Chapter 4 Water Requirements

Contents:

Tables

Figures

Chapter 4 Water Requirements

652.0400 General

Determination of irrigation water requirements requires a measurement or estimate of the rate of crop water use. Daily and weekly crop water use estimates are needed to schedule irrigation applications and determine minimum system capacities. Seasonal or annual water use is required to size irrigation reservoirs and diversion facilities and to establish water rights. Therefore, a procedure to determine both short- and long-term rates of water use is necessary. Chapter 2, Irrigation Water Requirements, NEH, Part 623, describes the processes needed to determine crop evapotranspiration and irrigation water requirements for a crop, field, farm, and project.

Crop evapotranspiration (ET_c), sometimes called crop consumptive use, is the amount of water that plants use in transpiration and building cell tissue plus water evaporated from an adjacent soil surface. Crop evapotranspiration is influenced by several major factors: plant temperature, ambient air temperature, solar radiation (sunshine duration/intensity), wind speed/movement, relative humidity/vapor pressure, and soil-water availability. Daily, weekly, monthly, and seasonal local crop water use requirements must be known. These data are essential for planning, designing, and operating irrigation systems and for making irrigation management decisions, such as determining when and how much to irrigate.

Seasonal water requirements, in addition to crop water needs, may also include water used for preplant irrigation, agricultural waste application, leaching for salt control, temperature control (for frost protection, bud delay, and cooling for product quality), chemigation, facilitation of crop harvest, seed germination, and dust control.

652.0401 Methods for determining crop evapotranspiration

(a) Direct measurement of crop evapotranspiration

Direct measurement methods for ET_c include:

- aerodynamic method
- detailed soil moisture monitoring
- lysimetry
- plant porometers
- regional inflow-outflow measurements

All these methods require localized and detailed measurements of plant water use. Detailed soil moisture monitoring in controlled and self-contained devices (lysimeters) is probably the most commonly used. Little long-term historical data outside of a few ARS and university research stations are available. Use of lysimetry is discussed in more detail in Chapter 2, Irrigation Water Requirements, NEH, Part 623. The use of soil moisture monitoring devices to monitor crop ET is described in NEH, Part 623, Chapter 1, Plant-Soil-Water Relationships.

(b) Estimated crop evapotranspiration—ET_c

More than 20 methods have been developed to estimate the rate of crop ET based on local climate factors. The simplest methods are equations that generally use only mean air temperature. The more complex methods are described as energy equations. They require real time measurements of solar radiation, ambient air temperature, wind speed/movement, and relative humidity/vapor pressure. These equations have been adjusted for reference crop ET with lysimeter data. Selection of the method used for determining local crop ET depends on:

- Location, type, reliability, timeliness, and duration of climatic data;
- Natural pattern of evapotranspiration during the year; and
- Intended use intensity of crop evapotranspiration estimates.

Although any crop can be used as the reference crop, clipped grass is the reference crop of choice. Some earlier reference crop research, mainly in the West, used 2-year-old alfalfa (ET_r). With grass reference crop (ET_o) known, ET estimates for any crop at any stage of growth can be calculated by multiplying ET_o by the appropriate crop growth stage coefficient (k_c), usually displayed as a curve or table. The resulting value is called crop evapotranspiration (ET_c). The following methods and equations used to estimate reference crop evapotranspiration, ET_o, are described in detail in Part 623, Chapter 2, Irrigation Water Requirements (1990). The reference crop used is clipped grass. Crop coefficients are based on local or regional growth characteristics. The following methods are recommended by the Natural Resources Conservation Service (NRCS).

(1) Temperature method

- FAO Modified Blaney-Criddle (FAO Paper 24)
- Modified Blaney-Criddle (SCS Technical Release No. 21). This method is being maintained for historical and in some cases legal significance. See appendix A, NEH, Part 623, Chapter 2, Irrigation Water Requirements.

(2) Energy method

- Penman-Monteith method

(3) Radiation method

- FAO Radiation method (FAO Paper 24)

(4) Evaporation pan method

The FAO Modified Blaney-Criddle, Penman-Monteith, and FAO Radiation equations represent the most accurate equations for these specific methods. They are most accurately transferable over a wide range of climate conditions. These methods and equations are also widely accepted in the irrigation profession today (ASCE 1990).

The intended use, reliability, and availability of local climatic data may be the deciding factor as to which equation or method is used. For irrigation scheduling on a daily basis, an *energy* method, such as the Penman-Monteith equation, is probably the most accurate method available today, but complete and reliable local real time climatic data must be available. For irrigation scheduling information on a 10+ day average basis, use of a *radiation* method, such as FAO Radiation, or use of a local evaporation pan, may be quite satisfactory.

For estimation of monthly and seasonal crop water needs, a *temperature* based method generally proves to be quite satisfactory. The FAO Modified Blaney-Criddle equation uses long-term mean temperature data with input of estimates of relative humidity, wind movement, and sunlight duration. This method also includes an adjustment for elevation. The FAO Radiation method uses locally measured solar radiation and air temperature.

652.0402 Crop evapotranspiration

Monthly and seasonal crop ET data for (state) was developed using the ______________ equation(s). Crop planting and harvest dates were determined by using local long-term mean temperature data and verified with university extension and local growers. The process provides:

- Estimated crop ET and net irrigation requirements by month and by season
- Amount of effective rainfall
- Estimated planting and harvest dates for all local crops

Note: The following crop ET and related tables and maps can be included to replace or simplify crop ET calculations. These maps and tables would be locally developed, as needed.

- Crop evapotranspiration tables, curves, and maps
- Climatic zone maps with peak month ET
- Precipitation maps
- Wind speed maps
- Relative humidity tables or maps
- Net solar radiation tables or maps

(a) Daily crop ET rate for system design

Estimates of daily or weekly crop ET rates are necessary to adequately size distribution systems. They are used to determine the minimum capacity requirements of canals, pipelines, water control structures, and irrigation application systems. Daily ET rates also influence the administration of wells, streams, and reservoirs from which irrigation water is diverted or pumped. To provide the required flows, daily (or several day averages) crop ET rate for the peak month must be used.

Estimated daily crop ET is not the average daily use for longer time periods. Daily crop ET is best estimated using real time day-specific information and the appropriate ET equation.

652.0403 Net irrigation water requirement

The net irrigation water requirement is defined as the water required by irrigation to satisfy crop evapotranspiration and auxiliary water needs that are not provided by water stored in the soil profile or precipitation. The net irrigation water requirement is defined as (all values are depths, in inches):

$$F_n = ET_c + A_w - P_e - GW - \Delta SW$$

where:

F_n = net irrigation requirement for period considered
ET_c = crop evapotranspiration for period considered
A_w = auxiliary water—leaching, temperature modification, crop quality
P_e = effective precipitation during period considered
GW = ground water contribution
ΔSW = change in soil-water content for period considered

Effective precipitation is defined as that portion of precipitation falling during the crop growing period that infiltrates the soil surface and is available for plant consumptive use. It does not include precipitation that is lost below the crop root zone (deep percolation), surface runoff, or soil surface evaporation.

Along with meeting the seasonal irrigation water requirement, irrigation systems must be able to supply enough water during shorter periods. The water supply rate generally is expressed in acre inches per hour or acre inches per day and can be easily converted to cubic feet per second or gallons per minute (1 ft^3/s = 1 ac-in/hr = 450 gpm). The simplified equation can be used:

$$QT = DA$$

where:

Q = flow rate, acre-inch per hour
T = time, hours
D = depth, inches (water applied or crop ET)
A = area, acres

The irrigation system must be able to supply net water requirements plus expected losses of deep percolation, runoff, wind drift, and evaporation. It must account for the efficiency of the irrigation decisionmaker to schedule the right amount of water at the right time and the ability of an irrigation system to uniformly apply that water across a field. Net and gross water application and system capacity are related by an estimated or measured application efficiency:

$$F_g = \frac{F_n}{E_a} \qquad C_g = \frac{C_n}{E_a}$$

where:
F_g = gross application, inches
F_n = net application, inches
E_a = application efficiency, expressed as decimal
C_g = gross system capacity, gallons per minute
C_n = net system capacity, gallons per minute

The designer must also account for system down time, i.e., moving of sprinklers, break downs, and water used on another field or by another irrigator, such as in a rotation delivery schedule. For sprinkler systems, it is common to use 22 hours per day or 6 days per week for actual water application time.

The most conservative method of designing irrigation system capacity is to provide enough capacity to meet the maximum expected or peak evapotranspiration rate of the crop. This normally is the peak daily rate, but can be any selected period. In the most conservative case, rainfall and stored soil moisture are not considered. This design procedure relies on determining the distribution of crop ET during the year for the principle irrigated crops. The crop ET for the peak day, week, and month also varies from year to year. A frequency or risk analysis can be provided whereby system capacity and related cost reduction may be realized. Where effective rainfall and maximum available soil-water storage are used, further reduction of system capacity and water supply may be realized.

See NEH, Part 623, Chapter 2, Irrigation Water Requirements, for further information on determining net irrigation requirement.

Table 4–1 displays an example calculation and tabular method of presenting monthly crop ET, effective precipitation (R_e), and net irrigation requirement (NIR) for pasture grass using FAO Blaney-Criddle equation. When determining crop ET from TR-21 (Modified Blaney-Criddle), crop ET was calculated and displayed using **normal** and **dry** years. **Normal** year (50% chance occurrence) precipitation would be equaled or exceeded in 1 out of 2 years. **Dry** year (80% chance of occurrence) precipitation would be equaled or exceeded 8 out of 20 years.

This process carried through the many computer software programs that were developed and became available in many states. However, computer software programs that have been developed when using FAO Blaney-Criddle equation, do not contain the **normal** and **dry** years calculation process. The **normal** and **dry** year concept for determining crop ET can still be used; however, basic input data of precipitation must be adjusted. Long-term mean data are typically displayed in NOAA climate data publications, and a frequency analysis must be obtained or provided to determine **dry** year precipitation. This concept can also apply to determination of crop ET during **wet** years.

Figure 4–1 displays monthly crop ET and monthly effective precipitation for an arid climate condition where effective precipitation during growing season is minimal. Figure 4–2 shows monthly crop ET and effective precipitation for a subhumid climate condition where effective precipitation can meet crop ET during the early and latter part of the growing season.

Note: Where precipitation exceeds crop evapotranspiration, an opportunity exists for leaching of nutrients and pesticides. This may occur if soil moisture is at field capacity so that precipitation will provide the excess soil water available for leaching. These displays are then basic water budgets in graphic form.

Table 4–1 Example tabular display—crop evapotranspiration using FAO Blaney-Criddle equation

Owner John Irrigator Location Redmond Latitude 44°16' Elevation 1/ 2500 ft

Crop Pasture Crop curve number used 17 Planting date Apr 17 Harvest date Oct 24

Item	April	May	June	July	Aug	Sep	Oct	Total
Mean temp (°F)	44.2	50.8	58.8	64.3	64.0	56.3	48.3	
Mean precip (in)	0.53	0.66	0.80	0. 46	0.52	0.39	0.58	3.94
Effective precip—R_e (in)	0.37	0.44	0.59	0.34	0.38	0.24	0.35	2.71
Ratio sun/cloud	.70	.70	.90	.90	.90	.70	.70	
Rel hum (%)	20-50	20-50	20-50	20-50	20-50	20-50	20-50	
Ave wind (mph)	4-10	4-10	4-10	4-10	4-10	4-10	4-10	
Crop ET (in/mo)	0.76	3.55	6.41	7.47	6.43	3.27	1.23	29.12
Net irrig req—NIR (in/mo)	0.39	3.11	5.82	7.13	6.05	3.03	0.88	26.41

1/ Crop ET is corrected downwards 10% per 1,000 meters above sea level.

Figure 4–1 Example monthly crop evapotranspiration, arid climate in normal year

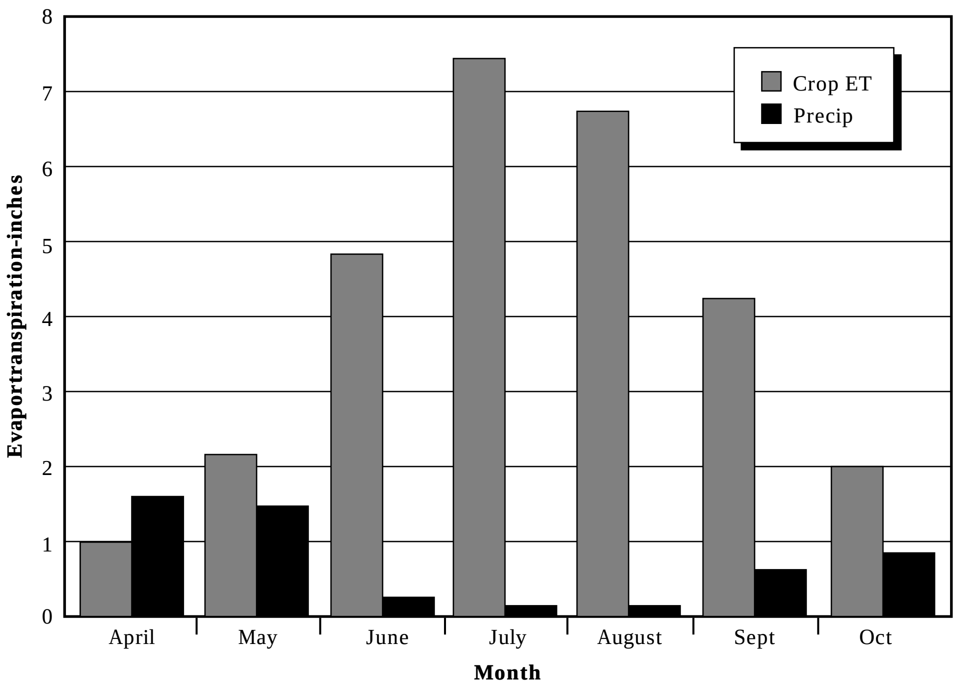
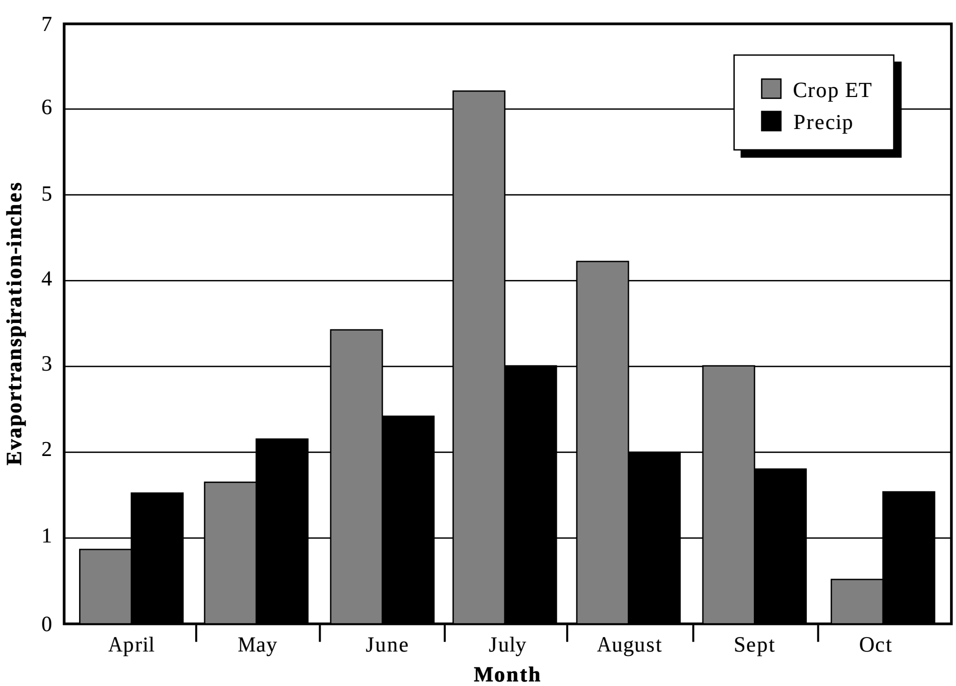


Figure 4–2 Example monthly crop evapotranspiration, subhumid climate in normal year



652.0404 Management allowable soil-water depletion

Management Allowable Depletion (MAD) is generally defined for each local crop. It is a grower's management decision based on yield and product quality objectives whether or not to fine tune generalized MAD values. MAD is the greatest amount of water to be removed by plants before irrigation so that undesirable crop water stress does not occur. Historically, an allowable depletion of between 30 and 60 percent of the soil Available Water Capacity (AWC) has been used for management purposes. See Chapter 3, Crops, for summary of recommended MAD levels for various crops. Estimated irrigation frequency, in days, is based on the MAD level for the AWC in the total crop root zone and the estimated crop ET.

Irrigation frequency, in days, can be determined by:

$$\frac{\text{MAD} \times \text{Total AWC for crop root zone in inches}}{\text{Daily ET}_c \text{ rate in inches/day}}$$

652.0405 Auxiliary water requirements (other needs)

In addition to crop evapotranspiration water requirements, irrigation systems can also meet special needs of crops and soils. These other uses need to be considered when determining the seasonal water requirements and minimum system capacities. Auxiliary uses include the following and are described in more detail in NEH, Part 623, Chapter 2, Irrigation Water Requirements:

- Leaching requirement for salinity and sodicity management
- Frost protection (fruits, citrus, berries, vegetables)
- Bud delay
- Crop and soil cooling
- Wind erosion and dust control
- Chemigation
- Plant disease control
- Seed germination

652.0406 Water table contribution

Upward flow of water from a water table can be used to meet part of or all the seasonal crop water requirement. Reasonable estimates need to be made of the water supplied by a water table. See figure 2–6 in chapter 2 of this guide. Methods to predict upward soil-water flow rates (upflux) from a water table are given in NEH Part 623, Chapter 2, Irrigation Water Requirements, and in the water table management software program DRAINMOD. Soil parameters required for these procedures are quite variable and may require field data to evaluate specific sites.

652.0407 Water requirements for soil-water budget/balance analysis

The components of a soil-water budget/balance analysis must include all water going *in* and all water going *out* of an area for the period of consideration. The basic purpose for such an analysis is to determine the location of all water applied. Generally a soil-water budget analysis is determined for a period involving a month, an irrigation season, a year, or maybe even for an average over several years. Availability of climatic data may also dictate the time period for the analysis. For example, if long-term mean temperature is the only reliable data available, determining monthly and seasonal water requirements may be the most accurate analysis that can be done. This would dictate a reasonably accurate analysis period of a month or longer.

If complete and reliable daily climatic data (temperature, solar radiation, wind movement, and relative humidity) are available nearby, then a daily soil-water accounting or balance can be developed because accurate daily water requirements can be estimated. The soil-water budget/balance analysis process is a tool that can be used for determining gross water applied and contributions of irrigation water and precipitation to downstream surface water and ground water. The soil-water budget/balance can be displayed in equation form as follows (sum may be positive if soil water is stored in the plant root zone):

$$F_g = ET_c + A_w + D_P + RO + SDL - P - GW - \Delta SW$$

where:

F_g = Gross irrigation water applied during the period considered
ET_c = Crop evapotranspiration during the period considered
A_w = Water applied for auxiliary purposes during the period considered
D_p = Deep percolation below the root zone from irrigation and precipitation
RO = Surface runoff that leaves the site from irrigation and precipitation

SDL = Spray, drift losses, and canopy intercept evaporation from sprinkler irrigation system during the period considered
P = Total precipitation during the period considered
GW = Ground water contribution to the crop root zone during the period
ΔSW = Change in soil-water content within the crop root zone during the period

Note: Only those factors that apply to the site under consideration need to be used. Typically all factors would not be used for an analysis of one site.

Generally the soil-water budget analysis can be thought of as supporting a planning process where the soil-water balance analysis can be thought of as supporting an operational process. With appropriate soil-water content monitoring, accurate estimated daily crop ET and measurement of system inflow and surface outflow, a reliable daily soil-water balance can be developed. These daily values can be summarized for any desirable longer period that data are available.

The period of reliable climatic data is key to the soil-water budget/balance analysis. For development of a soil-water balance, only immediate past events are evaluated. It is not an irrigation scheduling tool. For example, a soil-water balance is an analysis process of what water went where for the last year, last month, last week, last event, or from some specific date up to the present time. Each rainfall and irrigation event versus daily crop ET and soil-water content change can be evaluated. It requires appropriate and current monitoring of soil-water content, irrigation water applied, onsite rainfall measurement, runoff, and full climatic data for daily crop ET determination.

For development of a soil-water budget, historic climate data along with estimated or measured soil-water content, irrigation flows, and losses would be used. The time period for an analysis for an average condition is whatever is necessary to provide reliable data. As an example, a site with fairly consistent climate from year to year, but with a rather short number of years record, might provide satisfactory results. Whereas a site with wide ranging climate from year to year might require a much longer period of record. An analysis showing the average for the last 5 years, or for a specific year of importance, could use climate data for that specific period only.

Table 4–2 displays a simple and basic soil-water budget using assumed and estimated values. The input data can be refined to whatever degree is necessary with field observations or measurements, or both. In this table, a water surplus of 1.7 inches for the season is indicated, and the water will go into deep percolation below the root zone.

A soil-water budget can be developed for planning purposes or as an evaluation tool. As the example shows, the consultant can use any level of accuracy desired or necessary.

(a) Example soil-water budget

A simplified soil-water budget would be displayed using the following assumptions:

- Crop is grain corn.
- Mature rooting depth = 48 inches.
- Total AWC = 8.0 inches.
- MAD = 50%.
- Soil profile is at field capacity at start of season.
- Sprinkler irrigation system with gross application for each irrigation = 6.0 inches.
- Application efficiency of 67% providing a net application = 4.0 inches.
- DU = 100% with no surface runoff.
- Precipitation infiltration for all season = 70% of total.
- No contribution from a shallow water table.

All crop ET, irrigation, and precipitation units are in inches.

Additional and more detailed examples of a soil-water budget and a soil-water balance are in Chapter 8, Project and Farm Irrigation Water Requirements.

Table 4–2 Example soil-water budget

Month	Crop ET	Soil water used	Precipitation total	Precipitation effect [1/]	Irrigations no.	Irrigations net water applied	Water def. (–)	Water surplus (+)
May	2.3	2.3	3.0	2.1	0	0	0.2	
June	4.8	5.0	2.0	1.4	1	4.0		0.4
July	8.1	8.1	0	0	2	8.0	0.1	
Aug	6.6	6.7	0	0	2	8.0		1.3
Sept	2.0	2.0	1.5	1.0	0	0	1.0	
Total	23.8	24.1		4.5	5	20		1.7 [2/]

1/ Assuming all effective precipitation infiltrated into the soil.
2/ Typically lost to deep percolation. The total is in inches.

652.0408 State supplement