Calculation of 2020 Irrigation Depletions for 2020 Level Modified Streamflows

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Executive Summary

Irrigation depletion adjustments to streamflow address the question: *how would streamflow in past years be different if the irrigation extent, crop mix, and irrigation technology in the past were similar to current conditions?* This adjustment is sensitive to two key factors: 1) irrigation depletions on a per acre basis, and 2) surface-water irrigated acreage adjustment (the difference between surface water irrigated extent in 2018 and each past year). Several methodological aspects affect these key factors: data sources for the crop mix, crop water demand estimation, data sources for irrigation extent, partitioning of irrigation demand between surface and ground water sources, assumptions related to diversion efficiencies and return flow efficiencies, e.g. how much more water than estimated crop water demand is actually diverted and what fraction of that diversion is returned to the stream and at what lag time, and finally, data availability for model calibration. This report describes the methodology and 2020 level depletion adjustments by region in detail. It should be noted that the terms *irrigation depletion adjustments* and *incremental depletions* are used interchangeably in this report. In this executive summary we

(a) provide a short summary of key methodological improvements from the 2010 Level Modified Streamflows report, and
(b) answer the questions: *Does the current study result in additional modified streamflow or reduced modified streamflow as compared to the 2010 Level Modified Streamflows study? What are the key drivers of these changes?*

Key methodological improvements:

In the current study, we utilized

- the WSDA Agricultural Land Use Geodatabase and the USDA Cropland Data Layer to get a spatially-explicit crop-mix and include a broader range of crop categories in order to capture more detailed crop-specific differences in irrigation demands.
- a coupled crop-hydrology model that uses the Penman-Monteith equation and accounts for dynamic crop growth to obtain better estimates of crop water demands.
- a remote sensing-based data product MIrAD (Brown and Pervez, 2014) that covers the full spatial extent of the study area to better capture irrigation extent.
- a spatially explicit meteorological data set GridMET (Abatzoglou, 2013) for the United States and a downscaled global climate model dataset Livneh et al. (2013) for Canada, to better capture spatial variations in demands.

Changes in comparison to 2010 Level Modified Streamflows (prior study):

How much is the change?

The current depletions study will generally result in an increase to modified streamflows as compared to estimates from the prior study (Table ES-1). However, there are subareas with decreases in modified streamflow as well (e.g., the Flathead Irrigation District, parts of the Umatilla subarea, and the Kennewick Irrigation district). The changes are listed by subarea in Table ES-1. It should be noted that this report only discusses changes to modified streamflows resulting from changes to incremental depletions. Several other factors will additionally impact modified streamflows, which are captured separately in the 2020 Level Modified Flows Report prepared by the Bonneville Power Administration.

Table ES-1 lists the incremental depletions for the prior study and current study as well the difference in these incremental depletions. Two sets of incremental depletion comparisons are provided:

(a) for the water year 1929 - the first year of Modified Flows calculations. In general, 1929 typically has the largest incremental depletions as there was no significant irrigated agriculture at that time in comparison with current conditions.
(b) averaged across the common timeframe in the current and prior studies (1929-2008).

A positive (negative) difference in incremental depletion is indicative of an increase (decrease) in modified streamflows between the current and prior studies. For example, row 9 of Table ES-1 indicates that the subarea Upper Flathead (FLT) has on average 19 cubic feet per second (cfs) higher Modified Flows in 1929 as compared to the prior study. The range of monthly differences for 1929 are provided within the parentheses. So, while current modified flows are 19 cfs higher on average than the prior study, differences in monthly flow estimates ranged from 43 cfs lower to 148 cfs higher than estimates from the prior study.

Why does it change?

The changes in Table ES-1 can be explained by changes in the *current irrigated agriculture conditions* as quantified in this study versus the prior study. Table ES-2 provides estimates of the three key potential drivers (total irrigated area, fraction of that total fed by surface water sources, and crop water demand) of the changes listed in Table ES-1. It should be noted that if estimates change between 2010 Level and 2020 Level, this could either indicate a real change in irrigation, and/or be a result of the prior or current estimates being incorrect. For example, the total irrigated acres in the subarea Chelan-Entiat-Wenatchee-W Banks Lake (CEW) *did not* decrease by 60,600 acres between 2010 and 2020 Levels. Rather the 2010 Level estimate was too high relative to the trend in the time series once 2020 irrigation levels were included. A similar situation occurred in the subarea Palouse-Lower Snake (PLS) as well were the estimated total irrigated acres “decreased” by 77,800 acres, perhaps largely because of a 2010 Level overestimation. In most cases the changes were small, and large changes were generally attributed to an error in the 2010 Level data, which did not have the advantage of the sophisticated tools and analyses available in this effort.

The increase or decrease in any of the potential drivers across the current and prior studies will result in a corresponding change in modified flows as well. Sometimes drivers change in the same direction resulting in additive changes to modified flows. Other times, the change in modified flows is a function of the net change due to competing effects. For example, in the FLT subarea, estimates of total irrigated acres decreased 25% between the 2010 and 2020 studies. However, the estimate for the fraction of total area being fed by surface water sources increased leading to the aforementioned average increase of 19 cfs. The dominant driver of change varies by subarea (Table ES-2).

Quantifying irrigation depletion adjustments is a challenging task, especially in a place like the Columbia River Basin with great diversity in terms of crop mix, agricultural practices, and human influences. While key uncertainties in estimating diversion and return flow efficiencies, and past irrigated acreage, and paucity of data in the Canadian parts of the region remain, the methodological modifications made as part of this study will provide meaningful improvement to the irrigation depletion adjustments as part of the 2020 Level Modified Streamflow report. Additionally, input datasets and modeling frameworks are under continuous improvement by our team (and other teams) and can be leveraged by future Modified Flow Projects.

*Table ES-1. Incremental depletions for 1929 and 80-year average incremental depletions (1929-2008) 5D (from 2010 Modified Flows), 6D (2020 Modified Flows) and the difference between 5D and 6D. The flow numbers in each row are average for the year, followed by the monthly range (low, high). Subareas with a * next to them are in Canada. Data for the Grand Coulee Dam are not shown in this table as they are not incremental depletions.*

	Incremental Depletions for 1929 (cfs)						Average Incremental Depletions (1929-2008) (cfs)					
	5D		6D		Difference		5D		6D		Difference	
Subarea	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**
Upper Columbia & Kootenay												
*Hugh Keenleyside (ARD)	-3	(-9, 0)	1	(-1, 6)	4	(-1, 16)	0	(-9, 18)	3	(-3, 31)	3	(-10, 18)
*Upper Columbia above Mica (UPC)	-2	(-6, 0)	3	(-4, 31)	5	(-3, 36)	5	(-11, 66)	7	(-8, 90)	1	(-34, 37)
*Columbia at Trail (CTR)	-3	(-13, 1)	0	(0, 0)	3	(-1, 13)	-1	(-13, 4)	1	(-1, 11)	2	(-2, 13)
*East Kootenay above Newgate (EKO)	-22	(-89, 9)	1	(-2, 14)	23	(-11, 103)	0	(-90, 145)	10	(-14, 161)	10	(-54, 116)
Kootenai – Montana (KMT)	5	(-11, 36)	4	(-6, 32)	-1	(-20, 9)	8	(-16, 81)	6	(-8, 60)	-2	(-47, 10)
Kootenai – Idaho (KID)	-1	(-6, 1)	0	(0, 0)	1	(-1, 6)	0	(-6, 15)	1	(-1, 20)	0	(-11, 7)
*West Kootenay (WKO)	-7	(-38, 4)	-2	(-16, 1)	5	(-3, 22)	5	(-39, 126)	5	(-17, 128)	0	(-43, 22)
*Brilliant (BRI)	0	(-1, 2)	1	(-1, 5)	0	(-1, 3)	4	(-6, 38)	3	(-4, 31)	-1	(-20, 6)
Pend Oreille and Spokane												
Upper Flathead (FLT)	-34	(-201, 17)	-14	(-97, 6)	19	(-43, 148)	-3	(-203, 150)	2	(-98, 134)	6	(-113, 149)
Flathead Irrigation District (FID)	-149	(-676, 78)	-162	(-780, 64)	-13	(-265, 243)	6	(-712, 358)	-43	(-810, 102)	-48	(-269, 243)
Upper Clark Fork (UCF)	-33	(-70, -12)	55	(-90, 323)	88	(-59, 391)	-22	(-117, 61)	66	(-95, 435)	88	(-60, 405)
Bitterroot (BIT)	62	(-113, 439)	81	(-99, 429)	19	(-111, 166)	46	(-113, 439)	66	(-99, 429)	20	(-111, 166)
Lower Clark Fork (LCF)	5	(-18, 42)	10	(-18, 68)	5	(-22, 43)	17	(-36, 176)	19	(-29, 175)	2	(-91, 61)
* Pend Oreille Basin (POC)	-2	(-6, 0)	0	(0, 2)	2	(-1, 6)	0	(-6, 4)	1	(-1, 12)	1	(-3, 11)
Pend Oreille Basin in USA (PEN)	5)	(-7, 32)	3	(-4, 33)	-1	(-24, 11)	8	(-10, 61)	6	(-7, 70)	-2	(-43, 22)
Spokane Valley (SPV)	1	(-46, 97)	3	(-23, 66)	1	(-70, 33)	14	(-47, 145)	11	(-23, 98)	-3	(-80, 33)
Mid-Columbia												
*Kettle (KET)	-10	(-37, 2)	-1	(-2, 2)	9	(-4, 38)	14	(-37, 210)	23	(-45, 358)	9	(-150, 228)
Ferry Stevens (FER)	-26	(-76, -2)	1	(-8, 22)	27	(-1, 86)	-2	(-79, 76)	16	(-12, 132)	17	(-40, 120)
*Okanogan (OKA)	46	(-91, 327)	60	(-82, 371)	14	(-136, 112)	96	(-137, 805)	98	(-117, 747)	1	(-317, 153)
Methow-Okanogan (OKM)	4	(-15, 42)	35	(-23, 168)	31	(-11, 126)	17	(-20, 157)	47	(-28, 267)	30	(-13, 143)
Chelan-Entiat-Wenatchee-W Banks Lake (CEW)	-223	(-850, 87)	-12	(-31, -2)	211	(-90, 819)	-156	(-858, 87)	37	(-38, 248)	193	(-90, 820)
Wanapum Return Flows (WRF)	79	(56, 118)	84	(61, 115)	4	(-3, 13)	35	(-23, 118)	39	(-15, 115)	4	(-3, 13)
Priest Rapids Return Flows (PRF)	252	(180, 362)	234	(180, 333)	-17	(-48, 42)	112	(-175, 362)	95	(-223, 333)	-17	(-48, 42)

	Incremental Depletions for 1929 (cfs)						Average Incremental Depletions (1929-2008) (cfs)					
	5D		6D		Difference		5D		6D		Difference	
Subarea	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**
Lower Snake												
Upper Snake (UPS)	-87	(-313, 11)	-19	(-28, -10)	67	(-26, 287)	-19	(-328, 218)	29	(-80, 345)	48	(-26, 292)
Lower Snake (LWS)	14	(-12, 68)	4	(-7, 38)	-10	(-44, 7)	11	(-12, 75)	3	(-20, 43)	-9	(-49, 7)
Grande Ronde at Wenaha (WEN)	-22	(-182, 292)	59	(-179, 596)	81	(-89, 469)	-28	(-230, 356)	54	(-188, 646)	83	(-112, 482)
Clearwater (CLR)	-1	(-4, 4)	3	(-4, 32)	4	(-2, 30)	0	(-22, 26)	4	(-6, 58)	3	(-16, 34)
Palouse-Lower Snake (PLS)	-242	(-797, 22)	-30	(-63, -11)	212	(-36, 734)	-187	(-891, 59)	5	(-146, 198)	193	(-44, 746)
Lower Columbia												
Pumping to Blocks 2 & 3 (B23)	-32	(-75, 0)	-30	(-75, 0)	2	(-5, 8)	-11	(-75, 0)	-11	(-75, 0)	1	(-75, 8)
McNary Return Flows (MRF)	564	(369, 741)	544	(409, 647)	-19	(-94, 81)	313	(-115, 741)	264)	(-182, 647	-49	(-543, 113)
Kennewick (KEN)	126	(107, 137)	41	(34, 51)	-84	(-98, -68)	77	(0, 137)	-2	(-69, 51)	-78	(-98, -1)
Walla Walla (WWA)	-128	(-387, -8)	-102	(-250, -11)	26	(-80, 186)	-48	(-387, 217)	-32	(-250, 206)	16	(-80, 186)
Pumping from McNary to Umatilla (UMP)	-66	(-234, 0)	-12	(-37, 0)	55	(-1, 197)	-12	(-234, 234)	39	(-37, 396)	51	(-1, 197)
Return flow from McNary pumping to Umatilla (UMR)	15	(5, 27)	2	(1, 4)	-13	(-23, -5)	4	(-20, 27)	-8	(-43, 4)	-12	(-23, 0)
Pumping from John Day to Morrow/Gilliam + Returns (JDP)	-102	(-426, 38)	-95	(-357, 30)	7	(-29, 81)	-23	(-426, 437)	-13	(-357, 479)	9	(-30, 110)
Umatilla River & Willow Creek (UMW)	75	(-159, 504)	-85	(-139, -23)	-160	(-604, 20)	56	(-163, 522)	-91	(-359, 86)	-147	(-608, 86)
John Day (JDA)	-13	(-31, -4)	73	(-96, 357)	86	(-68, 361)	-2	(-147, 89)	80	(-104, 439)	81	(-70, 376)
Pumping from John Day to Northside + Returns (NSJ)	-98	(-322, 34)	-218	(-805, 72)	-120	(-490, 38)	-69	(-322, 34)	-185	(-805, 74)	-116	(-519, 74)
Deschutes - White River Wapanita Project (WHT)	-2	(-10, 2)	9	(-6, 33)	10	(-8, 43)	13	(-20, 141)	29	(-35, 188)	16	(-16, 91)
Klickitat Basin KLC)	-30	(-248, 28)	9	(-7, 42)	39	(-35, 290)	-25	(-248, 29)	13	(-19, 123)	38	(-39, 300)
Hood River (HOD)	-14	(-81, 58)	6	(-71, 121)	20	(-4, 63)	4	(-96, 123)	25	(-86, 185)	21	(-18, 67)
White Salmon (WHS)	10	(-10, 55)	10	(-8, 47)	0	(-10, 14)	11	(-15, 83)	12	(-14, 84)	1	(-14, 27)
Pumping from McNary to Northside (NSM)	-276	(-782, 0)	-120	(-365, 0)	156	(-14, 453)	-201	(-790, 0)	-69	(-372, 35)	132	(-14, 456)
Return flow from McNary pumping to Northside (NSR)	62	(22, 110)	23	(8, 41)	-39	(-69, -14)	50	(0, 120)	15	(-5, 48)	-35	(-72, -1)
Willamette												
Fern Ridge (FRN)	-7	(-28, 1)	-2	(-9, 0)	4	(-1, 19)	-4	(-28, 1)	0	(-9, 3)	4	(-1, 20)
Willamette (WMT)	-296	(-1255, 60)	-273	(-1110, 47)	23	(-70, 253)	-75	(-1273, 375)	-89	(-1125, 220)	-14	(-199, 258)

*Table ES-2. Comparison between 2010 and 2020 Modified Flows values for total irrigated area, surface water fraction, and crop water demand. The color of cells in the difference columns indicate the extent to which these factors drove the differences in depletions. Blue cells mean that change resulted in greater streamflow (less depletion) in 2020 as compared to 2010, while red cells indicate that change resulted in less streamflow (more depletion). Darker hues indicate greater differences. Subareas with a * next to them are in Canada. Incremental depletions for subareas part of the Columbia Basin Project are directly calculated from gage observations, and are not listed in this comparison table.*

	Total Irrigated Area (1000 acres)			Surface Water Fraction			Crop Water Demand (ac-ft/1000 ac)		
Subarea	**2010**	**2020**	**Difference**	**2010**	**2020**	**Difference**	**2010**	**2020**	**Difference**
Upper Columbia & Kootenay									
* Hugh Keenleyside (ARD)	2.2	0	-2.2	100%	100%	0%	1,258	902	-356
* Upper Columbia above Mica (UPC)	6.2	1.1	-5.1	100%	100%	0%	1,168	559	-609
* Columbia at Trail (CTR)	0.5	0.4	-0.1	100%	100%	0%	1,399	902	-497
* East Kootenay above Newgate (EKO)	14.9	3.3	-11.6	100%	100%	0%	1,464	553	-911
Kootenai - Montana (KMT)	5.4	3.7	-1.7	95%	96%	+1%	1,727	832	-895
Kootenai - Idaho (KID)	2.8	1.6	-1.2	55%	66%	+11%	1,619	937	-682
* West Kootenay (WKO)	5.7	3.9	-1.8	100%	100%	0%	1,414	775	-639
* Brilliant (BRI)	0.4	0	-0.4	100%	100%	0%	1,430	902	-528
Pend Oreille and Spokane									
Upper Flathead (FLT)	32.1	24.1	-8.0	77%	84%	+7%	1,238	706	-532
Flathead Irrigation District (FID)	102.6	127.2	+24.6	97%	99%	+2%	1,637	1,244	-393
Upper Clark Fork (UCF)	148.4	99.7	-48.7	99%	99%	0%	1,149	1,293	+144
Bitterroot (BIT)	87.5	72.4	-15.1	98%	99%	+1%	1,659	1,419	-240
Lower Clark Fork (LCF)	15.6	10.7	-4.9	90%	96%	+6%	1,642	1,200	-442
* Pend Oreille Basin (POC)	1.1	0.1	-1.0	43%	50%	+7%	1,551	957	-594
Pend Oreille Basin in USA (PEN)	3.6	2	-1.6	43%	68%	+25%	1,401	957	-444
Spokane Valley (SPV)	29.8	24.7	-5.1	100%	100%	0%	1,759	1,167	-592
Mid-Columbia									
* Kettle (KET)	16.1	4.7	-11.4	100%	100%	0%	1,657	887	-770
Ferry Stevens (FER)	22.5	9	-13.5	76%	63%	-13%	1,679	1,035	-644
* Okanogan (OKA)	62.8	38.9	-23.9	100%	100%	0%	1,529	1,133	-396
Methow-Okanogan (OKM)	40.5	33.1	-7.4	76%	58%	-18%	1,980	1,791	-189
Chelan-Entiat-Wenatchee-W Banks Lake (CEW)	111.7	51.1	-60.6	89%	83%	-6%	2,490	2,218	-272

Subarea	Total Irrigated Area (1000 acres) 2010	2020	Difference	Surface Water Fraction 2010	2020	Difference	Crop Water Demand (ac-ft/1000 ac) 2010	2020	Difference
Lower Snake									
Upper Snake (UPS)	121.5	100.3	-21.2	96%	95%	-1%	1,989	1,471	-518
Lower Snake (LWS)	13.1	15	+1.9	97%	95%	-2%	2,341	1,043	-1298
Grande Ronde at Wenaha (WEN)	118.9	83	-35.9	88%	79%	-9%	1,766	1,324	-442
Clearwater (CLR)	4.7	1.9	-2.8	79%	76%	-3%	2,012	1,074	-938
Palouse-Lower Snake (PLS)	146.4	68.6	-77.8	73%	57%	-16%	2,081	1,721	-360
Lower Columbia									
Walla Walla (WWA)	104.8	117.6	+12.8	77%	66%	-11%	1,626	1,390	-236
Pumping from McNary to Umatilla (UMP)	40.6	5.1	-35.5	53%	75%	+22%	1,608	1,603	-5
Return flow from McNary pumping to Umatilla (UMR)	40.6	5.1	-35.5	53%	75%	+22%	1,608	1,603	-5
Pumping from John Day to Morrow/Gilliam + Returns (JDP)	81.2	71.4	-9.8	53%	54%	+1%	1,608	1,660	+52
Umatilla River & Willow Creek (UMW)	40.6	131.8	+91.2	53%	67%	+14%	1,608	1,695	+87
John Day (JDA)	57.9	26.8	-31.1	91%	81%	-10%	1,918	1,830	-88
Pumping from John Day to Northside + Returns (NSJ)	47.8	117.7	+69.9	75%	77%	+2%	2,245	1,626	-619
Deschutes - White River Wapanita Project (WHT)	10.4	6.4	-4.0	62%	51%	-11%	1,532	2,124	+592
Klickitat Basin (KLC)	41.9	13.2	-28.7	75%	29%	-46%	984	1,589	+605
Hood River (HOD)	39.8	31.8	-8.0	78%	78%	0%	1,943	1,943	0
White Salmon (WHS)	1.8	4.6	+2.8	47%	28%	-19%	1,573	1,801	+228
Pumping from McNary to Northside (NSM)	109.6	55.3	-54.3	75%	77%	+2%	2,245	1,659	-586
Return flow from McNary pumping to Northside (NSR)	109.6	55.3	-54.3	75%	77%	+2%	2,245	1,659	-586
Willamette									
Fern Ridge (FRN)	6.1	1.9	-4.2	61%	62%	+1%	1,705	1,453	-252
Willamette (WMT)	304.6	290.2	-14.4	56%	64%	+8%	1,232	1,048	-184

1. Introduction

Irrigation depletions are a critical component in the calculation of Modified Flows. Modified Flows are defined as “the historical stream flows that would have been observed if current irrigation depletions existed in the past and the effects of river regulation were removed (except for the Upper Snake, Deschutes, and Yakima basins where current upstream reservoir regulation practices are included)”. Modified flow calculations start with historical streamflow gage and reservoir observations which are then adjusted to reflect current practices that are different from historical practices (BPA, 2011).

This technical report is a description of the irrigation depletion adjustment calculation methodology that is applied to Columbia River Basin (CRB) for 2020 Level Modified Streamflows (referred to hereafter as 2020 Modified Flows). This work builds upon methodology developed and tested in the Umatilla Basin (WSU, 2018). A description of the methodology, differences in comparison with the 2010 Level Modified Streamflows (referred to hereafter as 2010 Modified Flows), and discussion of key sources of uncertainly are provided in the sections below. As an accompaniment to this document, daily irrigation depletion data are also provided, as they were for previous Modified Flows publications.

2. Methodology

To summarize the methodology, there are two major steps in the irrigation depletion calculation. The first is a calculation of crop-specific irrigation water demands and average monthly irrigation needs over 1000 acres, weighted by the crop mix in the region of interest for current conditions. This average monthly irrigation need is then converted to an average monthly depletion by accounting for diversion and return flow efficiencies.

The second step involves estimating how surface water irrigation extent has changed over the years and applying the average monthly depletions for current conditions to yearly changes in surface water irrigation extent to get a time series of adjustment of irrigation depletions. As in the 2010 and prior Modified Flows, this effort also utilizes the USGS water use surveys to estimate a surface versus ground water percent split of current irrigation acres. The current irrigated acres are estimated from spatially-explicit satellite imagery. The time series of historical irrigated acreages is retained from prior efforts with the exception of the 2010 values where revision were made utilizing the new methodology.

Table 1 lists the various assumptions and steps in the calculation of irrigation depletion as used in 2010 Modified Flows and compares those against the current methodology. Steps 1 through 6 correspond to calculating the average monthly irrigation depletions per 1000 acres. The remaining steps correspond to the calculation of a time series of irrigation depletion adjustments.

Table 1: Summary of steps in the calculation of irrigation depletion adjustments in 2010 and 2020 Modified Flows.

Steps	2010 Modified Flows	2020 Modified Flows
1) Identification of crop mix	County level statistics from USGS surveys and USDA census/surveys	Spatially explicit WSDA agricultural land use Geodataset (Washington), USDA Cropland Data Layer (U.S. outside of Washington), Annual Crop Inventory (Canada). See 2.1.3.
2) Identification of irrigation extent	County level statistics from the most recent USGS water use surveys and USDA Census of Agriculture (U.S.) Statistics Canada data (Canada) applied with scaling factor of 1.25. Past irrigation extent time series retained as is from prior reports.	A remote-sensing based approach modeled after the MODIS Irrigated Agriculture Dataset (MIrAD) (Pervez and Brown, 2010) for current extent for 2008 and 2018. See 2.1.4.1. Prior to 2008, the irrigation extent time series is retained as is from prior reports.
3) Meteorological input data	Data from a few select representative stations.	Livneh (Livneh et al., 2013) for Canada and GridMET (Abatzoglou, 2013) for U.S. Both datasets are spatially interpolated from weather station observations. See 2.1.1.
4) Calculation of monthly average crop water demand per 1000 acres.	Blaney-Criddle Method - driven by select station-based weather data and weighted by crop area.	Spatially explicit VIC-CropSyst model (1/16° resolution) driven by spatially explicit weather data at the same resolution. The VIC-CropSyst model uses the Penman-Monteith equation and dynamically calculates crop water demand. See 2.3.
5) Estimation of diversions per 1000 acres for each sub region.	Output of Step 4 divided by diversion efficiency. In some locations, these assumptions come from USBR records based on diversion and return flow observations. The exact sources of assumptions is not cataloged.	Output of Step 4 divided by diversion efficiency. Retained diversion efficiency assumptions from the 2010 Modified Flows. See 2.1.5.

6) Estimation of return flows per 1000 acres for each sub region	Output of Step 5 multiplied by return flow efficiency. In some locations, these assumptions come from USBR records based on diversion and return flow observations. The exact sources of assumptions is not cataloged.	Output of Step 5 multiplied by return flow efficiency. Retained return flow efficiency assumptions from the 2010 Modified Flows. See 2.1.5.
7) Estimation of monthly average depletions as combination of Steps 5 and 6.	Sum of monthly estimates from Steps 5 and 6.	Sum of monthly estimates from Steps 5 and 6.
8) Surface and ground water irrigation split fraction	County level USGS water use surveys for U.S. and a fraction of 1 for Canada.	County Level USGS water use surveys (U.S.). The U.S. time series of split fractions were smoothed to address data issues (unreasonably large year-to-year fluctuations). See 2.1.6. Surface water fraction was assumed to be 1 in Canada (same as 2010 Modified Flows) because no other data was available.
9) Split surface water irrigated areas by irrigation type for each sub region.	County level USGS water use surveys and Statistics Canada data (Canada).	County level USGS water use surveys and Statistics Canada data (Canada). See 2.1.7.
10) Create time series of surface water irrigated acres by irrigation type and calculate the difference in irrigated acres between 2018 and each historical year.	Time series from prior Modified Flows studies and the latest year's information from the USGS county level statistics.	2008 and 2018 data calculated based on irrigation extent split calculations for those years (see previous steps). For prior years, data from 2010 Modified Flows used with adjustment made for 1980 – 2008 based on the change in surface water irrigation split fraction (Step 8). See 2.1.8.
11) Estimate daily depletion time series.	Monthly average irrigation depletions (Step 7) applied to time series of yearly differences in acres (Step 10). Calculated at a monthly time step and then disaggregated to a daily time step.	Same methods used as for 2010 Modified Flows.

Though it is not typical for Modified Flows efforts to recalculate depletions for prior years, there were instances in which more accurate data was available. At the request of Bonneville Power Administration, the data for previous years was adjusted to create a time series that better reflected reality. Where these adjustments to past data occurred in many subbasins, they are described in Section 2.1. Where such adjustments affect a more limited region, they are described in the results (Section 4) for that region.

In the remainder of this section, the input datasets used in the calculations are described (Section 2.1), followed by an explanation of how these inputs were used to develop the spatially explicit data on crop mix, irrigation, and irrigation type (Section 2.2) necessary for the application of a coupled crop-hydrology model, VIC-CropSyst (Sections 2.3-2.6) and calculation of irrigation depletion adjustments.

2.1 Input Datasets

2.1.1 Meteorological data

For weather inputs, we used two data sets: Livneh (Livneh et al., 2013) and GridMET (Abatzoglou, 2013). The Livneh dataset provides daily maximum temperature, daily minimum temperature, daily total precipitation, and daily average wind speed. Besides the variables the Livneh dataset provides, GridMET also includes daily shortwave solar radiation, daily maximum, and daily minimum relative humidity. For this project, we used the Livneh dataset for the Canadian portion of the CRB and used GridMET for U.S. portion (over the boundary area, wherever GridMET is available, it will be used). The GridMET dataset is used over the U.S. due to a known cold bias in the Livneh datset where a constant temperature lapse rates is used (Walton and Hall, 2018). Both of these two datasets are spatially interpolated from weather station observations. Because the datasets are based on most of the same observations, and because there are no subareas crossing the U.S.-Canada border, data continuity concerns were minimized at the U.S.-Canada border. The Livneh dataset covers the entire continental U.S. and the Canadian portion of the CRB from the year 1915 to the year 2015 with a spatial resolution of 1/16°. GridMET covers the entire continental U.S. from the year 1979 to current, with a spatial resolution of 1/24°. The GridMET dataset has been aggregated to 1/16° resolution at daily time step. When using Livneh, we used the Variable Infiltration Capacity model (VIC) internal weather generator (the MT-CLIM based algorithm) to estimate solar radiation and humidity to calculate reference and actual evapotranspiration (ET). In contrast, when using GridMET, the solar radiation and humidity (daily maximum and minimum) are directly ingested into the model. The advantages of Livneh et al. (2013) are that the dataset goes back to 1915 and is available for the Canadian parts of the Columbia River Basin (CRB) as well. The disadvantage is that it has a known cold bias (Walton and Hall, 2018). The advantage of GridMET is that temperature biases are not apparent at the time of this project. However, this dataset is only available post 1979, and is not yet available for the Canadian part of the CRB.

2.1.2 Soil data

Soil information is needed for VIC-CropSyst simulations (see Section 2.3). Some of the soil parameters needed by VIC-CropSyst, (e.g., soil texture, saturated hydrologic conductivity, bulk density) were obtained from the Digital General Soil Map of the United States or STATSGO2 (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053629) for the U.S. portion of the basin; and from Soil Landscapes of Canada version 3.2 (http://sis.agr.gc.ca/cansis/nsdb/slc/v3.2/index.html) for the Canadian portion of the basin. For each VIC grid cell, these soil properties were identified by overlaying its centroid with the soil map unit polygons of the applicable soil data set. A detailed list of the soil parameters needed by VIC can be found at https://vic.readthedocs.io/en/master/Documentation/Drivers/Classic/SoilParam/. For those hydrological properties that were calibrated can be found in the calibration Section 2.4.1 and in Appendix A.

2.1.3 Crop distribution

Three data sources for crop distributions are used for this project. The first one is the Cropland Data Layer (CDL) from USDA for 2018 (https://www.nass.usda.gov/Research_and_Science/Cropland/SARS1a.php). This data set is produced annually mainly by using high spatial resolution satellite imagery (e.g., 30-meter Landsat TM/ETM+, 56-meter AWiFS, 10-meter SENTINEL-2) and extensive checking against agricultural ground truth data (Boryan et al., 2011). The second source is the Washington State Department of Agriculture (WSDA) Agricultural Land Use Geodatabase developed by and attributes are updated via ground surveys or by using outside sources such as the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) CDL. (https://agr.wa.gov/departments/land-and-water/natural-resources/agricultural-land-use). The current map we used for this report contains crop data collected and stored for Washington as of 12/31/2018. The third data source (particularly for Canadian portion of the CRB) is Annual Crop Inventory (ACI) developed by the Earth Observation Team of the Science and Technology Branch at Agriculture and Agri-Food Canada (AAFC) (https://open.canada.ca/data/en/dataset/ba2645d5-4458-414d-b196-6303ac06c1c9). This product has a 30-meter resolution since 2011 and we used the 2018 data for this report.

2.1.4 Irrigation extent

2.1.4.1 Methodology for irrigation extent

To determine a spatially-explicit distribution of irrigation extent for the CRB, we followed an approach similar to the one used by Pervez and Brown (2010) to create the MODIS Irrigated Agriculture Dataset (MIrAD). This product utilizes three datasets - the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery, the National Land Cover Database (NLCD), and county level irrigated area aggregate statistics from the USDA - to create a 250 m resolution dataset of irrigation extent for the continental U.S. (Figures 1 and 2). The first dataset is used to quantify a 16-day smoothed time series of Normalized Difference Vegetation Index (NDVI) from which the annual peak NDVI value is selected. The second is used to identify a cropland mask. The third is used to obtain an aggregate irrigation extent threshold in each county. Under the assumption that peak annual NDVI is typically higher in the presence of irrigation, this product ranks all 250 m resolution grids in the decreasing order of NDVI and spatially assigns grids as irrigated until the cumulative irrigated area in a county matches the threshold irrigated acreage statistics for the county. For this project, we recreated the MIrAD product for 2017 (to coincide with the 2017 USDA census data) using the same methodology as Pervez and Brown (2010) with one exception; we used the USDA CDL as the cropland mask rather than the NLCD to mask irrigable land given that it is more recent. We also extended the product to the Canadian region of the CRB by utilizing the ACI product and using the Statistics Canada Census of Agriculture summary statistics for aggregate regional district electoral area irrigated acreage. **We used this process to develop a spatially-explicit irrigation extent for both 2008 and 2018. While this allowed us to update irrigation extent and depletions used in 2010 Modified Flows (from 2008), we do not have the necessary information to recreate irrigation extent in prior years.**

In addition to spatially-explicit irrigation extent for model simulations, this dataset was also used to determine the fractional contribution of each county's irrigated area to each subarea. For each subarea, the percent contribution of each county was calculated as follows:

$$CP = 100\% \times (Irr_{sa}/\mathrm{Irr}_{tot}) \quad (1)$$

where CP is the percent contribution of irrigated land within the target county to the subarea (%), Irr_{sa} is the irrigated land of the target county that falls within the subarea (acres), and Irr_{tot} is the total irrigated land in the target county (acres).

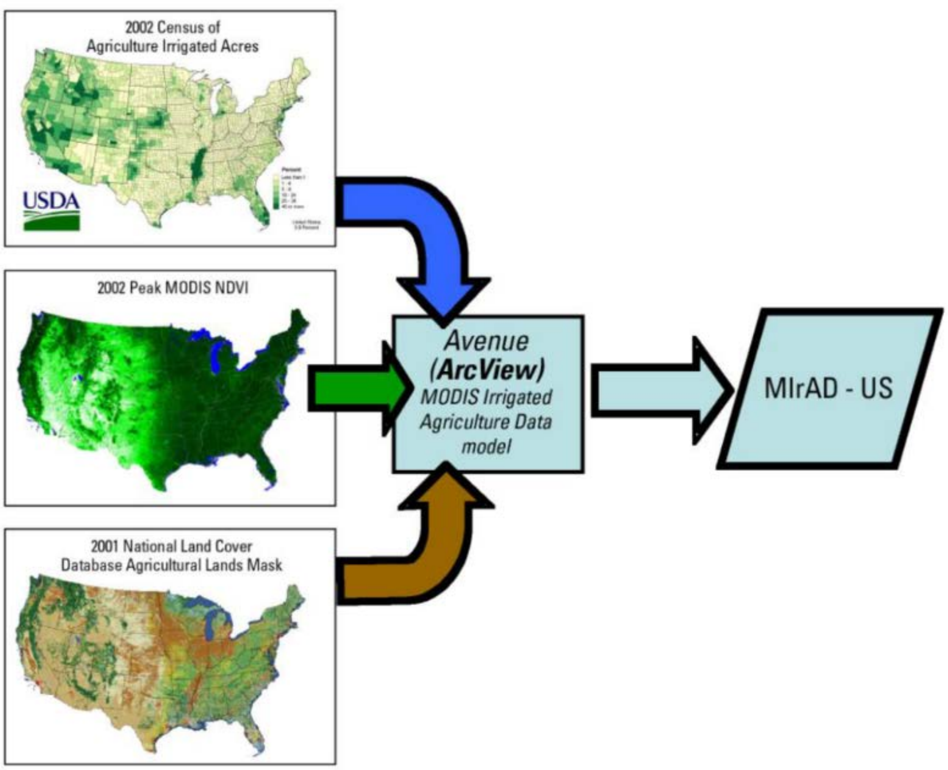

Figure 1. Modis Irrigated Agriculture Dataset (MIrAD) approach. (Source: Brown and Pervez, 2014)

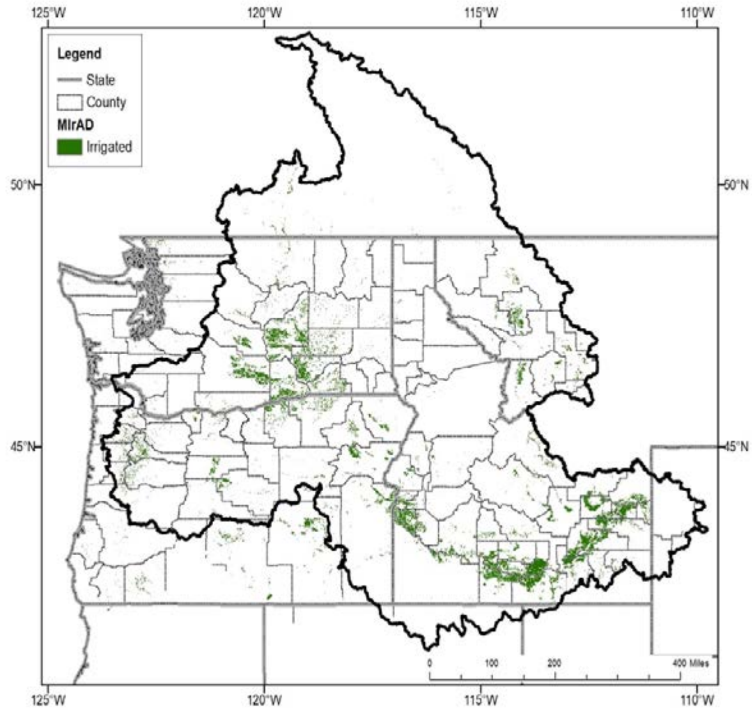

Figure 2. 2017 MIrAD irrigation extent for the study area.

2.1.4.2 Comparing 2008 MIrAD-based estimates with prior estimates

When comparing MIrAD-based irrigated extent for 2008 to the methodology applied in 2010 Modified Flows (Figure 3), the MIrAD-based product resulted in lower overall irrigation extent in general (with a few exceptions). This is one of the reasons we decided to update the 2008 data for methodological consistency.

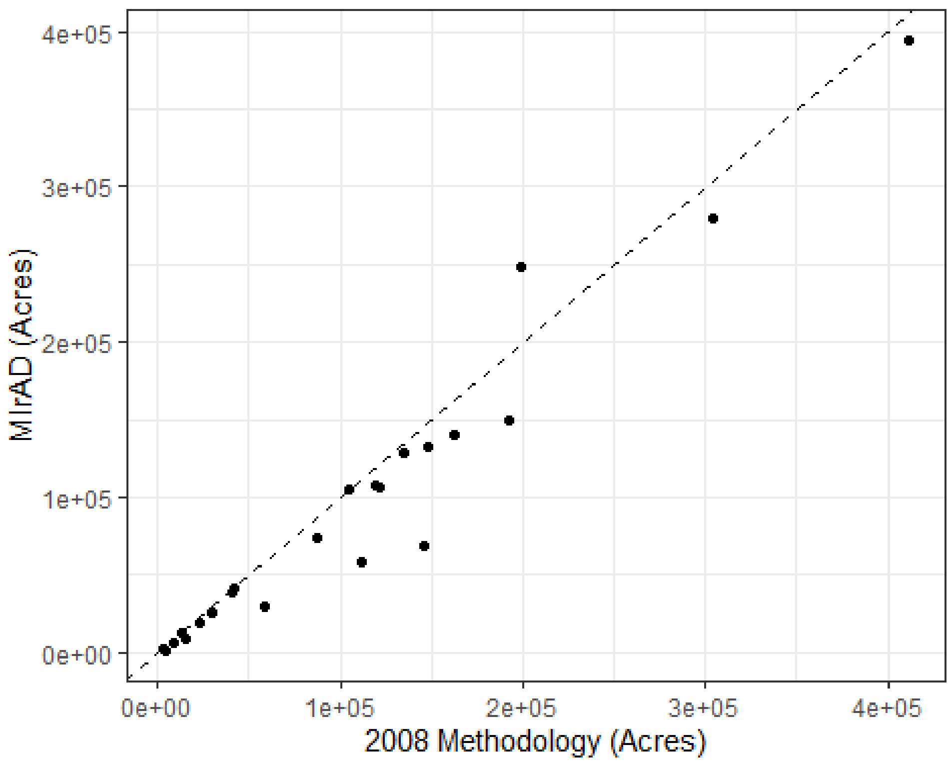

Figure 3. 2008 Subarea irrigated area using MIrAD compared to methodology used in 2010 Modified Flows.

2.1.5 Diversion and return efficiency assumptions

On-farm losses must be included in calculating the total water requirement. These on-farm losses include: (1) deep percolation due to non-uniform application; (2) field runoff because of inadequate facilities and/or inefficient land management; (3) evaporation, particularly in the case of sprinkler application; and, (4) farm distribution system losses as from ditches used in gravity irrigation. The total amount of water required is estimated by dividing the crop irrigation requirement by irrigation efficiency.

Sprinkler and gravity irrigation methods have different diversion and return flow efficiency percentages. Each subarea may have a different set of percent efficiencies for both irrigation methods. Since diversion and return flow efficiency percentages were not available for micro-irrigation, the sprinkler diversion and return flow efficiencies were also used for micro-irrigation. Tables in the results section of this document show diversion and return efficiencies for each sub-region.

VIC-CropSyst accounts for return flows based on irrigation technology-specific efficiencies. However, there are other sources of return flows that are not modeled, such as from seepage in distribution canals. These other sources are relatively large in contribution and therefore we do not use return flow estimates from VIC-CropSyst. Instead we retained the 2010 Modified Flows return-flow efficiency assumptions. Though we attempted to update diversion and return flow efficiencies by contact with Extension experts, no new values were available for use. We did ensure that return flow assumptions were larger than VIC-CropSyst based irrigation-technology related return flow estimates.

Return-flow efficiency values used in the 2010 Modified Flow Report were originally used in the 1980 Modified Flow Report and carried forward to subsequent reports. For Oregon, Washington, and Idaho, the efficiencies were obtained from King et al. (1980). For Montana the values were obtained from a Soil Conservation Service report on irrigation efficiency (SCS, 1976) The work in these two cited references was based on actual measurements and included annual diversion requirements for both gravity and sprinkler methods of water application. For the Canadian subareas, gravity and sprinkler efficiencies were not provided by Statistics Canada, and, in the absence of other data, were assumed to be the same for the 2020 study as the 2010 study.

2.1.6 Surface water fraction

In addition to total irrigated area, the fraction of surface water irrigation to total irrigated area is necessary in determining total surface water depletion adjustments. This surface water split is calculated from USGS Water Use surveys conducted every five years. These surveys provide estimates of surface and ground water withdrawal amounts, from which the surface water fraction can be calculated. The USGS Water User survey data show a high degree of variability from survey to survey which is not realistic and is likely an artifact of survey responses. Therefore, we smoothed the data using the Locally Estimated Scatterplot Smoothing (LOESS) methodology. A LOESS smoother is a type of low pass filter that combines multiple regression models in a k-nearest-neighbor-approach where the number of neighbors included in the local regression is controlled with the span parameter (Cleveland and Devlin, 1988). We applied LOESS with a span parameter of 1.1 to the county level time series of surface water fraction (Figure 4) for the time frame 1980-2015. Surface water fraction data is not available prior to 1980. For a span parameter of 1.1, the width of the weighting window is 110 percent of the length of the dataset. It means that larger weights are applied to data at extremes of the local regression than for a span parameter of one.

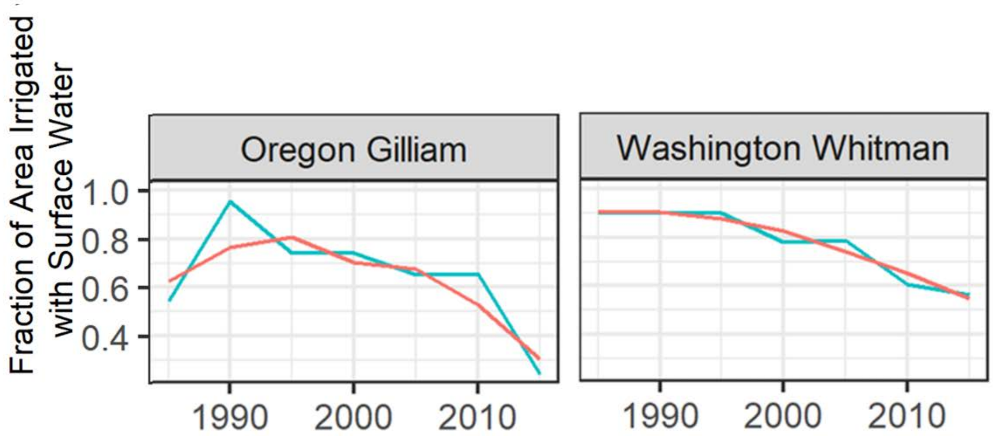

Figure 4. Time series of USGS and LOESS smoothed surface water fraction for 2 selected counties.

The LOESS smoothing resulted in larger differences to surface water fractions in some counties (e.g., Gilliam County, Oregon) and smaller differences in others (e.g., Whitman County, Washington) as seen in Figure 4. The smoothed surface water fractions by county for 2018 are provided in Section 4 (tables with 2015 USGS data).

The smoothed county level surface water fraction was then aggregated to the subarea level by weighting by each county's contribution to the irrigated acreage in a subarea (described in Appendix D). The subarea level surface water fractions for 2008 and 2018 are provided in Section 4 (summary tables comparing 2010 Modified Flows and 2020 Modified Flows).

No data was available for the Canadian subareas so we assumed all irrigation withdrawals were from surface water sources. This was the same assumption made for Canada surface water fraction in the 2010 Modified Flows Report.

2.1.7 Irrigation type

For subareas in the U.S., USGS county level water use survey data (USGS, 2015) was used to split surface water irrigated acres by three irrigation technology types – gravity, sprinkler, and micro-irrigation. Gravity systems - also referred to as flood or surface irrigation systems - are the oldest systems and pond the entire soil surface with water. These tend to be the most inefficient systems with large losses. Sprinkler irrigation systems are planned systems that use a set of pressurized pipes/nozzles to disperse water. These systems are more efficient then gravity systems. There are a wide variety of sprinkler systems with varying efficiencies. Drip or micro-irrigation systems are also planned systems, but they are designed to target water application directly to the root zone under low pressure conditions. These are relatively new (and more expensive) technologies that are increasingly being adopted given their high efficiencies. Micro-irrigation has been included as an irrigation type since the 2010 Modified Flow Report. County level data were rescaled to the subarea level using a weighted average of surface water irrigated area (by technology) for each county contributing to the subarea.

For subareas in Canada, the following fractions were used for irrigation type using data from Statistics Canada (2018) for the Columbia and Okanogan basins and applying it to neighboring subareas which do not have relevant data. Farm numbers were used as a proxy for percent irrigated area under each type of irrigation (Table 2).

Table 2. Irrigation type fractions for subareas in Canada. Note that data from Okanogan were used for Okanogan (OKA) and Kettle (KET), while fractions for the Columbia Basin were used for Pend Oreille Canada (POC), Hugh Keenleyside (ARD), Upper Columbia above Mica (UPC), Columbia at Trail (CTR), Brilliant (BRI), East Kootenay above Newgate (EKO), and West Kootenay (WKO). Due to rounding, totals may not sum to 100%.

Subarea	Sprinkler (%)	Micro (%)	Gravity (%)
POC	68	18	15
ARD	68	18	15
UPC	68	18	15
CTR	68	18	15
BRI	68	18	15
EKO	68	18	15
WKO	68	18	15
OKA	48	52	0
KET	48	52	0

2.1.8 Time series for surface water irrigated acres

Historical surface water irrigated acres were constructed using the 2010 Modified Flows time series with some adjustments. First rather than retaining 2008 irrigated acreage, we calculated irrigated area using the MIrAD process for both 2008 and 2018 for methodological consistency. These data were added to the time series of irrigated area ranging from 1928 to 1998 (retained from prior Modified Flows studies) to create a time series ranging from 1928 to 2018. Given that the Modified Flows studies occur every 10 years, this time series is typically available at intervals of 10 years, from which data for years in between need to be interpolated linearly. For additional years when USGS Water Use surveys are available (1988 and 1999), we used the smoothed surface water split fraction (Section 2.1.6) to adjust surface water irrigated. The original irrigated acreage estimates for 1988 and 1999 were multiplied by a ratio (LOESS smoothed surface water fraction / raw USGS surface water fraction) corresponding to each year. An annual time series of changes in surface water irrigated acres (as compared to 2018 levels) was then determined by subtracting 2018's surface water irrigated acres from the irrigated acres in each past year with interpolation as needed. The difference in 2018 is zero.

2.2 Association of Irrigation Extent and Type with Specific Crops

The VIC-CropSyst model requires a spatially-explicit representation of the crop mix in each grid, along with the information of whether it is irrigated and the type of irrigation technology used. These data are available through the WSDA Agricultural Land Use Geodatabase for Washington State. To determine these values outside Washington State, we combined MIrAD (irrigation extent) and the USDA CDL (crop mix). Both MIrAD and the USDA CDL were aggregated to the VIC grid cell level (1/16° resolution in latitude and longitude) to estimate the total irrigated area for each grid cell and the total area for each crop present in that grid cell. Irrigated area was first allocated to crops which are assumed to be "always irrigated" as per expert knowledge and remaining irrigated area was then equally distributed across all remaining crops. In the case that the total irrigated area was less than the area of crops assumed to be "always irrigated", those crops were still considered to be irrigated, resulting in higher total irrigated area in the grid than derived from MIrAD. This dataset is solely for the purpose of VIC-CropSyst calculations and simulating crop-weighted crop water demand. Therefore, these additional irrigated acres that are an artifact of combining two datasets are not reflected in aggregated subarea-level irrigated acreage (based solely on the MIrAD dataset) used for calculating depletion adjustments. Crops considered to be "always irrigated" for both the CDL (U.S.) and ACI (Canada) are detailed in Appendices B-1 and B-2, respectively.

2.3 VIC-CropSyst Model Description

For this study, we applied the newly developed version (V3) of VIC-CropSyst, which couples the macro-scale hydrologic VIC (Variable Infiltration Capacity) model (Liang et al., 1994) and the CropSyst crop growth model (Stockle et al., 1994; 2003) to estimate irrigation depletions. In this approach, hydrology except plant transpiration is handled by VIC, while crop growth, plant transpiration, phenology and management are handled by CropSyst (Figure 5). VIC-CropSyst tightly integrates regional scale hydrologic and agricultural systems and has been used for long-term projections of Columbia River surface water supply and irrigation demands (e.g., Hall et al., 2016; Yorgey et al., 2011).

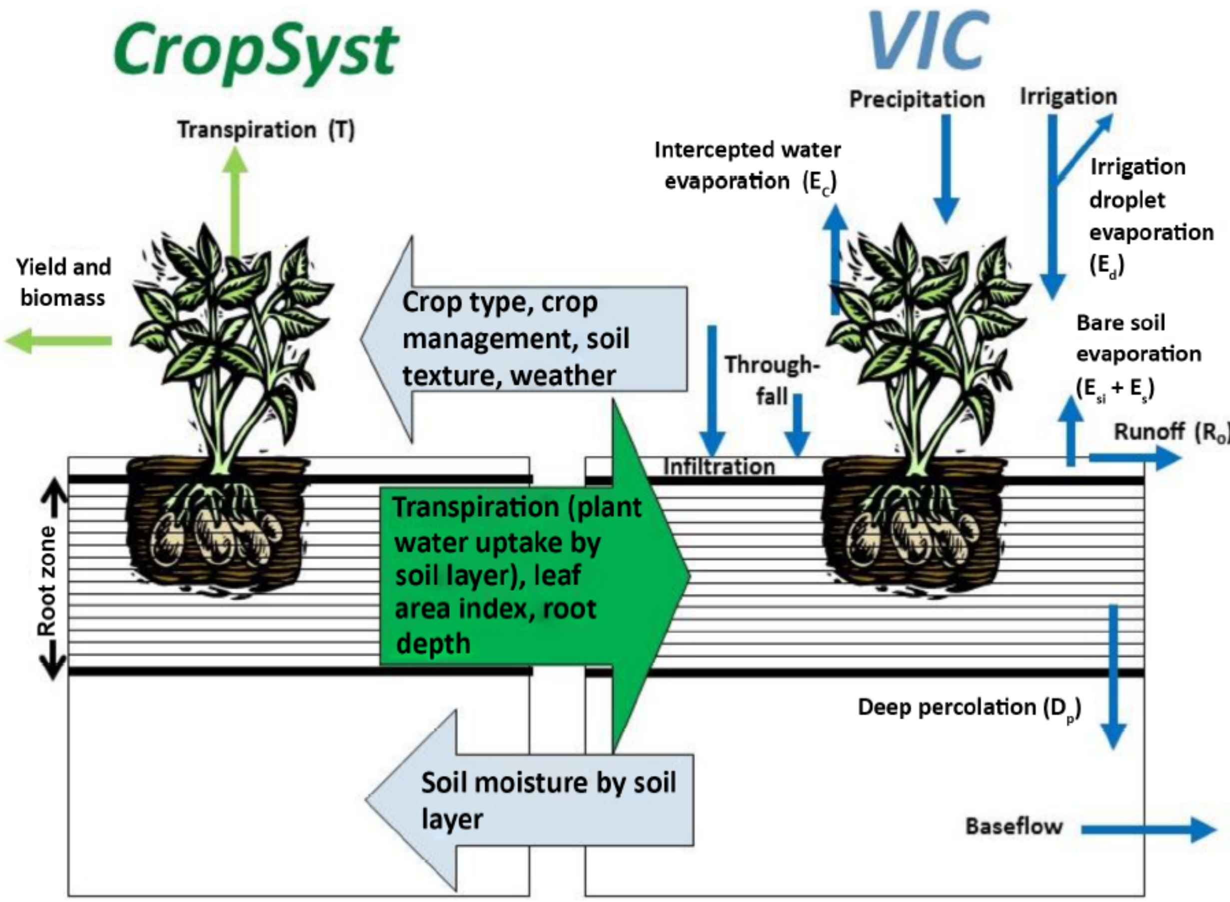

Figure 5. This schematic shows how VIC and CropSyst are coupled. VIC provides the availability of water and energy to CropSyst. CropSyst uses this information to grow the crop, produce biomass and yield, and simulate transpiration. CropSyst passes back the information that is needed by VIC (e.g., the distribution of transpiration uptake in different soil layers, leaf area index (LAI), and root depth) to simulate the hydrologic and energy cycles, and the scheduling of irrigation. (Source: Malek et al., 2017)

The VIC model is a spatially-distributed, physically-based macro-scale (with a spatial resolution of 1/16th - 2°) land surface model which solves both water and energy budgets at every time step (from 1 to 24 h). For each grid cell, sub-grid variability in land cover and topography is based on statistical relationships. VIC models moisture and energy fluxes between the land surface and the atmosphere and includes shallow subsurface (frozen and unfrozen) moisture, snow, lake, and wetland dynamics (Andreadis et al., 2009; Bowling and Lettenmaier, 2010; Cherkauer and Lettenmaier, 1999). VIC has been evaluated and applied at multiple scales including global (Adam et al., 2009; Barnett et al., 2005; Nijssen et al., 1997), over the U.S. (Livneh et al., 2013; Maurer et al., 2002), and over the Columbia River Basin (Elsner et al., 2010; Hamlet and Lettenmaier, 1999; 2007; Liu et al., 2013).

CropSyst is a mechanistic crop growth, phenology, and management model that captures a spectrum of biological, physical and chemical processes. The "growth engine" in the model is based on both solar radiation capture efficiency and water/transpiration-use efficiency, modulated by weather conditions affecting atmospheric evaporative demand and vapor pressure deficit, and by soil conditions and irrigation management affecting available water. Crop water demand (evapotranspiration) is determined from a crop coefficient factor (kc)[1] at full canopy and ground coverage determined by canopy leaf area index (LAI). This produces integration of crop production, weather and management with atmospheric warming and atmospheric CO_2 concentration, including responses to drought-induced water shortages. CropSyst has been evaluated in multiple studies (e.g., Benli et al., 2007; Stockle et al., 2010, 1996) with respect to crop biomass and yield production, crop water use, and in relation to crop response to water deficit. Note that CropSyst is invoked for each fraction of a VIC grid cell that is occupied by that crop (so may be invoked repeatedly for a single VIC grid cell; see Figure 6).

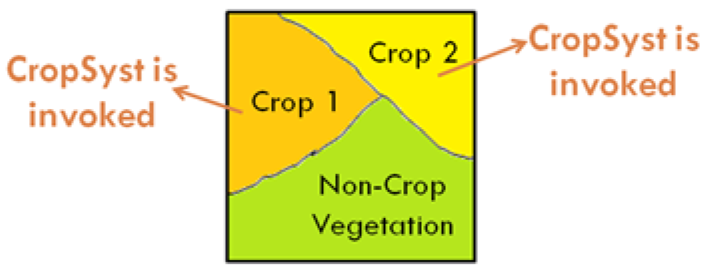

Figure 6. An illustration of how heterogeneity in land cover is handled in VIC-CropSyst. The model is run for each of the "sub-grids" that are associated with each land cover type. These sub-grids are not explicitly located in space but are lumped together as a single unit for each grid cell. CropSyst is invoked only for the sub-grids occupied by cropland. (Source: Stockle et al., 2014)

VIC-CropSyst simulates irrigation water loss either with predefined irrigation efficiency and loss parameters, or through mechanistic approach, which is described in detail by Malek et al. (2017). However, for reasons described in Section 2.1.5, we retained the 2010 Modified Flows diversion and return-flow efficiency assumptions. The model set for estimating crop water demand (CWD) is described in Section 2.6.

2.4 VIC-CropSyst Model Calibration

2.4.1 Hydrologic calibration

In addition to the input values specified in section 2.1, VIC parameters also include watershed-scale hydrologic properties that either cannot be measured directly or have significant spatial variations that need to be calibrated by iteratively comparing simulated results against observations. The following five parameters in VIC-CropSyst are automatically calibrated: BI, Ds_{MAX}, Ds, Ws, and D2:

- BI is the parameter controlling the shape of variable infiltration capacity curve;

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[1] Crop factor coefficient (kc) incorporates crop characteristics (changes in vegetation and ground cover) and averaged effects of evaporation from the soil.

- Ds_{MAX} is the maximum baseflow from the lowest soil layer;
- Ds is the fraction of Ds_{MAX} where non-linear baseflow begins;
- Ws is the fraction of the maximum soil moisture (of the lowest soil layer) where non-linear baseflow occurs; and,
- D2 is the soil depth of the lowest soil layer. These are the standard VIC parameters used for calibration.

More details about and the normal ranges of these parameters can be found in Appendix A.

2.4.1.1 Calibration methods

The automatic calibration is based on the multi-objective complex evolution (MOCOM-UA) global optimization method (Yapo et al., 1998). Six metrics/objectives are selected to evaluate model performance:

1) Nash-Sutcliff model efficiency coefficient (NSE):

$$\mathrm{NSE} = 1 - \frac{\sum_{t=1}^{T}\left(Q_m^t - Q_o^t\right)^2}{\sum_{t=1}^{T}\left(Q_o^t - \overline{Q_o}\right)^2} \tag{2}$$

where $\overline{\mathrm{Qo}}$ is the mean of observed discharges, and Q_m^t and Q_o^t are modeled and observed discharge at time t (here we use monthly time step), respectively.

2) Nash-Sutcliffe efficiency with logarithmic values (Ln NSE)

To account for the effect of low flows in our evaluation of model performance, we use the logarithmic value of Q_m^t and $Q\ _o^t$ in equation 2.

3) Relative bias in annual flow

$$\mathrm{RelBias} = \left|\frac{\overline{Q_m}}{\overline{Q_o}} - 1\right| \tag{3}$$

$\overline{Q_m}$ and $\overline{Q_o}$ are the average annual modeled flow and observed flow, respectively.

4) Coefficient of determination r^2

$$r^2 = \left(\frac{\sum_{t=1}^{T}\left(Q_o^t - \overline{Q_o}\right)\left(Q_m^t - \overline{Q_m}\right)}{\sqrt{\sum_{t=1}^{T}\left(Q_o^t - \overline{Q_o}\right)^2}\sqrt{\sum_{t=1}^{T}\left(Q_m^t - \overline{Q_m}\right)^2}}\right)^2 \tag{4}$$

5) Absolute average peak flow difference (AvgPeakDiff)

$$\mathrm{AvgPeakDiff} = \left|\overline{Q_o^{peak}} - \overline{Q_m^{peak}}\right| \tag{5}$$

The average peak flow is calculated from average monthly flow (i.e., the maximum value).

6) Root mean square error (RMSE)

$$\text{RMSE} = \sqrt{\frac{\sum_{t=1}^{T}\left(Q_o^t - Q_m^t\right)^2}{T}} \tag{6}$$

The multiple objective of the calibration is to get the Pareto set, that is, solutions that cannot be improved without degrading at least one of the other objectives. To standardize the above matrices, the NSE, Ln NSE, and r^2 metrics are multiplied by -1 (as greater numbers are preferable for these metrics) and the standardized variable is minimized.

2.4.1.2 Calibration data sets and screening

Because the calibration model runs were performed under no irrigation conditions (i.e., no water withdrawal from streams for irrigation) and reservoir influences, naturalized streamflow data sets were used for model calibration. We used four major data sources for this report (with the total number of stations for this calibration shown):

1) streamflow from USGS GAGES-II Reference stations and the drainage area larger than 200 km^2 (33 stations);

2) No Regulation No Irrigation (NRNI) data products from USACE (197 stations);

3) naturalized streamflow from Columbia Basin Climate Change Scenarios Project (CBCCSP) of University of Washington (166 stations); and,

4) naturalized streamflow for the Umatilla basin (1 station) (Figure 7).

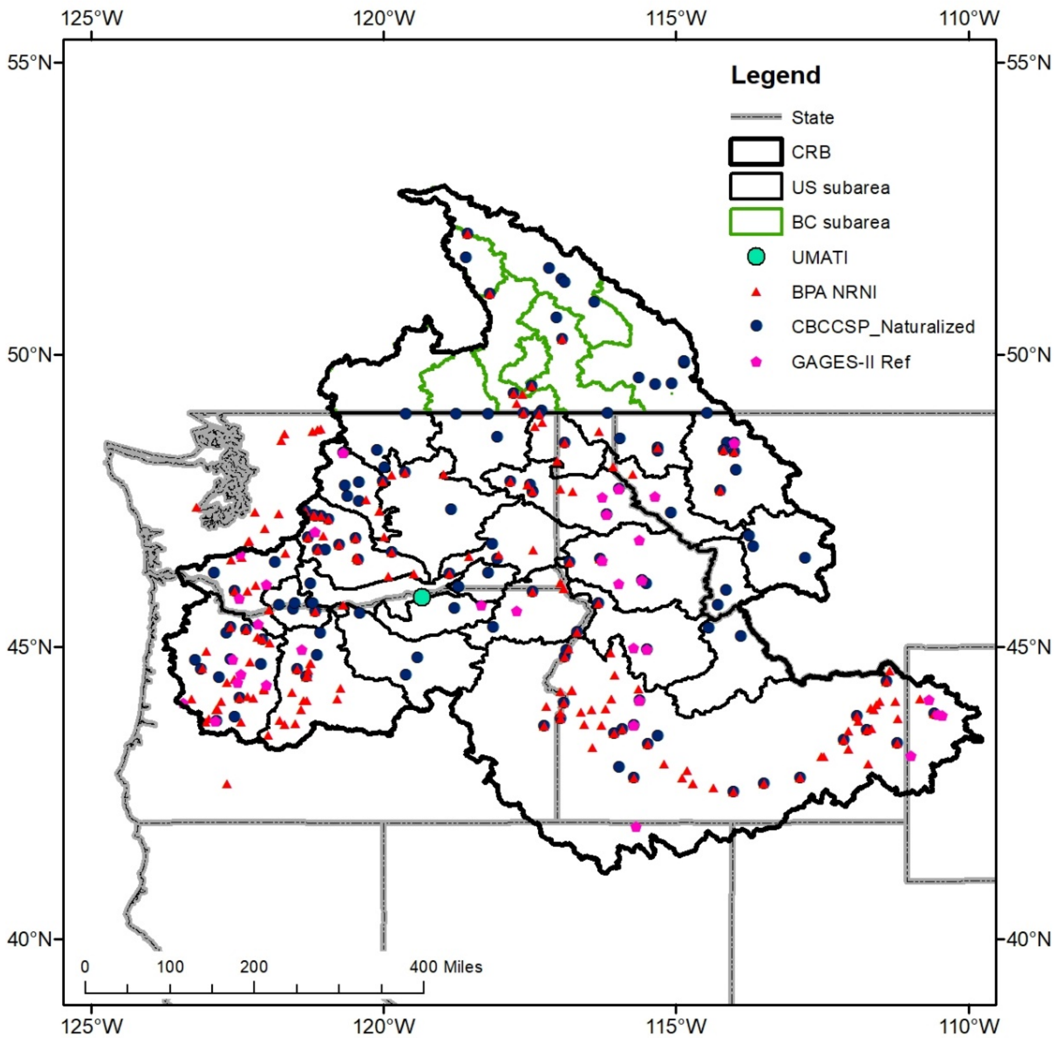

Figure 7. Hydrological gauges/stations with naturalized streamflow data for model calibration. (Note: this figure shows all stations. We screened these to a smaller set of stations for our own use. CRB: Columbia River Basin; US: United States; BC: British Columbia, Canada; UMATI: Umatilla; NRNI: No Regulation No Irrigation; CBCCSP: The Columbia Basin Climate Change Scenarios Project; GAGES-II Ref: Geospatial Attributes of Gages for Evaluating Streamflow, Version II, reference sites)

The corresponding grid cells for each station were identified by using VIC grid cell flow direction and the estimated accumulated area (comparing with each station's contribution area). Among these 397 stations, 317 of them were successfully identified with a corresponding VIC grid cell (by visual interpretation with VIC generated watershed boundary with 1:250,000 scale of USGS Hydrologic unit codes (HUC) boundary map) (https://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml). To eliminate biases due to inconsistencies in drainage area and because of the limitations of VIC in simulating small watersheds, we used the following approach. We only selected the stations with drainage areas larger than 500 km^2 and that are within 25% error in calculated drainage area (note that the flow direction file created using GIS and a digital elevation model gives the VIC-simulated drainage area; this is compared to the drainage area reported with the streamflow observations). After this screening process, 274 stations were left for the calibration process. If several datasets provided the same stations, the order of priority of use was as follows: USGS reference gauges > NRNI > CBCCSP naturalized flow.

2.4.1.3 Calibration procedure

The calibration was conducted using a nested approach, in which the most up-stream stations were calibrated first, followed by the remaining grid cells at the next station downstream, etc., until the whole watershed was calibrated. For example, the most up-stream (headwater) stations was set to a level 0 and with increasing levels moving downstream. Through this iteration, 39 levels are identified over the CRB basin. Figure 8 (which contains 5 levels from level 0 to 4 for an example watershed) depicts an example of the hierarchy of watershed levels.

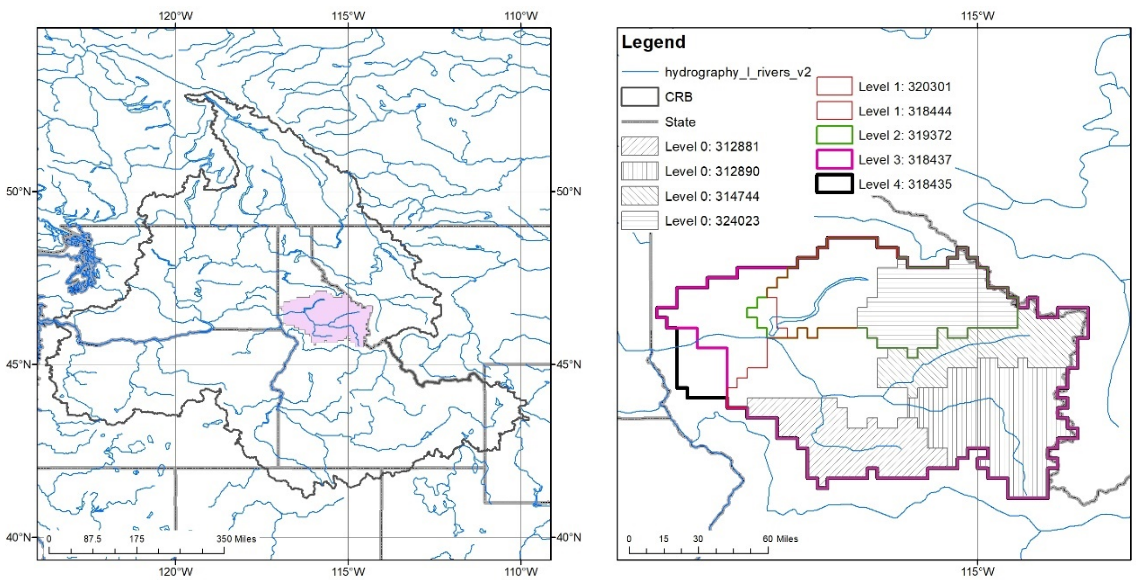

Figure 8. Example watershed levels for model calibration. (The left panel show the location of this sampling watershed; the right panel shows the watershed boundaries for different levels.)

For model calibration, we compared routed model output from 1980-current for comparison against naturalized streamflow. The routing is conducted with the VIC routing post-process developed by Lohmann et al. (1996, 1998). If the observations (after the year 1981) were less than two years, the station was removed from analysis and the calibration moved to the next level. If the maximum of the average NSE and Ln NSE was equal or higher than 0.5, then we accepted the calibrated soil parameters for this watershed (and set the station as valid); otherwise, this station was removed from calibration and steps into the upper level watershed for calibration. The final calibration results can be found in Section 2.5.1.

2.4.2 CropSyst parameterization and calibration

2.4.2.1 CropSyst parameterization

CropSyst crop parameters describe the crop's phenology, canopy growth, transpiration, biomass production, and yield. These parameters are crop and region-specific and there is no single standard source of information. Initially, the crop parameter values were taken from existing model applications in the region (Malek et al., 2017, 2018; Rajagopalan et al., 2018).

For the purposes of this project, given that we were not interested in crop response to stress, the critical parameters that needed fine-tuning through communications with local experts were planting and harvest dates, timing of various phenological (growth) stages and canopy cover at different growth stages. To account for site-specific and local variation in crop growth/ development, management information collected from field trials (under ten years old), including average sowing, flowering and heading (when available), harvest dates, total irrigation water applied and yield were used as the main source of calibration information. These field trials, conducted mostly by University Extension employees, include a range of management practices and crop varieties that represent the diversity of farmers' practices in the Pacific Northwest. Moreover, information from local growers, USDA NASS information on usual planting and harvest dates (USDA NASS, 2019), and other sources of literature were used to ensure the parameters used reflect reality in terms of actual practices in a region.

We parameterized and calibrated the CropSyst model for the main agricultural area spread across the U.S. part of CRB; for most of Oregon, eastern Washington, southern Idaho and western Montana. Eleven calibration sites were used to run the CropSyst simulation; these were compared against yields records and crop cycle development length information (when available) from field trials. In this regional crop calibration type, the simulations and field trials locations were not the same since the planting and harvest dates used for calibration (based on USDA crop calendar) were not necessarily the same as from the trials. Moreover, for calibration, we used only one soil type and the forcing data used represents the climate condition of the grid cells. The field trials and calibration site locations used in this project are shown in the map below (Figure 9) and (Table 3).

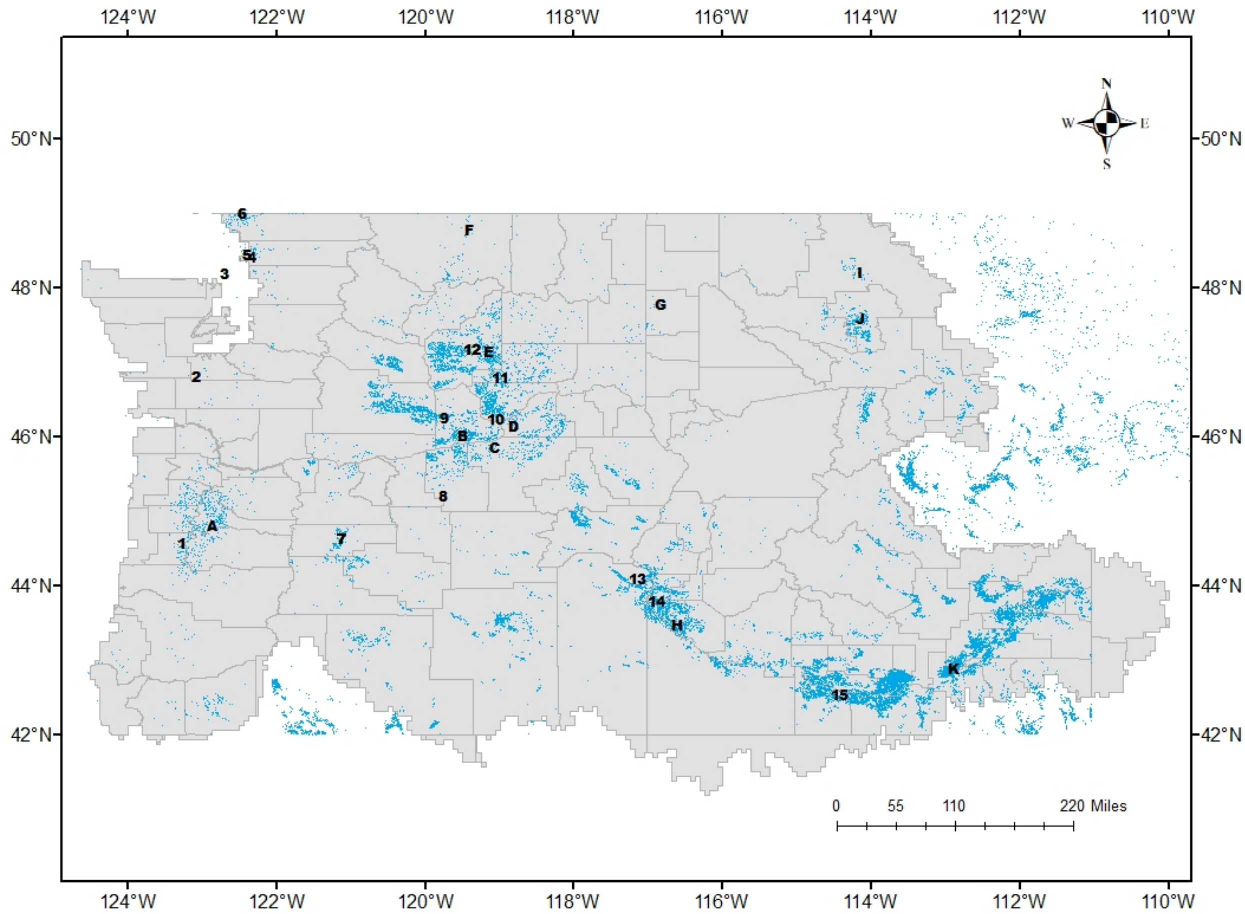

Figure 9. Field trials (numbers), model calibration (letters) sites and the irrigated extent area (MIrAD) in the U.S. Columbia River Basin. See Table 3 for calibration and field trials site details.

Table 3. Field trials and model calibration site descriptions used in this project.

Site code	Site name	Site description	Longitude	Latitude
A	Marion County_OR	Calibration	-122.85000	44.81000
B	Benton County_WA	Calibration	-119.48000	46.02000
C	Umatilla County_OR	Calibration	-119.06000	45.85000
D	Walla Walla County_WA	Calibration	-118.81000	46.14000
E	Grant County_WA	Calibration	-119.14000	47.14000
F	Okanogan County_WA	Calibration	-119.40000	48.78000
G	Kootenai County_ID	Calibration	-116.84000	47.78000
H	Canyon County_ID	Calibration	-116.61000	43.48000
I	Flathead County_MT	Calibration	-114.15000	48.21000
J	Lake County_MT	Calibration	-114.15000	47.59000
K	Bingham County_ID	Calibration	-112.89000	42.89000
1	Corvallis_OR	Field trial	-123.26205	44.56457
2	Thurston_WA	Field trial	-123.08100	46.80600
3	Island_WA	Field trial	-122.69500	48.19500
4	Mount Vernon_WA	Field trial	-122.33410	48.42120
5	Skagit_WA	Field trial	-122.38800	48.44000
6	Whatcom_WA	Field trial	-122.45000	48.99600
7	Madras_OR	Field trial	-121.12917	44.63056
8	Hardman_OR	Field trial	-119.75561	45.20000
9	Yakima Valley_WA	Field trial	-119.74000	46.26000
10	Pasco_WA	Field trial	-119.10060	46.23960
11	Othello_WA	Field trial	-119.04947	46.79472
12	Moses Lake_WA	Field trial	-119.30597	47.18068
13	Ontario_OR	Field trial	-117.08416	44.09313
14	Parma_ID	Field trial	-116.94278	43.78611
15	Kimberly_ID	Field trial	-114.36476	42.53380

The CropSyst stand-alone *version 4.0* was used to calibrate 25 crops including cereal grains, vegetables, fruits, root crops, legumes, forages, and oil seeds crops (Table 4). A detailed list of parameters used in this study are provided in Appendix E.

Table 4. Crop names (common and scientific) and types calibrated in this project.

Crop name	Scientific name	Crop type & metabolic pathway [a]
Alfalfa	*Medicago sativa*	Perennial_forage_C3
Apple	*Malus domestica*	Perennial_fruit_C3
Barley_spring	*Hordeum vulgare*	Annual_cereal_C3
Beans_dry	*Phaseolus vulgaris*	Annual_legume_C3
Blueberry	*Cyanococcus*	Perennial_fruit_C3
Canola	*Brassica napus*	Annual_oilseed_C3
Cherry	*Prunus avium*	Perennial_fruit_C3
Clover	*Trifolium*	Perennial_forage_C3
Corn_grain	*Zea mays*	Annual_cereal_C4
Corn_sweet	*Zea mays subsp. mays*	Annual_cereal_C4
Grape_wine	*Vitis vinifera or V. labrusca*	Perennial_fruit_C3
Grass_pasture	----------	Perennial_forage_C3
Hops	*Humulus lupulus*	Perennial_vegetable_C3
Lentil	*Lens culinaris*	Annual_cereal_C3
Mint	*Mentha*	Perennial_forage_C3
Oats	*Avena sativa*	Annual_cereal_C3
Onions	*Allium cepa*	Annual_bulb_C3
Pears	*Pyrus*	Perennial_fruit_C3
Peas_dry	*Pisum sativum*	Annual_legume_C3
Potatoes	*Solanum tuberosum*	Annual_tuber_C3
Radish	*Raphanus raphanistrum subsp. sativus*	Annual_vegetable_C3
Sod_seed_grass	----------	Annual_grass_C3
Triticale	×*Triticosecale*	Annual_cereal_C3
Wheat_spring	*Triticum*	Annual_cereal_C3
Wheat_winter	*Triticum*	Annual_cereal_C3

[a] C3 and C4 refer to different metabolic pathways for carbon fixation for photosynthesis in plants.

Parameters for most other crops were estimated by approximation to this basic set. Biomass production and yield information for some crops that have small production acreage were not readily available. For those crops, the primary parameterization emphasis was on canopy cover and water use, by approximation to crops in the basic set; thus, yield outputs for these crops should not be considered definitive.

2.5 Calibration Results

2.5.1 Hydrological calibration results

Figure 10 shows the distribution of NSE along the drainage area. Figure 11 and Appendix C show the final calibrated stations/watersheds and the values for evaluation metrics. Overall, with increasing drainage area, the model gives better results in terms of NSE.

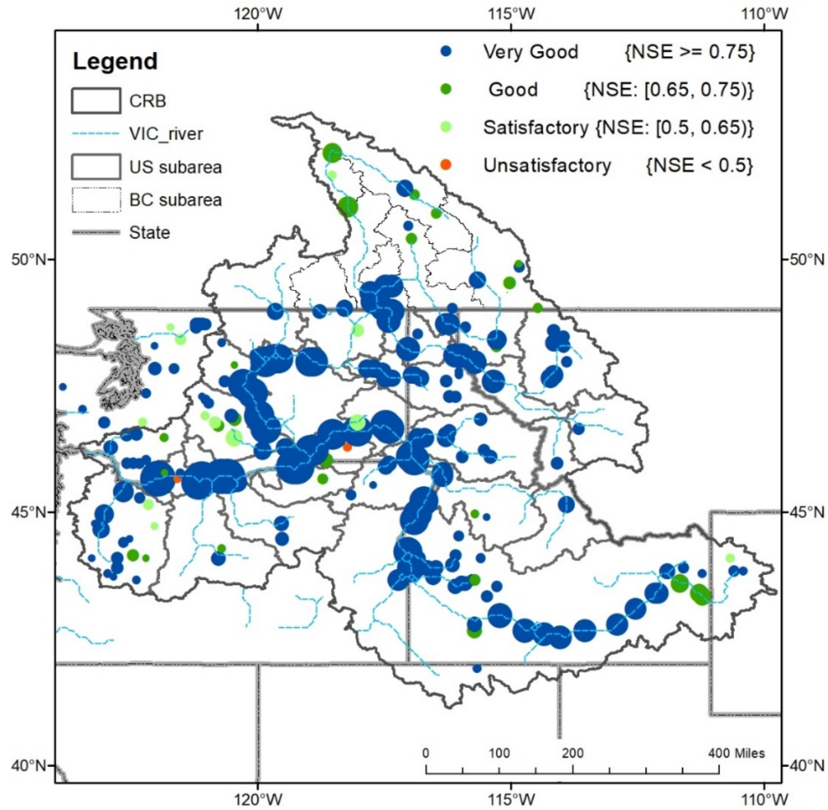

Figure 10. NSE values and its distributions of stations that were used for model calibration and their relationships with the size of drainage area. NSE categories for each calibration station and the symbol for them are scaled with drainage area.

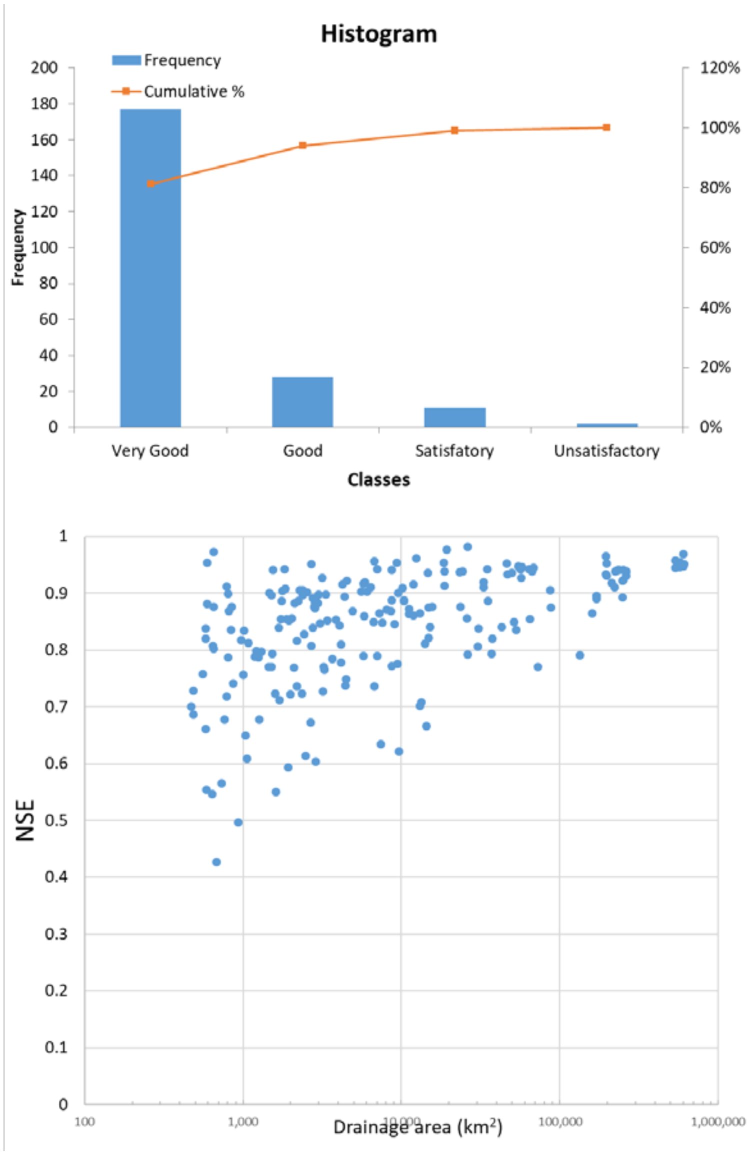

Figure 11. NSE values and its distributions of stations that were used for model calibration (shown in Figure 10). Top panel: left y-axis and column bars: the number of stations/basins falls in each NSE ranking/categories and the right y-axis and line shows the accumulative percentage; Bottom panel: NSE value distributions for each station with various drainage area.

2.5.2 CropSyst calibration results

Crop calibration was performed by adjusting the crop development (phenological stages), canopy growth (leaf area index [LAI] and Green area index [GAI] [2] at key events such as peak and

[2] Both green area index (GAI) and leaf area index (LAI) are simulated by CropSyst model. GAI and LAI measure the projected area of leaves over a unit of land (m^2/m^2). The main difference between the two variables is that LAI considers the green and dead leaves for evapotranspiration (evaporation + transpiration) estimations while GAI considers only green leaves for transpiration estimation.

senescence) and above ground dry matter assimilation (yield formation) based on available trial information.

Primary emphasis was focused on the crop length and also the occurrence of a few important phenological events such as: crop emergence, beginning and end of flowering, beginning of yield formation, end of vegetative growth, and maturity if reached. As an illustration, different development patterns for some crop types explored in this project are presented below (Figure 12).

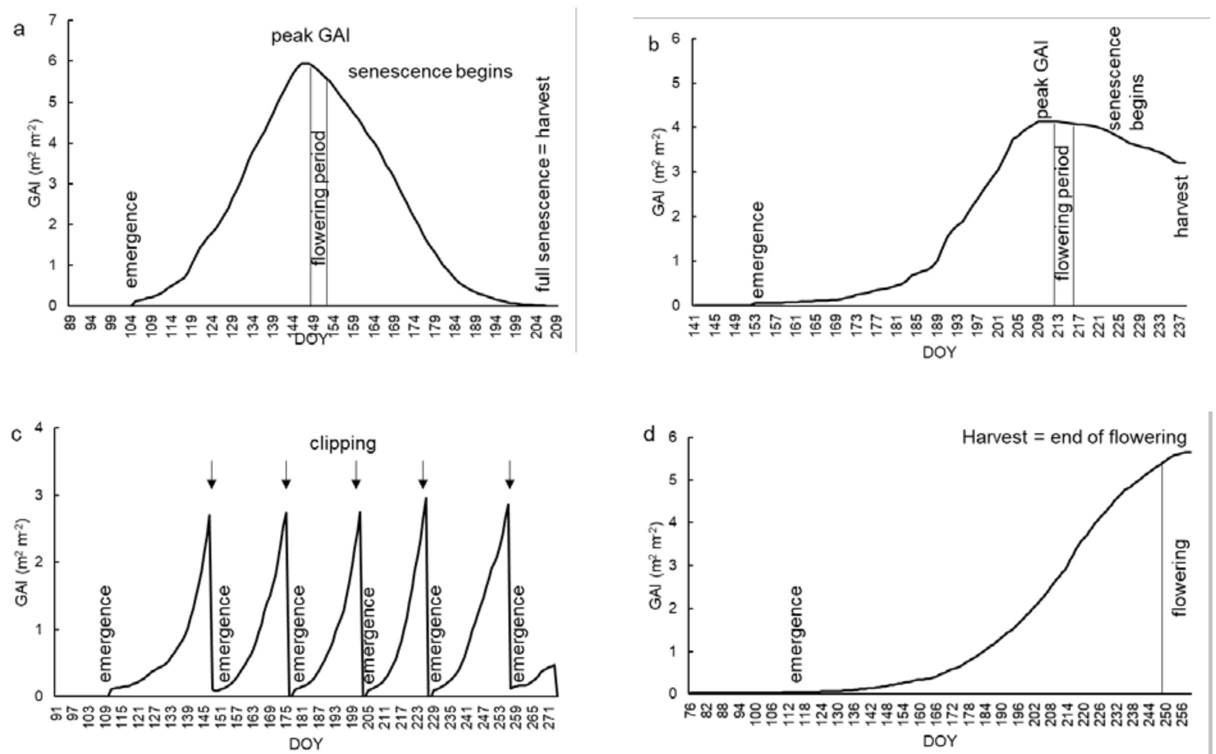

Figure 12. CropSyst simulated Green Area Index (GAI, m^2 m^{-2}) development and phenological stage events for a) Oats in Marion County, Oregon - 1981, b) Sweet corn in Marion County, Oregon - 1980 c) Grass pasture in Grant County, Washington -1983 and d) Hops in Marion County, Oregon - 1993.

Using the most common planting date, growing degree-day parameters were adjusted to approximate flowering and maturity dates typical for a particular site location within the CRB. Next, canopy cover (peak, beginning and full senescence – if reached) and above ground dry matter were calibrated concomitantly since canopy development drives crop water use, which is intrinsically related to yield. In this step, adjustments in the initial, maximum, and green canopy cover at the time of maturity (biomass accumulation has ended) were made. The simulated green area index (from 1980 to 2016) for oats, hops, pasture grass and mint are presented (Figure 13).

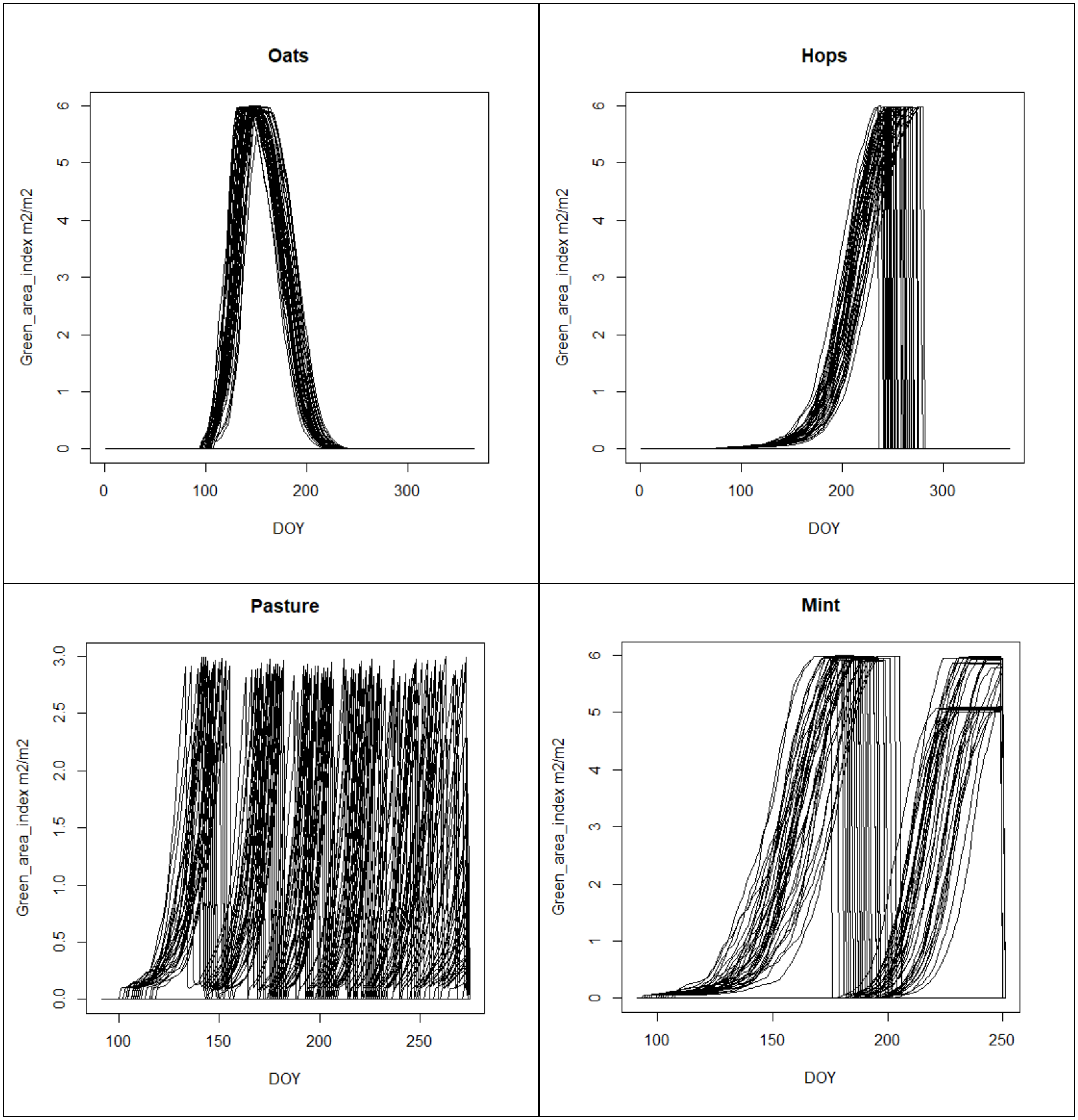

Figure 13. Thirty-six years of green area index simulation for Oats, Hops and Mint in Marion County, Oregon and Pasture grass in Flathead County, Montana.

For yield assessment, small adjustments to the transpiration-use efficiency and harvest index parameters to fine-tune the simulated yields were made when necessary. Calibration was considered finalized when simulated yields presented the same range of variation as the local experiments (on dry basis).

2.6 VIC-CropSyst Simulation Design

The simulation was conducted from the start of 1979 to end of 2015 and the mean irrigated water demand between 1986 to 2015 was used as the crop water demand (CWD). The simulations between 1979-1985 were used as the "spin-up" period to obtain initial state/soil moisture. For this report, the CWD was calculated as the deficit to field capacity from soil layers to the root depth whenever the Maximum Allowable Deficit (MAD) above the observation depth (crop-specific) was less than 0.2 for all crops. For alfalfa, pastureland, and other perennial crops (fruit trees), the first irrigation event was triggered when the soil moisture (above the observation depth) was less than 0.5; i.e., we set the MAD as 0.5 for the first irrigation event. After that threshold was reached, subsequent irrigation events were triggered by soil moisture less than MAD 0.2.

3. Calculating Depletion Adjustments (D) and Accumulated Depletion Adjustments (DD)

3.1 Calculating Depletion Adjustments (D)

Table 1 lists the series of steps involved in the calculation of depletion adjustments. The steps used are identical to those used in the 2010 Modified Flows project, although the data sources have been updated as noted in Table 1 and described in section 2.1 of this report. There are two main parts to these steps. First is the calculation of depletions per 1000 acres for current conditions. Grid-level average annual VIC-CropSyst crop water demands over the last 30 years (representative of "current conditions") are aggregated to a subarea-level crop water demand (CWD) per 1000 acres. This aggregation process area weights the crop-specific water demand. Crop water demand is then post-processed with a diversion efficiency assumption (accounts for all losses between the diversion of surface water and what is used on-farm by the crop) and a return flow efficiency assumption (accounts for the part of the diversion that is not used by the crop or lost to the atmosphere and returns to the stream) to quantify monthly depletions per 1000 acres under "current" irrigation conditions (current crop mix and irrigation technology).

Second is the calculation of depletion adjustments – a quantification of how past observed gage flows (that reflect past irrigation acreage and practices) need to be adjusted to estimate what those observations look like under current irrigated acreage and practices. These adjustments are a daily time series. To calculate the adjustment, we estimated a time series of surface water irrigated acres by irrigation type and from this created a time series of change in acres for every year in the past as compared to 2018. Data was available for a select time points in the past and a linear interpolation provided the complete time series of changes in acres in units of 1000s of acres. By multiplying this annual time series of changes in irrigated acres with monthly depletions per 1000 acres, we get a monthly time series of depletion adjustments. This was then disaggregated to a daily time series of depletion adjustments which was used as is or added to depletion adjustments from other sub-regions to get cumulative depletion adjustments.

An example detailed calculation for one subarea is provided in Appendix D.

3.2 Calculating Accumulated Depletion Adjustments (DD)

Accumulated depletion adjustments for a region are the sum of depletion adjustments from multiple contributing areas to the region. Often, only part of an area contributes to the region and these fractional contributions are part of the equations that quantify the accumulated depletions (Table 5). These fractional contributions were updated based on the relative irrigated acreages in contributing areas. For this, the contributing watershed is first delineated for each point where accumulated depletions are calculated. This is overlaid with the MIrAD irrigation extent dataset to determine the fraction of irrigated extent within the region for each contributing area. This results in updated DD equations (Table 5). Shaded rows correspond to equations that have changed as compared to the 2010 Modified Flows project.

Table 5. Equation comparisons for calculating accumulated depletions (DDs) in the 2010 Modified Flows (left), and for 2020 Modified Flows (right). Shaded cells indicate differences.

2010	2020
Upper Columbia and Kootenay	
MCD5DD = UPC5D	MCD6DD = UPC6D
RVC5DD = UPC5D + (0.35) ARD5D	RVC6DD = UPC6D
ARD5DD = UPC5D + ARD5D	ARD6DD = UPC6D + ARD6D
LIB5DD = EKO5D + (0.85) KMT5D	LIB6DD = EKO6D + (0.348) KMT6D
MCD5DD = UPC5D	MCD6DD = UPC6D
RVC5DD = UPC5D + (0.35) ARD5D	RVC6DD = UPC6D
ARD5DD = UPC5D + ARD5D	ARD6DD = UPC6D + ARD6D
LIB5DD = EKO5D + (0.85) KMT5D	LIB6DD = EKO6D + (0.35) KMT6D
BFE5DD = EKO5D + KMT5D	BFE6DD = EKO6D + KMT6D
COR5DD = EKO5D + KMT5D + KID5D + WKO5D	COR6DD = EKO6D + KMT6D + KID6D + WKO6D
BRI5DD = COR5DD + BRI5D	BRI6DD = COR6DD + BRI6D
MUC5DD = ARD5DD + BRI5DD + (0.45) CTR5D	MUC6DD = ARD6DD + BRI6DD + (0.93) CTR6D
CTR5DD = ARD5DD + BRI5DD + CTR5D	CTR6DD = ARD6DD + BRI6DD + CTR6D
Pend Oreille and Spokane Basins	
KER5DD = FLT5D + FID5D	KER6DD = FLT6D + FID6D
TOM5DD = FLT5D + FID5D + UCF5D + BIT5D + (0.84) LCF5D	TOM6DD = FLT6D + FID6D + UCF6D + BIT6D + (0.92) LCF6D
NOX5DD = TOM5DD + (0.16) LCF5D	NOX6DD = TOM6DD + (0.01) LCF6D
CAB5DD = NOX5DD	CAB6DD = NOX6DD
ALF5DD = CAB5DD + (0.72) PEN5D	ALF6DD = CAB6DD + (0.55) PEN6D
BOX5DD = CAB5DD + PEN5D	BOX6DD = CAB6DD + PEN6D
BDY5DD = BOX5DD	BDY6DD = BOX6DD
SEV5DD = BDY5DD + POC5D	SEV6DD = BDY6DD + POC6D
COE5DD = RAT5D + SPO5D	COE6DD = RAT6D + SPO6D
UPF5DD = COE5DD + SPV5D	UPF6DD = COE6DD + SPV6D
Mid-Columbia Basin	
GCL5DD = CTR5DD + SEV5DD + UPF5DD + KET5D + FER5D + GCL5D	GCL6DD = CTR6DD + SEV6DD + UPF6DD + KET6D + FER6D + GCL6D
WEL5DD = GCL5DD + OKA5D + OKM5D + (0.01) CEW5D	WEL6DD = GCL6DD + OKA6D + OKM6D
RRH5DD = GCL5DD + OKA5D + OKM5D + (0.4) CEW5D	RRH6DD = GCL6DD + OKA6D + OKM6D + (0.18) CEW6D
RIS5DD = GCL5DD + OKA5D + OKM5D + CEW5D	RIS5DD = GCL6DD + OKA6D + OKM6D + CEW6D
WAN5DD = RIS5DD + WRF5D*	WAN6DD = RIS6DD + WRF6D*
PRD5DD = WAN5DD + PRF5D*	PRD6DD = WAN6DD + PRF6D*
YAK5DD = YAK5R** – YAK5H	YAK6DD = YAK6R** – YAK6H

Lower Snake Basin	
BRN5DD = BRN5R** – BRN5A	BRN6DD = BRN6R** – BRN6A
ANA5DD = BRN5DD + UPS5D + LWS5D + WEN5D	ANA6DD = BRN6DD + UPS6D + LWS6D + WEN5D
LWG5DD = ANA5DD + CLR5D	LWG6DD = ANA6DD + CLR6D
LMN5DD = LWG5DD + PLS5D	LMN6DD = LWG6DD + PLS6D
Lower Columbia Basin	
MCN5DD = YAK5DD + PRD5DD + MRF5D* + B235D* + LMN5DD + NSM5D + KEN5D + (0.4)NSR5D + UMP5D + WWA5D	MCN6DD = YAK6DD + PRD6DD + MRF6D* + B236D* + LMN6DD + NSM6D + KEN6D + (0.67) NSR6D + UMP6D + WWA6D
NSR5D + UMP5D + WWA5D	NSR6D + UMP6D + WWA6D
JDA5DD = MCN5DD + NSJ5D + UMW5D + UMR5D + (0.6) NSR5D + JDP5D + JDA5D	JDA6DD = MCN6DD + NSJ6D + UMW6D + UMR6D + (0.332) NSR6D + JDP6D + JDA6D
ROU5DD = ROU5R** – ROU5A	ROU6DD = ROU6R** – ROU6A
PEL5DD = ROU5DD + 200 CFS RETURN FLOW	PEL6DD = ROU6DD + 200 CFS RETURN FLOW
TDA5DD = JDA5DD + PEL5DD + WHT5D	TDA6DD = JDA6DD + PEL6DD + WHT6D
BON5DD = TDA5DD + HOD5D + WHS5D + KLC5D	BON6DD = TDA6DD + HOD6D + WHS6D + KLC6D
Willamette	
ALB5DD = (0.25) WMT5D	ALB6DD = (0.20) WMT6D
SLM5DD = (0.4) WMT5D	SLM6DD = (0.31) WMT6D
SVN5DD = (0.93) WMT5D	SVN6DD = (0.40) WMT6D

4. Results

For each subbasin, the following are presented:

- map of the region and list of subareas within the region;
- description of methodological adjustments unique to the region;
- tables of summary input and calculated data; and
- figures comparing 2020 and 2010 depletion adjustments and plots of the two main factors that explain the differences in depletion adjustment (time series of surface water irrigated acres, and monthly distribution of crop water demand) are provided.

Figure 14 is an example to guide the reader on how to analyze results figures for each subarea, and understand why there are differences in results between this study and the prior 2010 Modified Flows study. For each subarea, there are plots similar to Figure 14. Parts (c) and (d) provide information to interpret differences between the time series of incremental depletions from the 2010 and 2020 Modified Flows (shown in parts (a) and (b) respectively). Part (c) corresponds to the time series of surface water irrigated acres; this helps interpret annual-scale changes in the magnitude and general patterns of depletion adjustments. Part (d) corresponds to the monthly fractional distribution of crop water demand; this helps interpret within-year changes in depletion adjustments (e.g. timing of peak depletions). In these figures, the blue color corresponds to 2010 Modified Flows and the red color corresponds to the 2020 Modified Flows. In addition, changes in the magnitude of crop water demand is a third factor that affects the magnitude of depletion adjustments. However, given that it is a less significant a factor as compared to acreage changes shown in part (c), it is not shown in these figures.

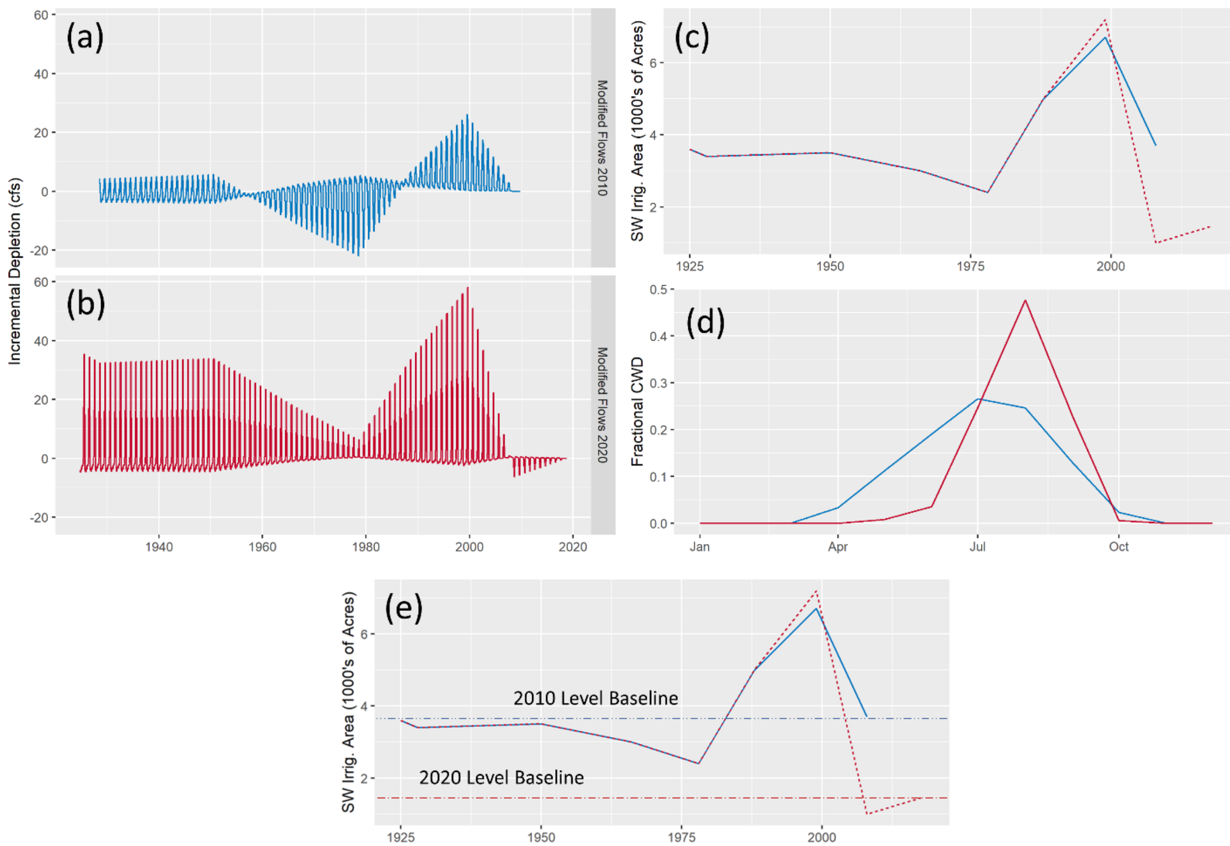

Figure 14: Example figure to understand how result figures for each subarea can be analyzed to understand differences between results of this study and the 2010 Modified Flows study. Blue color corresponds to 2010 Modified Flows and the red color corresponds to the 2020 Modified Flows.

To understand why the 2020 incremental depletions are different from 2010 incremental depletions, it is important to note that the baseline "current" acreage against which all prior years are compared could be different. This is evident in Figure 14 part (e) - which is a copy of Figure 14 part (c) - but highlighting the respective baseline acreages with horizontal lines.

The baseline acreage from 2010 Modified Flows is higher than acreage estimates of some years and lower than others (Figure 14 part (e)). Therefore, in part (a) the depletion adjustments fluctuate between positive and negative adjustments. The period from 1955 to 1985 has negative depletion adjustments. This is because a lower acreage than the baseline acreage in these years, implies that more water would have been removed from the stream if those years had the higher baseline irrigation extent.

In contrast, new data for current conditions in 2020 indicate a lower baseline than all pre-2008 years (Figure 14 part (e)). The 2008 values have been adjusted downward based on new information, resulting in higher than baseline acreage between 2008 and 2018. Therefore, the 2020 depletion adjustments have a different direction of change than the 2010 depletion adjustments - positive pre-2008 and negative between 2008 and 2018. Additionally, for most of the time series, the magnitude of acreage differences with the 2020 baseline are much larger than those with the 2010 baseline. This results in the 2020 depletions adjustments being generally larger in magnitude.

Figure 14 part (d) indicates that for this example subarea, the 2020 Modified Flows project resulted in a shift of crop water demands to later in the season and for the peak demand to be higher as compared to the 2010 Modified Flows study. This will manifest as a change in the within-year timing and magnitude of peak depletions adjustments. These changes are hard to discern in the resolution of Figure 14, but will be apparent in a stretched figure with a higher time resolution.

Each subarea is unique in terms of differences between the results from the 2020 Modified Flows study and the prior 2010 Modified Flows study. The analysis steps followed here can be extended to all result figures to understand the primary cause of differences in results between this 2020 study and the prior 2010 study.

4.1 Upper Columbia and Kootenay Basins

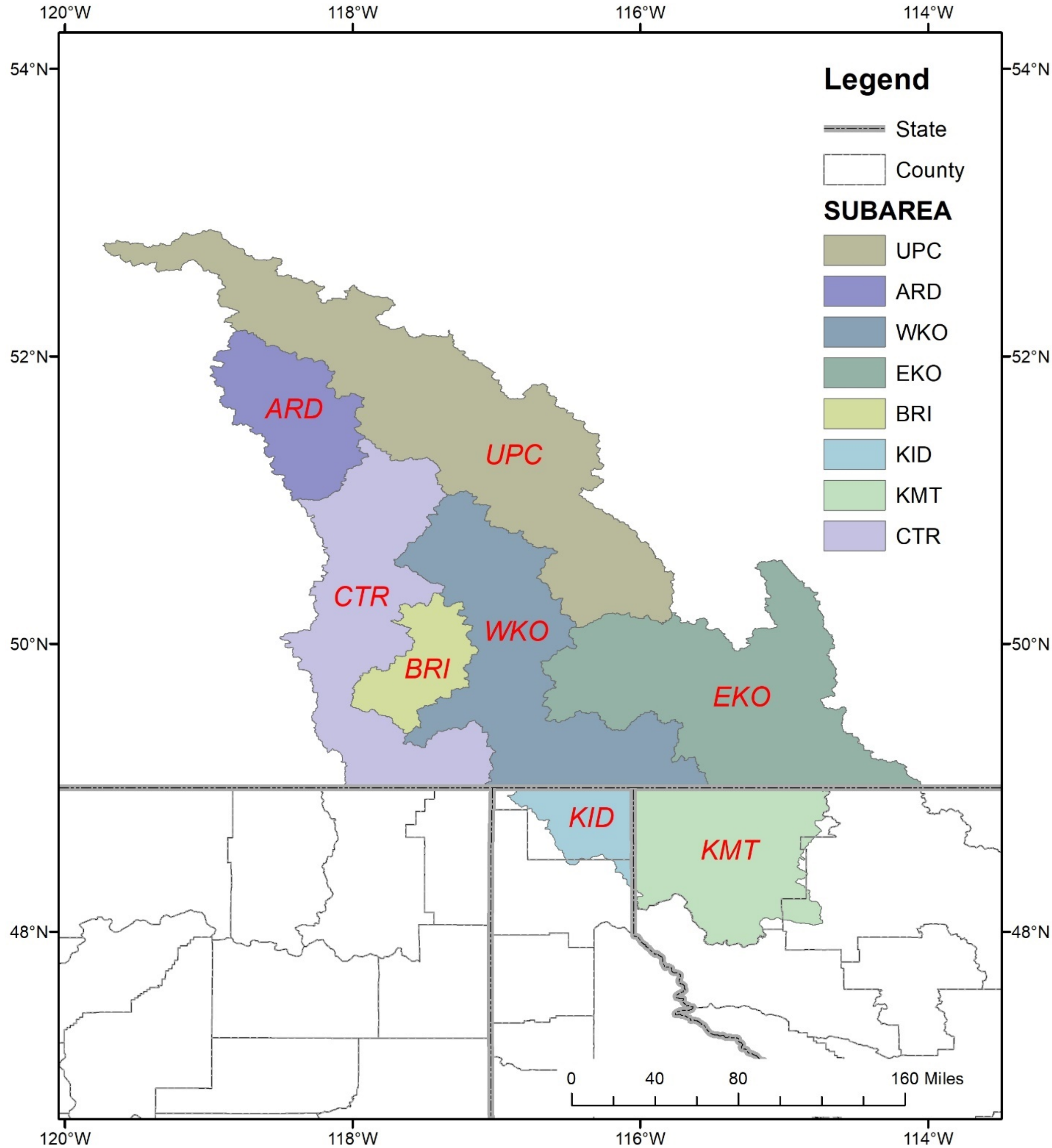

Figure 15. Map showing location of subareas within the Upper Columbia and Kootenay Basins. Subarea codes defined in Table 6, below.

Table 6. Basin, code, name, and subarea for areas in the Upper Columbia and Kootenay Basins described in this section.

Basin	**Code**	**Name**	**Subarea**
Upper Columbia	ARD	Canada - Hugh Keenleyside	CA 08ND
Upper Columbia	UPC	Canada - Upper Columbia above Mica	CA 08NA + 08NB + 08NC
Upper Columbia	CTR	Canada - Columbia at Trail	CA 08NE
Kootenay	BRI	Canada - Brilliant	CA 08NJ
Kootenay	EKO	Canada - East Kootenay above Newgate	CA 08NG + 08NK + 08NP
Kootenay	KMT	Kootenai - Montana	Subarea 5b
Kootenay	KID	Kootenai - Idaho	Subarea 5a
Kootenay	WKO	Canada - West Kootenay	CA 08NH

4.1.1 Description of and justification for methodology used that was specific to the region

This region has paucity of data and large uncertainties in terms of irrigated acreage, crop mix, irrigation technology, and efficiency estimates. However, since there is minimal irrigation here as compared to the U.S., the impacts of these uncertainties on modified flows are likely minimal as well. Similar to approaches taken by prior studies, we tried to reduce known biases in irrigated acreage with scaling factors. However, irrigated acreage estimates in this study ended up much lower than the 2020 Modified Flows estimates, likely due to the change in irrigation extent identification methodology. These nuances are elaborated below.

Irrigation extent data sources for Canada (Statistics Canada Census of Agriculture) are generally available at a course resolution with significant uncertainty. The 2010 Modified Flows study applied a 1.25 scaling factor to the Census of Agriculture summary information to address a general low bias in the data. While we tried to use more region-specific scaling, data limitations did not allow that. The Ministry of Agriculture is undertaking an effort to inventory irrigated lands. While this data was not available in time for this study, it will likely provide better quality data for future studies.

The MIrAD process spatially distributes irrigation extent within a subarea using aggregate information. Unlike the U.S. where aggregate information is available at county scales (generally similar in size to subareas), in Canada aggregate information is available at a much larger spatial domain than subareas. This creates additional uncertainty in the spatial distribution process. In spite of this uncertainty, given all other data uncertainties in Canada, we determined that there is merit in being consistent in methodology across U.S. and Canada.

For the Canadian subareas Hugh Keenleyside (ARD) and Brilliant (BRI) the original MIrAD file did not have any irrigated cropland, so VIC-CropSyst could not be run for those regions. To account for this, we used the average CWD from an adjacent area (Columbia at Trail; CTR). Crop water demand was calculated even for areas where MIrAD showed no current irrigated acreage because it is necessary to calculate a time series for depletions (based on change in acres between current conditions and past years). Data on irrigation type was incomplete for Canadian subareas, thus irrigation type information from Statistics Canada for the Columbia and Okanogan Basin were applied to neighboring subareas (see section 2.1.7).

In several Canadian subareas (particularly Upper Columbia above Mica and East Kootenay above Newgate) the estimates of irrigated area were dramatically lower in this study than for the 2010 Modified Flows. Much of this is likely due to a change in methodology, but lack of information precludes us from hypothesizing whether prior results were overestimates or if current results are underestimates. Likewise, in Kootenai-Montana, the 2010 surface water irrigated acres were revised from 5,200 acres (in the 2010 Modified Flows) to 2,900 acres (using the methodology of this study).

Sources of uncertainty relevant to the entirety of the Columbia River Basin are discussed in Section 5.

4.1.2 Tables with Summary Data

Crop distribution

Crop distributions are listed for crops comprising at least 1% of total irrigated area. Note that the total acreage shown may include crops that are not shown on the table because of their small contribution total acres. The irrigated area totals here may not exactly match the "total irrigated area" used for depletion calculation and shown in the Summary tables comparing 2010 Modified Flows and 2020 Modified Flows. This is an artifact of our process to translate non-crop specific MIrAD irrigation extent to crop-specific irrigation extent as described in the methodology Section 2.2.

Canada - Hugh Keenleyside

Crop	Irrigated area (acres)	Percent of total

No data available - used crop breakdown of Columbia at Trail

Canada - Upper Columbia above Mica

Crop	Irrigated area (acres)	Percent of total
Canola	138	61.6%
Bean Dry	34	15.0%
Barley	20	9.0%
Corn	12	5.4%
Pasture	11	5.1%
Spring Wheat	7	3.0%
Total	**224**	

Canada - Columbia at Trail

Crop	Irrigated area (acres)	Percent of total
Generic Orchards	1,353	85.0%
Generic	121	7.6%
Grape Wine	107	6.7%
Total	**1,592**	

Canada - Brilliant

Crop	Irrigated area (acres)	Percent of total

No data available - used crop breakdown of Columbia at Trail

Canada - East Kootenay above Newgate

Crop	Irrigated area (acres)	Percent of total
Canola	738	27.1%
Pasture	713	26.1%
Barley	542	19.9%
Spring Wheat	349	12.8%
Bean Dry	136	5.0%
Pea Green	121	4.4%
Corn	79	2.9%
Total	**2,729**	

Subarea 5b - Kootenai-Montana

Crop	Irrigated area (acres)	Percent of total
Pasture	2,674	88.9%
Alfalfa Hay	329	10.9%
Total	**3,009**	

Subarea 5a - Kootenai-Idaho

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	11,459	99.4%
Total	**11,528**	

Canada - West Kootenay

Crop	Irrigated area (acres)	Percent of total
Generic	164	86.3%
Spring Wheat	10	5.3%
Alfalfa Hay	5	2.7%
Pasture	4	2.0%
Barley	3	1.8%
Canola	3	1.4%
Total	**190**	

County fractions

Subarea 5b - Kootenai-Montana

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Montana	Flathead	0.01	247
Montana	Lincoln	0.88	3,413
		TOTAL	**3,660**

Subarea 5a - Kootenai-Idaho

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Idaho	Boundary	0.82	1,637
		TOTAL	**1,637**

Crop water demand monthly fraction by crop (for crops comprising at least 1% of irrigated area)

Canada - Hugh Keenleyside (used data from Columbia at Trail)

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	1.8	6.3	93.0	314.1	306.8	144.4	36.1	0.0	0.0	902
Diversion distribution %	0.0%	0.0%	0.0%	0.2%	0.7%	10.3%	34.8%	34.0%	16.0%	4.0%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Generic Orchards	85.0%	0.0	0.0	0.0	0.0	0.0	1.1	3.9	3.7	1.8	0.5	0.0	0.0	11.0
Generic	7.6%	0.0	0.0	0.0	0.0	0.2	1.5	4.8	3.0	0.3	0.0	0.0	0.0	9.8
Grape Wine	6.7%	0.0	0.0	0.0	0.0	0.0	0.0	0.8	3.5	1.7	0.4	0.0	0.0	6.4

Canada - Upper Columbia above Mica

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.0	34.1	160.9	272.6	81.6	8.9	0.0	0.0	0.0	559
Diversion distribution %	0.0%	0.0%	0.0%	0.0%	6.1%	28.8%	48.8%	14.6%	1.6%	0.0%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Canola	61.6%	0.0	0.0	0.0	0.0	0.4	2.6	4.9	5.3	3.6	0.1	0.0	0.0	16.9
Bean Dry	15.0%	0.0	0.0	0.0	0.0	1.1	3.5	6.3	6.2	3.6	1.0	0.0	0.0	21.6
Barley	9.0%	0.0	0.0	0.0	0.1	2.3	2.6	0.1	0.0	0.0	0.0	0.0	0.0	5.1
Corn	5.4%	0.0	0.0	0.0	0.0	0.8	3.7	6.9	2.5	0.0	0.0	0.0	0.0	13.9
Pasture	5.1%	0.0	0.0	0.0	0.0	0.2	2.0	5.9	6.3	4.2	1.3	0.0	0.0	19.9
Spring Wheat	3.0%	0.0	0.0	0.0	0.0	0.7	2.1	3.0	0.1	0.0	0.0	0.0	0.0	5.9

Canada - Columbia at Trail

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	1.8	6.3	93.0	314.1	306.8	144.4	36.1	0.0	0.0	902
Diversion distribution %	0.0%	0.0%	0.0%	0.2%	0.7%	10.3%	34.8%	34.0%	16.0%	4.0%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Generic Orchards	85.0%	0.0	0.0	0.0	0.0	0.0	1.1	3.9	3.7	1.8	0.5	0.0	0.0	11.0
Generic	7.6%	0.0	0.0	0.0	0.0	0.2	1.5	4.8	3.0	0.3	0.0	0.0	0.0	9.8
Grape Wine	6.7%	0.0	0.0	0.0	0.0	0.0	0.0	0.8	3.5	1.7	0.4	0.0	0.0	6.4

Canada – Brilliant (used data from Columbia at Trail)

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	1.8	6.3	93.0	314.1	306.8	144.4	36.1	0.0	0.0	902
Diversion distribution %	0.0%	0.0%	0.0%	0.2%	0.7%	10.3%	34.8%	34.0%	16.0%	4.0%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Generic Orchards	85.0%	0.0	0.0	0.0	0.0	0.0	1.1	3.9	3.7	1.8	0.5	0.0	0.0	11.0
Generic	7.6%	0.0	0.0	0.0	0.0	0.2	1.5	4.8	3.0	0.3	0.0	0.0	0.0	9.8
Grape Wine	6.7%	0.0	0.0	0.0	0.0	0.0	0.0	0.8	3.5	1.7	0.4	0.0	0.0	6.4

Canada - East Kootenay above Newgate

	Water requirement (ac-ft/1000 acres) by month for all crops												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.0	33.2	116.2	246.9	119.7	36.0	1.1	0.0	0.0	553
Diversion distribution %	0.0%	0.0%	0.0%	0.0%	6.0%	21.0%	44.6%	21.6%	6.5%	0.2%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Canola	27.1%	0.0	0.0	0.0	0.0	0.7	2.4	3.7	0.4	0.0	0.0	0.0	0.0	7.3
Pasture	26.1%	0.0	0.0	0.0	0.0	0.1	0.7	1.8	2.7	1.4	0.0	0.0	0.0	6.6
Barley	19.9%	0.0	0.0	0.0	0.0	0.4	1.1	2.7	1.0	0.2	0.0	0.0	0.0	5.4
Spring Wheat	12.8%	0.0	0.0	0.0	0.0	0.5	1.4	3.1	0.9	0.1	0.0	0.0	0.0	6.0
Bean Dry	5.0%	0.0	0.0	0.0	0.0	0.0	1.0	4.0	2.6	0.2	0.0	0.0	0.0	7.9
Pea Green	4.4%	0.0	0.0	0.0	0.0	0.4	1.1	3.4	2.3	0.3	0.0	0.0	0.0	7.6
Corn	2.9%	0.0	0.0	0.0	0.0	0.2	1.5	4.4	1.9	0.0	0.0	0.0	0.0	8.1

Subarea 5b - Kootenai-Montana

	Water requirement (ac-ft/1000 acres) by month for all crops												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.4	32.1	86.1	242.0	307.6	159.8	4.0	0.0	0.0	832
Diversion distribution %	0.0%	0.0%	0.0%	0.0%	3.9%	10.3%	29.1%	37.0%	19.2%	0.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	88.9%	0.0	0.0	0.0	0.0	0.4	1.1	2.9	3.4	1.8	0.0	0.0	0.0	9.8
Alfalfa Hay	10.9%	0.0	0.0	0.0	0.0	0.1	0.6	2.8	5.7	2.6	0.1	0.0	0.0	11.8

Subarea 5a - Kootenai-Idaho

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.0	0.3	9.6	243.6	464.3	214.1	4.6	0.0	0.0	937
Diversion distribution %	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	26.0%	49.6%	22.9%	0.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	99.4%	0.0	0.0	0.0	0.0	0.0	0.1	2.9	5.6	2.6	0.1	0.0	0.0	11.2

Canada - West Kootenay

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.0	37.2	166.6	388.2	170.5	12.4	0.0	0.0	0.0	775
Diversion distribution %	0.0%	0.0%	0.0%	0.0%	4.8%	21.5%	50.1%	22.0%	1.6%	0.0%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Generic	86.3%	0.0	0.0	0.0	0.0	0.5	2.2	4.9	2.0	0.1	0.0	0.0	0.0	9.7
Spring Wheat	5.3%	0.0	0.0	0.0	0.0	0.2	1.5	3.9	0.9	0.0	0.0	0.0	0.0	6.5
Alfalfa Hay	2.7%	0.0	0.0	0.0	0.0	0.0	0.0	1.4	4.5	2.4	0.0	0.0	0.0	8.5
Pasture	2.0%	0.0	0.0	0.0	0.0	0.0	0.0	1.2	3.2	1.5	0.0	0.0	0.0	5.9
Barley	1.8%	0.0	0.0	0.0	0.0	0.2	1.0	4.0	1.7	0.0	0.0	0.0	0.0	6.9
Canola	1.4%	0.0	0.0	0.0	0.0	0.3	2.5	4.3	0.6	0.0	0.0	0.0	0.0	7.7

2015 USGS data

Subarea 5b - Kootenai-Montana

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Montana	Flathead	0.84	37.9	0.0	3.7	41.6
Montana	Lincoln	0.98	3.1	0.0	2.0	5.0

Subarea 5a - Kootenai-Idaho

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Idaho	Boundary	0.66	13.2	0	22.4	35.6

Diversion and return flow volumes (ac-ft/1000 ac) based on sprinkler/gravity efficiencies

Canada - Hugh Keenleyside

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*902*	*902*
Diversion Efficiency (%)	*74%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1220**	**-1805**
Return Efficiency (%)	*22%*	*45%*
Return Flow (ac-ft per 1000 ac)	**268**	**812**

Canada - Upper Columbia above Mica

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*559*	*559*
Diversion Efficiency (%)	*63%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-887**	**-1117**
Return Efficiency (%)	*33%*	*45%*
Return Flow (ac-ft per 1000 ac)	**293**	**503**

Canada - Columbia at Trail

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*902*	*902*
Diversion Efficiency (%)	*63%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1433**	**-1805**
Return Efficiency (%)	*33%*	*45%*
Return Flow (ac-ft per 1000 ac)	**473**	**812**

Canada - Brilliant

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*902*	*902*
Diversion Efficiency (%)	*63%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1433**	**-1805**
Return Efficiency (%)	*33%*	*45%*
Return Flow (ac-ft per 1000 ac)	**473**	**812**

Canada - East Kootenay above Newgate

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*553*	*553*
Diversion Efficiency (%)	*63%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-878**	**-1106**
Return Efficiency (%)	*33%*	*45%*
Return Flow (ac-ft per 1000 ac)	**290**	**498**

Subarea 5b - Kootenai-Montana

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*832*	*832*
Diversion Efficiency (%)	*63%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1321**	**-1664**
Return Efficiency (%)	*33%*	*45%*
Return Flow (ac-ft per 1000 ac)	**436**	**749**

Subarea 5a - Kootenai-Idaho

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*937*	*937*
Diversion Efficiency (%)	*63%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1487**	**-1873**
Return Efficiency (%)	*33%*	*45%*
Return Flow (ac-ft per 1000 ac)	**491**	**843**

Canada - West Kootenay

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*775*	*775*
Diversion Efficiency (%)	*63%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1230**	**-1550**
Return Efficiency (%)	*33%*	*45%*
Return Flow (ac-ft per 1000 ac)	**406**	**697**

Depletions per unit area

Canada - Hugh Keenleyside

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			7.0%	19	19	**0.3**		JAN			7.0%	57	57	**0.9**
FEB			6.0%	16	16	**0.3**		FEB			6.0%	49	49	**0.9**
MAR	0.0%	0	5.0%	13	13	**0.2**		MAR	0.0%	0	5.0%	41	40	**0.7**
APR	0.2%	-3	4.0%	11	8	**0.1**		APR	0.2%	-4	4.0%	32	28	**0.5**
MAY	0.7%	-8	5.0%	13	5	**0.1**		MAY	0.7%	-12	5.0%	41	28	**0.5**
JUN	10.3%	-125	8.0%	21	-104	**-1.7**		JUN	10.3%	-185	8.0%	65	-120	**-2.0**
JUL	34.8%	-425	10.0%	27	-398	**-6.5**		JUL	34.8%	-629	10.0%	81	-547	**-8.9**
AUG	34.0%	-414	14.0%	38	-377	**-6.1**		AUG	34.0%	-613	14.0%	114	-499	**-8.1**
SEP	16.0%	-196	12.0%	32	-163	**-2.7**		SEP	16.0%	-290	12.0%	97	-192	**-3.2**
OCT	4.0%	-48	11.0%	30	-19	**-0.3**		OCT	4.0%	-72	11.0%	89	18	**0.3**
NOV			10.0%	27	27	**0.5**		NOV			10.0%	81	81	**1.4**
DEC			8.0%	21	21	**0.3**		DEC			8.0%	65	65	**1.1**
Total	100.0%	-1220	100.0%	268	-951			Total	100.0%	-1805	100.0%	812	-993	

Canada - Upper Columbia above Mica

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			6.0%	18	18	**0.3**
FEB			5.0%	15	15	**0.3**
MAR			4.0%	12	12	**0.2**
APR	0.0%	0	4.0%	12	12	**0.2**
MAY	6.1%	-54	7.0%	20	-34	**-0.6**
JUN	28.8%	-255	9.0%	26	-229	**-3.8**
JUL	48.8%	-433	11.0%	32	-401	**-6.5**
AUG	14.6%	-130	13.0%	38	-92	**-1.5**
SEP	1.6%	-14	14.0%	41	27	**0.5**
OCT	0.0%	0	11.0%	32	32	**0.5**
NOV			9.0%	26	26	**0.4**
DEC			7.0%	20	20	**0.3**
Total	100.0%	-887	100.0%	293	-594	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			6.0%	30	30	**0.5**
FEB			5.0%	25	25	**0.4**
MAR			4.0%	20	20	**0.3**
APR	0.0%	0	4.0%	20	20	**0.3**
MAY	6.1%	-69	7.0%	35	-33	**-0.5**
JUN	28.8%	-322	9.0%	45	-276	**-4.6**
JUL	48.8%	-545	11.0%	55	-490	**-8.0**
AUG	14.6%	-164	13.0%	65	-98	**-1.6**
SEP	1.6%	-17	14.0%	70	53	**0.9**
OCT	0.0%	0	11.0%	55	55	**0.9**
NOV			9.0%	45	45	**0.8**
DEC			7.0%	35	35	**0.6**
Total	100.0%	-1117	100.0%	503	-615	

Canada - Columbia at Trail

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			6.0%	28	28	**0.5**
FEB			5.0%	24	24	**0.4**
MAR	0.0%	0	4.0%	19	19	**0.3**
APR	0.2%	-3	4.0%	19	15	**0.3**
MAY	0.7%	-10	7.0%	33	23	**0.4**
JUN	10.3%	-147	9.0%	43	-105	**-1.8**
JUL	34.8%	-499	11.0%	52	-447	**-7.3**
AUG	34.0%	-486	13.0%	61	-425	**-6.9**
SEP	16.0%	-230	14.0%	66	-164	**-2.7**
OCT	4.0%	-57	11.0%	52	-5	**-0.1**
NOV			9.0%	43	43	**0.7**
DEC			7.0%	33	33	**0.5**
Total	100.0%	-1433	100.0%	473	-960	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			6.0%	49	49	**0.8**
FEB			5.0%	41	41	**0.7**
MAR	0.0%	0	4.0%	32	32	**0.5**
APR	0.2%	-4	4.0%	32	28	**0.5**
MAY	0.7%	-12	7.0%	57	44	**0.7**
JUN	10.3%	-185	9.0%	73	-112	**-1.9**
JUL	34.8%	-629	11.0%	89	-539	**-8.8**
AUG	34.0%	-613	13.0%	106	-507	**-8.3**
SEP	16.0%	-290	14.0%	114	-176	**-3.0**
OCT	4.0%	-72	11.0%	89	18	**0.3**
NOV			9.0%	73	73	**1.2**
DEC			7.0%	57	57	**0.9**
Total	100.0%	-1805	100.0%	812	-993	

Canada - Brilliant

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			6.0%	28	28	**0.5**
FEB			5.0%	24	24	**0.4**
MAR	0.0%	0	4.0%	19	19	**0.3**
APR	0.2%	-3	4.0%	19	15	**0.3**
MAY	0.7%	-10	7.0%	33	23	**0.4**
JUN	10.3%	-147	9.0%	43	-105	**-1.8**
JUL	34.8%	-499	11.0%	52	-447	**-7.3**
AUG	34.0%	-486	13.0%	61	-425	**-6.9**
SEP	16.0%	-230	14.0%	66	-164	**-2.7**
OCT	4.0%	-57	11.0%	52	-5	**-0.1**
NOV			9.0%	43	43	**0.7**
DEC			7.0%	33	33	**0.5**
Total	100.0%	-1433	100.0%	473	-960	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			6.0%	49	49	**0.8**
FEB			5.0%	41	41	**0.7**
MAR	0.0%	0	4.0%	32	32	**0.5**
APR	0.2%	-4	4.0%	32	28	**0.5**
MAY	0.7%	-12	7.0%	57	44	**0.7**
JUN	10.3%	-185	9.0%	73	-112	**-1.9**
JUL	34.8%	-629	11.0%	89	-539	**-8.8**
AUG	34.0%	-613	13.0%	106	-507	**-8.3**
SEP	16.0%	-290	14.0%	114	-176	**-3.0**
OCT	4.0%	-72	11.0%	89	18	**0.3**
NOV			9.0%	73	73	**1.2**
DEC			7.0%	57	57	**0.9**
Total	100.0%	-1805	100.0%	812	-993	

Canada - East Kootenay above Newgate

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			6.0%	17	17	**0.3**		JAN			6.0%	30	30	**0.5**
FEB			5.0%	14	14	**0.3**		FEB			5.0%	25	25	**0.4**
MAR	0.0%	0	4.0%	12	12	**0.2**		MAR	0.0%	0	4.0%	20	20	**0.3**
APR	0.0%	0	4.0%	12	11	**0.2**		APR	0.0%	0	4.0%	20	19	**0.3**
MAY	6.0%	-52	7.0%	20	-32	**-0.5**		MAY	6.0%	-66	7.0%	35	-31	**-0.5**
JUN	21.0%	-185	9.0%	26	-159	**-2.7**		JUN	21.0%	-233	9.0%	45	-188	**-3.2**
JUL	44.6%	-392	11.0%	32	-360	**-5.9**		JUL	44.6%	-493	11.0%	55	-439	**-7.1**
AUG	21.6%	-190	13.0%	38	-152	**-2.5**		AUG	21.6%	-239	13.0%	65	-175	**-2.8**
SEP	6.5%	-57	14.0%	41	-16	**-0.3**		SEP	6.5%	-71	14.0%	70	-2	**0.0**
OCT	0.2%	-2	11.0%	32	30	**0.5**		OCT	0.2%	-3	11.0%	55	52	**0.8**
NOV			9.0%	26	26	**0.4**		NOV			9.0%	45	45	**0.8**
DEC			7.0%	20	20	**0.3**		DEC			7.0%	35	35	**0.6**
Total	100.0%	-878	100.0%	290	-588			Total	100.0%	-1106	100.0%	498	-608	

Subarea 5b - Kootenai-Montana

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			7.0%	31	31	**0.5**
FEB			6.0%	26	26	**0.5**
MAR		0	5.0%	22	22	**0.4**
APR	0.5%	-1	4.0%	17	17	**0.3**
MAY	13.7%	-51	5.0%	22	-29	**-0.5**
JUN	21.3%	-137	8.0%	35	-102	**-1.7**
JUL	28.7%	-384	10.0%	44	-341	**-5.5**
AUG	25.3%	-488	14.0%	61	-427	**-6.9**
SEP	10.5%	-254	12.0%	52	-201	**-3.4**
OCT		-6	11.0%	48	42	**0.7**
NOV			10.0%	44	44	**0.7**
DEC			8.0%	35	35	**0.6**
Total	100.0%	-1321	100.0%	436	-885	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			7.0%	52	52	**0.9**
FEB			6.0%	45	45	**0.8**
MAR		0	5.0%	37	37	**0.6**
APR	0.5%	-1	4.0%	30	29	**0.5**
MAY	13.7%	-64	5.0%	37	-27	**-0.4**
JUN	21.3%	-172	8.0%	60	-112	**-1.9**
JUL	28.7%	-484	10.0%	75	-409	**-6.7**
AUG	25.3%	-615	14.0%	105	-510	**-8.3**
SEP	10.5%	-320	12.0%	90	-230	**-3.9**
OCT		-8	11.0%	82	74	**1.2**
NOV			10.0%	75	75	**1.3**
DEC			8.0%	60	60	**1.0**
Total	100.0%	-1664	100.0%	749	-915	

Subarea 5a - Kootenai-Idaho

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			7.0%	34	34	**0.6**
FEB			6.0%	29	29	**0.5**
MAR			5.0%	25	25	**0.4**
APR	0.0%	0	4.0%	20	20	**0.3**
MAY	0.0%	0	5.0%	25	24	**0.4**
JUN	1.0%	-15	8.0%	39	24	**0.4**
JUL	26.0%	-387	10.0%	49	-338	**-5.5**
AUG	49.6%	-737	14.0%	69	-668	**-10.9**
SEP	22.9%	-340	12.0%	59	-281	**-4.7**
OCT	0.5%	-7	11.0%	54	47	**0.8**
NOV			10.0%	49	49	**0.8**
DEC			8.0%	39	39	**0.6**
Total	100.0%	-1487	100.0%	491	-996	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			7.0%	59	59	**1.0**
FEB			6.0%	51	51	**0.9**
MAR			5.0%	42	42	**0.7**
APR	0.0%	0	4.0%	34	34	**0.6**
MAY	0.0%	-1	5.0%	42	42	**0.7**
JUN	1.0%	-19	8.0%	67	48	**0.8**
JUL	26.0%	-487	10.0%	84	-403	**-6.6**
AUG	49.6%	-929	14.0%	118	-811	**-13.2**
SEP	22.9%	-428	12.0%	101	-327	**-5.5**
OCT	0.5%	-9	11.0%	93	83	**1.4**
NOV			10.0%	84	84	**1.4**
DEC			8.0%	67	67	**1.1**
Total	100.0%	-1873	100.0%	843	-1030	

Canada - West Kootenay

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			7.0%	28	28	**0.5**
FEB			6.0%	24	24	**0.4**
MAR			5.0%	20	20	**0.3**
APR			4.0%	16	16	**0.3**
MAY	4.8%	-59	5.0%	20	-38	**-0.6**
JUN	21.5%	-265	8.0%	32	-232	**-3.9**
JUL	50.1%	-617	10.0%	41	-576	**-9.4**
AUG	22.0%	-270	14.0%	57	-213	**-3.5**
SEP	1.6%	-19	12.0%	49	29	**0.5**
OCT	0.0%	0	11.0%	45	44	**0.7**
NOV			10.0%	41	41	**0.7**
DEC			8.0%	32	32	**0.5**
Total	100.0%	-1230	100.0%	406	-824	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			7.0%	49	49	**0.8**
FEB			6.0%	42	42	**0.7**
MAR			5.0%	35	35	**0.6**
APR			4.0%	28	28	**0.5**
MAY	4.8%	-74	5.0%	35	-39	**-0.6**
JUN	21.5%	-334	8.0%	56	-278	**-4.7**
JUL	50.1%	-777	10.0%	70	-707	**-11.5**
AUG	22.0%	-340	14.0%	98	-243	**-3.9**
SEP	1.6%	-25	12.0%	84	59	**1.0**
OCT	0.0%	0	11.0%	77	76	**1.2**
NOV			10.0%	70	70	**1.2**
DEC			8.0%	56	56	**0.9**
Total	100.0%	-1550	100.0%	697	-852	

Surface water irrigated acres

Canada - Hugh Keenleyside

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	0.7	0.7
1928	0.0	0.0	0.7	0.7
1950	0.0	0.0	1.0	1.0
1966	0.6	0.0	0.7	1.3
1978	1.2	0.0	0.9	2.1
1988	4.1	0.0	0.5	4.6
1999	4.0	0.0	0.4	4.4
2008	2.0	0.0	0.2	2.2
2018	0	0	0	0.0

Canada - Upper Columbia above Mica

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	4.6	4.6
1928	0.0	0.0	4.7	4.7
1950	0.0	0.0	6.4	6.4
1966	3.5	0.0	5.1	8.6
1978	5.8	0.0	6.0	11.8
1988	10.0	0.0	4.0	14.0
1999	11.0	0.0	2.8	13.8
2008	4.9	0.0	1.3	6.2
2018	0.8	0.2	0.2	1.1

Canada - Columbia at Trail

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	0.3	0.3
1928	0.0	0.0	0.3	0.3
1950	0.0	0.0	0.5	0.5
1966	0.3	0.0	0.5	0.8
1978	0.5	0.0	0.4	0.9
1988	1.6	0.0	0.2	1.8
1999	1.6	0.0	0.1	1.7
2008	0.4	0.0	0.1	0.5
2018	0.3	0.1	0.1	0.4

Canada - Brilliant

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	0.5	0.5
1928	0.0	0.0	0.5	0.5
1950	0.0	0.0	0.9	0.9
1966	0.5	0.0	0.7	1.2
1978	2.0	0.0	1.8	3.8
1988	3.7	0.0	0.5	4.2
1999	3.6	0.0	0.4	4.0
2008	0.4	0.0	0.0	0.4
2018	0.0	0.0	0.0	0.0

Canada - East Kootenay above Newgate

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	4.6	4.6
1928	0.0	0.0	4.7	4.7
1950	0.0	0.0	6.5	6.5
1966	4.6	0.0	8.1	12.7
1978	8.2	0.0	10.4	18.6
1988	20.0	0.0	6.6	26.6
1999	27.2	0.0	3.0	30.2
2008	13.4	0.0	1.5	14.9
2018	2.2	0.6	0.5	3.3

Subarea 5b - Kootenai-Montana

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	6.8	6.8
1928	0.0	0.0	7.0	7.0
1950	0.0	0.0	7.0	7.0
1966	2.2	0.0	6.0	8.2
1978	5.9	0.0	5.4	11.3
1988	4.8	0.0	4.4	9.2
1999	2.4	0.0	6.5	8.9
2008	2.7	0.0	0.2	2.9
2018	2.2	0.0	1.3	3.5

Subarea 5a - Kootenai-Idaho

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	0.9	0.9
1928	0.0	0.0	1.0	1.0
1950	0.0	0.0	1.0	1.0
1966	0.8	0.0	0.6	1.4
1978	2.9	0.0	0.1	3.0
1988	2.3	0.0	0.0	2.3
1999	2.4	0.0	0.0	2.4
2008	0.6	0.0	0.9	1.5
2018	0.4	0.0	0.7	1.1

Canada - West Kootenay

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	1.8	1.8
1928	0.0	0.0	1.8	1.8
1950	0.0	0.0	4.0	4.0
1966	2.7	0.0	3.6	6.3
1978	6.3	0.0	5.6	11.9
1988	10.5	0.0	4.0	14.5
1999	15.3	0.0	1.9	17.2
2008	5.1	0.0	0.6	5.7
2018	2.6	0.7	0.6	3.9

Summary tables comparing 2010 Modified Flows and 2020 Modified Flows

The following tables offer a comparison of key data from 2010 Modified Flows and 2020 Modified Flows. Note that for U.S. Subareas, irrigation extent and surface water split was recalculated for data from the 2010 report (2010 revised) using the approach described in the methodology, and these new values were used in the time series.

Canada - Hugh Keenleyside

	2010	2020
Total irrigated area (1000 acres)	2.2	0.0
Surface water split (% SW)	100%	100%
Surface water irrigated area (1000 acres)	2.2	0.0
Crop water demand (ac ft per 1000 acres)	1,258	902

Canada - Upper Columbia above Mica

	2010	2020
Total irrigated area (1000 acres)	6.2	1.1
Surface water split (% SW)	100%	100%
Surface water irrigated area (1000 acres)	6.2	1.1
Crop water demand (ac ft per 1000 acres)	1,168	559

Canada - Columbia at Trail

	2010	2020
Total irrigated area (1000 acres)	0.5	0.4
Surface water split (% SW)	100%	100%
Surface water irrigated area (1000 acres)	0.5	0.4
Crop water demand (ac ft per 1000 acres)	1,399	902

Canada - Brilliant

	2010	2020
Total irrigated area (1000 acres)	0.4	0.0
Surface water split (% SW)	100%	100%
Surface water irrigated area (1000 acres)	0.4	0.0
Crop water demand (ac ft per 1000 acres)	1,430	902

Canada - East Kootenay above Newgate

	2010	2020
Total irrigated area (1000 acres)	14.9	3.3
Surface water split (% SW)	100%	100%
Surface water irrigated area (1000 acres)	14.9	3.3
Crop water demand (ac ft per 1000 acres)	1,464	553

Subarea 5b - Kootenai-Montana

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	5.4	3.1	3.7
Surface water split (% SW)	95%	95%	96%
Surface water irrigated area (1000 acres)	5.2	2.9	3.5
Crop water demand (ac ft per 1000 acres)	1,727	[redacted]	832

Subarea 5a - Kootenai-Idaho

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	2.8	3.0	1.6
Surface water split (% SW)	55%	51%	66%
Surface water irrigated area (1000 acres)	1.5	1.5	1.1
Crop water demand (ac ft per 1000 acres)	1,619	[redacted]	937

Canada - West Kootenay

	2010	2020
Total irrigated area (1000 acres)	5.7	3.9
Surface water split (% SW)	100%	100%
Surface water irrigated area (1000 acres)	5.7	3.9
Crop water demand (ac ft per 1000 acres)	1,350	775

4.1.3 Figures

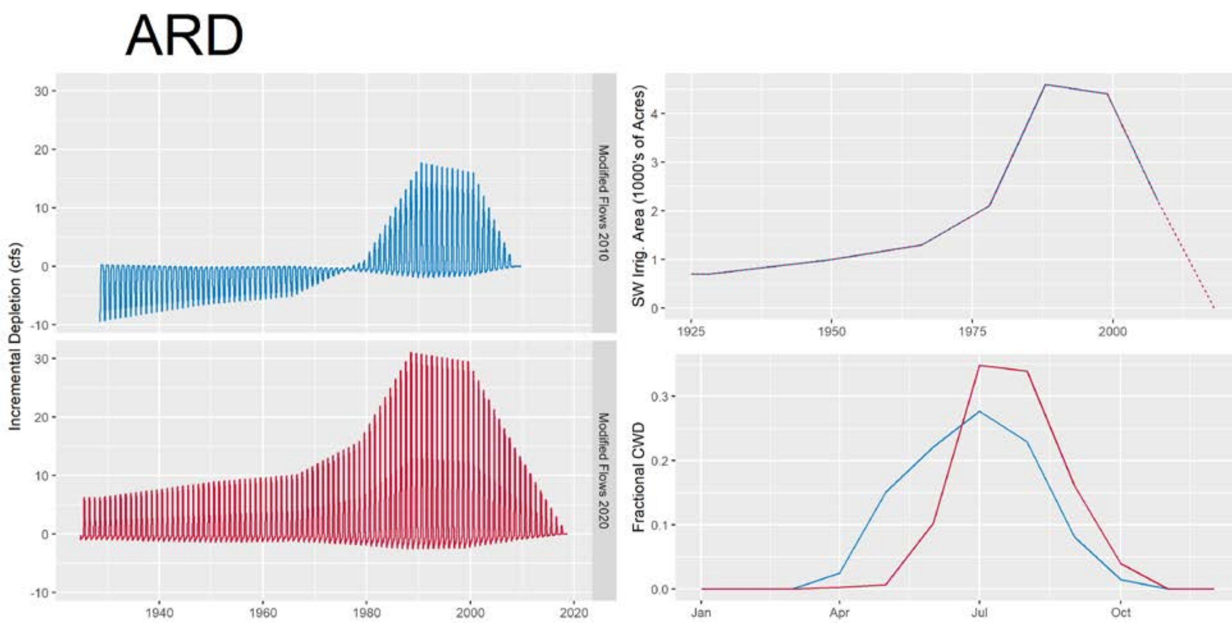

Figure 16. Canada – Hugh Keenleyside (ARD): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the ARD subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

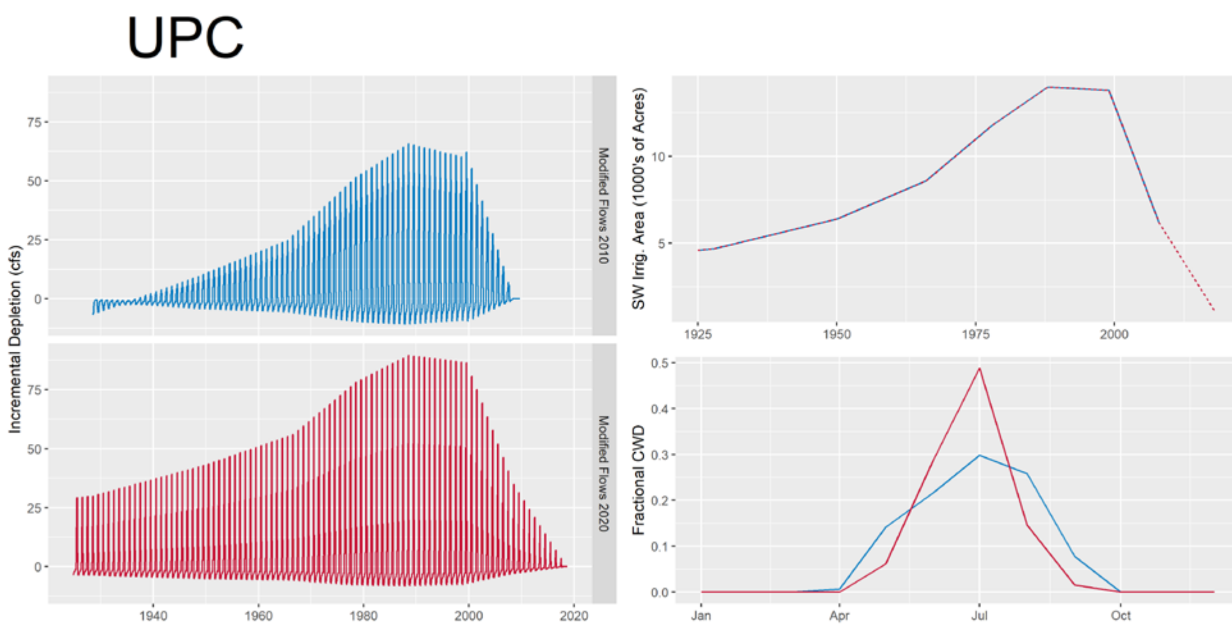

Figure 17. Canada – Upper Columbia above Mica (UPC): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the UPC subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

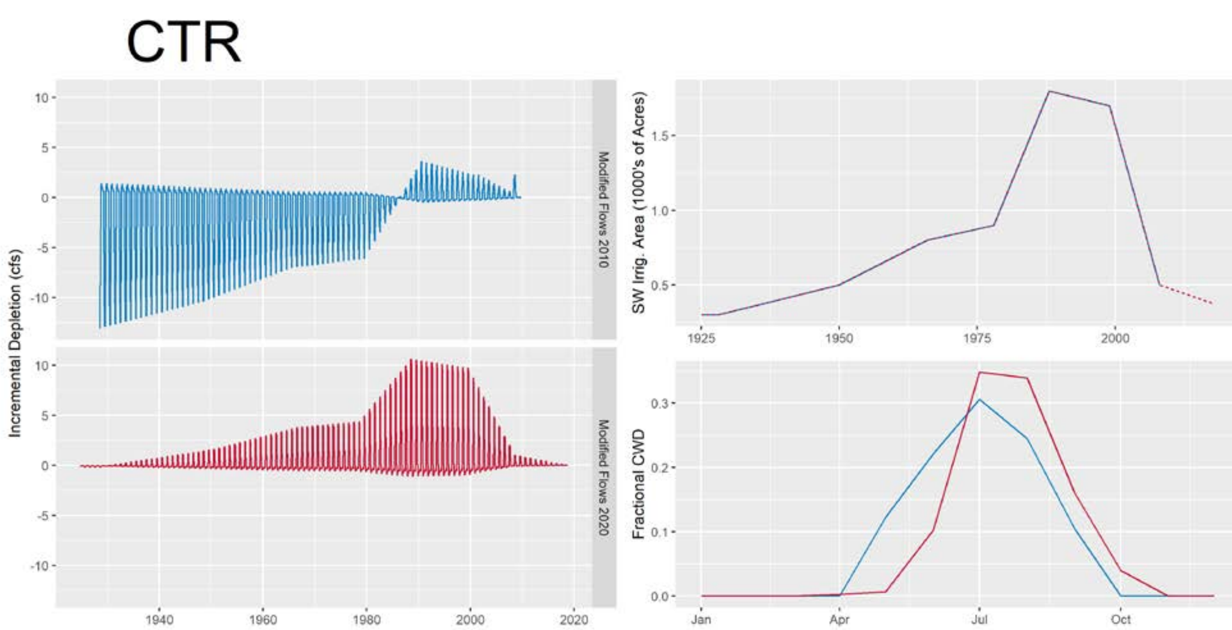

Figure 18. Canada – Columbia at Trail (CTR): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the CTR subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

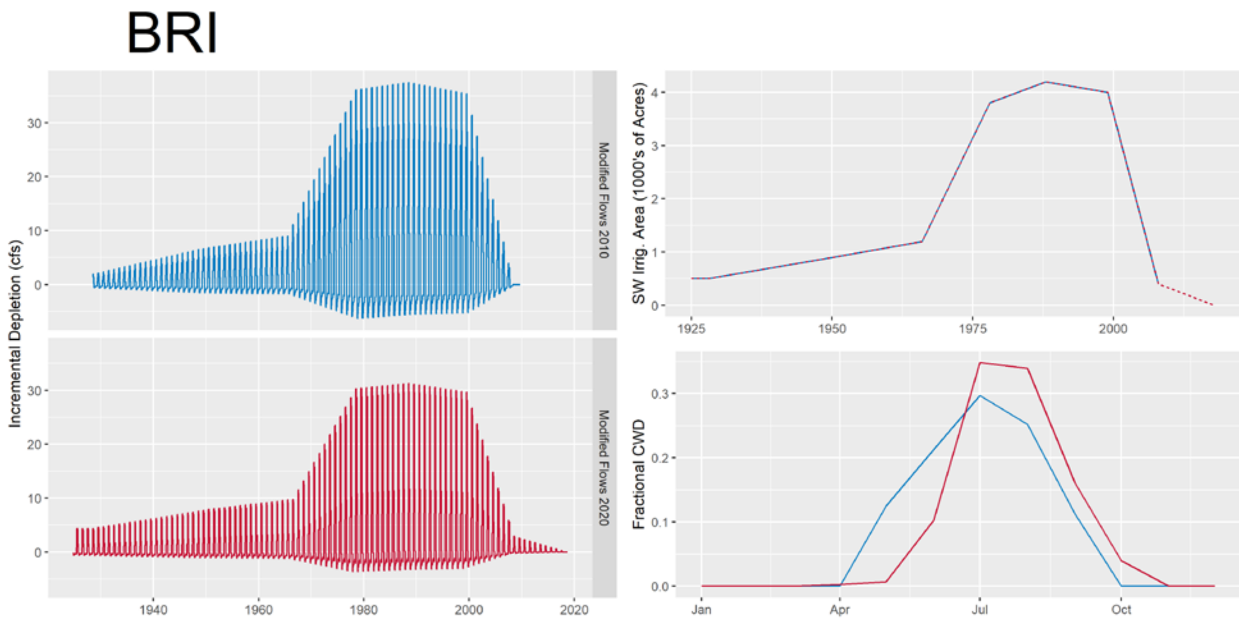

Figure 19. Canada – Kootenay above Brilliant (BRI): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the BRI subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

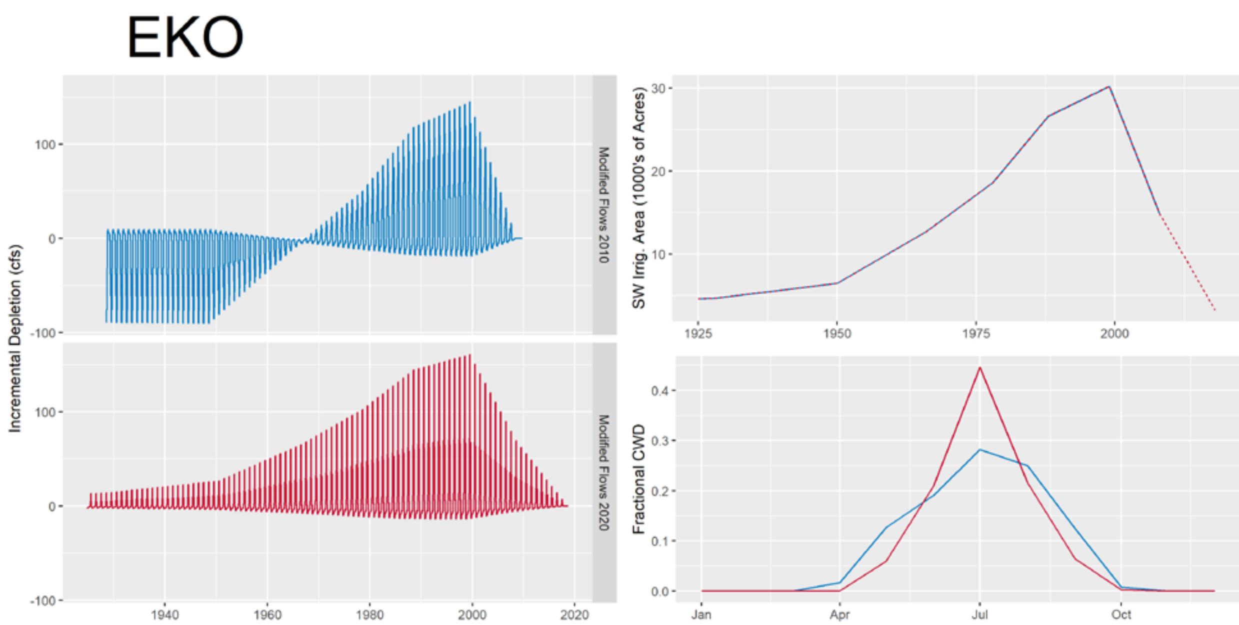

Figure 20. Canada – East Kootenay above Newgate (EKO): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the EKO subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

Figure 21. Subarea 5b – Kootenai Montana (KMT): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the KMT subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

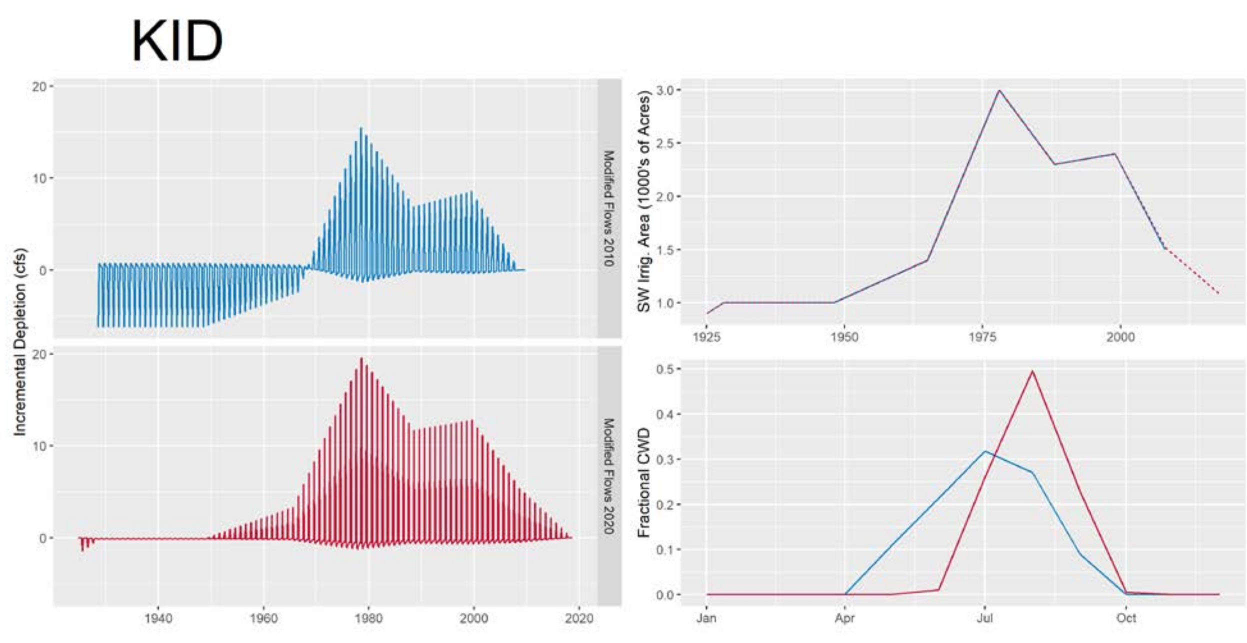

Figure 22. Subarea 5a – Kootenai Idaho (KID): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the KID subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

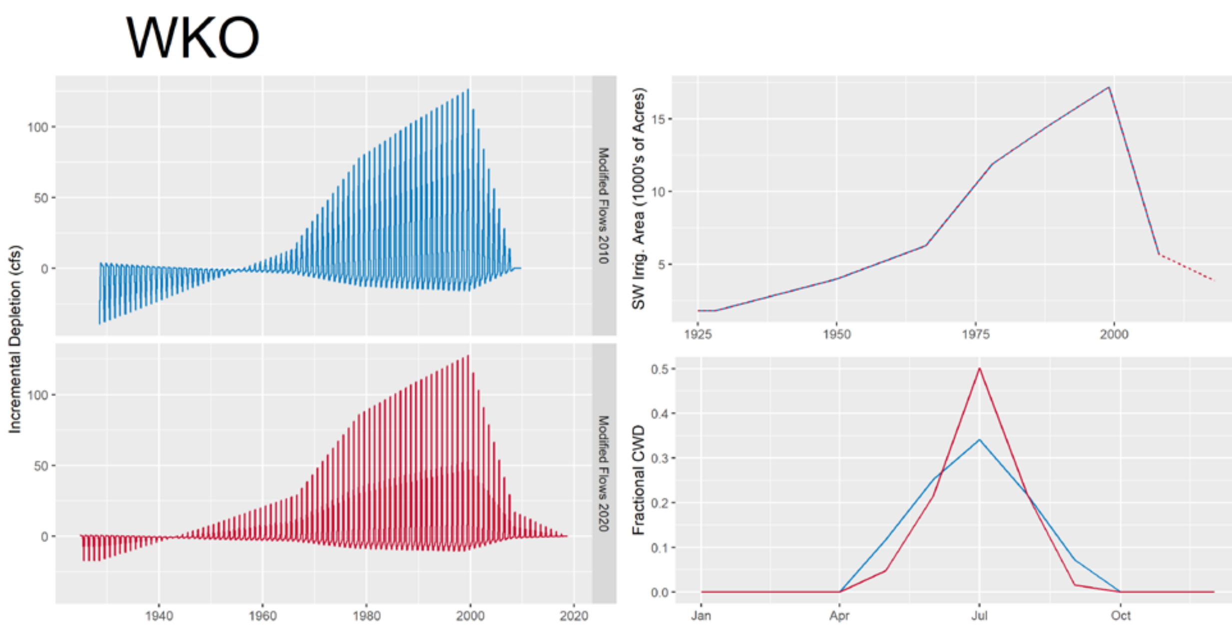

Figure 23. Canada – West Kootenay (WKO): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the WKO subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

4.2 Pend Oreille and Spokane Basins

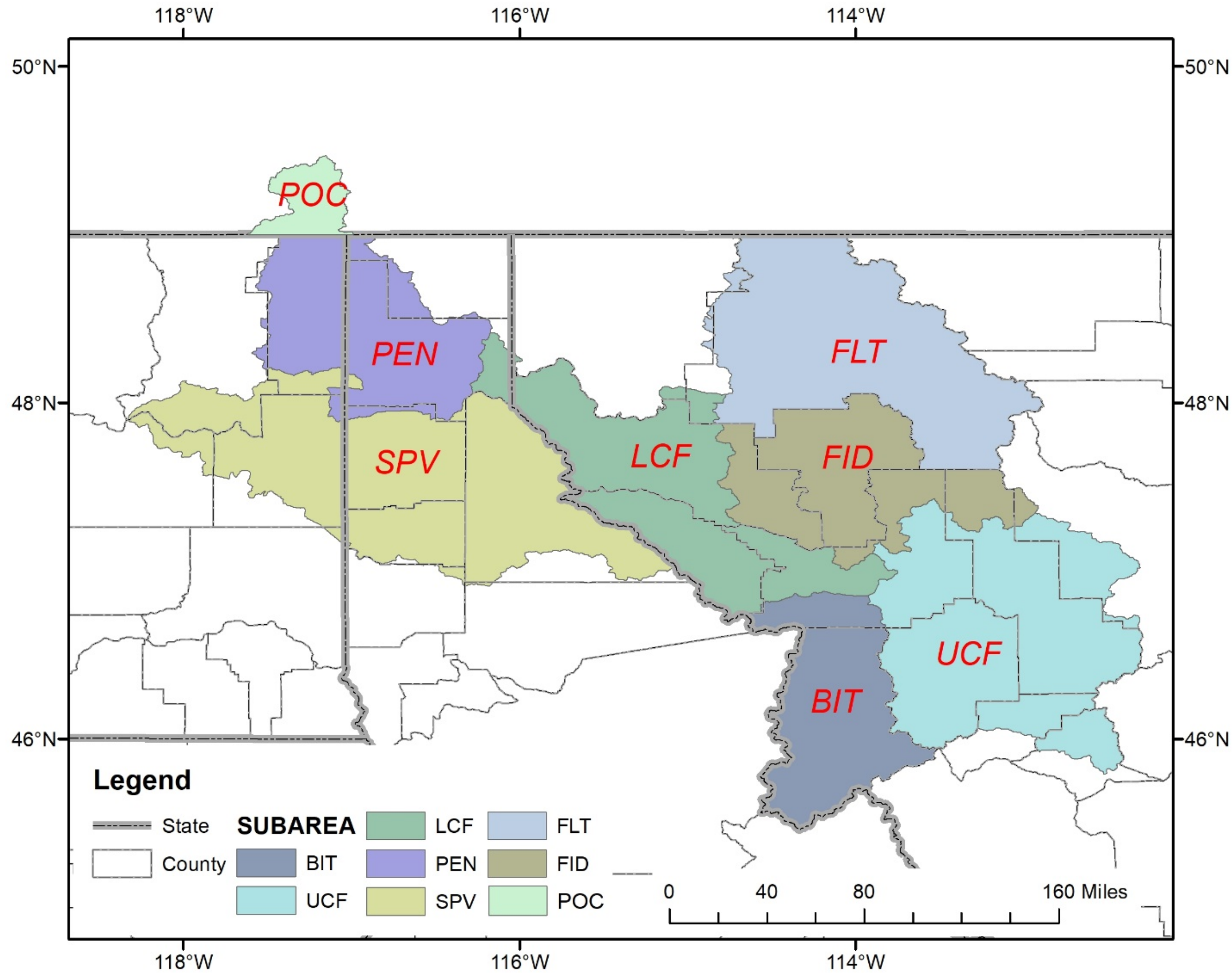

Figure 24. Map showing location of subareas within the Pend Oreille and Spokane Basins. Subarea codes defined in Table 7, below.

Table 7. Basin, code, name, and subarea for areas in the Pend Oreille and Spokane Basins described in this section.

Basin	**Code**	**Name**	**Subarea**
Pend Oreille	FLT	Upper Flathead	Subarea 4a
Pend Oreille	FID	Flathead Irrigation District	Subarea 4b
Pend Oreille	BIT	Bitterroot	Subarea 1
Pend Oreille	UCF	Upper Clark Fork	Subarea 2
Pend Oreille	LCF	Lower Clark Fork	Subarea 3
Pend Oreille	PEN	Pend Oreille Basin in USA	Subarea 6
Pend Oreille	POC	Canada - Pend Oreille Basin	Part of CA 08NE
Spokane	RAT	Rathdrum Prairie Canal	
Spokane	SPV	Spokane Valley	Subarea 7
Spokane	SPO	Spokane Valley Farms Canal	

4.2.1 Description of and justification for methodology used that was specific to the region

This regional does not have many methodological nuances unique to it, and the general methodology is followed except for one small aspect mentioned below which is specific to the Canadian part of the region. A small percentage of the irrigated area in this region falls within the Pend Oreille Basin in Canada (POC) subarea. For POC, given minimal irrigated cropland identified the by MIrAD process, VIC-CropSyst could not be run. To account for this, we used the average crop water demand of an adjacent area (Pend Oreille U.S.A.; PEN) as a proxy for POC. In general, across this subarea, less crop water demand and a later within-season shift in both the start and peak in irrigation withdrawals were noted over the 2010 Modified Flows report. Corrections to total irrigated acreage were also made to the 2008 estimates across most of this subbasin.

Sources of uncertainty relevant to the entirety of the Columbia River Basin are discussed in Section 5.

4.2.2 Tables with Summary Data

Crop distribution

Crop distributions are listed for crops comprising at least 1% of total irrigated area. Note that the total acreage shown may include crops that are not shown on the table because of their small contribution total acres. The irrigated area totals here may not exactly match the "total irrigated area" used for depletion calculation and shown in the Summary tables comparing 2010 Modified Flows and 2020 Modified Flows. This is an artifact of our process to translate non-crop specific MIrAD irrigation extent to crop-specific irrigation extent as described in the methodology Section 2.2.

Subarea 4a - Upper Flathead

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	29,788	91.7%
Pasture	1,240	3.8%
Spring Wheat	591	1.8%
Total	**32,490**	

Subarea 4b - Flathead Irrigation District

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	102,630	76.2%
Pasture	25,579	19.0%
Corn	2,055	1.5%
Spring Wheat	1,709	1.3%
Potato	1,385	1.0%
Total	**134,614**	

Subarea 1 - Bitterroot

Crop	Irrigated area (acres)	Percent of total
Pasture	52,114	72.0%
Alfalfa Hay	19,268	26.6%
Total	**72,401**	

Subarea 2 - Upper Clark Fork

Crop	Irrigated area (acres)	Percent of total
Pasture	60,348	58.6%
Alfalfa Hay	41,859	40.6%
Total	**102,980**	

Subarea 3 - Lower Clark Fork

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	10,713	79.7%
Pasture	2,616	19.5%
Total	**13,447**	

Subarea 6 - Pend Oreille Basin, USA

Crop	Irrigated area (acres)	Percent of total
Pasture	1,383	58.1%
Alfalfa Hay	973	40.8%
Total	**2,382**	

Canada - Pend Oreille Basin in Canada

Crop	Irrigated area (acres)	Percent of total

No data available - used crop breakdown of nearby area Pend Oreille U.S.A.

Subarea 7 - Spokane

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	13,289	35.7%
Pasture	8,069	21.7%
Winter Wheat	4,469	12.0%
Potato	2,669	7.2%
Sod Seed	2,534	6.8%
Canola	1,346	3.6%
Pea Dry	1,040	2.8%
Corn	738	2.0%
Spring Wheat	635	1.7%
Medicinal Herb	503	1.4%
Clover Hay	422	1.1%
Total	**37,219**	

County fractions

Subarea 4a - Upper Flathead

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Montana	Flathead	0.98	24,077
		TOTAL	**24,077**

Subarea 4b - Flathead Irrigation District

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Montana	Lake	1.00	105,498
Montana	Missoula	0.17	2,842
Montana	Sanders	0.94	18,904
		TOTAL	**127,244**

Subarea 1 - Bitterroot

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Montana	Missoula	0.06	942
Montana	Ravalli	1.00	71,413
		TOTAL	**72,355**

Subarea 2 - Upper Clark Fork

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Montana	Deer Lodge	0.53	6,996
Montana	Granite	1.00	31,738
Montana	Lewis and Clark	0.05	2,224
Montana	Missoula	0.26	4,324
Montana	Powell	1.00	53,884
Montana	Silver Bow	0.22	541
		TOTAL	**99,707**

Subarea 3 - Lower Clark Fork

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Montana	Flathead	0.01	139
Montana	Lincoln	0.07	263
Montana	Mineral	1.00	649
Montana	Missoula	0.51	8,525
Montana	Sanders	0.06	1,174
		TOTAL	**10,749**

Subarea 6 - Pend Oreille Basin, USA

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Idaho	Bonner	1.00	973
Idaho	Boundary	0.02	31
Washington	Pend Oreille	0.94	958
		TOTAL	**1,961**

Subarea 7 - Spokane

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Idaho	Benewah	1.00	201
Idaho	Kootenai	1.00	13,915
Idaho	Shoshone	1.00	77
Washington	Lincoln	0.01	293
Washington	Spokane	0.74	8,247
Washington	Stevens	0.27	1,915
Washington	Whitman	0.01	31
		TOTAL	**24,680**

Crop water demand monthly fraction by crop (for crops comprising at least 1% of irrigated area)

Subarea 4a - Upper Flathead

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.0	4.9	21.5	180.3	315.1	180.1	4.1	0.0	0.0	706
Diversion distribution %	0.0%	0.0%	0.0%	0.0%	0.7%	3.0%	25.5%	44.6%	25.5%	0.6%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	91.7%	0.0	0.0	0.0	0.0	0.0	0.1	2.0	3.9	2.3	0.0	0.0	0.0	8.4
Pasture	3.8%	0.0	0.0	0.0	0.0	0.1	0.5	2.7	3.7	1.8	0.0	0.0	0.0	8.7
Spring Wheat	1.8%	0.0	0.0	0.0	0.0	1.0	2.3	4.2	0.3	0.0	0.0	0.0	0.0	7.7

Subarea 4b - Flathead Irrigation District

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	4.0	47.9	147.6	409.9	415.0	214.0	5.6	0.0	0.0	1,244
Diversion distribution %	0.0%	0.0%	0.0%	0.3%	3.9%	11.9%	33.0%	33.4%	17.2%	0.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	76.2%	0.0	0.0	0.0	0.0	0.4	1.7	5.0	5.4	2.8	0.1	0.0	0.0	15.3
Pasture	19.0%	0.0	0.0	0.0	0.2	1.0	1.7	4.4	4.1	2.4	0.1	0.0	0.0	13.8
Corn	1.5%	0.0	0.0	0.0	0.0	0.4	3.2	7.0	2.1	0.0	0.0	0.0	0.0	12.7
Spring Wheat	1.3%	0.0	0.0	0.0	0.0	2.5	3.7	4.6	0.1	0.0	0.0	0.0	0.0	10.9
Potato	1.0%	0.0	0.0	0.0	0.0	1.4	1.4	5.7	5.7	1.4	0.0	0.0	0.0	15.6

Subarea 1 - Bitterroot

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.8	43.9	146.0	219.0	395.8	359.8	246.2	7.2	0.0	0.0	1,419
Diversion distribution %	0.0%	0.0%	0.1%	3.1%	10.3%	15.4%	27.9%	25.4%	17.4%	0.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	72.0%	0.0	0.0	0.0	0.6	1.9	2.4	4.6	4.2	2.9	0.1	0.0	0.0	16.7
Alfalfa Hay	26.6%	0.0	0.0	0.0	0.3	1.3	3.1	5.2	4.8	3.2	0.1	0.0	0.0	18.0

Subarea 2 - Upper Clark Fork

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.8	72.2	134.7	177.7	357.4	330.4	213.2	7.0	0.0	0.0	1,293
Diversion distribution %	0.0%	0.0%	0.1%	5.6%	10.4%	13.7%	27.6%	25.5%	16.5%	0.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	58.6%	0.0	0.0	0.0	0.8	1.6	2.0	3.9	3.7	2.4	0.1	0.0	0.0	14.6
Alfalfa Hay	40.6%	0.0	0.0	0.0	1.0	1.6	2.4	4.8	4.3	2.8	0.1	0.0	0.0	16.9

Subarea 3 - Lower Clark Fork

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	2.8	36.0	126.4	382.3	415.4	231.3	6.2	0.0	0.0	1,200
Diversion distribution %	0.0%	0.0%	0.0%	0.2%	3.0%	10.5%	31.9%	34.6%	19.3%	0.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	79.7%	0.0	0.0	0.0	0.0	0.5	1.6	4.8	5.4	3.0	0.1	0.0	0.0	15.3
Pasture	19.5%	0.0	0.0	0.0	0.0	0.3	1.1	3.5	3.6	2.0	0.0	0.0	0.0	10.6

Subarea 6 - Pend Oreille, USA

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.0	3.5	31.8	237.3	446.2	233.8	4.5	0.0	0.0	957
Diversion distribution %	0.0%	0.0%	0.0%	0.0%	0.4%	3.3%	24.8%	46.6%	24.4%	0.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	58.1%	0.0	0.0	0.0	0.0	0.1	0.6	3.8	4.8	2.6	0.1	0.0	0.0	11.8
Alfalfa Hay	40.8%	0.0	0.0	0.0	0.0	0.0	0.0	1.5	6.2	3.2	0.1	0.0	0.0	11.0

Canada - Pend Oreille Basin in Canada (used data from Pend Oreille U.S.A.)

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.0	3.5	31.8	237.3	446.2	233.8	4.5	0.0	0.0	957
Diversion distribution %	0.0%	0.0%	0.0%	0.0%	0.4%	3.3%	24.8%	46.6%	24.4%	0.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	58.1%	0.0	0.0	0.0	0.0	0.1	0.6	3.8	4.8	2.6	0.1	0.0	0.0	11.8
Alfalfa Hay	40.8%	0.0	0.0	0.0	0.0	0.0	0.0	1.5	6.2	3.2	0.1	0.0	0.0	11.0

Subarea 7 - Spokane

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.3	7.7	66.7	169.1	365.5	350.7	182.4	24.3	0.0	0.0	1,167
Diversion distribution %	0.0%	0.0%	0.0%	0.7%	5.7%	14.5%	31.3%	30.1%	15.6%	2.1%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	35.7%	0.0	0.0	0.0	0.0	0.0	0.3	3.9	6.5	3.3	0.1	0.0	0.0	14.1
Pasture	21.7%	0.0	0.0	0.0	0.0	0.1	1.7	5.0	4.7	3.0	0.1	0.0	0.0	14.6
Winter Wheat	12.0%	0.0	0.0	0.0	0.8	3.0	4.2	3.6	0.1	1.4	2.0	0.0	0.0	15.1
Potato	7.2%	0.0	0.0	0.0	0.0	1.2	2.7	6.9	7.2	2.1	0.0	0.0	0.0	20.2
Sod Seed	6.8%	0.0	0.0	0.0	0.0	1.9	3.6	1.3	0.0	0.0	0.0	0.0	0.0	6.8
Canola	3.6%	0.0	0.0	0.0	0.0	1.8	4.9	5.0	0.3	0.0	0.0	0.0	0.0	12.0
Pea Dry	2.8%	0.0	0.0	0.0	0.0	1.2	4.1	6.9	2.5	0.0	0.0	0.0	0.0	14.7
Corn	2.0%	0.0	0.0	0.0	0.0	0.9	3.9	6.9	1.3	0.0	0.0	0.0	0.0	13.1
Spring Wheat	1.7%	0.0	0.0	0.0	0.0	0.8	3.1	4.1	0.1	0.0	0.0	0.0	0.0	8.1
Medicinal Herb	1.4%	0.0	0.0	0.0	0.0	0.0	1.6	3.9	5.0	0.9	0.0	0.0	0.0	11.4
Clover Hay	1.1%	0.0	0.0	0.0	0.0	1.0	2.6	4.6	4.7	3.2	0.1	0.0	0.0	16.2

2015 USGS data

Subarea 4a - Upper Flathead

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Montana	Flathead	0.84	37.9	0.0	3.7	41.6

Subarea 4b - Flathead Irrigation District

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Montana	Lake	0.99	132.1	0.0	1.2	133.3
Montana	Missoula	0.96	24.9	0.0	6.2	31.1
Montana	Sanders	0.98	20.6	0.0	0.7	21.3

Subarea 1 - Bitterroot

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Montana	Missoula	0.96	24.9	0.0	6.2	31.1
Montana	Ravalli	0.99	34.4	0.6	46.4	81.5

Subarea 2 - Upper Clark Fork

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Montana	Deer Lodge	1.00	15.4	0.0	5.2	20.6
Montana	Granite	1.00	26.7	0.0	29.8	56.5
Montana	Lewis and Clark	0.98	31.0	0.0	15.3	46.2
Montana	Missoula	0.96	24.9	0.0	6.2	31.1
Montana	Powell	1.00	31.6	0.0	36.7	68.3
Montana	Silver Bow	0.99	3.9	0.0	0.5	4.4

Subarea 3 - Lower Clark Fork

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Montana	Flathead	0.84	37.9	0.0	3.7	41.6
Montana	Lincoln	0.98	3.1	0.0	2.0	5.0
Montana	Mineral	0.89	0.2	0.0	0.3	0.5
Montana	Missoula	0.96	24.9	0.0	6.2	31.1
Montana	Sanders	0.98	20.6	0.0	0.7	21.3

Subarea 6 - Pend Oreille Basin, USA

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Idaho	Bonner	0.74	1.2	0.0	1.0	2.2
Idaho	Boundary	0.66	13.2	0.0	22.4	35.6
Washington	Pend Oreille	0.50	0.7	0.0	0.0	0.7

Subarea 7 - Spokane

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Idaho	Benewah	0.84	1.3	0.0	1.6	2.9
Idaho	Kootenai	0.63	24.7	0.0	5.9	30.5
Idaho	Shoshone	0.53	0.5	0.0	0.0	0.5
Washington	Lincoln	0.20	23.7	1.6	0.0	25.3
Washington	Spokane	0.11	10.7	0.6	0.0	11.3
Washington	Stevens	0.65	6.1	0.6	0.0	6.6
Washington	Whitman	0.55	4.1	0.4	0.0	4.5

Diversion and return flow volumes (ac-ft/1000 ac) based on sprinkler/gravity efficiencies

Subarea 4a - Upper Flathead

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*706*	*706*
Diversion Efficiency (%)	*63%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1121**	**-1412**
Return Efficiency (%)	*33%*	*45%*
Return Flow (ac-ft per 1000 ac)	**370**	**635**

Subarea 4b - Flathead Irrigation District

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1244*	*1244*
Diversion Efficiency (%)	*63%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1975**	**-2488**
Return Efficiency (%)	*33%*	*45%*
Return Flow (ac-ft per 1000 ac)	**652**	**1120**

Subarea 1 - Bitterroot

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1419*	*1419*
Diversion Efficiency (%)	*67%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-2117**	**-2837**
Return Efficiency (%)	*29%*	*45%*
Return Flow (ac-ft per 1000 ac)	**614**	**1277**

Subarea 2 - Upper Clark Fork

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1293*	*1293*
Diversion Efficiency (%)	*67%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1931**	**-2587**
Return Efficiency (%)	*29%*	*45%*
Return Flow (ac-ft per 1000 ac)	**560**	**1164**

Subarea 3 - Lower Clark Fork

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1200*	*1200*
Diversion Efficiency (%)	*68%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1765**	**-2401**
Return Efficiency (%)	*28%*	*45%*
Return Flow (ac-ft per 1000 ac)	**494**	**1080**

Subarea 6 - Pend Oreille Basin in USA

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*957*	*957*
Diversion Efficiency (%)	*74%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1294**	**-1914**
Return Efficiency (%)	*22%*	*45%*
Return Flow (ac-ft per 1000 ac)	**285**	**861**

Canada - Pend Oreille Basin in Canada

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*957*	*957*
Diversion Efficiency (%)	*74%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1294**	**-1914**
Return Efficiency (%)	*22%*	*45%*
Return Flow (ac-ft per 1000 ac)	**285**	**861**

Subarea 7 - Spokane

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1167*	*1167*
Diversion Efficiency (%)	*81%*	*45%*
Required Diversion (ac-ft per 1000 ac)	**-1440**	**-2593**
Return Efficiency (%)	*16%*	*50%*
Return Flow (ac-ft per 1000 ac)	**230**	**1296**

Depletions per unit area

Subarea 4a - Upper Flathead

Sprinkler System

Month	DIVERSION %	DIVERSION ac-ft per 1000 ac	RETURN FLOW %	RETURN FLOW ac-ft per 1000 ac	DEPLETION ac-ft per 1000 ac	DEPLETION **cfs per 1000 ac**
JAN			6.0%	22	22	**0.4**
FEB			5.0%	18	18	**0.3**
MAR	0.0%	0	5.0%	18	18	**0.3**
APR	0.0%	0	5.0%	18	18	**0.3**
MAY	0.7%	-8	9.0%	33	25	**0.4**
JUN	3.0%	-34	10.0%	37	3	**0.0**
JUL	25.5%	-286	11.0%	41	-245	**-4.0**
AUG	44.6%	-500	12.0%	44	-456	**-7.4**
SEP	25.5%	-286	11.0%	41	-245	**-4.1**
OCT	0.6%	-7	10.0%	37	30	**0.5**
NOV			9.0%	33	33	**0.6**
DEC			7.0%	26	26	**0.4**
Total	100.0%	-1121	100.0%	370	-751	

Gravity System

Month	DIVERSION %	DIVERSION ac-ft per 1000 ac	RETURN FLOW %	RETURN FLOW ac-ft per 1000 ac	DEPLETION ac-ft per 1000 ac	DEPLETION **cfs per 1000 ac**
JAN			6.0%	38	38	**0.6**
FEB			5.0%	32	32	**0.6**
MAR	0.0%	0	5.0%	32	32	**0.5**
APR	0.0%	0	5.0%	32	32	**0.5**
MAY	0.7%	-10	9.0%	57	47	**0.8**
JUN	3.0%	-43	10.0%	64	21	**0.3**
JUL	25.5%	-361	11.0%	70	-291	**-4.7**
AUG	44.6%	-630	12.0%	76	-554	**-9.0**
SEP	25.5%	-360	11.0%	70	-290	**-4.9**
OCT	0.6%	-8	10.0%	64	55	**0.9**
NOV			9.0%	57	57	**1.0**
DEC			7.0%	44	44	**0.7**
Total	100.0%	-1412	100.0%	635	-777	

Subarea 4b - Flathead Irrigation District

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			6.0%	39	39	**0.6**
FEB			5.0%	33	33	**0.6**
MAR	0.0%	0	5.0%	33	33	**0.5**
APR	0.3%	-6	5.0%	33	26	**0.4**
MAY	3.9%	-76	9.0%	59	-17	**-0.3**
JUN	11.9%	-234	10.0%	65	-169	**-2.8**
JUL	33.0%	-651	11.0%	72	-579	**-9.4**
AUG	33.4%	-659	12.0%	78	-580	**-9.4**
SEP	17.2%	-340	11.0%	72	-268	**-4.5**
OCT	0.5%	-9	10.0%	65	56	**0.9**
NOV			9.0%	59	59	**1.0**
DEC			7.0%	46	46	**0.7**
Total	100.0%	-1975	100.0%	652	-1323	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			6.0%	67	67	**1.1**
FEB			5.0%	56	56	**1.0**
MAR	0.0%	0	5.0%	56	56	**0.9**
APR	0.3%	-8	5.0%	56	48	**0.8**
MAY	3.9%	-96	9.0%	101	5	**0.1**
JUN	11.9%	-295	10.0%	112	-183	**-3.1**
JUL	33.0%	-820	11.0%	123	-697	**-11.3**
AUG	33.4%	-830	12.0%	134	-696	**-11.3**
SEP	17.2%	-428	11.0%	123	-305	**-5.1**
OCT	0.5%	-11	10.0%	112	101	**1.6**
NOV			9.0%	101	101	**1.7**
DEC			7.0%	78	78	**1.3**
Total	100.0%	-2488	100.0%	1120	-1368	

Subarea 1 - Bitterroot

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			5.0%	31	31	**0.5**		JAN			5.0%	64	64	**1.0**
FEB			4.0%	25	25	**0.4**		FEB			4.0%	51	51	**0.9**
MAR	0.1%	-1	4.0%	25	23	**0.4**		MAR	0.1%	-2	4.0%	51	49	**0.8**
APR	3.1%	-66	4.0%	25	-41	**-0.7**		APR	3.1%	-88	4.0%	51	-37	**-0.6**
MAY	10.3%	-218	9.0%	55	-163	**-2.6**		MAY	10.3%	-292	9.0%	115	-177	**-2.9**
JUN	15.4%	-327	10.0%	61	-265	**-4.5**		JUN	15.4%	-438	10.0%	128	-310	**-5.2**
JUL	27.9%	-591	13.0%	80	-511	**-8.3**		JUL	27.9%	-792	13.0%	166	-626	**-10.2**
AUG	25.4%	-537	15.0%	92	-445	**-7.2**		AUG	25.4%	-720	15.0%	192	-528	**-8.6**
SEP	17.4%	-367	13.0%	80	-288	**-4.8**		SEP	17.4%	-492	13.0%	166	-326	**-5.5**
OCT	0.5%	-11	10.0%	61	51	**0.8**		OCT	0.5%	-14	10.0%	128	113	**1.8**
NOV			7.0%	43	43	**0.7**		NOV			7.0%	89	89	**1.5**
DEC			6.0%	37	37	**0.6**		DEC			6.0%	77	77	**1.2**
Total	100.0%	-2117	100.0%	614	-1503			Total	100.0%	-2837	100.0%	1277	-1561	

Subarea 2 - Upper Clark Fork

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			5.0%	28	28	**0.5**		JAN			5.0%	58	58	**0.9**
FEB			4.0%	22	22	**0.4**		FEB			4.0%	47	47	**0.8**
MAR		-1	4.0%	22	21	**0.3**		MAR	0.1%	-2	4.0%	47	45	**0.7**
APR		-108	4.0%	22	-85	**-1.4**		APR	5.6%	-144	4.0%	47	-98	**-1.6**
MAY	2.7%	-201	9.0%	50	-151	**-2.5**		MAY	10.4%	-269	9.0%	105	-165	**-2.7**
JUN	27.5%	-265	10.0%	56	-209	**-3.5**		JUN	13.7%	-355	10.0%	116	-239	**-4.0**
JUL	35.8%	-533	13.0%	73	-461	**-7.5**		JUL	27.6%	-715	13.0%	151	-563	**-9.2**
AUG	30.2%	-493	15.0%	84	-409	**-6.7**		AUG	25.5%	-661	15.0%	175	-486	**-7.9**
SEP	3.8%	-318	13.0%	73	-245	**-4.1**		SEP	16.5%	-426	13.0%	151	-275	**-4.6**
OCT		-10	10.0%	56	46	**0.7**		OCT	0.5%	-14	10.0%	116	102	**1.7**
NOV			7.0%	39	39	**0.7**		NOV			7.0%	81	81	**1.4**
DEC			6.0%	34	34	**0.5**		DEC			6.0%	70	70	**1.1**
Total	100.0%	-1931	100.0%	560	-1371			Total	100.0%	-2587	100.0%	1164	-1423	

Subarea 3 - Lower Clark Fork

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			2.0%	10	10	**0.2**		JAN			2.0%	22	22	**0.4**
FEB			1.0%	5	5	**0.1**		FEB			1.0%	11	11	**0.2**
MAR	0.0%	0	0.0%		0	**0.0**		MAR	0.0%	0	0.0%		0	**0.0**
APR	0.2%	-4	0.0%		-4	**-0.1**		APR	0.2%	-6	0.0%		-6	**-0.1**
MAY	3.0%	-53	6.0%	30	-23	**-0.4**		MAY	3.0%	-72	6.0%	65	-7	**-0.1**
JUN	10.5%	-186	15.0%	74	-112	**-1.9**		JUN	10.5%	-253	15.0%	162	-91	**-1.5**
JUL	31.9%	-562	18.0%	89	-473	**-7.7**		JUL	31.9%	-765	18.0%	194	-570	**-9.3**
AUG	34.6%	-611	20.0%	99	-512	**-8.3**		AUG	34.6%	-831	20.0%	216	-615	**-10.0**
SEP	19.3%	-340	16.0%	79	-261	**-4.4**		SEP	19.3%	-463	16.0%	173	-290	**-4.9**
OCT	0.5%	-9	11.0%	54	45	**0.7**		OCT	0.5%	-12	11.0%	119	106	**1.7**
NOV			7.0%	35	35	**0.6**		NOV			7.0%	76	76	**1.3**
DEC			4.0%	20	20	**0.3**		DEC			4.0%	43	43	**0.7**
Total	100.0%	-1765	100.0%	494	-1271			Total	100.0%	-2401	100.0%	1080	-1320	

Subarea 6 - Pend Oreille Basin in USA

Sprinkler System															
								Gravity System							
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION		
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**	
JAN			8.0%	23	23	**0.4**		JAN			8.0%	69	69	**1.1**	
FEB			6.0%	17	17	**0.3**		FEB			6.0%	52	52	**0.9**	
MAR	0.0%	0	6.0%	17	17	**0.3**		MAR	0.0%	0	6.0%	52	52	**0.8**	
APR	0.0%	0	6.0%	17	17	**0.3**		APR	0.0%	0	6.0%	52	52	**0.9**	
MAY	0.4%	-5	6.0%	17	12	**0.2**		MAY	0.4%	-7	6.0%	52	45	**0.7**	
JUN	3.3%	-43	7.0%	20	-23	**-0.4**		JUN	3.3%	-64	7.0%	60	-3	**-0.1**	
JUL	24.8%	-321	10.0%	28	-292	**-4.8**		JUL	24.8%	-475	10.0%	86	-389	**-6.3**	
AUG	46.6%	-603	11.0%	31	-572	**-9.3**		AUG	46.6%	-892	11.0%	95	-798	**-13.0**	
SEP	24.4%	-316	11.0%	31	-285	**-4.8**		SEP	24.4%	-468	11.0%	95	-373	**-6.3**	
OCT	0.5%	-6	11.0%	31	25	**0.4**		OCT	0.5%	-9	11.0%	95	86	**1.4**	
NOV			10.0%	28	28	**0.5**		NOV			10.0%	86	86	**1.4**	
DEC			8.0%	23	23	**0.4**		DEC			8.0%	69	69	**1.1**	
Total	100.0%	-1294	100.0%	285	-1009			Total	100.0%	-1914	100.0%	861	-1053		

Canada - Pend Oreille Basin in Canada

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			8.0%	23	23	**0.4**		JAN			8.0%	69	69	**1.1**
FEB			6.0%	17	17	**0.3**		FEB			6.0%	52	52	**0.9**
MAR	0.0%	0	6.0%	17	17	**0.3**		MAR	0.0%	0	6.0%	52	52	**0.8**
APR	0.0%	0	6.0%	17	17	**0.3**		APR	0.0%	0	6.0%	52	52	**0.9**
MAY	0.4%	-5	6.0%	17	12	**0.2**		MAY	0.4%	-7	6.0%	52	45	**0.7**
JUN	3.3%	-43	7.0%	20	-23	**-0.4**		JUN	3.3%	-64	7.0%	60	-3	**-0.1**
JUL	24.8%	-321	10.0%	28	-292	**-4.8**		JUL	24.8%	-475	10.0%	86	-389	**-6.3**
AUG	46.6%	-603	11.0%	31	-572	**-9.3**		AUG	46.6%	-892	11.0%	95	-798	**-13.0**
SEP	24.4%	-316	11.0%	31	-285	**-4.8**		SEP	24.4%	-468	11.0%	95	-373	**-6.3**
OCT	0.5%	-6	11.0%	31	25	**0.4**		OCT	0.5%	-9	11.0%	95	86	**1.4**
NOV			10.0%	28	28	**0.5**		NOV			10.0%	86	86	**1.4**
DEC			8.0%	23	23	**0.4**		DEC			8.0%	69	69	**1.1**
Total	100.0%	-1294	100.0%	285	-1009			Total	100.0%	-1914	100.0%	861	-1053	

Subarea 7 - Spokane

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			4.0%	9	9	**0.1**
FEB			4.0%	9	9	**0.2**
MAR	0.0%	0	3.0%	7	7	**0.1**
APR	0.7%	-9	4.0%	9	0	**0.0**
MAY	5.7%	-82	11.0%	25	-57	**-0.9**
JUN	14.5%	-209	14.0%	32	-177	**-3.0**
JUL	31.3%	-451	15.0%	35	-417	**-6.8**
AUG	30.1%	-433	14.0%	32	-401	**-6.5**
SEP	15.6%	-225	12.0%	28	-198	**-3.3**
OCT	2.1%	-30	9.0%	21	-9	**-0.2**
NOV			5.0%	12	12	**0.2**
DEC			5.0%	12	12	**0.2**
Total	100.0%	-1440	100.0%	230	-1210	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			4.0%	52	52	**0.8**
FEB			4.0%	52	52	**0.9**
MAR	0.0%	-1	3.0%	39	38	**0.6**
APR	0.7%	-17	4.0%	52	35	**0.6**
MAY	5.7%	-148	11.0%	143	-6	**-0.1**
JUN	14.5%	-376	14.0%	181	-194	**-3.3**
JUL	31.3%	-812	15.0%	194	-618	**-10.0**
AUG	30.1%	-779	14.0%	181	-598	**-9.7**
SEP	15.6%	-405	12.0%	156	-250	**-4.2**
OCT	2.1%	-54	9.0%	117	63	**1.0**
NOV			5.0%	65	65	**1.1**
DEC			5.0%	65	65	**1.1**
Total	100.0%	-2593	100.0%	1296	-1296	

Surface water irrigated acres

Subarea 4a - Upper Flathead

	Irrigated acres (1000s of acres)			
Year	Sprinkler	Micro	Gravity	Total
1925	0.0	0.0	6.2	6.2
1928	0.0	0.0	6.0	6.0
1950	0.0	0.0	8.5	8.5
1966	9.4	0.0	16.7	26.1
1978	21.9	0.0	13.4	35.3
1988	21.7	0.0	13.3	34.9
1999	27.4	0.0	9.2	36.5
2008	15.9	0.0	1.7	17.7
2018	18.3	0.0	1.8	20.1

Subarea 4b - Flathead Irrigation District

	Irrigated acres (1000s of acres)			
Year	Sprinkler	Micro	Gravity	Total
1925	0.0	0.0	31.8	31.8
1928	0.0	0.0	33.8	33.8
1950	0.0	0.0	93.8	93.8
1966	30.6	0.0	86.3	116.9
1978	78.9	0.0	48.4	127.3
1988	72.0	0.0	44.1	116.1
1999	91.1	0.0	30.4	121.5
2008	77.6	0.0	26.5	104.1
2018	123.6	0.0	2.3	125.9

Subarea 1 - Bitterroot

	Irrigated acres (1000s of acres)			
Year	Sprinkler	Micro	Gravity	Total
1925	0.0	0.0	111.0	111.0
1928	0.0	0.0	108.0	108.0
1950	0.0	0.0	108.0	108.0
1966	36.0	0.0	70.0	106.0
1978	65.4	0.0	46.0	111.4
1988	55.3	0.0	39.0	94.4
1999	70.2	0.0	23.4	93.6
2008	47.0	0.5	24.8	72.3
2018	30.8	0.6	40.2	71.6

Subarea 2 - Upper Clark Fork

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	125.8	125.8
1928	0.0	0.0	125.0	125.0
1950	0.0	0.0	128.0	128.0
1966	5.7	0.0	121.6	127.3
1978	32.4	0.0	94.9	127.3
1988	36.6	0.0	107.4	144.0
1999	77.9	0.0	63.7	141.6
2008	70.7	0.0	60.6	131.4
2018	50.7	0.0	48.4	99.1

Subarea 3 - Lower Clark Fork

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	15.3	15.3
1928	0.0	0.0	15.5	15.5
1950	0.0	0.0	20.0	20.0
1966	8.0	0.0	19.0	27.0
1978	21.1	0.0	8.8	29.9
1988	13.5	0.0	5.6	19.1
1999	11.3	0.0	4.3	15.6
2008	5.7	0.0	2.2	7.9
2018	8.2	0.0	2.1	10.3

Subarea 6 - Pend Oreille Basin in USA

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	3.5	3.5
1928	0.0	0.0	3.6	3.6
1950	0.0	0.0	5.3	5.3
1966	5.2	0.0	1.8	7.0
1978	8.2	0.0	0.0	8.2
1988	5.2	0.0	2.8	7.9
1999	5.0	0.0	0.0	5.0
2008	1.1	0.0	0.4	1.6
2018	0.8	0.0	0.5	1.3

Canada - Pend Oreille Basin in Canada

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	0.2	0.2
1928	0.0	0.0	0.2	0.2
1950	0.0	0.0	0.4	0.4
1966	0.3	0.0	0.3	0.6
1978	0.6	0.0	0.5	1.1
1988	0.6	0.0	0.3	0.9
1999	0.9	0.0	0.2	1.1
2008	0.9	0.0	0.2	1.1
2018	0.0	0.0	0.0	0.0

Subarea 7 - Spokane

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1928	0.0	0.0	24.6	24.6
1987	31.7	0.0	3.6	35.3
1992	32.3	0.0	4.1	36.4
1995	37.0	0.0	2.8	39.8
2000	25.6	0.0	3.1	28.7
2002	25.5	0.0	2.4	27.9
2005	26.5	0.0	2.9	29.4
2007	22.7	0.9	2.2	25.8
2008	22.7	0.7	2.8	26.3
2018	20.2	0.3	4.2	24.7

Summary tables comparing 2010 Modified Flows and 2020 Modified Flows

The following tables offer a comparison of key data from 2010 Modified Flows and 2020 Modified Flows. Note that for U.S. Subareas, irrigation extent and surface water split was recalculated for data from the 2010 report (2010 revised) using the approach described in the methodology, and these new values were used in the time series.

Subarea 4a - Upper Flathead

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	32.1	22.0	24.1
Surface water split (% SW)	77%	80%	84%
Surface water irrigated area (1000 acres)	24.8	17.7	20.1
Crop water demand (ac ft per 1000 acres)	1,238		706

Subarea 4b - Flathead Irrigation District

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	102.6	106.7	127.2
Surface water split (% SW)	97%	98%	99%
Surface water irrigated area (1000 acres)	99.6	104.1	125.9
Crop water demand (ac ft per 1000 acres)	1,637		1,244

Subarea 1 - Bitterroot

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	87.5	73.6	72.4
Surface water split (% SW)	98%	98%	99%
Surface water irrigated area (1000 acres)	85.4	72.3	71.6
Crop water demand (ac ft per 1000 acres)	1,659		1,419

Subarea 2 - Upper Clark Fork

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	148.4	132.6	99.7
Surface water split (% SW)	99%	99%	99%
Surface water irrigated area (1000 acres)	146.8	131.4	99.1
Crop water demand (ac ft per 1000 acres)	1,149		1,293

Subarea 3 - Lower Clark Fork

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	15.6	8.6	10.7
Surface water split (% SW)	90%	92%	92%
Surface water irrigated area (1000 acres)	14.1	7.9	10.3
Crop water demand (ac ft per 1000 acres)	1,642	[redacted]	1,200

Subarea 6 - Pend Oreille Basin in USA

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	3.6	2.7	2.0
Surface water split (% SW)	43%	59%	68%
Surface water irrigated area (1000 acres)	1.5	1.6	1.3
Crop water demand (ac ft per 1000 acres)	1,401	[redacted]	957

Canada - Pend Oreille Basin in Canada

	2010	2020
Total irrigated area (1000 acres)	1.1	0.1
Surface water split (% SW)	100%	100%
Surface water irrigated area (1000 acres)	1.1	0.1
Crop water demand (ac ft per 1000 acres)	1,551	957

Subarea 7 - Spokane

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	29.8	26.3	24.7
Surface water split (% SW)	100%	100%	100%
Surface water irrigated area (1000 acres)	29.8	26.3	24.7
Crop water demand (ac ft per 1000 acres)	1,759	[redacted]	1,167

4.2.3 Figures

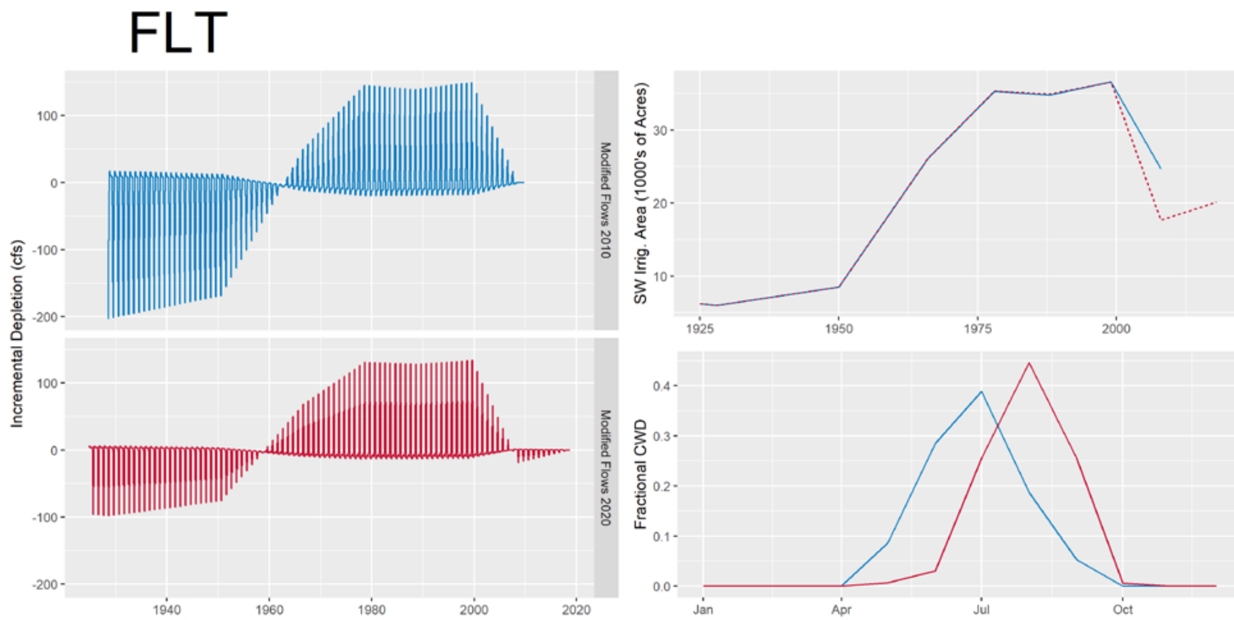

Figure 25. Subarea 4a – Upper Flathead (FLT): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the FLT subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

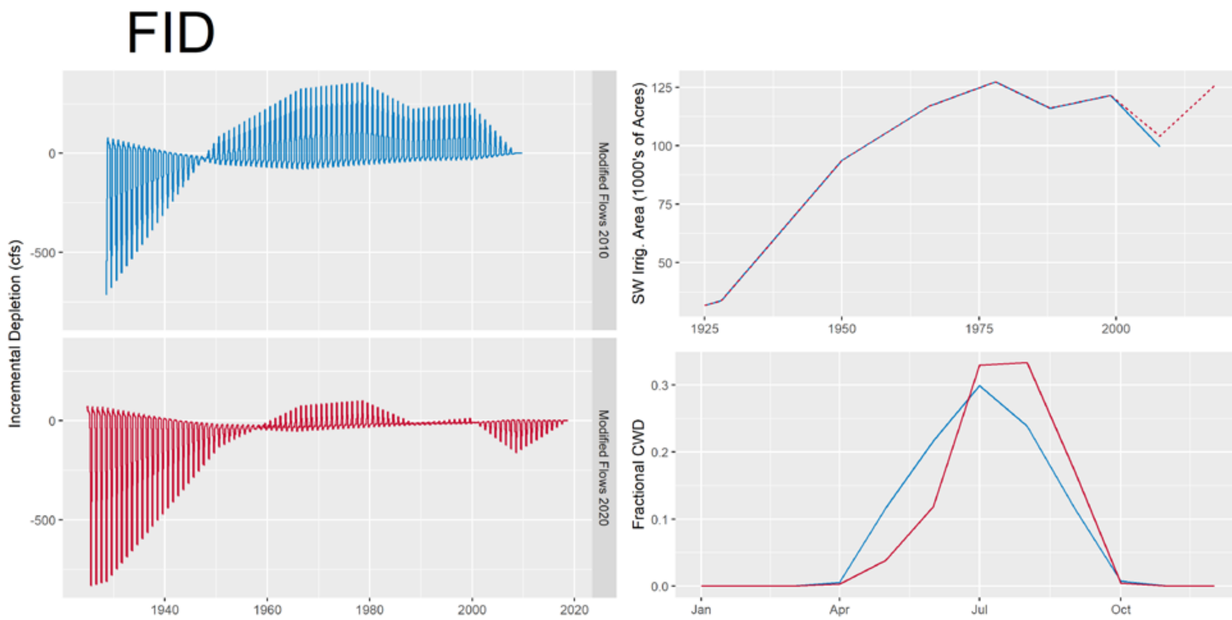

Figure 26. Subarea 4b – Flathead Irrigation District (FID): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the FID subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

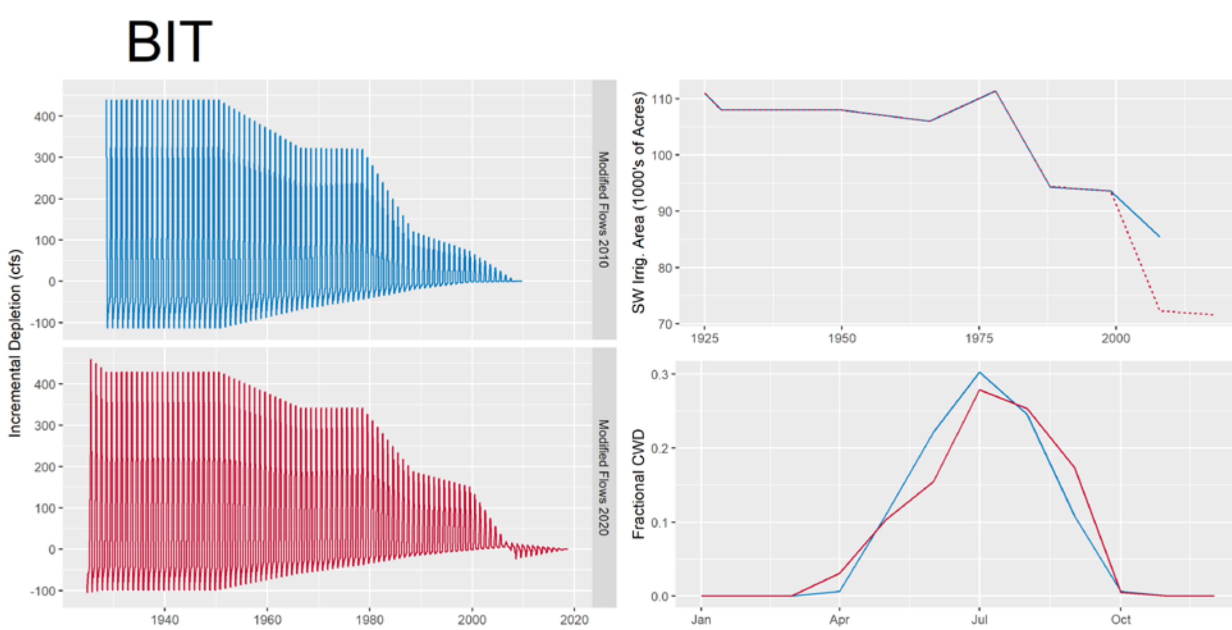

Figure 27. Subarea 1 – Bitterroot (BIT): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the BIT subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

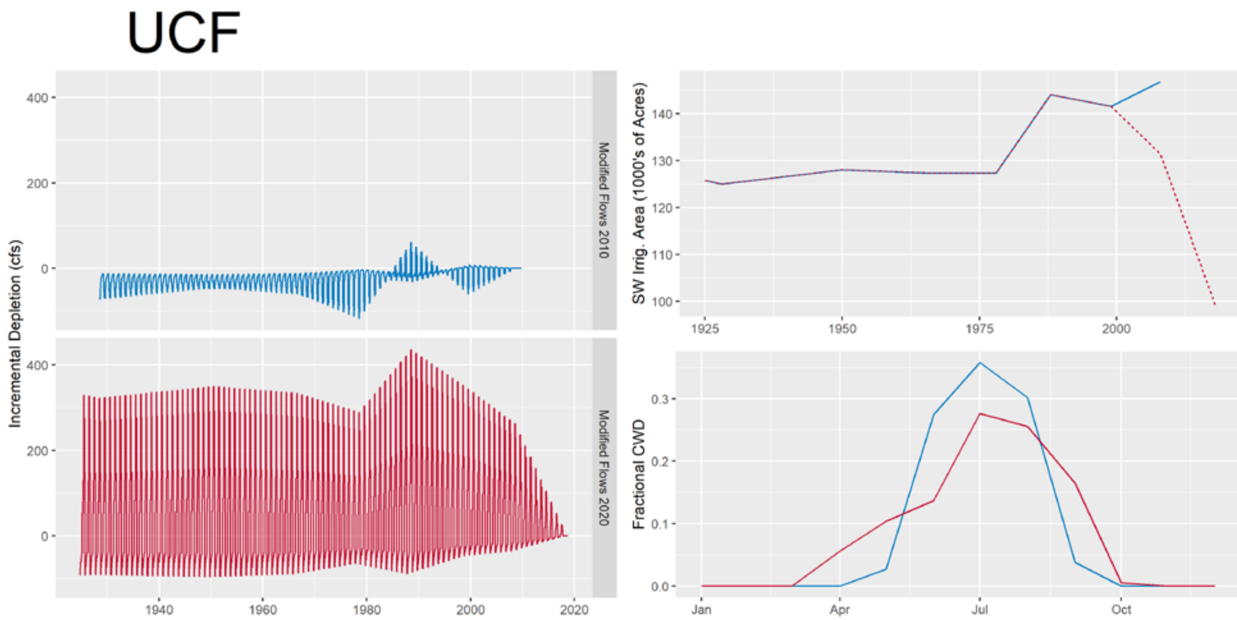

Figure 28. Subarea 2 – Upper Clark Fork (UCF): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the UCF subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

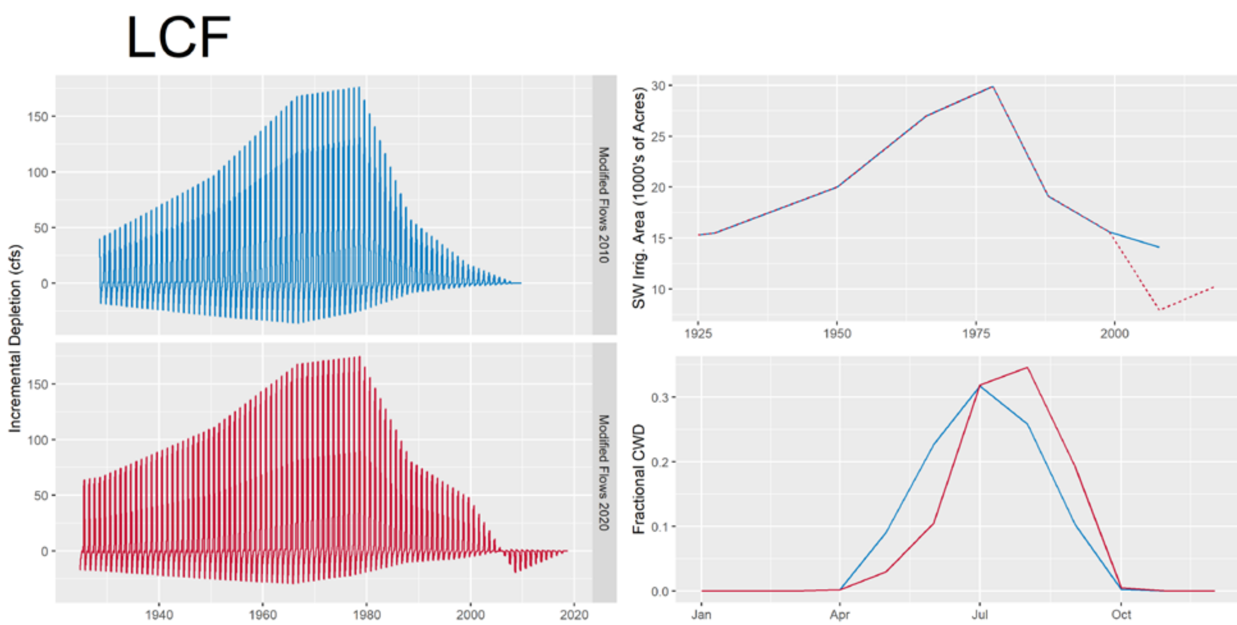

Figure 29. Subarea 3 – Lower Clark Fork (LCF): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the LCF subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

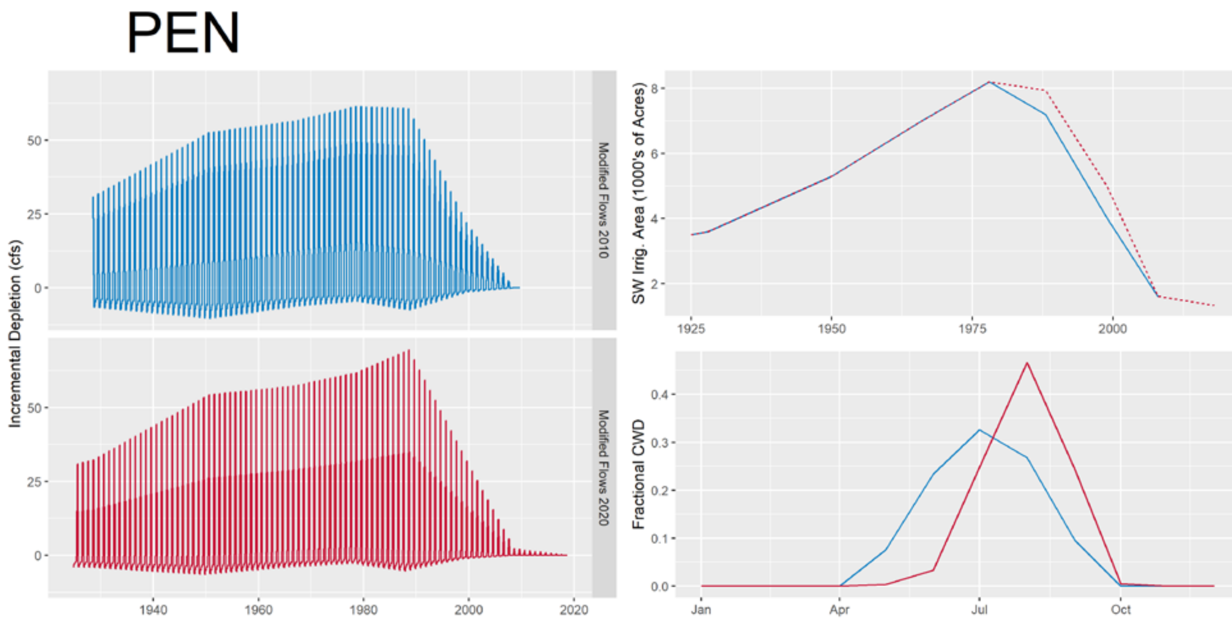

Figure 30. Subarea 6 – Pend Oreille Basin in USA (PEN): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the PEN subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

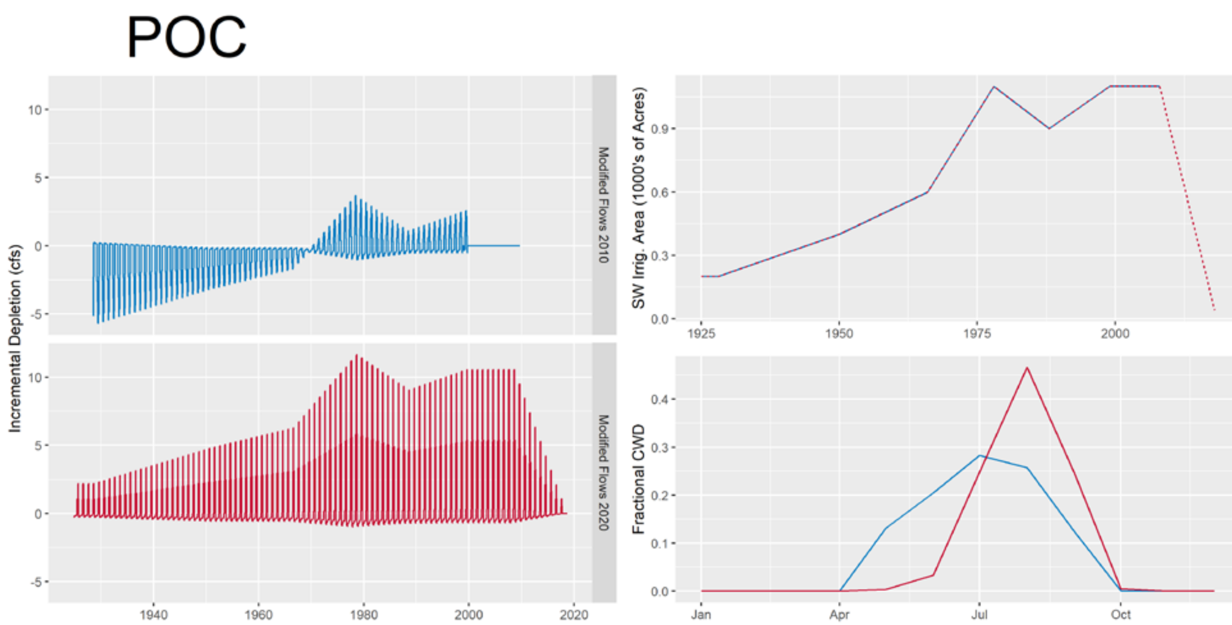

Figure 31. Canada – Pend Oreille Basin (POC): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the POC subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

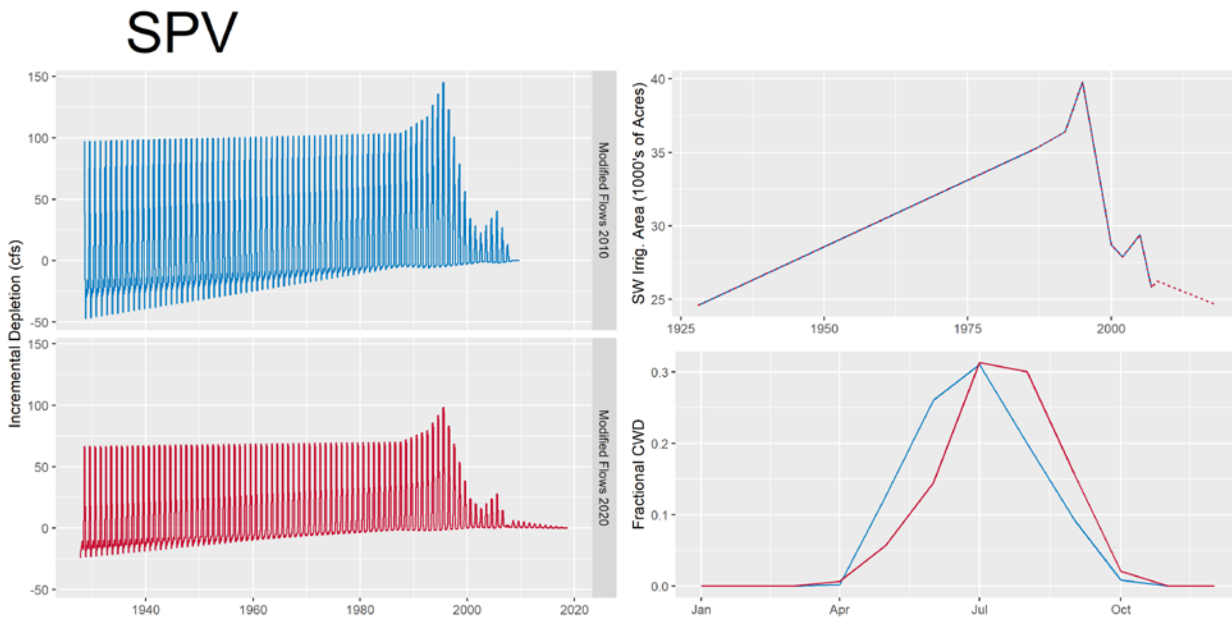

Figure 32. Subarea 7 – Spokane Valley (SPV): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the SPV subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

4.3 Mid-Columbia Basin

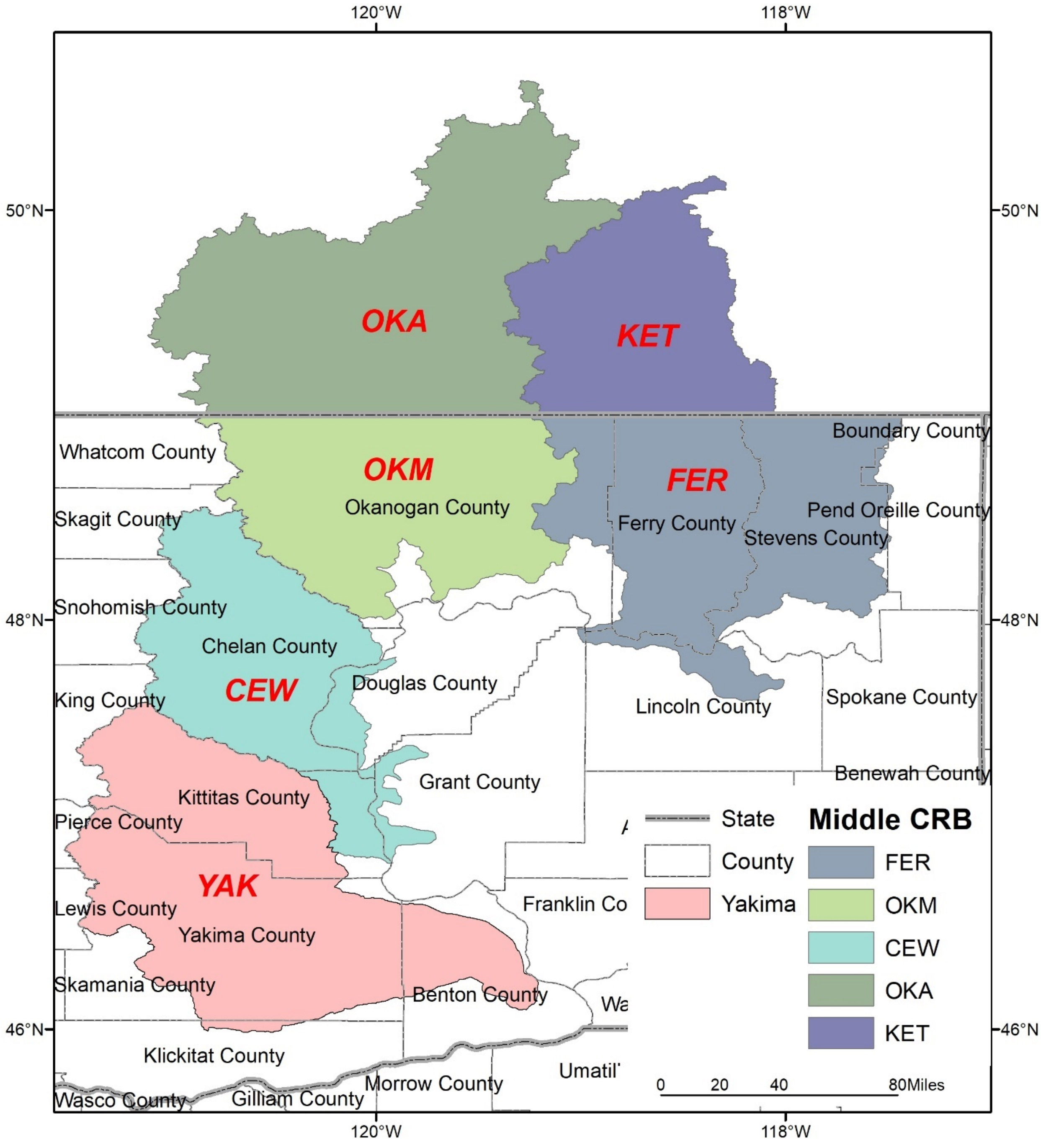

Figure 33. Map showing location of subareas within the Mid-Columbia Basin. Subarea codes defined in Table 8, below. The Columbia Basin Project has a different process for calculating depletion adjustments (see Appendix F) and is not shown in this figure although it is part of the Mid-Columbia region.

Table 8. Basin, code, name, and subarea for areas in the Mid-Columbia Basin described in this section.

Basin	Code	Name	Subarea
Mid-Columbia	GCL	Grand Coulee	
Mid-Columbia	OKA	Canada - Okanogan	CA 08NL + 08NM
Mid-Columbia	OKM	Methow-Okanogan	Subarea 9
Mid-Columbia	KET	Canada - Kettle	CA 08NN
Mid-Columbia	FER	Ferry Stevens	Subarea 8
Mid-Columbia	CEW	Chelan-Entiat-Wenatchee-W Banks Lake	Subarea 10
Mid-Columbia	WRF	Wanapum Return Flows	
Mid-Columbia	PRF	Priest Rapids Return Flows	
Mid-Columbia	YAK	Yakima	

4.3.1 Description of and justification for methodology used that was specific to the region

Irrigation withdrawals and return flow calculations are complex in the mid-Columbia basin. Irrigation subbasins have been redefined in several Modified Flows publications as better information has become available over the decades. For the part of the basin making up the Columbia Basin Project, irrigation water is withdrawn on complex schedules what are, at times, independent of crop water demands. Flows return to the mainstem Columbia at several points between Chief Joseph and McNary Dams through a series of canals and subsurface flows. Thus, the methodology described in this report for the rest of the CRB was not directly applied to the Columbia Basin Project. However, the crop water demand and irrigation extent calculation methods described in this report was used to cross check with field measurements and data provided by the U.S. Bureau of Reclamation and other sources. Details for irrigation depletion calculations for this complex part of the basin are described in Appendix F. Yakima River Basin depletion adjustments are directly provided to BPA by USBR and not discussed in this section.

For the Chelan-Entiat-Wenatchee-W Banks Lake subarea, we updated the boundaries of the area noted as “West of Banks Lake. The 2010 Modified Flows Report had the following text about the area West of Banks Lake: “*Lands irrigated in the area west of Banks Lake are located along the Columbia River, thus diversions and return flows are treated as if the Columbia was the direct water source. The irrigation west of Banks Lake is combined with the irrigation in the Chelan, Entiat and Wenatchee Basins, and the total irrigation depletions are applied between Chief Joseph and Rock Island Dams.”* This text description did not seem to match the shape of the geographic extent in the related figure in the 2010 report. We readjusted the boundaries to match the description in the text. Figure 34 shows the new updated boundary in comparison with the old boundary.

Data on irrigation type was incomplete for Canadian subareas, thus irrigation type information from Statistics Canada for the Okanogan Basin of Canada and applied to the Kettle subarea (Canada) included in this region (see section 2.1.7). Sources of uncertainty relevant to the entirety of the Columbia River Basin are discussed in Section 5.

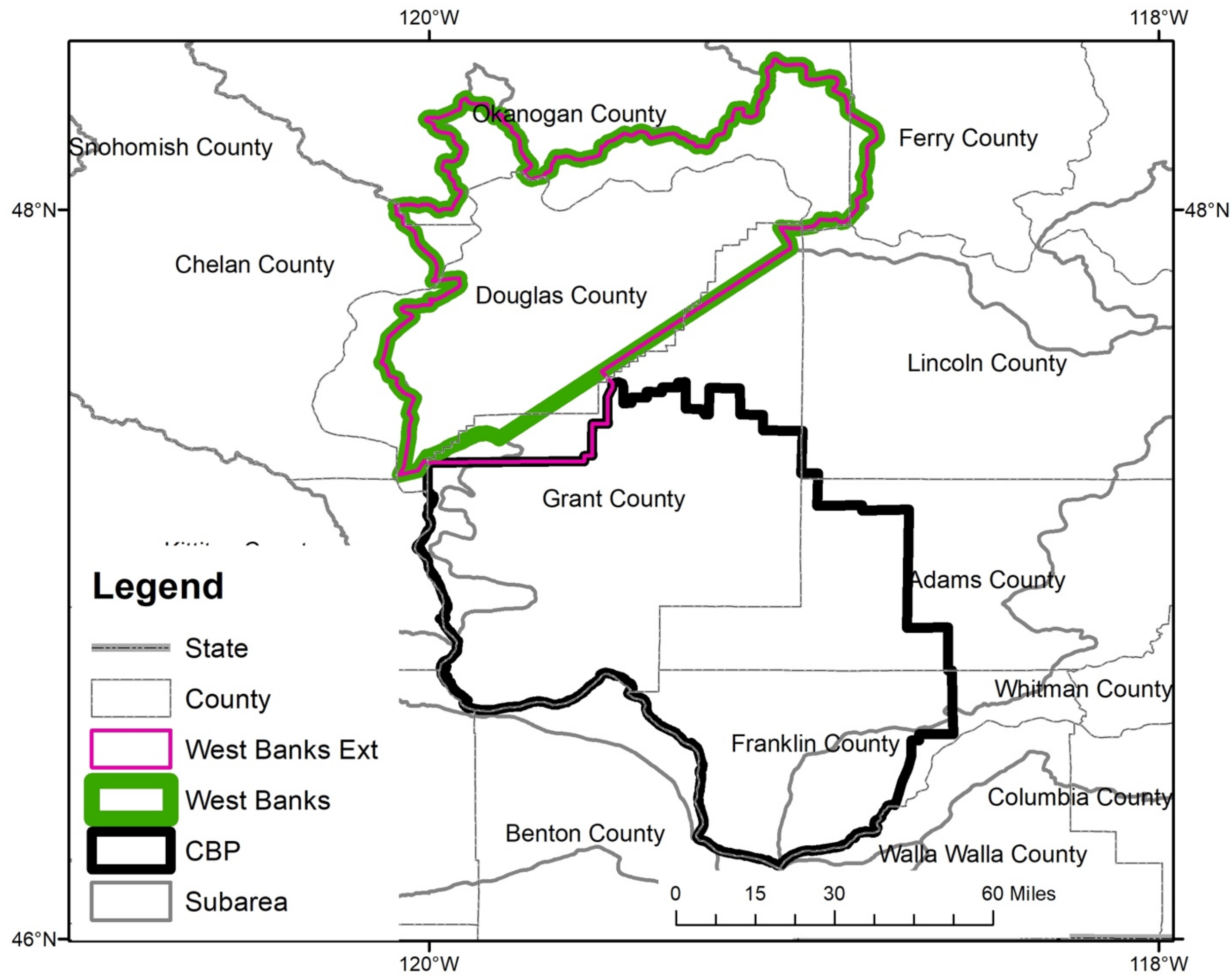

Figure 34. Boundaries of Columbia Basin Project (CBP; black), West of Banks Lake from 2010 Modified Flows (green), and West of Banks Lake from this study (pink).

4.3.2 Tables with Summary Data

Crop distribution

Crop distributions are listed for crops comprising at least 1% of total irrigated area. Note that the total acreage shown may include crops that are not shown on the table because of their small contribution to total acres. The irrigated area totals here may not exactly match the "total irrigated area" used for depletion calculation and shown in the Summary tables comparing 2010 Modified Flows and 2020 Modified Flows. This is an artifact of our process to translate non-crop specific MIrAD irrigation extent to crop-specific irrigation extent as described in the methodology Section 2.2.

Canada - Okanagan

Crop	Irrigated area (acres)	Percent of total
Generic Orchards	22,671	59.6%
Grape Wine	8,136	21.4%
Pasture	6,247	16.4%
Total	**38,068**	

Subarea 9 - Methow-Okanogan

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	13,541	29.6%
Apples	12,216	26.7%
Pasture	11,368	24.8%
Pear	3,537	7.7%
Cherry	2,920	6.4%
Corn	1,188	2.6%
Total	**45,807**	

Canada - Kettle

Crop	Irrigated area (acres)	Percent of total
Generic Orchards	1,399	34.6%
Pasture	1,133	28.1%
Grape Wine	998	24.7%
Generic Vegetable	283	7.0%
Corn	140	3.5%
Canola	41	1.0%
Total	**4,040**	

Subarea 8 - Ferry-Stevens

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	8,663	49.9%
Pasture	6,764	39.0%
Barley	772	4.4%
Winter Wheat	621	3.6%
Total	**17,356**	

Subarea 10 - Chelan-Entiat-Wenatchee-W Banks Lake

Crop	Irrigated area (acres)	Percent of total
Apples	24,078	27.6%
Cherry	10,964	12.6%
Alfalfa Hay	10,909	12.5%
Pear	10,125	11.6%
Pasture	8,399	9.6%
Winter Wheat	6,027	6.9%
Bean Dry	3,496	4.0%
Corn	2,989	3.4%
Potato	2,244	2.6%
Grape Wine	1,968	2.3%
Corn Sweet	1,820	2.1%
Mint	1,384	1.6%
Onions	1,290	1.5%
Total	**87,311**	

County fractions

Subarea 9 - Methow-Okanogan

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Washington	Chelan	0.00	15
Washington	Okanogan	0.72	33,097
		TOTAL	**33,112**

Subarea 8 - Ferry-Stevens

State	County	County Fraction	Contributing Irrigated Acres MIrAD)
Washington	Ferry	0.96	1,884
Washington	Lincoln	0.03	927
Washington	Okanogan	0.02	911
Washington	Stevens	0.73	5,266
		TOTAL	**8,988**

Subarea 10 - Chelan-Entiat-Wenatchee-W Banks Lake

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Washington	Chelan	0.98	21,189.25
Washington	Douglas	0.03	571.43
Washington	Grant	0.06	29,343.72
		TOTAL	**51,104**

Crop water demand monthly fraction by crop (for crops comprising at least 1% of irrigated area)

Canada - Okanagan

	Water requirement (ac-ft/1000 acres) by month for all crops												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.0	32.9	172.3	333.2	345.6	193.8	55.5	0.0	0.0	1,133
Diversion distribution %	0.0%	0.0%	0.0%	0.0%	2.9%	15.2%	29.4%	30.5%	17.1%	4.9%	0.0%	0.0%	100.0%

		Water requirement by month (inches) for crops making up 1% or more of irrigated area												
Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Generic Orchards	59.6%	0.0	0.0	0.0	0.0	0.4	2.7	4.5	4.4	2.4	0.8	0.0	0.0	15.3
Grape Wine	21.4%	0.0	0.0	0.0	0.0	0.0	0.4	3.4	4.6	2.7	0.9	0.0	0.0	12.0
Pasture	16.4%	0.0	0.0	0.0	0.0	0.6	1.8	2.9	2.9	1.7	0.0	0.0	0.0	10.0

Subarea 9 - Methow-Okanogan

	Water requirement (ac-ft/1000 acres) by month for all crops												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.2	8.5	162.8	325.3	491.9	461.2	285.7	55.7	0.0	0.0	1,791
Diversion distribution %	0.0%	0.0%	0.0%	0.5%	9.1%	18.2%	27.5%	25.7%	16.0%	3.1%	0.0%	0.0%	100.0%

		Water requirement by month (inches) for crops making up 1% or more of irrigated area												
Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	29.6%	0.0	0.0	0.0	0.0	1.1	2.6	5.6	5.6	3.5	0.1	0.0	0.0	18.6
Apples	26.7%	0.0	0.0	0.0	0.0	2.3	5.3	7.0	6.8	4.1	1.5	0.0	0.0	27.0
Pasture	24.8%	0.0	0.0	0.0	0.2	2.0	3.2	5.0	5.0	3.4	0.1	0.0	0.0	18.8
Pear	7.7%	0.0	0.0	0.0	0.1	2.8	5.0	6.8	6.1	3.1	1.4	0.0	0.0	25.3
Cherry	6.4%	0.0	0.0	0.0	0.2	3.5	4.9	5.2	4.4	3.0	1.4	0.0	0.0	22.7
Corn	2.6%	0.0	0.0	0.0	0.0	1.5	5.0	6.1	0.6	0.0	0.0	0.0	0.0	13.1

Canada - Kettle

	Water requirement (ac-ft/1000 acres) by month for all crops												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.0	9.8	65.6	261.6	316.5	185.3	47.9	0.0	0.0	887
Diversion distribution %	0.0%	0.0%	0.0%	0.0%	1.1%	7.4%	29.5%	35.7%	20.9%	5.4%	0.0%	0.0%	100.0%

		Water requirement by month (inches) for crops making up 1% or more of irrigated area												
Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Generic Orchards	34.6%	0.0	0.0	0.0	0.0	0.0	0.8	4.7	4.8	2.8	1.0	0.0	0.0	14.2
Pasture	28.1%	0.0	0.0	0.0	0.0	0.0	0.7	2.6	2.9	1.7	0.0	0.0	0.0	7.9
Grape Wine	24.7%	0.0	0.0	0.0	0.0	0.0	0.0	0.8	4.4	3.0	0.8	0.0	0.0	9.0
Generic Vegetable	7.0%	0.0	0.0	0.0	0.0	1.1	2.5	5.0	1.0	0.0	0.0	0.0	0.0	9.7
Corn	3.5%	0.0	0.0	0.0	0.0	0.2	1.9	4.9	4.3	1.3	0.2	0.0	0.0	12.8
Canola	1.0%	0.0	0.0	0.0	0.0	1.1	3.1	4.4	0.8	0.0	0.0	0.0	0.0	9.4

Subarea 8 - Ferry-Stevens

	Water requirement (ac-ft/1000 acres) by month for all crops												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	2.0	24.7	96.5	235.5	343.3	316.7	16.3	0.0	0.0	1,035
Diversion distribution %	0.0%	0.0%	0.0%	0.2%	2.4%	9.3%	22.8%	33.2%	30.6%	1.6%	0.0%	0.0%	100.0%

		Water requirement by month (inches) for crops making up 1% or more of irrigated area												
Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	49.9%	0.0	0.0	0.0	0.0	0.1	0.8	2.9	4.2	3.9	0.1	0.0	0.0	12.1
Pasture	39.0%	0.0	0.0	0.0	0.0	0.1	0.9	2.1	4.9	4.5	0.1	0.0	0.0	12.5
Barley	4.4%	0.0	0.0	0.0	0.0	1.1	3.5	5.7	0.5	0.0	0.0	0.0	0.0	10.8
Winter Wheat	3.6%	0.0	0.0	0.0	0.6	2.9	4.0	4.5	0.3	1.4	2.4	0.0	0.0	16.1

Subarea 10 - Chelan-Entiat-Wenatchee-W Banks Lake

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	9.8	47.8	264.4	483.0	558.0	479.7	282.5	92.6	0.0	0.0	2,218
Diversion distribution %	0.0%	0.0%	0.4%	2.2%	11.9%	21.8%	25.2%	21.6%	12.7%	4.2%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Apples	27.6%	0.0	0.0	0.0	0.2	2.9	6.3	7.8	7.4	4.3	1.8	0.0	0.0	30.7
Cherry	12.6%	0.0	0.0	0.0	0.3	3.3	6.0	6.2	5.0	3.4	1.6	0.0	0.0	25.8
Alfalfa Hay	12.5%	0.0	0.0	0.1	0.7	3.8	5.7	7.5	7.2	4.8	0.1	0.0	0.0	29.9
Pear	11.6%	0.0	0.0	0.0	0.1	2.5	6.2	7.6	6.8	3.5	1.3	0.0	0.0	28.0
Pasture	9.6%	0.0	0.0	0.0	0.4	3.4	4.7	6.4	6.2	4.1	0.1	0.0	0.0	25.5
Winter Wheat	6.9%	0.0	0.0	1.5	4.0	6.5	5.2	0.4	0.0	1.6	2.8	0.0	0.0	21.9
Bean Dry	4.0%	0.0	0.0	0.0	0.0	0.0	5.2	7.9	6.2	1.3	0.0	0.0	0.0	20.7
Corn	3.4%	0.0	0.0	0.0	0.0	2.7	7.4	6.4	0.1	0.0	0.0	0.0	0.0	16.6
Potato	2.6%	0.0	0.0	0.0	0.0	3.7	5.8	8.7	8.3	2.3	0.0	0.0	0.0	28.8
Grape Wine	2.3%	0.0	0.0	0.0	0.0	1.2	4.3	7.7	7.3	3.6	1.4	0.0	0.0	25.5
Corn Sweet	2.1%	0.0	0.0	0.0	0.0	1.9	6.2	7.3	0.5	0.0	0.0	0.0	0.0	15.9
Mint	1.6%	0.0	0.0	0.0	1.7	3.4	5.7	6.4	7.6	1.4	0.0	0.0	0.0	26.3
Onions	1.5%	0.0	0.0	0.0	1.2	2.8	2.2	0.0	0.0	0.0	0.0	0.0	0.0	6.2

2015 USGS data

Subarea 9 - Methow-Okanogan

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Washington	Chelan	0.93	16.9	0.1	0.0	17.0
Washington	Okanogan	0.58	47.8	3.2	0.5	51.5

Subarea 8 - Ferry-Stevens

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Washington	Ferry	0.75	2.2	0.2	0.0	2.4
Washington	Lincoln	0.20	23.7	1.6	0.0	25.3
Washington	Okanogan	0.58	47.8	3.2	0.5	51.5
Washington	Stevens	0.65	6.1	0.6	0.0	6.6

Subarea 10 - Chelan-Entiat-Wenatchee-W Banks Lake

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Washington	Chelan	0.93	16.9	0.1	0.0	17.0
Washington	Douglas	0.8	17.2	1.0	0.0	18.2
Washington	Grant	0.77	310.1	20.0	85.7	415.8

Diversion and return flow volumes (ac-ft/1000 ac) based on sprinkler/gravity efficiencies

Canada - Okanagan

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1133*	*1133*
Diversion Efficiency (%)	*63%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1798**	**-2266**
Return Efficiency (%)	*33%*	*45%*
Return Flow (ac-ft per 1000 ac)	**593**	**1020**

Subarea 9 - Methow-Okanagan

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1791*	*1791*
Diversion Efficiency (%)	*57%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-3143**	**-3583**
Return Efficiency (%)	*39%*	*45%*
Return Flow (ac-ft per 1000 ac)	**1226**	**1612**

Canada - Kettle

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*887*	*887*
Diversion Efficiency (%)	*63%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1408**	**-1774**
Return Efficiency (%)	*33%*	*45%*
Return Flow (ac-ft per 1000 ac)	**465**	**798**

Subarea 8 - Ferry-Stevens

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1035*	*1035*
Diversion Efficiency (%)	*81%*	*45%*
Required Diversion (ac-ft per 1000 ac)	**-1278**	**-2300**
Return Efficiency (%)	*16%*	*50%*
Return Flow (ac-ft per 1000 ac)	**204**	**1150**

Subarea 10 - Chelan-Entiat-Wenatchee-W Banks Lake

	Sprinkler	**Gravity**
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*2218*	*2218*
Diversion Efficiency (%)	*55%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-4032**	**-4435**
Return Efficiency (%)	*41%*	*45%*
Return Flow (ac-ft per 1000 ac)	**1653**	**1996**

Depletions per unit area

Canada - Okanogan

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			6.0%	36	36	**0.6**		JAN			6.0%	61	61	**1.0**
FEB			5.0%	30	30	**0.5**		FEB			5.0%	51	51	**0.9**
MAR	0.0%	0	4.0%	24	24	**0.4**		MAR	0.0%	0	4.0%	41	41	**0.7**
APR	0.0%	0	4.0%	24	23	**0.4**		APR	0.0%	0	4.0%	41	40	**0.7**
MAY	2.9%	-51	7.0%	42	-10	**-0.2**		MAY	2.9%	-65	7.0%	71	7	**0.1**
JUN	15.2%	-273	9.0%	53	-219	**-3.7**		JUN	15.2%	-343	9.0%	92	-252	**-4.2**
JUL	29.4%	-530	11.0%	65	-464	**-7.6**		JUL	29.4%	-667	11.0%	112	-555	**-9.0**
AUG	30.5%	-549	13.0%	77	-472	**-7.7**		AUG	30.5%	-692	13.0%	133	-559	**-9.1**
SEP	17.1%	-308	14.0%	83	-225	**-3.8**		SEP	17.1%	-388	14.0%	143	-245	**-4.1**
OCT	4.9%	-88	11.0%	65	-23	**-0.4**		OCT	4.9%	-111	11.0%	112	1	**0.0**
NOV			9.0%	53	53	**0.9**		NOV			9.0%	92	92	**1.5**
DEC			7.0%	42	42	**0.7**		DEC			7.0%	71	71	**1.2**
Total	100.0%	-1799	100.0%	594	-1205			Total	100.0%	-2266	100.0%	1020	-1247	

Subarea 9 - Methow-Okanogan

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			4.0%	49	49	**0.8**
FEB			4.0%	49	49	**0.9**
MAR	0.0%	0	3.0%	37	36	**0.6**
APR	0.5%	-15	4.0%	49	34	**0.6**
MAY	9.1%	-286	11.0%	135	-151	**-2.5**
JUN	18.2%	-571	14.0%	172	-399	**-6.7**
JUL	27.5%	-863	15.0%	184	-679	**-11.0**
AUG	25.7%	-809	14.0%	172	-638	**-10.4**
SEP	16.0%	-501	12.0%	147	-354	**-6.0**
OCT	3.1%	-98	9.0%	110	13	**0.2**
NOV			5.0%	61	61	**1.0**
DEC			5.0%	61	61	**1.0**
Total	100.0%	-3143	100.0%	1226	-1917	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			4.0%	64	64	**1.0**
FEB			4.0%	64	64	**1.2**
MAR	0.0%	0	3.0%	48	48	**0.8**
APR	0.5%	-17	4.0%	64	48	**0.8**
MAY	9.1%	-326	11.0%	177	-148	**-2.4**
JUN	18.2%	-651	14.0%	226	-425	**-7.1**
JUL	27.5%	-984	15.0%	242	-742	**-12.1**
AUG	25.7%	-922	14.0%	226	-697	**-11.3**
SEP	16.0%	-571	12.0%	193	-378	**-6.4**
OCT	3.1%	-111	9.0%	145	34	**0.5**
NOV			5.0%	81	81	**1.4**
DEC			5.0%	81	81	**1.3**
Total	100.0%	-3583	100.0%	1612	-1970	

Canada - Kettle

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			6.0%	28	28	**0.5**		JAN			6.0%	48	48	**0.8**
FEB			5.0%	23	23	**0.4**		FEB			5.0%	40	40	**0.7**
MAR			4.0%	19	19	**0.3**		MAR			4.0%	32	32	**0.5**
APR	0.0%	0	4.0%	19	19	**0.3**		APR	0.0%	0	4.0%	32	32	**0.5**
MAY	1.1%	-15	7.0%	33	17	**0.3**		MAY	1.1%	-19	7.0%	56	37	**0.6**
JUN	7.4%	-104	9.0%	42	-62	**-1.0**		JUN	7.4%	-131	9.0%	72	-59	**-1.0**
JUL	29.5%	-415	11.0%	51	-364	**-5.9**		JUL	29.5%	-523	11.0%	88	-435	**-7.1**
AUG	35.7%	-502	13.0%	60	-442	**-7.2**		AUG	35.7%	-633	13.0%	104	-529	**-8.6**
SEP	20.9%	-295	14.0%	65	-230	**-3.9**		SEP	20.9%	-371	14.0%	112	-260	**-4.4**
OCT	5.4%	-76	11.0%	51	-25	**-0.4**		OCT	5.4%	-96	11.0%	88	-8	**-0.1**
NOV			9.0%	42	42	**0.7**		NOV			9.0%	72	72	**1.2**
DEC			7.0%	33	33	**0.5**		DEC			7.0%	56	56	**0.9**
Total	100.0%	-1407	100.0%	464	-943			Total	100.0%	-1773	100.0%	798	-975	

Subarea 8 - Ferry-Stevens

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			4.0%	8	8	**0.1**		JAN			4.0%	46	46	**0.7**
FEB			4.0%	8	8	**0.1**		FEB			4.0%	46	46	**0.8**
MAR	0.0%	0	3.0%	6	6	**0.1**		MAR	0.0%	0	3.0%	34	34	**0.6**
APR	0.2%	-2	4.0%	8	6	**0.1**		APR	0.2%	-4	4.0%	46	42	**0.7**
MAY	2.4%	-30	11.0%	22	-8	**-0.1**		MAY	2.4%	-55	11.0%	126	72	**1.2**
JUN	9.3%	-119	14.0%	29	-91	**-1.5**		JUN	9.3%	-214	14.0%	161	-53	**-0.9**
JUL	22.8%	-291	15.0%	31	-260	**-4.2**		JUL	22.8%	-523	15.0%	172	-351	**-5.7**
AUG	33.2%	-424	14.0%	29	-395	**-6.4**		AUG	33.2%	-763	14.0%	161	-602	**-9.8**
SEP	30.6%	-391	12.0%	25	-366	**-6.2**		SEP	30.6%	-704	12.0%	138	-566	**-9.5**
OCT	1.6%	-20	9.0%	18	-2	**0.0**		OCT	1.6%	-36	9.0%	103	67	**1.1**
NOV			5.0%	10	10	**0.2**		NOV			5.0%	57	57	**1.0**
DEC			5.0%	10	10	**0.2**		DEC			5.0%	57	57	**0.9**
Total	100.0%	-1278	100.0%	204	-1073			Total	100.0%	-2300	100.0%	1150	-1150	

Subarea 10 - Chelan-Entiat-Wenatchee-W Banks Lake

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			4.0%	66	66	**1.1**		JAN			4.0%	80	80	**1.3**
FEB			4.0%	66	66	**1.2**		FEB			4.0%	80	80	**1.4**
MAR	0.4%	-18	3.0%	50	32	**0.5**		MAR	0.4%	-20	3.0%	60	40	**0.7**
APR	2.2%	-87	4.0%	66	-21	**-0.3**		APR	2.2%	-96	4.0%	80	-16	**-0.3**
MAY	11.9%	-481	11.0%	182	-299	**-4.9**		MAY	11.9%	-529	11.0%	220	-309	**-5.0**
JUN	21.8%	-878	14.0%	231	-647	**-10.9**		JUN	21.8%	-966	14.0%	279	-687	**-11.5**
JUL	25.2%	-1014	15.0%	248	-767	**-12.5**		JUL	25.2%	-1116	15.0%	299	-817	**-13.3**
AUG	21.6%	-872	14.0%	231	-641	**-10.4**		AUG	21.6%	-959	14.0%	279	-680	**-11.1**
SEP	12.7%	-514	12.0%	198	-315	**-5.3**		SEP	12.7%	-565	12.0%	240	-325	**-5.5**
OCT	4.2%	-168	9.0%	149	-20	**-0.3**		OCT	4.2%	-185	9.0%	180	-6	**-0.1**
NOV			5.0%	83	83	**1.4**		NOV			5.0%	100	100	**1.7**
DEC			5.0%	83	83	**1.3**		DEC			5.0%	100	100	**1.6**
Total	100.0%	-4032	100.0%	1653	-2379			Total	100.0%	-4435	100.0%	1996	-2439	

Surface water irrigated acres

Canada - Okanagan

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	84.0	84.0
1928	0.0	0.0	80.4	80.4
1950	0.0	0.0	93.0	93.0
1966	51.5	0.0	65.6	117.1
1978	72.2	0.0	61.5	133.7
1988	77.3	0.0	25.8	103.1
1999	120.2	0.0	4.7	124.9
2008	60.4	0.0	2.4	62.8
2018	23.0	24.7	0.0	47.7

Subarea 9 - Methow-Okanogan

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	32.0	32.0
1928	0.0	0.0	31.3	31.3
1948	0.0	0.0	35.0	35.0
1966	16.0	0.0	18.5	34.5
1978	39.4	0.0	0.0	39.4
1988	42.4	0.0	0.9	43.3
1999	41.4	0.0	0.0	41.4
2008	26.4	1.8	0.3	28.5
2018	17.8	1.2	0.2	19.2

Canada – Kettle

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	4.5	4.5
1928	0.0	0.0	4.6	4.6
1950	0.0	0.0	5.8	5.8
1966	4.9	0.0	10.7	15.6
1978	11.8	0.0	21.1	32.9
1988	20.6	0.0	27.1	47.7
1999	23.0	0.0	26.9	49.9
2008	7.4	0.0	8.7	16.1
2018	2.6	2.8	0.0	5.3

Subarea 8 - Ferry-Stevens

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	5.7	5.7
1928	0.0	0.0	5.7	5.7
1948	0.0	0.0	10.0	10.0
1966	11.0	0.0	10.0	21.0
1978	19.4	0.0	2.3	21.7
1988	22.1	0.0	0.5	22.5
1999	17.0	0.0	0.3	17.4
2008	13.8	0.9	0.0	14.7
2018	5.2	0.4	0.0	5.6

Subarea 10 - Chelan-Entiat-Wenatchee-W Banks Lake

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	36.3	36.3
1928	0.0	0.0	37.2	37.2
1948	0.0	0.0	48.0	48.0
1966	30.5	0.0	25.4	55.9
1978	61.5	0.0	1.0	62.5
1988	61.3	0.0	0.0	61.3
1999	58.2	0.0	0.0	58.2
2008	43.8	3.0	4.7	51.5
2018	35.7	1.4	5.3	42.3

Summary tables comparing 2010 Modified Flows and 2020 Modified Flows

The following tables offer a comparison of key data from 2010 Modified Flows and 2020 Modified Flows. Note that for U.S. Subareas, irrigation extent and surface water split was recalculated for data from the 2010 report (2010 revised) using the approach described in the methodology, and these new values were used in the time series.

Canada - Okanagan

	2010	2020
Total irrigated area (1000 acres)	62.8	38.9
Surface water split (% SW)	100%	100%
Surface water irrigated area (1000 acres)	62.8	38.9
Crop water demand (ac ft per 1000 acres)	1,529	1,133

Subarea 9 - Methow-Okanogan

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	40.5	38.7	33.1
Surface water split (% SW)	76%	73%	58%
Surface water irrigated area (1000 acres)	31.0	28.5	19.2
Crop water demand (ac ft per 1000 acres)	1,980		1,791

Canada - Kettle

	2010	2020
Total irrigated area (1000 acres)	16.1	4.7
Surface water split (% SW)	100%	100%
Surface water irrigated area (1000 acres)	16.1	4.7
Crop water demand (ac ft per 1000 acres)	1,657	887

Subarea 8 - Ferry-Stevens

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	22.5	19.1	9.0
Surface water split (% SW)	76%	77%	63%
Surface water irrigated area (1000 acres)	17.1	14.7	5.6
Crop water demand (ac ft per 1000 acres)	1,679		1,035

Subarea 10 - Chelan-Entiat-Wenatchee-W Banks Lake

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	111.7	58.8	51.1
Surface water split (% SW)	89%	88%	83%
Surface water irrigated area (1000 acres)	99.0	51.5	42.3
Crop water demand (ac ft per 1000 acres)	2,490	[redacted]	2,218

4.3.3 Figures

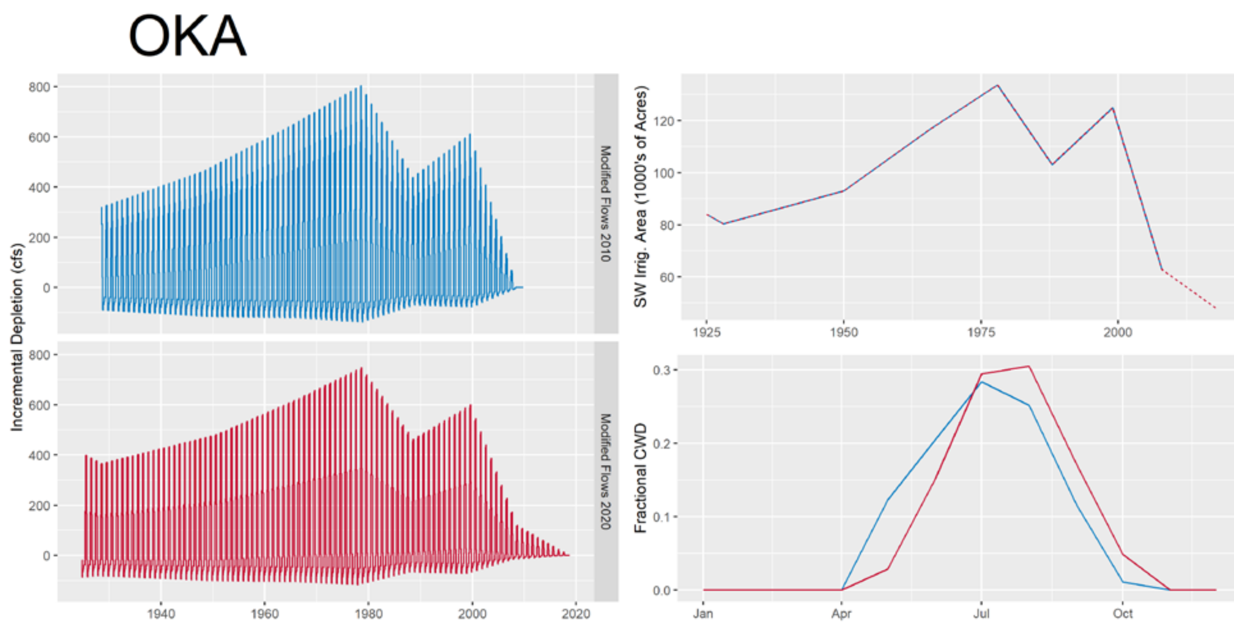

Figure 35. Canada - Okanogan (OKA): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the OKA subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

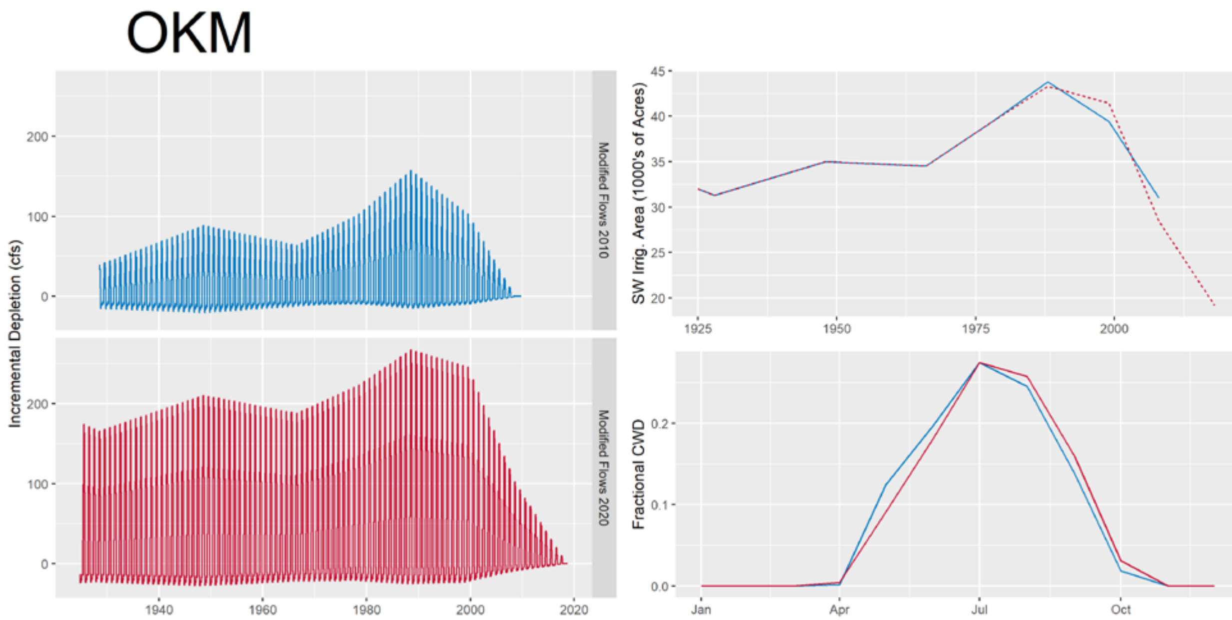

Figure 36. Subarea 9 – Methow-Okanogan (OKM): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the OKM subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

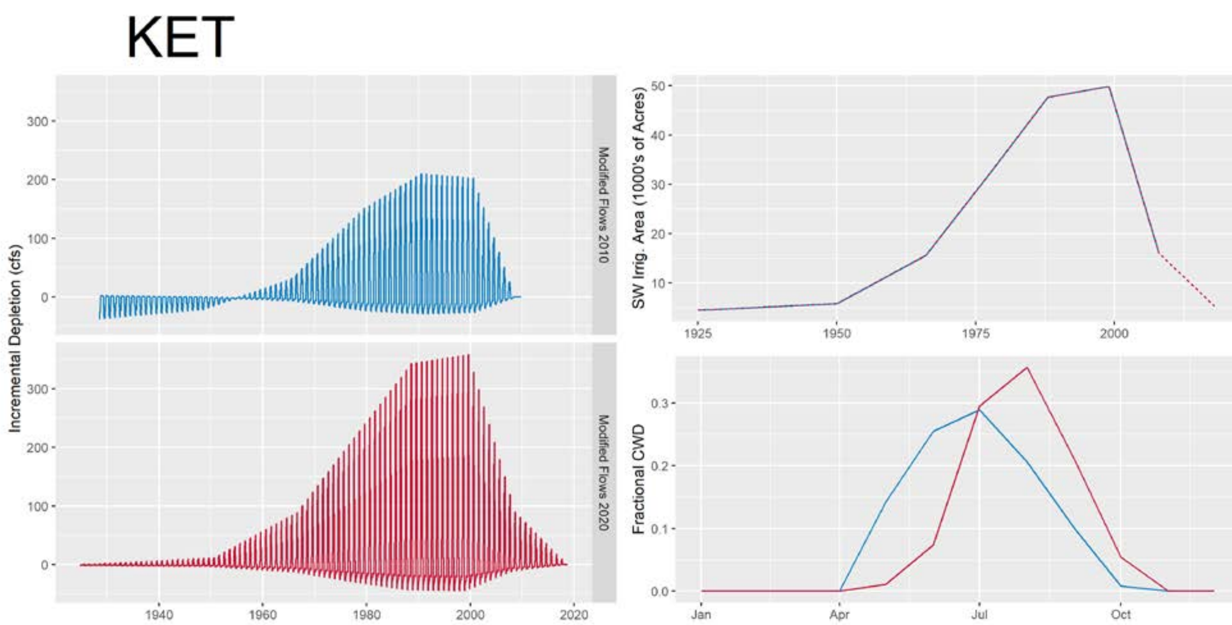

Figure 37. Canada - Kettle (KET): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the KET subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

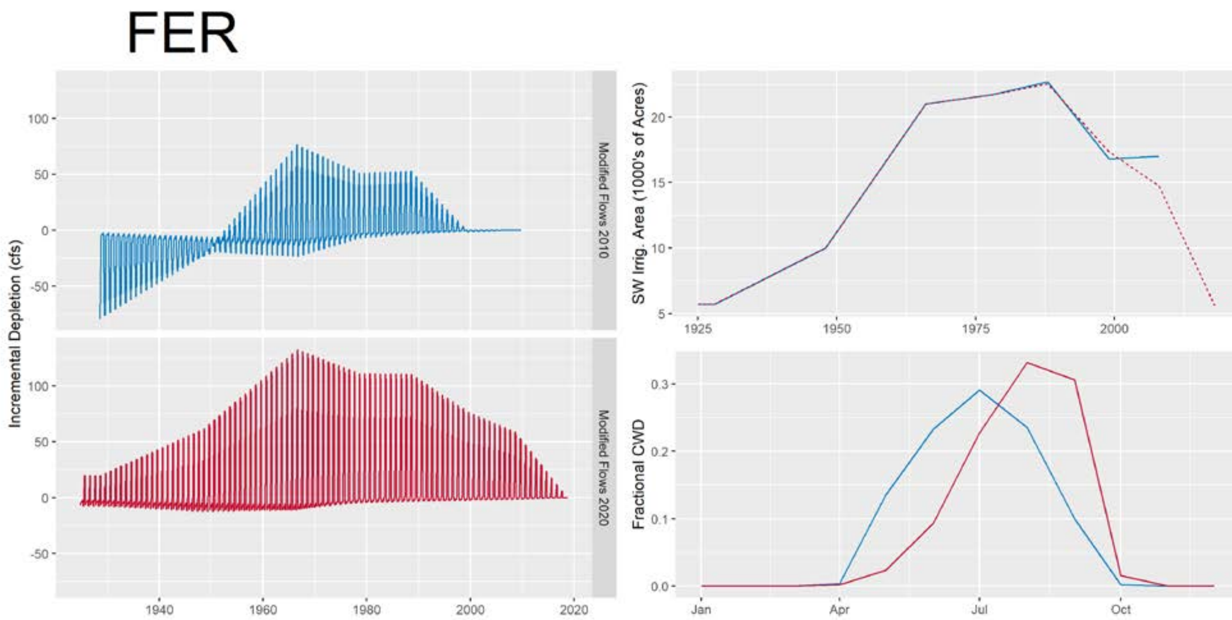

Figure 38. Subarea 8 – Ferry Stevens (FER): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the FER subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

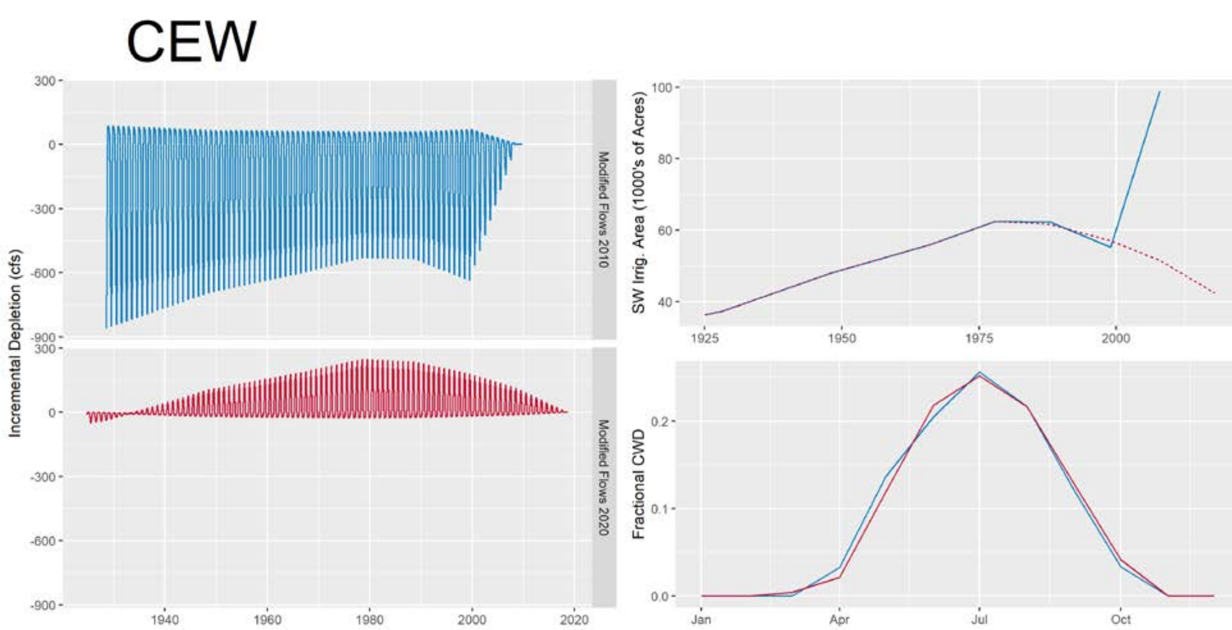

Figure 39. Subarea 10 – Chelan-Entiat-Wenatchee-W. Banks Lake (CEW): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the CEW subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

4.4 Lower Columbia and Lower Snake Basins

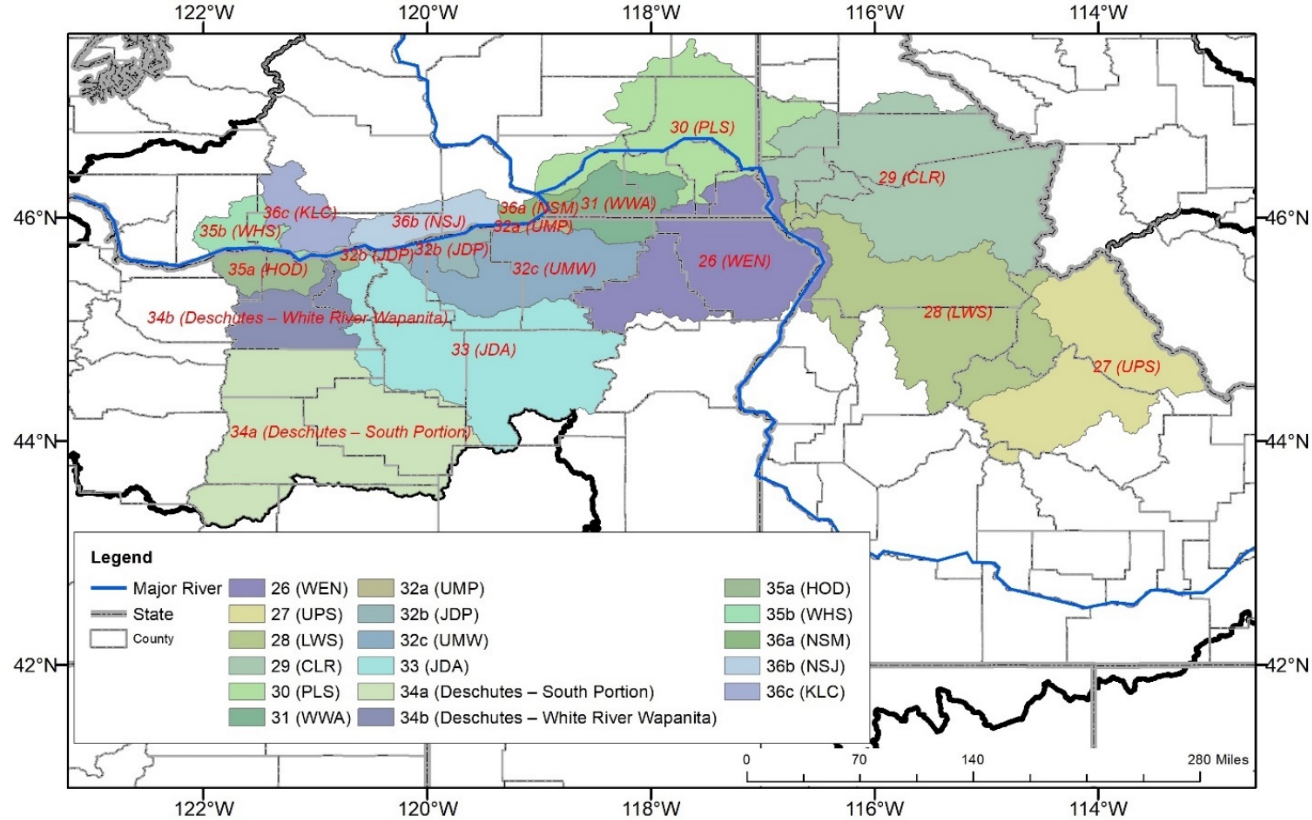

Figure 40. Map showing location of subareas within the Lower Columbia and Lower Snake Basins. Subarea codes defined in Table 9, below.

Table 9. Basin, code, name, and subarea for areas in the Lower Columbia and Lower Snake Basins described in this section.

Basin	Code	Name	Subarea
Lower Snake	WEN	Grande Ronde at Wenaha	Subarea 26
Lower Snake	UPS	Upper Snake	Subarea 27
Lower Snake	LWS	Lower Snake	Subarea 28
Lower Snake	CLR	Clearwater	Subarea 29
Lower Snake	PLS	Palouse-Lower Snake	Subarea 30
Lower Columbia	B23	Pumping to Blocks 2 & 3	
Lower Columbia	MRF	McNary Return Flow	
Lower Columbia	KEN	Kennewick	
Lower Columbia	WWA	Walla Walla	Subarea 31
Lower Columbia	UMP	Pumping from McNary to Umatilla	Subarea 32a(1)
Lower Columbia	UMR	Return flow from McNary pumping to Umatilla	Subarea 32a(2)
Lower Columbia	JDP	Pumping from John Day to Morrow/Gilliam + Returns	Subarea 32b
Lower Columbia	UMW	Umatilla River & Willow Creek	Subarea 32c
Lower Columbia	JDA	John Day	Subarea 33
Lower Columbia	--	Deschutes - South Portion	Subarea 34a
Lower Columbia	WHT	Deschutes - White River Wapanita Project	Subarea 34b
Lower Columbia	HOD	Hood River	Subarea 35a
Lower Columbia	WHS	White Salmon	Subarea 35b
Lower Columbia	NSM	Pumping from McNary to Northside	Subarea 36a(1)
Lower Columbia	NSR	Return flow from McNary pumping to Northside	Subarea 36a(2)
Lower Columbia	NSJ	Pumping from John Day to Northside + Returns	Subarea 36b
Lower Columbia	KLC	Klickitat Basin	Subarea 36c

4.4.1 Description of and justification for methodology used that was specific to the region

The Lower Columbia and Lower Snake Basins are complex basins, and we made the largest number of adjustments to the methodology in this region as compared to others. The main adjustments include changes to the boundaries of subareas 32 and 36 to better reflect reality, capturing the appropriate set of pumps that correspond to Kennewick Irrigation District, and re-partitioning the fraction contribution of various components of subarea 32. These modifications as well as other nuances such as Columbia Exchange Program that are unique to this region are discussed in more detail below.

Sources of uncertainty relevant to the entirety of the Columbia River Basin are discussed in Section 5.

Partitioning of Subareas 32 and 36

In the 2010 Modified Flows, Subareas 32 and 36 were partitioned into sections as described below.

Subarea 32 was partitioned into three sections: (a) Pumping from McNary to Umatilla + Returns (UMP/UMR), (b) Pumping from John Day to Morrow & Gilliam counties + Returns (JDP), and (c) Umatilla River and Willow Creek (UMW).

Subarea 36 was partitioned in two steps. First, there is a small section of Subarea 36, the Kennewick Irrigation District, where depletions are determined with a different method, as discussed further below. That area is separated out. Second, the remainder acreage is then partitioned into three sections – (a) Pumping from McNary to Northside + Returns (NSM/NSR), (b) Pumping from John Day to Northside + Returns (JDP), and (c) Klickitat (KLC).

In this study, while subarea partition naming conventions were retained from the 2010 Modified Flows, changes were made to the boundaries of the polygons comprising Subareas 32 and 36 (Figure 41). For Subarea 36, the primary changes made were shifting the boundary between NSM and NSJ based on information provided by Tim Waters (WSU Extension Franklin and Benton Counties). For the 2010 Modified Flows, a portion of an area South of the Columbia was included in Subarea 36b (NSJ). For this report, we moved that area into Subarea 32b (JDP). Another change is that we were able to calculate updated fractions of irrigated acres in each part of the respective subareas using MIrAD. We used this methodological adjustment to update the fractions used in 2010 as well. Comparisons between 2010 values and 2020 irrigated area and fractions are shown in Table 10.

Table 10. Comparison of irrigated area and fractions for Subareas 32 and 36 in 2010 Modified Flows and 2020 Modified Flows.

	2010		2020	
	Irrigated area (acres)	**Fraction of subarea**	**Irrigated area (acres)**	**Fraction of subarea**
Subarea 32 (Total)	160,653	100%	207,584	100%
32a (UMP/UMR)	40,163	25%	5,112	2.5%
32b (JDP)	80,326	50%	71,367	34.4%
32c (UMW)	40,163	25%	131,105	63.2%
Subarea 36 (Total)	189,617	100%	139,799	100%
36a (NSM/NSR)	104,289	55%	55,274	29.7%
36b (NSJ)	45,508	24%	71,367	63.2%
36c (KLC)	39,820	21%	13,158	7.1%
Total of Subareas 32 & 36	**350,270**		**347,383**	

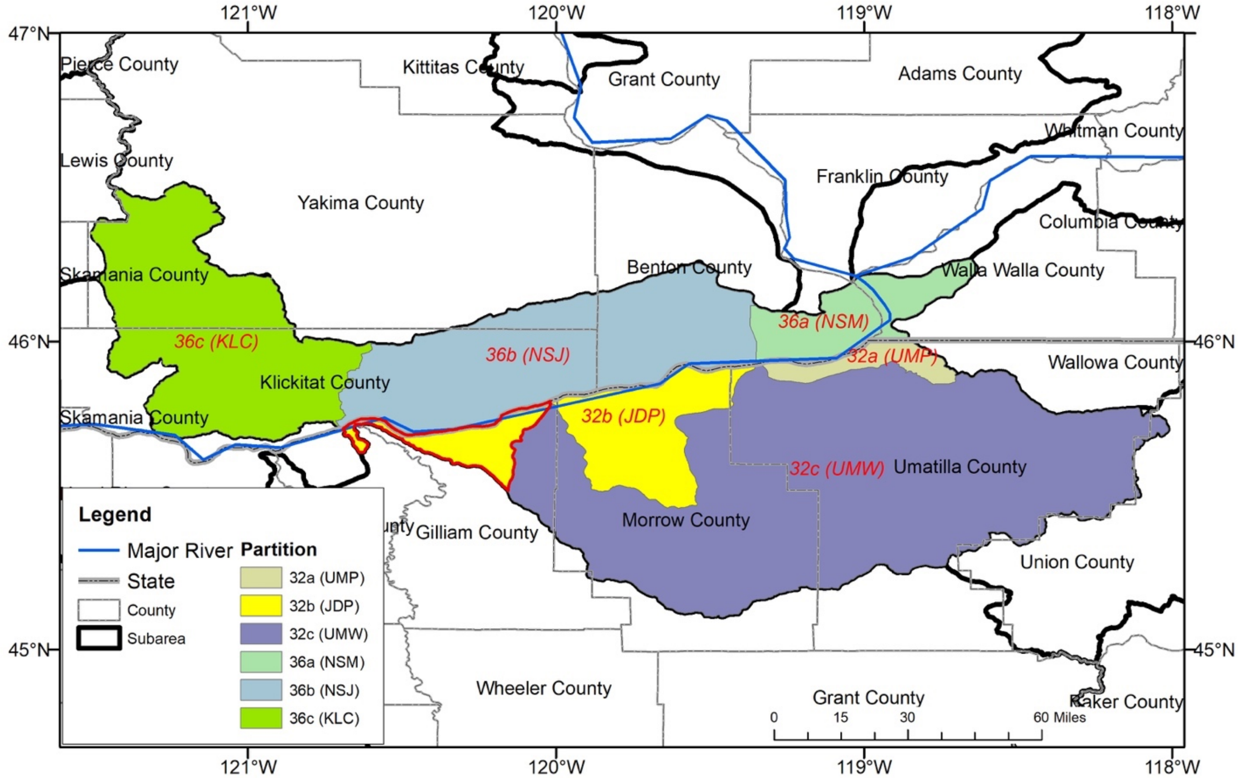

Figure 41. Partitioning of Subareas 32 and 36 for this study. Part of the yellow area (JDP) (with red-color line boundary) was included in NSJ in the 2010 Modified Flows.

Kennewick Irrigation Area

The return flow from the Kennewick irrigation area was determined through pumping data obtained from the U.S. Army Corps of Engineers (Walla Walla district). In the 2010 Modified Flows, KEN return flows included the following pumps: 2C, 4A, 5D, 6B, 12-1, 12-1A, 12-2, 15C, 15D, 15E, 15E-1. However, during this study, it was determined that 12-1, 12-1A, and 12-2 should not be included in KEN6D as they are located on the Pasco side of the Columbia River and are associated with the returns from the Columbia Basin Project contributing to McNary Return Flows (MRF) (See Figure F-5 in Appendix F). The 2010 Modified Flows accounted for these return flows in both MRF5D and KEN5D, thus double counting. Our revision corrected the double counting error.

Surface Water Split for Umatilla County, Oregon

As a result of water rights research conducted in the 2018 Umatilla study (WSU, 2018), the surface water/groundwater split was updated for Umatilla County, Oregon to 75%/25% from 52%/48% based on a report by Umatilla County (2008). To reflect this change, the smoothed surface water fraction for Umatilla County was adjusted for 2005 data and all more recent data. This change impacted Subareas 32a, 32b, and 32c.

Umatilla/Columbia Exchange

A portion of Subarea 32 is involved in the Umatilla/Columbia Exchange, a program in which several irrigation districts that usually divert from the Umatilla River, pull water from the Columbia River during a large portion of the irrigation season. The irrigation districts affected are Stanfield (10,850 acres), Hermiston (9,720 acres), and West Extension (10,379 acres) irrigation districts (Figure 42; acreages from https://owrc.org/membership/district-members).

Stanfield and Hermiston irrigation districts are located within UMW, while West Extension irrigation district is located within JDP.

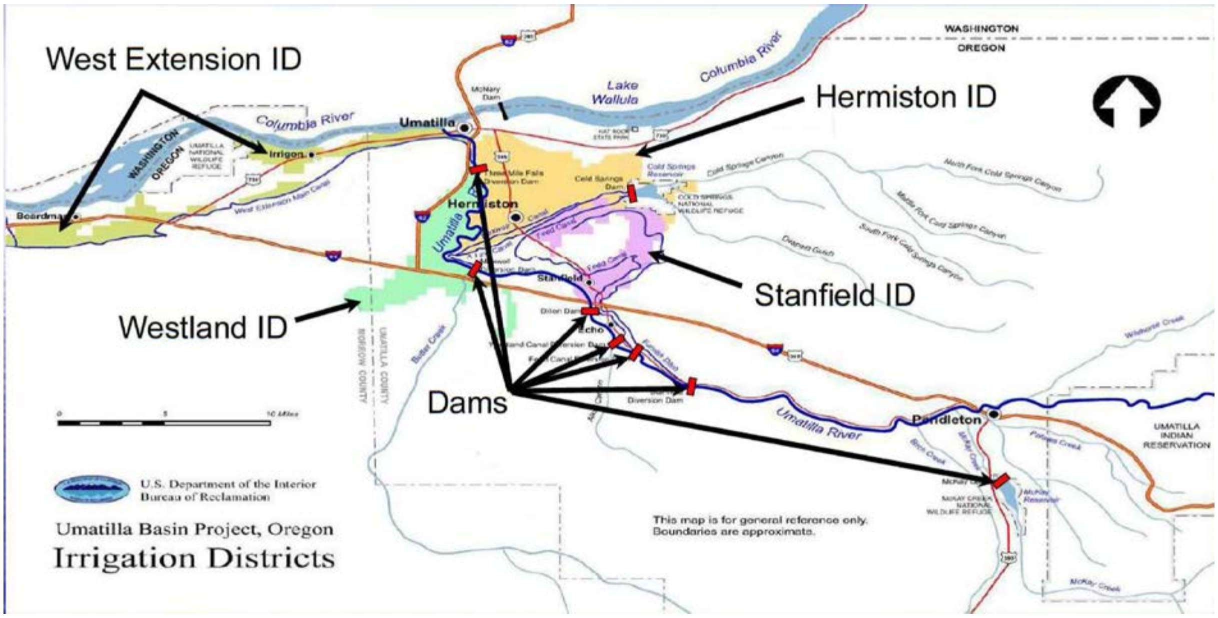

Figure 42. Map of Umatilla irrigation districts. Source: Marvin, 2012

Although the Umatilla/Columbia Exchange certainly affects streamflow, there was not enough information available at the time of this report to account for these effects in the results. Exchange diversion data received from Chester Sater of the USBR Umatilla Office and information gathered through a conversation with Ray Kopacz, manager of the Stanfield Irrigation District indicated that this exchange was in effect for only part of the year and the timing fluctuated from year to year. This made it hard to quantify average "current" conditions. The implication of ignoring this is that diversions from the Umatilla River are over estimated, but this is a small fraction of flows in the Columbia River and do not have a significant impact on those flows.

4.4.2 Tables with Summary Data

Crop distribution

Crop distributions are listed for crops comprising at least 1% of total irrigated area. Note that the total acreage shown may include crops that are not shown on the table because of their small contribution total acres. The irrigated area totals here may not exactly match the "total irrigated area" used for depletion calculation and shown in the Summary tables comparing 2010 Modified Flows and 2020 Modified Flows. This is an artifact of our process to translate non-crop specific MIrAD irrigation extent to crop-specific irrigation extent as described in the methodology Section 2.2.

Subarea 26 - Grande Ronde at Wenaha

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	65,835	65.8%
Pasture	17,235	17.2%
Medicinal Herb	4,154	4.1%
Sod Seed	3,534	3.5%
Winter Wheat	2,324	2.3%
Spring Wheat	2,047	2.0%
Sugarbeets	1,271	1.3%
Potato	959	1.0%
Total	**100,105**	

Subarea 27 - Upper Salmon

Crop	Irrigated area (acres)	Percent of total
Pasture	68,011	67.1%
Alfalfa Hay	31,159	30.7%
Spring Wheat	1,272	1.3%
Total	**101,408**	

Subarea 28 - Lower Salmon

Crop	Irrigated area (acres)	Percent of total
Pasture	14,225	65.1%
Alfalfa Hay	7,401	33.9%
Total	**21,842**	

Subarea 29 - Clearwater

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	25,484	94.3%
Mustard	976	3.6%
Total	**27,023**	

Subarea 30 - Palouse-Lower Snake

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	20,955	20.1%
Potato	17,549	16.9%
Winter Wheat	13,364	12.8%
Apples	12,360	11.9%
Corn	12,072	11.6%
Pasture	7,938	7.6%
Corn Sweet	5,309	5.1%
Onions	2,998	2.9%
Pea Green	1,508	1.4%
Carrots	1,124	1.1%
Barley	1,094	1.1%
Cherry	1,006	1.0%
Grape Juice	1,005	1.0%
Grass Seed	1,002	1.0%
Total	**104,079**	

Subarea 31 - Walla Walla

Crop	Irrigated area (acres)	Percent of total
Winter Wheat	32,052	32.2%
Alfalfa Hay	21,402	21.5%
Sod Seed	14,062	14.1%
Pasture	8,436	8.5%
Apples	4,134	4.2%
Corn	3,752	3.8%
Potato	2,579	2.6%
Grape Wine	2,516	2.5%
Pea Dry	2,014	2.0%
Pea Green	1,795	1.8%
Bean Dry	1,747	1.8%
Corn Sweet	1,202	1.2%
Total	**99,479**	

Subarea 32a - Pumping From McNary to Umatilla (UMP)

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	3,284	32.0%
Corn	1,557	15.2%
Potato	1,423	13.9%
Winter Wheat	1,179	11.5%
Medicinal Herb	573	5.6%
Onions	520	5.1%
Mustard	509	5.0%
Grape Wine	450	4.4%
Mint	200	1.9%
Apples	109	1.1%
Blueberry	104	1.0%
Barley	104	1.0%
Total	**10,268**	

Subarea 32b - Pumping from John Day to Morrow & Gilliam Counties (JDP)

Crop	Irrigated area (acres)	Percent of total
Corn	21,005	28.2%
Alfalfa Hay	20,698	27.8%
Potato	13,053	17.5%
Winter Wheat	5,421	7.3%
Onions	4,104	5.5%
Medicinal Herb	2,323	3.1%
Grape Wine	1,662	2.2%
Cherry	1,606	2.2%
Carrots	1,088	1.5%
Apples	1,042	1.4%
Spring Wheat	797	1.1%
Total	**74,535**	

Subarea 32c -Umatilla River & Willow Creek

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	51,600	40.2%
Winter Wheat	32,512	25.3%
Corn	15,279	11.9%
Potato	13,333	10.4%
Medicinal Herb	2,547	2.0%
Onions	2,079	1.6%
Pea Green	1,875	1.5%
Spring Wheat	1,645	1.3%
Grape Wine	1,373	1.1%
Mustard	1,333	1.0%
Cherry	1,317	1.0%
Total	**128,397**	

Subarea 33 - John Day

Crop	Irrigated area (acres)	Percent of total
Pasture	15,434	51.1%
Alfalfa Hay	11,735	38.9%
Winter Wheat	1,479	4.9%
Rye	492	1.6%
Total	**30,178**	

Subarea 34a - Deschutes - South Portion

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	53,553	45.2%
Pasture	47,046	39.7%
Sod Seed	5,135	4.3%
Carrots	4,756	4.0%
Spring Wheat	2,023	1.7%
Winter Wheat	1,206	1.0%
Total	**118,407**	

Subarea 34b - Deschutes - White River Wapanita Project

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	9,826	80.9%
Winter Wheat	859	7.1%
Pasture	546	4.5%
Cherry	381	3.1%
Pear	225	1.9%
Apples	132	1.1%
Total	**12,137**	

Subarea 35a - Hood River

Crop	Irrigated area (acres)	Percent of total
Cherry	14,608	38.7%
Pear	12,677	33.6%
Alfalfa Hay	3,948	10.5%
Winter Wheat	3,279	8.7%
Pasture	1,254	3.3%
Apples	844	2.2%
Grape Wine	498	1.3%
Total	**37,726**	

Subarea 35b - White Salmon

Crop	Irrigated area (acres)	Percent of total
Pasture	2,979	37.4%
Cherry	1,308	16.4%
Alfalfa Hay	1,298	16.3%
Pear	1,197	15.0%
Grape Wine	355	4.5%
Apples	284	3.6%
Medicinal Herb	278	3.5%
Winter Wheat	151	1.9%
Total	**7,974**	

Subarea 36a - Pumping from McNary to North Side

Crop	Irrigated area (acres)	Percent of total
Potato	23,262	27.2%
Winter Wheat	17,692	20.7%
Corn	10,531	12.3%
Corn Sweet	7,686	9.0%
Pasture	5,076	5.9%
Onions	4,798	5.6%
Apples	4,550	5.3%
Alfalfa Hay	3,631	4.2%
Grape Wine	1,784	2.1%
Cherry	1,655	1.9%
Pea Green	1,234	1.4%
Mint	933	1.1%
Total	**85,506**	

Subarea 36b - Pumping from John Day to North Side

Crop	Irrigated area (acres)	Percent of total
Potato	25,804	17.5%
Corn	18,844	12.8%
Grape Wine	18,260	12.4%
Winter Wheat	13,671	9.3%
Onions	12,510	8.5%
Corn Sweet	12,157	8.2%
Sod Seed	8,191	5.6%
Pea Green	7,177	4.9%
Alfalfa Hay	5,685	3.9%
Carrots	5,664	3.8%
Mint	4,669	3.2%
Pasture	3,254	2.2%
Apples	2,942	2.0%
Blueberry	2,832	1.9%
Sugarbeets	2,051	1.4%
Total	**147,423**	

Subarea 36c - Klickitat Basin

Crop	Irrigated area (acres)	Percent of total
Pasture	12,716	75.0%
Alfalfa Hay	2,715	16.0%
Winter Wheat	971	5.7%
Barley	372	2.2%
Total	**16,965**	

County fractions

Subarea 26 - Grande Ronde at Wenaha

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Idaho	Adams	0.02	463
Idaho	Nez Perce	0.26	201
Oregon	Union	0.86	41,545
Oregon	Wallowa	1.00	40,448
Washington	Asotin	0.63	293
		TOTAL	**82,950**

Subarea 27 - Upper Salmon

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Idaho	Blaine	0.01	232
Idaho	Custer	0.51	30,348
Idaho	Lemhi	0.99	69,699

Subarea 28 - Lower Salmon

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Idaho	Adams	0.36	7,135
Idaho	Custer	0.00	154
Idaho	Idaho	0.25	386
Idaho	Valley	0.43	7,351
		TOTAL	**15,027**

Subarea 29 - Clearwater

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Idaho	Idaho	0.75	1,158
Idaho	Latah	0.40	62
Idaho	Lewis	1.00	185
Idaho	Nez Perce	0.70	541
		TOTAL	**1,946**

Subarea 30 - Palouse-Lower Snake

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Idaho	Latah	0.60	93
Idaho	Nez Perce	0.04	31
Washington	Adams	0.10	12,911
Washington	Asotin	0.37	170
Washington	Columbia	0.36	834
Washington	Franklin	0.17	34,085
Washington	Garfield	1.00	819
Washington	Lincoln	0.00	93
Washington	Spokane	0.26	2,888
Washington	Walla Walla	0.09	10,672
Washington	Whitman	0.99	5,992
		TOTAL	**68,587**

Subarea 31 - Walla Walla

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Oregon	Umatilla	0.23	27,506
Washington	Columbia	0.64	1,483
Washington	Walla Walla	0.78	88,618
		TOTAL	**117,607**

Subarea 32a - Pumping From McNary to Umatilla

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Oregon	Umatilla	0.09	10,224
		TOTAL	**10,224**

Subarea 32b - Pumping from John Day to Morrow & Gilliam Counties

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Oregon	Morrow	0.62	68,788
Oregon	Umatilla	0.01	695
		TOTAL	**69,483**

Subarea 32c -Umatilla River & Willow Creek

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Oregon	Gilliam	0.54	4,015
Oregon	Morrow	0.37	41,128
Oregon	Umatilla	0.72	85,962
		TOTAL	**131,105**

Subarea 33 - John Day

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Oregon	Gilliam	0.21	1,591
Oregon	Grant	0.71	18,626
Oregon	Jefferson	0.00	31
Oregon	Morrow	0.00	386
Oregon	Sherman	0.60	371
Oregon	Wasco	0.01	154
Oregon	Wheeler	1.00	5,606
		TOTAL	**26,765**

Subarea 34b - Deschutes - White River Wapanita Project

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Oregon	Sherman	0.05	31
Oregon	Wasco	0.30	6,394
		TOTAL	**6,425**

Subarea 35a - Hood River

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Oregon	Hood River	1.00	16,710
Oregon	Sherman	0.35	216
Oregon	Wasco	0.69	14,826
		TOTAL	**31,753**

Subarea 35b - White Salmon

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Washington	Klickitat	0.18	4,602
Washington	Skamania	0.14	31
		TOTAL	**4,633**

Subarea 36a - Pumping from McNary to North Side

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Washington	Benton	0.40	81,452
Washington	Walla Walla	0.26	29,097
		TOTAL	**110,549**

Subarea 36b - Pumping from John Day to North Side

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Oregon	Gilliam	0.25	1,884
Washington	Benton	0.53	109,251
Washington	Klickitat	0.30	7,429
Washington	Yakima	0.00	1,004
		TOTAL	**119,568**

Subarea 36c - Klickitat Basin

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Washington	Klickitat	0.52	12,849
Washington	Yakima	0.00	309
		TOTAL	**13,158**

Crop water demand monthly fraction by crop (for crops comprising at least 1% of irrigated area)

Subarea 26 - Grande Ronde at Wenaha

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.7	8.3	50.8	161.4	412.9	427.3	251.6	11.5	0.0	0.0	1,324
Diversion distribution %	0.0%	0.0%	0.1%	0.6%	3.8%	12.2%	31.2%	32.3%	19.0%	0.9%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	65.8%	0.0	0.0	0.0	0.1	0.3	1.5	5.2	6.0	3.6	0.1	0.0	0.0	16.8
Pasture	17.2%	0.0	0.0	0.0	0.1	0.6	2.0	4.6	4.4	3.1	0.1	0.0	0.0	14.9
Medicinal Herb	4.1%	0.0	0.0	0.0	0.2	0.6	2.8	4.8	5.5	1.1	0.0	0.0	0.0	15.0
Sod Seed	3.5%	0.0	0.0	0.0	0.2	2.8	4.1	1.1	0.0	0.0	0.0	0.0	0.0	8.2
Winter Wheat	2.3%	0.0	0.0	0.1	1.0	3.0	4.5	3.6	0.2	1.4	2.5	0.0	0.0	16.3
Spring Wheat	2.0%	0.0	0.0	0.0	0.0	1.8	3.8	5.7	1.2	0.0	0.0	0.0	0.0	12.5
Sugarbeets	1.3%	0.0	0.0	0.0	0.0	2.3	5.2	4.8	0.2	0.0	0.0	0.0	0.0	12.5
Potato	1.0%	0.0	0.0	0.0	0.0	1.5	2.6	6.8	7.1	2.2	0.0	0.0	0.0	20.2

Subarea 27 – Upper Salmon

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	1.1	71.5	156.5	237.9	393.7	359.1	243.9	7.4	0.0	0.0	1,471
Diversion distribution %	0.0%	0.0%	0.1%	4.9%	10.6%	16.2%	26.8%	24.4%	16.6%	0.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	67.1%	0.0	0.0	0.0	1.0	2.0	2.6	4.4	4.2	2.9	0.1	0.0	0.0	17.1
Alfalfa Hay	30.7%	0.0	0.0	0.0	0.6	1.6	3.2	5.2	4.7	3.2	0.1	0.0	0.0	18.8
Spring Wheat	1.3%	0.0	0.0	0.0	0.0	3.8	6.9	6.3	0.4	0.0	0.0	0.0	0.0	17.4

Subarea 28 – Lower Salmon

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	1.4	14.7	77.2	311.5	395.8	235.1	7.0	0.0	0.0	1,043
Diversion distribution %	0.0%	0.0%	0.0%	0.1%	1.4%	7.4%	29.9%	38.0%	22.5%	0.7%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	65.1%	0.0	0.0	0.0	0.0	0.2	1.0	3.8	4.3	2.7	0.1	0.0	0.0	12.2
Alfalfa Hay	33.9%	0.0	0.0	0.0	0.0	0.1	0.6	3.5	5.6	3.1	0.1	0.0	0.0	13.1

Subarea 29 – Clearwater

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.4	8.2	38.0	265.2	512.4	244.4	6.0	0.0	0.0	1,074
Diversion distribution %	0.0%	0.0%	0.0%	0.0%	0.8%	3.5%	24.7%	47.7%	22.7%	0.6%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	94.3%	0.0	0.0	0.0	0.0	0.0	0.3	3.1	6.5	3.1	0.1	0.0	0.0	13.0
Mustard	3.6%	0.0	0.0	0.0	0.0	1.3	4.1	4.7	0.4	0.0	0.0	0.0	0.0	10.4

Subarea 30 - Palouse-Lower Snake

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	12.2	47.7	223.4	384.6	470.5	348.8	174.5	59.7	0.0	0.0	1,721
Diversion distribution %	0.0%	0.0%	0.7%	2.8%	13.0%	22.3%	27.3%	20.3%	10.1%	3.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	20.1%	0.0	0.0	0.0	0.0	1.3	3.9	6.6	6.6	4.0	0.1	0.0	0.0	22.5
Potato	16.9%	0.0	0.0	0.0	0.0	2.2	5.1	8.4	7.7	1.5	0.0	0.0	0.0	24.9
Winter Wheat	12.8%	0.0	0.0	1.1	3.6	5.3	2.4	0.3	0.0	1.7	3.5	0.0	0.0	17.9
Apples	11.9%	0.0	0.0	0.0	0.3	4.2	6.4	8.0	7.1	3.6	1.7	0.0	0.0	31.2
Corn	11.6%	0.0	0.0	0.0	0.0	2.3	6.7	5.3	0.1	0.0	0.0	0.0	0.0	14.3
Pasture	7.6%	0.0	0.0	0.0	0.0	2.2	4.4	6.0	5.9	3.8	0.1	0.0	0.0	22.5
Corn Sweet	5.1%	0.0	0.0	0.0	0.0	1.6	4.6	6.4	0.2	0.0	0.0	0.0	0.0	12.8
Onions	2.9%	0.0	0.0	0.0	0.9	2.3	1.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3
Pea Green	1.4%	0.0	0.0	0.0	0.0	2.2	5.9	7.1	1.2	0.0	0.0	0.0	0.0	16.4
Carrots	1.1%	0.0	0.0	0.0	0.9	2.5	1.1	0.0	0.0	0.0	0.0	0.0	0.0	4.5
Barley	1.1%	0.0	0.0	0.0	0.1	2.1	5.4	5.1	0.1	0.0	0.0	0.0	0.0	12.8
Cherry	1.0%	0.0	0.0	0.0	1.0	5.1	5.2	5.3	5.0	3.4	1.7	0.0	0.0	26.9
Grape Juice	1.0%	0.0	0.0	0.0	0.0	1.1	7.0	8.4	7.5	2.8	0.9	0.0	0.0	27.8
Grass Seed	1.0%	0.0	0.0	0.0	1.7	5.2	2.7	0.0	0.0	0.0	0.0	0.0	0.0	9.6

Subarea 31 - Walla Walla

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	8.1	64.3	203.9	235.2	309.8	271.1	187.7	109.7	0.0	0.0	1,390
Diversion distribution %	0.0%	0.0%	0.6%	4.6%	14.7%	16.9%	22.3%	19.5%	13.5%	7.9%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Winter Wheat	32.2%	0.0	0.0	0.3	2.2	4.1	2.3	0.1	0.0	1.7	3.7	0.0	0.0	14.4
Alfalfa Hay	21.5%	0.0	0.0	0.0	0.0	0.1	1.3	7.3	8.5	5.0	0.1	0.0	0.0	22.3
Sod Seed	14.1%	0.0	0.0	0.0	0.4	5.3	2.4	0.0	0.0	0.0	0.0	0.0	0.0	8.1
Pasture	8.5%	0.0	0.0	0.0	0.0	0.4	4.4	6.6	6.2	3.8	0.1	0.0	0.0	21.6
Apples	4.2%	0.0	0.0	0.0	0.0	1.9	6.5	8.2	7.1	3.6	1.6	0.0	0.0	28.9
Corn	3.8%	0.0	0.0	0.0	0.0	1.5	5.4	4.7	0.1	0.0	0.0	0.0	0.0	11.7
Potato	2.6%	0.0	0.0	0.0	0.0	1.5	4.5	8.2	7.6	1.6	0.0	0.0	0.0	23.4
Grape Wine	2.5%	0.0	0.0	0.0	0.0	0.0	0.5	7.1	7.9	3.2	1.0	0.0	0.0	19.7
Pea Dry	2.0%	0.0	0.0	0.0	0.0	1.7	5.5	6.9	0.8	0.0	0.0	0.0	0.0	14.9
Pea Green	1.8%	0.0	0.0	0.0	0.0	1.1	4.5	7.0	1.5	0.0	0.0	0.0	0.0	14.1
Bean Dry	1.8%	0.0	0.0	0.0	0.0	0.0	3.7	7.5	5.3	0.6	0.0	0.0	0.0	17.2
Corn Sweet	1.2%	0.0	0.0	0.0	0.0	1.4	4.0	6.1	0.2	0.0	0.0	0.0	0.0	11.7

Subarea 32a - Pumping From McNary to Umatilla (UMP)

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	2.6	26.2	199.9	405.1	439.8	329.2	159.7	40.7	0.0	0.0	1,603
Diversion distribution %	0.0%	0.0%	0.2%	1.6%	12.5%	25.3%	27.4%	20.5%	10.0%	2.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	32.0%	0.0	0.0	0.0	0.0	2.2	5.2	6.3	5.9	3.8	0.1	0.0	0.0	23.5
Corn	15.2%	0.0	0.0	0.0	0.0	2.3	6.8	5.2	0.0	0.0	0.0	0.0	0.0	14.4
Potato	13.9%	0.0	0.0	0.0	0.0	2.0	5.0	8.4	7.7	1.6	0.0	0.0	0.0	24.7
Winter Wheat	11.5%	0.0	0.0	0.3	2.0	4.2	3.0	0.2	0.0	1.7	3.2	0.0	0.0	14.6
Medicinal Herb	5.6%	0.0	0.0	0.0	0.3	2.5	4.5	5.9	6.8	1.3	0.0	0.0	0.0	21.3
Onions	5.1%	0.0	0.0	0.0	0.9	2.3	1.1	0.0	0.0	0.0	0.0	0.0	0.0	4.4
Mustard	5.0%	0.0	0.0	0.0	0.0	1.9	5.4	4.6	0.3	0.0	0.0	0.0	0.0	12.1
Grape Wine	4.4%	0.0	0.0	0.0	0.0	0.0	3.0	8.0	7.3	2.9	1.1	0.0	0.0	22.4
Mint	1.9%	0.0	0.0	0.0	0.9	3.0	4.7	6.4	6.9	1.3	0.0	0.0	0.0	23.2
Apples	1.1%	0.0	0.0	0.0	0.0	3.6	6.5	8.2	7.5	3.8	1.7	0.0	0.0	31.3
Blueberry	1.0%	0.0	0.0	0.0	0.0	2.8	6.2	6.9	4.1	2.7	1.3	0.0	0.0	24.0
Barley	1.0%	0.0	0.0	0.0	0.1	1.9	5.8	3.7	0.0	0.0	0.0	0.0	0.0	11.4

Subarea 32b - Pumping from John Day to Morrow & Gilliam Counties (JDP)

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	11.6	37.4	233.5	432.8	455.8	308.5	145.3	35.1	0.0	0.0	1,660
Diversion distribution %	0.0%	0.0%	0.7%	2.3%	14.1%	26.1%	27.5%	18.6%	8.8%	2.1%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Corn	28.2%	0.0	0.0	0.0	0.0	2.2	7.0	5.1	0.1	0.0	0.0	0.0	0.0	14.3
Alfalfa Hay	27.8%	0.0	0.0	0.0	0.0	2.8	4.9	6.4	6.0	3.9	0.1	0.0	0.0	24.2
Potato	17.5%	0.0	0.0	0.0	0.0	2.2	5.2	8.6	7.8	1.5	0.0	0.0	0.0	25.3
Winter Wheat	7.3%	0.0	0.0	1.9	4.2	5.9	3.5	0.2	0.0	1.7	4.1	0.0	0.0	21.5
Onions	5.5%	0.0	0.0	0.0	0.9	2.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1
Medicinal Herb	3.1%	0.0	0.0	0.0	0.7	2.8	4.7	6.2	7.1	1.3	0.0	0.0	0.0	22.8
Grape Wine	2.2%	0.0	0.0	0.0	0.0	0.7	4.1	7.9	7.2	3.0	1.2	0.0	0.0	24.1
Cherry	2.2%	0.0	0.0	0.0	1.1	5.4	5.4	5.3	4.9	3.3	1.7	0.0	0.0	27.1
Carrots	1.5%	0.0	0.0	0.0	0.9	2.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0
Apples	1.4%	0.0	0.0	0.0	0.9	5.1	6.5	8.1	7.3	3.8	1.9	0.0	0.0	33.6
Spring Wheat	1.1%	0.0	0.0	0.0	0.1	5.5	7.3	2.1	0.0	0.0	0.0	0.0	0.0	15.0

Subarea 32c -Umatilla River & Willow Creek

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	13.9	55.5	214.4	391.1	421.8	319.5	201.4	77.4	0.0	0.0	1,695
Diversion distribution %	0.0%	0.0%	0.8%	3.3%	12.6%	23.1%	24.9%	18.9%	11.9%	4.6%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	40.2%	0.0	0.0	0.0	0.1	1.7	4.8	7.0	6.5	4.2	0.1	0.0	0.0	24.3
Winter Wheat	25.3%	0.0	0.0	0.6	2.3	4.3	3.7	0.5	0.0	1.7	3.4	0.0	0.0	16.5
Corn	11.9%	0.0	0.0	0.0	0.0	2.3	6.7	5.5	0.1	0.0	0.0	0.0	0.0	14.6
Potato	10.4%	0.0	0.0	0.0	0.0	2.2	4.9	8.4	7.8	1.8	0.0	0.0	0.0	25.0
Medicinal Herb	2.0%	0.0	0.0	0.0	0.9	2.7	4.7	6.4	6.9	1.3	0.0	0.0	0.0	22.9
Onions	1.6%	0.0	0.0	0.0	0.9	2.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	4.3
Pea Green	1.5%	0.0	0.0	0.0	0.0	1.2	4.5	7.3	2.1	0.0	0.0	0.0	0.0	15.0
Spring Wheat	1.3%	0.0	0.0	0.0	0.1	4.1	6.6	3.0	0.0	0.0	0.0	0.0	0.0	13.9
Grape Wine	1.1%	0.0	0.0	0.0	0.0	0.2	3.7	7.4	7.2	3.0	1.1	0.0	0.0	22.6
Mustard	1.0%	0.0	0.0	0.0	0.0	1.9	5.4	4.8	0.2	0.0	0.0	0.0	0.0	12.4
Cherry	1.0%	0.0	0.0	0.0	0.8	5.0	5.4	5.5	5.0	3.4	1.7	0.0	0.0	26.7

Subarea 33 - John Day

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	5.5	43.6	159.0	308.6	489.6	466.6	332.5	24.0	0.0	0.0	1,830
Diversion distribution %	0.0%	0.0%	0.3%	2.4%	8.7%	16.9%	26.8%	25.5%	18.2%	1.3%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	51.1%	0.0	0.0	0.0	0.4	1.7	3.1	5.5	5.5	4.0	0.1	0.0	0.0	20.3
Alfalfa Hay	38.9%	0.0	0.0	0.1	0.4	1.7	4.1	6.8	6.7	4.7	0.1	0.0	0.0	24.6
Winter Wheat	4.9%	0.0	0.0	0.9	2.7	4.9	5.1	2.0	0.0	1.6	3.3	0.0	0.0	20.5
Rye	1.6%	0.0	0.0	0.0	0.5	2.1	4.9	7.9	3.7	0.4	0.0	0.0	0.0	19.4

Subarea 34b - Deschutes - White River Wapanita Project

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	10.9	70.7	230.2	397.4	522.8	494.7	362.2	34.7	0.0	0.0	2,124
Diversion distribution %	0.0%	0.0%	0.5%	3.3%	10.8%	18.7%	24.6%	23.3%	17.1%	1.6%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	80.9%	0.0	0.0	0.1	0.7	2.4	4.7	6.7	6.5	4.7	0.1	0.0	0.0	25.9
Winter Wheat	7.1%	0.0	0.0	0.7	2.7	5.3	4.9	1.0	0.0	1.6	2.7	0.0	0.0	18.9
Pasture	4.5%	0.0	0.0	0.0	0.7	3.1	4.2	6.2	5.9	4.5	0.1	0.0	0.0	24.7
Cherry	3.1%	0.0	0.0	0.1	1.3	3.9	5.5	6.1	5.1	3.8	1.9	0.0	0.0	27.7
Pear	1.9%	0.0	0.0	0.2	1.5	3.9	5.6	7.5	6.8	4.0	2.0	0.0	0.0	31.5
Apples	1.1%	0.0	0.0	0.1	1.0	3.7	5.6	7.5	7.3	5.1	2.1	0.0	0.0	32.3

Subarea 35a - Hood River

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	3.6	27.8	202.3	396.8	493.4	431.6	282.2	105.3	0.0	0.0	1,943
Diversion distribution %	0.0%	0.0%	0.2%	1.4%	10.4%	20.4%	25.4%	22.2%	14.5%	5.4%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Cherry	38.7%	0.0	0.0	0.0	0.2	3.6	5.2	5.6	4.9	3.4	1.5	0.0	0.0	24.6
Pear	33.6%	0.0	0.0	0.0	0.0	1.1	4.7	7.1	6.2	3.4	1.0	0.0	0.0	23.4
Alfalfa Hay	10.5%	0.0	0.0	0.0	0.1	1.1	4.3	7.3	6.8	4.6	0.1	0.0	0.0	24.3
Winter Wheat	8.7%	0.0	0.0	0.5	2.5	5.2	4.7	0.8	0.0	1.7	3.1	0.0	0.0	18.5
Pasture	3.3%	0.0	0.0	0.0	0.1	1.0	3.3	5.4	5.3	3.5	0.1	0.0	0.0	18.7
Apples	2.2%	0.0	0.0	0.0	0.0	0.8	4.9	7.1	6.5	4.1	1.2	0.0	0.0	24.7
Grape Wine	1.3%	0.0	0.0	0.0	0.0	0.1	1.7	6.8	7.2	4.3	1.4	0.0	0.0	21.5

Subarea 35b - White Salmon

Water requirement (ac-ft/1000 acres) by month for all crops

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL

Total Water Required by Crops		0.0	0.0	0.7	13.6	125.7	329.0	500.7	481.5	295.1	54.4	0.0	0.0	1,801
Diversion distribution %		0.0%	0.0%	0.0%	0.8%	7.0%	18.3%	27.8%	26.7%	16.4%	3.0%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	37.4%	0.0	0.0	0.0	0.0	0.6	3.5	5.5	5.3	3.5	0.1	0.0	0.0	18.4
Cherry	16.4%	0.0	0.0	0.0	0.6	4.3	5.4	5.8	5.3	3.6	1.6	0.0	0.0	26.7
Alfalfa Hay	16.3%	0.0	0.0	0.0	0.1	1.1	2.3	6.5	7.0	4.3	0.1	0.0	0.0	21.3
Pear	15.0%	0.0	0.0	0.0	0.0	1.3	5.4	7.1	6.5	3.3	1.0	0.0	0.0	24.7
Grape Wine	4.5%	0.0	0.0	0.0	0.0	0.5	2.2	6.6	6.9	4.4	1.5	0.0	0.0	22.1
Apples	3.6%	0.0	0.0	0.0	0.1	1.2	5.3	7.3	7.0	4.3	1.3	0.0	0.0	26.3
Medicinal Herb	3.5%	0.0	0.0	0.0	0.0	0.3	3.0	5.4	4.9	1.0	0.0	0.0	0.0	14.7
Winter Wheat	1.9%	0.0	0.0	0.3	2.2	4.9	5.6	2.1	0.1	1.5	2.8	0.0	0.0	19.4

Subarea 36a - Pumping from McNary to North Side

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	17.1	71.6	263.4	383.0	430.8	292.2	128.2	73.1	0.0	0.0	1,659
Diversion distribution %	0.0%	0.0%	1.0%	4.3%	15.9%	23.1%	26.0%	17.6%	7.7%	4.4%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Potato	27.2%	0.0	0.0	0.0	0.0	2.4	5.3	8.4	7.8	1.6	0.0	0.0	0.0	25.5
Winter Wheat	20.7%	0.0	0.0	1.0	3.6	5.6	2.5	0.0	0.0	1.7	3.4	0.0	0.0	17.9
Corn	12.3%	0.0	0.0	0.0	0.0	2.5	6.8	5.3	0.1	0.0	0.0	0.0	0.0	14.6
Corn Sweet	9.0%	0.0	0.0	0.0	0.0	1.7	4.7	6.5	0.2	0.0	0.0	0.0	0.0	13.1
Pasture	5.9%	0.0	0.0	0.0	0.0	3.1	4.2	5.8	5.6	3.6	0.1	0.0	0.0	22.4
Onions	5.6%	0.0	0.0	0.0	1.0	2.7	1.5	0.0	0.0	0.0	0.0	0.0	0.0	5.2
Apples	5.3%	0.0	0.0	0.0	0.3	4.5	6.1	7.8	7.0	3.5	1.7	0.0	0.0	30.8
Alfalfa Hay	4.2%	0.0	0.0	0.0	0.0	1.4	5.8	6.9	6.1	4.0	0.1	0.0	0.0	24.3
Grape Wine	2.1%	0.0	0.0	0.0	0.0	0.0	3.0	7.7	6.9	2.8	1.0	0.0	0.0	21.5
Cherry	1.9%	0.0	0.0	0.0	0.7	5.6	5.7	5.7	5.2	3.5	1.8	0.0	0.0	28.2
Pea Green	1.4%	0.0	0.0	0.0	0.0	2.5	6.1	7.3	1.4	0.0	0.0	0.0	0.0	17.3
Mint	1.1%	0.0	0.0	0.0	0.2	2.6	4.4	6.3	6.7	1.2	0.0	0.0	0.0	21.4

Subarea 36b - Pumping from John Day to North Side

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	10.3	61.2	260.6	404.6	437.6	286.6	116.6	48.4	0.0	0.0	1,626
Diversion distribution %	0.0%	0.0%	0.6%	3.8%	16.0%	24.9%	26.9%	17.6%	7.2%	3.0%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Potato	0.175	0.0	0.0	0.0	0.0	3.0	5.7	8.7	8.0	1.6	0.0	0.0	0.0	26.9
Corn	0.128	0.0	0.0	0.0	0.0	2.5	7.1	5.4	0.1	0.0	0.0	0.0	0.0	15.0
Grape Wine	0.124	0.0	0.0	0.0	0.0	1.1	4.5	8.2	7.9	3.8	1.5	0.0	0.0	27.0
Winter Wheat	0.093	0.0	0.0	1.3	4.1	6.1	3.1	0.1	0.0	1.7	3.4	0.0	0.0	19.7
Onions	0.085	0.0	0.0	0.0	1.4	2.8	1.6	0.0	0.0	0.0	0.0	0.0	0.0	5.8
Corn Sweet	0.082	0.0	0.0	0.0	0.0	1.9	5.6	6.5	0.2	0.0	0.0	0.0	0.0	14.1
Sod Seed	0.056	0.0	0.0	0.0	2.1	5.8	3.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0
Pea Green	0.049	0.0	0.0	0.0	0.0	2.5	6.3	7.4	1.6	0.0	0.0	0.0	0.0	17.7
Alfalfa Hay	3.9%	0.0	0.0	0.0	0.2	3.5	5.6	7.4	7.1	4.7	0.1	0.0	0.0	28.7
Carrots	3.8%	0.0	0.0	0.0	1.3	2.8	1.4	0.0	0.0	0.0	0.0	0.0	0.0	5.5
Mint	3.2%	0.0	0.0	0.0	0.8	3.0	4.8	6.3	7.2	1.3	0.0	0.0	0.0	23.4
Pasture	2.2%	0.0	0.0	0.0	0.6	4.0	5.1	7.1	6.9	4.5	0.1	0.0	0.0	28.3
Apples	2.0%	0.0	0.0	0.0	0.7	4.9	6.3	8.0	7.2	3.7	1.9	0.0	0.0	32.7
Blueberry	1.9%	0.0	0.0	0.0	0.2	2.7	6.2	7.2	4.2	2.7	1.4	0.0	0.0	24.4
Sugarbeets	1.4%	0.0	0.0	0.0	0.1	6.5	7.4	2.0	0.0	0.0	0.0	0.0	0.0	16.0

Subarea 36c - Klickitat Basin

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.5	8.2	66.1	331.9	453.3	421.0	288.2	20.2	0.0	0.0	1,589
Diversion distribution %	0.0%	0.0%	0.0%	0.5%	4.2%	20.9%	28.5%	26.5%	18.1%	1.3%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	75.0%	0.0	0.0	0.0	0.0	0.5	3.7	5.1	5.1	3.5	0.1	0.0	0.0	18.0
Alfalfa Hay	16.0%	0.0	0.0	0.0	0.0	0.5	4.3	7.6	7.1	4.6	0.1	0.0	0.0	24.2
Winter Wheat	5.7%	0.0	0.0	0.1	1.7	4.8	6.2	2.9	0.0	1.6	2.8	0.0	0.0	20.0
Barley	2.2%	0.0	0.0	0.0	0.1	2.5	5.5	6.9	0.5	0.0	0.0	0.0	0.0	15.4

2015 USGS data

Subarea 26 - Grande Ronde at Wenaha

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Idaho	Adams	0.97	2.3	0.0	5.3	7.6
Idaho	Nez Perce	0.89	23.2	0.0	21.2	44.5
Oregon	Union	0.67	53.4	0.0	21.8	75.2
Oregon	Wallowa	0.94	30.5	0.0	17.1	47.6
Washington	Asotin	0.42	0.6	0.0	0.0	0.6

Subarea 27 - Upper Salmon

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Idaho	Blaine	0.63	34.7	0.0	21.0	55.8
Idaho	Custer	0.91	8.8	0.0	10.6	19.4
Idaho	Lemhi	0.98	8.5	0.0	12.1	20.6

Subarea 28 - Lower Salmon

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Idaho	Adams	0.97	2.3	0.0	5.3	7.6
Idaho	Custer	0.91	8.8	0.0	10.6	19.4
Idaho	Idaho	0.94	12.2	0.0	12.6	24.8
Idaho	Valley	0.94	1.1	0.0	2.0	3.0

Subarea 29 - Clearwater

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Idaho	Idaho	0.94	12.2	0.0	12.6	24.8
Idaho	Latah	0.40	17.7	0.0	31.2	48.9
Idaho	Lewis	0.73	8.0	0.0	5.8	13.8
Idaho	Nez Perce	0.89	23.2	0.0	21.2	44.5

Subarea 30 - Palouse-Lower Snake

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Idaho	Latah	0.40	17.7	0.0	31.2	48.9
Idaho	Nez Perce	0.89	23.2	0.0	21.2	44.5
Washington	Adams	0.44	102.4	4.2	22.6	129.2
Washington	Asotin	0.42	0.6	0.0	0.0	0.6
Washington	Columbia	0.85	3.9	0.1	0.0	4.0
Washington	Franklin	0.77	167.4	11.6	15.9	194.9
Washington	Garfield	0.87	0.8	0.0	0.0	0.8
Washington	Lincoln	0.20	23.7	1.6	0.0	25.3
Washington	Spokane	0.11	10.7	0.6	0.0	11.3
Washington	Walla Walla	0.62	80.9	6.1	0.0	87.0
Washington	Whitman	0.55	4.1	0.4	0.0	4.5

Subarea 31 - Walla Walla

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Oregon	Umatilla	0.75	90.2	16.7	4.5	111.3
Washington	Columbia	0.85	3.9	0.1	0.0	4.0
Washington	Walla Walla	0.62	80.9	6.1	0.0	87.0

Subarea 32a - Pumping From McNary to Umatilla

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Oregon	Umatilla	0.75	90.2	16.7	4.5	111.3

Subarea 32b - Pumping from John Day to Morrow & Gilliam Counties

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Oregon	Morrow	0.54	53.4	14.3	5.1	72.7
Oregon	Umatilla	0.75	90.2	16.7	4.5	111.3

Subarea 32c - Umatilla River & Willow Creek

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Oregon	Gilliam	0.30	10.4	0.0	2.3	12.7
Oregon	Morrow	0.54	53.4	14.3	5.1	72.7
Oregon	Umatilla	0.75	90.2	16.7	4.5	111.3

Subarea 33 - John Day

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Oregon	Gilliam	0.30	10.4	0.0	2.3	12.7
Oregon	Grant	0.96	6.3	0.0	6.2	12.5
Oregon	Jefferson	0.93	47.2	2.9	8.8	59.0
Oregon	Morrow	0.54	53.4	14.3	5.1	72.7
Oregon	Sherman	0.22	2.0	0.0	0.2	2.1
Oregon	Wasco	0.52	17.7	0.4	0.8	18.8
Oregon	Wheeler	0.94	2.5	0.0	3.7	6.1

Subarea 34b - Deschutes - White River Wapanita Project

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Oregon	Sherman	0.22	2.0	0.0	0.2	2.1
Oregon	Wasco	0.52	17.7	0.4	0.8	18.8

Subarea 35a - Hood River

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Oregon	Hood River	0.98	18.3	1.0	0.0	19.3
Oregon	Sherman	0.22	2.0	0.0	0.2	2.1
Oregon	Wasco	0.52	17.7	0.4	0.8	18.8

Subarea 35b - White Salmon

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Washington	Klickitat	0.27	17.5	1.2	1.3	20.0
Washington	Skamania	0.64	0.5	0.0	0.0	0.5

Subarea 36a - Pumping from McNary to North Side

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Washington	Benton	0.82	150.6	6.1	14.3	170.9
Washington	Walla Walla	0.62	80.9	6.1	0.0	87.0

Subarea 36b - Pumping from John Day to North Side

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Oregon	Gilliam	0.30	10.4	0.0	2.3	12.7
Washington	Benton	0.82	150.6	6.1	14.3	170.9
Washington	Klickitat	0.27	17.5	1.2	1.3	20.0
Washington	Yakima	0.78	155.8	10.9	51.9	218.5

Subarea 36c - Klickitat Basin

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Washington	Klickitat	0.27	17.5	1.2	1.3	20.0
Washington	Yakima	0.78	155.8	10.9	51.9	218.5

Diversion and return flow volumes (ac-ft/1000 ac) based on sprinkler/gravity efficiencies

Subarea 26 - Grande Ronde at Wenaha

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1324*	*1324*
Diversion Efficiency (%)	*86%*	*45%*
Required Diversion (ac-ft per 1000 ac)	**-1540**	**-2943**
Return Efficiency (%)	*10%*	*50%*
Return Flow (ac-ft per 1000 ac)	**154**	**1472**

Subarea 27 - Upper Salmon

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1471*	*1471*
Diversion Efficiency (%)	*67%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-2196**	**-2942**
Return Efficiency (%)	*29%*	*45%*
Return Flow (ac-ft per 1000 ac)	**637**	**1324**

Subarea 28 - Lower Salmon

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1043*	*1043*
Diversion Efficiency (%)	*66%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1580**	**-2086**
Return Efficiency (%)	*30%*	*45%*
Return Flow (ac-ft per 1000 ac)	**474**	**938**

Subarea 29 - Clearwater

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1074*	*1074*
Diversion Efficiency (%)	*76%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1414**	**-2149**
Return Efficiency (%)	*20%*	*45%*
Return Flow (ac-ft per 1000 ac)	**283**	**967**

Subarea 30 - Palouse-Lower Snake

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1721*	*1721*
Diversion Efficiency (%)	*76%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-2265**	**-3443**
Return Efficiency (%)	*20%*	*45%*
Return Flow (ac-ft per 1000 ac)	**453**	**1549**

Subarea 31 - Walla Walla

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1390*	*1390*
Diversion Efficiency (%)	*80%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1737**	**-2779**
Return Efficiency (%)	*16%*	*45%*
Return Flow (ac-ft per 1000 ac)	**278**	**1251**

Subarea 32A & B - Pumping from John Day (to Morrow & Gilliam) & McNary (to Umatilla)

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1603*	*1603*
Diversion Efficiency (%)	*75%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-2138**	**-3206**
Return Efficiency (%)	*20%*	*45%*
Return Flow (ac-ft per 1000 ac)	**428**	**1443**

Subarea 32C - Umatilla River & Willow Creek

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1695*	*1695*
Diversion Efficiency (%)	*90%*	*45%*
Required Diversion (ac-ft per 1000 ac)	**-1883**	**-3767**
Return Efficiency (%)	*6%*	*50%*
Return Flow (ac-ft per 1000 ac)	**113**	**1883**

Subarea 33 - John Day

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1830*	*1830*
Diversion Efficiency (%)	*78%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-2346**	**-3659**
Return Efficiency (%)	*18%*	*45%*
Return Flow (ac-ft per 1000 ac)	**422**	**1647**

Subarea 34b - Deschutes - White River Wapanita Project

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*2124*	*2124*
Diversion Efficiency (%)	*50%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-4247**	**-4247**
Return Efficiency (%)	*40%*	*40%*
Return Flow (ac-ft per 1000 ac)	**1699**	**1699**

Subarea 35a - Hood River

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1943*	*1943*
Diversion Efficiency (%)	*84%*	*45%*
Required Diversion (ac-ft per 1000 ac)	**-2313**	**-4318**
Return Efficiency (%)	*12%*	*50%*
Return Flow (ac-ft per 1000 ac)	**278**	**2159**

Subarea 35b - White Salmon

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1801*	*1801*
Diversion Efficiency (%)	*50%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-3601**	**-3601**
Return Efficiency (%)	*40%*	*40%*
Return Flow (ac-ft per 1000 ac)	**1441**	**1441**

Subarea 36A & 36B - Pumping from John Day & McNary to Northside, & Return from MCN

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1659*	*1659*
Diversion Efficiency (%)	*75%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-2212**	**-3319**
Return Efficiency (%)	*20%*	*45%*
Return Flow (ac-ft per 1000 ac)	**442**	**1493**

Subarea 36C - Klickitat

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1589*	*1589*
Diversion Efficiency (%)	*50%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-3179**	**-3179**
Return Efficiency (%)	*40%*	*40%*
Return Flow (ac-ft per 1000 ac)	**1272**	**1272**

Depletions per unit area

Subarea 26 - Grande Ronde at Wenaha

Sprinkler System								Gravity System						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			8.0%	12	12	**0.2**		JAN			8.0%	118	118	**1.9**
FEB			8.0%	12	12	**0.2**		FEB			8.0%	118	118	**2.1**
MAR	0.1%	-1	6.0%	9	8	**0.1**		MAR	0.1%	-2	6.0%	88	87	**1.4**
APR	0.6%	-10	6.0%	9	0	**0.0**		APR	0.6%	-18	6.0%	88	70	**1.2**
MAY	3.8%	-59	6.0%	9	-50	**-0.8**		MAY	3.8%	-113	6.0%	88	-24	**-0.4**
JUN	12.2%	-188	6.0%	9	-178	**-3.0**		JUN	12.2%	-359	6.0%	88	-270	**-4.5**
JUL	31.2%	-480	7.0%	11	-469	**-7.6**		JUL	31.2%	-918	7.0%	103	-815	**-13.2**
AUG	32.3%	-497	10.0%	15	-481	**-7.8**		AUG	32.3%	-950	10.0%	147	-802	**-13.0**
SEP	19.0%	-293	11.0%	17	-276	**-4.6**		SEP	19.0%	-559	11.0%	162	-397	**-6.7**
OCT	0.9%	-13	11.0%	17	4	**0.1**		OCT	0.9%	-26	11.0%	162	136	**2.2**
NOV			11.0%	17	17	**0.3**		NOV			11.0%	162	162	**2.7**
DEC			10.0%	15	15	**0.3**		DEC			10.0%	147	147	**2.4**
Total	100.0%	-1540	100.0%	154	-1386			Total	100.0%	-2943	100.0%	1472	-1472	

Subarea 27 - Upper Salmon

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			5.0%	32	32	**0.5**
FEB			5.0%	32	32	**0.6**
MAR	0.1%	-2	4.0%	25	24	**0.4**
APR	4.9%	-107	8.0%	51	-56	**-0.9**
MAY	10.6%	-234	9.0%	57	-176	**-2.9**
JUN	16.2%	-355	11.0%	70	-285	**-4.8**
JUL	26.8%	-588	12.0%	76	-511	**-8.3**
AUG	24.4%	-536	13.0%	83	-453	**-7.4**
SEP	16.6%	-364	12.0%	76	-288	**-4.8**
OCT	0.5%	-11	9.0%	57	46	**0.8**
NOV			6.0%	38	38	**0.6**
DEC			6.0%	38	38	**0.6**
Total	100.0%	-2196	100.0%	637	-1559	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			5.0%	66	66	**1.1**
FEB			5.0%	66	66	**1.2**
MAR	0.1%	-2	4.0%	53	51	**0.8**
APR	4.9%	-143	8.0%	106	-37	**-0.6**
MAY	10.6%	-313	9.0%	119	-194	**-3.2**
JUN	16.2%	-476	11.0%	146	-330	**-5.5**
JUL	26.8%	-787	12.0%	159	-628	**-10.2**
AUG	24.4%	-718	13.0%	172	-546	**-8.9**
SEP	16.6%	-488	12.0%	159	-329	**-5.5**
OCT	0.5%	-15	9.0%	119	104	**1.7**
NOV			6.0%	79	79	**1.3**
DEC			6.0%	79	79	**1.3**
Total	100.0%	-2942	100.0%	1324	-1618	

Subarea 28 - Lower Salmon

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			5.0%	24	24	**0.4**
FEB			5.0%	24	24	**0.4**
MAR	0.0%	0	4.0%	19	19	**0.3**
APR	0.1%	-2	8.0%	38	36	**0.6**
MAY	1.4%	-22	9.0%	43	20	**0.3**
JUN	7.4%	-117	11.0%	52	-65	**-1.1**
JUL	29.9%	-472	12.0%	57	-415	**-6.8**
AUG	38.0%	-600	13.0%	62	-538	**-8.8**
SEP	22.5%	-356	12.0%	57	-299	**-5.0**
OCT	0.7%	-11	9.0%	43	32	**0.5**
NOV			6.0%	28	28	**0.5**
DEC			6.0%	28	28	**0.5**
Total	100.0%	-1580	100.0%	474	-1106	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			5.0%	47	47	**0.8**
FEB			5.0%	47	47	**0.8**
MAR	0.0%	0	4.0%	38	38	**0.6**
APR	0.1%	-3	8.0%	75	72	**1.2**
MAY	1.4%	-29	9.0%	84	55	**0.9**
JUN	7.4%	-154	11.0%	103	-51	**-0.9**
JUL	29.9%	-623	12.0%	113	-510	**-8.3**
AUG	38.0%	-792	13.0%	122	-670	**-10.9**
SEP	22.5%	-470	12.0%	113	-358	**-6.0**
OCT	0.7%	-14	9.0%	84	70	**1.1**
NOV			6.0%	56	56	**0.9**
DEC			6.0%	56	56	**0.9**
Total	100.0%	-2086	100.0%	938	-1147	

Subarea 29 - Clearwater

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			8.0%	23	23	**0.4**
FEB			8.0%	23	23	**0.4**
MAR	0.0%	0	6.0%	17	17	**0.3**
APR	0.0%	0	6.0%	17	17	**0.3**
MAY	0.8%	-11	6.0%	17	6	**0.1**
JUN	3.5%	-50	6.0%	17	-33	**-0.6**
JUL	24.7%	-349	7.0%	20	-329	**-5.4**
AUG	47.7%	-674	10.0%	28	-646	**-10.5**
SEP	22.7%	-322	11.0%	31	-290	**-4.9**
OCT	0.6%	-8	11.0%	31	23	**0.4**
NOV			11.0%	31	31	**0.5**
DEC			10.0%	28	28	**0.5**
Total	100.0%	-1414	100.0%	283	-1131	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			8.0%	77	77	**1.3**
FEB			8.0%	77	77	**1.4**
MAR	0.0%	0	6.0%	58	58	**0.9**
APR	0.0%	-1	6.0%	58	57	**1.0**
MAY	0.8%	-16	6.0%	58	42	**0.7**
JUN	3.5%	-76	6.0%	58	-18	**-0.3**
JUL	24.7%	-530	7.0%	68	-463	**-7.5**
AUG	47.7%	-1025	10.0%	97	-928	**-15.1**
SEP	22.7%	-489	11.0%	106	-382	**-6.4**
OCT	0.6%	-12	11.0%	106	94	**1.5**
NOV			11.0%	106	106	**1.8**
DEC			10.0%	97	97	**1.6**
Total	100.0%	-2149	100.0%	967	-1182	

Subarea 30 - Palouse-Lower Snake

Sprinkler System

Month	DIVERSION %	DIVERSION ac-ft per 1000 ac	RETURN FLOW %	RETURN FLOW ac-ft per 1000 ac	DEPLETION ac-ft per 1000 ac	DEPLETION **cfs per 1000 ac**
JAN			7.0%	32	32	**0.5**
FEB			6.0%	27	27	**0.5**
MAR	0.7%	-16	5.0%	23	7	**0.1**
APR	2.8%	-63	7.0%	32	-31	**-0.5**
MAY	13.0%	-294	9.0%	41	-253	**-4.1**
JUN	22.3%	-506	11.0%	50	-456	**-7.7**
JUL	27.3%	-619	11.0%	50	-569	**-9.3**
AUG	20.3%	-459	11.0%	50	-409	**-6.7**
SEP	10.1%	-230	11.0%	50	-180	**-3.0**
OCT	3.5%	-79	8.0%	36	-42	**-0.7**
NOV			7.0%	32	32	**0.5**
DEC			7.0%	32	32	**0.5**
Total	100.0%	-2265	100.0%	453	-1812	

Gravity System

Month	DIVERSION %	DIVERSION ac-ft per 1000 ac	RETURN FLOW %	RETURN FLOW ac-ft per 1000 ac	DEPLETION ac-ft per 1000 ac	DEPLETION **cfs per 1000 ac**
JAN			7.0%	108	108	**1.8**
FEB			6.0%	93	93	**1.7**
MAR	0.7%	-24	5.0%	77	53	**0.9**
APR	2.8%	-95	7.0%	108	13	**0.2**
MAY	13.0%	-447	9.0%	139	-307	**-5.0**
JUN	22.3%	-769	11.0%	170	-599	**-10.1**
JUL	27.3%	-941	11.0%	170	-771	**-12.5**
AUG	20.3%	-698	11.0%	170	-527	**-8.6**
SEP	10.1%	-349	11.0%	170	-179	**-3.0**
OCT	3.5%	-119	8.0%	124	5	**0.1**
NOV			7.0%	108	108	**1.8**
DEC			7.0%	108	108	**1.8**
Total	100.0%	-3443	100.0%	1549	-1894	

Subarea 31 - Walla Walla

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			7.0%	19	19	**0.3**		JAN			7.0%	88	88	**1.4**
FEB			6.0%	17	17	**0.3**		FEB			6.0%	75	75	**1.3**
MAR	0.6%	-10	5.0%	14	4	**0.1**		MAR	0.6%	-16	5.0%	63	46	**0.8**
APR	4.6%	-80	7.0%	19	-61	**-1.0**		APR	4.6%	-129	7.0%	88	-41	**-0.7**
MAY	14.7%	-255	9.0%	25	-230	**-3.7**		MAY	14.7%	-408	9.0%	113	-295	**-4.8**
JUN	16.9%	-294	11.0%	31	-263	**-4.4**		JUN	16.9%	-470	11.0%	138	-333	**-5.6**
JUL	22.3%	-387	11.0%	31	-357	**-5.8**		JUL	22.3%	-620	11.0%	138	-482	**-7.8**
AUG	19.5%	-339	11.0%	31	-308	**-5.0**		AUG	19.5%	-542	11.0%	138	-405	**-6.6**
SEP	13.5%	-235	11.0%	31	-204	**-3.4**		SEP	13.5%	-375	11.0%	138	-238	**-4.0**
OCT	7.9%	-137	8.0%	22	-115	**-1.9**		OCT	7.9%	-219	8.0%	100	-119	**-1.9**
NOV			7.0%	19	19	**0.3**		NOV			7.0%	88	88	**1.5**
DEC			7.0%	19	19	**0.3**		DEC			7.0%	88	88	**1.4**
Total	100.0%	-1737	100.0%	278	-1459			Total	100.0%	-2779	100.0%	1251	-1529	

Subarea 32A (1) - Pumping From McNary to Umatilla

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN						**0.0**		JAN						**0.0**
FEB						**0.0**		FEB						**0.0**
MAR	0.2%	-3			-3	**-0.1**		MAR	0.2%	-5			-5	**-0.1**
APR	1.6%	-35			-35	**-0.6**		APR	1.6%	-52			-52	**-0.9**
MAY	12.5%	-267			-267	**-4.3**		MAY	12.5%	-400			-400	**-6.5**
JUN	25.3%	-540			-540	**-9.1**		JUN	25.3%	-810			-810	**-13.6**
JUL	27.4%	-586			-586	**-9.5**		JUL	27.4%	-880			-880	**-14.3**
AUG	20.5%	-439			-439	**-7.1**		AUG	20.5%	-658			-658	**-10.7**
SEP	10.0%	-213			-213	**-3.6**		SEP	10.0%	-319			-319	**-5.4**
OCT	2.5%	-54			-54	**-0.9**		OCT	2.5%	-81			-81	**-1.3**
NOV						**0.0**		NOV						**0.0**
DEC						**0.0**		DEC						**0.0**
Total	100.0%	-2138	0.0%		-2138			Total	100.0%	-3206	0.0%		-3206	

Subarea 32A (2) - Return flow from MCN pumping to Umatilla

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			3.0%	13	13	**0.2**
FEB			3.0%	13	13	**0.2**
MAR			3.0%	13	13	**0.2**
APR			3.0%	13	13	**0.2**
MAY			9.0%	38	38	**0.6**
JUN			12.0%	51	51	**0.9**
JUL			12.0%	51	51	**0.8**
AUG			15.0%	64	64	**1.0**
SEP			13.0%	56	56	**0.9**
OCT			12.0%	51	51	**0.8**
NOV			9.0%	38	38	**0.6**
DEC			6.0%	26	26	**0.4**
Total	0.0%		100.0%	428	428	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			3.0%	43	43	**0.7**
FEB			3.0%	43	43	**0.8**
MAR			3.0%	43	43	**0.7**
APR			3.0%	43	43	**0.7**
MAY			9.0%	130	130	**2.1**
JUN			12.0%	173	173	**2.9**
JUL			12.0%	173	173	**2.8**
AUG			15.0%	216	216	**3.5**
SEP			13.0%	188	188	**3.2**
OCT			12.0%	173	173	**2.8**
NOV			9.0%	130	130	**2.2**
DEC			6.0%	87	87	**1.4**
Total	0.0%		100.0%	1443	1443	

Subarea 32B - Pumping from John Day to Morrow & Gilliam Counties

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			3.0%	13	13	**0.2**		JAN			3.0%	45	45	**0.7**
FEB			3.0%	13	13	**0.2**		FEB			3.0%	45	45	**0.8**
MAR	0.7%	-15	3.0%	13	-2	**0.0**		MAR	0.7%	-23	3.0%	45	22	**0.4**
APR	2.3%	-50	3.0%	13	-37	**-0.6**		APR	2.3%	-75	3.0%	45	-30	**-0.5**
MAY	14.1%	-311	9.0%	40	-271	**-4.4**		MAY	14.1%	-467	9.0%	134	-333	**-5.4**
JUN	26.1%	-577	12.0%	53	-524	**-8.8**		JUN	26.1%	-866	12.0%	179	-686	**-11.5**
JUL	27.5%	-608	12.0%	53	-555	**-9.0**		JUL	27.5%	-912	12.0%	179	-732	**-11.9**
AUG	18.6%	-411	15.0%	66	-345	**-5.6**		AUG	18.6%	-617	15.0%	224	-393	**-6.4**
SEP	8.8%	-194	13.0%	58	-136	**-2.3**		SEP	8.8%	-291	13.0%	194	-96	**-1.6**
OCT	2.1%	-47	12.0%	53	6	**0.1**		OCT	2.1%	-70	12.0%	179	109	**1.8**
NOV			9.0%	40	40	**0.7**		NOV			9.0%	134	134	**2.3**
DEC			6.0%	27	27	**0.4**		DEC			6.0%	90	90	**1.5**
Total	100.0%	-2213	100.0%	443	-1771			Total	100.0%	-3320	100.0%	1494	-1826	

Subarea 32C - Umatilla River & Willow Creek

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			4.0%	5	5	**0.1**
FEB			3.0%	3	3	**0.1**
MAR	0.8%	-15	2.0%	2	-13	**-0.2**
APR	3.3%	-62	3.0%	3	-58	**-1.0**
MAY	12.6%	-238	8.0%	9	-229	**-3.7**
JUN	23.1%	-435	12.0%	14	-421	**-7.1**
JUL	24.9%	-469	13.0%	15	-454	**-7.4**
AUG	18.9%	-355	14.0%	16	-339	**-5.5**
SEP	11.9%	-224	13.0%	15	-209	**-3.5**
OCT	4.6%	-86	12.0%	14	-72	**-1.2**
NOV			10.0%	11	11	**0.2**
DEC			6.0%	7	7	**0.1**
Total	100.0%	-1883	100.0%	113	-1770	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			4.0%	75	75	**1.2**
FEB			3.0%	57	57	**1.0**
MAR	0.8%	-31	2.0%	38	7	**0.1**
APR	3.3%	-123	3.0%	57	-67	**-1.1**
MAY	12.6%	-476	8.0%	151	-326	**-5.3**
JUN	23.1%	-869	12.0%	226	-643	**-10.8**
JUL	24.9%	-937	13.0%	245	-692	**-11.3**
AUG	18.9%	-710	14.0%	264	-446	**-7.3**
SEP	11.9%	-448	13.0%	245	-203	**-3.4**
OCT	4.6%	-172	12.0%	226	54	**0.9**
NOV			10.0%	188	188	**3.2**
DEC			6.0%	113	113	**1.8**
Total	100.0%	-3767	100.0%	1883	-1883	

Subarea 33 - John Day

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			4.0%	17	17	**0.3**		JAN			4.0%	66	66	**1.1**
FEB			3.0%	13	13	**0.2**		FEB			3.0%	49	49	**0.9**
MAR	0.3%	-7	2.0%	8	1	**0.0**		MAR	0.3%	-11	2.0%	33	22	**0.4**
APR	2.4%	-56	3.0%	13	-43	**-0.7**		APR	2.4%	-87	3.0%	49	-38	**-0.6**
MAY	8.7%	-204	8.0%	34	-170	**-2.8**		MAY	8.7%	-318	8.0%	132	-186	**-3.0**
JUN	16.9%	-396	12.0%	51	-345	**-5.8**		JUN	16.9%	-617	12.0%	198	-420	**-7.1**
JUL	26.8%	-628	13.0%	55	-573	**-9.3**		JUL	26.8%	-979	13.0%	214	-765	**-12.4**
AUG	25.5%	-598	14.0%	59	-539	**-8.8**		AUG	25.5%	-933	14.0%	231	-703	**-11.4**
SEP	18.2%	-426	13.0%	55	-371	**-6.2**		SEP	18.2%	-665	13.0%	214	-451	**-7.6**
OCT	1.3%	-31	12.0%	51	20	**0.3**		OCT	1.3%	-48	12.0%	198	150	**2.4**
NOV			10.0%	42	42	**0.7**		NOV			10.0%	165	165	**2.8**
DEC			6.0%	25	25	**0.4**		DEC			6.0%	99	99	**1.6**
Total	100.0%	-2346	100.0%	422	-1923			Total	100.0%	-3659	100.0%	1647	-2012	

Subarea 34b - Deschutes - White River Wapanita Project

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			3.0%	51	51	**0.8**
FEB			3.0%	51	51	**0.9**
MAR	0.5%	-22	3.0%	51	29	**0.5**
APR	3.3%	-141	3.0%	51	-90	**-1.5**
MAY	10.8%	-460	9.0%	153	-308	**-5.0**
JUN	18.7%	-795	12.0%	204	-591	**-9.9**
JUL	24.6%	-1046	12.0%	204	-842	**-13.7**
AUG	23.3%	-989	15.0%	255	-734	**-11.9**
SEP	17.1%	-724	13.0%	221	-504	**-8.5**
OCT	1.6%	-69	12.0%	204	134	**2.2**
NOV			9.0%	153	153	**2.6**
DEC			6.0%	102	102	**1.7**
Total	100.0%	-4247	100.0%	1699	-2548	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			3.0%	51	51	**0.8**
FEB			3.0%	51	51	**0.9**
MAR	0.5%	-22	3.0%	51	29	**0.5**
APR	3.3%	-141	3.0%	51	-90	**-1.5**
MAY	10.8%	-460	9.0%	153	-308	**-5.0**
JUN	18.7%	-795	12.0%	204	-591	**-9.9**
JUL	24.6%	-1046	12.0%	204	-842	**-13.7**
AUG	23.3%	-989	15.0%	255	-734	**-11.9**
SEP	17.1%	-724	13.0%	221	-504	**-8.5**
OCT	1.6%	-69	12.0%	204	134	**2.2**
NOV			9.0%	153	153	**2.6**
DEC			6.0%	102	102	**1.7**
Total	100.0%	-4247	100.0%	1699	-2548	

Subarea 35a - Hood River

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			3.0%	8	8	**0.1**		JAN			3.0%	65	65	**1.1**
FEB			3.0%	8	8	**0.1**		FEB			3.0%	65	65	**1.2**
MAR	0.2%	-4	3.0%	8	4	**0.1**		MAR	0.2%	-8	3.0%	65	57	**0.9**
APR	1.4%	-33	3.0%	8	-25	**-0.4**		APR	1.4%	-62	3.0%	65	3	**0.1**
MAY	10.4%	-241	9.0%	25	-216	**-3.5**		MAY	10.4%	-450	9.0%	194	-255	**-4.2**
JUN	20.4%	-472	12.0%	33	-439	**-7.4**		JUN	20.4%	-882	12.0%	259	-623	**-10.5**
JUL	25.4%	-587	12.0%	33	-554	**-9.0**		JUL	25.4%	-1096	12.0%	259	-837	**-13.6**
AUG	22.2%	-514	15.0%	42	-472	**-7.7**		AUG	22.2%	-959	15.0%	324	-635	**-10.3**
SEP	14.5%	-336	13.0%	36	-300	**-5.0**		SEP	14.5%	-627	13.0%	281	-346	**-5.8**
OCT	5.4%	-125	12.0%	33	-92	**-1.5**		OCT	5.4%	-234	12.0%	259	25	**0.4**
NOV			9.0%	25	25	**0.4**		NOV			9.0%	194	194	**3.3**
DEC			6.0%	17	17	**0.3**		DEC			6.0%	130	130	**2.1**
Total	100.0%	-2313	100.0%	278	-2035			Total	100.0%	-4318	100.0%	2159	-2159	

Subarea 35b - White Salmon

Sprinkler System									**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION				Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**				%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			3.0%	43	43	**0.7**			JAN			3.0%	43	43	**0.7**
FEB			3.0%	43	43	**0.8**			FEB			3.0%	43	43	**0.8**
MAR	0.0%	-1	3.0%	43	42	**0.7**			MAR	0.0%	-1	3.0%	43	42	**0.7**
APR	0.8%	-27	3.0%	43	16	**0.3**			APR	0.8%	-27	3.0%	43	16	**0.3**
MAY	7.0%	-251	9.0%	130	-122	**-2.0**			MAY	7.0%	-251	9.0%	130	-122	**-2.0**
JUN	18.3%	-658	12.0%	173	-485	**-8.2**			JUN	18.3%	-658	12.0%	173	-485	**-8.2**
JUL	27.8%	-1001	12.0%	173	-829	**-13.5**			JUL	27.8%	-1001	12.0%	173	-829	**-13.5**
AUG	26.7%	-963	15.0%	216	-747	**-12.1**			AUG	26.7%	-963	15.0%	216	-747	**-12.1**
SEP	16.4%	-590	13.0%	187	-403	**-6.8**			SEP	16.4%	-590	13.0%	187	-403	**-6.8**
OCT	3.0%	-109	12.0%	173	64	**1.0**			OCT	3.0%	-109	12.0%	173	64	**1.0**
NOV			9.0%	130	130	**2.2**			NOV			9.0%	130	130	**2.2**
DEC			6.0%	86	86	**1.4**			DEC			6.0%	86	86	**1.4**
Total	100.0%	-3601	100.0%	1441	-2161				Total	100.0%	-3601	100.0%	1441	-2161	

Subarea 36A (1) - Pumping from McNary to Northside

Sprinkler System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN						**0.0**
FEB						**0.0**
MAR	1.0%	-23			-23	**-0.4**
APR	4.3%	-95			-95	**-1.6**
MAY	15.9%	-351			-351	**-5.7**
JUN	23.1%	-511			-511	**-8.6**
JUL	26.0%	-574			-574	**-9.3**
AUG	17.6%	-390			-390	**-6.3**
SEP	7.7%	-171			-171	**-2.9**
OCT	4.4%	-97			-97	**-1.6**
NOV						**0.0**
DEC						**0.0**
Total	100.0%	-2212			-2212	

Gravity System

Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN						**0.0**
FEB						**0.0**
MAR	1.0%	-34			-34	**-0.6**
APR	4.3%	-143			-143	**-2.4**
MAY	15.9%	-527			-527	**-8.6**
JUN	23.1%	-766			-766	**-12.9**
JUL	26.0%	-862			-862	**-14.0**
AUG	17.6%	-584			-584	**-9.5**
SEP	7.7%	-256			-256	**-4.3**
OCT	4.4%	-146			-146	**-2.4**
NOV						**0.0**
DEC						**0.0**
Total	100.0%	-3319			-3319	

Subarea 36A (2) - Return flow from MCN pumping to Northside

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			3.0%	13	13	**0.2**		JAN			3.0%	45	45	**0.7**
FEB			3.0%	13	13	**0.2**		FEB			3.0%	45	45	**0.8**
MAR			3.0%	13	13	**0.2**		MAR			3.0%	45	45	**0.7**
APR			3.0%	13	13	**0.2**		APR			3.0%	45	45	**0.8**
MAY			9.0%	40	40	**0.6**		MAY			9.0%	134	134	**2.2**
JUN			12.0%	53	53	**0.9**		JUN			12.0%	179	179	**3.0**
JUL			12.0%	53	53	**0.9**		JUL			12.0%	179	179	**2.9**
AUG			15.0%	66	66	**1.1**		AUG			15.0%	224	224	**3.6**
SEP			13.0%	58	58	**1.0**		SEP			13.0%	194	194	**3.3**
OCT			12.0%	53	53	**0.9**		OCT			12.0%	179	179	**2.9**
NOV			9.0%	40	40	**0.7**		NOV			9.0%	134	134	**2.3**
DEC			6.0%	27	27	**0.4**		DEC			6.0%	90	90	**1.5**
Total			100.0%	442	442			Total			100.0%	1493	1493	

Subarea 36B - Pumping from John Day to Northside + Returns

Sprinkler System								**Gravity System**						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			3.0%	13	13	**0.2**		JAN			3.0%	44	44	**0.7**
FEB			3.0%	13	13	**0.2**		FEB			3.0%	44	44	**0.8**
MAR	0.6%	-14	3.0%	13	-1	**0.0**		MAR	0.6%	-21	3.0%	44	23	**0.4**
APR	3.8%	-82	3.0%	13	-69	**-1.2**		APR	3.8%	-122	3.0%	44	-78	**-1.3**
MAY	16.0%	-347	9.0%	39	-308	**-5.0**		MAY	16.0%	-521	9.0%	132	-389	**-6.3**
JUN	24.9%	-540	12.0%	52	-487	**-8.2**		JUN	24.9%	-809	12.0%	176	-634	**-10.6**
JUL	26.9%	-584	12.0%	52	-532	**-8.6**		JUL	26.9%	-875	12.0%	176	-700	**-11.4**
AUG	17.6%	-382	15.0%	65	-317	**-5.2**		AUG	17.6%	-573	15.0%	220	-354	**-5.8**
SEP	7.2%	-155	13.0%	56	-99	**-1.7**		SEP	7.2%	-233	13.0%	190	-43	**-0.7**
OCT	3.0%	-65	12.0%	52	-13	**-0.2**		OCT	3.0%	-97	12.0%	176	79	**1.3**
NOV			9.0%	39	39	**0.7**		NOV			9.0%	132	132	**2.2**
DEC			6.0%	26	26	**0.4**		DEC			6.0%	88	88	**1.4**
Total	100.0%	-2168	100.0%	434	-1734			Total	100.0%	-3252	100.0%	1463	-1789	

Subarea 36C - Klickitat

Sprinkler System

Month	DIVERSION %	DIVERSION ac-ft per 1000 ac	RETURN FLOW %	RETURN FLOW ac-ft per 1000 ac	DEPLETION ac-ft per 1000 ac	DEPLETION **cfs per 1000 ac**
JAN			3.0%	38	38	**0.6**
FEB			3.0%	38	38	**0.7**
MAR	0.0%	-1	3.0%	38	37	**0.6**
APR	0.5%	-16	3.0%	38	22	**0.4**
MAY	4.2%	-132	9.0%	114	-18	**-0.3**
JUN	20.9%	-664	12.0%	153	-511	**-8.6**
JUL	28.5%	-907	12.0%	153	-754	**-12.3**
AUG	26.5%	-842	15.0%	191	-651	**-10.6**
SEP	18.1%	-576	13.0%	165	-411	**-6.9**
OCT	1.3%	-40	12.0%	153	112	**1.8**
NOV			9.0%	114	114	**1.9**
DEC			6.0%	76	76	**1.2**
Total	100.0%	-3179	100.0%	1272	-1907	

Gravity System

Month	DIVERSION %	DIVERSION ac-ft per 1000 ac	RETURN FLOW %	RETURN FLOW ac-ft per 1000 ac	DEPLETION ac-ft per 1000 ac	DEPLETION **cfs per 1000 ac**
JAN			3.0%	38	38	**0.6**
FEB			3.0%	38	38	**0.7**
MAR	0.0%	-1	3.0%	38	37	**0.6**
APR	0.5%	-16	3.0%	38	22	**0.4**
MAY	4.2%	-132	9.0%	114	-18	**-0.3**
JUN	20.9%	-664	12.0%	153	-511	**-8.6**
JUL	28.5%	-907	12.0%	153	-754	**-12.3**
AUG	26.5%	-842	15.0%	191	-651	**-10.6**
SEP	18.1%	-576	13.0%	165	-411	**-6.9**
OCT	1.3%	-40	12.0%	153	112	**1.8**
NOV			9.0%	114	114	**1.9**
DEC			6.0%	76	76	**1.2**
Total	100.0%	-3179	100.0%	1272	-1907	

Surface water irrigated acres

Subarea 26 - Grande Ronde at Wenaha

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	90.7	90.7
1928	0.0	0.0	92.1	92.1
1950	1.1	0.0	95.4	96.5
1966	20.0	0.0	77.0	97.0
1978	55.0	0.0	32.7	87.7
1988	43.2	0.0	35.5	78.7
1999	55.0	0.0	29.6	84.6
2008	64.8	0.0	32.2	97.1
2018	43.9	0.0	22.0	65.9

Subarea 27 - Upper Salmon

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	83.5	83.5
1928	0.0	0.0	84.3	84.3
1950	0.0	0.0	107.4	107.4
1966	4.0	0.0	118.4	122.4
1978	27.6	0.0	93.4	121.0
1988	22.6	0.0	81.8	104.4
1999	26.0	0.0	73.3	99.4
2008	43.1	0.0	58.5	101.6
2018	40.8	0.0	54.7	95.5

Subarea 28 - Lower Salmon

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	15.8	15.8
1928	0.0	0.0	16.6	16.6
1950	0.0	0.0	16.6	16.6
1966	1.0	0.0	15.6	16.6
1978	3.0	0.0	14.6	17.6
1988	2.4	0.0	10.3	12.7
1999	2.7	0.0	13.0	15.7
2008	3.5	0.0	8.5	12.0
2018	6.0	0.0	8.3	14.3

Subarea 29 - Clearwater

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	3.6	3.6
1928	0.0	0.0	3.4	3.4
1950	0.0	0.0	3.5	3.5
1966	2.0	0.0	1.0	3.0
1978	2.4	0.0	0.0	2.4
1988	5.0	0.0	0.0	5.0
1999	6.9	0.0	0.3	7.2
2008	0.5	0.0	0.5	1.0
2018	0.7	0.0	0.8	1.5

Subarea 30 - Palouse-Lower Snake

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	27.6	27.6
1928	0.0	0.0	26.6	26.6
1946	0.0	0.0	26.6	26.6
1950	13.3	0.0	14.3	27.6
1966	23.0	0.0	3.0	26.0
1978	56.1	0.0	0.1	56.2
1988	62.9	0.0	0.0	62.9
1999	65.0	0.0	0.1	65.1
2008	41.0	2.7	3.5	47.2
2018	27.6	1.5	10.1	39.2

Subarea 31 - Walla Walla

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	26.2	26.2
1928	0.0	0.0	25.8	25.8
1946	0.0	0.0	25.8	25.8
1950	7.3	0.0	28.3	35.6
1966	5.4	0.0	42.8	48.2
1978	60.4	0.0	15.0	75.4
1988	87.8	0.0	3.1	90.9
1999	112.8	0.0	0.5	113.3
2008	77.4	3.8	1.7	83.0
2018	69.9	7.0	0.8	77.7

Subarea 32a - Pumping From McNary to Umatilla

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	0.0	0.0
1950	0.0	0.0	0.0	0.0
1966	8.1	0.0	0.0	8.1
1978	37.8	0.0	0.0	37.8
1988	45.4	0.0	0.0	45.4
1999	35.3	0.0	0.0	35.3
2008	5.2	0.0	0.5	5.7
2018	3.1	0.6	0.2	3.8

Subarea 32b - Pumping from John Day to Morrow & Gilliam Counties

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	0.0	0.0
1966	0.0	0.0	0.0	0.0
1978	74.0	0.0	0.0	74.0
1988	92.3	0.0	0.0	92.3
1999	71.8	0.0	0.0	71.8
2008	32.4	0.0	3.3	35.7
2018	33.6	0.0	3.4	36.9
2018	28.5	7.6	2.7	38.8

Subarea 32c -Umatilla River & Willow Creek

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	50.2	50.2
1928	0.0	0.0	50.6	50.6
1946	0.0	0.0	52.0	52.0
1950	11.0	0.0	41.6	52.6
1966	18.7	0.0	27.3	46.0
1978	22.5	0.0	15.4	37.9
1988	25.6	0.0	19.9	45.5
1999	22.8	0.0	12.7	35.5
2008	89.5	0.0	8.5	98.0
2018	70.0	13.4	4.9	88.3

Subarea 33 - John Day

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	45.3	45.3
1928	0.0	0.0	47.1	47.1
1946	0.0	0.0	50.3	50.3
1966	10.0	0.0	46.4	56.4
1978	15.9	0.0	41.9	57.8
1988	18.4	0.0	24.1	42.5
1999	39.9	0.0	16.1	56.0
2008	10.7	0.0	18.0	28.7
2018	11.8	0.1	9.7	21.6

Subarea 34b - Deschutes - White River Wapanita Project

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	5.5	5.5
1928	0.0	0.0	5.5	5.5
1966	5.0	0.0	8.9	13.9
1978	6.8	0.0	10.2	17.0
1988	13.1	0.0	0.7	13.8
1999	10.9	0.0	1.2	12.1
2008	5.1	0.0	0.2	5.3
2018	3.1	0.1	0.1	3.3

Subarea 35a - Hood River

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	25.2	25.2
1928	0.0	0.0	25.2	25.2
1950	0.0	0.0	30.0	30.0
1966	20.0	0.0	16.9	36.9
1978	35.0	0.0	0.0	35.0
1988	32.2	0.0	0.7	32.9
1999	38.4	0.0	0.0	38.4
2008	30.6	0.8	0.7	32.0
2018	23.4	0.9	0.4	24.8

Subarea 35b - White Salmon

	Irrigated acres (1000s of acres)			
Year	Sprinkler	Micro	Gravity	Total
1925	0.0	0.0	4.8	4.8
1928	0.0	0.0	4.8	4.8
1950	0.0	0.0	4.8	4.8
1966	0.3	0.0	4.8	5.1
1978	0.5	0.0	4.8	5.3
1988	4.7	0.0	1.6	6.3
1999	6.8	0.0	0.7	7.4
2008	1.0	0.1	0.1	1.2
2018	1.1	0.1	0.1	1.3

Subarea 36a - Pumping from McNary to North Side

	Irrigated acres (1000s of acres)			
Year	Sprinkler	Micro	Gravity	Total
1925	0.0	0.0	3.2	3.2
1928	0.0	0.0	3.2	3.2
1950	0.0	0.0	3.2	3.2
1966	4.1	0.0	0.0	4.1
1978	34.1	0.0	0.0	34.1
1988	41.3	0.0	0.0	41.3
1999	45.2	0.0	0.0	45.2
2008	40.5	2.4	3.2	46.1
2018	38.0	1.9	2.7	42.6

Subarea 36b - Pumping from John Day to North Side

	Irrigated acres (1000s of acres)			
Year	Sprinkler	Micro	Gravity	Total
1925	0.0	0.0	0.0	0.0
1928	0.0	0.0	0.0	0.0
1950	0.0	0.0	0.0	0.0
1966	0.0	0.0	0.0	0.0
1978	15.0	0.0	0.0	15.0
1988	18.1	0.0	0.0	18.1
1999	19.6	0.0	0.0	19.6
2008	84.9	4.8	9.1	98.8
2018	79.6	3.2	7.9	90.7

Subarea 36c - Klickitat Basin

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	7.2	7.2
1928	0.0	0.0	7.2	7.2
1950	0.5	0.0	7.3	7.8
1966	0.2	0.0	7.5	7.7
1978	5.2	0.0	4.0	9.2
1988	10.1	0.0	1.6	11.6
1999	11.7	0.0	1.1	12.9
2008	2.2	0.1	0.2	2.5
2018	3.3	0.2	0.3	3.8

Summary tables comparing 2010 Modified Flows and 2020 Modified Flows

The following tables offer a comparison of key data from 2010 Modified Flows and 2020 Modified Flows. Note that for U.S. Subareas, irrigation extent and surface water split was recalculated for data from the 2010 report (2010 revised) using the approach described in the methodology, and these new values were used in the time series.

Subarea 26 - Grande Ronde at Wenaha

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	118.9	107.2	83.0
Surface water split (% SW)	88%	91%	79%
Surface water irrigated area (1000 acres)	104.5	97.1	65.9
Crop water demand (ac ft per 1000 acres)	1,766		1,324

Subarea 27 - Upper Salmon

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	121.5	106.1	100.3
Surface water split (% SW)	96%	96%	95%
Surface water irrigated area (1000 acres)	116.1	101.6	95.5
Crop water demand (ac ft per 1000 acres)	1,989		1,471

Subarea 28 - Lower Salmon

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	13.1	12.3	15.0
Surface water split (% SW)	97%	97%	95%
Surface water irrigated area (1000 acres)	12.7	12.0	14.3
Crop water demand (ac ft per 1000 acres)	2,341		1,043

Subarea 29 - Clearwater

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	4.7	1.2	1.9
Surface water split (% SW)	79%	81%	76%
Surface water irrigated area (1000 acres)	3.7	1.0	1.5
Crop water demand (ac ft per 1000 acres)	2,012		1,074

Subarea 30 - Palouse-Lower Snake

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	146.4	69.3	68.6
Surface water split (% SW)	73%	68%	57%
Surface water irrigated area (1000 acres)	107.3	47.2	39.2
Crop water demand (ac ft per 1000 acres)	2,081		1,721

Subarea 31 - Walla Walla

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	104.8	105.8	117.6
Surface water split (% SW)	77%	78%	66%
Surface water irrigated area (1000 acres)	81.4	83.0	77.7
Crop water demand (ac ft per 1000 acres)	1,626		1,390

Subarea 32a - Pumping from McNary to Umatilla

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	40.6	7.5	5.1
Surface water split (% SW)	53%	75%	75%
Surface water irrigated area (1000 acres)	21.4	5.6	3.8
Crop water demand (ac ft per 1000 acres)	1,608		1,603

Subarea 32b - Pumping from John Day to Morrow & Gilliam Counties

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	81.2	64.4	71.4
Surface water split (% SW)	53%	57%	54%
Surface water irrigated area (1000 acres)	42.8	36.8	38.6
Crop water demand (ac ft per 1000 acres)	1,608		1,603

Subarea 32c - Umatilla River & Willow Creek

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	40.6	140.8	131.8
Surface water split (% SW)	53%	61%	55%
Surface water irrigated area (1000 acres)	21.4	86.5	71.8
Crop water demand (ac ft per 1000 acres)	1,608		1,603

Subarea 33 - John Day

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	57.9	30.0	26.8
Surface water split (% SW)	91%	95%	81%
Surface water irrigated area (1000 acres)	52.8	28.7	21.6
Crop water demand (ac ft per 1000 acres)	1,918		1,830

Subarea 34b - Deschutes - White River Wapanita Project

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	10.4	7.2	6.4
Surface water split (% SW)	62%	96%	94%
Surface water irrigated area (1000 acres)	6.5	5.3	3.3
Crop water demand (ac ft per 1000 acres)	1,532		2,124

Subarea 35a - Hood River

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	39.8	38.3	31.8
Surface water split (% SW)	78%	84%	78%
Surface water irrigated area (1000 acres)	31.2	32.0	24.8
Crop water demand (ac ft per 1000 acres)	1,943		1,943

Subarea 35b - White Salmon

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	1.8	2.9	4.6
Surface water split (% SW)	47%	40%	28%
Surface water irrigated area (1000 acres)	0.9	1.2	1.3
Crop water demand (ac ft per 1000 acres)	1,573		1,801

Subarea 36a - Pumping from McNary to North Side

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	109.6	53.7	55.3
Surface water split (% SW)	75%	86%	77%
Surface water irrigated area (1000 acres)	81.8	46.1	42.6
Crop water demand (ac ft per 1000 acres)	2,245		1,659

Subarea 36b - Pumping from John Day to North Side

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	47.8	117.3	117.7
Surface water split (% SW)	75%	84%	77%
Surface water irrigated area (1000 acres)	35.7	98.8	90.7
Crop water demand (ac ft per 1000 acres)	2,245		1,659

Subarea 36c - Klickitat Basin

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	41.9	6.3	13.2
Surface water split (% SW)	75%	40%	29%
Surface water irrigated area (1000 acres)	31.2	2.5	3.8
Crop water demand (ac ft per 1000 acres)	2,245		1,659

4.4.3 Figures

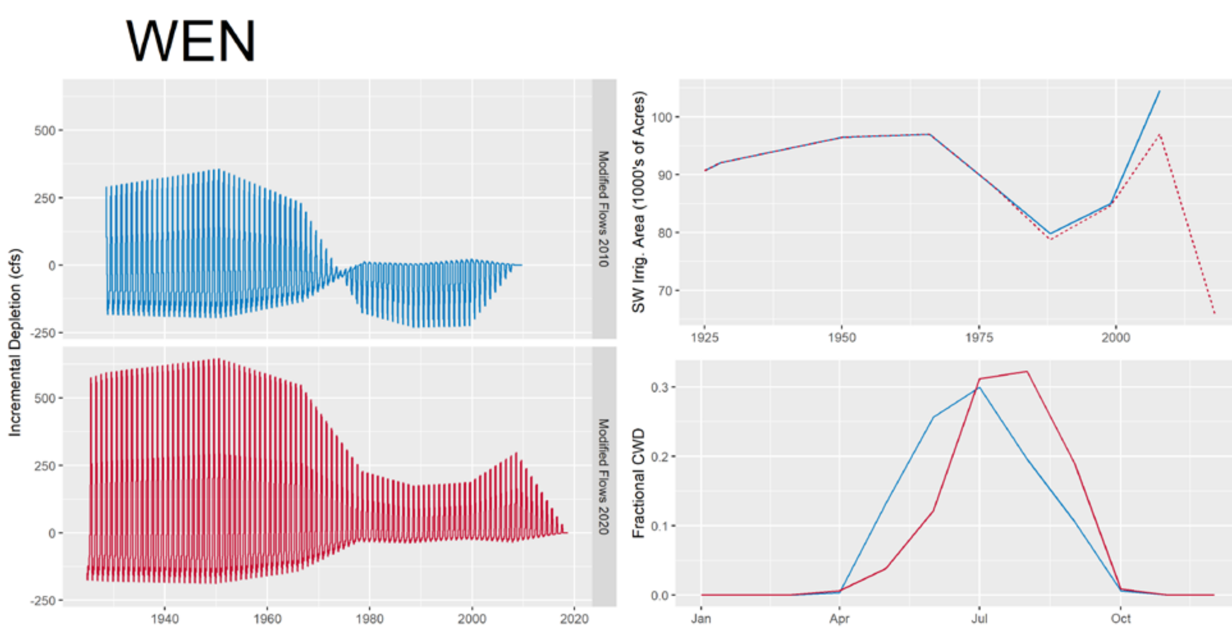

Figure 43. Subarea 26 – Grande Ronde at Wenahana (WEN): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the WEN subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

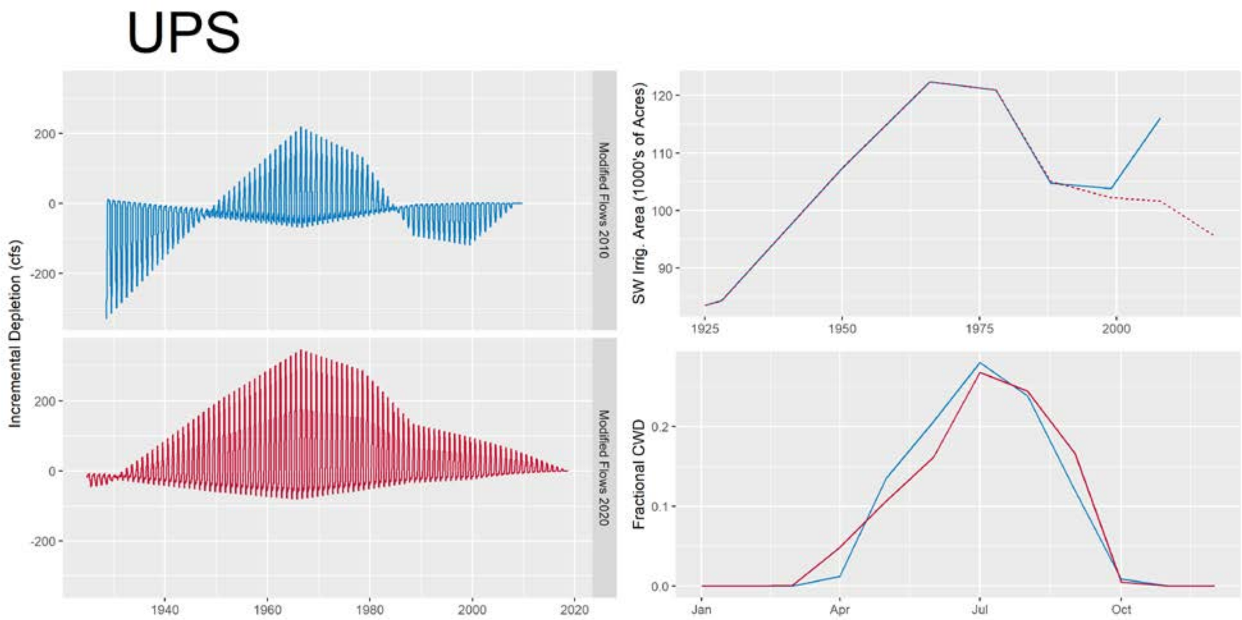

Figure 44. Subarea 27 – Upper Snake (UPS): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the UPS subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

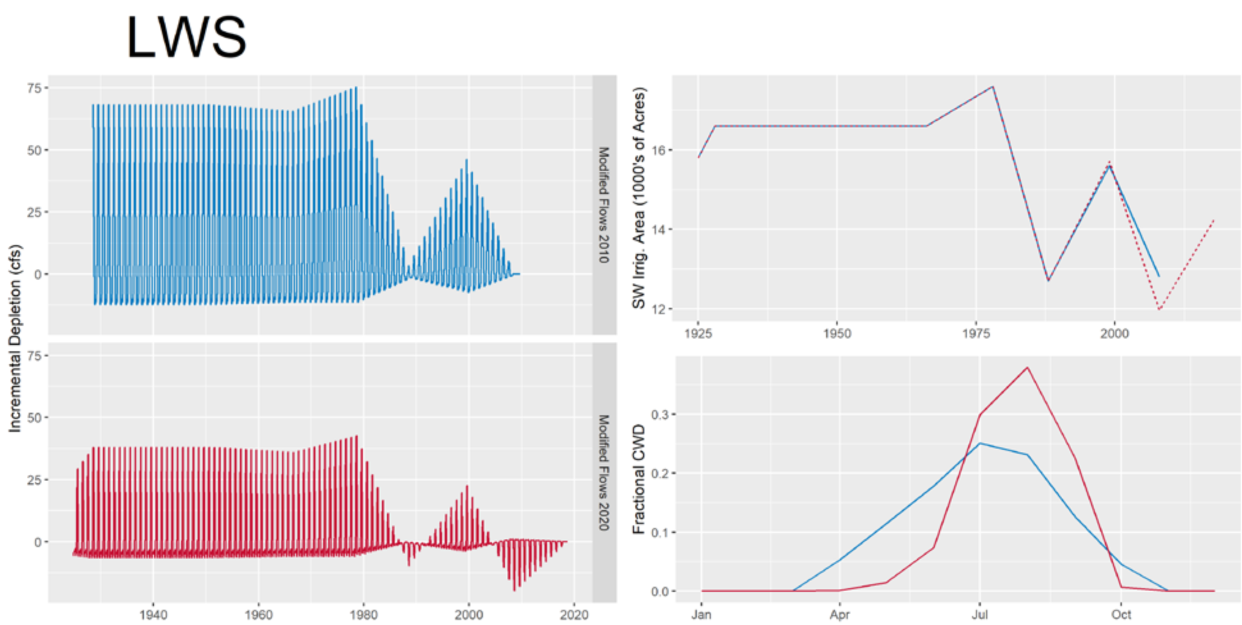

Figure 45. Subarea 28 – Lower Snake (LWS): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWS; bottom right) in the LWS subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

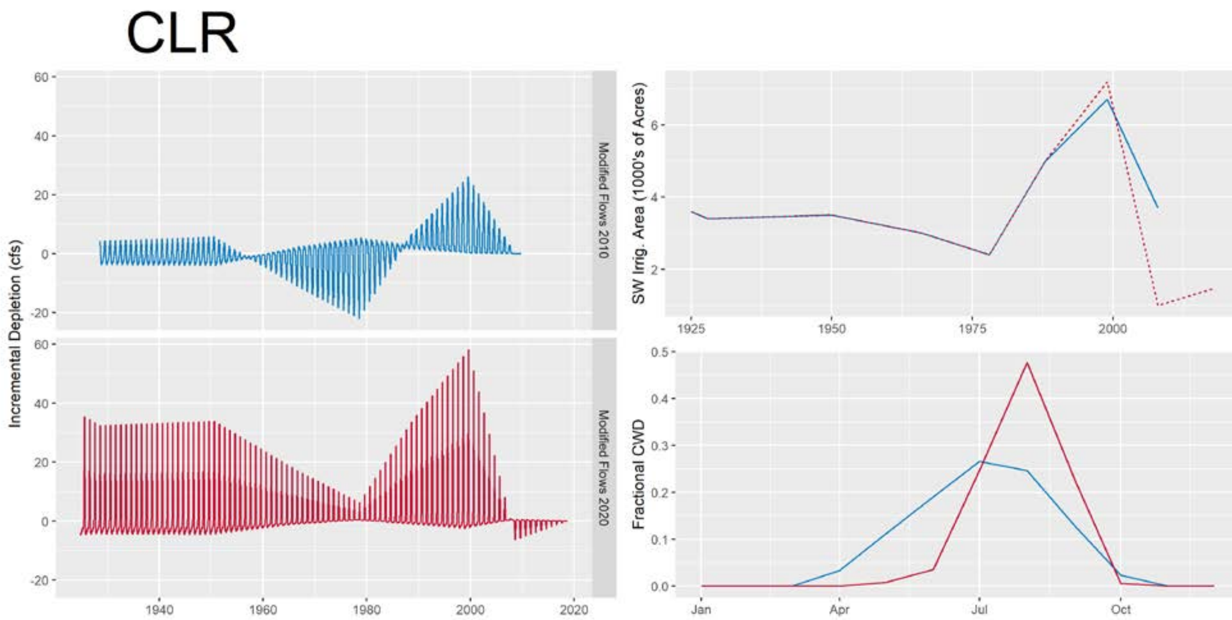

Figure 46. Subarea 29 – Clearwater (CLR): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the CLR subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

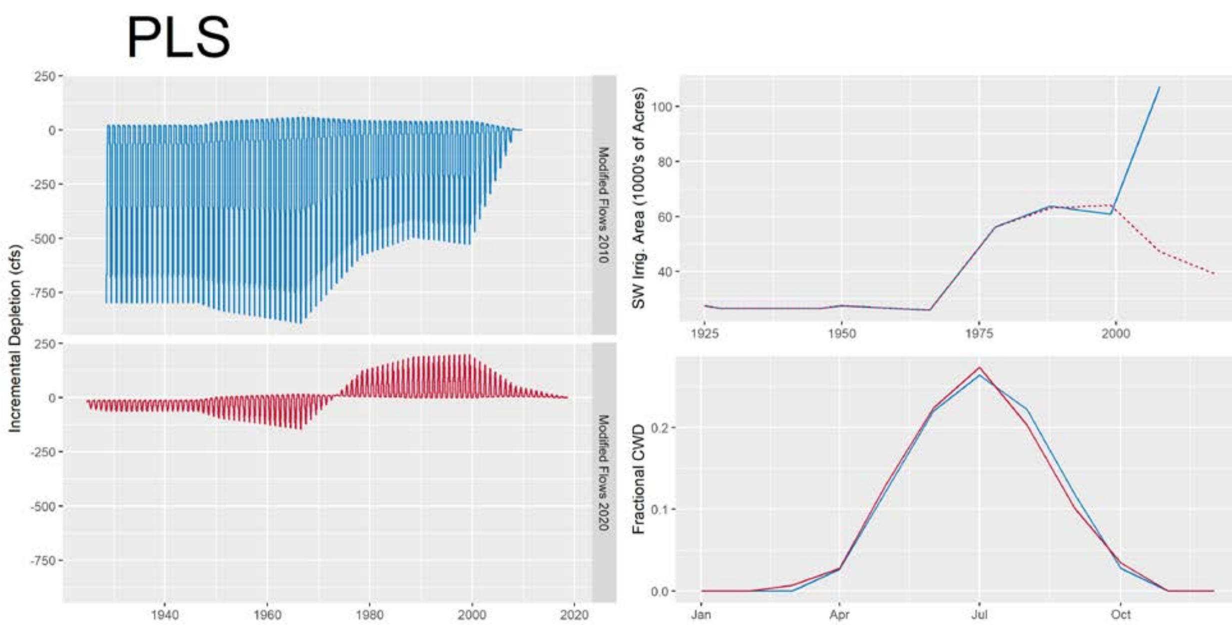

Figure 47. Subarea 30 – Palouse Lower Snake (PLS): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the PLS subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

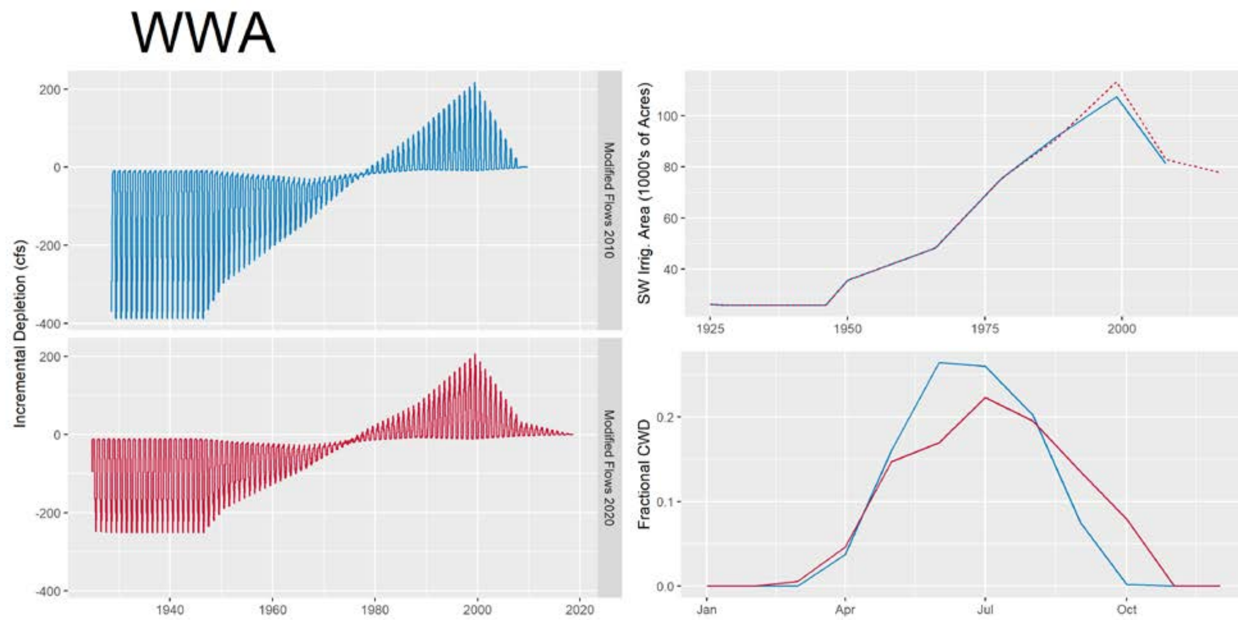

Figure 48. Subarea 31 – Walla Walla (WWA): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the WWA subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

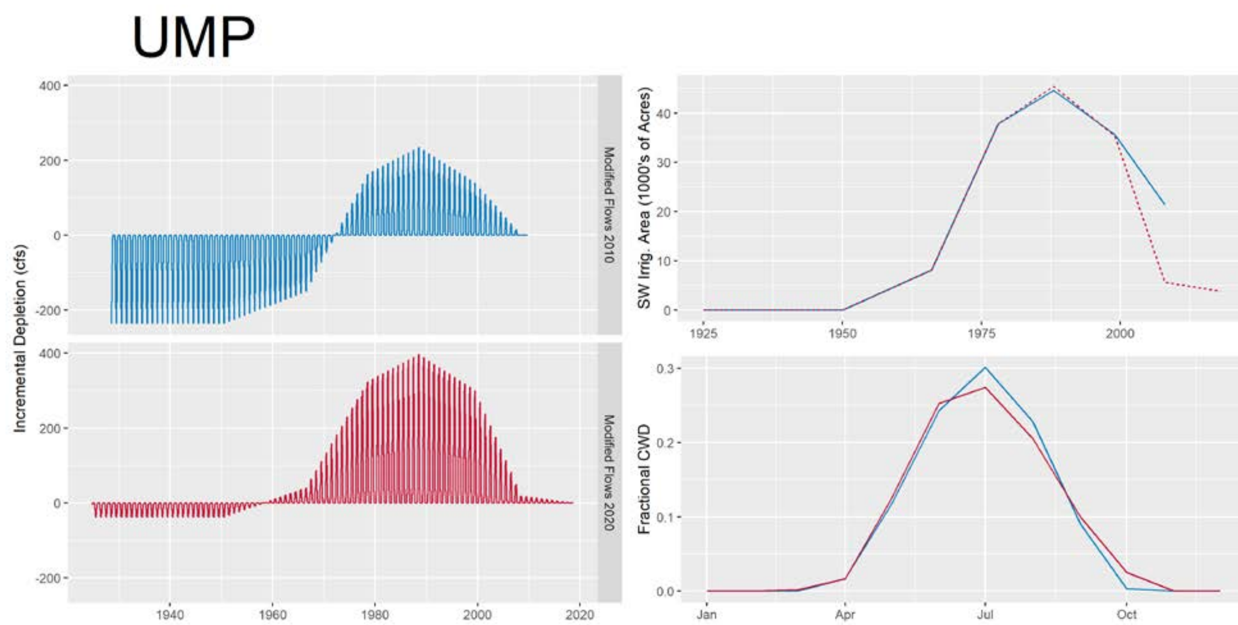

Figure 49. Subarea 32a(1) – Pumping from McNary to Umatilla (UMP): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the UMP subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

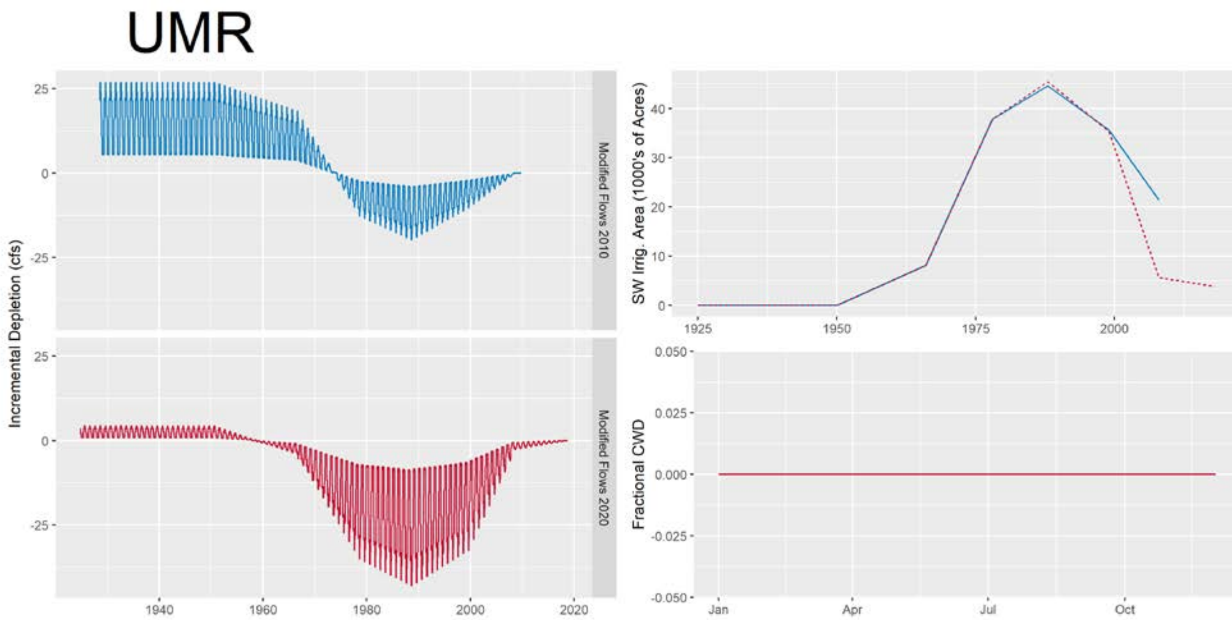

Figure 50. Subarea 32a(2) – Return flow from McNary pumping to Umatilla (UMR): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the UMR subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

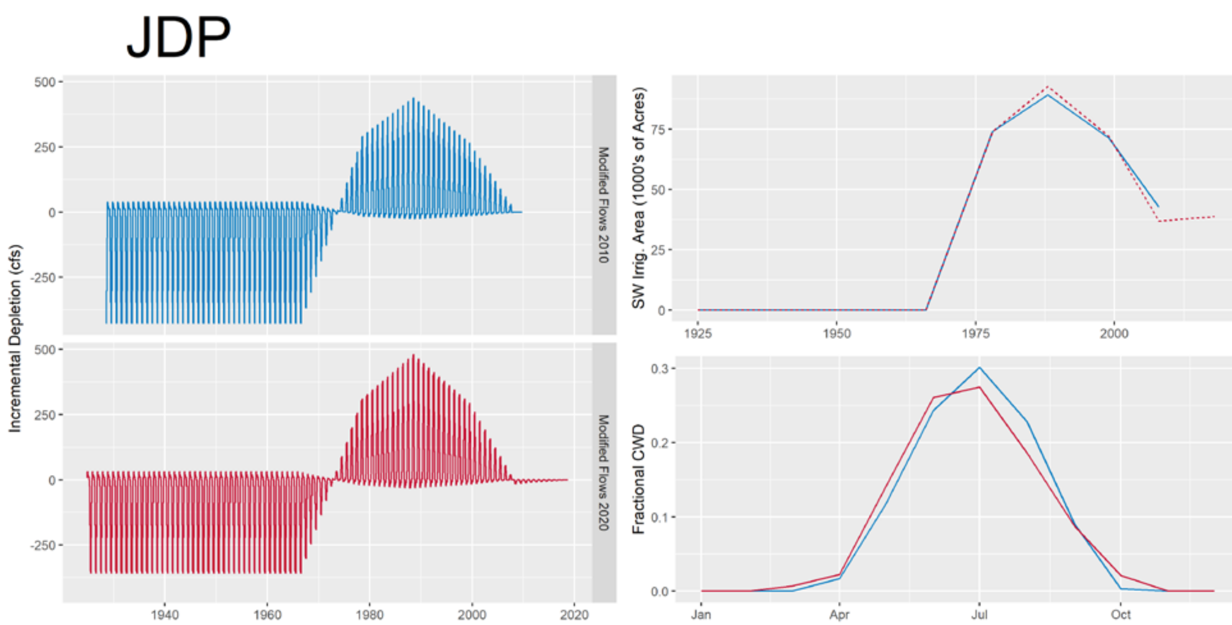

Figure 51. Subarea 32b – Pumping from John Day to Morrow/Gilliam + Returns (JDP): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the JDP subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

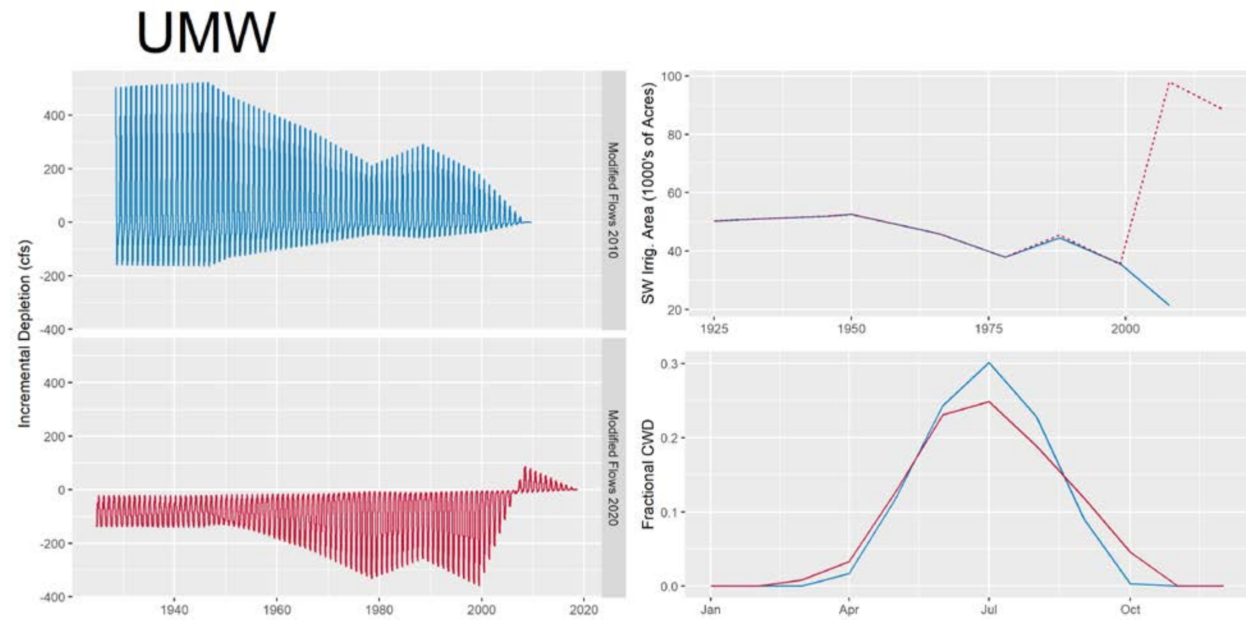

Figure 52. Subarea 32c – Umatilla River and Willow Creek (UMW): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the UMW subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

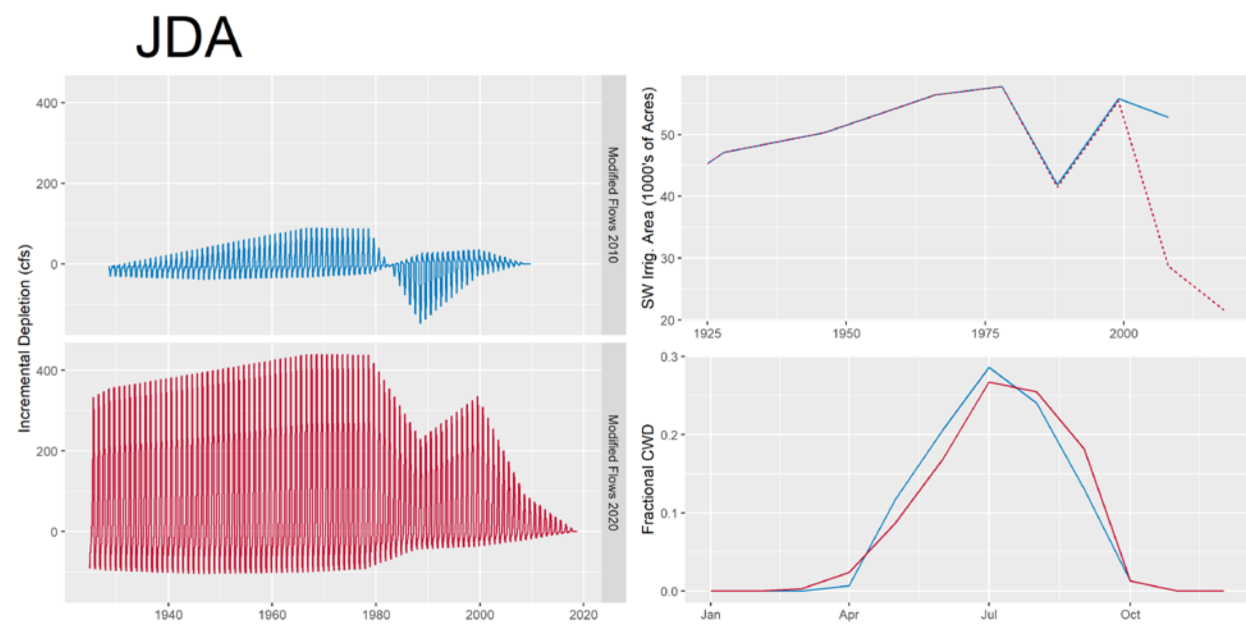

Figure 53. Subarea 33 – John Day (JDA): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the JDA subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

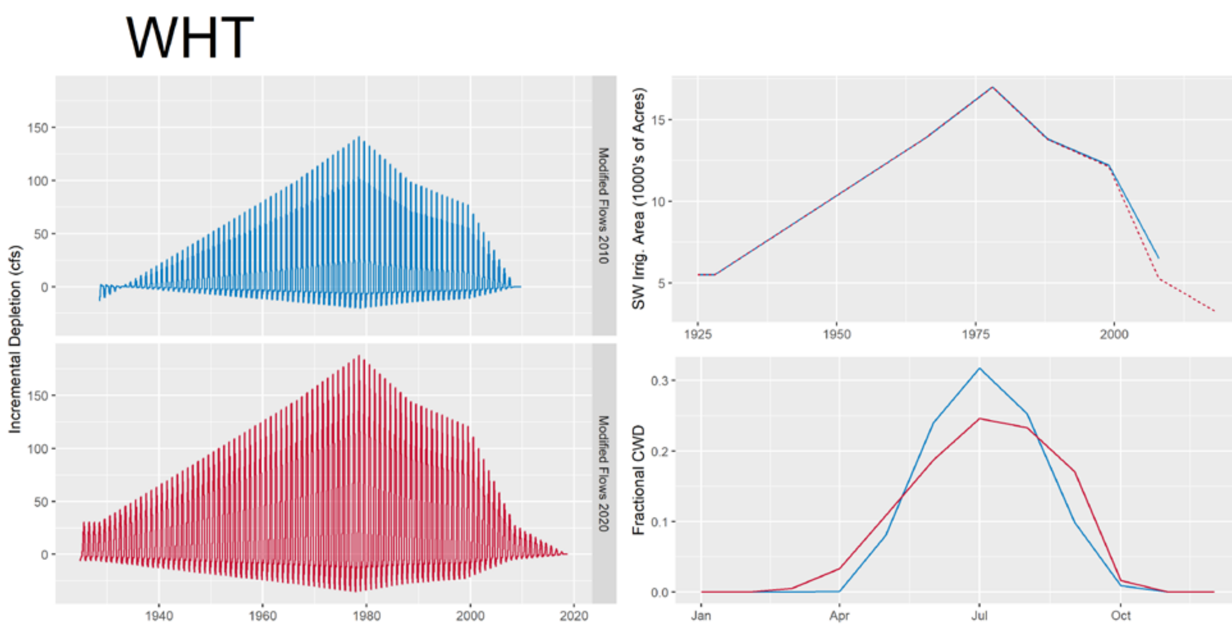

Figure 54. Subarea 34b – Deschutes – White River Wapanita (WHT): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the WHT subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

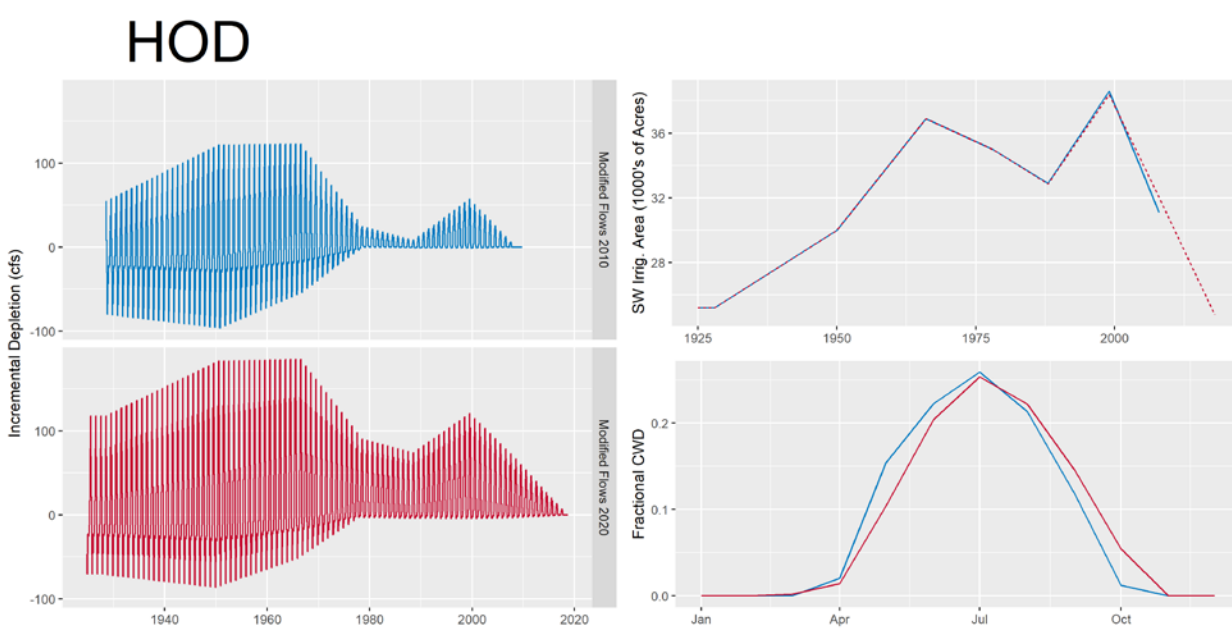

Figure 55. Subarea 35a – Hood River (HOD): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the HOD subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

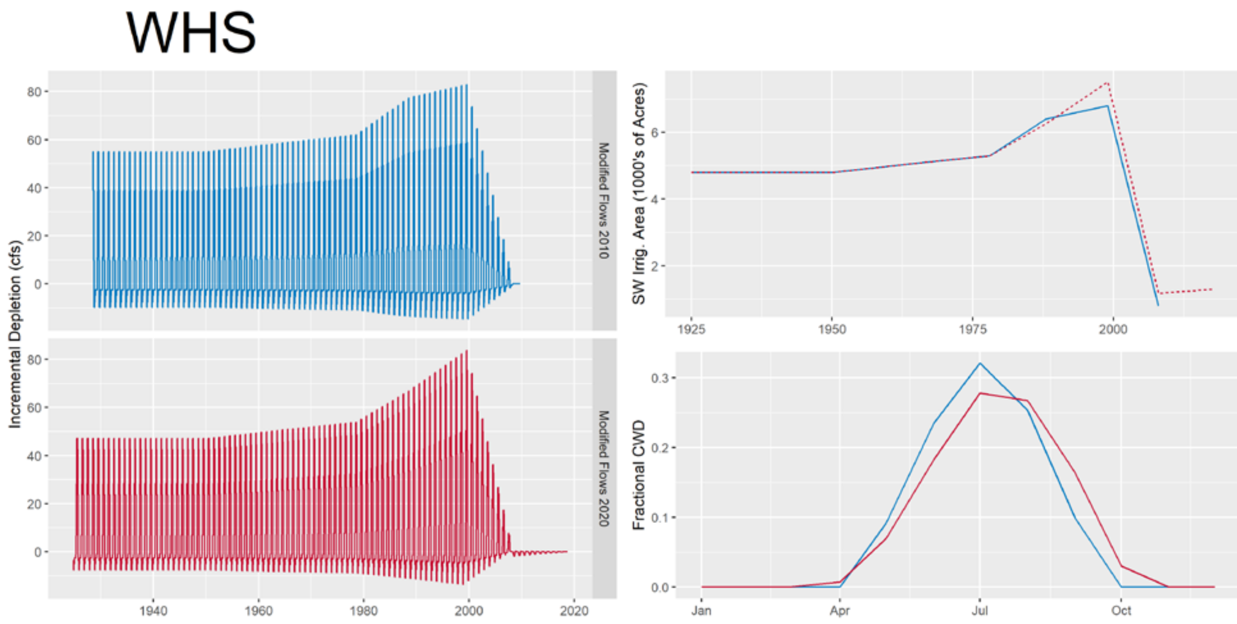

Figure 56. Subarea 35b – White Salmon (WHS): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the WHS subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

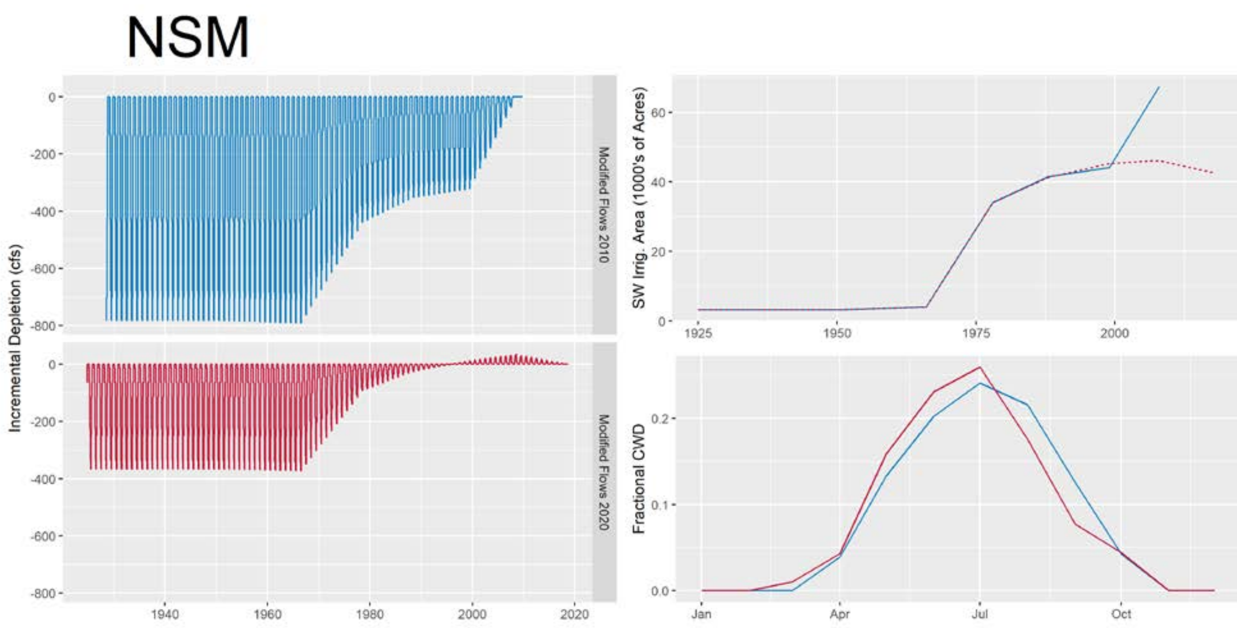

Figure 57. Subarea 36a (1) – Pumping from McNary to Northside (NSM): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the NSM subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

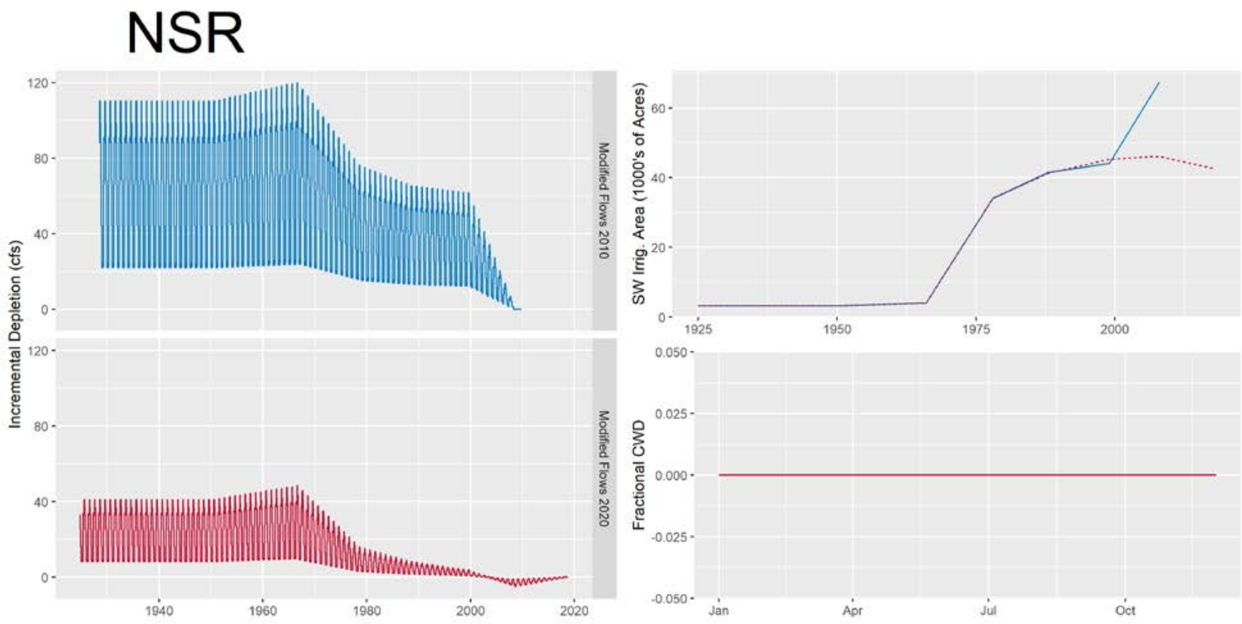

Figure 58. Subarea 36a (2) – Return flow from McNary pumping to Northside (NSR): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the NSR subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

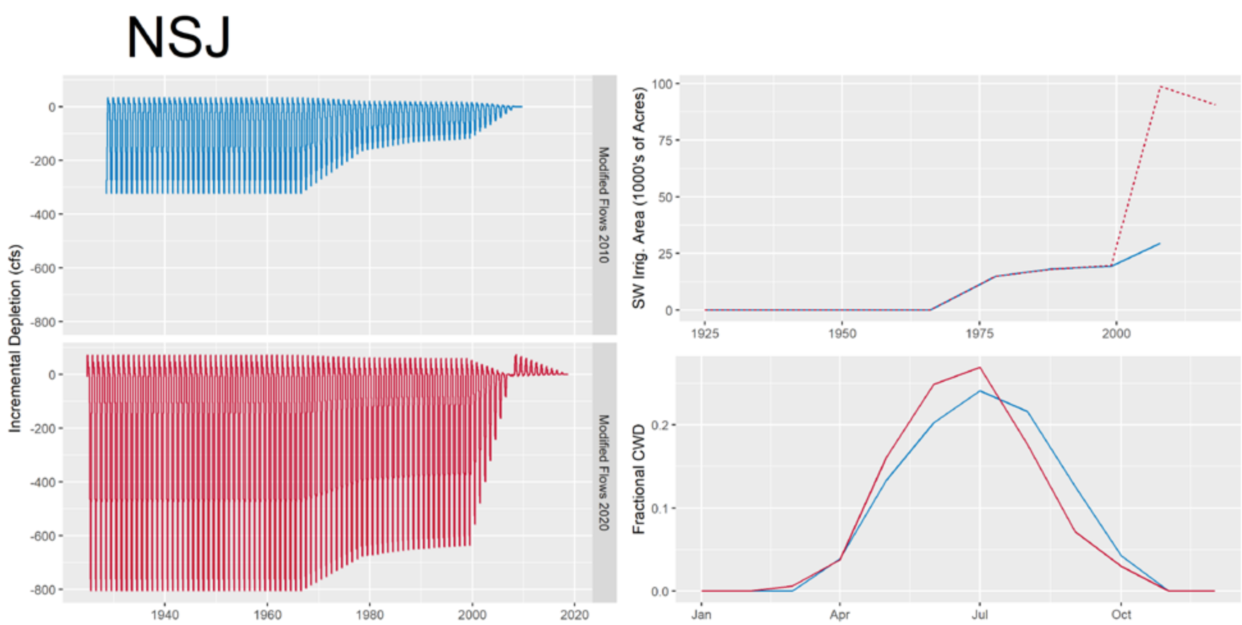

Figure 59. Subarea 36b - Pumping from John Day to Northside + returns (NSJ): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the NSJ subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

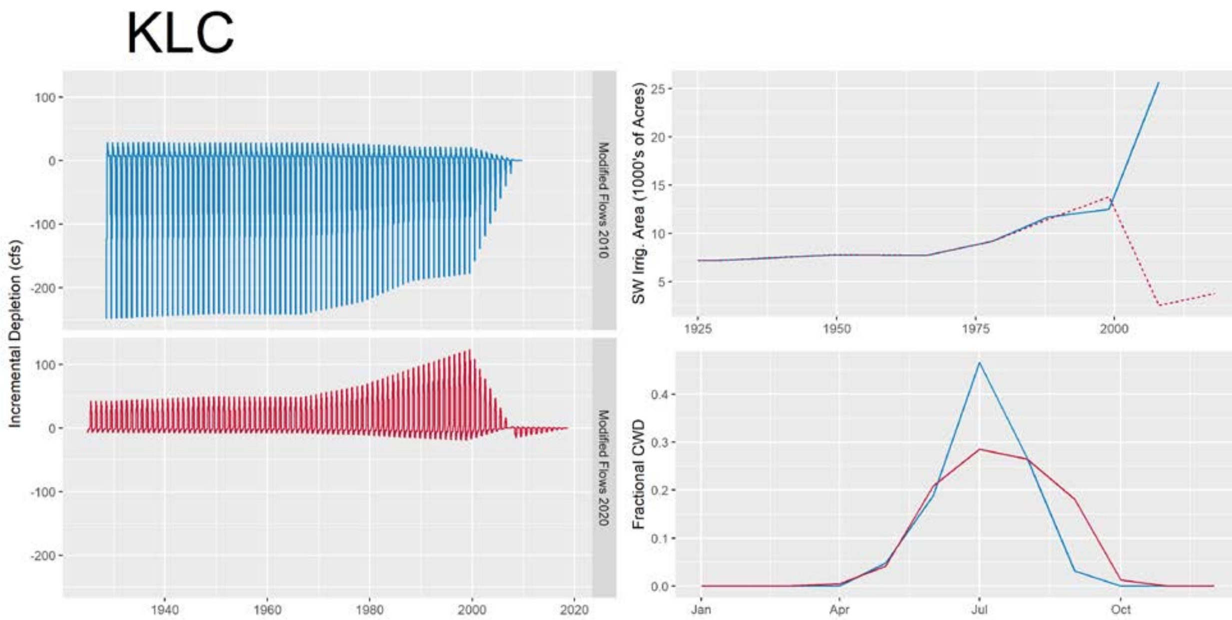

Figure 60. Subarea 36c - Klickitat (KLC): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the Klickitat subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

4.5 Willamette Basin

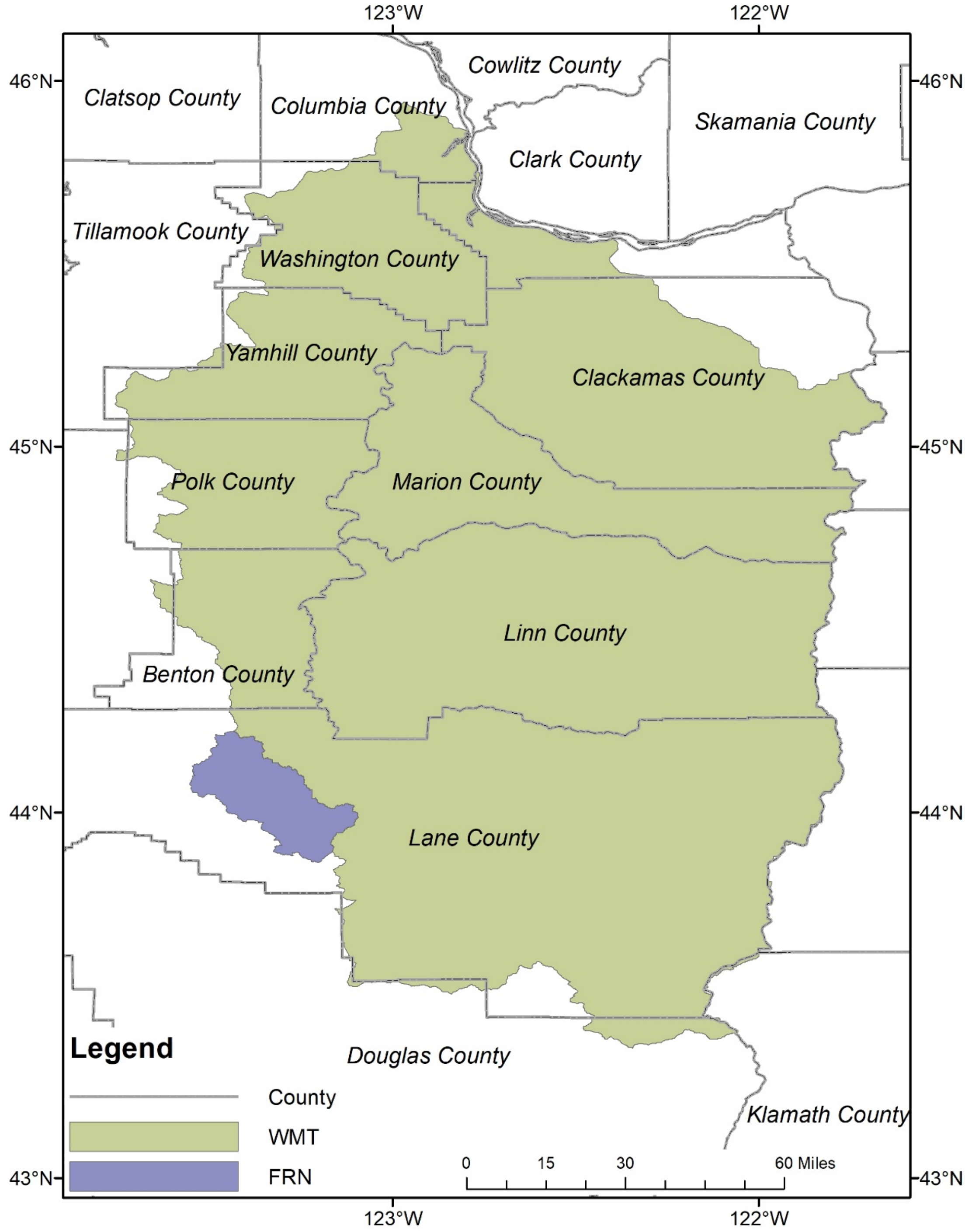

Figure 61. Map showing location of subareas within the Willamette Basin. Subarea codes defined in Table 11, below.

Table 11. Basin, code, name, and subarea for areas in the Willamette Basin described in this section.

Basin	Code	Name	Subarea
Willamette	FRN	Fern Ridge	Part of 38
Willamette	WMT	Willamette	Subarea 38

4.5.1 Description of and justification for methodology used that was specific to the region

The Willamette Basin is a large irrigated area (approximately 290,000 irrigated acres) with a diversity of crops. One of the challenges in determining crop water demand was understanding irrigation practices for sod-seed grass, which constitutes 21.6% of the irrigated area (most of which is assumed to be seed grass) and for which irrigation practices were not as well understood by the study team. Through contact with a number of extension experts in the region and by consulting relevant publications (Appendix G.5), crop water demand for this crop was adjusted accordingly. We also discovered that typically only about 20% of seed sod grass acres in this region is irrigated contrary to our expectation that it is never grown under rainfed conditions.

In addition, we made a minor update to the boundary of the Fern Ridge region based on a watershed delineation. Figure 62 shows the updated boundary.

Sources of uncertainty relevant to the entirety of the Columbia River Basin are discussed in Section 5.

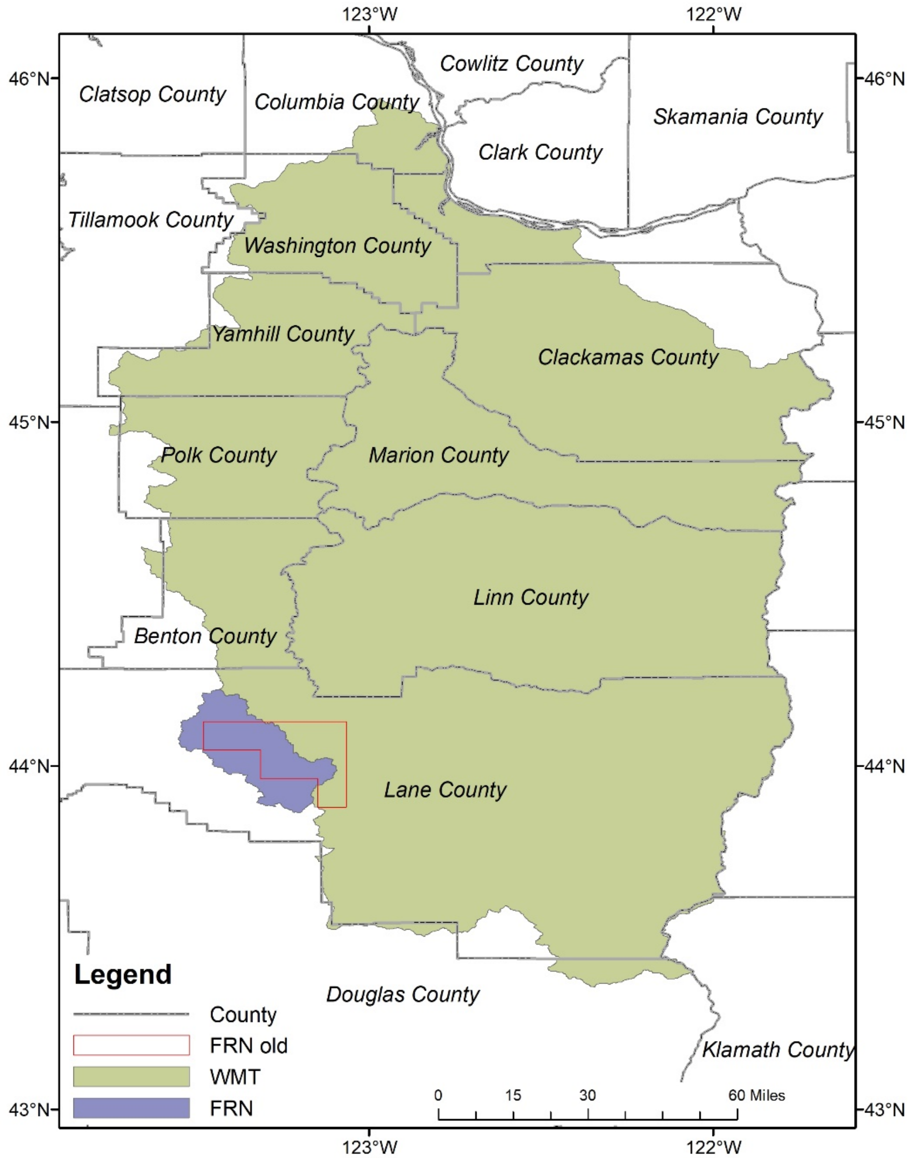

Figure 62. Map showing location of subareas within the Willamette Basin. FRN is the updated subarea boundary for Fern Ridge, while FRN old is the subarea boundary used in the 2010 Modified Flows.

Calculation of accumulated depletions

Site estimates of incremental depletions (D) reflect the change in irrigation over a specific subarea. The effects can be added to create accumulated depletions at specific sites within subareas. In the Willamette Basin there are three sites where accumulated depletions are calculated Albany (ALB), Salem (SLM), and T.W. Sullivan (SVN). The accumulated depletions at these sites are all contained within the Willamette basin and found by the following equations:

ALB6DD = 0.245*WMT6D

SLM6DD = 0.505*WMT6D

SVN6DD = 0.983*WMT6D

These equations are found by delineating the watershed for each point where accumulated depletions are calculated. The resulting shape files are combined with MIrAD to determine the fraction total irrigation in each watershed over the total irrigation in the Willamette Basin.

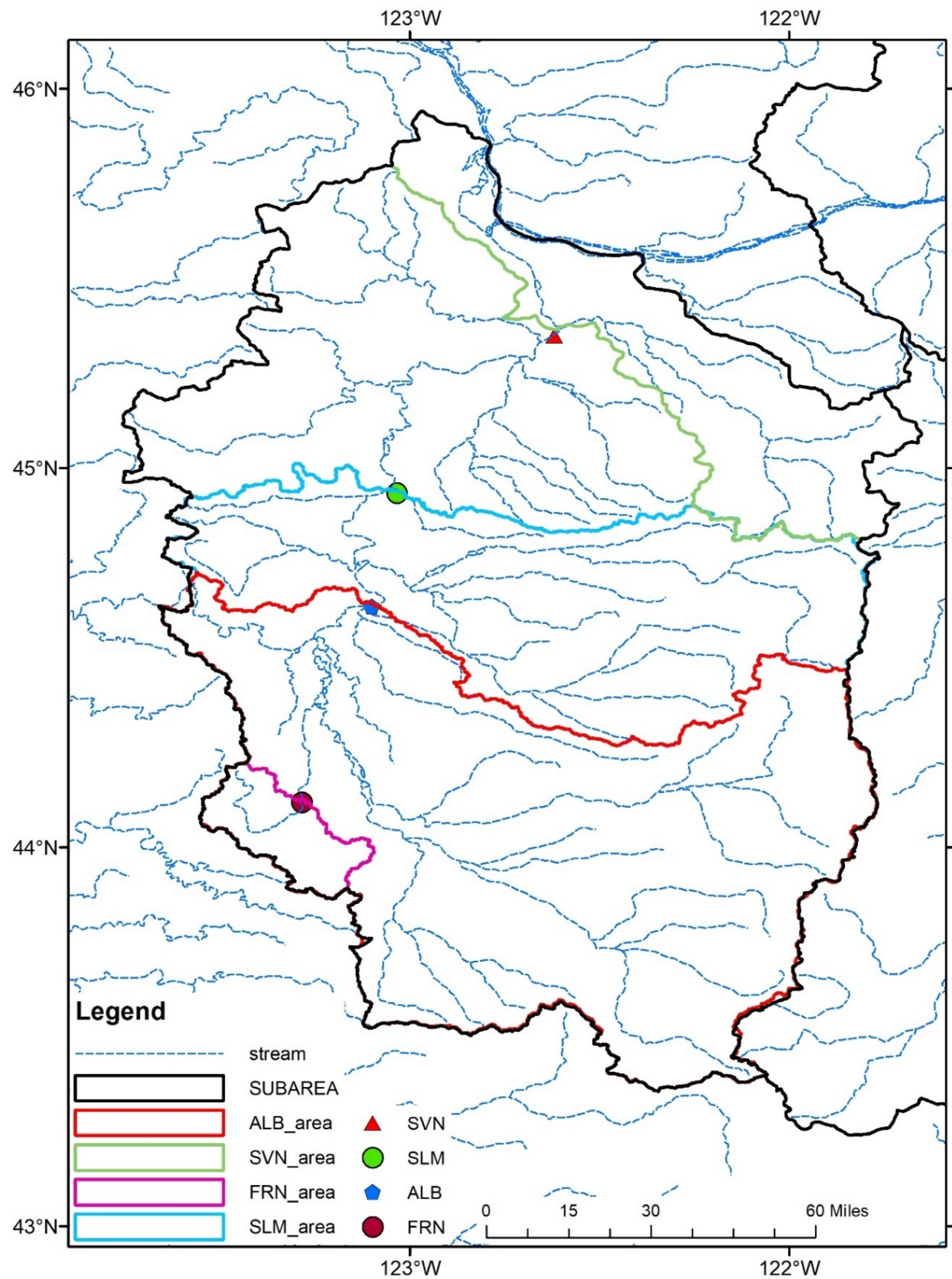

Figure 63. The control points Albany (ALB), Salem (SLM), and T.W. Sullivan (SVN) and the polygons represent the contributing/drainage area over these control points. The watershed boundaries are delineated from USGS 3-arc second (~90 meters) DEM data sets using ESRI Arcmap.

4.5.2 Tables with Summary Data

Crop distribution

Crop distributions are listed for crops comprising at least 1% of total irrigated area. Note that the total acreage shown may include crops that are not shown on the table because of their small contribution total acres. The irrigated area totals here may not exactly match the "total irrigated area" used for depletion calculation and shown in the Summary tables comparing 2010 Modified Flows and 2020 Modified Flows. This is an artifact of our process to translate non-crop specific MIrAD irrigation extent to crop-specific irrigation extent as described in the methodology Section 2.2.

Part of 38 - Fern Ridge

Crop	Irrigated area (acres)	Percent of total
Pasture	1,505	72.8%
Generic Fruit	389	18.8%
Sod Seed	52	2.5%
Corn	45	2.2%
Grape Wine	21	1.0%
Total	**2,067**	

Subarea 38 – Willamette

Crop	Irrigated area (acres)	Percent of total
Pasture	76,257	22.6%
Sod Seed	73,003	21.6%
Generic Fruit	70,832	21.0%
Corn	34,413	10.2%
Blueberry	13,621	4.0%
Hops	11,097	3.3%
Grape Wine	9,082	2.7%
Clover Hay	5,631	1.7%
Radish	4,756	1.4%
Cherry	4,738	1.4%
Squash	4,073	1.2%
Mint	4,030	1.2%
Alfalfa Hay	3,274	1.0%
Total	**337,383**	

County fractions

Subarea 38 - Willamette

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Oregon	Benton	0.99	27,815
Oregon	Clackamas	0.98	19,228
Oregon	Columbia	0.47	649
Oregon	Lane	0.88	15,599
Oregon	Linn	1.00	46,008
Oregon	Marion	1.00	105,081
Oregon	Multnomah	0.64	3,753
Oregon	Polk	1.00	24,572
Oregon	Washington	1.00	15,490
Oregon	Yamhill	1.00	31,969
		TOTAL	**290,163**

Crop water demand monthly fraction by crop (for crops comprising at least 1% of irrigated area)

Part of 38 - Fern Ridge

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	0.7	52.1	231.4	426.7	436.5	284.4	21.7	0.0	0.0	**1,453**
Diversion distribution %	0.0%	0.0%	0.0%	0.1%	3.6%	15.9%	29.4%	30.0%	19.6%	1.5%	0.0%	0.0%	**100.0%**

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	72.8%	0.0	0.0	0.0	0.0	0.4	2.6	4.9	5.3	3.6	0.1	0.0	0.0	16.9
Generic Fruit	18.8%	0.0	0.0	0.0	0.0	1.1	3.5	6.3	6.2	3.6	1.0	0.0	0.0	21.6
Sod Seed	2.5%	0.0	0.0	0.0	0.1	2.3	2.6	0.1	0.0	0.0	0.0	0.0	0.0	5.1
Corn	2.2%	0.0	0.0	0.0	0.0	0.8	3.7	6.9	2.5	0.0	0.0	0.0	0.0	13.9
Grape Wine	1.0%	0.0	0.0	0.0	0.0	0.2	2.0	5.9	6.3	4.2	1.3	0.0	0.0	19.9

Subarea 38 - Willamette

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	2.6	74.9	206.1	326.7	274.1	143.3	20.7	0.0	0.0	**1048.5**
Diversion distribution %	0.0%	0.0%	0.0%	0.2%	7.1%	19.7%	31.2%	26.1%	13.7%	2.0%	0.0%	0.0%	**100.0%**

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Pasture	22.6%	0.0	0.0	0.0	0.0	0.2	1.8	4.5	4.8	3.1	0.1	0.0	0.0	14.5
Sod Seed	21.6%	0.0	0.0	0.0	0.1	2.2	2.3	0.1	0.0	0.0	0.0	0.0	0.0	4.7
Generic Fruit	21.0%	0.0	0.0	0.0	0.0	0.5	3.2	6.0	5.6	2.9	0.7	0.0	0.0	18.9
Corn	10.2%	0.0	0.0	0.0	0.0	0.8	3.1	5.7	1.5	0.0	0.0	0.0	0.0	11.1
Blueberry	4.0%	0.0	0.0	0.0	0.0	0.8	3.8	5.3	3.1	1.9	0.6	0.0	0.0	15.4
Hops	3.3%	0.0	0.0	0.0	0.1	0.4	1.5	5.1	5.5	1.5	0.0	0.0	0.0	14.2
Grape Wine	2.7%	0.0	0.0	0.0	0.0	0.1	0.8	4.4	6.1	3.6	1.0	0.0	0.0	15.9
Clover Hay	1.7%	0.0	0.0	0.0	0.0	1.0	2.3	4.5	4.8	3.3	0.1	0.0	0.0	15.9
Radish	1.4%	0.0	0.0	0.0	0.7	1.3	2.4	4.1	0.0	0.0	0.0	0.0	0.0	8.6
Cherry	1.4%	0.0	0.0	0.0	0.0	1.0	3.0	4.2	4.0	2.5	0.7	0.0	0.0	15.6
Squash	1.2%	0.0	0.0	0.0	0.0	1.1	3.4	2.7	0.0	0.0	0.0	0.0	0.0	7.2
Mint	1.2%	0.0	0.0	0.0	0.0	0.4	2.5	4.1	5.1	0.9	0.0	0.0	0.0	13.0
Alfalfa Hay	1.0%	0.0	0.0	0.0	0.0	0.1	0.5	4.3	6.5	3.4	0.1	0.0	0.0	14.8

2015 USGS data

Subarea 38 Willamette

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Oregon	Benton County	0.76	50.7	0.5	0.0	51.2
Oregon	Clackamas County	0.46	38.6	1.2	0.0	39.8
Oregon	Columbia County	0.88	3.5	0.0	0.0	3.5
Oregon	Lane County	0.62	43.6	0.9	0.0	44.4
Oregon	Linn County	0.53	57.9	1.8	0.0	59.7
Oregon	Marion County	0.46	156.2	8.2	0.0	164.3
Oregon	Multnomah County	0.58	9.8	0.1	0.0	9.9
Oregon	Polk County	0.82	37.7	0.4	0.0	38.0
Oregon	Washington County	0.91	68.8	2.1	0.0	70.9
Oregon	Yamhill County	0.85	57.2	2.4	0.0	59.6

Diversion and Return Flow Volumes (ac-ft/1000 ac) based on Sprinkler/Gravity Efficiencies

Part of 38 - Fern Ridge

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1453*	*1453*
Diversion Efficiency (%)	*76%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1912**	**-2907**
Return Efficiency (%)	*20%*	*45%*
Return Flow (ac-ft per 1000 ac)	**382**	**1308**

Subarea 38 - Willamette

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	*1048*	*1048*
Diversion Efficiency (%)	*76%*	*50%*
Required Diversion (ac-ft per 1000 ac)	**-1379**	**-2096**
Return Efficiency (%)	*20%*	*45%*
Return Flow (ac-ft per 1000 ac)	**276**	**943**

Depletions per unit area

Subarea 38 - Willamette

Sprinkler System								Gravity System						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	**cfs per 1000 ac**
JAN			4.0%	11	11	0.2		JAN			4.0%	38	38	0.6
FEB			4.0%	11	11	0.2		FEB			4.0%	38	38	0.7
MAR		0	4.0%	11	11	0.2		MAR		0	4.0%	38	38	0.6
APR	0.2%	-3	4.0%	11	8	0.1		APR	0.2%	-5	4.0%	38	33	0.5
MAY	7.1%	-99	5.0%	14	-85	-1.4		MAY	7.1%	-150	5.0%	47	-103	-1.7
JUN	19.7%	-271	12.0%	33	-238	-4.0		JUN	19.7%	-412	12.0%	113	-299	-5.0
JUL	31.2%	-430	17.0%	47	-383	-6.2		JUL	31.2%	-653	17.0%	160	-493	-8.0
AUG	26.1%	-361	18.0%	50	-311	-5.1		AUG	26.1%	-548	18.0%	170	-378	-6.2
SEP	13.7%	-189	13.0%	36	-153	-2.6		SEP	13.7%	-287	13.0%	123	-164	-2.8
OCT	2.0%	-27	9.0%	25	-2	0.0		OCT	2.0%	-41	9.0%	85	44	0.7
NOV			6.0%	17	17	0.3		NOV			6.0%	57	57	1.0
DEC			4.0%	11	11	0.2		DEC			4.0%	38	38	0.6
Total	100.0%	-1380	100.0%	276	-1104			Total	100.0%	-2097	100.0%	944	-1153	

Surface water irrigated acres

Part of 38 - Fern Ridge

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1925	0.0	0.0	5.7	5.7
1928	0.0	0.0	5.7	5.7
1948	0.0	0.0	10.0	10.0
1966	11.0	0.0	10.0	21.0
1978	19.4	0.0	2.3	21.7
1988	22.1	0.0	0.5	22.5
1999	17.0	0.0	0.3	17.4
2008	13.8	0.9	0.0	14.7
2018	5.2	0.4	0.0	5.6

Subarea 38 - Willamette

	Irrigated acres (1000s of acres)			
Year	**Sprinkler**	**Micro**	**Gravity**	**Total**
1928	0.0	0.0	3.9	3.9
1950	48.8	0.0	5.8	54.6
1966	137.1	0.0	5.4	142.5
1978	214.4	0.0	5.1	219.5
1988	199.0	0.0	1.0	200.0
1999	183.1	0.0	3.1	186.3
2008	154.6	3.8	0.5	158.8
2018	179.6	6.1	0.0	185.6

Summary tables comparing 2010 Modified Flows and 2020 Modified Flows

Part of Subarea 38 - Fern Ridge

	2010	**2010 (revised)**	**2020**
Total irrigated area (1000 acres)	6.1	1.6	1.9
Surface water split (% SW)	61%	65%	62%
Surface water irrigated area (1000 acres)	3.7	1.0	1.2
Crop water demand (ac ft per 1000 acres)	1,705	[redacted]	1,453

Subarea 38 - Willamette

	2010	2010 (revised)	2020
Total irrigated area (1000 acres)	304.6	278.1	290.2
Surface water split (% SW)	56%	57%	64%
Surface water irrigated area (1000 acres)	171.7	158.8	185.6
Crop water demand (ac ft per 1000 acres)	1,242	[redacted]	1,048

4.5.3 Figures

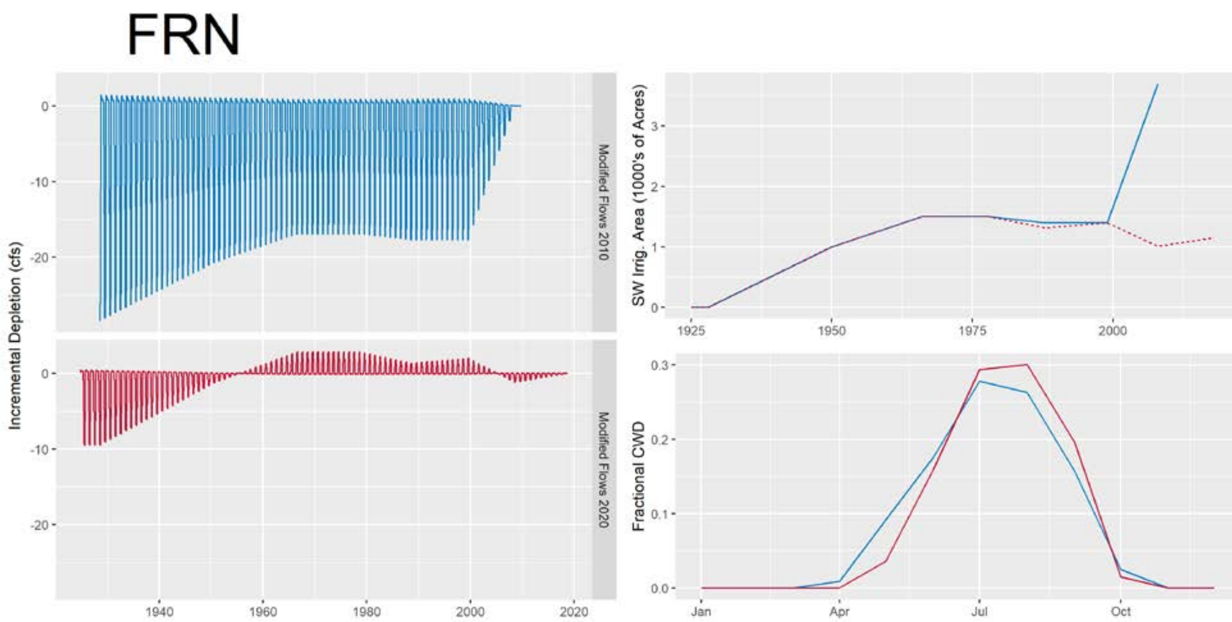

Figure 64. Fern Ridge (part of Subarea 38; FER): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the FER subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

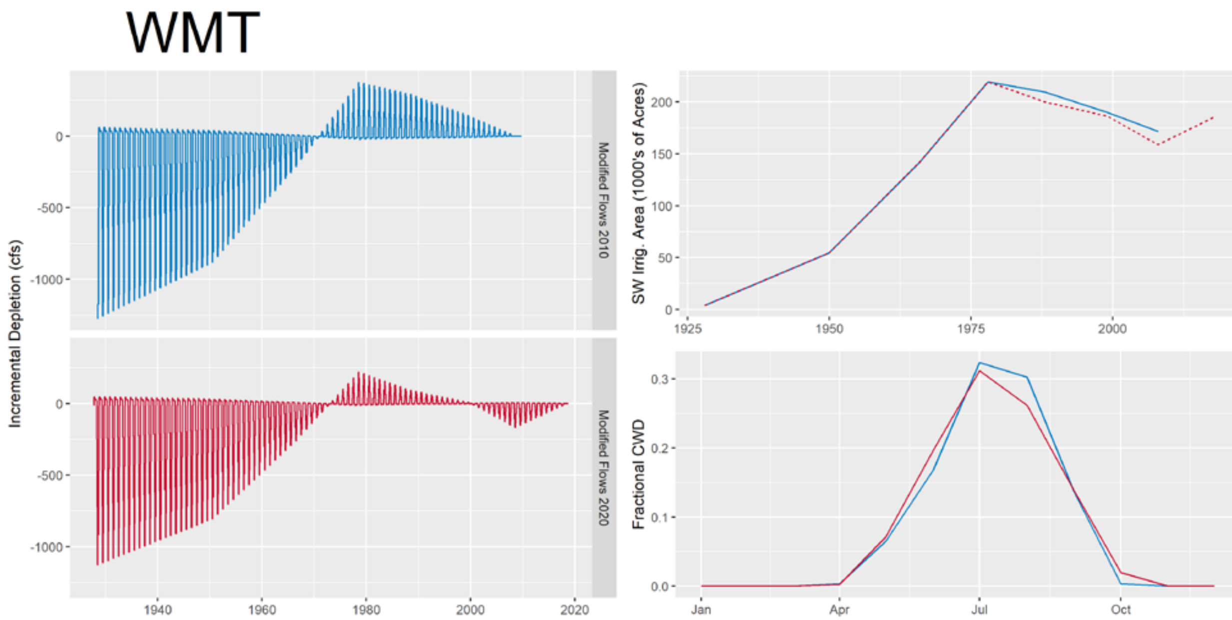

Figure 65. Subarea 38 – Willamette (WMT): incremental depletion from 2010 Modified Flows (top left, blue) and 2020 Modified Flows (bottom left, red), and comparison of surface water (SW) irrigated area in thousands of acres (top right) and fractional crop water demand (CWD; bottom right) in the WMT subarea showing values from 2010 (blue) and 2020 (red) Modified Flows.

4.6 Klamath Basin

According to local experts contacted (see Appendix G.6), surface water irrigated acres have been stable for the last 50 years. For this reason, the Klamath Basin was not updated as part of this study.

5. Sources of Uncertainty

Depletion adjustments are sensitive to quantification of two key factors: 1) irrigation depletions per unit area, and 2) acreage adjustment for past years (i.e., the difference between irrigation extent in 2018 and each past year until 1928). The first provides an estimate of depletions under current irrigation conditions (crop mix, irrigation technology, on-farm and conveyance efficiencies etc.) on a per unit area basis. The second determines how annual surface-water irrigated acreage under evolving irrigation technologies changed as compared to 2018 as a baseline. Accurate estimates of current and past acreage are crucial. There are several sources of uncertainty in the quantification of these factors, and they are described in detail below.

Calculation of irrigation depletions per unit area

New to the 2020 Modified Flows, VIC-CropSyst was used to capture the magnitude and timing of crop-specific irrigation demands. However, uncertainties in model inputs such as meteorology, pedology, and cropping systems translate to uncertainty in model outputs. Calibration of the hydrologic model (VIC), and the parameterization and calibration of the crop model component (CropSyst) also introduce uncertainty, as do assumptions around the efficiencies of diversion and return flows. Each of these are described below.

Hydrologic Model Calibration: VIC calibrations are for soil parameters. This calibration is conducted at catchment levels based on either reconstructed naturalized streamflow (e.g., NRNI datasets) or observations from catchments without significant human disturbances. Since the response of hydrologic processes to climate and land surface varies spatially within a catchment, the calibrated soil parameters averaged over entire catchment cannot represent these spatial variations. Additionally, there is no specified groundwater reservoir in the model and the interactions between surface and ground water are ignored. This missing mechanism may result in overly calibrated rainfall-runoff parameters at the expense of capturing groundwater processes, leading to uncertainly in model output. However, while hydrologic output such as runoff and streamflow are quite sensitive to this calibration process, crop-specific output such as irrigation demands – which is the critical output for this project - are not as sensitive to the hydrologic calibration process (Rajagopalan et al., 2018).

Crop Model Parameterization and Calibration: Extensive regional crop parameterization helps reduce uncertainties inherent to the crop modeling process. Since it is not uncommon to encounter inconsistency in the collection and recording of such data in the literature, uncertainty is inevitable. Mechanistic crop models are typically designed to represent plant growth and development at a point scale, thus conventional crop model calibration methods tend to target the field scale. For regional-scale simulations, upscaling leads to additional uncertainty. Moreover, the input variability in a large and heterogeneous area are difficult to capture (Xiong et al., 2008; Balkovic et al., 2013).

While it is challenging to address all parameters in the calibration process, it is possible to identify parameters that most strongly affect the model output using a sensitivity analysis approach. The sensitivity analysis identifies which parameters need to be most carefully quantified to assess the state of the environmental system, and which environmental factors should be preferentially managed. Based on previous studies involving sensitivity analysis for the CropSyst model (Confalonieri, 2010; Confalonieri, et al., 2006), this study focused on the adjustment of key phenology-related crop parameters.

Besides crop parameters, regional crop management practices such as planting and harvest dates, irrigation scheduling, and harvest criteria significantly influence crop model estimates. Such management decisions are particularly difficult to characterize because they depend on individual farmer decisions rather than a response to physical conditions. Furthermore, these decisions vary significantly farm to farm. This study considered a limited number of representative irrigation strategies to reasonably approximate irrigation practices. Soil moisture depletions trigger automatic determination of irrigation application amounts and scheduling for all cropping systems throughout the study area.

Diversion and Return Flow Efficiency: In addition to the crop water demands, diversion and return flow efficiency assumptions are critical to depletion estimation. These vary across areas and quantification is difficult due to scaling issues and paucity of information. Where diversion and return flow data exist, this can be used to improve estimates, however these data are not always readily available. While the USGS Water Use surveys provide surface and ground water split percentages at a county level, there are large uncertainties in these estimates. Additional uncertainties are created in translating county-level data to subarea-level data. However, there was no instance where the efficiency values (as used for the 2010 Modified Flows) were changed as a result of these contacts because: 1) the scale at which the local expert provided information did not match the scale of analysis (e.g., the experts knew diversion efficiency for a specific irrigation district, but not for a whole subarea), or 2) there was no quantitative information provided that would allow a change in assumption.

Irrigated acreage in current and past years

Irrigation extent has a significant impact on depletion estimates, and there is significant uncertainty around estimates of current irrigated extent. While Washington state has highly accurate spatially-explicit crop-specific information about irrigation extent and implementation, no such data sources exist for other parts of the Columbia River Basin. The 2010 study utilized a satellite-imagery based method similar to Brown and Pervez (2014) to create spatially-explicit irrigation extent information for the CRB. This data product, however, does not provide irrigation extent associated with specific crops. Additionally, methodological nuances result in aggregate irrigation extent being bounded by county-level USDA Census of Agriculture acreage estimates and these are uncertain to begin with. We applied this methodology in the Canadian part of the basin as well. However, input information was generally available at a coarser scale than for the U.S. leading to uncertainties in the characterization of the spatial extent of irrigation.

While satellite-based imagery products can provide better estimates of current irrigation extent, the depletion adjustments critically depend on the time series of irrigation extent and changes in irrigation extent over time. The 2020 Modified Flows study carries over past acreage from prior studies (prior to 2008) but then extends the irrigation acreage time-series using the satellite-based imagery (starting in 2008). Therefore, unlike the prior Modified Flows studies where only the current year acreage information is updated and the rest of the time series is left unchanged, in the 2020 Modified Flows we updated both the 2018 and 2008 data, given we had access to satellite imagery in both time frames. Therefore, although uncertainties in irrigation extent shrink with improved methodologies since 2008, large uncertainties remain in acreage estimates prior to 2008. Given that the difference in acreage between current conditions and each past year is a critical component of depletion adjustments, uncertainty in past acreage is likely the most important source of uncertainty in depletion adjustment estimates. Unfortunately, this is the hardest to resolve as well, given that there is a paucity of documentation and information in the level of detail we need, back to 1928.

Each Modified Flows study updates the methodology for recent irrigated acreage estimates, and retains estimates of irrigated extent from Modified Flows calculations for prior years. It is important to mention that, while the update provided in the current study will decrease uncertainty for recent irrigation extent, it does have the potential to increase overall uncertainty in incremental depletions. For example, consistent data sources/methodology in the entire time series of irrigated acreage might also mean consistent biases. Therefore, even if the time series is incorrect, differences in acres between current and past conditions could be closer to reality because biases cancel out or reduce when differences are calculated. On the other hand, methodological improvement for only "current" level estimates would reduce/remove bias in current estimates, but retain them in prior estimates, and biases no longer cancel out when differences are quantified. To avoid this additional uncertainly, one possibility would be to continue a less accurate methodology for the benefit of consistency. However, without sufficient information about past data sources or methodology prior to 2010 Modified Flows, the benefits of improving the methodology for current estimates using vast technological improvements in irrigation extent and crop type identification outweighed the potential for inadvertently increasing uncertainty in incremental depletions in some areas. Where possible, we extended the new methodology back to 2008 data as well. Future Modified Flows studies should consider extending new methodologies as far into the past as possible for consistency.

6. Conclusions

The 2020 Modified Flows made several improvements in the methodology for irrigation depletion adjustments as compared to the 2010 Modified Flows.

Estimation of crop water demand was improved by (a) consideration of a broader range of crops (b) utilization of spatially-explicit input datasets and parameterization, and (c) application of a modeling framework that is able to capture the spatial heterogeneity in inputs, the dynamic nature of crop growth, and the variable, non-linear response of depletions to these factors. Estimates of recent (since 2008) irrigated acreage were also improved through incorporation of satellite-imagery based datasets. We investigated unusual patterns in the time series of irrigation depletion adjustments as well as discrepancies between results from 2020 and 2010 Modified Flows. In several instances, issues were resolved by updating prior data, and/or adjusting the methodology.

Quantifying irrigation depletion adjustments is a challenging task, especially in a place like the Columbia River Basin with great diversity in the crop mix, agricultural practices, and human influences. While uncertainties remain, improvements made as part of this 2020 Modified Flows effort bring irrigation depletion adjustments closer to reality. Additionally, input datasets and modeling frameworks are under continuous improvement by our team (and other teams) and can be leveraged by future Modified Flow Projects. Quantifying past irrigated acreage remains a challenging problem with no clear path for resolution. Future studies would benefit from efforts to better characterize this aspect.

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8. Glossary

Term	Meaning/Expansion
AvgPeakDiff	Absolute average peak flow difference
AAFC	Agriculture and Agri-Food Canada
ACI	Annual Crop Inventory
BPA	Bonneville Power Administration
Calibration parameter: BI	The parameter controlling the shape of variable infiltration capacity curve
Calibration parameter: D2	The soil depth of the bottom most soil layer
Calibration parameter: Ds	The fraction of Ds_{MAX} where non-linear baseflow begins
Calibration parameter: Dsmax	The maximum baseflow from the lowest soil layer
Calibration parameter: Ws	The fraction of the maximum soil moisture (of the lowest soil layer) where non-linear baseflow occurs
CBCCSP	Columbia Basin Climate Change Scenarios Project
CDL	Cropland Data Layer
CP	percent contribution of irrigated land within the county to the subarea
CRB	Columbia River Basin
CWD	crop water demand
DEM	(delineated from USGS 3-arc second (~90 meters) DEM data sets)
ET	Evapotranspiration
FAO	Food and Agricultural Organization of the United Nations
GAI	Green Area Index
GridMET	A dataset of daily high-spatial resolution (~4 km, $1/24^{th}$ degree) surface meteorological data covering the contiguous U.S. from 1979-yesterday
HUC	Hydrologic unit code
Irr_{sa}	irrigated land of the target county that falls within the subarea
Irr_{tot}	the total irrigated land in the target county
kc	crop coefficient factor
LAI	leaf area index
Ln NSE	Nash-Sutcliff model efficiency coefficient with logarithmic values
LOESS	locally estimated scatterplot smoothing
MAD	Maximum Allowable Deficit
MIrAD-US	(MODIS) Irrigated Agriculture Dataset for the United States (MIrAD-US)
MOCOM-UA	multi-objective complex evolution
MODIS	Moderate Resolution Imaging Spectroradiometer
MT-CLIM	Mountain Climate Simulator
NASS	National Agricultural Statistics Service
NLCD	National Land Cover Database
NDVI	Normalized Difference Vegetation Index

Term	Meaning/Expansion
NSE	Nash-Sutcliff model efficiency coefficient
NSF	National Science Foundation
$\underline{Q}_o$	mean of observed discharges
Q_m^t	modeled discharge at time t
Q_o^t	observed discharge at time t
r^2	Coefficient of determination
RelBias	Relative bias in annual flow
RMSE	Root mean square error
STATSGO2	United States General Soil Map
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USGS	United State Geological Survey
VIC	Variable Infiltration Capacity model
WSDA	Washington State Department of Agriculture

Appendix A: VIC Soil Parameters

Appendix A.1 Calibrated Soil Parameters and its Ranges over the CRB

Variable Name	Unit	# Dimensions	Description	Range (Min, Middle, Max, Mean)
Ds	N/A	1	The fraction of Dsmax where non-linear (rapidly increasing) baseflow begins. With a higher value of Ds, the baseflow will be higher at lower water content in lowest soil layer.	0.0004 0.2617 0.9771 0.3676
Dsmax	mm/day	1	Maximum baseflow that can occur from the lowest soil layer	0.0314 3.8070 29.9709 8.0600
Ws	N/A	1	The fraction of the maximum soil moisture (of the lowest soil layer) where non-linear baseflow occurs. This is analogous to Ds. A higher value of Ws will raise the water content required for rapidly increasing, non-linear baseflow, which will tend to delay runoff peaks.	0.0502 0.4677 0.9965 0.4992
BI	N/A	1	Defines the shape of the Variable Infiltration Capacity curve. It describes the amount of available infiltration capacity as a function of relative saturated grid cell area. A higher value of BI gives lower infiltration and yields higher surface runoff.	0.0022 0.1992 0.2981 0.1836
D2	Meter	1	Soil depth of the bottom layer: [typically 0.1 to 1.5 meters; this range is for the depth of each layer in traditional 3-layer VIC model run]. Soil depth effects many model variables. In general, for runoff considerations, thicker soil depths slow down (baseflow dominated) seasonal peak flows and increase the loss due to evapotranspiration.	0.0241 1.9347 2.9968 1.7693

Appendix A.2 List of Major Other VIC Gridded Soil Parameters and their Ranges over the CRB.

Variable Name	Unit	# Dimensions	Description	Range (Min, Middle, Max, Mean)
c	N/A	1	Exponent used in baseflow curve, normally set to 2	2
expt	N/A	[nlayer]	Exponent n (=3+2/lambda) in Campbell's eqn for hydraulic conductivity	3.4 12.7 43.7 13.2
Ksat	mm/day	[nlayer]	Saturated hydrologic conductivity	0 473 5087 630
depth	m	[nlayer]	Thickness of each soil moisture layer	0.003 0.1 3.0 0.2
avg_T	Celsius Degree	1	Average soil temperature, used as the bottom boundary for soil heat flux solutions	-7. 5.3 12.2 5.0
dp	m	1	Soil thermal damping depth (depth at which soil temperature remains constant through the year, ~4 m)	4
bubble	cm	[nlayer]	Bubbling pressure of soil. Values should be > 0.	5.9 8.6 56.7 9.8
quartz	fraction	[nlayer]	Quartz content of soil	0.00 0.41 0.98 0.45
bulk_dens_min	kg/m3	[nlayer]	Bulk density of soil layer	1115 1468

				2050 1472
soil_dens_min	kg/m3	[nlayer]	Soil particle density, normally 2685 kg/m3	1485 2650 2650 2617
rough	m	1	Surface roughness of bare soil	0.01
snow_rough	m	1	Surface roughness of snowpack	0.03
annual_prec	mm	1	Average annual precipitation	161 678 5523 826
avg_July_Temp	Celsius Degree	1	Average July air temperature	6.6 17.5 24.9 17.4
Clay	fraction	[nlayer]	Clay content of soil	0.01 0.15 0.88 0.19

Appendix B: List of Crops Defined as Always Irrigated

Appendix B.1: Crop Data Layer (U.S.)

Crops listed in USDA's Crop Data Layer as always irrigated.

Alfalfa	Misc Vegs & Fruits
Apples	Mustard
Apricots	Onions
Asparagus	Other Tree Crops
Blueberries	Peaches
Broccoli	Pears
Buckwheat	Peppers
Cabbage	Plums
Caneberries	Pop or Ornamental Corn
Cantaloupes	Potatoes
Carrots	Pumpkins
Cauliflower	Radishes
Cherries	Rape Seed
Corn	Rye
Cranberries	Sod/Grass Seed
Cucumbers	Sorghum
Double Crop Barley/Corn	Spelt
Double Crop Oats/Corn	Squash
Double Crop WinWht/Corn	Strawberries
Garlic	Sugarbeets
Grapes	Sweet Corn
Greens	Sweet Potatoes
Herbs	Tomatoes
Hops	Turnips
Lettuce	Walnuts
Mint	Watermelons

Appendix B.2: Agricultural Crop Inventory (Canada)

Crops listed in Statistics Canada’s Agricultural Crop Inventory (ACI) as always irrigated.

Berries

Blueberry

Canola / Rapeseed

Corn

Cranberry

Fruits

Herbs

Hops

Mustard

Orchards

Other Berry

Other Fruits

Other Vegetables

Potatoes

Sod

Spelt

Sugarbeets

Tomatoes

Vegetables

Vineyards

Appendix C: Model Calibration Parameters

Table C-1. Metrics of calibration results for each station

GRID_ID/ Watershed	neg_NSE	neg_LnNSE	RelBias	neg_r^2	AvgPeak Diff	RMSE	NSE	Evaluation_class
250710	-0.834	-0.816	0.094	-0.851	3.9	3.6	0.834	1
260016	-0.849	-0.885	0.162	-0.939	457.9	226.3	0.849	1
260939	-0.836	-0.854	0.184	-0.937	477.4	236.8	0.836	1
261845	-0.736	-0.755	0.145	-0.778	27.1	20	0.736	2
261861	-0.854	-0.755	0.163	-0.917	377	219.6	0.854	1
261880	-0.841	-0.887	0.184	-0.947	485	232.5	0.841	1
263701	-0.789	-0.788	0.12	-0.827	19.1	13.7	0.789	1
263746	-0.82	-0.852	0.219	-0.947	540	247.6	0.82	1
266493	-0.77	-0.347	0.254	-0.904	459.6	288.5	0.77	1
268392	-0.838	-0.91	0.19	-0.951	498.2	227.9	0.838	1
272057	-0.951	-0.884	0.026	-0.954	20.3	15.8	0.951	1
272125	-0.702	-0.625	0.331	-0.949	470.3	209.4	0.702	2
273038	-0.792	-0.849	0.252	-0.953	557.9	253.7	0.792	1
273039	-0.856	-0.933	0.145	-0.958	464.1	220.1	0.856	1
273052	-0.708	-0.654	0.316	-0.946	464.1	201.8	0.708	2
274831	-0.943	-0.9	0.055	-0.955	74.3	41.7	0.943	1
274844	-0.942	-0.898	0.069	-0.948	7	15.4	0.942	1
275761	-0.957	-0.902	0.053	-0.966	59.4	38.2	0.957	1
275762	-0.917	-0.894	0.089	-0.945	94.8	45.1	0.917	1
275829	-0.712	-0.565	0.051	-0.713	8.8	7.2	0.712	2
275830	-0.666	-0.457	0.367	-0.952	517.1	233.4	0.666	2
276586	-0.835	-0.578	0.084	-0.854	22.5	20.6	0.835	1
276669	-0.806	-0.435	0.294	-0.839	7.2	47.5	0.806	1

GRID_ID/ Watershed	neg_NSE	neg_LnNSE	RelBias	neg_r^2	AvgPeak Diff	RMSE	NSE	Evaluation_class
276692	-0.856	-0.898	0.135	-0.931	64.8	30.4	0.856	1
276693	-0.722	-0.83	0.263	-0.915	103.6	41.3	0.722	2
277507	-0.881	-0.926	0.109	-0.929	17.4	12.5	0.881	1
277608	-0.941	-0.866	0.061	-0.951	76.4	42.9	0.941	1
278433	-0.899	-0.956	0.112	-0.936	11.7	13.7	0.899	1
278529	-0.909	-0.658	0.146	-0.942	106	56	0.909	1
278621	-0.812	-0.793	0.133	-0.909	9.3	8.6	0.812	1
279538	-0.871	-0.861	0.114	-0.892	76.9	49.4	0.871	1
279559	-0.852	-0.79	0.227	-0.904	61.3	42.9	0.852	1
279562	-0.817	-0.741	0.14	-0.852	42.6	19	0.817	1
280292	-0.77	-0.786	0.079	-0.783	24.8	62.8	0.77	1
280385	-0.791	-0.248	0.248	-0.918	578.9	387.3	0.791	1
280390	-0.848	-0.712	0.242	-0.937	211	92.9	0.848	1
280393	-0.865	-0.77	0.217	-0.94	197.7	87.7	0.865	1
280471	-0.769	-0.539	0.273	-0.92	43.6	21.1	0.769	1
281326	-0.859	-0.736	0.223	-0.928	173.7	79.7	0.859	1
283068	-0.954	-0.962	0.022	-0.954	4.5	8.9	0.954	1
283076	-0.884	-0.737	0.003	-0.885	33.4	52.3	0.884	1
283085	-0.686	-0.692	0.13	-0.759	18.1	19.6	0.686	2
283108	-0.789	-0.507	0.214	-0.808	7.9	15.5	0.789	1
283171	-0.888	-0.703	0.146	-0.927	168.2	80.1	0.888	1
283191	-0.798	-0.76	0.242	-0.924	43.8	23.7	0.798	1
283270	-0.65	-0.545	0.414	-0.83	92.5	43.2	0.65	2
284009	-0.723	-0.666	0.102	-0.772	88	77.5	0.723	2
284111	-0.886	-0.48	0.188	-0.911	42.1	30.6	0.886	1
285024	-0.865	-0.487	0.194	-0.936	698.1	420.5	0.865	1

GRID_ID/ Watershed	neg_NSE	neg_LnNSE	RelBias	neg_r^2	AvgPeak Diff	RMSE	NSE	Evaluation_class
285893	-0.677	-0.745	0.118	-0.69	1	3.6	0.677	2
287718	-0.896	-0.955	0.072	-0.911	50.8	44.7	0.896	1
288648	-0.802	-0.795	0.225	-0.92	54.5	37.7	0.802	1
288696	-0.81	-0.77	0.175	-0.887	13.6	20.1	0.81	1
289680	-0.77	-0.313	0.283	-0.825	48.9	33.7	0.77	1
291423	-0.962	-0.934	0	-0.969	56.9	136	0.962	1
292368	-0.554	-0.598	0.01	-0.555	0.9	22.2	0.554	3
293277	-0.973	-0.972	0.031	-0.974	2	9.4	0.973	1
293336	-0.849	-0.825	0.22	-0.933	61.5	45.2	0.849	1
294306	-0.89	-0.571	0.153	-0.933	591	391.6	0.89	1
295257	-0.838	-0.884	0.143	-0.887	28.8	12.2	0.838	1
296064	-0.977	-0.965	0.008	-0.98	37.8	182.5	0.977	1
296162	-0.661	-0.564	0.261	-0.74	13.2	12.8	0.661	2
296163	-0.895	-0.583	0.145	-0.932	568.1	383.8	0.895	1
296181	-0.718	-0.671	0.309	-0.807	43	20.8	0.718	2
298862	-0.55	-0.73	0.228	-0.705	66.9	72.7	0.55	3
298994	-0.775	-0.735	0.067	-0.807	117.9	50.3	0.775	1
299877	-0.895	-0.591	0.153	-0.938	619.3	396.2	0.895	1
300715	-0.883	-0.933	0.013	-0.884	0.5	37	0.883	1
301710	-0.855	-0.836	0.127	-0.867	5.4	12.5	0.855	1
302566	-0.982	-0.964	0.019	-0.983	53.7	222.7	0.982	1
304501	-0.82	-0.816	0.258	-0.92	24.5	13.3	0.82	1
305374	-0.947	-0.888	0.089	-0.961	2704.5	2097.8	0.947	1
305386	-0.913	-0.88	0.08	-0.933	18.1	54	0.913	1
306289	-0.951	-0.909	0.071	-0.96	2246.8	2025.3	0.951	1
306295	-0.427	-0.608	0.015	-0.501	8.2	27.4	0.427	4

GRID_ID/ Watershed	neg_NSE	neg_LnNSE	RelBias	neg_r^2	AvgPeak Diff	RMSE	NSE	Evaluation_class
306303	-0.969	-0.886	0.042	-0.977	210	1455	0.969	1
306341	-0.723	-0.741	0.035	-0.788	29.4	18.2	0.723	2
307237	-0.946	-0.891	0.095	-0.961	2886.1	2118.9	0.946	1
307239	-0.955	-0.9	0.001	-0.968	888.7	1749.6	0.955	1
307307	-0.943	-0.935	0.011	-0.949	255.1	184.6	0.943	1
308147	-0.7	-0.646	0.129	-0.797	4.6	18.6	0.7	2
308152	-0.756	-0.795	0.049	-0.775	0.4	16.8	0.756	1
308235	-0.887	-0.928	0.138	-0.939	511	244.3	0.887	1
310044	-0.945	-0.896	0.095	-0.96	2946	2139.3	0.945	1
310045	-0.958	-0.908	0.002	-0.97	899.5	1680	0.958	1
310073	-0.869	-0.888	0.106	-0.911	64.8	57.6	0.869	1
310919	-0.908	-0.948	0	-0.909	6.5	58.9	0.908	1
310921	-0.904	-0.945	0.03	-0.905	17.5	60.5	0.904	1
310923	-0.839	-0.911	0.115	-0.894	56.9	63	0.839	1
311002	-0.772	-0.847	0.211	-0.901	120.4	78.6	0.772	1
311055	-0.839	-0.913	0.092	-0.903	38.6	22.7	0.839	1
311853	-0.797	-0.876	0.084	-0.857	48.5	52.2	0.797	1
311910	-0.749	-0.721	0.109	-0.789	16.2	17.1	0.749	2
311938	-0.918	-0.795	0.129	-0.951	998.3	547.7	0.918	1
312865	-0.911	-0.838	0.139	-0.955	1236.3	630.6	0.911	1
312881	-0.765	-0.811	0.115	-0.837	21	30.6	0.765	1
312890	-0.868	-0.853	0.156	-0.886	44.7	93.3	0.868	1
314674	-0.811	-0.877	0.042	-0.85	54.9	99.4	0.811	1
314689	-0.931	-0.563	0.11	-0.965	262.4	632.5	0.931	1
314690	-0.939	-0.888	0.101	-0.961	1400.4	719.7	0.939	1
314744	-0.898	-0.731	0.063	-0.903	63.8	64.7	0.898	1

GRID_ID/ Watershed	neg_NSE	neg_LnNSE	RelBias	neg_r^2	AvgPeak Diff	RMSE	NSE	Evaluation_class
315554	-0.92	-0.915	0.062	-0.932	28.9	94.9	0.92	1
315609	-0.821	-0.853	0.007	-0.854	36.6	97.3	0.821	1
315629	-0.497	-0.655	0.085	-0.594	3.1	8.5	0.497	4
318355	-0.741	-0.797	0.121	-0.798	8.1	22	0.741	2
318377	-0.621	-0.712	0.14	-0.733	97.6	128.9	0.621	3
318435	-0.938	-0.92	0.038	-0.94	234.4	218.6	0.938	1
318437	-0.937	-0.916	0.044	-0.939	246.3	221.1	0.937	1
318444	-0.936	-0.904	0.078	-0.941	233.4	148.6	0.936	1
319271	-0.784	-0.854	0.153	-0.85	86	108.7	0.784	1
319274	-0.847	-0.885	0.069	-0.86	52.6	71.1	0.847	1
319336	-0.939	-0.888	0.102	-0.961	1400.1	720	0.939	1
319372	-0.91	-0.891	0.083	-0.918	140.2	95	0.91	1
320272	-0.923	-0.791	0.146	-0.963	1596.8	805.8	0.923	1
320301	-0.903	-0.895	0.119	-0.927	155.9	94.6	0.903	1
321171	-0.941	-0.9	0.092	-0.953	1847.3	1534.3	0.941	1
321210	-0.922	-0.787	0.148	-0.963	1598.3	809	0.922	1
321270	-0.905	-0.919	0.076	-0.916	7.8	10	0.905	1
322084	-0.672	-0.809	0.128	-0.796	33.8	50.4	0.672	2
322137	-0.893	-0.812	0.034	-0.931	672.6	782.1	0.893	1
322976	-0.816	-0.835	0.205	-0.888	60.5	67.3	0.816	1
322988	-0.565	-0.757	0.194	-0.705	32.7	35.3	0.565	3
323011	-0.614	-0.755	0.161	-0.77	38.2	53.9	0.614	3
323056	-0.634	-0.62	0.282	-0.738	19.4	28.7	0.634	3
323945	-0.738	-0.765	0.112	-0.787	27.6	63.5	0.738	2
324023	-0.852	-0.872	0.127	-0.876	160.1	82.9	0.852	1
324864	-0.609	-0.652	0.146	-0.698	9	30.4	0.609	3

GRID_ID/ Watershed	neg_NSE	neg_LnNSE	RelBias	neg_r^2	AvgPeak Diff	RMSE	NSE	Evaluation_class
324872	-0.778	-0.819	0.021	-0.815	20.4	56.3	0.778	1
324881	-0.941	-0.896	0.093	-0.954	1780.2	1520.8	0.941	1
326681	-0.912	-0.927	0.101	-0.927	8.1	29.1	0.912	1
328577	-0.771	-0.83	0.067	-0.819	20.7	44.4	0.771	1
329504	-0.787	-0.819	0.006	-0.815	8.4	42.4	0.787	1
330431	-0.758	-0.682	0.089	-0.77	16.5	22.8	0.758	1
330509	-0.892	-0.862	0.136	-0.929	91.4	51.8	0.892	1
330511	-0.828	-0.829	0.208	-0.933	94.9	54	0.828	1
331341	-0.788	-0.87	0.008	-0.803	14.9	27.1	0.788	1
331375	-0.941	-0.894	0.095	-0.954	1776.1	1520.3	0.941	1
333171	-0.876	-0.846	0.102	-0.904	23	37	0.876	1
334153	-0.898	-0.891	0.042	-0.902	57.5	56.3	0.898	1
334156	-0.94	-0.892	0.096	-0.953	1698.3	1494.6	0.94	1
335078	-0.902	-0.894	0.087	-0.916	68	50.8	0.902	1
335148	-0.807	-0.789	0.104	-0.817	6.7	56.2	0.807	1
335163	-0.947	-0.92	0.008	-0.947	186.1	284.1	0.947	1
336057	-0.865	-0.847	0.059	-0.918	133.9	129.7	0.865	1
336058	-0.872	-0.819	0.029	-0.917	117.8	126.4	0.872	1
336059	-0.863	-0.825	0.038	-0.913	166.6	127.9	0.863	1
336068	-0.9	-0.837	0.01	-0.91	50.6	115.8	0.9	1
336109	-0.938	-0.893	0.008	-0.944	67.5	188.6	0.938	1
336993	-0.888	-0.844	0.046	-0.916	110.5	122.5	0.888	1
336994	-0.887	-0.854	0.055	-0.916	164.5	123.6	0.887	1
337008	-0.876	-0.771	0.134	-0.892	16.1	18	0.876	1
337038	-0.954	-0.902	0.043	-0.959	15.9	152.6	0.954	1
337912	-0.875	-0.786	0.002	-0.916	116.3	128.7	0.875	1

GRID_ID/ Watershed	neg_NSE	neg_LnNSE	RelBias	neg_r^2	AvgPeak Diff	RMSE	NSE	Evaluation_class
337936	-0.868	-0.828	0.088	-0.876	5.7	14.6	0.868	1
338768	-0.843	-0.893	0.031	-0.847	55.6	128.1	0.843	1
338774	-0.794	-0.829	0.041	-0.799	2.6	68.4	0.794	1
338800	-0.905	-0.886	0.078	-0.914	41.5	36.6	0.905	1
338835	-0.876	-0.67	0.068	-0.911	82.9	132.6	0.876	1
338837	-0.841	-0.503	0.069	-0.897	134.3	142.5	0.841	1
339721	-0.729	-0.894	0.208	-0.884	22.5	14.2	0.729	2
340659	-0.939	-0.889	0.098	-0.953	1661.6	1473.7	0.939	1
340673	-0.934	-0.897	0.109	-0.952	1764.2	1453.2	0.934	1
340674	-0.965	-0.931	0.052	-0.969	516.1	1036.7	0.965	1
340725	-0.942	-0.918	0.05	-0.946	7.8	304.2	0.942	1
340754	-0.886	-0.895	0.008	-0.888	14.2	19.3	0.886	1
341590	-0.952	-0.908	0.111	-0.974	1456.6	1189.4	0.952	1
341591	-0.931	-0.881	0.118	-0.952	1853.2	1486.3	0.931	1
342512	-0.922	-0.868	0.006	-0.942	27.4	32.9	0.922	1
342575	-0.946	-0.924	0.025	-0.947	43.6	307.8	0.946	1
342577	-0.927	-0.9	0.072	-0.938	265.5	356.4	0.927	1
344416	-0.943	-0.93	0.024	-0.948	166.5	350.1	0.943	1
345264	-0.808	-0.818	0.096	-0.84	1.6	33.6	0.808	1
345372	-0.736	-0.676	0.076	-0.754	5.4	15.5	0.736	2
345393	-0.916	-0.843	0.094	-0.924	55.7	69.5	0.916	1
346213	-0.787	-0.829	0.226	-0.895	75.2	39.7	0.787	1
346318	-0.916	-0.882	0.027	-0.918	24.4	188.5	0.916	1
346320	-0.894	-0.809	0.075	-0.904	39.9	80.7	0.894	1
347128	-0.594	-0.69	0.136	-0.712	69.3	85.7	0.594	3
347228	-0.876	-0.879	0.163	-0.907	243.8	230.6	0.876	1

GRID_ID/ Watershed	neg_NSE	neg_LnNSE	RelBias	neg_r^2	AvgPeak Diff	RMSE	NSE	Evaluation_class
348177	-0.927	-0.829	0.116	-0.945	66.2	49.5	0.927	1
349059	-0.9	-0.74	0.092	-0.907	29.1	25.1	0.9	1
349968	-0.604	-0.558	0.046	-0.624	10	12.1	0.604	3
350030	-0.853	-0.82	0.16	-0.889	68.1	75.1	0.853	1
350837	-0.547	-0.571	0.138	-0.642	60.6	40.5	0.547	3
350845	-0.882	-0.876	0.066	-0.897	9	63.8	0.882	1
350930	-0.854	-0.792	0.109	-0.876	7.6	22	0.854	1
351773	-0.891	-0.879	0.018	-0.895	14.4	60.7	0.891	1
351774	-0.874	-0.869	0.084	-0.896	12	62.2	0.874	1
351775	-0.876	-0.868	0.07	-0.893	6	61.2	0.876	1
351776	-0.897	-0.894	0.048	-0.902	4	49.7	0.897	1
351852	-0.91	-0.899	0.098	-0.921	202.6	256	0.91	1
351853	-0.92	-0.902	0.081	-0.927	93.3	246.8	0.92	1
352762	-0.941	-0.921	0.028	-0.948	252.1	357	0.941	1
355510	-0.846	-0.784	0.165	-0.883	49.3	68.1	0.846	1
355524	-0.903	-0.833	0.026	-0.905	12.7	43.6	0.903	1
355547	-0.939	-0.923	0.027	-0.945	219.9	368.6	0.939	1
356460	-0.954	-0.814	0.041	-0.956	6.2	53.6	0.954	1
356472	-0.945	-0.927	0.02	-0.948	119.3	372	0.945	1
356494	-0.941	-0.65	0.049	-0.948	2.4	12.5	0.941	1
356521	-0.678	-0.575	0.415	-0.899	50.1	37.3	0.678	2
358325	-0.875	-0.823	0.208	-0.943	1957.8	1376.8	0.875	1
360182	-0.905	-0.848	0.196	-0.966	1683.7	1216.1	0.905	1
361108	-0.794	-0.773	0.276	-0.922	1486.1	988.5	0.794	1
361111	-0.936	-0.886	0.109	-0.95	385.3	451	0.936	1
362969	-0.933	-0.878	0.104	-0.945	224.7	408.3	0.933	1

GRID_ID/ Watershed	neg_NSE	neg_LnNSE	RelBias	neg_r^2	AvgPeak Diff	RMSE	NSE	Evaluation_class
362971	-0.952	-0.896	0.112	-0.969	254.8	334.8	0.952	1
363936	-0.727	-0.809	0.273	-0.854	104.1	53.7	0.727	2
364854	-0.861	-0.857	0.142	-0.879	60.9	146.2	0.861	1
368579	-0.773	-0.848	0.237	-0.849	57.7	28.1	0.773	1
369507	-0.711	-0.865	0.096	-0.802	14.6	10.4	0.711	2
376897	-0.736	-0.504	0.371	-0.921	107.3	105.1	0.736	2
380608	-0.824	-0.834	0.279	-0.905	36.3	57.9	0.824	1
384329	-0.747	-0.785	0.217	-0.808	25.6	41.1	0.747	2
386157	-0.709	-0.808	0.326	-0.899	1538.8	866.1	0.709	2
389890	-0.673	-0.842	0.317	-0.816	99.4	54.3	0.673	2
391743	-0.908	-0.91	0.15	-0.93	29.4	109.4	0.908	1
395432	-0.633	-0.7	0.349	-0.842	82.1	49	0.633	3
401928	-0.7	-0.82	0.304	-0.865	882.4	633.8	0.7	2

Appendix D: Example Calculation

Lower Clark Fork is used as an example in the rest of this section to explain the calculations of the final depletion values for Lower Clark Fork basin. For more details about other subareas, refer to Section 4 of this report where information by river basin is provided.

Step 1: Identification of crop mix.

Crop distribution for each subbasin was determined using the spatially explicit WSDA Agricultural Land Use Geodatabase (within Washington) and the USDA Cropland Data Layer (U.S. outside of Washington). For Canada, the Annual Crop Inventory was used. (See 2.1.3.) Note that while all crops occurring in a subbasin were included in calculations, only those comprising at least 1% of irrigated area are included in tables.

Subarea 3 - Lower Clark Fork

Crop	Irrigated area (acres)	Percent of total
Alfalfa Hay	10,713	79.7%
Pasture	2,616	19.5%
Total	13,447	

Step 2: Identification of irrigation extent

A remote-sensing based approach modeled after the MODIS Irrigated Agriculture Dataset (MIrAD) was used to determine irrigated acres. See 2.1.4.1.

A county fraction was calculated representing the portion of the county's irrigated acres that fall within the subarea of interest.

> For example, for Flathead County in Montana, 1% of Flathead County's irrigated area (or 139 acres) falls within the Lower Clark Fork subarea.

Subarea 3 - Lower Clark Fork

State	County	County Fraction	Contributing Irrigated Acres (MIrAD)
Montana	Flathead	0.01	139
Montana	Lincoln	0.07	263
Montana	Mineral	1.00	649
Montana	Missoula	0.51	8,525
Montana	Sanders	0.06	1,174
		TOTAL	10,749

Step 3: Meteorological input data

See 2.1.1

Step 4: Calculation of monthly average crop water demand per 1000 acres

This step uses a spatially explicit VIC-CropSyst model (1/16° resolution) driven by spatially explicit weather data at the same resolution (see Step 3). The VIC-CropSyst model uses the Penman-Monteith equation and dynamically calculates crop water demand by month for each crop in the subbasin. See 2.3.sert

Subarea 3 - Lower Clark Fork

Water requirement (ac-ft/1000 acres) by month for all crops

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Total Water Required by Crops	0.0	0.0	0.0	2.8	36.0	126.4	382.3	415.4	231.3	6.2	0.0	0.0	1,200
Diversion distribution %	0.0%	0.0%	0.0%	0.2%	3.0%	10.5%	31.9%	34.6%	19.3%	0.5%	0.0%	0.0%	100.0%

Water requirement by month (inches) for crops making up 1% or more of irrigated area

Crop	% irrig. area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Alfalfa Hay	79.7%	0.0	0.0	0.0	0.0	0.5	1.6	4.8	5.4	3.0	0.1	0.0	0.0	15.3
Pasture	19.5%	0.0	0.0	0.0	0.0	0.3	1.1	3.5	3.6	2.0	0.0	0.0	0.0	10.6

Step 5: Estimation of diversions per 1000 acres for each sub region

Calculated as the output of Step 4 divided by diversion efficiency.

For Subarea 3 – Lower Clark Fork, the diversion efficiency is assumed to be 68% for sprinkler irrigation and 50% for gravity irrigation. See 2.1.5.

For sprinkler irrigation on an annual basis, for each 1,200 ac-ft of water required by crops, 1,200 ac-ft / 68% must be diverted, or 1,765 ac-ft.

For gravity irrigation on an annual basis, for each 1,200 ac-ft of water required by crops, 1,200 ac-ft / 50% must be diverted, or 2,401 ac-ft. (Note that the value here is 2.401 rather than 2.400 because the values presented in tables and text are rounded, but original values are used for calculations).

Step 6: Estimation of return flows per 1000 acres for each subregion

Calculated as the output of Step 5 multiplied by return flow efficiency. See 2.1.5.

For Subarea 3 – Lower Clark Fork, the return efficiency is assumed to be 28% for sprinkler and 45% for gravity.

For sprinkler irrigation on an annual basis, for each 1,765 ac-ft of water diverted, 1,765 * 28% is returned, or 494 ac-ft.

For gravity irrigation on an annual basis, for each 2,401 ac-ft of water diverted, 2,401 * 45% is returned, or 1,080 ac-ft.

Subarea 3 - Lower Clark Fork

	Sprinkler	Gravity
Total Volume of Water Required by crops (ac-ft per 1000 ac)	1200	1200
Diversion Efficiency (%)	68%	50%
Required Diversion (ac-ft per 1000 ac)	-1765	-2401
Return Efficiency (%)	28%	45%
Return Flow (ac-ft per 1000 ac)	494	1080

Step 7 - Estimation of monthly average depletions as combination of Steps 5 and 6.

The calculations from Steps 5 and 6 were also completed on a monthly basis, allowing for depletion values by month for sprinkler and gravity irrigation systems.

Subarea 3 - Lower Clark Fork

Sprinkler System								Gravity System						
Month	DIVERSION		RETURN FLOW		DEPLETION			Month	DIVERSION		RETURN FLOW		DEPLETION	
	%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	cfs per 1000 ac			%	ac-ft per 1000 ac	%	ac-ft per 1000 ac	ac-ft per 1000 ac	cfs per 1000 ac
JAN	0.0%	0	2.0%	10	10	0.2		JAN	0.0%	0	2.0%	22	22	0.4
FEB	0.0%	0	1.0%	5	5	0.1		FEB	0.0%	0	1.0%	11	11	0.2
MAR	0.0%	0	0.0%	0	0	0.0		MAR	0.0%	0	0.0%	0	0	0.0
APR	0.2%	-4	0.0%	0	-4	-0.1		APR	0.2%	-6	0.0%	0	-6	-0.1
MAY	3.0%	-53	6.0%	30	-23	-0.4		MAY	3.0%	-72	6.0%	65	-7	-0.1
JUN	10.5%	-186	15.0%	74	-112	-1.9		JUN	10.5%	-253	15.0%	162	-91	-1.5
JUL	31.9%	-562	18.0%	89	-473	-7.7		JUL	31.9%	-765	18.0%	194	-570	-9.3
AUG	34.6%	-611	20.0%	99	-512	-8.3		AUG	34.6%	-831	20.0%	216	-615	-10.0
SEP	19.3%	-340	16.0%	79	-261	-4.4		SEP	19.3%	-463	16.0%	173	-290	-4.9
OCT	0.5%	-9	11.0%	54	45	0.7		OCT	0.5%	-12	11.0%	119	106	1.7
NOV	0.0%	0	7.0%	35	35	0.6		NOV	0.0%	0	7.0%	76	76	1.3
DEC	0.0%	0	4.0%	20	20	0.3		DEC	0.0%	0	4.0%	43	43	0.7
Total	100.0%	-1765	100.0%	494	-1271			Total	100.0%	-2401	100.0%	1080	-1320	

Step 8 - Surface and ground water irrigation split fraction

County Level USGS water use surveys (U.S.). The U.S. time series of split fractions were smoothed to address data issues (unreasonably large year-to-year fluctuations).The smoothed surface water fraction was then aggregated to the subarea level as described in 2.1.4.1. See 2.1.6.

Subarea 3 - Lower Clark Fork

State	County	Surface Fraction (Smoothed)	Sprinkler	Micro	Gravity	Total Irr Area (USGS)
			1000 acres			
Montana	Flathead	0.84	37.9	0.0	3.7	41.6
Montana	Lincoln	0.98	3.1	0.0	2.0	5.0
Montana	Mineral	0.89	0.2	0.0	0.3	0.5
Montana	Missoula	0.96	24.9	0.0	6.2	31.1
Montana	Sanders	0.98	20.6	0.0	0.7	21.3

To aggregate the county level data to the subbasin level, the following equation was used:

sw_fr_pred = sum(county_fr*sw_pred*total_ir)/sum(county_fr*total_ir)

sw_fr_pred = smoothed surface water fraction at the subarea level

county_fr = fraction of irrigated area in each county that is contained within the subarea

sw_pred = smoothed surface water fraction at the county level

total_ir = total irrigated area at the county level

For Lower Clark Fork,

sw_fr_pred = [(0.01*0.84*41.63) + (0.07*0.98*5) + (1.00*0.89*0.47) + (0.51*0.96*31.08) + (0.06*0.98*21.31)] / [(0.01*41.63) + (0.07*5) + (1.00*0.47) + (0.51*31.08) + (0.06*21.31)]

=0.96

Step 9 - Split surface water irrigated areas between sprinkler and gravity irrigation types for each sub region.

County level USGS water use surveys were used for this step. See 2.1.7.

Similarly, fractions of gravity irrigation (as a fraction of total irrigation) were aggregated from the county level to the subbasin level, using the following formula.

sur_fr = sum(county_fr*flood_ir)/sum(county_fr*total_ir)

sur_fr = fraction of gravity irrigation at the subarea level

county_fr = fraction of irrigated area in each county that is contained within the subarea

flood_ir = acres of gravity irrigation at a county level

For Lower Clark Fork,

sur_fr = [(0.01*3.7) + (0.07*1.95) + (1.00*0.32) + (0.51*6.2) + (0.06*0.72)] / [(0.01*41.63) + (0.07*5) + (1.00*0.47) + (0.51*31.08) + (0.06*21.31)]

=0.20

Fractions for sprinkler and micro irrigation types are aggregated to the subbasin level in a similar manner.

To calculate surface water irrigated acres by irrigation type, the following formula was used (example shown for gravity irrigation only):

sw_sur_ac = sw_fr_pred * sur_fr * irr_area

sw_sur_ac = surface water gravity irrigation (acres)

sw_fr_pred = smoothed surface water fraction at the subarea level

sur_fr = fraction of gravity irrigation at the subarea level

irr_area = irrigated area in subbasin as determined by MIrAD

Step 10 - Create time series of surface water irrigated acres for sprinkler and gravity irrigation types and calculate the difference in irrigated acres between 2018 and each historical year

The 2008 and 2018 data are calculated based on irrigation extent split calculations for those years as detailed in previous steps. For prior years, data from the 2010 Modified Flows was used. However, an adjustment was made for the years 1980 – 2008. This was based on the change in surface water irrigation split fraction after the smoothing discussed in Step 8. See 2.1.8.

Subarea 3 - Lower Clark Fork

	Irrigated acres (1000s of acres)			
Year	Sprinkler	Micro	Gravity	Total
1925	0.0	0.0	15.3	15.3
1928	0.0	0.0	15.5	15.5
1950	0.0	0.0	20.0	20.0
1966	8.0	0.0	19.0	27.0
1978	21.1	0.0	8.8	29.9
1988	13.5	0.0	5.6	19.1
1999	11.3	0.0	4.3	15.6
2008	5.7	0.0	2.2	7.9
2018	8.2	0.0	2.1	10.3

For each subbasin, a summary table was created for comparison of original values for 2010 Modified Flows, updates to 2010 Modified Flows irrigated area and surface water split using the methodology described in this report, and the values calculated using this methodology for 2020 Modified Flows.

Subarea 3 - Lower Clark Fork

	2010	**2010 (revised)**	**2020**
Total irrigated area (1000 acres)	15.6	8.6	10.7
Surface water split (% SW)	90%	92%	92%
Surface water irrigated area (1000 acres)	14.1	7.9	10.3
Crop water demand (ac ft per 1000 acres)	1,642		1,200

Appendix E: Crop Parameters

Appendix E.1: Main Crop Parameters for CropSyst Simulation

[crop]	Alfalfa	Barley_ spring	Canola	Clover_ hay	Corn_grain
harvest_part	complete	grain	grain	complete	grain
C_species	C3	C3	C3	C3	C4
land use	pasture	small_grain	row_crops	pasture	row_crops
[growth]					
TUE_scaling_coef (-)	0.4	0.5	0.5	0.50	0.40
TUE_at_1pKa_VPD (g BM/kg)	7.0	6.5	3.0	2.8	8.0
RUE_global (g/MJ)	1.2	1.5	1.3	1.1	2.2
min_tolerable_temp (°C)	0.0	0.0	0.0	0.0	0.0
max_tolarable_temp (°C)	45.0	40.0	45.0	45.0	40.0
low_threshold_limit_temp (°C)	10.0	15.0	10.0	10.0	10.0
high_threshold_limit_temp (°C)	25.0	28.0	25.0	25.0	30.0
LWP_reduces_canopy_expansion (kPa)	-1100	-1000	-800	-1100	-1000
LWP_stops_canopy_expansion (kPa)	-1300	-1200	-1200	-1300	-1200
harvest index (-)	1.0	0.48	0.45	1.0	0.53
[transpiration]					
ET_crop_coef (-)	1.2	1.05	1.1	1.03	1.20
max_water_uptake (mm/day)	12.0	10.0	8.5	12.0	10.0
stomatal_closure_leaf_water_pot (kPa)	-1200	-1300	-1000	-1200	-1000
wilt_leaf_water_pot (kPa)	-1800	-1800	-1500	-1800	-1600
kc (-)	0.50	0.50	0.50	0.50	0.50
[canopy_cover]					
initial fraction	0.01	0.01	0.01	0.01	0.01
maximum fraction	0.95	0.95	0.95	0.95	0.95
[phenology]					
maturity_significant	FALSE	TRUE	TRUE	FALSE	TRUE
clipping_resets	TRUE	FALSE	FALSE	TRUE	FALSE
emergence (°C day)	25	83	120	100	75
peak_LAI (°C day)	900	1067	500	1070	630
max_root_depth (°C day)	4300	1067	500	1070	630
flowering (°C day)	--	1117	540	--	700
filling (°C day)	--	1233	670	--	800
beginning senescence (°C day)	--	1283	640	--	900
maturity (full senescence) (°C day)	--	1900	1700	--	1500
base_temp (°C)	5.0	3.0	3.0	0.0	8.0
cutoff_temp (°C)	22.0	22.0	22.0	34.0	30.0
[root]					
max_root_depth (m)	2.0	1.5	1.5	0.9	1.5
root_lenght_at_emergence (cm)	180.0	5.0	3.0	85.0	2.0

[crop]	**Corn_sweet**	**Dry_bean**	**Grass_ pasture**	**Hops**	**Lentil**
harvest_part	grain	grain	complete	complete	grain
C_species	C4	C3	C3	C3	C3
land use	row_crop	row_crop	pasture	row_crop	row_crop
[growth]					
TUE_scaling_coef (-)	0.50	0.5	0.5	0.5	0.5
TUE_at_1pKa_VPD (g BM/kg)	8.0	3.0	3.0	3.75	2.0
RUE_global (g/MJ)	2.1	1.1	1.3	1.5	1.1
min_tolerable_temp (°C)	5.0	0.0	0.0	0.0	0.0
max_tolarable_temp (°C)	45.0	45.0	45.0	40.0	45.0
low_threshold_limit_temp (°C)	32.0	10.0	10.0	10.0	10.0
high_threshold_limit_temp (°C)	36.0	25.0	25.0	30.0	25.0
LWP_reduces_canopy_expansion (kPa)	-1200	-800	-1100	-1000	-800
LWP_stops_canopy_expansion (kPa)	-1500	-1200	-1300	-1200	-1200
harvest index (-)	0.45	0.45	1.0	0.3	0.35
[transpiration]					
ET_crop_coef (-)	1.15	1.15	1.04	1.10	1.05
max_water_uptake (mm/day)	10.0	8.5	12.5	10.0	10.0
stomatal_closure_leaf_water_pot (kPa)	-1300	-1000	-1200	-1200	-1200
wilt_leaf_water_pot (kPa)	-1600	-1500	-1800	-1600	-1500
kc (-)	0.55	0.50	0.45	0.5	0.5
[canopy_cover]					
initial fraction	0.01	0.1	0.1	0.1	0.1
maximum fraction	0.90	0.95	0.95	0.95	0.85
[phenology]					
maturity_significant	TRUE	TRUE	FALSE	TRUE	TRUE
clipping_resets	FALSE	FALSE	TRUE	FALSE	FALSE
emergence (°C day)	30	100	100	1	100
peak_LAI (°C day)	475	600	870	2100	650
max_root_depth (°C day)		650	870	1113	640
flowering (°C day)	490	650	--	1313	700
filling (°C day)	570	740	--	1461	740
beginning senescence (°C day)	480	700	--	2120	740
maturity (full senescence) (°C day)	1200	2100	--	2125	1600
base_temp (°C)	8.0	3.0	0.0	5.0	3.0
cutoff_temp (°C)	26.0	22.0	24.0	23.0	22.0
[root]					
max_root_depth (m)	1.5	0.6	0.9	1.5	0.6
root_lenght_at_emergence (cm)	3.0	2.0	80.0	5.0	2.0

[crop]	Mint	Oats	Onion	Peas_dry	Potato
harvest_part	leaf	grain	bulb	grain	tuber
C_species	C3	C3	C3	C3	C3
land use	pasture	small_grain	row_crop	small_grain	row_crop
[growth]					
TUE_scaling_coef (-)	0.5	0.45	0.45	0.5	0.5
TUE_at_1pKa_VPD (g BM/kg)	3.5	6.0	7.5	5.0	5.0
RUE_global (g/MJ)	1.6	1.6	1.5	1.15	2.2
min_tolerable_temp (°C)	7.0	0.0	0.0	0.0	0.0
max_tolarable_temp (°C)	40.0	45.0	45.0	45.0	45.0
low_threshold_limit_temp (°C)	20.0	10.0	10.0	10.0	10.0
high_threshold_limit_temp (°C)	40.0	25.0	25.0	25.0	30.0
LWP_reduces_canopy_expansion (kPa)	-1000	-800	-800	-800	-800
LWP_stops_canopy_expansion (kPa)	-1400	-1200	-1200	-1200	-1200
harvest index (-)	0.95	0.53	0.40	0.45	0.80
[transpiration]					
ET_crop_coef (-)	0.9	1.05	1.0	1.05	1.1
max_water_uptake (mm/day)	14.0	10.0	10.0	10.0	12.0
stomatal_closure_leaf_water_pot (kPa)	-1300	-1300	-1200	-1200	-700
wilt_leaf_water_pot (kPa)	-1600	-2000	-1500	-1500	-1200
kc (-)	0.5	0.50	0.40	0.50	0.55
[canopy_cover]					
initial fraction	0.1	0.01	0.01	0.01	0.01
maximum fraction	0.95	0.95	0.95	0.95	0.88
[phenology]					
maturity_significant	TRUE	TRUE	TRUE	TRUE	TRUE
clipping_resets	FALSE	FALSE	FALSE	FALSE	FALSE
emergence (°C day)	25	86	25	65	200
peak_LAI (°C day)	830	555	795	720	1350
max_root_depth (°C day)	300	555	795	750	1313
flowering (°C day)	950	615	--	750	636
filling (°C day)	1000	675	--	850	665
beginning senescence (°C day)	1500	705	860	900	1450
maturity (full senescence) (°C day)	1700	1555	1253	2100	2115
base_temp (°C)	5.0	3.0	10.0	3.0	2.0
cutoff_temp (°C)	30.0	22.0	30.0	25.0	26.0
[root]					
max_root_depth (m)	2.0	2.0	0.6	0.6	2.0
root_lenght_at_emergence (cm)	150.0	3.0	2.0	2.0	2.0

[crop]	Radish	Sod_seed_ grass	Triticale	Wheat_ spring	Wheat_ winter
harvest_part	root	grain	grain	grain	grain
C_species	C3	C3	C3	C3	C3
land use	row_crop	pasture	small-grain	small_grain	small_grain
[growth]					
TUE_scaling_coef (-)	0.5	0.5	0.45	0.5	0.55
TUE_at_1pKa_VPD (g BM/kg)	8.9	5.0	6.8	5.25	4.3
RUE_global (g/MJ)	1.6	1.6	1.5	1.5	1.5
min_tolerable_temp (°C)	0.0	0.0	0.0	0.0	0.0
max_tolarable_temp (°C)	45.0	45.0	40.0	40.0	40.0
low_threshold_limit_temp (°C)	10.0	10.0	10.0	10.0	10.0
high_threshold_limit_temp (°C)	25.0	25.0	30.0	30.0	30.0
LWP_reduces_canopy_expansion (kPa)	-800	-1100	-1000	-1000	-1000
LWP_stops_canopy_expansion (kPa)	-1200	-1300	-1200	-1200	-1200
harvest index (-)	0.46	0.2	0.48	0.48	0.45
[transpiration]					
ET_crop_coef (-)	1.0	1.04	1.1	1.1	1.1
max_water_uptake (mm/day)	8.5	8.5	10.0	10.0	10.0
stomatal_closure_leaf_water_pot (kPa)	-1000	-1200	-1200	-1200	-1200
wilt_leaf_water_pot (kPa)	-1500	-1800	-1600	-1600	-1600
kc (-)	0.45	0.45	0.50	0.50	0.50
[canopy_cover]					
initial fraction	0.01	0.01	0.01	0.001	0.01
maximum fraction	0.95	0.95	0.95	0.95	0.95
[phenology]					
maturity_significant	TRUE	TRUE	TRUE	TRUE	TRUE
clipping_resets	FALSE	FALSE	FALSE	FALSE	FALSE
emergence (°C day)	25	20	85	85	185
peak_LAI (°C day)	420	410	940	525	2100
max_root_depth (°C day)	420	410	1113	252	2100
flowering (°C day)	500	430	1110	565	2143
filling (°C day)	600	600	1233	722	2382
beginning senescence (°C day)	800	600	1024	806	2382
maturity (full senescence) (°C day)	1000	1300	2235	1390	3325
base_temp (°C)	3.0	5.0	3.0	3.0	0.0
cutoff_temp (°C)	22.0	24.0	23.0	23.0	23.0
[root]					
max_root_depth (m)	0.15	0.6	1.5	1.5	1.7
root_lenght_at_emergence (cm)	2.0	10.0	2.0	2.0	2.0

Appendix E.2: Main Crop Parameter Used in this Study for CropSyst Simulation (Fruit Crops)

[crop]	Apple	Blueberry	Cherry	Grape_wine	Pear
harvest_part	fruit	fruit	fruit	fruit	fruit
C_species	C3	C3	C3	C3	C3
[growth]					
TUE_scaling_coef (-)	0.5	0.5	0.5	0.5	0.5
TUE_at_1pKa_VPD (g BM/kg)	5.0	5.0	5.0	5.0	5.0
RUE_global (g/MJ)	1.6	1.6	1.6	1.6	1.6
min_tolerable_temp (°C)	3.0	3.0	3.0	3.0	3.0
max_tolarable_temp (°C)	45.0	45.0	45.0	45.0	45.0
low_threshold_limit_temp (°C)	10.0	10.0	10.0	10.0	10.0
high_threshold_limit_temp (°C)	25.0	25.0	25.0	25.0	25.0
LWP_reduces_canopy_expansion (kPa)	-800	-800	-800	-800	-800
LWP_stops_canopy_expansion (kPa)	-1200	-1200	-1200	-1200	-1200
harvest index (-)	0.5	0.5	0.5	0.5	0.5
[transpiration]					
ET_crop_coef (-)	1.15	1.05	1.15	1.10	1.15
max_water_uptake (mm/day)	10.0	10.0	10.0	10.0	10.0
stomatal_closure_leaf_water_pot (kPa)	-1200	-1000	-1200	-1200	-1200
wilt_leaf_water_pot (kPa)	-1600	-1600	-1600	-1600	-1600
kc (-)	0.5	0.5	0.5	0.5	0.5
[canopy_cover]					
initial fraction	0.1	0.1	0.1	0.1	0.1
maximum fraction	0.6	0.9	0.6	0.6	0.6
[phenology]					
chill_requirement (hours)	500	1200	600	150	600
bud break (°C day)	300	550	150	100	140
peak_LAI (°C day)	550	1000	550	725	550
flowering (°C day)	250	370	90	185	123
filling (°C day)	260	550	260	300	260
rapid_fruit_growth (°C day)	800	800	1360	800	800
Senescence (°C day)	3500	1501	3500	3500	3500
maturity (°C day)	2700	1500	1360	1200	2340
full_senescence (°C day)	3500	1700	3500	3500	3500
base_temp (°C)	0.0	0.0	0.0	10.0	0.0
cutoff_temp (°C)	25.0	25.0	22.0	25.0	25.0
[root]					
max_root_depth (m)	1.15	0.45	1.0	1.15	1.15
root_lenght_at_emergence (cm)	115.0	45.0	100.0	115.0	115.0
[inactive_period]					
consider_inactive_days	6	3	6	6	6
inducement_temperature (°C)	4.0	4.0	4.0	4.0	4.0

Appendix F: Methodology for Calculating Irrigation Depletion for Columbia Basin Project

A comprehensive return flow study was performed for the Columbia Basin Project (CBP) as part of the 2010 Modified Flows report. We retained a similar methodology, with a few exceptions as described in relevant sections of this appendix, and updated "current" data with 2018 data we received from the U.S. Bureau of Reclamation (USBR) and other sources. In the instances where the 2008 and 2018 data were substantially different, we investigated the 2008 data with input from USBR and made some adjustments to the 2008 data as described in the respective sections below. These adjustments to the 2008 data involved only depletions and return flows associated with McNary Dam. *For clarity and continuity between reports, the descriptive text from the 2010 Level Modified Streamflows (Section 4) is mostly reproduced here "as is." Some text updates were made to provide more detailed information or better clarity or describe changes to the methodology. All the data and tables used in the depletion adjustment calculations (section F.5) have been modified to reflect values for 2020 Level Modified Streamflows. We also added section F.6 which described diversions in more detail and section F.7 which shows depletion comparisons across 2010 and 2020 Level Modified Streamflows.*

F.1 Introduction

The USBR CBP uses water withdrawn from the Franklin D. Roosevelt Reservoir at the Grand Coulee Dam to supply irrigation water to over 671,000 acres of crops in central Washington. A pumping plant diverts water from Franklin D. Roosevelt Reservoir into Banks Lake, where it is stored for irrigation flows to be used by the CBP. The irrigation water is moved throughout the CBP through a series of canals and wasteways (Figure F-1). Not all of the water applied to the crops is used by the plants. The excess water flows back into the wasteways or groundwater and eventually discharges into the Columbia River as return flows. Return flows are accounted for at three different reservoirs on the Columbia River: Wanapum, Priest Rapids, and McNary. Return flows consist of two main parts, (a) surface flow through wasteways and (b) groundwater flows.

F.2 Purpose of Analysis

The purpose of this analysis is to calculate the incremental return flows at Wanapum, Priest Rapids, and McNary projects, labeled WRF6D, PRF6D and MRF6D. Typically a 6D depletion dataset incorporates both diversions and return flows, but for these three areas, the 6D values will be positive every month because they constitute return flows only. Most of the return flows at Wanapum, Priest Rapids, and McNary projects result from irrigation water pumped from the Franklin D. Roosevelt Reservoir at Grand Coulee Dam into Banks Lake. Return flows from irrigation in northern parts of the CBP get stored in the Potholes Reservoir and are reused to irrigate southern parts before this second wave of return flows join the Columbia River. In addition to pumping from the Grand Coulee dam - accounted for in the GCL6D dataset - a small part of the irrigation water for the CBP is supplied by pumping downstream of the confluence of the Snake and Columbia Rivers. This pumping diversion is accounted for in the dataset B236D, as explained further in Section F.4.2

F.3 Columbia Basin Project Overview

The CBP is a multipurpose development located in the central part of the State of Washington. The project contains extensive irrigation works which extend southward from the Grand Coulee Dam across the Columbia Plateau 125 miles to the vicinity of Pasco, Washington where the Snake and Columbia Rivers join.

Principal project features include Grand Coulee Dam, Franklin D. Roosevelt Lake, Grand Coulee Powerplant Complex, switchyards, and a pump-generating plant. Primary irrigation facilities are the Feeder Canal, Banks Lake, the Main, West, and East High and East Low Canals, O'Sullivan Dam, Potholes Reservoir, and Potholes Canal. There are 333 miles of main canals, 1,993 miles of laterals, and 3,498 miles of drains and wasteways on the project. All of the principal features have been constructed, except the East High Canal and the extension of the East Low Canal, on which construction has been deferred.

Figure F-1 shows a map of the Columbia Basin Project. Throughout this report, references are made to various 'blocks' within the Project area, and can be located in the map. Blocks are delineations of irrigated areas.

The widely distributed irrigation works that extend southward from the Grand Coulee Pump-Generating Plant begin with the short feeder canal which carries water to Banks Lake, the equalizing reservoir. This 27-mile–long reservoir occupies the floor of the upper Grand Coulee between North Dam near the town of Coulee Dam, Washington, and Dry Falls Dam in the northern end of the irrigable area. The West, East High, and East Low Canals are fed by the Main Canal and carry water over a large portion of the project area. O'Sullivan Dam, in the central part of the project, created the Potholes Reservoir where return flows from the northern part of the project area are recaptured. The Potholes Canal extends into and serves the southern part of the project area.

Main Canal

The main Canal begins at the headworks of Dry Falls Dam and consists of unlined and concrete-lined sections. Total length of the canal, including siphons, tunnels, and Billy Clapp Lake, is 18.4 miles. The first 1.8 miles from Dry Falls Dam to the Bacon Siphon and Tunnel structures has been increased in capacity from 13,200 to 19,300 cfs. Bacon Siphon and Tunnel structures consist of two siphons, each about 1000 feet long, and two tunnels, each about 2 miles long, that carry the water to Billy Clapp Lake. This lake, some 6 miles long and formed by the construction of the earthfill Pinto Dam is a segment of the canal system. Very difficult and expensive construction of a canal of equal length was thus avoided.

East Low Canal

The East Low Canal, having an initial capacity of 4,500 cfs, also begins at the bifurcation of the Main Canal. The Canal extends southerly in a contour course through the rolling eastern uplands, passes through or near the towns of Moses Lake and Warden, and terminates just east of the Scooteney Reservoir. An extension of the canal, on which construction has been deferred, would have carried water southward and to the east of the towns of Connell, Mesa, and Eltopia.

RECLAMATION
Managing Water in the West

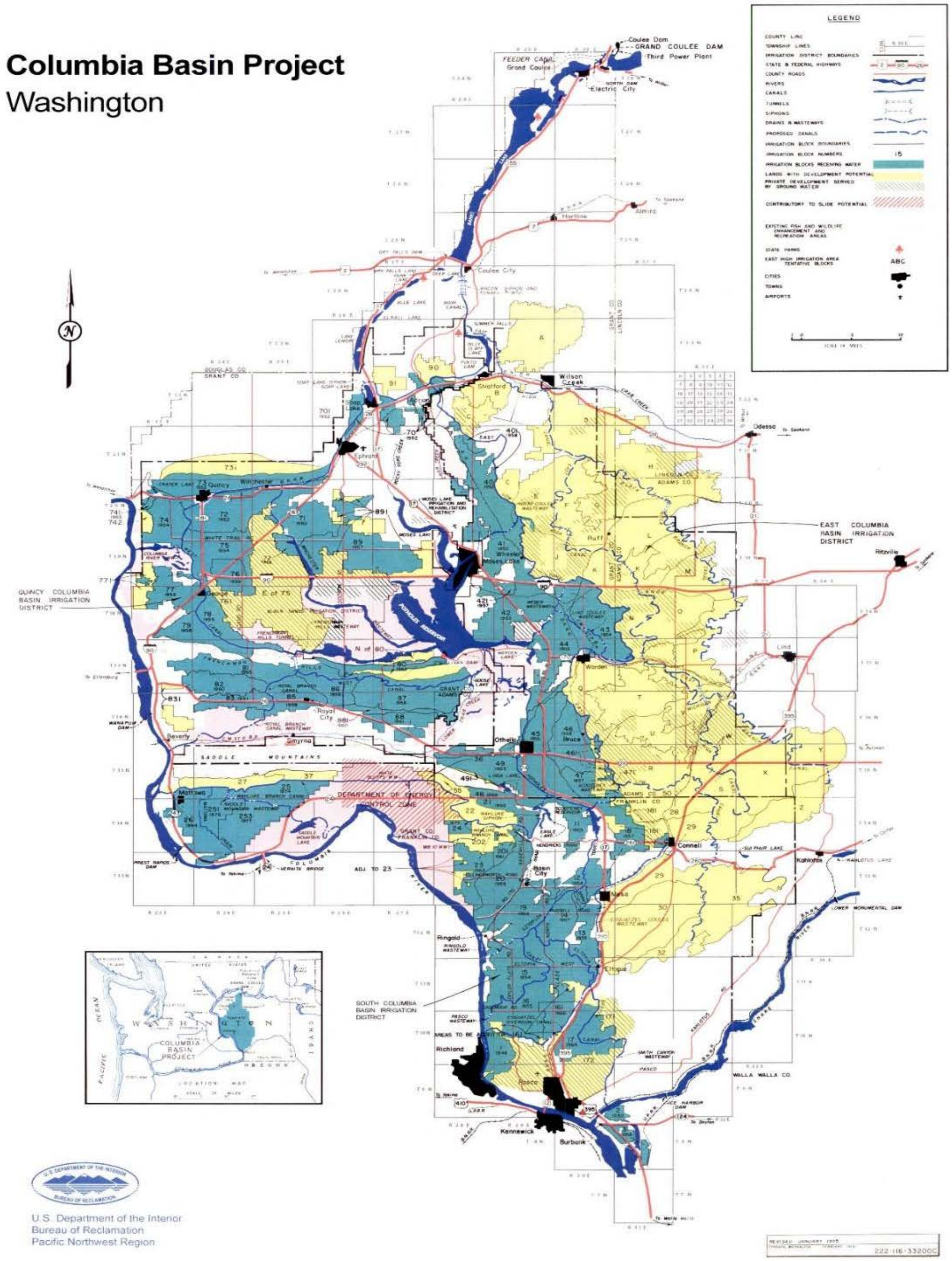

Figure F-1. Columbia Basin Project (USBR 1984)

West Canal

The West Canal has an initial capacity of 5,100 cfs and a length of 82.2 miles. It is one of two canals formed by the bifurcation of the Main Canal. The West Canal skirts the northwest periphery of the project and en-route is carried across the lower Grand Coulee end of Soap Lake. The canal continues around the upper margin of Quincy Basin to the northern base of Frenchman hills, which it penetrates with a 9,000-foot tunnel, ending in an easterly branch across the Royal Slope. The capacity of the canal is reduced progressively as water is diverted into lateral distribution systems built to serve the entire northwestern portion of the project.

O'Sullivan Dam

O'Sullivan Dam, one of the larger zoned earth fill dams in the United States, is on Crab Creek about 15 miles south of Moses Lake. The 27,900 acre Potholes Reservoir formed by the dam collects return flows from all irrigation in the upper portion of the project for reuse in the southern portion. Active storage capacity of the reservoir is 332,200 acre- feet. A system of wasteways has been built on both the West and East Low Canals to provide additional safety for the canals and a means of delivering water into Potholes Reservoir to supplement the natural and return flows.

Potholes Canal

The Potholes Canal has a capacity of 3,900 cfs, begins at the headworks of O'Sullivan Dam, and extends 62.4 miles in a southerly direction to irrigate lands that eventually will total about 234,000 acres (at present 203,678 acres are being served) in the southwestern and south-central portions of the project. Irrigation Blocks 2 and 3, about 5,000 acres (at present 3460 acres) located in the southernmost tip of the South District, receive irrigation water pumped directly from the rivers: Block 2 from the Snake River and Block 3 from the Columbia River.

East High Canal

This proposed 88-mile long canal, designed for an initial capacity of about 7,500 cfs, will divert water from the Main Canal immediately above Summer Falls and Billy Clapp Lake, and will serve lands east of the East Low Canal extending from the northernmost point of the project area south to Washtucna Coulee.

Relift Pumping Plants

About 360,000 acres of the irrigable lands within the project are located at elevations higher than the gravity canals and laterals. Some of these high lands are now being served by re-lift pumping plants at various points within the projects

F.4. Return Flow – General

Return flow is calculated as two components – surface water return via wasteways, and direct groundwater return. Surface water return flow in the wasteways consist of operational wastes and farm run-off, as well as some groundwater that seeps into the wasteways. Direct groundwater return is returned directly into the Columbia River from the western most blocks of the Columbia

Basin Project. These western most blocks are adjacent to the river. Both surface and groundwater returns vary on a monthly basis and their monthly percentage distributions are different as well. While surface water return flow has no lag time, the groundwater return flow is lagged; the percentage distribution used for the groundwater component was taken from Mundorff (1952), and is shown in Table F-2.

F.4.1 Return flow from lands irrigated by Banks Lake

The Columbia Basin Project was divided into three return flow units or areas. They are:

(1) Potholes Unit, (2) Crab Creek Unit, and (3) South Unit. These return flow unit boundaries do not coincide with irrigation district boundaries. Certain blocks in the East and Quincy Irrigation districts, for instance, have return flow which drains into Potholes Reservoir and are part of the Potholes Return Flow Unit.

(1) Potholes Unit

Potholes Unit is the area between Banks Lake and Potholes Reservoir, and is made up of irrigation land north of Blocks 79, 78, 44 and 43. Most of the return flow from the blocks within the Potholes Unit flows to the Potholes Reservoir and does not result directly in return flow to the Columbia River. If at all any of the irrigation blocks contribute return flow to the Columbia River, they would be from the western portion of the blocks – Blocks 74, 77 and 79 – and this flow was estimated to be less than 5 cfs and hence considered negligible. Therefore, for the purposes of this study, Potholes Unit does not contribute return flow to the Columbia River.

(2) Lower Crab Creek Unit

Lower Crab Creek Unit is the area south of Potholes Reservoir, and north of Lower Crab Creek and Saddle Mountains, and is made up of Blocks 80, 81, 82, 83, 85, 86, 87, 88, and part of 49. Return flow from this unit enters the Columbia River at two locations – Wanapum Reservoir and Priest Rapids Reservoir.

The return flow to Wanapum Reservoir is the sum of the surface water flow from three different wasteways, and direct groundwater flow from some western blocks of the unit, Blocks 82, 81 (part) and 83 (part). These return flows get applied at Wanapum as WRF6D.

The remainder of the return flow from the Lower Crab Creek Unit enters Crab Creek. The flows in Crab Creek account for water from two sources: (1) seepage through O'Sullivan Dam foundation on Potholes Reservoir and (2) spill from Potholes Reservoir and groundwater migration from irrigated lands east of the Potholes Canal. During the pre-project period (prior to 1948), the Potholes Reservoir area contained an area of springs; and Crab Creek in its lower reaches had little flow in comparison to current conditions. For instance, during water year 1948, the USGS gage "Crab Creek near Smyrna" had a monthly mean flow of only 18 cfs in February and 26 cfs in September. These flows represent the high and low monthly means for that water year. The recorded flows of "Crab Creek near Beverly" (just downstream of Smyrna) for water year 2008 show a low monthly mean of 160 cfs in March and a high of 318 cfs in October. This is a substantial increase in the discharge of Crab Creek since irrigation was initiated

The return flow to Priest Rapids reservoir is the surface water flow from Crab Creek (USGS Gage 12472600 – Crab Creek near Beverly) and two other wasteways, plus the direct groundwater flow from Block 26 (part). These return flows get applied at Priest Rapids as PRF6D.

(3) South Unit

South Unit is the area south of Lower Crab Creek Unit all the way to the Snake River, including a couple of blocks south of the Snake River. Return flow from this unit is applied at McNary Reservoir. The return flow here is surface water flows from eight different wasteways, one drain and one diversion channel, plus direct groundwater return flow from the western blocks 25, 26, 251 and 253. These return flows are applied at McNary and constitute not all, but part of MRF6D. The components that make up the rest of MRF6D are explained in the next section.

F.4.2 Return flow from other sources

Below is a list of return flow from other sources which lie within the South Unit. The return flows from all sources listed below join the Columbia River at McNary Reservoir and contribute toward MRF6D.

(a) Block 1
(b) Blocks 2 and 3
(c) Springs at Ringold
(d) Pumping west of Pasco

Apart from irrigation water from Banks Lake, there are certain areas within the Columbia Basin Project that receive irrigation diversions from other sources. Blocks 1, 2 and 3 in the South Unit receive irrigation diversions via pumping from the Snake and Columbia Rivers.

(a) Block 1

Block 1 is located north-west of the Snake and Columbia River confluence and west of Pasco. In 1948, the water supply to Block 1 was provided by pumping from the Columbia River. Following the construction of Potholes Canal, pumping was discontinued, and the canal provided the necessary water. The return flow from Block 1 enters McNary reservoir, and consists of both surface and ground water returns.

(b) Blocks 2 and 3

Blocks 2 and 3 are located south-east of the Snake and Columbia River confluence, and water is supplied to them via pumping from the Columbia and Snake rivers. The return flow from Blocks 2 and 3 enters McNary Reservoir, and consists of both surface and ground water returns. It should be noted that the pumping diversions from the Columbia and Snake rivers for irrigating Blocks 2 and 3, are accounted for in a separate dataset called B236D. The pumping data is provided by the USBR. Along with MRF6D, B236D is added towards the calculation of the accumulated depletions at McNary Dam, MCN6DD.

Apart from return flows from irrigated lands, two other sources of return flows include the Springs at Ringold, WA, and pumping west of Pasco, WA.

(c) <u>Springs at Ringold, WA</u>

The Columbia River from Coyote Rapids (5.5 miles downstream from the Vernita State Highway 24 Bridge at RM 382.6) to the Esquatzel Diversion Canal has cut into the Ringold Formation, which is essentially impermeable. The springs at Ringold emerge from a gravel-filled hanging valley cut into the Ringold Formation and are return flow exclusively. The 2000 and 2010 Level Modified Flow Studies used a constant 25 cfs per month as the return flow from the springs at Ringold. The assumption made in the 2010 Modified Flows Studies was that this is an impermeable formation, and hence it is unlikely that the return flow has changed much since the 2000 level study. We retain the 25 cfs per month assumption in the 2020 Level Modified Flow Study as well.

(d) <u>Pumping west of Pasco, WA</u>

The USACE has constructed flood protection levees west of Pasco, WA. Return flow to the Columbia River West of Pasco collects behind the levees at Pasco and is pumped into McNary Reservoir by the USACE. Pumping data was provided by the USACE.

F.5 Return Flow – Details

Return Flows = (a) Surface water Return Flows + (b) Groundwater Return Flows

<u>(a) Surface water Return Flow</u>

USBR provided the 2018 monthly volume of water flowing into the Columbia River via wasteways at Wanapum, Priest Rapids and McNary. At McNary there are two additional sources of surface water return flow: pumping from behind levees, and flow from springs.

<u>(b) Groundwater Return Flow</u>

The return flows from groundwater are calculated as:

Groundwater Return Flow Volume (ac-ft) = Groundwater Return Flow Rate (ac-ft/ac) * Irrigated Acres (ac) * Monthly Return Flow Distribution (%)

<u>Groundwater Return Flow Rate</u>

The water available for return flows is the total water that has been diverted for irrigation (diversions), minus the water used by the crops and lost to evaporation (depletions).

Diversions minus depletions equal surface runoff, plus canal operational waste plus the groundwater return flow. Diversions are the sum of the farm delivery plus the canal operational waste plus the canal losses. This can be shown with the equations below:

Available Return Flow = Div – Dep = S + W +G (Equation 1)

$$Div = FD + W + L \text{ (Equation 2)}$$

where,

Div = diversions

Dep = Depletions

S = Surface Runoff

W = Canal Operational Waste

G = Groundwater Return Flow

FD = Farm Delivery

L = Canal Losses

The USBR calculates the volumes of water for the variables listed above except for groundwater return flow. To calculate the volume of groundwater return flow, Equation 2 is substituted into Equation 1:

$$(FD + W + L) – Dep = S + W + G.$$

Rearranging and simplifying this equation produces: $G = FD + L – Dep – S$.

Data provided by the USBR 2007 Monthly Water Distribution report was put into the above equation to yield groundwater return flow rates of 2.23 ac ft/ac into Wanapum Reservoir, 1.58 ac ft/ac into Priest Rapids Reservoir, and 2.14 ac ft/ac into McNary Reservoir (Table F-1). Given we did not receive data for Canal Losses or Farm Deliveries for 2018, we retained the groundwater return flow rates from the 2010 Modified Flows study (Table F-1).

Table F-1. Groundwater Return Flow and Variables

Return Flow Reservoir	**Farm Delivery[1] (FD)**	**Canal Loss[1] (L)**	**Depletion[2] (Dep)**	**Surface Runoff[3] (S)**	**Groundwater Return Flow Rate**
	(ac ft/ac)	**(ac ft/ac)**	**(ac ft/ac)**	**(ac ft/ac)**	**(ac ft/ac)**
Wanapum	3.74	1.51	2.3	0.72	**2.23**
Priest Rapid	3.85	0.75	2.3	0.72	**1.58**
McNary	3.67	1.49	2.3	0.72	**2.14**

[1]From USBR 2007 [2]From CRWMG, 1988 [3]From CRWMG, 1988

Irrigated Acres

This is the acreage of the irrigation blocks that contribute groundwater flow directly into the Columbia River, and are mostly located on the western edge of the Columbia Basin Project boundary, close to the Columbia River.

Monthly Return Flow Distribution

There is a lag from the time the water is applied to the crops to the time it returns to the Columbia River. Mundorff (1952) studied the return flows, including the groundwater component, in the Columbia Basin Project in the early 1950s. The report accounts for the lag time of the groundwater return flow distributed as a percentage by month, as shown in Table F-2. These values from the 2010 Level Modified Flows study were retained in this study as well.

Table F-2. Groundwater Return Flow Distribution

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Distribution (%)	8.5	7.5	6.7	6.2	5.8	6.2	7.7	9.7	10.7	10.8	10.5	9.7	100

To calculate the return flow volume from groundwater, the total irrigated acres contributing return flow to a reservoir are multiplied by the groundwater return flow rate, which in turn is multiplied by the monthly percent distribution shown in Table F-2. These percentages from the 2010 Level Modified Flows were retained in this study as well.

F.5.1 Return flows to Wanapum Reservoir (WRF6D)

Wanapum is the upstream most location where return flows from the Columbia Basin project gets applied. WRF6D gets included into the calculation of the accumulated depletions at Wanapum, WAN6DD. For this location, there were no changes in the methodology or updates to the 2008 data as compared to the 2010 Modified Flows study. We just updated the data to 2020 levels using recent data.

(a) Surface water Return Flow - Wasteways

The USBR provided 2018 measured flows in the following wasteways (Figure F-2, Table F-3):

- W61CWW
- Sand Hollow (Consists of the following wasteways)
    - RBBCWW2
    - RB4WW
    - W61FWW
    - RB5WW1
    - RB4GWW
    - RB5WW2
    - RB4H2WW
    - RB4LWW
- RB5J1W

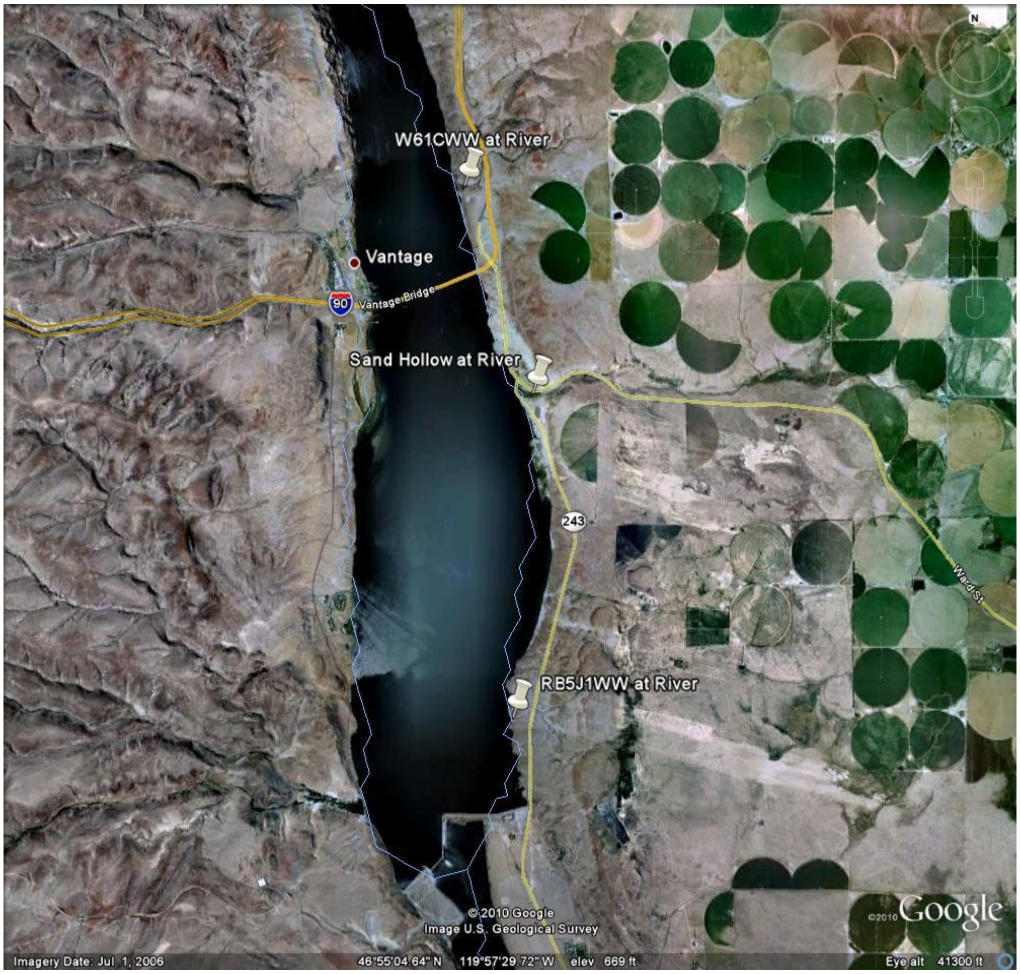

Figure F-2. Discharge Locations of Wasteways with Return Flow to Wanapum Reservoir Map from Google Maps. (Source: 2010 Modified Flows)

Table F-3. Wasteway Return Flows to Wanapum Reservoir

Measured Surface Water Return Flows		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
W61CWW		0	0	0	4	0	0	0	0	0	24	0	0	28
RB5J1WW		0	0	24	67	33	88	3	15	25	21	0	0	276
Sand Hollow	RBBCWW2	0	0	36	129	136	141	156	169	152	94	0	0	1,013
	RB4WW	0	0	32	119	128	94	103	105	104	76	0	0	760
	W61FWW	0	0	12	103	123	98	27	95	92	69	0	0	620
	RB5WW1	0	0	404	1,148	1,136	1,255	810	1,054	1,087	671	0	0	7,564
	RB4GWW	0	0	19	64	56	68	39	32	54	41	0	0	373
	RB5WW2	0	0	6	34	21	18	38	57	43	31	0	0	248
	RB4H2WW	0	0	10	33	38	41	59	59	57	44	0	0	340
	RB4LWW	0	0	29	76	67	58	78	100	80	51	0	0	539
Total (ac-ft)		**0**	**0**	**572**	**1,776**	**1,738**	**1,861**	**1,311**	**1,687**	**1,693**	**1,123**	**0**	**0**	**11,761**
Total (cfs)		0	0	9	30	28	31	21	27	28	18	0	0	

<u>(b)</u> <u>Groundwater Return Flow-Blocks 82 & 83</u>

All of the groundwater return flows from Block 82, 75% of Block 81, and 25% of Block 83 enter Wanapum Reservoir. The USBR reported that in 2018, Block 81 had 13,825 irrigated acres, Block 82 had 9,715 irrigated acres, and Block 83 had 6,932 irrigated acres. When each block's irrigated acreage is multiplied by the block's contributing percentage to Wanapum Reservoir, it is found that a total of 21,817 irrigated acres contribute groundwater return flow to Wanapum Reservoir. This acreage multiplied by the return flow rate of 2.23 acre feet/acre gives a total of 48,652 acre feet of water that will become groundwater return flow. This total is multiplied by the percentages shown in Table F-2 to give the monthly distribution of the groundwater return volume, which is then converted to cfs units (shown as the second row in Table F-4).

<u>(c)</u> <u>Total Return Flow</u>

The total wasteways return flows are added to the groundwater return flow estimates to produce a total monthly return flow volume for the 2020 levels of irrigation (Table F-4). These are used to create the incremental return flow dataset at Wanapum (WRF6D).

Creation of the WRF6D dataset is a two-step process.

Step 1: Given that we do not have a time series of "actual" depletions in the past - where each year's depletion corresponds to irrigation levels for that specific year - we need to recreate that dataset from the prior study's WRF5D dataset. For that, we start with WRF5D (depletion adjustment dataset for 2010 levels) dataset and add the 2010 level depletions to the entire time series (1928-2008). This converts the depletion adjustment dataset to a time series of depletions where each year's depletion corresponds to that specific year's irrigation condition.

Step 2: We subtract the 2020 level depletions (last row of Table F-4) from every year of the time series (1928-2018) from step 1. This gives WRF6D - the time series of depletion adjustments (incremental return flows) for 2020 levels of irrigation. From 1928 through 1948, there were no return flows because the Columbia Basin project was not yet in place, so the incremental return flows were simply the values as shown in Table F-4. From 1948 through 2018, the incremental return flows were interpolated between 10 year increments of calculated data such that the increment in 2018 was zero. WRF6D contributes toward the accumulated depletions (WAN6DD) at Wanapum Dam.

Table F-4. Total Return Flows to Wanapum Reservoir

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Groundwater Returns (cfs)	69	61	54	50	47	50	62	78	86	87	85	78
Wasteway Flows (cfs)	0	0	9	30	28	31	21	27	28	18	0	0
Total Return Flows (cfs)	**69**	**61**	**63**	**80**	**75**	**81**	**84**	**106**	**115**	**105**	**85**	**78**

F.5.2 Return flows to Priest Rapids Reservoir (PRF6D)

Priest Rapids is the second location where return flows from the Columbia Basin project are applied. PRF6D gets included into the calculation of the accumulated depletions at Priest Rapids, PRD6DD. For this location, there were no changes in the methodology or updates to the 2008 data as compared to the 2010 Modified Flows study. We just updated the data to 2020 levels using recent data.

(a) Surface water Return Flow - Wasteways

To determine the return flow into Priest Rapids Reservoir via the wasteways, the USBR provided measured water flows for 2018 in the following wasteways (Figure F-3, Table F-5)

- Crab Creek at Beverly (USGS Gage # 12472600)
- Priest Rapids Wasteways
- WB48E Wasteway
- WB48D Wasteway

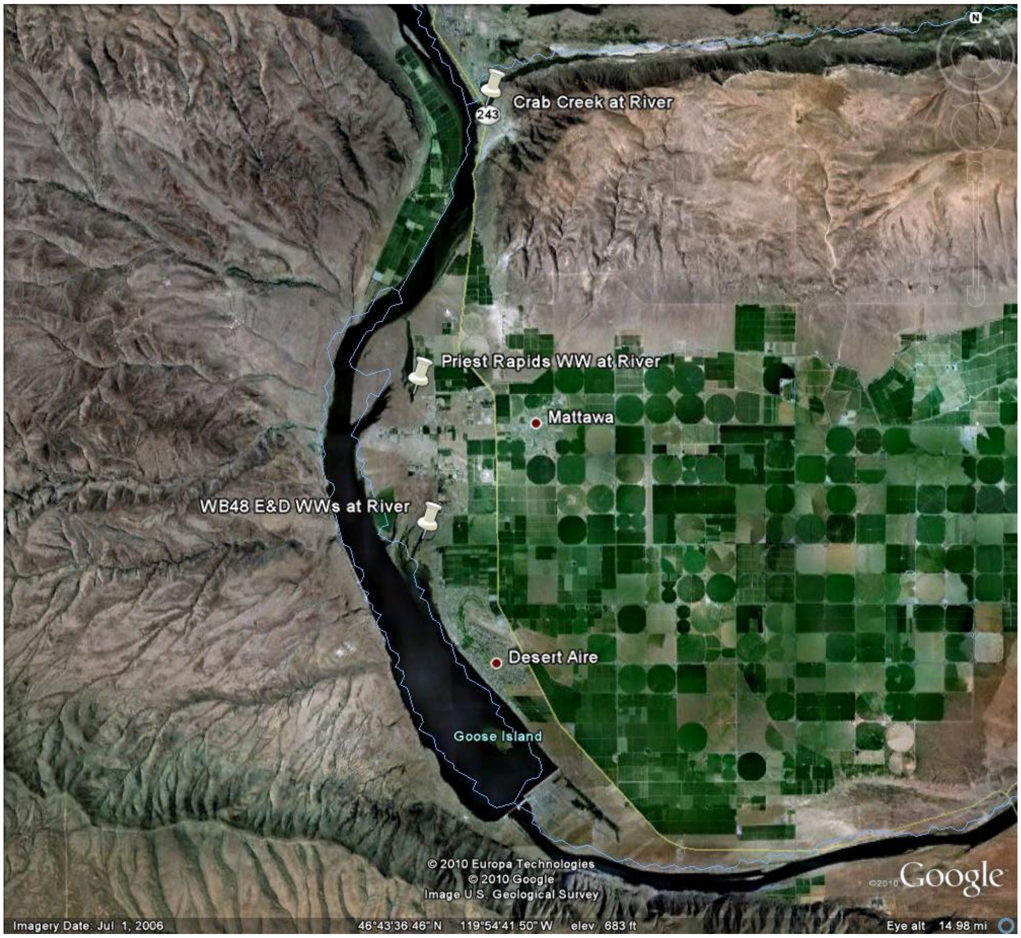

Figure F-3. Discharge Locations of Wasteways with Return Flow to Priest Rapids Reservoir Map from Google Maps (Source: 2010 Modified Flows)

Table F-5. Wasteway Return Flows to Priest Rapids Reservoir

Measured Surface Water Return Flows	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Crab Creek @ Beverly	12,317	9,475	9,612	14,870	11,929	10,020	8,251	12,454	15,124	17,437	10,189	10,122	141,800
Priest Rapids WW	0	0	724	1,765	1,359	1,617	1,438	1,537	1,607	1,250	0	0	11,296
WB48EWW	0	0	30	91	83	83	92	83	89	62	0	0	615
WB48DWW	0	0	43	92	87	80	92	83	89	62	0	0	630
Total (ac-ft)	**12,317**	**9,475**	**10,408**	**16,819**	**13,458**	**11,801**	**9,874**	**14,158**	**16,909**	**18,811**	**10,189**	**10,122**	**154,341**
Total (cfs)	**200**	**171**	**169**	**283**	**219**	**198**	**161**	**230**	**284**	**306**	**171**	**165**	

(b) Groundwater Return Flow – Block 26

Approximately 75% of the groundwater return flow from Block 26 enters Priest Rapids Reservoir. The USBR reported that in 2018, Block 26 had 11,864 irrigated acres; therefore, groundwater return flow from approximately 8,898 acres will enter Priest Rapids Reservoir. This is multiplied by the return flow rate of 1.58 acre feet/acre producing an estimated 14,059 acre feet of groundwater return flow entering Priest Rapids Reservoir. This total is multiplied by the percentages shown in Table F-2 to give the monthly distribution of the groundwater return volume, which is then converted to cfs (shown in Table F-6).

(c) Total Return Flow

The return flows from the wasteways in Table F-5 are added to the groundwater return flows to produce total monthly return flow volume estimates in cfs (Table F-6). These 2020 level return flows are used to create the incremental return flow dataset at Priest Rapids (PRF6D).

Creation of the PRF6D dataset is a two-step process.

Step1: Given that we do not have a time series of "actual" depletions in the past - where each year's depletion corresponds to irrigation levels for that specific year - we need to recreate that dataset from the prior study's PRF5D dataset. For that, we start with PRF5D (depletion adjustment dataset for 2010 levels) dataset and add the 2010 level depletions to the entire time series (1928-2008). This converts the depletion adjustment dataset to a time series of depletions where each year's depletion corresponds to that specific year's irrigation condition.

Step2: We subtract the 2020 level depletions (last row of Table F-6) from every year of the time series (1928-2018) from step 1. This gives PRF6D - the time series of depletion adjustments (incremental return flows) for 2020 levels of irrigation. From 1928 through 1948, there were no return flows because the Columbia Basin project was not yet in place, so the incremental return flows were simply the values as shown in Table F-6. From 1948 through 2018, the incremental return flows were interpolated between 10 year increments of calculated data such that the increment in 2018 was zero. PRF6D contributes toward the accumulated depletions (PRF6DD) at Priest Rapids Dam.

Table F-6. Total Return Flows to Priest Rapids Reservoir

Measured Surface Water Return Flows	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Groundwater return (cfs)	22	19	17	16	15	16	20	25	27	27	27	25
Wasteway flows (cfs)	200	171	169	283	219	198	161	230	284	306	171	165
Total Return Flows(cfs)	**222**	**190**	**186**	**298**	**234**	**214**	**180**	**255**	**311**	**333**	**198**	**189**

F.5.3 Return flows to McNary Reservoir (MRF6D)

McNary is the last location downstream where return flows from the USBR Columbia Basin Project are accounted for. MRF6D gets included into the calculation of the accumulated depletions at McNary, MCN6DD. Return flows to McNary Reservoir are made up of (a) surface water return flows from wasteways, pumping from behind levees, and flow from springs, (b) groundwater return flow from Blocks 25, 26, 251, & 253, and surface and ground water return flows from Blocks 1, 2 & 3. We made some methodological adjustments and updated some 2008 values as well; the specifics of adjustments are described in the relevant sections below.

(a) Surface water Return Flow – Wasteways, Pumping & Springs

In addition to the wasteways, additional sources of surface water return flows at McNary are pumping from behind levees west of Pasco, and flow from springs at Ringold.

Wasteways

To determine the return flow into McNary Reservoir via the wasteways, the USBR provided measured water flows for 2018 in the following wasteways (Figure F-4, Table F-7):

- Mattawa Drain
- WB10 Wasteways 1
- WB5 Wasteways 1
- Pasco Wasteways
- PE16.4 Wasteways
- Esquatzel Diversion Channel
- BP1WW (also called BPWW)
- BP2 Wasteways
- BP3 Wasteways
- PP4.3 Wasteway

Table F-7. Wasteway Return Flows to McNary Reservoir. Values are from 2018 unless otherwise noted.

Measured Surface Water Return Flows	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Mattawa Drain[a]	0	0	495	742	605	661	685	669	714	601	0	0	**5,172**
WB10WW1	1,194	1,049	1,115	1,860	1,430	1,224	805	1,035	1,404	1,480	1,464	1,004	**15,064**
WB5WW1	1,379	922	1,535	6,680	5,316	4,173	3,707	4,510	4,709	3,374	653	623	**37,581**
PascoWW	0	0	1,513	1,904	1,638	1,765	1,972	1,462	1,777	2,325	0	0	**14,356**
PE16.4WW	0	0	117	877	1,549	1,934	2,223	1,991	1,162	760	0	0	**10,614**
EsquatzelWW[b]	10,059	8,450	11,265	10,249	10,599	9,625	9,978	11,523	10,358	11,056	8,674	6,614	**118,450**
BP1WW (BPWW)[c]	0	0	0	61	63	61	63	63	61	44	0	0	**414**
BP2WW	0	0	26	63	65	63	65	65	63	48	0	0	**459**
BP3WW	0	0	34	63	65	63	65	65	63	46	0	0	**465**
PP4.3WW	0	0	888	1490	539	524	607	575	594	436	0	0	**5,654**
Total (ac-ft)	**12,632**	**10,421**	**16,494**	**23,248**	**21,264**	**19,433**	**19,485**	**21,289**	**20,192**	**19,568**	**10,790**	**8,240**	**203,057**
Total (cfs)	**205**	**188**	**268**	**391**	**346**	**327**	**317**	**346**	**339**	**318**	**181**	**134**	

[a] 2018 data unavailable from USBR. Values provided are the 2008 values reproduced as is.

[b] Average of 2009-2011. More recent data was unavailable. The gates became non -operational and the wasteway was free flowing after 2011.

[c] Wasteway was not included in 2010 Modified Flows, but according to USBR contributes to the return flows to McNary.

Figure F-4. Discharge Locations of Wasteways with Return Flow to McNary Reservoir Map from Google Maps (Source: 2010 Modified Flows)

Updates to 2008 data: The 2008 data were updated for two wasteways (EsquatzelWW and PE16.4WW) after corresponding with USBR and confirming discrepancies in the data used in the 2010 Modified Flows study. The original 2008 data from the 2010 Modified Flows study and the adjustment made in this current study are listed in Table F-8. While the exact reasons for the discrepancy could not be traced down, the updated data is more in line with recent data received from USBR.

Methodological adjustment in the 2020 Modified Flows study: The Wasteway BP1WW was not considered in the 2010 Modified Flows study. After confirmation from USBR that this wasteway contributed to return flows at McNary, we added it for this study. The wasteway EsquatzelWW does not have data for 2018. The gates are non-functional and the gage was decommissioned in 2011. However, the wasteways do capture return flows, and to reflect this condition, the average of flows measured between 2009 and 2011 was used. Updated data for the Mattawa Drain was not received and the 2008 data was used in its place.

Table F-8. 2008 Adjusted Wasteway Return Flows to McNary Reservoir

	Flow (cfs)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Original	PE16.4WW	65	64	80	169	167	171	184	203	238	210	120	81
Original	EsquatzelWW[b]	61	60	71	86	102	113	111	65.1	72	70	45	32.2
Updated	PE16.4WW	0	0	5	20	29	30	40	35	23	15	0	0
Updated	EsquatzelWW[b]	136	142	154	115	120	88	111	160	188	182	154	137

Pumping from behind levees

The USACE Walla Walla District has constructed flood protection levees west of Pasco, Washington. The return flows west of Pasco collect behind these levees which the Corps then pumps into the reservoir behind McNary Dam. The USACE provided the 2018 pumping records, but we did not use them for reasons described below.

Updates to 2008 data: The 2020 Modified Flows used data from three pumps (12-1, 12-1A, and 12-2) as return flows west of Pasco. Upon reviewing the data, it became apparent that data reported for 12-1 was the sum of data for 12-1 and 12-1A. This resulted in double counting of flows in the 2010 Modified Flows. Additionally, after corresponding with the USACE (Hammond, personal communication), we confirmed that there is an additional pump (17A) that is to the west of Pasco and east of the Columbia River (see Figure F-5) which likely also captures return flows from the CBP. We could not procure 2008 and 2018 data for pump 17A in time for this project. The 2000 Modified Flows used a constant 100 cfs flow assumption. The 2010 Modified Flow estimates (after adjusting for double counting in 12-1) were about 70% lower than the 2000 assumption (likely because data from pump 17A was missing). Assuming that the 2000 Modified Flow data is likely closer to reality, the 2008 data was returned to a constant 100 cfs, with the assumption retained for this report, as well.

Methodological adjustment in the 2020 Modified Flows study: For reasons mentioned in the above paragraph, we reverted to the 2000 Modified Flows assumption: a constant return flow of 100 cfs (see Table F-9). We recommend that future modified flows projects should collect data from pumps 12-1,12-2 and 17A (see Figure F-5) and update the time series as far back as data is available.

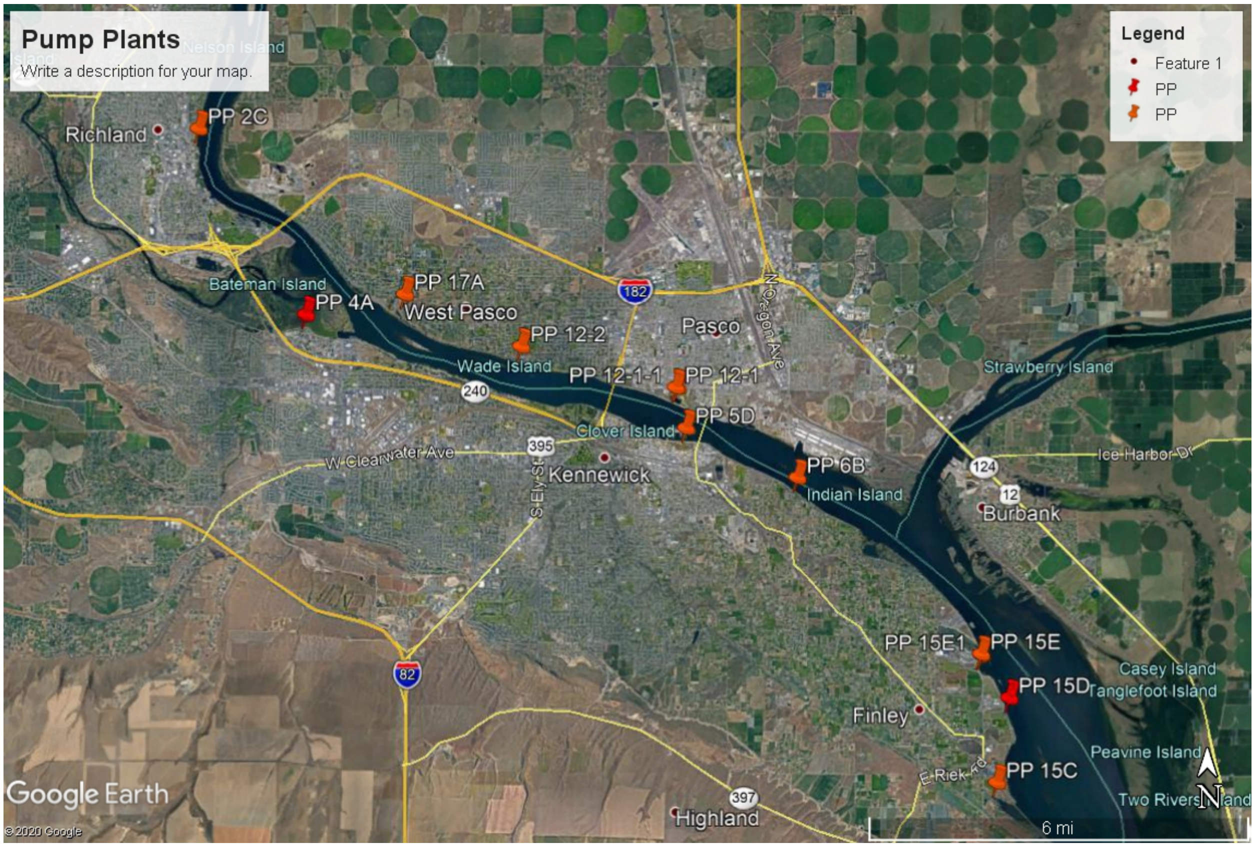

Figure F-5. Location of U.S. Army Corps of Engineers pumps (Provided by John Hammond, USACE, Walla Walla District). The pumps to the east of the Columbia River can be assumed to relate to return flows from CBP and the pumps to the west of the Columbia River can be assumed to relate to return flows from the Kennewick Irrigation District (KEN6D in the main report).

Table F-9. Adjustments to 2008 Pumping at Pasco

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Original* (cfs)	75	67	89	94	66	87	86	81	82	74	73	76
Updated (cfs)	100	100	100	100	100	100	100	100	100	100	100	100

* These original values include some double counting as described above. If that is adjusted for, flows will be about half of the listed numbers.

Flow from springs

The Columbia River from Coyote Rapids (5.5 miles downstream from the Vernita State Highway 24 Bridge at RM 382.6) to the Esquatzel Diversion Canal has cut into the Ringold Formation, which is essentially impermeable. The springs at Ringold emerge from a gravel-filled hanging valley cut into the Ringold Formation and are exclusively return flows. The 2000 Level Modified Flow Study used 25 cfs per month as the return flow from the springs at Ringold. Because this is an impermeable formation, it is unlikely that the return flow has changed much since the 2000 level study. Therefore, the 25 cfs per month assumption was retained in the 2010 and 2020 Modified Flows studies.

(b) Groundwater Return Flow – Blocks 25, 26, 251, & 253

All of the groundwater return flows from Blocks 25, 251, 253, and 25% of Block 26 enter McNary Reservoir. USBR reported that in 2018 Block 25 had 11,864 irrigated acres, Block 251 had 8,752 irrigated acres, Block 253 had 11,712 irrigated acres, and Block 26 had 12,931 irrigated acres. When each block's irrigated acreage is multiplied by the block's contributing percentage to McNary Reservoir, it is found that a total of 35,562 irrigated acres contribute groundwater return flow to McNary Reservoir. This acreage multiplied by the 2.14 acre feet/acre gives a total of 76,103 acre feet of water that will become groundwater return flow. This total is multiplied by the percentages shown in Table F-2 to give the monthly distribution of the groundwater return volume, which is then converted to cfs (shown in Table F-15).

(c) Surface and Groundwater Return Flows from Blocks 1, 2 & 3

Block 1 return flows are discussed after Blocks 2 and 3.

Blocks 2 and 3

The USBR reported that 4,627 acres were irrigated in 2018 for Blocks 2 and 3. Location of pumps and wasteways are shown in Figure F-6.

Figure F-6. Location of pumps and wasteways for Blocks 2 & 3. BP1 and BP1WW provide the feed and waste for Block 2. BP2, BP2WW, BP3, and BP3WW provide the feed and waste for Block 3. Image courtesy of John Anderson, USBR.

The return flow for Blocks 2 and 3 is made up of two surface water return flow components - surface runoff from irrigation and lateral runoff – and a groundwater return flow component.

Table F-10. Diversions to Blocks 2 and 3 (ac-ft)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Total Diversion (ac-ft)	0	0	572	1821	3062	6558	4612	4383	2686	1055	0	0

The total return flow rate from Blocks 2 and 3 is calculated by taking the total diversion (Div) and subtracting estimates of lateral losses (LL), lateral wastes (LW), and non-irrigation deliveries (Nid). The remainder after these subtractions is the farm delivery requirement. Based on VIC-CropSyst simulations, the crop consumptive use is estimated at 1.84 ac-ft/acre, which is subtracted from the farm delivery requirement to give a total return flow rate of 1.42 ac-ft/acre (Table F-11). In other words:

Total return flow rate = (Div – LL – LW – Nid) – Crop consumptive use

Approximately 80 percent of the total return flow rate, 1.14 ac-ft/acre (Table F-11), is estimated to be the ground water return flow rate. The remaining 20 percent, 0.284 ac-ft/acre (Table F-11), is the return flow rate from the runoff component of the surface water return flow. The lateral waste component of the surface water return flow is 0.305 ac-ft/acre (Table F-11).

The total acreage of Blocks 2 and 3 (4,627 acres) was multiplied by each of the three return flow rates to get the total annual volume, which was then distributed across the months according to distribution percentages. The groundwater return is distributed using percentages from Table F-2 (shown again in Table F-12), while the two surface water returns were distributed using separate percentages shown in Table F-12 below. These surface water percentages were obtained from the West and East canals runoff data provided by USBR.

Notes for 2010 level data: We did not make any changes to the 2010 level data for this particular area. However, we note that the irrigated acreage for blocks 2 and 3 used in the 2010 Modified Flows study (3460 acres from 2007 USBR monthly report) seems a bit low as compared to acreage records for 2008 to 2018 of around 4,600 acres. It is unlikely that there was this sudden increase in irrigation acreage between 2007 and 2008. Given that we were unable to procure alternate sources for the 2007 data within the timeframe of this project, we retained the data from the 2010 Modified Flows report. It may be worth revisiting this at the time of the next study. This acreage assumption affects diversion and loss rates expressed in units of acre ft /acre in the 2010 Modified Flows study. Given the percentages listed in Table F-11 come from this 2010 data, the data in Table F-11 will also be affected.

Methodological change in the 2020 Modified Flows Study: In the 2010 Modified Flows project, data for diversions, lateral losses, lateral waste, and non-irrigation deliveries were all provided by USBR. In the current study, we only received diversion data and not the other components. Therefore, we used the 2010 data to compute other values as percentages of diversion (computed percentages are noted in Table F-11) and applied those percentages to the 2018 diversions to get estimates of other variables. In the 2010 Modified Flows study, the crop consumptive use was provided by USBR. In this study we updated this to VIC-CropSyst based crop consumptive use estimates (area weighted by the irrigated crop mix).

Table F-11. Blocks 2 and 3 Return Flow Rates

		ac-ft/ac
Total Diversion (Div) (Table F-10)		4.7
Lateral Losses (LL) (15% of Div)		-0.713
Measured Lateral Wastes (LW) (7% of Div)		-0.305
Non-Irrigation Deliveries (Nid) (9% of Div)*		-0.421
Farm Delivery Requirement (FD) (69% of Div)*	Subtotal =	3.6
Consumptive Use (VIC-CropSyst estimates)		-1.84
Total Return Flow rate	Total =	1.42
Groundwater Return Flow Rate	80% of total =	1.14
Surface water Return Flow Rate : 1st Component - Surface Runoff from Irrigation	20% of total =	0.284
Surface water Return Flow Rate : 2nd Component - Measured Lateral Waste (LW)	from Table F-9 (LW)	0.305

*Percent of total diversion calculated based on values in Table 4.9 from the 2010 Level Modified Flows Report

Table F-12. Blocks 2 and 3 Return Flow

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
	Groundwater Return: Total Volume = 4627 ac * 1.14 ac-ft/ac = 5263 ac-ft												
Groundwater return distribution (%)	8.5%	7.5%	6.7%	6.2%	5.8%	6.2%	7.7%	9.7%	10.7%	10.8%	10.5%	9.7%	100.0%
Groundwater return (ac-ft)	447	395	353	326	305	326	405	511	563	568	553	511	**5,263**
	Surface water Return 1 – Surface Runoff: Total Volume = 4,627 ac * 0.284 ac-ft/ac = 1,316 ac-ft												
Surface water return distribution 1 (%)	0.0%	0.0%	1.4%	13.1%	16.3%	16.8%	17.0%	12.9%	13.3%	9.2%	0.0%	0.0%	100.0%
Surface water return 1 (ac-ft)	0	0	18.4	172	214	221	224	170	175	121	0	0	**1,316**
	Surface water Return 2 – Lateral Waste: Total Volume = 4,627 ac * 0.305 ac-ft/acre = 1,411 ac-ft												
Surface water return distribution 2 (%)	0.0%	0.0%	1.5%	14.1%	14.9%	13.8%	12.5%	16.4%	15.0%	11.9%	0.0%	0.0%	100.0%
Surface water return 2 (ac-ft)	0	0	21.2	199	210	195	176	231	212	168	0	0	**1,411**
	Total Return to McNary Reservoir												
Total Mean Monthly Return (ac-ft)	447	395	393	697	729	742	805	912	950	857	553	551	**7,990**
Total Mean Monthly Return (cfs)	7	7	6	12	12	13	13	15	16	14	9	8	

Block 1

The methodology used to calculate the total return flow from Block 1 to McNary is the same as that used at Blocks 2 and 3. The return flow rates used in Block 1 are as follows:

The return flow from Block 1 was calculated based on the irrigated acreage provided by USBR (5,827 acres in 2018). Monthly percentage distributions of the various return flows are the same as for Blocks 2 and 3. The return flow rates used in Block 1, were obtained from the USBR for the 2010 Level Modified Flows Study, and we retained these numbers (Table F-13).

Table F-13. Block 1 Return Flow Rate

Groundwater Return Flow Rate (ac-ft/ac)	**2.1**
Surface water Return Flow Rate: 1st Component (ac-ft/ac) **– Surface Runoff from Irrigation**	**0.4**
Surface water Return Flow Rate: 2nd Component (ac-ft/ac) **– Measured Lateral Waste (LW) (from Table 9)**	**0.3**

Table F-14. Block 1 Return Flow

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
	Groundwater Return: Total Volume = 5,827 acres * 2.1 ac-ft/acre = 12,236 ac-ft												
Groundwater return distribution (%)	8.5%	7.5%	6.7%	6.2%	5.8%	6.2%	7.7%	9.7%	10.7%	10.8%	10.5%	9.7%	100%
Groundwater return (ac-ft)	1,040	918	820	759	710	759	942	1,187	1,309	1,321	1,285	1,187	**12,236**
	Surface water Return 1 – Surface Runoff: Total Volume = 5,827 ac * 0.4 ac-ft/ac = 2,331 ac-ft												
Surface water return distribution 1 (%)	0.0%	0.0%	1.4%	13.1%	16.3%	16.8%	17.0%	12.9%	13.3%	9.2%	0.0%	0.0%	100%
Surface water return 1 (ac-ft)	0	0	33	305	380	392	396	301	310	214	0	0	**2,331**
	Surface water Return 2 – Lateral Waste: Total Volume = 5,827 ac * 0.3 ac-ft/ac = 1,748 ac-ft												
Surface water return distribution 2 (%)	0.0%	0.0%	1.5%	14.1%	14.9%	13.8%	12.5%	16.4%	15.0%	11.9%	0.0%	0.0%	100%
Surface water return 2 (ac-ft)	0	0	26	246	260	241	219	287	262	208	0	0	**1,748**
	Total Return to McNary Reservoir												
Total Mean Monthly Return (ac-ft)	1,040	918	879	1,310	1,350	1,391	1,557	1,774	1,881	1,744	1,285	1,187	**16,315**
Total Mean Monthly Return (cfs)	17	17	14	22	22	23	25	29	32	28	22	19	

(d) Total Return Flow

The return flows from the wasteways shown in Table F-7, the pumping west of Pasco (constant value of 100cfs), the return flow from the springs at Ringold (constant value of 25 cfs), the return flows from Block 2 and 3 shown in Table F-12 and the return flow from Block 1 shown in Table F-14 are added to the groundwater return flows to produce the total monthly return flow volume into McNary Reservoir for 2020 levels of irrigation (shown in Table F-15). These are used to create the incremental return flow dataset at McNary (MRF6D).

Creation of the MRF6D dataset is a two-step process.

Step1: Given that historical "actual" depletions were unavailable, which include each year's depletion corresponds to irrigation levels for that specific year, we recreate that dataset from the prior study's MRF5D dataset. For that, we start with MRF5D (depletion adjustment dataset for 2010 levels) dataset and add the 2010 level depletions to the entire time series (1928-2008). This converts the depletion adjustment dataset to a time series of depletions where each year's depletion corresponds to that specific year's irrigation condition.

Step 2: We subtract the 2020 Level depletions (last row of Table F-15) from every year of the time series (1928-2018) resulting from step 1. This gives MRF6D - the time series of depletion adjustments (incremental return flows) for 2020 levels of irrigation. From 1928 through 1948, there were no return flows because the Columbia Basin project was not yet in place, so the incremental return flows were simply the values as shown in Table F-15. From 1948 through 2018, the incremental return flows were interpolated between 10 year increments of calculated data such that the increment in 2018 was zero. MRF6D contributes toward the accumulated depletions (MCN6DD) at McNary Dam.

Table F-15. Total Return Flows to McNary Reservoir

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Groundwater Return (cfs)	107	95	85	78	73	78	97	123	135	136	133	123
Wasteway Flows (cfs)	205	188	268	391	346	327	317	346	339	318	181	134
Pumping at Pasco (cfs)	100	100	100	100	100	100	100	100	100	100	100	100
Springs at Ringold (cfs)	25	25	25	25	25	25	25	25	25	25	25	25
Blocks 2 &3 (cfs)	7	7	6	12	12	13	13	15	16	14	9	8
Block 1 (cfs)	17	17	14	22	22	23	25	29	32	28	22	19
Total Return Flow (cfs)	**449**	**415**	**481**	**614**	**570**	**558**	**567**	**625**	**639**	**616**	**456**	**392**

Methodological changes in the 2020 Modified Flows study: A plot of the MRF5D dataset from the 2010 Modified Flows study shows an unexpected spike in 1980 (see Figure F.8). Given that we did not find a justification for this spike, and that this spike was absent in the MRF4D dataset, we readjusted the interpolation in this study to ignore the 1980 data and perform a straight line interpolation between data for 1970 and 1990 to remove this spike.

F.5.5 Accumulated Depletions at McNary (MCN6DD)

Similar to the 2010 Modified Flows study, the following is the formula for accumulated depletions at McNary.

MCN6DD = YAK6DD + PRD6DD + MRF6D + B236D + LMN6DD + NSM6D + KEN6D + (0.668)*NSR6D + UMP6D + WWA6D

F.6 Diversions

Related to the CBP, two sets of diversion related depletion adjustment datasets are provided. The first is net pumping from Grand Coulee Dam to Banks Lake, and the second is pumping from Columbia and Snake Rivers to irrigate Blocks 2 and 3 of the CBP.

To estimate the pumping diversions at Grand Coulee, a 2020 Level diversion schedule of how much net water was removed from Franklin D. Roosevelt Lake into the Banks Lake was estimated. Some of the pumps at the Grand Coulee project can be reversed to pump water back from Banks Lake to Grand Coulee to generate additional hydropower when the demand exists. Since water can flow both ways, the net diversion into Banks Lake for irrigation was determined by averaging the difference between pumping data in FDR5P and reverse pumping in FDR5G. In other words, the GLD6D dataset is the average net pumping (FDR6P- FDR6G).

For 2020 Modified Flows, Reclamation provided averaged withdrawals for each month from WY2010-WY2018, except for April and August when split month withdrawals were provided. However, the averaged months were not continuous. Instead, the averages excluded months between 2010 and 2018 when significant plant maintenance was conducted and resulted in unrepresentative pumping and pump-generation schedules. The following periods were excluded from the averaging:

- August 1, 2011 through April 30, 2012
- November 1, 2013 through January 31, 2014
- December 1, 2015 through December 31, 2017.

The five year averages are detailed in Figure F-7.

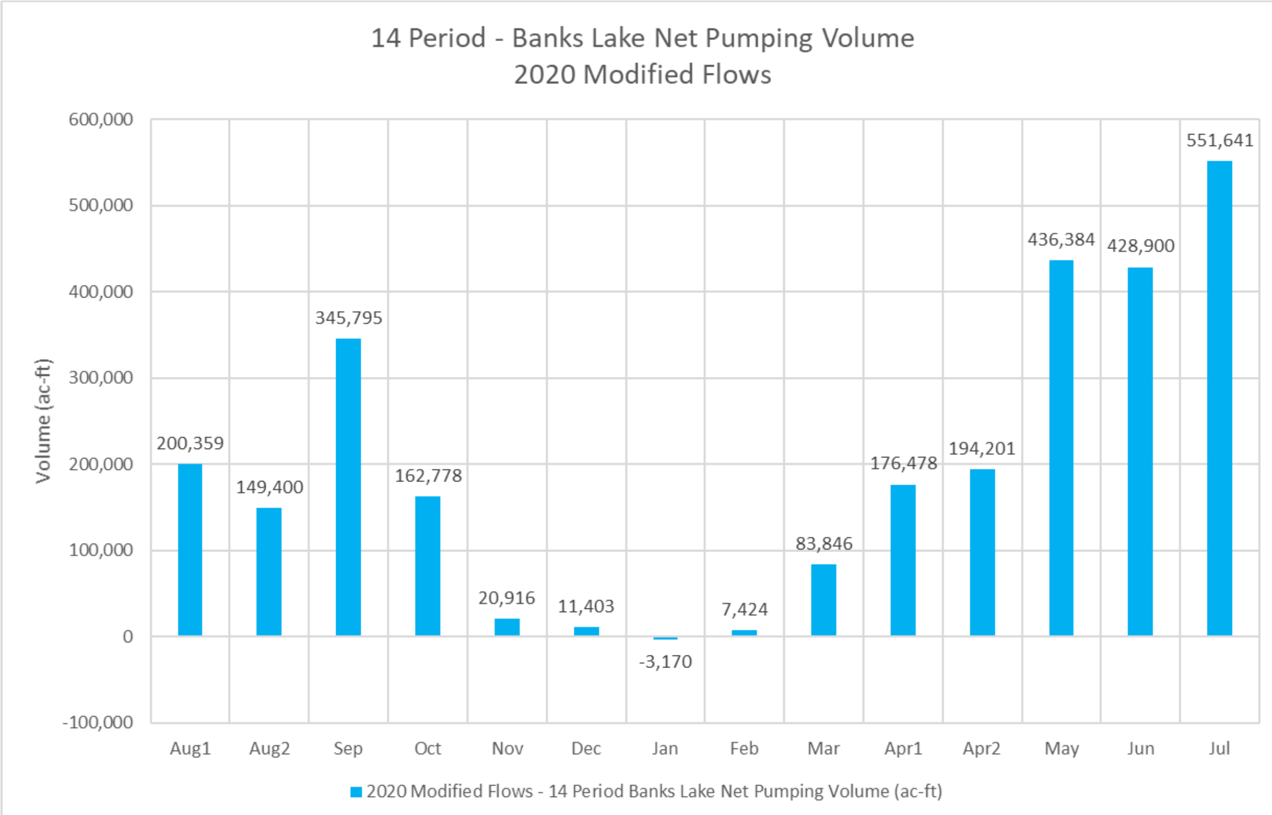

Figure F-7: Five-year averaged net pumping from Franklin D. Roosevelt Reservoir into Banks Lake for 2020 Modified Flows. Aug1=August 1-15, Aug2=August 16-31, Apr1=April 1-15, Apr2=April 16-30. Provided by Joel Fenolio and Peter Cooper, USBR.

It should be noted that there is no direct correlation between the timing of when pumping occurred at Grand Coulee, when the water stored in Banks Lake is applied to the crops and when the flows are returned downstream. GCL6D is calculated monthly except for April and August which are split in half to improve temporal resolution during these months.

It should also be noted that the GCL6D does not conform to the typical expectation of a 6D dataset (where data corresponds to the streamflow adjustment to be made so that streamflow in the past corresponds to current irrigation levels, and therefore the 2020 adjustments have a value of 0 and past adjustments prior to start of irrigated agriculture are the current depletion levels). Instead, in the GLC6D dataset, current level depletions are provided as D values in all years. This special method is consistent with prior Modified Flows projects. At the time of calculating modified flows, adjustments are made so the modified flows reflect the time series changes in depletion due to the diversions at Grand Coulee. Specifically, when modified flows are computed, the difference between the GLC6D dataset and the actual observed net diversion from Franklin D. Roosevelt is computed to reflect the historical changes in depletions. This methodology was used because a historical record of all flow diverted for irrigation was available for the entire existence of the CBP. Depletions did not need to be estimated from irrigated acreage and crop water demand as with most of the other areas. As noted in section F.4.2, the pumping diversions from the Columbia and Snake rivers for irrigating Blocks 2 and 3, are accounted for in a separate dataset called B236D. This pumping data is provided by the USBR.

F.7 Comparisons with 2010 Modified Flows

This section has a series of figures that compare the CBP related depletion adjustment time series across the 2010 and 2020 Level Modified Flows datasets. As the figures (Figures F.8 to F.12) show, the main differences are in the incremental flows at McNary (see Figure F.10). The differences are discussed with each individual figure below.

Wanapum Return Flows

There is a small decrease in the Wanapum incremental return flow in the 2020 Modified Flows as compared to the 2010 Modified flows. But the patterns and magnitudes of incremental return flows are similar.

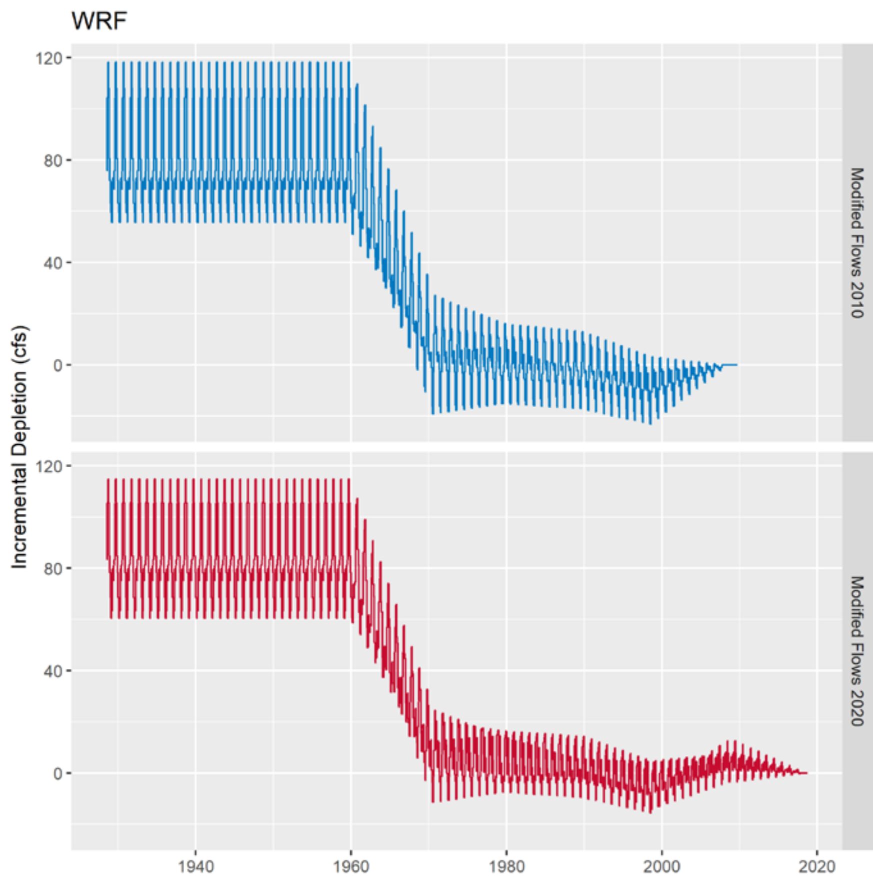

Figure F-8. Wanapum Return Flows (WRF): incremental depletion from 2010 Modified Flows (top, blue) and 2020 Modified Flows (bottom, red).

Priest Rapids Return Flows

There is a small decrease in the Priest Rapids incremental return flow in the 2020 Modified Flows as compared to the 2010 Modified flows. But the patterns and magnitudes of incremental return flows are similar.

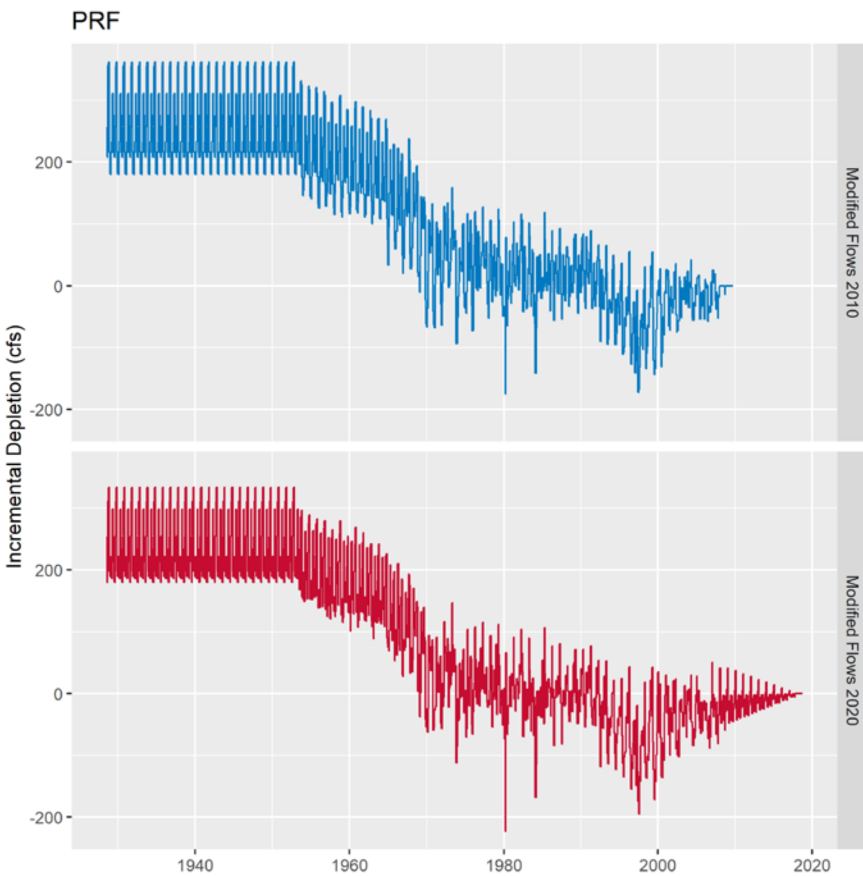

Figure F-9. Priest Rapids Return Flows (PRF): incremental depletion from 2010 Modified Flows (top, blue) and 2020 Modified Flows (bottom, red).

McNary Return Flows

The McNary incremental return flows have the largest differences across the 2010 and 2020 level modified flows. The pattern is different because the spike in 1980 in the 2010 Modified flows was deemed an error and adjusted as described in section F.5. In addition, the magnitude of flows are lower. This is due to the net effect of multiple changes described in section F.5: primarily, a decrease in wasteway return flows, increase in the Kennewick return flows, and increased irrigated acreage in blocks 2 and 3.

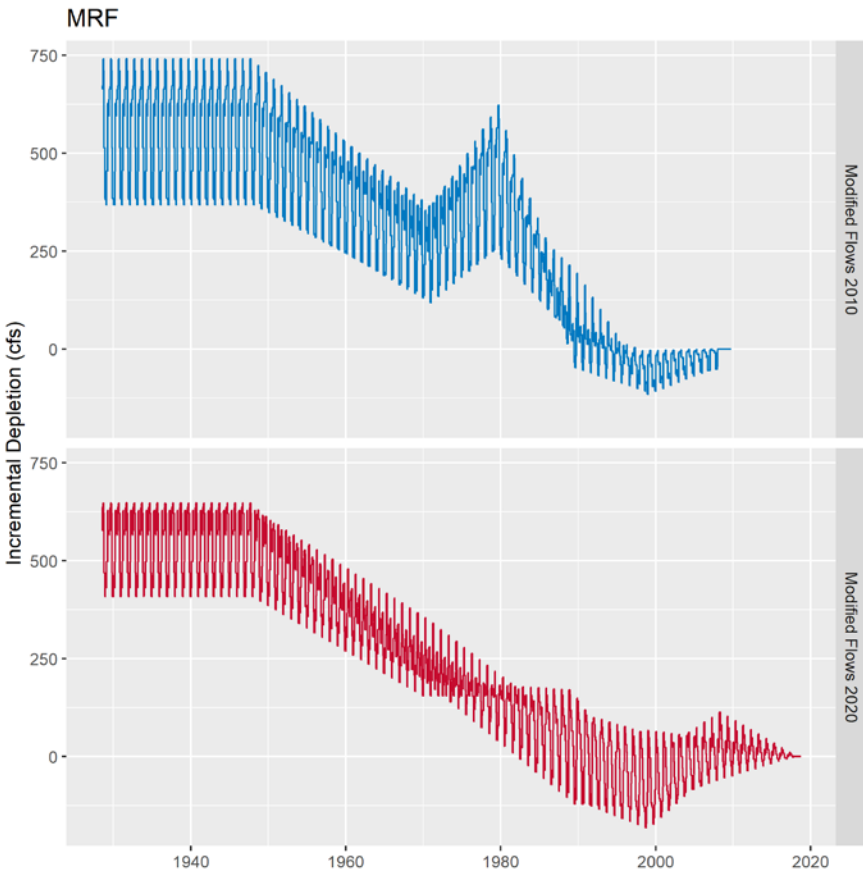

Figure F-10. McNary Return Flows (MRF): incremental depletion from 2010 Modified Flows (top, blue) and 2020 Modified Flows (bottom, red).

Diversions for Blocks 2 and 3

Diversions for Blocks 2 and 3 are comparable between 2010 and 2020 Modified Flows.

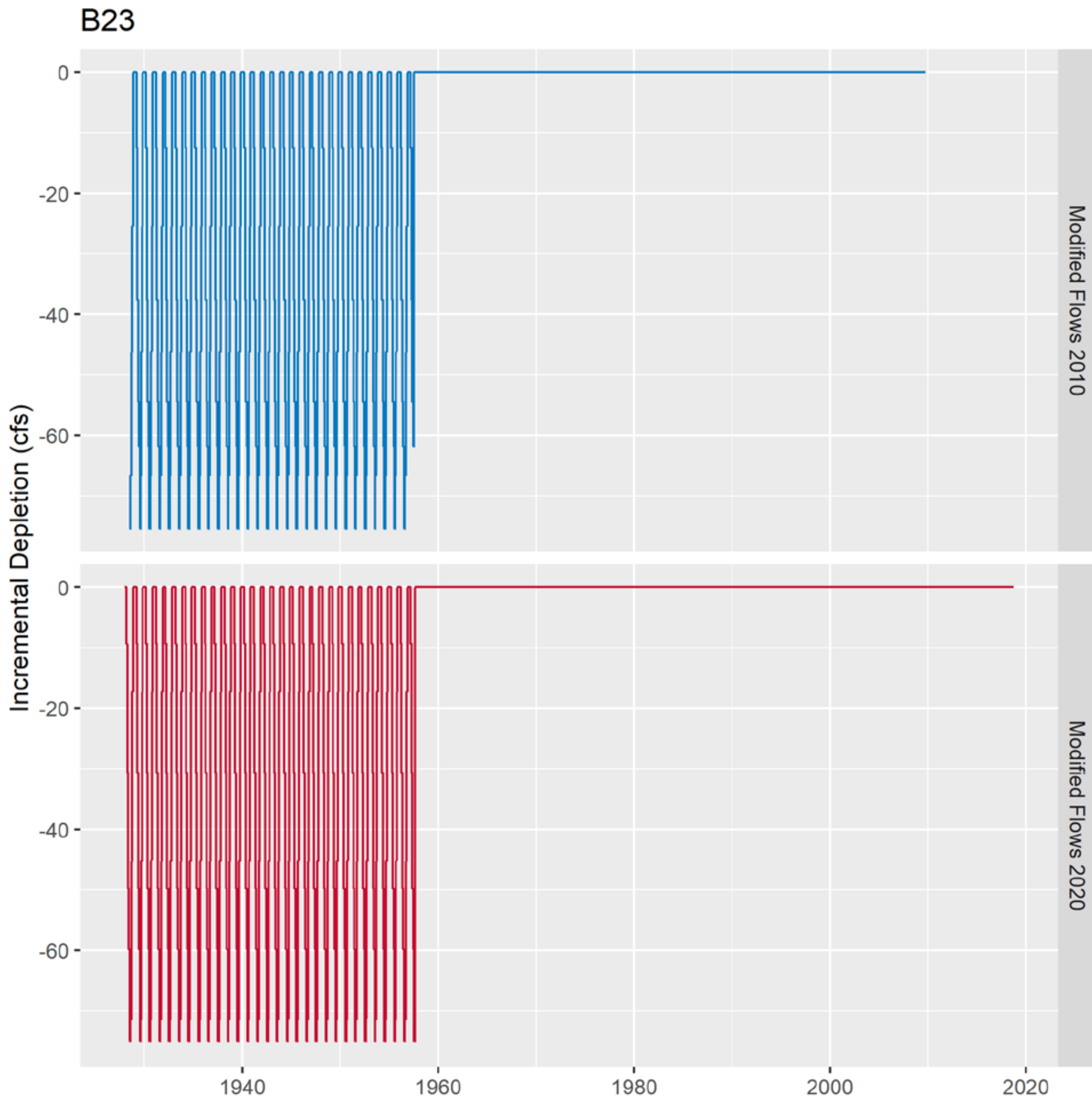

Figure F-11. Pumping to Blocks 2 & 3 (B23): incremental depletion from 2010 Modified Flows (top, blue) and 2020 Modified Flows (bottom, red).

Net Diversions at Grand Coulee

The 2010 and 2020 level diversion estimates are largely similar, as there has not been much change in irrigated agriculture in the basin.

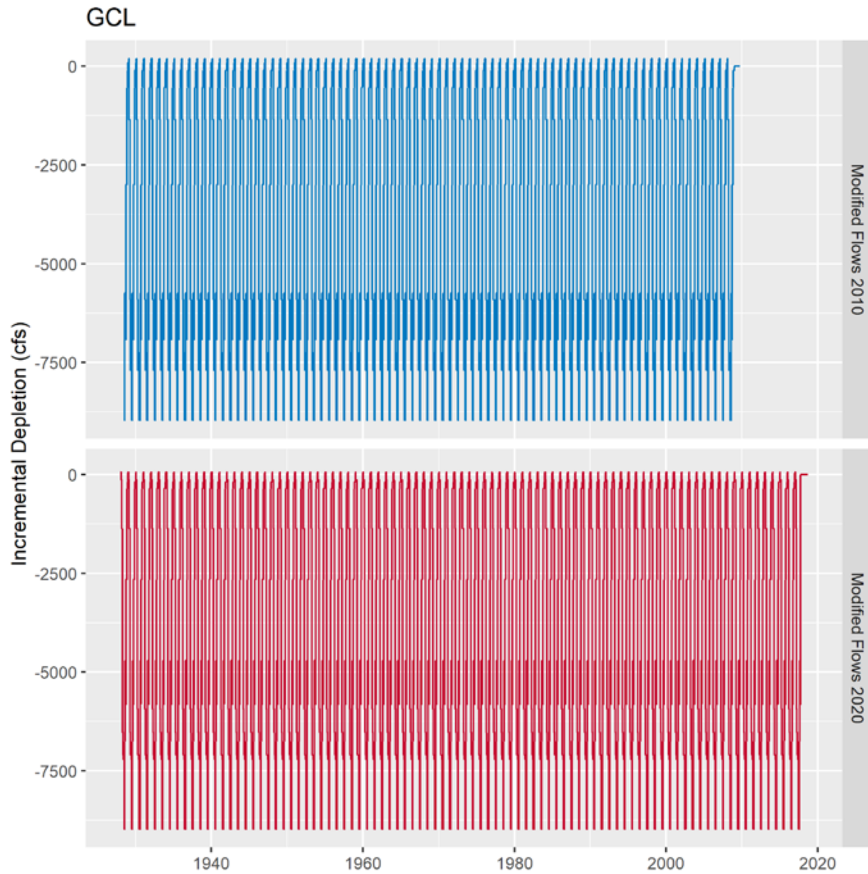

Figure F-12. Net pumping from Grand Coulee: incremental depletion from 2010 Modified Flows (top, blue) and 2020 Modified Flows (bottom, red).

F.8 References

Commission, Depletions Task Force, Columbia River Water Management Group (October, 1988).

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USBR, 2007. 2007 Monthly Water Distributions Report. US Bureau of Reclamation, Department of Interior.

Appendix G: Local Extension Experts Contacted or Relevant Publications Reviewed (By Basin)

Appendix G.1. Upper Columbia and Kootenay Basins

Contacts

Stephanie Tam, British Columbia Ministry of Agriculture

Publications

British Columbia Agricultural Land Use Inventories
https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/agricultural-land-and-environment/strengthening-farming/planning-for-agriculture/agricultural-land-use-inventories

Regional District of North Okanogan Agricultural Land Use Inventory. 2013-2014.
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Appendix G.2. Pend Oreille and Spokane Basins

Contacts

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Zach Miller, Superintendent, Montana State University Western Ag Research Center, Corvallis MT

Paul Smidansky, NRCS Irrigation engineer, Bozeman, MT

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Melissa Shaar, Hydrologist for Water Management Bureau of Montana DNRC

Jack Stivers, Montana State University Extension Agent, Lake County

Patrick Mangan, Montana State University Extension Agent, Ravalli County

Sean Johnson, NRCS Supervisory District Conservationist, Kalispell MT

David Ketchum, DNRC Hydrologist, State of Montana, Missoula MT

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Publications

British Columbia Agricultural Land Use Inventories
https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/agricultural-land-and-environment/strengthening-farming/planning-for-agriculture/agricultural-land-use-inventories

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Water Resources Survey – Flathead and Lincoln Counties. 1965. State of Montana.

Water Resources Survey – Granite County. 1959. State of Montana.

Water Resources Survey – Lake County. 1963. State of Montana.

Water Resources Survey – Powell County. 1959. State of Montana.

Water Resources Survey – Ravalli County. 1958. State of Montana.

Water Resources Survey – Sanders County. 1969. State of Montana.

Appendix G.3. Mid-Columbia Basin

Contacts

John Anderson & Clyde Lay USBR Ephrata Office (Columbia Basin Project data)

Alex Hammond, U.S. Army Corps of Engineers Walla Walla office (US ACE pumping data)

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Appendix G.4. Lower Columbia/Snake Basin

Contacts

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Shannon Williams, University of Idaho Extension Lemhi County

Tim Waters, Washington State University Extension Franklin and Benton Counties

Darrin Walenta, Oregon State University Extension, Union County

John "Bink" Ramos, Crop Consultant, Nutrien

Troy Peters, Washington State University

Howard Niebling, University of Idaho Extension Specialist

Publications

Marvin, R. 2012. Umatilla Basin Project: Cooperative Exchange of Columbia River Water for Instream Flows. https://acwi.gov/monitoring/conference/2012/B1/B1Marvin20120501v4.pdf

Umatilla County, 2008. Umatilla Basin 2050 Subbasin Water Management Plan. http://www.co.umatilla.or.us/planning/pdf/2050%20Plan%20Final.pdf

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Appendix G.5. Willamette Basin

Contacts

Betsy Verhoeven, OSU Extension

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Jereme Degarlais, Army Corp of Engineers

Chad Higgins & Maria Wright, OSU Biological and Ecological Engineering

Ken Stahr, Jordan Beamer, and Mellony Hoskinson, OWRD

Publications

Jaeger W.K, Plantinga A.J., Langpap C., Bigelow DP, Moore KM. 2017. Water, Economics, and Climate Change in the Willamette Basin, Oregon. OSU Extension Service Publication EM 9157. https://catalog.extension.oregonstate.edu/em9157

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Kalinin, A. (2013). Right as Rain? The Value of Water in Willamette Valley Agriculture (MS Thesis). Oregon State University, Corvallis, Ore. http://hdl.handle.net/1957/42123

Appendix G.6. Klamath Basin

Contacts

Danette Watson, Water Master, OWRD

Paul Simmons, Interim Executive Director, Klamath Water Users Association

Corregidor

Appendix F.6.: A small clarification to the original report, published on April 14, 2020, was made in September, 2020. Fourteen period pumping diversions, provided by Reclamation from Grand Coulee to Banks Lake were averaged over all years from WY2010 through WY2019, excluding maintenance years. The original report incorrectly indicated that only five years of data was averaged to obtain the diversion schedule.