US Army Corps of Engineers®
Portland District

Willamette Basin Review Feasibility Study

APPENDIX B

Agricultural Irrigation Demand Analyses

June 2019

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Executive Summary

This document provides the results of seven separate methods of estimating agricultural irrigation (AI). Baseline irrigation is the volume of water withdrawn from groundwater or surface water to satisfy AI needs during the baseline analysis year of 2014. Two AI baseline irrigation estimates are based on an irrigation diversion duty rate of 2.5 acre-feet of water per acre irrigated. Four AI baseline irrigation estimates are founded in the calculation of crop-specific evapotranspiration (ET) – both of which rely on data from the U.S. Department of Agriculture's Cropland Data Layer. One estimate develops an AI baseline irrigation estimate based on reported water use (i.e., actual AI diversions).

Table ES-1 provides a summary of the baseline estimates by contract reach, with the estimates identified as follows:

- Estimate 1: Permitted Duty Diverted Water Demand
- Estimate 2: Irrigated Land Factor Adjusted Permitted Duty Diverted Water Demand
- Estimate 3: Permitted Blaney-Criddle Diverted Water Demand
- Estimate 4: Permitted Penman-Monteith Diverted Water Demand
- Estimate 5: Irrigated Land Factor Adjusted Blaney-Criddle Diverted Water Demand
- Estimate 6: Irrigated Land Factor Adjusted Penman-Monteith Diverted Water Demand
- Estimate 7: Reported Use Factors Applied to Study Area

Table ES-1
Consolidated 2014 Baseline Irrigation Estimates – Acre Feet Per Year

Contract Reach	Estimate 1	Estimate 2	Estimate 3	Estimate 4	Estimate 5	Estimate 6	Estimate 7
1	274,800	109,300	387,600	293,100	150,900	114,100	219,100
2	32,700	11,300	45,200	37,900	15,900	13,300	16,200
3	83,300	36,300	107,700	87,600	46,200	37,500	41,900
4	41,500	22,900	55,500	46,500	29,500	24,700	34,800
5	90,200	44,000	126,800	107,200	61,100	51,600	85,200
6	53,300	28,500	76,100	64,700	40,400	34,400	34,900
7	54,900	29,100	77,600	66,300	40,500	34,600	43,900
8	12,100	4,100	15,700	13,200	5,300	4,500	16,100
9	900	400	1,300	1,100	600	500	2,600
10	3,300	1,600	4,600	3,900	2,000	1,700	3,700
11	1,500	800	1,800	1,500	1,000	800	2,600
12	200	200	300	200	200	200	1,200
13	7,900	5,400	10,200	8,700	6,900	5,900	8,900
14	1,000	400	1,100	900	500	400	1,900
15	600	400	600	500	500	400	1,300
Total	**658,200**	**294,700**	**912,200**	**733,400**	**401,500**	**324,500**	**514,400**

Table ES-1 shows baseline estimates ranging from 294,700 acre feet per year to 912,200 acre feet per year.

Baseline irrigation Estimates 1 and 2 are based on the typical legal maximum duty of 2.5 acre-feet per acre applied to all cropland with AI permits in the study area. Estimate 1 baseline irrigation is filtered based on whether cropland identified in the CDL falls within a valid POU as identified by WRIS. Estimate 1 for the baseline year totals 658,200 acre-feet. Estimate 2 reflects the application of the Census of Agriculture irrigation factor in an attempt to estimate how much of the legally allowable duty of 2.5 acre-feet per acre would typically be used. Baseline irrigation Estimate 2 for the baseline year totals 294,700 acre-feet.

Estimates 3 and 4 represent the results of diverted water demand (DWD) calculated from the evapotranspiration methods filtered on the basis of whether or not the CDL falls within a valid POU as identified by WRIS. The baseline irrigation of Estimate 3 (permitted Blaney-Criddle DWD) totals 912,200 acre-feet for the baseline year. The baseline irrigation of Estimate 4 (permitted Penman-Monteith DWD) totals 733,400 acre-feet for the baseline year.

Estimates 5 and 6 also represent the diverted water demand calculated from the evapotranspiration methods filtered on the basis of crop and county-specific factors developed from multiple years of Census of Agriculture data. Estimate 5 irrigation for the baseline year amounts to 401,500 acre-feet, while Estimate 6 AI irrigation for the baseline year amounts to 324,500 acre-feet.

Estimate 7 is unique in that it is based on actual reported diversion for irrigation use data. While universal coverage of reported diversion for irrigation use throughout the study area would have been optimal for this analysis, the factors developed from available data appear to have yielded a valid baseline irrigation estimate of 514,400 acre-feet – squarely in the middle of the other estimates.

Estimates 3 and 5 were dropped from further analyses.

Table ES-2 provides the baseline estimate and the projected irrigation for each ten-year increment of the analysis period.

Table ES-2
Projected Irrigation Estimates Incorporating Growth in Permitted Acres – Acre Feet

Year	Estimate 1	Estimate 2	Estimate 4	Estimate 6	Estimate 7
2014	658,200	294,700	733,400	324,500	514,400
2020	680,300	316,800	757,500	348,200	526,400
2030	717,200	353,700	797,700	387,600	546,400
2040	754,000	390,500	837,900	427,100	566,500
2050	790,800	427,300	878,100	466,500	586,500
2060	827,700	464,200	918,300	506,000	606,500
2070	864,500	501,000	958,500	545,400	626,500
Total Increase	**206,300**	**206,300**	**225,100**	**220,900**	**112,100**
Percent Increase	**31%**	**70%**	**31%**	**68%**	**22%**

Based on feedback from the irrigation stakeholder group in December 2016, the Corps and WRD recommend using Estimate 1 as the baseline and projected agricultural irrigation demand estimate for water supply storage from the Willamette Valley Project reservoirs. Estimate 1 is based on a duty rate of 2.5 acre-feet per acre applied to acres under cultivation according to the 2014 CDL and are permitted for agricultural irrigation. Estimate 1 baseline 2014 irrigation is 658,200 acre-feet and projected irrigation incorporating growth in permitted acres in 2070 is 864,500 acre-feet, reflecting a total increase of 206,300 acre-feet of agricultural irrigation from the baseline year of 2014 to 2070, and 184,200 acre-feet over the 50-year over the period of analysis from 2020 to 2070. These values are shown in Table ES-3

Table ES-3
Recommended Agricultural Irrigation Projected Estimate – Acre Feet

Year	Recommended (Estimate 1)	Increase from Year 2020
2014	658,200	n/a
2020	680,300	
2030	717,200	36,900
2040	754,000	73,700
2050	790,800	110,500
2060	827,700	147,400
2070	864,500	184,200

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Agricultural Irrigation Demand Analyses for the Willamette Basin Review Feasibility Study

1 Background

The first step in evaluating the reallocation of a portion of the Willamette Valley Project storage for water use is to identify the reallocation 'need,' or in other words the amount of water and associated water supply storage that should be considered for reallocation. Water from the Willamette River and associated tributaries is distributed to Municipal and Industrial (M&I), Self-Supplied Industrial (SSI), and agricultural users throughout the Willamette River Basin for multiple end uses. Therefore, a water demand analysis was completed to assess the existing and future needs for water supply storage from the Willamette Valley Project reservoirs.

1.1 Objective

Agricultural water use varies widely across Oregon, but as a category, it accounts for the largest volume of water demand in the state. The Oregon Water Resources Department (WRD) is responsible for granting and managing water rights in the state. Until the 1990s, there were no requirements for agricultural irrigation (AI) water users to report actual water use volumes. All AI water permits previously granted have no record of water volume used during the irrigation season. Only 17 percent of water rights in Oregon require the reporting of water use; therefore, full accounting of AI water use within the Willamette River Basin is impossible. The analysis described in this document focuses on estimating existing and expected future agricultural irrigation water demand and supply within the Willamette River Basin[1]. The period of analysis used in this evaluation is 2020 through 2070, with 2014 used for the baseline evaluation.

1.2 Agriculture in the Willamette River Basin

Agricultural commodities in the Willamette River Basin are among the most diverse found anywhere in the United States. In 2011, the Willamette River Basin accounted for more than 40 percent of Oregon's gross farm sales. Six Willamette River Basin counties (Marion, Clackamas, Washington, Linn, Yamhill, and Polk) are in the top 10 counties statewide for gross farm and ranch sales. The Willamette River Basin leads the state in nursery stock and caneberry production.

Oregon is ranked first in the United States for the production of blackberries, boysenberries, hazelnuts, black raspberries, ryegrass seed, orchard grass seed, sugarbeets, crimson clover, fescue, red clover, Christmas trees, and potted azaleas, all of which are predominately grown in the Willamette River Basin. More than 170 varieties of agricultural crops are grown and sold in the basin.

[1] Agricultural water demand for general use (e.g., livestock watering) is provided in a separate document.

Oregon agriculture is a key traded sector, ranking first in volume of exported products and third in value of exported products. About 80 percent of Oregon's agricultural production leaves the state, with about 40 percent leaving the country.

Agricultural irrigation diversions in the Willamette River Basin are not centralized as is the case in other major river basins in Oregon. There are eight irrigation districts in the study area; however, most irrigation needs are met via individual wells or diversions. In the Willamette River Basin, there are more than 18,000 water rights permitted for irrigation uses, representing 65 percent of all authorized water rights.

Commercial irrigated agriculture did not start simultaneously with the settlement of the basin. Under dry land farming conditions, farmers raised crops that matured early or crops that were drought resistant. The expansion of agricultural irrigation was slow until the 1940s. There were about 1,000 irrigated acres of farmland in the Willamette River Basin in 1911 and 3,000 irrigated acres in 1920. By 1930, the basin contained 5,000 irrigated acres, which increased to 27,000 acres by 1940. A dramatic increase in the number of irrigated acres occurred in the Willamette River Basin during the postwar decades. In 1964, approximately 194,000 acres were irrigated in the basin (Oregon Water Resources Board, 1967). Irrigated acreage increased to about 282,000 by 1987; however, the rate of irrigation expansion in the Willamette River Basin decreased during the 1980s.

Since 1991, over 36,800 acres have been permitted for agricultural irrigation use, at an average rate of 1,473.5 acres each year.

1.3 Organization of the Report

This report is organized under eight additional sections and three attachments.

Section 2 describes concepts regarding agricultural irrigation, which include Net Irrigation Water Requirement and Diverted Water Demand. Two methods of calculating these two metrics also are introduced in this section: duty and evapotranspiration. The Blaney-Criddle and Penman Monteith methods for calculating evapotranspiration are also introduced.

Section 3 describes major data sources for analyses described throughout this document, and provides a definition of the study area limits.

Section 4 provides a description of methods used to calculate Diverted Water Demand through both the duty and evapotranspiration methods. Using a step-by-step example, Section 4 also describes the calculation of Net Irrigation Water Requirement and Diverted Water Demand using both the Blaney-Criddle and Penman Monteith equations introduced in Section 2.

Section 5 describes the three different methods used to distinguish between irrigated and non-irrigated cropland to estimate baseline irrigation volumes from Diverted Water Demand calculations.

Section 6 provides a summary and analysis of the baseline irrigation estimates developed within this report.

Section 7 provides a description of the methodology used to incorporate anticipated increases in permitted agricultural irrigation acreage on the baseline irrigation estimates.

Section 8 provides a description of the methodology used to incorporate future climate change impacts on the baseline irrigation estimates. Climate variability and the validity of 2014 as the baseline year is discussed.

Section 9 discusses the impact of Minimum Perennial Streamflows on select agricultural irrigation water rights, and provides an estimate of the acre-feet of water rights that may be at risk.

This document also includes three attachments so that the main flow of the document would not be disrupted by extensive analytical details and the presentation of multiple repetitive tables.

Attachment A provides an extensive table of crop coefficients for crops in the Willamette River Basin that were identified by the U.S. Department of Agriculture's Crop Data Layer.

Attachment B provides detailed sample calculations for the Penman-Monteith method of deriving reference crop evapotranspiration. The Penman-Monteith equation is briefly described and used in the Section 4 of the main document.

Attachment C provides a listing of crops in the Willamette River Basin identified in the U.S. Department of Agriculture's Crop Data Layer with a cross-reference identified for major crop groupings derived from the Census of Agriculture. Also included in this attachment are numerous tables that have been derived from Census of Agriculture data, and adjusted baseline diversion demand by county and major Census crop group.

2 Agricultural Irrigation Water Demand: Overview of Concepts

The theoretical diverted water demand (DWD) is the volume of water that could be withdrawn from a water source (either surface water or groundwater), transported to a place of use, and applied to crops for agricultural irrigation purposes. DWD estimates were calculated in two ways, as:

1. the legal maximum allowable volume of water to be withdrawn, also referred to as "duty" (usually 2.5 acre-feet per acre irrigated); and
2. the consumptive use of water by crops through evapotranspiration for optimal crop growth.

Diverted water demand does not consider whether land associated with a specific crop is irrigated. Baseline irrigation is that portion of DWD estimated to be currently satisfied through AI.

Baseline and projected irrigation estimates are constructed using a spatially-based approach, which reflects the use of geo-spatially organized data available at the basin, county, and state level. This document provides estimates of baseline and projected irrigation in three ways, as:

1. adjustments to DWD by determining where crops are grown on lands with an AI water right;
2. adjustments to DWD through the application of county-level irrigation factors developed from the U.S. Department of Agriculture's Census of Agriculture (2012, 2007, 2002, and 1997); and
3. application of AI DWD factors developed through analyses of data obtained from the Oregon Water Resources Department's Water Rights Information System.

2.1 Net Irrigation Water Requirement and Diverted Water Demand

Understanding the difference between diverted water demand and net irrigation water requirement (NIWR) is an important concept in understanding AI diverted water demand. Descriptions are provided below and illustrated in Figure 2-1.

Net Irrigation Water Requirement (NIWR) is the portion of crop consumptive demand met by irrigation water. Crop consumptive demand is defined as the volume of water required to grow a well-watered crop under optimal conditions with a full water supply. Crop consumptive demand is assumed to have been met first with effective precipitation, or the amount of precipitation that satisfies a portion of crop needs. The remaining portion of crop consumptive demand is quantified as the NIWR, which is the volume of water needed to make up the difference between what a crop would naturally receive through precipitation and what is needed for a well-watered crop under ideal growing conditions.

NIWR = Crop Consumptive Demand – Effective Precipitation

Applied Water Demand is the volume of water required for application on a field through irrigation to meet crop consumptive demand. Applied water demand is larger in volume than

NIWR due to factors such as on-farm application efficiency, which varies by irrigation technique (e.g., sprinklers, flood).

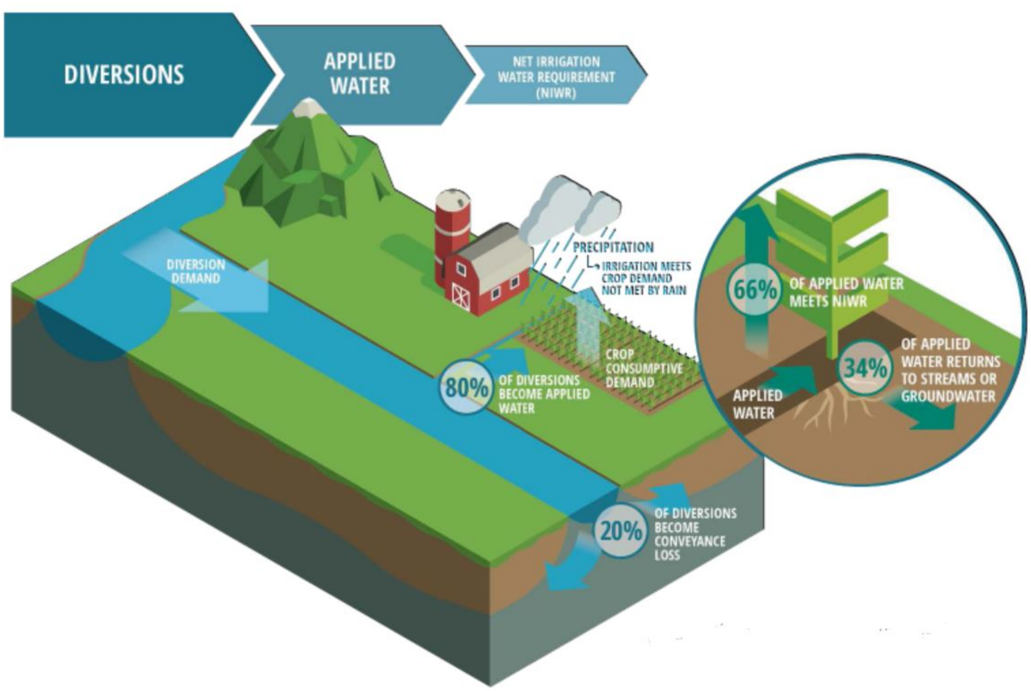
Applied Water Demand = NIWR + Irrigation Losses

Diverted Water Demand is the volume of water that must be diverted from surface water (or extracted from groundwater) to meet full applied water demand for all the farms in a given distribution network. Diverted water demand is larger in volume than applied water demand, as many of the canals that supply irrigation water experience conveyance losses, such as seepage to groundwater through unlined portions of the network as well as losses to evaporation.

Diverted Water Demand = Applied Water Demand + Conveyance Losses

It should be noted that NIWR and its associated DWD are merely estimates, and the actual amount of water consumed by plants may be different from what was estimated in this analysis. Also, it is important to remember that the calculation of NIWR and its associated DWD are based on equations developed through empirical studies throughout the United States and abroad. The equations are based on the results of those empirical studies, and the goal of those equations is to approximate the actual (and measured) diversions from streams and wells for AI.

Figure 2-1
Illustration of Diversions, Applied Water, and NIWR



2.2 Identification of Methods Used to Calculate NIWR

Two separate methods were used to calculate NIWR for this report: Blaney-Criddle; and Penman-Monteith.

Both the Blaney-Criddle and Penman-Monteith methods calculate evapotranspiration for a "reference crop", though the calculation differs between the two methods in determining reference crop evapotranspiration. Both methods require spatially-referenced (i.e., at the location of the crop under investigation) climatic data in the calculation of reference evapotranspiration, though the climatic data required by the Penman-Monteith method is more extensive.

Once the reference crop evapotranspiration value is obtained, the remaining steps required to calculate NIWR are identical for the two approaches, which is fully described in Section 4 of this document.

3 Data Sources and Study Area Limits

Several sources of data were used in the analysis and are described prior to the study area definition, as the data sources were instrumental in defining the limits of the study area for this analysis.

3.1 Data Sources

Major data sources used in this analysis each provided specific data elements used in the analysis. Each data source is described in this section.

1. Cropland under production
2. Climate data for the Willamette River Basin
3. Crop coefficients for Willamette River Basin crops identified in the Cropland Data Layer
4. Irrigated cropland
5. Oregon Water Rights Information System data
6. Census of Agriculture, county-level data

3.1.1 U.S. Department of Agriculture's Cropland Data Layer

The identification of cropland and crops in agricultural production relied exclusively on data obtained from the U.S. Department of Agriculture's 2014 Cropland Data Layer (CDL)[2] – a GIS-based crop-specific land cover data layer with a ground resolution of 30 meters that covers the contiguous United States.

The CDL is produced using satellite imagery and remote sensing techniques, and its data are intended for geographic display and analysis at the state level. Crop classification accuracy of the CDL ranges from 85% to 95% across the United States, and its data offers crop acreage throughout the growing season. Based on the CDL, there are approximately 1.8 million acres of cropland in the Willamette River Basin, growing seventy-one different crops (excluding nursery and greenhouse plants/crops).

Figure 3-1 shows the coverage of agricultural crops within the Willamette River Basin, as identified in the CDL. As shown in the figure, agricultural crops are clustered around the Willamette River and its major tributaries.

Figure 3-2 provides an example of data available from the CDL within the Willamette River Basin at a more detailed resolution level. Each point shown in the figure represents a corner of a 900 square meter grid, and the CDL identifies the crop located at each point. Predominant crops identified for the example area also are labeled on the figure to aid in later discussions.

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[2] The CDL is produced by the USDA National Agricultural Statistics Service, and is available at: (http://www.nass.usda.gov/Research_and_Science/Cropland/SARS1a.php

Figure 3-1
CDL Coverage of Agricultural Crops throughout the Willamette River Basin

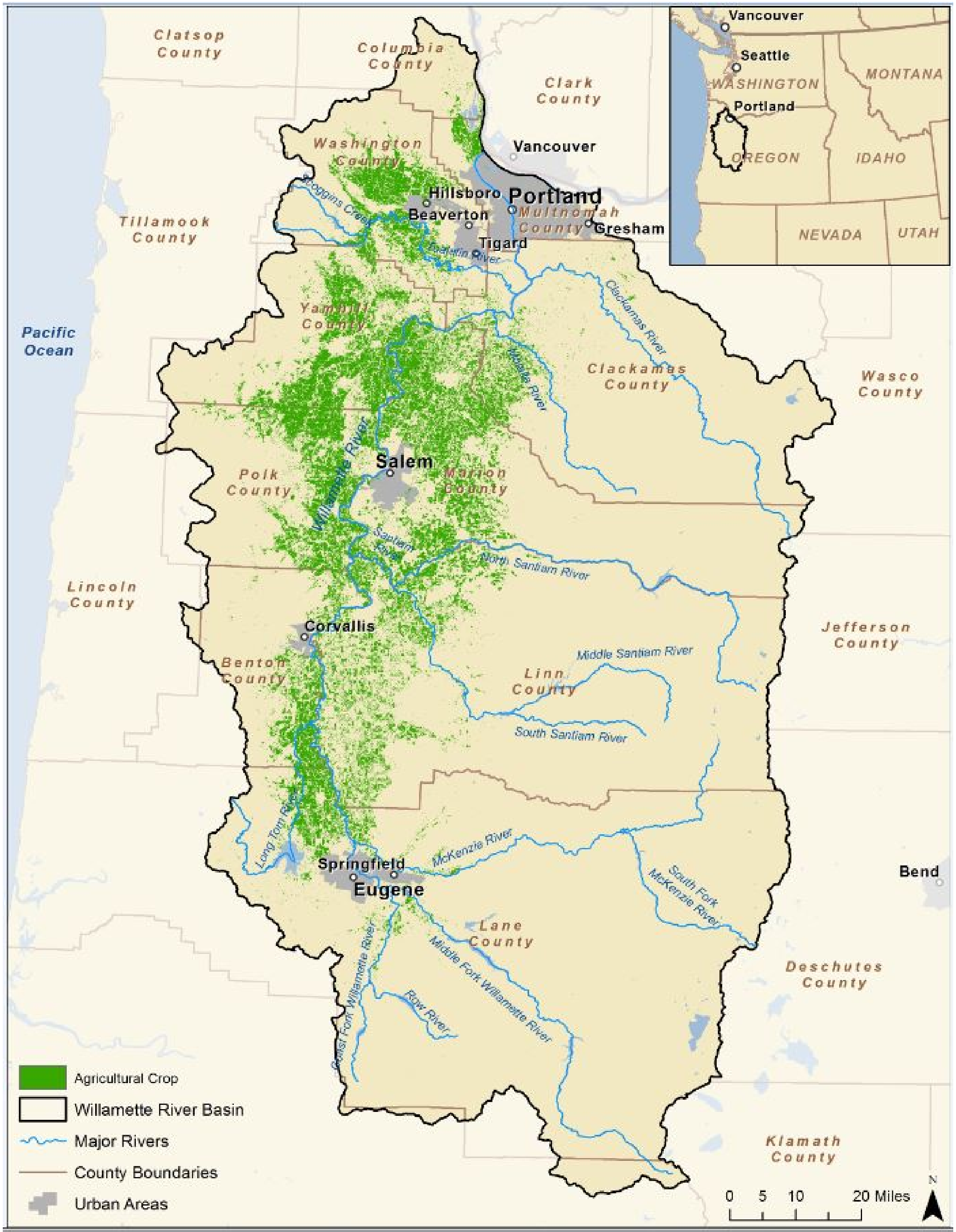
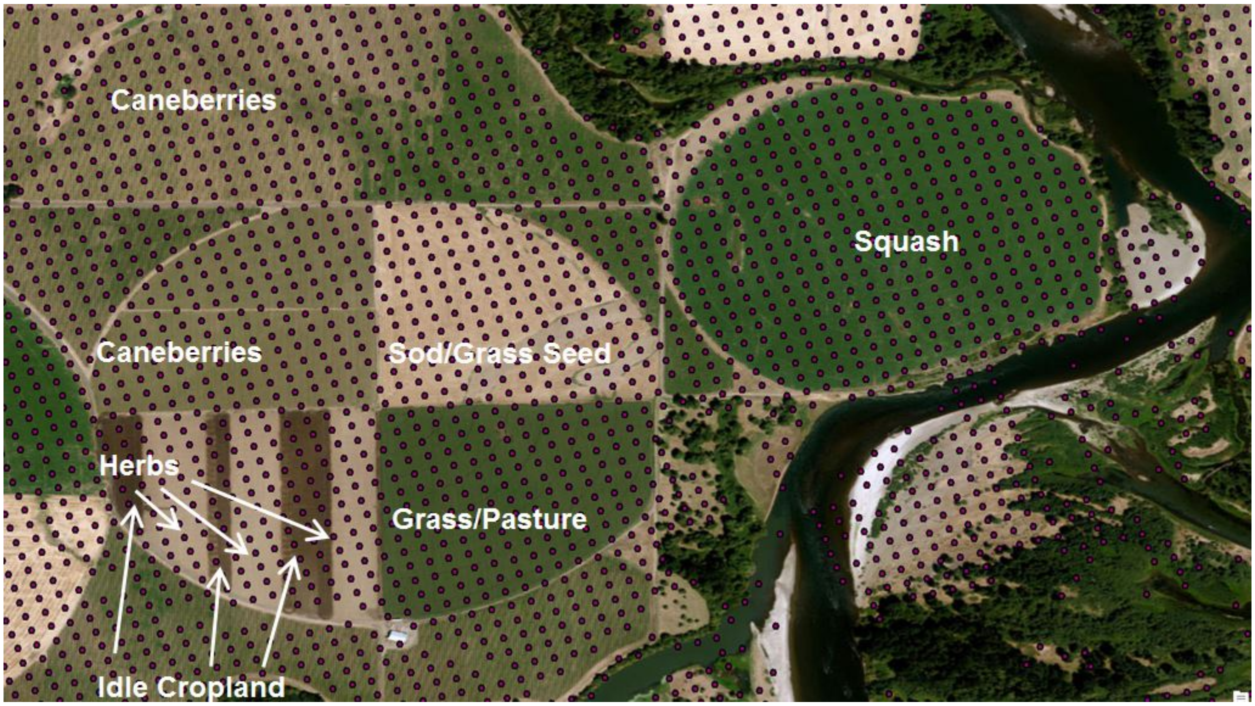


Figure 3-2
Representative Area Showing 900 Square Meter CDL Grids and Identified Crops



3.1.2 Climate Data

Climate data were used in this analysis to calculate the diverted water demand using the Blaney-Criddle and Penman-Monteith methods of estimating reference evapotranspiration and associated NIWR.

PRISM

Climate data used were obtained from the PRISM[3] AN81m timeseries database, which is developed from available observed data from all approved weather stations for the highest spatial consistency. PRISM data sets are the official spatial climate data of the USDA, and the data have been in continuous development and peer review since 1991.

The database is a statistical mapping system that provides a continuous 4 kilometer by 4 kilometer grid of surface climate elements by interpolating between measured observed weather station data using a weighted regression scheme. The regression scheme takes into account complex climate regimes associated with orography, rain shadows, temperature inversions, slope aspect, coastal proximity, and other climate-influencing factors. Specific data taken from AN81m and used in the calculation of the reference crop evapotranspiration are monthly mean temperature, mean

[3] PRISM is an acronym for Parameter elevation Regression on Independent Slopes Model, and is developed by the PRISM Climate Group, Northwest Alliance for Computational Science and Engineering at Oregon State University. Data are available at http://www.prism.oregonstate.edu; accessed July 2015

maximum temperature, mean minimum temperature, and mean dew point temperature.[4] Gridded precipitation data available from PRISM also was used in this analysis to calculate NIWR.

Figure 3-3 provides a representation of PRISM coverage throughout the Willamette River Basin, with each grid covering 16 square kilometers.

AgriMet

AgriMet is a network of agricultural weather stations dedicated to crop water use modeling and operated by the US Bureau of Reclamation. Daily mean solar radiation and mean wind speed required for the calculation of reference evapotranspiration using the Penman-Monteith method were obtained from the AgriMet weather stations in Aurora, OR[5] and Corvallis, OR[6].

US Geological Survey (USGS) Digital Elevation Model

The USGS developed a national digital elevation model (DEM) with elevation values provided in a 10 meter grid. Elevations of individual crops were used in the Penman-Monteith calculation of mean air pressure in the calculation of NIWR.

Figure 3-4 provides a representation of the topographic variation depicted by the USGS DEM throughout the Willamette River Basin. Low elevations are portrayed in green and high elevations are shown in white.

[4] Precipitation data available from PRISM also was used in this analysis, and is discussed in Section 4.4

[5] Data are available at http://www.usbr.gov/pn/agrimet/agrimetmap/araoda.html; accessed August 2016.

[6] Data are available at http://www.usbr.gov/pn/agrimet/agrimetmap/crvoda.html; accessed August 2016.

Figure 3-3
PRISM Data Coverage throughout the Willamette River Basin

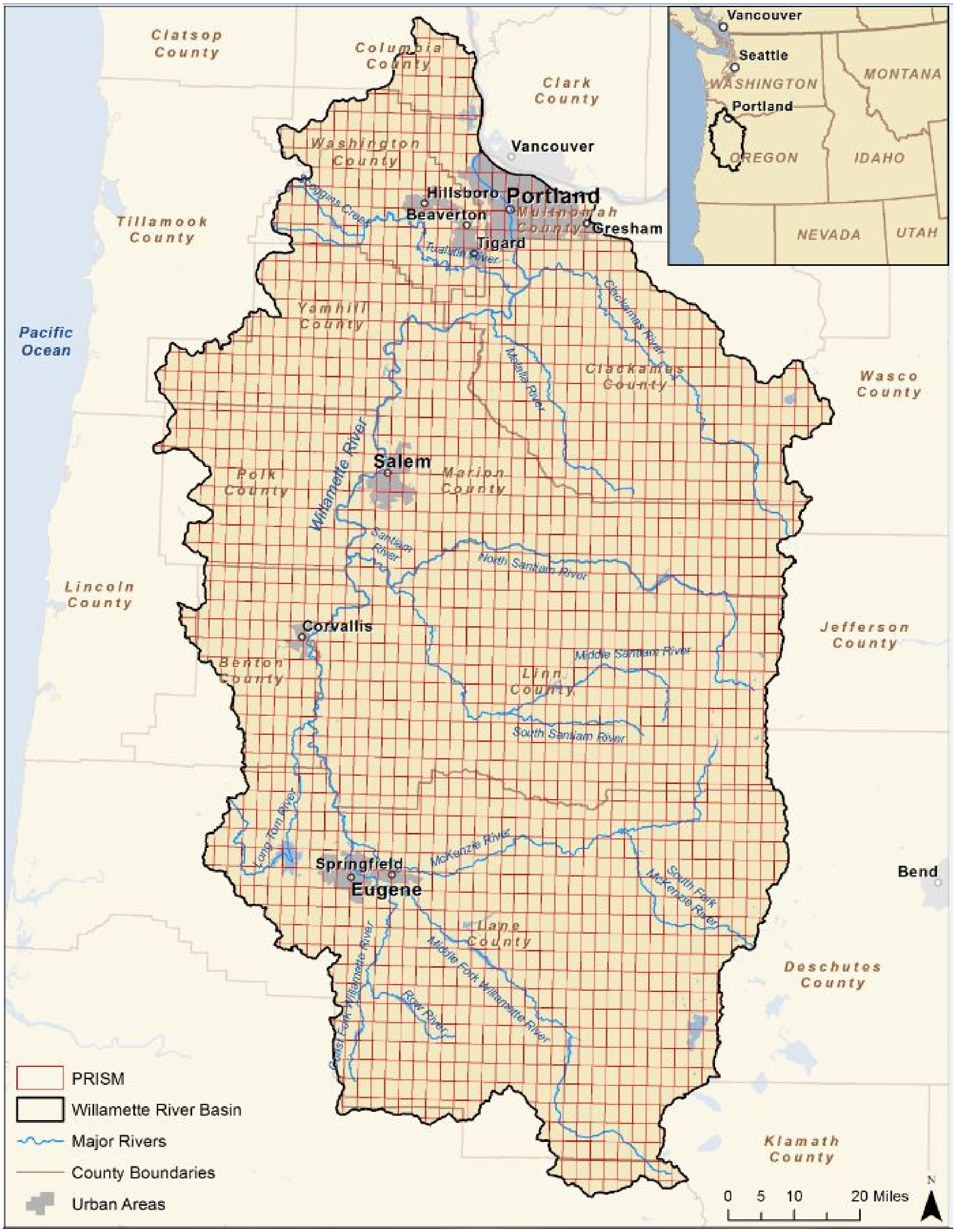


Figure 3-4
Topographic variation throughout the Willamette River Basin

3.1.3 Crop Coefficients

Water use through evapotranspiration by a type of crop (e.g., blueberries) is scaled relative to the reference crop evapotranspiration (ETo), by a crop-specific coefficient (referred to as Kc). Crop coefficients are always greater than zero, and vary with growth stage of the crop over the growing season. Crop coefficients used in this analysis were taken directly from the Oregon Department of Agriculture's (ODA) preliminary analysis of the Willamette River Basin. ODA cited that most Kc values for crops identified in the CDL for the Willamette River Basin were calculated by the AgriMet Program[7] and several other regional and international sources listed below.

- Oregon State University (OSU) Extension Service
- USDA Natural Resources Conservation Service (NRCS)
- USDA Agricultural Research Service (ARS) at University of Nebraska-Lincoln
- Washington State Extension
- British Columbia Ministry of Agriculture, Food and Fisheries
- Peer-reviewed journals
- Industry/trade associations
- United Nations Food and Agriculture Organization (UN FAO).

Attachment A provides a listing of crop coefficients provided by ODA and used in this analysis.

3.1.4 Oregon Water Rights Information System Data

The Oregon Water Resources Department (WRD) is responsible for assuring that sufficient and sustainable water supplies are available to meet the state's current and future water needs. WRD maintains extensive databases and online tools for accessing information about water rights[8]. Their main tool is the Water Rights Information System (WRIS), a warehouse of information containing water use applications, permits, water right certificates, transfers, leases and related information. Among the files available are ArcGIS geodatabases – one for each of Oregon's major river basins. The geodatabase for the Willamette River Basin was selected for use in this analysis, and contains over 52,000 records of information on water rights issued.

Of particular importance to this analysis is Place of Use (POU) data, as POUs represent lands on which the permitted withdrawal of water (surface or groundwater) can be applied. WRD has been mapping water rights in a geographic information system (GIS) since 1990, and the initial effort of compiling the water rights layers for the state was completed in 1999. The GIS layers have been linked directly to data attributes stored and managed in WRIS since 2004, and Figure 3-5 depicts the geographic coverage of POU data within the Willamette River Basin. POU GIS data were used to determine which lands within the basin have the legal right to agricultural irrigation.

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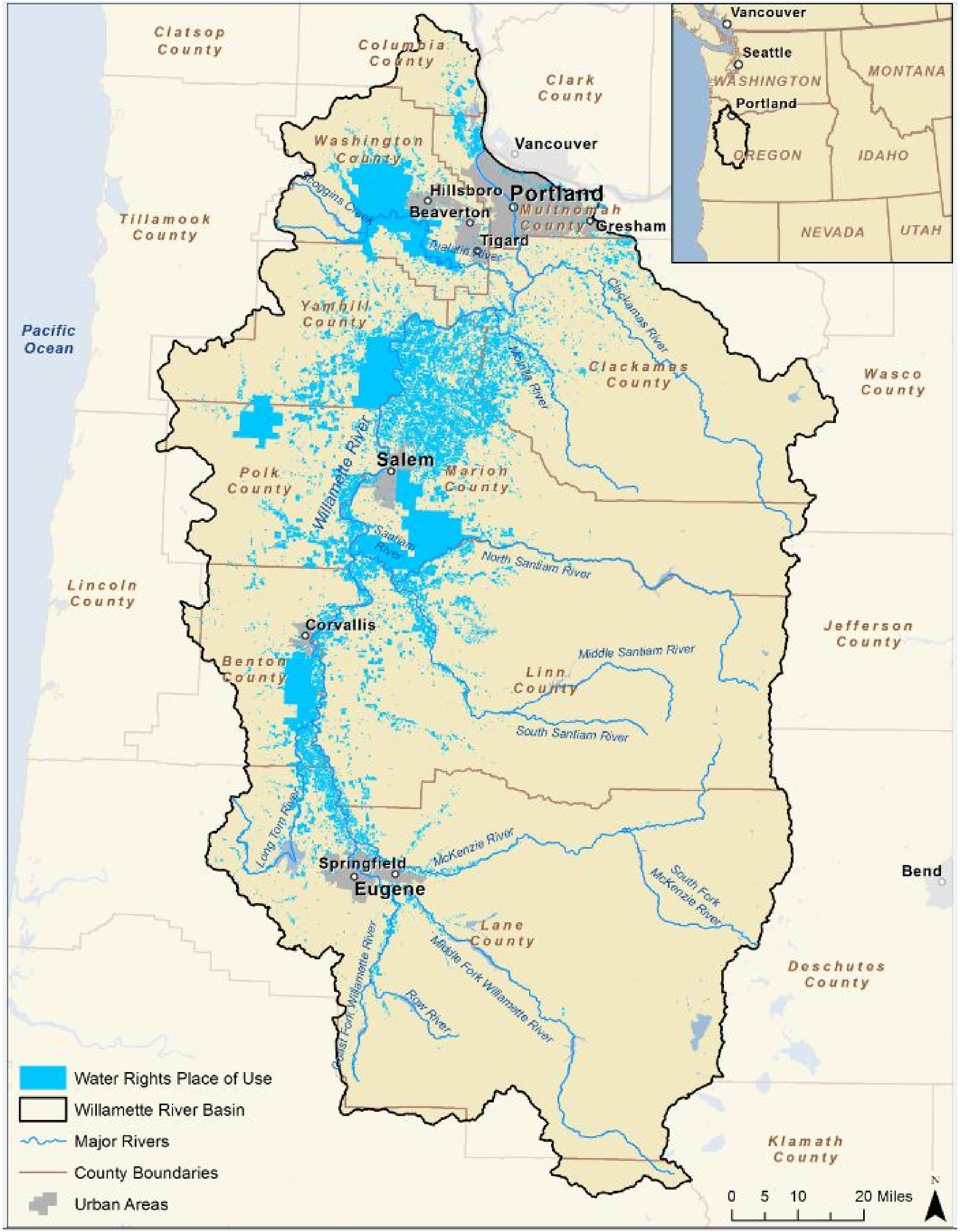
[7] Available at http://www.usbr.gov/pn/agrimet/proginfo.html; accessed in May 2015.

[8] Water Use Reports also are available through WRIS, and were obtained for use in the analysis described in this document. Their use in the analysis is discussed in Section 6.

Figure 3-5
WRIS POU Data Coverage throughout the Willamette River Basin



3.1.5 Census of Agriculture

County level segmentation of census data were obtained from the U.S. Department of Agriculture, Census of Agriculture for 2012, 2007, 2002, and 1997. Summary values of harvested acreage and harvested acreage irrigated are presented for major crop groups. These values were used to adjust NIWR-derived diverted water demand volumes by estimating that portion of a crop grown within a county under irrigation.

3.2 Study Area

The Willamette Basin Review Feasibility Study area for AI demand was defined by those lands capable and suitable for agricultural production and likely to be irrigated. The study area was subdivided by river segments as defined by the US Bureau of Reclamation contract reaches for obtaining stored water contracts.

3.2.1 Study Area Limits

Not all agricultural land located within the Willamette River Basin can cost-effectively access water released from the Willamette Valley Project reservoirs. For this reason, the project study area was not defined as the entire Willamette River Basin. Rather, the project area was defined as a four mile (linear) boundary from the Willamette River mainstem and tributaries on which Willamette Valley Project reservoir dams are located.

A four mile boundary was selected as a result of analyses conducted using WRIS POU data. The analyses showed that the closest edge of over 90 percent of all Willamette River Basin POUs are located within 1.25 miles of the Willamette River or a major tributary on which a Willamette Valley Project reservoir is located. As the distance increased to four miles, the corresponding percent of POU edges within the four-mile distance increased to 95 percent. Additional one-mile increments in distance yielded no appreciable increase in the number of POUs captured. The geographic extent of the study area is depicted on Figure 3-6.

The extent of the study area was further refined to include only those lands capable and suitable for agricultural production. Capability was determined by soil classification. Only those lands in the 4-mile buffer study area classified by the Natural Resources Conservation Service as "Lands Suited to Cultivation" are considered potentially irrigable. These areas were determined using the SSURGO-STATSGO soils classification with Unirrigated Capability Class or Irrigated Capability Class of 1, 2, 3 or 4.[9] Suitability was determined by identifying the Oregon zoning classification. Only areas classified as Exclusive Farm Use or Mixed Farm Forest are considered suitable for agriculture. To accommodate anticipated urban growth impacts on agricultural lands, Urban Growth Boundaries (UGBs) were removed from consideration. UGBs are lines drawn on planning and zoning maps to show where a city expects to experience growth for the next 20 years. The resulting modifications to the study area represent lands zoned as exclusive farm use or mixed farm forest, but not within a UGB.[10] Total acreage defined in the four-mile buffer (outlined on

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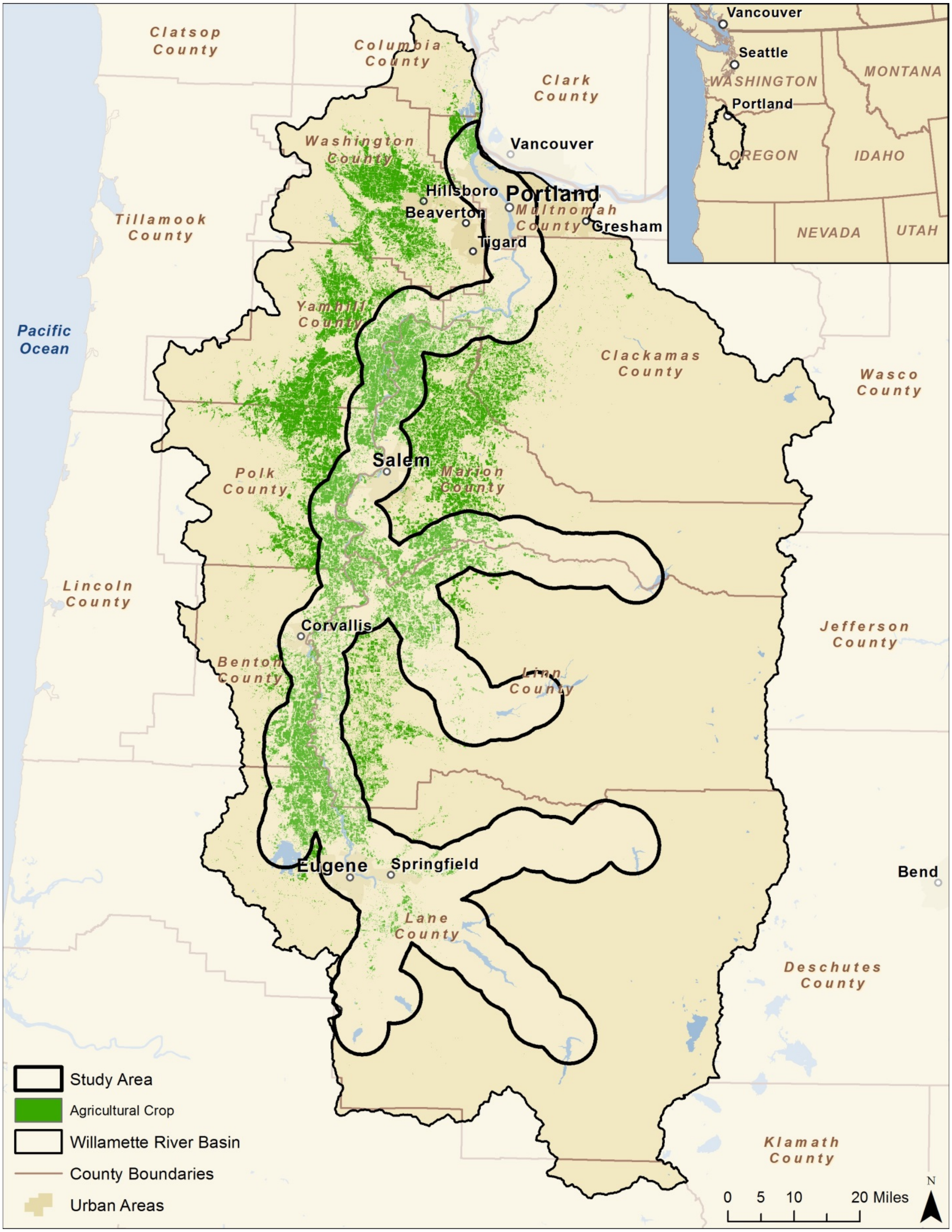
[9] See http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053631

[10] Zoning classification and UGBs at http://spatialdata.oregonexplorer.info/geoportal/catalog/main/home.page

Figure 3-6) is 1.9 million acres, though the total study area as defined by the “capable and suitable” criteria and acreage under agricultural production in 2014 amounts to roughly 573,000 acres.

Figure 3-6
Geographic Extent of the Study Area with CDL Overlay



3.2.2 Study Area Subdivisions

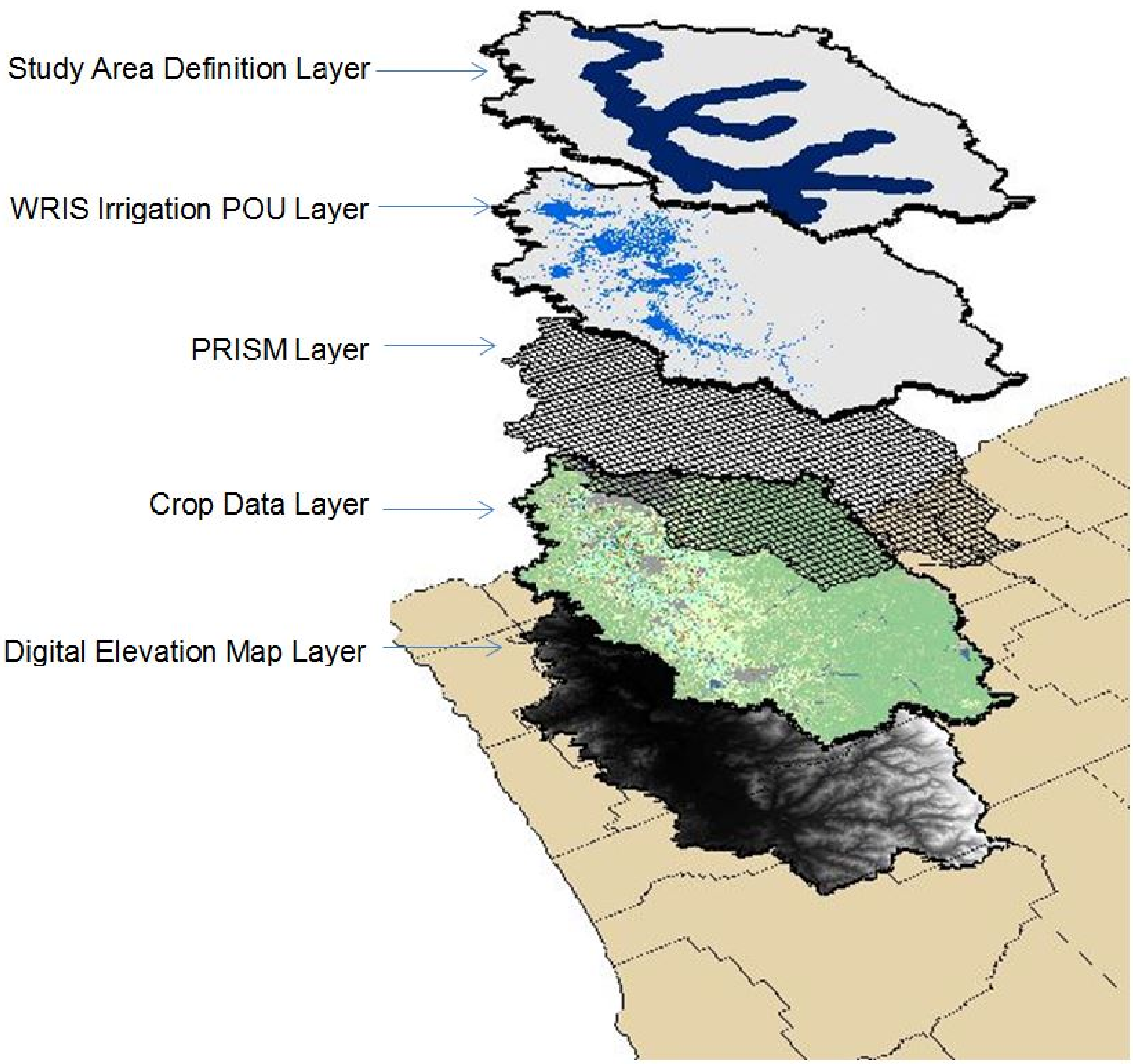
The US Bureau of Reclamation (BOR) is responsible for issuing storage contracts for water to be released from the Willamette Valley Project reservoirs during the conservation release season. The BOR has subdivided the Willamette River and tributaries associated with Willamette Valley Project reservoirs into 15 contract reaches based on the reservoirs contributing to flow within the reach. As shown in Figure 3-7, this study uses the same reach designations to subdivide the study area.

Figure 3-7
Study Area Reaches

3.2.3 Geospatial Framework

Major databases used in this analysis were integrated within a Geographic Information System (GIS) framework. Data are available at the layer level, and the specific location of data available from each layer can be joined to data from another layer solely on the basis of location. Major databases used in this analysis are shown on Figure 3-8, which illustrates the concept of the geospatial framework.

Figure 3-8
Illustration of the Inter-Related Geographic Features of Data Used in the Analysis



4 Diverted Water Demand

As defined in Section 2, diverted water demand (DWD) is theoretical volume of water that could be diverted from its source, transported to a place of use, and applied to crops for agricultural irrigation purposes. DWD can be calculated in two ways:

1. apply the average duty of 2.5 acre-feet per acre to croplands as identified in the CDL; and
2. calculate the crop demand of NIWR due to crop evapotranspiration.

4.1 DWD: Duty Method

Duty is typically defined as the quantity of water that is diverted to satisfy the irrigation water requirements in a given area. Oregon does not have a statutorily set duty of water, though permits often contain specific duties. The vast majority of permits issued for irrigation specify a duty rate of 2.5 acre-feet of water per acre irrigated, while most permits issued for nursery use specify a duty rate of 5.0 acre-feet of water per acre irrigated. Out of 551,650 acres with agricultural irrigation permits in the entire Willamette River Basin, only 22,550 acres are specified to be irrigated at a rate exceeding 2.5 acre-feet of water per acre irrigated, whereas 527,600 acres in the Willamette River Basin are specified to be irrigated at a rate of 2.5 acre-feet of water per acre irrigated.[11]

The calculation of DWD using duty represents the legal maximum of agricultural irrigation that could be applied to crops. Calculating diverted water demand by the application of the average duty requires the determination of the number of acres under cultivation and multiplying by 2.5 acre-feet per acre, as given below.

$$\text{DWD} = \text{acres under cultivation} * 2.5\ \text{acre-feet/acre}$$

Table 4-1 depicts total diverted water demand within the entire Willamette River Basin and the Study Area based on acres under cultivation according to the 2014 CDL. Table 4-2 shows the DWD as derived by the duty method for each contract reach within the study area.

Table 4-1
Total Diverted Water Demand: Duty Method

Extent	Total Acres	Crop Acres	Duty (ac-ft/ac)	DWD (ac-ft)
Willamette River Basin	7,337,900	1,769,300	2.5	4,423,200
Study Area	1,890,100	572,600	2.5	1,431,500

[11] About 1,500 acres in the Willamette River Basin are specified to be irrigated at a rate lower than 2.5 acre-feet of water per acre irrigated

Table 4-2
Diverted Water Demand by Reach: Duty Method

Contract Reach	Study Area Crop Acres	Duty (ac-ft/ac)	DWD (ac-ft)
1	190,424	2.5	476,060
2	15,832	2.5	39,581
3	60,160	2.5	150,401
4	67,510	2.5	168,775
5	85,261	2.5	213,152
6	53,060	2.5	132,650
7	61,993	2.5	154,982
8	9,959	2.5	24,896
9	940	2.5	2,351
10	4,134	2.5	10,334
11	2,646	2.5	6,615
12	557	2.5	1,393
13	17,112	2.5	42,781
14	1,583	2.5	3,957
15	1,438	2.5	3,595
Total	**572,609**		**1,431,522**

It is important to note that the DWD figures in the tables above represent a theoretical legal maximum volume of water that could be used to irrigate crops under production. These values have not been adjusted to reflect whether irrigation occurs on the agricultural lands under production. As such, these volumes of water are not representative of water withdrawn from groundwater, the Willamette River, or its tributaries.

4.2 DWD: Evapotranspiration Methods

As introduced in Section 2.2, two separate methods were used to calculate NIWR due to crop evapotranspiration: Blaney-Criddle; and Penman-Monteith. This section provides an example of the step-by-step procedures used in calculating NIWR and the associated diverted water demand for each of the two methods. In general, calculations follow the steps outlined below.

Step 1: Identify Active Cropland and Crops within the Willamette River Basin

Step 2: Calculate Reference Evapotranspiration for a Crop Grid

Step 3: Calculate Monthly Crop Evapotranspiration for the Crop Grid

Step 4: Calculate Monthly Net Irrigation Water Requirements

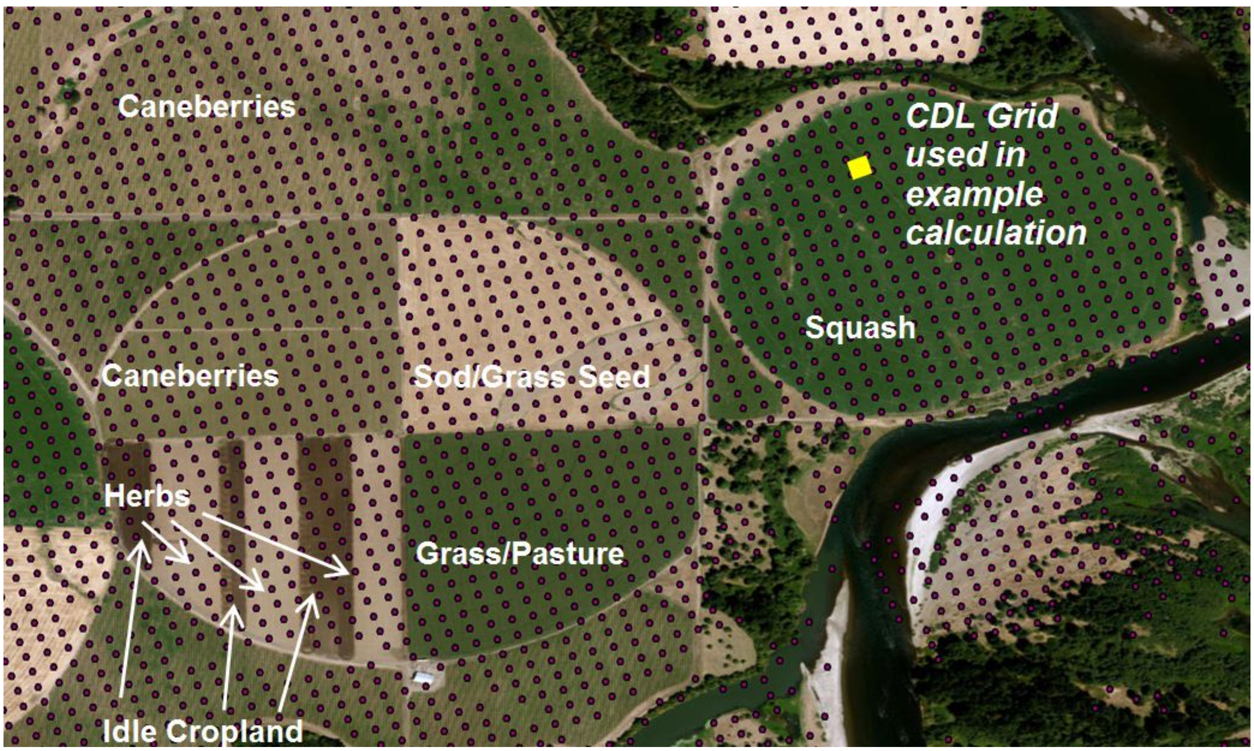
Step 5: Calculate Applied Water Demand and Diverted Water Demand

Step 6: Calculate Acre-Feet of Diverted Water Demand

4.2.1 Step 1: Identify Active Cropland and Crops within the Willamette Basin

Cropland and crops in agricultural production data were obtained from the CDL (see discussion in Section 3 above). Figure 4-1 (a repeat of Figure 3-2 above) shows a sample area of the CDL within the Willamette River Basin (-123.2268° longitude; 44.4218° latitude). As mentioned above, each point shown in the figure represents a corner of a 900 square meter grid, and the CDL identifies the crop located at each point – the squash crop will be carried through in this example – specifically the area highlighted in yellow.

Figure 4-1
CDL Representation of Example Area



4.2.2 Step 2: Calculate Reference Evapotranspiration for a Crop Grid

As introduced in Section 2.1 both the Blaney-Criddle and Penman-Monteith methods calculate evapotranspiration for a "reference crop", which is referred to as Reference Evapotranspiration (ETo). Reference Evapotranspiration (ETo) is defined as the rate of evapotranspiration from a standardized reference crop that is actively growing, not limited by soil moisture, and is at full cover and standardized height. The reference crop for Oregon is grass. In this example, ETo is calculated for the CDL crop grid location shown in yellow on Figure 4-1 above. It is important to note that all the climate data used in the calculation of ETo are specific to the yellow crop grid location, using data from the closest overlay match (see Section 3 above).

Blaney-Criddle Calculation of ETo

The Blaney-Criddle formula for calculating ETo, is given by the equation below.

$$\mathrm{ETo} = p * \cdot (0.46 \cdot \mathrm{Tmean} + 8)$$

Where:

ETo	=	Reference Evapotranspiration (monthly in mm/d);
Tmean	=	mean daily temperature (degrees C); and
p	=	mean daily percent of annual daytime hours (for latitude of site)

Blaney-Criddle Equation Data Sources

The source for Tmean data is the PRISM database (see Section 3.1.2), the source for p mean daily percent of annual daytime hours (p) were obtained from Doorenbos and Pruitt (1977), which provides monthly averages of daytime hours by month and latitude.

Blaney-Criddle Equation Strengths and Weaknesses

The primary strengths of the Blaney-Criddle calculation of ETo are the relative simplicity of the equation and the readily available supporting required data sources; however, the exclusive reliance on mean daily temperature and latitude does not take into consideration many other climatic variables that play a role in crop water needs.

Penman-Monteith Calculation of ETo

The Penman-Monteith formula for calculating ETo, is given by the equation below, and a detailed example of a sample calculation is provided in Attachment B.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T + 273} u_2 (e_s^0 - e_a)}{\Delta + \gamma(1 + C_d u_2)}$$

Where:

ETo	=	Reference Evapotranspiration (monthly in mm/d)
R_n	=	net radiation at the crop surface (MJ/m2/d);
G	=	soil heat flux density (MJ/m2/d);
T	=	mean daily air temperature at 2 m height (°C);
u_2	=	wind speed at 2 m height (m/s);
e_s^0	=	saturation vapor pressure (kPa);
e_a	=	actual vapor pressure (kPa);
Δ	=	slope of the vapor pressure curve (kPa/°C);
γ	=	psychrometric constant (kPa/°C);
C_n	=	the numerator constant for the reference crop and time step (900 mm/d for grass and daily time step); and

C_d = the denominator constant for the reference crop and time step (0.34 mm/d for grass and daily time step).

Penman-Monteith Equation Data Sources

Climate data required for the calculation of reference evapotranspiration were obtained from several sources. This analysis used a monthly time-step for all variables.

Temperature. Mean air temperature, mean minimum air temperature, mean maximum air temperature, and mean dew point temperature were obtained from the PRISM monthly timeseries database (see Section 3.1.2).

Solar Radiation and Wind Speed. Daily mean solar radiation and mean wind speed were acquired from the AgriMet weather stations in Aurora, Oregon and Corvallis, Oregon[12]. Monthly mean values for solar radiation and wind speed were calculated for each weather station for each month from May through September 2014. Crops were assigned monthly values for each parameter according to the closest weather station.

Elevation. Elevation in meters above sea level is required for the calculation of mean air pressure. The elevation at the centroid within each crop polygon was extracted from the Oregon 10-meter Digital Elevation Model[13].

Penman-Monteith Equation Strengths and Weaknesses

The primary strength of the Penman-Monteith calculation of ETo is the incorporation of the many climatic variables influencing crop water demands; however, the rigorous physically-based analytical method requires the availability of many climate parameters, some of which may be unavailable. Since only two weather stations in the area provide daily measures of solar radiation and wind speed, these climate variables do not share the same spatial resolution and variability as those obtained from the PRISM data. This paucity of data sources results in input values used in the calculation that do not represent the anticipated heterogeneity of local climate. It is noteworthy that both the US Bureau of Reclamation and the Oregon Water Resources Departement use the Penman-Monteith calculation of ETo to estimate water use.

Example Calculation Results of Step 2: Monthly ETo Values

Table 4-3 shows the results of the ETo calculation for the Blaney-Criddle formula and the Penman-Monteith formula. Results are shown for May through September – the period during which releases of water for AI demand are permitted from Willamette Valley Project reservoirs.

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[12] Data are available at http://www.usbr.gov/pn/agrimet/agrimetmap/araoda.html and http://www.usbr.gov/pn/agrimet/agrimetmap/crvoda.html, both accessed August 2016

[13] Data are available at https://library.uoregon.edu/map/gis_data/or_10mdem.htm; accessed August 2016.

Table 4-3
Monthly ETo Values for Sample Location: Blaney-Criddle and Penman-Monteith

Month	Blaney-Criddle	Penman-Monteith
May	4.849	3.889
Jun	5.422	4.428
Jul	5.996	5.703
Aug	5.600	5.145
Sep	4.603	3.823

4.2.3 Step 3: Calculate Monthly Crop Evapotranspiration for the Crop Grid

In this step, daily evapotranspiration is calculated for each specific crop for each CDL grid, and then multiplied by the number of days in the month. The yellow-highlighted grid (squash crop) for which ETo was calculated in Step 2 is carried through this step.

Evapotranspiration for a particular crop type (ETc) is defined as the rate of evapotranspiration of a specific crop (squash in this example calculation) under standard conditions. Standard conditions mean that the crop is grown in a large field under excellent agronomic and soil water conditions. ETc differs from ETo as the ground cover, canopy characteristics and aerodynamic resistance of the crop are distinctly different from the reference crop.

ETc is calculated relative to evapotranspiration of the reference crop by scaling ETo with a crop-specific crop coefficient defined as Kc[14]. Generally speaking, Kc is the ratio of ET of the type of crop being examined (ETc) to the ET of the reference crop (ETo). Kc values for a crop vary with the growth stage of the crop during months of the growing season.

The calculation of monthly ETc is given by:

$$\text{ETc} = \text{ETo} * \text{Kc} * \text{Days in Month}$$

The calculation of monthly ETc for the example CDL grid and squash crop throughout the five-month conservation release season for the Willamette Valley Project reservoirs is provided in Tables 4-4 and 4-5. Table 4-4 shows the calculation of ETc for the example squash crop using ETo calculated by the Blaney-Criddle method, and Table 4-5 shows the calculation of ETc for the example squash crop using ETo calculated by the Penman-Monteith method.

[14] Crop coefficients (Kc) are discussed in Section 3.1.3 above. The full set of crop coefficients used in this analysis are provided in Attachment B.

Table 4-4
Calculation of Monthly ETc Values for Squash Grid Using Blaney Criddle ETo

Month	Blaney-Criddle ETo	Kc Squash	ETc Squash (mm)	Days	Monthly ETc Squash (mm)
May	4.849	0.526	2.551	31	79.068
Jun	5.422	0.700	3.795	30	113.862
Jul	5.996	0.820	4.917	31	152.418
Aug	5.600	1.000	5.600	31	173.600
Sep	4.603	1.000	4.603	30	138.090

Table 4-5
Calculation of Monthly ETc Values for Squash Grid Using Penman-Monteith ETo

Month	Penman-Monteith ETo	Kc Squash	ETc Squash (mm)	Days	Monthly ETc Squash (mm)
May	3.889	0.526	2.046	31	63.414
Jun	4.428	0.700	3.100	30	92.988
Jul	5.703	0.820	4.676	31	144.970
Aug	5.145	1.000	5.145	31	159.495
Sep	3.823	1.000	3.823	30	114.690

4.2.4 Step 4: Calculate Monthly Net Irrigation Water Requirements

Net Irrigation Water Requirement (NIWR) is defined as the volume or depth of water required, in addition to precipitation, to grow a well-watered crop under optimal conditions. Crop consumptive demand is assumed to have been met first with effective precipitation, or the amount of precipitation that satisfies a portion of crop needs. The remaining portion of crop consumptive demand is quantified as the NIWR, which is the volume of water needed to make up the difference between what a crop would naturally receive through precipitation and what is needed for a well-watered crop under ideal growing conditions.

NIWR is calculated as:

$$\text{NIWR} = \text{ETc (monthly)} - (\text{monthly precipitation} * 0.80)$$

Where:

ETc (monthly) = Monthly Crop-Specific Evapotranspiration (calculated in Step 3 above); and

Monthly Precipitation	=	Monthly precipitation expressed in depth, and
0.80	=	The percent of precipitation that falls on a plant and the surrounding soil surface that infiltrates, reaches the root zone and is effectively taken up by the plant. This factor also is referred to as Effective Precipitation.[15]

Note: The equation is not permitted to yield a negative value.

As indicated above, monthly precipitation data is required for this calculation. Precipitation data was obtained from the PRISM data (described in Section 3.1.2) for each crop grid associated with its geographical distribution. Precipitation data for the example grid is used in the calculations for this section.

The calculation of NIWR throughout the five-month conservation release season for the Willamette Valley Project reservoirs is provided in Tables 4-6 and 4-7. Table 4-6 shows the calculation of NIWR for the example squash crop using ETc yielded by the Blaney-Criddle method's calculation of ETo, and Table 4-7 shows the calculation of NIWR for the example squash crop using ETc yielded by the Penman-Monteith method's calculation of ETo.

Table 4-6
Calculation of Monthly NIWR Values for Squash Grid Using Blaney-Criddle ETc

Month	Blaney-Criddle Monthly ETc Squash Grid (mm)	Monthly Precipitation (mm)	Effective Precipitation Factor	NIWR Squash (mm)
May	79.139	44.33	0.80	43.68
Jun	113.862	26.27	0.80	92.85
Jul	152.418	10.32	0.80	144.16
Aug	173.6	4.26	0.80	170.19
Sep	138.09	30.03	0.80	114.07

[15] The Oregon Department of Agriculture provided the effective precipitation factor value.

Table 4-7
Calculation of Monthly NIWR Values for Squash Grid Using Penman-Monteith ETc

Month	Penman-Monteith Monthly ETc Squash Grid (mm)	Monthly Precipitation (mm)	Effective Precipitation Factor	NIWR Squash (mm)
May	63.414	44.33	0.80	27.95
Jun	92.988	26.27	0.80	71.97
Jul	144.970	10.32	0.80	136.71
Aug	159.495	4.26	0.80	156.09
Sep	114.690	30.03	0.80	90.67

4.2.5 Step 5: Calculate Applied Water Demand and Diverted Water Demand

Applied Water Demand is defined as water required for application on a field through irrigation to meet crop net irrigation water requirement. Applied water demand is larger in volume than NIWR due to factors such as on-farm application efficiency, which varies by irrigation technique (e.g., sprinklers, flood). An average irrigation application efficiency of 80 percent[16] was used for all crops in this analysis, and applied water demand is calculated as

$$\text{Applied Water Demand} = \text{NIWR} \div 0.80$$

Diverted Water Demand is defined as water that must be diverted from surface water (or extracted from groundwater) to meet full applied water demand for a specific crop. Diversion demand is larger in volume than applied water demand, as many of the canals that supply irrigation water experience conveyance losses, such as seepage to groundwater through unlined portions of the network as well as losses to evaporation. An average conveyance efficiency of 80 percent[17] was used for all crops in this analysis, and diverted water demand is calculated as:

$$\text{Diverted Water Demand} = \text{Applied Water Demand} \div 0.80$$

The calculation of Applied Water Demand and Diverted Water Demand throughout five-month conservation release season is provided in Tables 4-8 and 4-9. Table 4-8 shows the calculation of NIWR for the example squash crop using NIWR yielded by the Blaney-Criddle method's calculation of ETo, and Table 4-9 shows the calculation of NIWR for the example squash crop using NIWR yielded by the Penman-Monteith method's calculation of ETo.

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[16] The Oregon Department of Agriculture provided the average irrigation application efficiency factor value.

[17] The Oregon Department of Agriculture provided the average conveyance efficiency factor value. This value was also used by the Oregon Water Resources Department in estimates of statewide long term water demand forecasts. See https://www.oregon.gov/OWRD/WRDPublications1/OWRD_2015_Statewide_LongTerm_Water_Demand_Forecast.pdf

Table 4-8
Applied Water Demand and Diverted Water Demand for Squash Crop Grid Using Blaney-Criddle NIWR

Month	Blaney-Criddle Monthly NIWR Squash Grid (mm)	Applied Water Demand (mm)	Diverted Water Demand (mm)
May	43.68	54.59	68.24
Jun	92.85	116.06	145.07
Jul	144.16	180.20	225.25
Aug	170.19	212.74	265.93
Sep	114.07	142.58	178.23

Table 4-9
Applied Water Demand and Diverted Water Demand for Squash Crop Grid Using Penman-Monteith NIWR

Month	Penman-Monteith Monthly NIWR Squash Grid (mm)	Applied Water Demand (mm)	Diverted Water Demand (mm)
May	27.95	34.94	43.68
Jun	71.97	89.96	112.45
Jul	136.71	170.89	213.61
Aug	156.09	195.11	243.89
Sep	90.67	113.34	141.68

4.2.6 Step 6: Calculate Acre-Feet of Diverted Water Demand

Steps 1 through 5 are conducted using a standard crop grid size of 900 square meters (the size of a CDL grid), and diverted water demand is expressed as millimeters – the areal extent of diverted water demand has not yet been expressed as a definitive volume. In this step, the volume of diverted water demanded by the 900 square meter crop grid is calculated, and converted to acre-feet for subsequent steps in the analysis.

Table 4-10 shows the calculation of Diverted Water Demand in acre-feet for the example squash crop using millimeters of Diverted Water Demand (with no areal measurement) yielded by the Blaney-Criddle method's calculation of ETo. Table 4-11 shows the calculation of Diverted Water Demand in acre-feet for the example squash crop using millimeters of Diverted Water Demand (with no areal measurement) yielded by the Penman-Monteith method's calculation of ETo.

Table 4-10
Acre-Feet of Diverted Water Demand for Squash Crop Grid Using Blaney-Criddle mm Diverted Water Demand (DWD)

Month	CDL Crop Grid Size (Sq Meters)	CDL Crop Grid Size (Acres)	DWD (mm)	DWD (feet)	DWD (acre-feet)
May	900	0.2224	68.24	0.224	0.050
Jun	900	0.2224	145.07	0.476	0.106
Jul	900	0.2224	225.25	0.739	0.164
Aug	900	0.2224	265.93	0.872	0.194
Sep	900	0.2224	178.23	0.585	0.130
Total					**0.644**

Table 4-11
Acre-Feet of Diverted Water Demand for Squash Crop Grid Using Penman-Monteith mm Diverted Water Demand (DWD)

Month	CDL Crop Grid Size (Sq Meters)	CDL Crop Grid Size (Acres)	DWD (mm)	DWD (feet)	DWD (acre-feet)
May	900	0.2224	43.68	0.143	0.032
Jun	900	0.2224	112.45	0.369	0.082
Jul	900	0.2224	213.61	0.701	0.156
Aug	900	0.2224	243.89	0.800	0.178
Sep	900	0.2224	141.68	0.465	0.103
Total					**0.551**

4.2.7 Comparison of Intermediate and Final Example Calculations

Table 4-12 provides a summary of calculated values from Tables 4-3 through 4-11 for reference crop evapotranspiration (ETo), crop-specific evapotranspiration (ETc), net irrigation water requirement in millimeters (NIWR mm), diverted water demand in millimeters (DWD mm), and diverted water demand in acre-feet (DWD AF).

It is important to remember that the calculation results shown in the table are for the 900 square meter CDL grid of squash <u>at the particular location of that grid</u>. As different areas of the basin are examined, the calculation of ETo changes in response to the climatic characteristics (see extensive set of climatic input variables listed under Step 2 above). Also, as different crops are identified at those locations, the crop coefficient (Kc) changes to match the identified crop.

Table 4-12
Comparison of Intermediate and Final Calculations
of Blaney-Criddle and Penman Monteith Methods Calculation of ETo

Month	ETo		ETc		NIWR mm		DWD mm		DWD AF	
	BC	PM	BC	PM	BC	PM	BC	PM	BC	PM
May	4.85	3.89	79.07	63.48	43.68	26.65	68.24	41.64	0.050	0.030
Jun	5.42	4.43	113.86	92.98	92.85	72.20	145.07	112.82	0.106	0.082
Jul	6.00	5.70	152.42	144.97	144.16	135.68	225.25	212.00	0.164	0.155
Aug	5.60	5.15	173.60	159.48	170.19	155.78	265.93	243.40	0.194	0.178
Sep	4.60	3.82	138.09	114.68	114.07	89.80	178.23	140.31	0.130	0.102
Total									**0.644**	**0.547**

4.2.8 Summary of DWD by Evapotranspiration Methods

The NIWR-based calculations described above were executed for each 900 square meter grid of the CDL within the study area using both the Blaney-Criddle method and the Penman-Monteith method for the calculation of ETo. Each of the calculations for the entire study area follow the exact format and steps used in the example calculations, with no special considerations or exceptions. Tables 4-13 and 4-14 show the estimate of diverted water demand for the baseline year of 2014 as yielded by the two methods. Table 4-13 provides DWD estimates for the entire Willamette River Basin and the study area. In Table 4-14, the data are segmented by contract reach. Both tables provide diverted water demand totals without regard to whether or not cropland is irrigated. Additional steps were taken to distinguish between irrigated and non-irrigated cropland in the study area, as described in Section 5.

Table 4-13
Total Diverted Water Demand: ET Methods

Extent	Total Acres	Crop Acres	Blaney-Criddle DWD (acre-feet)	Penman-Monteith DWD (acre-feet)
Willamette River Basin	7,337,900	1,769,300	5,774,800	4,557,300
Study Area	1,890,100	572,600	1,938,100	1,574,400

Table 4-14
Diverted Water Demand: Entire Study Area Unfiltered

Contract Reach	Study Area Crop Acreage	Blaney-Criddle DWD (acre-feet)	Penman-Monteith DWD (acre-feet)
1	190,424	660,517	503,075
2	15,832	54,748	45,876
3	60,160	187,860	150,940
4	67,510	218,845	182,967
5	85,261	295,785	249,620
6	53,060	185,434	157,803
7	61,993	214,160	182,621
8	9,959	31,238	26,164
9	940	3,274	2,812
10	4,134	13,421	11,295
11	2,646	7,802	6,373
12	557	1,664	1,360
13	17,112	54,507	46,163
14	1,583	4,650	3,864
15	1,438	4,170	3,466
Total	**572,609**	**1,938,073**	**1,574,399**

5 Estimates of Baseline Irrigation

Baseline irrigation is the volume of water withdrawn from groundwater or surface water sources to satisfy AI needs during the baseline analysis year of 2014. As stated in Section 1, only 17 percent of water rights in Oregon require the reporting of water use, resulting in the inability to measure the volume of water used for irrigation occurring within the study area. The diverted water demand calculations described in Section 4 are a crop demand and do not reflect whether specific cropland is permitted for agricultural irrigation. Accordingly, additional analyses are required to estimate baseline irrigation within the study area.

Three different methods were used to estimate baseline irrigation volumes by:

1. filtering the duty based and NIWR derived DWD by spatial intersection of those crops in the study area with an AI water right as defined by the POU GIS layer;
2. adjusting the NIWR derived DWD through the application of county-level irrigation factors developed from the U.S. Department of Agriculture's Census of Agriculture (2012, 2007, 2002, and 1997); and
3. application of AI DWD factors developed through analyses of measured volumes of water used for irrigation obtained from the Oregon Water Resources Department's Water Rights Information System.

5.1 Method 1: Place of Use Spatial Intersection

Calculation of diverted water demand (as described in Section 4 above) merely expresses the crop's need for diverted water, but does not indicate whether the need for diverted water is legally authorized from existing supply sources for use. Therefore, it is necessary to segment the diverted water demand results of the analyses in order to distinguish between irrigated and non-irrigated cropland since the CDL does not provide such a distinction.

To identify legally authorized irrigated croplands, the analysis relied on water rights data from the WRIS database and its associated GIS layers. As discussed in Section 3.1.4, the Place of Use (POU) data contained in WRIS represents lands on which the permitted withdrawal of water (surface or groundwater) can be applied. POUs are mapped within the GIS layers of WRIS, and were used in this analysis as an overlay atop the study area boundaries and CDL to identify which 900 square meter CDL grids are associated with a primary water right (see Section 3.2.6).

Table 5-1 provides baseline irrigation estimates as derived from the duty method for croplands associated with an irrigation POU.

Table 5-1
Baseline Irrigation: Duty DWD Filtered by POU Designation

Contract Reach	Study Area Crop Acreage	Permitted Study Area Crop Acreage	Permitted Duty DWD (acre-feet)
1	190,424	109,939	274,847
2	15,832	13,069	32,672
3	60,160	33,331	83,328
4	67,510	16,586	41,465
5	85,261	36,091	90,228
6	53,060	21,321	53,303
7	61,993	21,949	54,872
8	9,959	4,845	12,113
9	940	367	918
10	4,134	1,319	3,298
11	2,646	612	1,529
12	557	85	212
13	17,112	3,172	7,930
14	1,583	380	951
15	1,438	222	556
Total	**572,609**	**263,289**	**658,222**

Table 5-2 provides baseline irrigation estimates as derived from evapotranspiration methods for croplands associated with an irrigation POU.

Table 5-2
Baseline Irrigation: NIWR DWD Filtered by POU Designation

Contract Reach	Study Area Crop Acreage	Permitted Study Area Crop Acreage	Permitted Blaney-Criddle DWD (acre-feet)	Permitted Penman-Monteith DWD (acre-feet)
1	190,424	109,939	387,647	293,072
2	15,832	13,069	45,243	37,913
3	60,160	33,331	107,706	87,564
4	67,510	16,586	55,490	46,542
5	85,261	36,091	126,760	107,230
6	53,060	21,321	76,091	64,736
7	61,993	21,949	77,623	66,300
8	9,959	4,845	15,687	13,213
9	940	367	1,296	1,115
10	4,134	1,319	4,573	3,880
11	2,646	612	1,849	1,521
12	557	85	261	214
13	17,112	3,172	10,217	8,661
14	1,583	380	1,110	922
15	1,438	222	639	529
Total	**572,609**	**263,289**	**912,194**	**733,410**

As shown in the tables above, croplands within the study area (as identified by the CDL) associated with a water right (as identified by WRIS POUs) are roughly 263,300 acres, which is less than half of all cropland in the study area. Baseline irrigation estimates shown in Table 5-2 also are less than half of the unfiltered diverted water demand totals shown in Table 4-14.

5.2 Method 2: Census of Agriculture Crop Irrigation Factors

The U.S. Department of Agriculture's National Agricultural Statistics Service (NASS) develops the Census of Agriculture (Census) every five years, collecting a myriad of data to provide an accurate representation of farm technologies, production, income, and demographics. As such, the Census is an extensive database of information on many facets of farming – including irrigation. Detailed Census tables for Oregon include information for all counties in the study area, and provide crop-specific information on acres harvested and acres irrigated.

The NASS "Quick Stats" program[18] was used to access Census data published in the 2012, 2007, 2002, and 1997 Census Reports for the study area counties (i.e., Benton, Clackamas, Lane, Linn, Marion, Multnomah, Polk, and Yamhill). Analysis of two crop groupings using the "Quick Stats" data downloaded proved problematic: berries and vegetables. Data used in this analysis for these two crop groupings relied instead on the detailed county-level tables provided in the Census for these two crop groups. Harvested acreage and irrigated acreage totals were assembled for each county within the study area using the following major crop groupings:

- berries;
- field crops;
- grass and field seed crops;
- hay, forage, silage;
- orchards;
- tree farms;
- vegetables; and
- wild hay.

In order to proceed with this method, each of the crops listed in the study area CDL were classified according to the major crop groupings listed above. Attachment C provides a list of the CDL crops that were categorized under each of the major crop groupings.

Individual tables were assembled for each crop group, all of which are also provided in Attachment C. For illustrative purposes, the Grass and Field Seed Crops tables are provided below as Tables 5-3 and 5-4 (which is merely a subset of the tables used for the full analysis, shown in Attachment C).

Table 5-4 shows grass and field seed crop acres harvested and irrigated as reported in the Census for the study area counties for Census years 2012, 2007, 2002, and 1997. As shown on the tables, the harvested acreages do not appear to vary widely across the years, though irrigated acreages do vary widely. While it cannot be known for certain why the irrigated acreage figures vary so widely,

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[18] Available at https://quickstats.nass.usda.gov/

climate information obtained from the PRISM database show that crops grown in 1997 would be significantly better watered from precipitation than in any of the other years for which Census data was obtained and analyzed (i.e., 2012, 2007, or 2002).

Table 5-3
Acres Harvested and Irrigated - 2012, 2007, 2002, 1997: Grass & Field Seed Crops

Study Area County	Acres Harvested 2012	Acres Harvested 2007	Acres Harvested 2002	Acres Harvested 1997	Acres Irrigated 2012	Acres Irrigated 2007	Acres Irrigated 2002	Acres Irrigated 1997
Benton	33,142	38,855	37,467	37,854	2,864	10,811	4,850	1,225
Clackamas	7,149	10,627	11,449	10,922	1,312	2,777	2,827	1,572
Lane	41,090	39,467	44,102	38,041	6,389	7,328	4,886	2,986
Linn	133,079	169,625	184,292	208,695	6,969	11,562	11,042	6,139
Marion	79,414	103,377	104,881	104,593	17,271	35,383	28,637	11,002
Multnomah	697	238	857	374	49	-	-	-
Polk	41,906	69,750	60,562	54,121	4,558	5,828	3,826	1,862
Yamhill	34,173	50,888	44,513	37,039	4,479	9,960	4,049	1,450
Total	**370,650**	**482,827**	**488,123**	**491,639**	**43,891**	**83,649**	**60,117**	**26,236**

The ratio of each county's Census year acres irrigated to acres harvested is shown as a percentage rate on Table 5-4. For each county in the study area, the maximum percentage (highlighted in the table) was carried forward in the analysis to be used as a factor to distinguish between irrigated and non-irrigated cropland for each specific crop and county. The maximum percentage was used as a conservative estimate to account for climate and crop market variability.

Table 5-4
Irrigated Portion of Harvested Acres - 2012, 2007, 2002, 1997: Grass & Field Seed

Study Area County	Irrigated Portion 2012	Irrigated Portion 2007	Irrigated Portion 2002	Irrigated Portion 1997
Benton	8.6%	27.8%	12.9%	3.2%
Clackamas	18.4%	26.1%	24.7%	14.4%
Lane	15.5%	18.6%	11.1%	7.8%
Linn	5.2%	6.8%	6.0%	2.9%
Marion	21.7%	34.2%	27.3%	10.5%
Multnomah	7.0%	0.0%	0.0%	0.0%
Polk	10.9%	8.4%	6.3%	3.4%
Yamhill	13.1%	19.6%	9.1%	3.9%
Total	**11.8%**	**17.3%**	**12.3%**	**5.3%**

Continuing with the Grass and Field Seed example, irrigated land factors as defined for specific crop-county groups (e.g., 27.8 percent for Benton County shown in Table 5-4) can be interpreted, for example, as:

On average, no more than 27.8 percent of the acreage used in successfully cultivating Grass and Field Seed crops in Benton County is irrigated. Therefore, 27.8 percent of the acres identified in the baseline analysis (through the CDL) as Grass and Field Seed crops in Benton County can be assumed to be irrigated. Further, 27.8 percent of the diverted water demand calculated by NIWR methods can be estimated as having been drawn from the Willamette River. its tributaries, or alluvial groundwater.

Table 5-5 provides irrigated land factor-adjusted AI diverted water demand for the study area Grass and Field Seed crop. The county-specific factors (which provide a distinction between irrigated and non-irrigated cropland) highlighted in Table 5-4 are applied to the diverted water demand calculations.

Table 5-5
NASS Adjusted Diverted Water Demand: Grass & Field Seed

Study Area County	CDL Based Acres	BC Based DWD (AF)	BC NASS Adjusted DWD (AF)	PM Based DWD (AF)	PM NASS Adjusted DWD (AF)
Benton	26,908	96,448	26,813	78,738	21,889
Clackamas	1,457	5,299	1,383	3,821	997
Lane	27,120	95,484	17,760	78,751	14,648
Linn	45,635	158,105	10,751	128,172	8,716
Marion	40,744	140,428	48,026	106,310	36,358
Multnomah	1,819	6,647	465	4,730	331
Polk	22,629	80,257	8,748	64,800	7,063
Yamhill	11,538	42,152	8,262	30,795	6,036
Total	**177,849**	624,820	**122,208**	496,119	**96,038**

As discussed above, the data shown on Tables 5-3, 5-4, and 5-5 are for illustrative purposes, and the full set of 24 data tables generated by the Census analysis are provided in Attachment C.

Table 5-6 provides estimates of baseline irrigation segmented by contract reach. As shown in the table, the total area analyzed is the entire study area of 573,000 acres. Using the irrigated land factors developed for each crop type (as depicted in Attachment C), the study area crop acreage was adjusted to provide that portion of crop acreage within each contract reach that is under irrigation, resulting in a total irrigated acreage of about 117,900 acres in the study area. The irrigation volume for the 2.5 acre-feet per acre duty method of estimating baseline irrigation is 294,700 acre-feet. The estimated baseline irrigation shown is roughly 402,000 acre-feet for irrigation calculations based on the Blaney-Criddle method of calculating ETo, and 325,000 acre-feet for irrigation calculations based on the Penman-Monteith method of calculating ETo.

Table 5-6
Baseline Irrigation: Adjusted by Census Irrigated Land Factors

Contract Reach	Study Area Crop Acreage	Irrigated Land Factor Adjusted Study Area Crop Acreage	Irrigated Land Factor Adjusted Duty DWD (acre-feet)	Irrigated Land Factor Adjusted Blaney-Criddle DWD (acre-feet)	Irrigated Land Factor Adjusted Penman-Monteith DWD (acre-feet)
1	190,424	43,720	109,300	150,947	114,091
2	15,832	4,537	11,343	15,878	13,347
3	60,160	14,528	36,320	46,245	37,485
4	67,510	9,144	22,861	29,520	24,708
5	85,261	17,593	43,981	61,062	51,614
6	53,060	11,412	28,530	40,435	34,399
7	61,993	11,652	29,129	40,493	34,575
8	9,959	1,647	4,117	5,327	4,481
9	940	159	396	559	480
10	4,134	623	1,558	2,023	1,707
11	2,646	323	807	971	794
12	557	69	172	203	166
13	17,112	2,152	5,379	6,927	5,869
14	1,583	169	423	500	416
15	1,438	157	393	454	377
Total	**572,609**	**117,884**	**294,709**	**401,544**	**324,510**

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5.3 Method 3: Reported Use Factors

Equation-based methods of estimating baseline irrigation (see Section 4 above) provide a statistically valid and scientifically accepted means of approximating DWD. Direct measurement of AI diversion, if available, would be the ideal and most accurate method. Were direct measurement data available throughout the study area, baseline irrigation simply could be aggregated for the study area, and the baseline irrigation estimate would be highly accurate and superior to all other estimates.

5.3.1 Reported Use Data Available from WRIS

Unfortunately, only about 17 percent of water rights in Oregon require the reporting of water use to WRD. Beginning in the 1990s, many water use permits issued to non-governmental entities include a water measurement and an annual use reporting requirement. While the set of AI water use authorizations included in WRIS total over 17,000, water use reports are only available for a small fraction of those permits.

Since complete coverage of direct measurement of AI diversion water volumes is not available, the set of available information was analyzed to determine whether a set of factors for scaling DWD to estimate baseline irrigation could be developed. These reported use factors could then be applied to POU data in the study area and provide an additional estimate of baseline irrigation.[19]

5.3.2 WRIS Data Filtered

Over 119,000 monthly water diversion records were obtained for the years 2000 through 2015. Each reporting entity provides a record for each month (January through December) and each year (2000 through 2015), which results in an extensive number of Irrigation Use reporting records in the database. The data were consolidated (i.e., all months and years combined into one record for each reporter), which reduced the initial set of data down to about 1,000 records – one record for each reporter as represented by the WRIS field "snp_id". Additional examination of the 1,000 records resulted in the removal of 613 records for the reasons listed below.

1. Reported water use data for irrigation districts and their members were excluded from consideration in the analysis. This is because in every case examined, if a particular reporter was a member of an irrigation district, water use data for the entire irrigation district was reported for each member (which was confirmed as common practice). Because the water use data was joined with the WRIS POU acreage data, use reported by irrigation districts and irrigation district members could not be related back to WRIS POU acreage data in any meaningful fashion. A listing of the irrigation districts and number of members for which data were removed from the database is provided below.

[19] This method is analogous to the method used to develop Municipal and Industrial (M&I) use for the Willamette Basin Review Feasibility Study. Available use metric data reported to WRD in the form of Water Management & Conservation Plans (WMCPs) were obtained for every M&I supplier, and factors were developed for and applied to M&I suppliers for whom a WMCP does not exist. While the data used in the M&I analysis was not "Reported Water Use Data", general similarities remain between the M&I water demand estimation method and the current irrigation estimation method described in this section.

   a. Santiam Water Control District (33 members removed from analysis)
   b. Muddy Creeks Irrigation District (15 members removed from analysis)
   c. Lacomb Irrigation District (2 members removed from analysis)
   d. Greenberry Irrigation District (2 members removed from analysis)
   e. Palmer Creek Water District (9 members removed from analysis)
   f. Queener Irrigation Improvement District (3 members removed from analysis)
   g. Gaines Water Improvement District (37 members removed from analysis)

2. Non-agricultural reporting entities were identified and excluded from consideration in the analysis. Typical entity types identified were schools (except specifically-named agricultural departments of universities), parks; golf courses; non-agricultural state and local jurisdiction agencies; and Federal agencies.

5.3.3 Development of Factors from Available Use Data

Seasonal totals for the conservation storage release season (May through September) of water use were calculated for each of the 387 water use authorizations, for each year from 2000 through 2015. As expected, the total water used by each reporter during the season varied widely. For this reason, no one year was selected as representing the amount of water a reporter would use. Rather, to ensure that the analysis captured an adequate amount of water for each reporter, the maximum value of diverted water reported for the 2000 through 2015 time period was selected from each reporter's seasonal totals for further use in factor development (referred to Seasonal Maximum Use, or SMU in the remainder of this section.

Each permit was linked to POU acreage data by snp_id (the overall organizing variable used to represent a water use authorization within WRIS), and the sum of POU acres for each of the reporters was calculated.

Next, aggregate sums were calculated for SMU and total POU acreage for the sample set. The ratio of SMU to POU acreage provides a factor with which an estimate of baseline irrigation throughout the study area can be calculated[20]. Examination of the data by representative size categories based on POU acreage revealed markedly different use factors than the overall total.

The reported use factors developed for this analysis are provided below in Table 5-7. The table shows the reported use factors segmented by six separate size categories, as represented by the reported data analyzed.

[20] It is important to note that the ratio of SMU to POU acres for each reporter was <u>not</u> the metric calculated as a use factor. Rather, the calculation was performed at the total levels.

Table 5-7
Factors for Acre-Feet of Water Used by Size Category

POU Size Category (Acres)	Total Maxim Water Use Reported (Acre-Feet)	Total POU Acreage (Acres)	Number of Observations	Acre-Feet Used Per Acre
1 to 25	2,167	931	57	2.33
25 to 50	3,769	2,089	56	1.80
50 to 100	9,730	6,235	83	1.56
100 to 200	15,997	14,278	100	1.12
200 to 350	14,459	16,323	60	0.89
Over 350	12,373	19,672	31	0.63
TOTAL	**58,495**	**59,527**	**387**	**0.98**

An analysis of the crops grown within each POU size category according to the 2014 CDL does not reveal a strong direct correlation between the type of crop grown and the POU size category, implying that the decrease in acre-feet used per acre as POU size category increases is not solely related to the plausible explanation that more irrigation intensive crops are grown on smaller farms. Additional factors likely influence the degree of irrigation of larger farms, such as the capital expenditures required to irrigate large areas. Table 5-8 depicts the percentage of type of crop (aggregated into three categories) grown within the POUs used for the reported use factor development.

Table 5-8
Percentage of Crops Grown by POU Size Category

POU Size Category (Acres)	Grasses and Pasture	Field Crops	Vegetables and Others
1 to 25	80%	10%	10%
25 to 50	78%	12%	10%
50 to 100	74%	13%	13%
100 to 200	73%	17%	10%
200 to 350	76%	15%	10%
Over 350	69%	23%	8%

5.3.4 Application of Reported Use Factors to Study Area POUs

The reported use factors were applied to all POU acreages throughout the study area on the basis of size category, which yields an estimate of study area baseline irrigation. Table 5-8 provides the results of the calculations segmented by size category, and Table 5-9 provides the results segmented by contract reach.

Table 5-9
Baseline Irrigation by POU Size Category: Diversion Factor Basis

POU Size Category (acres)	Total POU Acres in Study Area	Baseline irrigation (Acre-Feet)	Number of POUs in Size Category (Study Area)
1 to 25	43,772	101,860	4,362
25 to 50	61,031	110,125	535
50 to 100	81,393	127,017	127
100 to 200	72,896	81,675	1,715
200 to 350	32,875	29,123	1,161
Over 350	102,709	64,598	67
TOTAL	**394,677**	**514,398**	**7,967**

Table 5-10
Baseline Irrigation by Reach: Diversion Factor Basis

Contract Reach	Permitted Acres in Study Area	Baseline irrigation (acre-feet)
1	171,518	219,102
2	11,321	16,226
3	28,755	41,879
4	21,722	34,845
5	85,723	85,249
6	25,150	34,859
7	27,899	43,865
8	9,037	16,121
9	1,710	2,637
10	2,466	3,723
11	1,286	2,610
12	599	1,185
13	5,767	8,901
14	1,062	1,875
15	663	1,321
Total	**394,677**	**514,398**

6 Summary and Analysis of Baseline Irrigation Estimates

This section provides the consolidated set of baseline irrigation estimates for the study area developed throughout this document. Table 6-1 provides a listing of each estimate by contract reach, and irrigation figures presented in the table have been rounded for visual clarity - estimates are also numbered from 1 through 7 for visual clarity. A key to Estimates 1 through 7 are provided below:

- Estimate 1: Permitted Duty DWD
- Estimate 2: Irrigated Land Factor Adjusted Permitted Duty DWD
- Estimate 3: Permitted Blaney-Criddle DWD
- Estimate 4: Permitted Penman-Monteith DWD
- Estimate 5: Irrigated Land Factor Adjusted Blaney-Criddle DWD
- Estimate 6: Irrigated Land Factor Adjusted Penman-Monteith DWD
- Estimate 7: Reported Use Factors Applied to Study Area

Table 6-1 shows baseline estimates ranging from 311,800 acre feet per year to over 912,200 acre feet per year.

6.1 Summary of Baseline Irrigation Estimates

Baseline irrigation Estimates 1 and 2 are based on the typical legal maximum duty of 2.5 acre-feet per acre applied to all cropland with AI permits in the study area. Estimate 1 baseline irrigation is filtered based on whether cropland identified in the CDL falls within a valid POU as identified by WRIS. Estimate 1 for the baseline year totals 658,200 acre-feet. Estimate 2 reflects the application of the Census of Agriculture irrigation factor in an attempt to estimate how much of the legally allowable duty of 2.5 acre-feet per acre would typically be used. Baseline irrigation Estimate 2 for the baseline year totals 294,700 acre-feet.

Estimates 3 and 4 represent the results of diverted water demand calculated from the evapotranspiration methods filtered on the basis of whether or not the CDL falls within a valid POU as identified by WRIS. The baseline irrigation of Estimate 3 (permitted Blaney-Criddle DWD) totals 912,200 acre-feet for the baseline year. The baseline irrigation of Estimate 4 (permitted Penman-Monteith DWD) totals 733,400 acre-feet for the baseline year.

Estimates 5 and 6 also represent the diverted water demand calculated from the evapotranspiration methods filtered on the basis of crop and county-specific factors developed from multiple years of Census of Agriculture data. Estimate 5 irrigation for the baseline year amounts to 401,500 acre-feet, while Estimate 6 AI irrigation for the baseline year amounts to 324,500 acre-feet.

Estimate 7 is unique in that it is based on actual reported diversion for irrigation use data. While universal coverage of reported diversion for irrigation use throughout the study area would have been optimal for this analysis, the factors developed from available data appear to have yielded a valid baseline irrigation estimate of 514,400 acre-feet – squarely in the middle of the other estimates.

Table 6-1 provides a consolidated comparison of each of the rounded estimates of baseline irrigation.

Table 6-1
Consolidated Baseline Irrigation Estimates – Acre Feet Per Year

Contract Reach	Estimate 1	Estimate 2	Estimate 3	Estimate 4	Estimate 5	Estimate 6	Estimate 7
1	274,800	109,300	387,600	293,100	150,900	114,100	219,100
2	32,700	11,300	45,200	37,900	15,900	13,300	16,200
3	83,300	36,300	107,700	87,600	46,200	37,500	41,900
4	41,500	22,900	55,500	46,500	29,500	24,700	34,800
5	90,200	44,000	126,800	107,200	61,100	51,600	85,200
6	53,300	28,500	76,100	64,700	40,400	34,400	34,900
7	54,900	29,100	77,600	66,300	40,500	34,600	43,900
8	12,100	4,100	15,700	13,200	5,300	4,500	16,100
9	900	400	1,300	1,100	600	500	2,600
10	3,300	1,600	4,600	3,900	2,000	1,700	3,700
11	1,500	800	1,800	1,500	1,000	800	2,600
12	200	200	300	200	200	200	1,200
13	7,900	5,400	10,200	8,700	6,900	5,900	8,900
14	1,000	400	1,100	900	500	400	1,900
15	600	400	600	500	500	400	1,300
Total	**658,200**	**294,700**	**912,200**	**733,400**	**401,500**	**324,500**	**514,400**

6.2 Analysis of Baseline Irrigation Estimates

Underlying elements of NIWR-based estimates (Estimates 3 through 6) were evaluated to determine the validity of the AI baseline irrigation estimates yielded by the Blaney-Criddle and Penman-Monteith methods for calculating crop specific ET.

An examination of the calculated duty from each calculation was used in the analysis. As stated in Section 4.1, duty is typically defined as the quantity of water that is diverted to satisfy crop irrigation water requirements. Permits issued for irrigation typically specify a duty rate of 2.5 acre-feet of water per acre irrigated, whereas permits issued for nursery use usually specify a duty rate of 5.0 acre-feet of water per acre irrigated. Table 6-2 shows the duty for all crops analyzed by the Blaney-Criddle and Penman-Monteith methods of calculating crop specific ET values, and was calculated as the diverted water demand for each crop divided by acres for each crop.

Table 6-2
Seasonal Duty Rates Calculated by ET-Based Methods

Crop	Blaney-Criddle	Penman-Monteith
Alfalfa	6.3	4.9
Beans (Green, Snap, Pink, lentils)	3.0	2.2
Blueberries	2.5	1.9
Bluegrass	3.5	2.7
Broccoli	4.6	3.4
Cabbage	2.4	1.7
Camelina	4.2	3.1
Canola	4.1	3.2
Cauliflower	3.2	2.3
Cherries- Ground Cover	3.9	2.9
Clover/Wildflowers	4.0	3.1
Corn	3.6	2.8
Double Crop Winter Wheat/Corn	1.3	0.8
Fallow/Cover Crop	5.8	4.6
Grapes	3.0	2.2
Greens	3.1	2.5
Herbs	4.1	3.3
Hops	4.0	3.1
Mints (Spear, Pepper & Mint)	4.0	3.2
Miscellaneous Fruits & Vegs	3.8	2.7
Onion & Garlic	4.0	3.0
Other Crops	3.5	2.6
Other Hay/Non-Alfalfa	3.2	2.4
Other Tree Crops (Hazelnuts)	3.5	2.7
Pasture-grass	3.2	2.5
Peas	2.0	1.5
Peppers	2.9	2.2
Potatoes	3.5	2.4
Pumpkin	2.8	2.0
Radish	2.6	2.0
Sorghum	3.7	2.9
Spring Grains (including Oats & Barley)	3.6	2.7
Squash-Winter	2.9	2.2
Stone Fruit	3.5	2.7
Strawberries	3.9	2.8
Sugar Beets	3.4	2.7
Trailing Berries	3.2	2.5
Tree Fruit	3.7	2.7
Turnips	3.5	2.7
Winter Grains	4.0	3.1
Overall Average	**3.5**	**2.7**

As shown in Table 6-2 above, duty as calculated by the Blaney-Criddle method ranges from 1.5 acre-feet per acre to 6.3 acre-feet per acre, with an average of 3.5 acre-feet per acre. Duty as calculated by the Penman-Monteith method ranges from 0.8 acre-feet per acre to 4.9 acre-feet per acre, with an overall average of 2.7 acre-feet per acre.

Since the Blaney-Criddle based estimates show an average duty rate of 3.5 feet, it is highly unlikely that the overall population of agricultural irrigators actually exceed their permitted rate of 2.5 acre-feet per acre. Rather, it can only be concluded that the Blaney-Criddle based estimates do not represent baseline agricultural irrigation (i.e., an estimate of how much irrigation is used in the baseline year). As such, Estimates 3 and 5 will not be carried forward as valid estimates of baseline irrigation.

The Penman-Monteith estimates show an average duty rate of 2.7 feet, which also exceeds the typical permitted duty rate of 2.5 feet in Oregon. However, the duty rate of 2.7 feet yielded by the Penman-Monteith estimates is far more in line with the typical permitted duty rate for AI diversions in Oregon.

7 Projected Increases in Agricultural Irrigation Acreage

The annual rate by which AI could be increased as a means to develop projected irrigation use for the years 2020 through 2070 was assessed using two methods:

1. an analysis of AI permits through the WRIS database; and
2. an analysis of irrigated land reported from the U.S. Department of Agriculture's National Agricultural Statistics Service's (NASS) Census of Agriculture (Census).

7.1 WRIS Data Analysis

Water rights data representing the years 1905 through 2015 were examined in order to derive an annual rate of increased agricultural irrigation. A total of over 21,000 Points of Diversion (PODs) [21] are located within the study area boundaries for all uses of water (e.g., municipal, industrial, irrigation, nursery, fish culture, etc.). Because multiple diversions are associated with each permit, the data were consolidated down to a total of about 11,900 records. Out of the 11,900 records, 8,124 were identified through the WRIS "Use Code" field as permits developed for irrigation or nursery use. The 8,124 records were examined to identify records of irrigation and nursery use for the following types of non-agricultural irrigators:

1. schools, except specifically named agricultural departments of universities;
2. county and state parks;
3. golf courses;
4. cemeteries and churches;
5. non-agricultural state and local jurisdiction agencies; and
6. Federal agencies (e.g., US Fish & Wildlife Service).

The examination of non-agricultural irrigators resulted in the removal of 180 records from the analysis, leaving a total 7,944 records of AI permits granted in the study area over the years 1905 through 2015. A total of 602 of those 7,944 records of AI permits have been granted over the past 25 years (1991 through 2015), and were used to develop annual factors by which AI diversion demand grows over the period of analysis. This 25-year examination period was selected because expansion of AI within the basin began in the 1940s and leveled off in the 1990s (Jaeger, et al., 2017).[22]

Table 7-1 provides a contract reach summary of AI diversion permits granted over the 25-year examination period, the total amount of acreage to be irrigated by those permits, and the 25-year average of new AI acreage permitted per year.[23]

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[21] A Point of Diversion (POD) differs from the WRIS POU data element. The POD provides a reference to the point at which water is diverted from a Willamette Basin stream or well for a permit, while the POU provides a reference for the acres over which water drawn from a POD is applied.

[22] Jaeger, W., A.J. Plantinga, C. Langpap, D. Bigelow, and K. Moore. (2017) *Water, Economics, and Climate Change in the Willamette Basin, Oregon (EM 9157)*. Oregon State University Extension Service.

[23] While the table shows an average increase of 0.0 for Reach 15, the actual average increase over the 25-year period is 0.02 acres – too small to show a non-zero value at 1 decimal place.

Table 7-1
AI Permits 1991- 2015: Acreage Permitted and Average Annual Growth in Acres

Contract Reach	New AI Permits	Total New AI Permitted Acres	Average Annual Growth in Acres
1	353	23,159	926.4
2	11	1,222	48.9
3	37	1,708	68.3
4	27	1,988	79.5
5	34	2,144	85.7
6	26	2,130	85.2
7	28	1,290	51.6
8	44	914	36.5
9	2	10	0.4
10	2	375	15.0
11	22	1,606	64.3
12	6	28	1.1
13	8	247	9.9
14	1	18	0.7
15	1	1	0.0
Total	**602**	**36,839**	**1,473.5**

Table 7-2 shows the irrigated study area crop acreage for each contract reach for each estimate and the average annual growth of AI acreage by contract reach. Table 7-3 depicts the corresponding projected AI acreage calculated for the project period in ten year increments from 2020 through 2070. Each estimate shows a total increase in irrigated acreage of 82,518 acres over the project period.

Table 7-2
Irrigated Study Area Crop Acreage and Average Annual Growth in Acres

Contract Reach	Irrigated Study Area Crop Acreage			Average Annual Growth in Acres
	Estimate 1 & 4	Estimate 2 & 6	Estimate 7	
1	109,939	43,720	171,518	926.4
2	13,069	4,537	11,321	48.9
3	33,331	14,528	28,755	68.3
4	16,586	9,144	21,722	79.5
5	36,091	17,593	85,723	85.7
6	21,321	11,412	25,150	85.2
7	21,949	11,652	27,899	51.6
8	4,845	1,647	9,037	36.5
9	367	159	1,710	0.4
10	1,319	623	2,466	15.0
11	612	323	1,286	64.3
12	85	69	599	1.1
13	3,172	2,152	5,767	9.9
14	380	169	1,062	0.7
15	222	157	663	0.0
Total	**263,289**	**117,884**	**394,677**	**1,473.5**

Table 7-3
Projected Agricultural Irrigation Acreage

Year	Estimate 1	Estimate 2	Estimate 4	Estimate 6	Estimate 7
2014	263,289	117,884	263,289	117,884	394,677
2020	272,130	126,725	272,130	126,725	403,518
2030	286,866	141,460	286,866	141,460	418,254
2040	301,601	156,196	301,601	156,196	432,989
2050	316,336	170,931	316,336	170,931	447,725
2060	331,072	185,667	331,072	185,667	462,460
2070	345,807	200,402	345,807	200,402	477,195
Total Increase	**82,518**	**82,518**	**82,518**	**82,518**	**82,518**
Percent Increase	**31%**	**70%**	**31%**	**70%**	**21%**

AI acreage increase projected irrigation Estimate 1 is based on the typical legal maximum duty of 2.5 acre-feet per acre applied to all cropland with AI permits in the study area. Since Estimate 1 is based on whether cropland is permitted for AI, all forecasted increases to AI acreage are projected to be irrigated at the same duty of 2.5 acre-feet per acre. Estimate 1 demand grows from a baseline estimate of 658,200 acre-feet to an estimate of 864,500 in the year 2070.

Baseline irrigation Estimate 2 reflects the application of the Census of Agriculture irrigation factors to estimate the acres of irrigated cropland under production based on the crops grown according to the CDL and applying the typical legal maximum duty of 2.5 acre-feet per acre applied to all irrigated cropland. Since projected acreage increases are projections of cropland under irrigation, acreage totals are not reduced by the irrigation factors. Projected increases in AI acreage are also assumed to be irrigated at 2.5 acre-feet per acre. Baseline irrigation Estimate 2 for the baseline year totals 294,700 acre-feet, increasing to 501,100 acre-feet in 2070.

AI acreage increase projected irrigation Estimate 4 represent the results of diverted water demand calculated from the Penman-Monteith evapotranspiration method filtered on the basis of whether or not the CDL falls within a valid POU as identified by WRIS. It was assumed that the crops grown on the additional AI acreage are grown at the same proportion as the baseline within each contract reach. In this way, the associated ET crop demand was proportionally distributed in the projected increased acreage. The irrigation of Estimate 4 totals 733,400 acre-feet for the baseline year and increases to 958,500 by the year 2070.

Estimate 6 also represents the diverted water demand calculated from the Penman-Monteith evapotranspiration method filtered on the basis of crop and county-specific factors developed from multiple years of Census of Agriculture data. In a similar manner as Estimate 2, since projected acreage increases are projections of cropland under irrigation, acreage totals are not reduced by the irrigation factors, and all future AI acreage growth is assumed to be fully irrigated. Furthermore, in the same manner as Estimate 4, it was assumed that the crops grown on the additional AI acreage are grown at the same proportion as the baseline within each contract reach, such that the associated ET crop demand was proportionally distributed in the projected increased acreage. AI acreage increase projected irrigation Estimate 6 is 324,500 acre-feet for the baseline year and increases to 545,400 in year 2070.

Estimate 7, based on actual reported diversion for irrigation use data, assumes that use in additional AI acreage will be irrigated proportionally to the reported irrigation rates within each contract reach. AI acreage increase projected irrigation Estimate 7 is 514,400 acre-feet for the baseline year and increases to 626,500 in year 2070.

Table 7-4 provides a projected irrigation estimate implementing the AGR in each contract reach for every 10 years from 2020 through 2070 using each of the remaining irrigation estimation methods. It is important to distinguish that these estimates do not reflect increased lands in agricultural production (i.e. newly developed farmland), which would result in increased Diverted Water Demand (see Section 4), but rather an increase in permitted agricultural irrigation acreage on lands already in agricultural production (i.e. existing farmland that is newly irrigated).

Table 7-4
Agricultural Irrigation Acreage Increase Projected Irrigation Estimates – Acre Feet

Year	Estimate 1	Estimate 2	Estimate 4	Estimate 6	Estimate 7
2014	658,200	294,700	733,400	324,500	514,400
2020	680,300	316,800	757,500	348,200	526,400
2030	717,200	353,700	797,700	387,600	546,400
2040	754,000	390,500	837,900	427,100	566,500
2050	790,800	427,300	878,100	466,500	586,500
2060	827,700	464,200	918,300	506,000	606,500
2070	864,500	501,000	958,500	545,400	626,500
Total Increase	**206,300**	**206,300**	**225,100**	**220,900**	**112,100**
Percent Increase	**31%**	**70%**	**31%**	**68%**	**22%**

Recall that baseline irrigation Estimate 2 and Estimate 6 (year 2014 in Table 7-4) are calculated by adjusting the acreage associated with DWD through the application of county-level irrigation factors developed from the U.S. Department of Agriculture's Census of Agriculture. In contrast to the baseline irrigation estimate, since projected acreage increases are projections of cropland under irrigation, irrigated acreage totals are not reduced by the irrigation factors and are irrigated at either 2.5 acre-feet per acre (Estimate 2) or the associated ET crop demand proportionally distributed in the projected increased acreage (Estimate 6), thereby resulting in a greater percentage increase in comparison to the other projected irrigation estimates.

7.2 NASS Data Analysis

Future growth of agricultural irrigation acreage was also estimated from an analysis of irrigated land reported from the U.S. Department of Agriculture's National Agricultural Statistics Service's (NASS) Census of Agriculture (Census). Among the many statistics reported every five years in the Census is the total acres of irrigated land in each county. The counties within the Willamette River Basin include Benton, Clackamas, Columbia, Douglas, Lane, Lincoln, Linn, Marion, Multnomah, Polk, Washington, and Yamhill (see Figure 3-6). Note that not all counties are entirely within the basin; therefore, totals of irrigated lands within some counties include lands outside of the Willamette River Basin.

Table 7-5 depicts the sum of all irrigated acres for all counties within the basin for each of the Census years since 1987, as well as the five-year acreage increase and the associated annual acreage increase.

Table 7-5
NASS Irrigated Land 1987- 2012: Annual Growth in Acres

Census Year	Irrigated Acres	Five-Year Acreage Increase	Annual Growth in Acres
1987	253,699	26,045	5,209
1992	279,714	8,494	1,699
1997	288,208	2,927	585
2002	291,135	7,451	1,490
2007	298,586	-47,902	-9,580
2012	250,684		

The NASS Census data reveals considerable volatility in acres irrigated. This variation may be attributable to a variety of factors including specific climatic conditions during the Census survey year (i.e., a comparatively cool, wet year may not have required as much irrigation) and market factors (i.e., the economic recession during 2012 possibly resulted in fewer irrigated lands). It is noteworthy that the annual growth in irrigated acreage for the periods 1992 to 1997 and 2002 to 2007 is roughly similar to the rate of increase as determined from the analysis of WRIS data.

Since the NASS data analysis included areas outside the basin, used data collected only once every five years, and was subject to short-term climate- or market-driven volatility, results from the analysis were discarded in favor of the projected increases in agricultural irrigation provided by the WRIS data analysis.

8 Climate Change

Climate change refers to any long-term change in Earth's climate or the climate of a region. The following section describes the anticipated impact of future climate change on irrigation demand within the study area.

8.1 Willamette Water 2100 Project

Contemporaneous with this investigation, the Willamette Water 2100 Project[24] (WW2100) was undertaken to study and model current and anticipated water use within the Willamette River Basin from 2010 to 2100. The primary objectives of the WW2100 project were to:

- Identify and quantify the linkages and feedbacks among human, hydrologic, and ecologic dimensions of the water system,
- Make projections about where and when human activities and climate change will impact future water scarcities,
- Evaluate how biophysical and human system uncertainties affect these projections, and
- Evaluate how policy changes or other interventions might affect future water scarcities.

The WW2100 model integrates climate, hydrologic, ecological, and human systems models to simulate and forecast the distribution, movement, demand for and supply of water in the Willamette Basin. The project ran from October 2010 through September 2016. Preliminary model parameterization and results were published in 2014[25] and a final report was published in 2017[26]. The Corps was involved in WW2100 on a technical advisory group only. The study did not go through standard Corps review processes.

8.1.1 Preliminary Model (2014)

Preliminary WW2100 model parameters and results published in 2014 were based on future climate conditions generated using projections made by the MIROC5 general circulation model (GCM) run using RCP 8.5 (known as the reference case scenario). The MIROC5/RCP 8.5 dataset was generated as part of the Coupled Model Intercomparison Project Phase 5 (CMIP5).[27] Projected meteorology was downscaled to the finer spatial resolution needed for analysis at the Willamette River Basin scale. The MIROC5 model projects changes in future climate that are in the middle of the range of changes predicted by the three general circulation model/greenhouse gas emissions scenario combinations selected as representative scenarios for the WW2100 analysis. The three,

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[24] http://inr.oregonstate.edu/ww2100/about/project-overview

[25] Jaeger, W., A. Plantinga, R. Haggerty, and C. Langpap. (2014) *Anticipating Water Scarcity with Climate Change in the U.S. Pacific Northwest Using a Landscape Model of a Coupled Natural-Human System*. May 1, 2014. Paper for WCERE 2014, Istanbul, Turkey.

[26] Jaeger, W., A.J. Plantinga, C. Langpap, D. Bigelow, and K. Moore. (2017) *Water, Economics, and Climate Change in the Willamette Basin, Oregon (EM 9157)*. Oregon State University Extension Service. https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em9157.pdf

[27] https://pcmdi.llnl.gov/mips/cmip5/

representative general circulation models were run for two representative concentration pathways of greenhouse gas emissions (RCPs): RCP 8.5 and RCP 4.5. Selected representative scenarios are defined as follows: High climate scenario – HadGEM2-ES GCM/RCP 8.5, Reference case scenario -MIROC climate model run with RCP 8.5, Low Climate Change scenario- GFDL-ESM2M climate model run with RCP 4.5. The three GCM/RCP combinations selected as representative selections for the WW2100 analysis were determined to perform well for the Pacific Northwest. This selection process consisted of evaluating the outputs from 41 CMIP5 models to assess their ability to simulate observed climate of the 20th century. Conclusion regarding future climatology were made using the reference case scenario. The projections produced by the MIROC5 model run using RCP8.5 predict that summer temperatures (July through September) in the Willamette River Valley will increase an average of 0.57 ºC per decade between 2010 and 2100, and that there will be little change in precipitation magnitude and timing.

8.1.2 Final Model (2017)

Study findings and model parameterization published in 2017 reflect slightly different climate conditions used in the final WW2100 study[28] results as compared to those provided in 2014. Climate models used in WW2100 generate daily temperature, precipitation, and other variables from 2010 to 2100, based on a suite of General Circulation Model (GCM) outputs. The WW2100 conclusions are based on the results of three different GCMs run for two representative concentration pathways of greenhouse gas emissions (RCP 4.5, a middle of the road emissions scenario in which emissions are curbed in the mid-21st century, and RCP 8.5, a high emissions scenario in which human industry continues to emit greenhouse gases at a growing rate). To select the three GCMs used for analysis, the WW2100 climate team assessed 41 GCMs from the CMIP5 database for their effectiveness at being able to simulate climate in the Pacific Northwest. GCM-based results were evaluated according to their ability to recreate observed, hindcast (1850-2005) precipitation and temperature data. An additional criteria was that all requisite data for a given GCM must have been available for the selected downscaling technique. This second constraint limited the choices to 20 available GCMs. GCM output was downscaled to a 2.5-mile (4 km) resolution using the Multivariate Adaptive Constructed Analogs downscaling technique. This adjustment is necessary in the Willamette River Basin to account for the details of local topography and variations in climate.

The three selected annual mean temperature scenarios which closely span the spread of the uncertainty indicated by the results produced using the 20 GCMs are:

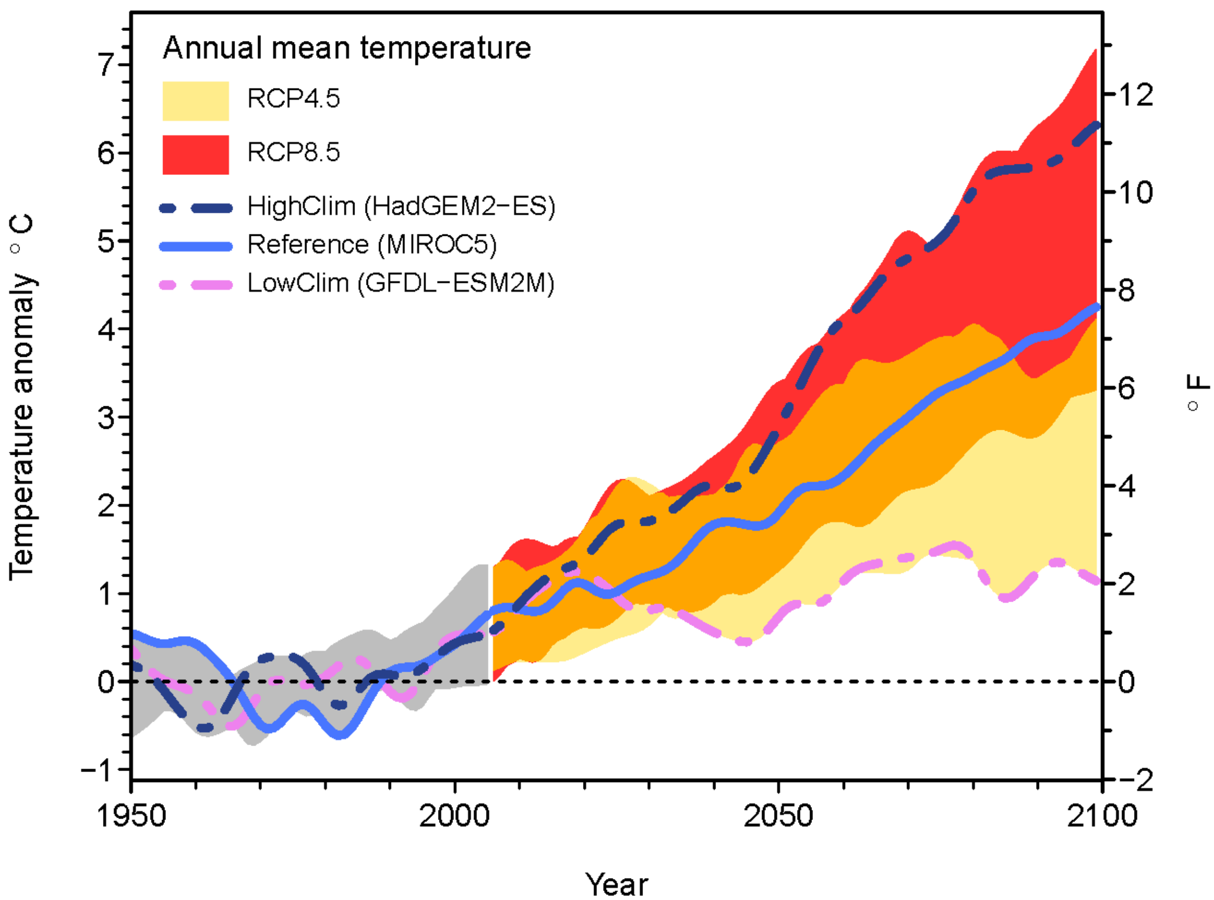
- WW2100 Reference case: increase of about 4° C over 90 years (0.044° C per year) [MIROC5 global climate model with the RCP 8.5 emissions scenario]
- WW2100 "Low climate change" scenario: increase of about 1° C over 90 years (0.011° C per year) [GFDL-ESM2M model, RCP 4.5 emissions scenario]

[28] A detailed explanation of WW2100 climate model evaluation and selection process is available at http://inr.oregonstate.edu/ww2100/analysis-topic/future-climate.

- WW2100 "High climate change" scenario: increase of about 6° C over 90 years (0.067° C per year) [HadGEM2−ES model, RCP 8.5 emissions scenario]

Figure 8-1 depicts changes in annual temperature for 1950 to 2100 relative to a historic baseline (1950-2005). Future projections are based on the outputs of the ensemble of 20 global circulation pathways run for RCP8.5 and RCP4.5 (40 downscaled climate simulations). Runs produced using the two different RCPs are indicated by the red and yellow, respectively, shaded regions on the plot. The orange region denotes where the two RCPs intersect. The three scenarios adopted as part of WW2100 are indicated by the three distinct traces. Note that the three representative traces are a good indication of uncertainty resulting from the multi-model ensemble runs (Source WW2100).

Figure 8-1
Changes in Annual Temperature for 1950-2100

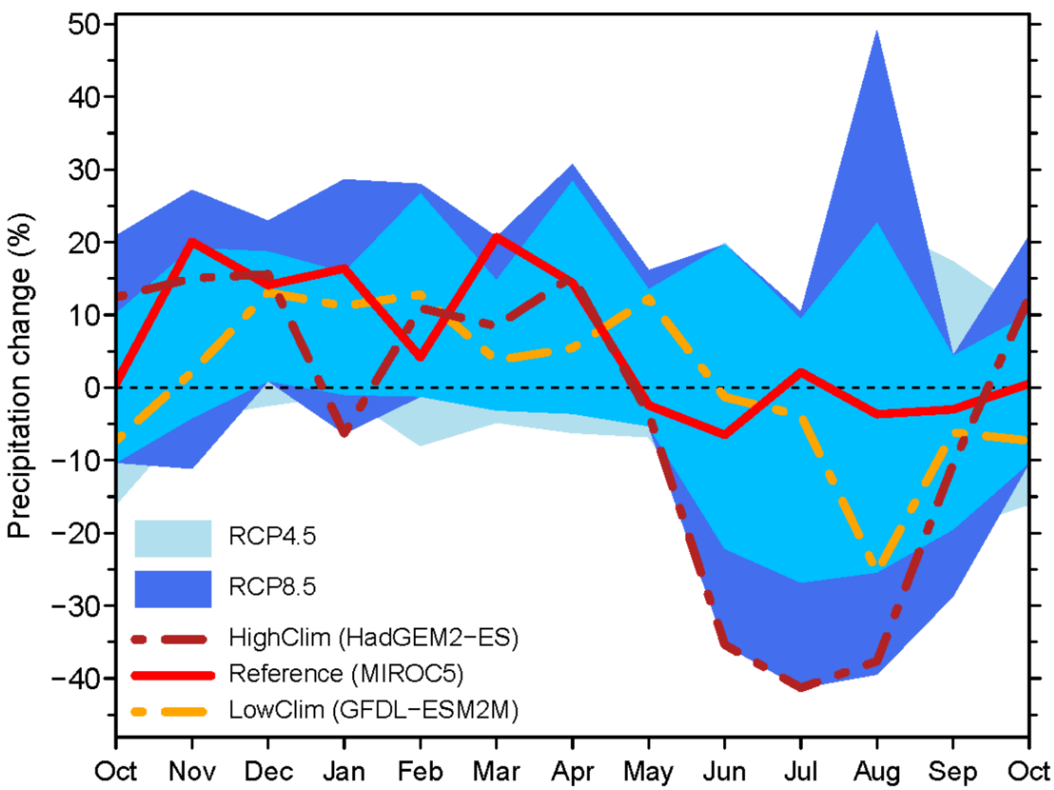


Results indicated that by the year 2100, temperatures in the Willamette River Basin will rise by 1°C to 7°C (2°F to 13°F). Summer temperatures are projected to warm about 2°C (3.6°F) more than winter temperatures. This conclusion is based on the two previously mentioned greenhouse gas emissions scenarios generated using the output from 20 different GCMs. There is a high degree of uncertainty associated with projected, future temperature estimates due to the use of GCMs (their inherent modeling assumptions, boundary conditions etc.), the natural variability of temperature, downscaling techniques applied and assumed greenhouse gas emissions scenarios.

In the case of precipitation, the climate model results based on 40 realizations of future precipitation projections (20 GCM models run for RCPs 4.5 and 8.5), do not unanimously show a trend towards wetter or drier conditions. The majority of models predict that winters will become slightly wetter and summers slightly drier, as shown in Figure 8-2. This figure shows the changes in mean monthly precipitation for the period 2050-2099 and from the period 1950-1999. WW2100 models showed a tendency toward wetter winters and drier summers, i.e., the tendency to rise above the zero line (wetter) in winter and to drop below the zero line in summer (drier).

Note that as with projected temperature results, there is a high degree of uncertainty associated with projected, future precipitation estimates due to the use of GCMs (their inherent modeling assumptions, boundary conditions etc.), the natural variability of precipitation, downscaling techniques applied and assumed greenhouse gas emissions scenarios. This is even greater spread (uncertainty) associated with projected precipitation than temperature.

Figure 8-2
Changes in Mean Precipitation, PNW, 1950-1999 and 2050-2099



Source: Willamette Water 2100, http://inr.oregonstate.edu/ww2100/analysis-topic/future-climate

Increases in temperature due to climate change will result in changes to the seasonality of precipitation. Precipitation will be more likely to fall as rain instead of snow, thus decreasing the development of winter snowpack. WW2100 indicates that subbasins within the Willamette Basin which have historically received the most snow can expect the percentage of snow contribution to the total precipitation to decrease from 25 to 33 percent by the middle of the 21st century. However, it should be noted that snowmelt plays a modest role in determining streamflows in the Basin. The projected decline in snowmelt is only 10 percent of the average precipitation from April to July.

Warmer temperatures and changes to the seasonality of precipitation were reflected in the use of irrigation and crop water needs for growth and development, according to the WW2100 model. Crop planting, irrigation, and harvesting are predicted to occur earlier. Irrigation water use would shift about one week earlier by mid-21st century (2040-2069) and two weeks earlier by late in the 21st century (2070-2099). More plant growth would take place during months with greater precipitation, lower temperatures, and higher levels of soil moisture. Consequently, the WW2100 study concluded that the impact of warmer temperatures is likely to reduce, rather than increase, irrigation on crops when compared to current conditions.

8.2 Irrigation Demand with Climate Change

Impacts of future climate change on irrigation demand were estimated by calculating the diverted water demand using the Penman-Monteith method. The WW2100 preliminary model parameters published in 2014 were the best available climate change estimates at the time that this analysis was carried out and were used to model climate change by increasing mean minimum, mean, and mean maximum monthly 2014 temperatures by 0.057 °C per year (linearly) and maintaining precipitation at 2014 levels. The decisions to maintain 2014 levels of precipitation was made because the WW2100 analysis indicated a considerable amount of uncertainty and lack of consensus regarding the magnitude and directionality of trends in precipitation.

The estimate of 0.057° C used in this study is within the range of the three estimates of projected temperature increases presented in the WW2100 in 2017 (reference case: 0.044° C per year, Lower estimate: 0.011° C per year, and upper estimate case: 0.067° C per year). The estimate of 0.057° C used in this study is slightly higher than the reference case (0.044° C per year) used in the final WW2100 modeling effort published in 2017.

Applying this temperature increase linearly to project future irrigation demand from water year 2014 to 2070 is a computational simplification, but is acceptable given the high degree of uncertainty associated with projected, future temperature estimates.

Although the model results were not available at the time of analysis, it is noteworthy that the change in irrigation demand projected as a result of a shift in the timing of the growing season modeled by WW2100 would not have been quantified in the Penman-Monteith Diverted Water Demand (DWD) calculations because the anticipated growing season shift is less than half of the monthly time-step used in the evapotranspiration modeling.

Table 8-1 shows the increase in agricultural irrigation diverted water demand as a result of increased temperature due to climate change at 10-year increments between 2020 and 2070 with respect to 2014 baseline conditions using each of the remaining baseline irrigation estimation methods. Contained within Table 8-1 are projected climate change irrigation estimates for Estimates 1, 2 and 7; however, because these estimates are not ET calculation based estimates (recall that Estimates 1 and 2 are based on permitted duty of 2.5 acre-feet per acre and Estimate 7 is based on actual AI diversion factors from use reported to WRD), there is no way to incorporate the impact of an annual temperature change into these estimates. Rather, the impact of future climate change on Estimates 1, 2, and 7 is based on the impacts of future climate change observed in Estimates 4 and 6, as represented by the annual percentage increase in future irrigation throughout the period of analysis (18.2% and 18.3%, respectively).

- Estimate 1: Permitted Duty DWD
- Estimate 2: Irrigated Land Factor Adjusted Permitted Duty DWD
- Estimate 4: Permitted Penman-Monteith DWD
- Estimate 6: Irrigated Land Factor Adjusted Penman-Monteith DWD
- Estimate 7: Reported Use Factors Applied to Study Area

Table 8-1
Climate Change Projected Irrigation Estimates – Acre Feet

Year	Estimate 1	Estimate 2	Estimate 4	Estimate 6	Estimate 7
2014	658,200	294,700	733,400	324,500	514,400
2020	671,400	300,600	748,100	331,000	524,700
2030	693,200	310,500	772,400	341,900	541,600
2040	714,800	320,200	796,500	352,500	558,400
2050	736,200	329,800	820,300	363,100	575,000
2060	757,300	339,300	843,900	373,600	591,400
2070	778,200	348,700	867,100	383,900	607,600
Total Increase (2014-2070)	**120,000**	**54,000**	**133,700**	**59,400**	**93,200**
Percent Increase (2014-2070)	**18%**	**18%**	**18%**	**18%**	**18%**

Total Increase (2020-2070)	**106,800**	**48,100**	**119,000**	**52,900**	**82,900**
Percent Increase (2020-2070)	**16%**	**16%**	**16%**	**16%**	**16%**

Overall effective duty estimates for 2014 and every 10 years from 2020 through 2070 using each of the remaining baseline irrigation estimation methods are presented in Table 8-2. Note that the overall effective duty estimates are aggregate values and actual duty values vary geographically for Estimates 4, 6, and 7. Also recall that the baseline irrigation quantities for Estimate 1 and Estimate 2 are based on the legal maximum allowable volume of water to be withdrawn (2.5 acre-feet per acre). Table 8-2 reveals that the Penman-Monteith ET calculation indicates an additional 0.46 acre-feet per acre of duty in 2070 would be needed to provide the same level of irrigation provided by 2.5 acre-feet per acre in 2014. This would be permissible with a change to Oregon Water Resources Department standard policy of issuing water rights of 2.5 acre-feet per acre duty for agricultural irrigation in the Willamette River Basin.[29]

Table 8-2
Climate Change Projected Overall Effective Duty Estimates – Acre Feet per Acre

Year	Estimate 1	Estimate 2	Estimate 4	Estimate 6	Estimate 7
2014	2.50	2.50	2.79	2.75	1.30
2020	2.55	2.55	2.84	2.81	1.33
2030	2.63	2.63	2.93	2.90	1.37
2040	2.71	2.72	3.03	2.99	1.41
2050	2.80	2.80	3.12	3.08	1.46
2060	2.88	2.88	3.21	3.17	1.50
2070	2.96	2.96	3.29	3.26	1.54
Total Increase (2014-2070)	**0.46**	**0.46**	**0.50**	**0.24**	**0.24**
Percent Increase (2014-2070)	**18%**	**18%**	**18%**	**18%**	**18%**

[29] See Oregon Revised Statute 537.621 (https://www.oregonlaws.org/ors/537.621)

8.3 Climate Variability

Climate variability refers to the natural fluctuations in the mean state of climate over a timescale spanning multiple years to a decade. Baseline irrigation estimates were developed using the most recent, complete climate and crop data available at the time of analysis; however, the PRISM and AgriMet climate data used in the baseline estimates only represent climate patterns for 2014. An assessment of additional potential baseline year climate conditions was warranted to assure that the baseline irrigation demands were not anomalous given potential alternative weather years.

Climate variability was assessed by determining the minimum and maximum diverted water demand based on climate conditions over a period of record using available data. Daily weather readings are available from both Corvallis and Aurora, OR AgriMet weather stations during the growing season beginning in 1999. Accordingly, diversion demand calculations using the Penman-Monteith method used in Estimate 4 were performed using the 2014 CDL and climate data obtained from PRISM and AgriMet for the years 1999 through 2014. Table 8-3 depicts the results of these analyses and ranks the years from lowest to highest diversion demand.

The years 2003 and 2010 were identified as the highest and lowest irrigation demand years respectively, thereby implying that the combination of temperature and precipitation in 2003 (hotter and drier) resulted in the greatest crop DWD and climate conditions in 2010 (cooler and wetter) result in the lowest crop DWD. It is important to note that the baseline year of 2014 ranked as the third highest demand year of the last sixteen years.

Table 8-3
Historical Penman-Monteith Total Diverted Water Demand – Acre Feet

Year	Estimate 4	Rank
1999	639,300	10
2000	662,100	8
2001	637,500	11
2002	713,678	5
2003	**797,500**	**1**
2004	607,600	13
2005	612,800	12
2006	758,400	2
2007	687,300	6
2008	719,300	4
2009	665,300	7
2010	**515,900**	**16**
2011	583,100	15
2012	657,900	9
2013	604,900	14
2014	733,400	3

Using the 2014 CDL and climate data obtained from PRISM and AgriMet for the years 2003 and 2010 (rather than those from 2014 in the baseline calculations), projected diverted water demand was calculated using the Penman-Monteith method by increasing mean minimum, mean, and mean maximum monthly temperatures by 0.057 °C per year and maintaining precipitation levels to depict the effect of climate change on the range of alternative baseline climate conditions. Note that the weather conditions existing in 2003 and 2010 were used as plausible alternative baseline conditions.

Tables 8-4 and 8-5 depict the low and high range, respectively for future irrigation for each of the estimates of future agricultural irrigation. In an identical fashion to the baseline climate change estimates provided in Table 8-1, projected climate change irrigation estimates for those estimates not based on an ET calculation (Estimates 1, 2 and 7) are based on the impacts of future climate change observed in Estimates 4 and 6 as represented by the annual percentage increase in future irrigation throughout the period of analysis.

Table 8-4
Climate Variability: Low Demand Climate Change Projected Irrigation Estimates – Acre Feet (2020-2070)

Year	Estimate 1	Estimate 2	Estimate 4	Estimate 6	Estimate 7
2020	474,100	212,500	528,700	234,200	369,100
2030	491,800	220,400	548,500	243,000	382,900
2040	509,500	228,400	568,200	251,700	396,600
2050	527,000	236,200	587,700	260,400	410,700
2060	544,400	244,100	607,100	269,000	423,700
2070	561,700	251,800	626,300	277,500	437,100
Total Increase (2020-2070)	**87,600**	**39,300**	**97,600**	**43,300**	**68,000**
Percent Increase (2020-2070)	**18%**	**18%**	**18%**	**18%**	**18%**

Table 8-5
Climate Variability: High Demand Climate Change Projected Irrigation Estimates – Acre Feet (2020-2070)

Year	Estimate 1	Estimate 2	Estimate 4	Estimate 6	Estimate 7
2020	740,600	331,700	824,600	364,900	577,600
2030	760,500	340,700	846,800	374,800	593,000
2040	780,200	349,600	868,800	384,700	608,300
2050	799,600	358,400	890,500	394,400	623,300
2060	818,800	367,000	912,000	404,000	638,200
2070	837,800	375,600	933,200	412,400	653,000
Total Increase (2020-2070)	**97,200**	**43,900**	**108,600**	**48,500**	**75,400**
Percent Increase (2020-2070)	**13%**	**13%**	**13%**	**13%**	**13%**

Figures 8-2 through 8-6 provide graphical representations of climate change projected irrigation estimates for Estimates 1, 2, 4, 6, and 7, respectively. Each figure depicts the baseline, high demand, and low demand for projected irrigation estimates in light of climate change. Values used in each table are listed in Tables 8-1, 8-4, and 8-5.

Figure 8-2
Estimate 1: Climate Change Projected Irrigation Estimates (Acre-Feet by Year)

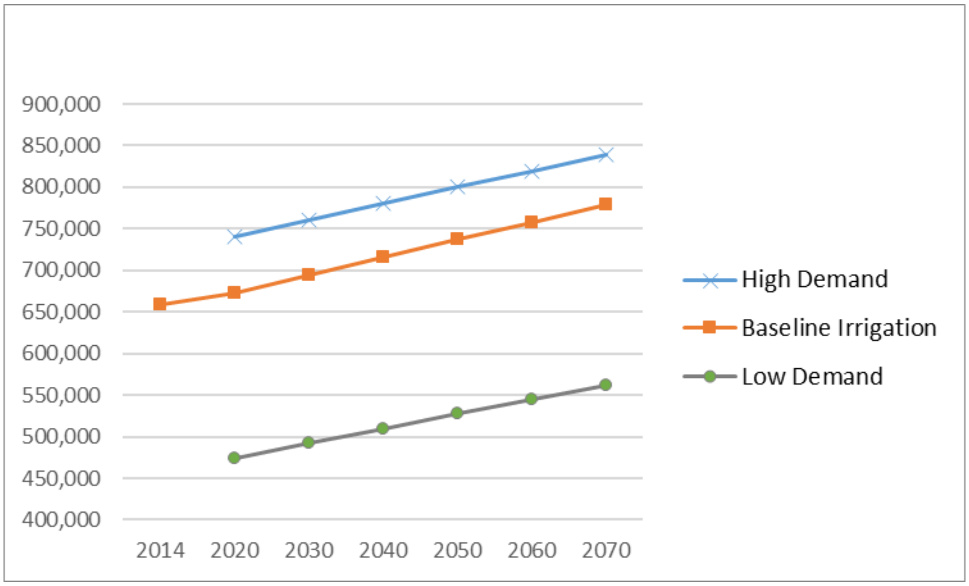


Figure 8-3
Estimate 2: Climate Change Projected Irrigation Estimates (Acre-Feet by Year)

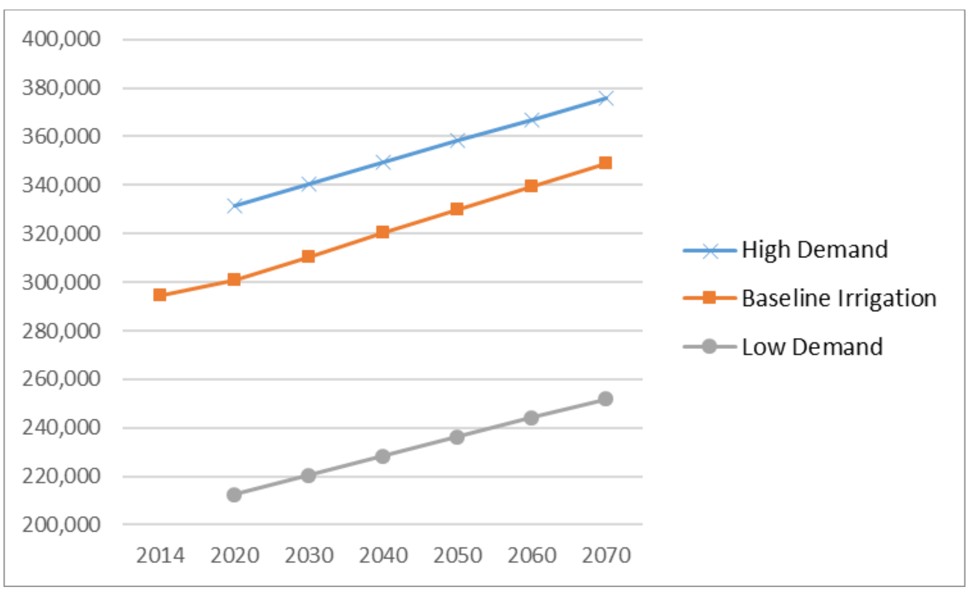


Figure 8-4
Estimate 4: Climate Change Projected Irrigation Estimates (Acre-Feet by Year)

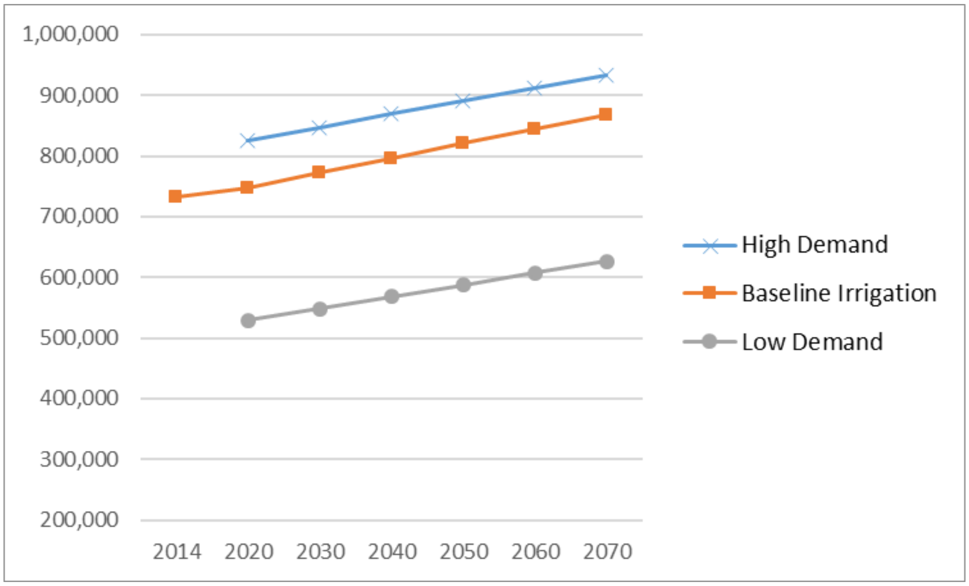


Figure 8-5
Estimate 6: Climate Change Projected Irrigation Estimates (Acre-Feet by Year)

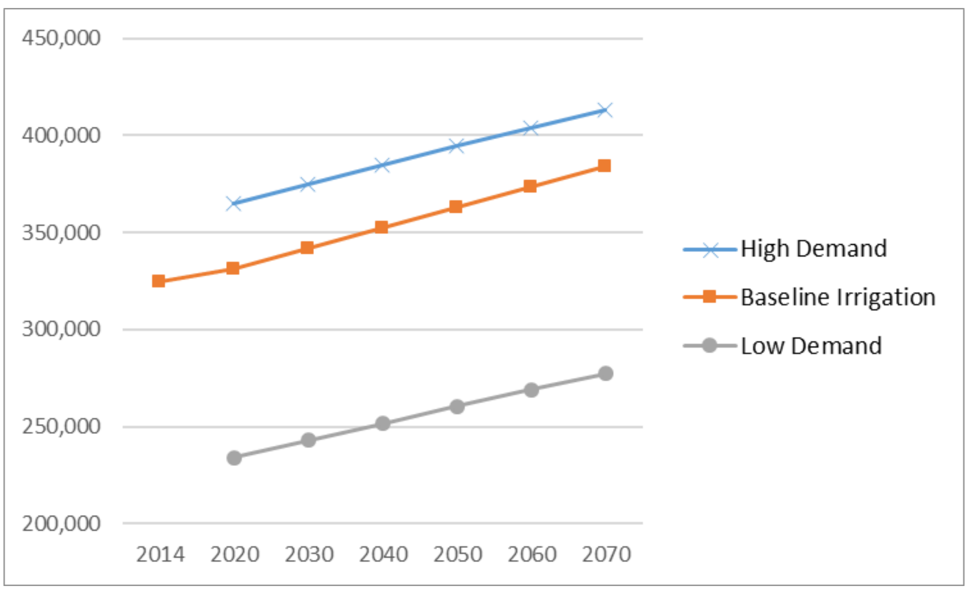
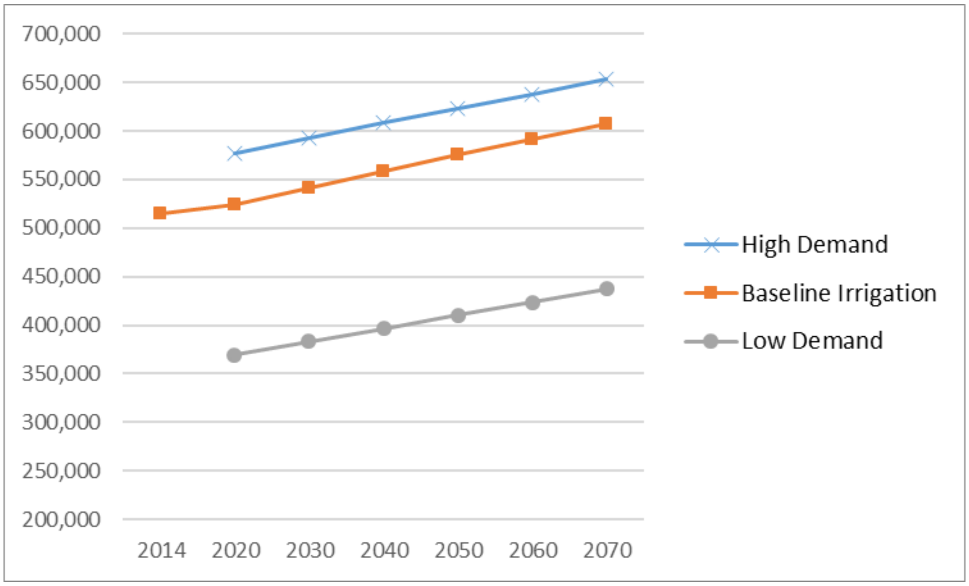


Figure 8-6
Estimate 7: Climate Change Projected Irrigation Estimates (Acre-Feet by Year)



The ranking of historical diverted water demand depicted in Table 8-3 and the climate variability projected irrigation estimates portrayed in Tables 8-4 and 8-5, as well as Figures 8-1 through 8-5, inform the baseline analysis and validate the applicability of 2014 as the baseline climate year. Ranked as the third highest diverted water demand year over the period of record, 2014 was not an anomalous climate year. Furthermore, climate conditions from 2014 provide a generally conservative estimate of future conditions. As such, high- and low-demand estimates are not carried forward in further analyses.

Future agricultural irrigation projections through the period of analysis were developed by incorporating increases based on both an annual rate of increased acreage under agricultural irrigation (see Section 7) and impacts of climate change.

Table 8-6 provides the projected irrigation estimates that include both growth in acreage and climate change-induced effects for each ten-year increment of the analysis period.

Table 8-6
Projected Irrigation Estimates Incorporating Climate Change Impacts and Growth in Acreage Under Agricultural Irrigation – Acre Feet

Year	Estimate 1	Estimate 2	Estimate 4	Estimate 6	Estimate 7
2014	658,200	294,700	733,400	324,500	514,400
2020	694,000	323,100	772,600	355,400	537,000
2030	755,400	372,400	840,200	408,100	575,400
2040	818,700	424,100	909,700	463,700	614,900
2050	884,200	477,800	981,900	521,500	655,400
2060	951,500	533,500	1,055,800	581,500	697,200
2070	1,020,900	591,500	1,132,000	644,100	739,900
Total Increase (2014-2070)	**362,700**	**296,800**	**398,600**	**319,600**	**225,500**
Percent Increase (2014-2070)	**55%**	**101%**	**54%**	**98%**	**44%**

9 Impact of Minimum Perennial Stream Flows on Agricultural Irrigation

Within the Willamette River Basin, there are several minimum perennial streamflows (MPSFs) that have yet to be converted to instream water rights, as required by state law. These MPSFs specify that a certain quantity of live flow, along with an unspecified amount of water released from storage, must be maintained on major tributaries and at several points along mainstem of the Willamette River to support aquatic life and to minimize pollution. MPSF's exist in tributaries below the Corps' Willamette Valley Project reservoirs. Once converted to an instream water right, the MPSFs will carry a priority date of June 22, 1964.

Until the State enters into a contract with the Corps of Engineers to release the stored water for the purpose of satisfying the in-stream water right, the Water Resources Department cannot require the release of the stored water or take actions to regulate in favor of the stored water portion of the MPSF (ORS 537.346). For purposes of regulating the distribution or use of water, any stored water released in excess of the needs of water rights calling on that stored water shall be considered natural flow (ORS 540.045(3)).

The conversion of the MPSFs to instream water rights may result in regulation of junior water rights in the future. It could also result in water users seeking supplemental water rights as a backup source of water. Existing live flow water rights could be supplemented from other sources, such as groundwater, storage from the Willamette Valley Projects, or other on-farm storage impoundments.

To account for this potential increased demand, an analysis was conducted to account for existing primary irrigation water rights, those that authorize the use of surface water, are junior to June 22, 1964, and withdraw water on stream reaches below the dams. This specific query was conducted using data maintained in the state's Water Right Information System (WRIS) database. Using these criteria, an estimated 62,050 acre-feet of water may be regulated in the future to satisfy a 1964 instream water right. It should be noted that this represents the worse-case scenario, where it has been assumed that the MPSF flow targets will not be met in the future, thereby triggering regulation.

10 Recommended Agricultural Irrigation Estimate

As stated in Section 1, only 17 percent of water rights in Oregon require the reporting of water use, resulting in the inability to measure the volume of water used for irrigation occurring within the study area. Each of the baseline irrigation estimation methods described in Section 5 was used to approximate how much agricultural irrigation is being withdrawn from water sources.

Based on feedback from the irrigation stakeholder group in December 2016, the Corps and WRD recommend using Estimate 1 as the baseline and projected agricultural irrigation demand estimate for water supply storage from the Willamette Valley Project reservoirs. Estimate 1 is based on a duty rate of 2.5 acre-feet per acre applied to acres under cultivation according to the 2014 CDL and are permitted for agricultural irrigation. Estimate 1 baseline 2014 irrigation is 658,200 acre-feet and projected irrigation incorporating growth in permitted acres in 2070 is 864,500 acre-feet, reflecting a total increase of 206,300 acre-feet of agricultural irrigation from the baseline year of 2014 to 2070, and 184,200 acre-feet over the 50-year over the period of analysis from 2020 to 2070. Table 10-1 summarizes these values.

Table 10-1
Recommended Agricultural Irrigation Projected Estimate – Acre Feet

Year	Recommended (Estimate 1)	Increase from Year 2020
2014	658,200	n/a
2020	680,300	
2030	717,200	36,900
2040	754,000	73,700
2050	790,800	110,500
2060	827,700	147,400
2070	864,500	184,200

Attachment A
Crop Coefficients for CDL-Identified Crops in the Willamette River Basin

Crop Name	May	Jun	Jul	Aug	Sep
Alfalfa	0.507	1.190	2.134	2.145	2.140
Beans (Green, Snap, Pink, lentils)	0.454	1.100	1.000	0.910	0.750
Blueberries	1.100	1.200	1.060	-	-
Bluegrass	1.155	1.065	0.975	0.885	0.780
Broccoli	1.110	1.310	1.297	1.270	1.177
Cabbage	0.980	1.130	0.648	0.450	0.300
Camelina	0.900	1.150	1.200	1.200	1.100
Canola	1.070	1.200	1.200	1.150	0.830
Cauliflower	1.050	1.050	0.950	0.750	0.620
Cherries- Ground Cover	0.740	1.060	1.250	1.240	0.990
Clover/Wildflowers	0.900	1.150	1.150	1.150	1.100
Corn	0.540	0.900	1.200	1.150	1.139
Double Crop Winter Wheat/Corn	0.950	-	-	0.550	0.620
Fallow/Cover Crop	0.700	1.170	2.000	2.000	1.620
Grapes	0.450	0.700	1.000	1.020	1.020
Greens	0.820	1.030	1.080	1.080	-
Herbs	0.900	1.100	1.200	1.200	1.100
Hops	0.780	1.220	1.280	1.250	0.770
Mints (Spear, Pepper & Mint)	1.110	1.140	1.140	1.100	1.000
Miscellaneous Fruits & Vegs	0.850	1.000	1.100	1.200	1.100
Onion & Garlic	0.780	1.147	1.200	1.200	1.100
Other Crops	0.700	0.950	1.100	1.200	0.800
Other Hay/Non-Alfalfa	0.830	0.998	1.000	0.921	0.768
Other Tree Crops (Hazelnuts)	0.750	0.880	1.100	1.150	0.950
Pasture-grass	0.845	0.983	0.946	0.920	0.869
Peas	0.733	0.730	0.700	0.550	0.284
Peppers	0.719	0.997	1.030	0.931	0.602
Potatoes	0.550	1.070	1.110	1.120	1.000
Pumpkin	0.570	0.720	0.920	1.000	0.800
Radish	0.740	0.900	0.890	0.700	0.550
Sorghum	0.800	1.050	1.100	1.100	0.950
Spring Grains (including Oats/Barley)	1.200	1.200	1.034	0.950	0.542
Squash-Winter	0.526	0.700	0.820	1.000	1.000
Stone Fruit	0.900	1.000	1.000	1.000	0.950
Strawberries	1.140	1.140	1.100	1.000	0.900
Sugar Beets	0.550	0.815	1.091	1.150	1.108
Trailing Berries	0.228	0.720	1.080	1.206	1.170
Tree Fruit	0.450	0.900	1.140	1.300	1.220
Turnips	0.750	1.000	1.100	1.050	0.950
Winter Grains	1.200	1.200	1.100	1.000	0.921

Attachment B
Penman-Monteith Sample Calculation of ETo

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List of Example Step Calculations

Penman-Monteith Equation

The calculation of the standardized reference evapotranspiration (ET_0) using the Penman-Monteith method for either grass (ET_{os}) or alfalafa (ET_{rs}) is given by the equation below.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T + 273} u_2(e_s^0 - e_a)}{\Delta + \gamma(1 + C_d u_2)}$$

Where:

ET_0	=	Reference Evapotranspiration (monthly in mm/d)
R_n	=	net radiation at the crop surface (MJ/m2/d);
G	=	soil heat flux density (MJ/m2/d);
T	=	mean daily air temperature at 2 m height (°C);
u_2	=	wind speed at 2 m height (m/s);
e_s^0	=	saturation vapor pressure (kPa);
e_a	=	actual vapor pressure (kPa);
Δ	=	slope of the vapor pressure curve (kPa/°C);
γ	=	psychrometric constant (kPa/°C);
C_n	=	the numerator constant for the reference crop and time step (900 mm/d for grass and daily time step); and
C_d	=	the denominator constant for the reference crop and time step (0.34 mm/d for grass and daily time step).

Data Sources

The reference evapotranspiration calculation is based on climatic data. Climate data required for the calculation of reference evapotranspiration were obtained from several resources. This analysis used a monthly time-step for all variables.

Temperature

Mean air temperature, mean minimum air temperature, mean maximum air temperature, and mean dew point temperature were obtained from the PRISM[30] monthly timeseries database.

Solar Radiation and Wind Speed

Daily mean solar radiation and mean wind speed were acquired from the AgriMet weather stations in Aurora, OR[31] and Corvallis, OR[32]. Monthly mean values for solar radiation and wind speed were calculated for each weather station for each month from May through September 2014. Crops were assigned monthly values for each parameter according to the closest weather station.

[30] See discussion of PRISM data sources in Section 3.

[31] Data are available at http://www.usbr.gov/pn/agrimet/agrimetmap/araoda.html; accessed August 2016.

[32] Data are available at http://www.usbr.gov/pn/agrimet/agrimetmap/crvoda.html; accessed August 2016.

Elevation

Elevation in meters above sea level is required for the calculation of mean air pressure. The elevation at the centroid within each crop polygon was extracted from the Oregon 10-meter Digital Elevation Model (DEM)[33].

Calculation Steps

Reference evapotranspiration using the Penman-Monteith method was calculated in a step-wise fashion following the outline provided by (Zotarelli, Dukes, Romero, Migliaccio, & Morgan, 2015). To simplify the overall calculation of ET_0, several terms are calculated separately.

Step 1: Mean monthly temperature (T_{mean})

Mean monthly temperature (°C) was obtained from the PRISM dataset.

Step 2: Mean monthly solar radiation (R_{ns})

The mean monthly solar radiation was obtained using daily solar radiation readings from the AgriMet weather stations at Aurora, OR and Corvallis, OR. Daily values provided in Langleys were converted to MJ/m^2/d and averaged to obtain a mean value for each month from May through September, 2014. Conversion from Langleys to MJ/m^2 was performed according to the following equation:

$$R_{ns}\left({}^{MJ}/_{m^2}\right) = 0.04184\, R_{ns}\,(Langleys)$$

Step 3: Mean monthly wind speed (u_2)

The mean monthly wind speed at 2 meters about the ground surface was obtained using daily mean wind speed readings from the AgriMet weather stations at Aurora, OR and Corvallis, OR. Daily values provided in miles/hour were converted to m/s. Since AgriMet weather stations record wind speeds at 3 meters above the ground surface, the measured wind speed was adjusted according to the following equation:

$$u_2 = u_h \frac{4.87}{\ln(67.8h - 5.42)}$$

Where:

u_2 = wind speed 2 meters above the ground surface (m/s);

u_h = wind speed at height of measurement above the ground surface (m/s);

h = height of the measurement above the ground surface (m);

ln = natural logarithm.

Adjusted mean wind speeds were averaged to obtain a mean value for each month from May through September, 2014.

[33] Data are available at https://library.uoregon.edu/map/gis_data/or_10mdem.htm; accessed August 2016.

Step 4: Slope of the saturation vapor pressure curve (Δ)

The slope of the saturation vapor pressure curve is a function of mean monthly temperature (see Step 1 above) and is calculated according to the following equation.

$$\Delta = \frac{4098\left[0.6108e^{\left(\frac{17.27 * T_{mean}}{T_{mean}+237.3}\right)}\right]}{(T_{mean} + 237.3)^2}$$

Where:

Δ = slope of the saturation vapor pressure curve;

T_{mean} = mean monthly air temperature (°C). See Step 1;

e = base of natural logarithm (2.7183).

Step 5: Atmospheric pressure (P)

Using a simplification of the ideal gas law, the mean atmospheric pressure can be estimated at a given elevation. The elevation of each crop polygon centroid was extracted from the Oregon 10-meter Digital Elevation Model. The mean atmospheric pressure at for each crop polygon is calculated according to the following equation.

$$P = 101.3\left(\frac{293 - 0.0065z}{293}\right)^{5.26}$$

Where:

P = atmospheric pressure (kPa);

z = elevation above sea level (m).

Step 6: Psychrometric constant (γ)

The psychrometric constant can be estimated as a function of atmospheric pressure according to:

$$\gamma = 0.000665\, P$$

Where:

γ = psychrometric constant (kPa/°C)

P = atmospheric pressure (kPa/°C); see Step 5.

Step 7: Delta Term (DT) [auxiliary calculation for Radiation Term]

The Delta Term is used to simplify the overall calculation of reference evapotranspiration and is used to calculate the Radiation Term.

$$DT = \frac{\Delta}{\Delta + \gamma(1 + 0.34u_2)}$$

Where:

DT = delta term;

Δ = slope of the saturation vapor curve; see Step 4;

γ = psychrometric constant (kPa/°C); see Step 6;

u_2 = wind speed (m/s); see Step 3.

Step 8: Psi Term (PT) [auxiliary calculation for Wind Term]

The Psi Term is used to simplify the overall calculation of reference evapotranspiration and is used to calculate the Wind Term.

$$PT = \frac{\gamma}{\Delta + \gamma(1 + 0.34u_2)}$$

Where:

PT = psi term;

Δ = slope of the saturation vapor curve; see Step 4;

γ = psychrometric constant (kPa/°C); see Step 6;

u_2 = wind speed (m/s); see Step 3.

Step 9: Temperature Term (TT) [auxiliary calculation for Wind Term]

The Temperature Term is used to simplify the overall calculation of reference evapotranspiration and is used to calculate the Wind Term.

$$TT = u_2\left(\frac{900}{T_{mean} + 273}\right)$$

Where:

TT = Temperature Term;

u_2 = wind speed (m/s); see Step 3.

T_{mean} = mean monthly air temperature (°C). See Step 1;

Step 10: Mean saturation vapor pressure derived from air temperature (e_s)

Saturation vapor pressure is calculated from air temperature. The mean saturation vapor pressure for a month is calculated as the mean between the saturation vapor pressure at the mean daily maximum and minimum air temperatures for the month.

$$e_s = \frac{0.6108e^{\left(\frac{17.27\,T_{max}}{T_{max}\,+\,237.3}\right)} + 0.6108e^{\left(\frac{17.27\,T_{min}}{T_{min}\,+\,237.3}\right)}}{2}$$

Where

e_s = mean saturation vapor pressure (kPa);

T_{max} = mean daily maximum air temperature (°C) as obtained from the PRISM dataset;

T_{min} = mean daily minimum air temperature (°C) as obtained from the PRISM dataset;

e = base of natural logarithm (2.7183).

Step 11: Actual vapor pressure (e_a), as derived from dew point temperature (T_{dp})[34]

$$e_a = 0.6108e^{\left(\frac{17.27\,T_{dp}}{T_{dp}+237.3}\right)}$$

Where

e_a = actual vapor pressure (kPa);

T_{dp} = mean monthly dew point temperature (°C) as obtained from the PRISM dataset.

Step 12: The inverse relative distance Earth-Sun (d_r)

$$d_r = 1 + 0.033cos\left(\frac{2\pi}{365}J\right)$$

Where

d_r = the inverse relative distance between the Earth and Sun.

J = the number of the day of the year (1 through 365). The mean day of the year for each month was used.

[34] The calculation of actual vapor pressure differs from that used in Zotarelli, et al (2015). Since mean dew point temperature is available from the PRISM data, equation 14 from http://www.fao.org/docrep/x0490e/x0490e07.htm was used.

Step 13: Solar declination (δ)

$$\delta = 0.409 sin\left(\frac{2\pi}{365}J - 1.39\right)$$

Where

δ	=	solar declination;
J	=	the number of the day of the year (1 through 365). The mean day of the year for each month was used.

Step 14: Sunset hour angle (ω_s)

$$\omega_s = \arccos[-\tan(\varphi)\tan(\delta)]$$

Where

ω_s	=	sunset hour angle;
φ	=	latitude expressed in radians, as provided by the coordinates of the centroid of the crop polygon;
δ	=	solar declination; See Step 13.

Step 15: Extraterrestrial radiation (R_a).

Extraterrestrial radiation can be estimated from the solar constant, solar declination, and time of the year as expressed by the inverse relative distance Earth-Sun.

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [(\omega_s \, sin\, \varphi \, sin\, \delta) + (cos\varphi \, cos\delta \, sin\, \omega_s)]$$

Where

R_a	=	extraterrestrial radiation ($MJ/m^2/d$);
G_{sc}	=	solar constant = 0.0820 ($MJ/\ m^2/min$);
d_r	=	the inverse relative distance between the Earth and Sun. See Step 12;
ω_s	=	sunset hour angle. See Step 14;
φ	=	latitude (radians);
δ	=	solar declination; See Step 13.

Step 16: Clear sky solar radiation (R_{so})

$$R_{so} = R_a(0.75 + 2 \times 10^{-5} z)$$

Where

R_{so} = clear sky solar radiation (MJ/m^2/d);

R_a = extraterrestrial radiation (MJ/m^2/d);

z = elevation above sea level (m), as extracted from the Oregon digital elevation model at the crop polygon centroid.

Step 17: Net solar or net shortwave radiation (R_{ns})

$$R_{ns} = R_s(1 - a)$$

Where

R_{ns} = net solar or shortwave radiation (MJ/m^2/d);

R_s = incoming solar radiation (MJ/m^2/d); See Step 2;

a = albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop.

Step 18: Net outgoing long wave solar radiation (R_{nl})

$$R_{nl} = \sigma \left[\frac{(T_{max} + 273.16)^4 + (T_{min} + 273.16)^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left[1.35\frac{R_s}{R_{so}} - 0.35\right]$$

Where

R_{nl} = net outgoing longwave radiation (MJ/m^2/d);

σ = Stefan-Boltzmann constant (4.903×10^{-9} MJ/K^4/m^2/d);

T_{max} = mean daily maximum air temperature (°C) as obtained from the PRISM dataset;

T_{min} = mean daily minimum air temperature (°C) as obtained from the PRISM dataset;

e_a = actual vapor pressure (kPa). See Step 11;

R_s = incoming solar radiation (MJ/m^2/d); See Step 2;

R_{so} = c lear sky solar radiation (MJ/m^2/d). See Step 16.

Step 19: Net radiation in equivalent of millimeters of evaporation (R_{ng})

Net radiation is the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing net longwave radiation (R_{nl}). This can be expressed in equivalent of millimeters of evaporation by applying a factor of 0.408.

$$R_{ng} = 0.408(R_{ns} - R_{nl})$$

Where

R_{ng} = net radiation in equivalent of evaporation (mm).

R_{ns} = net solar or shortwave radiation (MJ/m^2/d); See Step 17;

R_{nl} = net outgoing longwave radiation (MJ/m^2/d). See Step 18.

Step 20: Radiation Term (ET_{rad})

$$ET_{rad} = DT(R_{ng})$$

Where

ET_{rad} = radiation term (mm/d);

DT = Delta Term; See Step 7;

R_{ng} = net radiation in equivalent of evaporation (mm). See Step 19.

Step 21: Wind Term (ET_{wind})

$$ET_{wind} = PT \times TT\,(e_s - e_a)$$

Where

ET_{wind} = wind term (mm/d);

PT = Psi Term; See Step 8;

TT = Temperature Term; See Step 9;

e_a = actual vapor pressure (kPa); See Step 11b;

e_s = mean saturation vapor pressure (kPa); See Step 10.

Step 22: Reference Evapotranspiration (ET_0)

$$ET_0 = ET_{wind} + ET_{rad}$$

Where

ET_0 = reference evapotranspiration for grass reference crop (mm/d);

ET_{wind} = wind term (mm/d); See Step 22;

ET_{rad} = radiation term (mm/d); See Step 21.

Example calculations:

Step 1:
Temperature and dew point values were obtained from PRISM

Month	T_{min}	T_{mean}	T_{max}	T_{dp}
May	7.63	14.525	21.42	8.1899
June	9.03	16.15	23.27	9.45
July	12.41	21.16	29.91	12.1899
August	12.56	21.495	30.43	12.06
September	9.8	18.21	26.62	9.1899

Steps 2 and 3:
Daily mean wind and solar radiation values were obtained from the Corvallis AgriMet weather station. Monthly mean values were calculated.

Month	Wind (u_2)	Solar Radiation (R_{ns})
May	2.074	22.347
June	2.303	23.713
July	2.254	25.820
August	2.040	22.998
September	2.165	17.414

Step 4:
Slope of the saturation vapor pressure curve (Δ)

Month	Δ
May	0.106876
June	0.117114
July	0.154073
August	0.156862
September	0.131278

Step 5:
Atmospheric pressure as estimated from elevation of 73.52 meters above sea level.

$$P = 101.3\left(\frac{293-0.0065(73.51785)}{293}\right)^{5.26} = 100.434 \text{ kPa}$$

Step 6:
Psychrometric constant (γ) is a function of atmospheric pressure according to:

$$\gamma = 0.000665\ (100.434) = 0.066789\ kPa/°C$$

Steps 7-11:
Solving for the Delta Term, Psi Term, Temperature Term, mean saturation vapor pressure, and actual vapor pressure.

Month	DT	PT	TT	e_s	e_a
May	0.484112	0.302529	6.49279	1.798963	1.086723
June	0.495848	0.282776	7.166864	2.003018	1.183432
July	0.566332	0.245497	6.897407	2.831073	1.420224
August	0.581012	0.247384	6.235113	2.902024	1.408123
September	0.531003	0.270151	6.690634	2.349113	1.162872

Steps 12-14:
Solving for the inverse distance Earth-Sun, solar declination, and sunset hour angle, using the crop polygon centroid latitude of 44.421506 (decimal degrees), converted to 0.775302 (radians).

Month	J (day of year)	d_r	δ	ω_s
May	136.0	0.97702	0.332956	1.916562
June	166.5	0.968244	0.40717	2.007162
July	197.0	0.968023	0.371698	1.962783
August	228.0	0.976615	0.233213	1.805738
September	258.5	0.991436	0.033386	1.603533

Steps 15-19:
Solving for extraterrestrial radiation, clear sky radiation, net solar shortwave radiation, net outgoing longwave radiation, net radiation, and net radiation in equivalent of evaporation.

Month	R_a	R_{so}	R_{ns}	R_{nl}	R_{ng}
May	39.420592	29.623406	17.206944	4.371044	5.237047
June	41.877278	31.469533	18.259141	4.317776	5.688077
July	40.529468	30.456694	19.881508	5.088292	6.035632
August	35.52798	26.698224	17.708352	5.252549	5.081968
September	27.981436	21.027219	13.408457	5.155847	3.367068

Steps 20-22:
Solving for the ET terms

Month	ET_{rad}	ET_{wind}	ET_0
May	2.578759	1.310539	3.889298
June	2.8706	1.556937	4.427537
July	3.469728	2.233367	5.703095
August	2.993238	2.151332	5.14457
September	1.816444	2.006158	3.822603

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Attachment C
USDA Census of Agriculture Data Analysis Tables

Listing of CDL Crops Categorized by Census Major Crop Groupings

Census of Agriculture Crop Irrigation Factors Tables

1. Acres Harvested and Irrigated - 2012, 2007, 2002, 1997 by Census Major Crop Groupings

2. Irrigated Portion of Harvested Acres - 2012, 2007, 2002, 1997 by Census Major Crop Groupings

3. 2014 NAAS Adjusted Baseline Water Demand by Census Major Crop Groupings

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Listing of CDL Crops Categorized by Census Major Crop Groupings

Census Major Crop Group	CDL Crop
Berries	Blueberries Strawberries Trailing Berries
Field Crop	Camelina Canola Dbl Crop Winter Wheat/Corn Herbs Hops Mints (Spear, Pepper & Mint) Other Crops Sorghum Spring Grains (incl Oats/Barle Sugar Beets Winter Grains
Grass and Field Seed Crops	Bluegrass Clover/Wildflowers
Hay, Forage, Silage	Alfalfa Corn Other Hay/Non-Alfalfa
Orchard	Cherries- Grnd Cvr Grapes Other Tree Crops (Hazelnuts) Stone Fruit Tree Fruit
Vegetables	Beans (Grn, Snap, Pink, lentils) Broccoli Cabbage Cauliflower Greens Misc Fruits & Vegs Onion & Garlic Peas Peppers Potatoes Pumpkin Radish Squash-Winter Turnips
Wild Hay	Fallow/Cover Crop Pasture-grass

Table C-1
Acres Harvested and Irrigated - 2012, 2007, 2002, 1997: Berries

Study Area County	Acres Harvested 2012	Acres Harvested 2007	Acres Harvested 2002	Acres Harvested 1997	Acres Irrigated 2012	Acres Irrigated 2007	Acres Irrigated 2002	Acres Irrigated 1997
Benton	215	679	230	140	215	660	228	139
Clackamas	3,401	3,536	3,417	3,591	3,153	1,369	2,454	1,631
Lane	345	314	271	288	345	242	239	-
Linn	1,771	1,083	406	558	1,771	871	399	-
Marion	6,912	6,344	6,789	6,600	6,886	5,028	6,313	6,600
Multnomah	1,003	1,178	1,094	-	-	867	804	-
Polk	566	768	547	410	566	706	505	366
Yamhill	2,188	1,787	938	1,092	2,121	1,215	876	843
Total	**16,401**	**15,689**	**13,692**	**12,679**	**15,057**	**10,958**	**11,818**	**9,579**

Table C-2
Irrigated Portion of Harvested Acres - 2012, 2007, 2002, 1997: Berries

Study Area County	Irrigated Portion 2012	Irrigated Portion 2007	Irrigated Portion 2002	Irrigated Portion 1997
Benton	100.0%	97.2%	99.1%	99.3%
Clackamas	92.7%	38.7%	71.8%	45.4%
Lane	100.0%	77.1%	88.2%	0.0%
Linn	100.0%	80.4%	98.3%	0.0%
Marion	99.6%	79.3%	93.0%	100.0%
Multnomah	0.0%	73.6%	73.5%	
Polk	100.0%	91.9%	92.3%	89.3%
Yamhill	96.9%	68.0%	93.4%	77.2%
Total	**91.8%**	**69.8%**	**86.3%**	**75.6%**

Table C-3
2014 NAAS Adjusted Baseline Water Demand: Berries

Study Area County	CDL Based Acres in Production	BC Based Diversion Demand (AF)	BC NASS Adjusted Diversion Demand (AF)	PM Based Diversion Demand (AF)	PM NASS Adjusted Diversion Demand (AF)
Benton	493	1,591	1,591	1,358	1,358
Clackamas	61	193	179	141	131
Lane	57	156	156	130	130
Linn	555	1,729	1,729	1,462	1,462
Marion	729	2,154	2,154	1,695	1,695
Multnomah	260	819	603	593	436
Polk	205	551	551	445	445
Yamhill	927	2,526	2,448	1,881	1,823
Total	**3,287**	**9,719**	**9,411**	**7,707**	**7,482**

Table C-4
Acres Harvested and Irrigated - 2012, 2007, 2002, 1997: Field Crops

Study Area County	Acres Harvested 2012	Acres Harvested 2007	Acres Harvested 2002	Acres Harvested 1997	Acres Irrigated 2012	Acres Irrigated 2007	Acres Irrigated 2002	Acres Irrigated 1997
Benton	7,738	5,049	8,841	9,955	1,580	376	2,142	3,930
Clackamas	6,872	2,173	4,227	4,412	73	170	403	60
Lane	11,091	4,450	6,817	10,675	2,185	1,986	2,442	6,314
Linn	18,529	8,626	9,728	12,093	2,590	2,775	2,186	5,128
Marion	30,248	8,059	20,012	26,832	9,700	2,389	8,674	14,263
Multnomah	2,023	1,375	2,082	1,888	240	-	377	412
Polk	16,574	4,315	9,593	18,305	280	416	89	2,448
Yamhill	20,105	4,703	14,305	20,043	338	113	352	864
Total	**113,180**	**38,750**	**75,605**	**104,203**	**16,986**	**8,225**	**16,665**	**33,419**

Table C-5
Irrigated Portion of Harvested Acres - 2012, 2007, 2002, 1997: Field Crops

Study Area County	Irrigated Portion 2012	Irrigated Portion 2007	Irrigated Portion 2002	Irrigated Portion 1997
Benton	20.4%	7.4%	24.2%	39.5%
Clackamas	1.1%	7.8%	9.5%	1.4%
Lane	19.7%	44.6%	35.8%	59.1%
Linn	14.0%	32.2%	22.5%	42.4%
Marion	32.1%	29.6%	43.3%	53.2%
Multnomah	11.9%	0.0%	18.1%	21.8%
Polk	1.7%	9.6%	0.9%	13.4%
Yamhill	1.7%	2.4%	2.5%	4.3%
Total	15.0%	21.2%	22.0%	32.1%

Table C-6
2014 NASS Adjusted Baseline Water Demand: Field Crops

Study Area County	CDL Based Acres	BC Based Diversion Demand (AF)	BC NASS Adjusted Diversion Demand (AF)	PM Based Diversion Demand (AF)	PM NASS Adjusted Diversion Demand (AF)
Benton	5,011	20,070	7,923	16,579	6,545
Clackamas	848	3,226	336	2,338	244
Lane	5,199	20,227	11,964	16,848	9,965
Linn	8,190	31,995	13,568	26,270	11,140
Marion	13,064	49,709	26,424	37,651	20,014
Multnomah	1,091	3,966	866	2,833	618
Polk	4,911	19,321	2,584	15,891	2,125
Yamhill	4,347	16,097	694	11,843	511
Total	**42,662**	**164,610**	**64,357**	**130,251**	**51,161**

Table C-7
Acres Harvested and Irrigated - 2012, 2007, 2002, 1997: Grass & Field Seed Crops

Study Area County	Acres Harvested 2012	Acres Harvested 2007	Acres Harvested 2002	Acres Harvested 1997	Acres Irrigated 2012	Acres Irrigated 2007	Acres Irrigated 2002	Acres Irrigated 1997
Benton	33,142	38,855	37,467	37,854	2,864	10,811	4,850	1,225
Clackamas	7,149	10,627	11,449	10,922	1,312	2,777	2,827	1,572
Lane	41,090	39,467	44,102	38,041	6,389	7,328	4,886	2,986
Linn	133,079	169,625	184,292	208,695	6,969	11,562	11,042	6,139
Marion	79,414	103,377	104,881	104,593	17,271	35,383	28,637	11,002
Multnomah	697	238	857	374	49	-	-	-
Polk	41,906	69,750	60,562	54,121	4,558	5,828	3,826	1,862
Yamhill	34,173	50,888	44,513	37,039	4,479	9,960	4,049	1,450
Total	**370,650**	**482,827**	**488,123**	**491,639**	**43,891**	**83,649**	**60,117**	**26,236**

Table C-8
Irrigated Portion of Harvested Acres - 2012, 2007, 2002, 1997: Grass & Field Seed

Study Area County	Irrigated Portion 2012	Irrigated Portion 2007	Irrigated Portion 2002	Irrigated Portion 1997
Benton	8.6%	27.8%	12.9%	3.2%
Clackamas	18.4%	26.1%	24.7%	14.4%
Lane	15.5%	18.6%	11.1%	7.8%
Linn	5.2%	6.8%	6.0%	2.9%
Marion	21.7%	34.2%	27.3%	10.5%
Multnomah	7.0%	0.0%	0.0%	0.0%
Polk	10.9%	8.4%	6.3%	3.4%
Yamhill	13.1%	19.6%	9.1%	3.9%
Total	**11.8%**	**17.3%**	**12.3%**	**5.3%**

Table C-9
NASS Adjusted Baseline Water Demand: Grass & Field Seed

Study Area County	CDL Based Acres	BC Based Diversion Demand (AF)	BC NASS Adjusted Diversion Demand (AF)	PM Based Diversion Demand (AF)	PM NASS Adjusted Diversion Demand (AF)
Benton	26,908	96,448	26,836	78,738	21,908
Clackamas	1,457	5,299	1,313	3,821	947
Lane	27,120	95,484	17,729	78,751	14,622
Linn	45,635	158,105	10,777	128,172	8,736
Marion	40,744	140,428	48,064	106,310	36,387
Multnomah	1,819	6,647	467	4,730	333
Polk	22,629	80,257	8,729	64,800	7,048
Yamhill	11,538	42,152	8,250	30,795	6,027
Total	**177,849**	**624,820**	**122,165**	**496,119**	**96,009**

Table C-10
Acres Harvested and Irrigated - 2012, 2007, 2002, 1997: Hay, Forage, Silage

Study Area County	Acres Harvested 2012	Acres Harvested 2007	Acres Harvested 2002	Acres Harvested 1997	Acres Irrigated 2012	Acres Irrigated 2007	Acres Irrigated 2002	Acres Irrigated 1997
Benton	7,293	5,141	10,115	7,035	690	941	2,220	1,343
Clackamas	14,229	18,302	14,863	16,989	2,020	4,237	1,665	2,432
Lane	21,870	23,790	20,842	21,426	2,497	4,242	4,284	3,650
Linn	13,247	19,171	18,801	35,920	1,815	3,130	3,239	4,849
Marion	18,101	13,758	11,546	15,534	4,365	8,118	5,701	5,551
Multnomah	2,466	1,807	1,453	1,849	45	50	51	102
Polk	10,971	10,364	13,358	17,575	3,531	3,032	2,705	2,986
Yamhill	15,067	12,944	20,494	16,725	1,295	2,671	3,984	3,382
Total	**127,153**	**132,095**	**136,633**	**163,201**	**22,377**	**33,435**	**30,549**	**31,101**

Table C-11
Irrigated Portion of Harvested Acres - 2012, 2007, 2002, 1997: Hay, Forage, Silage

Study Area County	Irrigated Portion 2012	Irrigated Portion 2007	Irrigated Portion 2002	Irrigated Portion 1997
Benton	9.5%	18.3%	21.9%	19.1%
Clackamas	14.2%	23.2%	11.2%	14.3%
Lane	11.4%	17.8%	20.6%	17.0%
Linn	13.7%	16.3%	17.2%	13.5%
Marion	24.1%	59.0%	49.4%	35.7%
Multnomah	1.8%	2.8%	3.5%	5.5%
Polk	32.2%	29.3%	20.3%	17.0%
Yamhill	8.6%	20.6%	19.4%	20.2%
Total	**15.7%**	**25.1%**	**21.4%**	**18.3%**

Table C-12:
NASS Adjusted Baseline Water Demand: Hay, Forage, Silage

Study Area County	CDL Based Acres	BC Based Diversion Demand (AF)	BC NASS Adjusted Diversion Demand (AF)	PM Based Diversion Demand (AF)	PM NASS Adjusted Diversion Demand (AF)
Benton	2,288	8,508	1,867	7,105	1,559
Clackamas	1,704	5,708	1,323	4,095	949
Lane	6,713	21,970	4,516	18,191	3,739
Linn	3,392	11,836	2,039	9,769	1,683
Marion	8,618	31,481	18,576	24,553	14,488
Multnomah	1,184	4,527	250	3,238	179
Polk	2,560	8,941	2,878	7,220	2,324
Yamhill	4,504	17,047	3,518	12,560	2,592
Total	**30,963**	**110,018**	**34,966**	**86,732**	**27,512**

Table C-13
Acres Harvested and Irrigated - 2012, 2007, 2002, 1997: Orchards

Study Area County	Acres Harvested 2012	Acres Harvested 2007	Acres Harvested 2002	Acres Harvested 1997	Acres Irrigated 2012	Acres Irrigated 2007	Acres Irrigated 2002	Acres Irrigated 1997
Benton	1,540	1,445	1,311	992	479	354	386	138
Clackamas	6,234	5,316	5,487	5,210	637	514	535	399
Lane	5,824	5,396	5,421	5,036	1,464	1,217	1,410	984
Linn	2,918	2,312	2,080	2,494	1,615	1,035	1,137	732
Marion	11,724	10,174	9,907	11,881	3,659	2,266	4,527	3,116
Multnomah	259	153	190	200	80	26	76	46
Polk	7,806	7,279	7,030	7,381	1,424	1,352	1,130	400
Yamhill	15,658	15,080	14,703	14,411	2,922	3,019	3,469	1,367
Total	**51,963**	**47,155**	**46,129**	**47,605**	**12,280**	**9,783**	**12,670**	**7,182**

Table C-14
Irrigated Portion of Harvested Acres - 2012, 2007, 2002, 1997: Orchards

Study Area County	Irrigated Portion 2012	Irrigated Portion 2007	Irrigated Portion 2002	Irrigated Portion 1997
Benton	31.1%	24.5%	29.4%	13.9%
Clackamas	10.2%	9.7%	9.8%	7.7%
Lane	25.1%	22.6%	26.0%	19.5%
Linn	55.3%	44.8%	54.7%	29.4%
Marion	31.2%	22.3%	45.7%	26.2%
Multnomah	30.9%	17.0%	40.0%	23.0%
Polk	18.2%	18.6%	16.1%	5.4%
Yamhill	18.7%	20.0%	23.6%	9.5%
Total	**23.6%**	**20.7%**	**27.5%**	**15.1%**

Table C-15
NASS Adjusted Baseline Water Demand: Orchards

Study Area County	CDL Based Acres	BC Based Diversion Demand (AF)	BC NASS Adjusted Diversion Demand (AF)	PM Based Diversion Demand (AF)	PM NASS Adjusted Diversion Demand (AF)
Benton	1,199	4,266	1,327	3,548	1,104
Clackamas	1,308	4,546	485	3,279	350
Lane	1,755	6,083	1,582	5,098	1,326
Linn	1,325	4,654	2,576	3,853	2,132
Marion	5,686	20,219	9,239	14,977	6,844
Multnomah	65	223	89	159	64
Polk	2,436	8,519	1,582	6,893	1,280
Yamhill	6,406	22,357	5,275	16,336	3,854
Total	**20,182**	**70,867**	**22,156**	**54,142**	**16,953**

Table C-16
Acres Harvested and Irrigated - 2012, 2007, 2002, 1997: Tree Farms

Study Area County	Acres Harvested 2012	Acres Harvested 2007	Acres Harvested 2002	Acres Harvested 1997	Acres Irrigated 2012	Acres Irrigated 2007	Acres Irrigated 2002	Acres Irrigated 1997
Benton	8,039	7,400	12,443	-	10	-	-	-
Clackamas	16,358	24,211	23,738	-	34	196	-	-
Lane	3,261	4,117	3,030	-	72	94	-	-
Linn	3,085	3,423	1,939	-	97	88	-	-
Marion	11,326	14,016	14,317	-	104	1,896	-	-
Multnomah	338	345	619	-	-	19	-	-
Polk	6,991	8,100	6,133	-	10	-	-	-
Yamhill	1,479	2,497	1,813	-	7	-	-	-
Total	**50,877**	**64,109**	**64,032**	**-**	**334**	**2,293**	**-**	**-**

Table C-17
Irrigated Portion of Harvested Acres - 2012, 2007, 2002, 1997: Tree Farms

Study Area County	Irrigated Portion 2012	Irrigated Portion 2007	Irrigated Portion 2002	Irrigated Portion 1997
Benton	0.1%	0.0%	0.0%	n/a
Clackamas	0.2%	0.8%	0.0%	n/a
Lane	2.2%	2.3%	0.0%	n/a
Linn	3.1%	2.6%	0.0%	n/a
Marion	0.9%	13.5%	0.0%	n/a
Multnomah	0.0%	5.5%	0.0%	n/a
Polk	0.1%	0.0%	0.0%	n/a
Yamhill	0.5%	0.0%	0.0%	n/a
Total	**0.7%**	**3.6%**	**0.0%**	**n/a**

Table C-18:
NASS Adjusted Baseline Water Demand: Tree Farms

Study Area County	CDL Based Acres	BC Based Diversion Demand (AF)	BC NASS Adjusted Diversion Demand (AF)	PM Based Diversion Demand (AF)	PM NASS Adjusted Diversion Demand (AF)
Benton					
Clackamas					
Lane					
Linn					
Marion					
Multnomah					
Polk					
Yamhill					
Total					

Table C-19
Acres Harvested and Irrigated - 2012, 2007, 2002, 1997: Vegetables

Study Area County	Acres Harvested 2012	Acres Harvested 2007	Acres Harvested 2002	Acres Harvested 1997	Acres Irrigated 2012	Acres Irrigated 2007	Acres Irrigated 2002	Acres Irrigated 1997
Benton	3,080	5,849	8,458	10,330	2,888	5,596	8,364	10,330
Clackamas	3,882	3,265	3,754	5,200	3,351	2,719	3,138	5,049
Lane	1,590	1,718	2,880	5,701	1,464	1,650	2,839	5,586
Linn	7,877	5,545	6,454	10,081	7,269	5,418	6,256	10,073
Marion	23,381	24,420	31,323	38,498	21,373	22,237	29,637	37,894
Multnomah	2,505	2,571	3,267	4,607	1,711	2,145	2,744	3,921
Polk	4,190	1,552	2,535	2,565	3,753	1,503	2,501	2,480
Yamhill	4,499	3,692	6,644	7,565	3,841	3,250	6,465	7,538
Total	**51,004**	**48,612**	**65,315**	**84,547**	**45,650**	**44,518**	**61,944**	**82,871**

Table C-20
Irrigated Portion of Harvested Acres - 2012, 2007, 2002, 1997: Vegetables

Study Area County	Irrigated Portion 2012	Irrigated Portion 2007	Irrigated Portion 2002	Irrigated Portion 1997
Benton	93.8%	95.7%	98.9%	100.0%
Clackamas	86.3%	83.3%	83.6%	97.1%
Lane	92.1%	96.0%	98.6%	98.0%
Linn	92.3%	97.7%	96.9%	99.9%
Marion	91.4%	91.1%	94.6%	98.4%
Multnomah	68.3%	83.4%	84.0%	85.1%
Polk	89.6%	96.8%	98.7%	96.7%
Yamhill	85.4%	88.0%	97.3%	99.6%
Total	**89.5%**	**91.6%**	**94.8%**	**98.0%**

Table C-21
NASS Adjusted Baseline Water Demand: Vegetables

Study Area County	CDL Based Acres	BC Based Diversion Demand (AF)	BC NASS Adjusted Diversion Demand (AF)	PM Based Diversion Demand (AF)	PM NASS Adjusted Diversion Demand (AF)
Benton	1,409	4,001	4,001	3,294	3,294
Clackamas	643	1,856	1,802	1,326	1,288
Lane	864	2,416	2,381	2,010	1,982
Linn	1,587	4,248	4,245	3,450	3,448
Marion	4,685	13,893	13,675	10,518	10,353
Multnomah	644	2,029	1,727	1,431	1,218
Polk	1,238	3,266	3,222	2,576	2,541
Yamhill	1,219	3,519	3,506	2,556	2,547
Total	**12,288**	**35,228**	**34,560**	**27,162**	**26,671**

Table C-22
Acres Harvested and Irrigated - 2012, 2007, 2002, 1997: Wild Hay

Study Area County	Acres Harvested 2012	Acres Harvested 2007	Acres Harvested 2002	Acres Harvested 1997	Acres Irrigated 2012	Acres Irrigated 2007	Acres Irrigated 2002	Acres Irrigated 1997
Benton	1,690	1,740	784	1,168	-	-	39	269
Clackamas	5,323	4,760	4,432	3,878	223	264	219	-
Lane	7,022	8,712	6,419	6,388	312	866	678	187
Linn	6,249	4,353	4,510	4,596	456	304	601	389
Marion	3,280	2,421	2,008	2,143	260	214	96	217
Multnomah	1,011	866	698	984	-	-	-	-
Polk	2,171	2,054	1,343	1,550	229	134	-	-
Yamhill	3,165	2,479	2,061	2,140	143	260	189	37
Total	**29,911**	**27,385**	**22,255**	**22,847**	**1,623**	**2,042**	**1,822**	**1,099**

Table C-23
Irrigated Portion of Harvested Acres - 2012, 2007, 2002, 1997: Wild Hay

Study Area County	Irrigated Portion 2012	Irrigated Portion 2007	Irrigated Portion 2002	Irrigated Portion 1997
Benton	0.0%	0.0%	5.0%	23.0%
Clackamas	4.2%	5.5%	4.9%	0.0%
Lane	4.4%	9.9%	10.6%	2.9%
Linn	7.3%	7.0%	13.3%	8.5%
Marion	7.9%	8.8%	4.8%	10.1%
Multnomah	0.0%	0.0%	0.0%	0.0%
Polk	10.5%	6.5%	0.0%	0.0%
Yamhill	4.5%	10.5%	9.2%	1.7%
Total	**5.4%**	**7.5%**	**8.2%**	**4.8%**

Table C-24:
NASS Adjusted Baseline Water Demand: Wild Hay

Study Area County	CDL Based Acres	BC Based Diversion Demand (AF)	BC NASS Adjusted Diversion Demand (AF)	PM Based Diversion Demand (AF)	PM NASS Adjusted Diversion Demand (AF)
Benton	22,620	76,471	17,612	62,767	14,456
Clackamas	17,845	57,563	3,292	41,033	2,347
Lane	52,727	169,299	17,882	139,342	14,718
Linn	119,614	384,373	51,221	312,969	41,706
Marion	42,839	135,780	13,749	103,741	10,505
Multnomah	3,115	11,119	972	7,910	692
Polk	16,942	55,834	5,889	44,589	4,703
Yamhill	9,646	32,323	3,390	23,376	2,452
Total	**285,348**	**922,763**	**114,008**	**735,727**	**91,578**