HOW MUCH WATER DOES WHATCOM IRRIGATION ACTUALLY USE?[1]

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The simple answer is we don't know. We have various ways to estimate water use but almost no direct measurements of real-world, on-the-ground farm water use.

Why does that matter? Aren't estimates good enough? The answers depend on how the information is to be used. If we are interested only in rough estimates of the amount of water used for irrigation, the existing methods are okay. But if we are:

- Planning for possible future droughts,
- Implementing drought-response measures,
- Assessing the benefits of alternative irrigation technologies and scheduling practices,
- Assessing the hydraulic continuity between groundwater and surface waters,
- Estimating the costs and benefits of alternative water-supply and water-efficiency projects,
- Deciding who pays for new supplies and how much,

then – no – estimates will not do. In addition, accurate information on irrigation water use is essential because that sector accounts for about 70% of Whatcom County summer water.

To explore the similarities and differences among various methods that calculate irrigation water use, I compare five approaches, four based on evapotranspiration (ET) coefficients and the fifth using electricity consumption data for pumping irrigation water. The ET methods include ones developed by RH2 Engineering (RH2),[2] Washington State University (WSU),[3] Hirst,[4] and the Lower Nooksack Water Budget (LN).[5] The electricity data are from Puget Sound Energy (PSE). The Appendix explains these methods.

The remainder of this paper presents key results and their meaning. I focus on the main crops grown in Whatcom County – Grass/hay, Blueberry, Field Corn, Potato, and Raspberry – which

[1] I thank Tom Buroker, Andy Dunn, Greg Ebe, John Gillies, and Marty Maberry for their helpful comments on a draft of this paper.

[2] RH2 Engineering, *Quantification of Agricultural Irrigation Water Use and Water Rights*, prepared for PUD #1 of Whatcom County, Dec. 2016.

[3] Weather.wsu.edu.

[4] E. Hirst, *Whatcom Irrigation Water Use*, May 2016.

[5] J. Greenberg, "Water Management: Agricultural Water Use," Chapt. 7 in C. Bandaragoda, et al., *Lower Nooksack Water Budget*, Whatcom County, WA: WRIA 1 Joint Board, Dec. 2012.

account for 40,600 acres (98% of the total irrigated land).[6] To ensure a consistent comparison among methods, I use the same estimates of irrigated acreage and irrigation system efficiency[7] for the RH2, WSU, Hirst, and LN methods (Table 1 in the Appendix).

Before comparing results, recognize that the amount of irrigation water used for a particular field depends on many factors. These factors include crop type, irrigation-system type, maintenance of the irrigation equipment, soil characteristics, soil moisture, irrigation scheduling practices, and local weather conditions (rain, air temperature, humidity, solar insolation, wind speed, and so on). In addition, farmer decisions on whether to grow and/or irrigate field corn and grass depend on the price of the crop and current weather conditions.

ANNUAL RESULTS

Total Water Use: The RH2, WSU, Hirst and LN methods differ substantially in their estimates of water use across the five crops considered here (Fig. 1). The RH2 and Hirst estimates are close, and the WSU and LN numbers are similar. But, the WSU estimate is 70% greater than the Hirst estimate. This difference of 38,300 acre-feet a year is four times more than the City of Bellingham's annual water use (about 3 billion gallons/year).

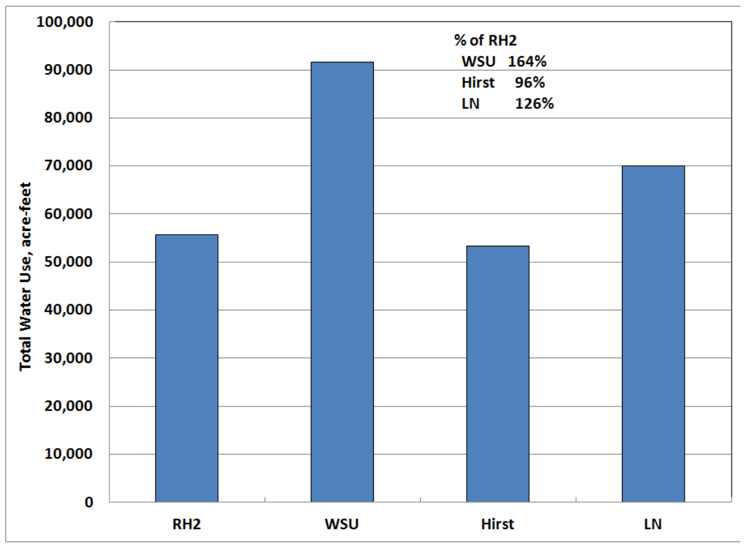

Fig. 1. Annual water use for agricultural irrigation in Whatcom County.

Water Use by Crop: The WSU, RH2, and Hirst methods show that grass uses the most irrigation water (Fig. 2). However, the methods differ on the relative water use for the other four crops. For example, the least water-intensive crop is raspberries according to WSU, blueberries according to Hirst, and corn according to RH2. These methods also differ in their estimates of the relative water-intensity of crops, with the ratio of the least-to-most water-intensive crop ranging from 54% for Hirst to 56% for RH2 and 68% for WSU. That is, the WSU method shows the least variation in water use among these five crops and the Hirst method shows the largest variation.

[6] These 2014 acreage estimates are from the Washington State Dept. of Agriculture (WSDA). The U.S. Dept. of Agriculture 2012 Census of Agriculture identified 35,500 acres of irrigated farmland in Whatcom County. Land and crops not considered here include: golf courses, Christmas trees, nurseries, and, of course, land that is not irrigated.

[7] Washington Dept. of Ecology, GUID-1210, *Water Resources Program Guidance: Determining Irrigation Efficiency and Consumptive Use*, Oct. 11, 2005.

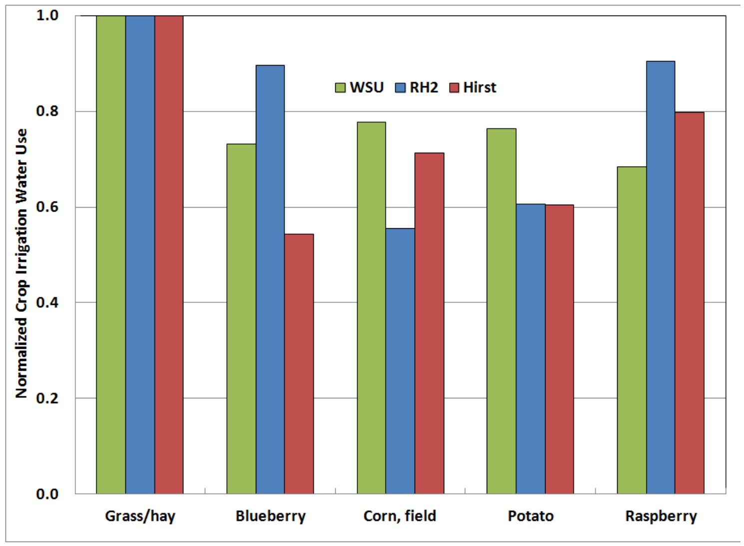

Fig. 2. Normalized (to grass) annual water use by crop type.

<u>Water Use by Year:</u> The WSU, Hirst, and PSE methods all estimate water use for individual years (Fig. 3), in this case 2013 through 2016. (The first two methods estimate water use directly, while the PSE electricity-use data provides only an indirect measure of water use.) These results are normalized to 2015, a drought year, when water use is expected to be unusually high. All three methods show lower water use for 2013 and 2014, with the PSE numbers showing much larger differences. Perhaps surprisingly, the Hirst method estimates 2016 water use higher than that for 2015.[8] The WSU and PSE methods show lower water use in 2016.

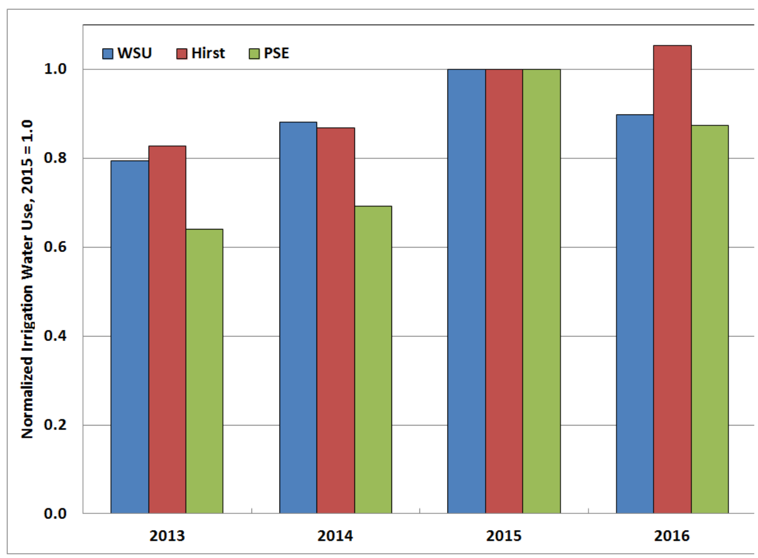

Fig. 3. Normalized (to 2015) annual water use by year.

MONTHLY RESULTS

<u>Normalized Water Use:</u> The methods show peak water use in July (WSU, LN) or August (Hirst, PSE), as shown in Fig. 4. The WSU and LN methods show much greater water use during the spring months (April through June) than do the Hirst and PSE approaches. The Hirst method shows zero irrigation water use in April and October. As a consequence, the concentration of irrigation water use during the summer months (July, August, September) is much lower for WSU and LN than for the other two methods: 55% and 62% of the annual total compared with 88 and 76%.

[8] Although total rainfall was lower in 2015 than in 2016 (8.9 vs. 11.9 inches), summer rainfall was lower in 2016 (2.7 vs. 4.3 inches), which explains Hirst's anomalous result.

Water Use by Crop: The WSU and Hirst methods estimate monthly crop-specific water use for each year. Fig 5 shows, as an example, water use for field corn for 2014. According to Hirst, the corn needs irrigation for only three months – July, August and September. WSU estimates a need for irrigation every month from April through September. The annual totals also differ substantially: 25,200 acre-feet according to WSU and 13,400 acre-feet according to Hirst.

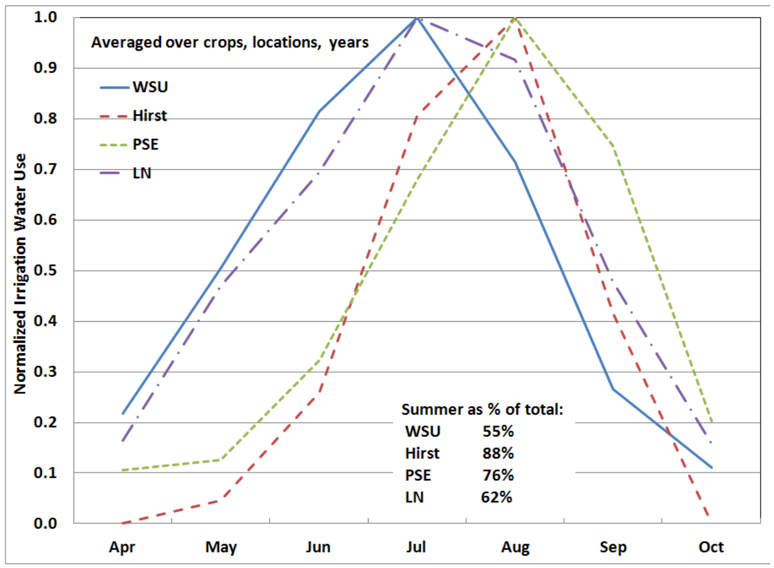

Fig. 4. Normalized (to peak-month usage) water use by month.

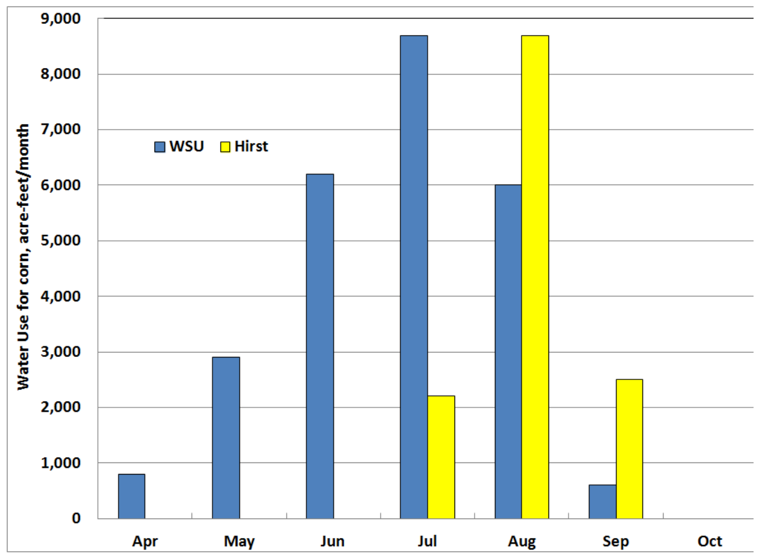

Fig. 5. WSU and Hirst estimates of monthly water use for field corn in 2014.

CONCLUSIONS

The five methods to estimate irrigation water use differ substantially in various ways:

- The RH2 and Hirst methods yield similar estimates of annual water use. The WSU and LN estimates are much higher.
- These methods agree that Grass/Hay is the most water-intensive crop (in terms of acre-feet/acre). However, they disagree on the relative rankings for the other primary crops irrigated in Whatcom County. For example, RH2 calculates corn as the least water intensive crop, Hirst calculates blueberry, and WSU calculates raspberry.
- The methods also differ substantially in their estimates of month-to-month variations in water use, with the WSU and LN methods showing much more water use during the spring months than either the Hirst or PSE methods. All four methods show rapid declines in water use from August to September to October.

Which of these methods is the most accurate? We have no way to answer that question because we lack a benchmark: metered water data from Whatcom County farms. These comparisons suggest that we know (as opposed to estimate) little about the details of agricultural irrigation water use. Even at the most aggregate level, the methods yield very different results. The details (e.g., monthly water use for a particular crop) also show major differences among methods. The actual discrepancies among these methods is surely greater than presented because of real-world (but unmeasured) differences in actual irrigation-system efficiencies and scheduling practices.

These results suggest strongly that there is no substitute for metering irrigation water use.[9] Absent such data we have no way to address the issues raised at the beginning of this paper.

[9] E. Hirst, *Metering Agricultural Water Use in Whatcom County*, Sept. 2015.

APPENDIX: DETAILS OF FIVE METHODS

RH2 Engineering: A key purpose of this recent study was to quantify agricultural irrigation water use in Whatcom County. The project developed estimates of annual water use for several crops using data from WSDA and estimates of Crop Irrigation Requirements (CIR) from the Washington Irrigation Guide (WIG). RH2 used estimates of irrigation system efficiency from the Washington Dept. of Ecology; the range is from 65% to 88%.

The WSDA data show, for 2014, the number of acres planted with different crops and the type of irrigation system (if any) used to irrigate that field. Because the WSDA data provide such detailed spatial disaggregation, RH2 was able to estimate irrigation water use for aggregated watersheds (nine), watersheds (41), and key drainages within each watershed. A strength of this study is its calculation of CIR for each irrigated field included in the WSDA database.

One problem with this study is its reliance on water-use estimates that were developed three decades ago: "CIR data utilized from the WIG include those numbers developed in 1985, except for crops (pasture/turf and field corn) that were reanalyzed and updated in 1992" as well as data from older WIGs. "These CIR estimates are based on 30 years of weather data collected from 1951 to 1980."[10]

> Current Washington State crop water requirement tables were created in the early 1980s, which are used widely for irrigation management, designing irrigation systems, hydrological studies and allocation of water rights throughout the State. The out-dated reference ET estimation equation (Blaney-Criddle) and old weather data were used to calculate crop water use. Crop coefficients that were used in the calculation do not have a clear origin. Also, some crops that have become economically important during the past decades are not included in the current version of this report.[11]

Table 1 summarizes the key results of this study. Grass/hay is the dominant crop, in terms of irrigated acres, annual water use, and water-use intensity. A total of about 41,000 acres of farmland were irrigated in 2014. Irrigation water use totaled almost 56,000 acre-feet, equivalent to 1.37 acre-feet/acre (16.4 inches).[12] [13]

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[10] See E. Hirst, *Future Prospects for Whatcom County Water Supply*, Feb. 2017 for data on changes in summer weather over the past few decades, especially higher air temperatures and lower rainfall.

[11] J. Greenberg, "Water Management: Agricultural Water Use," Chapter 7 of *Lower Nooksack Water Budget Project*, Dec. 2012, citing T. Karimi, *Revising Crop Coefficients for Washington State*, MS Thesis, Dept. of Biological System Engineering, Washington State University, May 2012.

[12] The RH2 report (Table 5) calculated total water use as 60,000 acre-feet, higher than the 55,700 acre-feet shown in Table 1 here because RH2 included more crops than the five considered here.

[13] Because the Washington Irrigation Guide did not include blueberries, RH2 assumed that blueberries required the same amount of water as raspberries.

Table 1. Key results from RH2 Engineering study

	Grass/hay	Blueberry	Corn, field	Potato	Raspberry	Total
Irrigated acres	12,400	5,400	11,600	1,600	9,600	40,600
CIR, ft	1.12	1.32	0.61	0.66	1.33	1.03
Irrigation efficiency, %	67%	88%	66%	65%	88%	74%
Acre-feet/ year	20,800	8,000	10,700	1,600	14,600	55,700
Acre-feet/acre	1.67	1.50	0.93	1.01	1.51	1.37

Washington State University: The WSU Irrigated Agriculture Research and Extension Center in Prosser, WA, maintains a website, AgWeathernet, which provides current and historical weather data throughout the state. The website, under the Irrigation tab, has a Water Use model that calculates daily ET coefficients for many crops at specific locations throughout Washington. The weather stations and calculations include four sites in Whatcom County: Lawrence, Lynden, Nooksack, and Ten Mile and can calculate irrigation estimates for any growing season during the past several years.

The calculations use the Penman-Monteith method to calculate ET coefficients.[14] [15] The method uses several weather variables, including solar radiation, soil heat flux, wind speed, humidity, and air temperature to calculate daily ET values. Curiously, rainfall is not a factor in this model.

I used the WSU model to calculate irrigation requirements for five crops,[16] for the four locations in Whatcom County using WSU's weather data for 2013, 2014, 2015, and 2016. For consistency, I used the same irrigated acreage and irrigation system efficiencies shown in Table 1. Table 2 shows the water-use intensity averaged across the four locations.

Table 2. Key results (acre-feet/acre) from WSU model

	Grass/hay	Blueberry	Corn, field	Potato	Raspberry	Total
Averages	2.76	2.02	2.15	2.11	1.89	91,600
2013	2.43	1.78	1.91	1.87	1.66	80,700
2014	2.22	2.15	2.75	2.20	1.56	89,400
2015	3.02	2.22	2.42	2.41	2.11	101,500
2016	2.79	2.02	2.12	2.06	1.87	91,200

[14] R.G. Allen et al., *FAO Irrigation and Drainage Paper, No 56: Crop Evapotranspiration*, United Nations Food and Agricultural Organization, 1998.

[15] Although the WSU website has no documentation on this Water Use model, Sean Hill (AgWeatherNet Operations Manager for WSU in Prosser) provided valuable information on the methodology.

[16] Based on advice from S. Hill, I converted the ET references values for alfalfa into values for grass by multiplying the alfalfa numbers by 0.81.

Hirst: I used crop-specific ET coefficients from a WSU technical report that is the basis for the forthcoming updated Washington Irrigation Guide.[17] These coefficients are for east-central Washington.[18] To convert to coefficients for northwestern Washington, I adjusted the east-central numbers for the shorter growing season on the west side, using growing season estimates from Peters; on average, the west-side coefficients are about 10% less than the east-side values.[19]

I used the same WSDA data used by RH2 Engineering on irrigated acres by crop and type of irrigation equipment used (drip, sprinkler, or big gun). Using the same estimates of equipment efficiency and acreage used by RH2, I calculated average irrigation efficiencies for each crop. I obtained data on monthly precipitation for the Clearbrook weather station and converted inches of rainfall into inches of irrigation using a method from the Natural Resources Conservation Service. I lowered the resultant ET coefficients by 25% to ensure that the overall irrigation requirements match that estimated by the U.S. Geological Survey for Whatcom County in 2010 (1.33 acre-feet of irrigation per acre of irrigated land).[20] The only weather variable that affects irrigation water use in the Hirst model is rainfall, the opposite of the WSU model, which incorporates several weather variables but not rainfall.

Table 3 shows results obtained with this model, overall and for the same four years shown in Table 2 for the WSU model.

Table 3. Key results (acre-feet/acre) from Hirst model

	Grass/hay	Blueberry	Corn, field	Potato	Raspberry	Total
Averages	1.65	0.90	1.18	1.00	1.32	53,323
2013	1.54	0.98	1.09	0.99	1.24	50,456
2014	1.62	0.94	1.15	0.97	1.34	52,890
2015	2.00	1.17	1.21	1.04	1.47	60,914
2016	2.04	1.16	1.39	1.21	1.52	64,256

Lower Nooksack Water Budget (LN): A project for the Water Resources Inventory Area (WRIA) 1 developed a water budget for the lower Nooksack River basin, which includes some of British Columbia and most of Whatcom County. The project calculated irrigation water use with the Topnet WN model (based on the Penman-Monteith method). Although this project includes estimates of the number of acres used for each crop and the type and efficiency of these irrigation systems, as above, I used the RH2 estimates for consistency. I increased the LN water use numbers by the ratio of the number of irrigated acres in Whatcom County (41,200) to the

[17] R.T. Peters, L. Nelson, and T. Karimi, *Consumptive Use and Irrigation Water Requirements for Washington*, Washington State University, 2012.
[18] Crop coefficients specific to western Washington are not available (T. Peters, personal communication, April 19, 2016).
[19] R.T. Peters, personal communications, Feb. 9 and 28, 2016.
[20] R.C. Lane and W.B. Welch, *Estimated Freshwater Withdrawals in Washington, 2010*, U.S. Geological Survey, Scientific Investigations Report 2015-5037, 2015.

number of irrigated acres in the Whatcom County portion of the lower Nooksack (33,300). Although the project calculated crop-specific numbers for each month, these details were not included in the report.

Puget Sound Energy (PSE): This approach differs from the first four in two ways. First, it uses data, not estimates. Second, it is indirect; it measures electricity use for pumping irrigation water and not the amount of water used.

PSE provided monthly data for almost 200 customers for the years 2013 through 2016. These 200 customers represent almost 40% of the farmers that irrigate in Whatcom County.[21] Although these data say nothing about the amount of water used to irrigate, they provide valuable insights into the month-to-month shape of that water usage (Table 4).

Table 4. Key results (kWh/customer) from PSE data

	2013	2014	2015	2016	Average
Apr	1,300	1,000	1,000	1,100	1,100
May	1,200	900	1,400	1,700	1,300
Jun	1,700	1,700	5,900	4,000	3,300
Jul	3,700	5,100	12,100	7,200	7,000
Aug	9,400	9,400	12,200	10,400	10,300
Sep	7,200	7,700	7,000	8,900	7,700
Oct	1,800	2,500	1,400	2,500	2,100
Total	26,300	28,300	41,000	35,800	32,800

The major limitation of these electricity-use data is the lack of knowledge about the crops grown using electricity. Although many farmers use electric pumps, others use diesel engines or the power-takeoff from their tractors to pump irrigation water. Even for those crops for which irrigation is powered by electricity, the amount of water pumped depends on the type of irrigation system and the water pressure.

Summary: Comparing the four methods that use ET coefficients is challenging because of stated and unknown (at least to me) differences in the models. As far as I could tell, none of these models accounts for soil moisture, especially water stored in the soil at the beginning of the growing season.

The methods also differ in their explicit treatment of different weather variables. The WSU model includes several local weather variables, but not rainfall. The Hirst approach is the opposite, with explicit consideration of precipitation but inclusion of no other weather variables. I could not determine what weather variables are included in the LN method. I suspect, but

[21] According to the 2012 Census of Agriculture (Table 1. County Summary Highlights: 2012), 570 farms in Whatcom County irrigate their land.

cannot know for sure, that the WSU and LN methods calculate substantial irrigation water uses in April, May and June because they do not account for rainfall and pre-season soil moisture.

More generally, it is important to distinguish among different concepts related to irrigation water use and crop water demands. The amount of water that a crop needs can be supplied by soil-moisture, rainfall, and irrigation. And the amount of irrigation water supplied to the system depends on its efficiency. It was sometimes challenging to determine which measure of water use each method used.