Technical Workshop on
Water Use Efficiency of Irrigation Practices

Date: November 29-30, 2004 (Monday and Tuesday)

Location: Red Lion Inn, Pasco, Washington

Participants: Dan Haller, P.E., Washington Department of Ecology, Central Regional Office
Dennis Kincaid, PhD, USDA-Agricultural Research Station (ARS), Idaho
Darryll Olsen, PhD, Benton County Water Conservancy Board (BCCB)
Leigh Nelson, P.E., United States Department of Agriculture (USDA)
Mark Nielson, Franklin Conservation District (FCD)
Robert Montgomery, P.E., Montgomery Water Group
Tom Spofford, P.E., USDA, Washington, DC (invited)
Robert Stevens, PhD, Washington State University
Allen Thompson, PhD, University of Missouri
Paul Wattenburger, PhD, P.E., IRZ Consulting
Fred Ziari, P.E., IRZ Consulting (FACILITATOR)

DRAFT AGENDA

Monday, November 29th, 2004

8:30 – 8:45 a.m. Introductions, Agenda Review, Group Process. (Fred Ziari, Workshop Facilitator and Participant)

8:45 – 9:10 a.m. Context for the Technical Workshop (20 min. presentations; 5 min. discussion)

1. Welcome; Washington Water Law (Keith Phillips)
2. Implications for Water Right Changes (Dan Haller)
3. Statutory context for return flows (Darryll Olsen)

9:10 – 9:30 a.m. Irrigation Requirements: Evapotranspiration, Frost Protection, Cooling, Salt Leaching, Germination, Return Period. (Leigh Nelson/15 min. presentation; 5 min. discussion)

9:30 – 9:45 a.m. Defining Key Water Use Components of the On-Farm Irrigation Water Budget: Evaporation (spray, canopy, soil), Transpiration, Wind Drift, Soil Reservoir, Leaks, Runoff, Deep Percolation. (Allen Thompson/10 min. presentation; 5 min. discussion)

9:45 – 10:15 a.m. Plant Evapotranspiration. (Paul Wattenburger/10 min. presentation, Allen Thompson/5 min. opening comments; 15 min. discussion)

10:15 – 10:30 a.m. Break

10:30 – 11:00 a.m. Spray Evaporative Loss and Wind Drift. (Dennis Kincaid/10 min. presentation; 20 min. discussion)

11:00 – 11:30 a.m. Canopy Loss. (Allen Thompson, 10 min. presentation; 20 min. discussion)

11:30 – 12:00 p.m. Irrigation Scheduling and the Soil Reservoir. (Bob Stevens, 10 min. presentation; 20 min. discussion)

12:00 – 1:00 p.m. Lunch

1:00 – 1:45 p.m. Irrigation Uniformity, Measurements and Estimates. (Mark Nielson, 15 min. presentation; 30 min. discussion)

1:45 – 2:30 p.m. Return Flows -- Deep Percolation and Runoff. (Bob Stevens, 15 min. presentation, Mark Nielson/5 min. opening comments; 25 min. discussion)

2:30 – 3:30 p.m. Sources of Irrigation Information in Washington – Benefits and Limitations, ET and Efficiency Assumptions. (Tom Spofford or his designee, 30 min. presentation, 30 min. discussion)

1. Washington Irrigation Guide, USDA/SCS/WSU (1985)
2. Irrigation Requirements for Washington, WSU, XB0925 (1982)
3. National Engineering Guide (USDA)
4. PAWS (WSU Cooperative Extension)
5. AGRIMET (Bureau of Reclamation)

3:30 – 3:45 a.m. Break

3:45 – 4:45 p.m. Irrigation Efficiencies: How are they calculated, what are the published ranges for different irrigation systems, how is it defined in Washington? (Tom Spofford or Leigh Nelson, 30 min. presentation, 30 min. discussion)

4:45 – 5:00 p.m. Summary of Monday's discussion; Preview of topics for Tuesday (Facilitator)

Tuesday, November 30th, 2004

8:30 – 10:30 a.m. From current understanding and information, which factors should be considered when determining irrigation efficiency, and how are those factors defined and bounded? (Facilitated Discussion for All)

1. What ET values should be used?
2. What efficiency values should be used?
3. What are the consumptive and nonconsumptive portions of irrigation efficiency for different irrigation systems?
4. What is the accuracy of our estimation methods?
5. How sensitive is the outcome to different assumptions?

10:30 – 10:45 a.m. Break

10:45 – 12:00 p.m. Recommendations on a Practical Approach. (Facilitated Discussion for All)

For the task of estimating the consumptive use of water in a given irrigation water rights case, how can irrigation efficiency be determined in a practical manner?

Updating the Washington Irrigation Guide

In 2008, the Department of Ecology (Ecology), Washington State University (WSU), and the United States Department of Agriculture's Natural Resource Conservation Service (NRCS) funded a project to update the Washington Irrigation Guide (WIG). This publication is the standard in Washington State for estimating crop water needs.

Q: Has the WIG ever been updated before?

A: Yes. The current WIG was published in 1985, with supplemental data added in 1992. Prior to the current WIG, similar publications were developed in 1982 (*Irrigation Requirements for Washington—Estimates and Methodology, or "Bulletin XB0925"*) and 1969 (*Circular 512*).

Q: Why update the WIG now?

A: There are 3 reasons that Ecology, WSU and NRCS decided to collaborate on an update to the WIG. First, it is an important guidance document used today by farmers, irrigation design professionals, and state agencies in their daily work. Having the most accurate and up-to-date information is important to those that use the WIG. Second, several decades worth of new climate data are available. The WIG uses climate data to estimate crop water needs. And third, better scientific formulas are now available to estimate crop water needs.

Q: Are there different methods to estimate crop water needs?

A: Yes. There are over 50 scientific formulae to estimate evapotranspiration (ET). ET is a term used to describe the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere. ET, combined with how much water is available from rainfall, determines how much irrigation water is needed to grow a crop. *Circular 512* (1969) used the modified Blaney-Criddle method to estimate ET, while *Bulletin XB0925* relied on the Doorenbos and Pruitt Blaney-Criddle method. The WIG (1985/1992) relied on both the FAO 24 Modified Blaney-Criddle and SCS Modified Blaney-Criddle methods. The current method for the new WIG will rely on the ASCE Standardized Penman-Monteith method.

FOR MORE INFORMATION

Information on this topic can be accessed through Ecology's website. The address is:
http://www.ecy.wa.gov/programs/wr/wig/wig.html

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The Penman-Monteith method predicts ET based on actual data and assumptions about local area temperatures, wind speed, solar radiation, and precipitation.

Q: How does the method of estimating ET affect how much water the crop needs?

A: Depending on what method is used, the estimate of crop water need can vary by ± 25%. For this reason, the American Society of Civil Engineers did a study of the most appropriate ET method to use when estimating crop water needs and determined that the Penman-Monteith method was preferable.

Q: How does the data in the Penman-Monteith equation affect crop water needs?

A: The current WIG (1985/1992) is based on average climate conditions from 1951 to 1980 over a limited number of weather stations. We now have access to many more stations around the state, and more recent data on rainfall, temperature, wind, relative humidity, solar radiation and other data. By updating the WIG to include newer data, the crop water needs will be more accurately predicted. WSU & NRCS applied standardized data cleaning methods to ensure that the data being used in the new WIG were based on best available science.

Q: How are peak water needs estimated?

A: The current WIG (1985/1992) included a method to translate average daily use to peak daily use to help in sizing irrigation infrastructure. However, the peak day estimate was still based on average rainfall and temperature conditions (as opposed to a drought year). *Bulletin XB0925* provided tables that showed the variation between average years and drought conditions on a 1:5, 1:10, and 1:20 year frequency. The new WIG will incorporate both of these tools allowing the user to specify the data set that best meets their need.

Q: Are peak water needs due to drought significantly different than average water needs?

A: Crops require more water in droughts because temperatures are hotter and rainfall is lower. Crops cannot always get the water they need during drought because water may not be physically available from the source, or legally available under the water right. If water is available, then crops may consume on the order of 10 to 15% more water depending on the severity of the drought. For example, *Bulletin XB0925* published crop water needs for average and drought years. Pasture in Ellensburg in an average year requires 32 inches, while in a 20-year drought it would need 36 inches. A particular water user's reaction to drought varies, from diverting more water if available, to diverting the same amount of water and becoming 10% more efficient that year, to diverting the same amount of water and deficit irrigating the crop that year which reduces crop yield.

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Q: How well documented was the old WIG?

A: Unfortunately, much of our understanding of how the old WIG was developed has been lost to time. We know the method of calculation and the data set used to develop the tables estimating crop water use. However, over the last 25 years, much of the actual data have been lost and the institutional memory of how it was developed is no longer available from the original authors. For example, the actual data sets and computations are not available, a bibliography of sources that provided the data are not available, data cleaning methods were not described, and sources of crop coefficients used to translate reference ET (e.g. grass) to a specific crop (e.g. apples) cannot be replicated. So while the WIG remains the standard ET guidance in Washington today, the underlying data are not well-documented. By contrast, all of the data in the new WIG will be documented, peer-reviewed and available, with both a written-published document and a web application.



Q: What is different in the results between the old WIG and the new WIG?

A: There are many differences that will be interesting to users of the WIG:

- The number of stations for which results are available increased from 90 to 232.
- The number of crops for which results are available increased from 40 to 76.
- Depending on specific locations, some crop irrigation requirements increase and some decrease.

Q: Does Ecology use the WIG when evaluating water rights?

A: Yes. Ecology routinely uses the current WIG when evaluating applications for new water right permits and applications for water right changes and transfers. In some cases this is required by statute because some water right transfer applications trigger a "consumptive use analysis," which requires Ecology to determine how much water is lost to ET from an irrigation water right. The WIG is the best source of information available to Ecology to comply with this statutory requirement. In other cases, Ecology uses information from the WIG, along with aerial photographs, to estimate historical water use when metered water or power data are not available to ascertain the extent that water was put to beneficial use in the past. When Ecology tentatively determines the extent and validity of a water right for the purpose of evaluating a water right transfer application, it tries to use multiple data sources to come up with the most accurate answer possible.

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Q: Until the new WIG is completed, what data will Ecology use when evaluating water rights?

A: Until the new WIG has been peer-reviewed and gone through a robust public review process, Ecology will continue using the old WIG. Ecology wants to make sure it and the public have confidence in the new numbers before adopting them and training staff in their use.

Q: Once the new WIG is finalized, will Ecology allow applicants to use the old WIG or an ET estimate other than the Penman-Monteith method?

A: Not unless there is a compelling scientific basis to do so. The new WIG is based on the best method available for estimating ET in Washington State, the most comprehensive data set available, and a peer-reviewed work product. Other methods and data sets may yield higher (or lower) numbers, but they won't necessarily be more accurate. Ecology will consider such requests on a case-by-case basis.

Q: What data set will Ecology use when evaluating water rights?

A: It depends on the type of analysis Ecology is required to do by statute. Generally, Ecology will try and match the data set to the statutory test prescribed.

- For extent and validity determinations, Ecology will use the WIG long-term average which is based on the most recent 30 year data set from 1980 to 2010. WSU and NRCS considered whether longer data sets would affect results, and generally the correlation was within an inch, so a standardized 30 year data set was selected for all of the stations.
- For new water right application, Ecology will use the WIG long-term average as a starting point for a reasonable water duty. However, it will also consider drought frequency in the local area and the ability of the proposed irrigation system to adapt to changing crop water demands. Ultimately, a certificate will only issue for the quantity of water put to beneficial use.
- For annual consumptive quantity (ACQ) evaluations triggered when someone seeks to add acres or purposes of use to a water right, or for trust water donations, Ecology will use the most recent 5-year period of water use directed in the statute.
- For impairment evaluations based on a consumptive use evaluation, Ecology will consider the highest consumptive use over the life history of the water right.
- For drought transfers, Ecology will consider using the climate data that best correspond to the frequency of the drought being experienced.

Q: What if I recently got a water right transfer approved under the old WIG and the new WIG would have given me a higher number?

A: Because Ecology typically uses multiple data sources to estimate historical beneficial use, it does not expect that the WIG update will dramatically affect recent decisions. However, Ecology's change authorizations are permissive and its extent and validity determinations are tentative in nature. An applicant may cancel a change authorization which remains in a valid development schedule, and may re-file a change application and seek a new tentative determination. Ecology will consider such applications on a case-by-case basis. In addition to the new WIG data, Ecology may require corroborating evidence

such as power or meter records, irrigation scheduling, or production records to confirm historical water use under the water right.

Q: What if the old WIG numbers were used in adjudicating my water right?

A: An adjudication court's determination of the extent and validity of a water right is final. If the court relied on the old WIG as part of the evidence of the total annual quantity confirmed, then changes in the new WIG cannot change the total annual quantity authorized (unlike for changes where Ecology's decisions are only tentative). However, adjudication courts typically do not assign a consumptive use value as an express limit of an adjudicated water right. Therefore, future transfers on adjudicated water rights can rely on the new WIG as one of several data sources in evaluating historical beneficial use.

Q: Will the WIG be updated in the future?

A: Yes. This is the fourth time the State has updated this guidance document and updates will occur in the future. It is likely that future updates will occur more often (e.g. every 5 years) rather than 25+ years apart since the last update to the WIG.

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GUID-1210 WATER RESOURCES PROGRAM GUIDANCE

DETERMINING IRRIGATION EFFICIENCY AND CONSUMPTIVE USE

Forward

In 2002, Ecology's Water Resources Program "Internal Policy Team" (IPT) began working on internal guidance for implementation of the "annual consumptive quantity" (ACQ) test required under RCW 90.03.380. The two-year effort culminated in the adoption of POL 1210 and PRO 1210, a policy and procedure to assist permit writers in administering this test. The need for further guidance was discussed in early 2004 around irrigation efficiency and determining consumptive use for ACQ-related changes. Because the need to understand and quantify consumptive use spanned multiple purposes of use (e.g. irrigation, dairy, stockwatering, domestic, industrial, etc.), IPT determined that revision and adoption of the internal Water Allocation Guidelines (PRO 1070, unsigned) would be necessary. Based on IPT's current workplan, this effort is slated for 2005.

In October 2004, the Benton County and Franklin County Water Conservancy Boards filed a lawsuit in Benton County Superior Court objecting to Ecology's selection of irrigation efficiencies and quantification of consumptive use associated with irrigation water right changes. Ecology and the Board's settled this lawsuit by agreeing to hold an irrigation efficiencies technical workshop to address this topic.

On November 29-30, 2004, Ecology held the workshop in Pasco, Washington. The conference was attended by irrigation experts from academia, government, and the private sector[1]. Dan Haller participated in the workshop on behalf of Ecology and Darryll Olsen participated on the behalf of the conservancy boards. 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. As the two-day workshop progressed, it was clear that this was an ambitious goal, with many variables, room for debate on issues of science and on-farm application, and challenges in measurement. Despite these challenges, Ecology did come away with a number of sound recommendations to address its core goals, including the following:

1. USDA-NRCS has prepared a National Irrigation Guide and is working on a new Washington State supplement to the National Guide. By January 2005, USDA-NRCS plans to submit a draft supplement for stakeholder review.

   Ecology plans to participate in this review and provide USDA-NRCS with a better understanding of how our permit writers use irrigation guides.

[1] Tom Spofford, USDA, Washington, D.C.; Leigh Nelson, USDA-NRCS, Ephrata; Allen Thompson, University of Missouri; Dennis Kincaid, USDA-ARS, Idaho; Robert Stevens, WSU, Prosser; Mark Nielson, Franklin County Conservation District, Pasco; Robert Montgomery, Montgomery Water Group, Kirkland; Fred Ziari and Paul Wattenburger, IRZ Consulting, Hermiston, Oregon.

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2. Within 2 years, USDA expects to update the crop irrigation requirement portion of the Washington Irrigation Guide. The new standard methodology is expected to be based on the Penman-Monteith ET equation, which was recently adopted by ASCE, after a prolonged study of more than 50 ET equations, as being the most accurate and easy to use. USDA has a simplified computer program to assist its staff in calculating ET that is currently based on the Blanney-Criddle formula. Part of the 2-year effort is expected to be updating this program to the new methodology. The software allows the user to specify the data set to calculate ET, which can include a long-term average (e.g. 30 years as in the case of the WIG), or year-by-year (which may be useful in ACQ calculations which require an average of the highest 2-years within the most recent five year period).

   Ecology plans to adopt USDA methodologies in quantifying ET and will consider use of the free USDA software internally for use with its permit writers.

   In the interim, Ecology will continue to use the Washington Irrigation Guide (WIG) as the definitive irrigation guidance document for the State, and will also use WSU PAWS, and the Bureau of Reclamation's AgriMet sites for supplemental information depending on the proximity of monitoring stations to proposed project sites, availability of data and the type of change requested. While Ecology is coordinating with USDA on adoption of new methodologies for the State, Ecology agrees that the use of WIG by water conservancy boards is appropriate. Following Ecology's adoption of a new State standard, Ecology will provide updated information and training to water conservancy boards.

3. USDA-NRCS is willing to assist with training of Ecology staff on irrigation efficiency, and calculation of ET and consumptive use.

   Ecology will work with USDA over the next 2 years to determine an appropriate training level.

4. The experts determined that there is no one irrigation efficiency number that can be applied to all irrigation systems of a particular type (e.g. center pivot or wheel line). 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. The experts recommended ranges for the different types of irrigation systems and identified a 2002 journal article[2] by Terry Howell, USDA as a good foundation for these ranges.

   Ecology has included a table of irrigation efficiency ranges within this guidance document, including directions for permit writers to use in assessing irrigation

[2] *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.

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management practices and determining how to select an appropriate irrigation efficiency from the range[3].

5. 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, 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).

   Ecology has included a table of the consumptive/non-consumptive balance of irrigation efficiency within this guidance document.

The following guidance document only provides information on consumptive use associated with irrigation use. Consistent with the IPT's workplan, development of consumptive use guidance on other irrigation issues (e.g. frost protection and cooling) and on non-irrigation issues (e.g. domestic, industrial, stockwatering, etc.) will be forthcoming.

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[3] Table 1 in the guidance document attached is contains a few modifications made by Ecology following the workshop. Notably, this includes the addition of common irrigation systems not discussed at the workshop (e.g. flood, lateral-move, handline), modification to the solid-set/wheelline sprinkler efficiencies, and additional description for the consumptive/non-consumptive portions of the irrigation efficiency.

DETERMINING IRRIGATION EFFICIENCY AND CONSUMPTIVE USE

Resource Contact:	Policy and Planning Section	Effective Date:	DRAFT
		Revised:	NEW

References: RCW 90.03.290, RCW 90.03.380(1), RCW 90.44.100, POL 1120, POL 1210, PRO 1210

Purpose: The purpose of this document is to provide guidance to water resources permitting staff for:

1. Determining irrigation efficiency; and
2. Determining consumptive use associated with irrigation.

Application:

1. When issuing new water rights for irrigation purpose of use, and when conducting tentative determinations of existing irrigation water rights, Ecology frequently must estimate or determine irrigation efficiency.
2. Ecology must determine the consumptive use of an irrigation right when:
   a. 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; and
   b. A change to enable irrigation of additional acres or an additional purpose of use is proposed, requiring application of the Annual Consumptive Quantity test.

Resources:

1. State of Washington Irrigation Guide (WIG), 1985 (amended 1990, amended 1992 for select western Washington crops)
2. Irrigation Requirements for Washington—Estimates and Methodology, 1982 (XB0925, reprinted 2001 EB1513)
3. National Irrigation Guide, 1997[4]
4. National Engineering Handbook, 1993[5]
5. WSU Public Agricultural Weather System (PAWS)[6]
6. Bureau of Reclamation AgriMet[7]

[4] http://www.wcc.nrcs.usda.gov/nrcsirrig/irrig-handbooks-part652.html
[5] http://www.info.usda.gov/CED/
[6] http://index.prosser.wsu.edu/
[7] http://www.usbr.gov/pn/agrimet/

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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

- "**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. It is defined as the ratio of the average low-quarter depth of infiltration to the average depth of infiltration.

- "**Evapotranspiration (ET)**". The sum total of plant transpiration, evaporation off of the plant foliage and the soil surface, and water used for plant growth.

- "**Field Capacity**". The water content at which drainage becomes negligible in a free-draining soil.

- "**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 minimum soil-water content when plants permanently wilt.

- "**Return Flow**". The sum of deep percolation and runoff that returns to waters of the State.

- "**Root Zone**". The effective depth of crop roots in the soil from which water is extracted.

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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.

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[8].

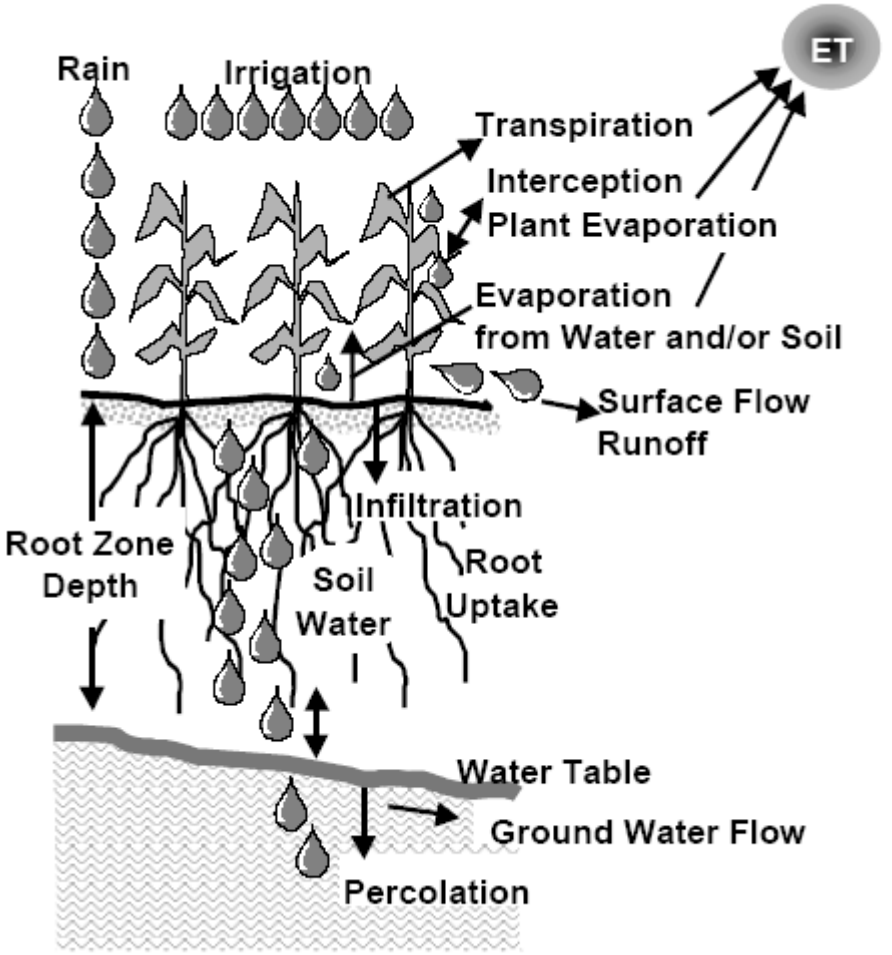


Figure 1: The Irrigation Water Budget

[8] 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 on the following page 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 site 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 demands 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[9]. The amount of water held on the canopy depends on crop leaf area, crop type, and growing season. 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%. Net canopy losses can be greater (10% or more) when application rates are low (e.g. center-pivots at high rotation speeds).

[9] Although XB0925 indicates that the crop irrigation requirements in Appendix B of the WIG include evaporation off the plant foliage, this does 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.

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- *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, it is considered return flow.

    - *Leaks*. Leaks are a function of system 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.

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

Method		Application Efficiency, Ea (%)[2]		Consumptive Use		Return Flow [5]
		Range	Average	%Ea Consumed [3]	CU Eff. [4]	Average
Surface:	Graded Furrow	50 – 80	65	5	95	30
	w/ tailwater reuse	60 – 90	75	5	95	20
	Level Furrow	65 – 95	80	5	95	15
	Graded Border	50 – 80	65	5	95	30
	Level Basins	80 – 95	85	5	95	10
	Flood	35 – 60	50	5	95	45
Sprinkler:	Periodic Move (Handline)	60 – 85	75	10	90	15
	Side Roll (Wheelline)	60 – 85	75	10	90	15
	Moving Big Gun	55 – 75	65	10	90	25
	Solid-Set—Overtree	55 – 80	70	15	85	15
	Solid Set--Undertree	60 – 85	75	10	90	15
Center-Pivot	Impact heads w/end gun	75 – 90	80	15	85	5
	Spray heads w/o end gun	75 – 95	90	10	90	0
	LEPA w/o end gun	80 – 98	92	5	95	3
Lateral-Move	Spray heads w/hose feed	75 – 95	90	10	90	0
	Spray heads w/canal feed	70 – 95	85	10	90	5
Microirrigation:	Trickle/Drip	70 – 95	88	5	95	7
	Subsurface Drip	75 – 95	90	0	100	10
	Microspray	70 – 95	85	10	90	5

1. The data presented herein should be used in conjunction with data gathered during the site investigation on a case-by-case basis. Historic irrigation practices for the individual farm will affect where in the efficiency range a particular water right applicant falls.
2. Ea = ET / Total Use. Total use can be obtained from water meter readings, estimated from power readings, or estimated from system capacity x run time.
3. %Ea Consumed reflects the portion of the irrigation efficiency that is consumptively used through evaporation (spray, wind, canopy) in addition to the ET.
4. CU Eff is the efficiency term to be used in the ACQ calculation and is equal to 100% - % Ea Consumed. For example, for a given year and crop, the Consumptive Use = ET / CU Eff. For a surface irrigation system, only an additional 5% above the ET is consumed, while in a center-pivot with impact heads, 15% above the ET is consumed. CU Eff values are based on the average Ea. If actual efficiency is less than the average, CU Eff does not typically increase; rather, additional return flow is present and can be a part of the tentative determination as long as the magnitude of the return flow does not constitute waste as defined in RCW 90.03.005. If actual efficiency is higher than the average, than the permit writer needs to determine how to reduce CU Eff and return flow quantities on a case-by-case basis. Systems more efficient than the average may reflect deficit irrigation or well-managed irrigation scheduling which would serve to reduce the return flow quantities before reducing CU Eff.
5. Average Return Flow = CU Eff – Ea Average. For systems with lower than average efficiency, return flows will be proportionately larger.

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How Do I Use Table 1 When Making a Tentative Determination of the Extent and Validity of an Existing Water Right?[10]

When making a tentative determination of the extent and validity of 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 is less than the ranges shown, the permit writer should consider whether such use is reasonable or whether it is waste of water as defined in RCW 90.03.005. If efficiency is higher than the range shown, this can inform the permit writer that the full ET may not have been satisfied (e.g. deficit irrigation).

If actual efficiency cannot be calculated due to unavailability of data, then the tentative determination is often made 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[11].
- Selection of an average efficiency from Table 1 is reasonable. The permit writer may also consider local custom 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.

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.[12]

- If the estimated or calculated efficiency is *equal* to the average Ea, the consumptive portion and average return flow portion of the Ea can be read directly from the table. For ACQ or consumptive use calculations, the crop ET can be divided by the term CU Eff to obtain the consumptive water duty per acre of land. Multiplying this value by the total acres provides the

[10] See POL 1120 for a more comprehensive discussion of tentative determinations.
[11] 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.
[12] 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).

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total consumptive use under the water right.

  - Example. Power meter data and the WIG are used to calculate an actual efficiency of 75% for handline sprinklers (an average system). Of the Ea term, 10% is consumed and 15% is return flow. For a crop ET of 3 feet, the total water duty (including return flow) is 3 feet / 0.75 or 4 feet. The consumptive water duty is 3 feet / 0.90 or 3.3 feet. 0.7 feet per acre is return flow.

- If the estimated or calculated efficiency is *less* than the average Ea, the consumptive portion of the Ea can be read directly from the table subject to site-specific information collected in the field by the permit writer. The return flow portion of the Ea will be the average return flow portion plus the difference in *project* efficiency and the *average* efficiency.

  - Example. Water meter data and the WIG 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 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. Of the Ea term, 10% is consumed and 32% is return flow. For a crop ET of 3 feet, the total water duty is 3 feet / 0.58 or 5.2 feet. The consumptive water duty is 3 feet / 0.9 or 3.3 feet. 1.9 feet per acre is return flow.

- If the estimated or calculated efficiency is *greater* than the average Ea, the consumptive portion of the Ea and the average return flow must also be consumed. Typically, systems that are more efficient than the average will first reduce return flow and then reduce consumptive use (e.g. deficit irrigation). The permit writer should obtain information on irrigation scheduling for the project to determine the consumptive / non-consumptive balance.

  - Example. Power meter data and the PAWS are used to calculate an actual efficiency of 85% for wheelline sprinklers. 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 concluded that of the Ea term, 10% is consumed and 5% is return flow. For a crop ET of 3 feet, the total water duty is 3 feet / 0.85 or 3.5 feet. The consumptive water duty is 3 feet / 0.9 or 3.3 feet. 0.2 feet per acre is return flow.

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. 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 a tentative determination of the extent and validity of the existing water right(s). This can inform the permit writer as to the actual efficiency of the project.

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 local custom in selecting an appropriate irrigation efficiency.

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