation design. Determine accumulated intake for the curve:

$$\text{Accumulated Intake} = c \times t^{n}$$

where:
c = y intercept at t = 1 minute
n = linear slope of line

From the plotted line: Using an engineer's scale, determine slope of line (n). The example shows 0.48 inches rise in 1-inch horizontal. Plotted line intercept (c) at 1 minute = 0.134 inches.

$$\text{Accumulated Intake} = \left(0.134\right) \times T^{0.48}$$

(iv) Automation of infiltration tests—Use of automatic water supply devices, pressure transducers or strip gauges for water level indication, and continuous water level recorders (data loggers) can substantially reduce labor compared to a manual testing process. Only one person would need to visit the test site periodically during the infiltration test after initial startup. The basic testing process and time of test are the same regardless. Five sets of equipment are needed except one data logger can handle water level data from all five cylinder infiltrometers.

Water level automation within buffer rings or dikes is simple. A water supply barrel, large diameter garden hose, and a float controlled valve can eliminate the need for manually adding water to buffer rings. Float controlled valves should be mounted on a durable stake where each valve can be raised or lowered to adjust the buffer ring water surface at each site.

Figure 9–35 Example cylinder infiltrometer test data accumulated intake for border irrigation design

Land user Joe Example
Date 7-24-84
Field office Billings

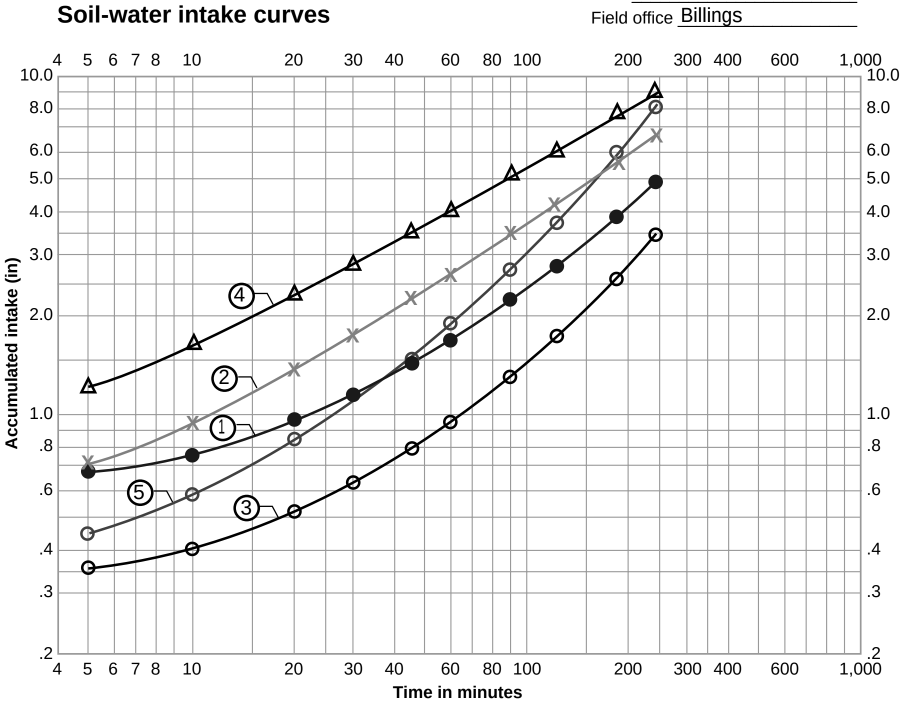
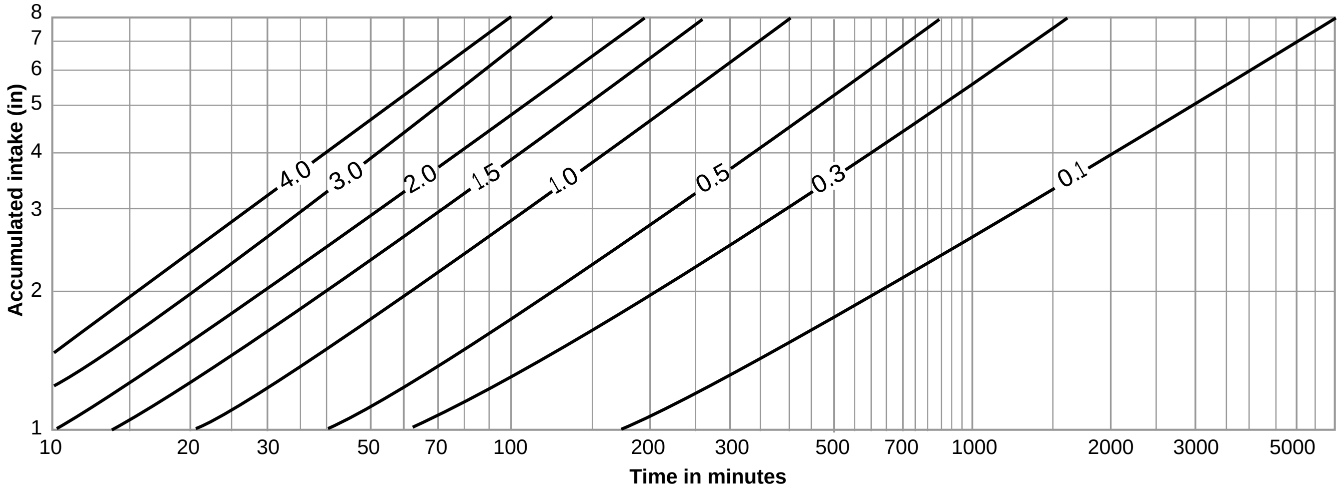


Figure 9–36 Standard intake families for border irrigation design

Land user ____________________
Date ________________________
Field office ___________________

Intake curve overlay

(Clear plastic overlay is available through NRCS State Office)



Intake Grouping for Border Irrigation Design

Instructions

1. Plot data from cylinder intake test on matching logarithmic paper using accumulated intake (inches) as ordinates and elapsed time (minutes) as abscissas. Draw line representing test results.
2. Place overlay over plotted curve, matching the intersection of the lines for 10 minutes time and 1-inch intake. Select the intake family that best represents the plotted curve within the normal irrigation range.

(2) Furrow

Manual procedures for measuring furrow intake rates are described in this part. Refer to NEH Section 15, Chapter 5, Furrow Irrigation, for additional information on inflow-outflow method of furrow intake determination.

(i) Equipment—Equipment needs for furrow inflow-outflow method include:

- Portable water flow measuring devices for determining inflow and outflow in each furrow (small broadcrested v-notch or trapezoidal flumes, v-notch weirs, or orifice plates). Water surface in furrow should not be raised above normal flow conditions by the measuring device.
- Auger, push type sampler, probe, shovel.
- 100-foot tape, lath, or wire flags.
- Level and rod to determine elevations at 100-foot stations down the length of the test furrows.
- Pocket tape and straight edge to measure furrow cross sections at two or three stations.

(ii) Site selection—Carefully preselect sites in advance for specific soil series, soil surface textures, and crop. Replicated measurements on a few typical soil series and surface textures provide more reliable information than single measurements on a large number of soils. On medium to high intake rate soil, two people can reasonably run one test in 1 day. On low intake soil, it may take 24 hours for a complete test that allows a full irrigation. Quite often a furrow intake test can be performed for an initial period of 3 to 4 hours, then by plotting on log-log paper and extending the accumulated intake versus time line, infiltration for latter parts of an irrigation is represented. If the line extension is within 10 percent of actual infiltration, performing long duration tests is not justified.

Measurements made on predominant soil series and surface textures for each land resource area at carefully selected model sites for each soil are suggested. Also, replicated measurements on a few typical dominant soils provide more reliable information than a single measurement on a large number of soils. The data can be projected to other close related soils.

A soil scientist should identify the soil series and surface texture at each furrow evaluation site. (Soil map units may contain inclusions.) Because of the inclusions or local soil series changes in the field, the test length generally is some portion of the full furrow length (50 to 200 feet recommended). Most testing is to identify infiltration characteristics for a soil series and surface texture, thus that soil series and texture should be measured. Sites should represent average soil conditions for the soil series and surface texture tested. Identify test site with reference to field edges or other permanent features in or near the field.

If field (instead of soil series and surface texture) infiltration characteristics are desired, measure the number of furrows and furrow length that best represents field conditions. Values obtained are good for that field and may represent field conditions for similar conditions and soil series.

(iii) Performing tests—Tests are performed using the following procedure:

Step 1—Set stakes or wire flags at 100-foot stations (use measuring tape), determine elevation at each station (use level and rod), and measure furrow cross sections at two or three stations (use pocket tape and straight edge). A uniform grade for the furrow length is desirable. The full furrow length does not need to be used; any length will work. The minimum evaluation length should be 50 to 100 feet for high intake rate soil and 100 to 200 feet for low intake rate soil. (The evaluator's ability to determine flow rate at each end of the furrow test section determines length.)

Step 2—Three adjacent furrows should be evaluated. Adjacent furrows on each side of the test area should also be irrigated simultaneously. This requires observers to walk either on top of the beds or in the adjacent irrigated furrows themselves. Use the same inflow stream size that the irrigator uses. However, the flow should be large enough to produce a fairly uniform rate of advance through the test section.

Start flow into furrows, record time, adjust streams so that flows into all test furrows are about equal. For advance rate data, record the time water in each furrow reaches each station. Two people are essential to perform tests where inflow rates are high or the soil provides fast advance rates. Periodically check water inflow rate and record time of readings. Inflow should be constant during the test. Record time water starts to flow through the outflow measuring device. Periodically measure and record time for outflow.

With field evaluations, outflow starts gradually and increases to a constant flow rate. It decreases after inflow shut-off and recession starts. Record time of inflow shut-off. Continue to periodically measure outflow and record times until flow stops. If ending the intake evaluation before completion of a full irrigation, take final inflow-outflow readings at the same time. The full irrigation time does not need to be used. The test should run sufficiently long for the outflow to become constant for at least 3 to 4 hours. This indicates infiltration is at a constant rate.

Step 3—Computation and evaluation procedures are described in NEH, Section 15, Chapter 5, Furrow Irrigation. Example of data collected from a field intake test are displayed in figures 5–23 to 5–28. The cumulative intake and associated opportunity time are plotted on log-log paper (fig. 9–37). This information defines the measured intake curve. This curve is then compared to standard intake-family curves in figure 9–38 to determine the most representative intake family. Example displayed indicates intake family for existing site condition, $I_f = 0.5$. Appropriate values of a and b are selected. Graded furrow detail evaluation procedure and example forms are described in section 652.0905(g)(3).

Step 4—Although not needed for the intake test, measuring the wetted bulb is desirable about 24 hours after the irrigation is completed. A probe or push type core sampler can be used to define the boundary line between wet and dry soil. Another method is to excavate a trench perpendicular across the furrow and observe and measure the wetted area. The soil moisture (after 24 hours) immediately below the furrow is generally considered to be field capacity (in medium to fine texture soil).

Often a previously irrigated set with the same soil series and surface texture is used for this purpose. Check wetted depth at 0, 20, 40, 60, 80 and 100 percent of the furrow length for distribution uniformity and adequacy of irrigation, if test is of equal duration to a regular irrigation. Observe root development location and pattern for a better understanding of the actual plant root zone.

Figure 9–37 Furrow accumulated intake versus time

Land user ____________________
Date _________________________
Field office ___________________

Accumulated intake vs. time

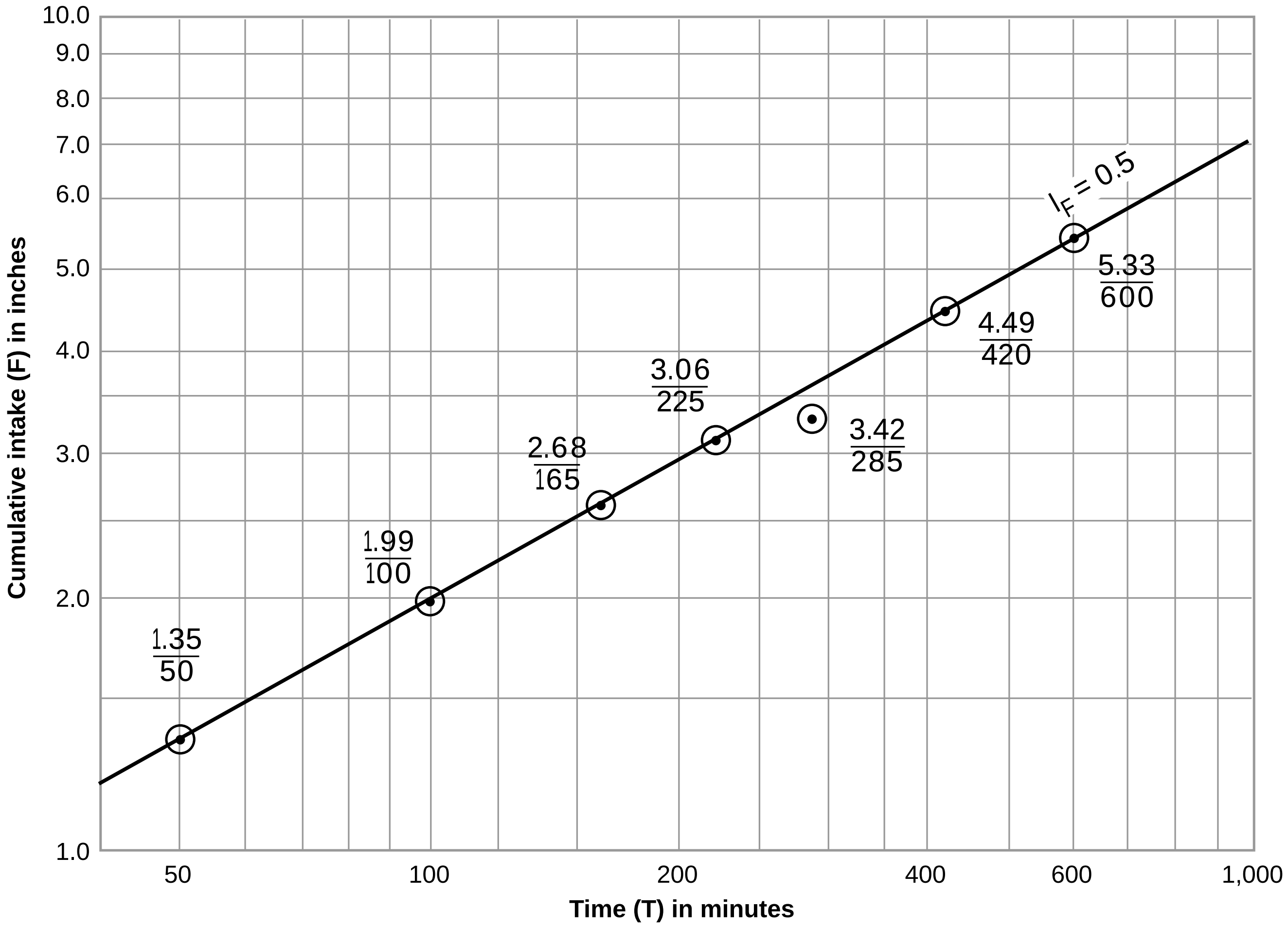
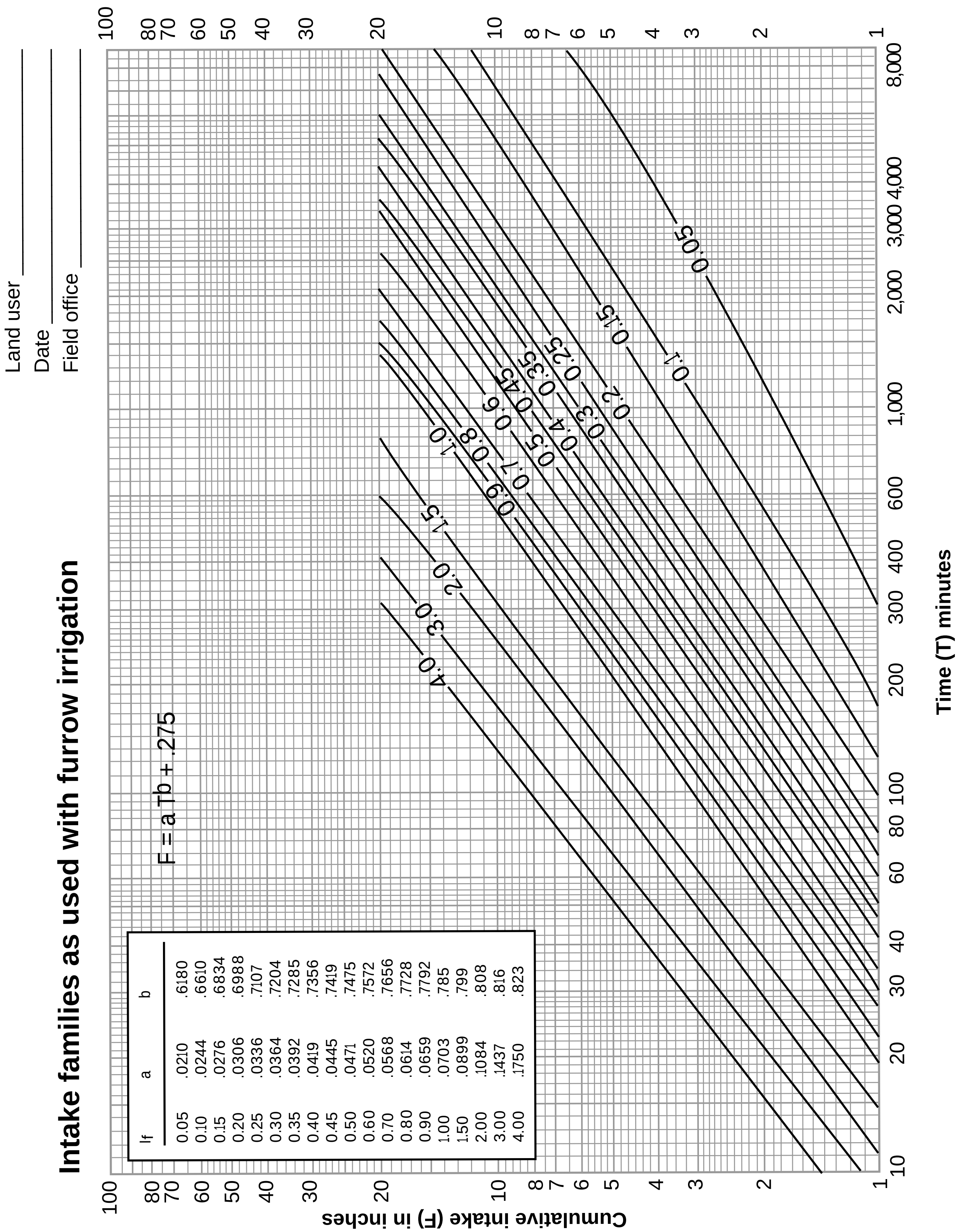


Figure 9–38 Intake families as used with furrow irrigation



If	a	b
0.05	.0210	.6180
0.10	.0244	.6610
0.15	.0276	.6834
0.20	.0306	.6988
0.25	.0336	.7107
0.30	.0364	.7204
0.35	.0392	.7285
0.40	.0419	.7356
0.45	.0445	.7419
0.50	.0471	.7475
0.60	.0520	.7572
0.70	.0568	.7656
0.80	.0614	.7728
0.90	.0659	.7792
1.00	.0703	.785
1.50	.0899	.799
2.00	.1084	.808
3.00	.1437	.816
4.00	.1750	.823

(3) Flowing furrow infiltrometer method

(i) Equipment—Equipment needed for flowing furrow infiltrometer method include:

- Auger, probe, push type core sampler, shovel, measuring tape.
- Flowing furrow infiltrometer device consisting of:
  - water supply
  - calibrated vertical sided water supply tank
  - pump for return of furrow outflow
  - upstream flow control valve sump that has measuring flume
  - downstream sump that has float controlled water supply valve
  - two hoses for inflow from water supply and return of furrow runoff to upstream sump.

The required water supply volume can be calculated by knowing the area irrigated by the test, in acres; planned depth of water application during the test, in inches; plus water volume contained in the furrow during the test and miscellaneous losses. Cross sectional area of the water supply tank should be such that the water surface elevation drops at least 2 feet during the test.

(ii) Site selection**—**Carefully preselect sites in advance for specific soil series and surface texture. Furrows are tested individually. Two people can reasonably run tests at two nearby sites in 1 day for medium to high intake rate soil.

Measurements made on predominant soil series and surface textures for each land resource area at carefully select model sites for each soil are suggested. Also, replicated measurements on a few typical dominant soils provide more reliable information than single measurements on a large number of soils. The data can be projected to other close related soils.

A soil scientist should identify soils series and surface textures at each test site. Each test site is relatively small (30- to 100-foot furrow length) to avoid soil inclusions and have a sufficient water supply. Identify test site with reference to field edges and local features.

(iii) Performing tests**—**With water from a water supply tank, start flow into the downstream furrow sump via the hose and float controlled valve. Water is immediately pumped (returned) to the upstream sump and measuring device where furrow inflow rate is adjusted with a value to the planned furrow flow rate or flow rate used by the irrigator. A near study water flow rate into the furrow and a constant furrow water storage volume should be obtained within about 5 minutes. Record the supply tank water surface elevation to start the test. Water lost by infiltration during the test is made up with new water from the water supply tank via hose and float control valve at the downstream pump sump.

Water surface elevation (or stage) in the water supply tank versus time is recorded about every 10 minutes. Although automated data recording may be available, manual recording is generally adequate. After initial set up, one operator should remain at the site throughout the test.

Typically, tests can be discontinued after 3 to 4 hours. If the plotted accumulated intake versus opportunity time can be extended for longer set times within about 10 percent of actual, conducting longer tests is not justified. Soils generally are more variable than additional accuracy obtained by running longer tests.

All data can be measured with small flumes or calibrated cans, pressure transducers, or strip gauges, and recorded using data loggers.

(iv) Calculations**—**With the cross sectional area of the vertical sided water supply tank known, the volume of water (in acre-inches) applied to the test area (furrow length times the furrow spacing) can be calculated. Accumulated furrow infiltration in acre-inches versus elapsed (opportunity) time can be plotted on log-log paper. Infiltration during the first 15 minutes to 1 hour can be significant when irrigating high intake, cracking or loose soil.

A composite curve for tests performed on the same soil series and surface texture can be plotted manually or a best fit curve can be calculated using all plotted points.

Additional water measurement detail is presented in section 652.0907.

(4) Sprinkler

A brief and generic type infiltration (application) test procedure is described here. Additional details depending on method used and type of application or infiltration test device are described in section 652.0907.

(i) Periodic move or set type sprinkler

Equipment needed:

- Catch containers or rain gauges.
- 100- to 250-milliliter graduated cylinder.
- Measuring tape, watch, recording forms.
- Stakes, rubber bands, or similar way to support catch containers or rain gauges above crop canopy.
- Miscellaneous sprinkler nozzles or spray heads and tools.
- Operating sprinkler lateral or sprinkler infiltrometer. When using an operating sprinkler lateral, first obtain permission to change sprinkler nozzles (and heads if necessary). Before performing the infiltration test, install valves (ball type preferred) in sprinkler head risers where nozzles and or heads may be changed. Valves in adjacent risers help to minimize getting wet.
- Sprinkler infiltrometer test device. The test device need only wet a small portion of a full circle so operators and observers are working on dry soil. A collection system is necessary to catch and recirculate water from the sprinkler or spray head area when it is not discharging water onto the soil surface. Sharp edged and vertical sided containers work; however, 4-inch or larger diameter sharp edged catch containers are preferred as they can more accurately catch precipitation. If containers are not vertical sided, the catch must be measured volumetrically and converted to depth in inches based on the open area at top of container. With some nozzle trajectory patterns, such as low angle sprinkler heads on short risers, water droplets are moving more horizontal than vertical. This type of sprinkler head presents a challenge, so the results are meaningful.

Site selection:

Carefully preselect sites in advance for specific soil series, surface textures, and crop. Replicated measurements (3 to 5) on a few typical extensive soils provide more reliable information than do a single measurement on a large number of soils. Two people can reasonably run two tests in 1 day if sites are close together and a water supply is relative accessible.

Measurements made on predominant soil series and surface textures for each land resource area at carefully select model sites for each soil are suggested. Also, replicated measurements on a few typical dominant soils provide more reliable information than a single measurement on a large number of soils. The data can be projected to other close related soils.

A soil scientist should identify and correlate soils series and surface texture at each test site. Because a test site is relatively small, inclusions in the field are generally not a problem. However, actual surface texture at the site needs to be known. Identify test site with reference to field edges and local features.

Describe soil surface conditions, such as surface organic debris, surface storage, soil condition, cultivation practices, and crop condition.

Performing tests:

Use the following procedure to measure maximum allowable sprinkler application rate:

Step 1—Catch containers are set in the wetted pattern in groups of three (suggested at 5-foot intervals). Care must be taken to avoid foot traffic in the area around each catch container where infiltration is observed. The observer must be able to see bare soil around each catch container. The maximum application rate typically occurs when soil has become wet and the initial high intake rate has passed. To pre-wet the site before the test is run may be necessary unless a full range of under-to-over application is desired.

When using an existing sprinkler system, increase nozzle size in two adjacent sprinkler heads. Install a valve just below the sprinkler head so discharge can be controlled when setting out, starting and stopping the test, and retrieving the catch containers. Excessive application rate needs to occur somewhere in the sprinkler or spray pattern. This provides a spot or area in the sprinkler pattern that is near the maximum application rate. Set out a linear series of catch containers in this area. Record time of start and stop of catch. Observe soil surface condition in the area around the containers for under application, adequate application, and over application rates.

Step 2—Observations are taken frequently (15 minutes) at each group of catch containers where application rates are categorized into three general classes: under, adequate, or over.

Step 3—At the conclusion of the test, the volume in each catch container is measured and converted to application rates expressed in inches per hour. The maximum allowable application rate based on visual observation can be displayed in table 2–8, Chapter 2, Soils. This value is used when designing fixed set or periodic move sprinkler systems on the kind of soil tested. Factors developed (or affirmed) in the local area are used to adjust the long-term maximum allowable application rate for shorter duration applications made with continuous move sprinkler systems. See continuous move system evaluation procedure.

(ii) Continuous move systems—center pivot or linear move (using catch containers)

Site selection:
Carefully preselect sites in advance for specific soil series, surface texture, and crop. Replicated measurements (3 to 5) on a few typical extensive soil series and surface textures provide more reliable information than a single measurement on a large number of soil series.

Measurements made on predominant soil series and surface textures for each land resource area at carefully select model sites for each soil are suggested. Also, replicated measurements on a few typical dominant soils provide more reliable information than a single measurement on a large number of soils. The data can be projected to other close related soils.

A soil scientist should identify and correlate soil series and surface texture at each test site. Identify test site with reference to span number, field edge, and direction from pivot. Specific location of test sites is not easy to identify until the pivot system has made several rotations and areas of runoff observed.

Soil surface condition must be described as to crop residue on the soil surface and soil surface storage, soil condition, and cultivation practices.

Performing tests:
Use the following procedure to measure maximum allowable sprinkler application rate:

Step 1—Place a minimum of five groups of catch containers or rain gauges (suggest three containers in a group) in a line perpendicular to the lateral in the area of observed maximum application rate. Distance between groups of catch containers depends on spray pattern width. Suggested maximum distance is 10 feet. For low pressure systems, the distance may be relatively short, 4 to 5 feet.

Step 2—Cover all containers. The center group of containers must be directly under the spray head when test is started, with equal groups of containers forward and rearward of the direction of movement.

Step 3—Quickly remove all covers from containers when spray nozzle is directly over the center group of containers. Observe intake characteristics of soil throughout the test.

Step 4—After 5 to 10 minutes of operation, cover containers as quickly as possible.

Step 5—Measure water volume caught in each container and convert to application rate in inches per hour. Average group of three containers into one value. Containers within a group are equal distance from the lateral. The group of containers with the largest quantity will represent the average application rate for that time duration (5 to 10 minutes). This approximates the maximum rate of the soil with a system similarly equipped moving at the given rate.

$$\frac{\text{Depth caught, inches}}{\text{Time of catch, min}}\left(60\text{ min/hr}\right) = \underline{\quad\quad}\text{ inches per hour}$$

Step 6—Duplicate tests at other locations along the lateral in the same general area. This tends to eliminate the effect of nozzle pattern and start-stop operation and the effect on application rate.

Step 7—Additional tests may be needed (closer toward the pivot or toward the end) to determine maximum soil intake rate for that site, depending on location of runoff. This point is not necessarily be easy to observe until after some practice. In fact, runoff may not occur at the same location each rotation.

(e) Automation of testing for maximum application rate

Use of a continuous recording rain gauge, such as the standard U.S. Weather Bureau tipping bucket rain gauge, makes the application rate evaluation process much easier. The gauge can be relocated in front of the moving pivot lateral and quickly set up for another test. Setting up one recording gauge is faster than setting out a series of catch containers. Limitations are crop height and elevation of spray or sprinkler heads above the ground. When used to catch the applied water during the entire pass, any increment of time can be used to plot application rate versus time. Because of the short application time with low pressure systems, timely observation of application and runoff is essential. Use of waterproof rain gear is recommended to be close enough to the catch device to make good visual observations at ground surface.

652.0906 Water measurement

(a) General

High irrigation application efficiencies require applying uniform, predetermined amounts of water onto the field at the proper time (irrigation scheduling). Measurement accuracy of applied water needs to be sufficient to make the decision: "When should irrigation change to another area or cease entirely?" Too often, plant water needs are measured or calculated accurately, then water is applied with no thought of measurement.

Refer to Water Measurement Manual, Bureau of Reclamation (1997) for flow characteristics, siting, rating tables, and recommended operation and maintenance of water measuring devices.

(b) Using water measurement

Water measurement has traditionally been used to regulate the division of irrigation water between groups (irrigation organizations, districts, or companies) or individuals. Irrigation districts or organizations in turn use water measuring to portion water between individuals within a district. Thus, water measurement is often perceived as a regulatory action. Water users also view the installation of water measurement devices as a cost and a nuisance with little return on investment.

The benefits of providing onfield water measurement for water management purposes are incalculable. Investment costs are often returned many times during one irrigation season. Typically, at least 10 to 30 percent additional area can be irrigated with the same amount of water. Inversely, 10 to 30 percent less water can be used to irrigate the same area when water is measured. Crop yield or quality of product almost always improves with improved water management. Applying a measured, predetermined amount of water onto a field at the proper time is the basis for good irrigation water management.

Several accurate methods are used to determine plant water needs and available soil water. Combining these two factors determines when and how much irrigation water to apply (irrigation scheduling). Where water supplies are not limited, over irrigation (with associated yield reduction or soil and water resource degradation) is by far the greatest irrigation water management problem. Water measurement onto the field can help avoid over (or under) irrigation.

Successful micro irrigation depends on an accurate knowledge of flow rates. Water measurement devices allow for determination of line or emitter plugging, which then allows for line flushing or chemical treatment. With sprinkler systems, water measurement devices allow for determination of worn and plugged nozzles and excessive gasket leaks. Unexplained changes in flow indicate something in the system has changed and needs attention. A good example may be worn sprinkler nozzles. They provide an opportunity for system flow to increase, especially where the pump can provide additional flow. Overall pump efficiency is often decreased.

(c) Basic hydraulic concepts

Flow measurement is based on specific predetermined hydraulic concepts. Measurement accuracy is strongly influenced by adherence to these concepts. For open channel weirs and fumes, water must pass through critical depth or two flow depths must be measured. With closed conduits the pipeline must be flowing full at the measuring device. This can be accomplished by dropping the pipeline below the hydraulic grade line.

(d) Open channel primary measuring devices

(1) Weirs

- Sharp-crested, triangular, rectangular, and trapezoidal
- Short-crested, such as OG weir
- Cipolletti (sharp crested trapezoidal)
- Broadcrested, trapezoidal, rectangular, and circular

(2) Flumes

- Long-throated (modified broadcrested weir) sometimes called Replogle or Ramp Flume.
- Short-throated, such as Palmer Bowles
- Parshall (no longer recommended for most installations)

(3) Gates and orifices

- Sluice
- Radial
- Armco Meter Gate (no longer in production)
- Orifice plates

(4) Current metering

- Mechanical and electrical

(5) Acoustic meters

- Cross path, transit time, single path, ultra sonic

(6) Other open channel measuring devices

- Vane-defection
- Volume and weight tanks
- Bucket and stop watch
- Volume drawdown
- Surface velocity/area
- Bubble curtain
- Chemical dilution

(e) Closed-pipeline primary measuring devices

(1) Differential head meters

- Orifice plates, end-cap orifices, etc.
- Ventura meters
- Pitot tubes
- Elbow meters
- Shunt meters

(2) Velocity meters

- Propeller meters
- Turbine meters
- Paddle-wheel turbines
- Electromagnetic

(3) Acoustic meters (fig. 9–39)

- Transit time, diametrical path, 2 or 4 transducers on opposite sides of pipe
- Transit time, diametrical path, reflective, 2 transducers on same side of pipe

- Transit time, chordal path, multiple transducers on opposite sides of pipe
- Doppler reflective type (like radar), ultrasonic

(4) Other closed pipe meters

- Siphon tubes
- Flow from vertical pipe
- Flow from horizontal pipe
- Vortex shedding
- Volume and weigh tanks

(f) Secondary measuring devices

(1) Head and pressure measurement

- Water stage recorders
- Pressure transducers
- Bubblers
- Pressure bulbs
- Pressure chambers (i.e. Mariott siphon)
- Weir stick
- Differential stage recorders
- Differential pressure transducers
- Ultrasonic water surface elevation detection

(2) Volume totalization

- Totalizing devices
- Integration
- Shunt meters

(3) Data storage and transmission

- Data loggers (mechanical, electronic, digital)
- Communication mechanisms (electronic, infrared, sonic)

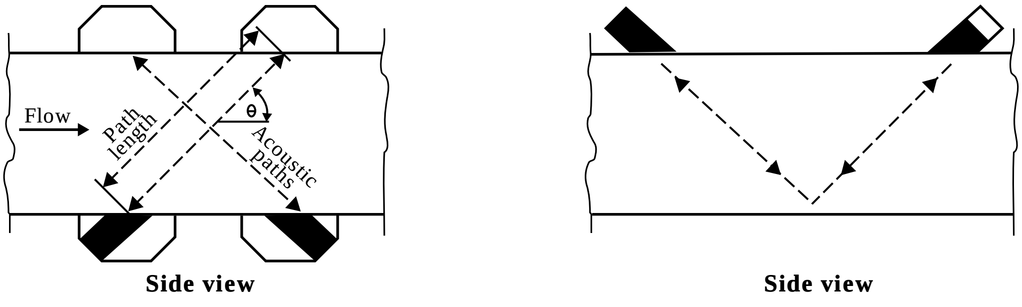
(g) Methods of water measurement

The chosen water measurement method should be sufficiently accurate to make factual water measurement decisions. These decisions include: Should the flow rate change? or, should the flow cease entirely?

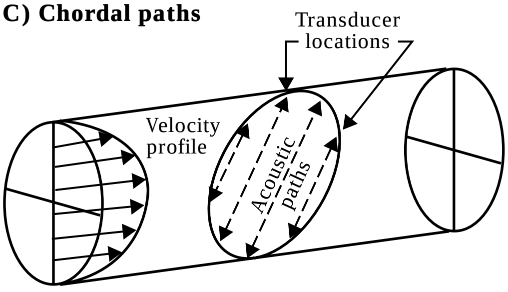
Figure 9-39 Transit-time acoustic flowmeters: diametrical path, diametrical path reflective, and chordal path transducer configuration

(A) Diametrical path w/ 4 transducers

(B) Diametrical path-reflective w/ 2 transducers



(C) Chordal paths



(h) Measuring method categories

Flow meters for pipe and open channel flows can be grouped into devices that primarily measure rate or volume of flow and those that primarily measure rate of flow. All fluid meters consist of two distinct subunits:

- The primary element that interacts with the fluid.
- The secondary element that translates the interaction into flow quantities (volumes, weights) or flow rates (quantity per unit time) that can be observed and acted on by an operator or by control equipment.

Basically all flow meters, whether for irrigation or industrial pipe flows, use at least one of a few basic physical principles and properties of fluids. These include fluid mass, weight, volume, viscosity, and mixing types of properties, as well as the electrical, magnetic, thermal, optical, and acoustical types. Force, momentum, and energy principles (including force-velocity effects on floats) are commonly used, as well as energy conversions (kinetic to potential or potential to kinetic), heat, or electromagnetic energy.

Other physical principles include electromagnetic or acoustical wave transmission, distortion, or refraction; reflection by the fluid or tracer particles in the fluid; unclear magnetic resonance behavior of certain polar-fluid molecules; and fluid such behaviors as wall clinging and vortex formations by shaped flow cavities and obstructions in the conduit. Representatives of these groups are in table 9–5.

Sometimes classifying a particular flow metering system is a problem when it is perceived to use more than one principle, or even the wrong principle. For example, ultrasonic doppler meters use ultrasonic waves as a type of radar system that detects the velocity of moving particles in a flow. Thus, it depends on the force-velocity effects of the fluid on suspended particles.

Almost all recent claims for new flow measuring techniques are improvements in the readout format or in the detection of some primary interaction with water flow. Such is the case with ultrasonic flow meters.

Meter classification, while giving a general framework and understanding of flow metering promises and limitations, is somewhat subjective. Variations occur between classifiers; thus the classification used in table 9–5 is not sacred, but is convenient for comparisons.

Table 9–5 Types and characteristics of flow meters

Meter type or method	Standard accuracy	Usual ratio max:min	Remarks
Flow rate meters			
Variable head and area (also see table 10–2)			
Weirs (thin plate)	1-5% of actual	>100:1	Lab calibrated
Weirs (short-crest)	1-5% of actual	>100:1	Lab calibrated
Flumes (short)	2-7% of actual	55:1	Lab calibrated
Flumes (long)	2-5% of actual	>35:1	Computable
Differential head			
Venturi	1%, full scale	5:1	Low head loss; tolerates slurries
Pitot tubes	1%, full scale	5:1	Point velocities
Orifice	0.5-1.5%, full scale	5:1	Low to high head loss; many shapes
Elbow	3-10%, full scale	3:1	Adds no further losses in line
Force-velocity meters			
Tracers, salts/dyes	1-2% of actual	20:1	Indicates flow velocity
Floats	5% of actual	10:1	Indicates flow velocity
Ultrasonic doppler	5-10%, full scale	10:1	Works best in dirty water
Special metering methods			
Electromagnetic	1% full scale	20:1	Conductive liquids
Ultrasonic, transmission	1% full scale	20:1	Only clean liquids
Vortex-shedding	1% of actual	100:1	No moving parts
Tracer dilution	2% of actual	100:1	Needs no flow area
Flow quantity meters			
Gravimetric			
Weigh tank	0.1% of actual	100:1	Good lab standard
Volumetric (quantity)			
Volume tank	1% of actual	10:1	Field and lab uses
Tipping bucket	1% of actual	100:1	Used on rain gages
Propeller	1% of actual	15:1	Can be rate meter
Paddle wheel	3% of actual	15:1	Can be rate meter
Turbine	0.5-1% of actual	15:1	Many blades
Positive displacement	1% of actual	20:1	Used for ag. chem

(i) Suitable measurement methods for irrigation and drainage

For irrigation delivery systems and drainage systems, open-channel flow measuring devices dominate. Therefore, this guide deals mostly with flumes and weirs. The classification of flumes and weirs, sometimes listed as part of the variable head and area group of flow meters and sometimes as part of the differential head group, convert potential energy to kinetic energy to cause critical flow. If enough potential energy is not converted because of a high downstream water surface elevation, the device becomes a Venturi flume. The general Venturi flume operates on the same theory as a Venturi meter in pipe flows. Because the pressure differences generally are small, their use requires two depth measurements of high precision, one upstream and one in the throat region. These precise measurements generally are not practical in the field. General Venturi flumes are not commonly used for this reason. Critical-flow flumes are a special case of the Venturi flume where the critical condition eliminates the need for the throat measurement.

Flumes and weirs can be subdivided into sharp-crested weirs, short-crested weirs, broadcrested weirs, short-throated flumes, and long-throated flumes. A summary of their general characteristics is shown in table 9–6.

(1) Sharp-crested weirs

Sharp-crested weirs are one of the oldest open channel flow measuring devices. Head-discharge equations were derived from laboratory ratings. They are influenced by the flow bending in the crest region. The location of upstream sidewalls and floor elevations, as well as the condition of sharpness at the sharp edge, are part of the calibration.

For usual open channel applications, the difference in water surface elevation between upstream and downstream must be large enough to allow complete free overfall. An exception may be sharp crested V-notch weirs where 30 to 40 percent submergence can sometimes be tolerated. The usual recommendation is that the downstream water surface be at least 2 inches (50 mm) below the crest of the weir opening. Adequate aeration of the nappe (between downstream weir wall and backside water surface) must be available.

(2) Short-crested weirs

The most common example of short-crested weirs is the V-notch weir sill. A V-notch, thick-sill weir has triangular openings with sides formed by slopes as flat as 10 horizontal to 1 vertical. A common format is to construct weirs as vertical retaining walls about 1.5 inches (40 mm) thick with the top edge receiving a prescribed bevel upstream and downstream of 3 horizontal to 1 vertical. The resulting edge has a horizontal portion that is about 4 inches (100 mm) wide.

(3) Broadcrested weirs

A wide variety of shapes can be included under broadcrested weirs, and a wide variety of discharge coefficients will be encountered. Most broadcrested weirs offer no advantage over flat-plate, sharp-crested weirs for measuring flows. As a result, broadcrested weirs are seldom used for measuring purposes. This does not imply that they cannot be used as accurate flow measuring devices because in some cases they are desirable. For example, if difficulty is expected in maintaining a flat-plate weir in good condition because of rusting, impact, or abrasion, a broadcrested weir should be used. If possible, the crest shape should conform to the shape of some other structure or model for which the coefficient of discharge has been experimentally determined. If this is not practicable, the crest must be calibrated either by field tests on the actual structure or by model studies of it.

(4) Movable weirs and adjustable weirs

Movable weirs are weir assemblies mounted in metal and timber frames that can be moved from one structure to another. The frames fit freely into slots provided in the structures and are not fastened in place. Adjustable weirs are weir assemblies mounted in metal frames permanently fastened to the structures. The weir blades in both the movable and the fixed frames can be raised or lowered to the desirable elevations, usually by threaded stems and hand wheels.

A sufficiently large pool must be provided upstream from the weir to slow and quiet the flow as it approaches the notch in the weir. A fixed head gauge is not generally useful for flow measurement if the weir is to be moved up or down because the zero of the gauge does not coincide with the elevation of the weir crest.

Table 9–6 Major operational characteristics of flumes and weirs

	Operational characteristics
Weirs	
Sharp-crested weirs (lab calibrated) Rectangular Triangular Cipolletti (trapezoidal) Circular	Easily constructed, well defined lab-calibrated history; high head-drop required (<100%); poor tolerance to submergence; primary accuracy ± 1 to 3% is intended.
Short-crested weirs (lab calibrated) V-notch, thick-sill weir Triangular profile flat-V (crump type)	Poor tolerance to submergence; high head-drop needed; primary accuracy, ± 3 to 5%.
Broadcrested weirs Square edge Approach ramp or rounded	Poor tolerance to submergence; high head-drop needed; primary accuracy, ± 3 to 5%.
Flumes	
Short-throated (lab calibrated) Cutthroat flume Parshall flumes [1/] H-flumes	Moderate tolerance to submergence; predictable, reliable flow limit is 60 to 70%; careful field construction needed; two head readings required to extend limit to about 90% primary accuracy is ± 3 to 5%.
Long-throated (computer calibrated) Rectangular Triangular Calibrations Circular Complex Palmer-Bowles	Good tolerance to submergence; predictable, reliable flow limit is about 85 to 90%; reliable computable ratings; primary accuracy is ± 2%; single head readings required; liberal construction tolerances. Trapezoidal can be based on as-constructed dimensions.
Long-throated (computable) modified broadcrested weir, Replogle or Ramp flumes	Good tolerance to submergence with very low head-drop required (< 1 inch for most irrigation flows) single head reading, easily constructed, one level critical surface, ± 2% primary accuracy, computable as built ratings.

1/ The Parshall flume has 10 critical surfaces that must be accurately constructed to meet published accuracy. Meeting this criterion often requires increased labor costs. Other types of flumes are more cost effective and provide similar accuracy.

(5) Short-throated flumes

The streamlines in the short-throated flumes are not as curved or variable as in the sharp-crested weirs. They include flumes with side contractions and bottom contractions (weirs not sharp-crested) with some type of transition section. However, the flow curves enough to again require the use of laboratory calibrations and flow coefficients. Familiar examples are the Parshall flume and the cutthroat flume. Deviations from standard plans may be difficult to evaluate without special field or model ratings.

(6) Long-throated flumes

These flumes are also called the computables because their construction specifications are such that parallel, not curvilinear, flow is produced. This allows accurate prediction of their hydraulic behavior. It also permits estimates of effects of construction anomalies. In these flumes, the streamline curvature is limited by providing gentle contractions from the upstream channel to the throat section. The throat section itself is made long enough (preferably about 1.5 times the maximum expected upstream head reading, referenced to the bottom centerline of the level throat) to provide nearly parallel flow through the control area. The horizontal location of the control section does not need to be precisely known. Its vertical reference is needed for total energy head computations. This vertical reference is most easily handled in the computations if the throat is level in the direction of flow. A 1 percent error in cross slope approximates an additional 1 percent error in accuracy.

(7) Long-throated flumes, modified broadcrested weir, Replogle or Ramp flumes

The modified broadcrested weir, sometimes called a Ramp flume or Replogle flume, has nearly the same operating characteristics as long-throated flumes. By definition, the long-throated flume is a cut-throat flume where the downstream or discharge portion of the flume has been eliminated. It is perhaps the most accurate and easiest to construct of all open channel, low head, flow measuring devices. The weir sill is the only critical surface, which is level. A 1 percent error in cross slope (the level bubble is not visible in the carpenter level site glass) approximates an additional 1 percent error in accuracy. The slope of the ramp up to the sill should approximate three horizontal to one vertical. The long-throated flume requires a short flume (usually less than 10 feet) or lined ditch. The long-throated flume can be located within any cross area. Computer software has been developed to calculate flow rates through any cross sectional area. Discharge flow rate tables have been developed for standard geometric cross sections.

The Replogle flume can be used as a measuring device in pressure pipelines. Two pressure (head) readings are needed in the pipeline, one in the throat and one upstream. The flume can be oriented in any direction.

Replogle flumes and certain properly dimensioned, broadcrested weirs form the class of computable flumes. These styles can be proportioned so that almost any flow can be measured. Small flows are least accurate to measure because of the difficulty of obtaining precision depth readings. Generally, flows larger than about 150 gallons per minute (10 L/s) can be measured with an error of less than 2 percent in an appropriately dimensioned flume. There is no theoretical upper limit on size. Replogle flumes capable of measuring over 3,000 cubic feet per second (85 m^3/s) have been constructed in Arizona.

For a complete treatment of these flumes, see *Flow Measuring Flumes for Open Channel Flow Systems,* by Bos, Replogle, and Clemmens (1991).

(j) Demands made on a measuring device

The actual selection of a flow measuring device type and size depends on its functional requirements, the required accuracy, the desired flow range, debris in water, installation location, and several other considerations discussed below.

(1) Functions of the device

Devices for measuring flow often serve two basic functions in their application. One is to indicate flow rate or volume, and the other is to control the flow rate or volume. In this section we distinguish between the measuring and control functions and emphasize measuring devices for open channel flows.

Good quality flow rate measurement and good quality control are best achieved with two separate devices. However, dual function devices are used. An example is a variable area orifice meter, such as an irrigation canal slide gate. Another is the vertically adjustable weir.

Most meters require some head loss to measure flow. Ultrasonic meters cause negligible head loss, but must introduce an outside source of sonic energy. Likewise, a piston pump used as a positive displacement meter can introduce a head gain into the measured flow, and uses power for pumping.

(i) Required head loss for pipe flow meters—Head loss implications for pipes and open channels differ considerably, as mentioned before. Available head loss in pipes is generally used to determine whether the meter can be successfully incorporated into the system. If not, pressure may need to be increased or another size or type of meter selected.

In pipe flows, available head loss can influence the type of differential head meter selected. Pipe meters vary widely in the pressure drop imposed. For example, the passive type orifice meters produce higher pressure drop than do Venturi meters. Propeller and turbine meters vary according to their special designs. Unfortunately, low head loss propellers and turbines generally trade off accuracy because they achieve their low loss by sampling a limited cross section of the flow. Active meters, including sonic and electromagnetic, introduce negligible head loss, but have generally been expensive.

(ii) Required head drop for open channels—The head loss requirement is particularly important in open channel water measuring devices. Most of these devices depend on creating critical flow at an overfall or channel contraction as is the case with flumes and weirs. This is in contrast to the head loss in pipes that is usually of little importance to the meter function itself, but is more important to the ability of the pipe system to deliver the needed flow rates.

(2) Accuracy of measurement

The accuracy of discharge measured with a particular structure is limited to the accuracy that a measurement can be reproduced. If two identical structures are independently and correctly constructed, then presented with flow at the same upstream sill-referenced head, both flow rates are not likely to be equal. For flumes and weirs constructed as described herein, the difference between the presented flow calibrations and absolute accuracy have been determined to be less than 2 percent.

In addition to the above uncertainty of error in the basic discharge equation, three other types of errors can affect either the primary meter type or the secondary readout device. They are systematic, random, and spurious errors.

(i) Systematic errors—These errors are generally associated with dimensional problems, such as gauge zero settings or area changes resulting from plant growths or soil deposits on the channel or pipe walls, or to structural deflections. Systematic errors can be corrected if they are known.

(ii) Random errors—If several people read a wall mounted gauge or dial and record a flow rate from a chart, the variation in flow readings should be randomly distributed about the true average. These errors are subject to statistical treatment.

(iii) Spurious errors—These errors invalidate the measurements because of human mistakes, recording equipment malfunction, or obstructions of normal flow.

In selecting a measuring device, appropriate precision and accuracy should be carefully specified. The purposes of the flow measurement should dominate this specification. For usual irrigation management processes, accuracies of about 5 percent are suitable. Accuracy needs to be sufficient to make a decision, such as to change flow rate or cease irrigation entirely. If one were trying to determine seepage losses by measuring inflow and outflow in a reach of canal, then plus or minus 1 percent may not be sensitive enough.

(3) Sediment discharge capability

Besides transporting water, almost all open channels transport some sediment and debris. Bedload sediment is generally the most difficult to accommodate in measuring devices. The ability of various long-throated flumes to carry sediment depends, among other things, on the absolute velocity of the water, the density and size of the sediment particles, and the sediment concentration. A general discussion is presented in *Flow Measuring Flumes for Open Channel Systems,* by Bos, Replogle, and Clemmens (1991).

A major condition appears to be the throat width. The flume or weir throat width should be as wide as, or wider than, the approach channel delivering the sediment (e.g., sills in trapezoidal channels). This is based on the observation that sediment moves in response to the water velocity immediately upstream. The slope of the ramp appears to play a small role in retarding sediment movement, particularly if it is on a slope of 3 or 4 horizontal to 1 vertical. This contradicts former practices that recommended leaving a continuing channel floor for sediment transport and constructing flumes with only side contractions.

(i) Passing of floating and suspended debris— Open channels transport various kinds and amounts of floating or suspended debris. To avoid catching debris, the staff gauge or recorder housing should be located to one side of the flow pattern. Most long-throated flumes are streamlined enough to avoid debris trapping unless the debris is larger than the throat. Parallel installations should have rounded piers that are at least 12 inches (300 mm) wide. Sharp-nosed and narrow piers tend to catch debris.

Most pipeline meters do not tolerate debris well, especially moss. Trash screens and racks should be used to keep debris out of the pipeline if it adversely affects the measuring device. Venturi, magnetic, sonic, and other meters that can handle suspended debris are described in a later section.

(k) Getting the most from open channel measuring devices

Most users desire to get the maximum performance and functions from a given gate, weir, meter, or metering system. This encourages attempts to try measuring and controlling flow with the same device. This is not generally recommended because it results in degraded measurement and degraded control. One exception might be the vertically movable flume. When adequately automated, it can measure flows with the precision of flumes and also control to the precision of the selected automation equipment. Equipment costs and labor may not compete with a fixed flume and regulating gate, which could also be automated. Another exception is the vertical moving sharp-crested weir. The weir is a cut-out in the upper part of a standard irrigation canal slide gate. Fluctuations in the water surface in the canal create a degraded measurement and require frequent operator control and monitoring.

(l) Matching requirements and meter capabilities

Selections of the measuring site and the appropriate measuring device are closely related. Some devices or structures are more appropriate for certain sites than others. Some sites require a certain device or structure. Site consideration, particularly for open channels, must be given to the exact location, elevation, and upstream and downstream flow conditions. This information is needed in addition to the general location and the structural shape.

In pipe flows, pipe pressures and head loss generally receive only passing attention. In open channel flows, head loss may be the prime consideration because of the sensitive relationships among the water surface, total energy, and flow rate.

The measuring method must be compatible with the water delivery method and purpose of the delivery. If flow rate is the needed information, then rate meters are usually appropriate. For open channel flows, rate meters generally are less expensive than totalizing meters. Pipeline meters that totalize from some kind of rotating impeller are less expensive than flow rate meters. For billing purposes, totalizing meters are usually specified.

Pipe flows, because of their fixed flow area, can accommodate many meter styles that basically provide a flow velocity that is combined with the inside pipe diameter to obtain flow rate. Open-channel flow meters add the complication of variable flow area.

(m) Open channel flow measurements

This section describes the design, selection, and installation of weirs and flumes in open channels. Frequency and duration of measurements determine whether to select a portable, temporary, or permanent measuring device or structure. A variety of portable structures are described in Bos, et al. (1991). Often permanent measuring structures, such as Replogle flumes, can be installed at all sites for equal or little increased cost over that required for installing mounting brackets at each site and purchasing portable flow measuring devices.

(1) Designing for open-channel flow measurements

The process of designing a flume or weir consists of three steps: selection of site, selection of head measurement technique, and selection of an appropriate structure. Design is a process between these steps. The order and importance of these steps depend on specific conditions encountered. If a structure to measure or regulate the flow rate is to function well, it must be selected properly. All demands that will be made on the structure should be listed and matched with the properties of known structures. Broadly speaking, these demands or operational requirements originate from four sources: hydraulic performance, construction and/or installation cost, ease with which the structure can be operated, and cost of maintenance.

(2) Locating and selecting the measuring site and device

All structures for measuring or regulating the rate of flow should be located in a channel reach where an accurate value of head can be measured. Also, sufficient head loss must be created to obtain a unique flow rate versus head relation (modular flow). The survey of a channel to find a suitable location for a structure should also provide information on a number of relevant factors that influence the performance of a future structure. These factors are described in the following paragraphs.

Upstream of the potential site, the channel should be straight and have a reasonably uniform cross-section for a length equal to about 10 times its average width. If a bend is closer to the structure, water elevations along the sides of the channel become different. Reasonably accurate measurements can be made (added error about 3%) if the upstream straight channel has a length equal to about two times its width. In this case the water level should be measured at the inner bend of the channel.

The channel reach should have a stable bottom elevation. In some channel reaches, sedimentation occurs in dry seasons or periods of low water. The sediment may be eroded again during the wet season. Such sedimentation can change the approach velocity toward the structure or may even bury a flow measuring structure. Erosion may undercut the foundation of the structure.

Water level in the channel generally should be predictable. Water surface elevations are affected by channel discharge, downstream confluences with other channels, operation of gates, and reservoir operation. Channel water surface elevations greatly influence the sill height to obtain modular flow through a measuring structure.

Based on channel water surface elevations and the required sill height in combination with the flow versus head relation of the structure, the possible inundation of upstream surroundings should be assessed. These inundations cause sedimentation because of the subsequent reduction in approach flow velocities.

Soil conditions at the site can influence the tendency for leakage around and beneath the measuring structure caused by the head differential. Excess leakage must be prevented at reasonable costs. Also, a stable foundation, without significant settling is important.

To avoid sedimentation upstream of the structure, sufficient head must be available in the selected channel reach to control flow velocities. For more details on sediment handling, see Bos, et al. (1991).

(3) Measurement of head

As discussed above, the accuracy of a flow measurement depends strongly on the true determination of the upstream, sill-referenced head. The success of a measuring structure often depends entirely on the effectiveness of the gauge or recorder used and desires of the operator.

A sill-reference head refers to the effective hydraulic control section. With broadcrested weirs and flumes, this section is located on the weir crest or flume throat, a distance of about one-third the length upstream of the downstream edge of the sill. The top of the sill (weir crest or invert of flume throat) must be level in the direction of the flow. If minor undulations are on the sill crest, it is recommended that the average level at the effective control section be used rather than the average level of the entire sill. See figure 9–40.

With sharp-crested weirs, hydraulic control occurs immediately upstream of the weir crest. Distance varies relative to approach velocities. Actual location can be observed by the light reflection pattern on the flowing water surface. See figure 9–41.

(4) Location of head measurement

The gauging or head-measuring station should be located sufficiently upstream to avoid detectable water surface drawdown, but close enough for the energy losses between the gauging station and approach section to be negligible. Typically, this distance varies between two and four times the total head loss upstream of the weir crest.

(5) Head measurement method

The head generally is measured either in the channel itself or in a stilling well located to one side of the channel. The stilling well is connected to the channel by a small pipe (to dampen head fluctuations). Many methods can be used to detect water surface elevation. Some use the electromagnetic properties of water and of the water-air interface. Other methods depend on reflecting a sonic wave from the water surface. Still other methods detect water depth with a variety of pressure sensing devices and deduce the head from that information. The most frequently encountered methods are vertical and sidewall mounted staff gauges in the canal or in a stilling well, or both, and float-operated recorders placed in a stilling well. Digital recorders and data logging devices are readily available and have typically replaced the continuous recording devices on rotating drums (ink pens and paper rolls).

(i) Stilling wells—Stilling wells facilitate the accurate reading of the water level at a gauging station where the water surface is disturbed by wave action. It can also house the float for a recorder system or other water surface detecting equipment. The size of the stilling well depends on the method used to measure the head. The diameter, if circular-shaped, ranges from a recommended minimum size of 4 inches (0.1 m) for hand-inserted dipsticks to over 20 inches (0.5 m) to accommodate large diameter floats. The pipe connecting the stilling well to the canal should be large enough to allow the stilling well to respond quickly to water level changes. In most cases the pipe diameter is about one-tenth the diameter of the stilling well. Further details on stilling wells are in Bos, et al. (1991).

(ii) Staff gauges—Periodic readings on a calibrated staff gauge can be adequate when continuous information on the flow rate is not required. Examples are canals where the fluctuation of flow is gradual. The gauge should be placed so the water level can be read from the canal bank. Staff gauges are commonly used where quick readings can be taken without entering a locked house to read a continuous recorder. The surface of the staff gauge should be kept clean.

For concrete-lined canals, the gauge can be mounted directly on the canal wall. The value, read on the sloping walls of trapezoidal-shaped canals, must be appropriately converted by scale or table to vertical head values before entering discharge tables. Tables are made for stilling well use or vertical gauge applications. For unlined canals, the gauge can be mounted onto a vertical support.

Most permanent gauges are enameled steel, cast aluminum, or some type of plastic resin. Enameled linear scales marked in English or metric units are available from commercial sources. Important flow rates can be noted on these scales by separate markings to avoid the need for tables to be always at hand.

Figure 9–40 Profile of long-throated flume (from Bos, Replogle, Clemmens)

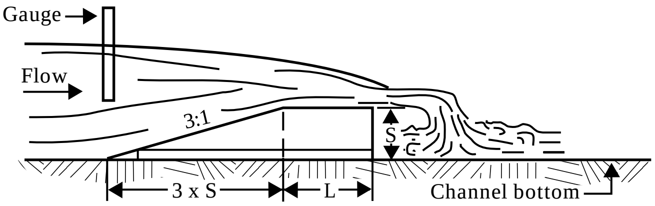
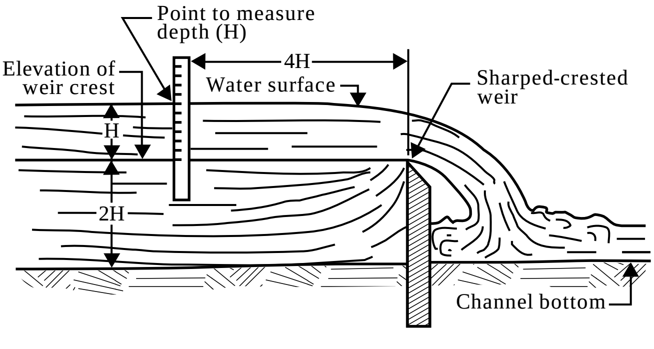


Figure 9–41 Profile of sharp-crested weir



Within an irrigation district or farm, it is frequently desirable to use a limited number of standard sized structures. The gauges of these structures can be conveniently marked directly in discharge units rather than in head or depth units.

(6) Selection of head-measurement device

The success or failure a water measuring structure and the value of the collected data depend closely on proper selection of a suitable head measurement device. The three most important factors that influence this selection are frequency of discharge measurement, allowable error in the head detection, and type of measurement structure under consideration.

(7) Gauge placement and zero-setting

The most important factor in obtaining accurate discharge measurements is the accurate determination of the sill referenced head. The upstream sill referenced head can be measured by a gauge or recorder only if the observed water level is known with respect to the weir sill (or flume crest) elevation at the control section. The method used to set (zero register) the gauge and recorder depends on the structure size, type, flow rate in the channel during the setting procedure, and available equipment. Standard surveying techniques are practical for accurate setting of most wall or staff gauges.

The canal side slopes only approximate the intended slope. To compensate partly for this, the gauge can be mounted so that a selected scale reading from the most frequently used range of the gauge coincides with the corresponding elevation for that reading. Thus, greatest reading errors occur in the flow ranges that are seldom used. If this procedure causes the zero end of the scale to be displaced by more than about 1/4 inch (5 mm), the actual side slope should be determined for adjustments to the calibration. This also should be done if accuracy over the full flow range is required.

Several methods are available for zeroing a water level recorder; three are particularly suitable. The recorder can be set when the canal is dry, when water is ponded over the flume, or when water is flowing through the flume. These zero-setting methods assume that the sill referenced elevation can be determined during the procedure. This is not always practical, especially on wide structures. A stable and permanent surveying benchmark should be added to these structures. The benchmark can be a metal rod or cap placed in concrete. Its elevation should have been previously established relative to the sill elevation. More detailed information on zero-setting procedures is in Bos, et al. (1991).

(8) Determining structure dimensions

Long-throated flumes and broadcrested weirs operate by using a channel contraction to cause critical flow. If there is not enough contraction, critical flow does not occur. Flow is then nonmodular, and gauge readings become meaningless. If there is too much contraction, the water surface upstream may be raised excessively and cause canal overtopping or other problems. The challenge facing the designer is to select the shape of the control section, or throat, so that critical flow occurs throughout the full range of discharges to be measured. Also, the designer must provide acceptable sensitivity and accuracy while not causing too much disruption in upstream flow conditions (sediment deposition, canal overtopping). This appears to be a difficult task, but existing design aids and rating tables make this task more manageable.

Flumes and weirs constructed of wood can be used. However, until flow through a wood structure begins, it must be weighted down or be well anchored to prevent flotation. If a wood structure floats after flow begins, the flume or weir is said to be submerged, thus unusable. A different size or structure should be installed.

(n) Pipeline flow meters and applications

Flow meters for pipelines are frequently used for irrigation water management decisions, particularly where pumped wells are used. Some flow meters are well established. Other less well known meters are described in some detail herein. The familiar meters are given less treatment because they are either well documented or are judged to be of limited application to irrigation. Yet another group is too new to irrigation to have an extensive history in this application; therefore, they are again given broader treatment.

Some of the newer pipe flow meters have very low head loss. They include vortex shedding meters, magnetic flow meters, and sonic flow meters. The last two meters can operate with no detectable head loss to the flow because no restrictions or mechanisms are inside the pipe.

(1) Venturi meters

Venturi meters represent one of the older, more reliable flow measuring methods called differential head meters. The head loss is low, and slurries pass readily. In irrigation works, small venturi meters are used for chemical injection applications. Sizes compatible with most irrigation wells generally are considered too costly. The flow range is similar to that of the orifice meters, which are described later in this chapter. These devices are well covered in the literature, and little new information is available. See: *Handbook of Hydraulics*, King and Brater, for a complete description of these meters.

Certain angles of convergence and divergence must be observed for standard venturi meter behavior. The conduit walls should converge relative to the centerline at about 10 degrees and diverge on the downstream side at about 5 to 7 degrees. Low velocity venturi meters have also been constructed from ordinary PVC pipe and fittings. Where throat lengths are at least three times the diameter of the pipe, fitting configuration appears to have little effect. Venture flow meters require two pressure taps, one in the throat and one upstream before convergence. Typically venturi flow meters have low head loss. To keep venturi flow meters to a reasonable size on large pipelines, they are often used as a shunt meter, where a much reduced part of the total flow is actually measured. The ratio must be known to project the measured flow to total pipe flow. Chemical injection systems often use a shunt Venturi.

(2) Pitot tubes

Like venturi meters, pitot tubes are well documented in King and Brater, 1954. The original version is named for Henri Pitot who used a bent glass tube to measure velocities in the River Seine in 1730. Pitot tubes have a narrow range of application similar to venturi meters. A flow-differential version is the standard prandtl tube that incorporates the impact pitot tube within a jacketed concentric outer tube. Holes in the side of this outer tube are used to detect the existing static pressure in the flow region.

The difference between the impact pressure and the static pressure represents the velocity head, from which the point velocity is computed. An impact pitot tube and a pipe wall piezometer tap are frequently used to accomplish the same thing. Several variations of pitot tube based devices are marketed. Most of the variations depend on careful laboratory calibration. Standard pitot tubes and the prandtl type tubes have a coefficient nearly equal to unity. These tubes are best used for intermittent and attended measurements because they are subject to clogging in all but the cleanest flows.

(3) Orifice meters

Many of the marketed flow meters, for other than residential use, are differential pressure types. Of these the most common type is the sharp-edged orifice plate. Thousands of these meters measure gas, liquid, and mixed fluid streams in pipelines around the world. The modern computer has given these primary measuring devices renewed importance.

Orifice flow meters are frequently used in irrigation applications for measuring well discharges and for injecting agricultural chemicals into irrigation flows. The latter are usually of small diameter and operational details generally are furnished by the manufacturer of the chemical injecting device. Consequently, larger diameter orifice plates in round pipes are primarily dealt with in this guide. Usual rusted pipe conditions and general maintenance for irrigation wells limit field accuracy in irrigation practice to no better than 3 to 5 percent of actual flow.

Most reliable flow meters require fairly stringent installation requirements. The orifice plate is no exception. Because abrupt pressure changes take place at the plate, the orifice plate is generally affected more by disturbed flows than other differential pressure meters. Poor installation of an otherwise properly designed orifice plate can result in 20 percent errors.

Orifice plate standards are based on extensive experimental data and can be applied with a fair degree of confidence. Anomalies still exist, however, and some of which will be discussed later.

Advantages of the orifice plate are its simplicity and the ability to select a proper calibration on the basis of the measurements of the geometry. Disadvantages of the orifice plate include the long, straight pipe length requirements and the complication of extending the measuring range beyond a ratio of about one to three.

The operating flow range can be changed by substituting an orifice plate with a different hole size. Tap locations based on pipe diameter rather than orifice diameter make this feasible because the same tap locations can be used for all orifice plate sizes. The pressure tap is located about one pipe diameter upstream of the orifice plate. In a continuous pipeline, the downstream pressure tap is located at the vena-contracta (immediately downstream and adjacent to the orifice plate).

The orifice plate should be mounted in such a way that inspecting at least the orifice plate and preferably the adjacent piping is possible. Portable orifice plate meters can be attached to the downstream end of discharge pipelines. Care should be taken to install the meter level and have the appropriate straight pipe length upstream of the orifice plate (generally a part of the meter).

(4) Rectangular sharp edged orifice/open channel applications

Rectangular orifices formed by a partly open, irrigation canal gate are frequently used as flow indicating devices. Accuracy of the primary opening, not including the errors of secondary detection of depth, can be within 5 percent of actual. Every gate should be calibrated for specific onsite conditions.

Early day miners in the West developed a flow term called *miners inches* where a rectangular orifice (2 inches high and up to 12 inches wide) was cut through a 2-inch wooden plank. Thus, a 2-inch by 10-inch orifice would deliver 20 miners inches. How to measure the standard 6-inch hydraulic head on the orifice varies between geographical areas. If the 6-inch head is measured from the horizontal center of the orifice to the upstream water surface, 1.0 miners inches = 1/40 cubic foot per second or 11.25 gallons per minute (applicable in Northern California, Arizona, Montana, Nevada, and Oregon). Where the 6-inch head is measured above the lower edge of the orifice, 1 miners inch = 1/50 cubic foot per second, or 9.0 gallons per minute (applicable in Southern California, Idaho, Kansas, New Mexico, North Dakota, South Dakota, Nebraska, and Utah). In Colorado, 38.4 miners inches = 1 cubic foot per second.

(5) Elbow meters

Elbow flow meters are made by drilling pressure taps midway along the bend centerline on the inside and the outside of the elbow bend (Spink 1967). This corresponds to 45 degree tapping for a 90 degree elbow bend. If the radius of the inside bend is accurately determined by plaster casting or other means, the discharge equation can be estimated to within 3 percent of actual. The differential pressure across the inside and outside taps is produced by velocity differential and by the centrifugal force of fluid in the elbow; velocity responds to about the square-root of the head differential.

(6) Current meters, propeller meters, and cuptype meters

Propeller meters are commonly used in open channel flows to measure velocities at various points in the channel cross-section. Cup type rotors are also used. The choice depends on whether the user wishes to detect velocities in the direction that the meter is pointing (propeller) or whether all velocities in the flow plane are to be detected, regardless of flow direction (cup type). Accurately determining cross-sectional area (especially depth), particularly with earth, grass lined, or cobbly bottom canals, is a major problem with open channel applications. Another is velocity distribution effects. The technician generally divides the channel into about 10 equally spaced, vertical sections. If standard flow profiles can be assumed, a single measurement at 0.6 of the depth from the surface gives reasonable results. This depth is typically used in shallow flows. When depths permit, 0.2 and 0.8 locations generally give more reliable results. In fixed section channels, well-trained operators using well-maintained equipment can expect results with errors less then plus or minus 5 percent of the actual flow rate.

A short, smooth, level concrete section is often constructed in the open channel where long-term measurements are made. This is done to reduce opportunities for errors. If a variety of flows over a wide flow depth for any stable cross section can be measured, the section can be rated. A staff gauge can then be used to measure depth and, with a rating table, converted to gallons per minute, cubic feet per second, or acre-inches per day. Occasionally, flow measurements are taken to check the rating table. USGS, state water resource agencies, and local irrigation organizations use this method to measure larger flows in canals and streams. Installation of a long-throated flume at these locations should be considered.

As mentioned, major errors with the current metering method may be with the cross-section area determination rather than velocity detection. For example, if a flow of 17-inch depth and 3-foot width is attempted in a grass-lined channel, an uncertainty of the flow depth and width may be greater than 1 inch (30 mm) or over 10 percent error in flow area. This uncertainty must be combined with velocity errors.

(7) Propeller meters

Propeller meters are frequently used in irrigation pipelines, particularly for flows from irrigation wells and at farm deliveries. Propeller meters offered for irrigation service generally stress ruggedness and durability over accuracy. Secondary readout devices are usually mechanical. Recently, electronic readouts have been offered. Most have less than plus or minus 3 percent error when installation specifications are followed. Errors in field installations frequently exceed plus or minus 5 percent because some of the pipe length requirements are hard to meet when retrofitting older piping installations. Vanes can be used to minimize nonstandard installation conditions.

The main difference between a propeller and a turbine meter is fewer blades on a propeller and the absence of a blade tip ring for blade stability. Propellers are often built with a swept-back design on two, three, or four blades so they tend to shed debris. Some pipe propellers are restrained by the nose with a long sweeping shaft so that the mounting also sheds trash.

(8) Turbine meters

Turbine meters are used extensively in the gas and petroleum industries. They are especially applicable to flows in high pressure lines. More often the related full-pipe diameter or part-pipe diameter blade is used.

Several problems are associated with the use of turbine meters. Unlike simpler meter types, turbine meters are viscosity-sensitive. Meters calibrated in water, for instance, give different meter-factor curves when used in another fluid. The reasons are complex and are associated with the combination of lift, drag, and friction forces affecting the rotor and the bearings differently. Turbine meters are also sensitive to installation conditions.

(i) Paddle wheel turbines—Although not really a propeller, a small paddle wheel turbine is widely used in large diameter irrigation pipelines and supply wells. It samples only the flow near the pipe wall. This velocity is converted to average flow velocity using general expectations about flow velocity profiles in pipes. This method of flow measurement is sensitive to velocity changes across the pipeline cross-section.

(9) Vortex-shedding flow meter

The vortex-shedding meter is a relative newcomer to pipeline flows. It is expected to essentially replace the orifice meter. Application in irrigation pipelines, particularly water delivered from wells, is a likely application. The most common form of the vortex-shedding flow meter is a strut or bluff body placed in a turbulent stream. Periodic vortices generated, travel several pipe diameters downstream in the mean velocity of the stream.

The phenomenon is demonstrated by air flowing past a flagpole, which generates vortices that alternate on either side of the flag causing it to wave. Applied to a flow meter, the rate of vortices generated (the rate of vortex reversals) when flow strikes the blunt obstruction, or bluff body, is sensed as a measure of passing flow. Passing vortices cause pockets of low pressure in the flow stream and allow for a variety of measurement techniques in commercial flow meters, including ultrasonic, thermal, mechanical, strain gauge, and differential pressure devices.

Little research has been reported on critical dimensions in the design of the bluff body (blunt obstruction) to enhance strength of vortices. One study was conducted in the United Kingdom by Lucas and Turner (1985). They developed the critical dimension of a T-shaped bluff body that optimizes measure accuracy. The response is linear with range abilities on the order of 100:1. The T-shaped buff body used has fast response capabilities with good accuracy, repeatability, and stable calibration conditions.

The major disadvantage of the T-shaped buff body is the need to a have sufficient flow rate to create vortices. However, the device can be used at low flow rates without special detection methods. Other known problems are associated with pipe vibrations. Outside vibration sources, such as from pump machinery, appear to interfere with vortex generation and detection.

Head loss across a vortex shedding flow meter is typically two pipe velocity heads, although this depends on the blockage caused by the particular bluff body. Fluid velocities of up to 150 feet per second can be handled; however, high flow rate limitations do exist. In liquids these would be dictated by the onset of cavitation at the meter. Despite these limitations, vortex shedding flow meters may eventually replace orifice plates at comparable cost.

(10) Magnetic flow meters

Magnetic, or electromagnetic, flow meters offer an excellent solution to problems of flow measurement in conductive liquids. In recent years they have become widely accepted in industry because of their many advantages. Some advantages are no moving parts, head loss equal to that of a similar length of pipe, and accurate measurements over a wide flow range.

The measuring principle is based on Faraday's law of electromagnetic induction. Essentially, electrically conductive liquid flowing though a magnetic field induces a voltage at right angles to the magnetic field and in the direction of flow. If the flux density is a constant, the pipe diameter is fixed, and the pipe is flowing full, then the induced voltage is proportional to the velocity of the flowing liquid. The voltage generated can be AC or DC, depending on the electrical source used to excite the coils that produce the magnetic field. Completing this system is a transmitter, which is a specially designed voltmeter, or more recently may include a microprocessor. The transmitter converts the low-level generated voltage to a usable output signal for flow-rate indication, totalization, or control.

In practice, voltage is sensed by two electrodes mounted in the same plane, but directly across an electrically insulated section of pipe. Since its invention in the late 1930s, the electromagnetic flow meter has been extensively developed. The developments include DC coil energization and weighted magnetic fields. More recent emphasis has been on coil design to reduce the size and power consumption of the flow meters, which has been about 20 to 30 watts.

Electromagnetic flow meters typically provide accuracy of between 0.5 and 1.0 percent of actual over a wide range. As long as a minimum electrical conductivity is present in the measured fluid, volumetric flow rate is measured without interference from entrapped solids.

(11) Ultrasonic flow meters

Ultrasonic meters, like many modern meters, were initially oversold. A particular problem is convincing users that the two basic systems using ultrasonic waves, the Doppler and the transit time meters, operate on completely different principles. The modern clamp-on transit-time meter can indicate flow rate to better than plus or minus 2 percent of actual, depending on design. The Doppler meters usually indicate plus or minus 5 percent. A major advantage of ultrasonic methods is the negligible head loss and the ability to install either portable or dedicated systems without line shutdown.

As mentioned, ultrasonics are applied to flow metering in two basic ways. This results in two basic meter types: transmission and reflection (Doppler). The transmission type establishes a sound path through the liquid in the pipe or channel. The reflection type depends on particles in the fluid that can reflect sound to the receiver, and is really just another way to detect particles in the flow. Sonic signals are about 100,000 cycles per second.

A major disadvantage of externally mounted ultrasonic meters is the need to know exact inside pipe diameter and inside wall surface condition. Ultrasonic meters work best on noncorrosive pipe materials unless the corrosion or built-up material (scale) can be determined. Calibration on a similar pipeline and known flow rate is recommended to compensate for these uncertainties.

Proper operation of both transit time and Doppler ultrasonic flow meters require:

- Acoustic contact between transducer face and pipe so the ultrasonic signal can be injected into the pipe. Machine grease or silicon grease can be used, or silicon rubber can be used if the device is to be permanently installed.
- The system should not be used with partially full pipes. The sensed velocity may be correct, but the flow area generally is wrong.
- The mounting of the transducer must be parallel to the axis of flow. The extreme top or bottom of horizontal pipe walls should not be used. This helps avoid problems with bubbles (top) or bedload sediment (bottom).

(i) Ultrasonic transit time (time-of-flight) meters—The ideal flow meter is one that can be installed on the outside of a pipe, but can give the performance of the best flow meters installed inside the line. Ultrasonic transit time meters have been developed toward these apparently conflicting but demanding criteria. Multiple beam, single path, systems have been installed on many pipelines, the most notable of which is the Alaskan oil pipeline. Single path transit time ultrasonic meters require a transmitter/receiver on opposite sides of a pipeline. With double path meters, only one side of the pipeline is used. A reflective path (one-sided) ultrasonic transit time meter reflects the sonic signal off the opposite inside wall of the pipeline. With both types, good contact must be made between the transmitter/receiver and outside pipeline wall. Both types send a sonic signal across the flow area at a 20 to 45 degree angle to the flow velocity.

These meters are popular for measurement of flows in large pipelines. Many transit time meters can be used on pipelines as small as 2 inches in diameter. They have also been used in some open canal systems. The flow must be relatively free of suspended materials that could reflect and spread the sonic energy. In pipes that are more than 3 feet in diameter, four paths across the full pipe are commonly used. The meters are relatively expensive and require an electric power source and trained technicians for assured operation.

Ultrasonic transit time flow meters require at least two transmitters and two receivers. Two sound paths are established in the fluid, usually along the same diagonal path, but in opposite directions. On one path, the sound travels with the direction of fluid flow (at an angle across the flow). On the other, the sound moves against the direction of fluid flow. The motion of the fluid causes a frequency or phase shift in each path, which is measured and converted to fluid velocity.

(ii) Ultrasonic, reflective type Doppler meter—The Doppler, or reflective type, meter developed to measure effluent flow also works on a frequency shift principle. The frequency shift occurs in the sound reflected from particles that are presumed to be moving at the same velocity as the fluid itself. Latest versions claim to operate with particle sizes below 100 micron and at a concentration of 100 parts per million or less. With the Doppler reflective type meter, only one transmitter and one receiver located on the same side of the pipeline are used. The sonic signal is reflected off the opposite inside pipeline wall. Sonic flow path is perpendicular to the pipeline centerline.

Doppler theory in this application is based on the assumption that the doppler shift is inversely proportional to the velocity of the particles in the liquid.

(iii) Ultrasonic meter for irrigation flow measurements—A particular exception to high cost and lack of ruggedness usually associated with ultrasonic transit time flow meters may be a recently introduced device designed for measuring both flow rate and total flow in irrigation pipelines that are flowing full. Badger Meter, Inc., sold the particular units observed to the New Magma Irrigation District, Central Arizona Irrigation and Drainage District, and Maricopa-Standfield Irrigation District, all in Arizona. They were put into service during the fall of 1986. (Use of brand names is for the reader’s reference and information and does not constitute endorsement by the author or USDA, NRCS.)

Called the Model 4420 Compusonic meter, it is a transit time, single path, ultrasonic flow meter. It uses battery power with solar panel recharging, and is microprocessor controlled to allow a sleep/wake-up mode to conserve power. It has two LCD displays, one three-digit display for flow rate and a six-digit display for totalized flow volume. It is programmable in BASIC to particular units. A serial communications port allows accumulated flow data to be dumped to a data logger. The meter has two internal totalizers. One cannot be reset and is displayed continuously. The other totalizer can be temporarily displayed in its place and can be reset to zero. Flow rate readings can be obtained by manual activation. Because of pipeline flow turbulence, 3 to 5 readings averaged over a 10-minute are recommended for best accuracy.

Sonic sensors are installed about 100 feet downstream from circular slide gates in pipes that are about 2 feet in diameter. Most of the pipelines are slightly curved. Sonic sensors are premounted on a stainless steel circular band that is inserted into the pipe immediately upstream of the outlet. The outlet is installed below the grade of the farm lateral it supplies, so the irrigation district pipeline stands full of water between deliveries. This should inhibit growth of crystals on the sensor faces. Sensors sample a single horizontal path across the pipe for 16 seconds every 15 minutes, or when manually activated. Best accuracy is claimed for flow velocities in excess of 0.5 foot per second, but detection of flow is practical at velocities as small as 0.1 foot per second. The angle of the single path beam is at 22 degrees across the pipe. Field checks against Replogle broadcrested weirs showed good agreement within less than plus or minus 3 percent for the four locations tested.

(12) Other measuring devices

Other meters or measuring devices having limited application to measuring irrigation flows are available. They are mentioned primarily as examples that meters exist using one or more of the common physical principles. Others are so uncomplicated as to require little explanation. For example a volume meter, which can consist of a calibrated container and stopwatch, can be used to measure flows from sprinkler heads, siphon tubes, or other small diameter conduits that have water flowing in a free-fall condition. Rotameters are sometimes used to monitor chemicals being metered into irrigation flows, such as for chemigation with pressurized irrigation systems. Many of these simple measuring procedures are described with applicable irrigation system evaluation procedures earlier in this chapter. Several open channel measuring devices are commercially manufactured in reduced sizes to provide small portable flow measuring devices for small channels or furrows. These devices include orifice plates, v-notch weirs, Replogle flumes, v-notch flumes, H-flumes, and Palmer-Bowles flumes.