Determining Irrigation Efficiency and Consumptive Use

Program Guidance

Issued October 2005

Publication 20-11-076

Updated March 2024

Water Resources Program

Washington State Department of Ecology

Olympia, Washington

Publication Information

This document is available on the Department of Ecology's website at:
https://apps.ecology.wa.gov/publications/summarypages/2011076.html

This document used to be Program Guidance 1210 (GUID-1210, adopted 2005). The Program converted it to this guidance and informational document in March 2020, and updated March 2024.

Contact Information

Water Resources Program
P.O. Box 47600
Olympia, WA 98504-7600
Phone: 360-407-6872

Washington State Department of Ecology — www.ecology.wa.gov

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Shoreline 206-594-0000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Union Gap 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

ADA Accommodation

The Department of Ecology is committed to providing people with disabilities access to information and services by meeting or exceeding the requirements of the Americans with Disabilities Act (ADA), Section 504 and 508 of the Rehabilitation Act, and Washington State Policy #188.

To request an ADA accommodation, contact Ecology by phone at 360-407-6872. For Washington Relay Service or TTY call 711 or 877-833-6341. Visit https://ecology.wa.gov/accessibility for more information.

Table of Contents

Figures and Tables

Figures

Tables

Definitions

The following definitions are intended within this policy:

- "**Application Efficiency (Ea)**". The ratio of the average depth of water infiltrated and stored in the root zone to the average depth of water applied, expressed as a percentage.
- "**Available Water Capacity (AWC)**". The portion of water in a soil that can be readily absorbed by plant roots of most crops. It is the amount of water stored in the soil between field capacity and permanent wilting point. Also called the Water Holding Capacity.
- **"Crop Irrigation Requirement (CIR)"**. Water supplied by irrigation to satisfy evapotranspiration that is not provided by water stored in the soil and precipitation. Where additional quantities of water are required for leaching, frost-protection, cooling and other miscellaneous crop requirements, these quantities are added to the CIR.
- **"Consumptive Use (CU)"**. Consumptive use includes crop evapotranspiration, and water evaporated during irrigation applications (e.g. spray, canopy and wind losses).
- "**Deep Percolation**". Water that infiltrates below the root zone, including water used for leaching and water resulting from non-uniform application of water for irrigation.
- "**Distribution Uniformity (DU)**". A measure of how evenly water infiltrates into the ground across a field during irrigation. DU is expressed as a percentage between 0 and 100 and is typically derived from "catch-can" testing in the field. It is defined as the ratio of the average depth of infiltration of the lowest quarter of measurements (e.g. lowest 25%) to the average depth of infiltration.
- "**Evapotranspiration (ET)**". The sum total of plant transpiration, evaporation off of the soil surface, and water used for plant growth.
- "**Field Capacity**". The water content at which drainage becomes negligible in a free-draining soil (e.g. the maximum amount of water held by the soil without drainage loss).
- "**Irrigation Scheduling**". All farmers schedule their irrigation to some degree. Irrigation scheduling as defined in the literature consists of 1) understanding how much *available water capacity* the farm has in its *root zone* for the crop being grown; 2) estimating crop *ET* to predict the interval between watering; and 3) field-truthing ET predictions with some kind of soil-moisture measurement.
- "**Management Allowed Depletion (MAD)**". This value, expressed in percent, is the percentage of the AWC in the root zone that plants can utilize before experiencing stress.
- "**Permanent Wilting Point**". The soil-water content when a plant permanently wilts.
- "**Return Flow**". The sum of deep percolation and runoff that returns to waters of the State or would return to waters of the State but is intercepted by a water user.
- "**Root Zone**". The effective depth of crop roots in the soil from which water is extracted.
- **"Total Irrigation Requirement (TIR)"**. Water supplied by irrigation to satisfy evapotranspiration, miscellaneous water requirements, and irrigation efficiency.

Irrigation 101: The Water Budget

Crops need water to grow (photosynthesis), to transport nutrients from the soil and for cooling (transpiration). During the course of irrigation, some water that is intended for the root zone ends up in other places. Some water lands on the soil and evaporates before it can infiltrate. Collectively, these components of the water budget are called *evapotranspiration* or ET, which is commonly described in inches, inches/day, or inches/acre/day.

In addition to ET, applied water can evaporate in the air (*spray evaporative loss*), it can evaporate off the plant canopy (*canopy loss*), it can blow off the irrigated property (*wind drift*), it can *runoff* the land if the application rate is greater than the soil infiltration rate, it can *leak* out of the conveyance or distribution system, and it can *deep percolate* past the root zone due to over-application or non-uniform application. The irrigation water budget is shown in Figure 1 below[1].

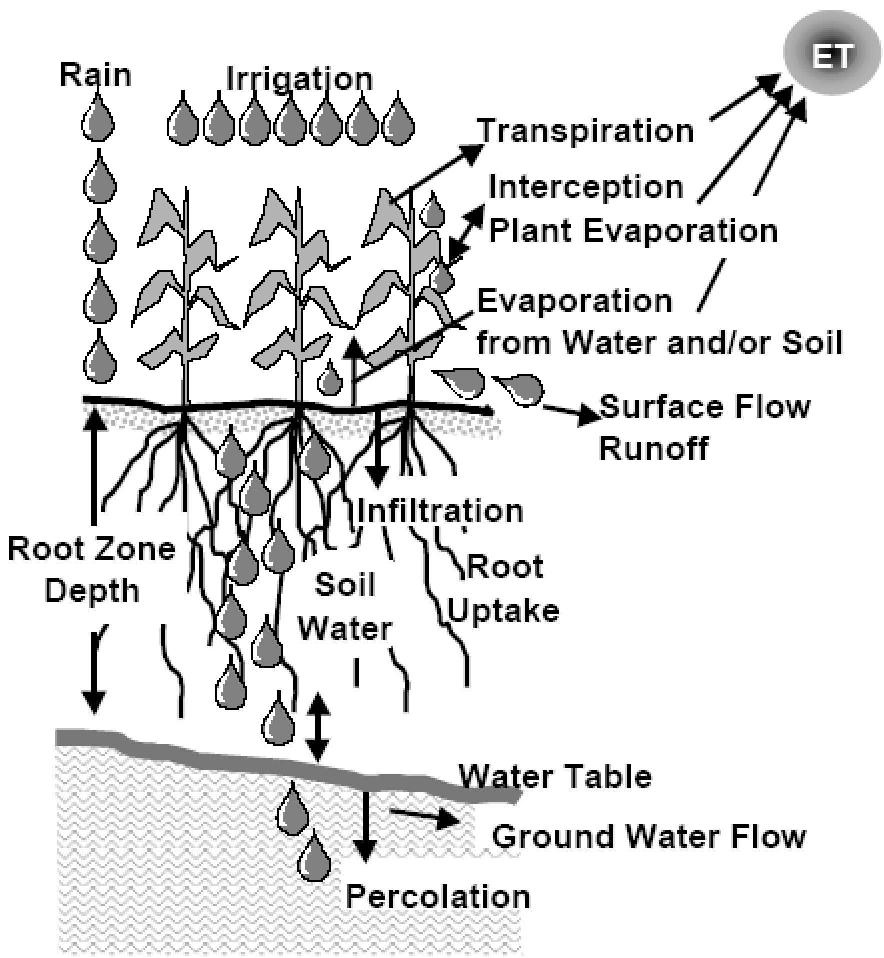

Figure 1. The Irrigation Water Budget

[1] Figure from *Irrigation Efficiency, Encyclopedia of Water Science*, Dr. Terry Howell, USDA, 2003.

Magnitude of Components of the Irrigation Water Budget

The magnitude of the components of the irrigation water budget vary according to numerous variables, the most important of which is how the irrigation system is actually managed (e.g. irrigation set times, maintenance practices, matching supply to demand, and other local conditions). The following provides a summary of each of the components and magnitude ranges. Table 1 summarizes this information for use in estimating irrigation efficiency and consumptive use.

- *Evapotranspiration*. There are over 50 different methods for calculating ET, including simple temperature methods (e.g. Blanney-Criddle) to more accurate energy methods (e.g. Penman-Monteith). The Washington Irrigation Guide utilized the SCS Blanney-Criddle Modified method and work done by WSU using the FAO 24 Blanney-Criddle method in XB 0925 to derive crop consumptive use estimates (WIG, page WA683.11(a)(2)). PAWS and AgriMet both cite the use of a Kimberly-Penman ET model. Depending on the monitoring station and the years selected, values among these data sources within Washington can vary by as much as 20%, but for most stations, the variance is on the order of 1-2 inches.
- *Irrigation Efficiency*. Irrigation efficiency represents the amount of water that needs to be applied in addition to the crop requirement for a particular type of irrigation system to meet the component system losses described below.
  - *Spray Evaporative Loss*. When water travels through the air during sprinkling, some water evaporates. The magnitude of evaporation depends on drop size (smaller drops evaporate quicker), drop travel time (e.g. sprinkler height off the ground, sprinkler angle, and wind), and environmental conditions (temperature, humidity, etc.). For sprinkler systems within low heights and low wind conditions (5 feet or less off the ground and 5 mph or lower average conditions), spray evaporative loss tends to be on the order of 2% or less. For higher elevations and wind conditions, evaporative losses can be > 10%.
  - *Canopy Loss*. When water travels from the sprinkler to the ground, some water lands on the plant canopy[2]. The amount of water held on the canopy depends on crop leaf area, crop type, and growth stage of the crop. Water that is retained on the canopy will evaporate fairly quickly once irrigation stops (e.g. 1 hr or less during the day). Water evaporating off the plant canopy cools the plant, which reduces the amount of transpiration for the day. However, because evaporation from a free water surface occurs at a faster rate than transpiration through the plant leaves, the ET on the day of irrigation is greater than the ET on the day before or the day after irrigation. The net increase in evaporative loss associated with canopy losses (after subtracting out the transpiration that would have occurred that day) is typically on the order of 3 – 5%.

[2] Although XB0925 indicates that the crop irrigation requirements in Appendix B of the WIG include evaporation off the plant foliage, in fact the figures provided do not include canopy losses. The WIG derives its ET estimates based on an assumption of a surface application (e.g. rill), applying a 2-inch application depth for a silt loam soil (Source: Tom Spofford, USDA).

Net canopy losses can be greater (10% or more) when application rates are low (e.g. center-pivots at high rotation speeds).

- *Wind Drift*. Wind can cause sprinkled water to drift out of the application area. If it drifts off the irrigated property, it is typically considered to be consumed (e.g. edge effects). If it drifts to the crop in another part of the field (more common), then subsequent evaporation of these droplets off the plant canopy or the soil cools the crop and reduces transpiration. The net consumptive magnitude of wind drift under most conditions is on the order of a few percent. However, under high average wind conditions, 10% or more, wind losses can be higher and can lead to decreased application uniformity.
- *Runoff*. When water is applied at a rate greater than the soil can infiltrate, it can lead to runoff. Runoff within a field may still be used by the crop, although areas of low elevation may be areas of deep percolation if runoff typically collects there. If runoff returns to waters of the State, it is considered to be return flow. Runoff is more prevalent in surface irrigation systems (10 – 40%) than in sprinkler systems, although some irrigation systems (e.g. center-pivot LEPA) can have runoff due to high application rates (2 – 20%).
- *Deep Percolation*. Deep percolation is common in both surface and sprinkler irrigation systems, the magnitude of which is heavily influenced by irrigation scheduling and soil type. Leaks, over-application and non-uniform application can all lead to deep percolation. If deep percolation returns to waters of the State or is intercepted but would otherwise return to waters of the State, it is considered return flow.
    - *Leaks*. Leaks are a function of system installation, age and system maintenance. Leaks can occur underground at joints and from cracks in the pipe due to age or improper bedding, and can occur above ground at sprinklers, valves and plugs. The National Engineering Handbook identifies the magnitude of leaks as 1 – 10%, with the lower end of the range indicative of a well-maintained system.
    - *Over-Application (Spring/Fall, Irrigation Scheduling)*. Over-application occurs when irrigation water is supplied in excess of the water storage capacity of the soil. Over-application most commonly occurs when irrigation demand is low (spring and fall), due to labor constraints (fixed irrigation times associated with hand-move systems), and due to non-uniformity of soils within a field (e.g. areas of sandy soil in a predominantly silt-loam field). Over-application can be estimated by comparing the sprinkler capacity and run time (e.g. gpm x irrigation hours) to the available water capacity of the soil (Appendix A in the WIG).
    - *Non-Uniform Application (DU)*. Sprinklers overlap in order to provide uniform application of water on the field. However, all sprinklers designs result in some areas of the field getting too much water and some areas not getting enough. Environmental conditions (e.g. wind) and system conditions (e.g. pressure and wear-and-tear on sprinklers) also affect uniformity. The DU is a measure of uniformity and indicates how much water the lowest ¼ of the field gets compared to the average. DU’s are typically derived from catch-can tests.

Calculating vs. Assuming Irrigation Efficiency

Irrigation efficiency (Ea) can be calculated by dividing the crop irrigation requirement (CIR) by the total water use (subject to the extent and validity of the water right).

Ea = CIR / Total Water Use

Because irrigation efficiency is heavily dependent on the type of system, the irrigation practice of the farmer and other case-specific factors, irrigation efficiency should be calculated where possible, rather than assumed. The CIR can be found in Appendix B of the WIG, from PAWS or AgrMet, or can be derived empirically. The total water use can be calculated from water meter data, power meter data or run-time information (e.g. average pump rate x average hours/day run x irrigation season).

Where total water use data is unavailable, irrigation efficiency may be assumed. However, system management is as important as the type of irrigation system in determining efficiency and each farm needs to be looked at on a case-by-case basis. Where possible, a site visit and interview with the farmer should be conducted to investigate irrigation practices. Table 1 provides reasonable irrigation efficiency ranges for different types of irrigation systems and based in part on work by Dr. Terry Howell [3] and Dr. Blaine Hanson[4]. Farmers that operate systems near the higher end of the range often exhibit the following:

- Newer system infrastructure
- Active maintenance program
- Knowledge of seasonal crop ET rates
- Scheduling irrigation in response to crop demand
- “Ground-truthing” of soil moisture

Farmers that operate systems near the lower end of the range may exhibit one or more of the following:

- Older system infrastructure
- Inadequate maintenance program
- Improper irrigation scheduling
- Labor constraints
- Site constraints (e.g. soils, topography, water delivery system)

[3] *Irrigation System Efficiencies*, Terry A. Howell, PhD, PE, USDA-Agricultural Research Station, Bushland, Texas, 2002 Proceedings of the Central Plains Irrigation Short Course and Exposition.

[4] *Practical Potential Irrigation Efficiencies*, Blaine R. Hanson, PhD, 1995 Proceedings of the First International Water Resources Conference.

Determining the Consumptive / Non-Consumptive Balance of the Total Water Use

During its preparation of this guidance document, Ecology consulted with industry experts, and collected literature on irrigation efficiency and consumptive use. These efforts culminated in a conference held in Pasco, Washington on November 29-30, 2004 attended by irrigation experts from academia, government, and the private sector. The experts were asked to assist Ecology to 1) understand and quantify the terms and factors that affect irrigation system efficiency, and 2) within each irrigation efficiency term, understand and quantify the consumptive/non-consumptive balance. The workshop included a prolonged discussion of the component elements of irrigation efficiency, including spray evaporative loss, canopy loss, wind drift, deep percolation, and runoff. These components vary based on numerous other variables[5], and were all dependent on irrigation scheduling and management. The experts recommended against individual quantification of these elements and focused instead on grouping and quantifying the consumptive (e.g. spray loss, canopy loss, and wind drift) and non-consumptive terms (e.g. deep percolation and runoff). The experts also agreed that this approach was reasonable in balancing the need for accuracy for the farmer, accuracy to protect existing water rights, and the need to issue timely permit decisions by Ecology.

Table 1 includes the term %Evap, which represents a grouping of the consumptive components of irrigation efficiency. The experts generally agreed that in any above-ground water application system, a 5% consumptive loss component was reasonable. As the point of application (e.g. sprinkler) was elevated above the ground, the consumptive components of irrigation efficiency (e.g. wind, spray loss, etc.) had more opportunity to evaporate water, resulting in higher consumptive losses (e.g 10% to 15%).

The %Evap term represents a percentage of the total applied water that is consumed during the act of transporting the water to the root zone. By adding the %Evap to the calculated or assumed irrigation efficiency (Ea), the balance between consumptive use (%CU) and return flow (%RF) can be obtained. While the %CU and %RF terms provided in the table represent reasonable assumptions based on Ecology's understanding of the underlying science, each applicant may submit site-specific information and calculations regarding their water use for consideration by the permit writer. The permit writer shall consider such information on a case-by-case basis. Example calculations are provided in the sections following the table.

[5] Variables discussed included site conditions, topography, type of system, irrigation scheduling, differences in ET estimates, effective vs. actual root zone, relative crop cover as a function of emergence and harvest, timing effects of deep percolation, in-field travel of water above ground and in the subsurface and others.

Table 1. Summary of Application Efficiency Ranges, Consumptive Use, and Return Flows[6]

Method		Application Efficiency, Ea (%)[7]		%Total Evaporated	% Total Use Consumed	Return Flow
		Range	Average, Ea_{avg}	%Evap	%CU, Average[8]	%RF, Average[9]
Surface:	Graded Furrow	50 – 80	65	5	70	30
	w/ tailwater reuse	60 – 90	75	5	80	20
	Level Furrow	65 – 95	80	5	85	15
	Graded Border	50 – 80	65	5	70	30
	Level Basins	80 – 95	85	5	90	10
	Flood	35 – 60	50	5	55	45
Sprinkler:	Periodic Move (Handline)	60 – 85	75	10	85	15
	Side Roll (Wheelline)	60 – 85	75	10	85	15
	Moving Big Gun	55 – 75	65	10	75	25
	Solid-Set—Overtree	55 – 80	70	15	85	15
	Solid Set--Undertree	60 – 85	75	10	85	15
	Pop-Up Impact	60 – 85	75	10	85	15
Center-Pivot	Impact heads w/end gun	75 – 90	80	15	95	5
	Spray heads w/o end gun	75 – 95	90	10	100	0
	LEPA w/o end gun[10]	80 – 98	92	5	97	3
Lateral-Move	Spray heads w/hose feed	75 – 95	90	10	100	0
	Spray heads w/canal feed	70 – 95	85	10	95	5
Microirrigation:	Trickle/Drip	70 – 95	88	5	93	7
	Subsurface Drip	75 – 95	90	0	90	10
	Microspray	70 – 95	85	10	95	5

[6] Calculate the actual water use from water meter data, power meter, or run-time data. In the absence of such data, the TIR (total irrigation requirement) = CIR / Ea, where CIR is the crop irrigation requirement from the WIG (Appendix B) and Ea is the case-specific application efficiency above.

[7] %Evap is the portion of the total irrigation requirement that is evaporated due to factors other than crop ET.

[8] Select appropriate %CU based on type of irrigation system. If calculated Ea is greater or less than Ea_{avg}, then %CU = Ea + %Evap. CU = TIR x %CU

[9] Select appropriate %RF based on type of irrigation system. If calculated Ea is greater or less than Ea_{avg}, then %RF = 100 - %CU. RF = TIR x %RF

[10] Low Energy Precision Application.

How Do I Use Table 1 When Making an Analysis of Water Use for a Tentative Determination of the Extent and Validity of an Existing Water Right?[11]

When evaluating total water use for an existing water right, the permit writer should attempt first to calculate actual efficiency rather than assume an efficiency from Table 1. Actual efficiency (Ea) can be determined by dividing ET for the crop(s) grown by total water use. Total water use can be calculated:

- From water meter data.
- By converting dedicated power meter data (kW-hr) to flow (see WAC 173-173-160).
- From system capacity (e.g. average pump rate x average hours/day run x irrigation season).

If actual efficiency cannot be calculated due to unavailability of data, then the total water use may be estimated by selecting an ET for the crop(s) grown, selecting efficiency, and estimating or measuring the irrigated acres.

- Selection of an ET will typically be based on the Washington Irrigation Guide, although depending on the location of the project to agricultural/weather stations, use of PAWS or AgriMet may be appropriate. Because the difference in ET predicted from these sources is typically small, permit writers may use any of these sources[12].
- Selection of an average efficiency from Table 1 is reasonable. The permit writer may also consider local custom and the design efficiency considered in the original water right authorization in determining an assumed efficiency.
- Estimation of irrigated acres is typically determined by GIS calculation from one or more state-wide aerial photo coverages, from parcel information, or by direct measurement using a professional survey or GPS.

The permit writer should use multiple means of estimating water use if the data is available. Where actual data is present, it should be used over methods of estimation unless a compelling reason exists to disregard it (e.g. water meter shown to be not calibrated, non-dedicated power meter). The permit writer must use best professional judgment in applying the guidance herein to the case-specific field conditions of each permitting decision.

[11] See POL 1120 for a more comprehensive discussion of tentative determinations.
[12] Ecology is currently working with USDA on adoption of a standard for the State in the calculation/estimation of ET. This guidance document may be updated in the future when Ecology identifies a preferred methodology.

How Do I Use Table 1 When Making Permitting Decisions Involving ACQ or Consumptive Use?

Once an actual or estimated efficiency is determined, the consumptive portion of the efficiency term can be obtained from Table 1.[13]

- If the estimated or calculated efficiency is ***equal*** to the average efficiency Ea_{avg}, the consumptive and return flow portions of the Ea can be read directly from the table. Then, the consumptive use and return flow can be calculated by multiplying those factors times the total irrigation requirement (TIR). Multiplying the CU by the total acres provides the total consumptive use under the water right.
    - Example 1. A farmer has 10 acres of pasture that he irrigates with handlines. No water or power meter data are available. The WIG crop irrigation requirement (CIR) from Appendix B for pasture is 3 ac-ft/ac. The farmer's water right allows an annual diversion of 40 ac-ft. Based on the table, the average handline is 75% efficient which is the same as that assumed in the original water right authorization. The total irrigation requirement (TIR) is (3) / (0.75) = 4 ac-ft / ac. The total water use estimate then is (4 ac-ft / ac) x (10 acres) = 40 ac-ft. From the table for average conditions, %CU is 85% and % RF is 15%. Therefore, the consumptive portion is (40 ac-ft) x (0.85) = 34 ac-ft and the RF = 6 ac-ft (40 ac-ft – 34 ac-ft).
- If the estimated or calculated efficiency is ***less*** than Ea_{avg}, the consumptive and return flow portions of the Ea must be calculated using the %Evap term. %CU is calculated by adding %Evap to the actual efficiency.
    - Example 2. Another farmer has 10 acres of pasture that he irrigates with handlines. Water meter data (51.7 ac-ft total use on 10 acres) and the WIG (assume 3 ac-ft/ac as in the example above) are used to calculate an actual efficiency of 58% for handline sprinklers. The water right in question did not specify a maximum annual volume. The permit writer considers the range of reasonable irrigation efficiencies in Table 1, and the factors under RCW 90.03.005 and the Supreme Court Case *Grimes,* and concludes that 58% efficiency for handlines is reasonable and non-wasteful in this case[14]. %CU is calculated by adding the %Evap term (10%) to the calculated efficiency of 58%, or 68%. The %RF term is calculated by 100 - %CU, or 32%. The TIR is the CIR divided by the actual efficiency of 58%, or 5.17 ac-ft/ac. Therefore, the total estimated water use for the 10 acres is 51.7 ac-ft (5.17 ac-ft/ac x 10 acres). The consumptive portion is (5.17 ac-ft/ac) x (0.68) x (10 acres) = 35.16 ac-ft and the RF = (5.17 ac-ft/ac) x (0.32) x (10 acres) = 16.54 ac-ft.

---

[13] The permit writer should verify efficiency and consumptive use estimates by comparing the estimates to information obtained from the water right file and from the site investigation. Information on the farmers irrigation scheduling can be used to ground-truth irrigation efficiency and consumptive use estimates (e.g. system capacity and irrigation set times).

[14] If the calculated efficiency were far below the reasonable efficiencies shown in the table, then a waste determination may be appropriate. No water right exists where water is wasted. Only a reasonable amount of water for the type of irrigation system used can be considered in a permit decision.

- If the estimated or calculated efficiency is *greater* than the average Ea, the consumptive and return flow portions of the Ea must also be calculated using the %Evap term. Typically, systems that are more efficient than the average will first reduce return flow and then reduce consumptive use of the crop (e.g. deficit irrigation). The permit writer should obtain information on irrigation scheduling for the project to determine the consumptive / non-consumptive balance.
    - Example 3. A third farmer has 10 acres of pasture irrigated with a wheelline. Power meter data and PAWS are used to calculate an actual efficiency of 85% for wheelline sprinklers (e.g. 34 ac-ft of crop irrigation requirement from PAWS divided by 40 ac-ft of measured water use from the power meter). The site investigation and interview demonstrates that the farmer scheduled his irrigation in response to crop needs. The farmer routinely visited the AgriMet website and obtained ET rates, dug holes for hand-moisture sensing, and changed the wheelline on 12-hour sets which was sufficient to refill the root zone. Based on this information, the permit writer could conclude that the farmer's irrigation practice had reduced return flows to a minimum. The percent consumptive use (%CU) would be calculated by adding the %Evap to the actual %Ea (10% + 85% = 95%) and return flow would be %RF = 5% (100% – 95%). Therefore, CU = 40 ac-ft x 95% or 38 ac-ft and RF = 40 ac-ft x 5% = 2 ac-ft.

How Do I Use Table 1 When Making Permitting Decisions on Applications for a New Water Right?

Applications for a new irrigation right may involve developed or undeveloped land. If the project involves undeveloped land or changes to existing land for new infrastructure, the permit writer may select an average efficiency from the table. The permit writer may also consider the Grimes factors in selecting an appropriate irrigation efficiency.

Where land is currently under irrigation and a new water right is sought (e.g. for additional water to meet a higher crop duty or a new source), Ecology will typically conduct an investigation of the existing water uses. This can inform the permit writer as to the efficiency required for the proposed project.