

Determining Irrigation Efficiency and Consumptive Use Public Review Draft

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[Application for a New Water Right](#) (Form ECY 040-1-14)

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Revised Code of Washington (RCW) 90.03.380 Right to water attaches to land—Transfer or change in point of diversion—Transfer of rights from one district to another—Priority of water rights applications—Exemption for small irrigation impoundments—Electronic notice of an application for an interbasin water rights transfer.

POL-1120 Conducting Tentative Determinations of Water Rights

POL-1200 Evaluation of Changes or Transfers to Water Rights

POL-1210 Evaluation of Changes to Enable Irrigation of Additional Acreage or the Addition of New Purposes of Use to Existing Water Rights

PRO-1210 Calculating and Applying the Annual Consumptive Quantity (ACQ)

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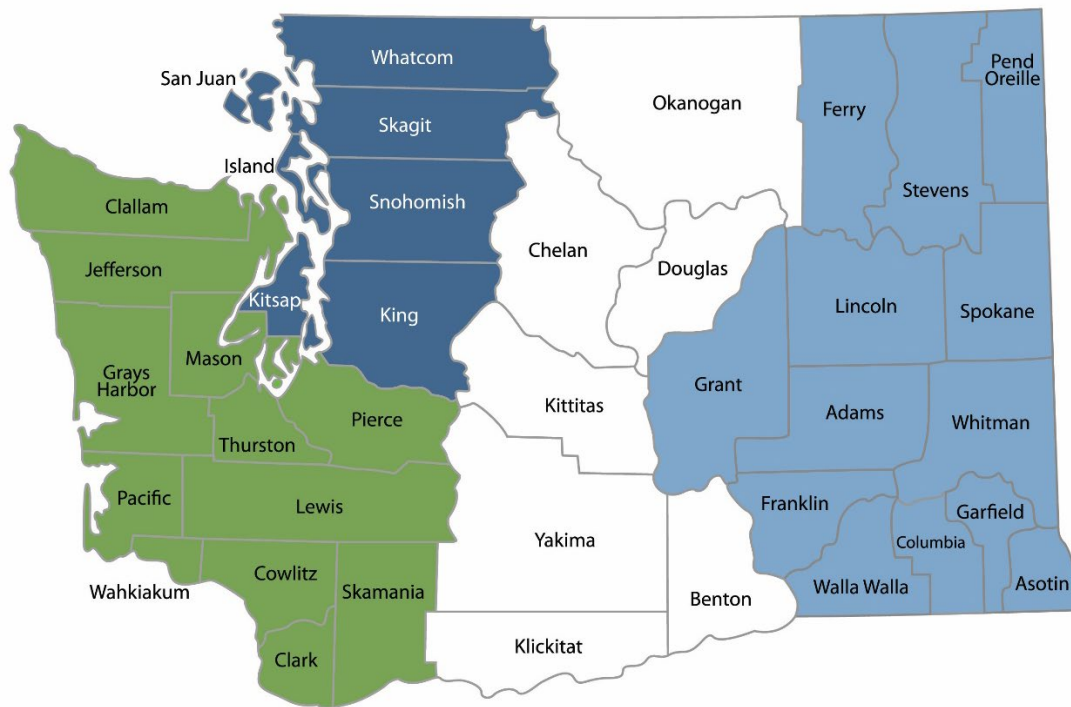
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Map of Counties Served



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360-407-6300

Northwest Region
206-594-0000

Central Region
509-575-2490

Eastern Region
509-329-3400

Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	PO Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	PO Box 330316 Shoreline, WA 98133	206-594-0000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 W Alder St Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 N Monroe Spokane, WA 99205	509-329-3400
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1. Introduction

This document guides Department of Ecology (Ecology) Water Resources Program staff in determining irrigation efficiency and consumptive use. Measuring irrigation efficiency and consumptive use is difficult and cost-prohibitive, so estimations from irrigation experts are used in practice. This guidance directs staff to the estimation data sources and methods currently available. The best practices and primary recommended model are detailed in the guidance. However, Ecology staff should use their best professional judgment to determine which best reflects real-world conditions in special circumstances.

Ecology frequently must estimate or determine irrigation efficiency and consumptive use:

- When a change in purpose is proposed that could increase the consumptive use of a water right and such increase could result in impairment of existing water rights.
- When a change to enable irrigation of additional acres or an additional purpose of use is proposed, requiring application of an Annual Consumptive Quantity (ACQ) determination.²
- When issuing new water rights for an irrigation purpose of use.
- When conducting tentative determinations of existing irrigation water rights.³
- When evaluating trust water applications.
- When determining whether water is being wasted.
- In the context of adjudications.
- In other situations.

Ecology contracted with Washington State University (WSU) to develop a comprehensive review of scientific literature to support updated estimates of the efficiency of every major type of irrigation system used in Washington State for this guidance. The resulting white paper is titled *Irrigation System Efficiencies for Washington State: Literature Review and Discussion of Irrigation Application Efficiency and Water Loss Destinations and How They Affect Long Term Water Availability* (Peters, 2025). The paper delves into the mechanics of irrigation application inefficiency components (runoff, deep percolation, spray losses, and evaporation), and how each irrigation system type performs according to scientific literature. This work was carried out by Dr. Troy Peters, a leading expert on agricultural irrigation at the WSU Irrigated Agriculture Research and Extension Center.

² RCW 90.03.380. See Policy 1210, *Policy for the Evaluation of Changes to Enable Irrigation of Additional Acreage or the Addition of New Purposes of Use to Existing Water Rights*, for applications of the RCW.

³ See Policy 1200, *Evaluation of Changes or Transfers to Water Rights*, for more information.

2. Definitions

Consumptive Use (CU) – Water that ends up as water vapor in the atmosphere or is metabolically incorporated into the tissue of the plant and is considered no longer available for further use within the watershed. Also known as effective use, it includes crop evapotranspiration, metabolic uptake, and water evaporated during irrigation application (e.g., spray, canopy and wind losses, and 10% of runoff). The water incorporated in the plant's tissue is a very small fraction of the total consumptive use and therefore generally not factored into consumptive use estimation methods.

Crop Irrigation Requirement (CIR) – Water that needs to be supplied by irrigation to satisfy evapotranspiration that is not provided by water stored in the soil and precipitation. This includes water required for miscellaneous crop requirements such as leaching, frost-protection, and cooling. It does not include water losses from inefficient irrigation systems such as deep percolation, runoff, or wind drift and evaporation.

Effective Precipitation (Pe) – The part of precipitation (Pt) that becomes available to plants for evapotranspiration.

Evaporation – The consumptive process of liquid water converting to water vapor.

Evapotranspiration (ET) – The sum of plant transpiration (plant water use) and evaporation off the soil surface or a wet plant canopy. Reference ET (ET_r) is the calculated ET of a fully irrigated and mature reference crop (alfalfa or short grass). Crop ET (ET_c) is the calculated ET of the specific crop under investigation and is generally referred to as ET in this document. ET_c is sometimes referred to as crop water demand or need.

Irrigation Application Efficiency (E_a) – The ratio of the average depth of water infiltrated and stored in the root zone for later use by the plant and evaporation (ET) to the average depth of water applied by the irrigation system, expressed as a percentage that represents the performance of the irrigation system at the field scale.

Return Flows (RF) – Any water that is appropriated using reasonably efficient practices and subsequently returns to the hydrologic system (e.g., stream or body of groundwater).

Total Irrigation Requirement (TIR) – Water that needs to be supplied by reasonably efficient irrigation practices to satisfy evapotranspiration, miscellaneous water requirements, and losses due to imperfect irrigation efficiency.

Transpiration – The process of water used consumptively by the plants by absorbing through the roots and eventually evaporating from plant cells.

3. Background

3.1 Crop Evapotranspiration and the Water Budget

Crops need water to grow (photosynthesis), to transport nutrients from the soil, and for cooling. Nearly all water taken up by the crop is consumptively used through **transpiration**. Crops also need varying amounts of water for cooling by **evaporation** from the canopy or soil surface, depending on factors such as the crop type, growth stage, weather conditions, and available water. Transpiration and evaporation together are shortened to **evapotranspiration (ET)**. All ET can be considered total and permanent water losses to the local hydrologic system (**consumptive use, CU**) since it is unlikely that this water vapor will have the chance to re-condense as rainfall and fall within the watershed.

The water that a crop needs to grow is supplied by a combination of natural sources (precipitation, stored soil moisture, and shallow groundwater⁴) and irrigation. The portion that must be provided by irrigation to grow and maintain healthy crops is the **crop irrigation requirement (CIR)**. This amount is a factor of the crop type and its surrounding conditions (temperature, humidity, wind speed, etc.) but doesn't include irrigation system losses.

The CIR is often estimated for a crop grown under ideal conditions (healthy and well-watered to maximize crop yields). In reality, crops can be grown successfully using less water (under some stress) as long as their soil water content stays above the permanent wilting point (Peters et al, 2013).

During irrigation, some water intended for the crop ends up in other places due to non-uniform irrigation or imperfect irrigation scheduling. These losses are considered inefficiencies of an irrigation system. Some losses are considered consumptive: water that blows off the irrigated property (wind drift), and evaporates into the air, off the plant canopy, and off the wet soil surface beyond what is needed for the crop. Some losses are considered nonconsumptive: water that runs off the land if the application rate is greater than the soil infiltration rate⁵

⁴ Shallow groundwater is not often present, and when it is then it is typically a small portion of the water used by a crop and therefore isn't considered here (Hopmans et al, 2002) (USDA, 1997). If Ecology staff are aware of the presence of shallow groundwater when evaluating irrigation water use then they should discuss water table management plans with the applicant, and evaluations of irrigation water needs with senior Ecology staff or irrigation experts.

⁵ 10% of field runoff can generally be considered consumptive use, because it can be assumed that it evaporates from tailwater ditches and weed growth. The other 90% can be considered nonconsumptive and a component of the return flows (Peters, 2025).

(runoff), leaks out of the conveyance or distribution system, and deep percolation past the root zone due to over-application or non-uniform application (altogether, **return flows, RF**).

The total of the irrigation inefficiencies (consumptive and nonconsumptive) plus the CIR is the **total irrigation requirement (TIR)**. Therefore, this amount is a factor of the crop type, growth conditions, and irrigation system type. In practice, this is the water that flows onto the field and can be measured by a water meter. However, TIR calculated from modeled estimates does not account for human error in applying irrigation water and likely underestimates total irrigation water use, usually the deep percolation component.⁶ The TIR (in feet) can be multiplied by the irrigated area (acres) to estimate the total amount diverted or withdrawn and used for irrigation of a crop (in acre-feet):

$$\text{Total irrigation water use} = \text{TIR} \times \text{irrigated area}$$

Irrigation Application Efficiency (irrigation efficiency, or Ea) can be expressed as a ratio of the irrigation water consumptively used by the crop (CIR) divided by the total water applied that needs to be supplied by irrigation (TIR):

$$Ea = CIR/TIR$$

This ratio, usually expressed as a percentage, is useful for expressing the effectiveness of irrigation systems. Where more of the applied water is used consumptively by the crop, the irrigation efficiency will be higher (up to 100%).

⁶ <https://irrigation.wsu.edu/Content/IrrigSysEfficiency.pdf>

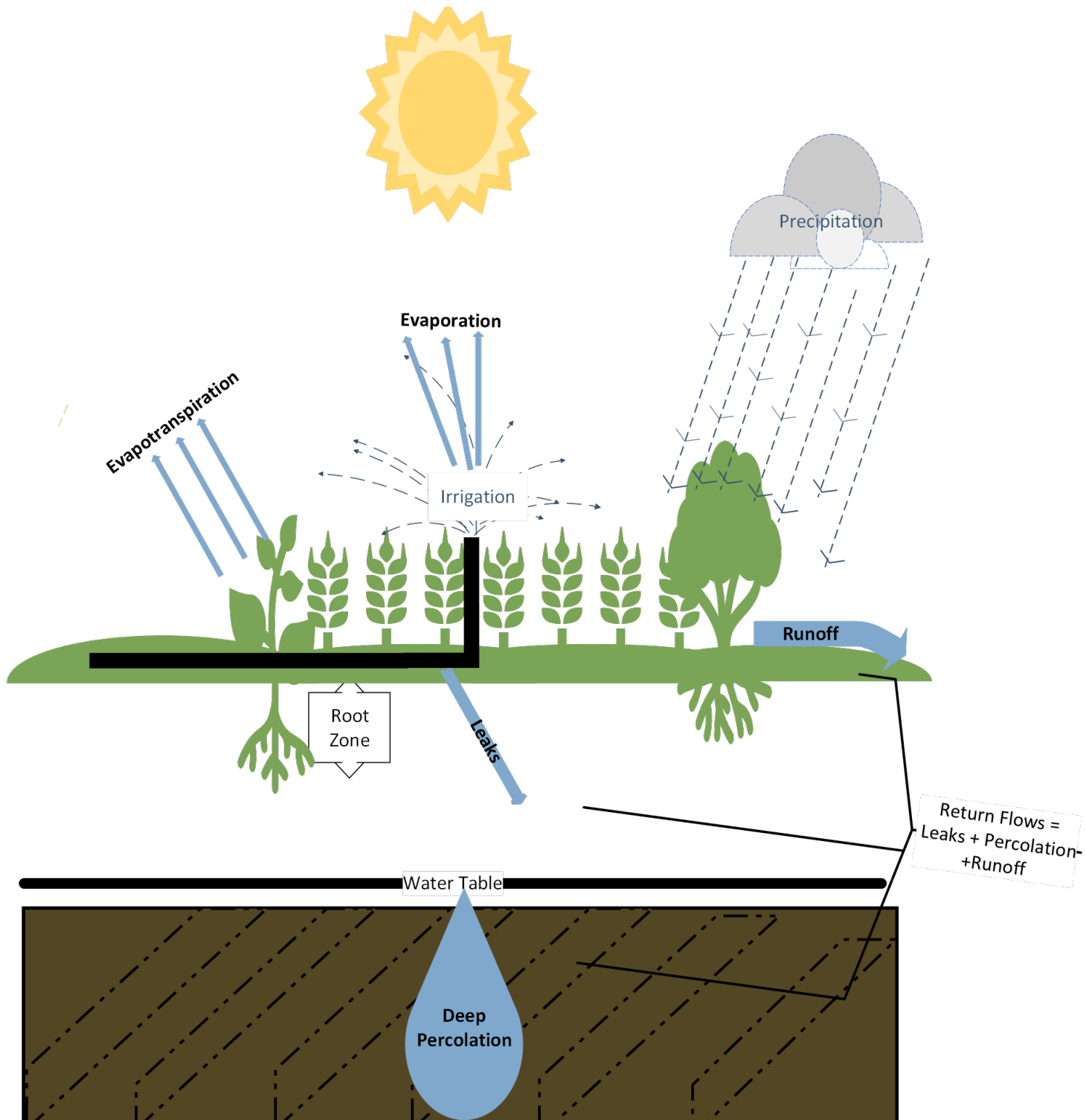


Figure 1: Irrigation Water Budget

3.2 Effective Precipitation

Precipitation (Pt) can be stored in the soil and later taken up by a crop and effectively used for crop ET, i.e., **Effective Precipitation, (Pe)**, unless it is not usable because it runs off the ground surface or exceeds the soil-water storage capacity and percolates below the crop root zone (USDA, 1993):

The crop irrigation requirement (CIR) can be estimated with what the crop needs (ET) less the amount that is provided by Pe:

$$\text{CIR} = \text{ET} - \text{Pe}$$

The contributions of Pe to the crop ET can vary in significance depending on factors such as the amount, intensity, and frequency of precipitation, the temperature and wind speed, topography, crop growth stage, depth of the root zone, and soil properties. If Pe satisfies all the crop's water needs (ET), then no irrigation is required ($\text{Pe} \geq \text{ET}$, $\text{CIR}=0$); any excess precipitation will not be effective. When no ET occurs, then $\text{Pe}=0$. Under some conditions, such as during hot and otherwise dry periods, all precipitation can be reasonably considered effective ($\text{Pe}=\text{Pt}$).

Pe is rarely measured in practice and can instead be estimated by methods that vary in complexity and ease of use. More complex methods include soil water balance models and crop modeling (Kumar et al, 2017). A simplified method to estimate monthly Pe from the U.S. Department of Agriculture Natural Resources Conservation Service (formerly the Soil Conservation Service), known as the USDA-SCS method (USDA, 1993), may be used. The Effective Water Use model (see Section 5.2 and Appendix A) uses the USDA-SCS method for estimating monthly Pe for each month of record for all WSU AgWeatherNet weather stations.

The USDA-SCS method uses the following equation to estimate monthly Pe:

$$\text{Pe} = \text{SF} \times (0.70917 \times \text{Pt}^{0.82416-0.11556}) \times 10^{(0.02426 \times \text{ETc})}$$

SF = soil water storage factor⁷

Pt = monthly precipitation

ETc = monthly crop ET⁸

⁷ The soil water storage factor is based on usable soil water storage in the crop root zone, in inches, and can vary greatly. Without site-specific information such as soil type, depth, and compaction, a usable soil water storage of 2 inches (SF = 0.93) or 3 inches (SF=1) can be assumed.

⁸ Crop ET estimations can be determined using methods described in Section 5.2.

A limitation of the USDA-SCS method is that soil water accumulation (carryover) from one month to the next is not accounted for, which may be a significant source of crop water use depending on conditions such as amount of precipitation and soil properties. Even with this recognized shortcoming, the USDA-SCS method is typically considered a reasonable method of estimation. If there are obvious discrepancies, other methods and data sources may be used at the discretion of the permit writer. Some methods, such as a soil water balance model, may require more information (ex. soil properties, daily soil water balance components, etc.) or modeling capabilities than are typically used in a water right permitting investigation.

4. Determining Irrigation Efficiency

Irrigation efficiency (Ea) can be calculated from an estimate of CIR (from data sources described in Section 5) and total irrigation water use volume measured by a water meter. The total water use volume (in acre-feet) is converted to TIR (in feet or inches, see Section 3).

$$Ea = CIR / TIR$$

When total water use is not available and Ea cannot be calculated, estimates of Ea may be used. **Table 1** summarizes the findings in the WSU irrigation efficiency white paper⁹ regarding estimates of the efficiency of each type of irrigation system as an average and a range, and quantifying the inefficiency components (runoff, deep percolation, wind drift and evaporation). %Evap is the portion of the TIR that is consumptive because it is evaporated due to the irrigation inefficiencies (rather than the CIR). Selection of the average Ea, %Evap, %CU, and %RF from Table 1 is often reasonable.

For further details on how each irrigation system's performance was determined, Ecology staff should refer to the white paper. An Irrigation Conversion Water Savings Destination calculator to estimate water savings and the destination of the water savings based on this table was developed by WSU and is available online.¹⁰

While the terms provided in Table 1 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. Irrigation efficiency is heavily dependent on the type of system, irrigation practices, and other site-specific factors. For example, conditions such as wind speed and vapor pressure deficit (aridity) can strongly influence irrigation efficiency. Where possible, a site visit and interview with the farmer should be conducted to investigate irrigation practices and conditions. The permit writer should consider such information on a case-by-case basis.

Farmers who operate systems near the higher end of the range often exhibit the following:

- Newer system infrastructure
- Active maintenance program
- "Ground-truthing" of soil moisture
- Real time leak detection
- Automation that reduces human error and inputs

⁹ <https://irrigation.wsu.edu/Content/IrrigSysEfficiency.pdf>

¹⁰ <http://irrigation.wsu.edu/Content/ConversionCalculator.html>

- Knowledge of seasonal crop ET rates
- Scheduling irrigation in response to crop demand
- Operating at the designed pressure and flow rates

Irrigation system efficiencies may change over time due to adoption of such practices.

Supporting documentation may be requested by Ecology staff to validate estimated changes in system efficiency year over year.

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

- Older system infrastructure
- Inadequate maintenance program, such as system plugs and leaks, and poorly operating pumps, valves, nozzles, gaskets, and seals
- Improper irrigation scheduling
- Operating manual systems, susceptible to human error
- Highly varying or improper pressures and flows (too high or too low)
- Site constraints (e.g. soils, topography, water delivery system)

Evaluation of the reasonableness of an irrigation efficiency estimate should recognize that water must be diverted in a quantity that compensates for inefficiencies but not exceeding those typical of the diversion/distribution systems being used. Water law precludes wasteful practices.¹¹ Only a reasonable amount of water for the type of irrigation system used can be considered in a permit decision. Wasteful practices should be reduced as much as possible. Determining reasonably efficient practices involves considering common local practices and customs and the adequacy of system maintenance.¹²

¹¹ RCW 90.03.005

¹² See *Ecology v. Grimes*, 121 Wn.2d 459, 852 P.2d 1044 (1993).

Table 1. Summary of Irrigation Efficiency Ranges, Consumptive Use, and Return Flows

Type	Irrigation System	Irrigation Efficiency Range (% Ea)	Irrigation Efficiency Avg. (% Ea _{avg})	Average Evaporated (% Evap)	Average Consumptive Use (% CU)	Average Return Flow (% RF)
Sprinkle	Pivot/Linear Mid-elevation spray application (MESA)	75-90	79	15	94	6
	Pivot/Linear Low-energy precision application (LEPA)	80-97	91	0	91	9
	Pivot/Linear Low-elevation spray application (LESA)	80-97	92	3	95	5
	Pivot/Linear (Top of Pipe)	50-70	56	40	96	4
	Hand Move	60-85	68	27	95	5
	Wheel Line	60-85	68	27	95	5
	Microsprinkler	80-90	75	18	93	7
	Undertree Orchard	75-93	77	16	93	7
	Solid Set Sprinklers	70-85	67	24	91	9
	Big Gun - Traveler	50-70	59	34	93	7
Surface	Furrow	30-90	62	6	68	32
	Graded Furrow	30-90	73	6	79	21
	Furrow w/ Surge	60-90	75	6	81	19
	Furrow w/ tailwater reuse	60-90	80	0	80	20
	Basin	40-95	75	0	75	25
	Border	40-90	65	6	71	29
	Contour Border	55-90	73	6	79	21
	Corrugation	40-75	50	7	57	43
	Wild Flood	25-85	35	8	43	57
Drip	Subsurface Drip	65-98	92	0	92	8
	Surface Drip	65-96	89	0	89	11
	Mobile Drip Irrigation	65-99	97	0	97	3

5. Determining Irrigation Consumptive Use

Historical and proposed consumptive use often must be determined in permitting decisions and always when conducting an annual consumptive quantity (ACQ) analysis. They can also be used to estimate total water use from irrigation when direct measurement is not available. Without complicated and expensive equipment, consumptive use cannot be directly measured and can only be estimated. No estimation method should be expected to be 100% accurate. Ecology staff should use their best judgement on a case-by-case basis to determine which method best reflects real-world conditions.

Per RCW 90.03.380(1)(c), the ACQ of an irrigated crop is “the estimated or actual annual amount of water diverted pursuant to the water right, reduced by the estimated annual amount of return flows, averaged over the two years of greatest use within the most recent five-year period of continuous beneficial use of the water right”. Using water meter data (as the only possible direct, on-the-ground measurement) is generally preferable over other data sources unless the meter data are deemed to be flawed or unreliable. Other records may be used to estimate total water used, including pump power records or pumping time and flow rate. However, these are often less reliable as they rely on pump and motor efficiency estimates that may not be accurate. See Section 5.1 for more information.

Where meter data or other records are not available or appear to be flawed, an ET estimate may be used to determine consumptive use (see Section 5.2). Some of the data sources and methods to determine consumptive use are described below. Some models estimate ET using a ‘reference ET’ from scientific literature, and some estimate ‘actual ET’ from satellite-data driven models. ET models do not account for situational miscellaneous crop requirements such as leaching, frost-protection, and cooling, which may be added as needed.

The Effective Water Use model (see below) is a reference ET based model that was developed by WSU irrigation expert Dr. Troy Peters in 2025 using the best available science for estimating consumptive use annually and as an average for the period of record. Annual estimates are provided for historical consumptive use analyses (ACQ), and averages are provided for best estimates of proposed water use. Ecology staff should use it as the preferred model for estimating consumptive use, and for corroborating other data sources.

Other data sources, some described below, may also be used for cases where it is shown that they are more accurate. Ecology staff can require evidence showing the validity of estimates, such as water use meter records or crop water use studies.¹³ In some cases, water use estimates should be compared across a variety of data sources to obtain the most accurate assessment of water use.

¹³ POL-1210 Section 4.c.

5.1 Determining Consumptive Use from Total Water Use

Consumptive use may be estimated using water meters (or other methods) to determine the annual amount of water diverted pursuant to the water right and reducing that amount by the estimated annual return flows from Table 1. Calculate the consumptive use by multiplying the % Total Consumptive Use (%CU) from Table 1 for the irrigation system type in use by the total annual quantity in volume (acre-feet), or the TIR in depth (inches or feet):

$$CU = \text{total water use} \times \%CU \text{ (volume)}$$

$$CU = \text{TIR} \times \%CU \text{ (depth)}$$

Ecology recommends that staff compare total water use data from the following sources against a water use estimate from the Effective Water Use model. Any significant discrepancy should be investigated to determine whether the total water use data source is reliable. If no reasonable explanation can provide for such a discrepancy, the ET based estimate may be the preferred data source for permitting decisions.

Water meter data are generally preferable over other data sources, unless deemed to be flawed or unreliable. The accuracy of meter data is dependent on the quality of the meter installation and frequency of the meter calibration. Chapter 173-173 WAC provides guidance on these procedures and requires that meters plus any secondary equipment such as data recorders register +/- 10% of the actual water passing through the system (WAC 173-173-100(2) and WAC 173-173-130(1)).

Power (energy) consumption data, where the electrical power meter is dedicated solely to a diversion pump, can be used to estimate the volume of water diverted. An equation to convert power meter data to water volume is described in WAC 173-173-160, using estimated pump and motor efficiencies, the vertical lift of system while pumping, and the number of kilowatt hours measured at the electric meter. Use of the method must be approved in writing by Ecology (WAC 173-173-160(1)(a)).

Timed pumping is a method of estimating the total volume used over a defined period using the flow rate (e.g., gallons per minute) multiplied by time (e.g., hours per day, days per week, etc.). The flow rate can be determined by either: c

- Measuring the diversion flow rate (by a clamp-on ultrasonic meter, a weir, a flume, or other method),
- Measuring or estimating the application rate of sprinkler nozzles from nozzle sizes and pressures at the sprinklers,¹⁴ or

¹⁴ <https://irrigation.wsu.edu/Content/Calculators/Sprinkler/Sprinkler-Application-Rate.php>

- Using pressure and flow rate estimates for the sprinkler from the manufacturer's literature.

Note that estimates of flow based on sprinkler application rate can vary due to varying numbers of sprinklers operating in different irrigation sets, system maintenance (e.g., different nozzle sizes due to wear or improper replacement, or system leakage). Varying system pressures can also result in different flow rates across an irrigation system if pressure regulators are not properly installed at each nozzle.

5.2 Determining Consumptive Use from ET Models

Online models provide easy-to-use estimates of crop ET that can be used to calculate irrigation consumptive use. Monthly data are usually sufficient for water right permitting decisions.

Data from web-based models are subject to change as their underlying data and methods are updated. Retaining the raw data file exported from a web-based model or a screenshot of the raw data, and documenting the date of data retrieval, is important for record keeping purposes.

There are two common methods of estimating ET from irrigation: reference ET and actual ET models. ET estimations are likely to vary by method, because the models rely on different data sources, underlying assumptions, and methods. If you have questions about the data sources, estimation accuracy, or practical applications, Ecology recommends contacting the model developers for assistance.

The **reference ET** method estimates crop water use as a function of how much water a reference crop (alfalfa or grass) needs to consume as a function of local weather conditions (via the reference ET, ET_r) as well as the actual crop's type and growth stages (via the crop coefficient, K_c). Throughout the growing season, a crop ET (ET_c , generally referred to here as ET) is calculated by multiplying the ET_r by K_c , on a daily interval:

$$ET_c = ET_r \times K_c$$

This is often presented as a monthly total, where ET_r and ET_c are typically measured in inches and K_c is a dimensionless coefficient.

The resulting ET_c is therefore crop type- and region-specific. However, reference ET estimations were developed using data from reference crops growing in well-watered, windless, and otherwise ideal growing conditions. Therefore, a reference ET approach results in a consumptive use estimate that assumes a crop is also grown under ideal conditions. Reference ET-based estimations may not reflect real-world conditions due to factors such as actual irrigation practices and customs, crop varieties, and climate variations, as well as sources of error in the ET_r and K_c .¹⁵

¹⁵ <https://irrigation.wsu.edu/Content/Fact-Sheets/IrrigationWaterRequirements4WA.pdf>

Basic information is needed to develop a consumptive use estimate using the reference ET method:

- Crop type: from applicant or, if needed, historical records such as sale records, historical property records, the Washington Department of Agriculture Crop Survey¹⁶, etc.
- Irrigated area: from applicant or, if needed, aerial imagery, parcel data, historical records, satellite data,¹⁷ etc.
- Location: choose the closest weather station with adequate data available for the model of choice.¹⁸
- Irrigation system type: from applicant or, if needed, aerial imagery, observations, etc.

ET is the sum of all the water that a plant needs to consume from all sources, including water supplied by precipitation, soil moisture, and irrigation, so the effective precipitation (Pe) must be removed to estimate the consumptive use only from irrigation (CIR):

$$\text{CIR} = \text{ET} - \text{Pe}$$

This can be combined with the irrigation efficiency to calculate TIR as:

$$\text{TIR} = \text{CIR} / \text{Ea}$$

Or, combined:

$$\text{TIR} = (\text{ET} - \text{Pe}) / \text{Ea}$$

where ET, Pe, and CIR are typically measured in inches. Some, not all, reference ET models remove the Pe to estimate the CIR (see Appendix A). Where Pe estimations are not provided, see Section 3.2.

Some, not all, reference ET models add the consumptive use from the irrigation system inefficiencies (%Evap from Table 1) to the CIR to provide the total consumptive use from irrigation. Where consumptive use is not provided, use the %CU from Table 1 to estimate the total consumptive use from CIR or ET (first calculate TIR, see above):

$$\text{CU} = \text{TIR} \times \% \text{CU}$$

Formulas for estimating ET have advanced considerably over time due to growing research and data availability, and staff should look to experts for the best available estimations. For example, the Washington Irrigation Guide Appendices A and B used Blaney-Criddle equations

¹⁶ <https://agr.wa.gov/departments/land-and-water/natural-resources/agricultural-land-use>

¹⁷ Annual composite Landsat data: <https://jstnbraaten.users.earthengine.app/view/landsat-timeseries-explorer#>
Sentinel or Landsat data (customizable), all images taken within most recent two years:
<https://jstnbraaten.users.earthengine.app/view/eo-timeseries-explorer>

¹⁸ Some weather stations should be used with caution or may not have a sufficient period of record or collect sufficient weather data for reference ET models.

and limited weather parameters and stations, as were available and considered the best available science at the time of their publication but are no longer considered to be so. The Effective Water Use model¹⁹ was developed by WSU irrigation expert Dr. Troy Peters in 2025 using all weather station data available from the WSU AgWeatherNet database of active weather stations. The reference ET, calculated using the American Society of Civil Engineers (ASCE) standardized Penman-Monteith equation, and crop coefficients used are best estimates according to Dr. Peters. Irrigation efficiencies from the white paper described in Section 4 are provided for estimating both consumptive use and total water use. The methods and data sources used therefore appear to be the best available science for estimating consumptive use using a reference ET model at the time of this publication and are therefore recommended for our typical use.

Other models²⁰ that use the reference ET method may be used where reasoning is provided as to why they are preferred over the Effective Water Use model. Some examples include:

- Washington Irrigation Water Needs (WSU)²¹
- AgWeatherNet Water Use Model (WSU)²²
- AgriMet Historical ET (Bureau of Reclamation)²³

Where there is sufficient evidence, case-by-case modifications may be made to ET estimates to better reflect real-world conditions. Some examples of evidence that may be sufficient to support modifications include:

- Peer-reviewed studies on water conservation methods or crop water needs.
- Site-specific assessments conducted by a qualified professional related to soil properties, precipitation, sub-irrigation, etc.
- Clearly documented crop water use records.

See Appendix A for guidance on using the Effective Water Use model in permit writing decisions, and Appendix B for sample calculations.

Actual ET (ET_a) refers to ET estimates from remote sensing models that reflect actual growing conditions as captured by satellite observations and integrated with weather station data.

¹⁹ <https://weather.wsu.edu/models/effective-water-use>

²⁰ The Washington Irrigation Guide (WIG), developed by the Natural Resources Conservation Service (US Department of Agriculture), crop irrigation requirements (Appendix A from 1985 and Appendix B from 1992) are not recommended for use by Ecology staff for estimating consumptive use at the time of this publication. The WIG values are considered outdated due to the methodology (FAO 24 Modified Blaney-Criddle and SCS Modified Blaney-Criddle models) and climate record (estimated as 1951-1980, with some later partial updates) used. In recent years (2021-2024), NRCS notified their staff that the WSU Washington Irrigation Water Needs model should be used in lieu of the WIG Appendices A and B.

²¹ https://irrigation.wsu.edu/Content/ET_IWR_For_WA.php

²² <https://weather.wsu.edu/>

²³ <https://www.usbr.gov/pn/agrimet/h2ouse.html>

Many of these models use the surface energy balance approach, by calculating the energy used in the evapotranspiration process as a residual of the energy balance and converting that energy estimate to a volume or depth of ET. Estimates between days with satellite observations are interpolated. Remote sensing models are an ongoing field of study, and are likely to continue improving in accuracy, resolution, and accessibility.

Actual ET (ET_a) accounts for water use from all water sources, natural (precipitation and soil water) and irrigation. To isolate the water used from irrigation, effective precipitation must be removed:

$$CU = ET_a - Pe$$

Where estimations of Pe are not provided, see the Effective Precipitation section above on how to estimate Pe. It is important to note that the USDA-SCS method of estimating Pe does not account for soil water accumulation (carryover), which may be a significant source of ET depending on factors such as amount of precipitation and soil content and characteristics.

TIR can then be calculated from the CU estimate:

$$TIR = CU / \%CU$$

OpenET²⁴ is a platform that provides estimates of actual ET from six remote sensing ET models, as well as the average ET from all six models with outliers removed, referred to as the ensemble (Melton et al, 2022). The ensemble is intended to provide a more accepted estimate of ET than any single model, by balancing out strengths and weaknesses of all the models. Accuracy studies comparing the modeled ET to ground-based ET measurements, primarily from eddy covariance stations, have shown that the ensemble outperforms any single model across a variety of agricultural settings (Volk et al, 2024). Additional studies are underway, and updates are continuously made to the OpenET platform.

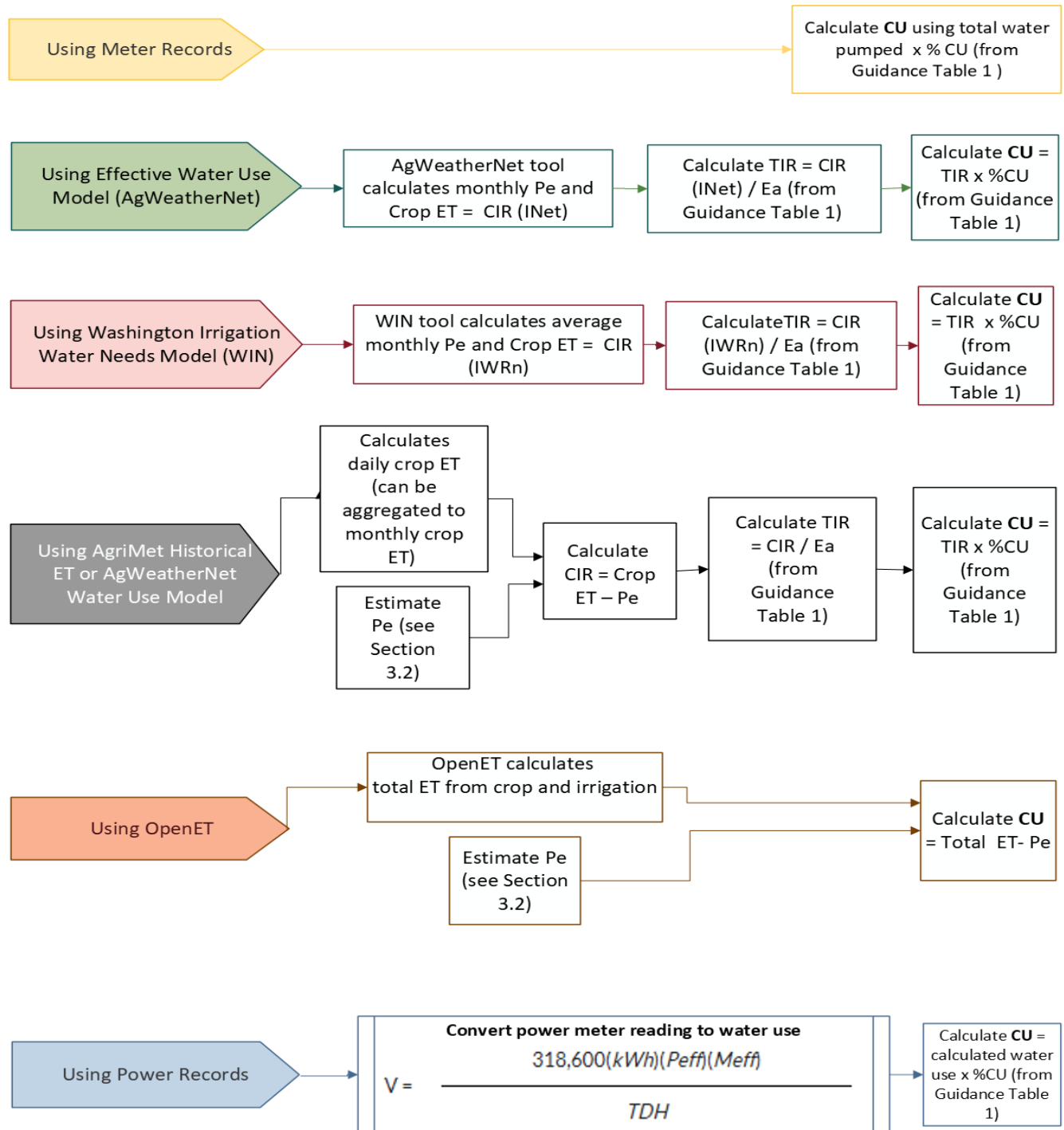
See Appendix A for guidance on using OpenET in permit writing decisions, and Appendix B for sample calculations.

²⁴ <https://openetdata.org>

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Appendix A: Steps to Estimate Consumptive Use from Various Data Sources



i: This appendix is intended to illustrate the processes fully described in the guidance document. Please reference the guidance for more details.

List of Abbreviations and Terms Used in the Appendix

CIR: crop irrigation requirement usually expressed in inches

CU: consumptive use usually expressed in inches

Ea: irrigation efficiency expressed as a ratio

ET: evapotranspiration usually expressed in inches

INet: Effective Water Use model term for crop irrigation requirement

IWRn: Washington Irrigation Water Needs model term for crop irrigation requirement

kWh: kilowatt hours for the time of pumping

Meff: motor efficiency in a decimal

Pe: effective precipitation usually expressed in inches

Peff: pump efficiency in a decimal

TDH: total dynamic head usually expressed in feet

TIR: total irrigation requirement usually expressed in inches

V: volume usually expressed in gallons

%CU: percent of consumptive use

Appendix B: Sample Calculations

Example 1: Calculating Consumptive Use Using Meter Data, and Reasonable Use Evaluation

Example scenario: A farm has 40 acres of grass (pasture) irrigated with a traveling big gun sprinkler. Their meter recorded total annual water use of 35.8 ac-ft. Based on Table 1, the average traveling big gun sprinkler is 93% consumptive (%CU=93%). Multiply to calculate the consumptive use (CU):

$$CU = 35.8 \text{ ac-ft} \times 0.93$$

$$CU = 33.3 \text{ ac-ft}$$

An extra step is to calculate the actual irrigation system efficiency (Ea), using data from the Effective Water Use model, to determine if it is reasonable and non-wasteful. Reasonably efficient irrigation practices are discussed in Section 4.

According to the weather station data closest to the farm, the average crop irrigation requirement (CIR, equivalent to WSU's term Net Irrigation Required) for the period of record is 8.4 inches. To calculate the Ea, the total water use from the meter data must be converted to TIR (in inches):

$$TIR = 35.8 \text{ acre-feet} / 40 \text{ acres}$$

$$TIR = 0.895 \text{ feet}$$

$$TIR = 0.895 \text{ feet} \times (12 \text{ inches} / 1 \text{ foot})$$

$$TIR = 10.7 \text{ inches}$$

The irrigation efficiency is calculated by dividing the CIR by the TIR:

$$Ea = 8.4 \text{ inches} / 10.7 \text{ inches}$$

$$Ea = 0.785$$

The irrigation efficiency as a percentage is therefore 78.5%, which is more efficient than the average irrigation efficiency of 59% for traveling big gun sprinklers. The irrigation efficiency is therefore considered reasonable and non-wasteful.

Example 2: Calculating Annual Consumptive Quantity Using the Effective Water Use Model

Note: The Effective Water Use model is hosted on the WSU AgWeatherNet website, which requires a free user account to access. From the home page, access the Effective Water Use tool from the menu bar by clicking on Models, then Effective Water Use under the Irrigation subheading. A copy of the raw data files should be saved for record keeping purposes.

Link: <https://weather.wsu.edu/models/effective-water-use>

Example scenario: A farm has 100 acres that is irrigated with center pivot/linear mid-elevation spray application (MESA). No water or power meter data are available. The farmer's water right allows an annual diversion of 250 ac-ft. They rotate crops annually, and in the last five years of continuous use, planted the following crops:

Year 1: Potatoes

Year 2: Beans

Year 3: Spinach

Year 4: Potatoes

Year 5: Beans

ET and Pe data for each year can be downloaded from the Effective Water Use website and used to calculate consumptive use for the Annual Consumptive Quantity evaluation.

The Effective Water Use model provides the following data for the closest weather station, all in inches:

Potatoes:

Year	May ETc	May Pe	Jun ETc	Jun Pe	Jul ETc	Jul Pe	Aug ETc	Aug Pe	Sep ETc	Sep Pe
1	2.13	0.04	6.93	0.79	10.74	0.31	8.47	0	1.58	0
4	2.6	0.39	7.06	0	9.17	0	6.61	0.18	1.04	0.05

Beans (dry):

Year	May ETc	May Pe	Jun ETc	Jun Pe	Jul ETc	Jul Pe	Aug ETc	Aug Pe
2	0.48	0.06	4.3	0	9.55	0.28	4.61	0.22
5	0.43	0.35	4.18	0	8.49	0	4.51	0.16

Spinach:

Year	Apr ETc	Apr Pe	May ETc	May Pe	Jun ETc	Jun Pe	Jul ETc	Jul Pe	Aug ETc	Aug Pe
3	2.83	0.1	4.93	0.15	6.93	0	8.12	0	0.39	0

For each month, the crop irrigation requirement (CIR) is calculated:

$$\text{CIR} = \text{ETc} - \text{Pe}$$

Determining Irrigation Efficiency and Consumptive Use

	Apr CIR	May CIR	Jun CIR	Jul CIR	Aug CIR	Sep CIR	Total CIR
Year 1 (potatoes)	0	2.09	6.14	10.43	8.47	1.58	20.24
Year 2 (beans)	0	0.42	4.3	9.27	4.39	0	18.38
Year 3 (spinach)	2.73	4.78	6.93	8.12	0.39	0	22.95
Year 4 (potatoes)	0	2.21	7.06	9.17	6.43	0.99	19.43
Year 5 (beans)	0	0.08	4.18	8.49	4.35	0	17.1

For each year, the consumptive use (CU) is calculated using %Ea and %CU from Table 1 (assumed to be average):

$$\text{TIR} = \text{CIR} / \%Ea$$

$$\text{CU} = \text{TIR} \times \%CU$$

	CIR	Ea (avg)	TIR	%CU (avg)	CU
Year 1 (potatoes)	20.24	79	25.62	94	24.08
Year 2 (beans)	18.38	79	23.27	94	21.87
Year 3 (spinach)	22.95	79	29.05	94	27.31
Year 4 (potatoes)	19.43	79	24.59	94	23.12
Year 5 (beans)	17.1	79	21.65	94	20.35

The two highest years of consumptive use are identified as Year 1 and Year 3, which average 25.7 inches. This average CU can be converted from depth to volume by multiplying the depth, 25.7 inches, by 100 acres to find the annual consumptive quantity eligible for change, 214.2 acre-feet.

Example 3: Calculating Consumptive Use and Total Water Use Using OpenET

Note: OpenET requires a free user account to access. From the home page, under the menu bar option Data Access, data can be accessed via the Data Explorer or OpenET API. A copy of the raw data files should be saved for record keeping purposes.

Link: <https://openetdata.org>

Example scenario: A farm irrigates 50 acres of various crops using surface drip irrigation. Water use, consumptive and total, can be estimated from ET data from OpenET. The ensemble results from OpenET are used in this scenario because no one model is assumed to perform better than others for this field. Data downloaded (to CSV) from the Data Explorer are provided in inches, as a running cumulative total for the year:

Month	Ensemble ET
Jan	0.3
Feb	0.4
Mar	1.3
Apr	3.4
May	6.5
Jun	12.4
Jul	20.8
Aug	27.7
Sep	31.9
Oct	33.0
Nov	33.5
Dec	34.0

The monthly ET can be calculated by removing the previous month's total. The irrigation season is known for this property to be from April to September, so the other months are taken out. The Effective Water Use model provides monthly Pe estimates from the closest weather station for the irrigation season of the year in question. The two data tables can be combined and the consumptive use (CU) estimated:

$$CU = \text{Total ET} - Pe$$

Month	Apr	May	Jun	Jul	Aug	Sep	Total
ET (in)	2.2	3.0	5.9	8.4	6.9	4.2	30.6
Pe (in)	1.2	0.6	0.3	0.1	0.0	0.2	2.4
CU (in)	1.0	2.4	5.6	8.3	6.9	4.0	28.2

The CU can be converted from depth to volume by multiplying the depth, 28.2 inches, by the area, 50 acres, for a volume of 117.5 acre-feet.

The total water use can be calculated from the consumptive use (%CU) from Table 1 for surface drip irrigation systems. Because the conditions of this property are considered to be average, the %CU is 89%.

$$\text{Total water use} = \text{CU} / \% \text{CU}$$

$$\text{Total water use} = 117.5 \text{ acre-feet} / 89\%$$

$$\text{Total water use} = 132.0 \text{ acre-feet}$$