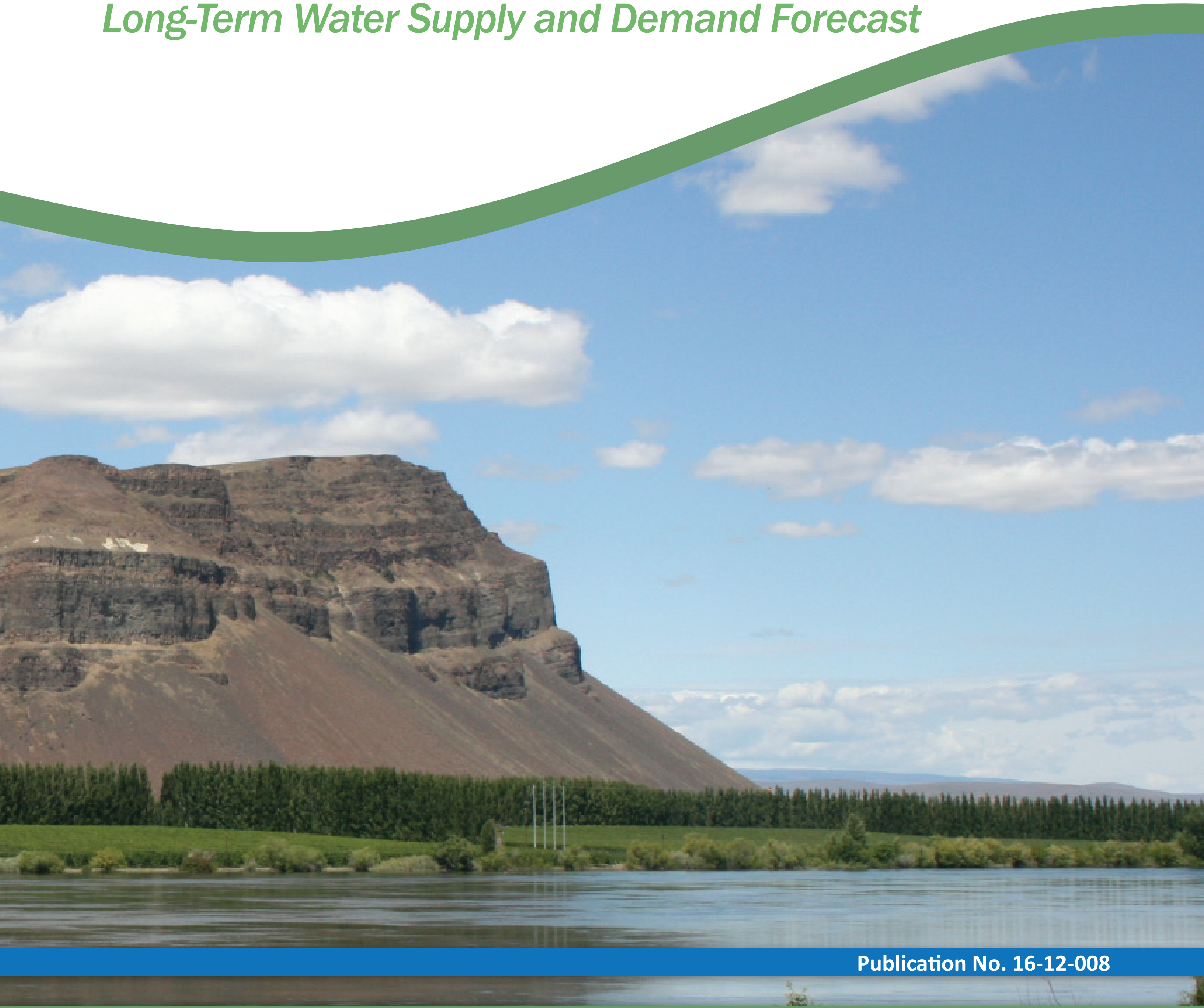
2016 Technical Supplement for the

# Columbia River Basin

## *Long-Term Water Supply and Demand Forecast*



Publication No. 16-12-008

Submitted February 2017 by:

Department of Ecology
State of Washington

in collaboration with

Washington State University

State of Washington Water Research Center

The University of Utah

Aspect

Washington Department of Fish and Wildlife

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*Cover photo: Columbia River below Wanapum Dam*

# Columbia River Basin
# Long-Term Water Supply and Demand Forecast

## 2016 Technical Supplement

Submitted to Washington State Department of Ecology by:
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Ecology Publication No. 16-12-008

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# INTRODUCTION – Purpose of the Technical Supplement

In December 2016 the Office of the Columbia River (OCR) released the *2016 Washington State Legislative Report: Columbia River Basin Long-Term Water Supply and Demand Forecast* (Ecology Publication No. 12-16-001). The Legislative Report summarized the results of studies that explored the impacts that future changes in climate, economic factors, and water management may have on the water supply and demand in the Columbia River Basin, with a particular focus on Washington State. This information will help legislators, water managers, industry, and agency professionals plan for future conditions that will likely be quite different from those we have experienced in the past, which were the conditions under which the water supply systems within the Columbia River Basin were built to reliably deliver water.

This Technical Supplement complements the 2016 Legislative Report, expanding on a number of aspects, namely:

- Providing methodological details underlying the approach, modeling, and results published in the 2016 Legislative Report *(SECTION 1 - Methodology underlying the 2016 Long-Term Water Supply and Demand Forecast).*
- Describing in further detail the outreach efforts that were carried out before and during the development of the 2016 Forecast, including the Forecast team's responses to public comments received during the public review period *(SECTION 2 – Outreach Efforts that Informed the 2016 Long-Term Water Supply and Demand Forecast).*
- Providing additional methodological detail, analysis, and results for the modules that targeted emerging policy issues *(SECTION 3 – Modules to Inform Key Policy Issues).* The five modules included in the 2016 Legislative Report were:
    - *Integrating Declining Groundwater Areas into Supply and Demand Forecasting*
    - *Pilot Application of METRIC Crop Demand Modeling in Washington State*
    - *Water Banking Trends in Washington and Western States*
    - *Effects of User-Pay Requirements on Water Permitting*
    - *Western Washington Supply and Demand Forecasting*

# SECTION 1 – Methodology Underlying the 2016 Long-Term Water Supply and Demand Forecast

## Approach Synopsis

### *Computer Modeling*

Surface water supplies reflect the total amount of surface water generated in a watershed. Water demand is the total amount of water needed for total instream uses—including hydropower and instream flow requirements—and out-of-stream uses, including agricultural demand (the dominant out-of-stream use), conveyance losses, and municipal and domestic demand.

Water supply and demand impact each other. Out-of-stream diversions reduce supply downstream, while water that is diverted but not consumptively used—such as water that is lost through leaks in municipal systems or return flows from irrigated fields—may return to the system and provide water supply downstream.

The Forecast's biophysical modeling component integrated and built upon four existing models (Figure 1):

1. **VIC:** Variable Infiltration Capacity, a land surface hydrology model (Liang et al. 1994).
2. **CropSyst:** Cropping Systems Simulation, a cropping system model (Stockle et al. 1994, 2003).
3. **ColSim:** Columbia Simulator, a reservoir operations model (Hamlet and Lettenmaier 1999).
4. **Yakima Riverware (**YAK-RW), a river and reservoir management model being used in the Yakima River Basin (https://wa.water.usgs.gov/projects/yakimawarsmp/warsmp/riverware.htm).

Each of these models has been used independently many times to simulate conditions in our region (e.g. Hamlet and Lettenmaier 1999; Stockle et al. 2010; Payne et al. 2004; Elsner et al. 2010; Maurer et al. 2002; Markoff and Cullen 2008; Hamlet et al. 2010; Jara and Stockle 1999; Marcos 2000; Pannkuk et al. 1998; Peralta and Stockle 2002; Kemanian 2003). In the earlier 2011 Forecast, VIC and CropSyst were integrated to exchange hydrologic and crop production information. What distinguishes this 2016 Forecast from those previous efforts is that the hydrological (VIC) and crop production (CropSyst) models are more tightly integrated, so that the interactions between the hydrological cycle and crop growth processes are better captured. This improves the simulation of crop water requirements, particularly during drought conditions.

#### Modeling Water Supply

For the supply analysis, the 2016 Forecast focused on surface water and shallow subsurface/surface hydrologic interactions, and did not analyze deep groundwater dynamics. It is recognized that deep groundwater supplies play a significant role in many parts of eastern Washington. However, due to time, resource, and data constraints, deep groundwater supplies were not considered in this Forecast. For this report, with the exception of the Odessa Subarea, it was assumed that water demand met by groundwater supplies would continue to be met by groundwater supplies in the future.

Surface water supplies for our region reflect the current management of the existing reservoir system. The integrated VIC-CropSyst model was thus linked to reservoir and water use curtailment models that enabled evaluation of how a changing water supply might impact future reservoir storage and releases, irrigation application amounts, crop yields, and how frequently some groups of water users might see their water use interrupted. The 2016 Forecast did not model all dams in the Columbia River Basin, as there are more than 400 dams (both storage and run-of-the-river) operated to meet a variety of purposes. Reservoir modeling captured operations of the major storage dams on the Columbia and Snake Rivers, and the five major reservoirs in the

Yakima Basin (Keechelus, Kachess, Cle Elum, Tieton and Bumping Lake). Dam management captured within ColSim included operations for power generation, flood control, instream flow targets, water storage, and stream flow regulation.

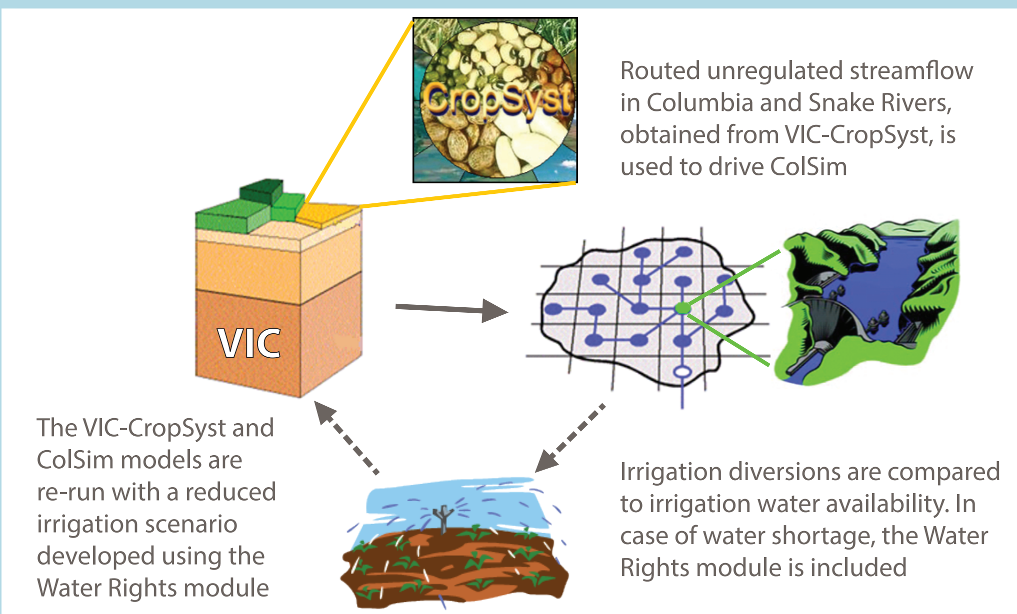
The modeling effort assumed that dam management would not change in the future. To better understand how changes in infrastructure and management could change the water supplies entering Washington State in the future, and to help interpret the modeling results, Washington State University (WSU), in collaboration with OCR, carried out a preliminary survey of basin water managers, to gain insights into water supply planning, project development, and water management (see the *Water Masters Survey* section, below).

## Biophysical Modeling

**VIC-CropSyst** simulates hydrologic cycle, soil water budgets, crop growth, crop yield to quantify the effects of each climate change scenario on regional streamflow and crop production.

**Key VIC-CropSyst inputs**: temperature, precipitation; wind speed; elevation; soil; land cover; irrigation extent and technology; crop distribution; crop phenology

**Key VIC-CropSyst outputs**: runoff; baseflow; routed unregulated streamflow; crop water requirement; crop yield




**ColSim** models reservoir operations on the mainstem Columbia and Snake Rivers.

**Key ColSim inputs:** routed streamflow in Columbia and Snake Rivers; key reservoir management decisions; irrigation diversion and other withdrawals

**Key ColSim outputs:** regulated streamflow; generated hydropower

**Water Rights module** accounts for the water shortage and creates a reduced irrigation scenario for VIC-CropSyst

**Key Water Rights module inputs**: difference between irrigation diversions and irrigation water availability; water rights information

**Key Water Rights Module outputs:** curtailment scenario

*Figure 1. Biophysical modeling framework for forecasting surface water supply and agricultural water demand across the Columbia River Basin.*

## Modeling Agricultural Water Demand

The integrated VIC-CropSyst model quantifies agricultural irrigation demand. Irrigation represents the largest out-of-stream water use in the Columbia River Basin and is a prominent driver of Washington's economy. The U.S. Geological Survey (USGS) estimated that agriculture represented 61% of out-of-stream water use statewide in 2005, considering municipal, domestic, irrigation, stock water, aquaculture, industrial, mining, and thermoelectric uses (Lane 2009). Within eastern Washington, irrigation represented 82% of all uses except thermoelectric (which could not be separated regionally due to limitations in data presentation). Agricultural water uses other than irrigation, including stock water, were not estimated for this Forecast. While stock water use is important within some watersheds, the magnitude of this use basin-wide is small relative to consumptive use for crops. In 2005, the U.S. Geological Survey estimated that within eastern Washington, stock water uses represented approximately 0.4% of out-of-stream water use, considering domestic, irrigation, stock water, aquaculture, industrial, and mining (Lane 2009). If stock water represents a significant proportion of water use in the future, it may merit additional attention in future forecasts.

To accurately simulate surface water supply and demand, the combined model needed accurate land use information for the entire Columbia River Basin, including upstream areas in other states and in British Columbia. The historical simulation (1981-2011) used recent crop mix information from the United States Department of Agriculture (USDA) for areas outside of Washington, and from the Washington State Department of Agriculture (WSDA) for areas inside the state (each of these datasets is described more fully in the *Methodology* section, below). The WSDA data were used in Washington because they provided slightly more precise data on the Washington crop mix when evaluated against the USDA data layer, and because they delineated irrigation extent. Irrigation extent outside of Washington was based on crop type, as the USDA data did not delineate this parameter. To capture the diversity of agriculture across Washington, nearly 40 groups of field and pasture crops, tree fruit, and other perennials were simulated. Because of the status of the Odessa groundwater area, all irrigated agriculture in this area that has been served by groundwater historically was assumed to need surface water by 2035 in order to grow irrigated crops.

## Estimating Municipal Water Demand

Municipal demand includes estimates of water delivered through municipal systems, as well as self-supplied sources. Municipal demand was only estimated within Washington State.

Municipal use represents a much smaller portion of water use than agriculture in the Columbia River Basin, but one that is important for supporting the continued prosperity of the region. The USGS estimated that domestic uses (including public and self-supplied) represents 11% of out-of-stream water use statewide in 2005, when considering domestic, agricultural irrigation, stock water, aquaculture, industrial, mining, and thermoelectric uses (Lane 2009). Within eastern Washington, domestic uses represent 13% of these uses except thermoelectric (which could not be separated regionally due to limitations in data presentation) (Lane 2009). For areas of the Columbia River Basin outside Washington State, WSU reviewed existing municipal projections. Within Washington, municipal demand, including self-supplied domestic use and municipally-supplied industrial use, was forecasted and then integrated into the modeling. This Washington focus led to increased uncertainty in watersheds that cross state boundaries and have sizeable population centers in neighboring states and provinces.

Municipal demands were incorporated into modeled water supply and agricultural water demand. This was done by withdrawing consumptive demand from the surface water system when water system plans or other evidence confirmed that municipal systems were supplied by surface water or by groundwater in close hydraulic continuity with surface water supplies.

## Estimating Hydropower Demand

The estimate of growth in water demand for hydropower generation in the Columbia River Basin was primarily based on the Northwest Power and Conservation Council's projections of growth in electricity demand by 2035, and assumptions regarding a preliminary estimate of the average flows needed to produce each MW of electricity in a sample of Washington State's existing hydropower facilities. The product of these two values provided a very preliminary estimate of the additional water that would need to flow through existing facilities to fulfill the growth in electricity demand.

### Reflecting Instream Flow Requirements

The waters of the Columbia River Basin support a variety of fish and other wildlife important to maintaining cultural, environmental, and recreational opportunities, including several Endangered Species Act (ESA)-listed threatened and endangered fish stocks. Wildlife and fish help support a vibrant tourism, recreation, and fishing industry in the Columbia River Basin, one that plays a vital role in maintaining the rural economy. While values specifically derived for eastern Washington were not available, recreational spending associated with fishing, hunting, and wildlife viewing was estimated to be $3.1 billion statewide in 2006, according to a study by the Washington Department of Fish and Wildlife (2007).

WSU's modeling integrated quantitative instream flow requirements in the Washington portion of the Columbia River Basin. Within watersheds, the highest adopted state and federal instream flows for each month were used to express current minimum flows for fish historically and in the 2035 forecast. State and federal instream flows along the mainstem were also compared to historical and future supplies.

### Model Outputs

The integrated hydrological, crop and water management models provided estimates of water supply and agricultural demand (Figure 2). Instream demands were not determined from model outputs, but were represented through the adopted state and federal instream flows, which were assumed to be the same in the historical (1981-2011) and future (2035) time periods. Historical and forecast municipal demands were included in the modeling framework by withdrawing the consumptive use portions from surface water availability. Demand of water to produce hydropower were also estimated separately.

The models were able to forecast a variety of potential impacts, including predicted surface water supply, total irrigation demand, unmet irrigation demand due to curtailment, and decreases in crop yield due to curtailment, and provide spatially specific results for each watershed.

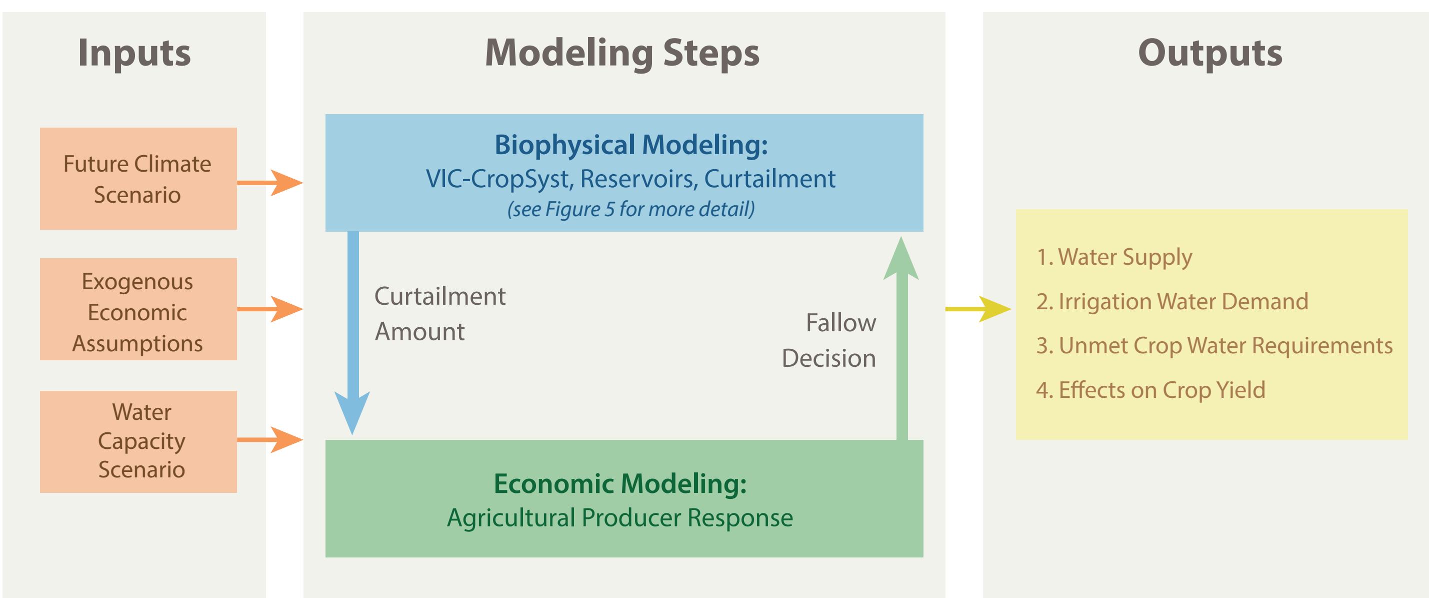



*Figure 2. Integration of biophysical modeling (surface water supply, crop dynamics and climate) with economic and policy (human decision-making) modeling.*

# Methodological Details

This section outlines in more detail the methodology used in this 2016 Forecast, and includes information on the extent of the study area, the data sources, a description of the various components of the model, as well as a description of the integrated modeling framework.

## *Study Area*

The Columbia River Basin is the fourth largest watershed in North America in terms of average annual flow, encompassing all or parts of Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming, and British Columbia (BC) (Figure 3). The basin drains approximately 258,000 square miles including nearly 40,000 square miles in British Columbia. For thousands of years, the 1250-mile long river has shaped the economy and lives of the indigenous people who lived near it. Over the past two hundred years, the basin has been developed extensively for hydropower generation, irrigation, navigation, and flood control. In fact, steamboats began operating on the river as early as 1836 and the first hydroelectric dam in the Pacific Northwest (PNW) was built on the Spokane River in 1885. The river is currently also managed for the protection of salmonid species listed under the Endangered Species Act, for municipal and industrial supplies, for the maintenance of water supplies in accordance with tribal treaties, and for recreation. This creates a myriad of competing demands for water.

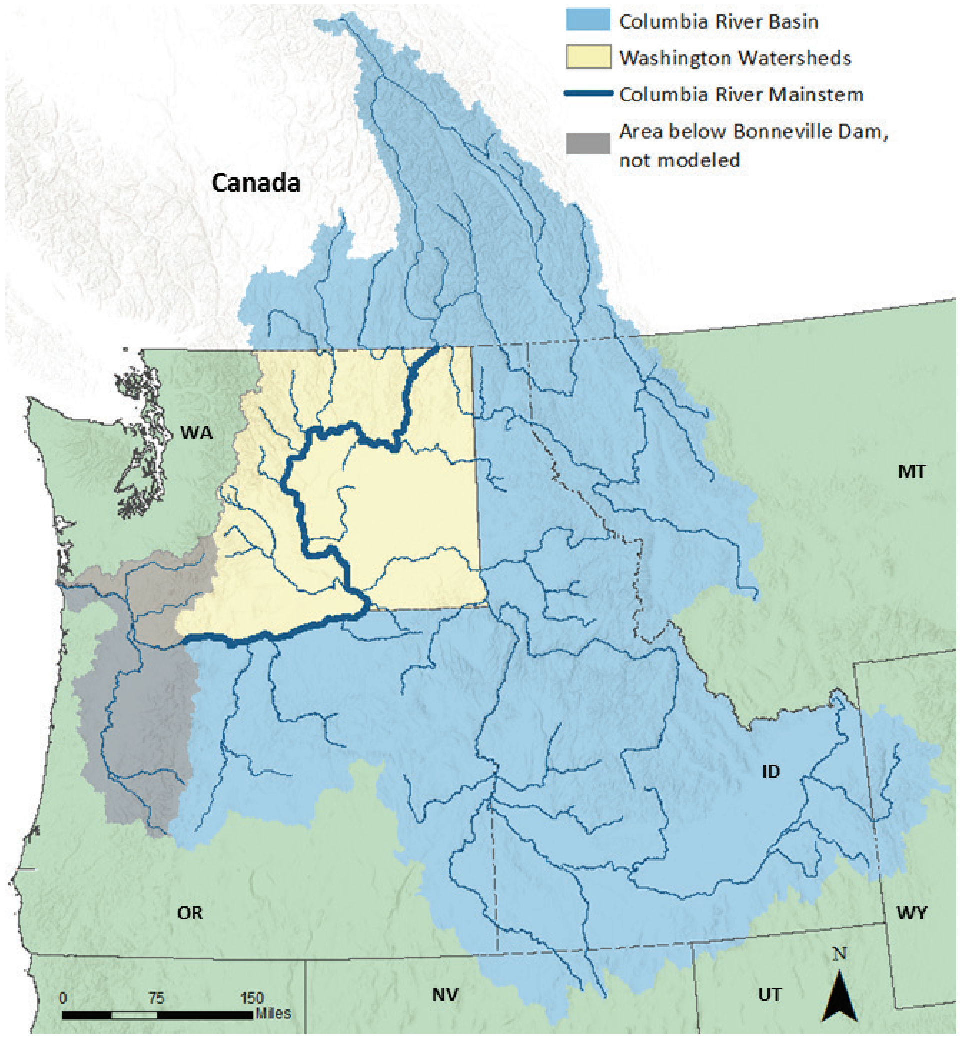



*Figure 3. Schematic of Columbia River Basin.*

Forecasting future water supply and demand in the Columbia River Basin is further complicated by the size and complexity of the river system, as well as the multiple jurisdictions through which it flows. Nevertheless, because reliable access to water is essential for existing and future regional economic growth and environmental and cultural enhancement, resource managers are tasked with conducting such forecasts. The urgency and importance of forecasting water supply and demand continues to grow, particularly as seasonal variations in water supply and demand have resulted in localized shortages with increasing regularity. Due to population growth, climate variability and change, and increased implementation of regulatory flow requirements, competing demands on the region's fresh water resources will likely increase in the future, particularly in summer months when demand is high. Water supply is also anticipated to decrease during these summer months of peak demand due to long-term shifts in temperature and precipitation, exacerbating summer unmet water demand.

## Data Sources for Integrated Modeling

### Climate Data

#### *Historical Climate Scenario*

VIC-CropSyst was run using a historical, gridded daily precipitation, temperature, and wind speed dataset developed by Abatzoglou and Brown (2012) to generate baseline simulations of historical (1981-2011) water supply and agricultural demand for each location.

#### *Future Climate Scenarios*

As input to VIC-CropSyst, climate projections from the Intergovernmental Panel on Climate Change's (IPCC's) Representative Concentration Pathways 4.5 (RCP4.5) and 8.5 (RCP8.5) were used, to forecast water supply and agricultural demand centering on the year 2035 (2020-2050). These climate inputs, generated from gridded outputs from seven different Global Circulation Models (GCM) participating in the Coupled Model Intercomparison Project Phase 5 (CMIP5), were downscaled using Multivariate Adapted Constructed Analogs (MACA) (Abatzoglou and Brown, 2012). Five scenarios from each of the IPCC's RCP4.5 RCP8.5 were selected from the available scenarios, so as to capture the entire spread of temperature and precipitation change projections for the area for the 2035s. This selection was made based on the spread of model

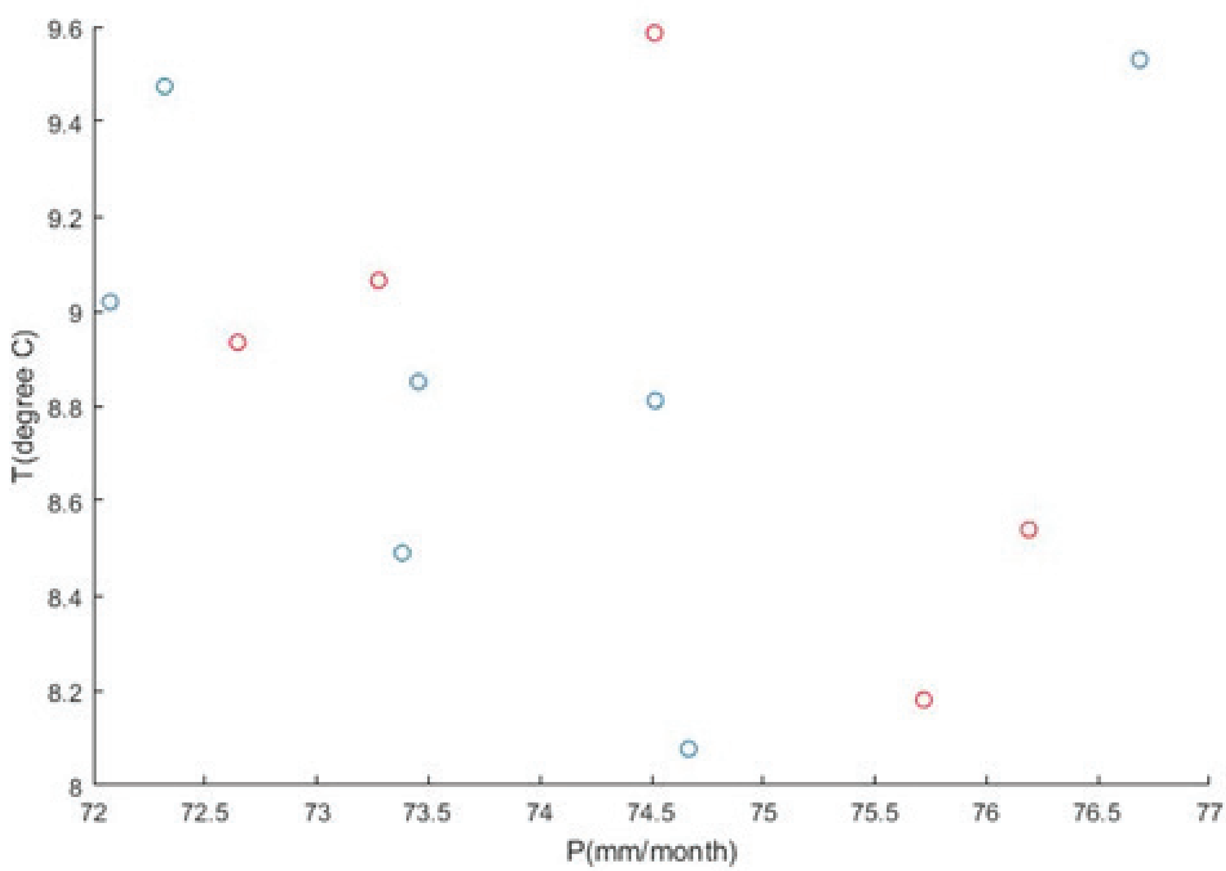



*Figure 4. RCP4.5 GCM projections considered for the Columbia River Basin, in precipitation and temperature space. Red circles represent the five scenarios selected for the 2016 Forecast.*

projections in precipitation and temperature space over the simulation period (Figures 4 and 5), along with their ranking based on streamflow sensitivity to precipitation and temperature for the Upper Columbia and the Yakima Basins.

The scenarios selected to represent RCP4.5 in the 2016 Forecast were GFDL-ESM2M, IPSL-CM5A-LR, GFDL-ESM2G, bcc-csm1-1, CanESM2; and for RCP8.5, GFDL-ESM2M, BNU-ESM, bcc-csm1-1-m, GFDL-ESM2G, CanESM2 were selected.

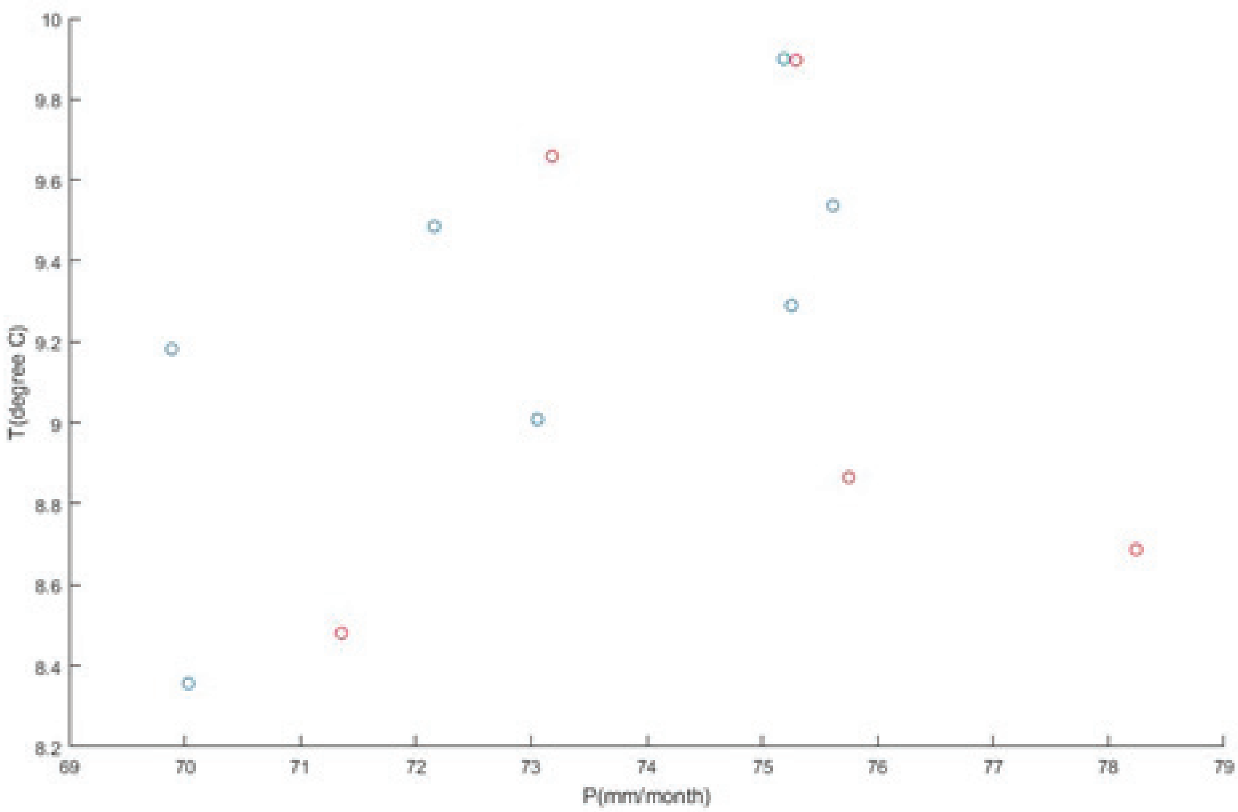



*Figure 5. RCP8.5 GCM projections considered for the Columbia River Basin, in precipitation and temperature space. Red circles represent the five scenarios selected for the 2016 Forecast.*

## Land Cover Data

Land cover and how it is incorporated into the models are important drivers of estimates of evapotranspiration, interception, infiltration and the runoff components of the hydrologic cycle. Elsner et al. (2010) used a land cover classification derived from Maurer et al. (2002) to run the Variable Infiltration Capacity (VIC) model (which is described in detail below) over the Pacific Northwest (Table 1). This dataset was based on the University of Maryland's global vegetation classification dataset (Hansen et al. 2000) and is described in Maurer et al. (2002). For each of the 1/16th degree grid cells, proportions of each of those vegetation classes (Table 1) within the grid cell were provided. When the proportions did not add up to one, the remaining fraction was treated within VIC as bare soil.

The original land use classification used by VIC, before it was coupled with CropSyst, had only one cropland class, and all crop parameters used were representative of a corn crop, leading to severe limitations in accurately reflecting irrigation water demand across the diversity of crops in the Columbia River Basin. To incorporate different crops into the modeling framework (described in more detail below), the VIC land use data was extended to include a full range of crop types (Table 2). This extension led to the landcover parameter sets provide information for 119 land cover and crop types altogether.

Two data layers were used to provide detailed data on current crops across the Columbia River Basin, as inputs to VIC-CropSyst:

- the United States Department of Agriculture (USDA, 2013), and
- the Washington State Department of Agriculture (WSDA, 2013).

These two GIS (Geographic Information System) crop layers provide the proportion of each crops in each VIC grid cell. Only the crops that occurred within at least 1% area of the total area of the grid cell were considered in the input file. The cropland data layer from the WSDA is the primary source of crop distribution information within Washington State, as it is more detailed than the USDA dataset. It is based on field surveys carried out by WSDA mapping specialists to inventory acreage across the state in crop production. WSDA's dataset also provides information on the irrigation method used, crop rotation (if used), and the dates of survey. The information on irrigation methods was used in the land cover characterization to identify whether or not the crop was irrigated. The USDA dataset provides crop distribution outside of Washington State. This satellite-based, high-resolution (30 m) crop data layer information is redistributed to the 1/16th degree scale. This dataset, however, does not have information on irrigation methods. The team used simple rules to identify irrigated crops outside of Washington State. High value crops such as corn, fruit crops, and potato were always considered irrigated, and other crops were never considered irrigated. The irrigation methods were assigned based on the dominant type of irrigation for that crop within the WSDA dataset. For example, if "sprinkler" was the dominant irrigation type for potato in Washington, potato was always considered irrigated by sprinkler method outside of Washington. Elsner et al.'s (2002) classification was used, unchanged, in the Canadian part of the Columbia River Basin, since detailed crop information from that region was not available.

*Table 1. Vegetation classes used in the original VIC implementation.*

| Class number | Vegetation Class |
|---|---|
| 1 | Evergreen Needleleaf |
| 2 | Evergreen Broadleaf |
| 3 | Deciduous Needleleaf |
| 4 | Deciduous Broadleaf |
| 5 | Mixed Cover |
| 6 | Woodland |
| 7 | Wooded Grasslands |
| 8 | Closed Shrublands |
| 9 | Open |
| 10 | Grasslands Shrublands |
| 11 | Cropland (corn) |

### *CropSyst Parameters for Crops*

CropSyst crop parameters describe the crop's phenology, canopy growth, transpiration, biomass production, and yield. These parameters are crop-specific, and for a basic set crops, are based on established values previously used in model applications in the region, as well as elsewhere in the world, over the last 15 years. Parameters for most other crops were estimated by approximation to this basic set. Biomass production and yield information for some crops that have small production acreage were not readily available. For those crops, the primary parameterization emphasis was on canopy cover and water use, by approximation to crops in the basic set; thus, yield outputs for these crops should not be considered definitive.

*Table 2. Field, pasture, tree fruit, and other perennial crops simulated in the model.*

| Field Crops | | Vegetables and Fruits | Pasture Crops | Tree Fruit and Other Perennial Crops | Other Perennial Crops |
|---|---|---|---|---|---|
| Winter Wheat | Millet | Sweet Corn | Alfalfa | Apple | Silviculture |
| Spring Wheat | Sorghum | Green Peas | Pasture | Cherry | Christmas Trees |
| Durum Wheat | Soybeans | Mint | Pasture Grass | Pear | Poplar |
| Barley | Spelt | Onions | Grass Hay | Peach or Nectarine | Daffodil |
| Potato | Canola | Asparagus | Bluegrass Hay | Plum | Tulip |
| Corn | Chickpea | Carrots | Timothy | Apricots | Sod Grass |
| Lentils | Mustard | Squash | Rye Grass | Hops | Green Manure |
| Dry Peas | Camelina | Garlic | Clover Hay | Grapes | Yellow Mustard |
| Sugar Beet | Safflower | Spinach | Vetch | Grape – Juice | Clover, Wildflowers |
| Canola | Beet Seed | Green Beans | Barley Hay | Grape – Wine | Sudangrass |
| Oats | Corn Seed | Herbs | Alfalfa Seed | Caneberry | Nursery Silviculture |
| Rye | Pea Seed | Turnips | Bluegrass Seed | Blueberry | Nursery Orchard, Vineyard |
| Dry Beans | Flax Seed | Watermelon | Ryegrass Seed | Cranberry | Nursery Ornamental |
| Buckwheat | Sugar Beet Seed | Green Beans | Fescue Seed | Strawberries | Walnuts |
| Triticale | Sunflower Seed | Broccoli | Grass Seed | Other Orchards | Conifer Seed |
| Sunflower | Rape Seed | Cabbage | Other Hays | | |
| Other Small Grains | | Cauliflower | | | |
| | | Cucumber | | | |
| | | Lettuce | | | |
| | | Peas | | | |
| | | Peppers | | | |
| | | Potatoes | | | |
| | | Pumpkin | | | |
| | | Radish | | | |
| | | Greens | | | |
| | | Dill | | | |
| | | Carrot Seed | | | |
| | | Spinach Seed | | | |

## Soils Data

In the conventional VIC setup a vertical distribution of three soil layers is usually used. In this version of VIC-CropSyst, a 17-layer system was introduced, by expanding the middle layer into 15 layers (Malek et al., in review). This increased layering helps the dynamic simulation of root growth by distributing the soil moisture across the rooting zone more accurately.

The STATSGO2 soil database is the primary source of data on soil classification, distribution and hydrological properties. Surveyed soil layers from STATSGO2 are redistributed into 1/16th degree resolution and 17 layers, providing data in the format required for VIC-CropSyst runs. Soil data for the Canadian portion of the Columbia River Basin was obtained from the 1/16th degree soil dataset developed by Elsner et al. (2010). This dataset is based on Maurer et al. (2002) which in turn is based on gridded datasets developed as part of the Land Data Assimilation System (LDAS; Mitchell et al. 1999) project. Empirical functions developed by Saxton et al. (1986) were implemented in VIC-CropSyst to estimate some soil parameters such as soil hydraulic conductivity, field capacity, wilting point, and bulk density, based on their relationships with soil texture (percent sand and clay).

## Water Management Data

### *Water Rights*

The Washington Department of Ecology's water rights (WRTS) database was used to obtain water rights information in Washington State. The database has information related to the water rights' priority date, purpose of use, appropriated water amount, point of withdrawal or diversion, and the place of use of the water right. This information was used primarily to model the curtailment process of water rights. Curtailment or interruption of certain water rights happens when there is insufficient water to meet all demands, including instream flow demands. The Department of Ecology provided a list of interruptible water rights along the Columbia River mainstem, the Snake River, three Water Resources Inventory Areas (WRIAs) in the central Washington region (Methow, Okanogan, and Wenatchee) and three WRIAs in the eastern Washington region (Walla Walla, Little Spokane, and Colville). This list was used, in conjunction with the water rights database, to locate the grid cells where interruptible water rights occur. The interruptible water rights include both surface and groundwater rights. However, for this study, only curtailment of surface water rights was modeled.

In the Yakima River Basin, where reservoir operations were modeled using Yakima RiverWare, the water right information used was what the U.S. Bureau of Reclamation (USBR) originally incorporated into the Yakima RiverWare model. For each irrigation district, this information consisted of a time-series of paper water right and observed diversions for non-proratable (senior) and proratable (junior) water right holders.

### *Water Masters Survey*

Understanding when water rights get curtailed based on priority and local hydrologic conditions is important to accurately forecast water demand. It affects what crops people may grow, the marketability of water rights to other parties, the price people pay for water rights, and other factors.

As described above, the Department of Ecology (Ecology) provided data on interruptible rights that are curtailed in response to adopted instream flows, which were used in both the 2011 and the 2016 Forecasts. Because these curtailment levels can be correlated to actual river flows, WSU was able to integrate the effects of these curtailments into the model. However, in some tributaries, water rights are also curtailed in response to calls from senior water right holders (e.g. the Yakima, Walla Walla, Okanogan River Basins, and others).

Right-by-right curtailment information for these occurrences does not readily exist in Ecology's database.

In the 2016 Forecast, WSU prepared a survey for Ecology water masters, to better understand this missing data set. Without this information, the model assumes 100% reliability for these water rights, which can overstate demand and economics of those water rights. Ecology water masters responded with information on the surveys (see *Appendix A – Water Masters Surveys*). However, the information was largely qualitative and not readily assimilated into the model, primarily because of competing work priorities during the 2015 drought.

WSU proposes that, in future updates of Ecology's WRTS database, a new Assignment Group be created that mimics the searchable feature that works well for junior water rights subject to instream flow curtailment. When a water master notes curtailment events, this information could be added to those water rights so WSU and Ecology could begin integrating these data directly into the model. Over time, this will bring into better focus the reliability and transferability of junior water rights.

Given that the WRTS database has just gone through a lengthy update, this recommendation may not occur in time to provide rigorous data for the 2021 Forecast. In the interim, therefore, WSU proposes that Ecology build a simple spreadsheet to track water right curtailment, to provide quantitative data to inform curtailment modeling in the 2021 Forecast.

### *Instream Flow Rules*

Instream flow rules at different locations in Washington State were used to determine whether or not there is a need to curtail interruptible water right holders. Interruptible water rights are those that can be curtailed in low flow years, if there is insufficient flow to fulfill instream flow requirements. The instream flow targets, on which curtailment decisions are made, may be based on Washington Administrative Codes (WAC) or low flow provisions inserted into individual water rights, called Surface Water Source Limitations (SWSL). Because it was not feasible to read low flow provisions related to SWSLs from each individual water right, the assumption was made that these provisions correspond with WAC rules.

In the WRIAs belonging to the Yakima River Basin (WRIAs 37, 38, and 39), interruption of water rights is based on a different mechanism. Instead of the binary "water on/water off" process in other areas, the Yakima follows a system of prorationing of interruptible water right holders. Prorationing is based on the calculation of the Total Water Supply Available (TWSA) every year. This includes streamflow, usable return flows, and reservoir storage. The level of proration is determined by matching the TWSA against demand, as detailed in Hubble (2012).

### *Reservoir Operations*

The reservoir operation rules for the Columbia River mainstem are exactly as used by Hamlet and Lettenmaier (1999). In the Yakima River Basin, reservoirs are operated according to the rules described in USBR's interim comprehensive basin operation plan (USBR 2002).

### *Naturalized Flows*

The integrated model requires data on "naturalized" or "reconstructed" stream flows to calibrate and correct for bias in estimates of simulated stream flow. The effects of human intervention have been removed from observed flows in those "naturalized" or "reconstructed" stream flows. This information was primarily collected from the Bonneville Power Administration's modified streamflow dataset (BPA, 2010). For the stations where "naturalized" stream flow data were unavailable from this source, "naturalized" flow provided from the University of Washington's Climate Impacts Group (UW CIG) (Elsner et al., 2010) were used. For locations where data was not available from any of these sources, it was not possible to perform bias correction on simulated stream flow outputs.

### *Diversions*

Irrigation diversion data for 2008, 2009, and 2010 for Banks Lake, which supplies water to the Columbia Basin Project irrigation area in central Washington, were provided by the Washington Department of Ecology. These data were used as a benchmark, to verify the VIC-CropSyst simulated irrigated demand, and to estimate channel conveyance losses.

## Municipal Use Information

### *Municipal Population Estimates*

Municipal water demand estimates were based on estimates of population and per capita water use. Census block population data were obtained from the Washington State Office of Financial Management (www.ofm.wa.gov/pop/gma). The population data were then used to estimate the number of individuals, by county, living in a particular WRIA. WRIA population was then forecast for 2035 by using an S-curve method.

### *Per Capita Water Usage, Wastewater Return, and Consumptive Use*

Public water supply, expressed in terms of gallons per capita per day (gpcd), was obtained from the USGS estimated water supply for Washington State counties in 2010 (Lane and Welch, 2015). These per capita public supply data were then multiplied by the population of each county present in a particular WRIA, and added across counties in a WRIA to obtain a total public supply value for each WRIA in 2010. This 2010 estimate of public water supply was then multiplied by the projected WRIA population estimated for 2015 and 2035, to get total public water supply estimates for the historical (2015) and forecast (2035) time periods, respectively. Growth in rural demand was considered likely to be met by groundwater supplies, but domestic wells were assumed to be shallow enough to impact surface water flows.

Wastewater returns by county were obtained from USGS reports (millions of gallons per day; http://wa.water.usgs.gov/data/wuse/). These data were only available for the years 1985, 1990, and 1995. Per capita wastewater returns were estimated by county as the mean wastewater returns of years 1985 and 1995, divided by the population present in a WRIA. Then the total wastewater returns for a WRIA for 2015 and 2035 was obtained using the population growth estimates, and following the procedure applied to public water supply, described above.

Consumptive use was estimated as the difference between public water supply use and wastewater returns in each WRIA.

### *Integration of Municipal Demand with VIC-CropSyst Modeling*

Municipal demand estimates were incorporated into modeling of water supply and agricultural water demand by withdrawing consumptive demand from the surface water system when water system plans or other evidence confirmed that municipal systems were supplied by surface water, or by groundwater in close hydraulic continuity with surface water supplies. Growth in rural demand was considered likely to be met by groundwater supplies, but it was assumed that domestic wells would be shallow enough to impact surface water flows. Because municipal systems account for only about 10% of consumptive water use in the Columbia River Basin (Lane 2009), no economic scenarios were developed to explore the impacts on municipal demand of variations in economic growth and trade.

## Hydropower Demand Information

As described in the 2016 Legislative Report, estimates of current and forecast instream demand for hydropower generation were not modeled in the 2016 Forecast. Instead, the team made preliminary estimates based on the projections of future energy needs obtained from the hydropower producers themselves.

The Northwest Power and Conservation Council (NWPCC) collects data on energy produced by the major hydroelectric dams in the Columbia River Basin, and other power entities regularly carry out extensive forecasting of electricity demand and power-generating capacity. For this Forecast, researchers reviewed available reports, including those carried out by the Bonneville Power Administration (BPA), Northwest Power and Conservation Council (NWPCC), Avista, Idaho Power, Portland General Electric (PGE), Grant County Public Utility District (PUD), Chelan County PUD, and Douglas County PUD. British Columbia (BC) Hydro documentation was also reviewed, though long-term planning documents were general in nature. In addition, newspaper articles and websites were examined for relevant content. Attempts were made to ensure the most recent information was included, and reviews were supported with conversations with staff at public utility districts in Washington State and Avista Utilities. A detailed description of the findings of this review can be found in *Appendix B – Hydropower in the 2016 Long-Term Water Supply and Demand Forecast*.

The Northwest Power and Conservation Council forecasts of growth in regional electricity demand were used to project future hydropower demand in the Columbia River Basin. A preliminary effort was made to translate the increased regional demand for electricity into flows needed to generate said electricity using hydropower. Net power generation and water right data for Grand Coulee, Rocky Reach, Rock Island, and Lake Chelan were averaged to develop an approximate power-to-water conversion factor of approximately 16 ac-ft/MW. Applying this conversion factor to the 2,200 to 4,800 MW that electricity demand is expected to grow by 2035 led to estimated increases in hydropower water demand of approximately 35,000 to 75,000 ac-ft. Because this projection is based on existing dams as opposed to new projects, and because these average numbers do not account for peak power needs, actual demand may be higher. Alternatively, if this demand is met via conservation, efficiency improvements, or non-hydro sources, the demand projections could be lower.

## Economic Forecasting

The mix of crops grown on irrigated farmland in Washington State is constantly changing. Crops vary in how much water they require and what time of the irrigation season they need it. Also, the value of water associated with each crop is different, which affects economic estimates of the cost of drought. Changes in crop mix can therefore have important implications for forecasting future water supply and demand.

In an effort to provide a more realistic projection of future crop water demand, a forecast of future cropping patterns was constructed using statistical models. The same general procedure was used as that described in the 2011 Forecast (Yorgey et al. 2011). All of the statistical models rely on historical crop acreage data provided by the USDA for Washington State. The statistical models analyze these data to identify trends in production for each crop, and the relationships between production for each crop (i.e. if one crop predictably tends to decrease as another increases, or if multiple crops tend to increase or decrease together). The result is a set of estimated parameters that characterize these relationships. These parameter estimates can then be used to extend those trends into the future, to make projections about future crop mix (in 2035).

Alternative modeling approaches could be used to produce such crop mix forecasts. Changes in cropping patterns are an outcome of changes in the underlying demand and supply for agricultural commodities in the local, regional, and global marketplace. Therefore, an alternative approach would be to build a mathematical model of the global agricultural system where one could alter the equations describing supply and demand. For example, increasing income levels or increases in the total population would lead to increased demand, causing an upward pressure on prices, and therefore an increase in the quantity supplied. Alternatively, climate change that negatively affects the productive potential of agriculture would reduce supply and increase the price. In the canonical economic model showing supply and demand curves, this would be represented by a leftwards shift in the supply curve.

The type of model that can directly simulate changes in these underlying factors is referred to as a computable general equilibrium (CGE) model. While a CGE model provides a great deal of flexibility to simulate a range of events, the approach has a number of drawbacks. First, they are very time-consuming to build and require a large number of assumptions. Second, previous research has shown that simpler time-series econometric models—that focus on the outcome of interest—produce more accurate predictions (Stock and Watson, 2001). If the task has been to understand the impact of a large event that has not occurred in recent history, then something akin to a CGE would be necessary. However, the goal of the economic forecasting in the 2016 Forecast was to produce a "best guess" at a future crop mix, with the underlying assumption that recent trends would continue into the future.

The primary model used in the 2016 Forecast to project the mix of the major crop categories in the Columbia River Basin was a vector autoregression (VAR) model. The VAR is a subcategory of time-series econometric models that consists of a system of regression equations where there is an equation for each crop group. The dependent variable is acreage allocated to a specific crop group in period t as a function of acreage in that crop and other crop groups in previous years. The sample used in the model to estimate the acreage uses data from 1990 to 2014. VAR is more efficient than estimating equation by equation because it accounts for correlation across the residuals. Intuitively, there is a fixed amount of irrigated land in Washington, so one should expect correlation across crops because increasing acreage in one crop necessitates a reduction in at least one other crop, everything else being equal.

Given limited sample sizes it is only possible to estimate a VAR model for a relatively small number of crops. This is an obstacle given the large number of crop types grown on irrigated land in Washington State. Therefore, for some of the specialty crops that constitute a relatively small amount of all the irrigated land in Washington a single equation time-series econometric model, referred to as an ARIMA model, was estimated. The most important crop of this type was, by far, blueberries. Blueberry acreage has gone from nearly zero to about 10,000 acres in eastern Washington in less than a decade, with no slow-down in sight. This is still a very small amount relative to other major crops, similar to wine grapes 20 years ago. However, continued growth will make blueberries an important crop in some locations. Other fruit and vegetable specialty crops, including various types of berries, constitute even less acreage and show much less significant growth, if any at all.

Special considerations were required for a few crops. First, for hay crops, the USDA only provides a full, annual time series of data for acres harvested (as opposed to acres planted). An assumption on the number of cuttings per year was therefore necessary in order to convert this number to planted acres. Second, the USDA data on irrigated wheat acreage for Washington ended in 2009. Given its importance in terms of total acreage, a statistical model was developed to estimate irrigated wheat acreage values from 2010 to 2014.

## Some Highlights in Crop Mix Trends

A brief overview of Historical data from USDA on crop acreage shares for major crop categories in Washington is shown below. One important highlight of trends in crop acreage shares (the percent of the total irrigated acreage planted to each crop) in Washington State is that, while some crops have increased significantly on a percentage basis, hay crops, cereal grains, and tree fruit accounted for most of the irrigated crop acreage throughout the period of historical USDA data used (Figure 6).

The historical data can also be expressed in terms of total irrigated acreage, which can also include the acreage results forecast using the VAR models (Figure 7; note that in this case the crop categories are different in that apples and cherries are used, instead of a combined "orchard" crop as in Figure 6). There are a few key findings worth highlighting:

- First, apples and cherries are expected to remain fairly constant, reflecting recent trends.

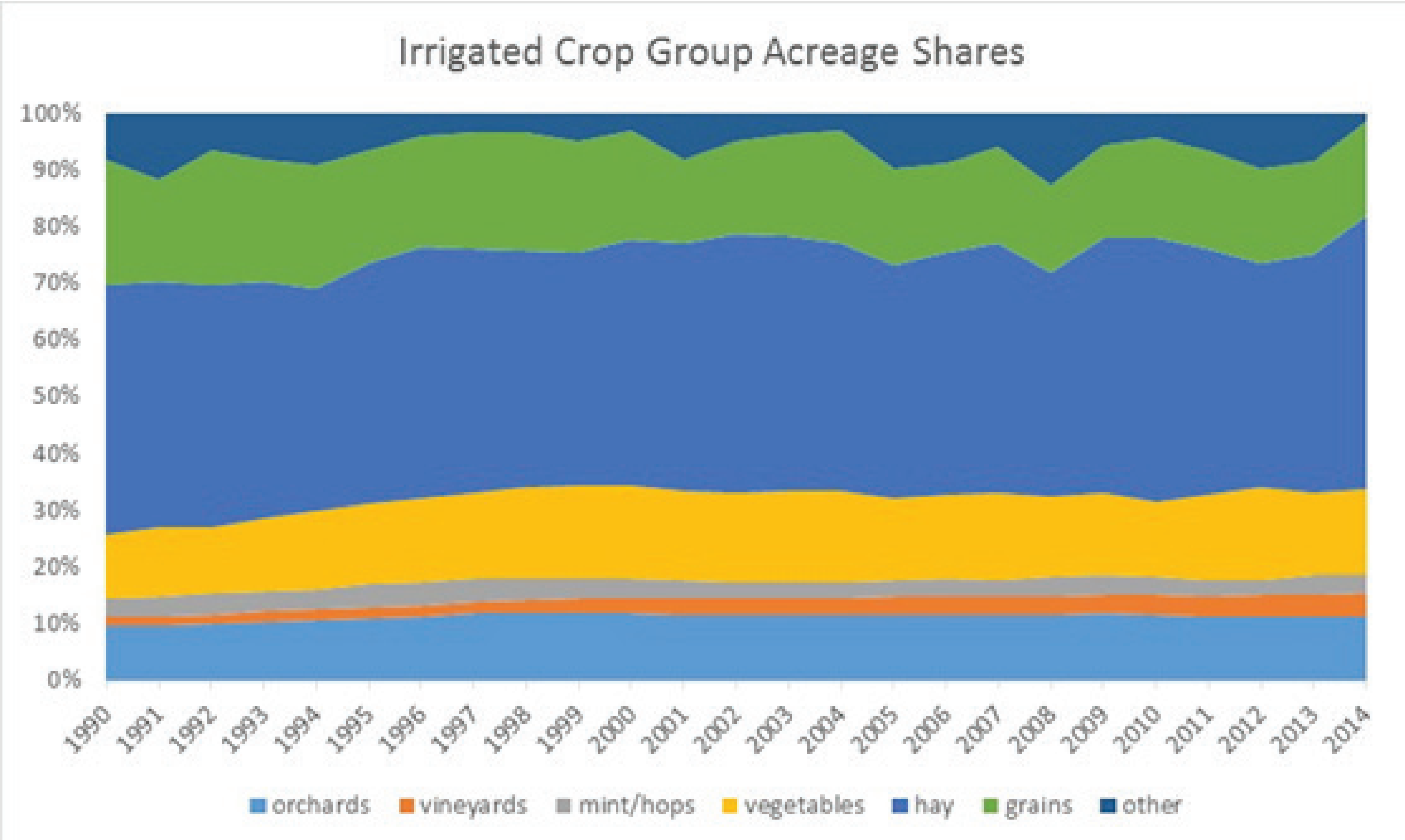



*Figure 6. Percent of total irrigated acreage in Washington State planted to different crops historically (1990-2014). Data source is the USDA's crop database, aggregated to the state level.*

- Second, vineyard acreage is projected to expand significantly on a percentage basis. This is potentially the most important result in terms of water use because vineyards often use much less water than other crops and are highly concentrated in specific locations.
- Third, the interannual variability in hay and grain crops is very large, and expected to continue to be so. This makes results very sensitive to what year of the forecast is selected.
- Fourth, the total amount of acreage across all the crops in the historical period is fairly close to constant. However, in the forecast the total amount of acreage projected to increase. The growth in acreage for vegetables, grains, and hay were clearly not offset by commensurate reductions in other crops.

This last highlight has important implications for integrating the projected crop mix into the biophysical modeling in the 2016 Forecast. The statistical model parameters in the econometric model do not provide a hard cap on acreage, even though the model tries to capture crops that tend to move in opposite directions. However, the biophysical modeling of water supply and demand has as a framing principle "Irrigation demands were modeled assuming that the land base for irrigated agriculture remained constant between the historical snapshot (1981-2011) and the future timeframe (2035), based on the understanding that increasing the irrigated acreage in the region is dependent on additional water development" (Hall et al. 2016). Therefore, an integration step between the economics and the biophysical models was required, to normalize total acreage

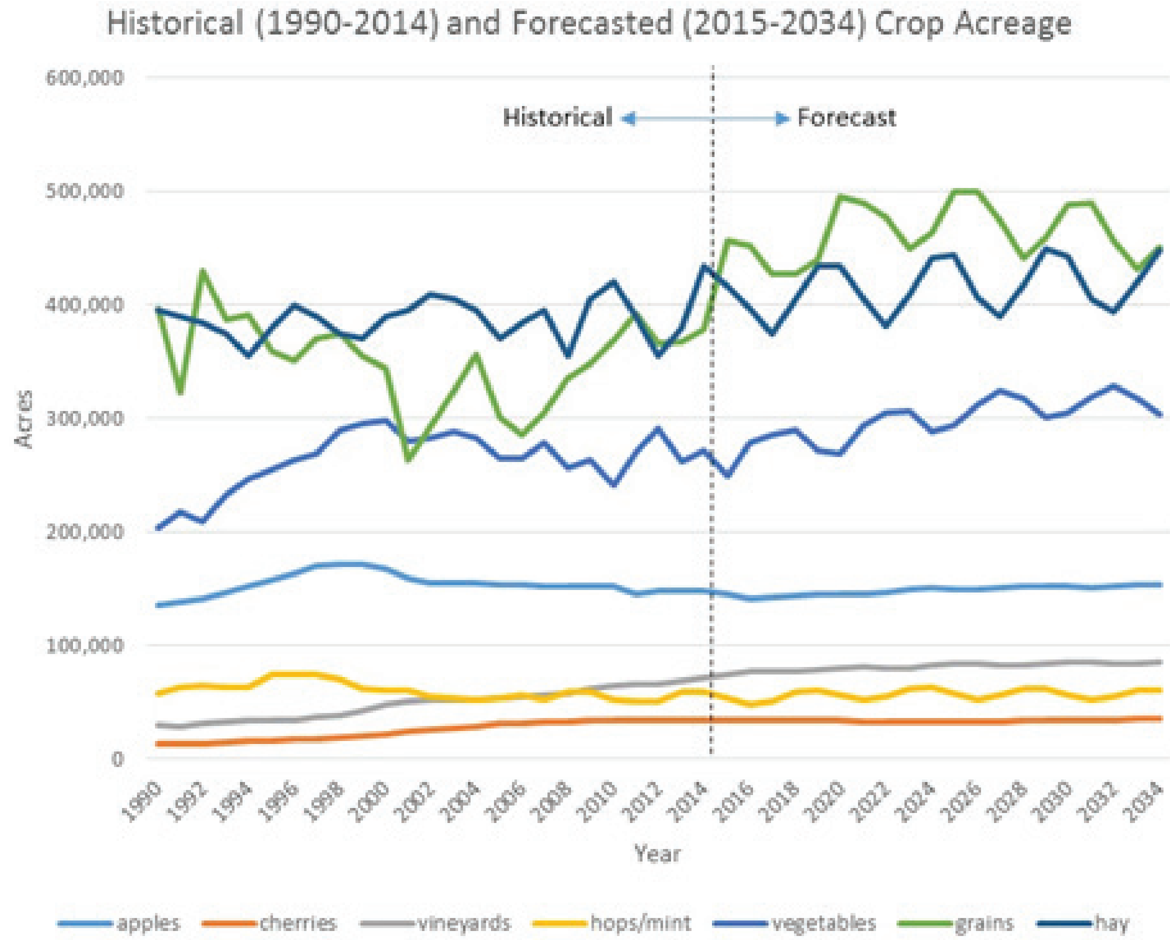



*Figure 7. Total irrigated crop acreage under different crop types in Washington State. Data source for the historical time period (1990-2014) is the USDA's crop database, aggregated to the state level. Forecast acreages (2015-2034) were projected using time-series econometric models.*

in the forecast period (2035) to the historical limit that is based on existing water rights (see the *Integration of Biophysical and Economic Modeling* section, below).

## Integrated Modeling Framework

The model used in the 2016 Forecast integrates and builds upon three existing models—VIC, CropSyst, and ColSim—that have been used independently in various studies to simulate conditions in the Columbia River Basin. What distinguishes the Forecast's integrated model from those independent studies is that VIC and CropSyst exchange hydrological and crop production information. The framework includes a biophysical modeling component and an economics modeling component (Figure 9). The biophysical modeling framework includes a hydrology model (VIC), a crop growth model (CropSyst), a physical system of reservoirs and dams (ColSim), and rule-based curtailment and prorationing modeling, all of which interact with each other as described in the following sections. The biophysical models also interact with the economic models for agricultural producer response.

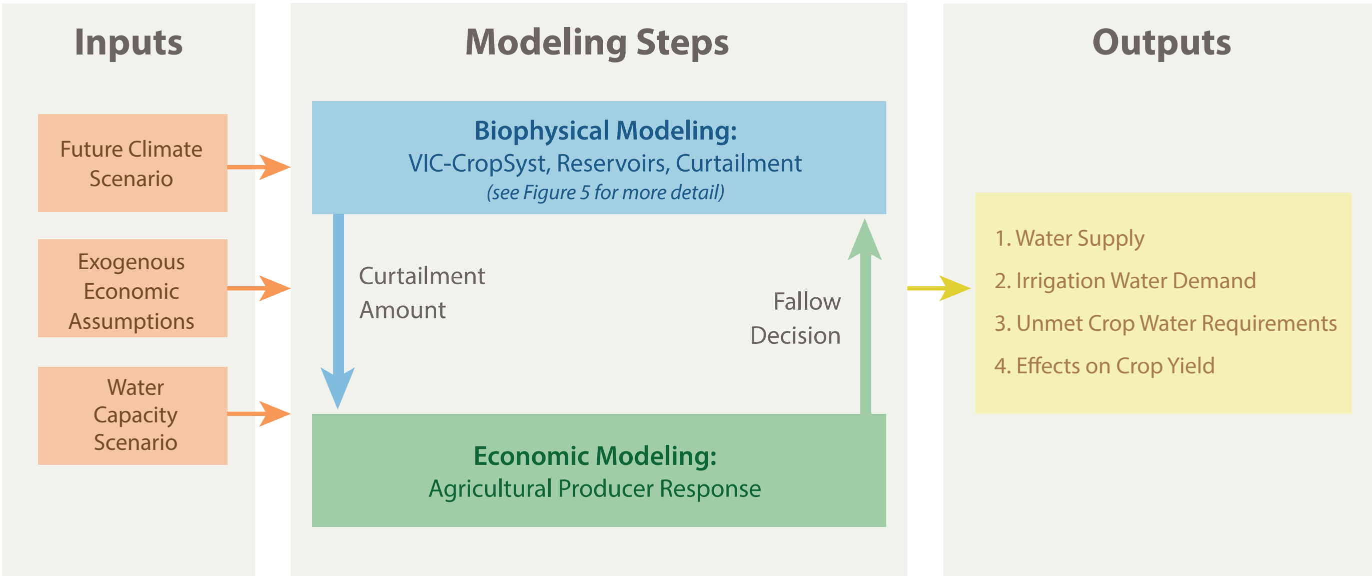



*Figure 8. Integration of biophysical modeling (surface water supply, crop dynamics and climate) with economic and policy (human decision-making) modeling.*

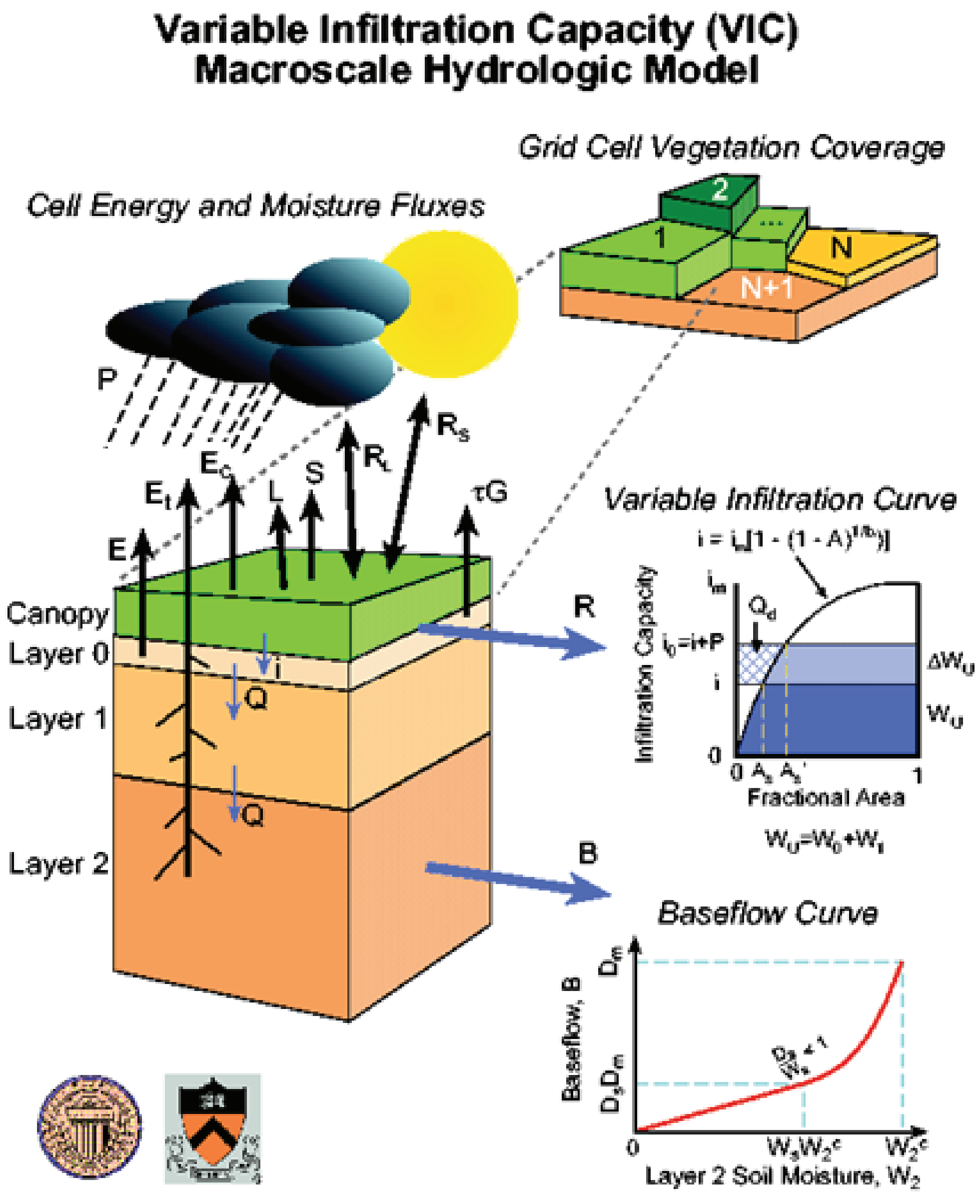



*Figure 9. Schematic of the VIC model.*

## Descriptions of the Biophysical Modeling Components

### *Hydrologic Model: VIC*

The Variable Infiltration Capacity (VIC; Liang et al., 1994, 1996; Gao et al. 2010) model is used to simulate land surface hydrology in the biophysical framework. It uses physically based mathematical formulations to solve energy and water balance equations at every time step (24 hours for the 2016 Forecast) and for every grid cell (1/16th degree). The VIC model uses meteorological forcing data (daily minimum and maximum temperature, precipitation and wind speed), soil, terrain, and land cover inputs to compute energy (e.g., latent and sensible heat) and water balance (e.g., surface runoff, infiltration and baseflow) components (Figure 9). The VIC model is run at a grid cell scale and uses the time-before-space conceptualization; i.e., the entire period of simulation is executed for a grid cell before moving to the neighboring grid cell. VIC simulates infiltration and surface runoff using the variable infiltration capacity curve proposed by Ren-Jun (1992). The VIC model saves the time series of runoff and baseflow generated at each grid cell. A separate routing model (Lohmann et al., 1998) then performs the streamflow routing as an off-line process after all of the grid cells in the basin are executed by VIC.

The VIC model has been widely used for basins across North America (Christensen et al., 2004; Vanrheenen et al., 2004; Hayhoe et al., 2007; Maurer, 2007; Huang et al., 2016). More specifically, VIC has been implemented to assess the climate change impacts over the Columbia River Basin (Hamlet and Lettenmaier, 1999; Payne et al., 2004; Elsner et al., 2010) for different Intergovernmental Panel on Climate Change (IPCC) future climate scenarios (1995, 2001 and 2007).

### *Cropping Systems Model: CropSyst*

The CropSyst model (Stöckle et al. 1994; Stöckle et al. 2003) is used in the 2016 Forecast to simulate crop growth. CropSyst is a cropping systems model based on mechanistic principles, allowing for applications to a large number of crops in any location worldwide. CropSyst is a multi-year, multi-crop model developed to serve as an analytical tool to study the effects of climate, soils, and management on cropping systems' productivity, nutrient cycling, and impacts on the environment. Management options within the model include crop rotation, cultivar selection, irrigation, nitrogen fertilization, tillage operations, and residue management. Depending on the process, CropSyst calculations are made at hourly or daily time steps. For the 2016 Forecast, a simplified version of CropSyst-v4 was used, that focuses on water use and productivity. This simplified version was extracted from the full version, and coupled with the VIC model (version 4.1.2-e). The coupled model was run at a daily time-step.

CropSyst has been evaluated and used in the Pacific Northwest (e.g., Pannkuk et al. 1998; Peralta and Stöckle 2002; Stöckle and Jara 1998; Kemanian 2003; Kemanian et al., 2007) and in many other locations worldwide (e.g., Stöckle et al. 2003; Sadras 2004; Benli et al. 2007; Todorovic et al., 2009; Marsal and Stöckle 2012). In addition to its capabilities for evaluating cropping systems, carbon sequestration dynamics, and greenhouse gas (GHG) emissions (e.g., Badini et al. 2007; Stockle et al. 2010; Kemanian and Stöckle 2010), CropSyst was recently enhanced to assess the effects of climate change on agricultural systems, particularly regarding plant responses to increasing warming and atmospheric carbon dioxide (Moriondo et al. 2011; Knox et al. 2012). These capabilities were utilized to assess the impacts of climate change on agriculture in eastern Washington (Stöckle et al., 2010b), and to assess the potential for carbon sequestration and carbon credits in the same region (Stöckle et al. 2010a; Zaher et al. 2013).

### *Reservoir Model: ColSim*

We use the Columbia Simulation Reservoir Model (ColSim) (Hamlet et al. 1999) to model the reservoir operations on the Columbia and Snake Rivers. ColSim is a system dynamics model that represents the key physical characteristics of the Columbia River water resources system and models the main storage reservoirs and run-of-the-river reservoirs on the mainstem Columbia River. It also includes the Snake, the Kootenai, the Clark Fork, and the Pend Oreille tributaries (Figure 10). Other smaller tributaries, such as the Yakima River, are not included in ColSim. Due to the regional importance of the Yakima River Basin, however, a separate reservoir framework, Yakima RiverWare, was used in the 2016 Forecast for the Yakima River (see the next section).

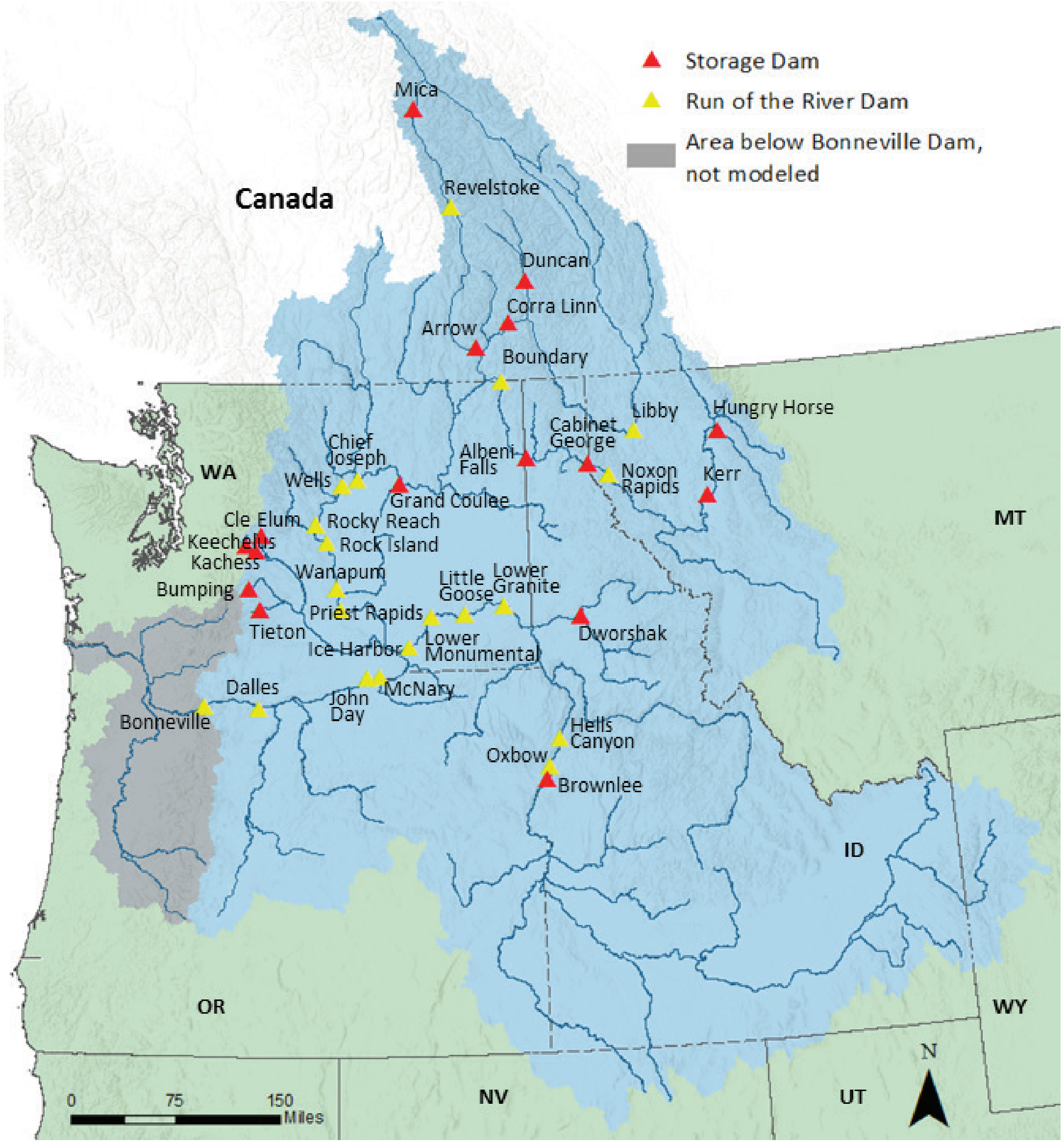



*Figure 10. Dams in the Columbia River Basin that are included in the ColSim Model (Rushi et al. 2016, in preparation).*

The ColSim model has been applied in numerous climate change studies (e.g., Hamlet et al. 2010, 2013; Adam et al. 2015). The model runs at a monthly time step and uses routed VIC-simulated streamflow—aggregated from a daily to monthly time-step—as its input. These streamflow inputs have been bias-corrected against naturalized streamflow data products prior to reservoir simulation. ColSim requires a January to September forecast of simulated streamflow; hence, it assumes a "perfect forecast". The operation rules of the water resources system for hydropower production, flood evacuation, and major flow targets that existed in 1999 were originally used in Hamlet and Lettenmaier (1999), and have been minimally modified since then to capture important changes to the operating rules (Alan Hamlet, personal communication).

### *Reservoir Model for the Yakima River Basin: Yakima RiverWare*

River and reservoir management in Yakima River Basin was modeled using a river system modeling tool, RiverWare ™ (RW). This is a general, multi-objective modeling tool that can handle complex river systems with multiple reservoirs and diversions with different operation objectives (Zagona et al., 2001). RiverWare has been parameterized to simulate river basins such as the Colorado (Fulp and Harkins, 2001), Truckee-Carson (Coors, 2006), and Yakima Rivers (Mastin and Vaccaro, 2002). Different objects can be schematically drawn in RW, and rules and policies corresponding to each of them can be defined by user. Objects in RW are river reaches, canals, reservoirs, and diversions connected in a network that represents water flow between these objects (Carron et al., 2000).

Yakima RiverWare (YAK-RW) was first introduced by the United States Bureau of Reclamation (USBR, 2008). Later it was modified by Vano et al. (2010) to handle multiple future climate scenarios. HDR Engineering Company further modified the model to simulate different infrastructural development scenarios (e.g. building a new dam) in the Yakima River Basin (USBR, 2011). YAK-RW comes with detailed information of infrastructure, management, and water rights in the Yakima River Basin. YAK-RW was integrated with VIC-CropSyst for a cost/benefit analysis of the individual projects in the Yakima River Basin Integrated Water Resource Management Plan (Yoder et al., 2014; Malek et al. in preparation).

For the 2016 Forecast, monthly bias-corrected inflows from VIC-CropSyst were used as input to the YAK-RW model to simulate total water supply available, prorationing and reservoir storage.

### *VIC-CropSyst Integration*

The two physically based models, VIC and CropSyst, were integrated in preparation for the 2011 Forecast, so as to enable seamless running of the coupled VIC-CropSyst model for all of the selected crops across the Columbia River Basin (Yorgey et al. 2011). For the 2016 Forecast, an upgraded and more tightly coupled version of VIC-CropSyst has been applied (Figure 11). In this upgraded version, hydrologic processes (except for plant transpiration) are handled by VIC, while the crop simulation—including crop growth, plant transpiration, phenology, and management—is accomplished by CropSyst.

The VIC model initiates a call to the CropSyst model when it encounters a crop class within a grid cell. On the first day of the simulation, VIC passes to the crop model: a) soil information, such as soil layer thickness and soil water content, b) the cropping pattern, and c) weather information, such as daily minimum and maximum temperature, wind speed, solar radiation, and relative humidity (Figure 12). CropSyst receives the above information from VIC and simulates crop growth using inputs such as crop characteristics and management (Figure 11).

In this upgraded version of the VIC-CropSyst, VIC first simulates the energy balance and estimates the available energy per time step (Liang et al., 1994; Cherkauer et al., 2003). This estimated energy is partitioned into energy components such as snowmelt and sublimation heat fluxes, ground heat flux, and sensible heat flux using an iterative approach (Malek et al. 2016, in review). Potential evapotranspiration is estimated from the remaining energy of the energy balance process. This potential evapotranspiration is partitioned into evapotranspiration components (Thompson et al., 1993). After generating potential transpiration and availability of soil moisture, CropSyst is activated, and uses this information to simulate crop growth. CropSyst then makes the extracted soil water amount available to VIC after accounting for the water required for the crop growth processes. VIC uses this information to calculate the water balance and update soil moisture to generate runoff and baseflow. For more details on the modeling process, please refer to Malek et al. (2016, in review).

When the crop reaches maturity, CropSyst harvests the crop and communicates the crop yield back to VIC. CropSyst also sends back variables such as current growth stage and biomass of the crop. Comparison of harvest day and day of emergence determines the length of the growing season for each crop.

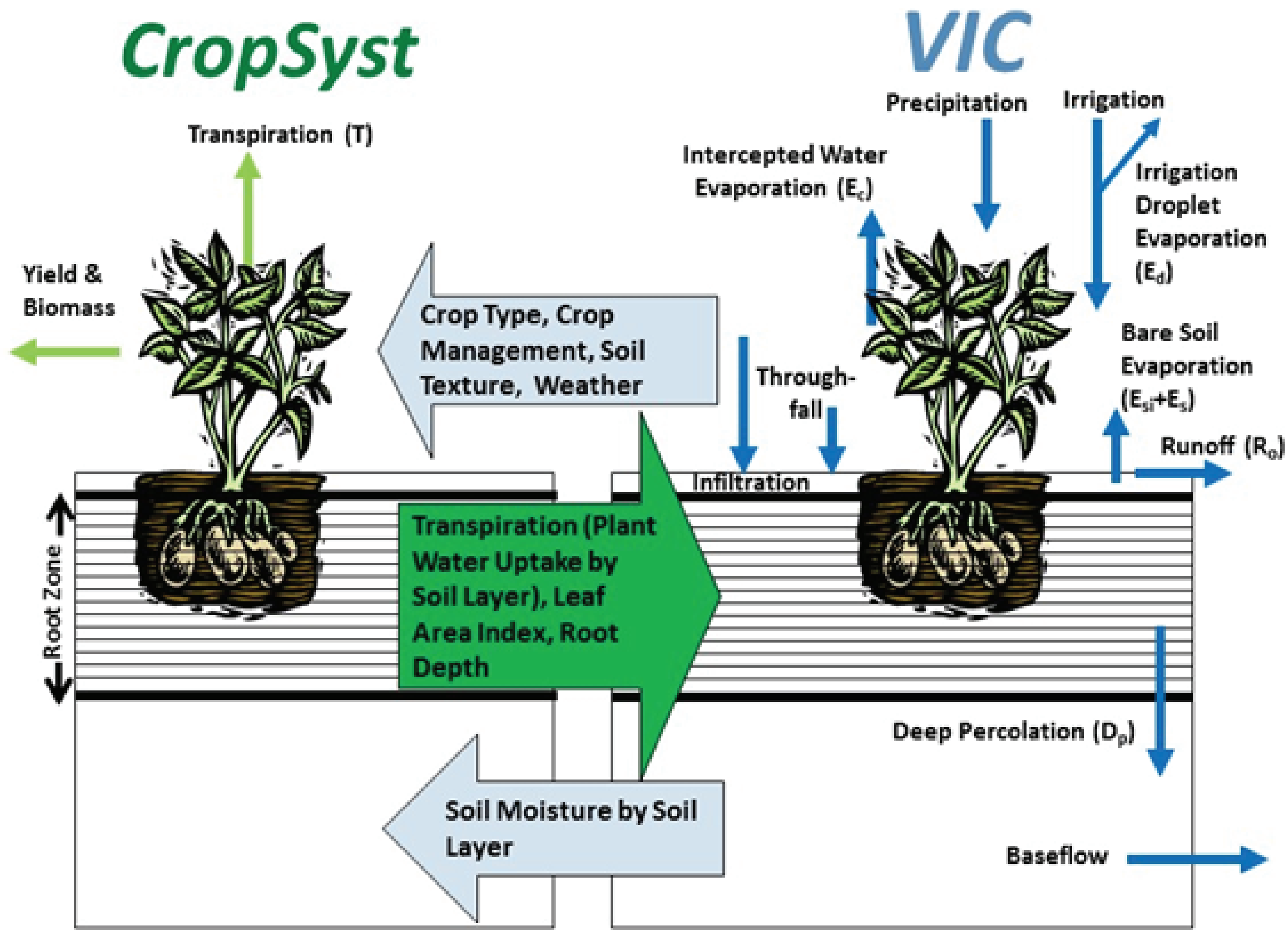



*Figure 11. A schematic of VIC and CropSyst coupling (Malek et al. 2016, in review).*

VIC-CropSyst simulates 40 different types of irrigation systems under four major categories: surface, center pivot, sprinkler, and drip irrigation systems. At each time step VIC-CropSyst determines the water stress, and the irrigation module calculates irrigation frequency, amount, and losses (Malek et al. 2016, in review). The simulated crop water need is used to irrigate the crop only when it is known to be irrigated. For an irrigated crop, when the water need crosses a certain threshold, this threshold amount of water is added to the top of the soil layer. The assumption behind this condition is that crops are not generally irrigated when there is only a small water deficit, and that the maximum amount of irrigation water that can be applied is a function of the irrigation method. The threshold amount is currently set to be 20 mm, and is held constant in time and space. The total irrigation water demand is then estimated as 20 mm/$\varepsilon$, where $\varepsilon$ is the efficiency of the irrigation method.

The land cover distribution within a grid cell controls when CropSyst is invoked within the VIC model (Figure 12). Note that VIC does not recognize the geographical location of a land cover type within a grid cell. It only uses the list of land cover types and their proportion within the grid cell. For this example, the original VIC implementation would be run once for the non-crop type land cover, and CropSyst would then be invoked twice, to simulate the crop growth for Crop 1 and Crop 2. The fluxes generated from the three sub-grid runs would then be aggregated based on their land-cover proportions in the grid cell.

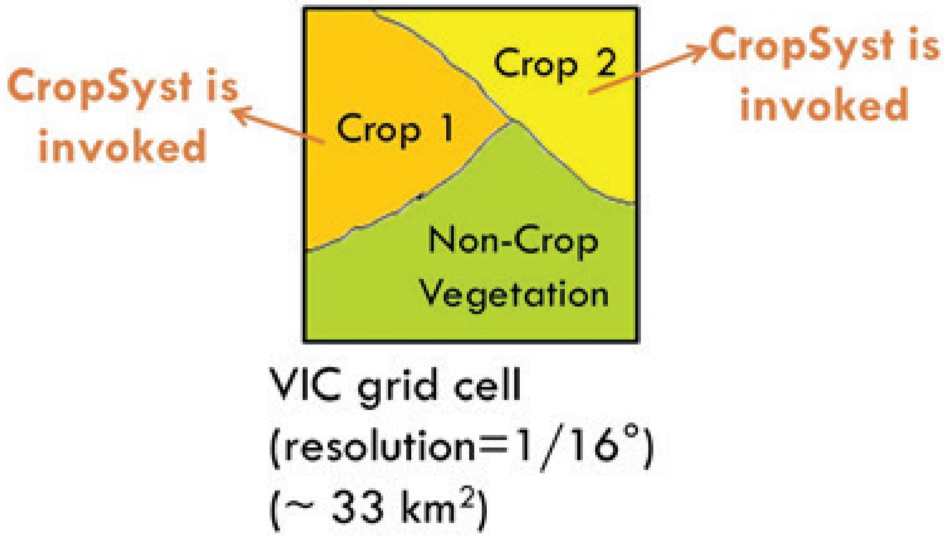



*Figure 12. An illustration of land-cover distribution in a VIC grid cell.*

### *Integration with Water Management*

Bias Correction

Output from hydrologic models sometimes inherit systematic bias arising from errors in the meteorological inputs, uncertainties from the calibrated parameters, and other sources. These types of error can lead to misleading information when used in water resources planning studies. Bias correction is a statistical approach which can reduce these type of errors while keeping the model derived physically-based signals mostly intact (Hamlet et al. 2003). A bias correction methodology explained in Wood et al. (2002) and Hamlet et al. (2003) was applied to the VIC-CropSyst routed flows to address the systematic biases in the model results before they are used as input to the reservoir models. The methodology is a percentile-based bias correction technique, which uses simulated historical flows and naturalized observed historical data to create statistics which help translate any simulated data point to its corresponding observed data point. This is accomplished by using the percentile of the simulated data in the simulated sample space, and finding the point which falls on the same percentile in the observed sample space. A detailed description of this methodology is provided by Hamlet et al. (2003).

Reservoirs

For each location modeled in the reservoir models, the following inputs were provided at a monthly time step:

- the VIC-CropSyst stream flows to that location (after bias correction),
- the full crop irrigation demands upstream of that location (until the location just upstream of it).

The reservoir model then deducts the demands, and provides estimates of resulting stream flows at that location. This stream flow estimate can then be compared to target instream flow requirements at that location.

Curtailment

The 2016 Forecast modeled the frequency and magnitude of curtailments in eastern Washington, on a weekly basis, for the historical time period (1981-2011), and forecasted curtailment for the 2020-2050 time period. Modeled water supply (historical or forecast) in the appropriate geography was compared to state or federal instream flow requirements, and the legislated trigger points for curtailment were used—in accordance with the relevant portions of the Washington Administrative Code, or the federal flow targets and prorationing system in the Yakima River Basin—to estimate how often interruptible and proratable water users would see their water use curtailed in those two time periods. For those locations in Washington State for which instream flow targets exist, if the routed VIC-CropSyst stream flow (from which surface water irrigation demand, including conveyance loss estimates, has been removed) was less than the target instream flow in any week, the demand from interruptible grid cells associated with that location were curtailed for that week.

Curtailment of interruptible water right holders at the watershed scale was modeled for the Walla Walla (WRIA 32), Wenatchee (45), Methow (48), Okanogan (49), Little Spokane (55), and Colville (59) watersheds. A curtailment model was used, that identified when the water supply left over after accounting for agricultural and municipal demands was insufficient to meet instream flow requirements, and estimated the reductions in irrigation by interruptible water right holders necessary to fulfill instream flow requirements. Curtailment of other water rights was not performed due to data and resource constraints. At these locations, due to unavailability of weekly naturalized flow, VIC-CropSyst's simulated flow was bias-corrected using rescaled weekly observed flow data from USGS gauges. Weekly observed flow at USGS gauges was rescaled by the factor estimated from the ratio of the monthly naturalized flow and monthly USGS gauge data.

Curtailment in the mainstem Columbia River was only performed for years when the April through September total unregulated flow volume at The Dalles Dam was projected to be less than 60 million acre-feet, in accordance with the relevant flow targets and curtailment trigger points.

In extreme low flow years, the Director of the Department of Ecology can reduce minimum instream flow requirements by up to 25%, if it is considered to be in the public interest. Such reductions, called "critical flow adjustments," are subject to certain flow conditions along the mainstem. The model did not account for this potential reduction, and hence could overestimate curtailment frequency and magnitude on the mainstem Columbia River.

*Separating irrigation demand into surface water withdrawal sources and groundwater withdrawal sources*

Irrigation demand estimates generated by VIC-CropSyst are total "top of crop" irrigation demand, and there is no distinction between demand met by groundwater sources and surface water sources. For considering irrigation demands in surface water management tools like reservoir models, these two sources of water that contribute to meeting the irrigation demand need to be separated. Due to a lack of spatially disaggregated information to make this split, the team assumed a 20%-80% split between groundwater and surface water sources for all areas other than the Yakima and the Odessa areas, based on the USGS's estimates of water use in Washington in 2005, that suggest that approximately 17% of irrigation usage in eastern Washington is from groundwater (Lane 2009). In the Yakima River Basin, a 10%-90% split was assumed, based on information related to groundwater pumpage for irrigation (Vaccaro and Sumioka, 2006), and on total adjudicated irrigation water demand in the Yakima River Basin (USBR 2002). In the Odessa subarea, a GIS map provided by the US Bureau of Reclamation was used to identify grid cells served by groundwater and surface water sources. 100% of the irrigation demand generated in the groundwater-sourced grid cells and surface water-sourced grid cells were allocated to groundwater sources and surface water sources, respectively. For the future (2035) scenarios, groundwater sources were assumed to be unavailable in the Odessa subarea, and the demands in all the grid cells would therefore need to be met with surface water sources.

## Integration of Biophysical and Economic Modeling

Using the forecasted crop acreage described in the *Economic Forecasting* section, two additional steps were required to integrate the future crop mix into the biophysical modeling. First, because the forecasting relies on USDA data aggregated to the state level, it was necessary to spatially disaggregate changes in crop acreage back to the resolution of the VIC-CropSyst grid cells (1/16th degree). The approach taken was to expand or contract acreage in grid cells where the crop is already grown, based on the projected crop mix values. A second adjustment was made to ensure the future total irrigated acreage conformed to the current extent. The potential for permitting new water rights—that could allow additional acres to be irrigated—was considered separately in the 2016 Forecast.

## Calibration and Evaluation

### *Hydrologic Calibration*

Hydrologic calibration for all the VIC-CropSyst grid cells within the Columbia River Basin boundary were performed by dividing the Basin into sub-basins. Calibration and validation were performed for two separate periods: 1980-1994 for calibration, and 1995-2006 for validation. To maximize data availability for the calibration, two locations (MILNE and WILFA) that only had observed naturalized streamflow data for a 10-year period (1980-1989) were still included in the calibration, though no additional data were available for these locations for the subsequent validation.

Calibration of the VIC-CropSyst stream flow outputs was performed using a multi-objective, automatic calibration tool called MOCOM-UA developed by the Land Surface Hydrology group at the University of Washington. This tool is based on an algorithm known as Multi-Objective Complex Evolution Procedure, developed at the University of Arizona (Yapo et al. 1998).

Six error metrics were considered in this process: squared correlation coefficient (R2), Nash Sutcliffe Efficiency (NSE), the NSE of log transformed data, annual volume error, mean hydrograph peak difference, root mean squared error (RMSE), and number of sign changes in the simulated stream flow errors. Five soil parameters—Dsmax, (the highest value of baseflow for a saturated soil layer), Ws (the soil moisture threshold below which the baseflow curve is linear), and Ds (the fraction of Dsmax where non-linear baseflow begins), bi (variable infiltration curve parameter), and depth of the base layer were used in the calibration. Out of these five parameters, only those which were sensitive to runoff and baseflow response were selected for calibration for a particular basin.

The majority of the locations at which the model outputs were evaluated had NSE values higher than 0.7 for both the calibration and validation periods, which is considered a good to excellent fit. Negative NSE values were observed at four locations, for the calibration or validation period, or for both. Although these sites showed low NSE values, their correlations with the observed naturalized flow were robust, indicating a bias in the system usually contributed from a systematic error such as precipitation input (Hamlet et al. 2013).

Another typical contribution of bias is from baseflow, since groundwater influence is not explicitly considered in the VIC model. Safeeq et al. (2014) observed poor performance of VIC simulations in northeastern Washington, where groundwater influence was very strong. The simulations in this Forecast showed very low confidence in this region, especially for the Colville River at Kettle Falls. Being a mesoscale modeling framework, VIC-CropSyst tends to perform better for large-scale basins, with simulation performance tending to increase with basin size (Table 3). A bias correction procedure (see the *Bias Correction* section, above) was applied on the simulated flow to reduce this systematic error for most of the locations used in the Forecast (Table 4).

### *Conveyance Losses*

VIC-CropSyst's estimated irrigation demands are "top of crop" demands and do not include conveyance loss estimates. Such losses needed to be added to the "top of crop" demands to obtain the surface water irrigation demands. The same percentages for conveyance loss as in the previous (2011) Forecast were adopted:

- 15% for irrigation demand originating from the Columbia Basin Project region,

- 10% for irrigation demand originating within a one-mile corridor of the Columbia River mainstem (this is assuming that the place of use of withdrawn water is closer to the point of withdrawal and there is less scope of losses associated with travel through a canal system),

- 25% for irrigation demand in the Yakima River Basin region,

- 25% loss for all other watersheds in Washington with a canal system, with the exception of

- the Methow River Basin, where a loss of 40% was assumed, based on information from the Methow's watershed plan.

- For watersheds without a canal system a loss of 10% was assumed.

One loss percentage was calculated for each watershed as a weighted average of the proportion of demands originating from the Columbia River one-mile corridor, the Columbia Basin Project area, and the remaining area in the watershed. The average conveyance loss percentage calculated for eastern Washington was around 20%, and this loss percentage was therefore assumed for demands originating outside of Washington State.

*Table 3. Calibration and validation results.*

| VIC Station Name | Location Name | Basin size (sq. mi.) | Calibration Period (1980-1994) | | | Evaluation Period (1995-2006) | | |
|---|---|---|---|---|---|---|---|---|
| | | | NSE | BIAS (%) | R | NSE | BIAS (%) | R |
| DALLE | COLUMBIA RIVER AT THE DALLES | 237000.00 | 0.76 | 25.44 | 0.96 | 0.78 | 24.4 | 0.95 |
| ICEHA | SNAKE RIVER AT ICE HARBOR DAM | 108500.00 | 0.74 | 25.67 | 0.48 | -0.45 | 24.4 | 0.95 |
| PRIRA | COLUMBIA RIVER AT PRIEST RAPIDS DAM | 96000.00 | 0.83 | 22.72 | 0.96 | 0.61 | 39.4 | 0.95 |
| RISLA | COLUMBIA RIVER AT ROCK ISLAND DAM | 89400.00 | 0.84 | 22.08 | 0.97 | 0.78 | 26.8 | 0.97 |
| ROCKY | COLUMBIA RIVER AT ROCKY REACH DAM | 87800.00 | 0.83 | 22.36 | 0.93 | 0.84 | -1.13 | 0.92 |
| WELLS | COLUMBIA RIVER AT WELLS DAM | 86100.00 | 0.85 | 20.65 | 0.98 | 0.83 | 24.1 | 0.97 |
| GCOUL | COLUMBIA RIVER AT GRAND COULEE DAM | 74700.00 | 0.81 | 25.72 | 0.98 | 0.89 | 17.2 | 0.97 |
| WANET | PEND DOREILLE RIVER AT WANETA DAM | 25800.00 | 0.69 | 33.67 | 0.97 | 0.26 | 73.5 | 0.95 |
| ALBEN | PEND OREILLE RIVER AT ALBENI FALLS DAM | 24200.00 | 0.63 | 32.38 | 0.79 | 0.42 | 40.6 | 0.86 |
| CORRA | KOOTENAY RIVER AT CORRA LINN DAM | 17700.00 | 0.76 | 29.39 | 0.94 | | | |
| MILNE | SNAKE RIVER AT MILNER | 17180.00 | 0.82 | 15.19 | 0.98 | 0.81 | 25.5 | 0.97 |
| REVEL | COLUMBIA RIVER AT REVELSTOKE DAM | 10200.00 | 0.89 | 9.82 | 0.97 | 0.85 | 24.1 | 0.97 |
| WILFA | WILLAMETTE RIVER ABOVE FALLS AT OREGON CITY | 10000.00 | 0.69 | 32.60 | 0.98 | 0.82 | 24.6 | 0.98 |
| LIBBY | KOOTENAI RIVER AT LIBBY DAM | 8985.00 | 0.27 | 54.06 | 0.98 | 0.82 | 25.2 | 0.98 |
| YAPAR | YAKIMA RIVER NEAR PARKER | 3660.00 | 0.11 | 47.05 | 0.91 | -2.1 | 158 | 0.92 |
| DWORS | N. FORK CLEARWATER AT DWORSHAK DAM | 2440.00 | 0.83 | -2.87 | 0.93 | 0.67 | 32.9 | 0.77 |
| COLKE | COLVILLE RIVER AT KETTLE FALLS | 1007.00 | 0.01 | 28.40 | 0.98 | 0.81 | 25.3 | 0.97 |

*Table 4. Simulated flow performance after bias correction. Only calibration stations for which bias correction was performed are shown.*

| VIC Station Name | Location Name | Basin size (sq. mi.) | Calibration Period (1980-1994) | | | Evaluation Period (1995-2006) | | |
|---|---|---|---|---|---|---|---|---|
| | | | NSE | BIAS (%) | R | NSE | BIAS (%) | R |
| DALLE | COLUMBIA RIVER AT THE DALLES | 237000 | 0.96 | -4.16 | 0.98 | 0.95 | 0.98 | 0.97 |
| ICEHA | SNAKE RIVER AT ICE HARBOR DAM | 108500 | 0.94 | -2.91 | 0.97 | 0.92 | -1.49 | 0.96 |
| PRIRA | COLUMBIA RIVER AT PRIEST RAPIDS DAM | 96000 | 0.97 | 4.05 | 0.99 | 0.94 | 9.88 | 0.98 |
| RISLA | COLUMBIA RIVER AT ROCK ISLAND DAM | 89400 | 0.97 | -6.25 | 0.99 | 0.96 | -0.49 | 0.98 |
| ROCKY | COLUMBIA RIVER AT ROCKY REACH DAM | 87800 | 0.97 | -4.59 | 0.99 | 0.96 | 1.18 | 0.98 |
| WELLS | COLUMBIA RIVER AT WELLS DAM | 86100 | 0.97 | -4.42 | 0.98 | 0.96 | 2.07 | 0.98 |
| WANET | PEND DOREILLE RIVER AT WANETA DAM | 25800 | 0.93 | 9.29 | 0.98 | 0.90 | 10.29 | 0.97 |
| ALBEN | PEND OREILLE RIVER AT ALBENI FALLS DAM | 24200 | 0.96 | -1.78 | 0.98 | 0.94 | -1.01 | 0.97 |
| CORRA | KOOTENAY RIVER AT CORRA LINN DAM | 17700 | 0.95 | 2.71 | 0.98 | 0.90 | 8.28 | 0.96 |
| REVEL | COLUMBIA RIVER AT REVELSTOKE DAM | 10200 | 0.94 | 0.29 | 0.97 | 0.90 | 10.52 | 0.96 |
| LIBBY | KOOTENAI RIVER AT LIBBY DAM | 8985 | 0.92 | 2.71 | 0.96 | 0.88 | 7.66 | 0.95 |
| YAPAR | YAKIMA RIVER NEAR PARKER | 3660 | 0.88 | -5.95 | 0.94 | 0.90 | -3.18 | 0.95 |
| SIMNI | SIMILKAMEEN RIVER NEAR NIGHTHAWK | 3550 | 0.86 | -9.75 | 0.93 | 0.81 | 15.94 | 0.95 |
| DWORS | N. FORK CLEARWATER AT DWORSHAK DAM | 2440 | 0.87 | 4.71 | 0.94 | 0.71 | 5.18 | 0.90 |
| LISPO | LITTLE SPOKANE RIVER NEAR DARTFORD | 698 | 0.74 | -5.19 | 0.87 | 0.79 | 6.00 | 0.91 |

# References


Abatzoglou, J. T., and T. J. Brown. 2012. A comparison of statistical downscaling methods suited for wildfire applications. International Journal of Climatology, 32(5), 772-780.

Adam, J. C., J. C. Stephens, S. H. Chung, M.P. Brady, R. D. Evans, C.E. Kruger, et al. 2015. BioEarth: Envisioning and developing a new regional earth system model to inform natural and agricultural resource management. Climatic Change, 129 (3-4), 555-571.

Badini, O., C. O. Stockle, J. W. Jones, R. Nelson, A. Kodio and M. Keita. 2007. A simulationbased analysis of productivity and soil carbon in response to time-controlled rotational grazing in the West African Sahel region. Agricultural Systems, 94, 87–96.

Benli, B., M. Pala, C. Stockle and T. Oweis. 2007. Assessment of winter wheat production under early sowing with supplemental irrigation in a cold highland environment using CropSyst simulation model. Agricultural Water Management, 93, 45–53.

Bonneville Power Administration. 2010. 2010 Level Modified Streamflow: 1928–2008 Diversion and Return Flow Patterns, Summation of Depletion Adjustments, 2010 Level Modified Streamflow Plus Technical Appendix), DOE/BP-4352. Portland, Oregon

Carron, J., E. Zagona, and T. Fulp, 2000. Uncertainty modeling in RiverWare. In Proceedings of the ASCE Watershed Management 2000 Conference, Ft. Collins, CO.

Cherkauer, K. A., L.C. Bowling, and D.P. Lettenmaier. 2003. Variable infiltration capacity cold land process model updates. Global and Planetary Change, 38(1), 151-159.

Christensen, N. S., A. W. Wood, N. Voisin, D. P. Lettenmaier and R. N. Palmer. 2004. The effects of climate change on the hydrology and water resources of the Colorado River basin. Climatic Change, 62, 337–363.

Coors, S. 2006. An Overview of the Truckee-Carson RiverWare Modeling System. In Proceedings of the Operations Management Conference 2006. Operating Reservoirs in Changing Conditions, 272-83. Available online at http://ascelibrary.org/doi/abs/10.1061/40875(212)27

Elsner, M. M., Cuo, L., Voisin, N., Deems, J. S., Hamlet, A. F., Vano, J. A., et al. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change, 102(1-2), 225-260.

Fulp, T., and J. Harkins. 2001. Policy analysis using RiverWare: Colorado River interim surplus guidelines. In Proceedings of ASCE World Water & Environmental Resource Congress.

Gao, H., Q. Tang, X. Shi, C. Zhu, T.J. Bohn, F. Su, et al. 2010. Water budget record from Variable Infiltration Capacity (VIC) model. Algorithm Theoretical Basis Document for Terrestrial Water Cycle Data Records.

Hall, S.A., J.C. Adam, M. Barik, J. Yoder, M.P. Brady, D. Haller, M.E. Barber, C.E. Kruger, G.G. Yorgey, M. Downes, C.O. Stockle, B. Aryal, T. Carlson, G. Damiano, S. Dhungel, C. Einberger, K. Hamel-Reiken, M. Liu, K. Malek, S. McClure, R. Nelson, M. O'Brien, J. Padowski, K. Rajagopalan, Z. Rakib, B. Rushi, W. Valdez. 2016. 2016 Washington State Legislative Report. Columbia River Basin Long-Term Water Supply and Demand Forecast. Publication No. 16-12-001. Washington Department of Ecology, Olympia, WA.

Hamlet, A. F. and D. P. Lettenmaier. 1999. Effects of climate change on hydrology and water resources in the Columbia River Basin. Journal of the American Water Resources Association, 35, 1597–1623.

Hamlet, A. F., S.Y. Lee, K. E. B. Mickelson and M. M. Elsner. 2010. Effects of projected climate change on energy supply and demand in the Pacific Northwest and Washington State. Climatic Change, 102, 103–128, doi:10.1007/s10584-010-9857-y.

Hamlet, A. F., M. M. Elsner, G.S. Mauger, S.Y. Lee, I. Tohver, and R. A. Norheim, 2013. An overview of the Columbia Basin Climate Change Scenarios Project: Approach, methods, and summary of key results. Atmosphere-ocean, 51(4), 392-415.

Hamlet, A. F., A. Snover, and D.P. Lettenmaier. 2003. Climate Change Scenarios for Pacific Northwest Water Planning Studies: Motivation, Methodologies, and a User's Guide to Applications.

Hansen, M., R. DeFries, J. R. G. Townshend and R. Sohlberg. 2000. Global land cover classification at 1 km spatial resolution using a classification tree approach. International Journal of Remote Sensing, 21, 1331–1364.

Hayhoe, K., Wake, C. P., Huntington, T. G., Luo, L., Schwartz, M. D., Sheffield, J., et al. 2007. Past and future changes in climate and hydrological indicators in the US Northeast. Climate Dynamics, 28(4), 381-407.

Huang, S., Q. Huang, J. Chang, and G. Leng. 2016. Linkages between hydrological drought, climate indices and human activities: a case study in the Columbia River basin. International Journal of Climatology, 36(1), 280-290.

Hubble, J. D. 2012. Yakima River Basin Integrated Water Resource Management Plan: Final Programmatic Environmental Impact Statement. Fish Benefits Analysis Technical Memorandum. US Bureau of Reclamation.

Jara, J. and C. O. Stockle. 1999. Simulation of corn water uptake using models with different levels of process detail. Agronomy Journal, 91, 256–265.

Kemanian, A. 2003. Radiation-based and transpiration-based modeling of barley and wheat growth. Ph.D. Dissertation, Washington State University. 88 p.

Kemanian, A. R. and C. O. Stockle. 2010. C-Farm. A simple model to evaluate the carbon balance of soil profiles. European Journal of Agronomy, 32, 22–29.

Kemanian, A. R., C. O. Stöckle, D. R. Huggins, and L. M. Viega. 2007. A simple method to estimate harvest index in grain crops. Field Crops Research, 103, 208–216.

Knox, J., T. Hess, A. Daccache, and T. Wheeler. 2012. Climate change impacts on crop productivity in Africa and South Asia. Environmental Research Letters, 7(3), 034032.

Lane, R. C. 2009. Estimated water use in Washington, 2005. U.S. Geological Survey, U.S. Department of the Interior, Reston, VA.

Lane, R.C., and W.B. Welch. 2015, Estimated freshwater withdrawals in Washington, 2010: U.S. Geological Survey Scientific Investigations Report 2015-5037, 48 p. Available online at http://dx.doi.org/10.3133/sir20155037. (Accessed January 23, 2017)

Liang, X., D. P. Lettenmaier, E. Wood and S. Burgess. 1994. A simple hydrologically based model of land surface water and energy fluxes for general circulation models. Journal of Geophysical Research 99D7, 14–415.

Liang, X., E. F. Wood and D. P. Lettenmaier. 1996. Surface soil moisture parameterization of the VIC-2L model: Evaluation and modification. Global and Planetary Change, 13, 195– 206

Lohmann, D., E. Raschke, B. Nijssen and D. Lettenmaier. 1998. Regional scale hydrology: I. Formulation of the VIC-2L model coupled to a routing model. Hydrological Sciences Journal, 43, 131–141.

Malek, K., J. C. Adam, C. O. Stockle, and M. Brady. In preparation. When should irrigators invest in more water-efficient technologies as an adaptation to climate change?

Malek, K., C. Stockle, K. Chinnayakanahalli, R. Nelson, M. Liu, K. Rajagopalan, M. Barik, and J. Adam. In review. VIC-CropSyst: A regional-scale modeling platform to simulate the nexus of climate, hydrology, cropping systems, and human decisions.

Marcos, J. 2000. Simulation-based assessment of alternative crops in the dryland Pacific Northwest. Ph.D. Dissertation, Washington State University.

Markoff, S. M. and A. C. Cullen. 2008. Impact of climate change on Pacific Northwest hydropower. Climatic Change, 87, 451–469.

Marsal, J., and C. O. Stöckle. 2012. Use of CropSyst as a decision support system for scheduling regulated deficit irrigation in a pear orchard. Irrigation Science, 30(2), 139-147.

Mastin, M. C., and J.J. Vaccaro. 2002. Watershed models for decision support in the Yakima River Basin, Washington (No. USGS-OFR-02-404). Department of Interior, Washington DC.

Maurer, E. P., A. W. Wood, J. C. Adam, D. P. Lettenmaier and B. Nijssen. 2002. A long-term hydrologically-based data set of land surface fluxes and states for the conterminous United States. Journal of Climate, 15, 3237–3251.

Maurer, E. P. 2007. Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California, under two emissions scenarios. Climatic Change, 82, 309–325.

Mitchell, K., P. Houser, E. Wood, J. Schaake, D. Tarpley, D. Lettenmaier, ... and B. Cosgrove. (1999). GCIP land data assimilation system (LDAS) project now underway. Gewex News, 9(4), 3-6.

Moriondo, M., C. Giannakopoulos, and M. Bindi. 2011. Climate change impact assessment: the role of climate extremes in crop yield simulation. Climatic Change, 104(3-4), 679-701.

Pannkuk, C., C. Stockle and R. Papendick. 1998. Evaluating CropSyst simulations of wheat management in a wheat-fallow region of the US Pacific Northwest. Agricultural Systems, 57, 121–134.

Payne, J. T., A. W. Wood, A. F. Hamlet, R. N. Palmer and D. P. Lettenmaier. 2004. Mitigating the effects of climate change on the water resources of the Columbia River basin. Climatic Change, 62, 233–256.

Peralta, J. M. and C. O. Stockle. 2002. Dynamics of nitrate leaching under irrigated potato rotation in Washington State: a long-term simulation study. Agriculture, Ecosystems & Environment, 88, 23–34.

Rushi, B.R., M. Barik, S.Y. Lee, J. Boll, M. Brady, J.E. Petrie, K. Rajagopalan, K. Malik, B. Cosens, J.C. Adam. Columbia river treaty renegotiation: potential impacts on agriculture, flood risk, hydropower and instream flows in the context of an altered climate (In Prep.).

Sadras, V. O. 2004. Yield and water-use efficiency of water-and nitrogen-stressed wheat crops increase with degree of co-limitation. European journal of agronomy, 21, 455–464.

Safeeq, M., G.S. Mauger, G. E. Grant, I. Arismendi, A.F. Hamlet, and S.Y. Lee. 2014. Comparing large-scale hydrological model predictions with observed streamflow in the Pacific Northwest: effects of climate and groundwater. Journal of Hydrometeorology, 15(6), 2501-2521.

Saxton, K. E., W. Rawls, J.S. Romberger, and R.I. Papendick. 1986. Estimating generalized soil-water characteristics from texture. Soil Science Society of America Journal, 50(4), 1031-1036.

Stock, J. H., and Watson, M. W. 2001. Vector autoregressions. The Journal of Economic Perspectives, 15(4), 101-115.

Stockle, C. and J. Jara. 1998. Modeling transpiration and soil water content from a corn (Zea Maize L.) field: 20 min vs. daytime integration step. Agricultural and Forest Meteorology, 92, 119–130.

Stockle, C. O., S. A. Martin and G. S. Campbell. 1994. CropSyst, a cropping systems simulation model: water/nitrogen budgets and crop yield. Agricultural Systems, 46, 335–359

Stockle, C. O., M. Donatelli and R. Nelson. 2003. CropSyst, a cropping systems simulation model. European Journal of Agronomy, 18, 289–307.

Stöckle, C. O., R. L. Nelson, S. Higgins, J. Brunner, G. Grove, R. Boydston, M. Whiting and C.Kruger. 2010. Assessment of climate change impact on Eastern Washington agriculture. Climatic Change, 102, 77–102.

Thompson, A. L., J.R. Gilley, and J.M. Norman. 1993. A sprinkler water droplet evaporation and plant canopy model: II. Model application. Transactions of the ASAE, 36(3), 743-750.

Todorovic, M., R. Albrizio, L. Zivotic, M. T. A. Saab, C. Stockle and P. Steduto. 2009. Assessment of AquaCrop, CropSyst, and WOFOST models in the simulation of sunflower growth under different water regimes. Agronomy Journal, 101, 509–521.

U. S. Bureau of Reclamation. 2002. Interim Comprehensive Basin Operating Plan for the Yakima Project, Washington.US Department of the Interior, US Bureau of Reclamation.

U.S. Bureau of Reclamation. 2008. Upper Columbia alternative flood control and fish operations. https://www.usbr.gov/pn/fcrps/hydro/varq/usace-rod-UCEIS-june2008.pdf (Accessed December 9, 2016)

U.S. Bureau of Reclamation. 2011. Yakima River Basin Integrated Water Resource Management Plan https://www.usbr.gov/pn/programs/yrbwep/2011integratedplan/plan/framework.pdf (Accessed January 17, 2017)

U.S. Department of Agriculture. 2013. Cropland Data Layer. Available online at https://www.nass.usda.gov/Research_and_Science/Cropland/Release/index.phpc

Vaccaro, J. J. and Sumioka. 2006. Estimates of ground water pumpage from the Yakima River basin aquifer system, Washington, 1960-2000. U.S. Geological Survey, U.S. Department of the Interior.

Vano, J. A., M. J. Scott, N. Voisin, C.O. Stöckle, A. F. Hamlet, K. E. Mickelson, ... and D.P. Lettenmaier. 2010. Climate change impacts on water management and irrigated agriculture in the Yakima River Basin, Washington, USA. Climatic Change, 102(1-2), 287-317.

VanRheenen, N. T., A. W. Wood, R. N. Palmer and D. P. Lettenmaier. 2004. Potential implications of PCM climate change scenarios for Sacramento-San Joaquin River Basin hydrology and water resources. Climatic Change, 62, 257–281.

Washington Department of Agriculture. 2013. Washington Department of agriculture land use geodatabase. Available online at http://agr.wa.gov/PestFert/NatResources/AgLandUse.aspx (Accessed November 20, 2014).

Washington Department of Fish and Wildlife. 2007. Fish and wildlife generate billions for Washington's economy. Available online at http://wdfw.wa.gov/publications/00570/wdfw00570.pdf (Accessed January 23, 2017)

Wood, A. W., E.P. Maurer, A. Kumar, and D.P. Lettenmaier. 2002. Long□range experimental hydrologic forecasting for the eastern United States. Journal of Geophysical Research: Atmospheres, 107(D20).

Yapo, P. O., H.V. Gupta, and S. Sorooshian. 1998. Multi-objective global optimization for hydrologic models. Journal of hydrology, 204(1), 83-97.

Yoder, J., J. Adam, M. Brady, J. Cook, and S. Katz. 2014. Benefit-Cost analysis of the Yakima basin integrated plan projects. Washington State Legislature.

Yorgey, G. G., K. Rajagopalan, K. Chinnayakanahalli, M.P. Brady, M.E. Barber, R. Nelson, et al. 2011. Columbia River Basin Long-Term Water Supply and Demand Forecast. Available online at https://fortress.wa.gov/ecy/publications/publications/1112011.pdf (Accessed January 23, 2017).

Zagona, E. A., T. J. Fulp, R. Shane, T. Magee, and H.M. Goranflo. 2001. Riverware: a generalized tool for complex reservoir system modeling. Journal of the American Water Resources Association 37(4), 913-929.

Zaher, U., C. Stöckle, K. Painter, and S. Higgins, 2013. Life cycle assessment of the potential carbon credit from no-and reduced-tillage winter wheat-based cropping systems in Eastern Washington State. Agricultural Systems, 122, 73-78.

Ren-Jun, Z. 1992. The Xinanjiang model applied in China. Journal of Hydrology, 135(1-4), 371-381.

# SECTION 2 – Outreach Efforts that Informed the 2016 Long-Term Water Supply and Demand Forecast

## Outreach Efforts

The team that developed the 2016 Columbia River Basin Long-Term Supply and Demand Forecast had already developed the 2011 Forecast. Feedback received during that earlier process was essential for planning for the 2016 Forecast. In addition, Washington State University researchers have given multiple presentations on the Columbia River Long-Term Supply and Demand Forecast to diverse groups in the intervening years. Some recent highlights of these outreach efforts included presentations to the:

- Water Resources Advisory Committee (March 16, 2015 and July 11, 2016),
- Bonneville Power Administration and Chelan Public Utility District representatives (May 5, 2015).
- Eastern Washington County Commissioners Policy Advisory Group (June 11, 2015 and July 15, 2016),
- group discussing the Columbia River Treaty (July 7, 2015),
- state agency outreach meeting (August 4, 2016),
- Columbia Basin Development League's Annual Conference (November 3, 2016),
- 9th Annual Water Rights Transfers Seminar (November 10, 2016),
- Lake Roosevelt Forum's Conference (November 15, 2016),
- Yakima Basin Storage Alliance (November 7, 2016),
- State Senate Agriculture, Water and Rural Economic Development Committee (November 15, 2016).
- The Washington Small Fruit Conference (December 2, 2016).

WSU researchers have also continued to obtain feedback from the Columbia River Policy Advisory Group (PAG), a group that provided input on the original modeling methods used in the 2011 Forecast. This group represents a range of stakeholder interests, and helps the Office of the Columbia River identify and evaluate policy issues. WSU's interactions with the PAG to inform the 2016 Forecast included presentations at their regular meetings, most recently on January 29, 2015 and August 4, 2016.

In addition, WSU carried out targeted outreach to agricultural, municipal, tribal, and federal professionals to identify any relevant datasets not yet incorporated into the modeling and updated analyses relevant to the 2016 Forecast. This process did not result in identification of major new datasets, but did provide qualitative information that helped inform the 2016 Forecast (for example, information about market expectations for various crops).

Finally, the Forecast team pursued input from stakeholders as the 2016 Forecast's preliminary results were being obtained. Input was received through a series of three public workshops in Richland, Wenatchee and Spokane, in June 2016. At each of these workshops the team presented and discussed preliminary results, and actionable feedback was requested from participants. The draft Legislative Report was simultaneously available online, and comments from the interested public were accepted during a month-long open public comment period. These comments were compiled together, and used to modify and expand the results reported in the final Legislative Report. The extent to which these comments influenced the final 2016 Legislative Report, and which comments will continue to influence the thinking and development of future Forecasts is detailed in the table below (Table 5).

# Responses to Public Comments

*Table 5. Compilation of comments received from the interested public during the three public workshops held in June 2016, and during the month-long public comment period held after the workshops. Team responses ranged from changes or additions included in the final Legislative Report, to comments that are being taken into consideration in identifying improvements or expansions for future forecasts.*

| PUBLIC COMMENT | FORECAST TEAM'S RESPONSE |
|---|---|
| ***Process Comments*** | |
| Always use microphone during workshop; provide portable mic for audience questions. | Will be considered for future public workshops. |
| ***Data Presentation Comments*** | |
| I would expect you to use the results generally in writing and planning around climate change impacts and concerns for resource managers in PNW region - focus on farmers, ranchers, forest landowners - in other words, present it in a way that can be useful to each of the different stakeholder groups. | Discussions are ongoing about additional outreach and outreach materials that could help share the results effectively with specific stakeholder groups. Additional presentations have already been made, including to: the Water Resources Advisory Committee (7/11/16), Eastern Washington County Commissioners Policy Advisory Group (7/15/16), Columbia River Policy Advisory Group (8/4/16), a state agency outreach meeting (8/4/16), the Columbia Basin Development League (11/3/16), the Lake Roosevelt Forum (11/15/16), and the State Senate Ag, Water & Rural Economic Development committee (11/15/16). |
| There are highlighted areas of declining groundwater, but they don't capture all the areas of known groundwater decline in the state. I recommend switching to degrees of decline in your presentation so that all areas are represented. | This report identified key areas of declining groundwater based on consultations with state agencies, but is not representative of all at-risk areas. The 2021 Forecast will consider whether additional areas are also worth tracking and evaluating. |
| Banking - Kittitas County bank is not in your graph for cost. How does their cost compare? | The Kittitas County water bank was launched after the data set for the draft was compiled, but has been added for the final report. |
| Where will this presentation be available to access later? | An updated version of the presentation, given to the Columbia River Policy Advisory Group on 8/4/16, is available online, here: http://www.ecy.wa.gov/programs/wr/cwp/images/816Forecast.pdf |
| On your metric model you have a high res map and it shows ET rates inches per *hour* higher than what I usually see per *day*. 0.7-0.8 inches per HOUR on map. This seems very high. | The preliminary analysis presented at the public workshops included some overestimation of the results in certain areas. With improvement in the model and better calibration, the results presented in the final report are comparable with other model estimates (Washington's Irrigation Guidelines; Food and Agriculture Organization of the United Nations). |
| ***Comments on Expected Use of Results*** | |
| As a hydrologist, I will use the forecast for various water resource assessment and management projects. | No response needed. |
| I hope to be able to communicate and support more sustainable use of H2O in our homes and gardens. | No response needed. |
| 1) expectations for additional water right changes for the conservancy Board; 2) expectations for municipal water availability over the next few years. | No response needed. |

| PUBLIC COMMENT (cont.) | FORECAST TEAM'S RESPONSE (cont.) |
|---|---|
| crops to be planted and future threats to water availability to ag. Higher world population mean each acre has to feed more people tomorrow than it does today. | No response needed. |
| I am most interested in irrigation supply for agricultural use. | No response needed. |
| ***Comments on Modeled Supply and Demand (Agricultural, Municipal, Hydropower)*** | |
| Somewhat surprised by the assumptions. What happens if we experience more years of excessive heat followed by excessive cold. How can we plan for that or other possible scenarios? | The supply and agricultural demand modeling presented in this Report used the best available science on what we might expect from the climate by 2035. These projections - like any projections 20 years into the future - are uncertain. There is agreement among all climate change scenarios that temperatures are likely to continue to increase, though the uncertainty around precipitation is higher. Though temperature and precipitation extremes were not specifically explored, the improved climate projections used in the 2016 Forecast (CMIP5 projections, downscaled to the Pacific Northwest) are better able to capture changes in temperature and precipitation extremes than the projections used in the previous forecast. For a detailed discussion of climate projections for the Pacific Northwest, please refer to *Dalton, M.M., Mote, P., Snover, A.K. (Editors) 2013. Climate Change in the Northwest: Implications for our Landscapes, Waters, and Communities. Island Press. Washington, DC,* available here: http://cses.washington.edu/db/pdf/daltonetal678.pdf |
| Just interested in digging into the projections about ag land use changes - would like to know more about what feeds into the model. | Final Legislative Report will be available in December 2016, with more detailed methodological information available in 2017. |
| Assuming agricultural footprint remains the same will be a mistake. More water available will encourage growth - economy, agriculture, fish, etc. | The final report includes a range of alternatives such as an initial estimate of the impact that expanding the irrigated acreage through water development projects (already planned by OCR) would have. A rough first estimate of the impact double cropping could have on irrigation demand is also included in the final report. |
| All things being equal at this latitude, increased heat units/CO2 will increase agricultural production and allow for production of high value crops, such as tree fruit, hops, grapes, etc. Increased heat units/CO2 also imply lower carbon inputs per unit of ag production. | The impact of increased temperatures and CO2 concentrations on crop growth (and associated water use) are quantified through the integrated model used in this study. The "carbon footprint" of such production, and changes in that footprint by 2035, are beyond the scope of this Report. |
| If the temps go up and stay there, all bets are off. Or if they go down and stay there? | The supply and agricultural demand modeling presented in this Report used the best available science on what we might expect from the climate by 2035. These projections - like any projections 20 years into the future - are uncertain. The results quantify that uncertainty by using climate projections under scenarios with different increases in greenhouse gas concentrations in the atmosphere (known as Representative Concentration Pathways), and using climate projections from different global climate models. There is agreement among all these scenarios that temperatures are likely to continue to increase, though the uncertainty around precipitation is higher. For a detailed discussion of climate projections for the Pacific Northwest, please refer to *Dalton, M.M., Mote, P., Snover, A.K. (Editors) 2013. Climate Change in the Northwest: Implications for our Landscapes, Waters, and Communities. Island Press. Washington, DC*, available here: http://cses.washington.edu/db/pdf/daltonetal678.pdf |

| PUBLIC COMMENT (cont.) | FORECAST TEAM'S RESPONSE (cont.) |
|---|---|
| Question why you are confident that future ag water needs will drop more than just your correction for irrigated pasture. If climate warms it will allow growers to grow longer season, higher value crops, replacing wheat and other lower value crops. | The modeling results provide some confidence that if crop mix changes follow the same trends they have in the recent past, and if double cropping is not a practice that leads to big changes in water use, demand will go down. The research team used existing data to project those trends in crop mix. The team is working on model improvements that would allow them to explore scenarios with double cropping, and determine its impact on water use. Such improvements, however, will not be completed in time to be included in this Report. In the interim, a rough calculation of the impact on demand should 10% of eligible cropland be double-cropped is provided. |
| Grape acres are slowly increasing and their overall % of total irrigated acres is VERY small, tree fruit is out pacing this dramatically. | According to USDA data tree fruit growth has slowed in the last 5-10 years relative to the previous 30, and also compared to wine grape acreage. Wine grape acreage is fairly small but it is similar in scale to apple acreage and also is concentrated in specific areas. The decrease in water use is not solely attributed to expanded wine grape acreage. |
| Surprised by variability estimating crops and uses. | Comment noted. |
| Surprised to see projections around declining irrigation demand. | The final report includes additional demand estimates based on scenarios of increases in double-cropping and increases in water available to expand irrigated acreage. These estimates help evaluate under what conditions water demand in 2035 could be greater than estimated, and greater than historical irrigation demand. |
| How much of reduced ag water demand can be attributed to a switch to low water use crops? Different irrigation systems? | The reductions in agricultural water demand that are expected due to changes in climate versus changes in crop mix are presented in Table 2, and in the Demand plots for each WRIA (see the *Forecast Results for Individual WRIAs* section). The modeling did not quantify the impact of improved efficiency in irrigation systems. Including these improvements would reduce the non-consumptive portion of agricultural demands, all other factors being equal. |
| When you talk about seniority of water rights, do you look at it on the Columbia River Basin scale? | The discussion of water rights and their seniority are focused within Washington State. Seniority relates to time when applications were approved within a particular watershed. |
| You aren't looking at technological changes farmers are using to be more water efficient when applying water. | The modeling results were obtained without estimating the potential impact of technological changes that lead to improved efficiency in water use, as the team was unaware of any efforts to estimate the impact of those changes in this region. Results therefore provide a benchmark from which discussions on the potential improvements in efficiency can relate to. |
| Did you include biofuel crops or plants? | The crops detailed in the modeling are listed in Box 4. If policy or other changes lead to an abrupt increase (or decrease) in the acreage growing biofuel crops, this trend would not be captured in the crop mix projections. |
| Regarding the lowered demand for irrigation water: when a producer switches to a lower demand crop (grapes) they will either spread the water over more acreage or sell that water, so I don't see a scenario where there will be this extra water. | This is a valid point. The estimates of reduced future agricultural demand should be interpreted as a benchmark against which estimates of spreading or water trading can be compared. The team is working on model improvements that would allow them to explore different management scenarios. For example, related to this, the team is looking into the effects of double cropping on water use. Such improvements, however, will not be completed in time to be included in this Report. |

| PUBLIC COMMENT (cont.) | FORECAST TEAM'S RESPONSE (cont.) |
|---|---|
| Why such wide swings between high demand in the last forecast, lower demand now, with higher demand anticipated again in the future? | Improvements that led to changes in the agricultural demand estimates between the 2011 Forecast and this 2016 Forecast include: improved, more regionally-appropriate climate projections (overall wetter); and improved (notably lower) estimates of irrigated pasture in eastern Washington. |
| It seems like there is more water in system early in the season and less at the back end; one solution might be to slow down the water early in the season to capture it for use when we need it later. That's the direction we should be going. Store in aquafers, etc. | The modeled results do point towards increased supply earlier in the season, followed by a longer period of low supply later in the season. This forecast should therefore inform OCR's decisions on what approaches would help meet different demands for water (including the examples offered here). |
| Are there other data sets that are like the irrigated pasture data set, in that we might see large fluctuations in demand? Large changes in the results? | The response given during the public meeting identified trends in double cropping as another factor that could lead to fluctuations in agricultural demand. The 2016 Forecast also focused on the current extent of irrigation, which could change in the future if water development projects make water available to expand irrigation. Though data on acreage where double cropping occurs were not available, the final report includes a very rough first estimate of the impact double cropping could have on irrigation demand, as well as an initial estimate of the impact expanding the irrigated acreage through water development projects would have. |
| The economics model uses county level crop data, but not sure why the cdl (crop data layer) from USDA was not used instead, as this data layer provides crop data at 30 m resolution every year. In addition, double cropping info is also available. In addition, when CO2 increased in the future, did the study consider increased crop biomass which was potentially affecting the water use efficiency? | The integrated biophysical models quantify the impact of increased CO2 concentrations on crop water use efficiency and growth. WSDA data were used instead of USDA's CDL because it provides much more detailed information related to irrigation, which is crucial for this assessment. However, the WSDA's crop data layer does not at this time provide details on double-cropping. Initial assumptions were made to provide a coarse estimate of the impact this practice might have on irrigation demand. |
| Double cropping effects on water will be minimal as more farmers use it in rotational cropping system. | The final report includes a demand estimate calculated for a preliminary scenario of potential increases in double-cropping, and has identified data collection improvements for the 2021 Forecast to better predict the influence of double-cropping. However, it is good to know that this may not be a critical part of total demand; we plan to explore this further in the future. |
| Double cropping needs to be considered. | The final report includes a demand estimate calculated for a preliminary scenario of potential increases in double-cropping, and has identified data collection improvements for the 2021 Forecast to better predict the influence of double-cropping. |
| Use groundwater as storage instead of traditional methods. | The final report includes aquifer storage and recovery as a water supply development tool to address declining groundwater supplies. |
| Increased population may not increase municipal demand. | Changes in future demand were based on recent historical estimates (1985-1995) of municipal/domestic consumptive use and population projections through 2035, since there is no database of consumptive use estimates for this decade. We are exploring alternative methods for estimating consumptive municipal water use for future water modeling work. It is important to mention that many water conservation measures decrease water diverted for municipal use, but not consumptive use. In this study we focus on the consumptive use portion (withdrawal minus wastewater returns). |

| PUBLIC COMMENT (cont.) | FORECAST TEAM'S RESPONSE (cont.) |
|---|---|
| People's behavior will change and homeowner use will decrease - this should not remain a constant in model. | There is a potential for per capita individual homeowner water demand to decrease in the future; however, data for accurately estimating these changes is currently very limited. We are exploring alternative methods for estimating consumptive municipal use for future water modeling work. It is important to mention that many water conservation measures decrease water diverted for municipal use, but not consumptive use. In this study we focus on the consumptive use portion (withdrawal minus wastewater returns). |
| There are some opportunities for waste water to be reused (associated with food processing); future may lie with storage and recovery. | The modeled results should inform OCR's decisions on what approaches would help meet different demands for water (including the examples offered here). |
| I have been attended 2 presentations by WSU, Ecology and Aspect. There seems to be a disjointed message I am hearing from irrigation districts/ producers/municipalities and reading in the Legislative Report.<br>1. The report states the demand for water will decrease 4.9%. This strikes a different picture given the general request from irrigation districts, municipalities and producers. Each entity is asking for more water. It is not a water issue as much as an economic issue. Businesses growing trees fruit and pulp are moving to alfalfa in the Morrow, Oregon area.<br>2. Producers are making economic decisions. Walt Butcher, Former WSU Ag Econ, told me, "Irrigating the CR Basin is not economically feasible." The basin is feeding the world and water is making it happen.<br>3. The Federal Govt. promised 1.2 million acres irrigated and their promise is half met. | 1. It is important to note that the 2016 Forecast projects demand for water will decrease under certain conditions. In many cases the request for more water is linked to conditions outside these boundaries, including demand in drought rather than average years, demand for additional growth in acreage, demand for these uses while double-cropping increases, etc.<br>2. Rough economic estimates of the benefits of OCR's recent water development projects (developed in the last 10 years) suggest that the benefits may have exceeded the cost of these projects, on average, given fairly reasonable assumptions on profitability for most irrigated crops.<br>3. The 2016 Forecast is meant to inform state government-level planning efforts. Political decisions at the Federal level, such as those related to the Columbia Basin Project, are therefore beyond the scope of the Forecast. |
| Hydropower needs to explore the requirements (assume this means demand) for power and the difference between what wind power and other sources besides hydropower, and how that will actually affect the need for more hydropower. | In this 2016 Forecast the research team relied on projections of hydropower energy demand made by the entities involved in hydropower production, mainly the Northwest Power and Conservation Council. Those projections were then coarsely translated into a demand for water in the Columbia River. |
| Surprised by magnitude of change for irrigation and total flow through Bonneville Dam. | Comment noted. The final report includes a range of alternatives to provide additional information on change in irrigation demand (e.g. an initial estimate of the impact that expanding the irrigated acreage through water development projects (already planned by OCR) would have is included, as well as a rough first estimate of the impact double-cropping could have on irrigation demand). |
| When you talk about hydroelectric, how do you factor in the future use of wind power and whatever else? | In this 2016 Forecast the research team relied on projections of hydropower energy demand made by the entities involved in hydropower production, mainly the Northwest Power and Conservation Council. Those projections were then coarsely translated into a demand for water in the Columbia River. |

| PUBLIC COMMENT (cont.) | FORECAST TEAM'S RESPONSE (cont.) |
|---|---|
| Can the model be down-scaled to address tributaries, sub-watershed features? Do the predictions get better? Is there a level of confidence with the existing model (answered: question was really about hydrologic models (not climate) and they are not better at a finer resolution; need better hydrologic models). | Without adequate observational data to parameterize and evaluate the model, hydrologic models are very limited in their ability to accurately capture watershed hydrology. As these observational datasets tend to be very limited at smaller scales, hydrologic models similarly are less accurate as resolutions become finer. Furthermore, we would use a different type of hydrologic model (e.g., a model that captures subsurface lateral flow) when running over small catchments. The focus of this study was to capture hydrologic processes over the tributary to basin scales, not the small catchment scale. |
| Did hydro consider only projects on the Columbia? Or tributaries too? | Hydropower projections were for the whole Columbia River Basin. However, translation of energy needs into water needed to produce such energy via hydropower were obtained from water rights information for Grand Coulee and Grant County PUD. |
| Request for clearer explanation of combined priority scores (in reference to fish score, habitat score, flow), and what could be done with this information (by using this as a strategy document, for example). | The Columbia River Instream Atlas will be described in detail in a separate Dept. of Ecology publication, in preparation. In the meantime, descriptions of the priority scores developed in the original CRIA in 2011 can be found here: https://fortress.wa.gov/ecy/publications/SummaryPages/1112015.html |
| Have you considered the river temperature with your fish score? | River temperature has not yet been incorporated into the fish score. Washington Dept. of Fish and Wildlife staff are aware of the need to do so, and working to include it, now that projections of river temperature are available. |
| You predict consistent conveyance loss, though lots of work has gone into reducing conveyance loss. Did you factor in aging infrastructure? How do you know those won't go down over time? | An important clarification is that this Forecast does not predict conveyance loss. It is due to lack of data to credibly predict changes in conveyance losses that the research team fell back on the assumption that conveyance losses, as a percentage of demand, would not change significantly by 2035. |
| One source for conveyance loss could be talk to Scott Revell, Roza Irrigation District. They made a lot of investments, they may have estimates on conveyance losses 10 years ago, just to include. | Comment noted. We will contact Mr. Revell. |
| What was the % used for conveyance loss? | Conveyance losses varied between 10-30% depending on the WRIA. For example, 25% was used for the Yakima and other WRIAs with a canal system, and 10% for WRIAs without any canal system. |
| ***Comments on Modules - Integrating Declining Groundwater Areas*** | |
| Groundwater flux differs considerably between basalt and alluvial aquifers. With declining water levels there is a change in storage and a domino effect due to transient state. This is difficult to simplify in 2D. | Agreed. The 2016 Forecast effort is simply a "state-of-the-science" evaluation. The 2021 Forecast is expected to investigate these issues further. |
| Be more specific - groundwater and aquifer are not interchangeable terms. | Comment noted. There is a balance between being scientifically accurate and ensuring the broader public understands the issues. |
| Groundwater means wells and the DOE is supposed to get annual reports from anyone with a well in the state of WA. That information should be available and integrated into your figuring. | Well logs were not required before 1977, and not all well users are required to report water level measurements. Some are, including public water systems, or those with water rights that are provisioned in this manner. |
| Is there long-term groundwater monitoring going on in Kittitas County and what has it shown? | Some monitoring in Kittitas County is ongoing. No significant regional declines have been documented to date, although there are isolated areas where physical supply is limiting. |

| PUBLIC COMMENT (cont.) | FORECAST TEAM'S RESPONSE (cont.) |
|---|---|
| You should be viewing groundwater as more connected to surface water, i.e. if groundwater declines it may dewater surface waters. | The groundwater declines described in the 2016 Forecast are a first step towards determining where it is most critical to integrate groundwater, and what data and models are available to do so. Improvements are being considered for the 2021 Forecast. |
| In terms of water supply in groundwater, did you look at the different uses (municipal vs irrigation) based on water quality? Since municipal have higher water quality standards to meet? | Differences in water quality are not addressed in the models used in the 2016 Forecast. |
| Not clear how surface water and groundwater use interact in model. | In the 2016 Forecast, groundwater is not integrated in the biophysical modeling. The Module on groundwater declines described in the 2016 Forecast is a first step towards determining where it is most critical to integrate groundwater, and what data and models are available to do so. Improvements are being considered for the 2021 Forecast. |
| You need to tie in water forecasts with all the other modules - climate change, population growth, and other needs. | The Modules targeted key policy issues and/or evaluated next steps to-wards integration of such topics (groundwater declines, METRIC, expansion to all Washington State) in future Forecasts. |
| When WA DOE talks of 20 year permit wait times, to the citizenry this sounds like government at its worst. | Comment noted. |
| These are fine - and may apply for a few years. But since this is the first time we've raised temperatures on the entire planet we don't know what will happen. I hope you have plans B, C, D, E, and F. | Comment noted. |
| ***Comments on Modules - Water Banking Trends*** | |
| Please address water banking and Ecology looking at tamping down the groundswell of water banks, looking at public interest criteria? What might that be? | The recommendation on public interest criteria is not meant to tamp down water banks. It is meant to provide Ecology some guidance so that the agency can focus the resources it is allocated for managing or processing water banks towards those water banks that are in the greater public interest. |
| Dept of Ecology and other regulatory agencies tend to look at water banking and other issues in a "bloodless" legalistic way without considering emotion, community, etc. creating conflict, thus provoking backlash among population. | Comment noted. |
| Ecology is supposed to administer water banks? | Ecology has statutory authority to hold trust water rights, which is the vehicle that most water banks use to operate. Actual administration of the bank is cooperatively determined via a trust water agreement between Ecology and the water banker (e.g. city, county, irrigation district, private party, etc.). |
| If banking has a one-time fee, how will metering be maintained over time? | Currently, no fee for metering exists. A one-time fee could be a step towards realizing the true cost of this program. Alternatively, an annual fee could be used. |
| Water banking is just one way of doing things. Ecology is heavy on this and promoting it very hard. You need to look 20+ year vision (what do you want to see in the future) and change statutes | Water banking is a water supply development tool across the state, among others available. This Forecast inventoried water markets across the Western United States, highlighted water banking in Washington over the past decade and identified potential improvements to water right transfers transaction cost and efficiencies. |

| PUBLIC COMMENT (cont.) | FORECAST TEAM'S RESPONSE (cont.) |
|---|---|
| Is the July 1st transparency retroactive? Or just for any transfers from that point on? | In the 2016 legislative session Senate Bill 6179 made changes to RCW 90.42.130 that requires Ecology to maintain certain water bank information from 2016 and forward. |
| ***Comments on Modules - Effects of User-Pay Requirements*** | |
| I would be concerned that user-pay permitting may skew water allocation. It would be sad to see agricultural producers lose opportunities to other entities with deeper pockets. | Comment noted. Any future user-pay modifications will be implemented with a robust public process to ensure all views are considered. |
| Columbia River water storage can solve most of the water concerns. Removing water in late winter when predicted flows are very high and storing this water for additional uses by all concerned parties - ag, fish, municipal, etc. No water will mean no economy. User fees can greatly offset cost over longer time frame. | Evaluating and developing opportunities for storage is part of OCR's statutory mission and funding, and OCR will continue to look for strategic ways to implement storage, along with other water supply development techniques. |
| User-pay surveys - were these incentivized? | A two-dollar incentive was sent with the request to complete the survey. This incentive was based on extensive research by the Social and Economic Science Research Center (https://sesrc.wsu.edu), who carried out this survey and has been doing research on survey effectiveness for decades. The Center's Director is among the leading survey researchers in the world. |
| ***Comments on Washington Department of Fish and Wildlife's Columbia River Instream Atlas*** | |
| Should be helpful, provided your assumptions are correct. | As in any type of ecological analysis or modelling effort – including the CRIA habitat scoring protocol – the assumptions should be articulated, and the sensitivity of results to specific assumptions should be evaluated. |
| Consideration of water quality and temperature impacts on the analysis. | Water quality in general – and temperature in particular – has profound impacts on the condition of aquatic habitats with respect to effects on fish survival and production. In the future, the CRIA Project should incorporate temperature data into the scoring methodology for habitat condition – especially in the context of climate change. |
| Will be a good tool to manage the river but needs to be updated regularly as new information and data are gathered. | The Forecast currently is updated every 5 years. In the intervening years, users can use the previous forecast as a benchmark, and use additional data to make informed estimates of at least the direction of change relative to that benchmark. |

| PUBLIC COMMENT (cont.) | FORECAST TEAM'S RESPONSE (cont.) |
|---|---|
| ***Other Comments or Questions*** | |
| Franklin County conservancy board - comment about Dept of Ecology sitting on permits for 20 years and not doing anything. If you are paying someone $50,000 a year and he only does 5 permits a year then yes, each is $10,000, but not through conservancy board. Dept of Ecology is concerned because they receive some of their funding from the general fund of the state, but whenever you increase the value of the land by improving its use, the tax base increases, funding the general fund. In essence they are being paid; that tax goes on forever more. Why penalize someone for trying to put together a project when the cost of a project is already really high? | The Legislature has requested that Ecology maintain an ongoing accounting of water right applications received, and this information is posted to Ecology's Internet site. To ensure that Ecology meets and/or exceeds the goal established by the State Legislature for water right decisions, Ecology has prioritized water rights processing. http://www.ecy.wa.gov/programs/wr/hq/fy2017-wractivity.html |
| Ecology does have a Hillis Rule in place, and so there are environmental benefits and public benefits that would expedite the process. | No response needed. |
| Given the perceived inability of Ecology to do much of anything regarding water rights in a timely manner, regarding statewide water plan, could another department do this work across the state? | The current mandate from the State Legislature makes Dept of Ecology the lead agency on the topic. The Legislature could decide to change that, though the team is currently unaware of any initiative to try and do so. |
| What are the next steps? | The final report will include a concluding section titled *Next Steps—Building Towards the 2021 Forecast.* |

# SECTION 3 – Modules to Inform Key Policy Issues

The 2016 Columbia River Basin Long-Term Supply and Demand Forecast included five modules focusing on key policy issues whose prominence is expected to increase in the next five years. These modules are:

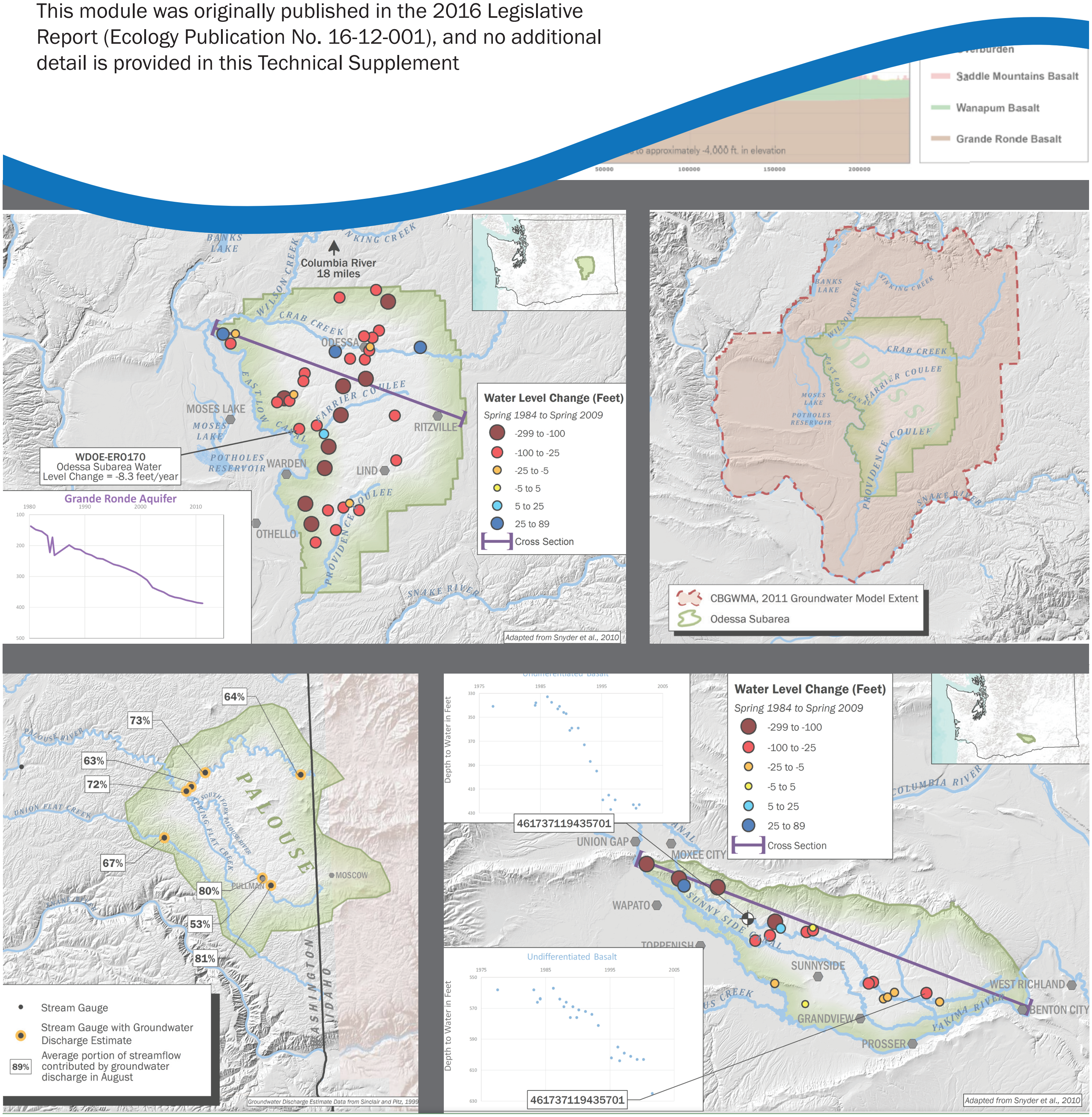
- *Integrating Declining Groundwater Areas into Supply and Demand Forecasting*
- *Pilot Application of METRIC Crop Demand Modeling in Washington State*
- *Water Banking Trends in Washington and Western States*
- *Effects of User-Pay Requirements on Water Permitting*
- *Western Washington Supply and Demand Forecasting*

The 2016 Legislative Report included a detailed chapter on each of these modules, summarizing what was done, the findings of the module, and how it relates to the 2016 or future Forecasts. This Technical Supplement complements the chapters in the Legislative Report, providing additional methodological and analytical details and in-depth results where needed.

Two of the five modules—*Integrating Declining Groundwater Areas into Supply and Demand Forecasting and Western Washington Supply and Demand Forecasting*—were published in their entirety in the 2016 Legislative Report, and no additional detail is provided in this Technical Supplement. In the interest of including the complete set of modules in this Supplement, the modules from the Legislative Report are repeated here. The other three modules in this Technical Supplement include additional detail to that provided in the Legislative Report.

# Integrating Declining Groundwater Areas into Supply and Demand Forecasting

This module was originally published in the 2016 Legislative Report (Ecology Publication No. 16-12-001), and no additional detail is provided in this Technical Supplement



Groundwater is a limited resource in the Columbia River basin, with declining groundwater levels documented in many locations. Groundwater scarcity has impacts on:

- Individual farmer crop choices based on varying water duties (e.g. orchard/vineyard versus seasonal crops)
- Long term economic and public finance outcomes for groundwater users and groundwater-dependent communities.
- Surface water supplies for both instream and ecological uses, and out-of-stream uses, based on increasing use of surface water and impacts to instream flows from declining groundwater levels.
- Public water supplies (use of groundwater may be more preferable and economical than treating surface water).

Previous Water Supply and Demand Forecasts presumed groundwater availability was not limiting the ability of water users to exercise water rights. The analysis and summary described here and in the area summary sheets in the 2016 Water Supply and Demand Forecast represent initial steps to integrate groundwater into the Forecast. The long-term goal of this work is to support better prediction of future water demand and the reliability of existing groundwater rights. In addition, this groundwater integration module provides decision makers with supporting documentation to prioritize investments in water supply development based on risk, feasibility of supply alternatives, review of existing projects addressing declining groundwater, and potential investigation needs.

## *Approach*

The groundwater module consists of two key elements. The first element consisted of a focused literature and data review and summary of declining groundwater across select areas in the Columbia Plateau. The second component has been outreach to inform key stakeholder groups about the incremental addition of groundwater supplies into the Forecast.

### Methodology

A select list of declining groundwater areas was developed through a literature review and consultations with the Washington State Department of Ecology (Ecology). Those areas are presented in Figure 1 and include:

- Black Rock – Moxee Area (Yakima County);
- Odessa Subarea;
- Palouse Groundwater Basin (Whitman County);
- Red Mountain – Badger Mountain Area (Benton County);
- Southwest Flank of the Rattlesnake Hills (Yakima and Benton Counties);
- Walla Walla Basin;
- West Plaines of Spokane;
- West Richland;
- White Salmon Groundwater Supply; and
- Horse Heaven Hills Area (Klickitat and Benton Counties).

Each of these areas were evaluated through a combination of literature review and GIS analysis.

Research was conducted using Water Availability Focus Sheets, Water Resource Inventory Area (WRIA) planning documents, and scientific literature from USGS and others. The literature review also included an assessment of available groundwater models that included the study areas.

As part of the GIS analysis, data was from the following sources:

- Ecology, Washington Department of Natural Resources (DNR), and United States Geological Survey (USGS) monitoring well databases;
- A state-wide Aquifer Storage and Recover (ASR) feasibility study (Gibson and Campana, 2014);
- The USGS stream gage database;
- A state-wide compilation of surface water baseflow estimates (Sinclair and Pitz, 1999);
- The Washington Department of Health (DOH) Sentry water system database; and
- Federal Census Data.

These data were then brought into a GIS framework, organized by area and summarized. Through research and GIS analysis, the hydrogeologic context, scope of groundwater decline, management context, risk, potential solutions, and data gaps were evaluated and summarized in each of the area summaries.

This executive summary discusses general trends in groundwater availability issues identified across the areas. The GIS framework will also available in electronic form.

### Outreach

As part of initiating integration of groundwater into the forecast, public outreach was conducted to inform key stakeholder groups about this work. Outreach meetings included:

- The Columbia River Policy Advisor Group (CRPAG), on January 29, 2015 and August 4, 2016.
- The County Commissioners Policy Advisory Group on August X, 2015.
- The Water Resources Advisory Committee (WRAC) on March 16, 2015 and July 18, 2016.
- Outreach letters sent to county commissioners, watershed planning units, state and federal agencies, and tribes in July 2015.
- Multi-agency meetings with the Washington Department of Fish and Wildlife (WDFW), DOH, DNR, the Washington State Department of Agriculture, and Ecology on May 12, 2015 and August 4, 2016.
- Public open houses in Wenatchee, Kennewick, and Spokane on June 21-23, 2016.

## *Guide to Area Summaries*

Graphical Area Summaries (4 pages each) of our findings for each of the areas of declining groundwater are included as part of the 2016 Forecast. The Area Summaries are organized into eight sections that describe the scope of declining groundwater, investigation needs, and potential and planned solutions. General findings from the study regarding groundwater occurrence and declines are summarized in Section 4 of this Executive Summary.

A key to the summaries is presented in Figure 2. The eight sections included are:

- Hydrogeologic Conceptual Model
- Surface Water-Groundwater Interaction

- Management Context
- Scope of Groundwater Decline
- Available Groundwater Models
- Potential Solutions
- Data Gaps
- Risk Factors

## *Findings on Groundwater Occurrence and Declines*

The Area Summaries present area-specific findings on groundwater occurrence and declines; however, there are general trends that are apparent throughout the Columbia River Basin. Our work builds upon and corroborates findings documented by USGS studies of groundwater availability across the Columbia Plateau (Vaccaro et al. 2015; Burns et al., 2012; and Snyder and Haynes, 2010). These studies documented key groundwater availability issues that are prevalent in the Columbia Plateau in Washington State (Burns et al., 2012):

- Widespread water-level declines due to pumping; and
- Reduction to stream baseflows and associated effects on water temperature and quality.

Our key general findings include:

- Most groundwater use in the Columbia Basin is derived from the Columbia Plateau Regional Aquifer System (CPRAS), an extensive series of basalt flows. The hydrogeologic setting is described in more detail later in this summary.
- Current volumes of groundwater withdrawals exceed quantities locally replenished by recharge from precipitation or surface water infiltration, and as a result, decreases in groundwater levels are occurring in many areas.
- Groundwater declines are further exacerbated in some areas by aquifer isolation related to geologic structures, including faults and folds. These can limit groundwater movement lateral and vertically.
- Instream flow requirements and senior surface water rights also drive limitations on groundwater supply in many areas, particularly in shallow overburden aquifers that are hydraulically well connected with surface water
- Groundwater levels in wells are declining at rates up to approximately 25 feet per year in the basin. The largest and most widespread declines occur in the Odessa Subarea in the central Columbia Plateau, and along the Southwest Flank of the Rattlesnake Hills in the Yakima Valley. Large localized groundwater declines have been documented in other areas such as the Horse Heaven Hills Area and the Black Rock - Moxee Area.
- Groundwater declines have been documented for many decades in most of the study areas. Municipalities in the Palouse groundwater basin have documented steady declines in groundwater levels since the early 20th century. Most of the study areas experienced increasing rates of groundwater decline through the 1970s and 1980s due to increased agricultural production and irrigation, with rates of decline continuing to the present day.
- Declining levels of groundwater may potentially be magnified and accelerated by the effects of global climate change in the coming years and decades (Pitz, 2016). For example, groundwater withdrawals may increase as a response to decreases in surface water availability resulting from climate change. Increases in irrigation demand due to warmer and drier conditions may also result. Increases in shallow groundwater

demand due to climate change could also degrade the ability of groundwater discharge to maintain aquatic habitat quality.

Additional general background, findings, and trends identified in the study are presented below.

## Hydrogeologic Setting

All of the study areas include aquifers within the CPRAS, the regional basalt aquifer system that provides much of the Columbia Basin's groundwater. This regional, multi-aquifer system covers approximately 44,000 mi2 within southeast Washington, northeast Oregon, and western Idaho.

The CPRAS is widespread and highly transmissive in its aquifer zones, and large quantities of water can typically be withdrawn from properly constructed wells. The aquifer is highly compartmentalized both vertically and horizontally and receives very limited recharge, particularly to deeper aquifer zones). While the aquifers are very transmissive, the aquifers store a relatively small amount of water, because they are made up of relatively thin basalt flow boundaries. Low storage, compartmentalization, and limited recharge lead to large declines in groundwater due to pumping.

CRRAS aquifer zones are made up of several thin but productive layers located between thick basalt flows with limited groundwater occurrence. The major aquifers from youngest to oldest are:

- Overburden deposits. Overburden deposits, where they exist, overlie basalt flows and are made up of unconsolidated to semi-consolidated sedimentary deposits and volcanic deposits. While the Wanapum and Grande Ronde supply most of the groundwater used in the Columbia Plateau. The overburden also contains productive and heavily utilized aquifers in some area such as the Southwest Flank of the Rattlesnake Hills in the Yakima Valley.

- Saddle Mountain Basalt. This unit is the shallowest and least widespread of the basalt aquifers. It occurs mostly in the west central portion of the CPRAS. The Saddle Mountain can be up to 1,000 feet.

- Wanapum Basalt. The Wanapum Basalt formation lies below the Saddle Mountain Basalt and is present throughout most of the study area. The thickness of the Wanapum ranges up to 1,200 feet.

- Grande Ronde Basalt. The Grande Ronde is the deepest and most extensive of the basalt formations that are heavily used for groundwater production. The thickness of the Grande Ronde is largely unknown but it may be greater than 14,000 ft. in some locations.

- Other findings regarding the hydrogeologic setting include:

- Although the CPRAS is wide spread, groundwater flow is highly compartmentalized due to structure and horizontal layering within CRBG (Kahle et al., 2011; Kinnison and Sceva, 1963; Hansen et al., 1994; Bauer and Hansen, 2000; Vaccaro et al., 2009).

- Because the interiors of individual basalt flows, or layers, are far more dense and massive than the interflow zones, they limit vertical flow between aquifers. As a result, groundwater flow occurs primarily horizontally through the interflow zones (Kahle et al., 2011), and there is little vertical flow of groundwater between aquifers and little recharge to deeper aquifers.

- Horizontally, groundwater flow is also compartmentalized by faults and folds that offset and truncate the highly transmissive interflow zones, particularly within the area known as the Yakima Fold Belt. Aquifer compartmentalization exacerbates groundwater declines from pumping because it restricts groundwater supply to a smaller area.

- Areas that have a high degree of aquifer compartmentalization include the Black Rock – Moxee Area, Horse Heaven Hills Area, West Richland, the Red Mountain – Badger Mountain Area, the Palouse Groundwater Basin, the West Plains of Spokane, and the City of White Salmon Water Supply Aquifer.

- Groundwater flow in the CPRAS is typically controlled by topography. The highest recharge from precipitation occurs along the margins of the CPRAS near the mountains.  Groundwater discharges from the CPRAS along the major rivers of the Columbia River Basin.

## Surface Water-Groundwater Interaction

Overburden aquifers are typically connected with streams in many areas including the Walla Walla and Yakima Basins (Vaccaro, 2011; GSI, 2007). Instream flow needs can impose limitations on groundwater supply from overburden aquifers in many areas. These include the Southwest Flank of Rattlesnake Hills in the Yakima Valley and in the Walla Walla Basin. Basalt aquifers, by contrast, are more hydraulically separated from surface water in most areas due to depth and compartmentalization by faulting, folding, and dense basalt flow interiors. More hydraulic connection can exist where river canyons have incised deep into the basalt, such as along the Columbia and Snake Rivers, portions of the Yakima River, and in the West Planes of Spokane. In areas such as these, streams can gain flow from basalt aquifers and loose flow to recharge basalt aquifers (Kahle et. al., 2011; Ecology, 2013c; and Drost, 1997).

## Management Context

The management context refers to the regulation of the surface and groundwater within the Area Summaries, including groundwater management areas and instream flow rules. Existing instream flow rules established by Ecology and Surface Water Source Limitations (SWSLs) established by WDFW can impose regulatory restrictions on groundwater use from aquifers in connection with surface water in areas such as the Yakima and Walla Walla Basins. This is particularly the case in overburden aquifers which are typically hydraulically well connected with streams and rivers.

Of the selected areas, only the Odessa Subarea is included in a groundwater management area. Legislation that established the area (chapter 173-128A, 173-130) limits groundwater withdrawals such that declines don't exceed 300 feet or 30 feet in 3 years.  As groundwater declines continue, Ecology will likely face additional pressure to adopt formal regulatory frameworks in basins where these are lacking now.

## Risk Factors

Large communities of people and several agricultural economies depend on groundwater resources in the study areas. Many of areas rely on groundwater primarily for agriculture, including the Odessa Subarea, Southwest Flank of the Rattlesnake Hills, Black Rock – Moxee Area, Horse Heaven Hills Area, and Red Mountain – Badger Mountain Area.

Several areas also rely on groundwater for municipal use as a primary water source, or during peak times and the dry season including the Odessa Area, Southwest Flank of the Rattlesnake Hills, West Plains of Spokane, Palouse Groundwater Basin, Walla Walla Basin, West Richland, and White Salmon.

The areas summarize in this report include an estimated total of 580,000 acres irrigated with groundwater and approximately 232,000 people served by public water systems that rely on groundwater.

## Solutions

Several projects either are planned or in progress in many of the areas to alleviate declining groundwater, and additional solutions are potentially feasible. These include both demand-oriented and supply-oriented solutions.

Supply-oriented solutions include moving groundwater users from groundwater to surface water sources. For example, a plan is underway to switch approximately 90,000 acres in the Odessa Subarea from groundwater irrigation to surface water irrigation. The switch to surface water is intended to reduce withdrawals and associated groundwater level declines with the local aquifers.

It may be impractical or costly switch to surface water in many areas, because surface water is often fully appropriated. In these areas, other solutions potentially available include Aquifer Storage and Recovery (ASR) and the creation of new surface water storage reservoirs. These options may be technically feasible in many of these areas, taking advantage of more abundant surface water during the winter with storage for later use during the summer. Similarly, shallow aquifer recharge is beneficial in many areas to maintain healthy stream flows during the summer by boosting groundwater discharge to streams.

Storage projects of all types are planned and being implemented in many of the areas including the Odessa Subarea, Horse Heaven Hills Area, White Salmon, South West Flank of the Rattlesnake Hills, and the Walla Walla Basin. Additional projects may be physically feasible in the Palouse, West Planes of Spokane, Red Mountain – Badger Mountain Area, and West Richland. While these solutions are considered physically feasible based on the aquifer setting and potential availability of surface, project feasibility will also depend on economics and regulatory considerations that have not been considered in detail in this study.

Demand side solutions are also being implemented or are feasible in many of the areas. Conservation plans are common in municipalities. Additional conservation measures can be implemented in many areas including xeriscaping, use of reclaimed water, crop type changes, and improved irrigation efficiencies. Currently, demand side solutions are largely voluntary or incentive based. As groundwater declines become more significant, mandatory measures instituted by state and local governments may become more common.

Each of the Area Summaries contains supply-side and demand-side measures that are applicable to each declining groundwater body.

## *Ongoing Integration of Groundwater into the Forecast*

### Summary of Potential Investigation Needs

This assessment of declining groundwater issues in Washington State was supported and made possible by existing documentation of research on groundwater availability that has been carried out in Washington State and made available to the public. Data gaps in knowledge regarding declining groundwater in the basin do exist, and additional investigation to both design solutions to existing problems and investigate new problems will be needed.

In addition, ongoing and expanded groundwater monitoring is essential. Additional modeling of groundwater availability is also considered needed to support management of groundwater into the future. Population increases, industry and agriculture changes, and climate change are all expected to alter patterns of groundwater use and aquifer water balances as time goes on. Potential investigation needs in the select areas of declining groundwater are summarized below:

#### *Groundwater Monitoring*

- We recommend that long-term groundwater monitoring be continued in many areas and that ease of access to groundwater level data be improved. The collection and analysis of water level elevations in wells through time is essential for the continuing evaluation of groundwater availability.

- Access to widespread and long term groundwater monitoring data allowed the USGS to estimate current trends in groundwater availability throughout the Columbia Basin (Vaccaro et al. 2015; Burns et al., 2012;

and Snyder and Haynes, 2010). Monitoring should be continued and expanded to evaluate availability into the future with more refinement and to provide continued historical trend information.

- A review of water level databases maintained by Ecology and the USGS indicated that for some areas with declining groundwater, historical water level monitoring has not continued into the present day or has not been uploaded to the databases. We recommend long-term monitoring with an expanded well network, and continued monitoring at wells that have historical data.

- In many areas, comprehensive groundwater monitoring efforts are being conducted by basin committees, irrigation districts, local water utilities and the Department of Natural Resources; however, not all data is not readily available in an easy to access central location on line.

- Ecology's monitoring well database is an effective and easy to use tool where water level data is consolidated and retrievable. An increase in submission of existing and future monitoring data would improve access to data and ease groundwater availability assessment. Our research indicates that there may be water level data in West Richland, White Salmon, Palouse, West Planes of Spokane, and Walla Walla that can be submitted to the Ecology database.

### *Groundwater Modeling*

- Groundwater modeling can support assessments of groundwater availability and historical trends and future impacts. An example of this is the assessment of regional trends in groundwater availability and water balances that Vaccaro et al. (2015) conducted for the CPRAS, and Ely et al. (2011) completed for the Yakima Valley. These models could be maintained and updated periodically with current water use data, climate projections, and additional data on the hydrogeologic systems to support accurate forecasts into the future.

- Local scale models could also be constructed to provide detailed analysis of groundwater availability and water balances within specific areas. In addition, smaller scale models can be useful for the assessment and design of potential storage projects such as ASR.

### *Hydrogeological Studies*

- Additional hydrogeologic studies can support the siting and design of storage projects, and also can be used to refine new or existing groundwater models for supporting groundwater management.

- Literature and WRIA planning documents reviewed as part of this study identified the need for a more refined characterization of aquifer compartmentalization and location of hydraulic barriers in the Horse Heaven Hills Area and the Palouse Groundwater Basin (WRIA 31 Planning Unit, 2008; TerraGraphics, 2011).

- WRIA planning documents also recommended increased exploration of the Grande Ronde aquifer for potential new sources of groundwater (WRIA 31 Planning Unit, 2008).

### *Storage Feasibility and Pilot Studies*

- ASR and SAR have been identified as potentially physically feasible within many areas (Gibson and Campana, 2014). These storage solutions have the potential to reduce declining groundwater or improve aquatic habitat by increasing groundwater discharge to streams.

- Prior to project implementation, potential additional analyses needed include hydrogeologic studies, including groundwater modeling, economic analysis, and pilot studies.

### *Conservation and Management Strategies*

Moving from voluntary to either incentive-based or mandated conservation strategies will likely be needed in some areas just to minimize groundwater decline-related impacts on existing water users. Because these efforts are likely to be best-received by the regulated community if they are initiated at the local level, County government and watershed planning units in areas with groundwater declines should be engaged to improve awareness and initiate conservation programs.

## Model Integration for 2021 Forecast

Decreases in surface water availability usually leads water users to switch to groundwater sources wherever groundwater is available and accessible. Because groundwater offers supplies that are often buffered from yearly hydrologic fluctuations, and in many cases from recharge over a geologic time-step, this has been a typical transfer protocol that has been encouraged by state agencies.  However, users in the areas described in this document will find it harder to convert their supplies to surface water because supply is generally not available in the summer without frequent interruption. These users instead may be forced into more extreme adaptation including crop change, field fallowing, participation in water supply projects with a mandatory cost-recovery component, strict conservation, or reuse.

WSU believes that OCR forecasting in 2021 would benefit from expanded assessment of these water right holders. We considered two approaches:

1. Direct integration of existing and new groundwater models with the existing modeling effort;

2. A more robust curtailment model that helps predict the effects of emerging groundwater curtailment on supply, demand, and economic factors.

The first option would allow assessment of the hydrologic aspects of surface and groundwater interactions, enabling quantification of the delayed effects of drought relief pumping on surface water availability in highly connected systems, improved assessment of return flows from irrigation water and conveyance losses, etc. However, direct integration of groundwater models with the current hydrologic models that are used for the Forecast is technically challenging, computationally intensive, and limited by the availability of consistent groundwater models over key areas in eastern Washington. Over time, we anticipate that the state-of-the-science will continue to evolve such that this more direct integration will be feasible for future forecasts. Alternatively, for the next forecast, we plan to instead focus on the role that groundwater plays within the regulatory context.

As part of the 2021 Forecast WSU proposes to identify the areas with declining groundwater and its potential links to surface water availability through a curtailment model, based in part on historical data. As a part of the 2016 Forecast, a surface water curtailment model has been developed which accounts for surface water availability and priority of water right holders to execute curtailment. The surface water curtailment model will be expanded for the 2021 Forecast to dynamically account for transitions between surface and groundwater use. Results from this curtailment model, historical groundwater information, and local observation wells will be used to establish a relationship between surface water and groundwater that can be analyzed as a function of current and future climate and water demand.

WSU envisions several focused efforts that will contribute to the predictive effort of a curtailment model that integrates declining groundwater areas, including:

1. Emerging areas of increased regulation either at the groundwater subbasin scale through closures, or targeted efforts through interviews with Ecology water masters.

2. County and State health jurisdiction efforts to ensure reliable public water supplies.

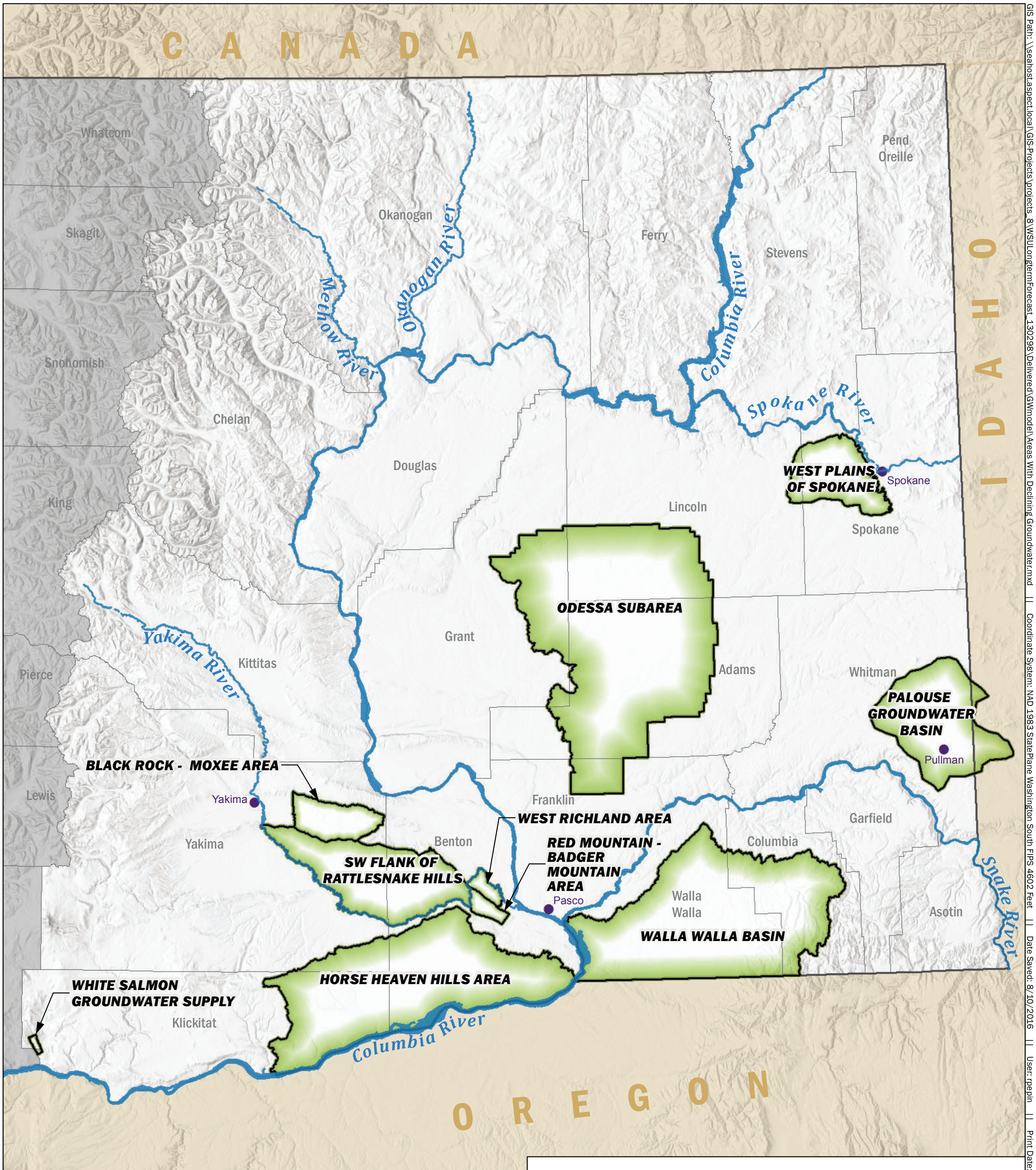
3. Assessments of priority-schemes in each declining groundwater subbasin to define those water rights most likely to first feel the brunt of new curtailment efforts, and the economic implications thereof.

4. Historical water use information from surface-to-ground and ground-to-surface transfers, as well as supplemental and emergency well authorizations, to help to identify the areas and conditions where water rights holders are switching between sources.

In order for this effort to be successful, WSU recommends more robust and continued investments in the data gaps shown on the Area Summaries to better understand declining groundwater levels and how dependence on groundwater may change, including in response to future climate change.

The groundwater module helped inform Ecology on the areas in Eastern Washington to prioritize for information gathering, outreach, and governmental coordination, if effects of groundwater declines on future forecasts are going to be better understood. Ecology uses each Forecast as an investment tool for future grant funding of supply projects, and will consider additional efforts to better understand how its water supply mission should be prioritized to address areas of groundwater decline.

Additional groundwater development is already limited in all areas in Washington where there are regulated or closed surface water bodies. The current focus on documented areas of decline is therefore a first step towards identifying the places where is it critical to integrate groundwater sup-ply modeling into future Forecasts.




**Selected Areas with Declining Groundwater**

Executive Summary
Longterm Forecast
Washington State

| | | | |
|---|---|---|---|
| Aspect CONSULTING | AUG-2016 | BY: EAC / SDM | FIGURE NO. |
| | PROJECT NO. 130298 | REVISED BY: RAP | 1 |

Basemap Layer Credits || USGS, NGA, NASA, CGIAR,N Robinson,NCEAS,NLS,OS,NMA,Geodatastyrelsen
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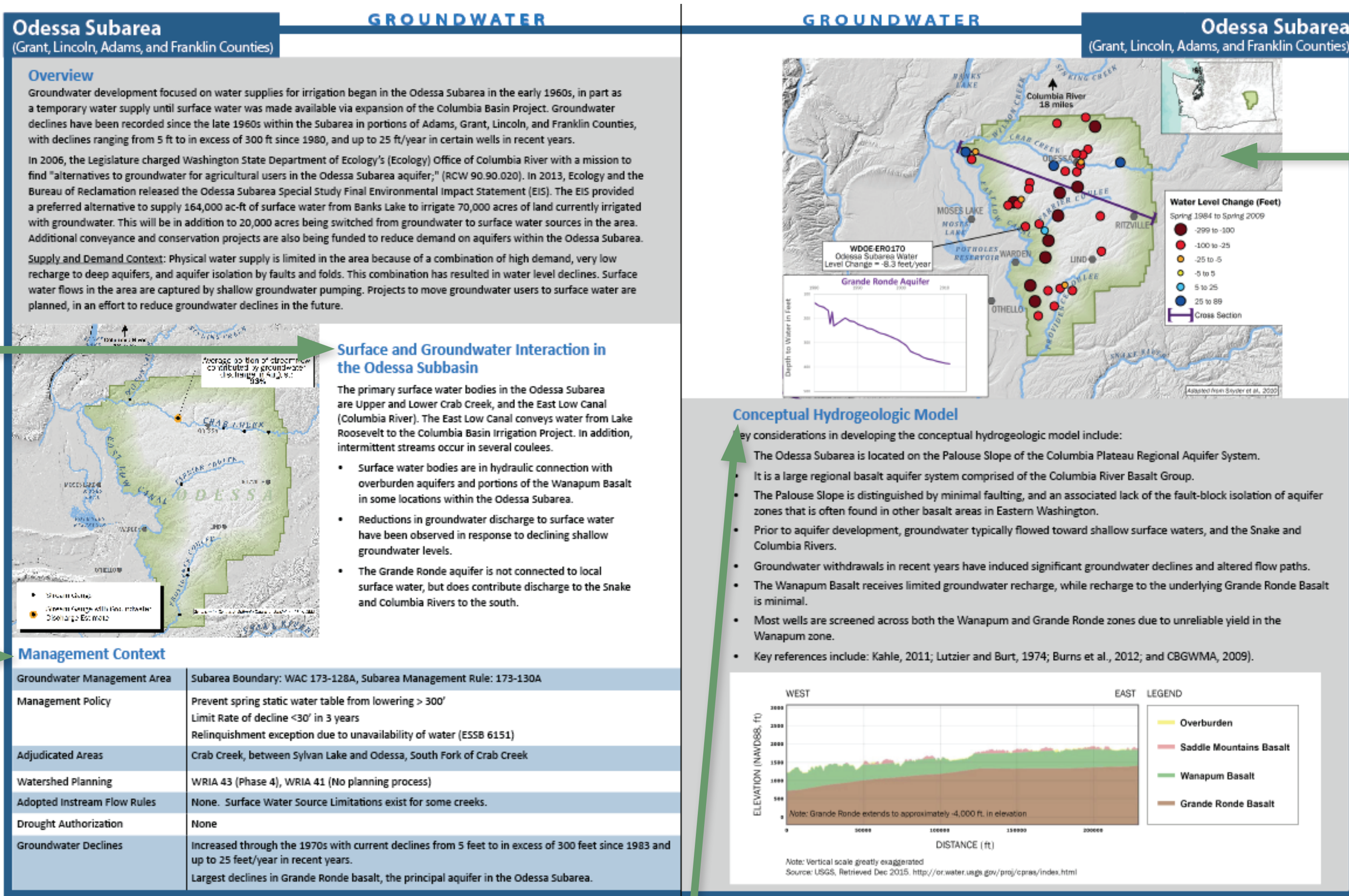
# How to Read the Groundwater Pages



GROUNDWATER

**Odessa Subarea**
(Grant, Lincoln, Adams, and Franklin Counties)

**Overview**

Groundwater development focused on water supplies for irrigation began in the Odessa Subarea in the early 1960s, in part as a temporary water supply until surface water was made available via expansion of the Columbia Basin Project. Groundwater declines have been recorded since the late 1960s within the Subarea in portions of Adams, Grant, Lincoln, and Franklin Counties, with declines ranging from 5 ft to in excess of 300 ft since 1980, and up to 25 ft/year in certain wells in recent years.

In 2006, the Legislature charged Washington State Department of Ecology's (Ecology) Office of Columbia River with a mission to find "alternatives to groundwater for agricultural users in the Odessa Subarea aquifer;" (RCW 90.90.020). In 2013, Ecology and the Bureau of Reclamation released the Odessa Subarea Special Study Final Environmental Impact Statement (EIS). The EIS provided a preferred alternative to supply 164,000 ac-ft of surface water from Banks Lake to irrigate 70,000 acres of land currently irrigated with groundwater. This will be in addition to 20,000 acres being switched from groundwater to surface water sources in the area. Additional conveyance and conservation projects are also being funded to reduce demand on aquifers within the Odessa Subarea.

Supply and Demand Context: Physical water supply is limited in the area because of a combination of high demand, very low recharge to deep aquifers, and aquifer isolation by faults and folds. This combination has resulted in water level declines. Surface water flows in the area are captured by shallow groundwater pumping. Projects to move groundwater users to surface water are planned, in an effort to reduce groundwater declines in the future.

**Surface and Groundwater Interaction in the Odessa Subbasin**

The primary surface water bodies in the Odessa Subarea are Upper and Lower Crab Creek, and the East Low Canal (Columbia River). The East Low Canal conveys water from Lake Roosevelt to the Columbia Basin Irrigation Project. In addition, intermittent streams occur in several coulees.

- Surface water bodies are in hydraulic connection with overburden aquifers and portions of the Wanapum Basalt in some locations within the Odessa Subarea.
- Reductions in groundwater discharge to surface water have been observed in response to declining shallow groundwater levels.
- The Grande Ronde aquifer is not connected to local surface water, but does contribute discharge to the Snake and Columbia Rivers to the south.

**Management Context**

| | |
|---|---|
| Groundwater Management Area | Subarea Boundary: WAC 173-128A, Subarea Management Rule: 173-130A |
| Management Policy | Prevent spring static water table from lowering > 300'<br>Limit Rate of decline <30' in 3 years<br>Relinquishment exception due to unavailability of water (ESSB 6151) |
| Adjudicated Areas | Crab Creek, between Sylvan Lake and Odessa, South Fork of Crab Creek |
| Watershed Planning | WRIA 43 (Phase 4), WRIA 41 (No planning process) |
| Adopted Instream Flow Rules | None. Surface Water Source Limitations exist for some creeks. |
| Drought Authorization | None |
| Groundwater Declines | Increased through the 1970s with current declines from 5 feet to in excess of 300 feet since 1983 and up to 25 feet/year in recent years.<br>Largest declines in Grande Ronde basalt, the principal aquifer in the Odessa Subarea. |

GROUNDWATER

**Odessa Subarea**
(Grant, Lincoln, Adams, and Franklin Counties)



**Conceptual Hydrogeologic Model**

Key considerations in developing the conceptual hydrogeologic model include:

- The Odessa Subarea is located on the Palouse Slope of the Columbia Plateau Regional Aquifer System.
- It is a large regional basalt aquifer system comprised of the Columbia River Basalt Group.
- The Palouse Slope is distinguished by minimal faulting, and an associated lack of the fault-block isolation of aquifer zones that is often found in other basalt areas in Eastern Washington.
- Prior to aquifer development, groundwater typically flowed toward shallow surface waters, and the Snake and Columbia Rivers.
- Groundwater withdrawals in recent years have induced significant groundwater declines and altered flow paths.
- The Wanapum Basalt receives limited groundwater recharge, while recharge to the underlying Grande Ronde Basalt is minimal.
- Most wells are screened across both the Wanapum and Grande Ronde zones due to unreliable yield in the Wanapum zone.
- Key references include: Kahle, 2011; Lutzier and Burt, 1974; Burns et al., 2012; and CBGWMA, 2009).



Note: Vertical scale greatly exaggerated
Source: USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

This section summarizes research on the degree of connectivity between surface water and important aquifers in each area. Groundwater discharge to surface water plays an important part in maintaining the quality of aquatic habitat in many Columbia Plateau streams by augmenting flows and maintaining cool temperatures during the summer. In some areas, surface water may also recharge groundwater.

The hydrogeologic conceptual model describe the hydraulic and geologic characteristics that affect groundwater availability and impacts from pumping. Hydrogeologic conditions, including the degree of aquifer compartmentalization, availability of recharge, and prominence of different aquifer zones vary between areas of the basin. A cross section illustrating the stratigraphy and compartmentalization is also included where available.

This section provides a summary of area groundwater policies, watershed planning, instream flow restrictions, water right adjudications, and other management criteria.

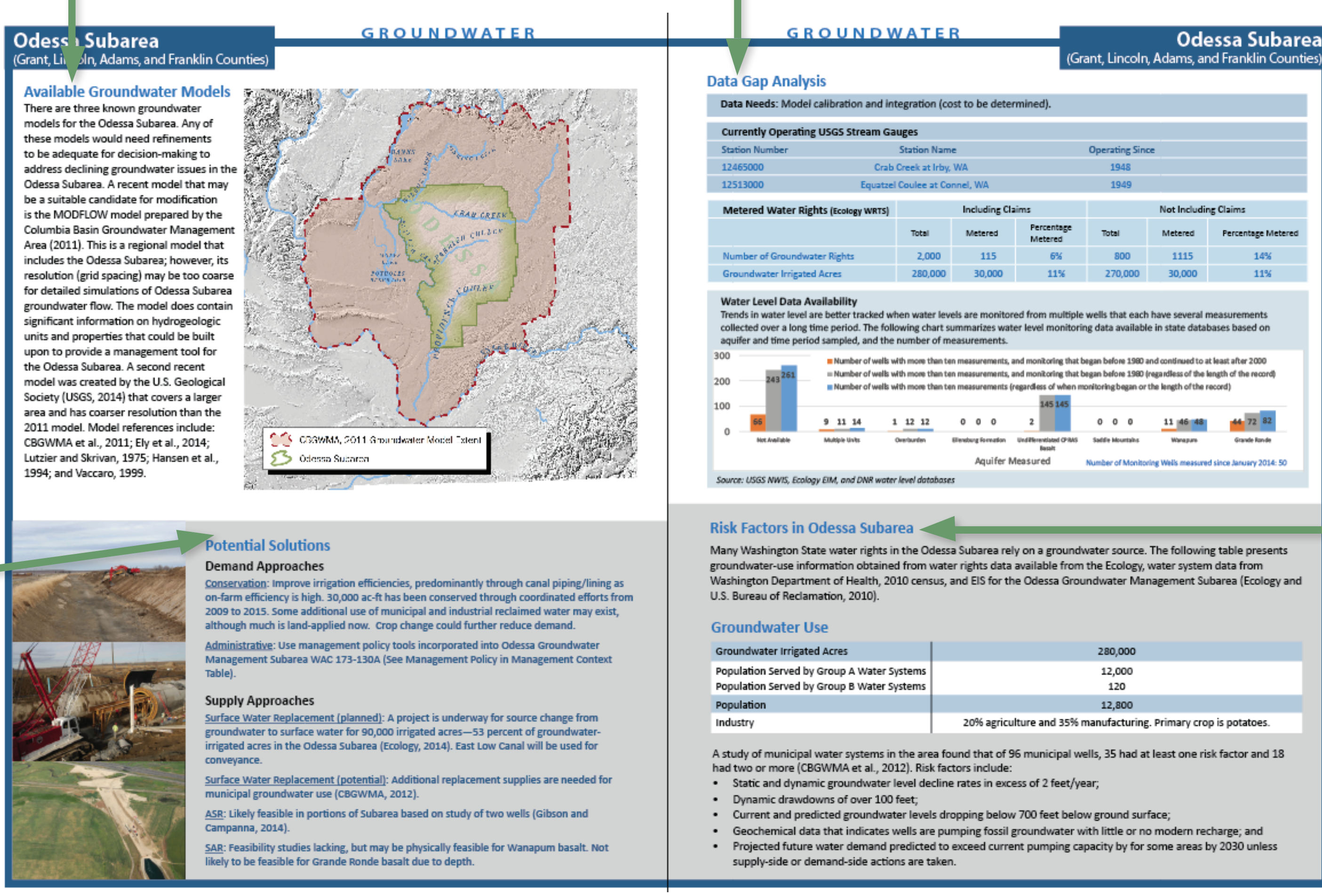
This section summarizes water supply or demand solutions that may be feasible, being planned or being implemented in each area. Supply side solutions include switching to new sources of water or storage. Demand oriented solutions work to decrease water use through measures such as conservation.

Measurements of groundwater declines are presented in maps for each geographic area. Maps include scaled dots or graphs representing the change in water levels over time.

This section summarizes metered water use data, stream flow data, and water level data available from Ecology and USGS databases in each area. Recommendations for future investigation, data collection, and studies are provided.

This section summarizes the availability of groundwater models in each of the areas. Numerical computer models of groundwater flow are an essential tool in groundwater resource management. Models can support forecasting of future groundwater availability, siting and design of water supply solutions.

This section comments on the risks associated with existing and future groundwater level declines. Where available, a summary of the number of residents, scale and nature of economic drivers, and acres of agriculture that rely on groundwater in each area is presented.



GROUNDWATER

**Odessa Subarea**
(Grant, Lincoln, Adams, and Franklin Counties)

## Available Groundwater Models

There are three known groundwater models for the Odessa Subarea. Any of these models would need refinements to be adequate for decision-making to address declining groundwater issues in the Odessa Subarea. A recent model that may be a suitable candidate for modification is the MODFLOW model prepared by the Columbia Basin Groundwater Management Area (2011). This is a regional model that includes the Odessa Subarea; however, its resolution (grid spacing) may be too coarse for detailed simulations of Odessa Subarea groundwater flow. The model does contain significant information on hydrogeologic units and properties that could be built upon to provide a management tool for the Odessa Subarea. A second recent model was created by the U.S. Geological Society (USGS, 2014) that covers a larger area and has coarser resolution than the 2011 model. Model references include: CBGWMA et al., 2011; Ely et al., 2014; Lutzier and Skrivan, 1975; Hansen et al., 1994; and Vaccaro, 1999.



## Potential Solutions

### Demand Approaches

Conservation: Improve irrigation efficiencies, predominantly through canal piping/lining as on-farm efficiency is high. 30,000 ac-ft has been conserved through coordinated efforts from 2009 to 2015. Some additional use of municipal and industrial reclaimed water may exist, although much is land-applied now. Crop change could further reduce demand.

Administrative: Use management policy tools incorporated into Odessa Groundwater Management Subarea WAC 173-130A (See Management Policy in Management Context Table).

### Supply Approaches

Surface Water Replacement (planned): A project is underway for source change from groundwater to surface water for 90,000 irrigated acres—53 percent of groundwater-irrigated acres in the Odessa Subarea (Ecology, 2014). East Low Canal will be used for conveyance.

Surface Water Replacement (potential): Additional replacement supplies are needed for municipal groundwater use (CBGWMA, 2012).

ASR: Likely feasible in portions of Subarea based on study of two wells (Gibson and Campanna, 2014).

SAR: Feasibility studies lacking, but may be physically feasible for Wanapum basalt. Not likely to be feasible for Grande Ronde basalt due to depth.

GROUNDWATER

**Odessa Subarea**
(Grant, Lincoln, Adams, and Franklin Counties)

## Data Gap Analysis

**Data Needs:** Model calibration and integration (cost to be determined).

| Currently Operating USGS Stream Gauges | | |
|---|---|---|
| Station Number | Station Name | Operating Since |
| 12465000 | Crab Creek at Irby, WA | 1948 |
| 12513000 | Equatzel Coulee at Connel, WA | 1949 |

| Metered Water Rights (Ecology WRTS) | Including Claims | | | Not Including Claims | | |
|---|---|---|---|---|---|---|
| | Total | Metered | Percentage Metered | Total | Metered | Percentage Metered |
| Number of Groundwater Rights | 2,000 | 115 | 6% | 800 | 1115 | 14% |
| Groundwater Irrigated Acres | 280,000 | 30,000 | 11% | 270,000 | 30,000 | 11% |

**Water Level Data Availability**
Trends in water level are better tracked when water levels are monitored from multiple wells that each have several measurements collected over a long time period. The following chart summarizes water level monitoring data available in state databases based on aquifer and time period sampled, and the number of measurements.



*Source: USGS NWIS, Ecology EIM, and DNR water level databases*

## Risk Factors in Odessa Subarea

Many Washington State water rights in the Odessa Subarea rely on a groundwater source. The following table presents groundwater-use information obtained from water rights data available from the Ecology, water system data from Washington Department of Health, 2010 census, and EIS for the Odessa Groundwater Management Subarea (Ecology and U.S. Bureau of Reclamation, 2010).

## Groundwater Use

| | |
|---|---|
| Groundwater Irrigated Acres | 280,000 |
| Population Served by Group A Water Systems<br>Population Served by Group B Water Systems | 12,000<br>120 |
| Population | 12,800 |
| Industry | 20% agriculture and 35% manufacturing. Primary crop is potatoes. |

A study of municipal water systems in the area found that of 96 municipal wells, 35 had at least one risk factor and 18 had two or more (CBGWMA et al., 2012). Risk factors include:

- Static and dynamic groundwater level decline rates in excess of 2 feet/year;
- Dynamic drawdowns of over 100 feet;
- Current and predicted groundwater levels dropping below 700 feet below ground surface;
- Geochemical data that indicates wells are pumping fossil groundwater with little or no modern recharge; and
- Projected future water demand predicted to exceed current pumping capacity by for some areas by 2030 unless supply-side or demand-side actions are taken.

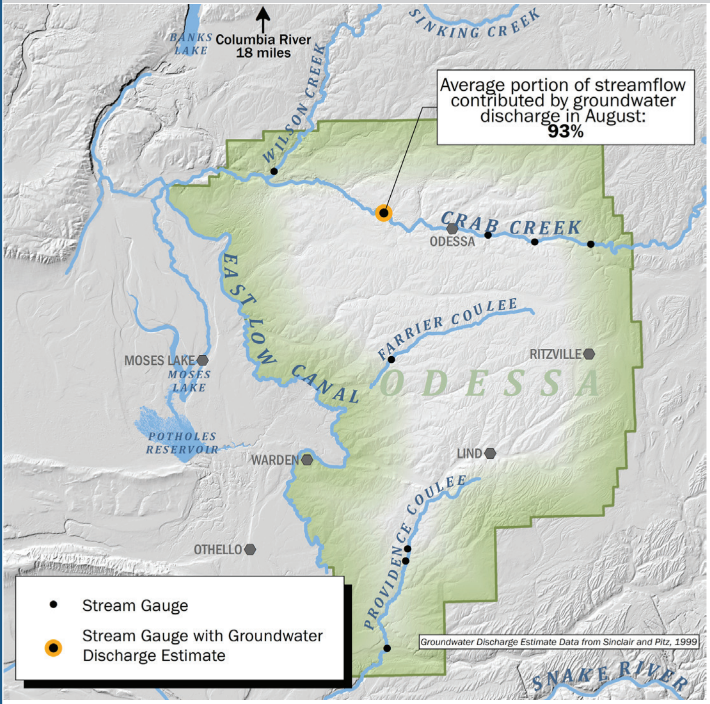
# Odessa Subarea
(Grant, Lincoln, Adams, and Franklin Counties)

## Overview

Groundwater development focused on water supplies for irrigation began in the Odessa Subarea in the early 1960s, in part as a temporary water supply until surface water was made available via expansion of the Columbia Basin Project. Groundwater declines have been recorded since the late 1960s within the Subarea in portions of Adams, Grant, Lincoln, and Franklin Counties, with declines ranging from 5 ft to in excess of 300 ft since 1980, and up to 25 ft/year in certain wells in recent years.

In 2006, the Legislature charged Washington State Department of Ecology's (Ecology) Office of Columbia River with a mission to find "alternatives to groundwater for agricultural users in the Odessa Subarea aquifer;" (RCW 90.90.020). In 2013, Ecology and the Bureau of Reclamation released the Odessa Subarea Special Study Final Environmental Impact Statement (EIS). The EIS provided a preferred alternative to supply 164,000 ac-ft of surface water from Banks Lake to irrigate 70,000 acres of land currently irrigated with groundwater. This will be in addition to 20,000 acres being switched from groundwater to surface water sources in the area. Additional conveyance and conservation projects are also being funded to reduce demand on aquifers within the Odessa Subarea.

Supply and Demand Context: Physical water supply is limited in the area because of a combination of high demand, very low recharge to deep aquifers, and aquifer isolation by faults and folds. This combination has resulted in water level declines. Surface water flows in the area are captured by shallow groundwater pumping. Projects to move groundwater users to surface water are planned, in an effort to reduce groundwater declines in the future.




## Surface and Groundwater Interaction in the Odessa Subbasin

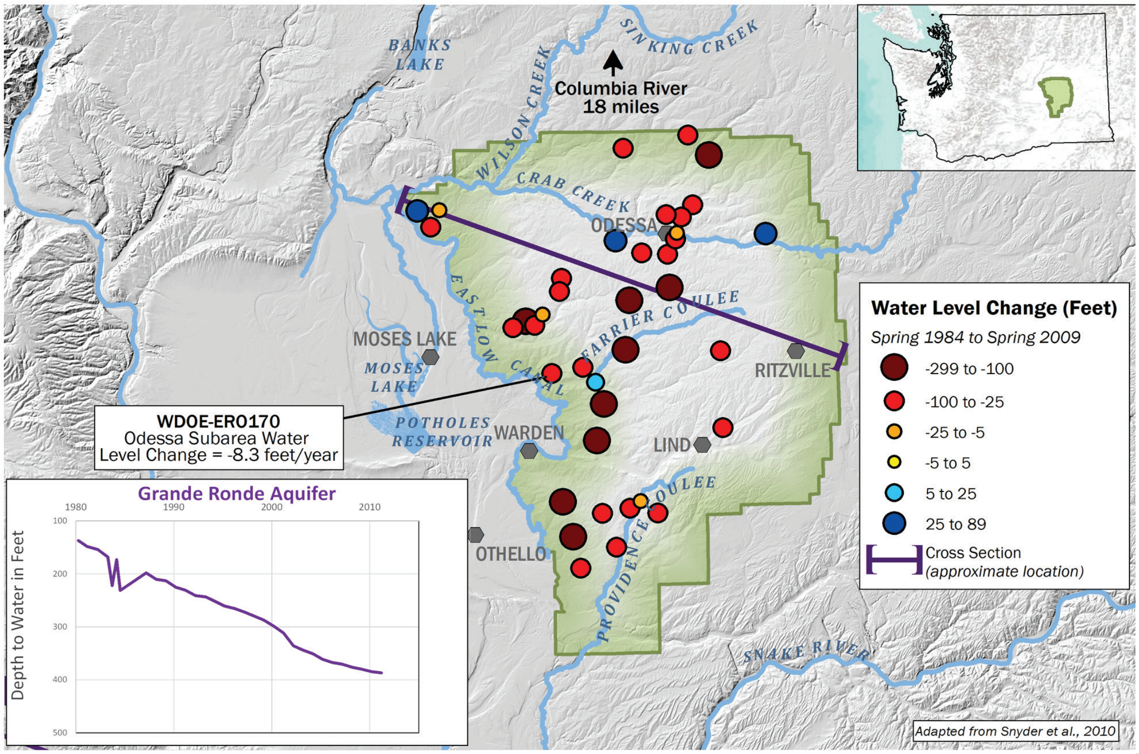
The primary surface water bodies in the Odessa Subarea are Upper and Lower Crab Creek, and the East Low Canal (Columbia River). The East Low Canal conveys water from Lake Roosevelt to the Columbia Basin Irrigation Project. In addition, intermittent streams occur in several coulees.

- Surface water bodies are in hydraulic connection with overburden aquifers and portions of the Wanapum Basalt in some locations within the Odessa Subarea.
- Reductions in groundwater discharge to surface water have been observed in response to declining shallow groundwater levels.
- The Grande Ronde aquifer is not connected to local surface water, but does contribute discharge to the Snake and Columbia Rivers to the south.

## Management Context

| | |
|---|---|
| Groundwater Management Area | Subarea Boundary: WAC 173-128A, Subarea Management Rule: 173-130A |
| Management Policy | Prevent spring static water table from lowering > 300'<br>Limit Rate of decline <30' in 3 years<br>Relinquishment exception due to unavailability of water (ESSB 6151) |
| Adjudicated Areas | Crab Creek, between Sylvan Lake and Odessa, South Fork of Crab Creek |
| Watershed Planning | WRIA 43 (Phase 4), WRIA 41 (No planning process) |
| Adopted Instream Flow Rules | None. Surface Water Source Limitations exist for some creeks. |
| Drought Authorization | None |
| Groundwater Declines | Increased through the 1970s with current declines from 5 feet to in excess of 300 feet since 1983 and up to 25 feet/year in recent years.<br>Largest declines in Grande Ronde basalt, the principal aquifer in the Odessa Subarea. |

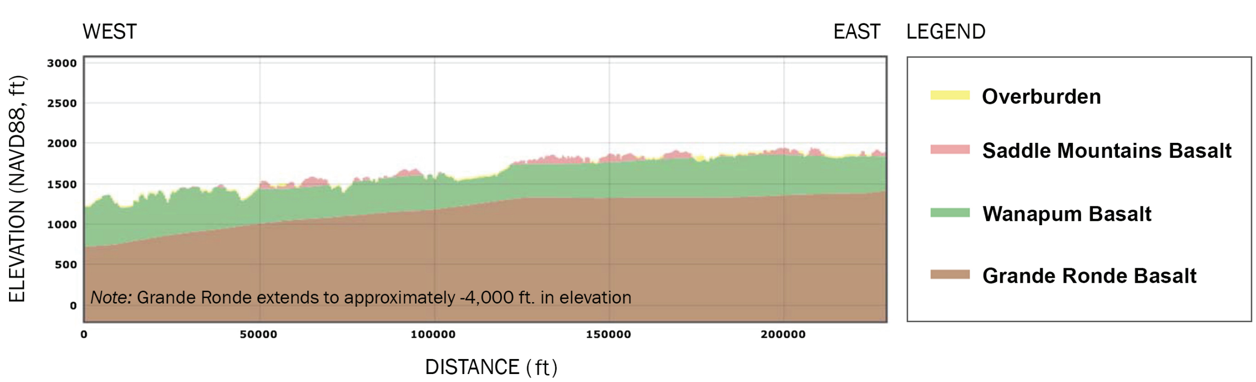
# Odessa Subarea
(Grant, Lincoln, Adams, and Franklin Counties)




## Conceptual Hydrogeologic Model

Key considerations in developing the conceptual hydrogeologic model include:

- The Odessa Subarea is located on the Palouse Slope of the Columbia Plateau Regional Aquifer System.
- It is a large regional basalt aquifer system comprised of the Columbia River Basalt Group.
- The Palouse Slope is distinguished by minimal faulting, and an associated lack of the fault-block isolation of aquifer zones that is often found in other basalt areas in Eastern Washington.
- Prior to aquifer development, groundwater typically flowed toward shallow surface waters, and the Snake and Columbia Rivers.
- Groundwater withdrawals in recent years have induced significant groundwater declines and altered flow paths.
- The Wanapum Basalt receives limited groundwater recharge, while recharge to the underlying Grande Ronde Basalt is minimal.
- Most wells are screened across both the Wanapum and Grande Ronde zones due to unreliable yield in the Wanapum zone.
- Key references include: Kahle, 2011; Lutzier and Burt, 1974; Burns et al., 2012; and CBGWMA, 2009).

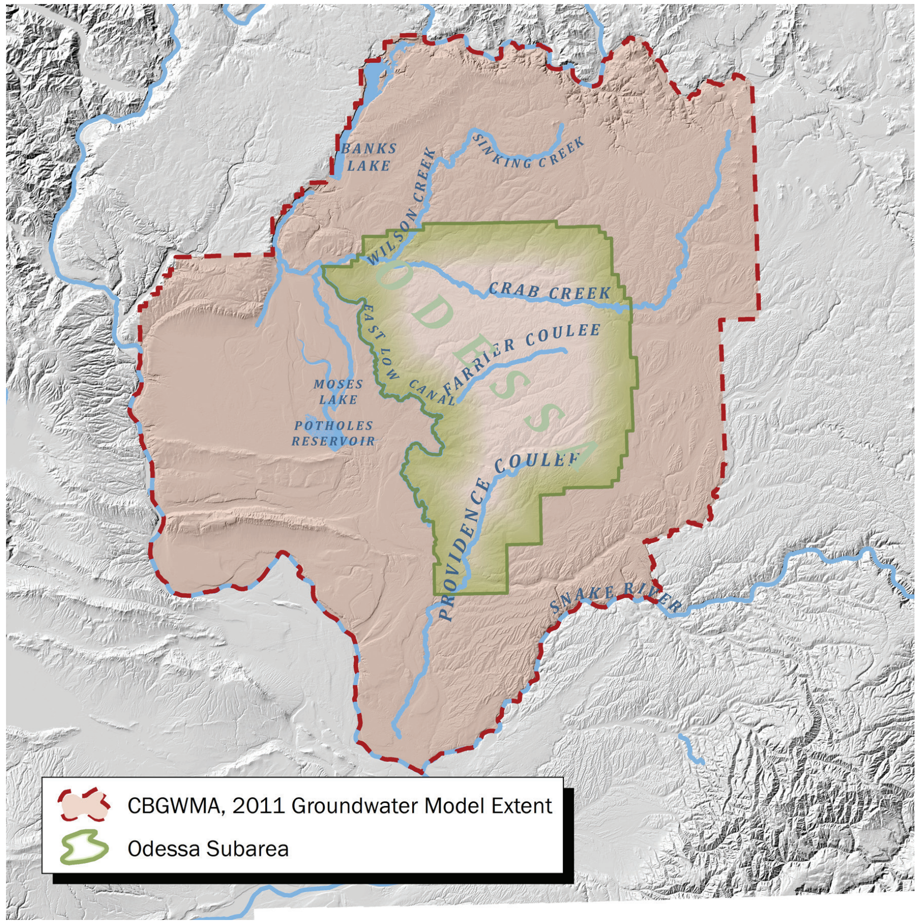



*Note:* Vertical scale greatly exaggerated
*Source:* USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

# Odessa Subarea
(Grant, Lincoln, Adams, and Franklin Counties)

## Available Groundwater Models

There are three known groundwater models for the Odessa Subarea. Any of these models would need refinements to be adequate for decision-making to address declining groundwater issues in the Odessa Subarea. A recent model that may be a suitable candidate for modification is the MODFLOW model prepared by the Columbia Basin Groundwater Management Area (2011). This is a regional model that includes the Odessa Subarea; however, its resolution (grid spacing) may be too coarse for detailed simulations of Odessa Subarea groundwater flow. The model does contain significant information on hydrogeologic units and properties that could be built upon to provide a management tool for the Odessa Subarea. A second recent model was created by the U.S. Geological Society (USGS, 2014) that covers a larger area and has coarser resolution than the 2011 model. Model references include: CBGWMA et al., 2011; Ely et al., 2014; Lutzier and Skrivan, 1975; Hansen et al., 1994; and Vaccaro, 1999.




## Potential Solutions

### Demand Approaches

Conservation: Improve irrigation efficiencies, predominantly through canal piping/lining as on-farm efficiency is high. 30,000 ac-ft has been conserved through coordinated efforts from 2009 to 2015. Some additional use of municipal and industrial reclaimed water may exist, although much is land-applied now. Crop change could further reduce demand.

Administrative: Use management policy tools incorporated into Odessa Groundwater Management Subarea WAC 173-130A (See Management Policy in Management Context Table).

### Supply Approaches

Surface Water Replacement (planned): A project is underway for source change from groundwater to surface water for 90,000 irrigated acres—53 percent of groundwater-irrigated acres in the Odessa Subarea (Ecology, 2014). East Low Canal will be used for conveyance.

Surface Water Replacement (potential): Additional replacement supplies are needed for municipal groundwater use (CBGWMA, 2012).

ASR: Likely feasible in portions of Subarea based on study of two wells (Gibson and Campana, 2014).

SAR: Feasibility studies lacking, but may be physically feasible for Wanapum basalt. Not likely to be feasible for Grande Ronde basalt due to depth.

## Data Gap Analysis

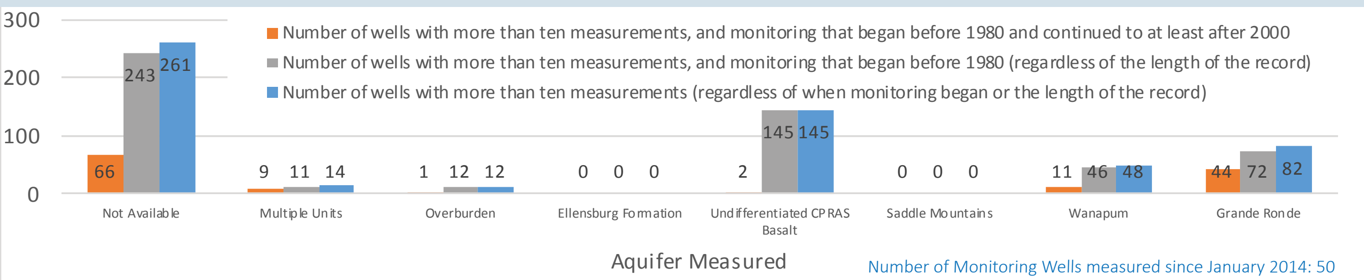
**Data Needs:** Model calibration and integration [estimated costs yet to be determined].

| **Currently Operating USGS Stream Gauges** | | |
|---|---|---|
| Station Number | Station Name | Operating Since |
| 12465000 | Crab Creek at Irby, WA | 1948 |
| 12513000 | Equatzel Coulee at Connel, WA | 1949 |

| **Metered Water Rights (Ecology WRTS)** | Including Claims | | | Not Including Claims | | |
|---|---|---|---|---|---|---|
| | Total | Metered | Percentage Metered | Total | Metered | Percentage Metered |
| Number of Groundwater Rights | 2,000 | 115 | 6% | 800 | 1115 | 14% |
| Groundwater Irrigated Acres | 280,000 | 30,000 | 11% | 270,000 | 30,000 | 11% |

### Water Level Data Availability

Trends in water level are better tracked when water levels are monitored from multiple wells that each have several measurements collected over a long time period. The following chart summarizes water level monitoring data available in state databases based on aquifer and time period sampled, and the number of measurements.




*Data Sources: USGS NWIS, Ecology EIM, and DNR water level databases*

## Risk Factors in Odessa Subarea

Many Washington State water rights in the Odessa Subarea rely on a groundwater source. The following table presents groundwater-use information obtained from water rights data available from the Ecology, water system data from Washington Department of Health, 2010 census, and EIS for the Odessa Groundwater Management Subarea (Ecology and U.S. Bureau of Reclamation, 2010).

## Groundwater Use

| | |
|---|---|
| Groundwater Irrigated Acres | 280,000 |
| Population Served by Group A Water Systems<br>Population Served by Group B Water Systems | 12,000<br>120 |
| Population | 12,800 |
| Industry | 20% agriculture and 35% manufacturing. Primary crop is potatoes. |

A study of municipal water systems in the area found that of 96 municipal wells, 35 had at least one risk factor and 18 had two or more (CBGWMA et al., 2012). Risk factors include:

- Static and dynamic groundwater level decline rates in excess of 2 feet/year;
- Dynamic drawdowns in excess of 300 feet;
- Current and predicted groundwater levels dropping below 700 feet below ground surface;
- Geochemical data that indicates wells are pumping fossil groundwater with little or no modern recharge; and
- Projected future water demand predicted to exceed current pumping capacity by for some areas by 2030 unless supply-side or demand-side actions are taken.

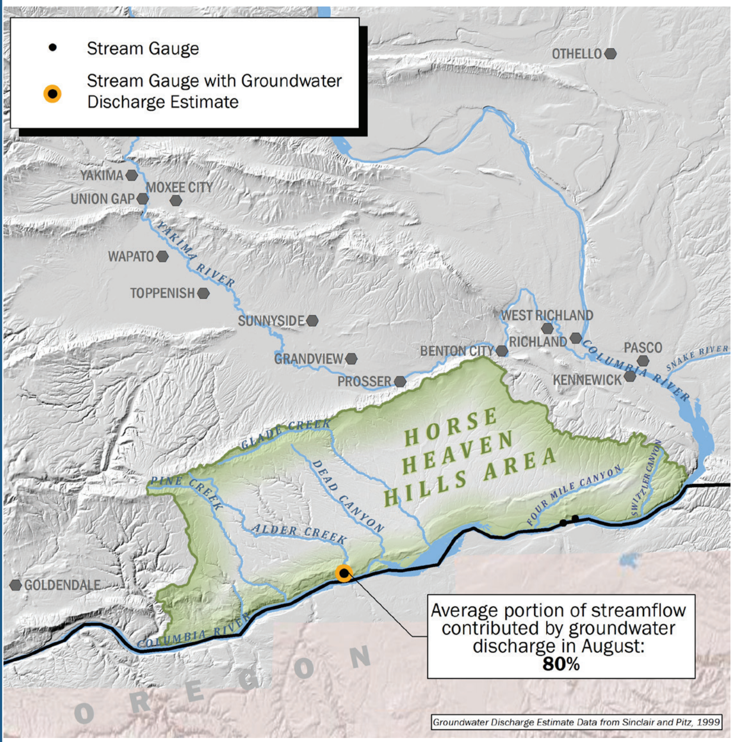
# Horse Heaven Hills Area
(Klickitat and Benton Counties)

## Overview

Significant groundwater supply development for irrigation in the Horse Heaven Hills Area began in the 1960s and continued to expand through at least the 1990s. Water level data indicate groundwater levels have declined significantly in deeper basalt units between 1983 and 2009. Total groundwater withdrawals were estimated in 2004 to total approximately 63,000 ac-ft/year. WRIA studies conclude that hundreds of thousands of additional acres could be available for irrigation and economic development if new irrigation supplies could be obtained.

A U.S. Geological Survey (USGS) study noted groundwater level increases of 5 to 25 or more feet in three wells in the Saddle Mountain Basalt, likely due to infiltration from excess irrigation; however, declines of 100 to 250 feet in the Wanapum Basalt, and 5 to 25 feet in the Grande Ronde Basalt have been identified. Groundwater level declines are concentrated along the Klickitat/Benton county line, in a portion of the aquifer system that is isolated by vertical faults and folds.

Supply and Demand Context: Physical water supply is limited in the area because of a combination of high demand, very low recharge to deep aquifers, and aquifer isolation by faults and folds. This combination has resulted in water level declines.




## Surface and Groundwater Interaction in the Horse Heaven Hills Area

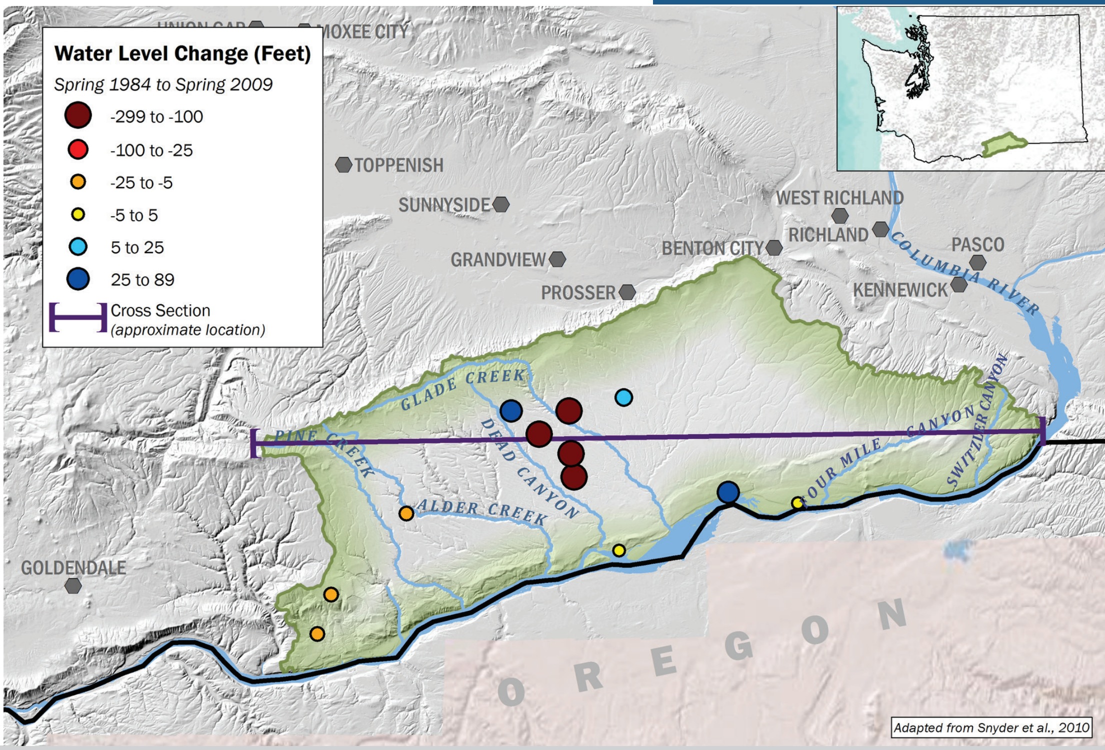
The primary surface water drainages in the Horse Heaven Hills Area are Wood Gulch, Pine, Alder, Dead, Glade, Four Mile, and Switzler Canyons, all of which drain to the Columbia River.

- Surface waters drain to the John Day Pool and portions of the McNary Pool of the Columbia River, which borders the planning area to the south. Groundwater not isolated by faults and folds also drains to the river. However, geologic folding in the Columbia Hills limits groundwater flow from much of the Horse Heaven Hills Area toward the Columbia River.
- All the major drainages in the Horse Heaven Hills Area are intermittent and with the exception of a few spring-fed reaches, stop running during the dry season (Aspect, 2004).
- Groundwater pumping results in a combination of decreases in groundwater discharge to the Columbia River and decreases in aquifer storage (i.e., groundwater declines).

## Management Context

| | |
|---|---|
| Adjudicated Areas | None (Ecology, 2006) |
| Watershed Planning | WRIA 31 (Plan completed [WRIA 31 Planning unit, 2008]; currently in phase 4, implementation) |
| Adopted Instream Flow Rules | Columbia River (WAC 173-563), John Day and McNary Pools (WAC 173-531A); No instream flow rules specific to WRIA 31, and none are planned. |
| Drought Authorization | Drought authorization program not in place. |
| Groundwater Declines | Steady declines in the Wanapum Basalt since the late 1970s with current declines in excess of 200 ft. Declines also observed in the Grande Ronde Basalt, but increases have been documented in the Saddle Mountain Basalt due to irrigation seepage. |

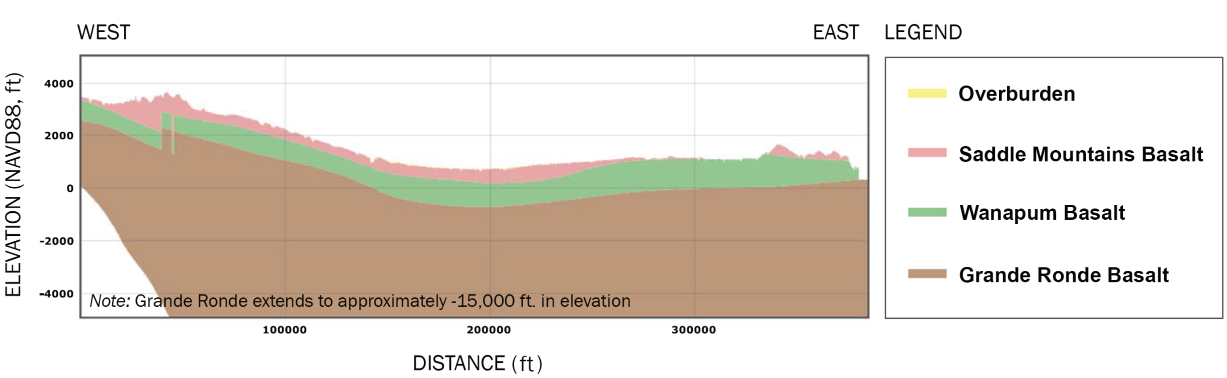
# Horse Heaven Hills Area
(Klickitat and Benton Counties)




## Conceptual Hydrogeologic Model

Considerations in developing the conceptual hydrogeologic model include:

- Horse Heaven Hills Area aquifer zones are part of the Columbia Plateau Regional Aquifer System.
- The primary aquifer zones from shallowest to deepest are the Saddle Mountain Basalt and the Wanapum Basalt. The Grande Ronde Basalt is present below the Wanapum, and is largely unexplored. However, the Grande Ronde likely has high pumping lifts, low recharge, and low water quality that may not be suitable for irrigation of most crop types.
- Groundwater generally flows from the Horse Heaven Hills toward the Columbia River and local drainage basins, unless limited by fault isolation.
- Fault block isolation of aquifer zones act to enhance groundwater declines. Geologic folding in the Horse Heaven Hills and the Columbia Hills cause additional isolation.
- Intensive irrigation with Colombia River water and Wanapum groundwater appears to be causing increases in groundwater levels in the Saddle Mountain Basalt. However, most agricultural wells are completed in the Wanapum Basalt where water levels are declining.
- As of 2004, groundwater production was estimated to exceed recharge by approximately 40 percent.
- Key references: Packard et al., 1996; WRIA 31 Planning Unit, 2008; Aspect, 2004; Aspect, 2011; and Aspect, 2014.

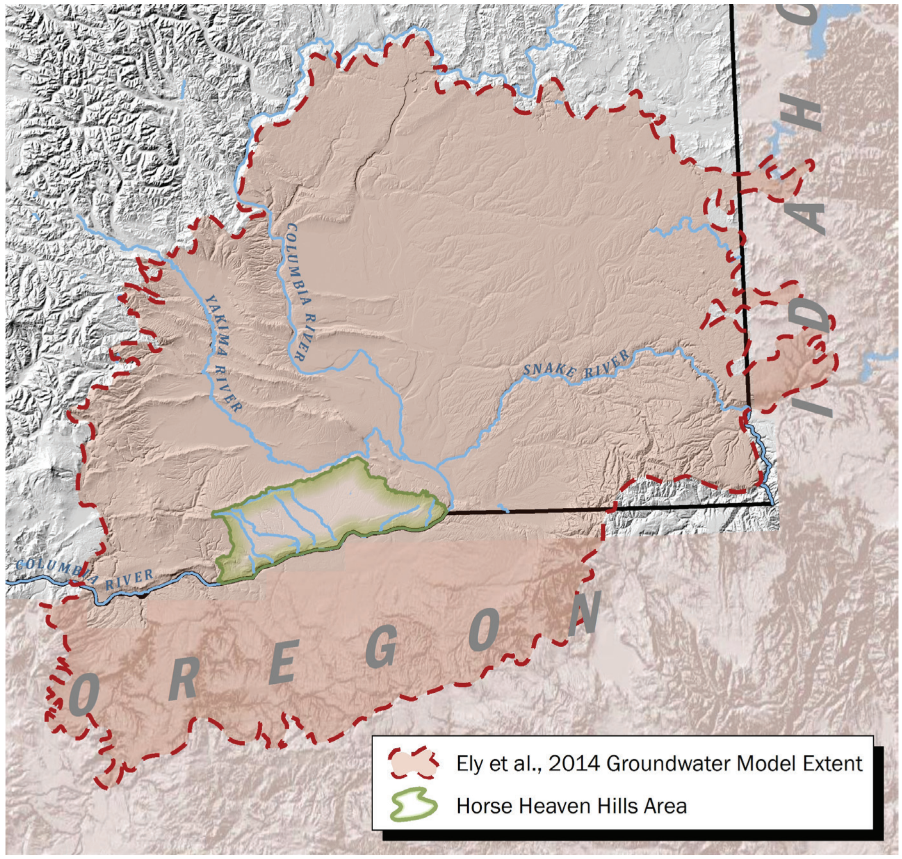



*Note:* Vertical scale greatly exaggerated
*Source:* USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

# Horse Heaven Hills Area
(Klickitat and Benton Counties)

## Available Groundwater Models

Groundwater models of the Horse Heaven Hills Area that are up to date and built to an appropriate scale have not been identified. Developing a new groundwater model to support aquifer management could integrate key assumptions from regional modeling (Ely et al., 2014) and older local modeling (Packard, et al., 1996). Modeling references include: Ely et al., 2014; Packard, et al., 1996; Hansen et al.,1994; and Vaccaro, 1999.




## Potential Solutions

### Demand Approaches

Conservation: Improve irrigation efficiencies.

Administrative: A groundwater management plan was considered in the WRIA 31 watershed planning process, but to date, it has not been further developed.

### Supply Approaches

Storage: Planning is underway for potential implantation of ASR; canal or off-channel storage (WRIA 31 Planning Unit, 2008).

Surface Water Replacement (potential): WAC Chapter 173-531A reserves supplies from the John Day and McNary Pools for 330,000 acres of irrigation to be developed by the year 2020, and 26,000 ac-ft/year of future municipal supply to the year 2020. Permitting is uncertain and may be limited by management related to salmonid survival and power production (WRIA 31 Planning Unit, 2008; Ecology, 2012).

Additional Groundwater: The Grande Ronde Basalt is largely unexplored, and may provide additional sources. However, low water quality may limit its usefulness (WRIA 31 Planning Unit, 2008).

ASR: Likely physically feasible in portions of area, based on a study of two wells in the area (Gibson and Campana, 2014).

SAR: Feasibility studies lacking, but likely physically feasible for the Saddle Mountain Basalt only based on existing groundwater increases in this unit.

WRIA 31 Planning: Detailed summary of potential and planned solutions can be found in the WRIA 31 planning documents

# Horse Heaven Hills Area
(Klickitat and Benton Counties)

## Data Gap Analysis

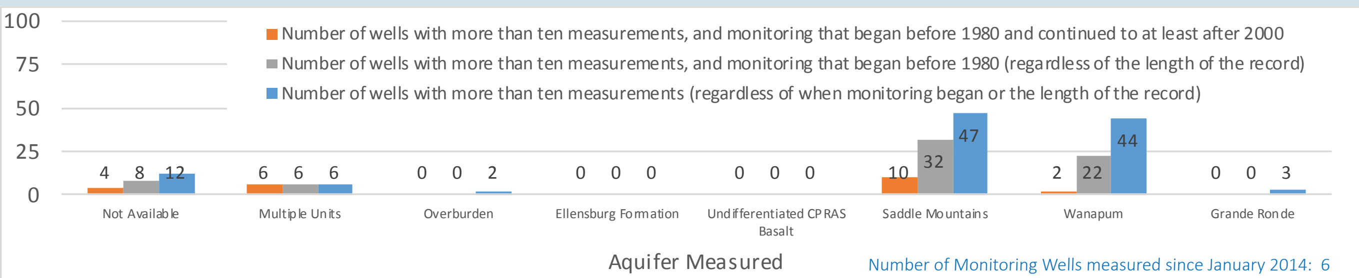
**Data Needs:** Aquifer testing to investigate geological structural controls, groundwater monitoring (particularly in all aquifers on the east side and in Grande Ronde), drilling exploration of the Grande Ronde, investigation of connectivity between basalt aquifers and Columbia River [estimated costs yet to be determined].

| Currently Operating USGS Stream Gauges |
|---|
| No USGS are stream gauges currently in operation |

| Metered Water Rights (Ecology WRTS) | Including Claims | | | Not Including Claims | | |
|---|---|---|---|---|---|---|
| | Total | Metered | Percentage Metered | Total | Metered | Percentage Metered |
| Number of Groundwater Rights | 440 | 20 | 5% | 130 | 20 | 15% |
| Groundwater Irrigated Acres | 39,000 | 11,000 | 28% | 37,000 | 11,000 | 30% |

### Water Level Data Availability

Trends in water level are better tracked when water levels are monitored from multiple wells that each have several measurements collected over a long time period. The following chart summarizes water level monitoring data available in state databases based on aquifer and time period sampled, and the number of measurements.




*Data Sources: USGS NWIS, Ecology EIM, and DNR water level databases*

## Risk Factors in Horse Heaven Hills Area

Many water rights in the Horse Heaven Hills Area rely on a groundwater source. The following table presents groundwater-use information obtained from water rights data available from the Washington Department of Ecology (Ecology), water system data from Washington Department of Health, and the 2010 census.

## Groundwater Use

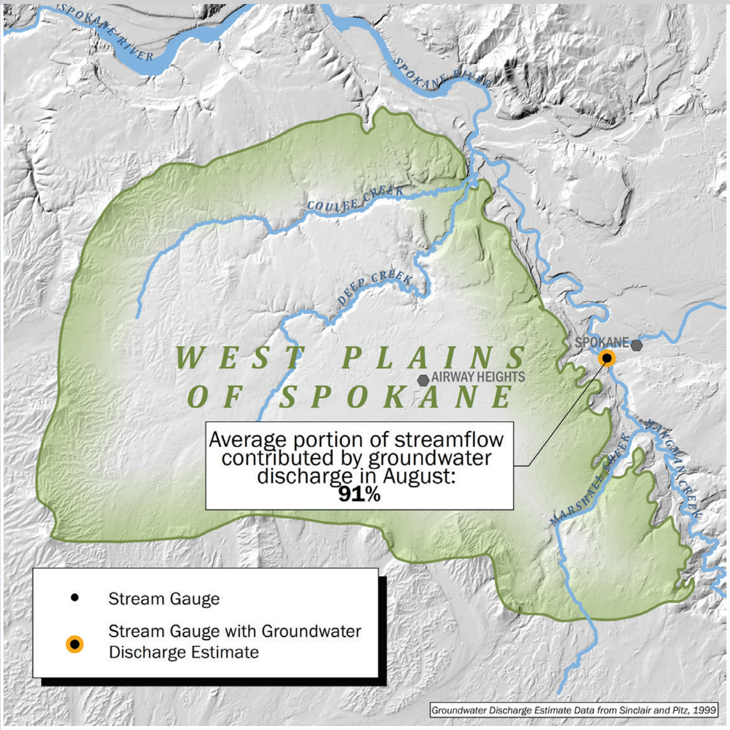
| | |
|---|---|
| Groundwater Irrigated Acres | 39,000 |
| Population Served by Group A Water Systems<br>Population Served by Group B Water Systems | 760<br>240 |
| Population | 1,570 |
| Industry | Primarily Agriculture: food processing, vegetable farming, and wineries; Roosevelt Landfill |

# West Plains of Spokane
(Spokane County)

## Overview

The West Plains of Spokane Area has experienced groundwater level declines in municipal water supply wells in recent years. Groundwater resources in the area consist of an isolated portion of the Columbia Plateau Regional Aquifer System that is reliant on local recharge. The aquifer system includes the Wanapum and Grande Ronde Basalts, and has a high degree of hydraulic connection with surface water. Existing instream flow rules and Surface Water Source Limitations implemented by the Washington Department of Fish and Wildlife limit the availability of new surface water supplies, along with groundwater in connection with surface water.

Supply and Demand Context: Physical water supply is limited in the West Plains of Spokane Area because of a combination of high demand, very low recharge to deep aquifers, and aquifer isolation due to aquifer boundaries where geologic layers thin and pinch out. This combination has resulted in water level declines. Surface water flows in the area are captured by shallow groundwater withdrawals, including withdrawals from the Wanapum Basalt, so new groundwater withdrawals are limited to prevent capture of flows from surface water sources that are closed or regulated.



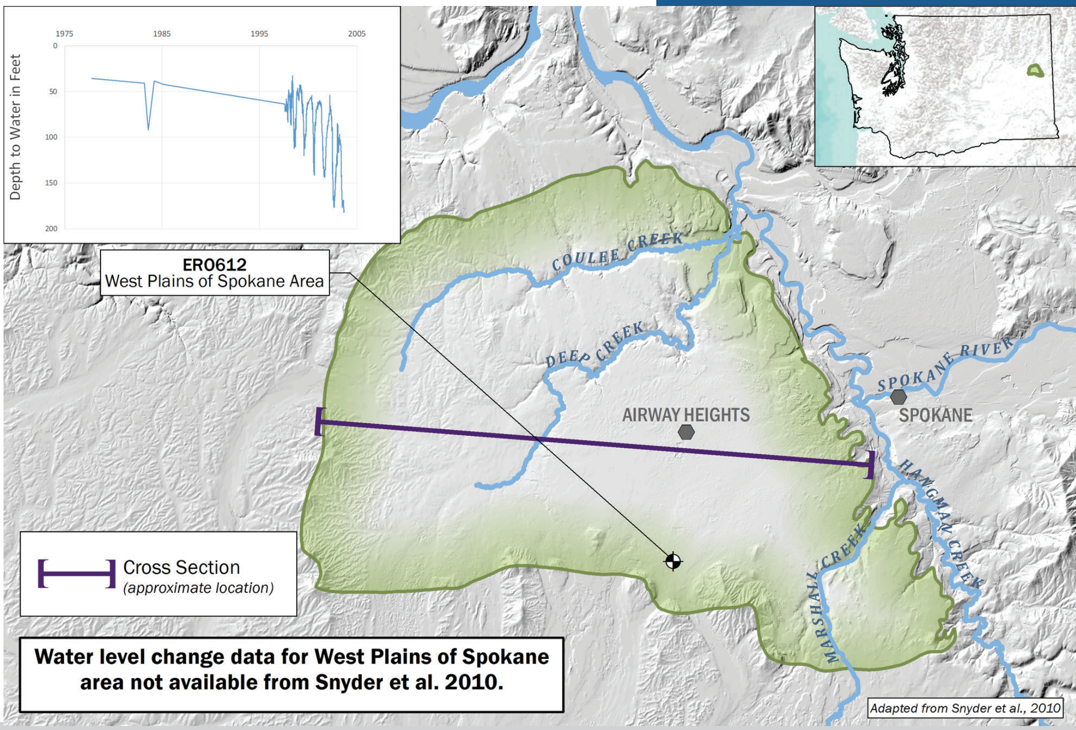

## Surface and Groundwater Interaction in the West Plains of Spokane

Surface water bodies that drain the West Plains of Spokane Area eventually discharge to the Spokane River. These tributaries include Coulee Creek and Deep Creek, which flow directly into the Spokane River, and Marshal Creek, which drains into Hangman Creek.

- There is a high degree of hydraulic connection between surface water and the basalt aquifers.
- Coulee Creek, Deep Creek, and Marshall Creek receive base flow from the Wanapum Aquifer in upper reaches of the drainages, and provide recharge to unconsolidated overburden materials and the Grande Ronde Basalt in lower reaches of their drainages.

## Management Context

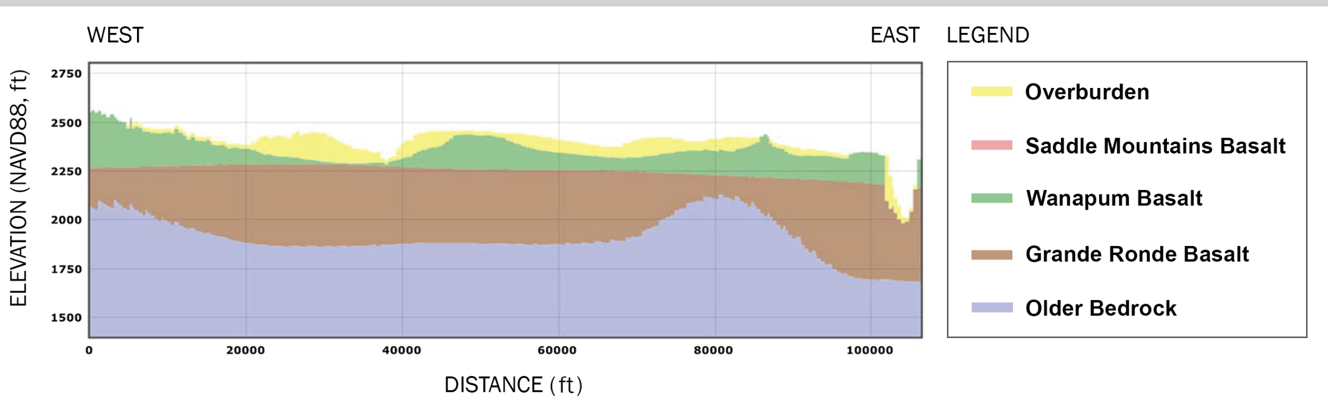
| | |
|---|---|
| Groundwater Management Area | None present |
| Management Policy | No new permits being issued |
| Adjudicated Areas | Crystal Springs Basin |
| Watershed Planning | Portions of WRIAs 54 (Phase 4 – Implementation), 54 (Phase 3 – Planning), and 56 (Phase 4 - Implementation. |
| Adopted Instream Flow Rules | Surface Water Source Limitations in place, including closures of Deep Creek and Marshal Creek Basins; the Bureau of Reclamation has a reserve on unappropriated waters in the Spokane River (RCW 90.40.030). Instream flow rules in place for Spokane River and SVRP aquifer (WAC 173-557). |
| Drought Authorization | No drought authorization program in place. |
| Groundwater Declines | 1 to 12 ft/year through the 2000s (McCollum and Hamilton, 2011). |




## Conceptual Hydrogeologic Model

Considerations in developing the conceptual hydrogeologic model include:

- The West Plains of Spokane Area is an isolated portion of the Columbia River Plateau Aquifer System that is bounded by older bedrock outcrops to the south and west, and Hangman Creek and the Spokane River to the north and east.
- The aquifer system in this area is reliant on local recharge, rather than the regional recharge that is more typical for the Columbia Plateau Regional Aquifer System.
- Recharge is estimated at 2.7 in/year, with groundwater flow generally northeast toward the Spokane River, toward other local surface water features, and toward the Spokane Valley-Rathdrum Prairie Aquifer.
- There is a high degree of hydraulic connection between surface water and groundwater in both the Wanapum and Grande Ronde Basalts.
- The Wanapum and overburden aquifers are isolated into distinct zones separated by the incised valleys of Coulee Creek, Deep Creek, and Marshall Creek
- The area is structurally complex with fracture zones, folding, and paleo channels, resulting in impedance of horizontal groundwater flow and atypical vertical hydraulic continuity between the Wanapum and Grande Ronde Basalts.
- Key references include: McCollum and Pritchard, 2010; Deobald and Buchanan, 1995; and Washington State Department of Ecology (Ecology), 2010, 2013a, 2013b.



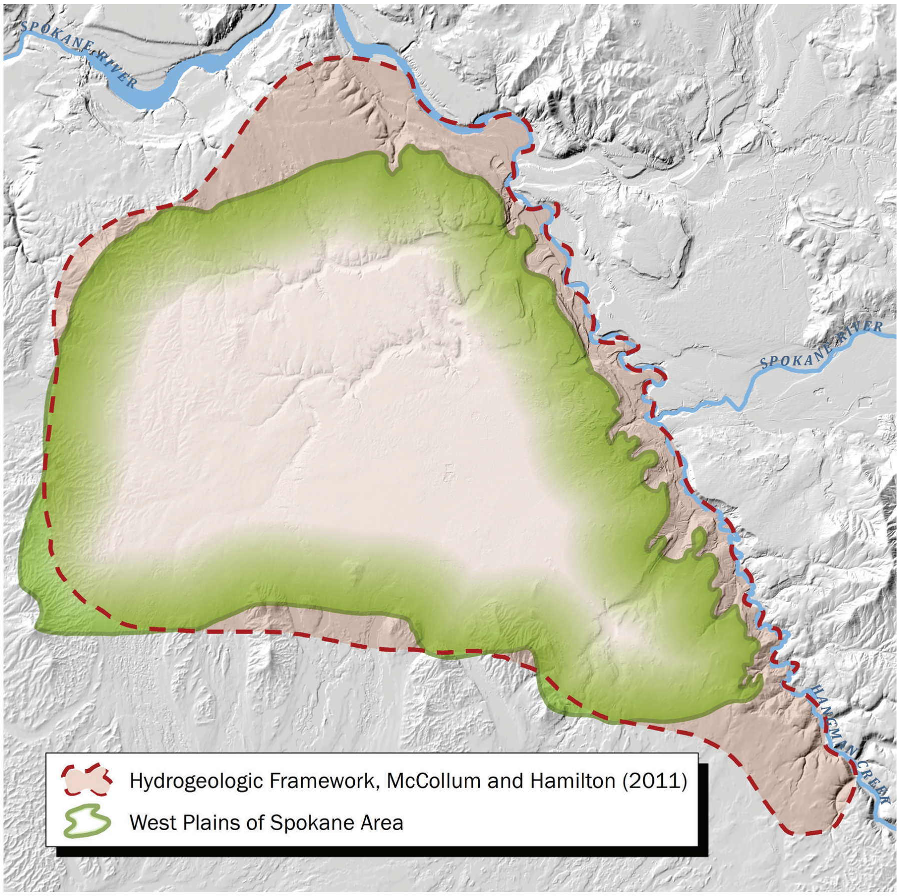

*Note:* Vertical scale greatly exaggerated

# West Plains of Spokane
(Spokane County)

## Available Groundwater Models

A review of the literature did not identify any known groundwater models that simulate the West Plains of Spokane Area; however, conceptual model elements and data have been assembled that could support construction of a groundwater model:

- McCollum and Hamilton (2011) developed a 3-dimensional hydrostratigraphic model.
- Ecology estimated recharge using the U.S. Geological Survey's (USGS) Deep Percolation Model (Ecology, 2013b).
- Groundwater/Surface Water Investigation (Ecology, 2013c)
- Groundwater Elevation monitoring and mapping (Ecology, 2013a).




## Potential Solutions

### Demand Approaches

Conservation: Greater domestic conservation for the City of Airway Heights and rural users could be implemented. Rural domestic uses with lawns that could be converted to xeriscaping. Agricultural uses could be acquired and put into trust for groundwater preservation.

Administrative: Ecology and Spokane County could collaborate on greater information sharing of risks to existing users. Future groundwater uses could be closed based on lack of physical availability.

### Supply Approaches

Surface Water Replacement (potential): Streams within the area are limited by Surface Water Source Limitation. New appropriations from the Spokane River may be limited by a Bureau of Reclamation reserve (RCW 90.40.030; Ecology, 2015).

ASR: May be physically feasible in portions of the area, based on a study of five wells (Gibson and Campana, 2014).

SAR: May be physically feasible for the Wanapum Basalt.

# West Plains of Spokane
(Spokane County)

## Data Gap Analysis

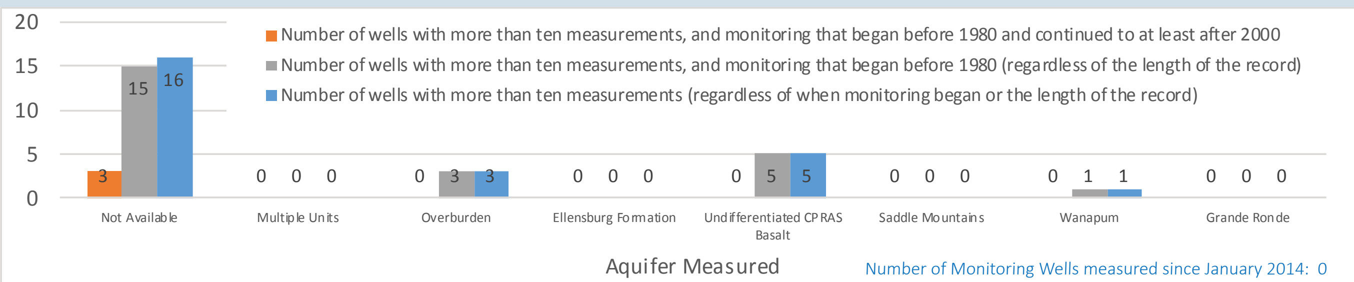
**Data Needs:** Continue long term groundwater monitoring of 75 wells initiated by Spokane County Water Resources (Ecology, 2013). A smaller subset of wells could be monitored based on availability of funds [estimated costs are $30,000 per year]. Stream gauging in Deep Creek, and Marshal Creek [estimated cost for installation of 2 gauges: $38,000, annual maintenance and operation costs: $34,000]

| Currently Operating USGS Stream Gauges |
|---|
| No USGS are stream gauges currently in operation |

| Metered Water Rights (Ecology WRTS) | Including Claims | | | Not Including Claims | | |
|---|---|---|---|---|---|---|
| | Total | Metered | Percentage Metered | Total | Metered | Percentage Metered |
| Number of Groundwater Rights | 1,700 | 15 | 1% | 260 | 15 | 6% |
| Groundwater Irrigated Acres | 9,500 | 630 | 7% | 7,500 | 630 | 8% |

### Water Level Data Availability

Trends in water level are better tracked when water levels are monitored from multiple wells that each have several measurements collected over a long time period. The following chart summarizes water level monitoring data available in state databases based on aquifer and time period sampled, and the number of measurements.




Note: However, additional water level data from 2011-2013 has been published, but is not reflected in database analysis (Ecology, 2013). Those data include 36 wells in the Wanapum and 45 wells in the Grande Ronde.

*Data Sources: USGS NWIS, Ecology EIM, and DNR water level databases*

## Risk Factors in West Plains of Spokane Area

Many water rights in the West Plains of Spokane Area rely on a groundwater source. The following table presents groundwater-use information obtained from water rights data available from Ecology, water system data from Washington Department of Health, and the 2010 census.

## Groundwater Use

| | |
|---|---|
| Groundwater Irrigated Acres | 9,500 |
| Population Served by Group A Water Systems | 14,500 |
| Population Served by Group B Water Systems | 540 |
| Population | 27,000 |
| Industry | Municipal and institutional:<br>Fairchild Air Force Base, Spokane International Airport, Airway Heights, City-operated Golf Course, correctional facility, and small industry. |

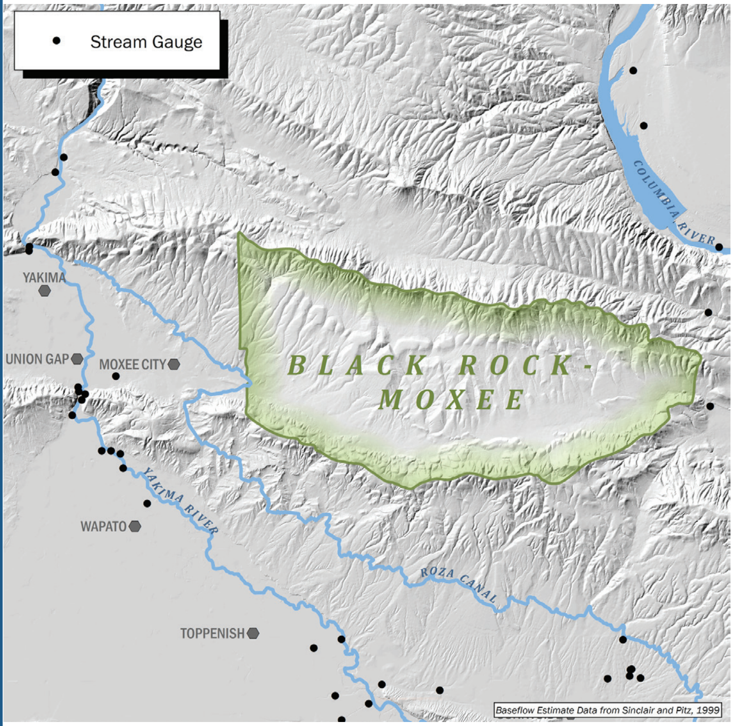
# Black Rock - Moxee Area
(Yakima County)

## Overview

Groundwater levels have declined on the order of 10 ft/year since the early 1980s in the Black Rock/Moxee Area in rural Yakima County. Groundwater is derived from a structurally isolated groundwater basin that lies within the Yakima Fold Belt. Local aquifers are part of the Columbia Plateau Regional Aquifer System, with groundwater declines observed in the Saddle Mountain, Wanapum, and Grande Ronde Basalt aquifer zones. The nearest surface water sources are the Roza Canal which supplies water to a small, southwestern portion of the area.

Groundwater use is primarily agricultural and small, rural domestic uses. Groundwater declines are greatest in the eastern portion of the Black Rock/Moxee Area. Deep groundwater declines are isolated from the western portion of the area, the Town of Moxee and the Yakima River, by the northeast-southwest trending Bird Canyon Fault.

Supply and Demand Context: Physical water supply is limited in the Black Rock/Moxee Area because of a combination of high demand, low recharge, and aquifer isolation by faults and folds. This combination has resulted in water level declines.




## Surface and Groundwater Interaction in the Black Rock / Moxee Area

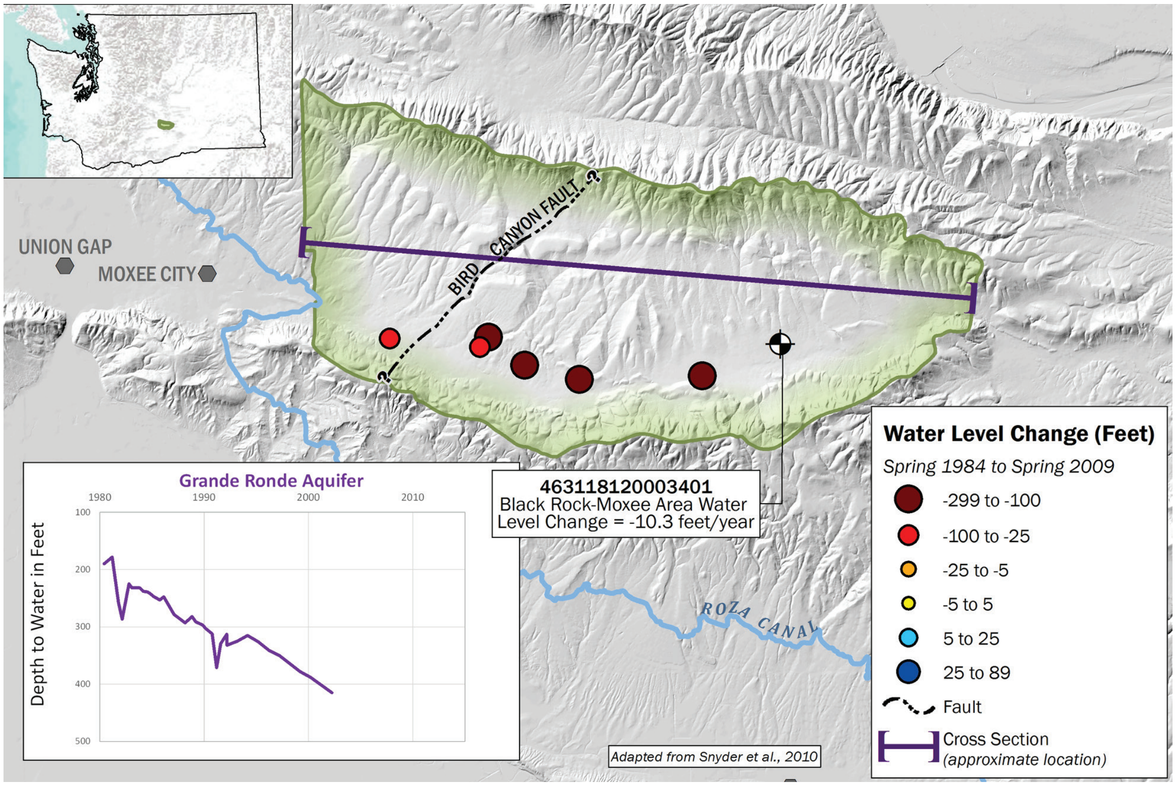
There are no perennial streams in the Black Rock/Moxee Area. The nearest major surface water bodies include the Yakima and Columbia Rivers, located several miles to the south and north of the area, respectively.

- The most prominent channel is Dry Creek, which is ephemeral and flows infrequently in response to intense precipitation events.
- Hydraulic connection between the two rivers and deep groundwater in the eastern portion Black Rock/ Moxee Area is likely severely limited by barriers to flow created by faults and folds that bound the area. Shallow groundwater in the Saddle Mountain Basalt and overburden, and groundwater west of the Bird Canyon Fault are likely in hydraulic connection with the Yakima River.
- The Roza Irrigation District and Selah-Moxee Irrigation District, located south and west of the Black Rock/ Moxee Area, convey water from the Yakima River. The Roza Irrigation District includes a small southwestern portion of the Black Rock/Moxee Area.

## Management Context

| | |
|---|---|
| Groundwater Management Area | None present |
| Management Policy | None in place |
| Adjudicated Areas | The Yakima River is currently under adjudication. |
| Watershed Planning | WRIA 37 (Currently in phase 4: Implementation) |
| Adopted Instream Flow Rules | Federal instream flow targets were set on the Yakima River at Parker and Prosser gages in the 1994 YRBWEP Phase II Act, Title XII of Public Law 103-434. Trust water quantities managed by Ecology are also added to these flow targets each year. |
| Drought Authorization | Supplemental wells authorized on a case-by-case basis in drought years (1:5 years on average). No drought applications were submitted during 2015 drought. |
| Groundwater Declines | Groundwater declines are greatest east of the Bird Canyon Fault: up to 6 ft/year in the Saddle Mountain unit, 12 ft/year in the Wanapum unit, and 13 ft/year in the Grande Ronde unit through the 1980s (Kirk and Mackie, 1993). Continued declines have persisted to the present (Snyder et al., 2010). |

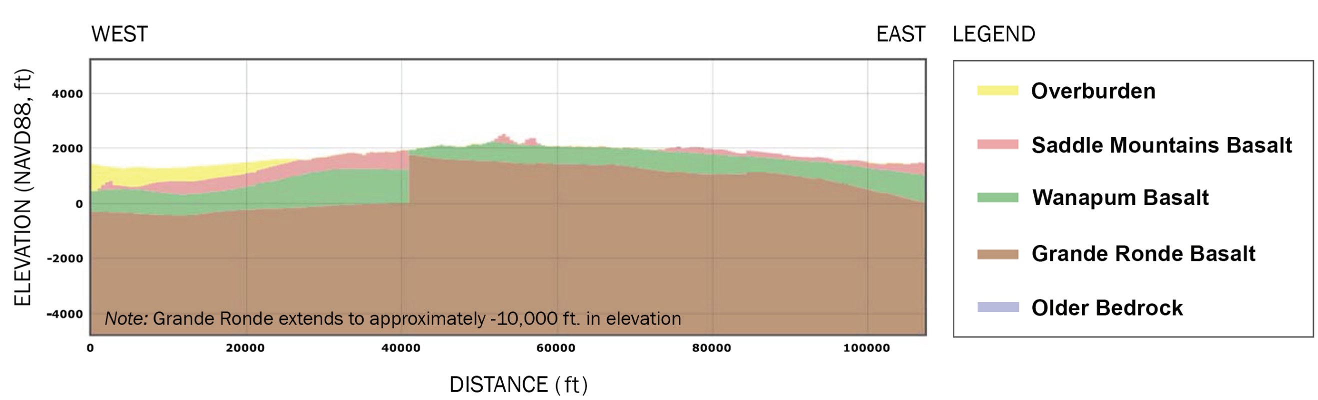
# Black Rock - Moxee Area
(Yakima County)




## Conceptual Hydrogeologic Model

Key considerations in developing the conceptual hydrogeologic model include:

- The primary water source is the Columbia Plateau Regional Aquifer System.
- The Black Rock/Moxee Area lies in the Yakima fold belt, characterized by east-west trending anticlines and isolated aquifer blocks caused by vertical faulting that forms barriers to horizontal groundwater flow.
- Irrigation water is withdrawn from isolated aquifer zones bounded to the north by Yakima Ridge and the South by the Rattlesnake Hills.
- Aquifer zones are further isolated by the northeast-southwest trending Bird Canyon Fault, which divides water-bearing zones from the Wanapum and Grande Ronde Basalt into two compartments east and west of the fault.
- Key reference: Kirk and Mackie, 1993.

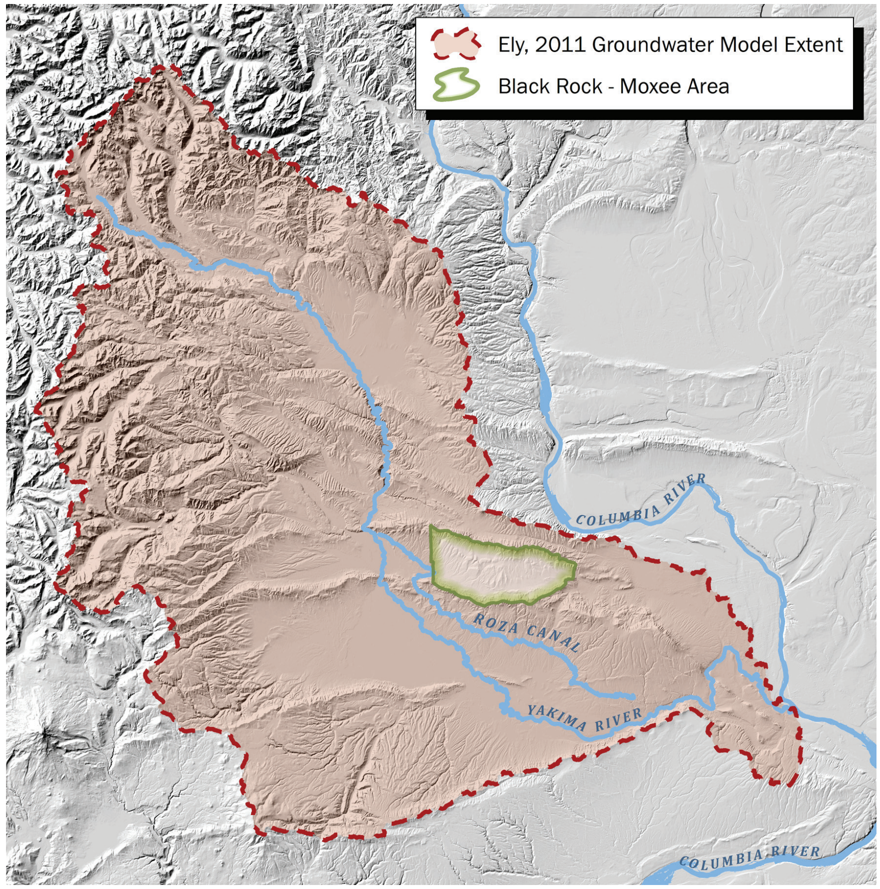



*Note:* Vertical scale greatly exaggerated
*Source:* USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

# Black Rock - Moxee Area
(Yakima County)

## Available Groundwater Models

Two known recent groundwater models have included the Black Rock/Moxee Area (Ely et al., 2014; and Ely et al., 2011). Both of these models would likely need refinements to be adequate to inform decision-making addressing declining groundwater issues in the Black Rock/ Moxee Area. There are additional, older models in the area, but they lack current data and interpretations included in the more recent models. Of the two recent models, the MODFLOW model of the Yakima Basin prepared by the U.S. Geological Society (USGS; Ely, 2011) is smaller and has a higher resolution. This is a regional model that includes the Black Rock/Moxee Area; however, its resolution (grid spacing) is likely still too coarse for detailed simulations of Black Rock/Moxee groundwater flow. The model does contain significant information on hydrogeologic units and properties that could be built upon to provide a management tool for the area. Model references: Ely et al., 2014; Ely et al., 2011; Hansen et al., 1994; and Vaccaro, 1999.




## Potential Solutions

### Demand Approaches

Conservation: Irrigation in the area is largely from center-pivots, so there are limited opportunities for on-farm conservation. Rural domestic uses have small lawns that could be converted to xeriscaping. Agricultural uses could be acquired and put into trust for groundwater preservation.

Administrative: Washington State Department of Ecology (Ecology) and Yakima County could collaborate on greater information sharing on risks to existing users. Future groundwater uses could be closed based on lack of physical availability.

### Supply Approaches

Surface Water Replacement (potential):

- A proposed reservoir storage project for the eastern portion of the Black Rock/Moxee Area was studied, but later abandoned (Bureau of Reclamation, 2004).
- Yakima River surface waters are unavailable for new use as a result of adjudication. Columbia River waters would need to be pumped over two large ridges in order to be conveyed to the area.
- Canal service from Roza Irrigation District or Selah-Moxee Irrigation District could be extended to supply a larger portion of the Black Rock/Moxee Area as direct irrigation source replacement or ASR.

ASR: Literature review did not identify any ASR studies in the area (Gibson and Campana, 2014). However, the structural geology appears to be suitable for ASR, based on fault block isolation, if an out-of-area water source becomes available for supplying ASR.

SAR: This is not considered feasible for the basalt aquifers in this area due to depth.

# Black Rock - Moxee Area
(Yakima County)

## Data Gap Analysis

**Data Needs:** Model calibration and integration, augmenting historic long term groundwater monitoring [estimated costs are yet to be determined] and a feasibilty study on water supply solutions [estimated cost is $50,000].

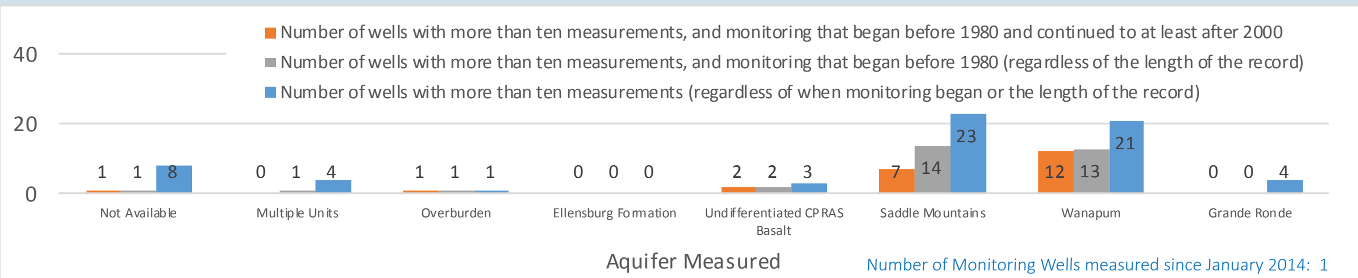
**Currently Operating USGS Stream Gauges**

Not Applicable

| **Metered Water Rights (Ecology WRTS)** | Including Claims | | | Not Including Claims | | |
|---|---|---|---|---|---|---|
| | Total | Metered | Percentage Metered | Total | Metered | Percentage Metered |
| Number of Groundwater Rights | 160 | 14 | 9% | 84 | 14 | 17% |
| Groundwater Irrigated Acres | 18,000 | 3,000 | 17% | 18,000 | 3,000 | 17% |

**Water Level Data Availability**

Trends in water level are better tracked when water levels are monitored from multiple wells that each have several measurements collected over a long time period. The following chart summarizes water level monitoring data available in state databases based on aquifer and time period sampled, and the number of measurements.




*Data Sources: USGS NWIS, Ecology EIM, and DNR water level databases*

## Risk Factors in Black Rock / Moxee Area

Water rights in the Black Rock/Moxee Area rely on a declining groundwater source. The following table presents groundwater use information obtained from water rights data available from Ecology, water system data from Washington Department of Health, and the 2010 census.

## Groundwater Use

| | |
|---|---|
| Groundwater Irrigated Acres | 18,000 |
| Population Served by Group A Water Systems | 0 |
| Population Served by Group B Water Systems | 57 |
| Population | 224 |
| Industry | Agriculture and Dairy |

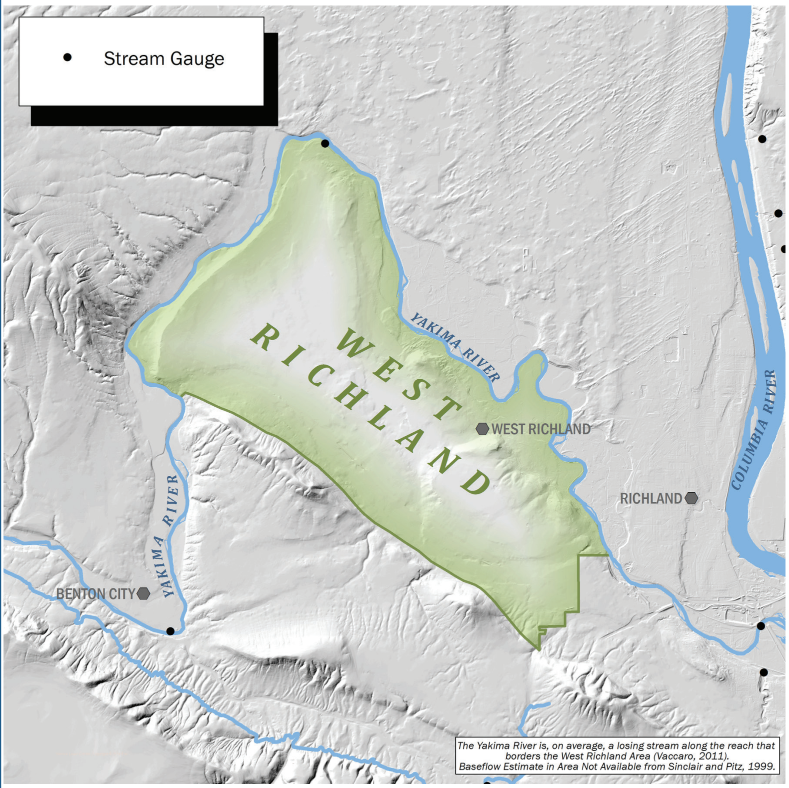
# West Richland
(Benton County)

## Overview

A groundwater level decline of 125 feet was observed on the north side of Red Mountain between 1976 and 2008, within the West Richland Area. In 2010, the City of West Richland was required to limit the instantaneous pumping rate (Qi) from their supply wells necessitating the installation of three new supply wells, because there was evidence that their existing water supply wells were impairing senior water rights. Private well users reported the need to deepen wells due to declining groundwater levels. Additionally, groundwater demands from exempt wells continue to increase and impact groundwater levels as lands outside the city limits are subdivided and developed for single family homes.

Available groundwater supply in this area is limited to shallower aquifers in the West Richland Area because groundwater quality begins to degrade at relatively shallow depths.

Supply and Demand Context: Physical groundwater supply is limited in the West Richland Area due to a combination of high demand very low recharge, poor water quality in deeper aquifers, and aquifer isolation by faults and folds. This combination has resulted in significant groundwater level declines.

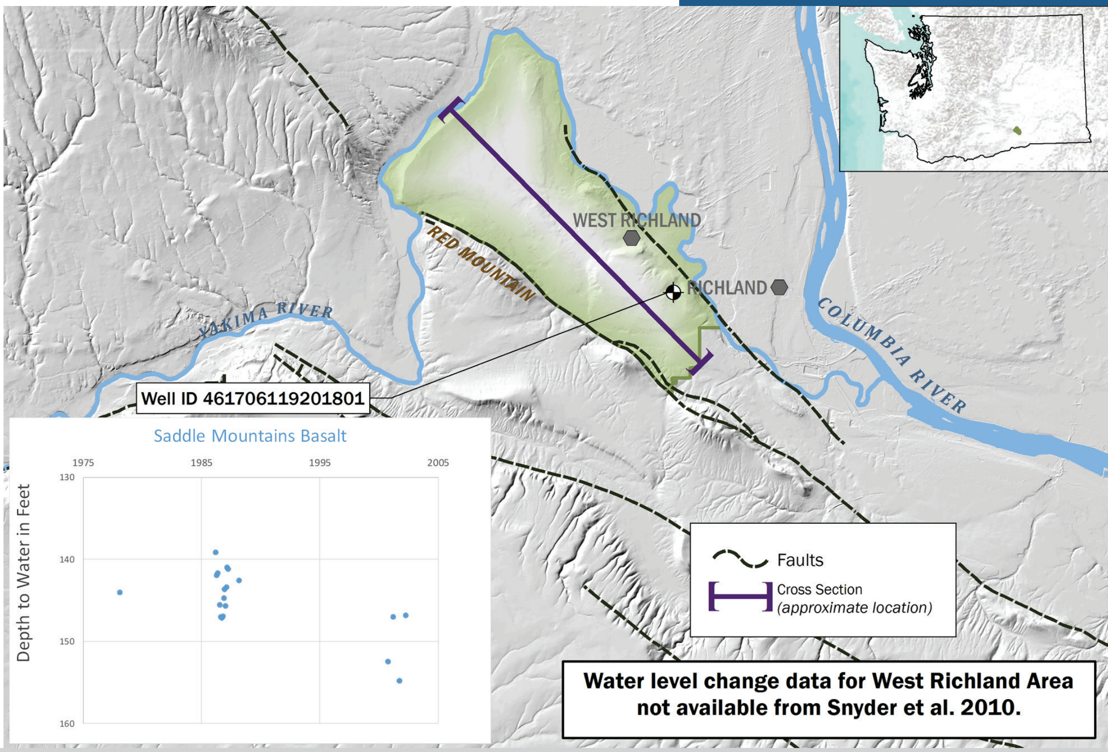



## Surface and Groundwater Interaction in the West Richland Area

The only major surface water body in the area is the Yakima River, which flows along the northwestern and northeastern boundaries of the area. Groundwater along the northeastern boundary of the area, downstream of river mile 17.4, is likely not in hydraulic connection with the Yakima River, because of the presence of folds and steeply dipping faults that likely form barriers to horizontal groundwater flow. However, between river mile 17.4 and river mile 24 along the north east edge of the area, the aquifer receives recharge from the Yakima River.

## Management Context

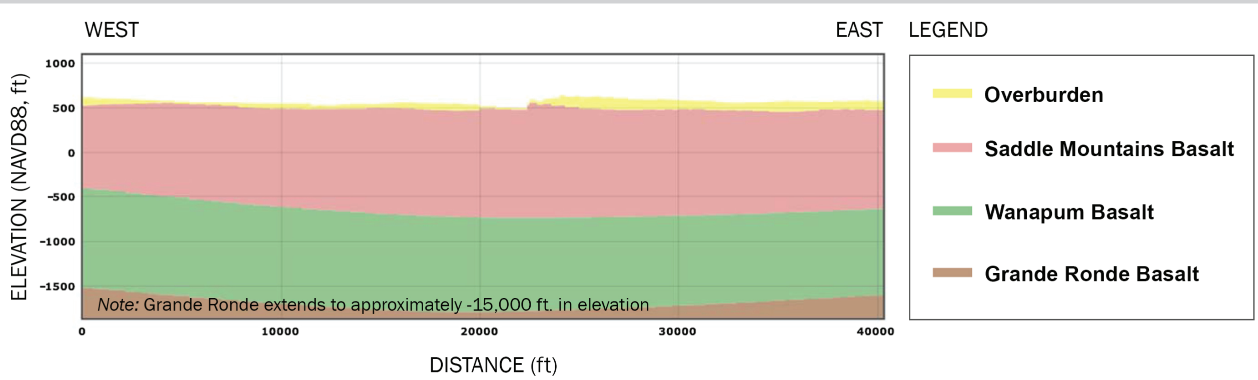
| | |
|---|---|
| Groundwater Management Area | None present |
| Management Policy | Instantaneous pumping rates (Qi) of City of West Richland production wells limited to prevent impairment of senior water rights. City is obligated to monitor water levels and report quarterly to Ecology. |
| Adjudicated Areas | The Yakima River is currently under adjudication. |
| Watershed Planning | WRIA 37 (Currently in phase 4: Implementation) |
| Adopted Instream Flow Rules | Target and instream flows managed by the Bureau of Reclamation. |
| Drought Authorization | Supplemental wells authorized on a case-by-case basis in drought years (1:5 years on average). |
| Groundwater Declines | Water levels declined 125 feet between 1976 and 2008 north of Red Mountain. |




## Conceptual Hydrogeologic Model

Key considerations in developing the conceptual hydrogeologic model include:

- The area is located in the Yakima Fold Belt of the Columbia River Plateau Regional Aquifer System.
- The basalt aquifers of the Columbia Basalt Group are used as the primary aquifers. The city of West Richland utilizes the Saddle Mountain Basalts for their water supply.
- The basalt aquifers of the West Richland Area are characterized by isolated aquifer blocks caused by folding and vertical faulting that forms barriers to horizontal groundwater flow.
- Water quality is poor in the lower portion of the Saddle Mountain Aquifer due to upward groundwater flow from deeper aquifers such as the Wanapum Aquifer through fractured rock and faults. Groundwater demand is predominantly focused on relatively shallow groundwater within the upper Saddle Mountain Aquifer, limiting the depth to which wells can be deepened.
- Sources of recharge to the Saddle Mountain Aquifer in the West Richland Area include, the Yakima River, upward groundwater flow from deeper aquifers along faults, precipitation, and irrigation return flows. Five percent of irrigation water is estimated to recharge the upper Saddle Mountain Aquifer as return flow.
- Key references include: Kahle (2011), Vaccaro (2009, 2011), Hoselton (2010), City of West Richland (2008).

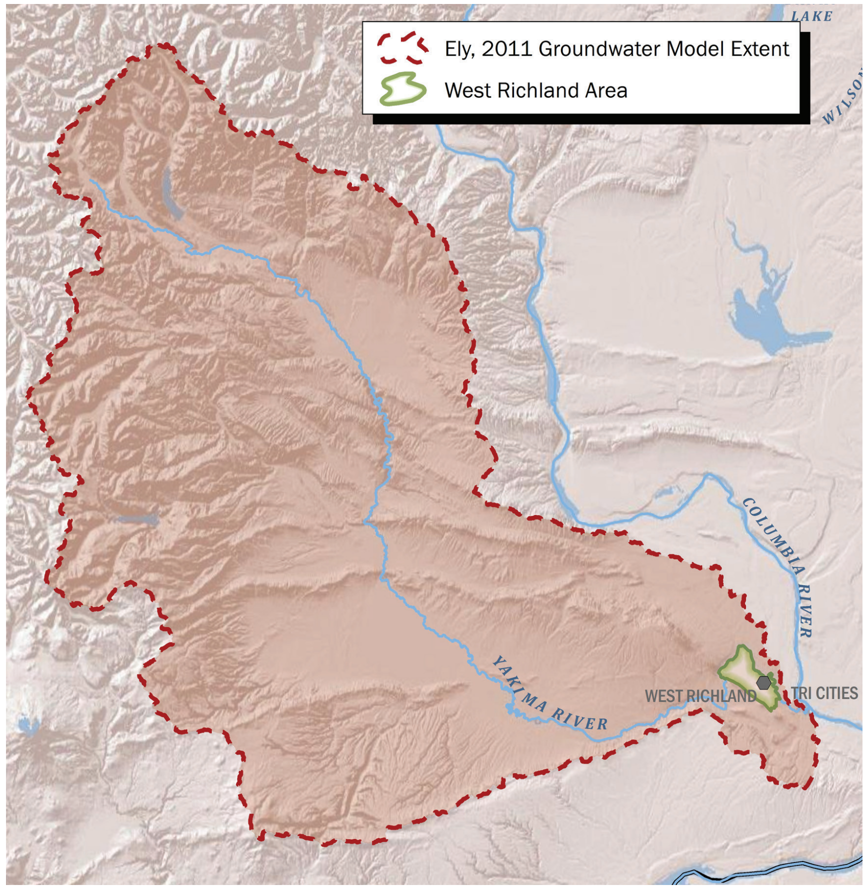


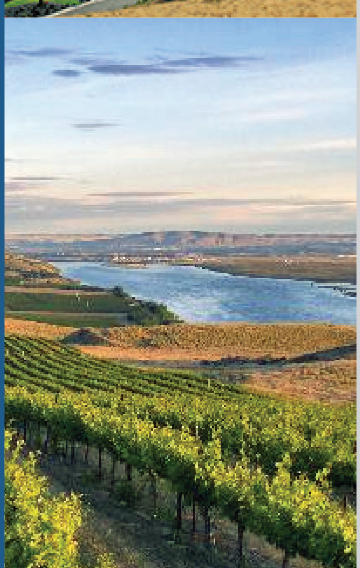

*Note:* Vertical scale greatly exaggerated
*Source:* USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

# West Richland
(Benton County)

## Available Groundwater Models

Two known, recent groundwater models have included the West Richland Area (Ely et al., 2014; and Ely et al., 2011). Both of these models would likely need refinements to be adequate for decision-making to address declining groundwater issues in the area. There are additional older models that overlap the area, but they lack current data and understanding included in the more recent models. Of the two recent models, the regional MODFLOW model of the Yakima Basin prepared by the U.S. Geological Society (USGS; Ely, 2011) is smaller and has a higher resolution; however, its resolution (grid spacing) is likely too coarse for detailed simulations of local groundwater flow. Additionally, there are significant inaccuracies in layer elevations within the West Richland area of the model. The models contain significant information on hydrogeologic units and properties that could be refined and built upon to provide a management tool for the area. A model of the Eastern Pasco Basin was recently constructed by the USGS, but it does not include the Red Mountain/Badger Mountain Area. Model references: Ely et al., 2014; Ely et al. 2011; Hansen et al., 1994; Vaccaro, 1999; and Heywood et al., 2016.



## Potential Solutions

### Demand Approaches

Conservation: Irrigation in the area is largely from center-pivots, so there are limited opportunities for on-farm conservation through improved irrigation methods. The City of West Richland has implemented a conservation plan.

Administrative: Shift exempt well users to the City of West Richland municipal water system. Limit rate of exempt well drilling through the county building permit process.

### Supply Approaches

Surface Water Replacement (potential): Yakima River surface waters are currently under adjudication. Columbia River water is supplied to this area via booster stations within City of West Richland service area; increased supply could be provided.

Well Deepening (potential): The ability to deepen wells is limited because groundwater quality begins to degrade at relatively shallow depths

ASR: May not be suitable in the area based on study of two wells (Gibson and Campanna, 2014).

SAR: Feasibility studies lacking.

## Data Gap Analysis

**Data Needs:** Available groundwater models require hydrostratigraphic refinement in the area. Also, adding the City water system water level data to the Ecology database is needed. [estimated costs are yet to be determined] .

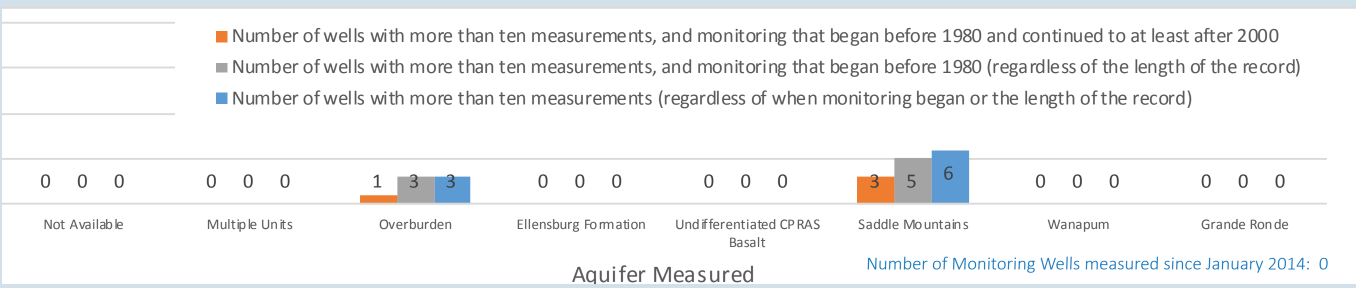
**Currently Operating USGS Stream Gauges**

Not Applicable

| Metered Water Rights (Ecology WRTS) | Including Claims | | | Not Including Claims | | |
|---|---|---|---|---|---|---|
| | Total | Metered | Percentage Metered | Total | Metered | Percentage Metered |
| Number of Groundwater Rights | 373 | 14 | 4% | 124 | 14 | 11% |
| Groundwater Irrigated Acres | 10,000 | 560 | 6% | 9,800 | 560 | 6% |

**Water Level Data Availability**

Trends in water level are better tracked when water levels are monitored from multiple wells that each have several measurements collected over a long time period. The following chart summarizes water level monitoring data available in state databases based on aquifer and time period sampled, and the number of measurements.




*Note: The City of West Richland is also conducting water level monitoring that is not reflected in chart above because it was not available in the databases.*
*Data Source: USGS, Ecology, and Washington DNR water level databases*

## Risk Factors in West Richland Area

Many state water rights in the West Richland Area rely on a groundwater source. The following table presents groundwater use information obtained from water rights data available from the Washington Department of Ecology, water system data from Washington Department of Health, 2010 census, and the City of West Richland Chamber of Commerce.

## Groundwater Use

| | |
|---|---|
| Groundwater Irrigated Acres | 10,000 |
| Population Served by Group A Water Systems<br>Population Served by Group B Water Systems | 12,400<br>403 |
| Population | 13,300 |
| Industry | Construction, agriculture, residential base mostly for workers who commute to work outside the area |

# Red / Badger Mountain Area
(Benton County)

## Overview

The Red Mountain/Badger Mountain Area is located south of the town of West Richland. Groundwater withdrawals to support irrigation began around 1975, with a significant increase beginning in 1985.

Groundwater declines were recorded in the range of 0.5 to 2.5 ft/year in 1987 in the Saddle Mountain and Wanapum Basalts. The area is used primarily for range and agricultural land. Groundwater in the area is isolated from the municipal supply wells of West Richland by faults and geologic folds.

Supply and Demand Context: Physical water supply is limited in the Red Mountain/Badger Mountain Area because of a combination of high demand, very low recharge, and aquifer isolation by faults and folds. This combination has resulted in water level declines.


## Surface and Groundwater Interaction in the Red Mountain/ Badger Mountain Area

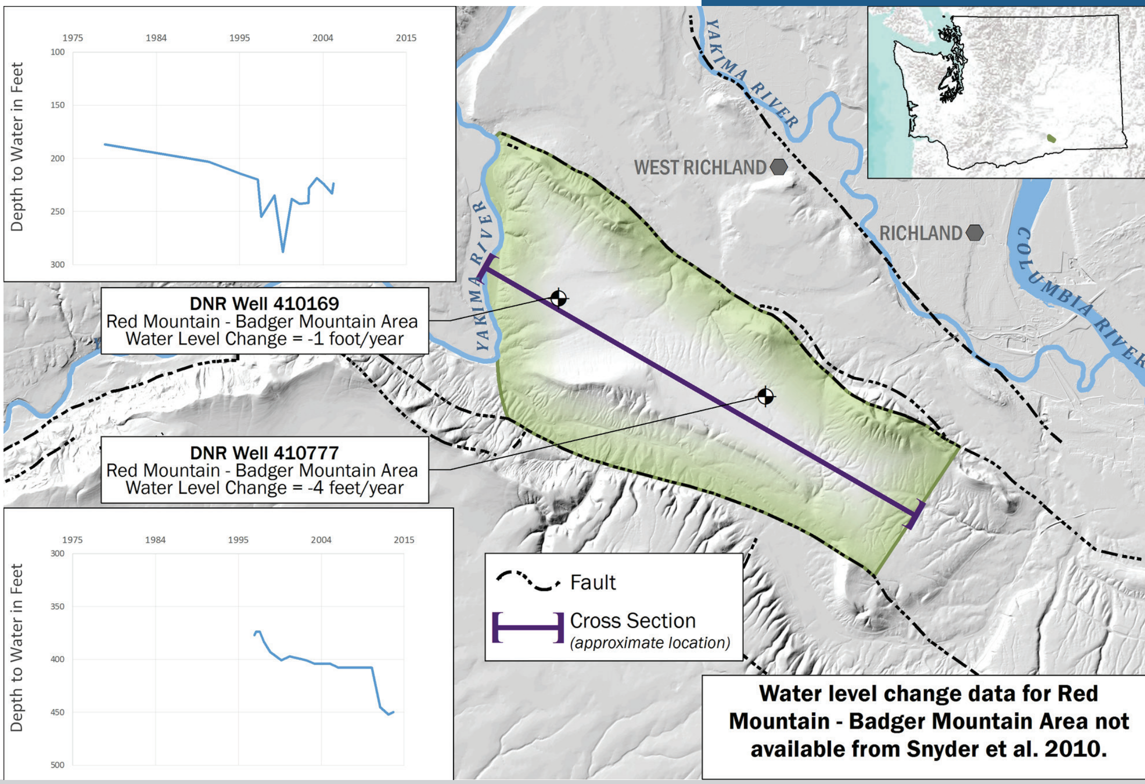
The only major surface water body in the Red Mountain/Badger Mountain Area is the Yakima River, which flows along the northwestern edge of the area.

- The Saddle Mountain Basalt is exposed and receives surface water recharge along this reach of the Yakima River.

## Management Context

| | |
|---|---|
| Groundwater Management Area | None present |
| Management Policy | None in place |
| Adjudicated Areas | Yakima River is currently under adjudication. |
| Watershed Planning | WRIA 37 (Phase 4 – implementation) |
| Adopted Instream Flow Rules | Target and instream flows managed by the Bureau of Reclamation. |
| Drought Authorization | Supplemental wells authorized on a case-by-case basis in drought years (1:5 years on average) |
| Groundwater Declines | As of 1987, declines of 0.5 to 2.5 ft/year were recorded in the Saddle Mountain and Wanapum Basalts. |

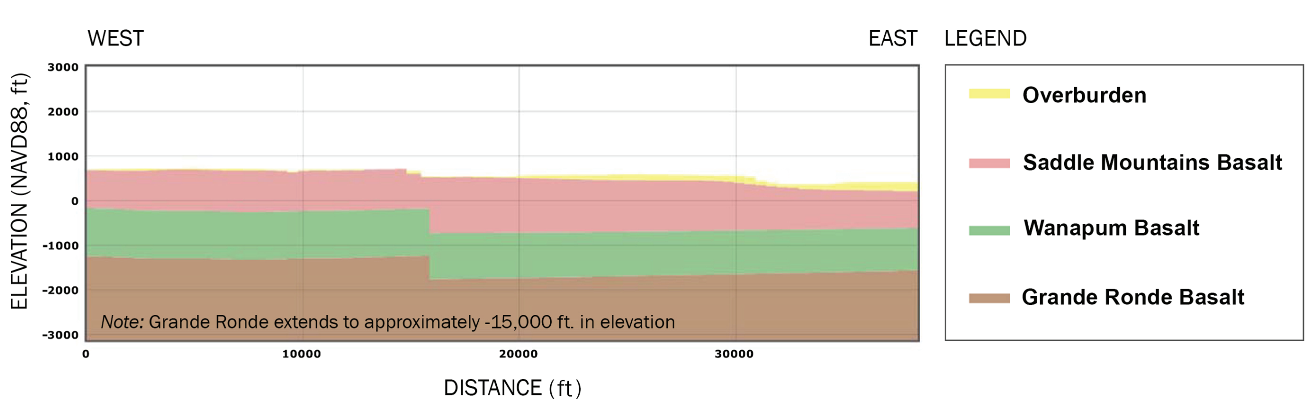
# Red / Badger Mountain Area
(Benton County)




## Conceptual Hydrogeologic Model

Considerations in developing the conceptual hydrogeologic model include:

- The area is located in the Pasco Basin of the Columbia Plateau Regional Aquifer System.
- Key aquifer zones in the area include the Pasco Gravels, Saddle Mountain Basalt, and Wanapum Basalt.
- The Pasco Basin is distinguished from the greater regional basalt aquifer system by the presence of the Pasco Gravels, a productive aquifer zone located within the overburden.
- The Pasco Gravels are overlain by low-conductivity Touchet Beds that reduce recharge.
- The area is bounded by the Badger Mountain Fault to the north, and faults and folds to the south that are potential barriers to horizontal groundwater flow.
- The area is separated from the municipal supply wells and local aquifer of West Richland by the Badger Mountain Fault.
- Key references include: Kahle, 2011; Vaccaro, 2009, 2011; Drost et al., 1997; and Brown, 1979.

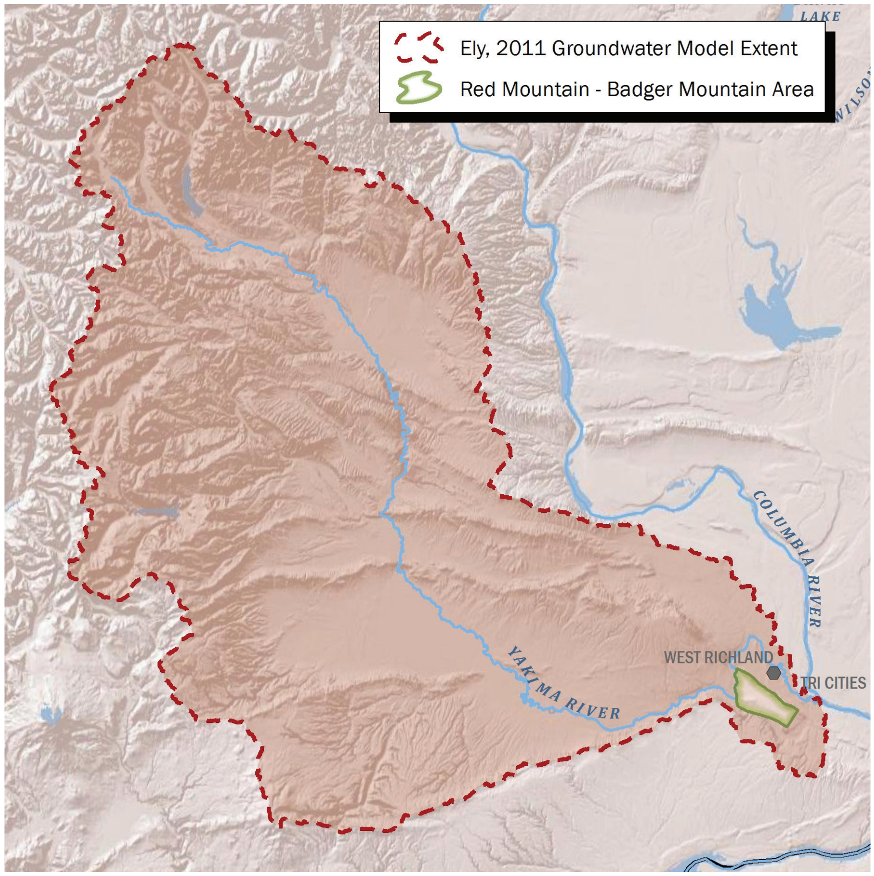



*Note:* Vertical scale greatly exaggerated
*Source:* USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

# Red / Badger Mountain Area
(Benton County)

## Available Groundwater Models

Two known, recent groundwater models have included the Red Mountain/Badger Mountain Area (Ely et al., 2014; and Ely et al., 2011). Both of these models would likely need refinements to be adequate for decision-making to address declining groundwater issues in the area. There are additional, older models that overlap the area, but they lack current data and understanding included in the more recent models. Of the two recent models, the regional MODFLOW model of the Yakima Basin prepared by the U.S. Geological Society (USGS; Ely, 2011) is smaller and has a higher resolution; however, its resolution (grid spacing) is likely too coarse for detailed simulations of local groundwater flow. Additionally, there are significant inaccuracies in layer elevation within the Red Mountain/ Badger Mountain area of the Model. The models contain significant information on hydrogeologic units and properties that could be refined and built upon to provide a management tool for the area. A model of the Eastern Pasco Basin was recently constructed by the USGS, but it does not include the Red Mountain/Badger Mountain Area. Model references: Ely et al., 2014; Ely et al. 2011; Hansen et al., 1994; Vaccaro, 1999; and Heywood et al., 2016.




## Potential Solutions

### Demand Approaches

Conservation: Irrigation in the area is largely from center-pivots, so there are limited opportunities for on-farm conservation. Rural domestic uses have small lawns that could be converted to xeriscaping. Agricultural uses could be acquired and put into trust for groundwater preservation.

Administrative: None anticipated.

### Supply Approaches

Surface Water Replacement (potential):

- Yakima River surface waters are currently under adjudication.

ASR: Literature review did not identify any ASR studies in the area (Gibson and Campana, 2014). However, the geology appears to be suitable for ASR if an out-of-area water source for ASR becomes available.

SAR: This is not considered feasible for the basalt aquifers in this area due to depth.

## Data Gap Analysis

**Data Needs:** Determine monitoring well aquifer zone, and making data available in Ecology database [estimated costs are yet to be determined].

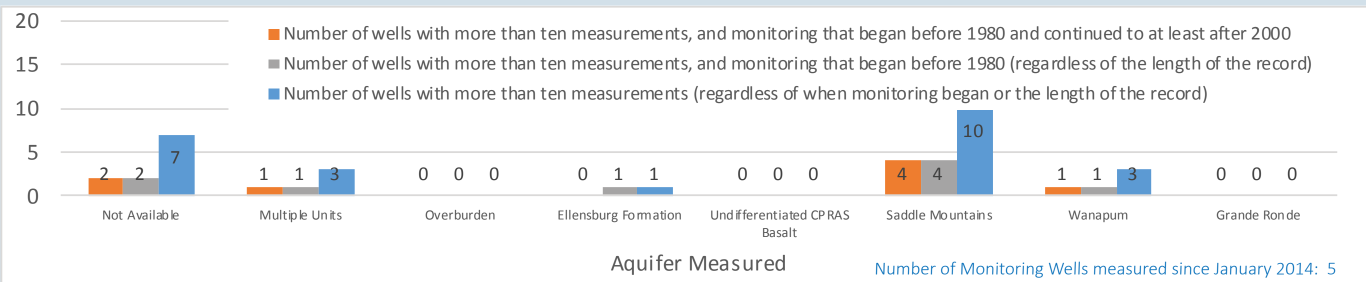
**Currently Operating USGS Stream Gauges**

There are currently no operating USGS stream gauges in this area.

| **Metered Water Rights** (Ecology WRTS) | Including Claims | | | Not Including Claims | | |
|---|---|---|---|---|---|---|
| | Total | Metered | Percentage Metered | Total | Metered | Percentage Metered |
| Number of Groundwater Rights | 160 | 13 | 8% | 122 | 13 | 11% |
| Groundwater Irrigated Acres | 9,600 | 1,700 | 18% | 9,000 | 1,700 | 19% |

**Water Level Data Availability**

Trends in water level are better tracked when water levels are monitored from multiple wells that each have several measurements collected over a long time period. The following chart summarizes water level monitoring data available in state databases based on aquifer and time period sampled, and the number of measurements.




*Data Sources: USGS NWIS, Ecology EIM, and DNR water level databases*

## Risk Factors in the Red Mountain / Badger Mountain Area

Many water rights in the Red Mountain/Badger Mountain Area rely on a groundwater source. The following table presents groundwater-use information obtained from water rights data available from Ecology, water system data from Washington Department of Health, and the 2010 census.

## Groundwater Use

| | |
|---|---|
| Groundwater Irrigated Acres | 9,600 |
| Population Served by Group A Water Systems | 710 |
| Population Served by Group B Water Systems | 230 |
| Population | 3,800 |
| Industry | Wineries and Agriculture (primarily vineyards) |

# White Salmon Area
(Klickitat County)

## Overview

In the early 2000s, the City of White Salmon (City) switched their supply from an unfiltered surface water source on Buck Creek to two groundwater wells. Although initially successful, the City soon experienced water supply shortages as a result of declining well yield in their flowing artesian wells caused by overuse of a hydrogeological bounded, low-recharge aquifer system. As a result, the City took a number of steps to ensure it maintained a reliable public water supply under Washington Department of Health rules, including:

- Implementing strict conservation measures, leak reductions, and rate adjustments to reduce demand.
- Reducing pumping rates from their wells.
- Constructing a new, slow sand filtration plant and reactivating their surface water diversion from Buck Creek.
- Developing an ASR project to store and recover treated water from Buck Creek.
- Pursuing new surface water rights and a new source on the White Salmon River.

Supply and Demand Context: Physical water supply is limited in the area because of a combination of high demand, very low recharge to deep aquifers, and aquifer isolation by faults. This combination has resulted in reduced well yield. Recent measures, including development of an ASR system, are expected to reduce groundwater declines in the future.

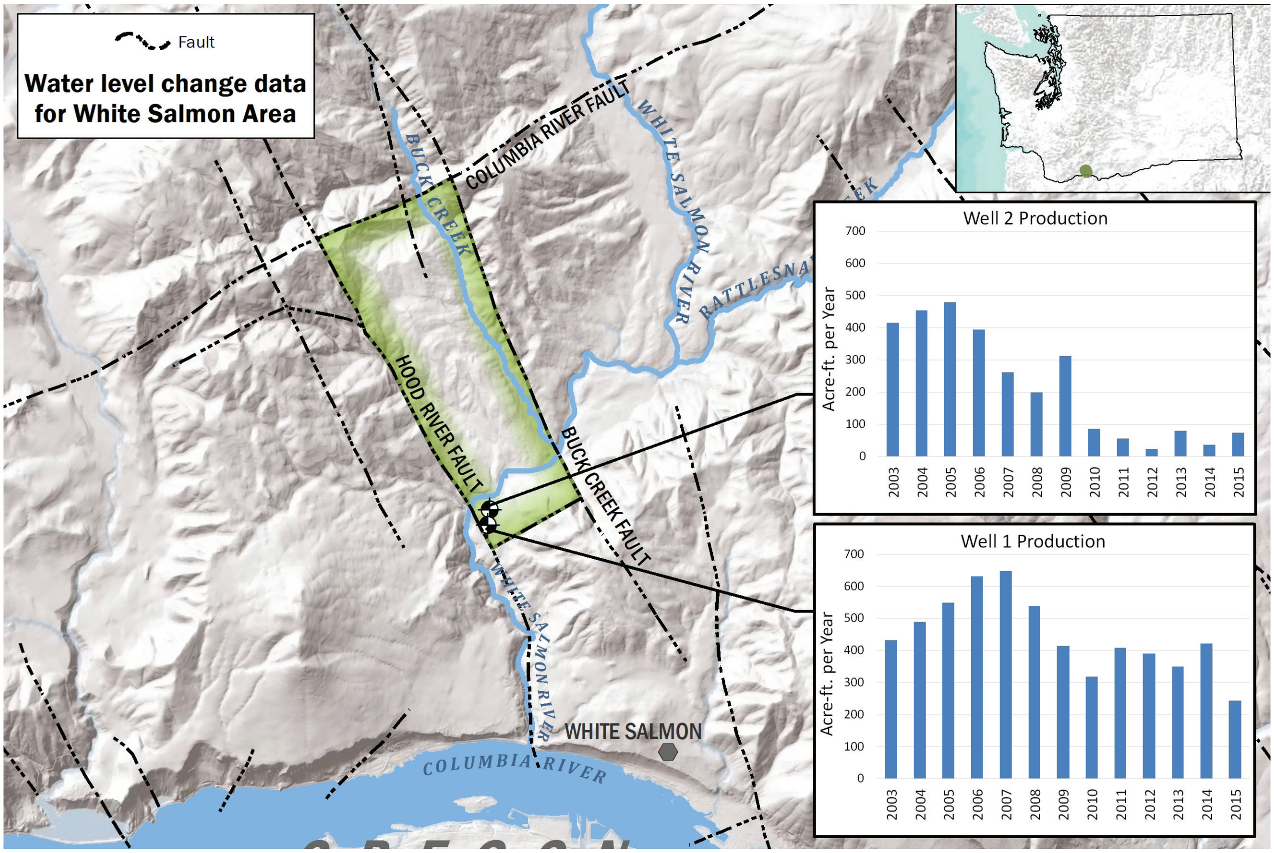

## Surface and Groundwater Interaction in the White Salmon Area

Surface water bodies near the City's wells include Buck Creek, the White Salmon River, and the Columbia River (much further to the south).

- A nearby reach of the White Salmon River was formerly Northwestern Lake, which was drained in 2011 with the removal of Condit Dam.
- The City's artesian water supply well is hydraulically isolated by adjacent faults and overlying massive basalt layers, and is likely not in strong hydraulic connection with surface water.
- The City's other well is interpreted to be in hydraulic connection with the White Salmon River (formerly Northwestern Lake) via highly fractured basalt encountered while drilling this well.

## Management Context

| | |
|---|---|
| Groundwater Management Area | None present |
| Management Policy | The City is implementing source control measures and new water supply development. |
| Adjudicated Areas | None |
| Watershed Planning | WRIA 29b; phase I on hold |
| Adopted Instream Flow Rules | No instream flow rule exists on White Salmon River. An adopted instream flow rule (WAC 173-563) and federal biological opinion exists for the Columbia River. |
| Drought Authorization | None |
| Groundwater Declines | White Salmon Water Supply Well: Steady drop in yield and shut in pressure since 2000 (6 ft/yr). |

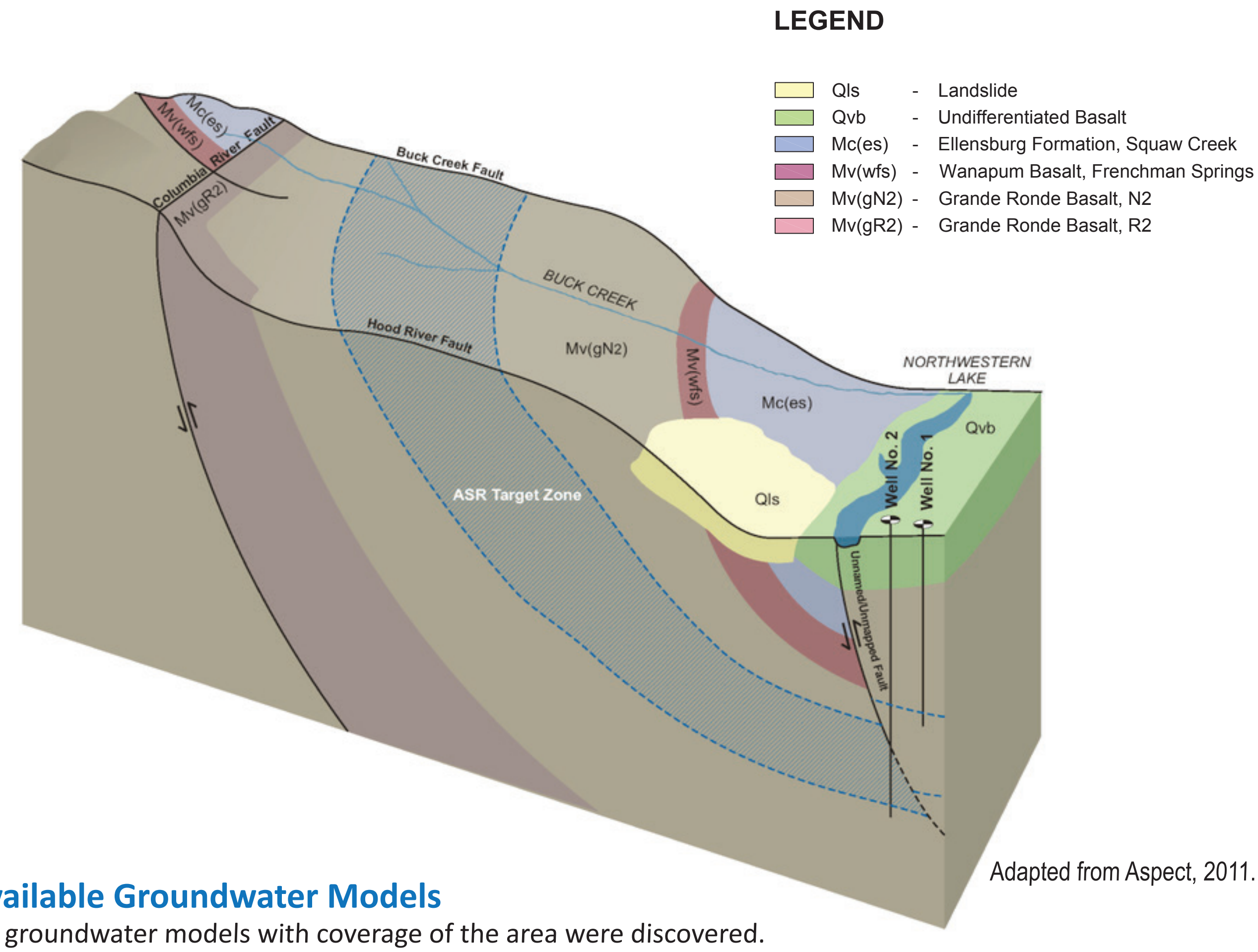



## Conceptual Hydrogeologic Model

Key considerations in developing the conceptual hydrogeologic model include:

- The City of White Salmon Groundwater Supply relies on fault-block aquifers located in the Grand Ronde Basalt.
- The aquifers are located in a heavily faulted portion of the Columbia Plateau Regional Aquifer System.
- The aquifer tapped by the artesian well is isolated by the Buck Creek Fault to the east, the Hood River Fault to the west, the Columbia River Fault to the north and upgradient, and an unnamed fault to the south and downgradient.
- The unnamed fault to the south likely provides a hydraulic connection through fracture flow between surface water and the aquifer tapped by the City's other well.
- The aquifer tapped by the artesian well appears to be well suited for ASR, given its fault-block isolation and limited hydraulic connection to surface water or other aquifers.
- A cross section is provided on the following page .
- Key references include: Kahle, 2011; Aspect, 2011; Aspect, 2015; Mark Yinger and Associates, 1999; Mark Yinger and Associates, 2001; Mark Yinger and Associates, 2002; and Aspect, 2011.

# White Salmon Area
(Klickitat County)




Adapted from Aspect, 2011.

## Available Groundwater Models

No groundwater models with coverage of the area were discovered.

## Potential Solutions

### Demand Approaches

Conservation: The City adopted a new water system plan in 2014 with conservation targets and funding over the next 6 years to improve conservation. The City has modified pumps and pump controls from its wells to reduce aquifer declines.

Administrative: The City has drought-year curtailment resolutions in place for outdoor lawn watering.

### Supply Approaches

Surface Water Replacement: The City is partnering with Washington State Department of Ecology (Ecology), Washington Water Trust, and other stakeholders on development of a new source on the White Salmon River.

ASR: The City of White Salmon has completed an ASR Pilot Study, and is currently in the permitting phase. The Pilot study indicated potential storage of 111 ac-ft (Aspect, 2015).

SAR: Likely not feasible for the Grand Ronde Basalt aquifer, given limited recharge pathways.

## Data Gap Analysis

**Data Needs:** WRIA assessment and planning [estimated costs are yet to be determined], ASR full-scale operation [estimated costs: city-supplied pumping costs and monitoring], White Salmon source replacement [estimated cost is $60,000 for appraisal with design/construction costs yet to be determined].

| Currently Operating USGS Stream Gauges | | |
|---|---|---|
| Station Number | Station Name | Operating Since |
| 14123500 | White Salmon River near Underwood, WA | 2015 |

| Currently Operating City of White Salmon Stream Gauges | | |
|---|---|---|
| Station Number | Station Name | Operating Since |
| N/A | City of White Salmon Buck Creek | 2011 |

| Metered Water Rights (Ecology WRTS) | Including Claims | | | Not Including Claims | | |
|---|---|---|---|---|---|---|
| | Total | Metered | Percentage Metered | Total | Metered | Percentage Metered |
| Number of Groundwater Rights | 16 | 1 | 6% | 7 | 1 | 14% |
| Groundwater Irrigated Acres | 7 | 0 | 0% | 7 | 0 | 0% |

| Number of Wells with Current Water Level Measurements |
|---|
| No current water level measurements are available in the databases. However, water levels are monitored in Wells 1 and 2, and within monitoring wells in the Well 1 aquifer by the City of White Salmon. |

*Data Sources: USGS, Ecology, and Washington DNR water level databases*

## Risk Factors in White Salmon Area

The following table presents groundwater-use information obtained from water rights data available from Ecology, water system data from Washington Department of Health, 2010 census, and the City of White Salmon.

## Groundwater Use

| | |
|---|---|
| Groundwater Irrigated Acres | 7 |
| Population Served by Group A Water Systems | 3,900 |
| Population Served by Group B Water Systems | 10<br>(Note: water systems serve a population outside the area.) |
| Population | 650 |
| Industry | Unmanned aeronautics manufacturing, agriculture, and outdoor recreation/tourism |

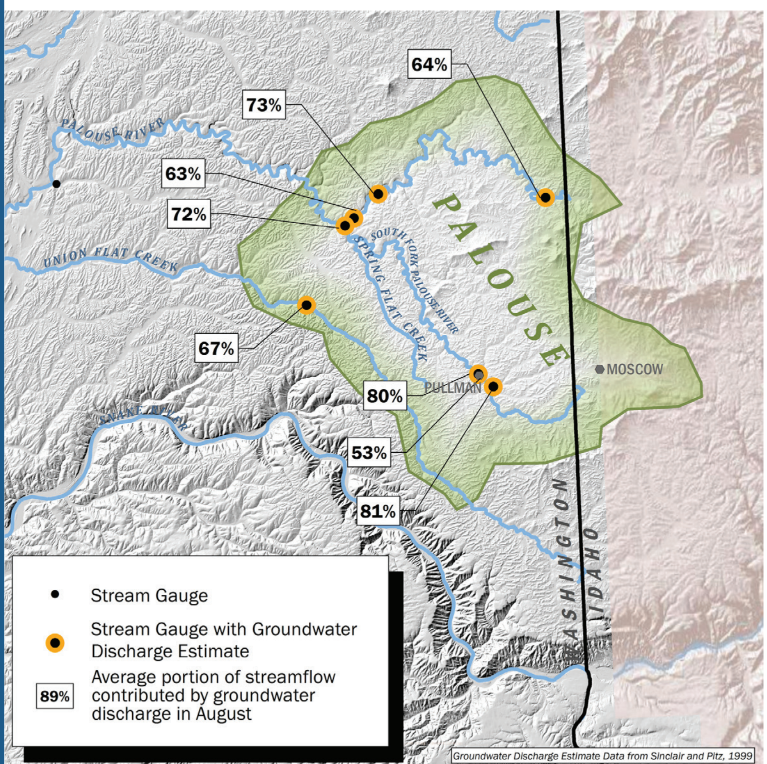
# Palouse Groundwater Basin
(Whitman County)

## Overview

Municipalities in the Palouse Groundwater Basin rely on groundwater supplied by deep basalt aquifers of the Columbia Plateau Regional Aquifer System that receive limited recharge. As a result, steady groundwater declines of 1 to 1.5 ft/year have been recorded in the basin since the 1910s.

Shallower aquifers, including overburden and Wanapum Basalt, are in hydraulic connection with surface bodies. Most groundwater withdrawals are from the Grande Ronde Basalt. Surface water relies on groundwater discharge to supply significant portions of dry season flows. Washington State Department of Ecology (Ecology) has concluded there is little to no groundwater available for new consumptive use.

Supply and Demand Context: Physical water supply is limited in the Palouse Groundwater Basin because of a combination of high demand, very low recharge to deep aquifers, and aquifer isolation by faults and aquifer boundaries where geologic layers thin and pinch out. This combination has resulted in water level declines. Surface water flows in the area are captured by groundwater pumping, including declines in the Wanapum Basalt, so new groundwater withdrawals are limited because they may capture flows from surface water sources that are closed or regulated.




## Surface and Groundwater Interaction in the Palouse Groundwater Basin

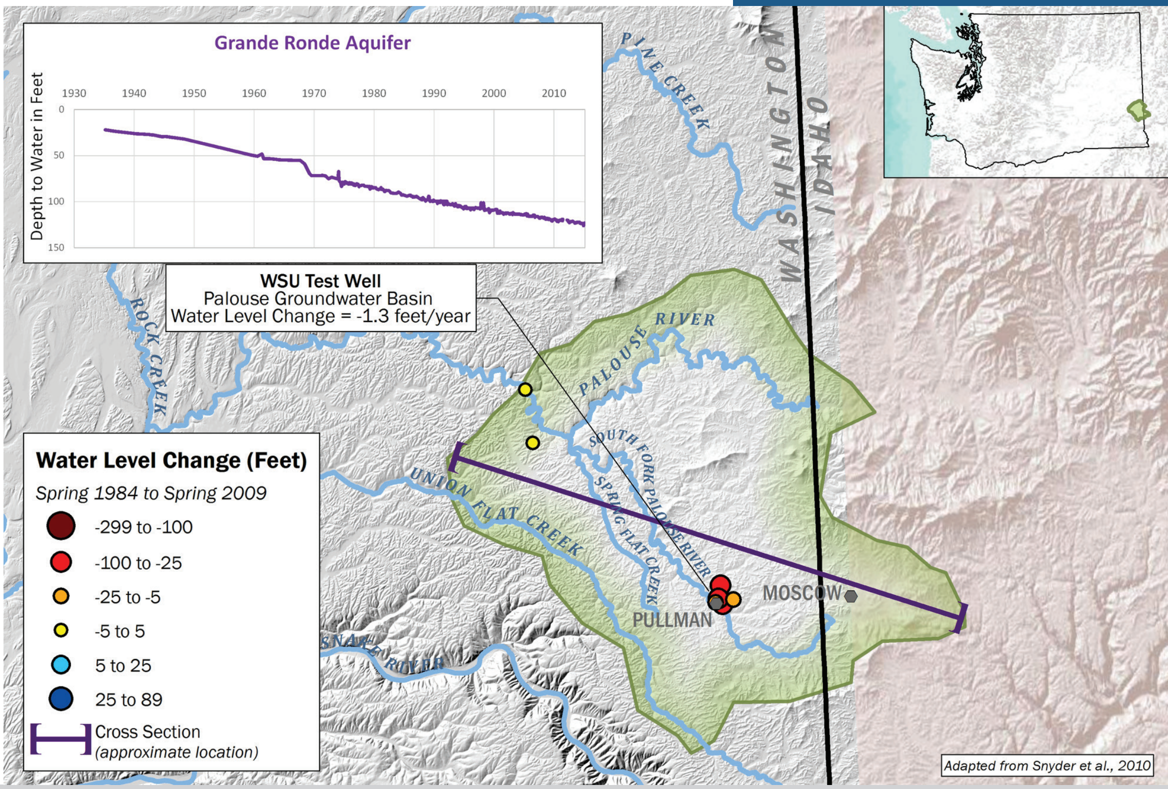
The primary surface water bodies in the Palouse Groundwater Basin include Union Flat Creek, and the South Fork of the Palouse River and its tributaries: Spring Flat Creek and Fourmile Creek.

- The streams are in hydraulic connection with the Palouse Loess, Scabland deposits, and Wanapum Basalt.
- Discharge is highest where streams have incised into the Wanapum Basalt.
- A significant portion of streamflow during the dry season is supplied by groundwater discharge.
- Deeper aquifer isolation caused by faulting and other geologic contacts can isolate the effects on surface water baseflows due to pumping, but also exacerbate groundwater declines.

## Management Context

| | |
|---|---|
| Groundwater Management Area | None present |
| Management Policy | None in place |
| Adjudicated Areas | None |
| Watershed Planning | WRIA 34 (Currently in Phase 4: implementation) |
| Adopted Instream Flow Rules | Surface water sources are subject to seasonal SWSL closures. |
| Drought Authorization | None |
| Groundwater Declines | Steady declines of 1 to 1.5 ft/year in the city of Pullman since the 1910s. Continued constant declines in the City Palouse Wells despite a decrease in pumping. |

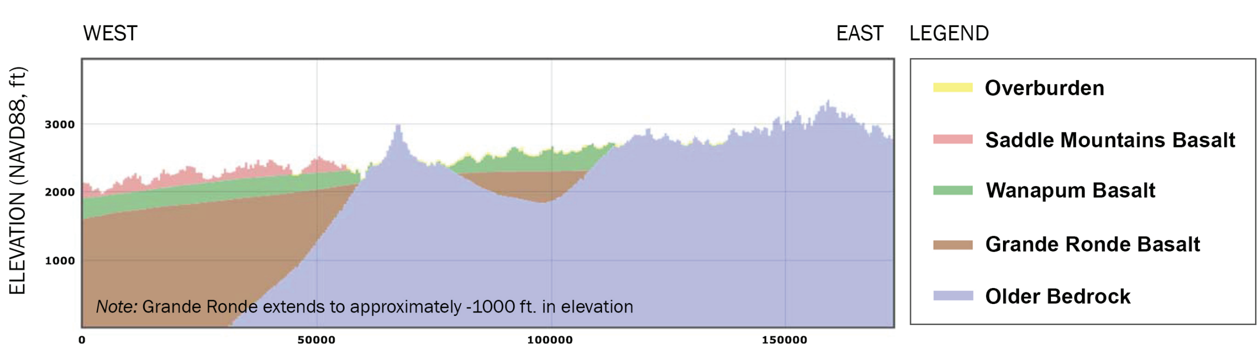
# Palouse Groundwater Basin
(Whitman County)




## Conceptual Hydrogeologic Model

Considerations in developing the conceptual hydrogeologic model include:

- The principal aquifer zones are the Wanapum and Grande Ronde Basalts, with the Grande Ronde used most heavily by municipalities and others.
- The eastern edge of the Palouse slope exhibits a high degree of aquifer isolation, due to faulting and contacts with older basement rocks.
- Overburden materials are important for supporting surface water baseflows, but are not widely used for water supply, due to low aquifer yields.
- Groundwater flow is generally southwest toward the Columbia, Snake, and Walla Walla Rivers.
- Significant recharge is limited to overburden and shallow basalts.
- Key references include: Folnagy, 2012; TerraGraphics, 2011; Larson, 1997; Hatthorn and Berber, 1994; Lum et al., 1990; Kahle, 2011; Golder, 2004; Heinman, 1994; and Lutziar and Burt, 1974.

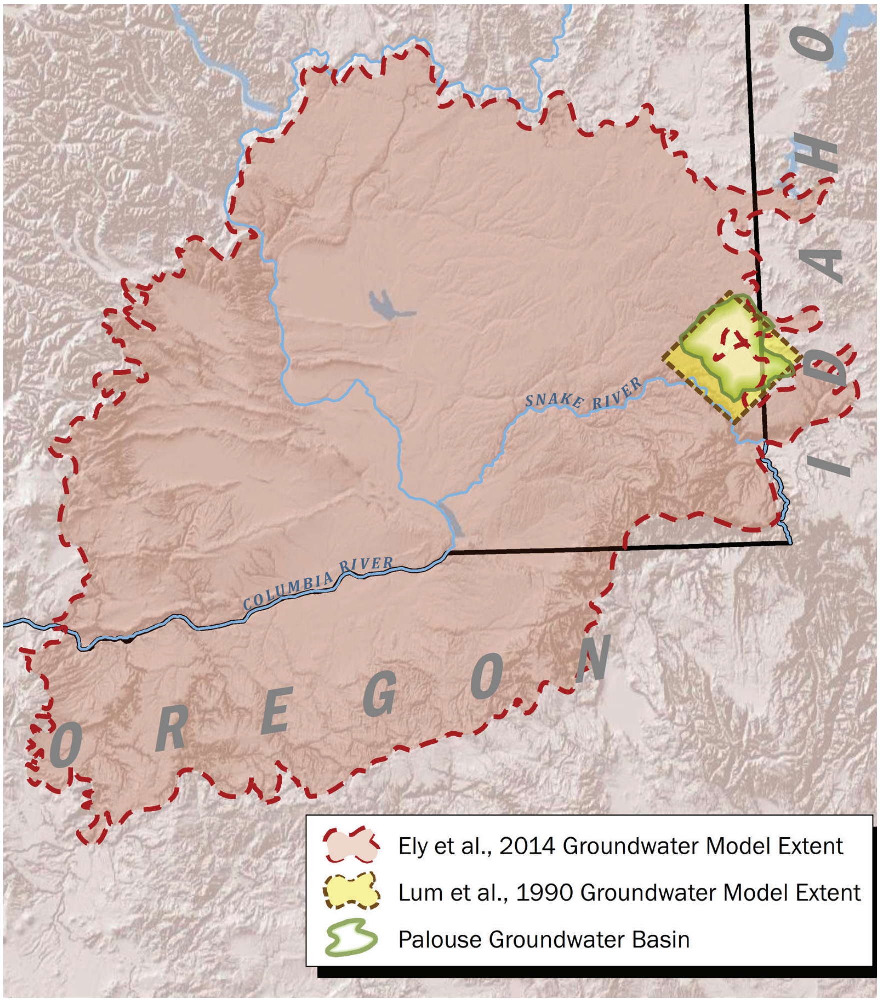


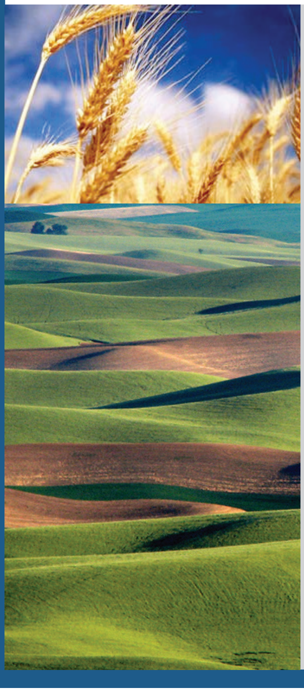

*Note:* Vertical scale greatly exaggerated
*Source:* USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

# Palouse Groundwater Basin
(Whitman County)

## Available Groundwater Models

Two known, recent groundwater models exist for the Palouse Groundwater Basin. Both of these models would need significant refinements to be adequate to aid decision-making that addresses declining groundwater issues in the Palouse Groundwater Basin. Known groundwater models include one focused on the Palouse Basin prepared by Lum et al., (1990) and modified in 1996, and a second more recent groundwater model constructed by Ely et al., (2014) that simulates the entire Columbia River Regional Aquifer System. This regional model includes portions of the Palouse Groundwater Basin; however, its resolution (grid spacing) is too coarse for detailed simulations of Palouse groundwater flow. The Lum et al., model has a more focused coverage of the Palouse Groundwater Basin, but it also has coarse grid spacing, and is based on data collected prior to 1985. The two models do contain significant information on hydrogeologic units and properties that could be built upon to provide a management tool for the Palouse Groundwater Basin. Model references include: Ely et al., 2014; Folnagy, 2012; Johnson et al., 1996; Lum et al., 1990; Lutzier and Skrivan, 1975; Hansen et al., 1994; Vaccaro, 1999; Barker, 1979; and Smoot, 1987.



## Potential Solutions

### Demand Approaches

Conservation: Cities of Palouse and Moscow have implemented several conservation measures: incentives and education to increase domestic water conservation with high efficiency appliances and xeriscaping; ordinances limiting lawn and garden irrigation; and upgrades to city irrigation systems.

Administrative: None planned

### Supply Approaches

Surface Water Replacement (potential): Limited by Surface Water Source Limitation (SWSL) seasonal closures.

ASR: Likely physically feasible in portions of area based on study of two wells (one of two wells suitable) (Gibson and Campana, 2014).

SAR: May be physically feasible for augmenting surface water flows, but would not be feasible for augmenting deeper basalt aquifer zones.

## Data Gap Analysis

**A comprehensive data gaps analysis identified the following "high priority" data needs for the Palouse Groundwater Basin (TerraGraphics, 2011):** Investigation of vertical groundwater barriers in West Pullman, surface water/groundwater interaction studies northwest of Pullman, yield optimization studies in Pullman-Moscow area for the Wanapum Basalt, and construction of a new groundwater modeling tool [estimated costs are yet to be determined].

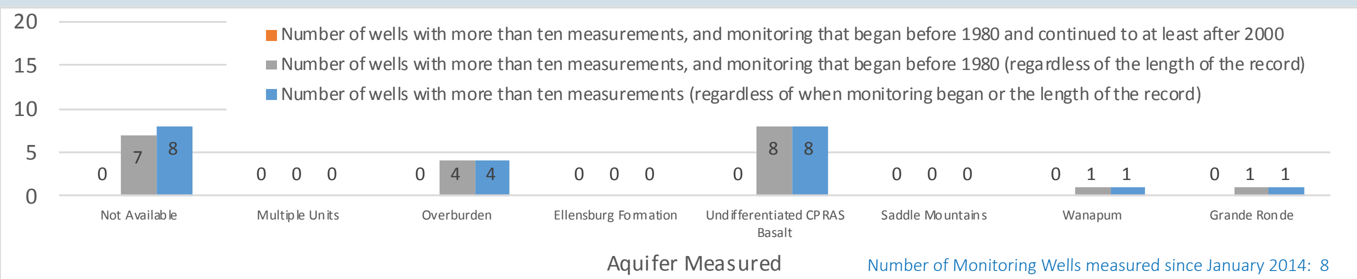
**Currently Operating USGS Stream Gauges**

| Station Number | Station Name | Operating Since |
|---|---|---|
| 13346000 | Palouse River Near Colfax, WA | 1955 |
| 13348000 | South Fork Palouse River At Pullman, WA | 1947 |
| 13348500 | Missouri Flat Creek At Pullman, WA | 1954 |
| 13350500 | Union Flat Creek Near Colfax, WA | 1953 |

| **Metered Water Rights (Ecology WRTS)** | Including Claims | | | Not Including Claims | | |
|---|---|---|---|---|---|---|
| | Total | Metered | Percentage Metered | Total | Metered | Percentage Metered |
| Number of Groundwater Rights | 820 | 20 | 2% | 95 | 20 | 21% |
| Groundwater Irrigated Acres | 11,000 | 0 | 0% | 300 | 0 | 0% |

**Water Level Data Availability**

Trends in water level are better tracked when water levels are monitored from multiple wells that each have several measurements collected over a long time period. The following chart summarizes water level monitoring data available in state databases based on aquifer and time period sampled, and the number of measurements.




Note: Additional monitoring by PBAC may not be accounted of in this analysis

*Data Sources: USGS NWIS, Ecology EIM, and DNR water level databases*

## Risk Factors in the Palouse Basin

Many water rights in the Palouse Groundwater Basin rely on a groundwater source. The following table presents groundwater-use information obtained from water rights data available from Ecology, water system data from Washington Department of Health, and the 2010 census.

## Groundwater Use

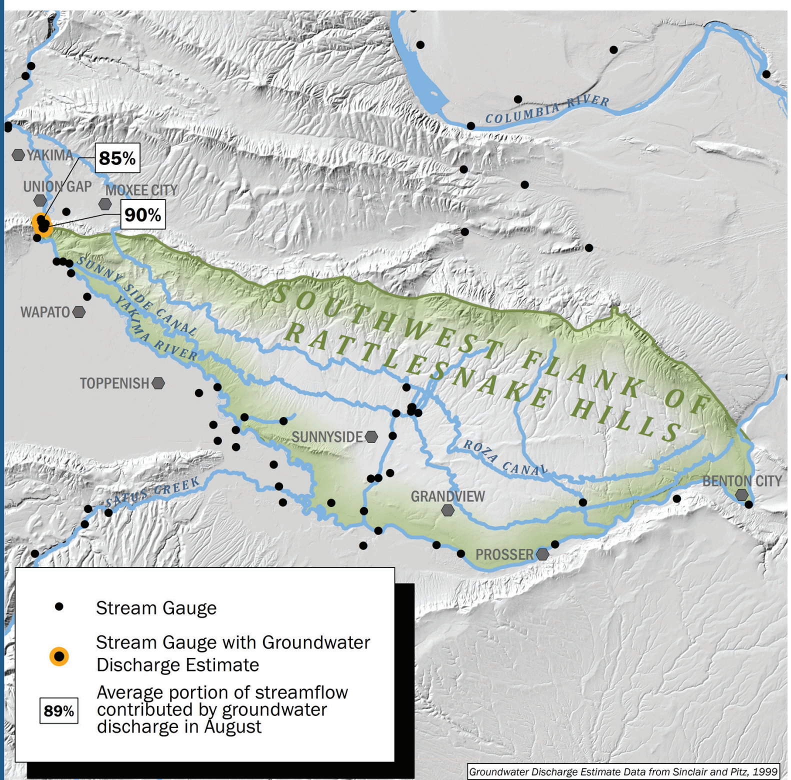
| | |
|---|---|
| Groundwater Irrigated Acres | 11,000 |
| Population Served by Group A Water Systems | 36,000 |
| Population Served by Group B Water Systems | 170 |
| Population | 38,000 |
| Industry | Washington State University;<br>Mostly agriculture: barley, wheat, dry peas, and lentils |

# SW Flank of Rattlesnake Hills
(Yakima and Benton Counties)

## Overview

The Southwest Flank of Rattlesnake Hills is adjacent to the Yakima River. The area supports significant agriculture and several municipalities that rely on both over-appropriated surface water supply and declining groundwater supplies. Groundwater declines from 21 ft to more than 150 ft have been recorded between 1986 and 2002. Groundwater declines have been documented in both the unconsolidated aquifer system and the underlying basalts of the Columbia Plateau Regional Aquifer System. Major projects are planned to address water resources and ecosystem issues in the Yakima Basin, including this area, under the Yakima River Basin Integrated Water Resource Management Plan.

Supply and Demand Context: Water supply is limited in this area due to intense pumping of aquifers that receive little recharge, and are interconnected with surface water systems reliant on baseflow. Groundwater demands increase in drought years when groundwater is used to supplement limited surface water supply. This combination results in groundwater declines and limitations in new groundwater withdrawals. Surface water flows are also impacted by groundwater withdrawals, including withdrawals from basalt aquifers, so new withdrawals are limited because they may impact surface water flows that are closed or regulated. Some projects implemented under the Yakima River Basin Integrated Water Resource Management Plan are expected to reduce groundwater declines and mitigate surface water impacts from pumping in the future.




## Surface and Groundwater Interaction in the Rattlesnake Hills

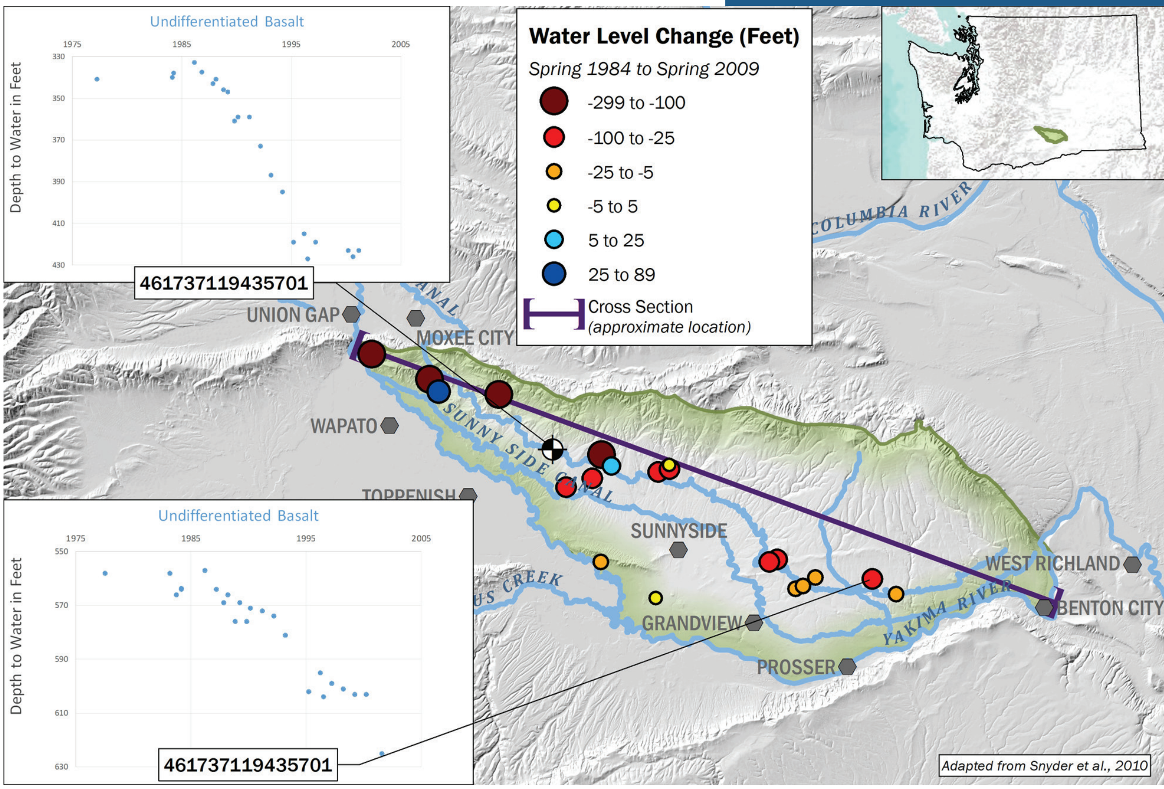
The primary surface water bodies in the Rattlesnake Hills include the Yakima River, and the Roza and Sunnyside Canals that supply Yakima River water to those respective irrigation districts.

- Groundwater in the area generally flows southwest toward the Yakima River.
- The Yakima River relies on groundwater discharge for much of its flow during the low-flow season.
- Pumping from both the overburden and basalt aquifers results in decreased discharge to the Yakima River, particularly from the overburden.
- Surface water shortages during drought years lead to increased groundwater demand.

## Management Context

| | |
|---|---|
| Groundwater Management Area | None present. |
| Management Policy | None at this time. |
| Adjudicated Areas | The Yakima River is currently under adjudication. |
| Watershed Planning | WRIA 37 (Phase 4 – implementation). |
| Adopted Instream Flow Rules | Target flows managed by the Bureau of Reclamation. |
| Drought Authorization | Case-by-case authorization, Roza alternate source wells. |
| Groundwater Declines | Generally between 21 and 150 ft from 1986 to 2002, and greater than 150 ft near Konnowak Pass. |

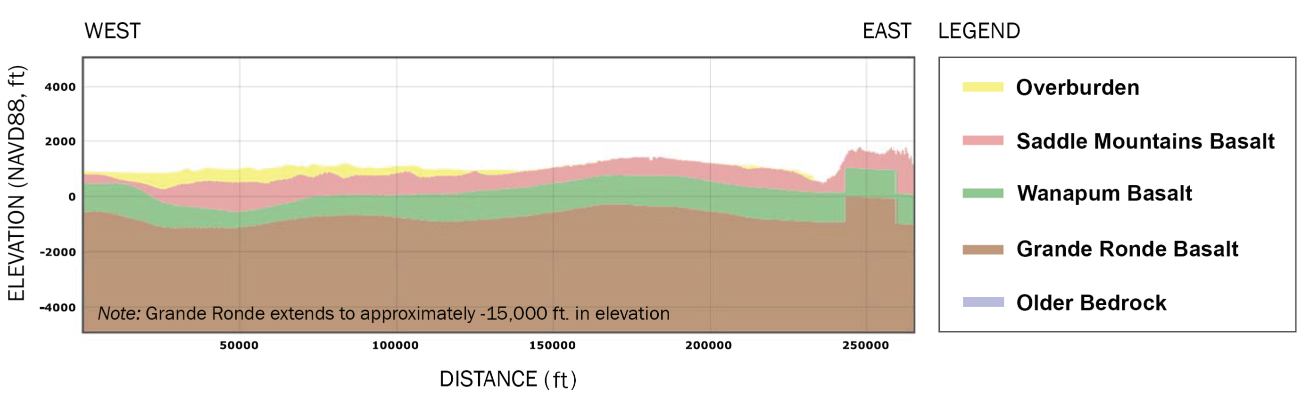
# SW Flank of Rattlesnake Hills
(Yakima and Benton Counties)




## Conceptual Hydrogeologic Model

Key considerations in developing the conceptual hydrogeologic model include:

- The area is located in the Toppenish Basin of the Columbia Plateau Regional Aquifer System.
- In addition to productive basalt aquifers, the area also contains thick sequences of productive gravels in the overburden.
- The area is bounded to the northwest by the Rattlesnake Hills, an anticlinal fold that creates a barrier to horizontal groundwater flow across the ridge northwest of Grandview.
- The overburden aquifers are heavily utilized. Wells further from the river and southeast of Grandview rely on groundwater withdrawals from the Saddle Mountain and Wanapum Basalts.
- Groundwater in this area discharges to wells and the Yakima River.
- Key references include: Kahle, 2011; Vaccaro, 2009, 2011; Ely, 2011; and Jones et al., 2006.

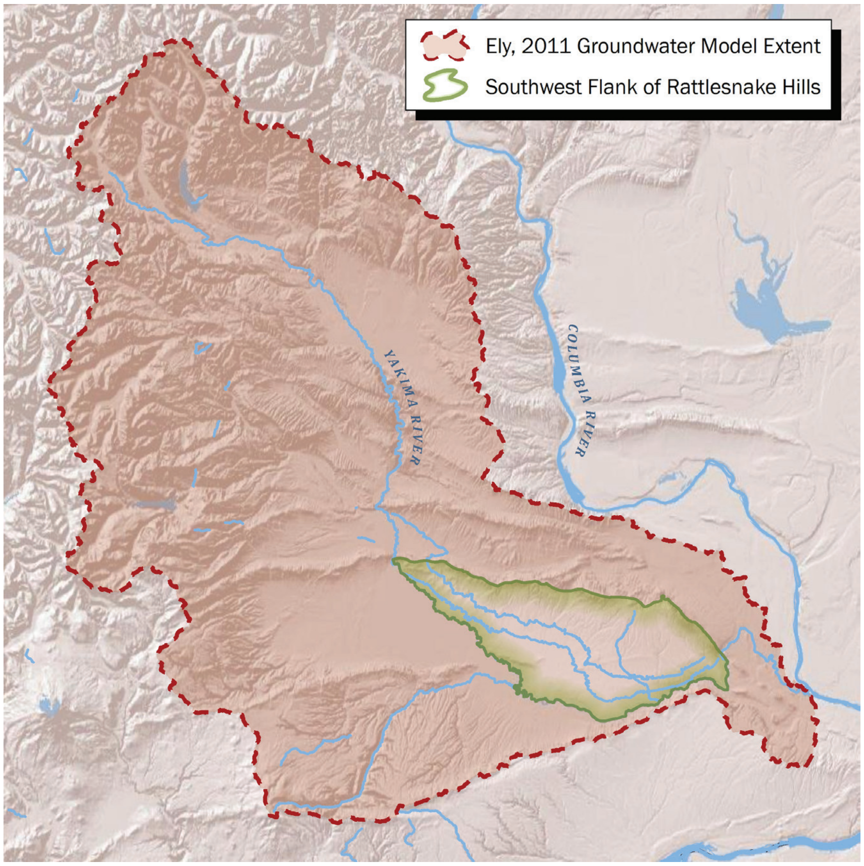


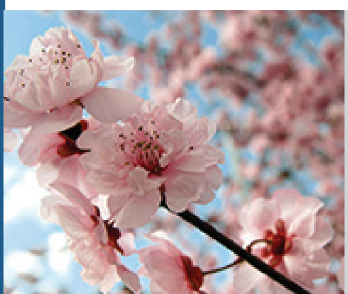

*Note:* Vertical scale greatly exaggerated
*Source:* USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

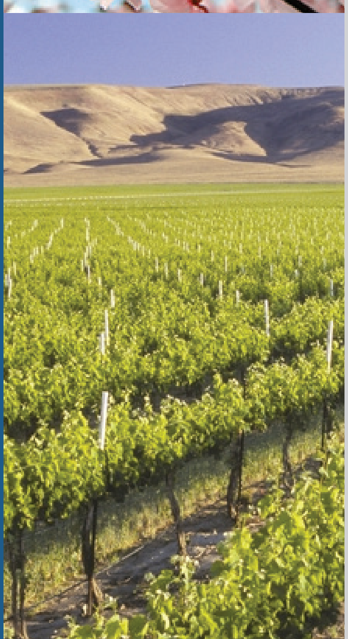
# SW Flank of Rattlesnake Hills
(Yakima and Benton Counties)

## Available Groundwater Models

The U.S. Geological Survey (USGS) has constructed a model of the Yakima Basin that provides good coverage of the Southwest Flank of the Rattlesnake Hills (Ely et al., 2011). The model scale is appropriate for assessing area-wide trends in groundwater conditions; however, it should be refined with current data to reflect current conditions. The model resolution (grid spacing) is too coarse for detailed simulations on a smaller scale for evaluation of potential groundwater recharge/enhancement projects. The model does contain significant information on hydrogeologic units and properties that could be used to support construction of a targeted higher-resolution model of the local areas. Another recent regional model constructed by the USGS is available that provides wider coverage of the area than the Yakima Basin model (Ely et al., 2014). Additional models are available, but they are broadly regional and/or are out of date. Model references: Ely et al., 2014; Ely et al. 2011; Hansen et al., 1994; and Vaccaro, 1999.





## Potential Solutions

The Bureau of Reclamation and the Washington Department of Ecology (Ecology) have prepared a plan focused on solutions to meet the water resources and ecosystem needs of the Yakima Basin as part of the Yakima River Basin Integrated Water Resource Management Plan (Bureau of Reclamation and Ecology, 2012).

### Demand Approaches

Conservation: Conservation measures are currently being carried out under the Yakima River Basin Water Enhancement Project Phase II and by various private organizations. Additional conservation measures for both municipal and agricultural uses are planned under the Yakima Basin Integrated Plan.

Administrative: None anticipated.

### Supply Approaches

Surface Water Replacement (planned): Several new surface water storage projects and enhancements to new storage projects are included in the preferred alternative under the Yakima Basin Integrated Plan.

Surface Water Replacement (potential): Yakima River water is currently under adjudication.

ASR: Likely physically feasible in some portions of the area, based on a study of five wells, with three determined to be unsuitable, one marginally suitable, and one suitable (Gibson and Campana, 2014). ASR is anticipated as part of the preferred alternative under the Yakima Basin Integrated Plan. The City of Yakima has planned a 5,000 to 10,000 ac-ft/year ASR program upstream of the Rattlesnake Hills Area.

SAR: SAR is anticipated as part of the preferred alternative under the Yakima Basin Integrated Plan. It is likely feasible for aquatic habitat enhancement. Pilot studies are planned.

## Data Gap Analysis

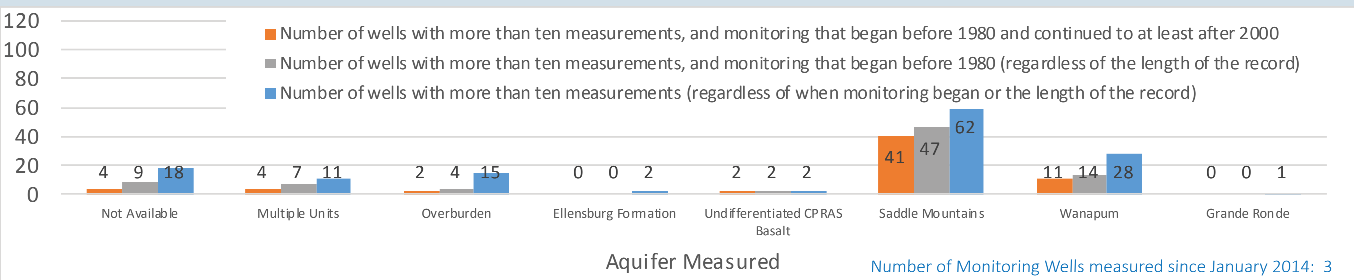
**Data Needs:** Continue historic groundwater modeling, and ASR/SAR pilot studies are planned [estimated costs are yet to be determined].

| Currently Operating USGS Stream Gauges | | |
|---|---|---|
| Station Number | Station Name | Operating Since |
| 12505450 | Granger Drain at Granger, WA | 1975 |
| 12510500 | Yakima River at Kiona, WA | 1948 |

| Metered Water Rights (Ecology WRTS) | Including Claims | | | Not Including Claims | | |
|---|---|---|---|---|---|---|
| | Total | Metered | Percentage Metered | Total | Metered | Percentage Metered |
| Number of Groundwater Rights | 4,500 | 77 | 2% | 905 | 77 | 9% |
| Groundwater Irrigated Acres | 66,000 | 4,800 | 7% | 63,000 | 4,800 | 8% |

### Water Level Data Availability

Trends in water level are better tracked when water levels are monitored from multiple wells that each have several measurements collected over a long time period. The following chart summarizes water level monitoring data available in state databases based on aquifer and time period sampled, and the number of measurements.




*Data Sources: USGS NWIS, Ecology EIM, and DNR water level databases*

## Risk Factors in the Southwest Flank of the Rattlesnake Hills

Many water rights in the area rely on a groundwater source. The following table presents groundwater-use information obtained from water rights data available from Ecology, water system data from Washington Department of Health, the 2010 census, and Vaccaro (2009).

## Groundwater Use

| | |
|---|---|
| Groundwater Irrigated Acres | 66,000 |
| Population Served by Group A Water Systems<br>Population Served by Group B Water Systems | 45,000<br>1,700 |
| Population | 67,000 |
| Hatcheries | Prosser Hatchery (Falll Chinnook and Coho Salmon |
| Industry | Agriculture includes orchards, grapes, and mixed row crops |

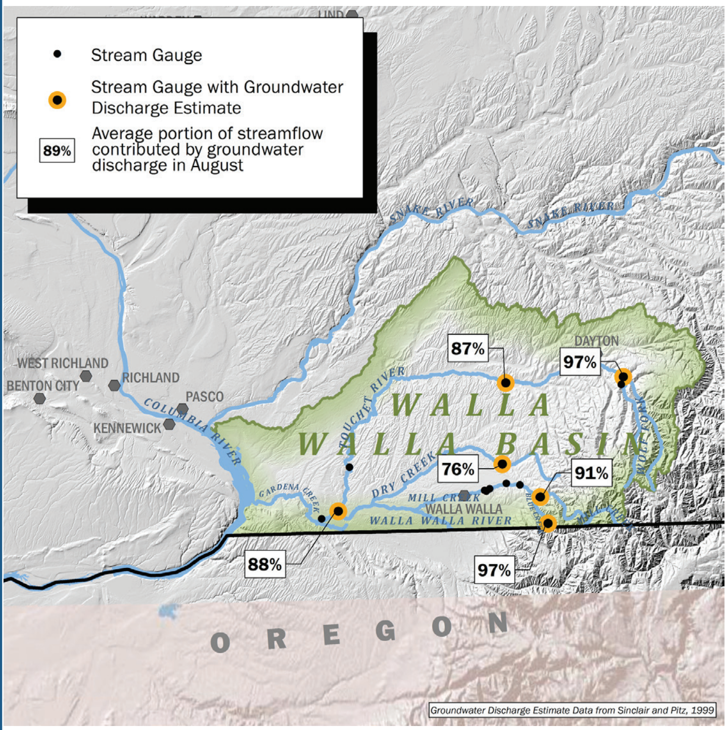
# Walla Walla Basin
(Walla Walla and Columbia Counties)

## Overview

Groundwater is estimated to be declining at a rate of 0.1 to 3.5 ft/year in the Walla Walla Basin in Washington. The basin extends south into Oregon, where declines have also been recorded. Groundwater declines have been documented in both the unconsolidated aquifer system and in the underlying Basalt of the Columbia Plateau Regional Aquifer System. The largest groundwater declines have occurred in the Wanapum Basalt unit of the regional aquifer system.

Groundwater use in the basin is primarily for irrigation. Municipal use of groundwater is generally limited to deep basalt wells that are used for emergency and peak supply. The unconsolidated aquifer has a high degree of connection with surface water and is subject to instream flow rules (WAC 173-532). One of the most significant recharge areas for the entire regional basalt aquifer system is along the east side of the basin in the Blue Mountains.

Supply and Demand Context: Physical water supply is limited in the area because of a combination of high demand, very low recharge to deep aquifers, and aquifer isolation by faults and aquifer boundaries where geologic layers thin and pinch out. This combination has resulted in water level declines. Surface water flows in the area are captured by shallow groundwater withdrawals from the unconsolidated aquifer, so new groundwater withdrawals are limited because they may capture flows from surface water sources that are closed or regulated. A recently permitted ASR system is expected to eventually reduce groundwater declines in the deep Wanapum basalt aquifers. Recently implemented SAR systems are expected to reduce impacts to surface water flows.



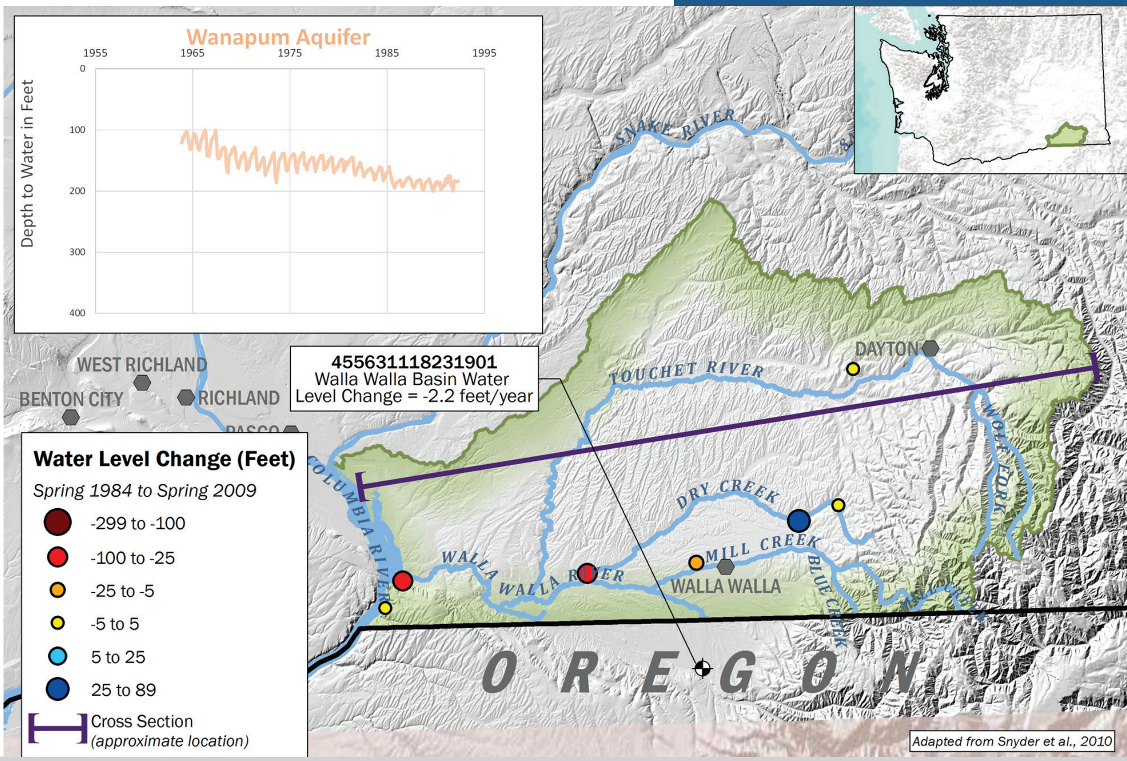

## Surface and Groundwater Interaction in the Walla Walla Basin

Major surface water bodies in the Walla Walla Basin include the Walla Walla River, Mill Creek, the Touchet River, and the North Fork of the Touchet River.

- Mill Creek is an important supply source for the City of Walla Walla.
- The rivers provide important salmon habitat.
- Surface waters are highly connected to the unconsolidated aquifer and are reliant on groundwater to maintain flows during the dry season.
- Unconsolidated aquifer withdrawals are limited by the 2007 instream flow rule.

## Management Context

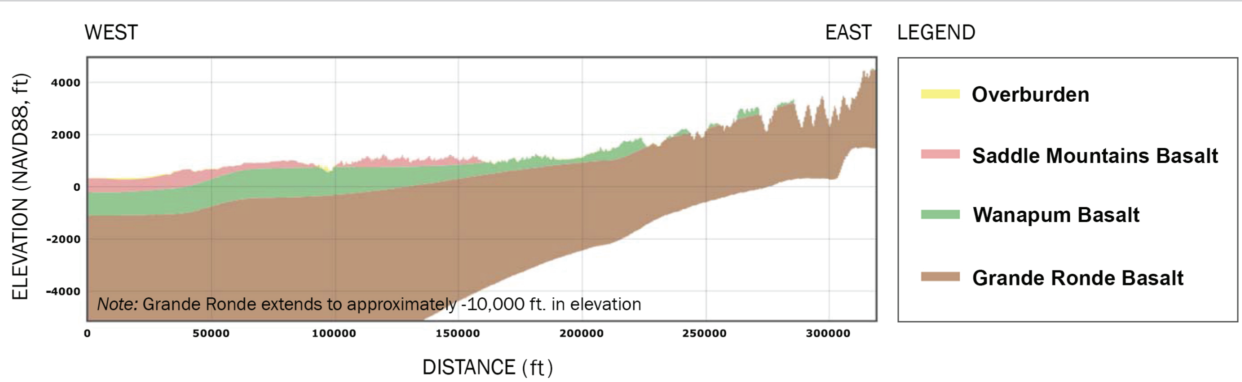
| | |
|---|---|
| Groundwater Management Area | None present |
| Management Policy | Limited to Instream flow rule (WAC 173-532) |
| Adjudicated Areas | Walla Walla River, Upper Stone Creek, Doan Creek, Touchet River, Dry Creek |
| Watershed Planning | WRIA 32 (currently in phase 4 implementation) |
| Adopted Instream Flow Rules | Walla Walla River, and its tributaries and headwaters (WAC173-532). Seasonal closures and no further consumptive appropriation of surface waters and shallow gravel aquifer water. |
| Drought Authorization | None |
| Groundwater Declines | Washington: 0.1 to 3.5 ft./year; Oregon: 6 to 7.5 ft./year (Burns et al., 2012). |




## Conceptual Hydrogeologic Model

Considerations in developing the conceptual hydrogeologic model include:

- Key aquifers in the Walla Walla Basin include the unconsolidated aquifer system and the underlying Columbia Plateau Regional Aquifer System.
- The unconsolidated aquifer system is also referred to as the suprabasalt or overburden aquifer in various documents.
- The unconsolidated system includes three coarse-grained units, which are separated by two fine-grained units, all of which are assumed by the Washington State Department of Ecology (Ecology) to have a high degree of hydraulic connection to surface water (WAC 173-532).
- Columbia Plateau Regional Aquifer System units from shallowest to deepest include the Saddle Mountain, Wanapum, and Grande Ronde Basalts.
- The Blue Mountains on the upland (east) end of the Walla Walla Basin comprise a significant recharge area for the entire basalt aquifer system (approximately 20 in/year).
- Basalt aquifers in the basin have a high degree of isolation caused by vertical faults that serve as barriers to groundwater flow, making them prone to groundwater declines.
- Key references include: Burns et al., 2012; GSI, 2007; HDR, 2013; Tolan et al., 1989; Kahle, 2011; Snyder et al., 2010; and PGG, 1995.

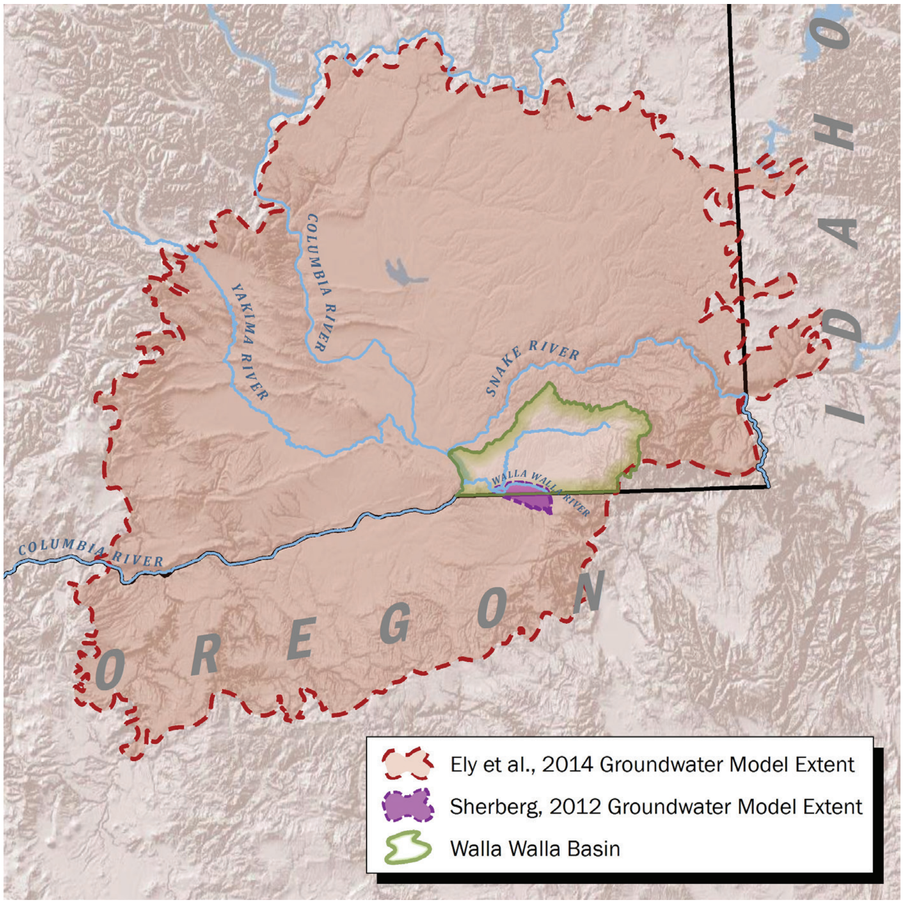


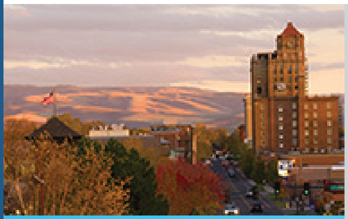

*Note:* Vertical scale greatly exaggerated
*Source:* USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

# Walla Walla Basin
(Walla Walla and Columbia Counties)

## Available Groundwater Models

At least three groundwater models have been developed for portions of the Walla Walla Basin. It is expected that any of these models would need refinements to be adequate for decision-making to address declining groundwater issues in the Walla Walla Basin. A candidate for building upon is the MODFLOW model prepared by Ely et al., (2014). This is a regional scale model covering the entire Columbia Plateau Regional Aquifer System. The model does contain significant information on hydrogeologic units and properties that could be used to support construction of a targeted, higher-resolution model of the basin. Model references in addition to Ely et al., include: Sherberg, 2012; Petrides-Jimenez et al., 2008; MacNish and Barker, 1976; Hansen et al., 1994; and Vaccaro, 1999.



## Potential Solutions

### Demand Approaches

Conservation: Irrigation efficiency improvements implemented. Walla Walla Water System Conservation Plan has been implemented.

Administrative: Instream flow rules have been implemented that restrict use of the unconsolidated aquifer.

### Supply Approaches

Surface Water Replacement (potential): Closed to new consumptive appropriation by instream flow rules. Source exchange projects using Columbia River water are a possible option in lower portions of the basin.

Surface Water Storage: One pilot project complete in Washington (WWBWC, 2016).

ASR: Permit issued for city of Walla Walla in 2015. Future ASR projects may be considered.

SAR: Several projects implemented since 2007: Two sites in Washington, eight sites in Oregon (WWBWC, 2016). Most feasible in unconsolidated aquifer system.

## Data Gap Analysis

**Data Needs:** Groundwater modeling, and ASR feasibility and pilot studies [estimated costs are yet to be determined].

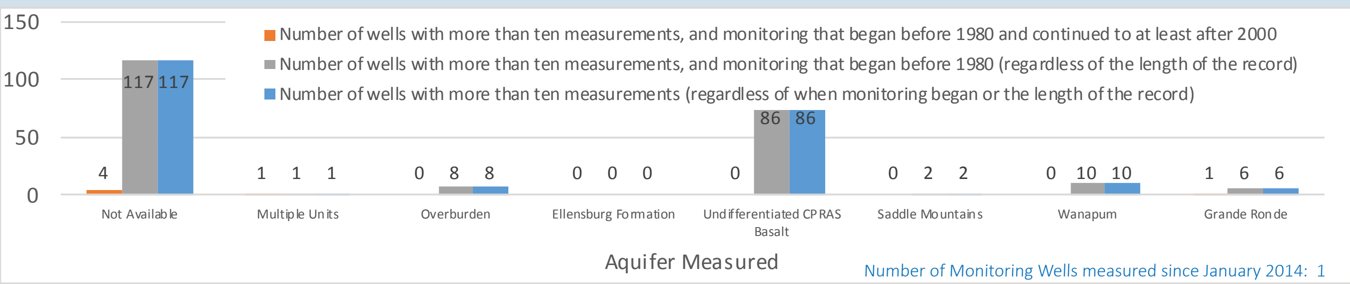
**Currently Operating USGS Stream Gauges**

| Station Number | Station Name | Operating Since |
|---|---|---|
| 14013000 | Mill Creek near Walla Walla, WA | 1924 |
| 14013500 | Blue Creek near Walla Walla, WA | 1973 |
| 14013700 | Mill Creek at Five Mile Road Br near Walla Walla, WA | 1997 |
| 14014000 | Yellowhawk Creek at Walla Walla, WA | 1952 |
| 14014500 | Garrison Creek at Walla Walla, WA | 1952 |
| 14015000 | Mill Creek at Walla Walla, WA | 1924 |
| 14016000 | Dry Creek near Walla Walla, WA | 1977 |
| 14018500 | Walla Walla River near Touchet, WA | 1951 |

| **Metered Water Rights (Ecology WRTS)** | Including Claims | | | Not Including Claims | | |
|---|---|---|---|---|---|---|
| | Total | Metered | Percentage Metered | Total | Metered | Percentage Metered |
| Number of Groundwater Rights | 4,300 | 181 | 4% | 1,700 | 181 | 11% |
| Groundwater Irrigated Acres | 78,000 | 6,900 | 9% | 70,000 | 3,000 | 4% |

**Water Level Data Availability**

Trends in water level are better tracked when water levels are monitored from multiple wells that each have several measurements collected over a long time period. The following chart summarizes water level monitoring data available in state databases based on aquifer and time period sampled, and the number of measurements.




Note: Additional monitoring by WWBC and City of Walla Walla may not be accounted for in this analysis.

*Data Sources: USGS NWIS, Ecology EIM, and DNR water level databases*

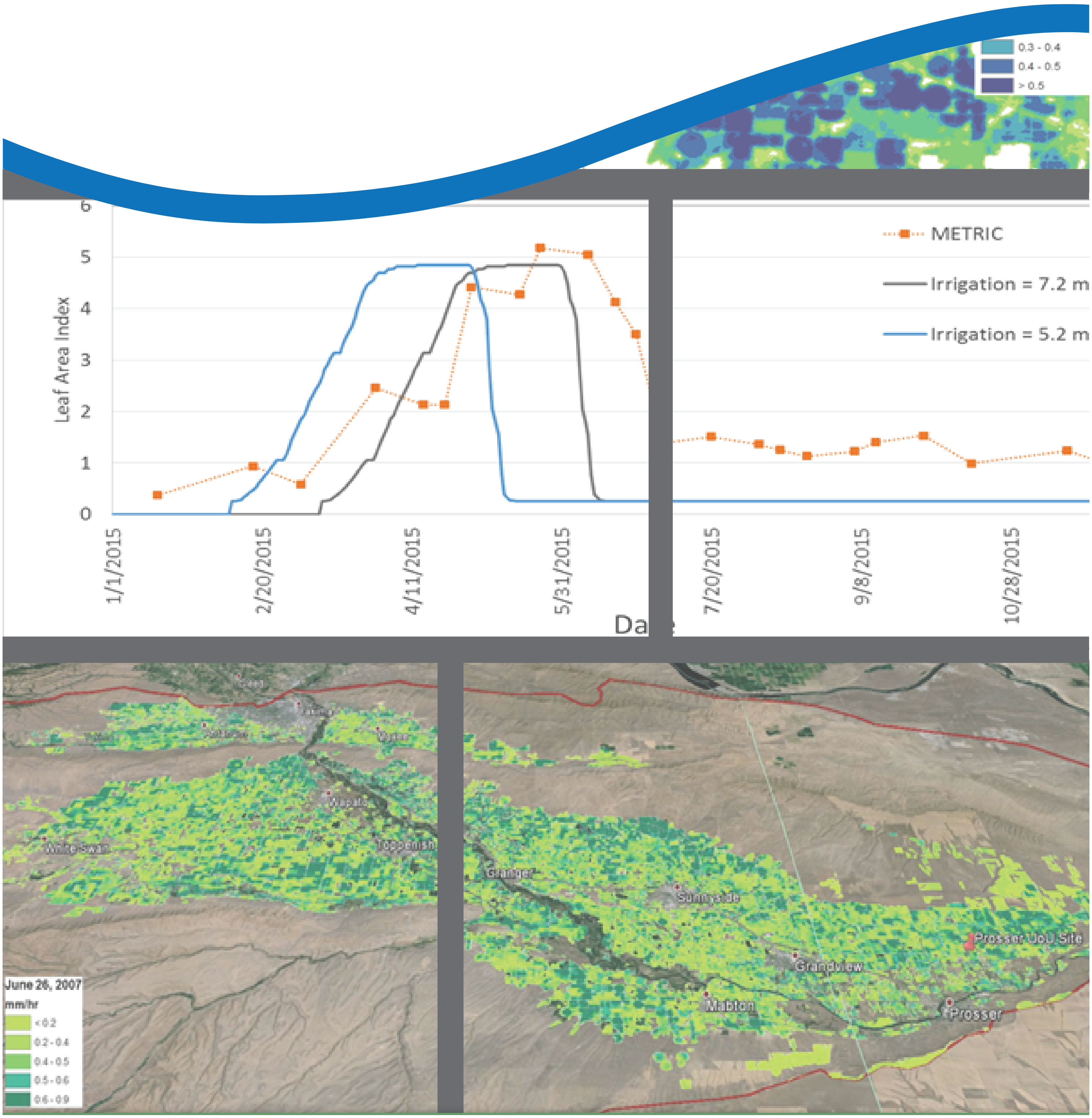
## Risk Factors in the Walla Walla Basin

Many water rights in the Walla Walla Basin rely on a groundwater source. The following table presents groundwater-use information obtained from water rights data available from Ecology, water system data from Washington Department of Health, and the 2010 census.

## Groundwater Use

| | |
|---|---|
| Groundwater Irrigated Acres | 78,000 |
| Population Served by Group A Water Systems | 54,000 |
| Population Served by Group B Water Systems | 300 |
| Population | 58,800 |
| Industry | Agriculture (14%), service industries (70%), manufacturing (13%) |

# Pilot Application of METRIC Crop Demand in Washington State



## *Introduction*

Predicting consumptive use rates at watershed scales that accurately capture spatial and temporal variability remains a challenge for water resources management and planning. Accurately determining where, when, and how much water is needed allows for effective water management and improved planning of future storage and allocation decisions (Ducnuigeen et al. 2015). A considerable amount of data is required to understand localized demands which is not adequately reflected by monthly or seasonally reported diversion records. The 2011 Columbia River Basin Water Supply and Demand Forecast pointed out several important gaps in data availability as well as those in the modeling framework. This module explains the progress made to address the data gap associated with watershed-scale consumptive use estimates and provides a guide to improve several of the limitations identified in the previous study. Specific limitations and data gaps presented were: 1) the inability to identify a parcel of land being irrigated by specific water rights and the uncertainty in water rights claims which caused uncertainty in amount of allocated water; 2) Irrigation extent data was available only for Washington (from WSDA). Crops outside Washington were assumed to be always irrigated in the model; (3) metered water data was limited and of mixed quality, so the modeled demand estimates were not extensively evaluated; and (4) crop modeling included a variety of crops, but the differences in crop types, farm management and irrigation types were considered the same for each crop. Small discrepancies in some of these aspects could amount to significant quantities of water in the watershed.

To address some of these limitations and gaps, this work presents use of a satellite based remote sensing technique to estimate consumptive use (as evapotranspiration) for three pilot watersheds in Eastern Washington. Satellite imaging of land surfaces has improved in quality over past few decades so remote sensing approaches to manage agricultural water use is getting popular (Figure 1). This module aims to present the modeling approach and results of using satellite remote sensing data to help address some of the aforementioned issues.

Agricultural water use largely corresponds to evapotranspiration (ET), which is the sum of evaporation from the ground plus transpiration from plants. Evapotranspiration is usually estimated using data from weather stations and crop coefficients (Kc). These crop coefficients are values set for a specific crop and growth stage under highly idealized conditions. The two major challenges in estimating crop coefficients for a watershed are (a) identifying crop type and (b) making assumptions on stages of crop growth, which can vary significantly across a watershed due to factors such as soil, management, and topography.  To overcome these challenges, a model - METRIC (Mapping Evapotranspiration at High Resolution and Internalized Calibration) (Allen et al. 2011) uses satellite images to derive crop coefficients without the need of assuming crop type and growth stages. This helps to improve the accuracy of evapotranspiration estimates for an entire watershed.

METRIC has been used for many applications in the western US. Some of them are (1) evaluation and adjudications of water rights in Idaho courts (2) complimenting metered water use data on a seasonal scale (3) Identification of areas of crop stress (4) assist in study of aquifer depletion and ground-water modeling.

*Figure 1. Satellite Images of Yakima watershed (Top) Landsat 5 image on June 19, 1993 (Bottom) Landsat 8 image on July 14, 2014.*

## Objectives

There are two major objectives of this module. The first objective is to develop and calibrate METRIC to estimate crop water use in three pilot watersheds in Eastern Washington: Okanagan, Walla Walla and Yakima. The second objective is to use the results of METRIC to refine parameters for CropSyst (crop production model used in Forecast) (Stöckle et al. 2003).

## METRIC

METRIC is a satellite-based image-processing tool and uses surface energy balance equation to calculate ET. The model calculates the total amount of energy reaching earth's surface from sun, proportion of energy that is reflected, diffused and absorbed by the surface and the atmosphere and energy that is lost from surface due to conduction and convection (see Figure 2). Since there should be a balance of incoming and outgoing energy to and from the earth's surface, any energy that is "left over" is used for ET.

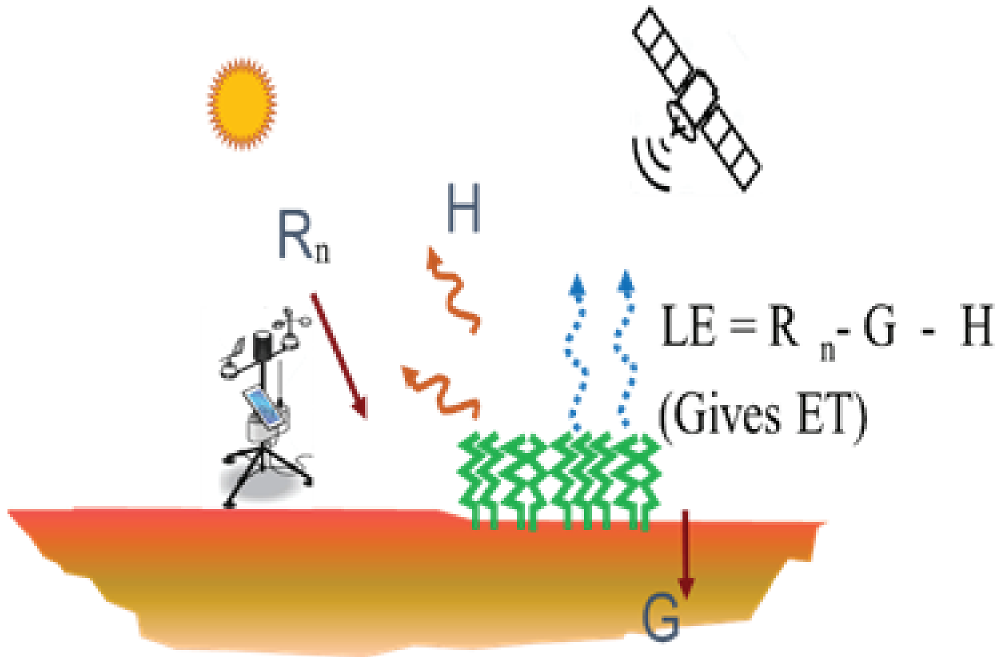



*Figure 2. Scientific Basis of METRIC. METRIC uses satellite imagery with weather data to estimate consumptive use using surface energy balance method.*

## Theoretical Basis

The theoretical basis of METRIC is SEBAL (Surface Energy Balance Algorithms for Land) model which was described by Bastiaanssen (1998). The principles and formulation of METRIC is described in Allen et. al (2007a). Evapotranspiration in METRIC is calculated as a residual of surface energy balance equation (Figure 2) as:

$$LE = R_n - G - H$$

where LE = latent heat energy consumed by ET; $R_n$ = net radiation (sum of all incoming and outgoing radiation); G = sensible heat flux conducted into the ground and H = sensible heat flux convected into the air.

In recent applications of METRIC, it has been treated as an "open platform" where the algorithms to compute the different components of energy balance equation can be chosen based on user preference. For this work, the algorithm and general system of equations for METRIC has been followed based on Allen et. al. (2007a) . Further improvements in the model were made based on Allen et. al. (2011) and Allen et. al. (2013b).

METRIC uses satellite measurement of narrowband reflectance and surface temperature for calculation of $R_n$. The algorithm developed $R_n$ has not changed since Allen et. al. (2007a). With the availability of advanced processed satellite products such as at-surface reflectance, the procedure for computation of surface albedo has been simplified. Soil heat flux (G) is computed as a fraction of $R_n$, based on surface temperature and vegetation indicators. Allen et. al. (2011) has been used to compute G. Sensible Heat Flux (H) is estimated from surface temperature, surface roughness and wind speed using buoyancy corrections. For applications into mountainous terrains, Allen et. al. (2013b) has been used. H is computed as:

$$H = \frac{\rho\, c_p\, dT}{r_{ah}}$$

where ρ is air density (kg/m3), cp is specific heat (J/kg/K), dT is temperature difference between two heights near surface blended layer and $r_{ah}$ is the aerodynamic resistance of heat transport in the blended layer.

In this equation, temperature difference near the surface (dT) is used rather than estimates of air and surface temperature because the error in estimating surface and air temperatures from satellite would be larger than the temperature differences between surface and air. This quantity (dT) is estimated using satellite based surface temperature and two points (a wet location and a dry location) in the satellite image. This is a calibration scheme, which is novel to METRIC and SEBAL. One of the major challenges in application of METRIC is this calibration process. For calibration of METRIC, a statistical procedure developed by Allen et. al. (2013a) was used.

## *Data Requirements*

### Satellite Imagery Data

METRIC was applied for this work using Landsat satellite imageries. The high resolution of Landsat, at 30 m, is useful for monitoring water consumption at field scales. It was downloaded using US Geological Survey's Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA) on demand interface (https://espa.cr.usgs.gov/). With this data product, terrestrial variables such as surface reflectance and land surface temperature which have been computed from the digital numbers (DN) are provided along with the raw digital numbers. These derivations ease application into METRIC and increase reproducibility since the procedure for converting DN to surface reflectance requires some assumptions.

Although METRIC has an automatic application process where much of the data is extracted automatically from different servers, Landsat products for the entire period of analysis described above were downloaded manually using a bulk ordering interface provided by the ESPA website.

### Weather Data

Calibration of METRIC requires computation of reference ET. Since, Landsat images are representation of a picture, sub-hourly weather data is desirable for calibration of METRIC. Standardized Penman-Monteith equation (Allen et al. 2005) is used to compute reference ET which is used for calibration of METRIC and extrapolation of instantaneous ET to daily or longer periods.

Three weather stations were installed at the three pilot watersheds to compute reference ET at these sites (Figure 3). Table 1 provides the exact station locations. Research grade sensors from Campbell Scientific were installed at these sites. There were five sensors used which measured data at 1-minute intervals:

1. 03002 RM Young Wind Sentry Set: This sensor was used to measure speed and direction of wind speed. It was installed precisely 2m above the ground surface.
2. CS650 Water content reflectometers: Three sensors were used to measure soil volumetric water content and soil temperature. They were installed aligned horizontally at depths of 10cm, 30 cm and 100 cm. Data was recorded for bulk electrical conductivity but was not used in the project.
3. HC2S3 Temperature and Relative humidity probe: This sensor was used to measure temperature and relative humidity at about 2m above the ground surface. One of the station at Walla Walla had some compromised data points when relative humidity was higher than 100%, when sprinklers and fans were turned on.
4. SP230 Heated Pyranometer: This sensor was used to measure incoming solar radiation. It was installed about 1.8 m above the ground surface.
5. TE525 Tipping Bucket Rain Gage: This rain gage sensor was used to measure rainfall. The least count of the device was 0.01 inches. These rain gages were initially installed at about 1 m above the ground. But the data was compromised because of irrigation water sprinklers, so it was moved at a height of about 2.5 m above the ground. This data was used to identify rainfall storms and had to be adjusted based on surrounding stations.

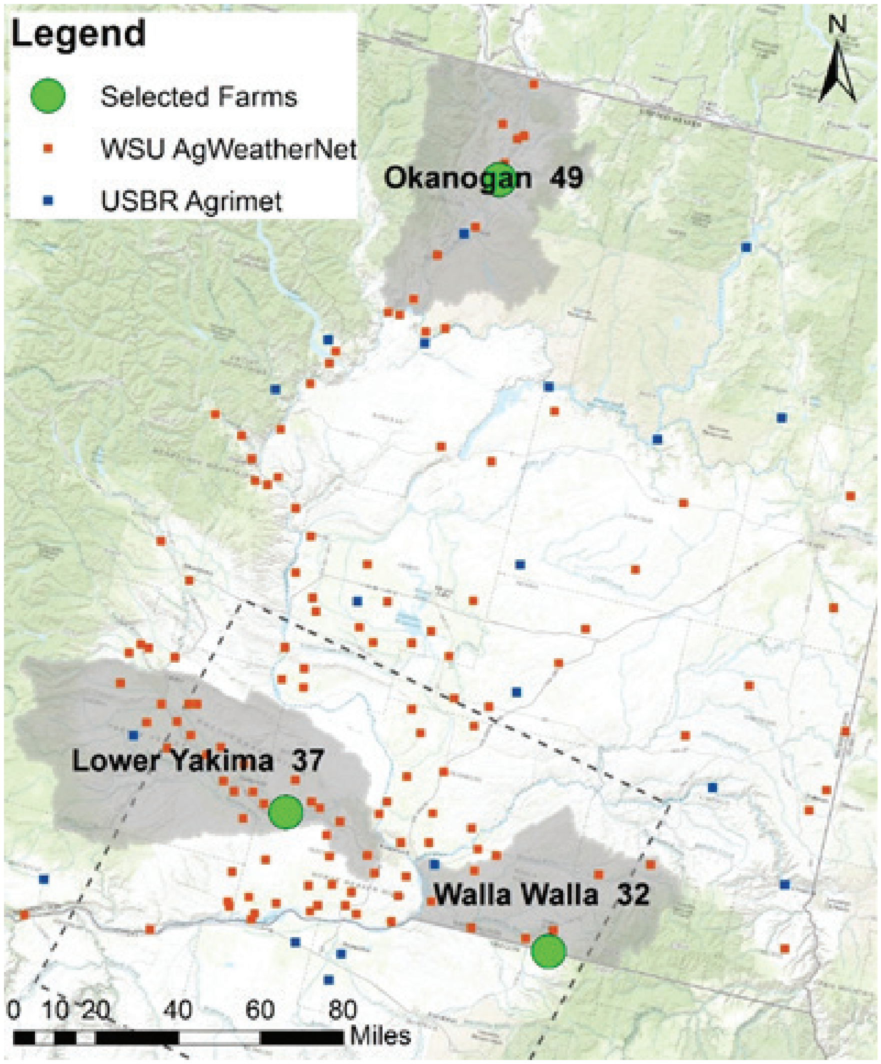



*Figure 3. Location of three selected watersheds for study. WSU Agweathernet and USBR Agrimet make up a dense network of weather stations in Eastern Washington which makes use of METRIC easier in this region.*

Table 1. Weather station locations.

| Station Site | Latitude | Longitude |
|---|---|---|
| Okanogan | 46.25584722 | -119.7290639 |
| Yakima | 46.00078333 | -118.2732694 |
| Walla Walla | 48.6199 | -119.4679889 |

Weather station sensors were installed on a CM106b Tripod. A BP24 12V-24Ah rechargeable battery was installed for uninterrupted power. An SP50 50W solar panel was installed to recharge the batteries. Additionally, a CH200 charging regulator was used to charge the batteries. A CR200X data logger was used to log the data from sensors and a RAVENXTV Airlink CDMA cellular modem was used to remotely send data from the site. A data logger support software provided by Campbell Scientific was installed and used to transfer data automatically from the sites using Verizon cellular service every three hours. The battery, modem and data logger were enclosed in ENC16/18 Weather resistant enclosure.

*Figure 4. Weather station at Prosser.*

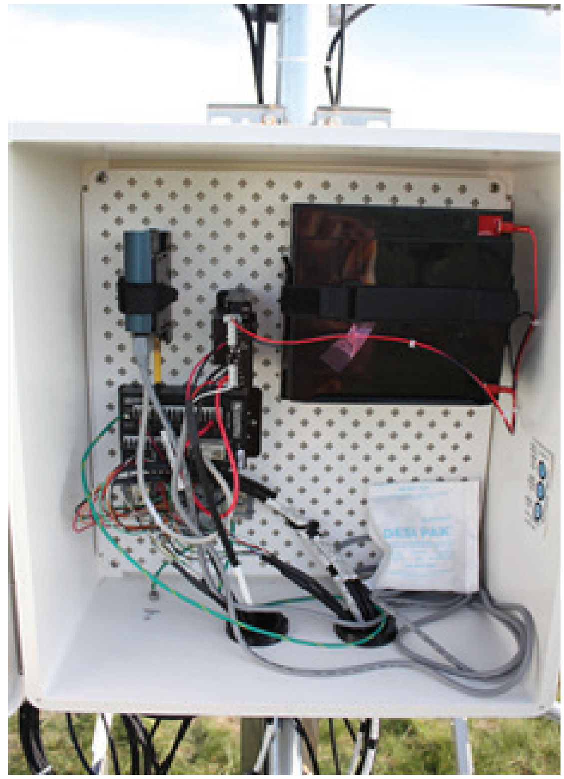


*Figure 5. Data logger and battery inside enclosure.*

Additionally, a network of sites is provided by Washington State University (WSU) called AgWeatherNet and a similar network of sites provided by United States Bureau of Reclamation (USBR) called AgriMet can provide weather data for METRIC for application in these regions (Figure 3).

### Additional Data

Along with satellite imageries and weather data, METRIC also requires Digital Elevation Model (DEM) data. DEM data was downloaded from USGS National Elevation Dataset (https://lta.cr.usgs.gov/NED). The resolution of DEM is 30m.

For calibration of METRIC, an area of interest (AOI) which contains primarily irrigated agricultural land needs to be selected. Alternatively, land use / land cover database from National Land Cover Dataset (https://www.mrlc.gov/) can be used. In this work, NLCD 2011 land use 81 and 82 has been used for calibration.

## *Methodology*

### Formulation and Automation of METRIC

METRIC was initially developed by Richard G. Allen in University of Idaho. The model's algorithm is available in published literature but the authors have not provided the application of this model, as a software.

According to the literature, METRIC had been developed by the authors using proprietary image processing software (ERDAS Imagine), specifically developed to work with remotely sensed satellite images. The use of this software limits the users of the model, as it is expensive and requires high-end computers and expert training. So, for this module, application of METRIC was done using a free software (Python) with some functionalities of a commonly used Geographic Information System (GIS) software (ESRI ArcGIS). Removing the platform dependence made the model easier and cheaper for users interested in water use in Washington.

Figure 6 shows the flow diagram for calculation of evapotranspiration using METRIC for this work. Except for the automatic extraction of Landsat images and NLCD Land cover, all other data are automatically extracted using extent and time of Landsat image metadata.

Major features added into application of METRIC for this module are:

1. Developed in a programming framework which makes it flexible and easier for future researchers or users to add or modify parts of the model.
2. Automation of various processes has reduced the necessity of highly trained experts to run the model. It has also made the model easier to use and less time consuming.
3. For application in the state of Washington, automatic extraction of weather data from USBR AgriMet sites and WSU AgWeatherNet stations have been implemented. This has made the use of this model in the state of Washington even easier.

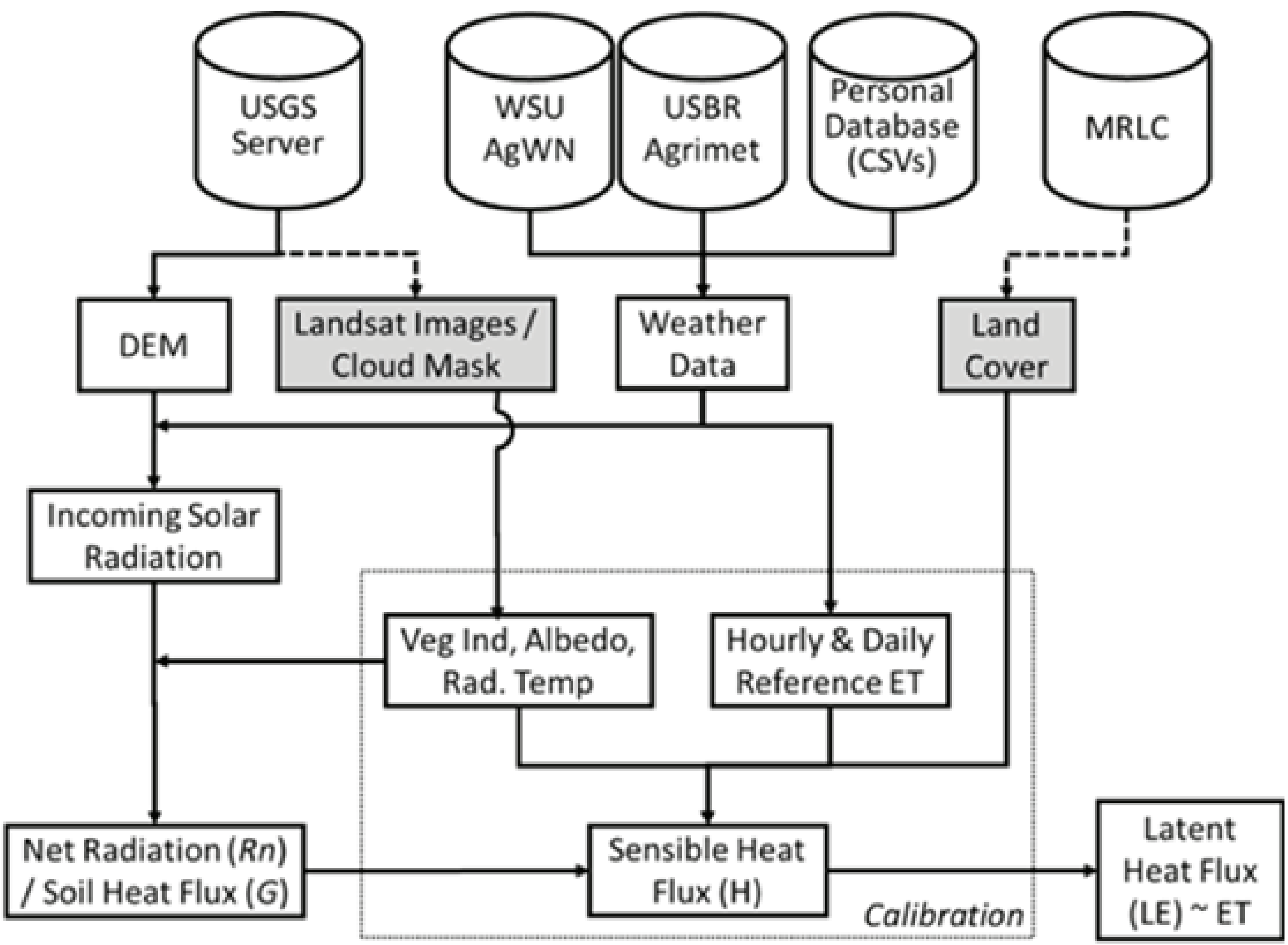



*Figure 6. Formulation of METRIC. Dashed arrows and gray boxes indicate that these processes have not yet been automated. Calibration has also been automated but the detailed steps are not shown here.*

## Calibration

Calibration of the model followed steps outlined in Allen et. al. (2013a). Since calibration process was also automated, NLCD land use classes 81 and 82 were chosen as area of interest (AOI) that contained irrigated agricultural land, as opposed to a constant AOI. This allowed using the model anywhere in the region.

This process of calibration required choosing a hot and cold pixel among a selected group of pixels in an image. For this work, properties of these pixels were analyzed and unless the differences between the pixel properties were not significantly different in the group, the closest pixel to the weather station was chosen. In Figure 7 it can be observed that properties for cold calibration pixels such as difference between net radiation and soil heat flux (Rn – G), and Surface albedo were similar for all the calibration pixels. In cases when these properties vary among the list of selected pixels, visual review of location needs to be done.

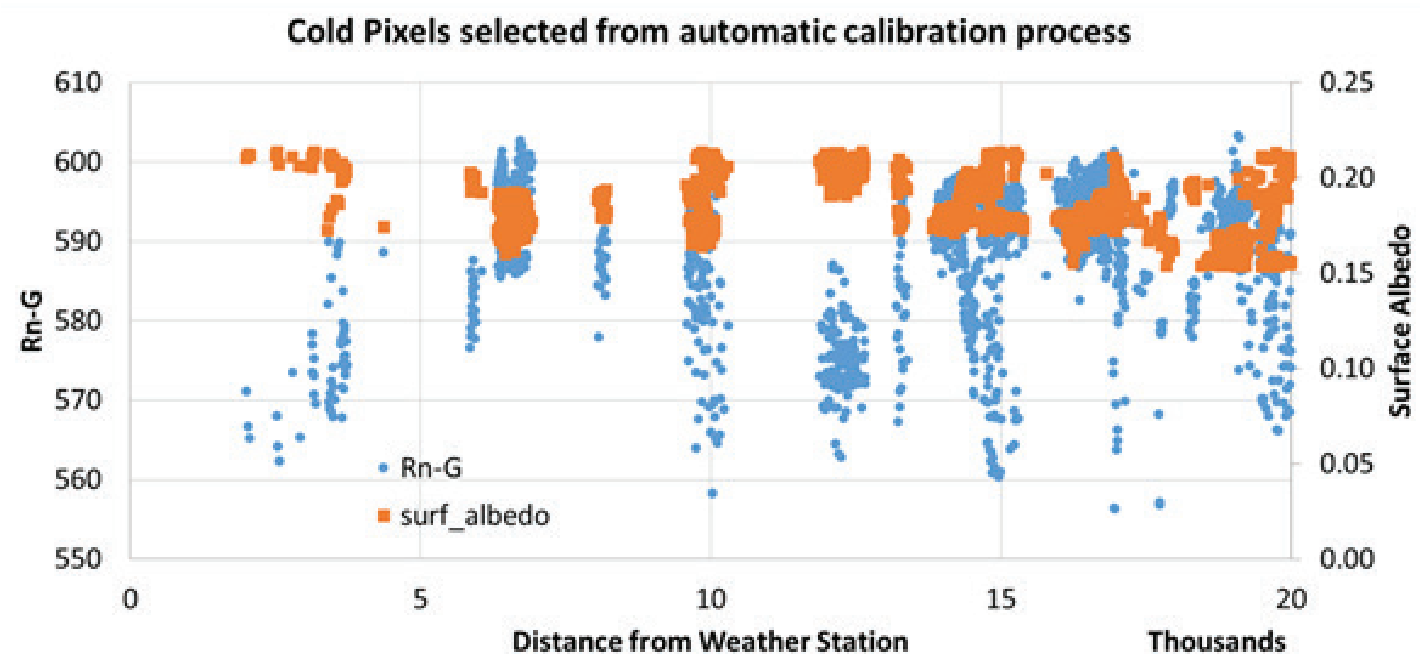



*Figure 7. Properties of a cold calibration pixels selected by the automation process. These pixels are within a distance of 20 km from a weather station. There are no significant differences in the properties of cold calibration pixel for this specific case, so the closest pixel to the weather station is selected.*

The original METRIC process uses a single station for calibration. In this work, the model was calibrated using all available stations within the image extent (Figure 8). This made the calibration process robust to larger weather station measurement errors and performed better with automation of calibration. Since Eastern Washington has a high density of WSU AgWeatherNet weather stations, this approach performed better.

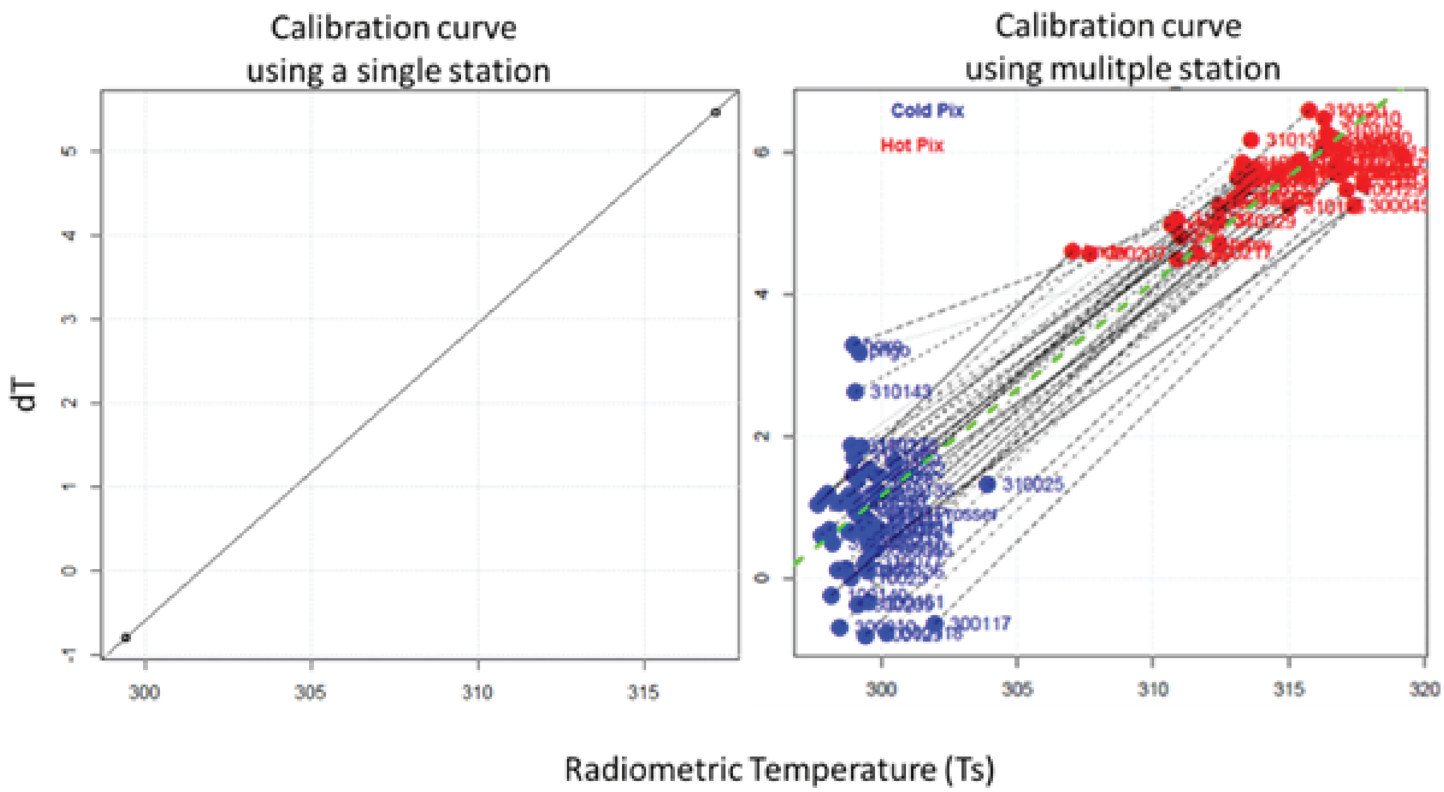



*Figure 8. Calibration of METRIC using single station vs. calibration using multiple stations. This method provided robust estimates of calibration parameters (linear model).*

## Model Validation

The results of the model was validated using eddy covariance flux tower data (provided freely by AmeriFlux (http://ameriflux.lbl.gov/). Since no AmeriFlux stations were available in Washington for agricultural land use, we used the closest station (Site Code: US-Tw3) in California for validation. Weather stations data provided by CIMIS (California Irrigation Management Information System) was used to run METRIC.

Individual components of METRIC could be validated using AmeriFlux site data. 22 cloud free images from 2015 were used for validation. Figure 9 (a-d) show the comparison of instantaneous values of different components of METRIC with ground measured values. Although some individual components such as sensible heat flux and Soil Heat flux show higher model errors, the calibration scheme of METRIC helps to correct the

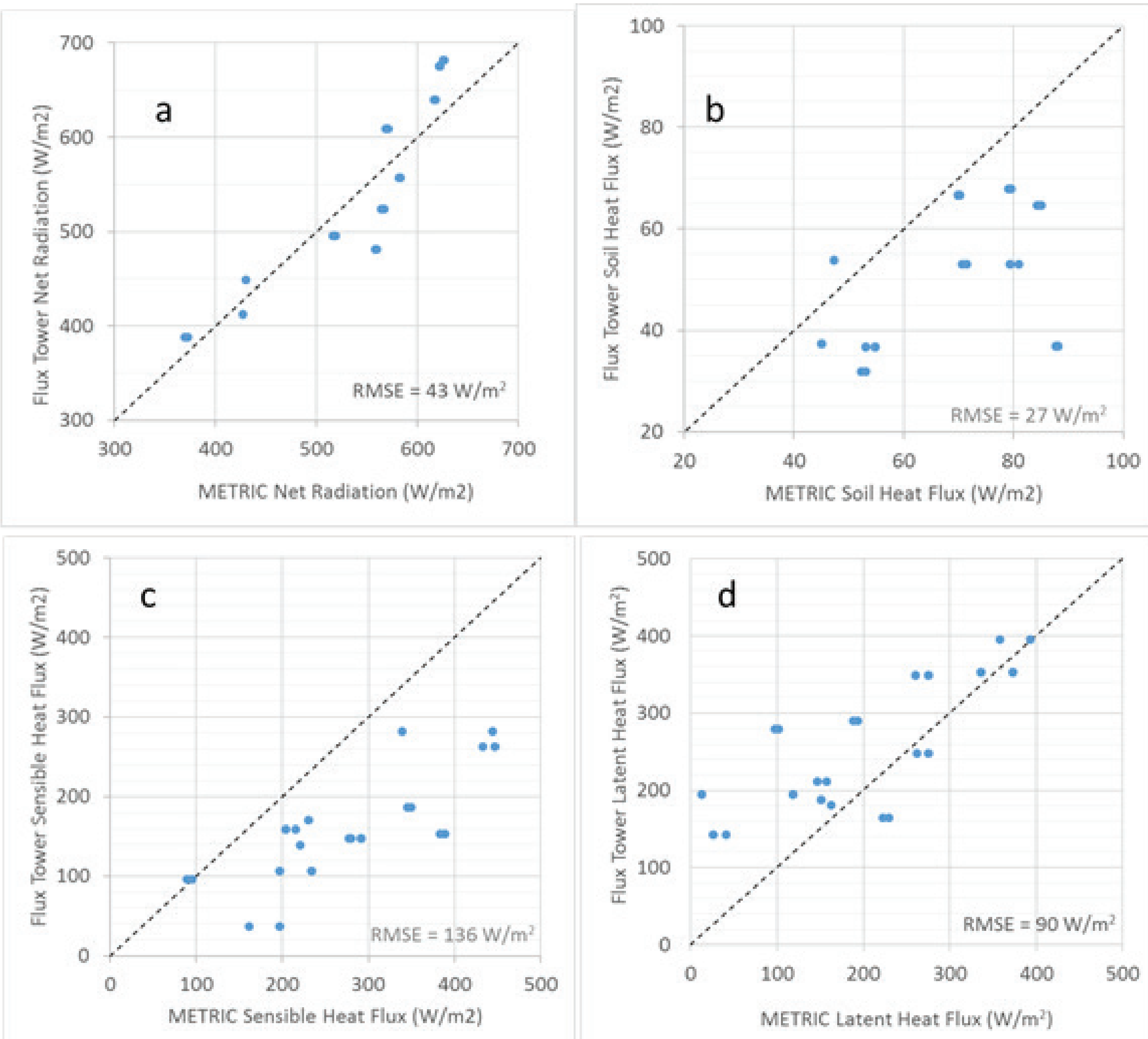



*Figure 9. Validation of each component of Surface Energy Balance of METRIC (a) Net Radiation (b) Soil Heat Flux (c) Sensible Heat Flux (d) Latent Heat Flux.*

error in latent heat flux (Allen et al. 2011). Additionally, daily and seasonal estimates of METRIC ET have better accuracy than instantaneous estimates when compared to lysimetric data for other METRIC applications (Allen et al. 2007b) .

### METRIC Output: Hourly, Daily and Monthly ET values from METRIC

Daily or seasonal values of ET from METRIC are usually more useful than instantaneous values. So, to compute daily and seasonal ET, reference evaporative fractions (ETrF) are computed which are then used with reference ET.

Daily ET is calculated as:

$$ET_{24} = Crad \times ETrF \times ET_{r24}$$

And ET over a period (month, season or year) is calculated as:

$$ET_{period} = \sum_{i=m}^{n} [(ET_r F_i)(ET_{r24i})]$$

where $ET_rF = ET_{inst} / ET_r$ and Crad = correction term for sloping terrain.

Figure 10 shows the instantaneous ET, Reference ET fraction and Daily ET values for three consecutive dates when satellite imageries were available. The total consumptive use for the period between July 16, 2015 and June 18, 2015 for the same area was computed by linearly interpolating Evaporative fraction and using reference ET for these dates for the same station (Figure 9). This figure also shows the high resolution ET maps that can be obtained from METRIC. At 30 m resolution, individual farms can be identified with their crop consumptive use.

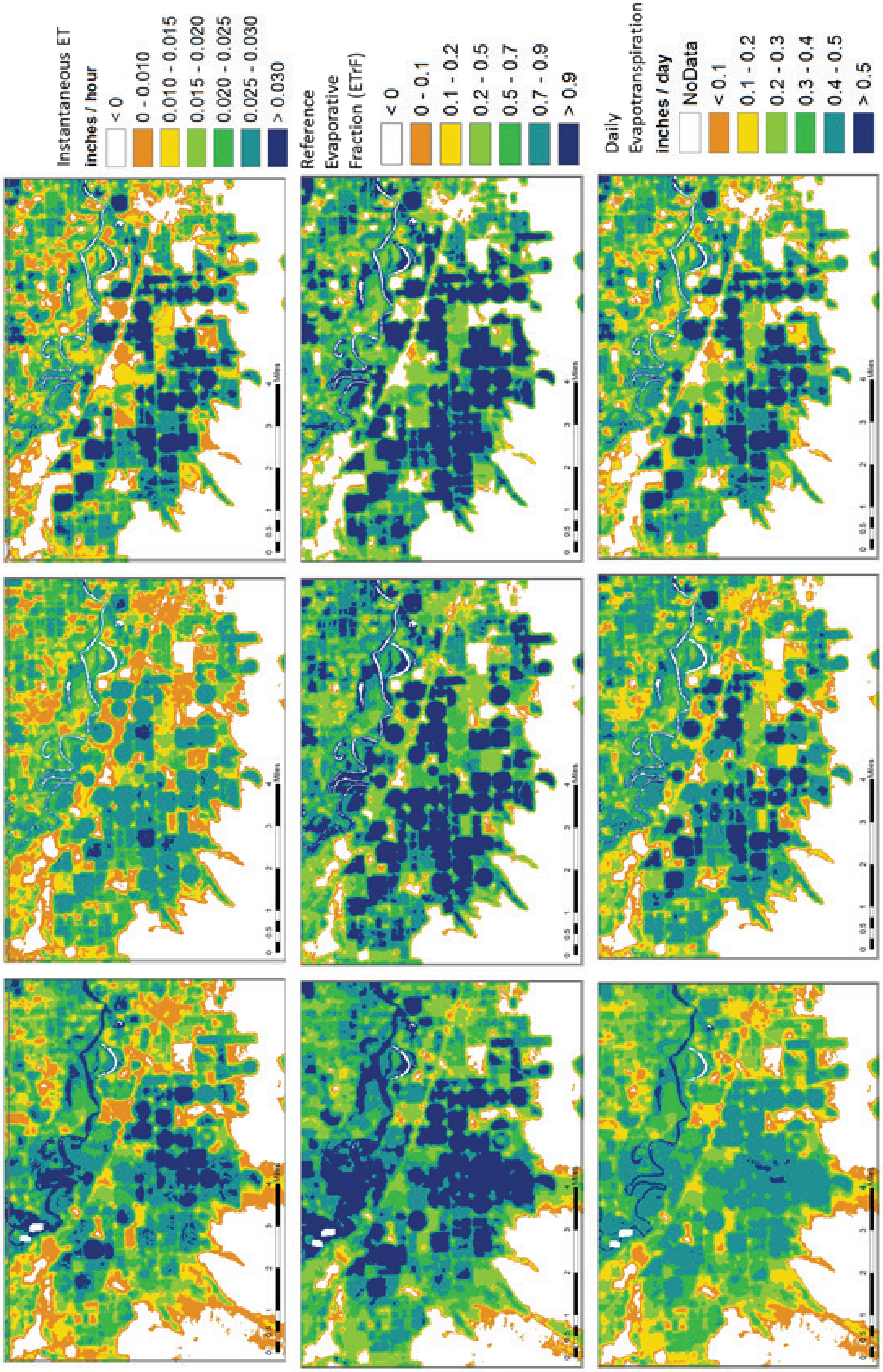
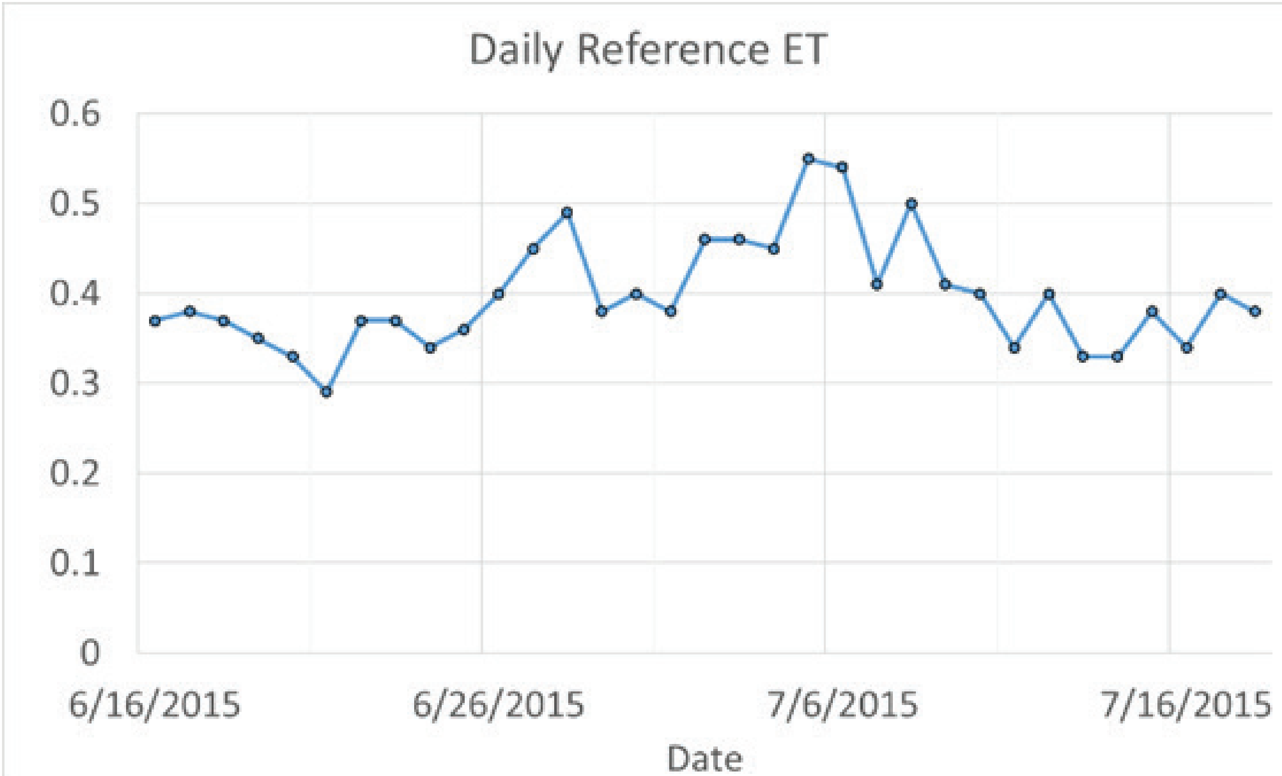



*Figure 10. METRIC can produce high resolution consumptive use maps. These results are for an area west of Prosser, Yakima.*



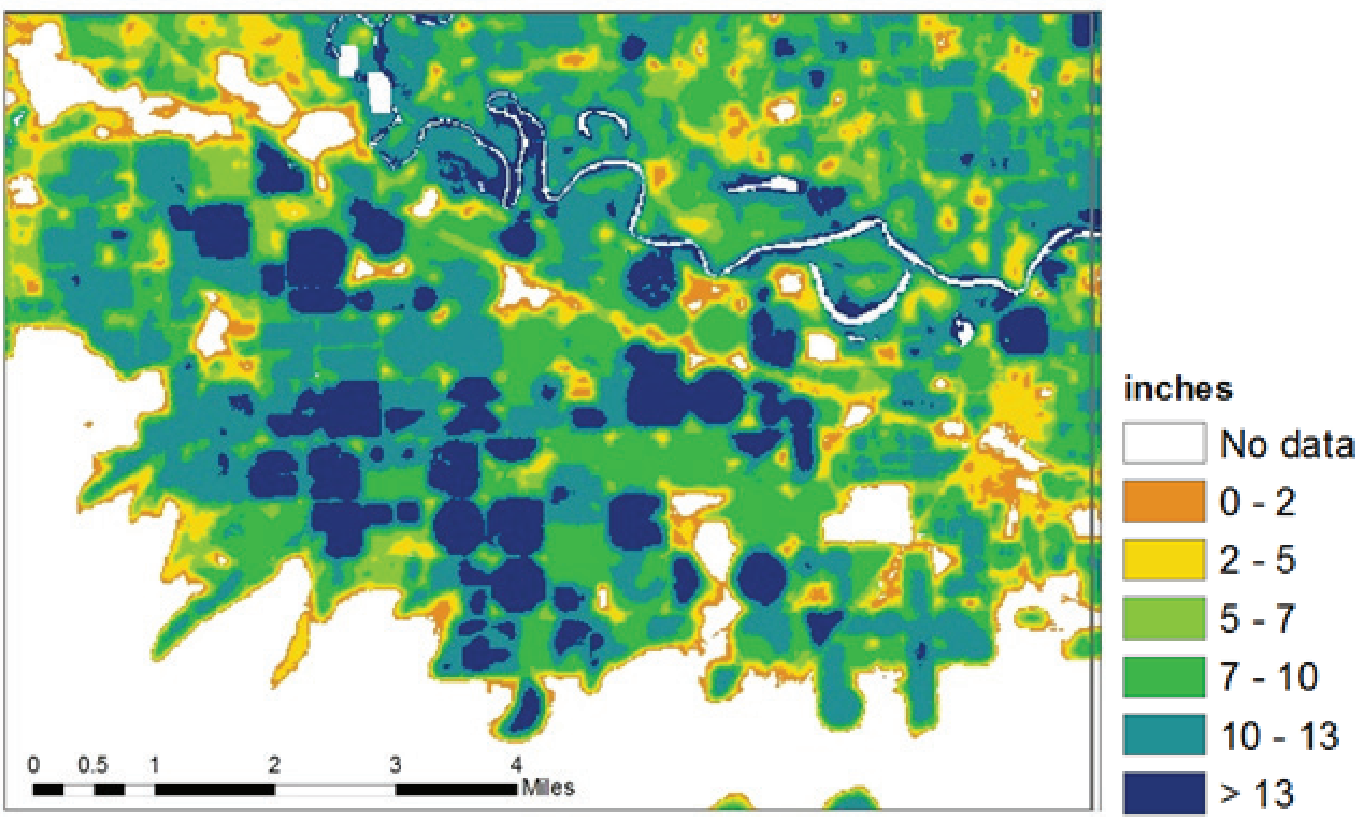




*Figure 11. Calculation of total consumptive use between June 16, 2015 and July 18, 2015.*

## METRIC Results for the Three Pilot Watersheds for 2015

Figure 13 through Figure 15 show the ET maps available for the summer of 2015. Only images with less than 30% cloud cover in the entire image were processed. The results presents ET images with cloud masked onto them. Negative values of ET in METRIC is common because of systematic errors caused due to various assumptions made in the energy balance process and some random error components. Based on design of the model, METRIC performs better in agricultural areas than in other land use types (Figure 12).

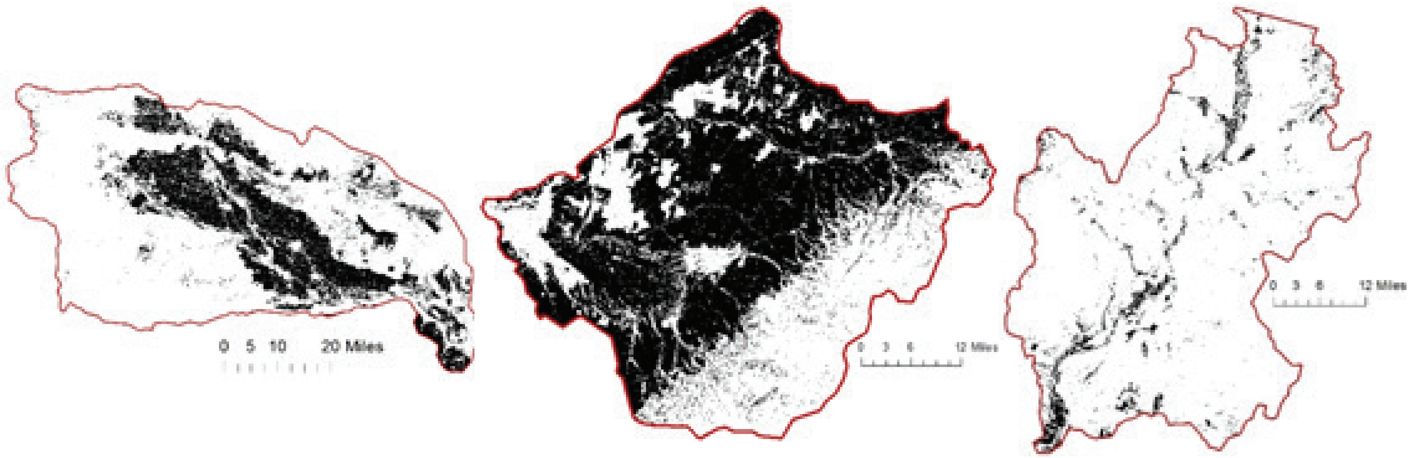



*Figure 12. Crop Land Use for the three pilot watersheds (Yakima, Walla Walla and Okanogan) (Data from CropScape 2015).*

Figure 13 shows the daily ET values from June to October 2015 for which Landsat 8 images were available. The ET values are higher for agricultural land use than other areas from June – September. The major crops in this watershed are Apples, Grapes, Corn, Alfalfa, Hops and pasture [from USDA crop data (2015)] which have high consumptive use during these months, which is evident in the results.

Figure 14 shows the daily ET values from mid-April to mid-August 2015 for which Landsat 8 images were available. Since much of the agricultural area in Walla Walla watershed is winter wheat, alfalfa and peas in 2015, we can see that the ET values peak for the months of May - July and show significant increases in consumptive use compared to previous months. The portion of agricultural land in this watershed is covered by winter wheat. WIG estimates winter wheat monthly irrigation requirement as 6.01 inches for May and 6.32 inches for June. We can see the increase in consumptive use in mid-June across the watershed but there was no usable image for the month of May, so there was no information about water use for the month of May.

Figure 15 shows the daily ET values from mid-May to mid-August 2015 for which Landsat 8 images were available. This watershed had the least acreage of agricultural land use compared to the other two, so increases in consumptive use was not as evident as were in the other two watersheds. The major crops in this watershed are apples and alfalfa, which have high water requirement from June – September in this region.

In these sets of images from Figure 15, we can see that the last image on August 19, 2015 has negative values on a large part of the image. This was due to the adulteration of image from smoke. This smoke was not masked from the downloaded image products which used algorithms for cloud masking.

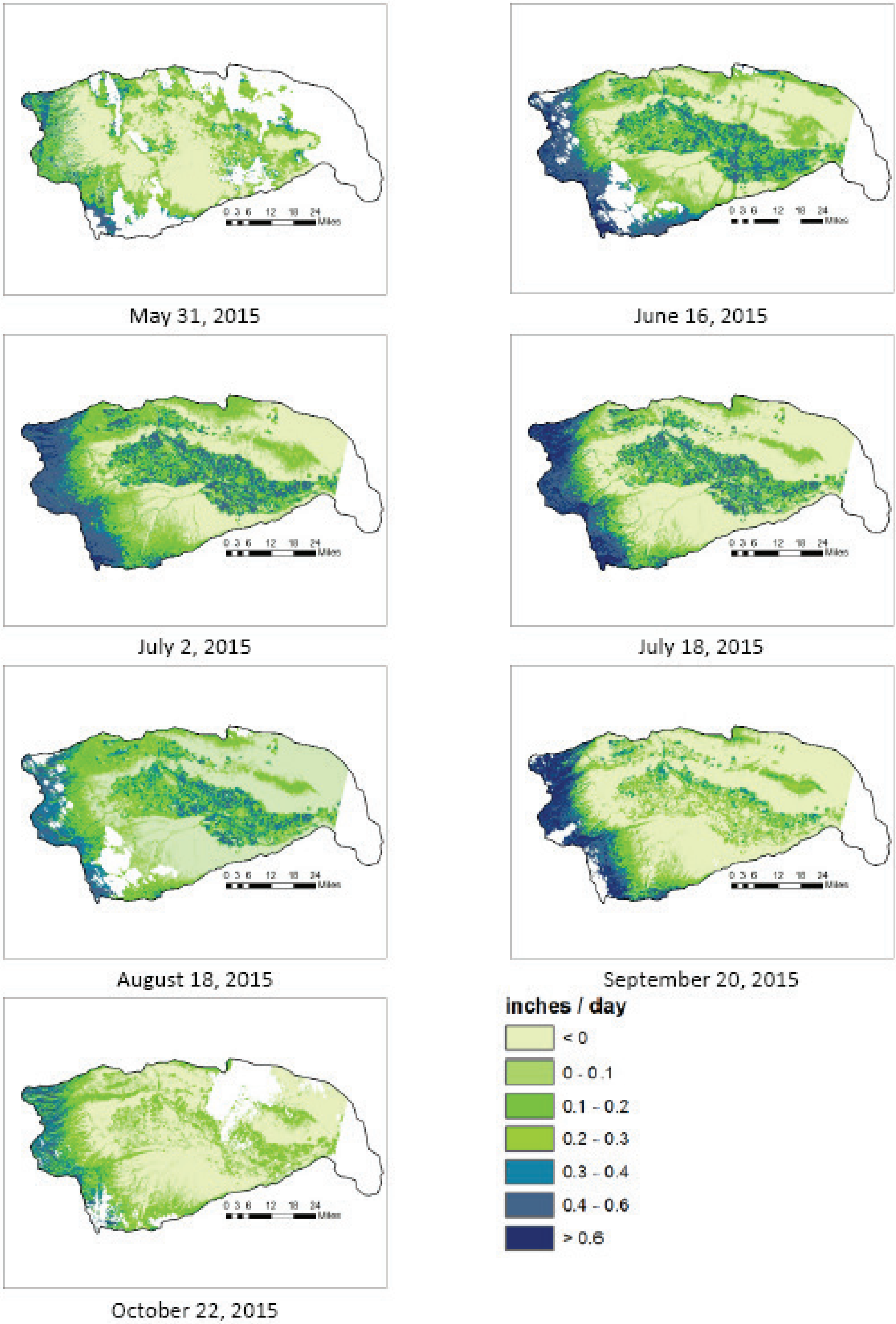



*Figure 13. Watershed ET for Yakima Watershed for 2015 using Landsat 8.*

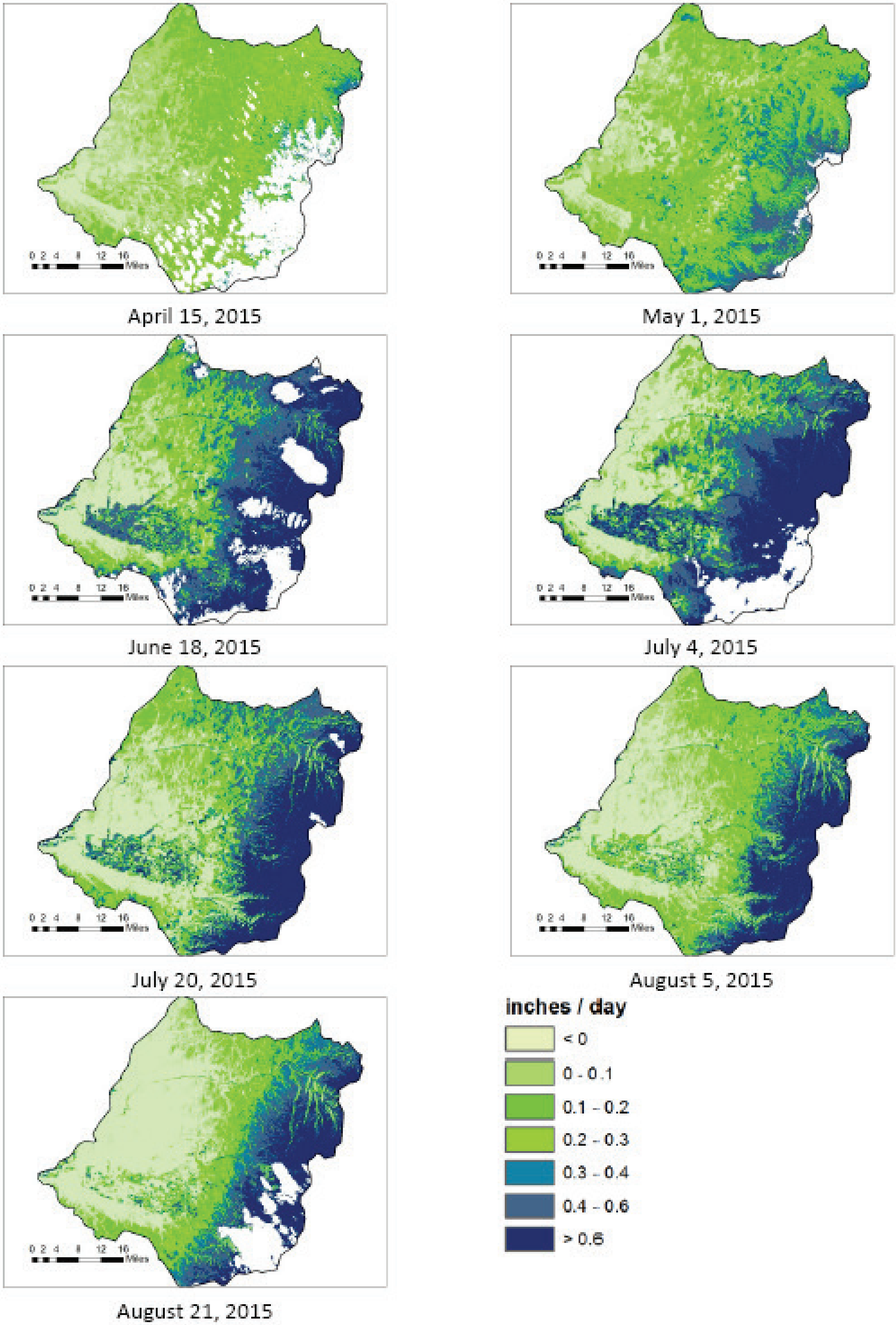



*Figure 14. Watershed ET for Walla Walla Watershed for 2015 using Landsat 8.*

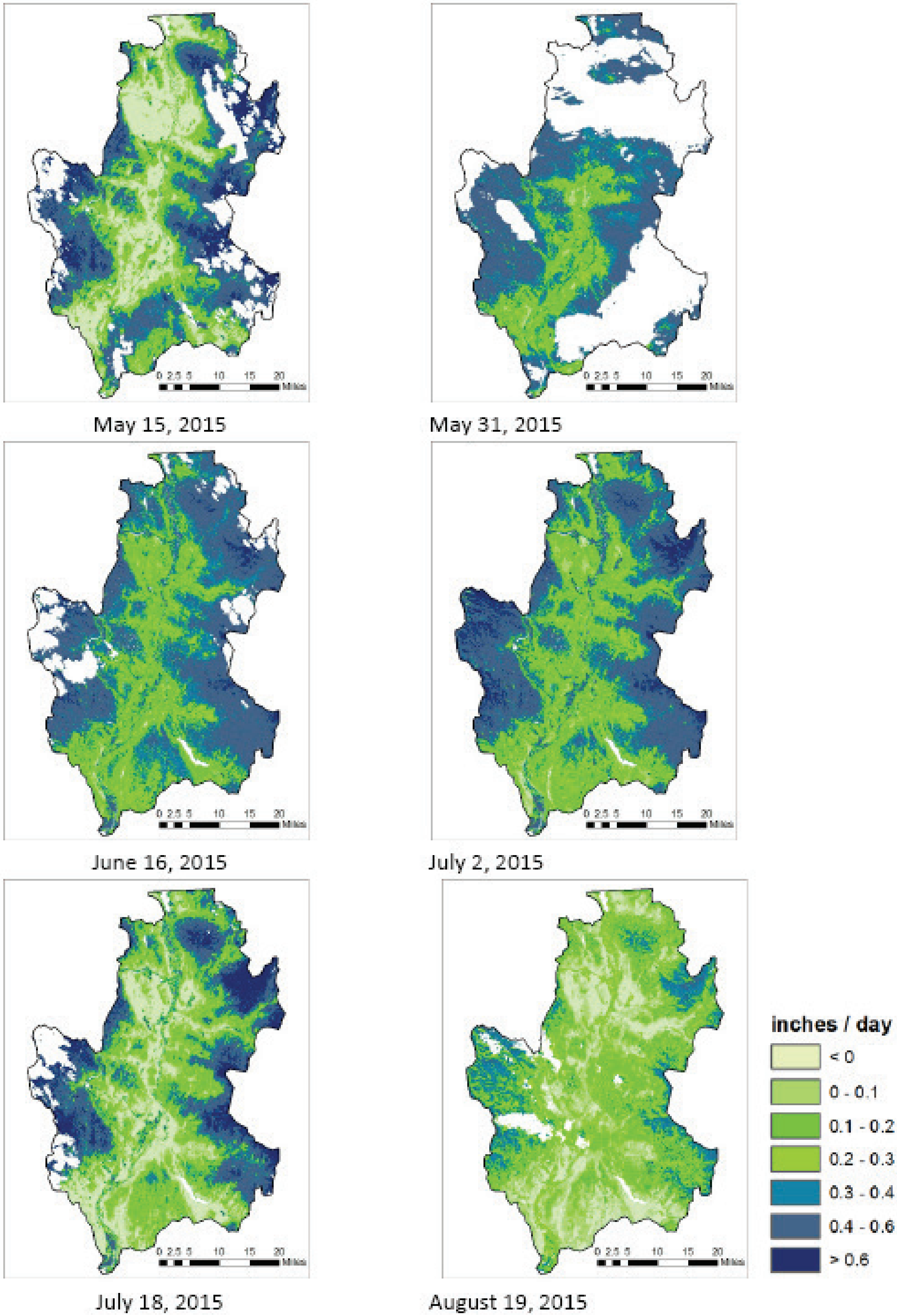



*Figure 15. Watershed ET for Okanogan Watershed for 2015 using Landsat 8.*

# Application of METRIC Results

## Comparison with WIG

Variability in ET estimates from METRIC could help in identifying differences in water use from month-to-month and from year-to-year. Current crop use estimates are often based on the Washington Irrigation Guide (Washington Irrigation Guidelines, 1985) which is based on long-term average from data in the 1950's to 1970's. While ET stations using more recent data exist from WSU AgWeatherNet and USBR's Agrimet, these are station specific locations, without the benefit of farm-scale ET estimates provided by METRIC. Figure 16 shows ET in August 2015 at the farm-scale for Roza Irrigation District for apples. For example, using the WIG for August would suggest an ET of 0.31 inches. By contrast, ET on the fields modeled by METRIC showed ET for two-thirds of the fields in excess of this quantity. This could be due to a variety of factors including updated weather data in METRIC, updated ET formula in METRIC, the fact that 2015 was a drought year, differences in apple varieties compared to when the WIG was established, or individual farmer irrigation practices. METRIC can be a complementary tool in assessing ET along with other current data sources.

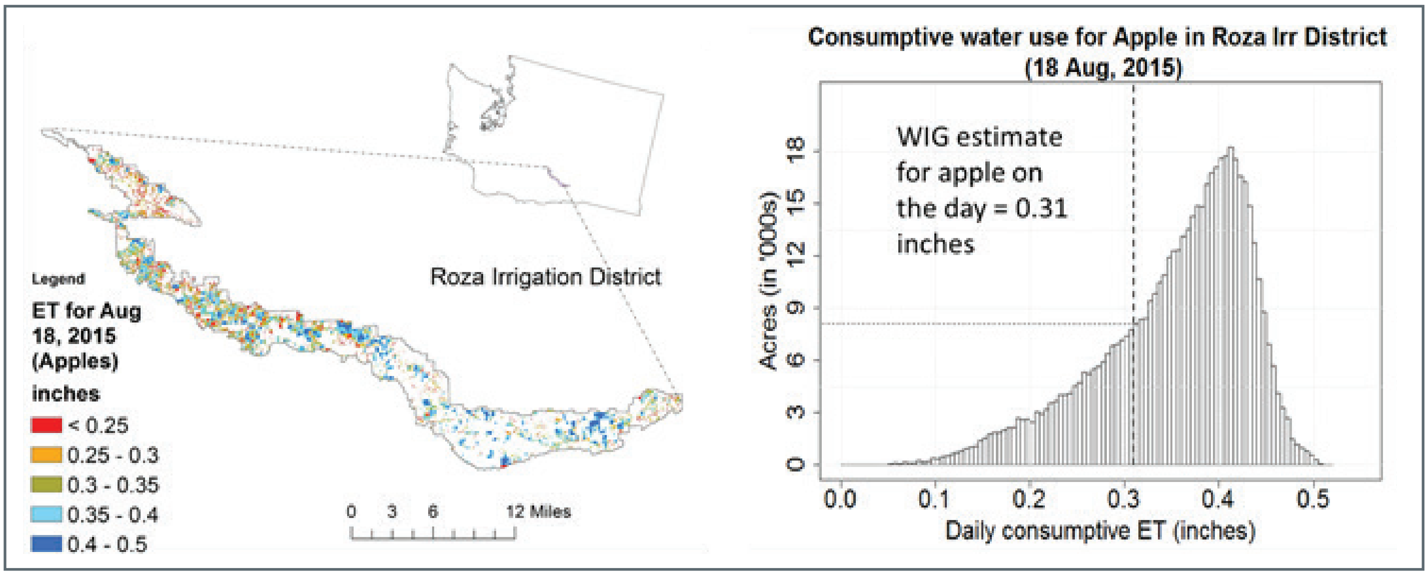



*Figure 16. Variability in ET estimates from METRIC could help in identifying differences in water use patterns for similar crops.*

## Water Use Variability/Efficiency of Different Crops Based on Watershed

METRIC results can be used understand how the variable water use is for a same crop in different watersheds. In the following figure, two major crops (Apple and alfalfa) in the three pilot watersheds, were selected. The scaled acreage of each crop for each watershed was plotted on Y-axis and the evaporative fraction (ET/ETr) was plotted on X-axis. We can see that in Figure 17 (a) that larger proportion of Okanogan watershed apple orchards have larger evaporative fraction than Yakima and Walla Walla. This indicates that use of water for apple per acre is higher than other two watersheds. Similarly, in Figure 17 (b) we can see that the variability in evaporative fraction is higher in Okanogan.

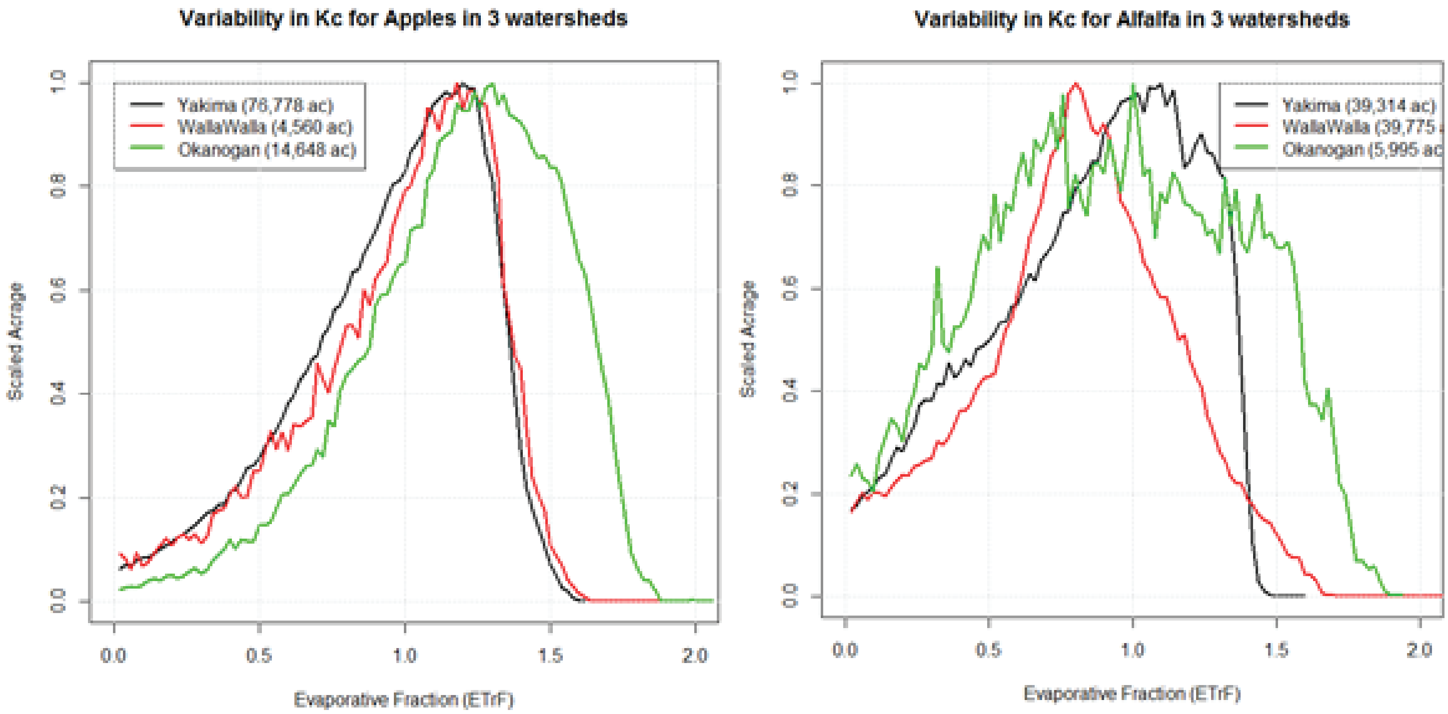



*Figure 17. Variability of evaporative fraction for the same crop in three pilot watersheds (a) Apples (b) Alfalfa.*

### Potential Issues with Application of METRIC

- The major issue in the use of METRIC is the lack of frequent captures of cloud-free satellite images. Landsat, the satellite which takes images used in this model, has a revisit time of 16 days and information is lost for almost a month for areas covered with cloud since they cannot be processed in METRIC. METRIC also requires high quality weather data and any errors that is introduced due to measurement error affects every pixel in the image.
- Although many processes within the model has been automated, there are still some parts of model which requires intervention from trained users. Due to this reason, we have limited confidence in this "hands-free" application of METRIC. Further research can help in improving confidence of our model results.

Some of these issues were addressed by using another model in conjunction with METRIC. This was implemented as the second objective of this module, where a crop simulation model (CropSyst) was used with METRIC.

## Coupling METRIC with CropSyst

### Why?

The issues mentioned above, with application of METRIC, along with some additional limitations such as the lack of model's capability to handle scenarios with changes in irrigation practices, crop management, and crop rotations motivated us to investigate the opportunities towards coupling METRIC with a Crop Model (CropSyst). A single parameter is used in the crop model for a single crop but growth and water use can vary highly for the same crop in a watershed (Figure 18). CropSyst is a daily crop simulation model which is the crop production model used in this Forecast.

The major advantage of coupling CropSyst and METRIC is that, if the consumptive use values are consistent between the two models, this would allow the crop model to estimate crop water use between the dates for which images are available. CropSyst could then be used to model scenarios with changes in irrigation practices, crop management, crop rotations, and to evaluate the effects of changes in water supply (e.g. curtailments) on crop water use during droughts.

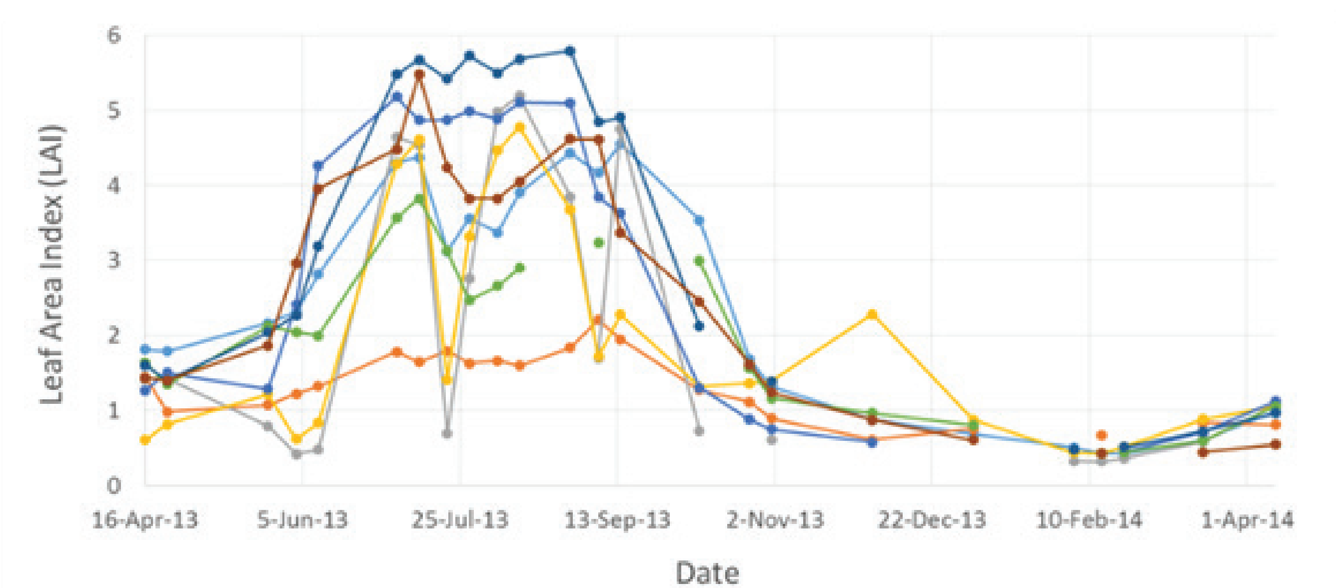




*Figure 18. Leaf Area Index (estimate of crop growth) of 10 selected orchards in Yakima showed high variability.*

### Pilot Application of METRIC with CropSyst (Pilot Study at Walla Walla)

A grape vineyard in Walla Walla, was used for a pilot study to investigate if METRIC results could be used to estimate irrigation parameters for CropSyst. When irrigation application rates provided by the irrigator were used in the crop model, crop growth (measured as Leaf Area Index) provided by two models (CropSyst and METRIC) did not match. But after the irrigation application rate was changed using inputs informed by METRIC, crop growth and water use data showed better agreement between the two models (Figure 19). The irrigation rate specified by the irrigator was 0.2 inches/week which when used in the crop model, did not produce same LAI as provided by METRIC which uses satellite imagery. When irrigation rate was increased to 0.3 inches/week based on METRIC results, the distribution of LAI from satellite imagery was replicated by CropSyst. This application has provided insights into the development of an algorithm to use satellite-based models to parameterize crop models.

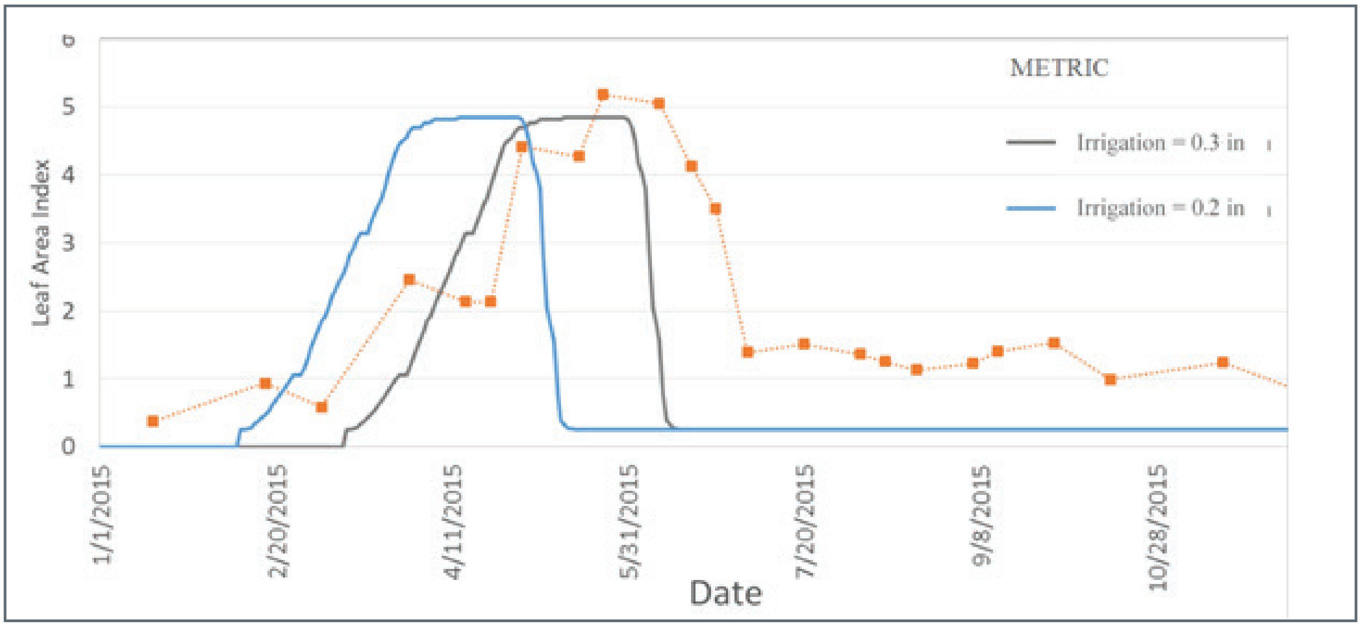



*Figure 19. Comparison of METRIC's and CropSyst's leaf area index (LAI) estimates for a grape vineyard in Walla Walla.*

## Summary of Lessons Learned

This work has paved a way for application of satellite based remote sensing model such as METRIC at a larger scale, spatially and temporally for the entire Columbia River Basin. An automated formulation METRIC is now available for application for future use. The removal of platform dependence from the original model (developed using ERDAS Imagine) with the use of freely available software (Python with some ArcGIS dependencies) will make METRIC easier to use in Washington.

Application of the model in three pilot watersheds in Eastern Washington provided high resolution consumptive use maps. A few applications of these maps were also presented. A major use of these maps is to identify the variability of water use in the watershed. Additionally, with the use of crop layers provided by USDA or WSDA, variability of water use for a specific crop can also be investigated for a specific part of the watershed. This can help identify differences in water requirements provided by conventional methods such as Washington Irrigation Guidelines (WIG). In an application presented, there were significant differences in water use, even within a region inside watershed.

As a pilot, METRIC results were used to parameterize CropSyst for a selected experimental location, which showed that crop growth can be estimated more accurately when using CropSyst with remote sensing results than using CropSyst alone. As a next step, in terms of coupling METRIC and CropSyst, algorithm is being developed to apply this coupling process to selected areas in the watershed. This would help in parameterization of the forecast model (VIC-CropSyst) for better prediction of water demands in the next forecast.

## Opportunities and Suggestions for the Future

1. Validation of METRIC in Eastern Washington: One of the major challenges in this work was validation of METRIC results for the study area. For better confidence in results and parameters of METRIC, installation of a few eddy covariance stations is suggested.

2. Advances in procedures and data for better estimation of ET using METRIC: There have been multiple advances in development of METRIC. These advances help to overcome some of the limitations of METRIC. The use of re-analysis weather data to interpolate between Satellite imageries have shown to provide more reliable estimates of evapotranspiration especially during cloudy days. There have also been advances in algorithms which offers to simulate surface energy fluxes and surface temperature for energy balance when thermal based surface temperature is not available (Dhungel 2014). These procedures have also been used to estimate moisture at soil surface and root zone which can be helpful for hydrologic modeling.

   Additionally, with the advent of freely available and powerful remote sensing tools such as Google Earth Engine and high resolution, more frequent satellite imagery, this model could be used to manage farms more efficiently. It could be a great tool for the users in these watersheds.

3. Find areas of double cropping: With the current modeling framework, it was not easy to identify areas of double cropping. With many parts of the watershed planting double crops, it is important to identify areas of double cropping. With remote sensing and METRIC, these areas can be identified.

4. Water rights identification and allocation: Identification of water right usage could be performed using METRIC results. Water rights are metered at multiple locations. If metered data can be collected and used with METRIC results, it would help complement metered data where it is not available in the watershed.

As seen in the results, variability in water use across a watershed can provide helpful information for future water rights allocation and developing water. A comparison of consumptive use and allocated water rights would provide helpful information on the return flows as well.

## *References*


Allen, R., A. Irmak, R. Trezza, J. M. H. Hendrickx, W. Bastiaanssen and J. Kjaersgaard, 2011. Satellite-based ET estimation in agriculture using SEBAL and METRIC. Hydrological Processes 25:4011-4027.

Allen, R., M. Tasumi and R. Trezza, 2007a. Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC)—Model. Journal of Irrigation and Drainage Engineering 133:380-394.

Allen, R. G., B. Burnett, W. Kramber, J. Huntington, J. Kjaersgaard, A. Kilic, C. Kelly and R. Trezza, 2013a. Automated Calibration of the METRIC-Landsat Evapotranspiration Process. JAWRA Journal of the American Water Resources Association 49:563-576.

Allen, R. G., M. Tasumi, A. Morse, R. Trezza, J. L. Wright, W. Bastiaanssen, W. Kramber, I. Lorite and C. W. Robison, 2007b. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)—Applications. Journal of irrigation and drainage engineering 133:395-406.

Allen, R. G., R. Trezza, A. Kilic, M. Tasumi and H. Li, 2013b. Sensitivity of Landsat-Scale Energy Balance to Aerodynamic Variability in Mountains and Complex Terrain. JAWRA Journal of the American Water Resources Association 49:592-604.

Allen, R. G., I. A. Walter, R. L. Elliott, T. A. Howell, D. Itenfisu, M. E. Jensen and R. L. Snyder, 2005. The ASCE Standardized Reference Evapotranspiration Equation, ASCE Publications, ISBN 0784475636

Bastiaanssen, W. G. M., M. Menenti, R. A. Feddes and A. A. M. Holtslag, 1998. A remote sensing surface energy balance algorithm for land (SEBAL). 1. Formulation. Journal of Hydrology 212–213:198-212.

Dhungel, R., 2014. Time integration of evapotranspiration using a two source surface energy balance model using narr reanalysis weather data and satellite based metric data, University of Idaho.

Ducnuigeen, J., S.N. Ahmed, K.R. Bencala, H.L.N. Moltz, A. Nagel, and C.L. Schultz, 2015. Interactive geospatial analysis tool for estimating watershed-casle consumptive use: Potomac River basin case study, Advances in Watershed Science and Assessment, 33:141-169.

Stöckle, C. O., M. Donatelli and R. Nelson, 2003. CropSyst, a cropping systems simulation model. European Journal of Agronomy 18:289-307.

USDA-NASS, 2015. USDA National Agricultural Statistics Service Cropland Data Layer. In: Published crop-specific data layer Washington, DC.

# Water Banking Trends in Washington and Western States

## 1. Summary and Introduction

Water banking is a water management tool used from meeting water demand. Understanding how water banks are working and maturing in Washington State (Washington) is a key element to the economic forecasting component of the 2016 Water Supply and Demand Forecast. Knowledge of water banking helps clarify how water rights will change in response to water supply shortages, curtailments, demographic changes, and climate change. The purpose of this module is to describe water banking activities in Washington and across the western United States, and provide recommendations on how to improve water banking in Washington. This module is intended to update a 2004 inventory authored by the Department of Ecology (Ecology) and WestWater Research titled "Analysis of Water Banks in the Western States" (Clifford et. al. 2004).

This chapter is designed to provide a general overview of what water banking is and of the organization of this report. Subsequent chapters describe the state of water banking in Washington and other states, barriers and/or constraints to water banking in Washington, and recommendations on how to incentivize and improve water banking.

### 1.1 Purpose of Water Banking

Water banking is an institutionalized process used to transfer water to new uses (MacDonnell, 1995). The water bank acts as an intermediary, bringing together buyers and sellers with known processes and procedures and some kind of public sanction for its activities (MacDonnell, 1995). The overall goal of a water bank is to facilitate water transfers using market forces. In Washington State, the legislature has identified additional objectives of water banking in RCW 90.42.100, which include:

- Making water supplies available when and where needed during times of drought;
- Improving stream flows and preserving instream values during fish critical periods;
- Reducing water transaction costs, time, and risk to purchaser;
- Facilitating fair and efficient reallocation of water from one beneficial use to another;
- Providing water supplies to offset impacts related to future development and the issues of new water rights;
- Facilitating water agreements that protect upstream community values while retaining flexibility to meet critical downstream water needs in times of scarcity.

While water banking is used as a water management tool throughout the United States, management and policy approaches to water banking have varied from state to state, and, within Washington, from basin to basin.

### 1.2 Water Banking Defined

The traditional definition for water banking states that it is an institutional mechanism used to facilitate the legal transfer and market exchange of water (Clifford et. al. 2004). However, the term "water banking" is used to refer to a variety of water management practices that extend beyond the traditional definition. Although water banking definitions and approaches differ, the common goal is to move water to where it is needed most.

Water banking is facilitated by an institution (the water bank) that operates as a broker, clearinghouse, or market-maker. A clearing house serves mainly as a repository for bid and offer information. Brokers connect or solicit buyers and sellers to create sales, and a market-maker attempts to identify buyers and price water to sell. Many banks pool water supplies from willing sellers and make them available as credits to willing buyers. Generally, a water bank sets the rules of water bank operations, determines which rights can be banked, certifies water quantities entering and leaving banks, sets terms and prices, and facilitates the regulatory requirements

(Figure 1). In Washington, many of these actions are defined in the Trust Water Right Agreement (TWRA) between the water bank and Ecology: determining which rights can be banked, certifying water quantities entering and leaving banks, and setting some of the rules of water bank operation such as quantities and locations of water banking.


*Figure 1. Water banking overview.*

More detailed information regarding water banking function and approach in Washington is provided in Chapter 2.

### 1.3 Water Banking Authority

States authorize banking in a variety of ways. Authorization ranges from explicit water banking legislative action, with oversight provided by state agencies and implied water banking policies and legislation that facilitates transfers, to watershed level actions, to the use of federal policies to support activities. In Washington, water banking has been authorized by the legislature through House Bill 1640 (2003) and the amendment of Chapter 90.42 of the Revised Code of Washington (RCW), with the Washington State Department of Ecology (Ecology) providing regulatory oversight.

Washington's water banking authority is described in Chapter 2. Chapter 3 provides a complete description of water banking activities in other states, and how these water banks are authorized.

### 1.4 Water Bank Functions

Water bankers provide various services to meet out-of-stream and instream water demands. The type of water bank model used and the purposes for which it is used are dictated by the driving water management goal, and the groups and individuals whom the water bank serves. There are four structural/ownership models of water banking that have emerged in Washington. These different structures, listed below, are generally based on funding type, bank administration, and bank purpose:

1. Public
2. Quasi-Government
3. Nongovernmental Organizations (NGO)
4. Private

Each model has different operating characteristics, structures, and roles. Chapter 2 provides more details about water bank models operating in Washington and the pros and cons of each model type.

## 1.5 Water Bank Models and Metrics

Water banks participate in water transactions for a variety of purposes and over varying water quantities, from residential groundwater use mitigation of less than one acre-foot[1], to permitted water rights leases and sales for thousands of acre-feet. There are also differences in the amount of consumptive and non-consumptive water transacted from water banks based on purpose and types of water use. To compare different banks and model types, it is important to have a comparable measurement system and specific metrics such as cost per unit, and units transacted. For the purposes of this report, a unit of mitigation is the quantity of water a water bank does business in.

The most important emerging metric for water banking involves basing transfers on consumptive use rather than total use. Consumptive use is defined in several Ecology laws, rules, and policies in varying ways, including:

- *"Water that is transpired by plants at the place of use, water that escapes from a reasonably efficient conveyance system or from the place of use but does not become return flows and water that is contained within a product or within a production byproduct"*, Policy 1210, Ecology.
- *"Consumptive use includes crop evapotranspiration, and water evaporated during irrigation applications (e.g. spray, canopy and wind losses)"*, Guidance 1210, Ecology.
- *"Consumptive use means use of water whereby there is a diminishment of the water source"*, WAC 173-500-050(5).
- *"'Annual consumptive quantity' means the estimated or actual annual amount of water diverted pursuant to the water right, reduced by the estimated annual amount of return flows, averaged over the two years of greatest use within the most recent five-year period of continuous beneficial use of the water right"*, RCW 90.03.380.

Consumptive use has emerged as a common water bank metric because in many over-appropriated or seasonally limited basins in Washington, downstream junior appropriators rely on return flows as part of their water supply availability. In such situations, any increase in consumptive use would result in actual or presumptive impairment of 3rd parties. As such, detailed calculation of consumptive use is becoming a standard in the water banking industry-- often requiring engineers, hydrogeologists, or other scientific professionals to interpret historic beneficial use via aerial photo coupled with scientific literature and real-time data on consumptive use (e.g., Washington Irrigation Guide, AgriMet, AgWeatherNet, and others). A generalized figure on the consumptive water budget is shown in Figure 2.

1 An acre-foot is a unit of volume equal to the amount of water required to cover on acre of land with a foot of water. There are 325,851 gallons in one acre-foot.

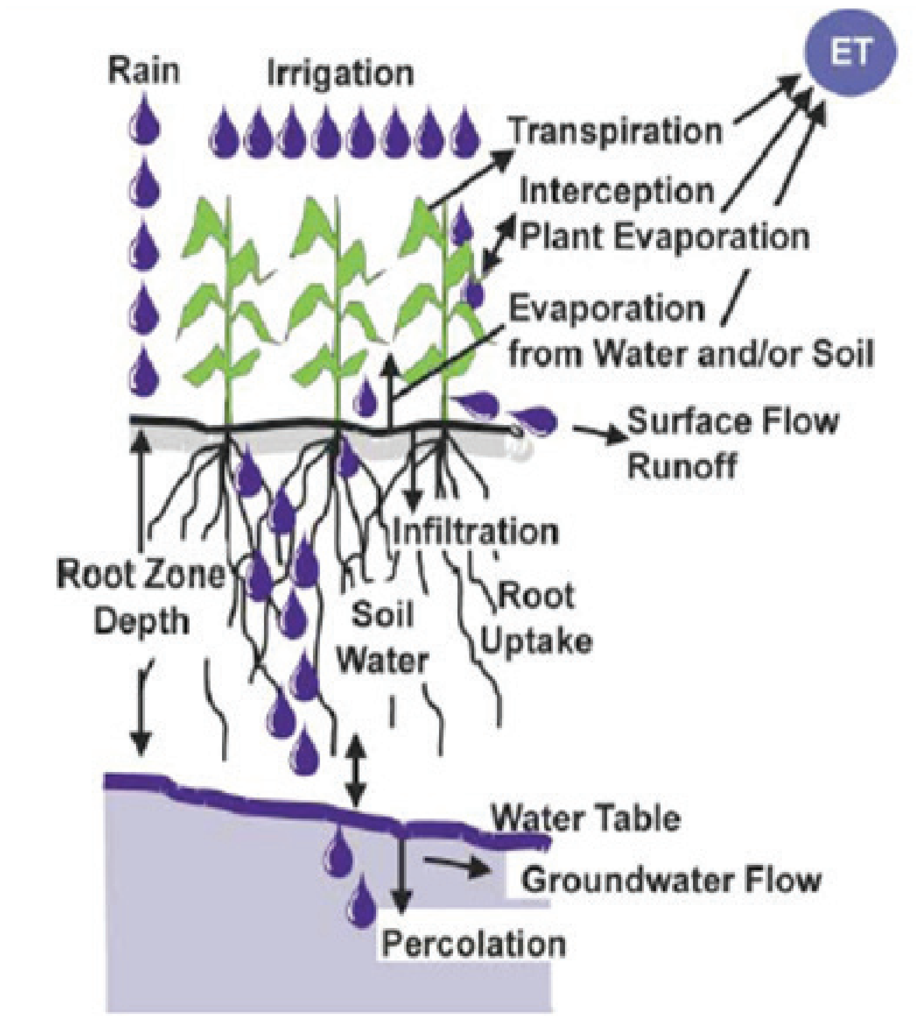



*Figure 2. Consumptive Use Components[2].*

Consumptive use metrics are also used in water banking for non-agricultural purposes, including domestic use, stockwater use, and commercial and industrial uses. For example, Ecology adopted the Upper Kittitas Rule, WAC 173-539A, which describes how domestic consumptive uses will be allocated in the context of water banks operating in the rule area.

*"Consumptive use will be calculated using the following assumptions: Thirty percent of domestic in-house use on a septic system is consumptively used; ninety percent of outdoor use is consumptively used; twenty percent of domestic in-house use treated through a wastewater treatment plant which discharges to surface water is consumptively used."* WAC 173-539A-050(3).

## 1.6 Water Banking Seeding Mechanisms

There are two primary concepts of water availability that drive water banking and seeding mechanisms: physical availability and legal availability. Some water banks make water physically available from their supply for withdrawal/diversion. Other water banks simply address legal availability so a new diversion/withdrawal will not impair another user.

2 "Irrigation Efficiency, Encyclopedia of Water Science", Howell, 2003.

An example of a water bank that supplies physical water is the Lake Roosevelt Incremental Storage Release Project. For this bank, water is made physically available for use by storing and releasing water from Lake Roosevelt (Figure 3). The Lake Roosevelt bank is discussed in more detail in section 2.3. Individual users who desire water from this bank must enter into a water service contract with Ecology's Office of Columbia River, along with obtaining a permit to use water. All the users from this bank physically access some of the water that is released, although there is some flexibility on the timing of releases relative to the timing of diversions, which are intended to maximize fish benefit in the Columbia River.

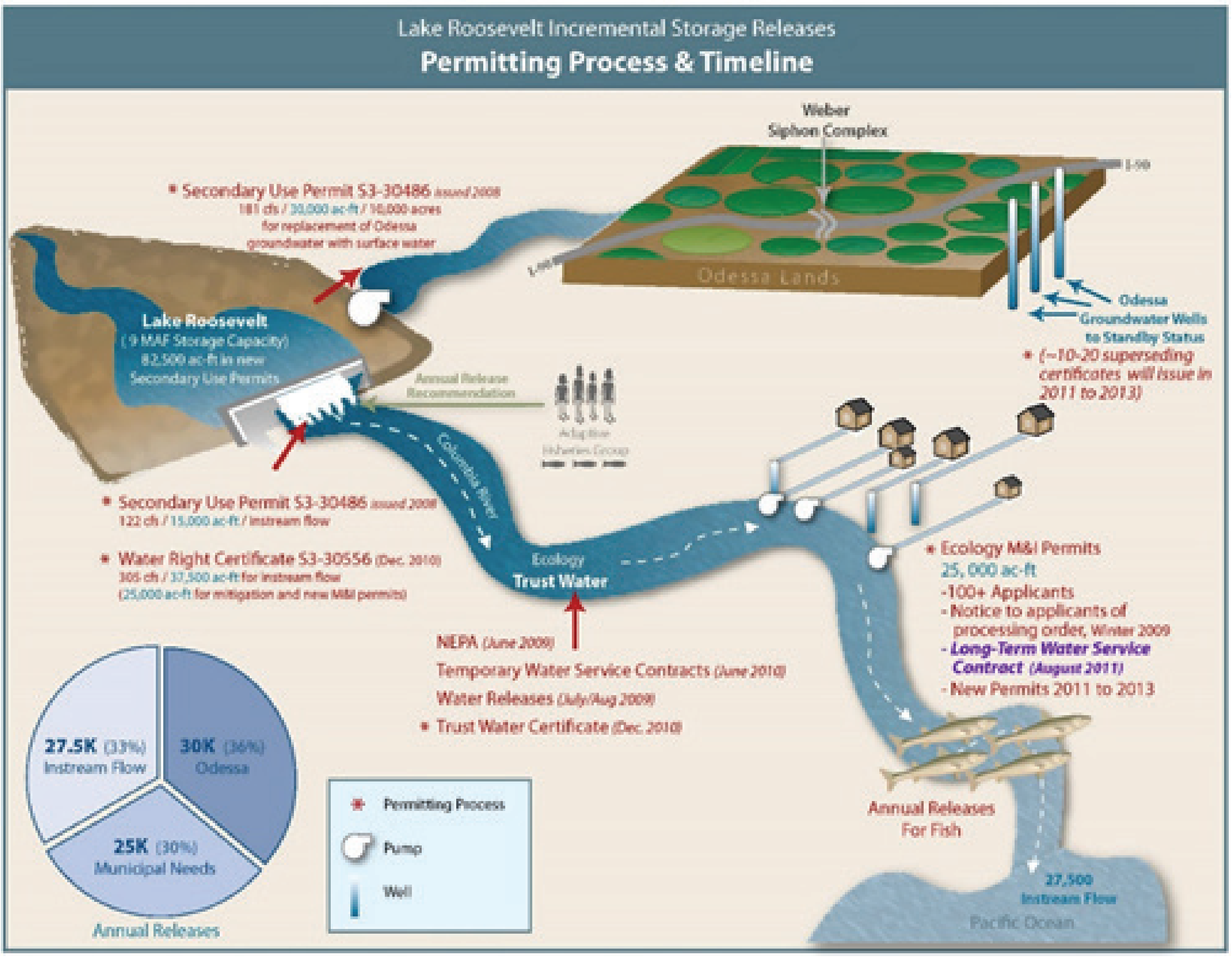



*Figure 3. Example of Physical Availability.*

Examples of banks trying to solve legal availability issues include the Yakima Basin water banks. In the Yakima Basin, the Bureau of Reclamation withdrew all unappropriated water on May 10, 1905 for the development of several irrigation projects. Because of this, any new use in the Yakima basin must be neutral with respect to the Yakima Basin's total water supply available (TWSA) at a gaging station on the Yakima River known as Parker (labeled PARW on Figure 4). This TWSA neutrality prevents impairment of the Bureau of Reclamation right or other senior water rights in the basin. To meet this requirement, water rights have been placed into the TWRP to offset new uses and ensure TWSA is not impacted at Parker. However, the new uses are not necessarily coupled to the banked water in a way that ensures physical access to the water in the bank. In this example, it is possible to mitigate for impacts to other water users, address legal availability of water, and not physically divert any of the banked water. The management of the Yakima Basin is illustrated in Figure 4.

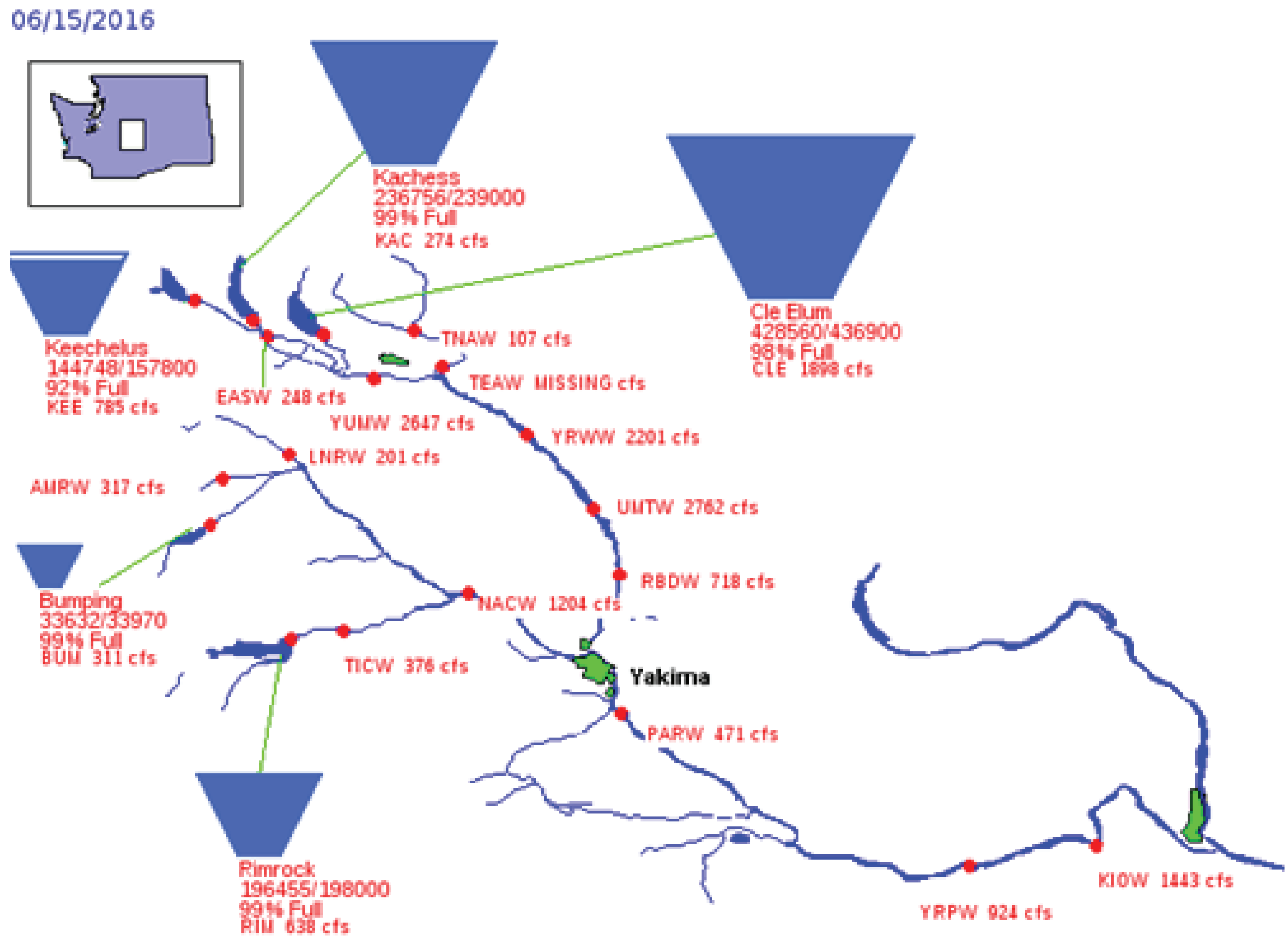



*Figure 4. Water Supply Graph for Yakima Basin.*

## 2. Washington State Market Activity and Participation

This chapter discusses Washington's water allocation framework, water banking policy, and water banking programs. Water banking models are compared in terms of their effectiveness in solving current and anticipated water problems.

### 2.1 Washington Water Allocation Framework

Washington, like other western states, has a prior appropriation framework for water allocation. In times of limited water availability, those who put water to beneficial use first (senior priority dates), have the right to the full use of the water before subsequent users (junior priority dates). Or, in other words, "first in time, first in right". In dry years, this allocation framework creates a system of "haves" and "have-nots". Those with earlier priority dates enjoy the right to use the full extent of their water right, while those with later priority dates often cannot. Water banking provides a market-based approach to solve this problem by allowing senior water to be reallocated for new uses.

An illustration of how the prior appropriation system works in Washington is provided below, using the Yakima Basin as an example. Federal rights in the Yakima Basin were reserved on May 10, 1905, when the U.S. Secretary of the Interior withdrew all the unappropriated surface waters of the Yakima River and tributaries for benefit of the proposed Yakima Reclamation Project, which includes five major reservoirs in the Yakima Basin.

This reservation essentially created 3 classes of water users, as described in Figure 5 below.

Historically, this has meant that in four-out-of-five years on average, there is sufficient water supply for all users in the basin. However, when drought occurs, which is on average once every five years, junior water right holders get no water, and proratables'[3] supplies are curtailed, but senior water rights receive their full water right. This system ensures that senior water users are not impaired. In principle, water banks and water markets allow proratable or junior water rights who suffer large losses from curtailment to lease or purchase water from senior water rights holders. Senior water users may choose to market water because they suffer relatively less economic harm due to drought because of farming choices such as forgoing late cuttings of hay or fallowing during a crop conversion.

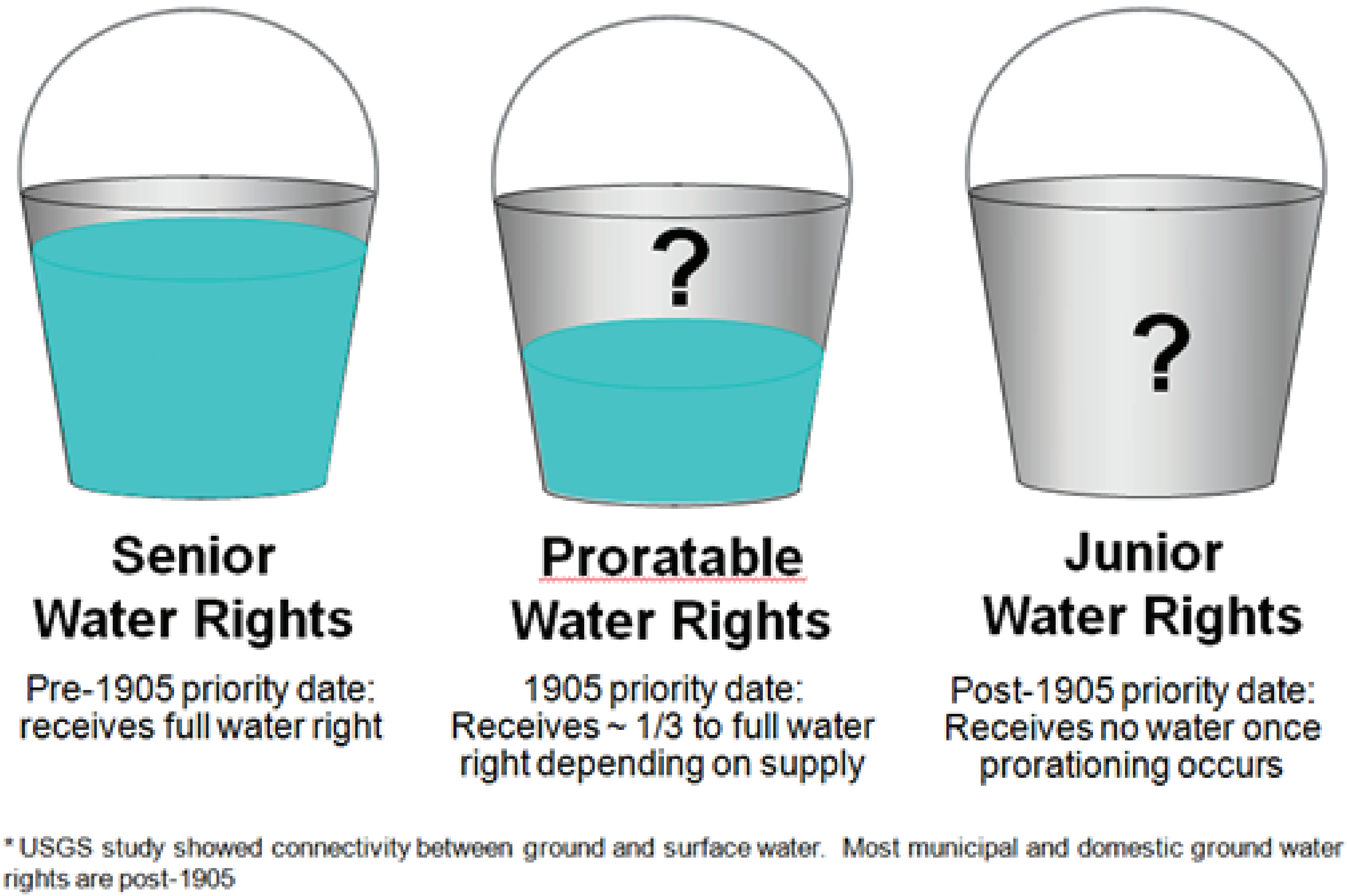



*Figure 5. Prior Appropriation System in Yakima Basin, Ecology Presentation, 2015.*

## 2.2 Washington Water Banking Statutory Review

### *Water Banking Authority*

Washington's statute governing water banking is authorized in RCW 90.42[4]. While the concept and use of the term water bank has been around for years, comprehensive state-wide water banking legislation was not passed by the Legislature until 2009[5]. A trust water right is any water right acquired by the state for management in the TWRP on a temporary or permanent basis. The TWRP provides a way to legally hold water rights for future uses without concern about having those rights relinquished for non-use per RCW 90.14.140(2)(h).

3 Proratable water rights are water rights that receive a pro rata portion when there is not enough water to meet demand.

4 A Yakima basin trust water statute also exists in RCW 90.38; however, it focuses strictly on the trust water right statute applicable to that County.

5 See in general RCW 90.42.100 through 130.

Water rights are typically held in trust to benefit instream flows or preserve groundwater, to protect them from relinquishment, to be considered beneficially used, or to offset new out-of-stream uses.

While in the TWRP, the water right maintains its original priority date, with a specified place of use (stream reach or aquifer), an instantaneous and annual quantity (typically specified as a monthly schedule), and a period of use (e.g., irrigation season, or year-round). These instream flow water right attributes are necessary for the trust water right to be beneficially used and account for the water right as instream flow to offset (mitigate) new water uses. Ecology's use of a water right it holds in trust is typically governed by a TWRA, which is a contract between the state and the owner of the water right describing the terms of the trust.

Trust water rights are considered beneficially used when they are exercised for incremental enhancement of instream flow. Ecology can provide notice of exercise of trust rights through a public notification process via the Internet (http://www.ecy.wa.gov/programs/wr/market/trstdocs. html).

Ecology has a statutory role in setting up water banks via the TWRP, although day-to-day administration of the banks ranges from full Ecology administration (e.g., Port of Walla Walla, Lake Roosevelt, Sullivan Lake, Cabin Owners) to 3rd party administration (e.g., Dungeness, Walla Walla). Potential water bank managers need to reliably fill this function in a way that meets the public trust standard. Managers currently include local government (i.e. counties, cities, or watershed-based water resource management entities), non-profit nongovernmental organizations, or private companies or individuals.

TWRP provides the fundamental authority for water banking. The source water right that is "banked" is held by Ecology in the TWRP. To use the water for out-of-stream mitigation, or issue mitigation credits from the bank, the TWRA specifies many of the rules such as location, quantities that can be used for mitigation, and the quantity of the mitigation credit. The water is held in the TWRP until its diversion authority is formally conveyed to the buyer. Ecology policy requires the use of the TWRP to ensure water availability at the new location, because it is a mechanism to protect water from other intervening users. Typically, this involves four procedural steps:

1. Attributes of a senior water right are changed, either by Ecology or a local conservancy board, including:
    a. The purpose of use, typically changed to instream flow and mitigation of new out-of-stream uses.
    b. The place of use changed from the former appurtenant land to the portion of river or aquifer where the bank will operate.
    c. The point of diversion is eliminated and replaced with a description of the "primary" and "secondary" reaches of the trust water right. The "primary" reach is quantified based on total use from the historic point of diversion to the historic return flow point. The "secondary" reach is quantified as the consumptive portion of the right below the historic return flow point (Figure 6).
    d. Extent and validity of the water right is analyzed.
2. Water is conveyed to trust by a contract or deed. Ecology must have ownership interest in the water right seeding the bank in order for it to reside in the trust program for water banking purposes.
3. A TWRA is adopted. The TWRA is a contract that describes the conditions under which Ecology will hold the water right in trust and release and/or permit water from the water bank, explaining the purposes, metrics, and the water right processing framework.
4. New mitigated water rights are issued by Ecology and debited from the water bank. Ecology issues water budget neutral (WBN) determinations for permit-exempt uses and Reports of Examination (ROE) and permits for all other uses. Accounting ensures that new "withdrawals" do not exceed the original "deposit".

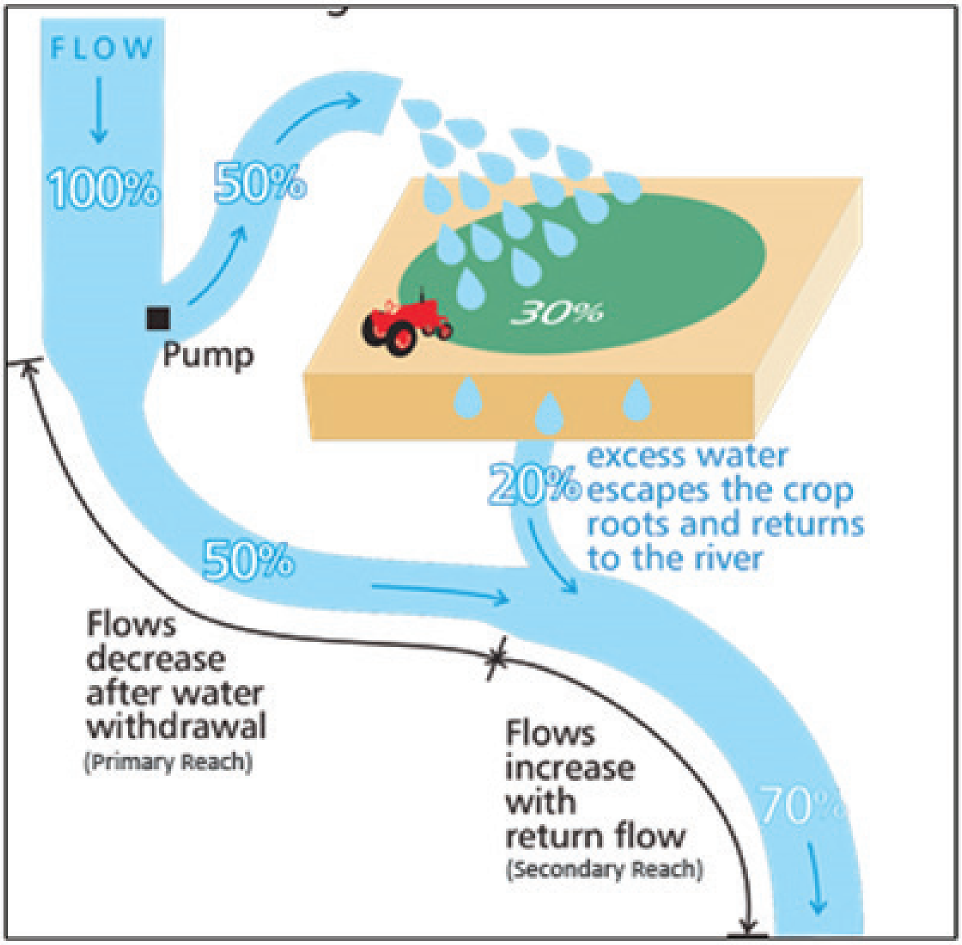



*Figure 6. Primary / Secondary Reach Example.*

Although Washington's TWRP was authorized in 1991, water banks have only significantly expanded in the last 10 years in response to several factors, including:

- River basin closures (i.e., basins closed to new water uses, such as in Upper Kittitas County); Adoption of new instream flows rules (e.g., Dungeness water exchange);
- Increased local collaboration to solve water supply problems (e.g., Walla Walla, White Salmon, Little Spokane and Methow Valley banks); and,
- New legislative focal areas (e.g. Office of Columbia River (OCR), Yakima Basin Cabin Owners (Cabin Owner) bank).

### *Proposed Water Banking Legislation*

Over the last five years, several bills have been introduced the concern water banking:

SSB 6179 (2016) Concerning water banking (Prime Sponsor: Senator Honeyford): This bill requires water rights accepted into trust to be "adequate". This bill also included transparency measures such directing Ecology to maintaining cost and fees, priority dates, and amount of water available for all water banks on their website. Additionally, the bill required consultation with stakeholders on water banking.

EHB 1187 (2016) Concerning best practices for water banks; originally introduced in 2015 with companion SB 5014 (Prime Sponsors: Representative Chandler and Senator Honeyford): These bills only applied to the Yakima Basin. The bill included transparency and consistency measures for water banks, including the posting of cost and fee schedules for water banks to agency websites and prohibiting preferential treatment in granting mitigation credits for similarly situated water uses. Additionally, these bills required water supplies for water banks to be "adequate, reliable and uninterruptible".

HB 2760/SB 6533 (2014) Concerning best practices for water banks (Prime Sponsors: Representative Chandler and Senator Honeyford): This bill included transparency and consistency measures such as filling fee schedules with Ecology and prohibiting preferential treatment in granting mitigation credits to similarly situated water uses with a few exceptions. Additionally, the bill required water supplies for water banks to be "adequate, reliable and uninterruptible."

SHB 1350 (2013) Providing options for local communities to balance growth of the community with water resource goals (Prime Sponsor: Representative Chandler): The purpose of this bill was to provide counties with dimmer switch authority, set exempt well withdrawal limits between 350 and 5000 gallons per day (gpd), establish county run water banks, and give counties reviewing prospective subdivisions the ability to rely on exempt wells as adequate sources for potable water.

HB 1589 (2011) Concerning trust water rights (Prime Sponsor: Representative Blake): This bill required Ecology to review trust water right applications within 45 days of receipt. Though, applicants could request an extension of 30 days.

Of these bills, only SB 6179 has passed. The passing of SB 6179 has resulted in the enactment of RCW 90.42.130. As of early 2017, Ecology is reformatting their website and soliciting information from water banks to meet the requirements of RCW 90.42.130.

### *Water Banking Case Law*

Case law on water rights issues has evolved based on several relevant recent decisions and is expected to continue to affect water rights decisions in Washington, given that several key decisions are currently pending. Below is a summary of significant legal cases that have impacted water bank development.

- *Postema v. Pollution Control Hearings Board* (Supreme Court of the State of Washington 2000). This decision defined the "one molecule" standard for instream flow impairment, meaning impairment does not need to be physically measureable, but scientifically acceptable methods that demonstrate de minimus impacts can constitute impairment.

- *Swinomish Indian Tribal Community v. Ecology* (Supreme Court of the State of Washington 2013). This decision invalidated reservations established in rule for new water uses, including exempt wells, created through amendments to the Skagit instream flow rule. It also decided that Ecology went beyond its statutory authority in applying overriding consideration of the public interest (OCPI) to rulemaking that conflicted with the established instream flows.

- *Whatcom County v. Hirst* (Court of Appeals of the State of Washington 2015). This decision essentially directs local governments to follow Ecology's interpretation of instream flow rules. According to the decision, if Ecology interprets a particular instream flow rule to provide a specific exemption for domestic exempt wells, then a county can rely on that interpretation in making water availability determinations related to land use decisions. This is the case even if there are unmet senior instream flows. This decision also acknowledges that each instream flow rule must be interpreted individually. Ecology has indicated that they are completing an analysis of each rule, and plan to provide their interpretation to local governments in the future. There is now (January 2017) a petition pending before the Washington Supreme Court on behalf of the appellants to review this decision, and as a result some uncertainty still exists regarding the final outcome of this case.

- *Foster v. Ecology* (Supreme Court of the State of Washington 2015). In this decision the Washington Supreme Court reversed Ecology's approval of the City of Yelm permit. The approval of this permit was based on the use of OCPI and an out-of-kind mitigation package. Ecology uses OCPI as a tool to approve water right permits when water availability is limited, but it believes the public benefits of approval outweigh any impacts on stream flows. This decision implies a fundamental change on how water-short basins can access water. The implication of this ruling is that no permanent water right will be able to rely on anything other than water-for-water mitigation, in-time and in-place, and no amount of out-of-kind or out-of-time mitigation can offset even de minimis (one molecule) impacts to adopted instream flows. This ruling makes it imperative that banks appropriately match supply and demand spatially and temporally because Ecology no longer has the ability to use OCPI and out-of-kind mitigation to permit new water uses.

Case law on exempt use, impairment of instream flows, conjunctive management of surface and groundwater, county building permit and Growth Management Act (GMA) responsibilities, and OCPI standards continue to be clarified by the court system. There is a corresponding trend towards county co-management with Ecology of the risk of future curtailment and the associated impacts on property values, on the ability to develop property, and on property transactions when instream flows are not met.

Based on the direction being provided by the courts, Ecology and Washington counties are exploring ways to co-manage risks, such as the evaluation of water bank feasibility for particular basins. In addition, Ecology is preparing an updated guidance document (*Guidelines for Determining Water Availability for Subdivisions and Buildings, 1993*) and has convened a stakeholder workgroup to provide input to Ecology during development of the guidance. The guidance document will address the roles and responsibilities of both Ecology and local governments in physical and legal water availability determinations.

One of the emerging challenges that is currently playing out in the courts, in stakeholder forums, and potentially within the Legislature, relates to the standard under which OCPI authority can be exercised by Ecology. This becomes important when seeding a water bank, and trying to match supply and demand through banking transactions while striving to reduce the risk of future curtailment, often to meet public health and safety reliability criteria.

The ability to use OCPI to address imperfect supply and demand matching in water banking is in a state of flux at this time. The *Swinomish Indian Tribal Community v. Ecology* case invalidated the 2006 Amendment to the Skagit Rule that provided water for new uses of the permit-exemption and clarified that OCPI should be used less broadly than Ecology applied it in this case. In *Foster v. Ecology* the courts determined that use of OCPI in the context of an individual permitting decision was inappropriate, despite relying in part on out-of-kind benefits (e.g. habitat, water quality, passage). The recently settled *Okanogan Wilderness League and Center for Environmental Law and Policy v. Ecology and Kennewick General Hospital* case considered under what standards OCPI needs to be used, and whether impairment exists if the functions and values of the instream flow are still met. This case was settled based on a combination of out-of-kind mitigation and a component of interruptibility of water use.

## 2.3 Washington Water Banking Programs

### *Water Bank Structures*

To date, water banks in Washington have operated under four general operational structures. Selection of the type of model depends on the regulatory environment, timing of regulatory action and water bank need, and the ability of Ecology and counties to agree on the standards for legal water availability and physical availability. The operational structures of Washington water banks include:

1. Public
2. Quasi-Government
3. Nongovernmental Organizations (NGO)
4. Private

Figure 7 provide a summary of the locations and types of water banks operating in Washington.

## PUBLIC

Public entities for the purpose of this section are considered to be state, county, city, or other local governments. Many public entities in the State operate water banks. In some cases, are called "water banks", in others "water exchanges". In some cases, water banks are named based on the entities served (e.g. Cabin Owners), or by the supply that seeded the bank (Lake Roosevelt Drawdown). Regardless of whether the public entity calls it a "water bank", it is a water bank if it uses the TWRP to convert senior water rights into new appropriations. However, the footprint of the public entity may range from simply fulfilling their typical regulatory function to a role that includes all formation, operation, and management functions of a water bank. Hybrid banks result when a public entity contracts with a third party to perform the non-regulatory functions.

Washington water banks formed, operated, and/or managed under the jurisdiction of local public entities for the purposes of providing domestic mitigation to-date include:

- Chelan County Reserve Program (County)
- Kittitas County Water Bank (County)
- White Salmon Water Bank (City)

Other potential water banks are being evaluated or are in development to facilitate counties in meeting legal availability requirements for domestic, exempt well water demand. These developing water banks are associated with areas of heightened groundwater management and groundwater rules in the following areas: Yakima County, Skagit County, Douglas County, Klickitat County, Water Resource Inventory Area (WRIA) 55 (Little Spokane) and WRIA 59 (Colville Basin).

In addition, Ecology, through the Office of Columbia River and Water Resources Program, is operating water banks and permitting water rights for new uses (inclusive of both domestic water use and other water uses) with the following programs: Lake Roosevelt Drawdown, Sullivan Lake, Cabin Owners, and the Port of Walla Walla.

## QUASI-GOVERNMENT AND NONGOVERNMENTAL ORGANIZATIONS (NGO)

Quasi-government organizations are considered to be entities formed by the legislature (i.e., Irrigation Districts, Walla Walla Watershed Management Partnership). Nongovernmental Organizations (NGOs) are considered to be entities operating under IRS tax code 501(c)3 (i.e. Washington Water Trust). Washington water banks that are formed, operated, and/or managed under the jurisdiction of quasi-government and NGO entities for the purposes of providing mitigation include:

- Dungeness Water Exchange (for domestic, rural irrigation, and stockwater uses)
- Walla Walla Water Exchange (for rural irrigation)

## PRIVATE

Private entities for the purpose of this section are considered to be private for-profit organizations incorporated under State and Federal Law. Currently, private water banks only operate in the Yakima Basin, where Groundwater Rule WAC 173-539A requires mitigation of all new groundwater uses.

In response to Groundwater Rule WAC 173-539A, private water banks formed to fill the new market demand of individual rural landowners who need to mitigate for new permit-exempt wells for domestic purposes. In December 2015, Kittitas County opened a public water bank in many areas that were formerly dominated by private water banks.

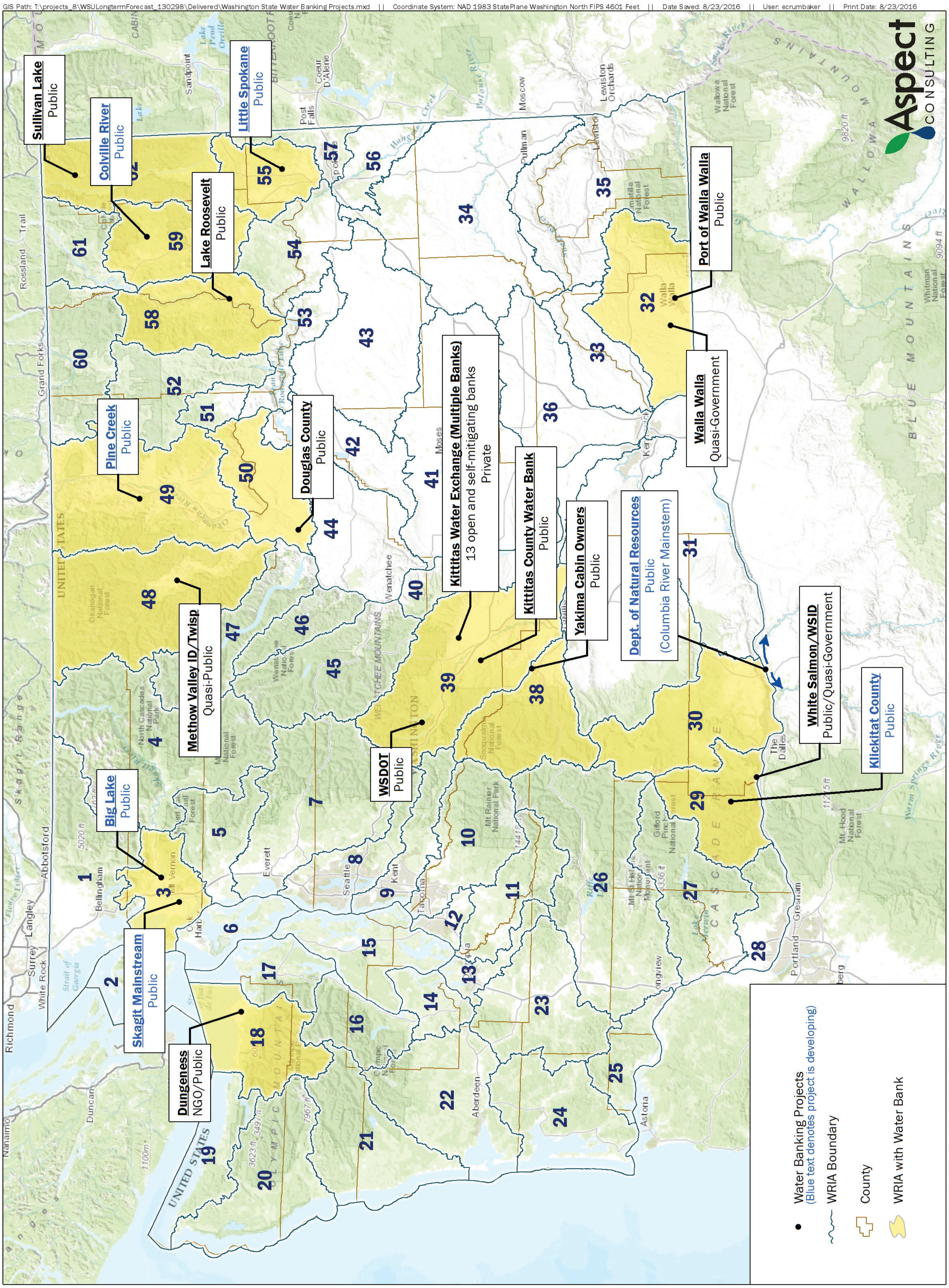



*Figure 7. Water Banking in Washington State by WRIA.*

### *Summary of Washington's Water Banks*

## YAKIMA BASIN CABIN OWNERS (PUBLIC)

The Cabin Owners water bank is a public water bank operated by Ecology. Washington State Senate Bill 6861, with an effective date of June 07, 2006, provided guidance and funding to Ecology to develop a water bank to help cabins and camps that get curtailed in dry years. Ecology seeded this bank with senior irrigation water rights they purchased, and they are using the Storage Exchange Contract to coordinate between U.S. Bureau of Reclamation's (Reclamation) and Ecology to manage seasonal rights to mitigate for new and out-of-priority uses. Because there is storage in the basin that is managed to meet federal instream flow targets, Reclamation and Ecology can mitigate instream flow impacts from the Cabin Owners water bank without having shoulder season impacts. To date, Ecology has mitigated for 349 cabins[6] at an average rate of $60/unit and $3,600/acre-foot consumptive.

Website: http://www.ecy.wa.gov/programs/wr/cro/sb6861.html

## PORT OF WALLA WALLA LEASE PROGRAM (PUBLIC)

The Port of Walla Walla Lease Program is a public bank operated by OCR. The purpose of this bank is to provide term leases to those needing temporary water from the Columbia River in Walla Walla County (or downstream). The bank was seeded through a lease from the Port of Walla Walla for 4,761 acre-feet of water. All leases are temporary and seasonal, and cost $105 per acre-foot per year.

Website: http://www.ecy.wa.gov/programs/wr/cwp/pww-permits.html

## LAKE ROOSEVELT INCREMENTAL STORAGE RELEASES PROGRAM (PUBLIC)

The Lake Roosevelt Incremental Storage Releases Program is operated by OCR and provides a source for up to 25,000 acre-feet of water to permit new municipal, domestic, and commercial/industrial uses from the Columbia River and groundwater in close communication with the river. To date, 41 water rights have been issued under this bank, totaling 5,056 acre-feet. Water rights issued under this program are permanent and cost $35 per acre-foot per year.

Website: http://www.ecy.wa.gov/programs/wr/cwp/cr_lkroos.html

## SULLIVAN LAKE WATER SUPPLY PROJECT (PUBLIC)

The Sullivan Lake Water Supply Project authorizes 9,400 acre-feet of water for use within Okanogan, Ferry, Stevens, Pend Oreille, Douglas, and Lincoln counties. In this legislatively defined project, half of the available quantity is to be used for domestic, municipal, commercial, and industrial uses, while the other half may be used for any other purposes, such as irrigation. The Sullivan Lake Water Supply Project is operated by OCR. Permanent water rights can be established under this program for $60 acre-foot per year for 25 years ($1,500 per acre-foot total).

Website: http://www.ecy.wa.gov/programs/wr/cwp/sullivan.html

## KITTITAS COUNTY WATER BANK (PUBLIC)

The Kittitas County Water bank is administered by Kittitas County. This bank was created after a settlement agreement between the County and Department of Ecology to resolve a case before the Eastern Washington Growth Management Hearings Board. To provide mitigation water to domestic water users, the County purchased four existing water banks and uses the Ecology/Reclamation Storage Exchange Contract to manage seasonal rights to mitigate for year-round new uses, just like the Cabin Owners program. Kittitas County issues

6 As of April 2016

water budget-neutral determinations for mitigation that is likely suitable, as determined by Ecology's suitability maps. The cost of participating in this program is $2195 per equivalent residential unit (ERU).

Website: https://www.co.kittitas.wa.us/health/programs/environmental-health/water-resources.aspx

## WASHINGTON STATE DEPARTMENT OF TRANSPORTATION (PUBLIC)

The Washington State Department of Transportation (WSDOT) established a water bank to offset water used for the I-90 construction project. WSDOT seeded their water bank with a senior surface water right to mitigate the potential impacts of their water use. This bank is not open to the public. WSDOT has recently applied to Ecology for a new temporary permit to irrigate vegetation associated with the Highway 410 Reconstruction project. This new permit would be mitigated by a small amount of water left in their bank that is not being used by the I-90 project. When the I-90 expansion project is complete, WSDOT may use the bank to mitigate water use for future WSDOT projects within the Yakima Basin.

## CITY OF WHITE SALMON/WHITE SALMON IRRIGATION DISTRICT (PUBLIC)

The City of White Salmon created a public water bank, within WRIA 29b, to provide for instream flow enhancement, municipal water supply, and other out-of-stream uses. The water bank was created by transferring 5,781acre-feet from the White Salmon Irrigation District and the City to the trust water rights program. To date, this water bank has been used for self-mitigation. The City currently has permitting authority to contract surplus water to new users through direct service from their municipal system. If indirect service were to be provided, additional authority from the state would be required under their TRWA.

White Salmon Irrigation District converted some of its surplus supply to instream flow and is in the process of negotiating a TWA with Ecology on how best to allocate it.

## DUNGENESS WATER EXCHANGE (PUBLIC/NGO PARTNERSHIP)

The Dungeness Water Exchange is a Public/NGO partnership water bank operated by Clallam County and Washington Water Trust (WWT). The Dungeness Water Management Rule, Chapter 173-518 WAC, went into effect on January 2, 2013 and required new uses of groundwater to be mitigated. Ecology provided administrative and seed funds to develop the water bank through the acquisition of senior irrigation rights, which were environmentally-protective in this case because it was determined that mitigation was not necessary outside the irrigation season. A portion of the bank involves development of infrastructure projects to shift the timing and recharge high flow events to increase base flow through groundwater augmentation. To date, WWT and Clallam County have conveyed an estimated 50 units of mitigation at a rate of $1,000/unit and $11,100/acre-foot consumptive.

Websites: http://www.washingtonwatertrust.org/water-exchange; and http://www.ecy.wa.gov/programs/wr/instream-flows/dungeness.html

## WALLA WALLA WATER EXCHANGE (QUASI-GOVERNMENT)

The Walla Walla Water Exchange is a Quasi-government water bank operated by the Walla Walla Watershed Management Partnership (WWWMP). The Walla Walla River Basin Rule, Chapter 173-532 WAC, was amended in September 2007 to require new outdoor irrigation uses of groundwater under the permit exemption to be mitigated. Ecology provided state administrative and seed funds to develop the water bank through the acquisition of senior irrigation rights. Only irrigation season offsets are being provided, so the use of irrigation rights for bank seeding is appropriate. To date, WWWMP has conveyed less than 10 units of mitigation at a rate of $2,000/unit and $3,600/acre-foot consumptive.

Website: http://www.wallawallawatershed.org/partnership/participate/138-wb-ewmp

## YAKIMA BASIN WATER EXCHANGES (PRIVATE SECTOR)

The Yakima Basin Water Exchanges are predominately a series of private water banks operated for-profit. The Yakima Basin Water Exchanges began when Ecology enacted a series of emergency groundwater rules in Upper Kittitas County beginning on July 16, 2009, requiring all new permit-exempt groundwater uses to be mitigated. On January 22, 2011, Ecology formalized the permanent Upper Kittitas Groundwater Rule, Chapter 173-539A WAC, creating long-term groundwater mitigation requirements. The State of Washington, through Ecology, has used public funds to provide regulatory administrative services (issuing Water Budget Neutral Determinations) and regulatory oversight. Private investors have seeded their own water banks and manage all of the administration, other than permitting and regulatory oversight of water accounting. Seeding has occurred through acquisition of senior irrigation rights, and either the use of the Ecology/Reclamation Storage Exchange Contract to cover offseason impacts, or use of private on-site storage-and-release ponds for off-season mitigation. To date, there have been several private water banks in the Yakima Basin established as part of the Yakima Basin Water Exchanges. Several of these banks have been purchased by other entities, and currently the Roth-Clennon and the Williams and Amerivest banks are operated as public banks by Kittitas County. Northland Resources, Starkovich, and the Land Lloyd Development banks are self-mitigating and not currently open to the general public.

- Bourne Bank
- Suncadia Bank
- JP Roan Bank
- Swiftwater Ranch
- Masterson Ranch
- Reecer Creek Golf Course (SC Aggregate)
- Williams and Amerivest (Kittitas County)
- Roth-Clennon (Kittitas County)
- Northland Resources
- Burchak Tillman Creek
- Central Cascade Lands Company (Yakima Mitigation Services)
- Williams – Cabin Owner Bank
- Starkovich
- Land Lloyd Development

These banks have conveyed an estimated 827 units of mitigation[7] at rates ranging from $1,250 per mitigation unit (or $41,600/acre-foot consumptive)[8] to $10,000 per mitigation unit (or $72,900/acre-foot consumptive.) These banks generally operate on the basis of suitability maps developed with Ecology as part of their TRWA's, and published on Ecology's website[9]. The suitability maps are based on potential impairment and show areas in green where the bank can supply mitigation water, areas in yellow where they may supply mitigation water in the future if additional study on Yakima River tributary impacts is completed, and areas in red where mitigation from a particular bank is likely unsuitable.

## METHOW VALLEY IRRIGATION DISTRICT (QUASI-GOVERNMENT)

Methow Valley Irrigation District (MVID) created a water bank to improve irrigation reliability, serve

7 Base data from 2015, with April 2016 updates for seven banks

8 The Starkovich bank and Land Lloyd Development bank were not included in price analysis provided here and elsewhere in the report because of the self-mitigating nature of these banks.

9 Yakima County Water Banks on Ecology's website: http://www.ecy.wa.gov/programs/wr/cro/wtrxchng.html

additional lands, provide municipal water for the Town of Twisp, and improve instream flows in the Twisp and Methow Rivers. The water bank was created by transferring 2,996 acre-feet of irrigation water to the TWRP. The Town of Twisp has received a new mitigated water right, based on a purchase and sale agreement between the MVID and the Town of Twisp. MVID received a new mitigated water right for their reconstructed irrigation delivery system. MIVD is currently working through an assignment process for members who received individual wells as a part of a district-wide improvement project managed by Trout Unlimited. This bank is self-mitigating and not currently open to the general public.

## DEVELOPING BANKS

Currently, there are several water banks being developed to address local water availability or reallocation needs. These banks are at different development stages.

### *Pine Creek, Okanogan County*

The Pine Creek water bank is an OCR project. OCR purchased a 958-acre-foot irrigation water right in Okanogan County to seed the Pine Creek bank. Currently, OCR is developing business rules on where and how to operate the bank. The water right was purchased by OCR and is held as an irrigation right in the TWRP, and a trust water ROE is pending.

### *Department of Natural Resources, Paterson*

The Department of Natural Resources (DNR) Patterson water bank is seeded by a 1,248 acre-foot DNR irrigation water right in Klickitat County. DNR has donated the water right into trust, and is developing their banking framework, which will likely be exclusively for use on DNR public lands. Before the bank launches, Ecology will change the right to instream flow and negotiate a Trust Water Right Agreement with DNR.

### *Big Lake Water Rights Mitigation Bank, Skagit County*

Ecology purchased 28.56 acre-feet of water from the Big Lake Water Association, a public water system in the Skagit Basin. Ecology will soon be announcing a draft mitigation proposal for the Big Lake water rights, including the area served by the mitigation and the process for obtaining mitigation credits. Ecology will seek input on the proposal before finalizing the mitigation project.

### *Upper Skagit Tribe Water Bank*

Ecology has awarded a grant to the Upper Skagit Tribe to launch a groundwater recharge and mitigation project in the Fisher Creek drainage or the Skagit Basin. Currently, this basin is closed to new water uses, including domestic permit-exempt wells. This proposed mitigation bank will utilize groundwater infiltration, thus retiming runoff and enhancing groundwater and streamflow levels. As of early 2017, this project is still in the planning stages.

### *Little Spokane Water Bank*

Spokane, Stevens, and Pend Oreille Counties are working together to evaluate the use of a water bank to address current and potential regulatory constraints on existing and new water uses in the Little Spokane Watershed. Spokane County commissioned a water banking feasibility study, and is currently (January 2017) in the process of developing a banking model and identifying potential seed water.

## 2.4 Summary of Washington Water Banking Metrics

### *Comparing Water Banks*

Water banks transact quantities of water for a variety of purposes, from groundwater use under the permit exemption of generally less than one acre-foot (i.e., indoor and outdoor domestic use for a single residence) to permitted water rights in the tens, hundreds, or thousands of acre-feet (i.e., irrigation, industrial and municipal uses). For example, one transaction from a private water bank in Kittitas County conveyed 0.137 acre-feet per year consumptive for indoor domestic use and irrigation of 500 square feet. Another transaction from OCR for the Sullivan Lake Water Bank conveyed 1,100 acre-feet per year to the City of Bridgeport as a new water right permit.

In order to compare the activity of water banks, this study compared units of mitigation and acre-foot consumption. A unit of mitigation is the quantity of water a water bank does business in. A unit of mitigation is a term of art used for comparison purposes in this study and is not defined in statue or rule. However, the concept of units of mitigation enables comparison of one water bank to the next when reporting transaction volumes (i.e. units of mitigation sold) and unit pricing (i.e. cost per unit). To standardize reporting across different bank metrics, when reporting acre-foot consumptive pricing, the study team has quantified water conveyed by the residential unit, and water conveyed by the acre-foot, to the acre-foot consumptive equivalent.

### *Water Bank Activity and Prices*

Selection of the type of water banking model is dependent on the regulatory environment, timing of the need for water bank development relative to regulatory actions, and ability of Ecology and counties to agree on the standards for legal water availability and physical availability.

Price, or the amount of money paid for one unit (not including fees), and volume of units transacted are highly variable across different water banking models, as shown in Table 1. Public water banks have the lowest overall price per unit and price per acre-foot, but also have the lowest number of units transacted to date. Private water banks account for the highest cost per unit and cost per acre-foot, and include the highest number of units transacted. Private water banks appear to the be the most productive based on the number of units transacted, but the units transacted is skewed in favor of private water banks based on the nature of regulatory actions related to rural growth and the scale of Upper Kittitas County in the Yakima Basin. A summary of transaction differences between public and private banks is provided in Figure 8 and in Table 1.

Table 1. Summary of Price of Water charged by Public/Private Water Banks (transactional fees not included)

| | Cost of Water/Unit | Cost/acre-foot consumptive |
|---|---|---|
| *Public* | | |
| Average | $920 | $1,290 |
| Minimum | $60 | $3,600 |
| Maximum | $1,700 | $1,000 |
| *Quasi-Government/NGO* | | |
| Average | $1,500 | $7,350 |
| Minimum | $1,000 | $3,600 |
| Maximum | $2,000 | $11,100 |
| *Private* | | |
| Average | $5,250 | $41,600 |
| Minimum | $1,250 | $27,000 |
| Maximum | $10,000 | $131,200 |
| Note:<br>Excludes annual rate programs and lease programs<br>Data collected through spring 2015 | | |

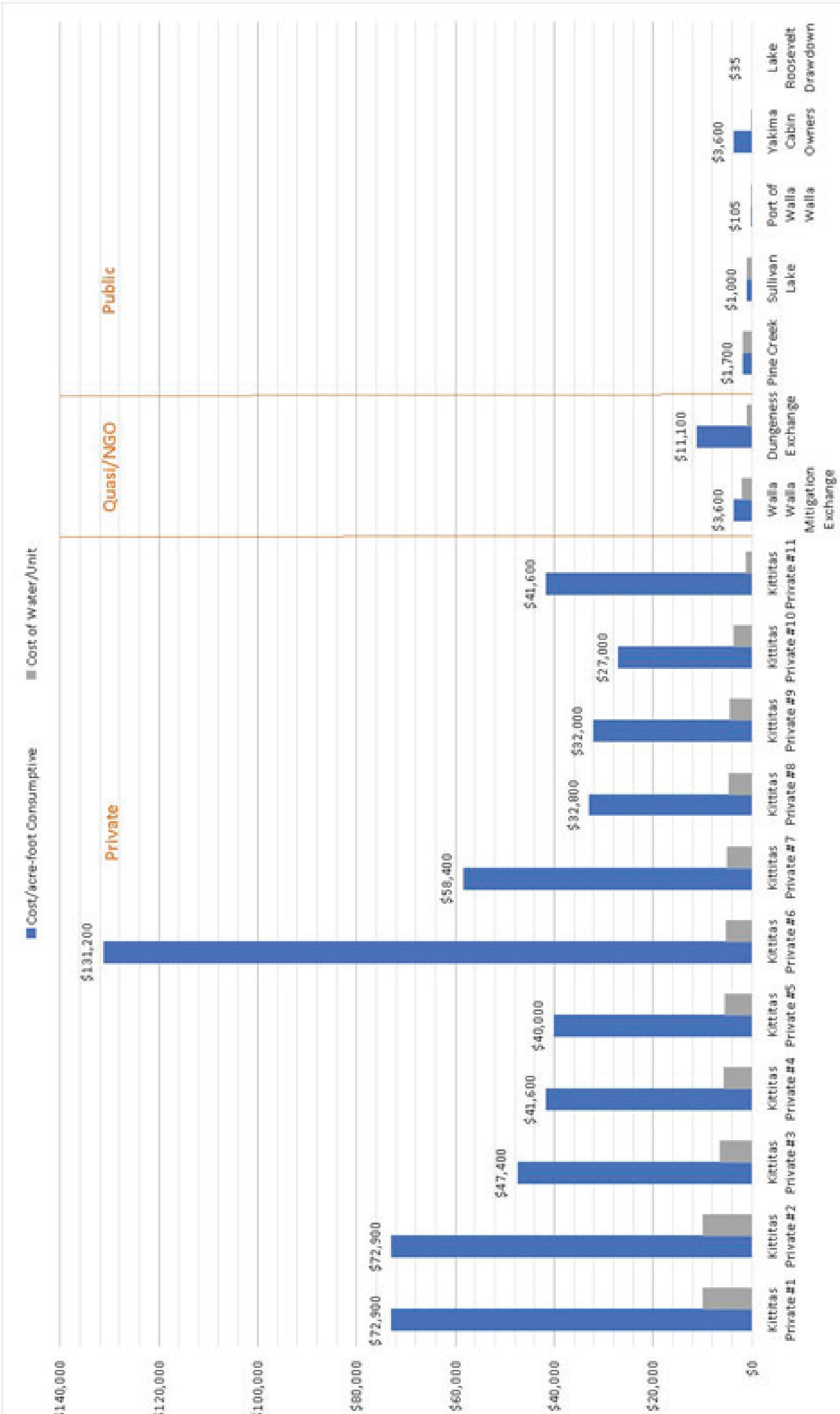



*Figure 8. Comparing Prices Among Different Water Bank Models*

Private banks appear to be the most expensive to participate in, having both the highest average unit price and the highest average price per consumptive acre-foot. Quasi-Governmental/NGO water banks have the second highest price, with public banks having the lowest price. The price differences between these bank models can likely be attributed to the quantity of water transacted, funding for bank formation, and whether or not the bank model operates for cost recovery or profit.

Private water banks also appear to be most active. Private banks have issued 827 mitigation credits compared to 53 mitigation credits issued by non-profit/quasi-governmental water banks, and 381 mitigation credits issued by public water banks. This is likely related to locations and markets served, as well as regulatory requirements for water banking. All of the private banks are located in Kittitas County, where WAC 173-139A withdrew all public groundwater within the upper Kittitas county from appropriation. Figure 9 show how many units have been transacted by each water banking model.

Within private water banks, there is competition for market share. Two of the water banks, Suncadia and Yakima Mitigation Services, have much higher activity than other private water banks. The reasons for this pattern are difficult to determine, but in at least one case, market dominance is likely due to that water bank being the first into the Kittitas County market, having high visibility, a marketing strategy, and a built-in customer base.

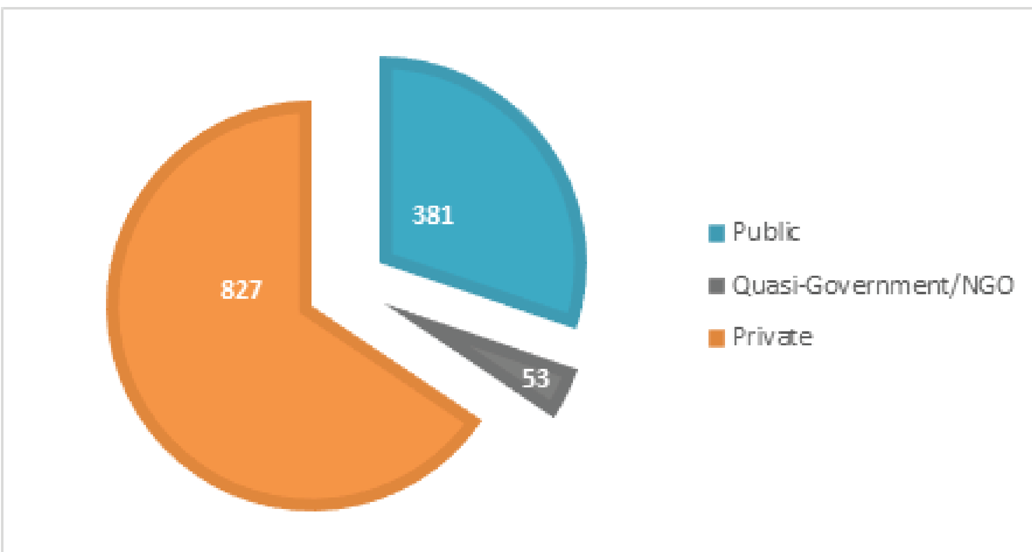



*Figure 9. Units Transacted by Banking Model*

## 2.5 Summary of Banking Effectiveness in Solving Water Problems

### *Comparing Models*

While there are various ownership models for water banks, all of the previously listed water banks were initiated with the common goal of providing reliable and legally defensible water transfers to their customer base. The following sections compare the effectiveness of each model to solve water problems, including discussion of the pros and cons of each model with respect to issues such as time and cost.

### PUBLIC WATER BANKS

As illustrated in Figure 6 and in Table 1, public water banks in Washington have accounted for an estimated 230 units of domestic mitigation transacted. With new public water banks coming online, the number of units transacted by public water banks may increase. Costs ranged from $1,000 per mitigation unit and consumptive acre-foot (Sullivan Lake), to $60 per mitigation unit and $3,600/acre-foot consumptive (Ecology, Yakima Basin Cabin Owners). Table 2 below summarizes the pros and cons associated with public water banks.

Table 2. Summary of Pros and Cons of Public Water Banks

| Pros | Cons |
|---|---|
| May be formed, operated, and/or managed by public entities | Timing – generally slow to establish (1 to 3 years) |
| Set parameters on pricing, unit volume, service area, etc., through public process; ability to manage market activity, trading zones, targeted users | Potential concerns over divestiture of assets; potential third-party litigation |
| Most favorable pricing to buyers | Minimal returns to sellers. Sustainability/duration based on low cost |
| Typically established and seeded through public funds | Restrictions on availability and use of public funds |
| Established to serve basic and extended public services (outside irrigation, stockwater, etc.) | Costs associated with bank management |
| | Reduced incentives for private banks to develop within the basin |

## QUASI-GOVERNMENT/NGO WATER BANKS

A summary of Quasi-Government and NGO water bank transaction costs and volumes is provided in Figure 6 and in Table 1. To date, Quasi-Government and NGO water banks have accounted for an estimated 53 units of domestic mitigation transacted at a price ranging from $1,000 per mitigation unit and $11,100/acre-foot consumptive (Dungeness Water Exchange, Clallam County/Washington Water Trust), to $2,000 per mitigation unit and $3,600/acre-foot consumptive (Walla Walla Watershed Management Partnership, Walla Walla Water Exchange). Table 3 summarizes the pros and cons of quasi-government and NGO Water Banks.

Table 3. Summary of Pros and Cons of Quasi-Government / NGO Water Banks

| Pros | Cons |
|---|---|
| May be formed, operated, and/or managed by public interest entities | Timing – generally slow to establish (1 to 3 years) |
| Typically set parameters on pricing, unit volume, service area, etc. through public process | Decreased concerns over divestiture of assets, although retained as a concern if NGO works on behalf of a public entity |
| Generally mid-range prices | Restrictions on availability and use of public funds |
| Usually established and seeded through public funds | Management of the water bank likely to be less costly than public banks |
| Established to serve basic and extended public services (outside irrigation, stock water, etc.) | Potential long-term fiduciary liability to managing entity |
| Ability to establish market activity, trading zones, etc. | |
| Sustainability, higher prices than public banks can extend longevity | |

## PRIVATE WATER BANKS

As illustrated in Figure 6 and Table 1, private water banks have accounted for an estimated 818 units of mitigation transacted in the Yakima Basin at a price ranging from $1,250 per mitigation unit, $41,600/acre-foot consumptive (Kittitas “Private” #11), to $10,000 per mitigation unit, $72,900/acre-foot consumptive (Kittitas “Private” #1 and 2). Table 4 summarizes the pros and cons of private water banks.

Table 4. Summary of Pros and Cons of Private Water Banks

| Pros | Cons |
|---|---|
| Timing – generally the quickest to establish (6 months to 1 year). This is because most private banks are seeded through trust water right rather than infrastructure changes (e.g. Lake Roosevelt drawdown, MVID). | Formed, operated, and managed to generate profit, with associated higher pricing. |
| Profit motive provides incentive to make water available for sale, and yields high return on investment for sellers | Generally highest prices and highest transaction costs, which do not incentivize bank participation |
| Usually serves basic and extended public services (outside irrigation, stock water, ext.) based on market demand | Limited ability to establish market activity, trading zones, etc. |
| Control over divestiture of assets | Sustainability – limited controls on longevity |

The analysis of benefits and challenges associated with different water banking structures in this report is tempered by the fact that there is incomplete transparency within individual water banks. Some banks have little incentive to publically disclose transactions, price points, internal business rules, and internal bank goals. In reality, each category of bank described in this report (e.g. private, public, NGO), operates along a spectrum of different service characteristics. Thus, wholesale comparisons likely fall short. Benefits and challenges associated with different water banking structures are expected to become more clear in the future as a result of legislative intervention via SB 6179, which requires water banks to operate in a more transparent manner as well as requiring Ecology to publish this information.

While each of the different models is associated with unique benefits and challenges, overall, each water bank allows for the reallocation of water to new uses. Using market forces and the regulatory framework provided in Washington, water banks provide a mechanism for those who would otherwise be excluded from a resource because of scarcity to gain access.

## *3. Water Banking in the Western U.S.*

This section summarizes the state of water banking activities in eleven western states of United States – Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, and Wyoming. The description of water banking for each state is different depending upon the nature of water banks operational in those states and availability of information. The information presented in this section includes the number of applications processed for leasing or renting water rights, associated prices, groundwater banking balances, number of water rights mitigation transactions, and other variables. Data were collected from various sources including water bank annual reports, water bank websites and personal communication with authorities.

### 3.1 Arizona

#### *Overview of Water Banking in Arizona*

All water banking activity in Arizona is governed by the Arizona Water Banking Authority (AWBA). The AWBA was established in 1996 in order to increase utilization of the state's Colorado River entitlement and to develop long-term storage credits for the state. The overarching objectives of the AWBA are to provide secure and reliable water supplies to municipal and industrial users, provide water to Native communities as required by settlement agreements, and assist California and Nevada through interstate banking arrangements.

In order to fulfill these objectives, the AWBA sponsors the storage and delivery of water from the Colorado River into central and southern Arizona through the Central Arizona Project (CAP) every year. The water is stored underground in existing aquifers (direct recharge) or is used by irrigation districts in lieu of pumping groundwater (indirect or in-lieu recharge). For each acre-foot stored, the AWBA accrues long-term storage credits that can be redeemed in the future when Arizona's communities or neighboring states need this backup water supply. Since its inception, the AWBA has banked approximately 4 million acre-feet of long-term storage credits, 3.4 million acre-feet of credits to provide back-up supplies during shortages to certain Arizona cities and Indian communities, and 600,000 acre-feet of credits for interstate purposes on behalf of the state of Nevada[10].

The AWBA has historically purchased excess water from the CAP when it is available. However, the water supply in the Colorado River is predicted to diminish in coming years. According to current projections, a water supply shortage is expected to be declared as early as 2016 in the lower basin of the Colorado River and may persist for the next decade[11]. Furthermore, excess water is available to the AWBA only after the Central Arizona Water Conservation District (CAWCD), a tax-levying public improvement district that manages and operates the Central Arizona Project canal, has fulfilled the water demands of its higher priority users. According to the priority system outlined by the U.S. Secretary of the Interior's 1983 Record of Decision, the excess water is the most junior priority behind municipal and industrial users, Indian water users, and non-Indian agricultural water users.[12] The AWBA focuses on various planning processes to identify specific actions to help them fulfill their objectives and responsibilities. Examples of such action planning processes include the following:

a. The Indian Firming Program, which is dedicated to addressing the state's obligations towards various water rights settlements

b. Amendment of AWBA's governing statutes to facilitate buying long term storage credits even when excess CAP water is not available

c. Planning intended to provide a framework for the recovery of long-term storage credits and the delivery of that water during future shortages

d. Dynamic modeling that can incorporate new information as it becomes available to predict the intensity and timing of water shortages

### *Trading Activity in Arizona*

The following tables summarize the water banking trading activity in terms of long-term storage credits for the AWBA. Table 5 shows the number and location of long-term storage credits accrued in 2014, Table 6 shows the cumulative long-term storage credits accrued through December 2014 and Table 7 shows the average annual cost to obtain a long-term storage credit for intrastate storage.

10 Annual Report. 2014. Arizona Water Banking Authority.
11 Annual Report. 2014. Arizona Water Banking Authority.
12 Arizona State Senate: Issue Brief. 2015. Arizona State Legislature.

Table 5. Number and Location of Long-term Storage Credits Accrued in 2014 (Acre-feet) [13].

| Funding Source | Phoenix AMA | Pinal AMA | Tucson AMA | Total |
|---|---|---|---|---|
| 4-cent Ad Valorem Tax | 23,435 | 6,584 | 17,977 | 47,996 |
| Withdrawal Fees | 3,144 | 6,429 | 2,314 | 11,886 |
| General Fund | - | - | - | - |
| Shortage Reparation | - | - | 7,750 | 7,750 |
| **Intrastate Total** | **26,579** | **13,013** | **28,041** | **67,632** |
| Interstate-Nevada | - | - | - | - |
| **Total** | **26,579** | **13,013** | **28,041** | **67,632** |

Table 6. Cumulative Long-term Storage Credits Accrued through December 2014 (Acre-feet) [14].

| Funding Source | Phoenix AMA | Pinal AMA | Tucson AMA | Total |
|---|---|---|---|---|
| 4-cent Ad Valorem Tax | 1,358,825 | 205,214 | 422,292 | 1,986,330 |
| Withdrawal Fees | 320,679 | 408,459 | 103,306 | 832,445 |
| General Fund | 42,316 | 306,968 | 54,546 | 403,830 |
| **Other Intrastate:** | | | | |
| Indian Firming Appropriation | - | - | 28,481 | 28,481 |
| Shortage Reparation | 20,642 | 60,507 | 17,822 | 98,970 |
| GSF Operator Full Cost Share | - | 14,125 | - | 14,125 |
| **Intrastate Total** | **1,742,462** | **995,273** | **626,477** | **3,364,181** |
| Interstate-Nevada | 51,009 | 440,241 | 109,791 | 601,041 |
| **Total** | **1,793,471** | **1,435,514** | **736,238** | **3,965,222** |

Table 7. Average Annual Cost to Obtain a Long-term Storage Credit for Intrastate Storage[15].

| Year | Credits | Funds Expended($) | Average cost ($/ acre-foot) | Ratio of groundwater storage facility (GSF) to underground storage facility(USF) |
|---|---|---|---|---|
| 1997 | 296,987 | 6,387,000 | 21.51 | 85:15 |
| 1998 | 202,542 | 7,143,000 | 35.27 | 68:32 |
| 1999 | 232,142 | 8,733,000 | 37.61 | 68:32 |
| 2000 | 272,123 | 11,163,000 | 41.02 | 60:40 |
| 2001 | 275,406 | 10,893,000 | 39.55 | 62:38 |
| 2002 | 262,317 | 13,700,000 | 52.23 | 64:36 |
| 2003 | 200,168 | 11,077,666 | 55.34 | 47:53 |
| 2004 | 251,456 | 17,855,997 | 71.01 | 41:59 |
| 2005 | 85,782 | 5,615,201 | 65.46 | 58:42 |
| 2006 | 162,342 | 14,720,277 | 90.67 | 17:83 |
| 2007 | 245,221 | 14,589,390 | 59.49 | 37:63 |
| 2008 | 203,373 | 8,168,100 | 40.16 | 65:35 |
| 2009 | 99,453 | 6,977,590 | 70.16 | 76:24 |
| 2010 | 181,214 | 26,027,947 | 143.63 | 21:79 |
| 2011 | 127,605 | 16,543,540 | 129.65 | 33:67 |
| 2012 | 125,503 | 17,314,052 | 137.96 | 42:58 |
| 2013 | 72,404 | 10,963,900 | 151.43 | 31:69 |
| 2014 | 67,795 | 12,048,490 | 177.72 | 24:76 |

13 Annual Report. 2014. Arizona Water Banking Authority
14 Annual Report. 2014. Arizona Water Banking Authority
15 Annual Report. 2014. Arizona Water Banking Authority

### 3.2 California

California water banking programs, including physical storage of groundwater as well programs for leasing of water rights, have historically been supported by state and federal policies. The concept of water banking was introduced in the state after the droughts of 1980s and early 1990s. However, water banking or leasing programs in early years were mostly temporary. The trend has shifted toward more permanent transfers in recent years and water banking programs have also become larger in scale.

Most of California's surface water is governed by the appropriative water rights doctrine. According to this doctrine's "use it or lose it" requirement, water rights lapse for any water not used for five consecutive years. The transfer of groundwater is less regulated by the state because California's water code does not apply to most groundwater in the state. In most counties, the transfer of groundwater depends on local ordinances. However, since many groundwater basins in the state are connected to a surface water source, pumping groundwater can reduce surface flows of these sources. The Department of Water Resources in California has developed guidelines that include restrictions on the locations of wells that can be used to pump groundwater.[16]

Table 8 provides a summary of groundwater banking balances in various regions of California.

Table 8. Groundwater Banking Balances and Activity by Region and End Use in California (acre-feet) [17].

| | Agriculture | Urban | Mixed Use | Total balance | Total withdrawals |
|---|---|---|---|---|---|
| S.F Bay Area | - | 551,277 | - | 551,227 | 130,343 |
| Kern County | 1,140,803 | 17,743 | 241,679 | 1,400,225 | 1,226,805 |
| Other San Joaquin Valley | 202,045 | 1875 | - | 203,920 | 93,467 |
| Southern California | - | 826,378 | - | 826,378 | 752,181 |
| Unspecified Region | - | - | 10,032 | 10,032 | 81,631 |
| Total Balance | 1,342,848 | 1,397,273 | 251,711 | 2,991,782 | |
| Total Withdrawals | 1,101,055 | 284,523 | 898,849 | | 2,284,427 |

Note - Balances are as of 2011, withdrawals are cumulative (1990-2011).

#### *Water Banks in Kern County*

Since the 1990s, numerous local agencies in Kern County, California, have developed banks. Today, there are 11 operational groundwater banks in Kern County. Among them, the Kern Water Bank is the largest bank that serves various public and private water agencies. Between 1990 and 2006, approximately 3 million acre-feet of physical water has been stored in these water banks. The majority of this water was withdrawn during dry conditions of the late 2000s. However, storage levels were restored back after a wet year in 2011.[18] Figure 7 below shows the groundwater banking balances for Kern County from 1990-2011. The balances represent the amount of groundwater remaining at the end of the given year. These banks mainly store water for offsite parties including agricultural agencies, urban agencies and the state of California. These banks do not have a formalized management regime and are dependent on local ordinances. They do have protocols to protect the local users from injury due to withdrawals from offsite parties.[19]

16 California's Water Market by the numbers: Update 2012. 2012. Hanak and Stryjewski.

17 Table 3. California's Water Market by the numbers: Update 2012. 2012. Hanak and Stryjewski. Data have not been found for subsequent years.

18 California's Water Market by the numbers: Update 2012. 2012. Hanak and Stryjewski

19 California's Water Market by the numbers: Update 2012. 2012. Hanak and Stryjewski

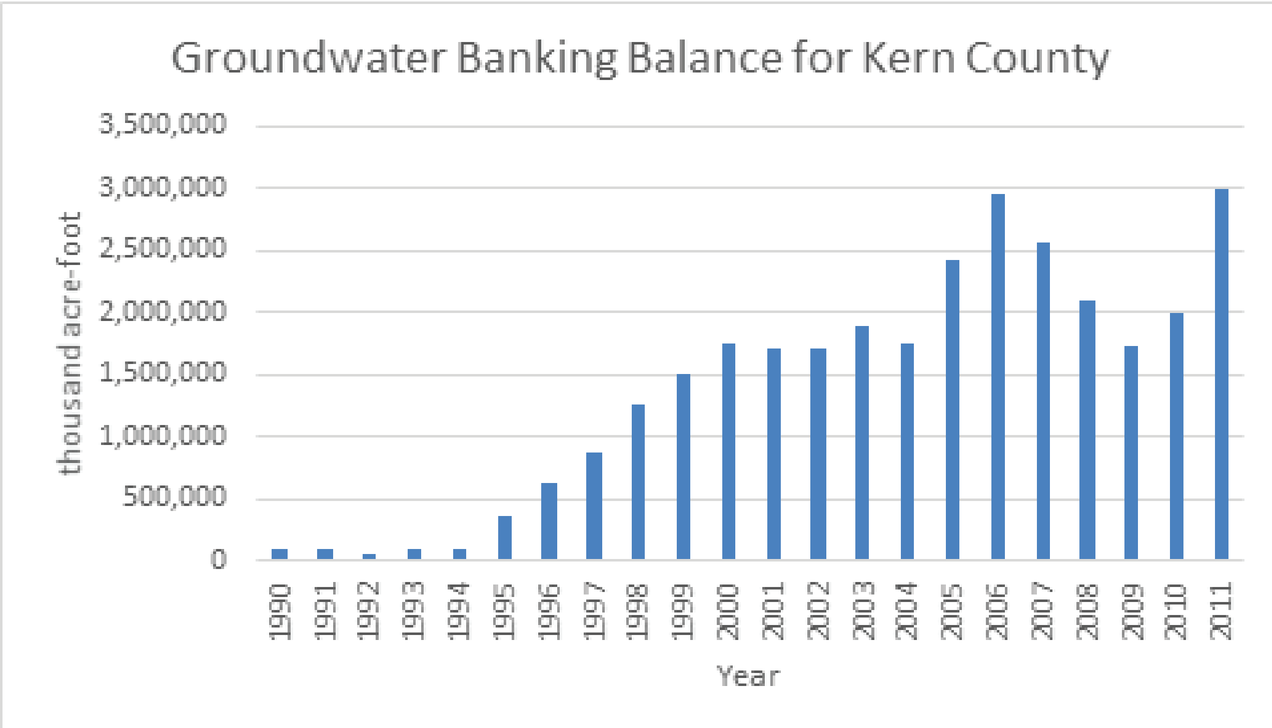



*Figure 10. Groundwater balances in Kern County, CA (1990-2011)* [20] *.*

### *Southern California Water Banks*

The water banks in southern California are administered by the Metropolitan Water District of Southern California (MWDSC). The MWDSC works with different local water agencies to meet the water needs of the region. It coordinates various groundwater banking operations in Southern California with various water districts in the region and provides the funding for infrastructure necessary for such operations. MWDSC initiated a storage program in the 1990s involving adjudicated basins and special groundwater management districts. The water was physically stored in these basins and pumped out when needed by the local agencies. The pumps and additional infrastructure funded by the MWDSC can be used by the local agencies for their own operations when not being used for MWDSC pumping.[21] Figure 11 below shows the groundwater banking balances for Southern California from 1990-2011.

20 Adapted from - California's Water Market by the numbers: Update 2012.Figure 13. 2012. Hanak and Stryjewski

21 California's Water Market by the numbers: Update 2012. 2012. Hanak and Stryjewski

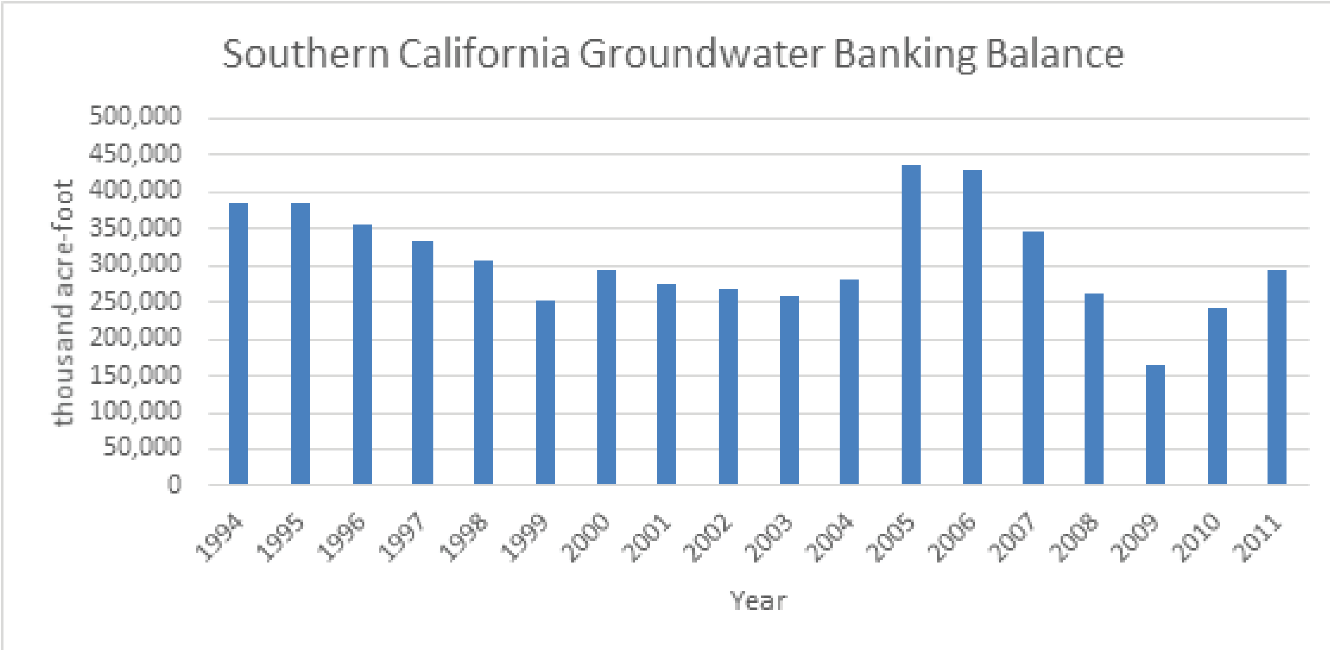



*Figure 11. Groundwater Banking Balances for Southern California (1994-2011)* [22] *.*

## *The Semitropic Groundwater Storage Bank*

The Semitropic Groundwater Storage Bank, located in Kern County, California began its operation in the 1990s. It is one of the largest groundwater banking operations in the world. It has currently six major banking partners who have supplied their surplus water to the bank, totaling 700,000 acre-feet. The project is capable of storing 1.65 million acre-feet of water and, if necessary, delivering 90,000 acre-feet of water to its banking partners via the California aqueduct.[23] Semitropic is the largest water bank in Kern County, and stores water for entities outside Kern County. It operates an informal conjunctive use program for its customers, who are mostly farmers. Semitropic has banking partners who deliver their surplus water to Semitropic during wet years. Semitropic's water banking is done in basins that already have secured the rights to store and withdraw water based on formalized adjudications or special management districts. On the other hand, the Kern County Water bank is operated based on semiformal agreements. [24]

The Semitropic water bank can be divided into the original water bank and the stored water recovery unit. The stored water recovery unit is a special groundwater banking program within the Semitropic Groundwater Storage Bank designed to increase storage, water recovery and pump-back capacity of the bank. Table 9 shows the breakdown of water allocation stakes between Semitropic's various banking partners.

22 Adapted from - California's Water Market by the numbers: Update 2012.Figure 14. 2012. Hanak and Stryjewski
23 Semitropic water storage district website - http://www.semitropic.com/BankingPartners.htm
24 Adapted from - California's Water Market by the numbers: Update 2012. 2012. Hanak and Stryjewski

Table 9. Allocation of Stakes Between Semitropic's Banking Partners [25].

| A. Original Water Bank | Stake (AF) |
|---|---|
| Metropolitan Water District of Southern California (MWDSC) | 350,000 |
| Santa Clara Valley Water District | 350,000 |
| Alameda County Water District | 150,000 |
| Newhall Land and Farming Company | 55,000 |
| San Diego County Water Authority | 30,000 |
| Zone 7 Water Agency | 65,000 |
| B. Stored Water Recovery Unit | |
| Poso Creek Water Company, LLC | 60,000 |
| San Diego County Water Authority | 15,000 |
| City of Tracy | 10,500 |
| Homer, LLC | 15,000 |
| Harris Farms, LLC | 10,500 |
| Unallocated | 64,250 |
| Uncommitted (used by all customers) | 474,750 |
| **TOTAL** | **650,000** |

## 3.3 Colorado

### *Arkansas River Basin Water Bank*

The Arkansas River Basin water bank was created in Colorado following the approval of Arkansas Water Bank Program by the Colorado General Assembly in 2001. The water bank was created with a goal to increase the availability of water for farmers, ranchers and cities through proper valuation of water rights. It allowed for one-year leasing programs for stored water within the Arkansas River Basin and its tributaries. The South Eastern Colorado Water Conservancy District was the chosen bank operator for this pilot program.

The water banking program was primarily designed to work through a website. The depositors and bidders were supposed to register themselves and detailed information about them would be available through the website. The price was supposed to be determined through negotiations between interested buyers and sellers. Various documents, sample contract agreements and forms were made available through the website to facilitate transactions between interested buyers and sellers. However, the program gathered very little interest. Only four individuals deposited water in the bank and three of them withdrew in light of no interest from the bidders.[26] Therefore, the original set up of the water bank created in 2003 was a failure. Some of the reasons for this failure were prices that were higher than market prices, a long timeline to complete transactions, questions related to the deliverability of water to various regions and the fact that it was a virtual water bank with no physical storage capabilities.[27]

A new statute was adopted in 2006 that made the water bank permanent. The Upper Arkansas Water Conservancy District (UAWCD) was authorized as the water bank operator in the Arkansas Basin. Various changes were made to the original water bank created in 2003. Some of the changes included an expedited transaction timeline and more authority conferred to the water bank operator, including setting the minimum

25 Semitropic water storage district website - http://www.semitropic.com/BankingPartners.htm
26 Analysis of Water Banks in the Western States. 2004. Department of Ecology and WestWater Research.
27 Update of the water banking in the Arkansas presented to the interim water resources review committee. 2013. Upper Arkansas Water Conservancy District

asking price. However, these modifications have not resulted in any trading activity through the bank. The UAWCD proposed to take over as bank operators, but this change has not yet come about and the project is currently not active.[28]

## 3.4 Idaho

Water banks in Idaho are separated onto two categories by the Idaho Department of Water Resources Board (IWRB); water supply banks and local rental pools. The Board's water supply bank handles water rights-related cases for all surface and groundwater throughout Idaho and is governed by the Idaho Department of Water Resources.

### *Board's Water Supply Bank*

The Idaho State Water Supply Bank was officially established in 1979 and is governed by the IWRB. The bank rules were amended once in 1980 and again in 1993. Through this bank, interested parties can lease their water rights into the bank or rent water rights from the bank for all surface and groundwater within Idaho. The leases and rentals are generally for one to five years in duration. The filing fee to lease a water right to the bank is between $250 - $500 per water right, with the potential for additional rental fees. The rate to rent a water right from the bank is $14 per acre-foot.[29]

The owner of a water right may offer to lease a portion or all of the water right through an application. The IWRB then makes the water under the leased right available to interested users. After a water right is leased, 90% of the rental fees are paid to the water rights owner and 10% of the rental fees go to the Board to cover administrative costs. In order to rent a water right through the bank, the interested party must submit an application to the Board for the designated rental fee and then the Board will try to match the needs of the renter with one of the rights in the bank.[30]

### *Trading activity in Idaho*

The 2014 annual report for the Idaho State Water Supply Bank mentions that there were 835 water rights leased into the water bank that represents 250,000 acre-feet of water on approximately 75,000 irrigable acres at the time of the report. The following figure summarizes the recent trading activity for Idaho State Water Supply Bank. Figure 9 shows the number of applications processed each year by the bank from 2010-2014, and Table 10 summarizes the application processing information of the IWRB's water supply bank for 2014.

28 Personal communication with Upper Arkansas Water Conservancy District. December, 2015.
29 Report for the Board's Water Supply Bank. 2014. Idaho Department of Water Resources Board.
30 Report for the Board's Water Supply Bank. 2014. Idaho Department of Water Resources Board.

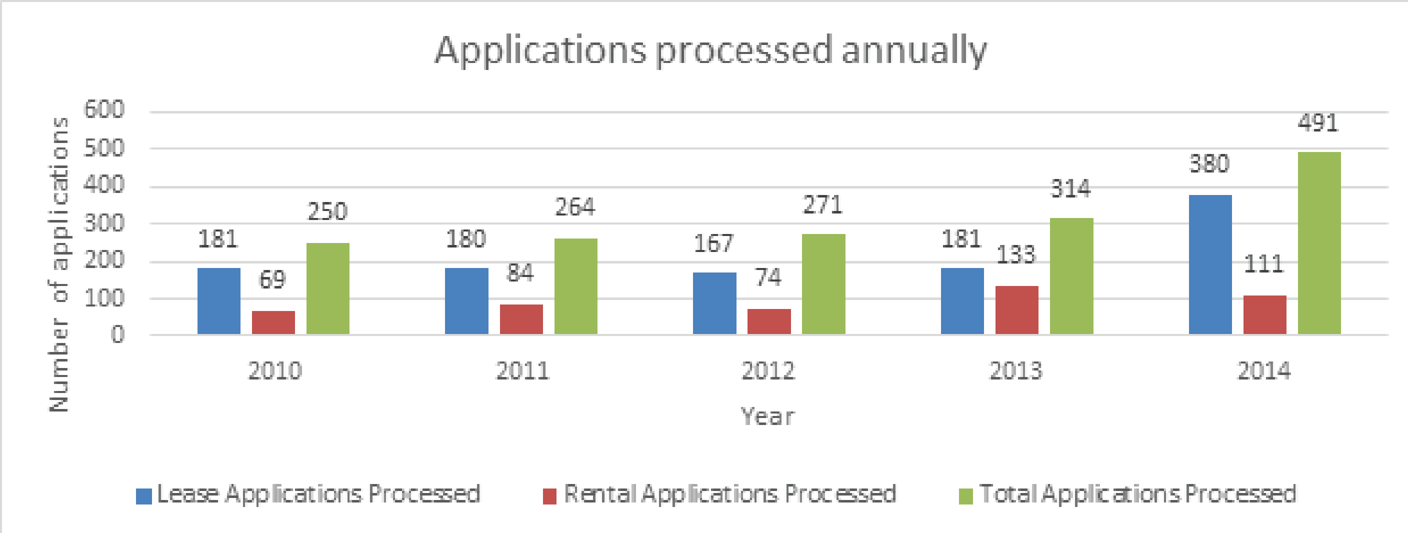



*Figure 12. Number of applications processed each year from 2010-2014*[31]

Table 10. Application Processing Data for IWRB's Water Supply Bank for 2014[32]

| Month | Lease Applcations Received | Lease Applications Pending | Lease Applications Processed | Rental Applications Received | Rental Applications Pending | Rental Applications Processed | Total Applications Received | Total Applications Processed |
|---|---|---|---|---|---|---|---|---|
| Jan | 136 | 136 | 24 | 37 | 37 | 1 | 173 | 25 |
| Feb | 40 | 152 | 27 | 18 | 54 | 3 | 206 | 30 |
| Mar | 49 | 174 | 39 | 14 | 65 | 11 | 239 | 50 |
| Apr | 38 | 173 | 41 | 13 | 67 | 14 | 240 | 55 |
| May | 55 | 187 | 57 | 8 | 61 | 17 | 248 | 74 |
| Jun | 14 | 144 | 23 | 5 | 49 | 18 | 193 | 41 |
| Jul | 22 | 143 | 31 | 6 | 37 | 12 | 180 | 43 |
| Aug | 7 | 119 | 18 | 3 | 28 | 8 | 147 | 26 |
| Sep | 16 | 117 | 12 | 6 | 26 | 5 | 143 | 17 |
| Oct | 4 | 109 | 31 | 0 | 21 | 14 | 130 | 45 |
| Nov | 2 | 80 | 27 | 1 | 8 | 6 | 88 | 33 |
| Dec | 0 | 53 | 50 | 0 | 2 | 2 | 55 | 52 |
| Sum | 383 | 3 | 380 | 111 | 0 | 111 | 3 | 491 |

## *Rental Pools*

Besides IWRB's water bank, there are five state-managed rental pools in Idaho. They are the Snake River rental pool (Water District 1), Boise River rental pool (Water District 63), Payette River Rental Pool (Water District 65), Payette River Basin on Lake Creek (Water District 65) and Lemhi River rental pool (Water District 74). Rental pools are governed by various committees appointed by the Idaho Water Resource Board. The rental pools are generally for reservoir storage water with the exception of Lemhi River basin, which uses natural flow water.[33] Information on the water banking activities of these rental pools was not readily available at the time of this report. However, the authorities at IWRB informed the team that they would publish the annual report for these rental pools in late 2016.

31 Report for the Board's Water Supply Bank. 2014. Idaho Department of Water Resources Board

32 Report for the Board's Water Supply Bank. 2014. Idaho Department of Water Resources Board

33 Idaho Department of Water Resources Website - https://www.idwr.idaho.gov/water-supply-bank/overview.html

## 3.5 Montana

No state water banks are in operation in the state of Montana. However, a private company, Grass Valley French Ditch Company, which is one of the oldest and largest irrigation companies in Missoula County, has recently created a private water bank. There has not been enough trading activity to report through this private water bank.

## 3.6 Nevada

Water banking in Nevada is not as advanced as in the neighboring state of Arizona. However, the Southern Nevada Water Authority (SNWA), which is a non-profit water agency established in 1991 to manage southern Nevada's water resources, oversees various banking programs and agreements in the state. The SNWA is currently engaged in three different water banking projects that account for nearly six years' worth of Nevada's allocation of the Colorado River water. The Colorado River water is shared by seven different US states as well as Mexico. Under the Colorado River Compact, Nevada receives 300,000 acre-feet of Colorado River water per year from the lower basin of the river.

### *Agreements with Arizona and California Water Banks*

The SNWA is currently engaged in agreements with the Arizona Water Bank and the California Water Bank for storage of water for future use by Nevada. As per the agreement with the Arizona Water Bank, SNWA has about 600,000 acre-feet of water stored in Arizona's aquifers for future use. Storing water in Arizona's aquifers costs the SNWA about $200 per acre-foot.[34] The SNWA can use 40,000 acre-feet of water stored in any given year and up to 60,000 acre-feet of water during a declared shortage. If the SNWA needs to use this water, Arizona will use the specified amount of water stored in its aquifers and forgo using the same amount of water from the Colorado River. Such water flows into Nevada and the SNWA distributes this water via various facilities located at Lake Mead.

Similarly, the SNWA has entered various agreements in the last decade with the California Water Bank. These agreements facilitate the storage of unused water from the Colorado River in California for future use by Nevada. More than 205,000 acre-feet of water had been stored in California as per these agreements by 2014. Another 150,000 acre-feet was stored in 2015 resulting in a total storage of 355,000 acre-feet. California pays $30 per acre-foot to store water in their banks.[35] The agreement between California and Nevada allows California to pay Nevada and use the stored water during drought. However, Nevada can withdraw and return the funds to California and recover water from this storage if needed. Nevada is eligible to use 30,000 acre-feet of this water per year.[36]

### *Southern Nevada Water Bank*

Starting in 1987, the Las Vegas Valley Water District and the City of North Las Vegas, both SNWA agencies, began pumping water from the Colorado River into the valley's primary groundwater aquifer whenever water demand was lower than Nevada's allocation of Colorado River water. This arrangement constitutes the Southern Nevada Water Bank (SNWB). The SNWB has stored about 337,000 acre-feet of water for future use since its inception until 2014. The stored water can be recovered by the SNWA under any water supply conditions.[37]

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34 Personal communication with Mack Bronson, Southern Nevada Water Authority. December 15, 2015.
35 Personal communication with Mack Bronson, Southern Nevada Water Authority. December 15, 2015.
36 Southern Nevada Water Authority website - http://www.snwa.com/ws/future_banking.html.
37 Southern Nevada Water Authority website - http://www.snwa.com/ws/future_banking.html

## 3.7 New Mexico

There is no comprehensive water banking program operating in New Mexico at present. In New Mexico, "the State Engineer is statutorily charged with supervising the state's water resources through the measurement, appropriation, and distribution of all ground and surface water in New Mexico, including streams and rivers that cross state boundaries"[38]. The State engineer has not authorized any water banking programs. The Water Resource Allocation Program (WRAP) administers water rights throughout the state. During 2009-2010 and 2010-2011, 2,904 surface water and 87,046 groundwater documents pertaining to the appropriation and use of surface water and groundwater were processed. The office of the state engineer also keeps track of total water stored in various state reservoirs. Table 11 below shows the data on the surface water documents processed in New Mexico from 2009-2011. Although there are currently no water banking programs in New Mexico, this table provides the information about the surface water rights documents processed in the state. This information can be useful when considering the viability of a hypothetical water banking program or a new water market in the state. Figure 10 shows the total reservoir storage for New Mexico from 2001-2011. Reservoirs are essentially stored surface water. Therefore, even though there are no formal water banking programs in New Mexico, these reservoirs can be used as water banks.

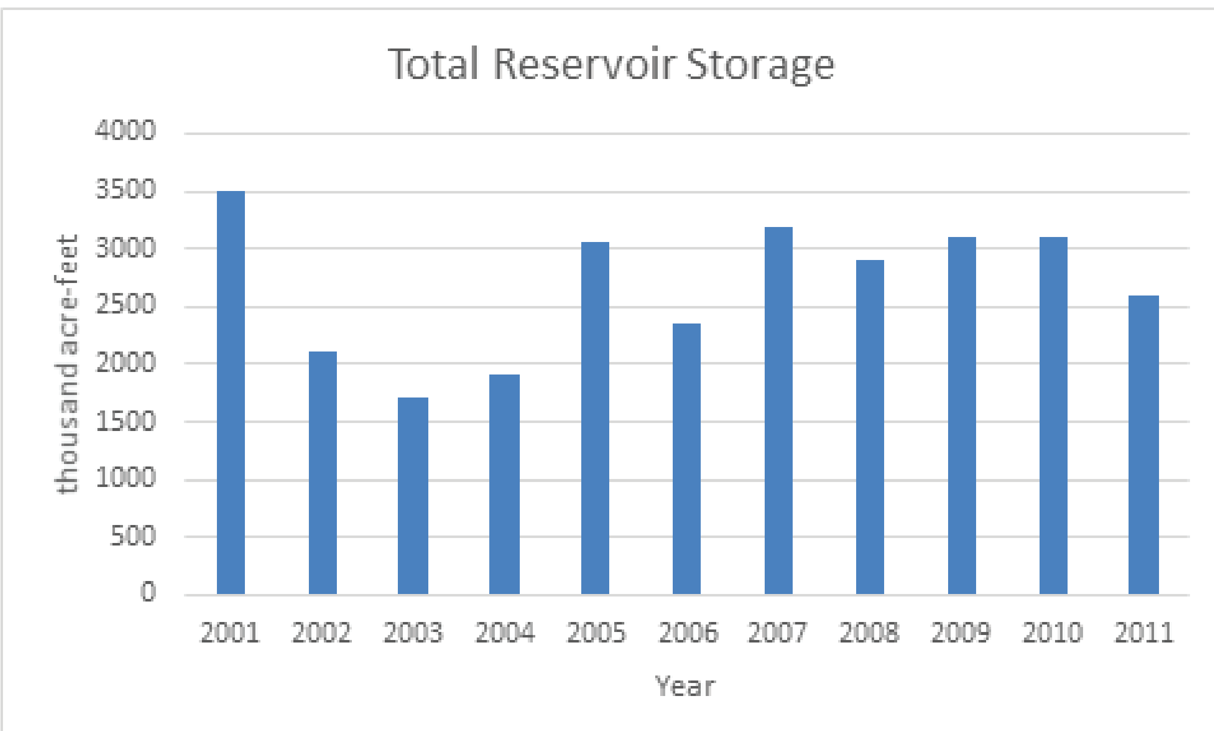


*Figure 13. Reservoir Storage in New Mexico (2001 – 2011)* [39]

38 Annual Report.2011. New Mexico Office of the State Engineer Interstate Stream Commission

39 Adapted from Annual Report.2011. New Mexico Office of the State Engineer Interstate Stream Commission

Table 11. Surface Water Documents Processed in NM (2009-2011)[40]

| | District | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Document Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | State Totals |
| Application for Extension of Time | - | 17 | 2 | 4 | 34 | 6 | - | 63 |
| Certificate of Construction | - | - | - | - | - | - | - | - |
| Change of Ownership | 63 | 75 | 61 | 13 | 124 | 471 | 11 | 818 |
| Change Point of Driver & Place/Pump of Use | 26 | 10 | 2 | 1 | 3 | 31 | 2 | 75 |
| Combine & Comingle | - | 1 | - | 1 | - | - | - | 2 |
| Declaration | 154 | 9 | 16 | 3 | - | 15 | 6 | 203 |
| Dedication of Retired Rights | - | 1 | - | - | - | - | - | 1 |
| Emergency Authorization | - | - | - | - | 1 | 2 | - | 3 |
| License to Appropriate or to Change Place and or/ Purpose of Use | - | - | - | - | - | - | - | - |
| Livestock impoundment Declarations | 2 | 2 | - | 8 | 1 | 1 | - | 13 |
| Livestock impoundment Permits | 3 | - | 1 | - | 28 | 28 | 1 | 35 |
| Meter Readings Processed thru WATERS | - | 14 | - | - | 27 | 27 | - | 41 |
| Miscellanous Surface Water Permits | - | 25 | - | 1 | 1 | 1 | - | 30 |
| Notice for Publication | 34 | - | 17 | 5 | 33 | 33 | 4 | 101 |
| Notice of Intent to Appropriate | 42 | - | - | - | - | - | - | 42 |
| Permit to Appropriate | - | 1 | - | 2 | 1 | 1 | - | 4 |
| Permit to hange Place and/or Purpose of Use | 2 | 6 | 4 | 1 | 6 | 6 | 2 | 27 |
| Permit to Change Point of Diversion | 3 | - | - | - | 8 | 8 | 1 | 12 |
| Permit to Change Point of Diversion from GW to Surface | 3 | 2 | - | - | 1 | 1 | - | 6 |
| Proof of Application of Water to Beneficial Use | 9 | 6 | 3 | - | 5 | 5 | 2 | 29 |
| Conservation Plan | - | 0 | 5 | - | - | - | - | 5 |
| Proof of Completion of Works | - | 0 | 6 | - | 3 | 3 | 1 | 13 |
| Supplemental | 1 | 9 | 6 | 1 | 1 | 1 | 1 | 19 |
| **Totals** | **342** | **178** | **123** | **40** | **188** | **640** | **31** | **1542** |

## 3.8 Oregon

### *Deschutes River Conservancy Mitigation Bank*

Deschutes Water Exchange Mitigation Bank was first established in 2003 after authorization from the Oregon Water Resources Commission (OWRC). In 2008, its name was changed to Deschutes River Conservancy Mitigation Bank. Anyone can apply to become a mitigation bank and successful applicants will be required to enter an agreement called the mitigation bank charter. In its first five years, this mitigation bank worked extensively with groundwater applicants, permit holders, irrigation districts, and landowners in the basin to lease water rights to instream use and generate mitigation credits. These mitigation credits were mostly temporary in nature ranging from one to five years. Participation in the bank has steadily increased, beginning with only one client in 2003 versus 33 clients in 2007.[41] Since 2007, the bank has shifted away from temporary mitigation credits generated by instream leases to now focus primarily on other permanent sources of mitigation. Since 2007, the bank has had an average of 30 clients each year.[42]

40 Annual Report.2011. New Mexico Office of the State Engineer Interstate Stream Commission
41 Deschutes Groundwater Mitigation Program: Five-Year Program Evaluation Report. 2008. Oregon Water Resources Department
42 Deschutes Groundwater Mitigation Program: Five-Year Program Evaluation Report. 2014. Oregon Water Resources Department

### *Trading activity in Oregon*

The following Figure 11 shows the number of mitigation transactions through the Deschutes River Conservancy (DRC) bank between 2008 and 2012. Figure 12 shows the annual volume of mitigated water generated through instream transfers and instream leases between 2003 and 2012.

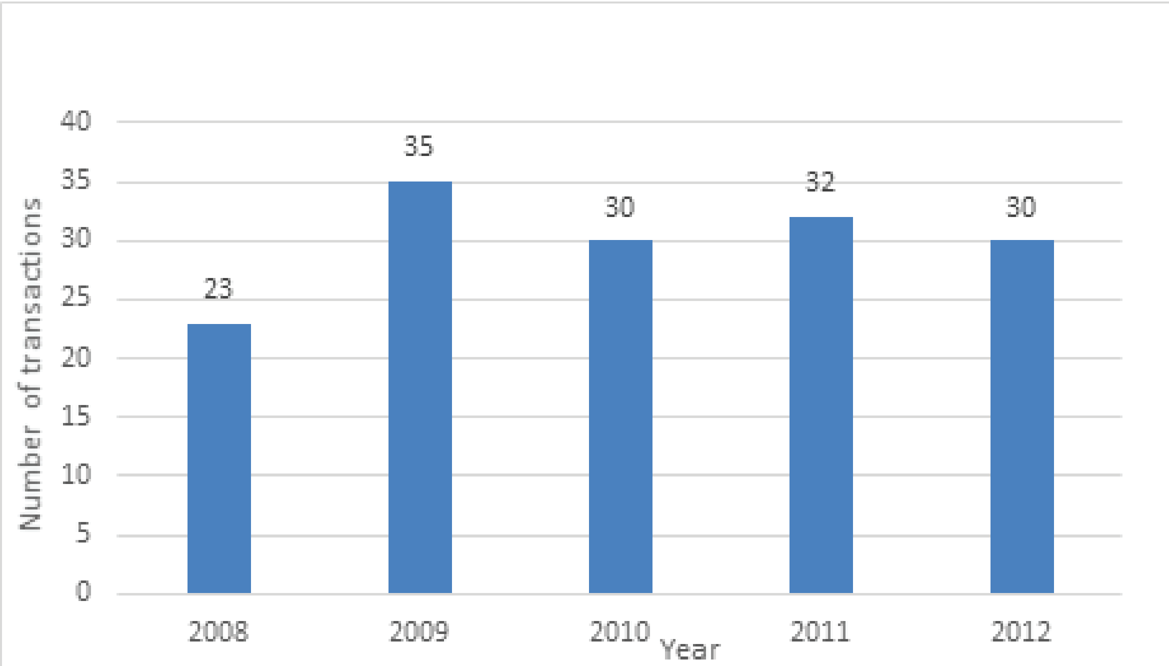


*Figure 14. Number of DRC Bank Mitigation Transactions by Year (2008-2012)[43]*


Figure 15. Annual Volume of Mitigation Water Generated through Instream Transfers and Instream Leases (2003-2012)[44]

43 Adapted from Deschutes Groundwater Mitigation Program: Five-Year Program Evaluation Report. 2014. Oregon Water Resources Department

44 Adapted from Deschutes Groundwater Mitigation Program: Five-Year Program Evaluation Report. 2014. Oregon Water Resources Department

Table 12 below comprises summary information on groundwater permits through the Deschutes Groundwater Mitigation Program for various regions by the end of 2012.

Table 12. Summary of Mitigated Groundwater Permits by Zone by the End of 2012[45]

| Zone of Impact | Number of Permits | Rate Approved by Permit | Maximum Volume(AF) Approved by Permit | Total Mitigation Obligation(AF) |
|---|---|---|---|---|
| General | 58 | 67.3 | 12746.4 | 6370.2 |
| Middle Deschutes | 8 | 0.92 | 221.5 | 129.8 |
| Crooked Riv-er | 10 | 14.8 | 5680.7 | 2385.5 |
| Whychus Creek | 11 | 4.4 | 1213.7 | 585.5 |
| Little Deschutes | 3 | 0.48 | 368.3 | 13.2 |
| Upper Deschutes | 5 | 0.29 | 76.8 | 46.1 |
| Totals | 95 | 88.2 | 20,307.40 | 9,530.30 |

## 3.9 Texas

### *Texas Water Bank*

The Texas Water Bank is governed by the Texas Water Development Board (TWDB). The Texas Water Bank was established in 1993 to facilitate the temporary or permanent transfer, sale, or lease of water and water rights throughout the state. The water bank maintains records of registry of water, water rights by potential buyers and sellers, and a listing of deposits. It also acts as a clearing-house for water marketing information and may facilitate price negotiations between potential buyers and sellers.

Any party interested in depositing their water rights for sale or lease can apply through the TWDB website. Surface water rights deposited in the bank are protected from cancellation while on deposit in the bank for an initial 10-year period and for an ensuing 10 years following the Texas Commission on Environmental Quality's approval relating to water rights transferred while on deposit in the bank. The TWDB may charge as much as 1% of the value of the water or water right received into the water bank to cover administrative expenses.[46] Sellers can also choose to simply post their water rights to the TWDB website without depositing their rights through the application process. Such water rights would not have associated administrative costs, but would also not be protected by the water bank rules.

### *Trading Activity in Texas*

The following tables, Table 13, Table 14 and Table 15, show the registry of deposits, buyers and sellers respectively through the Texas Water Bank.

45 Deschutes Groundwater Mitigation Program: Five-Year Program Evaluation Report. 2014. Oregon Water Resources Department
46 Texas Water Development Board website - http://www.twdb.texas.gov/waterplanning/waterbank/bank/index.asp

Table 13. Texas Water Bank: Registry of Deposits[47]

| Basin | River/ Stream | Quantity Available | Location | Comment | Posted |
|---|---|---|---|---|---|
| Colorado | Celery Creek | 27.93 acre-ft | Near the City of Menard | Lease | 5/1/00 |
| Colorado | Clear Creek thence San Saba | 41.47 acre-ft | Menard County, West of Menard | lease, at $50 per acre-ft per year | 7/16/02 |
| Colorado | Colorado River | 203 acre-ft | Mills County, North of Richland Springs | 5 year lease, at $50 per acre-ft per year | 8/21/01 |
| Colorado | San Saba River | 23 acre-ft | Menard County | Lease | 6/05/01 |
| Colorado | San Saba River | 15 acre-ft | Menard County | Lease | 3/30/04 |
| Colorado | San Saba River | 17 acre-ft | Menard County | lease, at $30 per acre-ft per year | 6/9/05 |
| Colorado | South Llano River | 145 acre-ft | Kimble County | Lease | 5/14/09 |
| Rio Grande | Rio Grande | 47 acre-ft | Zapata | Lease or Sale | 2/27/03 |

Table 14. Texas Water Bank: Registry of Buyers[48]

| Basin | Quantity Desired | Location | Comments |
|---|---|---|---|
| Canadian (Lake Meredith) | Seasonal (not provided) | Near the City of Canyon | Recreational facility |
| San Antonio (Medina River) | ~3000 acre-feet | Upstream of Lake Medina | Purchase or trade |

## *Texas Water Trust*

The Texas Water Trust is a program administered within the Texas Water Bank. However, it is designed specifically to acquire water rights through donations, sale or purchase for environmental purposes.

Any water right issued by the Texas Commission on Environmental Quality can be enlisted through the Texas Water Trust to preserve aquatic life and habitat. All deposits made to the trust are exempt from any fees from the TWDB. This can be done by following a simple procedure. One can contact a TWDB staff and interact with the Texas Parks and Wildlife Department to establish specific details of the trust contract for the water rights. Then the water right can be transferred to the trust after the approval from the Texas Commission on Environmental Quality.[49]

47 Texas Water Development Board website - http://www.twdb.texas.gov/waterplanning/waterbank/bank/index.asp
48 Texas Water Development Board website - http://www.twdb.texas.gov/waterplanning/waterbank/bank/index.asp
49 Texas Water Development Board website- http://www.twdb.texas.gov/waterplanning/waterbank/bank/index.asp

Table 15. Texas Water Bank: Registry of Sellers[50]

| Basin | Quantity Available | Location | Comments |
|---|---|---|---|
| Brazos - Mainstream | 2,440 acre-ft/yr | Waller County | Posted 2-28-09 |
| Brazos (on Slaton Draw trib - White River - Salt Fork) | 80 acre-ft/yr | Hale County, just upstream from Plainview | Posted 1-20-06 |
| Rio Grande | 743 acre-ft/yr | Presidio County | 1925 Priority Date - Sell or lease - Posted: 11-9-00 |
| Rio Grande (Groundwater) | 90 mgd (est.) | Val Verde County | Trinity-Edwards formation |
| Rio Grande (Groundwater) | 6 mgd (est.) | Val Verde County | Posted: 8-24-00 |
| Rio Grande (potable water) | 0.3 mgd (design desal facility) | Zapata County | Desalinized Groundwater |
| Colorado (South Llano River) | 25 acre-ft/yr | Kimble County, near Junction | Lease; 1893 priority date - Posted: 8-6-01 |
| Colorado (South Llano River) | 120 acre-ft/yr | Kimble County, near Junction | Lease; 1911 priority date - Posted: 8-6-01 |
| Colorado (San Saba River) | 100 acre-ft/yr | Menard County, west of Menard | Sell; 1904 priority date - Posted: 2-16-01 |
| Colorado | 140 acre-ft/yr | San Saba County | Lease - 1912 priority date |
| Colorado | 1000 acre-ft/yr | San Saba County | Certificate of Adjudication |
| Colorado (Kickapoo Creek within the Concho watershed - above Lake Ivy) | 63 acre-ft/yr | Concho County | Priority Date: 2-27-1956, Permited Use: Irrigation |
| Guadalupe River | 5 acre-ft/yr | Guadalupe County near Lake Dunlap | Lease, permitted for municipal or irrigation use - Posted: 03-29-2011 |
| Guadalupe River | 262.7 acre-ft/yr | Victoria County | Sell or lease; 1951 priority date - Posted: 10-14-02 |
| Guadalupe River | ~1500 acre-ft/yr | Near Victoria | Lease. Prefer Long-Term |
| San Antonio (Medina Watershed) | 27 acre-ft/yr | Bandera County | Elam Creek |
| San Antonio River | 284 acre-ft/yr | Goliad County | Lease for irrigation - Combine with 86 acre-feet right noted next |
| San Antonio River | 86 acre-ft/yr | Goliad County | Lease for irrigation - See above |
| San Antonio River (Elm Bayou) | 500 acre-ft/yr | Near Tivoli | Lease - Prefer Long-Term |
| Nueces | 720 acre-ft/yr | Uvalde County | Lease |
| Brazos (Brazos River) | 125 acre-ft/yr | Robertson County | Lease at $34.50 per acre-ft. Posted: 1-26-03 |
| Brazos | 1,300 acre-ft/yr | Milam County | Sell, Priority Date August 31, 1956 |
| Brazos (Little River) | 300 acre-ft/yr | Milam County | $45/af to lease; sale price negotiable: 1984 priority date |
| Rio Grande | 1500 acre-ft/yr | Hudspeth County | 800acft at 1924 priority, 700 ac-ft at 1909 priority; sale, posted 9/24/2013 |

50 Texas Water Development Board website http://www.twdb.texas.gov/waterplanning/waterbank/bank/index.asp

### *Trading Activity*

Table 16 shows all of the deposits made at the Texas Water Trust.

Table 16. Texas Water Trust: Deposits[51]

| River/Stream | Quantity | Term | Location | Date of Deposit | Comments |
|---|---|---|---|---|---|
| Rio Grande | 1236 Acre-ft | Perpetuity | Hudspeth Co. | 08/18/2003 | 2 Water Rights: (1) Certificate of Adjudication No. 23-914, (2) Permit No. 3041 |
| San Marcos Tributary to the Guadalupe River | 33,108 Acre-ft | Perpetuity | Hays Co. | 04/24/2006 | Certificate of Adjudication No. 18-3865D |

## 3.10 Utah

Although there are bills and statutes in the Utah State Legislature to allow for the creation of water banking programs in Utah, there are no formal water banks currently in operation. However, people from various regions within the state have voiced their concerns about the future availability of water and suggested water banking as a potential solution to the expected decline in water supply. [52]

## 3.11 Wyoming

There are no water baking programs in place in the State of Wyoming. Currently, there is no legislation under consideration to facilitate water banking activities.

# 4. Innovations in Water Allocation

Researchers, policy makers, water resource managers, and others have been working to develop efficient systems for water allocation. Efforts to create water banks, design new structures for water markets, establish mutually beneficial water rights contracts, and refine existing laws are ongoing. Many researchers have worked to understand which systems are suitable for particular regions based on local geography, types of water rights holders, climate and other characteristics of the region. These efforts or innovations in water research can be broadly categorized into the four types of market facilitation programs discussed below:

1. Water Banks
2. Smart Markets
3. Contractual Forms
4. Spot Markets

Following the discussion below of the types of ongoing market facilitation programs is a summary of the current state of water law initiatives to improve water allocation.

## Market Facilitation Programs

Market facilitation programs help to simplify the market by matching buyers and sellers interested in trading. Water banks and smart markets can be categorized as market facilitation programs. These programs focus on facilitating water markets by identifying interested buyers and sellers of water rights and creating a simple way for them to trade. Usually, the water rights holders are not entirely aware of the worth of their water rights. Individuals interested in buying or selling water rights often find it difficult to coordinate transactions on their own. Even if they can do so on their own, transactions take a long time and involve high transaction costs.

51 Texas Water Development Board website - http://www.twdb.texas.gov/waterplanning/waterbank/bank/index.asp

52 Utah's Water Future Developing a 50 -Year Water Strategy for Utah: Summary of Public Listening Sessions. Flint, 2013

### *Water Banks*

A water bank is an institutional mechanism designed to facilitate the voluntary trading of water on a temporary or a permanent basis.[53] Water banks can be used to sustain proper supply during droughts or dry years, store water for future use, promote water conservation and enforce laws regarding instream flows and others.[54] Water banks may also be used to match buyers and sellers, set prices, handle administrative water rights issues and ensure the validity of water rights.[55] The western United States has numerous water banks operating in various states. Water banks have also been successfully implemented in Australia.

Water banks can be set up in different ways. They can be set up as surface storage (reservoirs), as underground storage (aquifers) or as water trusts. Water banks vary in structure according to the needs and characteristics of the local community. Water banks in Southern California mostly serve the needs of the farmers. In contrast, Kittitas County Water Bank in Washington is established to provide mitigated water for domestic users after a legal case settlement between the County and the Department of Ecology. When water is physically stored in a reservoir, a surface water bank may be used to facilitate accounting and transactions over the use of the stored water over time and space. Such banking requires investment in infrastructure for moving the water to the reservoir and also for storing the water. With groundwater banking, the water that would have been pumped normally is left in the aquifer or surface water is directly added to the aquifer for future use. Often times, the laws governing groundwater are often less robust or well developed than those for surface water in western United States. For example, the water code in California does not apply to most groundwater in the state. Therefore, groundwater banking in California is dependent upon the local ordinances. The state only provides basic guidelines when it comes to groundwater banking. As a result, groundwater banking may be difficult to manage in western United States since a formalized management regime is often lacking. Finally, water trusts or institutional water banking only involve the transfer of water rights instead of physical storage of water for a certain period. Physical storage is not a defined component of institutional banking and hence the supply of water may not be very secure.[56] Institutional water banks only deal with the transfer of water rights or legal documents that entitle someone to access a specific amount of water from a specific place at a specific time.

An example of a water bank in the western United States is the Arizona Water Bank, which is set up as groundwater storage and is run by the AWBA. The AWBA cannot create or own any storage facilities or recover the water on its own. AWBA also does not act as an institutional bank to match the buyers and sellers. It is only concerned with the physical storage of water. The Colorado's Arkansas River Basin water bank is an example if a water bank that is not concerned with storage. See Section 3.3 for further discussion of Colorado's water bank.

### *Smart Markets*

Smart markets for water are usually auction-based markets that are run with the assistance of computer models that can manage the complexities of the given water market.[57] Such markets usually have a central hub or a website where buyers and sellers can trade without having to find trading partners on their own. Such markets can also incorporate various environmental and administrative constraints, such as restrictions on withdrawal of water that negatively affects some aspect of environment, and legal constraints that arise between two parties for transfer of water rights. These markets may reduce the transaction costs and make trading simpler by matching interested buyers and sellers more efficiently.

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53 Water Banks: A Tool for Enhancing Water Supply Reliability.2010. Colby and O'Donnell.

54 Analysis of Water Banks in the Western States. 2004. Washington State Department of Ecology and WestWater Research

55 Northwest Water Banking: Meeting instream and out of stream water needs in the Pacific Northwest. 2012. Cronin and Fowler

56 Water Banks: A Tool for Enhancing Water Supply Reliability.2010. Colby and O'Donnell

57 A Smart Market for Groundwater using the Eigenmodel Approach. 2007. Plagmann and Raffensperger.

## NEW ZEALAND

Researchers from the University of Canterbury in New Zealand have developed a smart market for groundwater rights based on analytical hydrology and a linear program. They use a hydrology simulation model to predict the behavior of a given aquifer and then use a program to maximize the economic value of pumped water subject to constraints on flows in the lowland streams. The objective of the program is to maximize the value of water instream flow constraints. A smart market like this eliminates the need to manually match buyers and sellers and carefully examines all the transactions simultaneously to ensure that all the regulatory constraints are satisfied. The smart market makes the price data immediately available and updates it temporally and spatially.

## NEBRASKA

The Mammoth Trading (https://mammothtrading.com/) algorithm is designed to match interested buyers and sellers of groundwater rights in the Twin Platte Natural Resources District. The algorithm is designed to reduce the complexity of local physical and regulatory systems and make trading groundwater rights easier. Mammoth Trading is currently developing a certified irrigated acreage market for groundwater rights in Nebraska. This is a computer-based market system that facilitates the purchase and sale of water rights. In this system, the transaction fee and benefits from trading are split evenly between the buyer and the seller, which is different from a typical brokerage.[58] This system could potentially be expanded in size to national or international levels and expanded in scope to serve broader markets such as surface water, wetland mitigation, storm water management, etc.

## NEW MEXICO

In New Mexico, a team of researchers developed a market structure based on a hydrological and economic model that evaluates if water leasing or a short-term reallocation of water rights is feasible in a river basin. The project aims to foster a flexible system during times of drought and reduce the traditionally long processing time for permanent transfers. A hydrological model is used to model the Rio Grande River between Cohiti and Elephant Butte Reservoirs in New Mexico. This model is then used in conjunction with an economic market model to facilitate water leasing if deemed feasible. The model can determine if water is actually available for potential trade and how much of it can be traded. It allows the buyers and sellers to voluntarily make offers and reach an agreement that helps to determine the price for water for the market.[59]

## TEXAS

Other smart water markets include Texas Water Exchange based in San Antonio, Texas that helps to match buyers and sellers of water rights efficiently. Texas Water Exchange helps the water users with buying, selling, and leasing of their water rights and acts as a consulting firm as well for the buyers and sellers. They claim to have numerous analytics packages geared to best serve the interest of their clients and large collection of water related data. They also provide hedging and mitigation services. Private companies like this can reduce transaction costs and allow the water markets to work efficiently.

### *Contractual Forms of Water Reallocation*

Water sales and leases can be carried out as a one-time transaction (e.g. a transfer of water use from a seller to a buyer for one growing season), for a mutually agreeable price. More complicated lease contracts allow for planning and better address the complexities and uncertainties of water use over time. Option contracts and spot markets are two common types of contractual forms in the water market.

58 Selling and buying water rights. National Science Foundation website - http://www.nsf.gov/mobile/discoveries/disc_summ.jsp?cntn_id=133173&org=NSF

59 Creating Real Time Water Leasing Market Institutions: An Integrated Economic and Hydrological Methodology. 2010. Broadbent, Brookshire, Coursey, and Tidwell.

## SPOT MARKETS

Spot markets are usually a one-time transaction between the buyer and the seller. A spot market is essentially the leasing of water rights for a temporary period. They are used especially in emergency situations such as drought or a dry year. The price of water rights in spot markets reflects the existing situation at the time of the transaction. In other words, price during a drought may be higher than during a time when water is available in abundance. Therefore, the buyers usually bear most of the risk associated with such transactions during droughts. The spot market also provides the benefits offered by option contracts. The water rights holders with excess supply of water can sell the surplus water easily without permanent transfer of water rights. Hence, the water can reach the user with the highest willingness to pay. Spot markets are usually even faster to work out than option contracts, and as a result involve even lower transaction costs. Since the ownership stays with the seller after the transaction, it provides the seller with a sense of security, especially in regions where rainfall and water levels can fluctuate.

An active spot market for water is in operation in Texas along the Rio Grande River. The Rio Grande Watermaster (RGW) office is charged with monitoring water use and enforcing water rights in the region. They are required to keep water balances for each individual water right owner. There are more than 800 water rights holders in the region with the rights distributed between farmers, municipalities, industries and individuals.[60] Therefore, it is a relatively broad and extensive market. The price in the spot market is determined by negotiations between the buyer and the seller and reflects the changing demand and supply of water. The RGW office behaves like a broker or a mediator to bring the buyers and sellers together. In other words, it acts like a smart market without charging any fee for the service. [61] The RGW office actively enforces the water rights and monitors the activities along the river to make sure that there is no breach of rules such as illegal pumping of water. This is important, as there is no incentive to buy water through a market mechanism if the rules are not strictly enforced.

## OPTIONS CONTRACTS

Option contracts are contracts that are contingent upon a specific set of circumstances. They may be contingent on circumstances including drought, increased demand etc. and are designed for temporary transfer of water rights. There is usually a fee associated with the activation of the contract.

Water rights sellers usually need to evaluate the value of their water rights given current and future demands. This is not always easy, especially in cases when the transfer of water rights is permanent. Sellers have to risk selling their rights at a lower price than their worth if they cannot realize the true value of their water rights. Such risks and uncertainties lead to significant transaction costs. Option contracts can help mitigate risks and uncertainties as they provide temporary access to buyers without compromising the ownership of the seller. The value of a water resource for a temporary period is much easier to estimate. Moreover, the time required to work out a permanent transfer is often long and complex.[62] Even after the buyers and sellers reach an agreement, it needs to be approved by a governing body. This adds more legislative and administrative costs to the process. All of these drawbacks can be mitigated by the use of option contracts in the water market.

60 Spot Market for Water along the Texas Rio Grande: Opportunities for Water Management. 1999. Yoskowitz

61 Spot Market for Water along the Texas Rio Grande: Opportunities for Water Management. 1999. Yoskowitz

62 Option contracting in the California water market. 2009. Tomkins and Weber.

Option contracting has been in practice in California for more than a decade now. The Metropolitan Water District (MWD) of southern California introduced option contracting by signing option contracts for water rights in 2003 with the Sacramento Valley agricultural water districts. The contract provided MWD with the access, but not the obligation, to purchase 146,230 acre-feet of water months into the future. They signed this contract following a two-year dry period as the water storage levels were decreasing. They opted to sign another option contract in 2005 following a dry year. However, the 2005 options were not called as spring rain improved the water storage situation that year.[63] Therefore, option contracts can be flexible in terms of implementation. These contracts were effective when there was increasing pressure on the state water supply. Research suggests that gains in joint payoffs for both buyers and sellers increased by 70–85% after these contracts were signed.[64] Working out a permanent transfer instead of option contracts would have taken considerably longer and the transaction costs would have been great. Option contracts avoid these inconveniences while allowing interested parties to realize the benefits of their trade faster.

# 5. Washington Water Banking Barriers and Improvements

This section summarizes water banking barriers and improvements identified through stakeholder surveys. This section includes the research team's outreach approach, survey questions, and responses. We also provide a summary of the cost of water banking to Washington State, and a summary of regulatory, funding, and operational barriers identified through our outreach efforts.

## 5.1 Outreach Approach and Survey

In order to identify issues, obstacles and opportunities for improvements to water banking in Washington, the team surveyed 12 water bank managers and stakeholders[65] . Surveys were generally conducted over the phone, with survey questions emailed to interviewees beforehand. All interviewees were informed prior to the interview that names would not be attributed to responses and responses would be aggregated across multiple survey respondents. This level of anonymity was provided so respondents would feel comfortable providing their opinions. Water bank managers were asked to answer questions about specific bank operation practices, and questions about their working relationship with Ecology. Water bank managers provided a variety of responses to the survey, including concerns over metering requirements and out-of-WRIA transfers. Several common themes emerged in survey responses. Barriers to effective water market functioning identified during the surveys are discussed below and in the Alternative Models and Recommendations section. Below is a list of the interview questions that were asked of water banking managers:

### *Banker-Centric Questions*

- What are your most significant categories of expenses (e.g., water purchase costs, labor/time, legal fees)?
- What is your schedule of charges (e.g., application fees, contracting, title fees, closing fee, deed, covenants, per acre-foot fees)?
- What factors led you to structure your schedule of charges as you have (i.e. transaction-based charges to cover transaction-specific costs, per acre-foot charges to cover per acre-foot costs, etc.; comparable sales, percent return on investment, buyer willingness to pay, etc.)?
- How do you accommodate varying degrees of certainty within each suitability zone? Do you pass uncertainties on to the buyer (i.e., contingency fee, retainer, higher up-front cost, etc.)?
- Have clients requested services/options that you do not currently provide? Are you considering such

63 Option Contracts in Practice: Contractual and Institutional Design for California Water Transfers. 2008. Tomkins, Weber, Freyberg, Sweeney, and Thompson.
64 Option Contracts in Practice: Contractual and Institutional Design for California Water Transfers. 2008. Tomkins, Weber, Freyberg, Sweeney, and Thompson.
65 Note that more interviews with water bank managers and stakeholders were attempted than were actually interviewed. In particular, the response rate amongst private water bank managers was lower than desired from the original outreach.

services? Why or why not (i.e., outdoor irrigation greater than 2,500 sq ft, no outdoor irrigation, indoor use greater than 350 gpd, stock watering, etc.)?

- What are the most important services that your water bank provides that were not available without the bank (e.g., outreach, information for the public, certainty of legal water availability, permanent and guaranteed solutions, and economic growth)?
- What services and activities do you offer that provide information, time savings, and reduce the administrative burden to your clients?
- For potential clients who inquire about water purchases from your bank but do not ultimately purchase water, what seem to be the most important reasons for non-purchase?
- What is the primary driver for a customer to participate in a water bank?
- If you were to change some things about water banking, what would you change?
- What are the most important difficulties and concerns that your clients voice when purchasing or considering water from your bank? How have you tried to address these? If you have been unsuccessful, what needs to change for these concerns and difficulties to be overcome?

### *Ecology-Centric Questions*

- We understand that you hold an agreement with Ecology to operate your water bank, or otherwise conduct business with Ecology. Is our understanding correct?
- Did you visit Ecology's websites about water banking? Before or after starting to negotiate with Ecology?
- Did you review any examples of trust water right agreements before negotiating with Ecology?
- Was the water right transfer to instream flows to establish the water bank accomplished through Ecology or through a conservancy board?
- Did you talk about your water right with Washington Water Trust or Trout Unlimited at any point?
- Did you work with an attorney or water consultant? From the beginning of the process? If not, at what point in the process?
- If so, does your attorney or consultant have experience working with Ecology?
- Did you or your attorney draft the trust water right agreement based on an example or template?
- Whom did you work with from Ecology?
- Did you consistently work with the same person at Ecology?
- Did you get a consistent message from Ecology about how the process of establishing a water bank would go? If not, what part of the experience deviated most from the message?
- Please provide recommendations for how Ecology could improve its working relationship with your bank and streamlining its activities in relation to water banking.
- Describe any legislation you feel provides an unnecessary or unwarranted barrier or cost to your banking activities.

- Describe any legislation that would facilitate water markets and/or your water bank activities.

For water bank stakeholders, the research team interviewed individuals who are professionally affected by water banking, including lenders, well drillers, and developers. Below is the list of questions we asked bank stakeholders:

- What is your business's region or service area?
- In what capacity do you work with water banks, and/or Ecology on groundwater management, if at all?
- Do you perceive any groundwater-related regulatory or legal risks to your business activities in your region or service area? If so, please describe these risks and any steps you have taken evaluate and/or mitigate those risks?
- Have you attended any Ecology public meetings, or workshops in your service area or region? If so, how effective was Ecology at communicating to the public? How would you recommend they communicate with the public next time?
- Do you feel Ecology has developed effective regulatory, legal, and management solutions to any groundwater issues you face? Please provide any recommendations you may have for Ecology to improve its regulatory and administrative process from your perspective.
- Anything else you would like to share?

## 5.2 Surveys of Water Bank Managers and Stakeholders

### *Water Bank Managers*

Water bank managers provided a variety of opinions to the above listed questions. Several common themes emerged from the survey. These themes included details about the cost of water banking, how price structure for banks is developed and benefits of water banking. Additionally, survey respondents provided insight into public concerns regarding water banking and barriers to water bank development. Table 17 illustrates key themes and concepts that emerged from the survey.

The majority of bank managers structured the price of mitigation credits around cost recovery, although affordability is a consideration for public banks and market value is a consideration for private banks. Most of the banks also strive to be responsive to demand for new services, although some in basins with multiple banks look to serve a niche and others are unsure if flexibility to provide new services would be in violation of their Trust Water Right Agreements. All those surveyed believe their banks are providing important benefits and solutions to water resource challenges. Benefits named included providing legally certain water supplies, economic development, technical assistance and education, and streamflow/ecological benefit.

The water bank managers also noted several concerns they hear from the general public. Many reported concerns over price of water and one indicated public concern regarding funds spent on bank development. Several interviewees indicated that people are skeptical about the science behind groundwater/surface water connection, regulatory rules, and basin closures. Additionally, public concern about regulatory overreach was cited by most. Metering requirements and data collection are also concerns for those interested in participating in water banks. Additional concerns included confusion over the process and the time to receive a permit or mitigation certificate. Most bank managers discussed outreach and education strategies they have employed to ease public concern.

Table 17. Summary of Water Bank Manager Survey

| Survey Themes | Responses |
|---|---|
| Significant Costs | Labor/Time; Legal Fees; Cost of Water |
| Reasons for Specific Cost Structures of Banks | Bank Model; Affordability; Cost Recovery; Market Value |
| Methods of Assessing Uncertainty | Limiting work to "likely suitable" zones; Conditional on Ecology Approval |
| Approaches to Address Market Demand for New Services | consider Providing New Services; Do Not Consider Providing New Services |
| Benefits Provided by Banks | Legally available water; Affordability; Streamlined process; Permit coordination; Economic Growth; Education; Streamflow benefits |
| Reasons for Customer Participation | Required; Legal certainty of water supply |
| Reasons for Customer Non-Participation | Cost; Limitations; Time; Risk; Process |
| Concerns Voiced by Clients/Public | Price; Cost recovery; Metering requirements; Regulatory over-reach; Confusing process; Time |
| Issues that Survey Respondents Would Change About Water Banking | Better metering technology; More agency coordination; Comprehensive groundwater modeling; General permits; Increased funding; Decreased costs; Priority dates of new rights; General Permits; Streamlined process |
| Areas in Which Ecology Could Be More Helpful | Consistent policy on mitigation requirements; More evaluation and follow-up after bank launch; More staff/faster processing; Better communication; General Permits |
| Legislative Barriers that Exist | No legislative barriers, but case law barriers |
| Ways in which the Legislature Could Improve Water Banking? | Defining impairment; Address challenges created in case law; Funding for Groundwater Modeling; Regulate out-of-WRIA transfers; Financial support |

When asked questions related to improving water banking, responses ranged from improving metering technology to legislative fixes for problematic case law. One recommendation when asked, "What would you change about water banking," was improved groundwater modeling to better understand spatially and temporally appropriate mitigation. Other recommendations included improving coordination between Ecology, the Department of Health, and local government, finding ways to reduce costs, increase funding for bank development, and provide a more streamlined approach and reduced processing time to issue mitigated permits, including the use of general permits.

While all bank managers reported having a positive working relationship with Ecology, and found Ecology's support helpful, most had recommendations on how Ecology could better serve bank managers. It was noted that Ecology does not currently have a consistent policy on what appropriate mitigation is, and that it varies by basin[66]. However, it was also recommended that Ecology maintain flexibility in water banking approaches in different basins. Water bank managers recommend that Ecology do more evaluation and follow-up after a bank launches to provide guidance on how to improve banks and also share lessons learned for future banks. One bank manager stated that there were surprises during the development of their bank, and that Ecology needs to communicate potential issues and have solutions that fit within contractual obligations for bank managers. Most bank managers recommended more staff at Ecology, so that water banks can be developed and permitted more quickly. Additional recommendations relate to speeding up the process of getting a mitigated permit, such as using more general permits or privatizing those portions of the process.

When asked, "What could the legislature do to improve water banking?", a common answer was for the legislature to address challenges created through case law. Specific rulings that were mentioned include the one molecule standard that arose from Postema, OCPI limitations from Swinomish and Foster, and permit requirements from Campbell and Gwinn. These cases and their implications for water banking are discussed in Section 5.4 and Section 2.2 of this report. It was recommended that the legislature define when and how

66 Ecology Policy 2035 provides guidance on water right mitigation.

Ecology can use OCPI. Additionally, respondents recommended the legislature define impairment, limit out-of-WRIA transfers, and provide more financial support for bank development.

### *Water Bank Stakeholders*

All stakeholders surveyed were directly impacted by the Upper Kittitas County Rule. As lenders, well drillers, and developers, their businesses depend directly on access to water and legal certainty. When asked what risks exist for their business, stakeholders expressed concerns regarding the cost of water from private banks and "red zones", which are areas in Kittitas County that do not have suitable mitigation. There were also responses related to concerns about decreased property values and impacts to the local economy. To address the perceived risk of groundwater regulation, one interviewee established a water bank.

All the stakeholders interviewed have previously attended Ecology's public meetings. When asked how effective Ecology was at communicating at public meetings, some stated that they felt Ecology did not listen to or address public comments. One interviewee stated that Ecology was not effective at communicating because water law and hydrology are complex issues, and agency staff were trying to explain them in an emotionally charged environment. This interviewee recommended working closer with local government and developing a comprehensive communication strategy that includes publishing information in local newspapers and agricultural and real estate trade journals.

All stakeholder interviewees agreed that Ecology has not yet developed an effective management solution, but for different reasons. One individual stated that Ecology needs to develop alternative access to water before issuing moratoriums. Additionally, it was suggested that the state should work with counties to develop public banks, because private banks price many out of the market. Another recommended slowly implementing closures and grandfathering people in and/or buying people out. It was also noted that water is still not available in much of Kittitas County. Another issue cited with the current management strategy is that the process to obtain a WBN determination is long, cumbersome, and legally complex. It was recommended that Ecology receive additional resources and staff to assist in water banking. Stakeholders expressed that and that the WBN process needs a legislative fix to allow easier and faster processing. Other concerns raised by bank stakeholders included out-of-WRIA transfers, perceived shortcomings in intergovernmental cooperation, and the need to ensure that Ecology staff are properly trained and have sufficient oversight to ensure consistent messaging.

## 5.3 Costs to Washington State

Establishing a water bank requires public investment, whether it is a public water bank or private water bank. Ecology may incur costs as a regulator, funder, incentivizer, banker, and auditor. Depending on the specific bank business rules, some of these costs can be recovered through program operation. This has been especially true with funding water purchases, where the cost of the water purchased is generally recouped through the sale of mitigation credits. However, one cost to the state that has not been recouped by any bank is the cost of staff time for state employees. Generally, Ecology works closely with bank developers to help with formation, permitting, and oversight. This organizational structure creates a large workload and cost burden to Ecology.

### *Hours Spent on Bank Development (per bank)*

Based on discussions with Ecology staff, the research team estimates that between 72 and 90 hours are spent developing a water bank. This development time includes working with an applicant to approve a concept, negotiating and drafting a trust water agreement, transferring the water right to the TWRP, consultation with stakeholders, developing suitability maps, transferring ownership, setting up a database record to track the bank, and posting to Ecology's website. This does not include the time spent initially to develop a water banking database, which required a large amount of staff time over a two-year period. Additionally, this estimate does not include the amount of time required to train staff on the topic of water banking and the details of each individual water bank, or the amount of staff time spent on customer service and responding to questions about water banking.

### *Bank Tracking and Issuing Mitigated Permits (per bank)*

As part of the agency's role providing regulatory oversight, Ecology sets up a mitigation portfolio in their water banking database to track each water bank. Ecology staff track the amount of mitigation water available in each bank, and the amount of water taken out of each bank. Ecology staff estimate that they spend 2-4 hours setting up mitigation portfolios for each water right used for water banking. Staff also spend approximately 30 minutes per transaction tracking water that comes out of water banks.

In addition to tracking the amount of water in each water bank, Ecology is responsible for issuing mitigated permits and WBN determinations. A WBN determination is an approval for the use of mitigation for permit-exempt uses. Based on information provided by Ecology, there is one full-time employee (FTE) who spends all of their time issuing mitigated permits and WBNs. Ecology has 1.2 FTEs who do hydrological work to support permitting and WBN decisions resulting from water banks, and a 0.5 FTE who supports this work, conducts stakeholder consultation, and provides management, review, and oversight. There are additional time expenditures related to customer service, and supervisory input, which we estimate increases the amount of staff-time spent on water banking by 25% to 50%.

An internal review from 2011 found that between June of 2010 and May of 2011, approximately 4 FTEs worked on water banking actives in Upper Kittitas County alone. This survey only includes permitting staff, not administrative and management time. Only 1.7 FTEs were allocated in rule implementation for Upper Kittitas County Water Banking.

## 5.4 Summary of Barriers to Water Banking Identified in Surveys

### *Regulatory*

The water bank surveys revealed several perceived regulatory barriers to water banking. Most of the barriers were identified as case law:

- *Postema v. Pollution Control Hearings Board*. This decision defined the "one molecule" standard for instream flow impairment. This makes it very difficult to find spatially and temporally appropriate mitigation.
- *Swinomish Indian Tribal Community v. Ecology and Foster v. Ecology*. These decisions have brought into question how Ecology has used OCPI in water right permitted decisions. These decisions bring uncertainty over the security of reserves and permitting decisions that depend on OCPI. The Foster decision also makes finding suitable mitigation difficult because of in-kind mitigation requirements and "shoulder season" impacts.
- *Ecology v. Campbell and Gwinn*. This decision specifies when permit-exempt[67] wells are appropriate for development and when a water right permit is required. Some interviewees stated that the permit requirement from Campbell and Gwinn made it more difficult to provide mitigation water to domestic uses because mitigated water right permits require an impairment analysis.

### *Funding*

Funding was another commonly cited barrier to effective water banking systems. The cost of forming, permitting, and managing a water bank can be very large. Water right valuations on the order of $1,500 to $6,500 per acre-foot of consumptive use are common, along with permitting costs on the order of $10,000 to $50,000, and further bank administration costs (marketing, processing, fee collection, escrow, etc.). While some banks have received funding from the state to help develop and seed a bank, others have been ineligible to receive state funding. Some water banks have been able to facilitate their formation by selling a portion of their water rights for instream flow enhancement. The cost of bank formation and limited funding from the State both impede bank development and create high costs for bank participation.

67 A permit-exempt well is a well that meets that stator exemption for a permit under RCW 90.44.050

### *Operational Barriers*

The two main operational barriers to water banking cited by interviewees were lack of public buy-in and lack of comprehensive groundwater modeling and studies. Many bank managers have conducted educational outreach to address public buy-in. Groundwater modeling is a more difficult and expensive operational barrier to overcome for water banking. Without groundwater modeling and studies, it is difficult for bank managers to determine appropriate mitigation strategies and there is uncertainty around availability and ESA impacts.

# *6. Alternative Models and Recommendations*

Following the evaluation of water banking in Washington and a review of water banking models from western states and other parts of the world, this section provides recommendations on improving the water banking environment in Washington. These recommendations are based on survey results, evaluations, and review of water banking in other states.

## 6.1 Metering Issues

Concerns over metering requirements were raised during surveys conducted with water bank managers and stakeholders. Currently, all water use must be metered, regardless of withdrawal size or permit-exempt status. Metering has been a requirement dating back to the origins of the water code in 1917 (RCW 90.03.360).

There are several reasons for the current metering protocols, including a 1999 Settlement Agreement that requires that 80% of all water use by volume be metered, reported, and tracked by Ecology. Although Ecology is in compliance with the 80% volumetric requirement, Ecology staff has an extensive amount of metering data to review and process, creating constraints on staff time and limitations to the usefulness of the data. Ecology achieved its initial compliance largely through metering of the largest water users in each of the fish-critical basins. However, maintaining compliance becomes increasingly challenging as many new small uses are added.

Additionally, this metering standard raises the cost to participate in water banking. Beyond simply increasing the number of Ecology staff to meet the current metering requirement, there are several policy and legislative changes that could improve efficiency:

- **Change Metering Requirements to No Metering for Permit-exempt Uses.** Indoor domestic use would be assigned a conservative permitting assumption (e.g., 350 gpd). Aerial photos and lawn evapotranspiration estimates would be used to verify outdoor use.

- **Change Metering Requirements to Outdoor Use Only.** Indoor uses would be assigned a conservative permitting assumption (e.g., 350 gpd), but outdoor uses would be required to be metered because they are much larger and have a significant consumptive use fraction.

- **Privatize Metering Data Reviews.** The Legislature could privatize metering data reviews and water bank audits to reduce the burden on Ecology. This would be similar to the business models adopted by the Legislature for Certified Water Right Examinations (CWRE) and Cost-Reimbursement processing.

## 6.2 Cost and Oversight for CWRE Reviews

A certified water rights exam (CWRE) is a privatized certification process for water rights. Bringing small permits through the CWRE process is expensive and requires a great deal of paperwork. For large permits, CWRE costs are relatively small in comparison to the overall water cost, and value of the water right. However, for small domestic uses, CWRE costs are high with respect to permitting/water right values. In addition to keeping the current requirement, one potential policy choice for improving the CWRE process to consider includes:

- **Waive CWRE requirement for small uses or streamline CWRE process.** Ecology reserves authority under the CWRE rule[68] to waive the CWRE requirement for small uses, or allow for a streamlined CWRE process that might include a one-page form and a photo of a water meter and outdoor use.

## 6.3 Permitted Domestic Users

The water banking survey identified the lack of process parity between permit-exempt and permitted uses for established water banks. Permit-exempt uses can typically receive mitigation certificates under water banks faster and at a lower cost than permitted uses. Since the bank's job is to fully offset impacts, regardless of whether they are permitted or exempt, a case can be made for streamlining permitting requirements similar to those required for permit-exempt uses. In addition to keeping the current requirement, there is one option for improving parity between permit-exempt and permitted uses to consider:

- **Change Legislation**: Ecology could request a legislative change or adopt rules to streamline mitigated domestic permits similar to the process employed for permit-exempt uses. For example, RCW 90.03.290 could be modified to eliminate the 4-part test for fully mitigated uses under a water bank established by a TWRA. Alternatively, Ecology could create a rule under RCW 90.42 that provides this same parity.

## 6.4 Out-of-WRIA Transfers

Out-of-WRIA transfers are a concern for both water bank managers and stakeholders. Although no specific constraints exist on transfers other than impairment, in practice, transfer mechanisms are predominately downstream. Once water rights are permanently transferred, it is challenging to transfer them back, because of perceived instream flow impacts of a secondary transfer (perhaps 5 years later) with no credit given to original transfer. This system creates pressure for downstream marketing, which will eventually limit the pool of available rights for transfer and cause inflationary pressures on market pricing. Adverse economic impacts will be felt in upstream counties, but the current system creates instream flow reach benefits.

This is a concern that has been raised to the Legislature before. In 2008, a legislative report was prepared over concerns regarding transfers out of northern counties and the resulting economic impacts[69]. In addition to keeping the current process, there are several legislative and policy options that could be used to address out-of-WRIA transfers:

- **Change legislation.** Legislation could be passed to prevent out of WRIA transfers that change the purpose of use to mitigation (similar to Family Farm Act (RCW 90.66.065(5)) and Office of the Columbia River out of WRIA transfer limitations (RCW 90.90.010(2)(a)) out of WRIA transfer limitations).

- **Adopt Public Interest Rules.** Ecology could adopt rules for a public interest test on water right transfers that would include environmental, tax, and job benefits/impacts. Ecology rules could provide greater clarity on detrimental impact to the public interest.

- **Change SEPA Requirements.** SEPA changes could require consideration of socio-economic impacts and mitigation options related to water right transfers to affected counties.

- **Incentivize Local Banks with Local Water Supply Mandate.** The Legislature could require counties consulted on local bank formation policies. RCW 90.03.380(9)(a) requires electronic notice to the board of county commissioners in the county of origin, but does not specifically require consultation. Alternatively, the Legislature could incentivize banks operated by local entities such as counties and public utility districts by providing:

    - First right of refusal to buy any out-of-WRIA transfer.

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68 WAC 173-165-120 states: "Ecology may waive the requirement to secure the services of a certified water right examiner if ecology has conducted the proof examination or determines that one is not necessary to issue a certificate of water right".

69 Protecting Local Economies (2008), http://www.ecy.wa.gov/programs/wr/wrac/images/pdf/wa_local_econ_web.pdf.

- Cost subsidy for local government banks with resource protection policies to give these kinds of banks a competitive advantage.

- **Allow for Upstream Transfers / Mitigation Credits.** Ecology could adopt rules or policies to allow for upstream transfers based on equivalent downstream transfers. This would require a database tracking the upstream and downstream movement of water right changes to ensure no net change in water supply to the environment or senior water users. For example, if a 1 cfs water right is transferred from River Mile 25 on the Okanogan River to River Mile 100 on the Columbia River, then that 1 cfs credit would be available to offset an equivalent upstream transfer in that same reach.

## 6.5 Cost of Water Banking to the State

Even for private water banks, there are substantial costs to the State for bank formation, permitting, and oversight. Each new bank that is formed creates a new unfunded obligation for Ecology. Currently, Ecology is struggling to meet demand for new bank formation because of obligations related to existing banks, and other Ecology business functions. Fees could be used to help cover bank formation or operational costs, or incentivize certain bank attributes that reduce Ecology staff impacts. In addition to keeping the current economic model, we have identified three options that could be used to reduce the cost of water banking to Ecology by providing a dedicated funding source to address the current competition of water bank formation with other Ecology business functions:

- **Charge a flat fee for developing a water bank.** RCW 90.03.470 could be amended by the Legislature to provide a water bank formation fee. This would cover Ecology upfront costs, and incentivize banks that solve larger regional problems, but would not cover ongoing costs.

- **Develop a scalable fee that is based on the size or life cycle of the water bank.** A scalable fee could be done in a way that would accommodate a larger range of bank options.

## 6.6 Groundwater Modeling

Lack of groundwater modeling makes it difficult to know how effectively the mitigation being sold from a water bank will offset the impacts posed from new uses. The issue of groundwater is discussed in more detail in the Groundwater Module of this report, and water banking may be a way to help address water shortages in areas of declining groundwater. To address issues with groundwater modeling, we recommend increasing groundwater modeling efforts. This work could be done by Ecology, USGS, or via a privatization model (e.g. using contractors to measure or model groundwater declines).

## 6.7 Rural Water Availability

Challenges exist to protecting instream flows and senior water right holders, while providing water for rural development. Current measures to address this issue include work by the Water Resources Advisory Committee and the development of a guidance document on this topic. Additional measures that could help Ecology address these challenges include:

- **Address *Postema* limitation through legislative change.** The impacts of Postema on water banking is discussed in Section 4.2 of this report. The Legislature could harmonize the Postema "one molecule standard" with a "functions and values" approach to addressing instream flow impacts.

- **Address OCPI limitations through legislative change.** The Legislature could adopt mitigation standards for in-kind and out-of-kind mitigation to address the limitations to using OCPI resulting from Foster and Swinomish decisions.

## 6.8 Funding Inequities

Legislative funding for water bank development comes in many forms, including: lump sums given to counties for bank development, grants for planning efforts, and acquisition funds to seed water banks through competitive grants. Developing funding guidelines could ease confusion regarding the funding process and help create a sense of equity in the funding system.

### 6.9 Public Interest Bank Formation Guidelines

There are statutory advantages to forming a water bank. Trust water is exempt from relinquishment, permitting is often streamlined, and consumptive use calculations for trust conveyances can be more favorable than under typical changes triggering the annual consumptive quantity test (RCW 90.03.380). As a result, Ecology is requested to form water banks associated with projects that have a wide range of public and private benefits. Some banks may rely on a single trust water right to meet a multitude of end uses, while others may rely on multiple trust water rights to mitigate one large proposed new use. Some banks are established to provide significant environmental benefit, and others have marginal or no environmental benefit. Given the increasing pressures on limited staff, Ecology could benefit from guidance on prioritization of bank formation:

- **Adopt water bank criteria.** The Legislature could adopt criteria for water bank formation to give Ecology guidance on how to prioritize its work.

- **Amend WAC 173-152-050 Criteria for Priority Processing of Competing Applications.** Ecology could adopt a policy or initiate rulemaking to amend WAC 173-152 to prioritize its work.

## *7. References*


Arizona Water Banking Authority(AWBA), 2014, Annual Report. Retrieved from Arizona, Water Bank Website: http://www.azwaterbank.gov/Documents/2014AnnualReportwltr.pdf

Arizona Senate, 2015, Arizona State Senate: Issue Brief. Retrieved from Arizona State Legislature Website : http://www.azleg.gov/briefs/Senate/ARIZONA%20WATER%20BANKING%20AUTHORITY.pdf

Broadbent, C. D., Brookshire, D.S, Coursey, D and Tidwell, V., 2010, Creating Real Time Water Leasing Market Institutions: An Integrated Economic and Hydrological Methodology. Journal of Contemporary Water Research & Education 144(1), 50-59.

Cimons, M., 2014, Selling and buying water rights | National Science Foundation. Retrieved August 9, 2015, from http://www.nsf.gov/mobile/discoveries/disc_summ.jsp?cntn_id=133173&org=NSF

Clifford, P. Landry, C. and Larsen-Hayden, Andrea, 2004. Analysis of Water Banks in the Western States. Published by Washington State Department of Ecology available at www.ecy.wa.gov/biblio/0411011

Clyde, S.E., 1989, Adapting to the changing demand for water use through continued refinement of the Prior Appropriation Doctrine: An alternative approach to wholesale reallocation. Natural Resources, 29(2), 435-455.

Colby, B. & O’Donnell, M., 2010, Water Banks: A Tool for Enhancing Water Supply Reliability.

Court of Appeals of the State of Washington, 2015, Whatcom County; Eric Hirst; Laura Leigh Brakke; Wendy Harris; David Stalheim and Futurewise v. Western Washington Growth Management Hearing Board. Retrieved March 3, 2016, from http://www.ecy.wa.gov/programs/wr/wrac/images/pdf/707965.pdf

Cronin, A.E & Fowler, L.B., 2012, Northwest Water Banking : Meeting instream and out of stream water needs in the Pacific Northwest. The Water Report (102), 10–16

Flint, T, 2013, Utah’s Water Future Developing a 50 -Year Water Strategy for Utah: Summary of Public Listening Sessions.Retrieved from Website: http://www.deseretnews.com/media/pdf/1242130.pdf

Hanak, E. and Stryjewski, E., 2012, California's Water Market, By the Numbers:Update 2012. Retrieved from Public Policy Institute of California Website : http://www.ppic.org/content/pubs/report/R_1112EHR.pdf

Idaho Water Resource Board (IWRB), 2014, Report for the Board's Water Supply Bank. Retrieved from the Idaho Water Resource Board Website : https://www.idwr.idaho.gov/files/water-supply-bank/2014-annual-report.pdf

Mack, Bronson, 2015, Southern Nevada Water Authority. Personal communication. December 15, 2015.

New Mexico Office of the State Engineer Interstate Stream Commission (NMOSEISC), 2011, 2009-2011 Annual Report.Retrieved from New Mexico Office of the State Engineer Website: http://www.ose.state.nm.us/Pub/AnnualReports/09-11-annual-rpt.pdf

Oregon Water Resources Department (OWRD), 2008, Deschutes Ground Water Mitigation Program: Five-Year Program Evaluation Report. Retrieved from Oregon state government Website: http://www.oregon.gov/owrd/docs/deschutes_mitigation_5_year_review_final_report.pdf

Plagmann, M., & Raffensperger, J., 2007, A Smart Market for Ground Water using the Eigenmodel Approach. MODSIM Conference, Christchurch NZ.

Scanga Jr, R, 2013, Update of the water banking in the Arkansas presented to the interim water resources review committee. Retrieved from Colorado state government website: https://www.colorado.gov/pacific/sites/default/files/13WaterResourcesUpdateonWaterBanking.pdf

Semitropic Water Storage District. (n.d.), 2015, Retrieved December 13, 2015, from http://www.semitropic.com/index.htm

Supreme Court of the State of Washington, 2000, John Postema v. Pollution Control Hearings Board, et al. Retrieved March 3, 2016, from http://www.ecy.wa.gov/programs/wr/caselaw/images/pdf/postema.pdf

Supreme Court of the State of Washington, 2013, Swinomish Indian Tribal Comm'y v. Dep't of Ecology. Retrieved March 3, 2016, from https://www.courts.wa.gov/opinions/index.cfm?fa=opinions.showOpinion&filename=876720MAJ

Supreme Court of the State of Washington, 2015, Sara Foster v. Washington State Department of Ecology; The City of Yelm; and Washington Pollution Control Hearings Board. Retrieved March 3, 2016, from http://www.ecy.wa.gov/programs/wr/wrac/images/pdf/90386-7Opinion.pdf

Southern Nevada Water Authority (SNWA). (n.d.), 2015, Retrieved December 13, 2015, from http://www.snwa.com/ws/future_banking.html

Texas Water Development Board (TWDB). (n.d.), 2015, Retrieved December 13, 2015, from http://www.twdb.texas.gov/waterplanning/waterbank/bank/index.asp

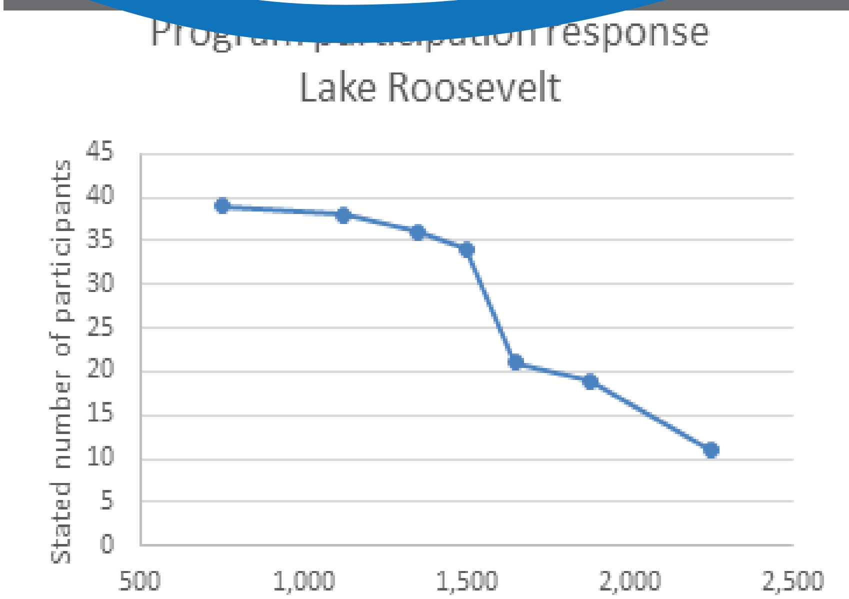
Tomkins, C., Weber, T., Freyberg, D.L., Sweeney, J.L, Thompson, B.H., 2008, Option Contracts in Practice: Contractual and Institutional Design for California Water Transfers. Policy Brief.

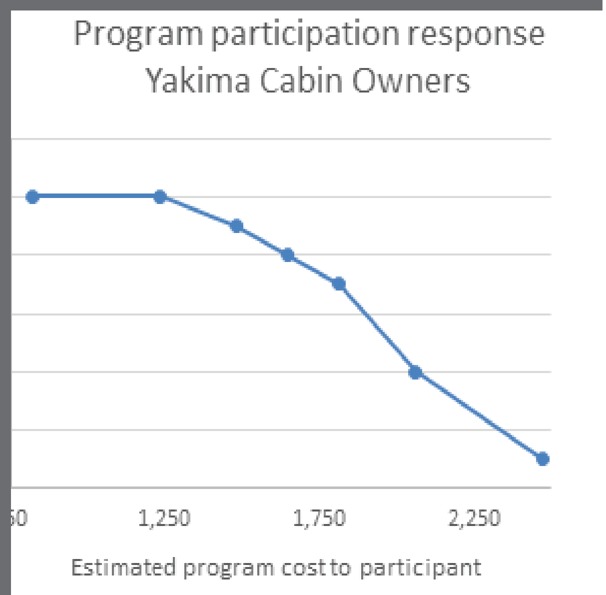
Tomkins, C., & Weber, T., 2009, Option contracting in the California water market. J Regul Econ Journal of Regulatory Economics, 37(2), 107-141.

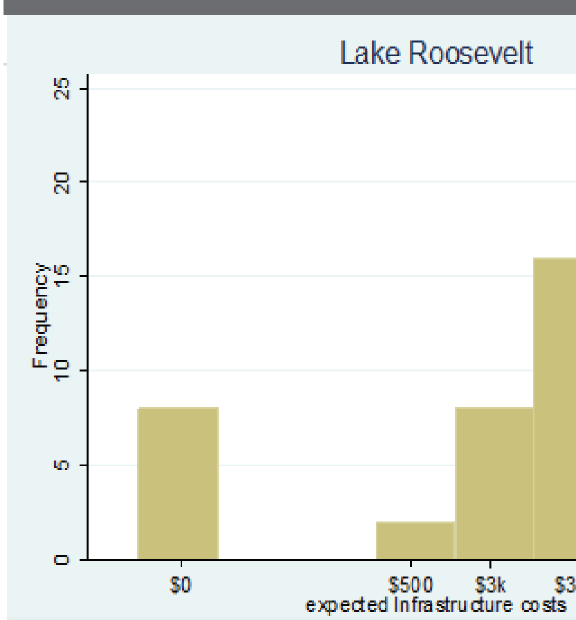
Van Bussum, M, 2011, The Board's Water Supply Bank. Retrieved from the Idaho Water Resource Board Website: https://www.idwr.idaho.gov/files/water-supply-bank/Basics-of-the-Bank.pdf

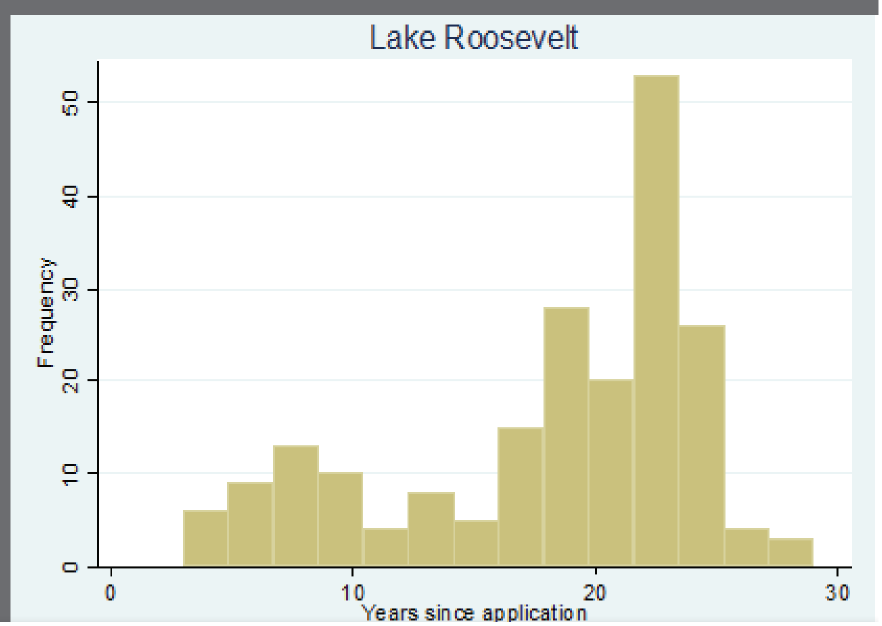
Yoskowitz, D.W., 1999, Spot Market for Water along the Texas Rio Grande: Opportunities for Water Management. Natural Resources, 39(2), 345-355

# Effects of User-Pay Requirements on Water Permitting



# *Water Service Programs: The Effects of Price and Other Factors on Participation*

## Introduction

When the mission of the Department of Ecology (Ecology) and its predecessor agencies was to authorize water rights to support development of the West, water was essentially free. Application costs were low (e.g. $2), and staff time needed to evaluate the 4-part test to issue a water right was completely subsidized by the State. The result was that from around 1920 through the 1970s, timely and nearly-free water rights application processing and approval was the norm in Washington State. Today, however, application filing fees are at least $50/application, priority processing fees are approximately $10,000, and reimbursement costs for water supply development are in the range of $1,500 to $3,000+/acre-foot (as a one-time cost), which may increase over time due to the costs of new water infrastructure projects and a range of other factors.

As a result, in the past 10 years, administrative and transactional fees have increased, and more applicants have declined water when made available, and have declined processing when opportunities arise. This negative response to increasing costs is adversely affecting Ecology's ability to reduce its backlog of water right applications in the face of legislative mandates to meet annual permit processing targets. For example, recent legislative budget provisions have established Ecology funding levels for permit staffing based on the assumption of processing 500 water right decisions per year. If Ecology has water available at the existing market cost, but an applicant declines processing and remains in the backlog, then it becomes more challenging to meet this water right permitting mandate.

Previous forecasts in 2006 and 2011 have presumed that when water is made available to applicants, they would accept processing of their application and implement their project. Recent behavior by applicants tells a different story. The 2016 Water Supply and Demand Forecast begins to take into account the true cost of processing and developing water supplies as it forecasts future water demand for Washington State, particularly given 2010 legislative amendments authorizing Ecology's Office of Columbia River (OCR) to recover the cost of developing water supplies. The Forecast Team evaluated the following six Ecology water supply case studies to assess the effect of water pricing and other factors on demand, and its associated impact on Ecology backlog:

- Lake Roosevelt Incremental Storage Releases Program
- Sullivan Lake Water Supply Program
- Wenatchee Basin Coordinated Cost-Reimbursement Program
- Cabin Owner's Mitigation Program
- Port of Walla Walla Lease Program
- Yakima Sub-Basin Mitigation Program

These programs included some kind of cost-reimbursement user-pay responsibilities. User-pay responsibilities vary from program-to-program, which offers a good opportunity to compare results across programs. Variation has included:

- Paying for processing a water right permit application, or paying for the cost of water supply development.
- Paying an annualized fee versus one-time cost.
- Paying a specified cost versus requiring individualized mitigation without a specified cost.

To better understand program variation and user reactions to it, the Forecast Team employed the following approach in its investigation:

1. Developed summaries of each of the six programs, including number of participants invited, cost of water, timing of program enrollment, and eligibility criteria.

2. Developed contact information for program participants based on Ecology databases.

3. Developed a survey (online and mail) to evaluate participant decision-making for the program they were offered, and how their decision would change if price, timing, or eligibility criteria were different.

4. Evaluated survey results on both a qualitative and statistical basis.

5. Evaluated Ecology / OCR bonding and user-pay business models relative to those used nationally.

6. Met with Ecology and discussed findings, and summarized how cost of water is likely to affect long-term demand.

7. Developed suggestions for improving program structure and administration, and applicant and legislative expectations for program outcomes.

The analysis and evaluation of survey responses includes a broad set of sample summary statistics of survey responses for each program, as well as summaries of the qualitative comments provided by respondents. More in-depth econometric analysis are provided for those programs with larger sample sizes to support it.

In summary, the Forecast Team concluded the following:

1. Many applications were submitted many years ago, and applicant circumstances have in many cases changed to the point that the water rights application itself is of relatively less value to the applicant.

2. Evidence presented here suggests that potential program participants respond to cost, and some potential participants opt out of the program due to fees that Ecology charges for cost recovery.

3. Applicants sometimes choose to keep applications on hold due to uncertainty about family or business situations, as well as uncertainty or lack of clarity about program costs or benefits, with the intent of resolving the decision when uncertainty is better resolved.

These findings are the basis for some indirect policy suggestions provided at the end of the report.

## Summary of Ecology User-Pay Programs

The following sections summarize six user-pay programs administered by Ecology over the last 10 years. Table 1 below the basic program descriptions provides a summary of the pricing. timing and participation, permanence of water, quantity limits, and purposes and places of use attributes for each program.

### *Lake Roosevelt Incremental Storage Releases Program*

The Lake Roosevelt Incremental Storage Releases Program provides up to 25,000 acre-feet per year of water available to permit new municipal, domestic, and commercial/industrial uses from the Columbia River and groundwater in close communication with the river (generally a one-mile corridor with the river). As of May 2016, approximately 20,000 acre-feet remains to be appropriated.

### *Sullivan Lake Water Supply Project*

OCR purchased 14,000 acre-feet per year from Pend Oreille Public Utility District to re-operate Sullivan Lake in Pend Oreille County. The Sullivan Lake Water Supply Project authorizes 9,400 acre-feet of water for use within the six northeast counties, with the balance for instream flow benefit. Half of the 9,400 acre-feet is to be used for domestic, municipal, commercial, and industrial uses, while the other half may be used for any other purposes such as irrigation.

### *Cabin Owners Mitigation Water*

During the 2001 and 2005 droughts in the Yakima basin, surface water users with adjudicated water rights junior to May 10, 1905 were ordered by the Yakima Superior Court administering the Acquavella Adjudication to stop using water. This curtailment order primarily affected cabin owners, seasonal domestic & recreational uses and youth camps, and the City of Roslyn. As directed by Senate Bill 6861, Ecology is selling mitigation to Yakima Basin Cabin Owners with junior water rights (post-1905), as well as some unauthorized water users, to offset their consumptive use of water during years of pro-rationing.

### *Wenatchee Cost-Reimbursement Program*

Following adoption of a Watershed Plan and instream flow rule in 2006, Chelan County petitioned Ecology to approve their facilitation of a coordinated cost reimbursement process to permit water to new uses under a reservation established in the Wenatchee River Instream Flow Rule, WAC 173-545. Participants in the Program would receive a permanent certificate of water right for their project. Initial outreach to applicants and preparation of a streamlined contracting and permitting process began in 2014. In March 2016, the Legislature passed ESSB 6513, which confirmed the reserve. Outreach to interested applicants began again in April 2016.

### *Port of Walla Walla Lease Program*

OCR entered into a 10-year lease of 4,761 acre-feet of water with the Port of Walla Walla. The Port of Walla Walla Lease Program is offered to use existing water rights held by the Port for mitigation of other uses while the Port pursues long-term redevelopment of new industrial uses. Initial outreach was through the OCR e-mail distribution list, website, and presentation to the Columbia River Policy Advisory Group. The available water was allocated on a first come-first served basis, and there was no formal opportunity for applicants to accept or decline processing.

### *Yakima Basin Mitigation*

Surface water has generally been unavailable in the Yakima basin since 1905 when USBR reserved all unappropriated water to build large irrigation storage projects. In 2012, the USGS completed a comprehensive groundwater study that showed that groundwater and surface water in the greater Yakima Basin were in hydraulic continuity. Ecology has given applicants the option to present a mitigation plan, be placed on hold while mitigation is pursued, or to be processed in the absence of mitigation, which will likely result in denial for any new consumptive uses.

Table 1. Summary of Attributes of Current Ecology User-Pay Programs.

| | Pricing | Timing and Participation | Permanence of Water | Quantity Limits | Purposes and Places of Use |
|---|---|---|---|---|---|
| Lake Roosevelt Incremental Storage Releases | $35 per acre-foot per year plus inflation adjustments; 40-year renewable contract | Since 2008, 208 applicants invited; As of May 2016, 42 approved to pay the $35/acre-foot annually; 48 applications were withdrawn or rejected; 108 applicants declined processing and asked to remain in the backlog of pending applications; 10 pending | Perpetual water service contract | "Reasonable use" limit for each application, 25,000 acre-feet overall | Water is only available for municipal, domestic, and commercial/industrial uses (agricultural irrigation is not permitted), in Lake Roosevelt Pool and down-stream. |
| Sullivan Lake Water Supply Program | Either one-time payment of $1,500 per acre-foot or $60 per acre-foot per year for 25 years | 30 days to accept or decline processing; permitting will be active until all of the 9,400 acre-feet allocated. As of May 2016, 135 applicants are eligible to participate, 1 applicant has been approved. | Permanent rights; applicant obtains ownership interest in water as mitigation for new use | "Reasonable use" limit for each application, 9,400 acre-feet overall. | Water is available for all uses; place of use limited to Douglas, Ferry, Lincoln, Okanogan, Pend Oreille, and Stevens counties in continuity with the Columbia River. |
| Cabin Owner's Mitigation Program | One-time fee of $3,643 per acre-foot, plus additional contracting and permit-ting fees. Majoity of buyers using fraction of one acre-foot | First come-first served basis; no applicant response timeline -- the project will continue until all water is appropriated, or the mitigation program runs out of funding. As of May 2016, 583 parcels were eligible to participate, and 53 mitigation contracts have been approved; 85 temporary surface water permits still pending | Permanent rights | Approximately 57 consumptive acre-feet per year to offset existing uses. Applicants are limited to what can be beneficially used indoors (typically up to 0.06 acre-feet/year) | Indoor domestic use for existing structures; Geographic area is Yakima Basin, Yakima County, Kittitas County, and Benton County. Uses must be water budget neutral with respect to Total Water Supply Available (TWSA) in the Yakima Basin |
| Wenatchee Basin Coordinated Cost | Depending on quantity (50 – 200+gpm), processing fees for Ecology, County, and Contractors: $7,900 - $14,600 | Initial applicants (2015) contacted and given 60-day eligibility offer; Now first-come-first served basis. As of May 2016, 110 applicants invited, 56 expressed interest and 13 are currently being processed. | Permanent rights | Includes uninterruptible and interruptible portions. Uninterruptible portions are limited by the 4 cfs rule reserve quantity, and specific subbasin reserves in WAC 173-545. Interruptible portion for agricultural irrigation is limited to water available when the instream flow is met. | Mitigation under the reserve is generally limited to non-agricultural irrigation purposes. The place of use of applicants must be within the Wenatchee basin. |

| | Pricing | Timing and Participation | Permanence of Water | Quantity Limits | Purposes and Places of Use |
|---|---|---|---|---|---|
| Port of Walla Walla Lease Program | $105 per acre-foot per year. Applicants must sign a temporary water service agreement. | First come-first served basis; program terminates on December 31, 2020, as a result of OCR's 10-year lease agreement with the Port. The number of temporary permits issued varies annually, but 4 temporary permits were processed to an approval in 2016. | Maximum term of 10 years, and all agreements will terminate on December 31, 2020. | Explicit limits per applicant. OCR has leased 4,761 acre-feet per year available for reallocation under this program. Currently, there are agree-ments in place for this entire quantity. | Must be for a use that can be terminated at the end of the lease (No domestic or other long-term uses may depend on it). Groundwater users must be in continuity with the river, although there are no specific allocation requirements as with the Lake Roosevelt Incremental Storage Releases Program. |
| Yakima Sub-Basin Mitigation Program | No water has been acquired on behalf of these applicants. Funding of individual mitigation plans is up to the project proponent. Therefore, pricing summaries for the program are not available. | Applicants given 90 days to respond. If no response, Ecology would process their applications without mitigation, leading to likely denial. In May 2012, Ecology solicited 411 pending groundwater right applicants. As of May 2016, 269 applicants responded, of whom 170 applicants requested to remain as pending applications, 63 withdrew their application, 27 requested their application be processed, and the remaining 9 needed to finish assigning the application to a 3rd party. Out of the 142 non-respondents, 15 applications have been processed to a denial without mitigation, 58 applications were rejected, and the remaining 69 applications will be processed without mitigation (and likely denial). | Permanent rights | None identified, as this is entirely dependent on the individual project. | Water would be available for any beneficial use, subject to appropriate mitigation, within the Yakima basin. |

## Program Participation Evaluation

Two sets of data were used to assess the determinants of program participation among water right applicants. The Department of Ecology keeps records of applicants that contains contact information, basic characteristics of the application and other related details. To augment this dataset, a survey was developed and delivered to water rights applicants for these programs based on the contact information provided in Ecology's database.

### *Department of Ecology Dataset*

Ecology maintains data on water right applicants as part of their Water Right Tracking System (WRTS) pursuant to RCW 90.54.030. Applicants are required to file basic contact information as part of the water right application filing process under RCW 90.03.250 and RCW 90.03.260. Applications are personal property and do not transfer automatically with property, but rather are assigned to successor applicants through the process outlined in RCW 90.03.310.

As part of each of the six user-pay programs, Ecology contacted applicants to verify their current contact information and whether they were interested in receiving water under the terms of the programs. The Forecast Team obtained this information as a foundational dataset to determine number of applicants for each program, current responses to program participation, and contact information for use in the user surveys.

### *Survey Objective and Content*

User surveys were designed to evaluate the reasons that people chose to either participate in the various programs offered or chose not to participate. The surveys are designed to better inform Ecology and OCR as they seek to develop new water supply projects, meet expectations of applicants, and meet legislative permitting mandates.

The survey design was based on standard economic methods to assess program participation decisions. In short, applicants are likely to participate in a program if they expect the benefits from participation to outweigh the costs to them of doing so at the time the decision is made. Therefore, the survey focuses on collecting information that is likely to be related to expected benefits and costs of participating in the program from the applicants' perspective. It is not possible to directly estimate all of these benefits and costs, but it is possible to collect data on the characteristics of individuals that are likely to be correlated with them. In addition, the Forecast Team utilized a widely used non-market valuation method called contingent valuation, anchored on the actual program fees and costs to more fully capture the willingness to pay for these programs, and assess the impact of program costs on participation rates.

The various categories of information collected from the survey can be summarized as:

- How the water from those programs was to be used (municipal, domestic, industrial, or irrigation).
- The expected cost of additional infrastructure used to put the water to beneficial use.
- The stated reason for accepting or declining to participate in the various programs.
- Questions about the likelihood of participation (or not) contingent on lower or higher initiation fees or service costs of the program itself, with the actual fees of the program being the reference point.
- Applicants were encouraged to supplement responses with qualitative statements that could also be helpful in determining how programs were received.

Copies of the actual survey questions are included in *Appendix A – Water Master Surveys*. Each survey was tailored to the specifics of the program to which it applies. There are questions in each survey for applicable programs that target applicants who chose to participate in the respective programs, those who chose not to participate, and those who chose to keep their application on hold. Questions about likely participation under hypothetical price variation using standard contingent valuation methods were designed to help identify price points at which respondents would either chose to participate or not (i.e., switch-point prices). In addition to searching for the price point at which those applicants would choose to participate, questions also asked about other factors (non-monetary) that may have led to the decision to opt out. Although these same sections were included in each of the surveys, prices vary in each as a percentage of the original participation costs. In addition, those programs which are limited to specific water uses only include questions that pertain to those uses. For example, the Port of Walla Walla Lease Program expires after a maximum of ten years and is therefore unsuitable for domestic or municipal use. Consequently, questions on that survey do not include questions about domestic or municipal use. Similarly, the Yakima Cabin Owners Mitigation Program only provides water for indoor domestic use. Consistent with this limitation, the survey associated with this program excludes any questions related to uses that do not fall into the indoor domestic use category.

Surveys were developed by the Forecast Team in consultation with the Department of Ecology, and were administered by the WSU Social and Economic Sciences Research Center (SESRC; https://sesrc.wsu.edu/). The usable sample size was maximized by utilizing the SESRC's sophisticated and well-founded multimode contact and survey methods, using phone, mail, and online contact approaches and a small incentive for survey participation (Dillman et al. 2014). Survey responses were accepted from March 5, 2016 through July 2016.

### *Survey Sample*

The survey samples for each program include all applicants in each respective program for whom contact information is available in Ecology database. Table 2 provides the initial sample sizes based on this data (these numbers therefore closely coincide to the corresponding numbers provided in column 3 of Table 1, except that some of the contact information in Ecology's WRTS database was out of date or otherwise unusable, so the actual initial samples are smaller to the extent that contact information did not reach actual applicants. The most common reason for this is likely due to land transfer, which does not automatically trigger an update of contact information with Ecology. As Table 2 indicates, the initial sample sizes vary by program from 4 to 378, for a total of 678 individuals initially contacted.

Table 2. Survey response rates by program.

| Program | Sample Size | Returned | Response Rate (%) |
|---|---|---|---|
| Lake Roosevelt | 214 | 66 | 30.8 |
| Sullivan Lake | 8 | 1 | 12.5 |
| Yakima Cabin Owners | 37 | 24 | 64.8 |
| Wenatchee Basin | 37 | 3 | 8.1 |
| Port of Walla Walla | 4 | 1 | 25 |
| Yakima Basin | 378 | 97 | 25.6 |
| Total | 678 | 192 | 28.3 |

## Overview of Survey Returns

Table 2 above provides information about the number of survey responses and response rates, by program. The Yakima Cabin Owners program had the highest response rate (64.8%), with 24 of 37 respondents contacted. The Yakima Basin program had the largest number of responses (97) for a response rate of 25.6%. On the other end of the spectrum, only one response was received from each of the Sullivan Lake and Walla Walla Programs, based on initial sample sizes of 8 and 4 contacts, respectively.

While Table 1 includes information about overall program participation rates, Table 3 provides information on program participation within our sample of survey respondents. For example, we received survey responses from 34 of the 42 applicants who chose to participate in the Lake Roosevelt program and pay the $35/acre-foot per year for water, 10 survey responses from the 48 who either declined or were ineligible, and 9 survey responses of the 108 or so who asked to remain on hold (note, however, that the number of individuals in these categories for whom we had contact information was lower than the numbers from Table 1).

Table 3. Program participation based on survey responses.

| Program | Accepted | Declined | On Hold | Ineligible | Don't Know | Other |
|---|---|---|---|---|---|---|
| Lake Roosevelt | 34 | 4 | 9 | 6 | 1 | 8 |
| Sullivan Lake | 0 | 0 | 0 | 0 | 0 | 1 |
| Yakima Cabin Owners | 18 | 1 | 4 | 1 | 0 | 24 |
| Wenatchee Basin | 0 | 1 | 0 | 0 | 1 | 1 |
| Port of Walla Walla | 1 | 0 | 0 | 0 | 0 | 3 |
| Yakima Basin | 5 | 11 | 32 | 43 | 0 | 6 |
| Total | 58 | 17 | 45 | 50 | 2 | 43 |

## Analysis of Survey Data on Individual Programs

The analysis below includes a broad set of sample summary statistics of survey responses for each program, as well as summaries of the qualitative comments provided by respondents to the extent provided in the survey responses. More in-depth econometric analysis are provided for those programs with larger sample sizes to support it. The summary for each program includes a section on survey response characteristics, program participation, price responsiveness, and a broader discussion on factors affecting participation.

### *Lake Roosevelt Incremental Storage Releases Program (LR)*

#### SURVEY RESPONSE CHARACTERISTICS

Ecology's database had a total of 214 unique applications for which contact information was available and to which surveys were sent. 66 surveys were returned with at least some of the questions answered, for a response rate of 30.8%.

#### PROGRAM PARTICIPATION

Of 62 survey respondents who indicated their status in the program, 34 (54.8%) of them are participating in the program, 4 have withdrawn their application (6.5%), and 9 (14.5%) have placed the application on hold, and 6 (9.7%) were found ineligible (see Table 3 for a summary). The remainder either did not answer or do not know about their status. The program participation rate in the sample is higher than the program participation rate for all applicants as indicated by Ecology's data, suggesting that program participants are more likely to have responded to the survey.

#### PRICE RESPONSIVENESS

The survey included questions asking whether respondents would change their program participation decision if program fees and charges were different. Table 4 shows that of those who are current program participants ("Accepted"), 19 said that they would have accepted the program even if program costs were 25% higher, while 13 said they would decline in response to this cost increase. Of those who would not decline at a cost increase of 25%, 11 said that they would decline if the price was 50% higher. Only one respondent who has declined the program responded to these cost questions, and this respondent would apparently be unresponsive to cost reductions.

Of those respondents whose applications are on hold, 4 out of 9 respondents would choose immediately to participate if the cost were 25% less. However, 4 respondents would not choose to participate now even if costs were 50% lower. Most respondents on hold also indicated little likely response to cost increases, suggesting that they were maintaining the "on hold" status for reasons other than price.

Table 4. Stated program participation given different prices.

| | Yes | No |
|---|---|---|
| Accepted (B12-B12B) N=34 | | |
| Would participate even if cost were 25% more | 19 | 13 |
| Would participate even if cost were 50% more | 11 | 7 |
| Would participate if cost were 10% but not if 25% more | 2 | 9 |
| Declined (B11-B11B) N=5 | | |
| Would participate if cost were 25% less | 0 | 1 |
| Would participate if cost were 10% less | 0 | 1 |
| Would participate if cost were 50% less but not 25% less | 0 | 1 |
| On hold (B14-B14E) N=9 | | |
| Would participate immediately if cost were 25% less | 4 | 5 |
| Would participate immediately if cost were 10% less | 2 | 1 |
| Would participate immediately if cost were 50% less but not 25% less | 1 | 4 |
| Would decline immediately if cost were 25% more | 2 | 7 |
| Would decline immediately if cost were 10% more | 0 | 6 |
| Would decline immediately if cost were 50% more but not 25% more | 0 | 3 |

From the responses in Table 4, the number of participants who would opt in or out relative to the 34 in the sample who are currently participating can be estimated. Table 5 utilizes a subset of the data in CE4 to infer the number of respondents who would opt in based on the number of participants who claim they would decline given price increases, and the number of non-participants (those who declined or are on hold) who would opt-in given lower prices.

Table 5. Stated price responsiveness of participation, Lake Roosevelt Program.

| price/cost | % change in cost/price | # who would opt in |
|---|---|---|
| $2,250 | 50 | 11 |
| $1,875 | 25 | 19 |
| $1,650 | 10 | 21 |
| $1,500 | 0 | 34 |
| $1,350 | -10 | 36 |
| $1,125 | -25 | 38 |
| $750 | -50 | 39 |

The pattern is a classic downward sloping demand curve: as prices increase, the number of respondents who claim would participate declines. Figure CE1 provides a graphical illustration of these data (Lake Roosevelt Program fees are $35/af/year (annual). These fees were translated into present value costs for survey respondents. The prices on the horizontal axis of Figure CE1 represent these 20-year total costs).

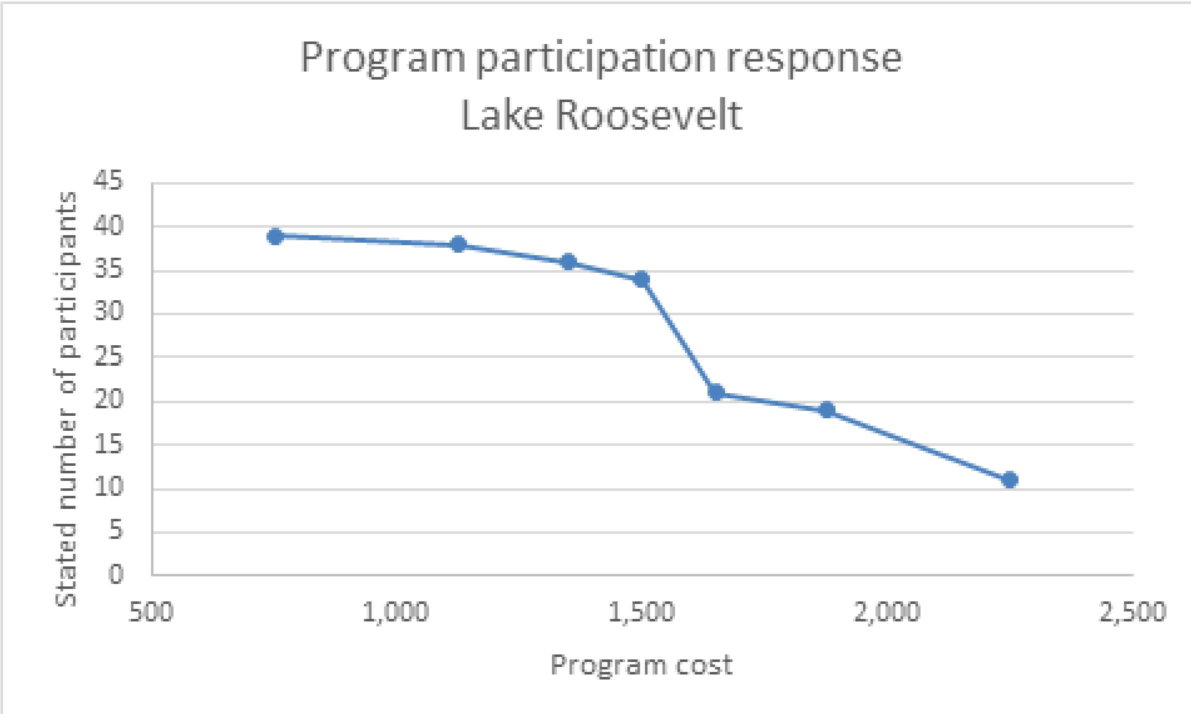



*Figure 1. Program participation demand as a function of price ($1,500 baseline).*

Further summarizing these numbers, it can be shown that the average elasticity of demand (the percentage change in participation resulting from a percentage change in price) is about -1.38; or that participation declines by 1.38% for a one percent increase in price. It is important to recognize that this analysis is based on a very small sample, which does not represent a statistically significant econometric estimate, and does not account for sample self-selection bias. So although the quantitative value is within a credible range, it should be interpreted with care.

Looking beyond price responsiveness, Table 6 below shows the number of respondents answering yes to four questions about why they are maintaining their applications on hold. These responses indicate that resolution of factors beyond the program or water itself may often be important determinants of maintaining their application on hold.

Table 6. Stated reasons for maintaining application on hold.

| Reason | # responding |
|---|---|
| Uncertain about the need or value of the use of water applied for (QB13A) | 2 |
| Uncertain about the total cost of program participation (QB13B) | 3 |
| Waiting for other unrelated family or business issues to be resolved before committing (QB13C) | 4 |
| Some other reason (QB13D) | 4 |

## FACTORS AFFECTING PARTICIPATION

The survey asked questions of respondents who declined participation about their reasons for declining (survey questions QA10A- QA10O). Table 7 provides these responses for the Roosevelt Lake program. There is a variety of reasons for non-participation, but a change in the need or potential use of the water applied for, and required costs of the program and/or water use are noted by several respondents as factors affecting their decision.

Table 7. Stated reasons for non-participation (decline to participate) in the LR program.

| Reasons (survey questions QA10A-QA10O) | # respondents indicating "important" or "somewhat important" |
|---|---|
| Sold the Property (QA10A) | 1 |
| Less or no need for the water due to land use change or other reason (QA10D+QA10E) | 4 |
| The price per unit volume or the for water service contract is too high (QA10F) | 1 |
| Cost of water contract, application processing and public notice is too high (QA10G) | 1 |
| Cost of required infrastructure investments to use the water is too high (QA10I) | 1 |
| Cost of acquiring mitigation right if required by the contract is too high (QA10J) | 3 |
| Program or contract terms are unclear (QA10K) | 2 |
| Inability to complete project on Ecology's timeframe requirement (QA10M) | 1 |
| Other factors (QA10O) | 1 |

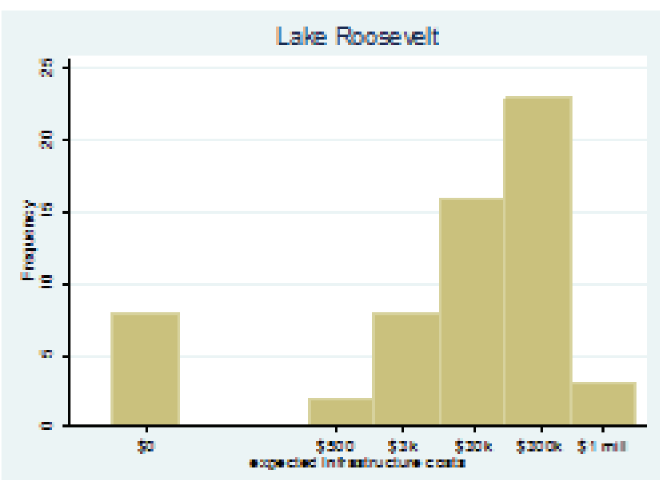



*Figure 2. Expected infrastructure costs to use water.*

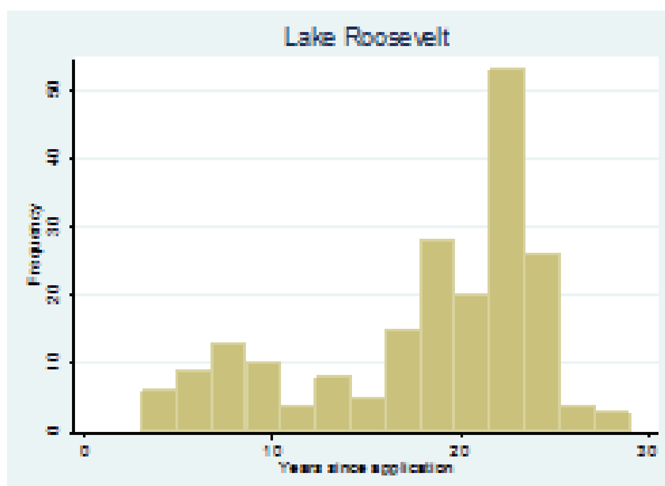



*Figure 3. Time since priority date of application.*

A histogram of infrastructure cost estimates is shown in Figure 2 (the x-axis is scaled in logarithmic terms). Expected infrastructure cost range from zero to about $1 million, with a mode of around $300,000.

A histogram of the number of years since application priority dates (as of 2016) is shown in Figure 3. The number of years since application ranges from 3 to 29 years, and the median and average number of years since priority date is 20 and 18, respectively. Regression analysis (see technical report) suggests that the longer the time from priority date, the more likely that respondents declined to participate in the program.

In this case, delays in applicants receiving water from the Columbia River can be traced to 1992 listings of salmon under the Endangered Species Act, litigation over the Federal BiOp (biological opinion) establishing fish flows on the Columbia River, lack of mitigation program requirements until OCR was created in 2006, and Lake Roosevelt Incremental Storage Releases Program environmental review, construction, and permitting.

## SUMMARY OF LAKE ROOSEVELT SURVEY RESULTS

Various factors are shown to affect program participation decisions. There is some indication that program cost requirements are affecting participation. Questions about changing participation decisions based on price variation suggest that current program participants are somewhat price responsive. Those respondents who have declined to participate exhibit less price responsiveness, suggesting that other factors may be driving non-participation among a large fraction of this set of respondents.

The response rate for this program was about 30%, and there is some evidence that program participants were more likely to respond than those in the sample who have declined (withdrawn their application). This suggests that while the data provides some insights into the participation decisions, some characteristics of these results may be affected by differential response rates, and some care should therefore be taken in interpretation of the results.

### *Yakima Basin Mitigation Program*

## SURVEY RESPONSE CHARACTERISTICS

Ecology's database had a total of 378 unique applications for which contact information was available and to which surveys were sent. Ninety-seven surveys were returned with at least some of the questions answered, for a response rate of 25.3%.

## PROGRAM PARTICIPATION

Of 97 survey respondents who indicated their status in the program, five (5.1%) of them intend to participate or have participated in the program, 11 intend to withdraw or have withdrawn their application (11.3%), and 32 (32.9%) intend to or have placed the application on hold, and 43 (44.3%) were found ineligible. The remainder either did not answer or do not know about their status. The program participation rate for applicants in the Yakima Basin Rollout program as indicated by Ecology's data is 25.6%, which is slightly lower than the program participation rate for all applicants (28.2%) suggesting that program participants are less likely to have responded to the survey.

## PRICE RESPONSIVENESS

There are no prices directly associated with the Yakima Basin Rollout programs. Interested parties have to find their own mitigation water and pay for it themselves. Therefore, there were no questions pertaining to price response in the survey for Yakima Mitigation Program, and unfortunately, the Forecast Team did not have access to information about the prices participants have paid for mitigation under this program.

## FACTORS AFFECTING PARTICIPATION

The survey asked questions of respondents who declined participation about their reasons for declining (questions QA10A- QA10L). For the Yakima Basin Mitigation program, Table 8 below shows the number of respondents' who stated various reasons for non-participation.

Table 8. Stated reasons for non-participation (decline to participate) in the Yakima Basin Mitigation program.

| Reasons (survey questions QA10A-QA10L) | # respondents indicating "important" or "somewhat important" |
|---|---|
| Sold the Property or Moved Away (QA10A+QA10B) | 6 |
| Less or no need for the water due to land use change or other reason (QA0D+QA10E) | 8 |
| The cost of acquiring mitigation right if required by the contract is too high (QA10F) | 4 |
| Burdensome eligibility demonstration requirements (QA10K) | 7 |
| Other factors (QA10L) | 7 |

Table 9 below show the number of respondents answering yes to 4 questions about why they are maintaining their applications on hold.

Table 9. stated reasons for maintaining application on hold.

| Reason | # responding |
|---|---|
| Uncertain about the need or value of the use of water applied for (QD14A) | 7 |
| Uncertain about the total cost of program participation (QD14B) | 11 |
| Waiting for other unrelated family or business issues to be resolved before committing (QD14C) | 5 |
| Some other reason (QD14D) | 11 |

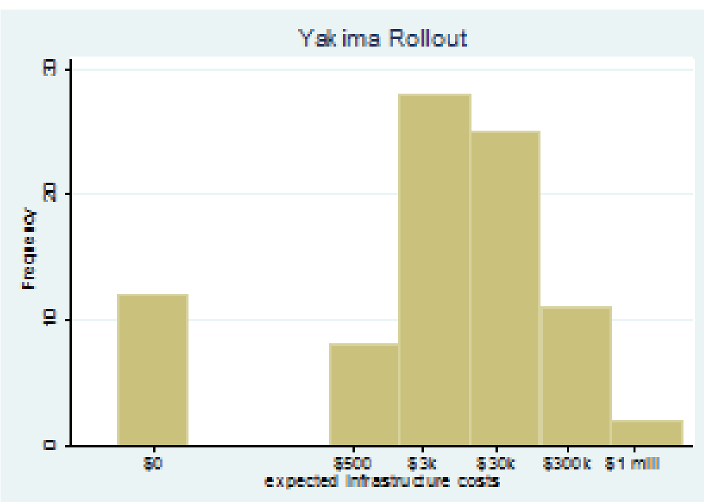



*Figure 4. Expected infrastructure costs.*

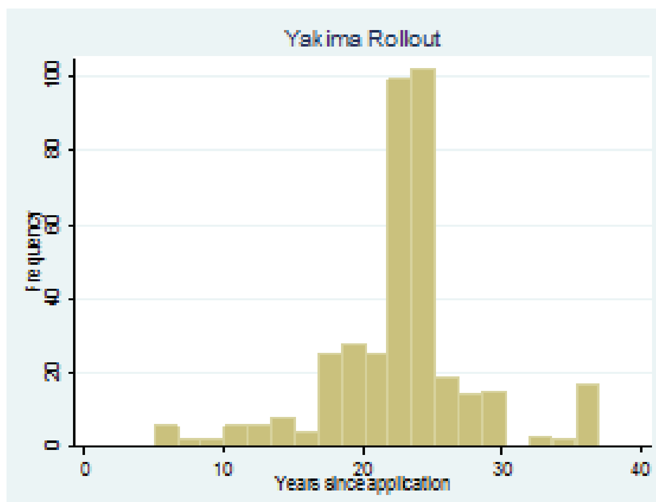



*Figure 5. Time since priority date of application.*

Infrastructure costs to use water are shown in Figure 4 (the x-axis is scaled in logarithmic terms). Expected infrastructure cost range from zero to about $4.4 million, with a mode of around $300,000.

A histogram of the number of years since application priority dates (as of 2016) is shown in Figure 5. The number of years since application priority dates (as of 2016) ranges from five to 37 years; the median and average number of years since priority date is 23 and 22.7, respectively.  Regression analysis (see technical report) suggests that the longer the time from priority date, the more likely that respondents declined to participate in the program.

## SUMMARY OF YAKIMA BASIN SURVEY RESULTS

Various factors are shown to affect program participation decisions.  There is some indication from stated reasons that uncertainty about program costs, uncertainty about the need of water and burdensome eligibility requirements are affecting participation.

The response rate for this program was about 25%, which is lower than the overall response rate for all programs. Since the program participants have to find their own mitigation water and pay for it themselves, there were no price response variables for this program.

### *Yakima Basin Cabin Owners Mitigation Program*

## SURVEY RESPONSE CHARACTERISTICS

Ecology's database had a total of 37 unique applications for which contact information was available and to which surveys were sent. Twenty-four surveys were returned with at least some of the questions answered, for a response rate of 64.8 %.

## PROGRAM PARTICIPATION

Of 24 survey respondents who indicated their status in the program, 18 (75%) of them are participating in the program, 1 has withdrawn his/her application (4.1%), and 4 (16.6%) have placed the application on hold, and 1 (4.1%) was found ineligible. The program participation rate in the sample is higher than the program participation rate for all applicants as indicated by Ecology's data, suggesting that program participants are more likely to have responded to the survey.

## FACTORS AFFECTING PARTICIPATION

The survey asked questions of respondents who declined participation about their reasons for declining (questions QA10A- QA10O).  However, there are no observations in the dataset for these question for the Yakima Cabin Owners Mitigation Program.

## PRICE RESPONSIVENESS

The survey included questions asking whether respondents would change their program participation decision if program fees and charges were different.

Table 10 shows that of those who are current program participants ("Accepted"), 14 said that they would have accepted the program even if program costs were 25% higher, while 11 said they would not have accepted in response to this cost increase.  Of those 14 who would not decline at a cost increase of 25%, 11 said that they would accept even if the price was 50% higher. Of those 2 who said they would decline in response to a 25 % cost increase, 1 said that he/she would accept if the cost was only 10 % higher instead of 25%.

Of those respondents whose have declined or have put their applications on hold, one out of five respondents would choose immediately to participate if the cost were 25% less. One respondent would not choose to participate now even if costs were 50% lower.

Table 10. Stated program participation given different prices.

| | Yes | No |
|---|---|---|
| Accepted (E15-E15B) N=18 | | |
| Would accept if cost were 25% more | 14 | 2 |
| Would accept if cost were 50% more | 11 | 2 |
| Would accept if cost were 10% but not if 25% more | 1 | 1 |
| Declined/On hold (E13-E13E) N=5 | | |
| Would participate if cost were 25% less | 1 | 1 |
| Would participate if cost were 10% less | 1 | 0 |
| Would participate if cost were 50% less but not 25% less | 0 | 1 |
| Would decline immediately if cost were 25% more | 0 | 1 |
| Would decline immediately if cost were 10% more | 0 | 0 |
| Would decline immediately if cost were 50% more but not 25% more | 0 | - |

Data from Table 10 can be used to calculate the number of survey respondents who claim that they would participate based on differences in program participation costs (mitigation costs). Using an estimated cost of $1,649 per respondent as a baseline, Table 11 provides these results, and Figure 6 provides a graphical illustration of program participation demand as a function of estimated program mitigation costs and fees per applicant, based on Table 11.

Table 11. the number of respondents who state they would opt into the program depending on program mitigation cost.

| Cost | % change in cost | # who would opt in |
|---|---|---|
| $2,474 | 50 | 11 |
| $2,061 | 25 | 14 |
| $1,814 | 10 | 17 |
| $1,649 | 0 | 18 |
| $1,484 | -10 | 19 |
| $1,237 | -25 | 20 |
| $824 | -50 | 20 |

As for the Lake Roosevelt respondents, an elasticity of demand can be calculated, which represents the percent change in participation that results in a percent change in program participation cost. In the case of the cabin owners, the average estimated elasticity is -0.57, which means that the number of participants will tend to decline by slightly more than one half of a percent for a one percent change in price. This is less price responsive than our estimate for the Lake Roosevelt program, which has an estimated elasticity of -1.38. There are many possible reasons that Cabin Owners may be less price responsive than Lake Roosevelt demanders. One reason may be that domestic users tend to be relatively price inelastic (unresponsive) in general as compared to many other users. The cabin owners program is also different than the other programs in that most of them already have junior water rights, and this may affect their price responsiveness as well. Cabin owners faced a regulatory imperative in the form of a Court order that would have precluded their use of water in drought years (1:5 frequency), which likely incentivized program participation and could account for the lower elasticity. Nonetheless, it should be noted again that the sample sizes are extremely small for inferring price responsiveness, so these numbers should not be considered statistically significant estimates, and should be interpreted with care.

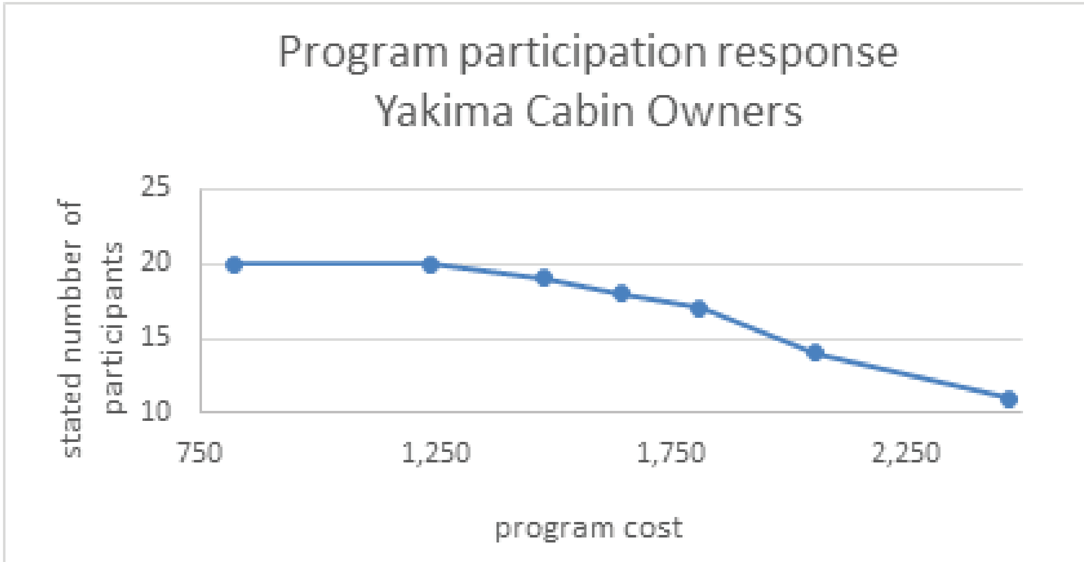



*Figure 6. Yakima Cabin owner program participation demand*

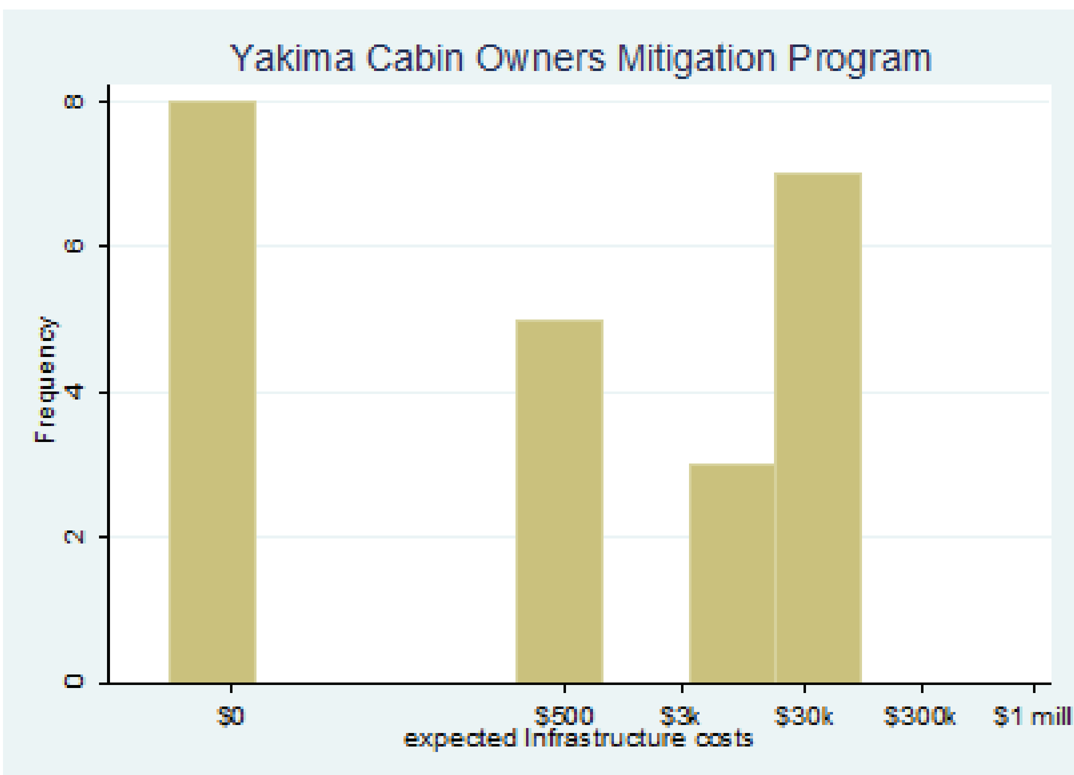



*Figure 7. Expected infrastructure costs to use water*

Infrastructure costs are shown in Figure 7 (the x-axis is scaled in logarithmic terms). Expected infrastructure cost range from zero to about $30,000, with a mode of $0. This is a much smaller cost range than the Lake Roosevelt distribution of infrastructure costs, which may also play some role in the difference in price responsiveness between the two.

## SUMMARY OF YAKIMA CABIN OWNERS SURVEY RESULTS

It is difficult to infer the factors that affect participation decisions in this program because there was no response from respondents on questions pertaining to factors affecting program participation. It was noticeable that program participants said they would still participate in the program even if there were cost increases. This indicates that the price was not a very significant factor in their decision to participate in the program. Some respondents who have their application on hold or who have withdrawn their application indicated that they would participate in the program if the costs were lower. So, price may have been a factor for some who withdrew or placed their application on hold, but stated price responsiveness was generally quite low.

### *Wenatchee Coordinated Cost Reimbursement Program*

## SURVEY RESPONSE CHARACTERISTICS

Ecology's database had a total of 37 unique applications for which contact information was available and to which surveys were sent. Three surveys were returned with at least some of the questions answered, for a response rate of 8.1 %.

## PROGRAM PARTICIPATION

Of three survey respondents who indicated their status in the program, none of them are participating in the program and one has withdrawn his/her application (33.3%). The remainder either did not answer or do not know about their status. The program participation rate in the sample is zero, suggesting that other non-respondents of the survey were likely to not participate in the program.

## FACTORS AFFECTING PARTICIPATION

Among the survey respondents, one respondent said that having a water supply from another water right or from an exempt well was an important or somewhat important factor for declining to participate in the program. Another respondent said that inability to complete the project on Ecology's timeframe requirement was an important or somewhat important factor for declining to participate in the program.

## PRICE RESPONSIVENESS

The survey included questions asking whether respondents would change their program participation decision if program fees and charges were different.

However, there were no respondents who participated in the program and the one respondent who indicated that he/she has declined to participate in the program did not answer questions pertaining to any change in his/her decision if the program fees were different.

Infrastructure costs are shown in Figure 8 (the x-axis is scaled in logarithmic terms). The two expected infrastructure costs are zero and about $3000.

A histogram of the number of years since application priority dates (as of 2016) is shown in Figure 9. The number of years since application priority dates (as of 2016) ranges from four to 24 years; the median and average number of years since priority date is 18 and 15.5, respectively. The one respondent who declined to participate in the program had been waiting for 21 years.

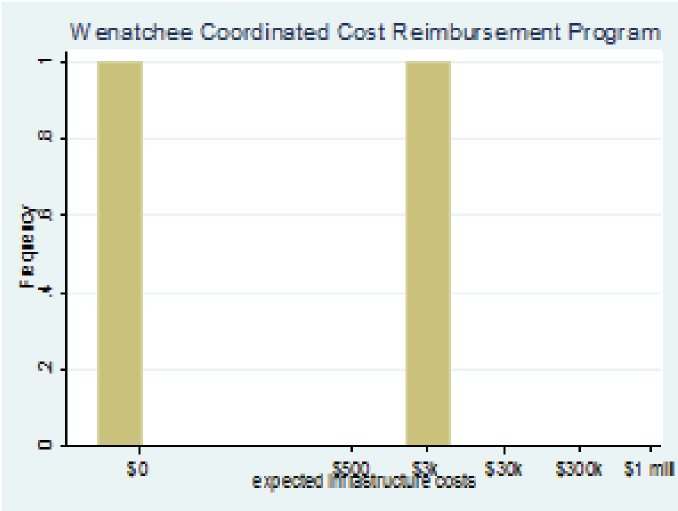



Figure 8. Expected infrastructure costs.

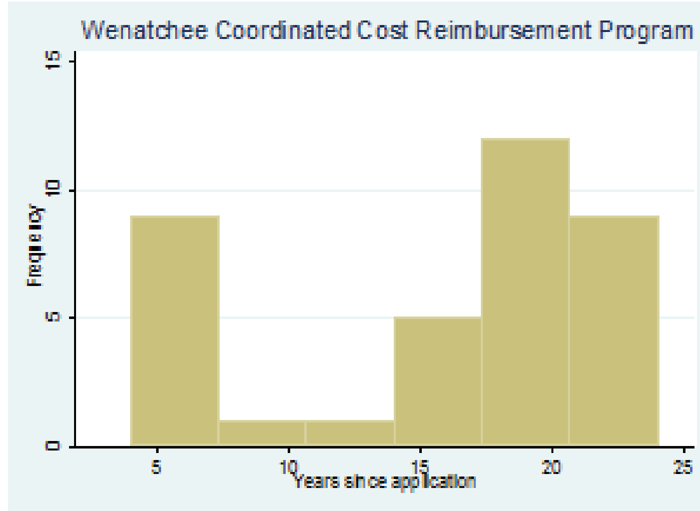



Figure 9. Time since priority date of application.

### *Port of Walla Walla Lease Program*

#### SURVEY RESPONSE CHARACTERISTICS

Ecology's database had a total of four unique applications for which contact information was available and to which surveys were sent. One survey was returned with at least some of the questions answered, for a response rate of 25 %.

#### PROGRAM PARTICIPATION

The one survey respondent who indicated his/her status in the program is participating in the program. The remaining three respondents either did not answer or do not know about their status. The program participation rate in the sample is 25%, suggesting that other non-respondents of the survey were likely to not participate in the program.

#### FACTORS AFFECTING PARTICIPATION

Among the survey respondents, one respondent said that inability to complete the project on Ecology's timeframe requirement was an important or somewhat important factor for declining to participate in the program and one respondent said that burdensome eligibility demonstration requirements was an important or somewhat important factor for declining to participate in the program.

#### PRICE RESPONSIVENESS

The survey included questions asking whether respondents would change their program participation decision if program fees and charges were different. One respondent who is participating in the program would have accepted the program even if program costs were 25% higher, while he/she would not have accepted if the program costs were 50% higher, suggesting moderate price responsiveness, but again, the sample size is too small to make inferences about the role that program fees play in water users' decisions.

### *Sullivan Lake Water Supply Project*

#### SURVEY RESPONSE CHARACTERISTICS

Ecology's database had a total of with unique applications for which contact information was available and to which surveys were sent. One survey was returned with at least some of the questions answered, for a response rate of 12.5 %.

The one survey respondent either did not answer or do not know about their status. The respondent did not answer questions pertaining to factors affecting the participation decision. The respondent also did not answer any questions related to change in decision when faced with a change in program cost and fees. There is no information on the infrastructure costs for this program. The number of years since application priority dates (as of 2016) ranges from 24 to 32 years; the median and average number of years since priority date is 24 and 25.2, respectively.

## Comparison of Ecology-Based Contracting/Bonding Finance Mechanisms with Out-of-State Programs

Because some price response by applicants is likely under all the program surveyed, the magnitude, term, and conditions for offering new water rights is an important factor in program participation.  The Forecast Team considered how other states have structured water supply programs.  In 2006, the Washington State Legislature created the Office of Columbia River with $200 million in revenue bond authority to finance water supply projects.  As of the date of this report, OCR has approximately $7 million remaining in bond authority.  The purpose of this section is to compare the bonding authority mechanisms used in Washington with those evaluated in other states.

### *Washington State Contracting Mechanism Summary*

As described in RCW 90.90.090-100, The Columbia River basin taxable bond water supply development account and the CRB water supply revenue recovery accounts are intended to fund water storage and pump exchange project planning, assessment, and implementation using taxable bonds (090) and from other sources. Ecology may enter into water service contracts with applicants receiving water from the program to recover all or a portion of the cost of water supply development.

### *Out-of-State Programs*

Various states have contracting/bonding finance mechanisms for water rights.  The most common finance mechanism in the United States is municipal bonding. A municipal bond is issued by a municipal government (state, city, or county) or its agency and purchased by individual and institutional investors. Municipal bonds can be divided into general obligation bonds and revenue bonds. General obligations bonds are issued by the government authorities and do not provide a direct source of revenue. They are repaid using general taxes. On the other hand, a revenue bond is usually paid by those who directly benefit from the project that is funded by the bond (Ajami & Christian-Smith, 2013).

In California, general obligation bonds have been extensively used to fund various water related projects in the last few decades. These bonds need to pass through both houses of the state legislature and gain voter approval. When a general obligation bond is passed in California, the voters agree to repay the bond through income taxes, corporate taxes and sales taxes that make up the state General Fund. Debt repayment has a higher priority within the General Fund. Thus, approval of general obligation bonds reduces the money available for other program financed through the General Fund. Therefore, it is not a reliable funding mechanism for projects related to water management and efficiency in the long run. Bond funds alone do not provide a steady, reliable source of funding and are subject to “boom and bust” cycles that make it difficult to plan (CA DWR et al. 2010).

Other states have different programs or agencies that finance water infrastructure or facilitate water management. In Arizona, there is an independent state agency named the Water Infrastructure Finance Authority (WIFA). WIFA manages Arizona’s water and wastewater through state revolving funds. The goal of WIFA is to maintain and improve water quality in Arizona by providing financial and technical assistance for basic water infrastructure. Public jurisdictions like cities, towns, special districts, county improvement districts and Indian tribes are eligible to get loans from WIFA. Federally owned systems, state owned systems and county owned systems are not eligible. WIFA provides loans to its applicants at or below the market interest rate and there is no associated application or closing costs.

Similarly, in Nevada, the Board for Financing Water Projects reviews, for possible approval, requests for grants for capital improvements to publicly owned and non-profit water systems submitted under the grant program and amends and adopts regulations for the grant program (NDEP, 2016). The grant program was created by the Nevada state legislature in 1991 to assist with the cost of improving publicly owned water systems in the state.

In New Mexico, the Water Project Fund was created within the New Mexico Finance Authority (NMFA) in 2001. The NMFA was charged with the administration of the Water Project Fund. Various water conservation, water reuse, water storage, water delivery and water management projects can be funded through the Water Project Fund. The NMFA makes decisions about the projects to be funded and recommends them to the state legislature (WPF, 2016).

The Oregon Water Resources Department has authority to enter a voluntary agreement with water rights applicants to expedite the processing of applications or other regulatory actions (OR DWR, 2016). Under such agreements, the applicant is responsible for paying the cost to hire additional staff, contract for services, or provide additional services to the applicant not otherwise available. Applicants interested in an estimate of the cost and timeline for expedited processing must submit a Reimbursement Authority Estimate Application along with a fee of $125.00 (OR DWR, 2016).

Various regional agencies also have been created to facilitate the financing of water infrastructure and water management. For example, the EPA Environmental Finance Center at Boise State University was created in 1995 and serves the Pacific Northwest and Intermountain states of Alaska, Idaho, Oregon and Washington with environmental financing issues related to drinking water and wastewater treatment needs in small communities (OETIEF, 2007).

## Summary and Policy Implications

This report focuses on potential reasons why Washington water rights applicants are in some cases choosing to not participate in water service programs provided by Ecology. To explore this question, the Forecast Team used data from Ecology on six existing water service programs and implemented a survey to collect data from participants and potential participants about their reasons for participation choices.

There are many possible reasons why individuals may choose not to participate. However, as noted in the introduction, we find evidence of three primary categories of reasons for program participation decisions within the six Ecology programs that were examined:

1. Many applications were submitted many years ago, and applicant circumstances have in changed to the point that the water rights application itself is of relatively less value to the applicant.

2. Potential program participants respond to cost, and some potential participants opt out of the program due to fees that Ecology charges for cost recovery.

3. Applicants sometimes choose to keep their applications on hold due to uncertainty about family or business situations, as well as uncertainty or lack of clarity about program costs and benefits, with the intent of making their decision when uncertainty is better resolved.

It is important to note that these findings do not suggest that time lags or cost-recovery programs are either good or bad from a policy or administrative perspective. Answering these questions is beyond the scope of this study. Results from the Forecast Team do suggest that these three factors affect outcomes; therefore, it may be useful to consider them for planning purposes.

Ecology faces several issues in addressing the backlog of water rights applications that are to some extent exacerbated by program non-participation. Our findings do not shed direct light on many of these challenges. However, an understanding that waiting times, cost effects, and program uncertainty have impacts on participation rates and hold-times is helpful in making policy and administrative decisions. For example, backlogs are exacerbated by applicants who subsequently choose to not participate, and so to the extent that permit application backlogs are problematic for Ecology, filtering out likely non-participants from the future applicant pool may help. There are several possible approaches this problem. Examples include:

- Ecology could adopt a new applicant form that requires more information to be submitted that is foundational to the application processing, such as a stamped hydro-geologic report, or independent 3rd party beneficial use analysis (e.g. by Certified Water Right Examiners). A higher bar to submit applications with additional information would reduce processing time and reduce speculative applications.
- Application processing fees under RCW 90.03.470 could be increased to close the gap between applicant expectations and actual costs. Application processing costs under cost-reimbursement are often on the order of $10,000 per application as opposed to applicant filing fees of $50 per application. If applicants bore a larger proportion of these subsidized costs, then speculative applications would be reduced, Ecology staffing-to-application ratios would be higher, and timelier processing would result.
- Ecology (by policy choice) currently allows applicants who are offered water with an opportunity for application processing and for their application to remain in line with all other backlogged applications if they decline such an opportunity. This practice affects Ecology's permitting backlog, especially when staff time is invested in pursuing application processing and the ultimate decision of an applicant is for their application to be "on-hold". Ecology or the Legislature could change permit backlog accounting to not include these applicants. Alternatively, applicants could be given a reasonable period of time to accept the water that has been developed, or have their application rejected. These applicants could reapply at a later date if they decided they were ready to proceed.
- The cost-reimbursement application processing statute (RCW 90.03.265) could be modified to require applicants to immediately participate in a cost-reimbursement processing program to ensure timely processing and a closer tie to expectations around cost of processing.

This study has several limitations. First, the Forecast Team relied on data for ongoing programs, and the available sample of eligible survey respondents was relatively small to begin with, especially for some individual programs. Second, the programs have substantially different structures. While this is useful in some ways for understanding how people respond to differing program structures, it also limits the extent to which data from separate programs can successfully be used together to make inferences. Third, survey response rates were of the order of 20% on average. While response rates this low or lower are common in survey-based social science research, it limits the statistical power of results. Further, because potential respondents had the choice to participate or not, participation decisions themselves can affect the outcome of analysis. For example, there is evidence that applicants who opted in to programs were more likely to complete the survey than those who opted out of participation; so our data over-represent the perspectives and situations on program participants, and under-represent non-participants. Although these issues suggest that the quantitative characteristics of the study should be interpreted with care, the qualitative patterns reported are robust and consistent with existing empirical work in related program participation studies and demand analysis in general.

These limitations of the study suggest possible improvements for planning future program rollouts, however. Survey-based demand/participation analysis such as this could be carried out prior to program roll-out to shed light on likely participation, and sample sizes may not be as limiting. Results suggest that duration since application, price concerns, and program uncertainty are topic areas to focus on when estimating likely ranges of participation rates prior to investment in water service projects.

## References

California Department of Water Resources (DWR), et al. 2010. “20x2020 Water Conservation Plan.” http://www.swrcb.ca.gov/water_issues/ht_topics/20x2020/docs/20x2020plan.pdf.

Ajami, N. and Christian-Smith, J. 2013. Beyond Water Pricing: An Overview of water Financing Options in California. Pacific Institute.

Dillman, Don A., Jolene D. Smyth, and Leah Melani Christian. Internet, phone, mail, and mixed-mode surveys: the tailored design method. John Wiley & Sons, 2014.

Nevada Division of Environmental Protection (NDEP), Board for Financing Water Projects. (n.d.). Retrieved April 06, 2016, from http://ndep.nv.gov/bffwp/bffwp.htm

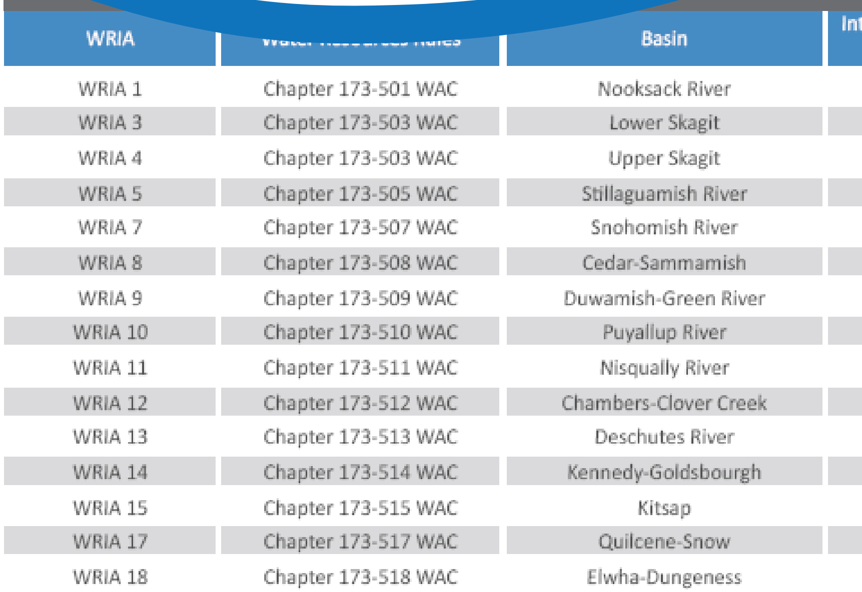
Water Project Fund (WPF). (n.d.). Retrieved April 06, 2016, from http://www.nmfa.net/financing/water-programs/water-project-fund/

Water Resources Department Reimbursement Authority (OR DWR). (n.d.). Retrieved April 06, 2016, from http://www.oregon.gov/owrd/pages/mgmt_reimbursement_authority.aspx

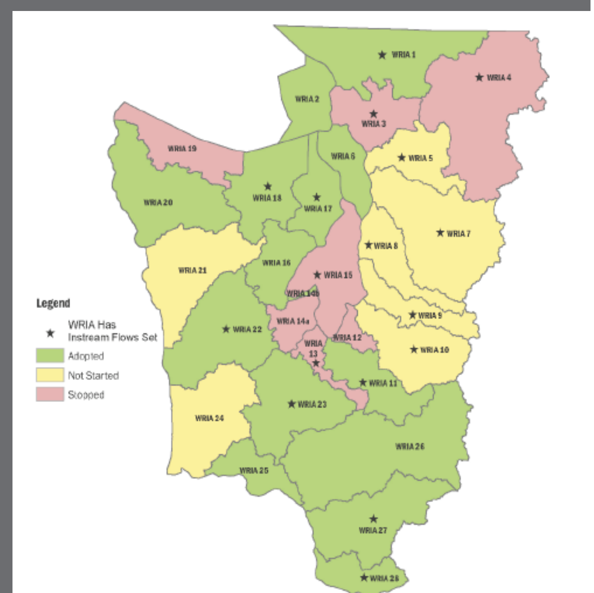
Office of the Chief Financial Officer, Office of Enterprise Technology and Innovation Environmental Finance Staff (OETIEF). 2007. Tools for Financing Water Infrastructure.

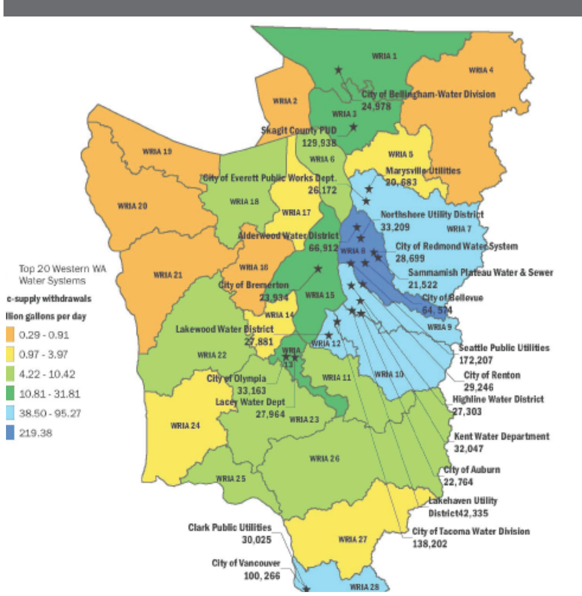
# Western Washington
# Supply and Demand Forecasting

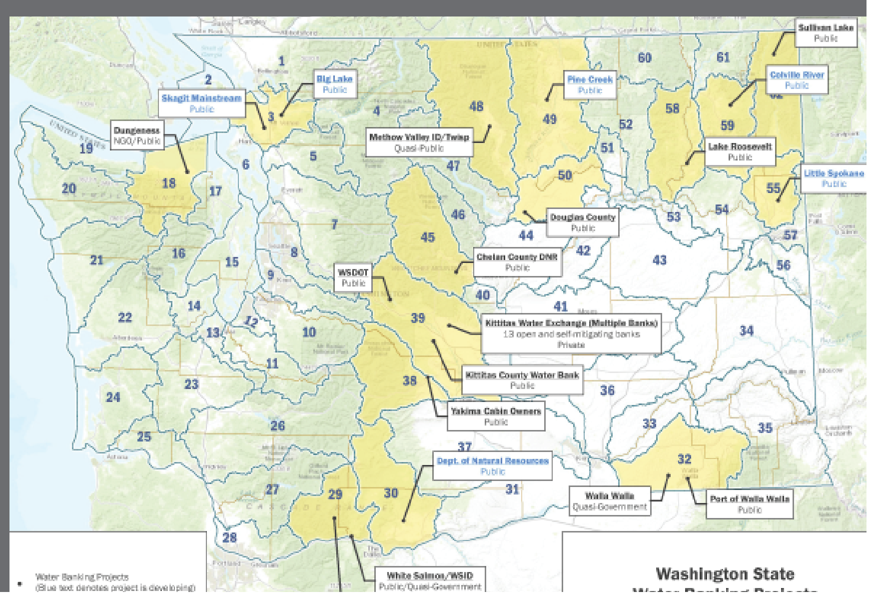
This module was originally published in the 2016 Legislative Report (Ecology Publication No. 16-12-001), and no additional detail is provided in this Technical Supplement



| WRIA | Water Resources Rules | Basin | Int |
|---|---|---|---|
| WRIA 1 | Chapter 173-501 WAC | Nooksack River | |
| WRIA 3 | Chapter 173-503 WAC | Lower Skagit | |
| WRIA 4 | Chapter 173-503 WAC | Upper Skagit | |
| WRIA 5 | Chapter 173-505 WAC | Stillaguamish River | |
| WRIA 7 | Chapter 173-507 WAC | Snohomish River | |
| WRIA 8 | Chapter 173-508 WAC | Cedar-Sammamish | |
| WRIA 9 | Chapter 173-509 WAC | Duwamish-Green River | |
| WRIA 10 | Chapter 173-510 WAC | Puyallup River | |
| WRIA 11 | Chapter 173-511 WAC | Nisqually River | |
| WRIA 12 | Chapter 173-512 WAC | Chambers-Clover Creek | |
| WRIA 13 | Chapter 173-513 WAC | Deschutes River | |
| WRIA 14 | Chapter 173-514 WAC | Kennedy-Goldsbourgh | |
| WRIA 15 | Chapter 173-515 WAC | Kitsap | |
| WRIA 17 | Chapter 173-517 WAC | Quilcene-Snow | |
| WRIA 18 | Chapter 173-518 WAC | Elwha-Dungeness | |



# Water Supply and Demand Issues

Washington State has increasing demands on water resources that are not limited to the Columbia River Basin. For this reason, preliminary planning efforts to extend long-term water forecasting work to Western Washington have been initiated as part of preparing the 2016 Columbia River Basin long-term supply and demand forecast. This report outlines the overall approach and available resources to be considered in extending the next update to the forecast, scheduled for 2021, to Western Washington.

Planning for extension of the forecast to Western Washington would be advantageous because it would:

- Provide a foundation for long-term management of Washington's water supply to address increases in water demand associated with growth, anticipated stresses on water supply due to climate change, and prioritization of funding for water management projects.
- Support evaluation of statewide water supply and demand trends;
- Fill in planning gaps in watershed planning jurisdictions that did not participate or did not adopt a watershed plan; and
- Allow budgetary planning for water supply projects that considers statewide supply issues and priority needs.
- Support potential collaboration with other states that have state water plans, such as Oregon, Idaho, and 33 states that either have adopted state water plans or have state water plans in progress;

## Regulatory, Legal, Policy Framework

The following sections provide a summary of the key regulatory, legal, and policy issues that would need to be considered in moving towards a statewide planning effort.

### Statutory Authorities for Planning and Forecasting

Sufficient planning authority exists in Washington to support development of a State Water Plan by the Department of Ecology. Some of the key planning authorities that would be used to support such development include:

- The Legislature gave Ecology broad planning authority to accomplish its environmental mission in RCW 90.54.010(1)(e): "The long-term needs of the state require ongoing assessment of water availability, use, and demand. A thorough inventory of available resources is essential to water resource management. Current state water resource data and data management is inadequate to meet changing needs and respond to competing water demands. Therefore, a state water resource data program is needed to support an effective water resource management program. Efforts should be made to coordinate and consolidate into one resource data system all relevant information developed by the department of ecology and other agencies relating to the use, protection, and management of the state's water resources."
- Under Chapter 90.82 RCW Watershed Planning Act, the Legislature provided comprehensive supply and demand authority. "The legislature finds that the local development of watershed plans for managing water resources and for protecting existing water rights is vital to both state and local interests."

### Instream Flow Rules

Instream flow rules have been established in many watersheds in subsections of Title 173 of the Washington Administrative Code (WAC), to support the mandate outlined in RCW 90.54.005 of providing sufficient water and habitat for fish. Establishment of instream flows also set priority dates for flows corresponding to the dates of each rule. As a result, new surface water rights approved in these basins are interruptible when instream flows are not met, unless approved mitigation has been established. In most areas, groundwater and surface water are considered by Ecology to be hydraulically connected, and newer post-rule unmitigated groundwater rights are also interruptible. As a result, it has become increasingly difficult to obtain new reliable water rights and corresponding water supplies.

In the OCR forecasts, WSU worked with Ecology's database to forecast how well instream flows are likely to be met in the future, and the effect of interruption on out-of-stream uses. This included:

- Comparing instream flow rule flows to different water year scenarios (e.g. dry, average, wet).
- Forecasting current and future shortfalls in meeting instream flows on a weekly basis.
- Forecasting the current and future risk of interruption to junior water users. A summary of interruptible water users by Western Washington watershed is provided in Table 1 below.

These same curtailment methodologies are applicable to Western Washington.

## Seawater Intrusion

Seawater intrusion is the movement of seawater into fresh water aquifers caused by natural processes or human activities, including pumping of groundwater. Intrusion of seawater into fresh water aquifers results in elevated chloride and sodium levels that in sufficient concentrations can render water non-potable. A general rule of thumb is that approximately 100 milligrams per liter (mg/L) of chloride is indicative of seawater intrusion, and concentrations over 250 mg/L chloride (EPA's secondary maximum contaminant level and DOH's drinking water limit) result in significant taste effects. All coastal areas in Washington State have the potential for seawater intrusion, and numerous cases of seawater intrusion have been documented, particularly in island communities. For example, Whidbey, Lopez, Marrowstone, Guemes Islands all have areas where seawater intrusion has been documented.

While Ecology does not have a formal seawater intrusion policy, several coastal counties have adopted policies on seawater intrusion. Examples include:

- Skagit County has an Interim Seawater Intrusion Policy that was adopted in 1994 and is currently being updated. The updated policy requires wells located at a distance of less than ½ mile from the coast to limit pumping rates to one, two, or three gallons per minute maximum, depending on measured chloride levels.
- Jefferson County has established seawater intrusion protection zones (SIPZs), which are defined as all land within ¼ mile of marine shorelines and additional areas within 1000 feet of a groundwater source with a history of chloride analyses above 100 mg/L have designations of 'at risk' or 'high risk', depending on chloride concentrations. County requirements include monitoring of chloride levels and groundwater pumping rates, and in high risk cases, a hydrogeologic assessment. Island County has implemented a similar approach based on risk levels and chloride concentrations.

Extension of water supply forecasting to Western Washington will need to consider limitations on local water supplies caused by seawater intrusion risks and prevention.

## Tidal Effects

All of the coastal counties in Western Washington have surface water bodies that are subject to tidal influences. For example, tidal influences on the Green-Duwamish river system extend approximately 11 miles upstream from river mouth, while the Columbia River has tidal effects that extend beyond the City of Vancouver, more than 100 miles upstream.

Water availability can be influenced by tidal effects on surface water systems. In watersheds where instream flow rules that limit water availability are in place, restrictions on water available may only be in place upstream from the influence of the mean annual high tide occurrence at low instream flow levels. For example, the instream flow rule for the Green-Duwamish River basin (WAC 173-509) specifically limits rule restrictions to upstream of approximately River Mile 11, the limit of tidal effects. Other instream flow rules, such as the Elwha-Dungeness River rule (WAC 173-518) restrict flows from the river mouth, regardless of tidal influence. Given the variability among instream flow rules in this regard, extension of the forecast to Western Washington will need to consider water availability in tidally-influenced areas on a case-by-case basis.

## Rainwater Collection

Rainwater collection by individual property owners provides a contribution to water availability in Western Washington. In certain areas, such as the San Juan Islands, rainwater harvesting is fairly commonplace.

In 2009, Ecology clarified its policy on rainwater collection, through the document 'Water Resources Program Policy Regarding Collection of Rainwater for Beneficial Use' (POL 1017). This policy includes the following language stating the purpose of the policy is to:

- "Clarify that a water right is not required for on-site storage and use of rooftop or guzzler collected rainwater."
- "Identify the Department of Ecology's intent to regulate the storage and use of rooftop of guzzler collected rainwater if and when the cumulative impact of such rainwater harvesting is likely to negatively affect instream values or existing water rights."

Based on this policy, the on-site storage and beneficial use of rooftop or guzzler collected rainwater is not subject to the permit process of RCW 90.03 (the state water code).

As part of extending the forecast to Western Washington, existing and potential use of rainwater will need to be considered as a component of water availability.

Table 1. Western WA Interruptible Water Rights by WRIAs

| WRIA | Water Resources Rules | Basin | Interruptible Water Rights |
|---|---|---|---|
| WRIA 1 | Chapter 173-501 WAC | Nooksack River | 118 |
| WRIA 3 | Chapter 173-503 WAC | Lower Skagit | 54 |
| WRIA 4 | Chapter 173-503 WAC | Upper Skagit | 10 |
| WRIA 5 | Chapter 173-505 WAC | Stillaguamish River | 27 |
| WRIA 7 | Chapter 173-507 WAC | Snohomish River | 100 |
| WRIA 8 | Chapter 173-508 WAC | Cedar-Sammamish | 94 |
| WRIA 9 | Chapter 173-509 WAC | Duwamish-Green River | 42 |
| WRIA 10 | Chapter 173-510 WAC | Puyallup River | 67 |
| WRIA 11 | Chapter 173-511 WAC | Nisqually River | 36 |
| WRIA 12 | Chapter 173-512 WAC | Chambers-Clover Creek | 9 |
| WRIA 13 | Chapter 173-513 WAC | Deschutes River | 63 |
| WRIA 14 | Chapter 173-514 WAC | Kennedy-Goldsbourgh | 29 |
| WRIA 15 | Chapter 173-515 WAC | Kitsap | 95 |
| WRIA 17 | Chapter 173-517 WAC | Quilcene-Snow | 25 |
| WRIA 18 | Chapter 173-518 WAC | Elwha-Dungeness | 26 |
| WRIA 22 | Chapter 173-522 WAC | Lower Chehalis River | 78 |
| WRIA 23 | Chapter 173-522 WAC | Upper Chehalis River | 338 |
| WRIA 25 | Chapter 173-525 WAC | Grays-Elochoman | 4 |
| WRIA 26 | Chapter 173-526 WAC | Cowlitz | 75 |
| WRIA 27 | Chapter 173-527 WAC | Lewis | 34 |
| WRIA 28 | Chapter 173-528 WAC | Salmon-Washougal | 49 |
| Total | | | 1373 |

## Legal Decisions Affecting Water Resources

Several recent legal decisions, pending cases, and policy initiatives are affecting or will potentially affect the availability of water supplies in Western Washington. In several basins statewide (e.g., Skagit, Dungeness, Kittitas, Yakima, Nooksack), regulatory uncertainty over legal water availability has created economic conditions that are politically challenging for counties. Specific examples include the following:

- In 2001, junior surface water users in the Yakima Basin, including 1,000 cabin owners and the City of Roslyn, were given a court-ordered water use curtailment. The curtailment resulted in a drop in property values, inability to obtain bank loans for refinancing, a less attractive market for cabin sales, and insurance challenges.
- In 2006, new groundwater use was restricted in the Upper Kittitas basin resulting in work stoppages on active homebuilding projects, and the inability to access bank loans.
- In 2013, a Washington State Supreme Court Decision (Swinomish Indian Tribal Community v. Ecology) invalidated a portion of an instream flow rule based on Overriding Considerations of the Public Interest (OCPI) that allowed exempt well development in Skagit and Snohomish Counties. As a result, approximately 500 existing homeowners and many undeveloped property owners are now faced with property devaluation, and the inability to access bank loans for refinancing and home sales.
- In 2015, the State Supreme Court cancelled the city of Yelm's water right permit. In reversing Ecology's approval of the Yelm's permit, the Court ruled that Ecology had also erroneously used the OCPI determination and violated existing instream flows. Ecology had conditioned approval on an "out-of-kind" mitigation package, based on a combination of retiring existing water rights, habitat protection, and stream restoration, to offset the water use from the permit. This decision suggests that any mitigation scenario that is not 'water for water' will no longer obtain approval from Ecology.

Case law on groundwater exempt use, impairment of instream flows, conjunctive management of surface and groundwater, county building permit and Growth Management Act (GMA) responsibilities, OCPI standards continue to be clarified by the court system. A key pending case under review by the state Supreme Court is:

- Whatcom County v. Hirst. The pending decision on this case could have significant ramifications for use of exempt wells and rural water supply in Western Washington. The lower court decision essentially directed local governments to follow Ecology's interpretation of instream flow rules. According to the decision, if Ecology interprets a particular instream flow rule to provide a specific exemption for domestic exempt wells, then a county can rely on that interpretation in making water availability determinations related to land use decisions. This is considered the case even if there are unmet senior instream flows. The current decision also acknowledges that each instream flow rule must be interpreted individually.

## Rural Water Supply Workshops

Ecology is leading a series of Rural Water Supply workshops with stakeholders, with a mission to find solutions to rural water supply limitations. Balancing instream and out of stream water uses has been a significant challenge for Ecology, especially in recent years. One goal of this process is to determine whether legislative action is appropriate in the future to address the limitations imposed by the courts on OCPI interpretations. Without new tools, future rural development in many basins could be significantly restricted by adoption of an instream flow rule. If this path is taken, it may take multiple legislative sessions for an agreement to be reached.

Ecology facilitated a number of meetings starting in 2014 and completed a report at the end of that year, with additional meetings being held on an ongoing basis.

## Water Availability Guidance for Counties

Ecology has also been working collaboratively with county representatives and interested stakeholders to update the 1993 Guidelines on determining water availability for new buildings. This ad hoc workgroup is developing guidance to assist counties in GMA requirements related to protection of water resources. Goals of this process include developing:

- Clear, specific guidance regarding legal water availability for local governments to use when making land use decisions is important to Ecology.
- A guidance tool that both local government and Ecology staff can use to aid this decision-making process is necessary to fulfill the obligations of state and local government.

Updating water availability guidance is linked with Ecology's development of a rural water strategy.

# Key Stakeholders

Key stakeholders that should be considered during extension of the supply and demand forecast to Western Washington include, state, county, and local regulatory and planning agencies, municipal and domestic water purveyors, agricultural groups and irrigation districts, hydropower operators. In addition to these, there are several regional stakeholder forums where water issues are regularly discussed.

The Washington State Department of Health (DOH) tracks water use from water purveyors and is a source of current and projected demand information from Water System Plans filed by purveyors. Water purveyors are periodically updating water demand projections as part of water system planning. Stakeholders with sources of information on water use and demand include:

- Cities
- Counties (comprehensive plans)
- DOH water use tracking
- Office of Financial Management (for supporting population estimates)
- United States Geological Survey (USGS) water projections

Agriculture is significant in Western Washington. According to the Washington State Department of Agriculture, there are 16,345 working farms with a wide variety of crops/animals in Western Washington. Agricultural stakeholders include:

- Washington State Water Resources Association (WSWRA)
- Washington State Farm Bureau (WSFB)
- Washington State Department of Agriculture (WSDA)
- United States Department of Agriculture (USDA)
- Office of Farmland Preservation (OFP)

Western Washington contains 25 hydroelectric sources (dams/plants). These hydroelectric sources are managed by various public utility districts and the Northwest Power and Conservation Council, which should be consulted to help inform forecasts of hydropower demand.

The Washington State Department of Fish and Wildlife (WDFW) helped coordinate the instream flow portion of the OCR Supply and Demand Forecast, and produced an Instream Atlas for key Columbia River tributaries. WDFW was consulted to help inform the basis for projections of instream flow demand, and the effects of potential supply changes on instream flows over time.

Several other regional stakeholder groups have an interest or can potentially provide information to support water supply and demand forecasting:

- Puget Sound Partnership – This is a state agency that focuses on efforts to restore and protect Puget Sound. It has an Action Agenda that identifies key ongoing programs, local priority actions, and other actions to be implemented on a biannual basis.

- Water Resource Advisory Council (WRAC) – This is an Ecology convened public forum for the exchange of information on water resources management in Washington. Topics include proposed rules, policies, legislation, legal constraints, budgetary issues, and drought responses.
- Climate Impacts Group (CIG) – This University of Washington based study group supports the development of climate resilience by advancing understanding and awareness of climate risks.
- Washington Water Utilities Council (WWUC) – A committee that monitors legislation that affects water utilities in Washington in an effort to ensure adequate high-quality potable water can be provided at the lowest reasonable cost.
- Chehalis Basin Work Group – Under the direction of the Governor in 2014, the Chehalis Basin Work Group developed a recommended suite of actions that would reduce flood damages in the near term, restore habitat for aquatic species, and consider long-term, large-scale flood damage reduction actions. The recommended suite of actions is known as the Chehalis Basin Strategy. The Strategy is a comprehensive and integrated approach to implementing flood damage reduction and aquatic species restoration actions in the Chehalis Basin.
- Watershed Planning Units – Local watershed plans are the expression of the public interest under RCW 90.82. Active planning units have detailed supply and demand information that would be useful for the forecast.

Although many of these organizations exist in the Eastern Washington community, the Office of Columbia River found it useful to form a Policy Advisory Group (PAG) that helped inform specific policy issues basin-wide, include the Forecast Effort (Figure 1). Ecology could consider whether a broad Statewide interest PAG might be appropriate.

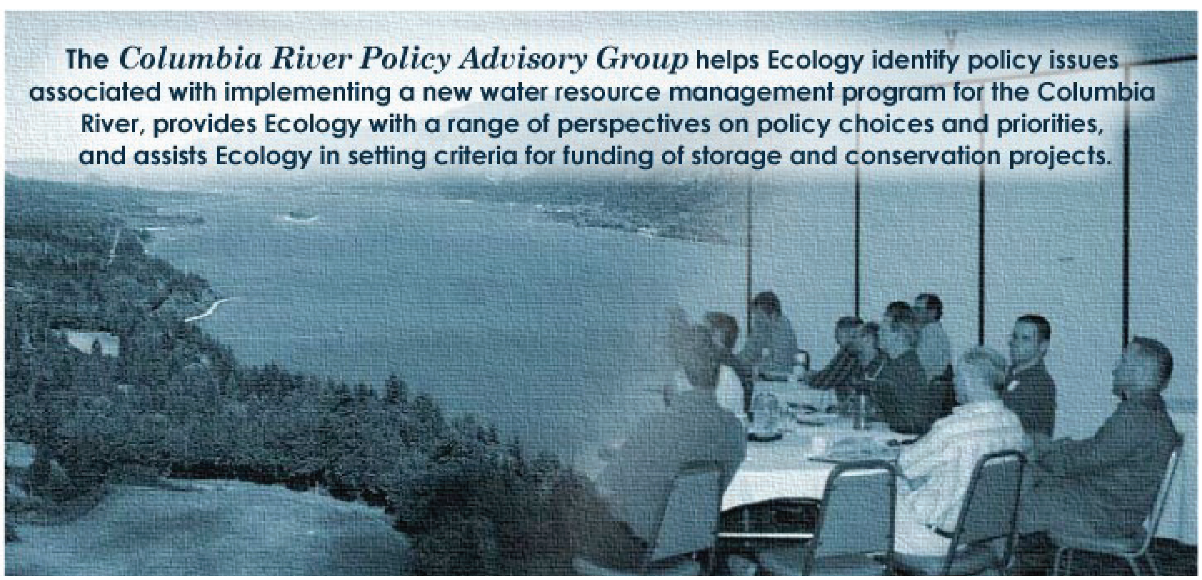



Figure 1. Columbia River Policy Advisory Group

# Key Published Documents and Supporting Data

In order to move towards a state water planning effort, we considered the availability of key published documents and supporting data that were foundational to the eastern Washington forecast, and their availability in western Washington. The following sections summarize key data sources and planning efforts that are available.

## Watershed Plans (WRIA)

There are 28 Water Resource Inventory Areas (WRIAs) in Western Washington under the Watershed Management Act (RCW 90.82/ESHB 2514), which are illustrated in Figure 2. Of the 28 watersheds, 15 have plans that have been adopted, seven have plans that have been started but not finished, and seven have not conducted planning. Instream flow rules are in place for 18 of the watersheds. Each adopted watershed plan required robust public participation. The plans outline the planning process, review technical assessment and findings, analyze alternatives, recommend an implementation program, and provide access to further pertinent documentation.

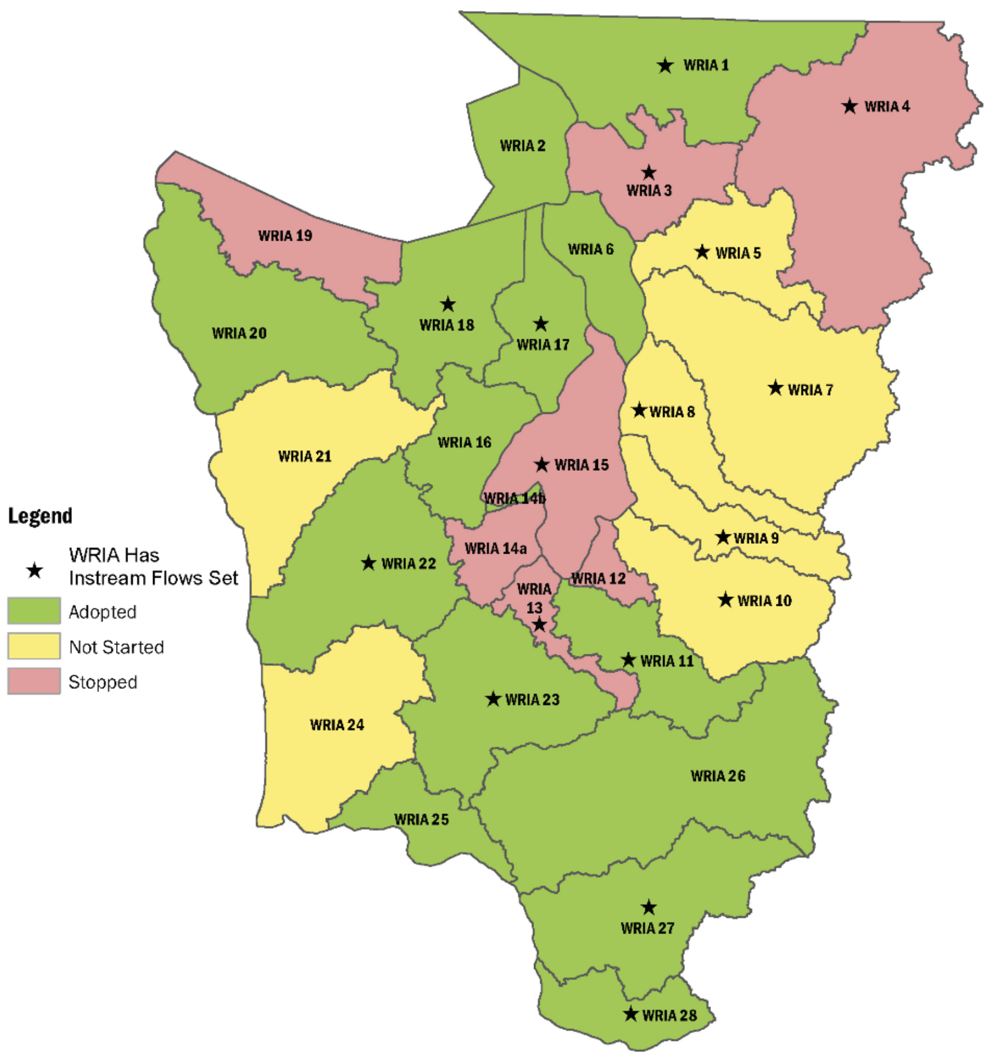



Figure 2. Western Washington WRIAs and Watershed Planning Status

# Comprehensive Water System Plans

Water system plans are required to be submitted to DOH for Group A systems and periodically updated. These planning documents provide key information on both water supply and current and future water demand.

Group A water systems have 15 or more service connections or regularly serve 25 or more people 60 or more days per year. State law requires all Group A public water systems to apply for an annual operating permit. (See Chapter 246-294 WAC.)

Group B public water systems serve fewer than 15 connections and fewer than 25 people per day. The Office of Drinking Water and local health jurisdictions regulate Group B systems in our state. (See Chapter 246-297 WAC.)

Figure 3 summarizes the number and types of water systems in Western Washington based on recent DOH information. Based on estimated public water system use, the top 20 Western Washington water systems are shown in Figure 4.

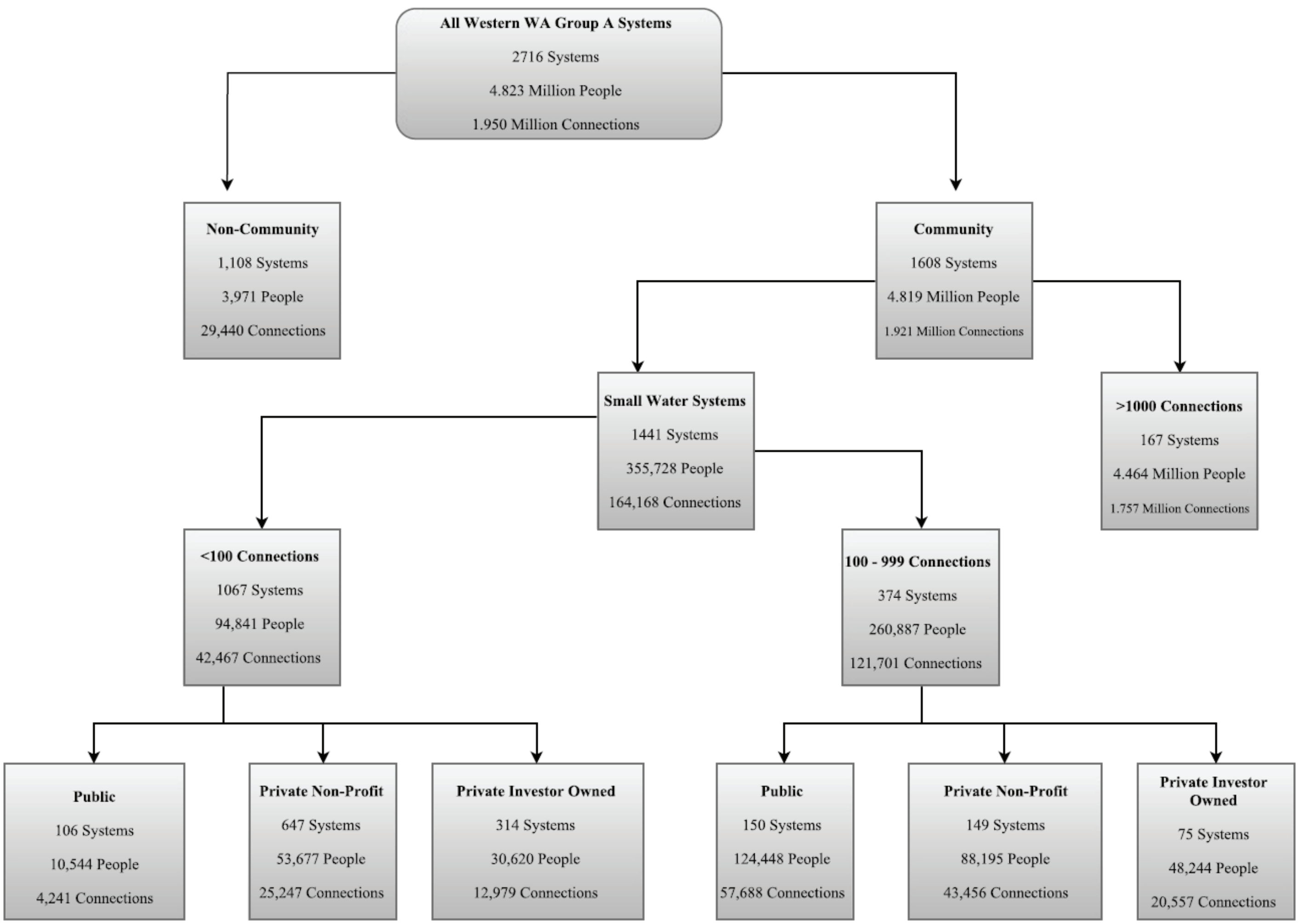



Figure 3. Summary of Water Systems in Western Washington

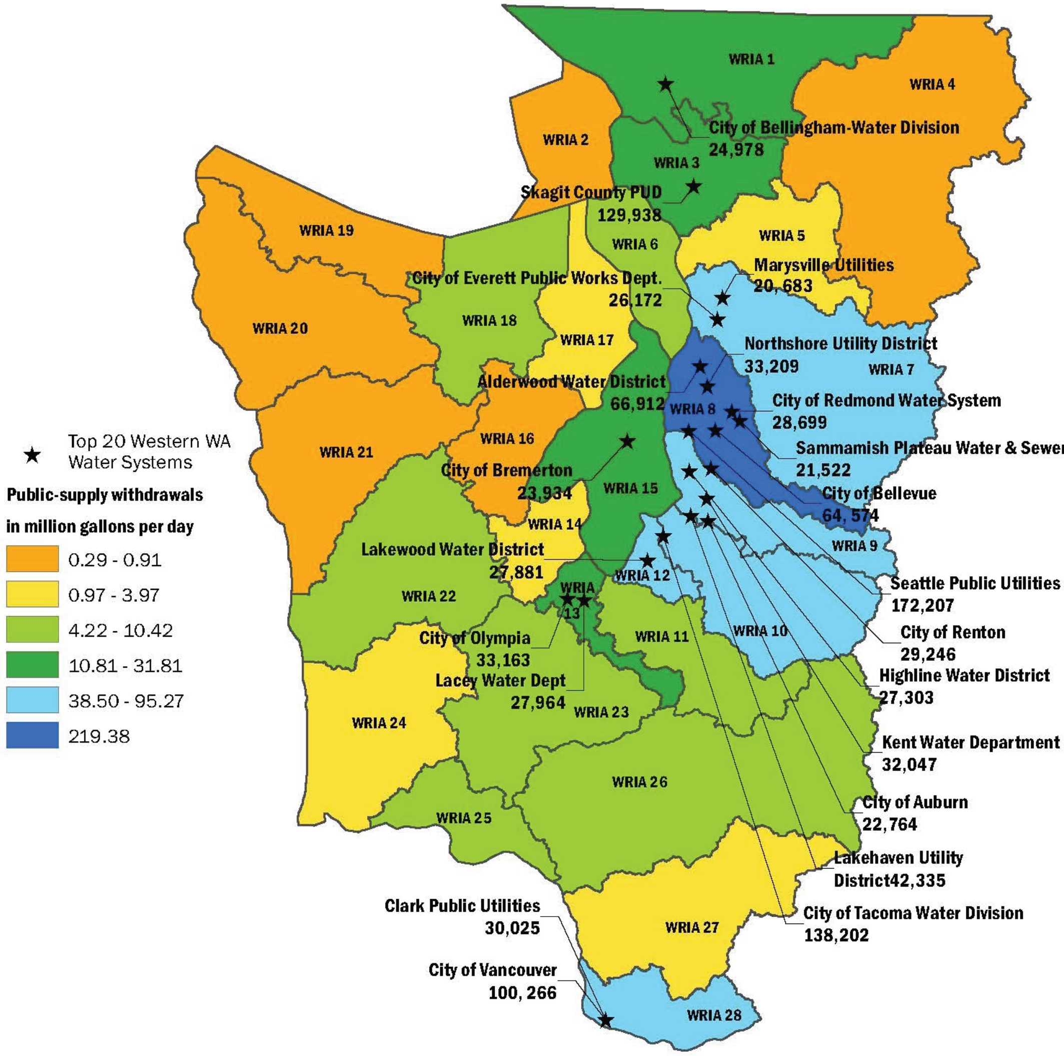



Figure 4. Estimated Public Water System Use and Top 20 Systems in Western Washington

# Growth Management Act Planning

Growth management planning is mandated in Washington State under the 1990 Growth Management Act (GMA) (RCW 36.70A) and can influence regional water demand patterns. Of the 19 counties in Western Washington, 11 counties are mandated to plan. In addition, one more county opted to plan, and four counties planned for critical areas and resource lands only.

GMA requires state and local governments to manage Washington's growth by identifying and protecting critical areas and natural resource lands, designating urban growth areas, preparing comprehensive plans and implementing them through capital investments and development regulations. Counties planning under GMA are required to adopt county-wide planning policies to guide plan adoption within the county and to establish urban growth areas (UGAs). State agencies are required to comply with comprehensive plans and development regulations of jurisdictions planning under the GMA.

Reference to the adopted plans can support an understanding of areas of significant population growth and increasing water demands. Figure 5 illustrates the extent of GMA planning in Western Washington.

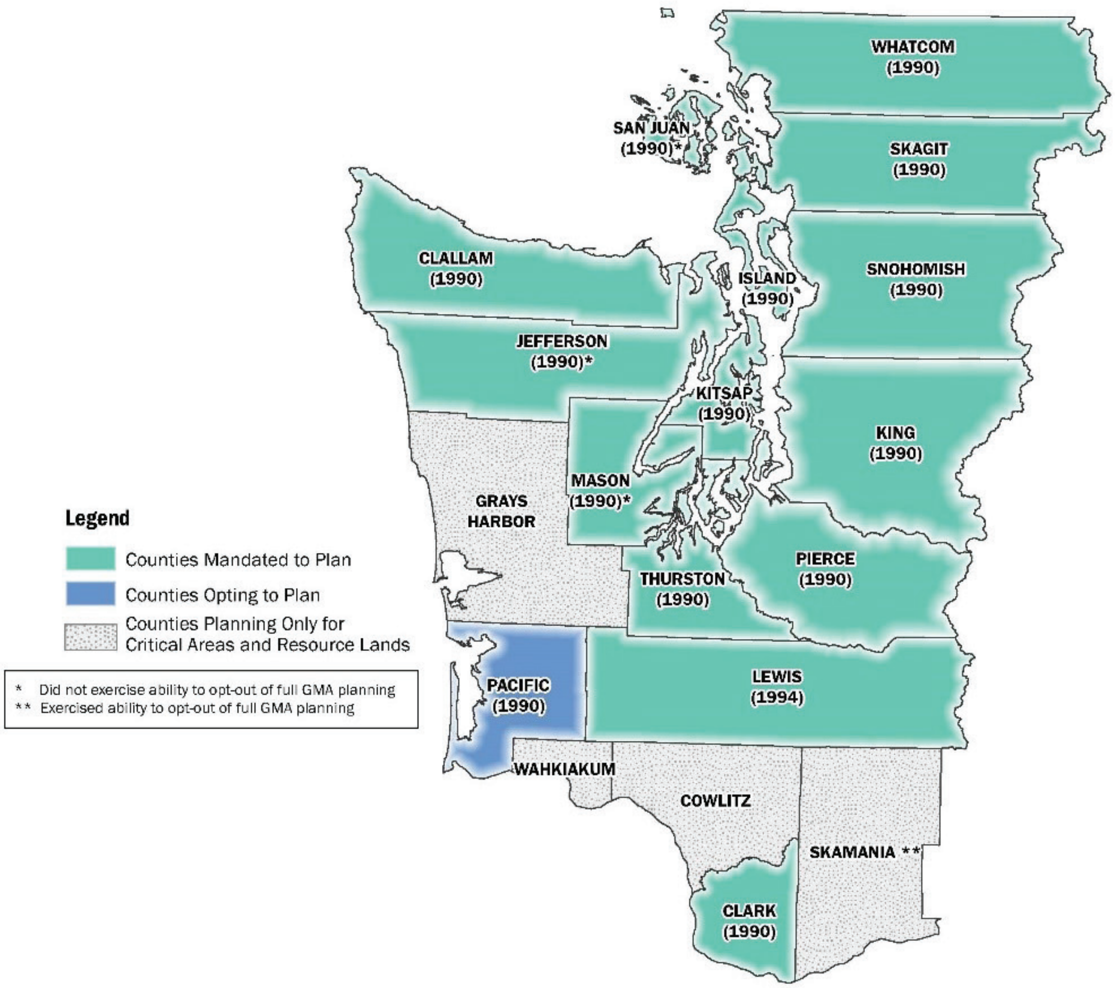



Figure 5. Growth Management Planning in Western Washington

Under the GMA, a Critical Aquifer Recharge Area (CARA) ordinance protects drinking water by preventing pollution and maintaining supply. The GMA defines CARAs as “areas with a critical recharging effect on aquifers used for potable water.” A Critical Aquifer Recharge Areas Guidance Document provides details on these steps. The following steps characterize where groundwater resources are important to the community and how to protect them.

- Identify where groundwater resources are located.
- Analyze the susceptibility of the natural setting where ground water occurs.
- Inventory existing potential sources of groundwater contamination.
- Classify the relative vulnerability of ground water to contamination events.
- Designate areas that are most at risk to contamination events.
- Protect by minimizing activities and conditions that pose contamination risks.
- Ensure that contamination prevention plans and best management practices are followed.
- Manage groundwater withdrawals and recharge impacts to:
- Maintain availability for drinking water sources.
- Maintain stream base flow from ground water to support in-stream flows, especially for salmon-bearing streams.

All cities and counties are required to plan for critical areas. For example, King County has 5 Groundwater Management Areas: East King County, Issaquah Creek Valley, Redmond-Bear Creek Valley, South King County, and Vashon-Maury Island.

# Stream Gauging

The USGS and Ecology collect streamflow data from stream gauging in Western Washington. The USGS collects data continuously at almost 400 streamflow, reservoir, water-quality, meteorological and groundwater sites in Washington State. Most of these data are transmitted via satellite and posted on-line in near real time.

The Department of Ecology's Environmental Assessment Program maintains a network of stream gauging stations that produce near real-time streamflow data for rivers and streams across the state. The networks of Western Washington Ecology and USGS stream gauges are shown on Figures 6 and 7, respectively.

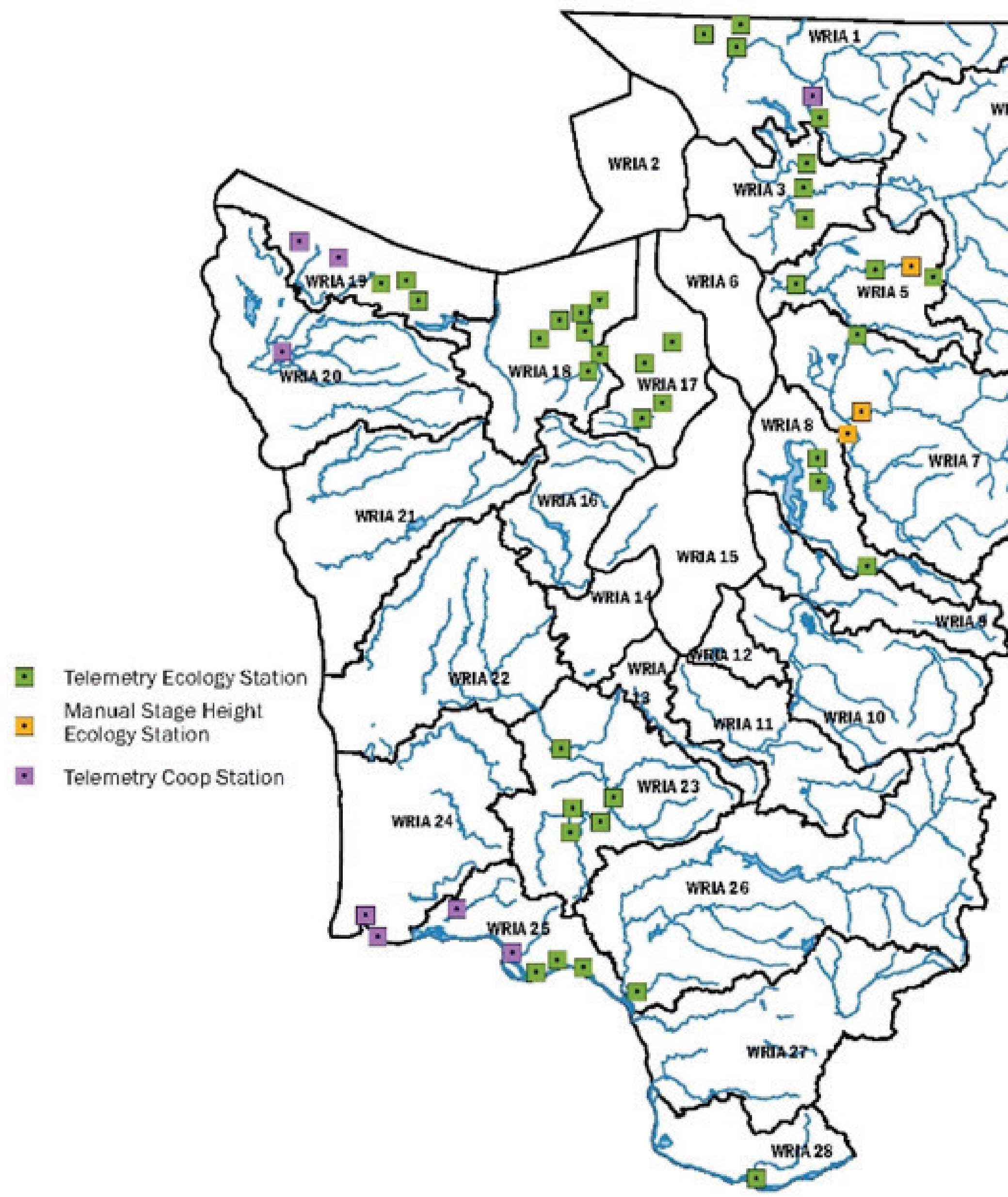



Figure 6. Ecology Stream Gage Network

# Key Surface and Groundwater Studies

A number of studies have been completed that focus on surface and groundwater supplies in Western Washington. Many water systems rely primarily on surface water derived from mountain snowpack and runoff, but groundwater is an important source of supply for many communities and for exempt well use. Several studies have also focused on evaluating hydraulic connection between surface water and groundwater.

Key surface and groundwater studies for reference in extending the supply and demand forecast to Western Washington can be found in the bibliography and include: regional models, watershed studies, county-led studies, including groundwater management plans.

For the OCR Forecast, initial planning efforts focused on surface water supplies only and groundwater was presumed to not be limiting for existing or future demand. In the 2016 Forecast, additional effort was made to characterize 10 areas in Eastern Washington where declining groundwater has a significant effect on supply to agricultural, municipal, and industrial users, as well as conjunctive impacts on instream flows. For the 2021 OCR Forecast, a more robust curtailment model is planned in areas with declining groundwater to more accurately reflect economic and environmental impacts. Similar scrutiny should be given to basins or areas in Western Washington where groundwater supplies may be limited.

## Climate Change Considerations

Climate change considerations in Western Washington are largely similar to overall considerations for the entire Pacific Northwest region where model predictions point to warmer temperatures, decreases in summer precipitation, increases in winter precipitation, more precipitation as rain instead of snow, reduced snowpack and earlier snowmelt, all of which affect seasonality and magnitude of water availability and demands. In addition, the coastal regions in Western Washington are directly affected by sea level rise. Key studies related to climate change in Western Washington are listed in the bibliography.

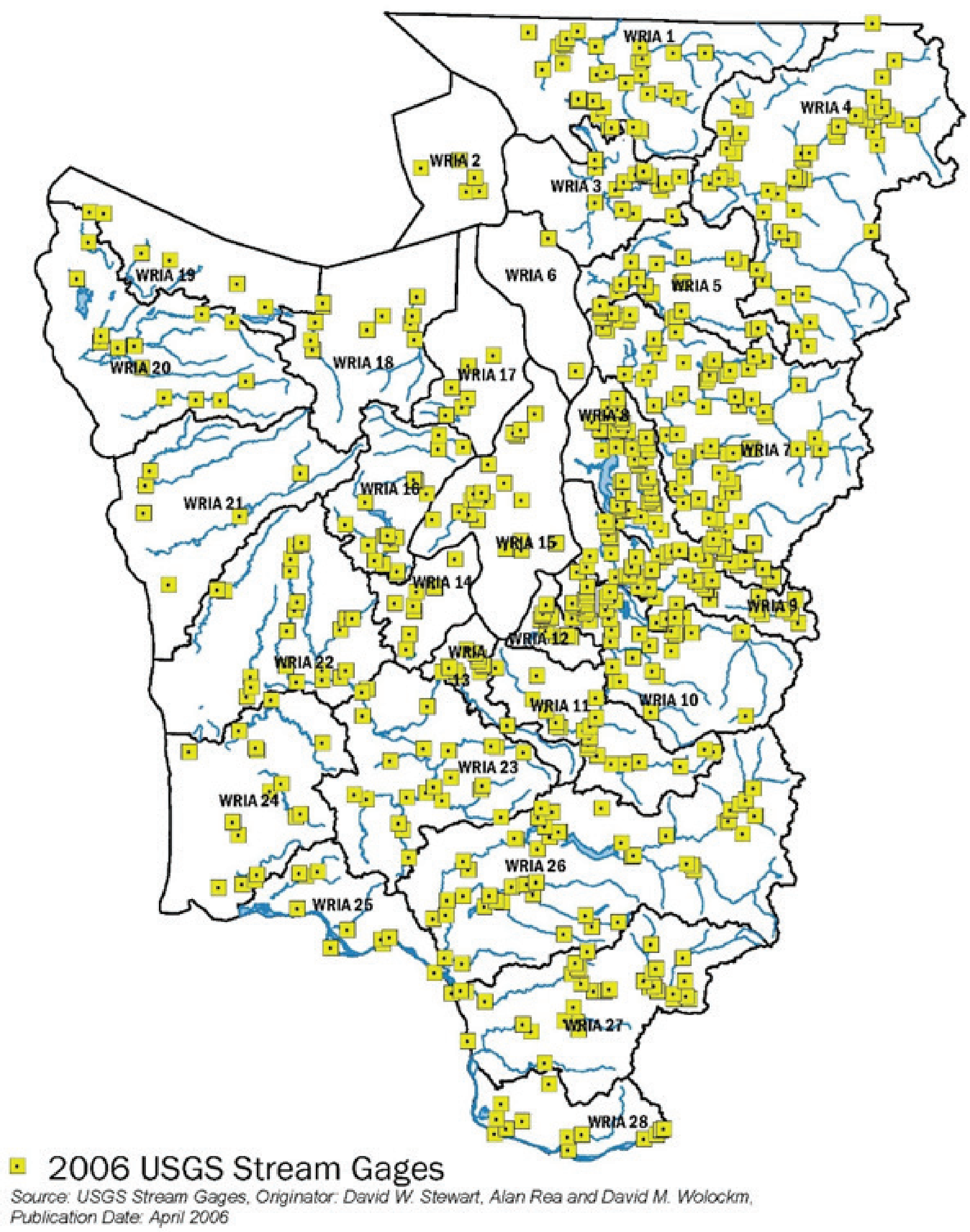



Figure 7. USGS Stream Gauges in Western Washington

Stakeholders have implemented various means of response to water supply limitations. These include water banking, conservation, and alternative source development, which are described in the following sections.

## Water Banking

Water banking is a water reallocation tool that can benefit both existing water rights holders and provide water for new uses to meet growing and changing water demands. The overall goal of a water bank is to facilitate water transfers using market forces. Figure 8 describes how a water bank bridges supply and demand needs.


Figure 8. Water Bank Process Diagram

Objectives of water banking often include:

- Reallocating reliable water supplies during dry years;
- Creating seasonal water supply reliability;
- Ensuring future water supplies for people, farms, and fish;
- Promoting water conservation;
- Maximizing water right extent and validity; and
- Ensuring compliance with instream flow rules and intrastate water agreements.

The majority of water banks in Washington are in Eastern Washington, but more are expected to develop in Western Washington over the next several years. Figure 9 depicts where water banks are currently operating or being studied throughout Washington State.

Water banking has been implemented or is in the process of being implemented in the following watersheds in Western Washington:

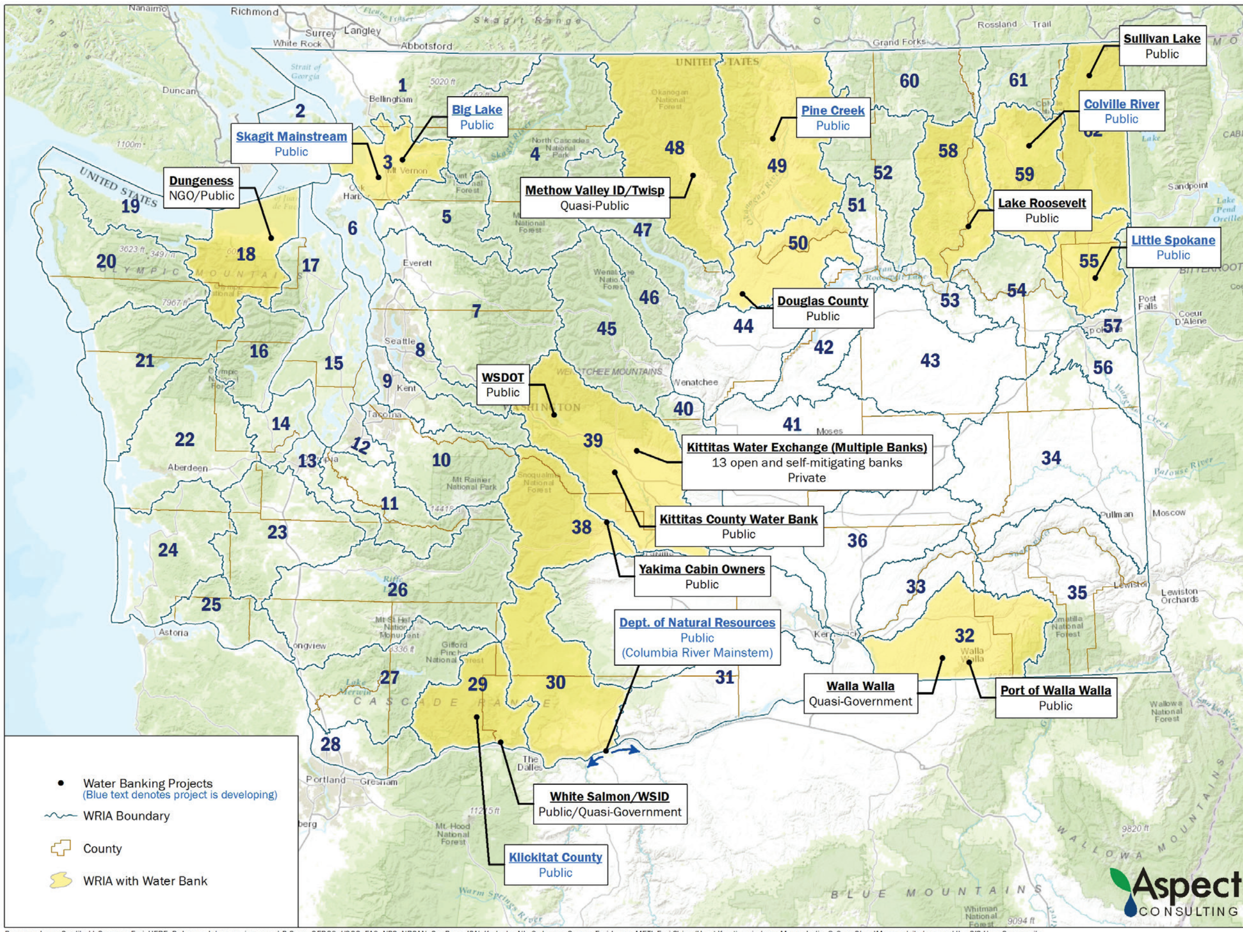


Figure 9. Water Banking in Washington.

- Dungeness Water Exchange (DWE) (active) – On January 2, 2013, the Dungeness Water Management Rule (Dungeness Rule) was adopted by Ecology. The Dungeness Rule is guides water use planning and decision-making for new water users, and sets policies to help protect the availability of water for current and future needs of people and the environment. All water use established after the Dungeness Rule was implemented needs to be mitigated. The DWE has restoration and mitigation programs. The mitigation packages are described below.

**Mitigation Package Descriptions**

| Package Description | Average Amount of Indoor Use (Gallons/Day) | Average Amount of Outdoor Use (Gallons/Day) | Amount of Irrigated Lawn Area (Square Feet) | Amount of Irrigated Lawn Area (Acres) |
|---|---|---|---|---|
| Indoor Only Package (minimal incidental outdoor use only) $1,000 | 150* (average) | 0 | 0 | 0 |
| Indoor with Basic Out-door Package $2,000 | 150* (average) | 89 | 2,500 sq. ft. (approx. 50 x 50 ft.) | .06 acres |
| Indoor with Extended Outdoor Package $3,000 | 150* (average) | 200 | 5,625 sq. ft. (approx. 75 x 75 ft.) | .13 acres |

*Note: The Exchange accounts for domestic mitigation using a standard average daily amount of 150 gallons (WAC 173-518-080 (b). This is the annual amount of water that the Exchange and the mitigation certificate purchaser agree upon as the basis for their transaction.

- Snoqualmie Valley Water Bank/Exchange (funded, implementation starting) – The Snoqualmie Watershed has instream flows that are frequently not met during the irrigation season. The future Snoqualmie Bank will facilitate intra-district seasonal and temporary water right transfers by moving water rights downstream, and implement conservation benefitting both in-stream and out of stream users. A draft agreement between Ecology and the future Snoqualmie Bank has been written. It builds on the water strategy development that the Snoqualmie Valley Preservation Alliance (SVPA) conducted through a Washington State Department of Agriculture-funded investigation.

- Skagit (in progress) – On April 14, 2001, the Skagit River Basin Water Management Rule (Skagit Rule) was adopted by Ecology then amended in 2006 to established finite “reservations” of surface and groundwater for future out-of-stream uses. On October 3, 2013, the Washington Supreme Court ruled that Ecology cannot set aside reservations of water where water was previously set aside to support set instream flows. This ruling means nearly 500 homes and businesses that have relied on the Skagit reservations for water supplies since 2001 and any new users will have to mitigate use.

## Conservation

Water conservation is a common method used to create more water availability from existing supplies. Some of the ways that conservation is being initiated and applied are:

- Water system conservation requirements for public water systems can include:
  - Collecting data and forecasting demand and setting conservation goals,
  - Calculate distribution system leakage and reducing leaks,
  - Outreach to residents to promote efficient water use,
  - Low water use infrastructure replacement programs,
  - Conservation-based rate structures,
  - Water reclamation or reuse, and
  - Lawn watering ordinanes, covenants, or buy-back programs.

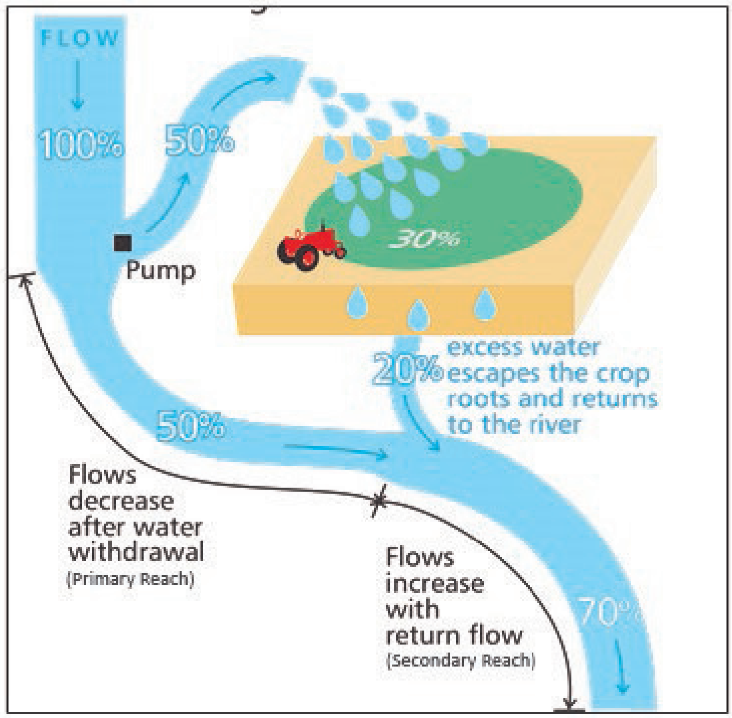



Figure 10: Conservation Benefits for Instream Flows

- Irrigation efficiency improvements can include:
  - Canal lining and pipe replacement
  - On-farm efficiency programs (drip, microspray sprinklers)
  - Automation to reduce spills
  - Re-regulation reservoirs

Conservation has the effect of making out-of-stream diversionary water rights meet increasing population or farming pressures, and benefiting instream flows. Figure 10 summarizes how conservation can benefit instream flows, which is often incentivized through state-funded grant programs, such as the Irrigation Efficiency Grant Program administered by Ecology.

Generally, there is continued regulatory and economic pressure for increased efficiency in water use, which can be considered in successive forecasts.

## Alternative Sources and Retiming of Water Availability

Seasonal precipitation has a great effect on supply and demand issues for both people and aquatic needs. To compensate for times of high demand and low supply, storage and reuse projects are being implemented in Western Washington that would be integrated into the forecasting effort, including the following:

- Aquifer Storage Recovery (ASR)/ Shallow Aquifer Recharge (SAR) – ASR and SAR increase existing groundwater supplies by artificially recharging groundwater. Water is stored during times of abundant supplies and withdrawn or allowed to enhance instream flows during times when water availability would be otherwise limited. Three operating ASR projects are Western Washington, and several other feasibility studies have been conducted. Use of SAR has also been investigated at several locations. Implementation of new ASR and SAR projects is anticipated in the future to address seasonal availability of water. Projects include:
    - Lakehaven Utility District ASR (active)
    - Sammamish Plateau Water & Sewer District ASR (active)
    - Seattle Public Utilities Highline Wellfield ASR (active)
    - Dungeness watershed SAR (under development)
    - Lacey, Olympia, Tumwater and Thurston County (LOTT) reclaimed water infiltration (under development)
- Surface storage projects – Surface reservoirs are commonly used for hydropower, irrigation, municipal water supply, and flood control. There are more than 1,100 dams in Washington with the majority of large dams built for hydropower uses. Some of the largest municipal supply reservoirs are the masonry/Chester Morse Reservoir Dams and South Fork Tolt River Dam for the City of Seattle, the Casad Dam/Union River Reservoir for the City of Bremerton, and the George Culmback Dam/Spada lake for Snohomish county and the City of Everett. Most flood control reservoirs were built by the U.S. Army Corps of Engineers. Some recent surface storage reoperation or enlargement projects include:
    - Lake Tapps Water Supply Project
    - Cowlitz Falls Dam
    - Indian Creek reservoir
    - Judy Reservoir Enlargement
- Reclaimed water – Use of reclaimed water is increasing in western Washington. Two demonstration projects in Sequim and Yelm were developed in 1998 and 1999 and now there are many sites actively using reclaimed water. Some examples include:
    - Sequim Water Reclamation Facility and Water Reuse System – In 1998, the City of Sequim upgraded its wastewater treatment facility into a Class A Water Reclamation Facility. The City developed a reclaimed water distribution system that seasonally diverts water for irrigation, toilet-flushing, stream flow augmentation, vehicle washing, street cleaning, fire truck water, and dust control uses.
    - Yelm Water Reclamation Facility and Reclaimed Water System – In 1999, the City of Yelm upgraded its wastewater treatment facility into a Class A Water Reclamation Facility. The City uses the reclaimed water for irrigation, school bus washing, and groundwater recharge.
    - Brightwater Water Reclamation Facility and conveyance system – The Class A reclaimed water treatment began in September 2011 and conveyance began full operations in fall of 2012. Water is used for irrigation and streamflow augmentation.
    - City of Renton Reclamation Facility – Class A reclaimed water for landscape irrigation
    - Westpoint Reclamation Facility – Class A reclaimed water for irrigation and plant process water
    - Chambers Creek Properties – Reclaimed water for site restoration and irrigation
    - King County South Plant Reclaimed Water Plant – Irrigation, wetland enhancement, sewer flushing, and street sweeping.

# Action Plan/Scoping Details – 2021 Supply/ Demand Forecast for Western Washington

This section describes whether data sets and approaches historically used to forecast supply and demand in Eastern Washington can be expanded to Western Washington watersheds. For a full description of the modeling and forecasting effort currently being used, see the 2016 Water Supply and Demand Forecast. Figure 11 below provides a summary of the integrated approach to modeling physical parameters, water rights, storage, crop demand, and economic drivers in the current forecasting effort.

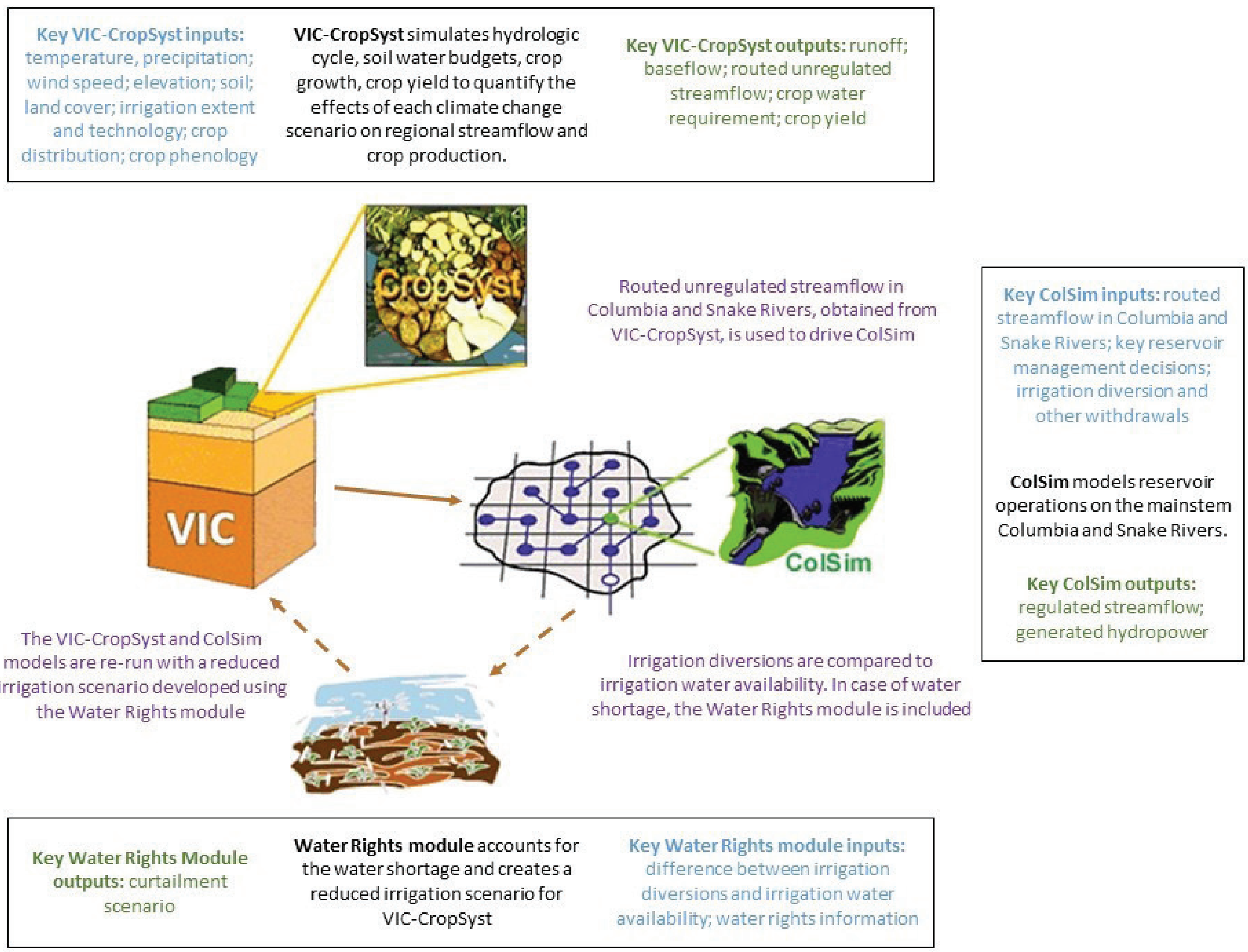



Figure 11: Overview of 2016 Water Supply and Demand Forecast Modeling

## Demand Estimates

### Agricultural demands

VIC-CropSyst is the modeling framework used to estimate irrigation demands for Eastern Washington in the 2016 forecast. The major inputs required by VIC-CropSyst are gridded meteorological data, land cover classification, irrigation extent classification, soil characteristics and elevation information. The data sources used to develop these inputs for Eastern Washington also extend to Western Washington and can be processed to create necessary inputs. Some of these data source include:

- U.S. Department of Agriculture long term projections
- U.S. Bureau of Reclamation reports/data compilations
- Washington State Department of Agriculture
- USGS investigations/data compilations
- Ecology water rights tracking system (for existing rights and pending applications)
- Modeled demands

Some additional considerations to be made for Western Washington include a needs assessment for the following.

- Do certain Western Washington WRIAS have small farm acreage as a significant fraction of total crop acreage? If the current data sources for cropland and irrigation extent classification do not capture small farm acreage, the modeled demands would be underestimated and other data sources will need to be explored in these WRIAs.
- What proportion of the Western Washington WRIA demands come from Nursery/Greenhouse, Aquaculture, Dairy and other Livestock activities which are not part of the current crop modeling efforts in Eastern Washington? The 2012 USDA Census of Agriculture indicates these to be leading commodities by market value for several WRIAS in Western Washington. An alternate method of estimating demands for these commodities both historically and under future climate projections may need to be explored.

## Municipal and Industrial Demands

A process similar to that used in Eastern Washington will be used to extend this to Western Washington. Rather than integrated modeling of these demands, forecasting would rely on the multitude of other required planning and forecasting responsibilities through local and state jurisdictions, including:

- Water system plans
- Census information for each Western Washington county is available at: http://quickfacts.census.gov/qfd/states/53000.html
- USGS data compilations
- Watershed planning documents
- Groundwater Management areas
- Ecology water rights tracking system (for existing rights and pending applications)

## Hydropower Demands

A process similar to that used in Eastern Washington will be used to extend this to Western Washington. A combination of published documents, information from the Northwest Power Planning Council, data from the FERC application tracking system and interviews will be used to assess these demands.

## Instream Flow and Interruptible Demands

Curtailment of water rights in Western WA are primarily based on instream flow rules. This is unlike Eastern Washington where curtailment is a combination of water rights subject to instream flow requirements as well as areas where junior rights holders are routinely curtailed to ensure senior rights are met. From a modeling perspective, the process used to identify curtailment in Eastern Washington interruptible rights subject to instream flow rules can be extended to Western Washington.

- Unmet demand from adopted instream flow rules for the Western Washington WRIAs would be evaluated by comparing adopted flows to a range of water year forecasts, including wet, dry, and average years both now and in the future.

- Interruptible right holders are available through the Department of Ecology's WRTS database, and the frequency of their interruption (and the resulting demand for water) can be forecasted.
- Evaluation of WRIA level supply and demand estimates will determine whether or not it is appropriate to estimate curtailment based on instream flow requirements for specific locations.
- Economic drivers and forecasting methods for Western Washington should be analogous to the approach used in the 2016 Water Supply and Demand Forecast.

## Supply Estimates

As in the previous forecasts, we will build on work by the Climate Impacts Group at University of Washington, to get supply estimates through VIC-CropSyst simulations.

Additional considerations for Western Washington include:

- Evaluation of whether a "large scale" model such as VIC-CropSyst is suitable to estimate supply for all WRIAs in Western Washington. As compared to Eastern Washington, some of the watersheds in Western Washington are much smaller in drainage area.
- Inventory Western Washington WRIAs where supply is regulated by reservoirs and results in significant shifts to the hydrograph. Ratio of reservoir capacities to inflow can be used to determine the list of reservoirs whose operations need to modeled to better capture supply in the respective WRIAs. Reservoir models can be inventoried and used where they exist (eg. Skagit basin).
- Tidal effects on supply in coastal WRIAS.
- Assess ground water versus surface water sources of supply by WRIA. Inventory WRIAs where location-specific ground water models might be needed to accurately represent supply, and where ground water declines are an important consideration. Ground water withdrawals as percentage of total withdrawals for the Agriculture, Municipal and industrial secotors are higher in Western Washington (40%) as compared to Eastern Washington (30%) (Lane and Welch, 2010).

# Summarize Scope and Conceptual Budget for 2021 Forecast

The 2021 effort in Western Washington will be exploratory in that the framework developed for Eastern Washington will be applied and evaluated to identify WRIAs where additional information or changes in the framework will be required to better capture supply and demand estimates in Western Washington. The scope includes the following.

- Apply the VIC-CropSyst framework to Western Washington.
  - Process and set up gridded input data including meteorological data, agricultural land use data, and irrigation extent for Western Washington.
  - Model calibration and evaluation.
  - Model application for supply and demand estimates.
- Estimate municipal/industrial and hydropower demands.
- WRIA level evaluation of appropriateness of VIC-CropSyst framework to capture supply and agricultural demand.
  - Comparison against published documents.
  - Stakeholder engagement (surveys, meetings, outreach materials, coordination with University of Washington, coordination with planning jurisdictions, coordination with Western Washington Tribes).

- Comparison of modeled demand categories relative to non-modeled demand categories – dairy/livestock, nursery/greenhouse, aquaculture demands, and demands from small farm acreage missing in the land cover data.
- Explore secondary sources of non-modeled category demand estimates in relevant WRIAs.

• Inventory WRIAs where regulation through reservoirs alters the hydrograph.
  - Dam inventory databases will be used to find reservoirs where the ratio WRIA level supply to reservoir storage is above a specific threshold.
  - Potential to use reservoir models where they currently exist or potential to create simple reservoir operations models will be explored.

• Unmet demand analysis based on instream flow requirements.
  - Information related to interruptible water right holders from the Department of Ecology's WRTS database and WAC instream flow rules will be use to estimate unmet demands.
  - Evaluation of unmet demand analysis based on supply and demand evaluation.
  - Economic curtailment analysis.

• Inventory of WRIAs where consideration of ground water modeling and ground water declines is important.
  - Ground water models where relevant will be explored for future use.

## Budget

The total budget effort for the 2016 Water Supply and Demand Forecast for Eastern Washington, including separate study efforts on related forecasting efforts related to METRIC, Water Banking, Declining Groundwater Supplies, Effects of User-Pay Requirements on Water Permitting, and West-Side Scoping was $1.8 million dollars over two years. Because this is the third such forecast by the Office of Columbia River, this effort benefited from some efficiency in stakeholder involvement, model foundation, and methodology. Some of the core research team has been together for the 2006, 2011, and 2016 forecast work, which also helped streamlining the process. However, the 5 modules developed during the 2016 Forecast were new efforts.

It is anticipated that extending this work to develop a holistic State Water Plan will require a significant effort. Western Washington stakeholders will rightly want robust involvement from plan inception to ensure their unique issues are being appropriately modeled. If unique policy research (e.g. like the 5 modules) is desired to address Western Washington issues, or to address emerging changes statewide by 2021, then those costs would need to be scoped separately.

WSU is projecting an overall budget requirement of $3 to $4 million for the 2021 Statewide Forecast to be completed over 2 years. In advance of the launch of such an effort, WSU recommends Ecology hold a series of scoping meetings with the parties identified herein, to ensure that the data sets, data gaps, policy issues, jurisdictional planning overlap, and other factors are adequately scoped. From those meetings, a more refined budget would be developed. Additionally, WSU recommends that several meetings be held with other key Western States with State Water Plans to understand their issues, identify successful modeling and stakeholder involvement tools, and budgetary considerations.

# Bibliography

| State | State Plan? | Resource | Comments |
|---|---|---|---|
| Alabama | N | http://governor.alabama.gov/assets/2014/04/AWAWG-Report-FINAL-2-Side-Print.pdf | In process |
| Alaska | N | http://dnr.alaska.gov/mlw/water/ | |
| Arizona | Y | http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/ | |
| Arkansas | Y | http://arkansaswaterplan.org/plan/ArkansasWaterPlan/Update.htm | |
| California | Y | http://www.water.ca.gov/waterplan/ | |
| Colorado | Y | https://www.colorado.gov/cowaterplan | |
| Connecticut | N | http://www.ct.gov/water/cwp/view.asp?a=4801&q=574956<br>https://www.cga.ct.gov/2013/rpt/2013-r-0159.htm | In process |
| Delaware | N | http://www.nj.gov/drbc/programs/basinwide/ | |
| Florida | Y | http://www.dep.state.fl.us/water/waterpolicy/fwplan.htm | |
| Georgia | Y | http://www.georgiawaterplanning.org/ | |
| Hawaii | Y | http://dlnr.hawaii.gov/cwrm/planning/hiwaterplan/ | |
| Idaho | Y | https://www.idwr.idaho.gov/waterboard/WaterPlanning/Statewaterplanning/State_Planning.htm | |
| Illinois | N | https://www.dnr.illinois.gov/WaterResources/Documents/Jan%202015%20-%20Action%20Plan%20for%20Statewide%20Water%20Supply%20Planning.pdf<br>http://www.isws.illinois.edu/wsp/ | In process |
| Indiana | N | http://www.indianachamber.com/index.php/water-study | Proposed |
| Iowa | N | http://www.iowadnr.gov/Environment/WaterQuality/IowaWaterPlan.aspx<br>http://www.agriculture.state.ia.us/WRCCArchives.asp | |
| Kansas | Y | http://kwo.org/Water-Plan.html | |
| Kentucky | N | http://water.ky.gov/Pages/default.aspx | |
| Louisiana | N | http://dnr.louisiana.gov/assets/OC/env_div/gw_res/WRC.Oct.13.Re.pdf | Proposed |
| Maine | N | http://www.maine.gov/dep/water/index.html | |
| Maryland | N | https://planning.maryland.gov/PDF/OurProducts/Publications/ModelsGuidelines/mg26.pdf | In process |
| Massachusetts | N | http://www.mass.gov/eea/docs/dep/water/laws/i-thru-z/iwrmp.pdf<br>https://www.cga.ct.gov/2013/rpt/2013-r-0159.htm | |
| Michigan | Y | http://www.michigan.gov/deq/0,4561,7-135-3313_3677_64891---,00.html | Draft |
| Minnesota | Y | https://www.eqb.state.mn.us/sites/default/files/documents/2010_Minnesota_Water_Plan.pdf | |
| Mississippi | N | http://www.deq.state.ms.us/mdeq.nsf/page/l&w_home | |
| Missouri | Y | http://www.dnr.mo.gov/env/wrc/statewaterplanMain.htm | |

| State | State Plan? | Resource | Comments |
|---|---|---|---|
| Montana | Y | http://dnrc.mt.gov/divisions/water/management/state-water-plan | |
| Nebraska | N | http://www.dnr.ne.gov/iwm/statewide-water-planning | |
| Nevada | Y | http://water.nv.gov/programs/planning/stateplan/ | |
| New Hampshire | N | https://www.cga.ct.gov/2013/rpt/2013-r-0159.htm | In process |
| New Jersey | N | http://www.nj.gov/dep/infofinder/topics/water.htm | |
| New Mexico | Y | http://www.ose.state.nm.us/Planning/state_plan.php | |
| New York | N | http://www.dec.ny.gov/chemical/290.html | |
| North Carolina | N | http://deq.nc.gov/about/divisions/water-resources/planning | |
| North Dakota | Y | http://www.swc.nd.gov/ | |
| Ohio | N | http://www.epa.ohio.gov/dsw/mgmtplans/208index.aspx | |
| Oklahoma | Y | http://www.owrb.ok.gov/supply/ocwp/ocwp.php | |
| Oregon | Y | http://www.oregon.gov/owrd/pages/law/integrated_water_supply_strategy.aspx | |
| Pennsylvania | Y | http://www.pawaterplan.dep.state.pa.us/statewaterplan/docroot/default.aspx<br>https://www.cga.ct.gov/2013/rpt/2013-r-0159.htm | |
| Rhode Island | Y | http://www.planning.ri.gov/statewideplanning/land/water.php<br>https://www.cga.ct.gov/2013/rpt/2013-r-0159.htm | |
| South Carolina | Y | http://www.dnr.sc.gov/water/waterplan/index.html | |
| South Dakota | Y | http://denr.sd.gov/dfta/wwf/statewaterplan/statewaterplan.aspx | |
| Tennessee | N | http://www.tn.gov/environment | |
| Texas | Y | http://www.twdb.texas.gov/waterplanning/swp/ | |
| Utah | Y | http://www.water.utah.gov/planning/swp/ex_swp.htm | |
| Vermont | N | http://dec.vermont.gov/watershed | |
| Virginia | Y | http://www.deq.virginia.gov/Programs/Water/WaterSupplyWaterQuantity/WaterSupplyPlanning/StateWaterResourcesPlan.aspx | |
| Washington | N | | Scoping |
| West Virginia | Y | http://www.dep.wv.gov/WWE/wateruse/WVWaterPlan/Pages/default.aspx | |
| Wisconsin | N | http://dnr.wi.gov/topic/surfacewater/planning.html | |
| Wyoming | Y | http://waterplan.state.wy.us/frameworkplan-index.html | |
| United States | | http://streamingwater.org/state-water-plans/ | Link to state planning |

## Washington Watershed Plans (WRIA)


1. http://www.ecy.wa.gov/water/wria/index.html


## Comprehensive Water System Plans


1. Seattle Public Utilities et al., 2007, 2007 Water System Plan, Volume 1, Prepared by Seattle Public Utilities, Brown and Caldwell, and Johansen Consulting, November 2006.
2. Tacoma Public Utilities, 2006a, 2006 Comprehensive Water Plan Update, Volume 1, Prepared by Tacoma Public Utilities Water Division, August 2, 2006.
3. Tacoma Public Utilities, 2006b, Green River Watershed Management Plan, Volume II, Prepared by Tacoma Public Utilities Water Division, August 2006
4. Alderwood Water and Wastewater District et al., 2009, 2009 Water Comprehensive Plan, Summary, Prepared by Alderwood Water and Wastewater District, HDR Engineering, Inc., and Confluence Engineering Group, August 2009.
5. City of Bellevue, 2015, City of Bellevue Water System Plan, Volume 1, Draft, Prepared by City of Bellevue, October 2015.
6. PACE Engineers, Inc., 2008, Lakehaven Utility District 2008 Comprehensive Water System Plan, Prepared by PACE Engineers, Inc., November 2008.
7. Gray & Osborne, Inc., 2009, Northshore Utility District, Water System Plan, Prepared by Gray & Osborne, Inc., March 2009.
8. PACE Engineers, Inc. and Aspect Consulting, LLC, 2011, City of Kent Public Works Department, 2011 Water System Plan, Prepared by PACE Engineers, Inc. and Aspect Consulting, LLC, 2011.
9. Public Utility District No. 1 of Skagit County, 2007, 2007 Water System Plan, Volume 1, Prepared by Public Utility District No. 1 of Skagit County, September 2008.
10. City of Everett et al., 2007, City of Everett 2007 Comprehensive Water Plan, Prepared by Everett Public Works, Everett Water Utility Committee, HDR Engineering, Inc., FCS Group, Inc., and Washington State Department of Health, November 21, 2007.
11. CH2MHILL, 2009, City of Bellingham 2009 Water System Plan, Prepared by CH2MHILL, September 2009.
12. CH2MHILL, 2012, City of Bellingham 2012 Water System Plan Update, Agency-Review Draft, Prepared by CH2MHILL, December 2012.
13. City of Vancouver and Carollo Engineers, 2015, City of Vancouver Comprehensive Water System Plan April 2015, Draft, Prepared by City of Vancouver and Carollo Engineers, June 2015.
14. City of Olympia Public Works and HDR Engineering, Inc., 2015, City of Olympia 2015-2020 Water System Plan, Prepared by City of Olympia Public Works and HDR Engineering, Inc., October 2015.
15. Clark County et al., 2011, Clark County Coordinated Water System Plan Update, Regional Supplement, Draft, Prepared by Clark County, Clark Public Utilities, Clark County and Washington State Departments of Health under the Clark County Water Utility Coordinating Committee, Mary 2011.
16. City of Lacey and Corollo Engineers, 2013, City of Lacey Water System Comprehensive Plan Update, Prepared by City of Lacey and Carollo Engineers, February 2013.
17. City of Bremerton, 2004, City of Bremerton Comprehensive Plan, City Service Appendix, Prepared by City of Bremerton, 2004.


## Regional Water Plans


1. Vaccaro, J.J., Hansen, A.J. Jr, and Jones, M.A., 1998, Hydrogeologic Framework of the Puget Sound Aquifer System, Washington and British Columbia, USGS
2. Vaccaro, J.J., 1992, Plan of Study for the Puget-Willamette Lowland Regional Aquifer System Analysis, Western Washington and Western Oregon, USGS

## Growth Management Planning Documents

1. http://www.whatcomcounty.us/1170/Comprehensive-Plan-Updates
2. http://www.skagitcounty.net/PlanningAndPermit/Documents/CompPlan/2007%20Comp%20Plan%20All-In-One.pdf
3. http://snohomishcountywa.gov/2139/Comprehensive-Plan
4. http://www.kingcounty.gov/depts/executive/psb/regional-planning/king-county-comprehensive-plan.aspx
5. https://www.co.pierce.wa.us/index.aspx?NID=950
6. http://lewiscountywa.gov/communitydevelopment/comprehensive-plan
7. https://www.clark.wa.gov/community-planning/documents
8. http://www.co.thurston.wa.us/planning/comp_plan/comp_plan_home.htm
9. http://www.co.mason.wa.us/code/comp_plan/
10. http://www.co.jefferson.wa.us/commdevelopment/compplangeneral.htm
11. http://www.clallam.net/LandUse/comprehensiveplan.html
12. http://www.co.pacific.wa.us/pdf%20files/Comprehensive%20Plan.pdf

## Stream Gauging

1. http://www.ecy.wa.gov/programs/eap/flow/index.html
2. http://waterdata.usgs.gov/wa/nwis/rt.

## Key Groundwater and Surface Water Studies


1. Dion, N.P., T.D. Oleson, and K.L. Payne, 1988, Preliminary Evaluation of the Ground-Water Resources of Bainbridge Island, Kitsap County, Washington, Untied States Geological Survey.
2. Drost, B.W., D.M. Ely, and W.E. Lum II, 1999, Conceptual Model and Numerical Simulation of the Ground-Water-Flow system in the Unconsolidated Sediments of Thurston County, Washington, United States Geological Survey.
3. Fasser, E.T. and R.J. Julich, 2009, Hydrographs Showing Ground-Water Level Changes for Selected Wells in the Lower Skagit River Basin, Washington, United States Geological Survey Data Series 441.
4. Fasser, E.T., K.H. Johnson and M.E. Savoca, 2009, Shallow Groundwater Movement in the Skagit River Delta Area, Skagit County, Washington, United States Geological Survey Scientific Investigations Report 2009-5208, 22 pages.
5. Golder Associates Inc., 2015, Johns Creek and Goldsborough Creek Groundwater Modeling Study, 2015.
6. Hydrogeologic Framework, Groundwater Movement, and Water Budget in Tributary Subbasins and Vicinity, Lower Skagit River Basin, Skagit and Snohomish Counties, Washington Scientific Investigations Report 2009-5270.
7. Johnson, K.H. and J.L. Jones, 2013, Transient Calibration of a Groundwater-Flow Model of Chimacum Creek Basin and Vicinity, Jefferson County, Washington—A Supplement to Scientific Investigations Report 2013-5160, United States Geological Survey.
8. Johnson, K.H. and M.E Savoca, Numerical simulation of the groundwater-flow system in tributary subbasins and vicinity, lower Skagit River basin, Skagit and Snohomish Counties, Washington Scientific Investigations Report 2010-5184, Prepared in cooperation with the Skagit County Public Works Department and the Washington State Department of Ecology and Skagit County Public Utility District No. 1.
9. Johnson, K.H., M.E. Savoa, and B. Clothier, Numerical simulation of the groundwater-flow system in the Chambers-Clover Creek Watershed and Vicinity, Pierce County, Washington Scientific Investigations Report 2011-5086, Prepared in cooperation with the Pierce Conservation District and the Washington State Department of Ecology.

10. Jones, J.L., K.H. Johnson, and L.M. Frans, 2013, Numerical Simulation of the Groundwater-Flow System in Chimacum Creek Basin and Vicinity, Jefferson County, Washington, Washington Scientific Investigations Report 2009-5270, United States Geological Survey.
11. Justin, G.B., R.J. Julich, and K.L. Payne, 2009, Hydrographs showing groundwater level changes for selected wells in the Chambers-Clover Creek watershed and vicinity, Pierce County, Washington, United States Geological Survey Data Series 453.
12. King County Department of Natural Resources and Parks, 2010, Working Draft Lowered Groundwater Levels in King County, Washington: A Preliminary Review of Reports, 2010.
13. Lane, R. C. and W.B Welch, 2010, Estimated freshwater withdrawals in Washington, 2010 Scientific Investigations Report 2015-5037.
14. Lindsay, C.S. and J.S. Koreny, 2003, Lower and Upper Skagit Watershed Plan, Samish River Sub-Basin, Ground Water Hydrology Evaluation, GeoEngineers.
15. McCarthy, K.A., 1996, Surface-water quality assessment of the Clover Creek basin, Pierce County, Washington, 1991-1992 Water-Resources Investigations Report 95-4181, United States Geological Survey.
16. Savoca, M.E., W.B. Welsh, K.H., Johnson, R.C. Lane, and E.T. Fasser, Hydrogeologic Framework, Groundwater Movement, and Water Budget in the Chambers-Clover Creek Watershed and Vicinity, Pierce County, Washington Scientific Investigations Report 2010-5055, Prepared in cooperation with the Pierce Conservation District and the Washington State Department of Ecology.
17. Sceva, Jack E., 1950, Preliminary report on the ground-water resources of southwestern Skagit County, Washington Ground-water Report 1, Prepared in cooperation with State of Washington, Department of Conservation and Development, Division of Hydraulics.
18. Schwartzman, P., 2008, 2008 Dungeness Groundwater Flow Model Design, Construction, Calibration and Results, Pacific Groundwater Group.
19. Turney, G.L., 1981, Quality of Ground Water in the Puget Sound Region, Washington, Untied States Geological Survey, 1981.
20. Welch, W.B., K.H. Johnson, M.E. Savoca, R.C. Lane, E.T. Fasser, A.S. Gendaszek, C. Marshall, B.G. Clothier, and E.N. Knoedler, 2015, Hydrogeologic framework, groundwater movement, and water budget in the Puyallup River Watershed and vicinity, Pierce and King Counties, Washington, United States Geological Survey Scientific Investigations Report 2015–5068, 54 pages, 4 plates, http://dx.doi.org/10.3133/sir20155068.

## Key Climate Change Considerations Studies

1. Dalton, Meghan M. Climate change in the Northwest: implications for our landscapes, waters, and communities. Island Press, 2013.
2. Hamman, Joseph J., et al. “Combined Effects of Projected Sea Level Rise, Storm Surge, and Peak River Flows on Water Levels in the Skagit Floodplain.” Northwest Science 90.1 (2016): 57-78.
3. Lee, Se-Yeun, Alan F. Hamlet, and Eric E. Grossman. “Impacts of Climate Change on Regulated Streamflow, Hydrologic Extremes, Hydropower Production, and Sediment Discharge in the Skagit River Basin.” Northwest Science 90.1 (2016): 23-43.
4. Mauger, Guillaume, Joseph Casola, Harriet Morgan, Ronda Strauch, Brittany Jones, Beth Curry, Tania Busch Isaksen, Lara Whitely Binder, Meade Krosby, and Amy Snover. “State of Knowledge: Climate Change in Puget Sound.” (2015).
5. Pitz, C. (2016) Predicted impacts of climate change on groundwater resources of Washington State. Department of Ecology. Publication number: 16-03-006
6. Stumbaugh, M., & Hamlet, A. F. (2016). Effects of Climate Change on Extreme Low-Flows in Small Lowland Tributaries in the Skagit River Basin.Northwest Science, 90(1), 44-56.
7. Vano, J.A., Voisin, N., Cuo, L., Hamlet, A.F., Elsner, M.M., Palmer, R.N., Polebitski, A. and Lettenmaier, D.P., 2010. Climate change impacts on water management in the Puget Sound region, Washington State, USA. Climatic Change, 102(1-2), pp.261-286.

# APPENDIX A – Water Master Surveys

## Background

In the 2016 Forecast, WSU prepared a survey (Figure A-1) for Department of Ecology water masters, to better understand the occurrence of curtailment of junior water rights in some tributaries, in response to calls from senior water right holders. Surveys were emailed out to Ecology water masters in spring of 2015. This was a particularly busy year for water masters, given the 2015 drought, so responses took a variety of forms. For example, some water masters completed the survey form, some were interviewed by the research team or responded via email, and some provided existing data they had available. This Appendix compiles the information received, staying true to the form it was received in, though reference to individual people were deleted.

To: Ecology Water Master and Senior Staff
From: WSU/Aspect/Ecology Forecast Team

**RE: Curtailment History by WRIA**

In support of the 2016 Columbia River Long Term Supply and Demand Forecast, we are seeking to document specific information about water rights in each WRIA that are periodically curtailed. This includes water rights that are interrupted in favor of more senior water rights holders, and water rights that are interrupted in favor of instream flows. We are planning to use this information to improve modeling of the impacts of future water shortages within WRIAs.

Please return this form by May 15, 2015. In the survey, some information is requested about each WRIA, while other more specific information is requested about rights within each subbasin that are curtailed. More than one subbasin form should be filled out if curtailment differs by subbasin within a WRIA.

Thank you very much for your contributions to this effort!

---

WRIA:

1. Are there water rights in this WRIA that have historically been, or currently are, periodically curtailed?
   - ☐ No. Please answer **question #2.**
   - ☐ Yes. Please complete all questions below.

2. Are there water right holders in this WRIA who have curtailment risk, but have not yet been actively curtailed?
   - ☐ No. If you answered No to BOTH questions #1 and #2, you have completed the survey – thank you! If you answered Yes to either questions #1 or #2, please continue the survey, answering all relevant questions.

   - ☐ Yes. Please tell us why these water rights holders have not been actively curtailed, and then continue on to all relevant questions below.

3. Who performs curtailment activities (e.g. Ecology Water Master, Stream Patrolman)? Please include names, phone numbers, and email for all relevant individuals.

4. Please list all sub-basins in this WRIA that have curtailment risk (for each of these sub-basins, please complete pages 3-4):

Please complete questions 5 through 9 for **each** subbasin that has curtailment risk. If you need extra space, please attach additional sheets. Please provide as much specific detail as possible.

5. Subbasin Name:

1

6. Priority date regarded as firm in this Subbasin for

   a. Average Years:

   b. For Drought Years:

7. Please tell us the historical period (if any) over which Ecology began curtailment activities in this WRIA and what prompted the initiation of those activities (e.g. adjudication, calls by seniors users, issuance of interruptible rights, incorporation of SWSL's into permit decisions).

8. How are curtailment activities performed in this subbasin? (e.g. 1-800 number with voluntary compliance, enforcement via active stream patrolman, etc.)

9. Subbasin Name:

| | |
|---|---|
| Number of water rights in this subbasin subject to curtailment | |
| Volume of water rights subject to curtailment | |
| Are water rights curtailed individually (meaning each one may be curtailed at a different time), or in groups/classes? | |
| If in groups, how many distinct groups/ classes are there in this sub-basin? | |
| Reason(s) for curtailment (e.g. instream flow not met, SWSL, senior call) | |
| Historical time period for which you have knowledge of curtailment in this subbasin | |
| Approximate frequency of curtailment in this subbasin, and duration/timing of curtailment. (e.g. approximately 1 year in 10, generally one week duration, generally July 1 – Oct ) | |
| Do you have historical knowledge of the specific years in which curtailment occurred? (If yes, we may follow up for more details.) | |
| If no historical documentation is available in this subbasin, how can Ecology capture this for future use? | |
| Spatial Information<br>Are curtailed rights in this subbasin: | |
| Mapped in GWIS? | |
| Searchable in WRTS? If so, by what parameter? | |
| Compiled with WR DOC ID#'s? If yes, how may we obtain this list? | |

2

*Figure A-1. Survey sent out by the WSU team and partners to Ecology water masters in spring 2015.*

## Survey Responses

### *Responses pertaining to the Central Region*

WRIA: 48

1. Are there water rights in this WRIA that have historically been, or currently are, periodically curtailed?

   ☐ No. Please answer **question #2**.

   X☐ Yes. Please complete all questions below.

2. Are there water right holders in this WRIA who have curtailment risk, but have not yet been actively curtailed?

   X☐ No. If you answered No to BOTH questions #1 and #2, you have completed the survey – thank you! If you answered Yes to either questions #1 or #2, please continue the survey, answering all relevant questions.

   ☐ Yes. Please tell us why these water rights holders have not been actively curtailed, and then continue on to all relevant questions below.

3. Who performs curtailment activities (e.g. Ecology Water Master, Stream Patrolman)? Please include names, phone numbers, and email for all relevant individuals.

4. Please list all sub-basins in this WRIA that have curtailment risk (for each of these sub-basins, please complete pages 3-4):
   Methow river including tributaries: Twisp and Chewuch Rivers

Please complete pages 3 **and** 4 for **each** subbasin that has curtailment risk. If you need extra space, please attach additional sheets. Please provide as much specific detail as possible.

5. Subbasin Name: Methow river incl. tributaries

6. Priority date regarded as firm in this Subbasin for

   a. Average Years: approx. 1982

   b. For Drought Years: approx. 1975

7. Please tell us the historical period (if any) over which Ecology began curtailment activities in this WRIA and what prompted the initiation of those activities (e.g. adjudication, calls by seniors users, issuance of interruptible rights, incorporation of SWSL's into permit decisions).

Since the 1980s orders have been issued in years when minimum instream flows were not anticipated to be met during the irrigation season (per ch 173-548 WAC, Water Resources Program in the Methow River Basin)

8. How are curtailment activities performed in this subbasin? (e.g. 1-800 number with voluntary compliance, enforcement via active stream patrolman, etc.)
   A toll free hotline is set up and orders are issued requiring water right holders to call each day to find out if the flow is above or below the minimum flow.

   In years when the forecast is average or above average, but the flow still goes below minimums at the end of the irrigation season (in late September or October), a letter is sent to water right holders requesting voluntary compliance for what's left of irrigation season.
9. Subbasin Name:

| | |
|---|---|
| Number of water rights in this subbasin subject to curtailment | 62 |
| Volume of water rights subject to curtailment | |
| Are water rights curtailed individually (meaning each one may be curtailed at a different time), or in groups/classes? | All at the same time based on flow at USGS gage at Pateros |
| If in groups, how many distinct groups/ classes are there in this sub-basin? | |
| Reason(s) for curtailment (e.g. instream flow not met, SWSL, senior call) | Instream Flow Rule Ch 173-548 WAC |
| Historical time period for which you have knowledge of curtailment in this subbasin | 2000 - 2015 |
| Approximate frequency of curtailment in this subbasin, and duration/timing of curtailment. (e.g. approximately 1 year in 10, generally one week duration, generally July 1 – Oct ) | Impossible to generalize – each year is very different.<br>Anywhere from one week to entire irrigation season. |
| Do you have historical knowledge of the specific years in which curtailment occurred? (If yes, we may follow up for more details.) | 2000, 2001, 2002, 2003, 2004, 2005, 2008, 2009, 2012, 2015<br>Per P. Crane, 1992, 1993, 1994 & one year in 1980s |
| If no historical documentation is available in this subbasin, how can Ecology capture this for future use? | Search CRO files for orders issued in 1980s and 1990s. |
| Spatial Information<br>Are curtailed rights in this subbasin: | |
| Mapped in GWIS? | yes |
| Searchable in WRTS? If so, by what parameter? | In wrts, not sure how to isolate them |
| Compiled with WR DOC ID#'s? If yes, how may we obtain this list? | Ask Admin staff who finalize and mail Orders |

WRIA:49

1. Are there water rights in this WRIA that have historically been, or currently are, periodically curtailed?

   ☐ No. Please answer **question #2**.

   X☐ Yes. Please complete all questions below.

2. Are there water right holders in this WRIA who have curtailment risk, but have not yet been actively curtailed?

   X☐ No. If you answered No to BOTH questions #1 and #2, you have completed the survey – thank you! If you answered Yes to either questions #1 or #2, please continue the survey, answering all relevant questions.

   ☐ Yes. Please tell us why these water rights holders have not been actively curtailed, and then continue on to all relevant questions below.

3. Who performs curtailment activities (e.g. Ecology Water Master, Stream Patrolman)? Please include names, phone numbers, and email for all relevant individuals.

4. Please list all sub-basins in this WRIA that have curtailment risk (for each of these sub-basins, please complete pages 3-4):
   Okanogan and Similkameen Rivers

Please complete pages 3 **and** 4 for **each** subbasin that has curtailment risk. If you need extra space, please attach additional sheets. Please provide as much specific detail as possible.

5. Subbasin Name: Okanogan and Similkameen Rivers

6. Priority date regarded as firm in this Subbasin for

   a. Average Years: 1982

   b. For Drought Years: 1975

7. Please tell us the historical period (if any) over which Ecology began curtailment activities in this WRIA and what prompted the initiation of those activities (e.g. adjudication, calls by seniors users, issuance of interruptible rights, incorporation of SWSL's into permit decisions).
   I am told regulation in accordance with the Instream Flow Rule Ch 173-549 WAC may have begun in the 1980s. The rule was adopted in 1976.

8. How are curtailment activities performed in this subbasin? (e.g. 1-800 number with voluntary compliance, enforcement via active stream patrolman, etc.)

In below average water years when flow begins to get close to minimums, a toll-free hotline is set up and Orders are issued requiring water right holders to call prior to irrigating to find out whether flow is above or below minimums.

In average years when the flow does go below minimums at the end of the irrigation season (late September or October), a letter is sent requesting voluntary compliance for whats left of the irrigation season.

9. Subbasin Name:

| | |
|---|---|
| Number of water rights in this subbasin subject to curtailment | 111 water right holders |
| Volume of water rights subject to curtailment | |
| Are water rights curtailed individually (meaning each one may be curtailed at a different time), or in groups/classes? | They are curtailed by reach in accordance with the Instream Flow Rule Ch 173-549 WAC (above or below gage locations depending on where river is above or below) |
| If in groups, how many distinct groups/ classes are there in this sub-basin? | 3 |
| Reason(s) for curtailment (e.g. instream flow not met, SWSL, senior call) | Ch 173-549 WAC (Water Resources Program in Okanogan River Basin WRIA 49) |
| Historical time period for which you have knowledge of curtailment in this subbasin | 2000 - 2015 |
| Approximate frequency of curtailment in this subbasin, and duration/timing of curtailment. (e.g. approximately 1 year in 10, generally one week duration, generally July 1 – Oct ) | Impossible to generalize – each year is different.<br>One week to entire irrigation season. |
| Do you have historical knowledge of the specific years in which curtailment occurred? (If yes, we may follow up for more details.) | 2001, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010,<br>2011, 2015 |
| If no historical documentation is available in this subbasin, how can Ecology capture this for future use? | Search CRO files for Orders issued in 1980s and 1990s |
| Spatial Information<br>Are curtailed rights in this subbasin: | |
| Mapped in GWIS? | yes |
| Searchable in WRTS? If so, by what parameter? | In wrts, not sure how to do a search for them |
| Compiled with WR DOC ID#'s? If yes, how may we obtain this list? | Ask Admin staff who finalize and mail out Orders |

WRIA:45

1. Are there water rights in this WRIA that have historically been, or currently are, periodically curtailed?
   ☐ No. Please answer **question #2**.
   X☐ Yes. Please complete all questions below.

2. Are there water right holders in this WRIA who have curtailment risk, but have not yet been actively curtailed?
   X☐ No. If you answered No to BOTH questions #1 and #2, you have completed the survey – thank you! If you answered Yes to either questions #1 or #2, please continue the survey, answering all relevant questions.

   ☐ Yes. Please tell us why these water rights holders have not been actively curtailed, and then continue on to all relevant questions below.

3. Who performs curtailment activities (e.g. Ecology Water Master, Stream Patrolman)? Please include names, phone numbers, and email for all relevant individuals.

4. Please list all sub-basins in this WRIA that have curtailment risk (for each of these sub-basins, please complete pages 3-4):
   Wenatchee River including Mission Creek

Please complete pages 3 **and** 4 for **each** subbasin that has curtailment risk. If you need extra space, please attach additional sheets. Please provide as much specific detail as possible.

5. Subbasin Name: Wenatchee river and Mission Creek

6. Priority date regarded as firm in this Subbasin for

   a. Average Years: ~1983

   b. For Drought Years: ~1982

7. Please tell us the historical period (if any) over which Ecology began curtailment activities in this WRIA and what prompted the initiation of those activities (e.g. adjudication, calls by seniors users, issuance of interruptible rights, incorporation of SWSL's into permit decisions).
   In the early 1980s after the Instream Flow Rule for the Wenatchee River Basin was adopted in 1983. Ch 173-545 WAC, as amended

8. How are curtailment activities performed in this subbasin? (e.g. 1-800 number with voluntary compliance, enforcement via active stream patrolman, etc.)
   In below average water years the toll-free 800 hotline is set up and when flows get close to minimums, Orders are issued requiring water right holders to call prior to irrigating, to fin d out if the rivers are above or below minimums.

9. Subbasin Name:

| | |
|---|---|
| Number of water rights in this subbasin subject to curtailment | 65 water right holders |
| Volume of water rights subject to curtailment | |
| Are water rights curtailed individually (meaning each one may be curtailed at a different time), or in groups/classes? | In groups above or below USGS gages |
| If in groups, how many distinct groups/ classes are there in this sub-basin? | 2 groups (below and above the Peshastin gage) |
| Reason(s) for curtailment (e.g. instream flow not met, SWSL, senior call) | Instream Flow rule |
| Historical time period for which you have knowledge of curtailment in this subbasin | 2000 - 2015 |
| Approximate frequency of curtailment in this subbasin, and duration/timing of curtailment. (e.g. approximately 1 year in 10, generally one week duration, generally July 1 – Oct ) | In 1980s and 1990s flows typically went below minimums around August & September. In the 2000s the timing has been much more variable. |
| Do you have historical knowledge of the specific years in which curtailment occurred? (If yes, we may follow up for more details.) | 1985, 1986, 1988, 1989, 1994, 1998.<br>2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010.<br>2012, 2013, 2014, 2015. |
| If no historical documentation is available in this subbasin, how can Ecology capture this for future use? | |
| Spatial Information<br>Are curtailed rights in this subbasin: | |
| Mapped in GWIS? | Yes |
| Searchable in WRTS? If so, by what parameter? | In wrts, not sure how to isolate |
| Compiled with WR DOC ID#'s? If yes, how may we obtain this list? | Ask Admin staff who finalize and mail out Orders |

DATE, 2015

To: Ecology Water Master and Senior Staff
From: Trevor Hutton, Melissa Downes, and WSU/Aspect Forecast Team

**RE: Curtailment History by WRIA**

In support of the 2016 Columbia River Long Term Supply and Demand Forecast, we are seeking to document specific information about water rights in each WRIA that are periodically curtailed. This includes water rights that are interrupted in favor of more senior water rights holders, and water rights that are interrupted in favor of instream flows. We are planning to use this information to improve modeling of the impacts of future water shortages within WRIAs.

Please return this form to Trevor Hutton by May 15, 2015. In the survey, some information is requested about each WRIA, while other more specific information is requested about rights within each subbasin that are curtailed. More than one subbasin form should be filled out if curtailment differs by subbasin within a WRIA.

If you have questions, please call Trevor Hutton at (509)454-4240.

Thank you very much for your contributions to this effort!

- Methow, WRIA 48, WAC 173-548 filed 12-28-1976
- Okanogan, WRIA 49 WAC 173-549 filed 7-14-1976, updated 6-20-1984
- Wenatchee, WRIA 45 WAC 173-545, ~~filed~~ adopted 6-03-1983, updated 12-11-2007
- Columbia River, WRIA 40, etc. WAC 173-563
- Entiat, WRIA 46, WAC 173-546, 5/03/2005 (filed), effective 7-03-2005
  - includes Mad River, effective 6-24-1980, last updated 3-30-1998, Roaring Cr. Adjudication, Johnson Cr. Adj.

Wenatchee sub-basins: Chumstick – Adjudicated, ~ fully appropriated, closed by WAC 173-545-090
Icicle Cr. Adj.
Peshastin –
Mission
Nahahum Canyon Adj.
Icicle Cr. Adj.
Chiwawa
Nason

Libby Cr. Adjudication, McFarland Cr. Adj.; Bear Cr./Davis Lake Adj.;
Beaver Creek adjudicated; Gold Cr. Adj.; Black Canyon Cr. Adj.; Wolf Cr. Adj.
Beaver Creek a constant regulatory need annually → Susan Burgess

Methow sub's ~ defined as closed in WAC 173-548-050 (4)(a) and… (4)(b) [a long list]

Okanogan subs – partial year (irrigation season) closure on all streams not conditioned with minimum flows (section …025)
WAC 173-549
- Bonaparte Creek regulation annually
- Johnson Creek Adj.
- Salmon Creek Adj. (No. FK.)
- Lower Antoine Cr. Adj.

Similkameen adjud.
Sinlahekin Cr. Adj.
Myers Cr. Adj.

Whitestone Lake Adj.
Chiliwist Cr. Adj.
Bonaparte Cr./Lake Adj.

→ all permits issued in these WRIA's after effective date of WACs = min flow interruptible permits

11-18-2015 ✓SI

Ecology's ^Water Availability "Info regarding your WRIA" from website on "watershed updates by WRIA"

WRIA 30 (Klickitat)

- Adjudications: Bird Creek/Frazier Creek, Bacon Creek (Glenwood area)
  stream patroller or 'local' regulation annually.
- WDFW Surface Water Source Limitations (SWSL's) on:
  ~~lower~~ Swale Creek, also (in Little Klickitat subbasin) Bloodgood + Bowman Creeks
- lower basin adjudications: Little Klickitat, Blockhouse Creek, Mill Creek
  upper ^Little Klickitat disputes (annually) → Scott Turner

WRIA 29 (White Salmon + Wind)

WDFW SWSL's on Buck Creek, Rock Creek, Trout Creek, 2 unn. tribs to Collins Creek, and 2 unn. tribs of Col. River.

WRIA 40 (Alkali - Squilchuck)

Stemilt ^Creek Adj.: stream patroller, annual regulation
Squilchuck Adjudication, annual regulation
Cummings Canyon Adj.

WRIA 44 (Moses Coulee)

Mostly GW disputes
Moses Coulee and
Douglas Creek are both water short

WRIA 37 (Lower Yakima)

ongoing Yak River SW adjudication

- KID is mostly proratable, got ~75% of full entitlement in 2015
- Wapato Irr Project partly proratable → 47% prorationing
- ~~Roza I~~
- Ahtanum Creek ^Adj., annual ~~severe~~ shortfall, annually - stream patroller, YN, ECY oversight
  non-Indian north side rights shut off July 10 every year "(Scott)"
- Sunnyside Division, 31.1% proratable, → 47% prorationing in 2015.
- no new unmitigated SW rights available

WRIA 38 (Naches)

- Cowiche Cr Adj., ECY (Scott) regulation annually (^time immemorial 1869-1872 rights ok; 1873 + junior off on 7-22-2015 (Scott))
- no new unmitigated SW rights available, GW restrictions tightening
  curtailed 1,084.47 acres of rights from 7/22-10/31, 2015 (858.07 still using rights, 226.4 acres assigned to TWR)

WRIA 47 (Chelan) Antoine Creek Adj. ~ annual regulation by ~~Scott~~ Susan? (ECY) or 'local'.

11-18-2015 ✓ SI Jenni,

WRIA 39 (Upper Yakima)

- Adjudications: Wenas Creek, Cooke Creek, Big Creek, Teanaway River,
- ongoing Yak River SW adjudication
- miscellaneous decrees: Manastash Creek, Wilson-Naneum Creeks, Taneum Creek,
- no new unmitigated SW rights or GW rights
- Big Creek, ECY stream patroller (Stan), but only need to shut off one right and only during prorationing periods in drought years – a 1906-priority ("Post-1905") right.
- Teanaway River, ECY stream patroller (Stan) 2015 drought: 1886 and junior rights shut off on 7-23-2015
  2nd regulation on 8-13-2015: shut off 1884 and 1885 rights.
  Leaving only time immemorial, 1882, and 1883 rights on

(*) 7-23-2015 curtailment: rights for 1,068.15 acres irrigation – ~685 acres being irrigated
  – ~545 acres with the right used for instream flow

8-13-2015 curtailment: additional rights (1884+1885) for 679.25 acres – 526.25 acres being irrigated
  – 153 acres assigned instream
  – 1884+1885 curtailment through 9/15/2015:
  – 14.531 cfs shut off (6.586 cfs instream, 7.945 cfs offstream irrig)
  – partial shut off (from 8/13-9/15 period) of 4,019.955 af (1,886.0 af instream, 2,133.95 af irrig. use)

– (*) 7-23-2015 curtailment: ~21.363 cfs, portion (from 7/23-9/15, 2015) of ~5,770 af.

- Manastash Cr. annual regulation, class 3 (1874 + junior) curtailed ~ July 5th; class 2 (1872) prorated
- Wilson-Naneum, stream patrollers (4) since ~1988, annual regulation above KRD highline canal, can supply 1855, 1870-1877 rights (~12 cfs above KRD) only, eff. 7/25, in avg. year. All junior + junior (1878) rights off above KRD ~ 7/25 [could satisfy old class 5 (Youngberg + Mayorga) (1877) + senior rights = 11.76 cfs]
- Taneum Creek, all are 1873-priority, all receive pro rata share of creek flow when < 98.0 cfs. = most of 4/1-10/31 irrig. season each year, except freshet period. Scott (ECY) + USBR + TCC
- Wenas Creek, stream patroller + ECY, generally 2 rounds of reg. each year. super juniors off ~ June 1st, juniors (class 5 or 13 (1874 or 1880)) (class 4 (1871)) off ~ July 10th. seniors sometimes not fully satisfied (1865, 1867, 1870)
- Cooke Creek (upper) historic regulation by me at Germain's (1872) to satisfy Ray Durgan (1870) (above KRD) → Scott (ECY)

1885 Tean. rights: ~~612.75~~ 640.25 acres (153 acres with instream, ~~45.9.75~~ 487.25 acres irrig. use) curtailed in part during 8/13-9/15 2015 period
~~5.716 cfs~~ (~~.84~~ cfs instream, ~~[illegible]~~ cfs irrig. use)
12.651 cfs (5.48 cfs instream, 7.171 cfs irrig. use)
3,862.855 af/yr (a portion of – during curtailment period) – [1,873.304 af instream, 1,989.551 af irrig use]

1884 Tean rights: 39 acres, 1.88 cfs (1.106 cfs instream, 0.774 cfs irrig. use),
[no I.F. acres] 157.1 af (12.7 af instream, 144.4 af irrig. use)

Tean. 1882 rights total: 20.2 acres, some instream 0.402 cfs, (0.094 cfs instream, 0.308 cfs offstream irrig) 100.24 af/yr, part of: part of (42.12 af instream, 58.12 af irrig. offstream)
1883 rights total: 417 acres (all instream), 8.4422 cfs, 2,502.4 part of [during curtailment period]

## *Notes from interview pertaining to the Central Region*

CRO 7 counties, 200+ square mile
Already good information about min instream flows. Start there – within these basins, a number of non-interruptible water rights that have been adjudicated and have needs for curtailment within these individual sub-basins.

Methow – WRIA 48 – min instream flows est dec 8 19. Libby creek, mcfarland creek adjutications, bear creek,davis lake, beaver creek adjustications. The stream patroller does the regulation annually – she would know the details. Junior water rights curtailed on beaver creek. Gold creek, black canyon creek, wolf creek adjudication. They occurred because of a shortage of water in these stream – pretty much every year. Adjutications done in 1920s – so water users have become accustiomed to regulating themselves. WAC doe of closed basins or sub-basins within the methow.

Okaganan, 1976, 1984 – basin plan establishes a closure on all streams not conditioned on min flows. Did a fair amount of regulation when he worked there 20 years ago. Johnson creek adjuticaiton – regulation. North fork salmon creek adjudication. Lower antoine. Simikleen.meyers creek. Whitestone lake, chillabus. Bonaparte lake. WRIA 49 – over-appropriated and require regulation of some sort every year.

Wenatchee, 1983, 2007 – senior water rights do get curtailed here. There is not an OCR water master right now. Several little adjutications and several sub-basin creeks that are water shorts. Some stick with adjusticated as a trib to Wenatchee. After 1908s adjudicated – did regulate in favor of senior chumstick water rights. Peshastin creek drops low on flow. Also mission creek. ? canyon, iccicyle creek, dowawa river, nation creek – need a stream patroller to do regulation in favor of senior. The neighborhood may be doing its own regulation fo junior rights.

Columbia river 1980

Klickitat – WRIA 30 – adjutications because of lack of floow. Bird creek frazser creek. Bacon creek (glenwood area). Stream patroller in the past who was required to regulate annually.

WDF – SWSL – swale creek in little Klickitat. Bloodgood and Pullman creek – flow limited.

Little Klickitat, etc. despites on upper Klickitat tributaries

Wria 29 – white salmon and wind. WDFW – SWSLs on buck creek, rock creek, trout creek, 2 unnamed tribs to Collins creek. 2 unnamed tribs to Columbia river.

Wria 40 – alkali/squillchuck. Stream patroller – annual regulation on ? creek. Records on file on which year they had to cut to priority date (*can we get this?*) squilchuck – annual regulation. Cummings canyon adj. – three draings are continguous to each other. Same stream patroller on all of these. Cummings canyon – small adj. – by locals.

WRIA 44 – moses coulee – neighbor gw dispuets. Moses coulle and douglas creek are water short – but in 8 years did not need to do any regulation there. Water master would over see future probs.

WRIA Chelan – antoine creek adj. chelan/okan border 1986-1994 period regulation – maybe get priority date from files. Water master would be doing regulation.

Yakima –
Lower yak – wria 37 – ongoing adjudication – filed in 1977. Kennick – mostly proratable and this menas the Yakima basin has a whole great body of 1905 priority projects by USBR. Subject to curtailment for rationing. Prorata share in drought years. SO far no drought so serious that the pre 1905 water rights have been curtailed. However, 1905 priority represent 54% of use in Yakima – in 1984 got 37% of full contract. 37% in 2001, 42% in 2005. 47% in 2015. At least a dozen or so years of minor priorationing.
KID about 75% of prioratable enittble in 2015. Kennewick better supply than other proratables in Yakima. 47% proratable

Sunnyside – 31.1%
Etc.

Tanem creek – north side – every year affected july10.
No new unmiticated surface water rights available (true in all Yakima/naches river basins)

Naches – wria 38 – scott turner is stream patroller – does regulation annually on cowachee creek. In 2015 scott was able to allow the Yakama nation rights to continue to irrigate. 1873 and all junior – curtailed in july and rest of the season. Every year – some curtailment on cowachee creek in favor of senior rights. July 15 – july 20 of ever year – curtailment starts there when freshet runs out.
184k water rights curtailed after july

Upper Yakima – wria 39 – a number of historic adjutications in 1920s – wenas, cook, teanaway, etc. ongoing Yakima river adjudication. Misc. decrees – dating from late 1800s to early 1900s – empirical evidence of water limit – menastash, Wilken-nanem, tanem creeks. As of 1988, stan was stream patroller for 2 creks in upper Yakima – big creek and for entire teanaway river sub-basin. Big creek – pretty good flow – not much in terms of diversionary water rights. 1906 priority right had to be curtailed (post 1905 right). Super-junior water rights. Post may 10 1905 water rights – get curtailed every time there is even a minor drought where the may 1905 rights have some level of prorationing. During entire period of prorationing. May be the entire irrigation season, beginning may 15.

Teanaway is more complex. Have not had to curtail upstream use even though made some decisions indicating that in 2001 and 2005, the junior rights had only half season availability. Shut off all 1886 and junior priority water rights on june 23 2015. Second round on aug 15 2015 – 1884 and 1885 priority water rights. Left only 1882 and 1883 yakama nation time immerrable rights – uncurtailed. 1068 acres of water rights shut off – 665 irrig and 545 assigned to temp or perm instream flow use in the teanway. On aug 13 had to cut deeper – an additional 679 acres. Of those acres, 526 were active irrigation rights. Some were instream flow. In terms of af aug 13 shut-off amounted.
Jly 23 and aug 13 quantities are additive.
In future it is possible that most jjunior water rights will need to be curtailed even on an average year.

Manasatash creek – annual regulation. Class 3 water rights – 1874 – curtailed every year about july 5 – dries up rapidly. The class 2 1872 rights are prorated and continue to get a lower share after july 5 or july 10. Wilson-nanem sub-basin – flow together then have bifurcation structures and split into separate creeks. 1978 order that appointment 4 stream patrollers int his sub-basin. Every year, need for regulation above the krd highlight canal. Every year in the 8 years he was water master, was able to supply water rights. Regulation was july 25 every year – cut off all water rights above – leaving only about 12 cfs above satisfiable from Wilson-anem creek systems. Oldest 1855 then 1870 priority. Then don't' have the original class 5 water right in front of him – perhaps late 1870s – can look this up. These are satisfiable. Everything 1880 and junior –

curtailed every year. 3 or 4 irrigation canals cross this system – a bunch of return flow water – the lower portion has nto suffered the need for curtailment – have used the imported irrig return flows that come into the lower creek.

Tanem creek – all 1873 priority – regulation nearly each year. Responsible party is scott turner. Usbr does a bit of management of water diversion at the lower ditch. Tanem canal company does major division in te middle.

Wenas creek – dan has a class 10 right that gets curtailed every year. 2 rounds of regulation each year on wenas creek – super users on jun1 – roughly class 12 1880 priority water rights and junir. Every year on june 1. Juniors (class 4 – class 11) get curtailed july 10 -15. Senior users 1865-1870 – also suffer regulation during most years and definitely in drought years. 1870 right is every year – some curtailment in later portion of season.

Cooke creek – upper Kittitas – 1872 german water right regulated – ongoing dispute every year about KRD canal – where highline crosses crooke creek. Havenot lately had to regulate because of return flows.

Yakima – no prirationing 2006-2014 – fully supply year. 2015 provides monthly break-out of forecasts and end of year levels. This year 47% at end of the year. Monthly break-out for 2015 – to get to Trevor.

Yakima River Basin (edited)

- On July 22, 2015 I curtailed all use on Cowiche Creek to users with 1873 or junior water right (notice attached). This only left 1872, 1871, 1870 and 1869 water rights left to use water.
- In the Ahtanum Basin all water rights are off on July 10th every year. I did not receive any calls or complaints in the Ahtanum from surface water users nor did the Stream Patroller request my assistance with anything.

Yakima River Basin -- Proration Levels In Recent Years
(Starting Water Year 1970)
Percentage of Entitlement

| Year | (1) Start of Pro-ration Period | (2) Storage Control Date | (3) S.C. Julian | Apr. | May | Jun | Jul | Aug | Sep | (4) End of Proration Period |
|---|---|---|---|---|---|---|---|---|---|---|
| 1970 | N/A | 1-Jul | 182 | | | | | | | N/A |
| 1971 | N/A | 16-Aug | 228 | | | | | | | N/A |
| 1972 | N/A | 17-Aug | 230 | | | | | | | N/A |
| 1973 | 6/10 ? | 1-May | 121 | | | 80% | 80% | 80% | 80% | end of sea |
| 1974 | N/A | 1-Aug | 213 | | | | | | | N/A |
| 1975 | N/A | 20-Jul | 201 | | | | | | | N/A |
| 1976 | N/A | 20-Jul | 202 | | | | | | | N/A |
| 1977 | 1-Apr | 1-Apr | 91 | 6-26% | 13-50% | 50% | 70% | 70% | 70% | end of sea |
| 1978 | N/A | 1-Jul | 182 | | | | | | | N/A |
| 1979 | 7/1 ? | 20-Apr | 110 | | | 75% | 75-46% | 46% | 100% | end of sea |
| 1980 | N/A | 1-Jul | 183 | | | | | | | N/A |
| 1981 | N/A | 15-Apr | 105 | | | | | | | N/A |
| 1982 | N/A | 10-Jul | 191 | | | | | | | N/A |
| 1983 | N/A | 20-Jun | 171 | | | | | | | N/A |
| 1984 | N/A | 10-Jul | 192 | | | | | | | N/A |
| 1985 | N/A | 20-Jun | 171 | | | | | | | N/A |
| 1986 | under avg use | 26-Apr | 116 | Hold | under | average | use | for | season | end of sea |
| 1987 | 1-Jun | 20-May | 140 | | | 73% | 70% | 68% | 68% | 16-Oct |
| 1988 | 1-Jul | 24-Jun | 176 | | | | 82% | 90% | 90% | end of sea |
| 1989 | N/A | 18-Jun | 169 | | | | | | | N/A |
| 1990 | N/A | 4-Jul | 185 | | | | | | | N/A |
| 1991 | N/A | 8-Jul | 189 | | | | | | | N/A |
| 1992 | 17-May | 17-May | 138 | | 58% | 58% | 58% | 58% | 58% | end of season |
| 1993 | 1-Jun | 13-Jun | 164 | NRP* 85,88,59% | NRP* 72,85,53% | 56% | 64% | 67% | 71-67% | 30-Sep |
| 1994 | 1-May | 1-Jun | 152 | NRP* | 47-35% | 34% | 39% | 39% | 37% | 30-Sep |
| 1995 | N/A | 1-Jul | 182 | | | | | | | N/A |
| 1996 | N/A | 26-Jun | 178 | | | | | | | N/A |
| 1997 | N/A | 21-Jul | 202 | | | | | | | N/A |
| 1998 | N/A | 26-Jun | 177 | | | | | | | N/A |
| 1999 | N/A | 29-Jul | 210 | | | | | | | N/A |
| 2000 | N/A | 1-Jul | 183 | | | | | | | N/A |
| 2001 | 1-May | 1-Jun | 152 | NRP* | 29% | 30% | 34% | 37% | 37% | 30-Sep |
| 2002 | N/A | 3-Jul | 184 | | | | | | | N/A |
| 2003 | 1-Aug | 20-Jun | 171 | | | "(97%) | "(97%) | 86% | 92% | 30-Sep |
| 2004 | 16-Jun | 16-Jun | 168 | | | 82% | 82% | 90% | 92% | 30-Sep |
| 2005 | 6-Apr | 25-May | 145 | 34% | 34% | 38% | 40% | 42% | 42% | 30-Sep |
| 2006 | N/A | 1-Jul | 182 | | | | | | | N/A |

| Year | (1) Start of Pro-ration Period | (2) Storage Control Date | (3) S.C. Julian | Apr. | May | Jun | Jul | Aug | Sep | (4) End of Proration Period |
|---|---|---|---|---|---|---|---|---|---|---|
| 2007 | N/A | 20-Jun | 171 | | | | | | | N/A |
| 2008 | N/A | 8-Jul | 190 | | | | | | | N/A |
| 2009 | N/A | 25-Jun | 176 | | | | | | | N/A |
| 2010 | Averted by cool & rain Spring | 3-Jul | 184 | 71% | 78% | 90% | 100% | 100% | 100% | N/A |
| 2011 | N/A | 23-Jul | 204 | | | | | | | N/A |
| 2012 | N/A | 15-Jul | 197 | | | | | | | N/A |
| 2013 | | 22-Jun | 173 | | | | | | | N/A |
| 2014 | | 18-Jun | 169 | | | | | | | N/A |
| 2015 | 15-Apr | 15-Apr | 105 | 60%Apr1, 54%Apr15 | 47% | 44% | 44%, 46% | 47% | 47% | |
| Year | (1) Start of Pro-ration Period | (2) Storage Control Date | (3) S.C. Julian | Apr. | May | Jun | Jul | Aug | Sep | (4) End of Proration Period |

NRP* = Natural Runoff Proportion (NRP).
(1) = Start of Proration Period
(2) = Storage Control Date
(3) = Julian Date for Storage Control
(4) = End of Proration Period
Typically the OWSA prorationing carried on at the same level as the TWSA unless otherwise noted.

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
*1250 W Alder St • Union Gap, WA 98903-0009 • (509) 575-2490*

# NOTICE OF WATER REGULATION - July 22, 2015

**To:** All Surface Water Right Holders & Claimants, Subbasin No. 18 (Cowiche Creek)

**From:** Scott Turner, Court-appointed Stream Patroller for Cowiche Creek Subbasin

**Subject:** Curtailment of Water Diversions from Cowiche and Its Tributaries

## Take Notice:

Cowiche Creek flows have dropped to 1.9 cubic feet per second (cfs) at the Department of Ecology Gage as of Monday July 20, 2015 and have dropped to under 1.0 cfs earlier this month. These flow levels are inadequate to fully satisfy senior-priority Cowiche Creek water rights. This dire water supply situation requires that I order the curtailment of all junior-priority water right diversions from Cowiche Creek in order to satisfy senior-priority water rights, in compliance with the 'first in time, first in right' tenet of Washington Water Law.

- Water rights enjoying 1869, 1870, 1871, and 1872 priority dates may continue to divert and use water until further notice.
- **All Cowiche Creek Subbasin water rights with 1873 and junior (more recent) priority dates must curtail their use of water beginning July 22, 2015, through the end of the Cowiche Creek Subbasin irrigation season on October 31, 2015, or until further notice from me.**

I was appointed Cowiche Creek Subbasin stream patroller by the Yakima Surface Water Rights Adjudication Court (Acquavella Court) in its April 9, 2015 "Order Pendente Lite Authorizing Interim Regulation of Cowiche, Manastash, First, and Swauk Creeks", which assigned me the authority and responsibility to "monitor and regulate diversions from those creeks between April 1 and October 31 of each year."

If you have a legally authorized alternate source please contact me so I can verify that the alternate source of water is being used instead of creek water. Examples of alternate sources of water are:

- A standby reserve ground water certificate;
- Shares in Yakima-Tieton Irrigation District.

If you wish to seek relief from this Notice of Regulation, you will need to:

- Contact me to discuss and clarify this matter further;
- Seek relief from the Acquavella Court.

I intend to monitor Cowiche Creek flow levels closely in the coming weeks. I will notify you of any improvement in water supply that would allow certain of the curtailed water rights to resume their diversions, beginning with 1873 priority. If water supply conditions worsen, I may also need to curtail 1872 priority water rights in order to satisfy the remaining most-senior priority water rights.

Scott Turner
Cowiche Creek Stream Patroller
(509) 457-7106
ST:SS/150727

## *Data provided for the Central Region*

Reports showing how much water was delivered to the classes on Manastash Creek through the consolidated diversions for the Manastash Water Ditch Association, Keach/Jensen, Reed and Hatfield ditches.

**Manastash Creek Report** **2015-04-15 Manastash Creek Report**

| WATER RIGHTS Before prorationing | Total of All Diversionary Rights | Total of all Trust (Completed ROEs) | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 22.20 | | 0.045 | 22.150 | | | | |
| MWDA Trust | | 5.81 | | 5.809 | | | | |
| Keach/Jensen | 20.30 | | 0.632 | | 5.467 | 1.170 | 1.17 | 1.926 |
| Keach Jensen Trust | 3.39 | 3.39 | 0.975 | | 2.414 | | | |
| Reed | 23.80 | | 7.926 | 4.155 | 1.050 | | 8.217 | 1.985 |
| Hatfield | 2.80 | | | | | | | |
| Totals | 72.485 | 9.198 | 9.578 | 32.114 | 8.931 | 1.170 | 9.387 | 3.911 |

**PRO-RATIONING CALCULATOR**

Enter Date Here

15-Apr

Enter Upstream Flow Here

44.34

Calculated diversion rates based on entering creek flow and date to the left

| | Diversion | Trust Water | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 22.20 | | 0.045 | 22.15 | | | | |
| MWDA Trust | | 5.81 | | 5.81 | | | | |
| KJ | 2.25 | | 0.632 | | 1.621 | 0 | 0.000 | 0 |
| KJ Trust | | 1.69 | 0.975 | | 0.72 | | | |
| Reed | 12.39 | | 7.926 | 4.16 | 0.31 | | 0.00 | 0.00 |
| Hatfield | 0.00 | | | | | | | |
| | 36.840 | 7.500 | 9.578 | 32.114 | 2.648 | 0 | 0 | 0 |

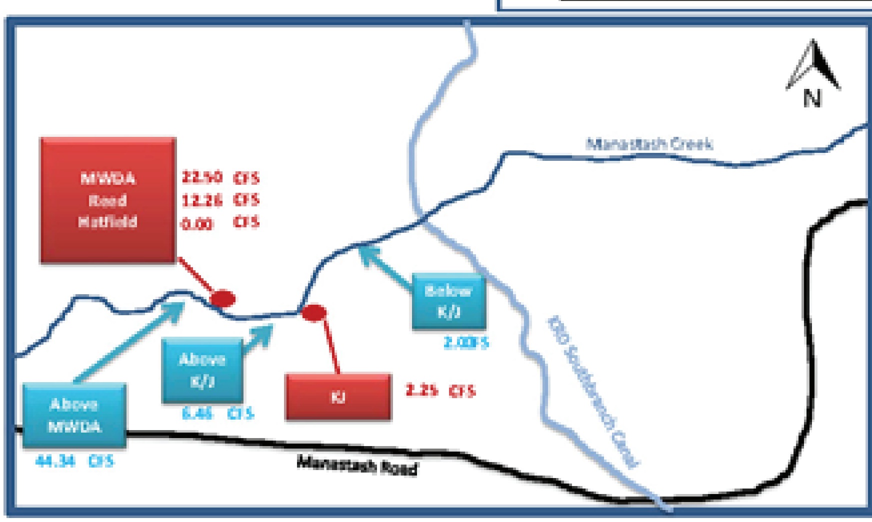
| Flow Measurements | CFS at Each Site |
|---|---|
| MCrk Upstream of MWDA | 44.34 |
| MWDA Diversion | 22.50 |
| Reed Diversion | 12.26 |
| Hatfield Diversion | 0.00 |
| MCrk Upstream of KJ | 6.46 |
| KJ Diversion | 2.250 |
| MCrk Downstream of KJ | 2.03 |

*Blue are Creek measurements with Flow Meter*

*Red are measurements with orifice plates at the diversions*

***Variations in actual flow measurements vs. calculated flow rates***

| | |
|---|---|
| -3.12 | *Water unaccounted for from upstream of MWDA to upstream of KJ (what's calculated to be there versus what's actually there)* |
| -2.18 | *Water unaccounted for from upstream of KJ to downstream of KJ (what's calculated to be there versus what's actually there)* |
| -5.30 | *Water unaccounted for from upstream of MWDA to downstream of KJ (what's calculated to be there versus what's actually there)* |



| WATER RIGHTS Before prorationing | Total of All Diversionary Rights | Total of all Trust (Completed ROEs) | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 22.20 | | 0.045 | 22.150 | | | | |
| MWDA Trust | | 5.81 | | 5.809 | | | | |
| Keach Jensen | 20.30 | | 0.632 | | 5.467 | 1.170 | 1.17 | 1.926 |
| Keach Jensen Trust | 3.39 | 3.39 | 0.975 | | 2.414 | | | |
| Reed | 23.80 | | 7.926 | 4.155 | 1.050 | | 8.217 | 1.985 |
| Hatfield | 2.80 | | | | | | | |
| Totals | 72.485 | 9.198 | 9.578 | 32.114 | 8.931 | 1.170 | 9.387 | 3.911 |

## PRO-RATIONING CALCULATOR

Enter Date Here

17-Apr

Enter Upstream Flow Here

47.6

Calculated diversion rates based on entering creek flow and date to the left

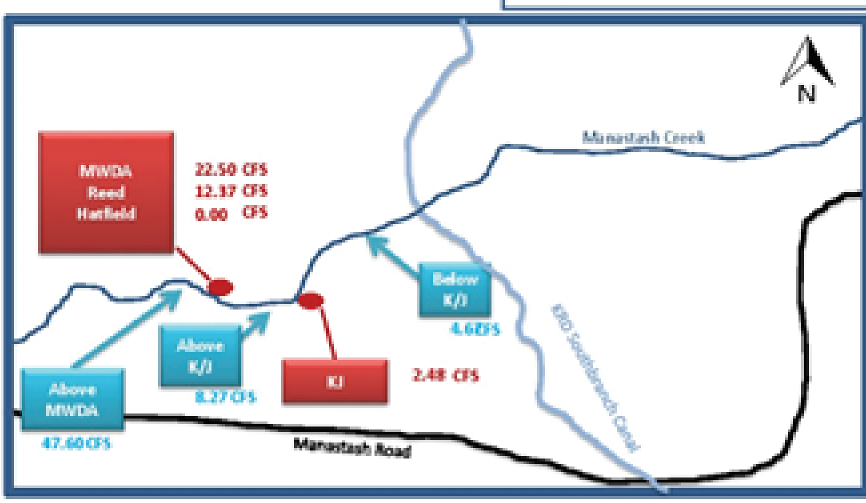
| | Diversion | Trust Water | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 22.20 | | 0.045 | 22.15 | | | | |
| MWDA Trust | | 5.81 | | 5.81 | | | | |
| KJ | 4.25 | | 0.632 | | 3.617 | 0 | 0.000 | 0 |
| KJ Trust | | 2.57 | 0.975 | | 1.60 | | | |
| Reed | 12.78 | | 7.926 | 4.16 | 0.69 | | 0.00 | 0.00 |
| Hatfield | 0.00 | | | | | | | |
| | 39.219 | 8.381 | 9.578 | 32.114 | 5.908 | 0 | 0 | 0 |

| Flows and Diversion Amounts | CFS at Each Site |
|---|---|
| MCrk Upstream of MWDA | 47.60 |
| MWDA Diversion | 22.50 |
| Reed Diversion | 12.37 |
| Hatfield Diversion | 0.00 |
| MCrk Upstream of KJ | 8.27 |
| KJ Diversion | 2.480 |
| MCrk Downstream of KJ | 4.67 |

*Blue are Creek measurements with Flow Meter*
*Red are measurements with orifice plates at the diversions*

***Variations in actual flow measurements vs. calculated flow rates***

| | |
|---|---|
| -4.46 | *Water unaccounted for from upstream of MWDA to upstream of KJ (what's calculated to be there versus what's actually there)* |
| -1.12 | *Water unaccounted for from upstream of KJ to downstream of KJ (what's calculated to be there versus what's actually there)* |
| -5.58 | *Water unaccounted for from upstream of MWDA to downstream of KJ (what's calculated to be there versus what's actually there)* |



| WATER RIGHTS Before prorationing | Total of All Diversionary Rights | Total of all Trust (Completed ROEs) | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 22.20 | | 0.045 | 22.150 | | | | |
| MWDA Trust | | 5.81 | | 5.809 | | | | |
| Keach Jensen | 20.30 | | 0.632 | | 5.467 | 1.170 | 1.17 | 1.926 |
| Keach Jensen Trust | 3.39 | 3.39 | 0.975 | | 2.414 | | | |
| Reed | 23.80 | | 7.926 | 4.155 | 1.050 | | 8.217 | 1.985 |
| Hatfield | 2.80 | | | | | | | |
| Totals | 72.485 | 9.198 | 9.578 | 32.114 | 8.931 | 1.170 | 9.387 | 3.911 |

PRO-RATIONING CALCULATOR

Enter Date Here

20-Apr

Enter Upstream Flow Here

47.13

Calculated diversion rates based on entering creek flow and date to the left

| | Diversion | Trust Water | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 22.20 | | 0.045 | 22.15 | | | | |
| MWDA Trust | | 5.81 | | 5.81 | | | | |
| KJ | 3.96 | | 0.632 | | 3.329 | 0 | 0.000 | 0 |
| KJ Trust | | 2.44 | 0.975 | | 1.47 | | | |
| Reed | 12.72 | | 7.926 | 4.16 | 0.64 | | 0.00 | 0.00 |
| Hatfield | 0.00 | | | | | | | |
| | 38.876 | 8.254 | 9.578 | 32.114 | 5.438 | 0 | 0 | 0 |

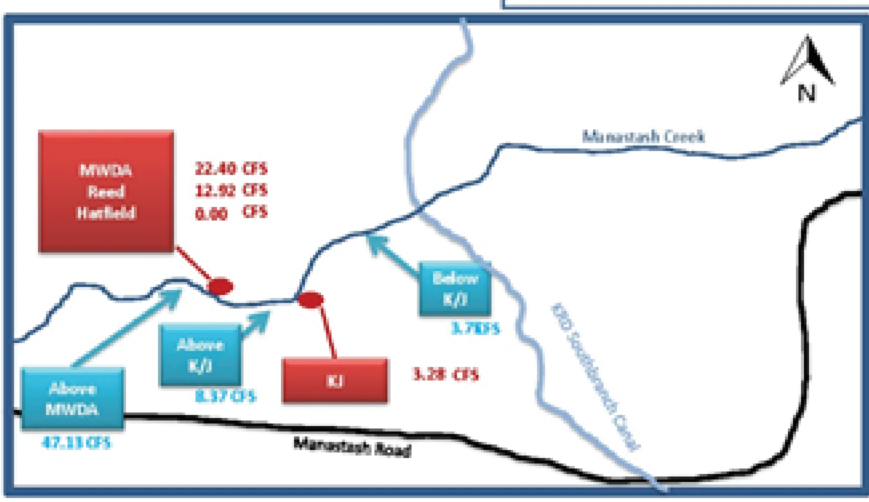
| Flows and Diversion Amounts | CFS at Each Site |
|---|---|
| MCrk Upstream of MWDA | 47.13 |
| MWDA Diversion | 22.40 |
| Reed Diversion | 12.92 |
| Hatfield Diversion | 0.00 |
| MCrk Upstream of KJ | 8.37 |
| KJ Diversion | 3.280 |
| MCrk Downstream of KJ | 3.75 |

*Blue are Creek measurements with Flow Meter*

*Red are measurements with orifice plates at the diversions*

***Variations in actual flow measurements vs. calculated flow rates***

| | |
|---|---|
| -3.44 | *Water unaccounted for from upstream of MWDA to upstream of KJ (what's calculated to be there versus what's actually there)* |
| -1.34 | *Water unaccounted for from upstream of KJ to downstream of KJ (what's calculated to be there versus what's actually there)* |
| -4.78 | *Water unaccounted for from upstream of MWDA to downstream of KJ (what's calculated to be there versus what's actually there)* |



| WATER RIGHTS Before prorationing | Total of All Diversionary Rights | Total of all Trust (Completed ROEs) | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 22.20 | | 0.045 | 22.150 | | | | |
| MWDA Trust | | 5.81 | | 5.809 | | | | |
| Keach Jensen | 20.30 | | 0.632 | | 5.467 | 1.170 | 1.17 | 1.926 |
| Keach Jensen Trust | 3.39 | 3.39 | 0.975 | | 2.414 | | | |
| Reed | 23.80 | | 7.926 | 4.155 | 1.050 | | 8.217 | 1.985 |
| Hatfield | 2.80 | | | | | | | |
| Totals | 72.485 | 9.198 | 9.578 | 32.114 | 8.931 | 1.170 | 9.387 | 3.911 |

PRO-RATIONING CALCULATOR

Enter Date Here

23-Apr

Enter Upstream Flow Here

46.35

Calculated diversion rates based on entering creek flow and date to the left

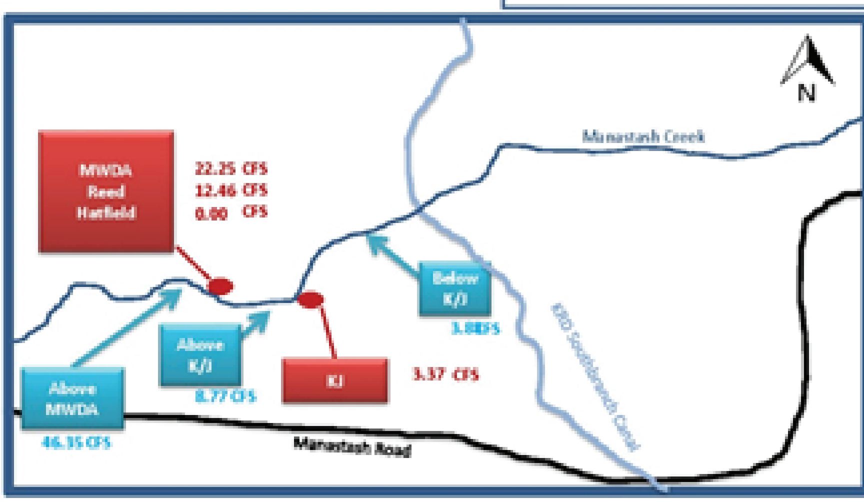
| | Diversion | Trust Water | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 22.20 | | 0.045 | 22.15 | | | | |
| MWDA Trust | | 5.81 | | 5.81 | | | | |
| KJ | 3.48 | | 0.632 | | 2.851 | 0 | 0.000 | 0 |
| KJ Trust | | 2.23 | 0.975 | | 1.26 | | | |
| Reed | 12.63 | | 7.926 | 4.16 | 0.55 | | 0.00 | 0.00 |
| Hatfield | 0.00 | | | | | | | |
| | 38.307 | 8.043 | 9.578 | 32.114 | 4.658 | 0 | 0 | 0 |

| Flows and Diversion Amounts | CFS at Each Site |
|---|---|
| MCrk Upstream of MWDA | 46.35 |
| MWDA Diversion | 22.25 |
| Reed Diversion | 12.46 |
| Hatfield Diversion | 0.00 |
| MCrk Upstream of KJ | 8.77 |
| KJ Diversion | 3.370 |
| MCrk Downstream of KJ | 3.88 |

*Blue are Creek measurements with Flow Meter*
*Red are measurements with orifice plates at the diversions*

***Variations in actual flow measurements vs. calculated flow rates***

| | |
|---|---|
| -2.87 | *Water unaccounted for from upstream of MWDA to upstream of KJ (what's calculated to be there versus what's actually there)* |
| -1.52 | *Water unaccounted for from upstream of KJ to downstream of KJ (what's calculated to be there versus what's actually there)* |
| -4.39 | *Water unaccounted for from upstream of MWDA to downstream of KJ (what's calculated to be there versus what's actually there)* |



| WATER RIGHTS Before prorationing | Total of All Diversionary Rights | Total of all Trust (Completed ROEs) | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| **MWDA** | 22.20 | | 0.045 | 22.150 | | | | |
| MWDA Trust | | 5.81 | | 5.809 | | | | |
| **Keach Jensen** | 20.50 | | 0.632 | | 5.467 | 1.170 | 1.17 | 1.926 |
| Keach Jensen Trust | 3.39 | 3.39 | 0.975 | | 2.414 | | | |
| **Reed** | 23.80 | | 7.926 | 4.155 | 1.050 | | 8.217 | 1.985 |
| **Hatfield** | 2.80 | | | | | | | |
| **Totals** | 72.485 | 9.198 | 9.578 | 32.114 | 8.931 | 1.170 | 9.387 | 3.911 |

## PRO-RATIONING CALCULATOR

Enter Date Here: 27-Apr

Enter Upstream Flow Here: 43.31

Calculated diversion rates based on entering creek flow and date to the left

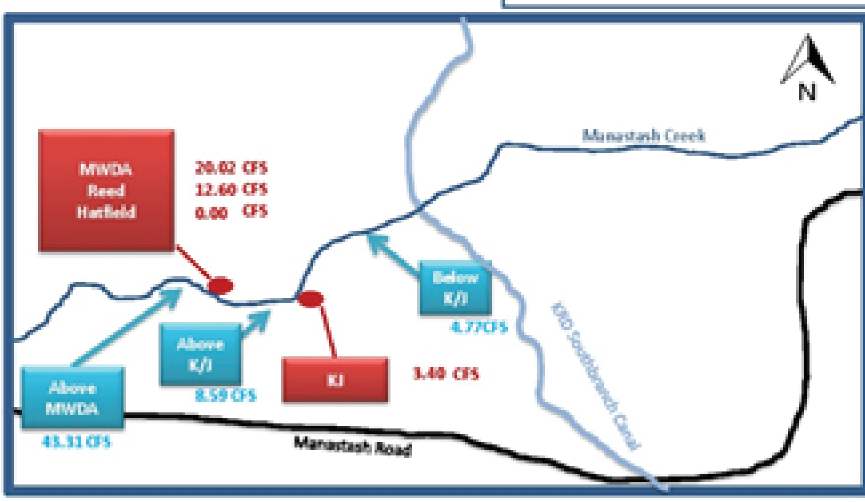
| | Diversion | Trust Water | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 22.20 | | 0.045 | 22.15 | | | | |
| MWDA Trust | | 5.81 | | 5.81 | | | | |
| KJ | 1.62 | | 0.632 | | 0.990 | 0 | 0.000 | 0 |
| KJ Trust | | 1.41 | 0.975 | | 0.44 | | | |
| Reed | 12.27 | | 7.926 | 4.16 | 0.19 | | 0.00 | 0.00 |
| Hatfield | 0.00 | | | | | | | |
| | 36.089 | 7.221 | 9.578 | 32.114 | 1.618 | 0 | 0 | 0 |

| Flows and Diversion Amounts | CFS at Each Site |
|---|---|
| MCrk Upstream of MWDA | 43.31 |
| MWDA Diversion | 20.02 |
| Reed Diversion | 12.60 |
| Hatfield Diversion | 0.00 |
| MCrk Upstream of KJ | 8.59 |
| KJ Diversion | 3.400 |
| MCrk Downstream of KJ | 4.77 |

*Blue are Creek measurements with Flow Meter*
*Red are measurements with orifice plates at the diversions*

***Variations in actual flow measurements vs. calculated flow rates***

| | |
|---|---|
| -2.10 | *Water unaccounted for from upstream of MWDA to upstream of KJ (what's calculated to be there versus what's actually there)* |
| -0.42 | *Water unaccounted for from upstream of KJ to downstream of KJ (what's calculated to be there versus what's actually there)* |
| -2.52 | *Water unaccounted for from upstream of MWDA to downstream of KJ (what's calculated to be there versus what's actually there)* |



| WATER RIGHTS Before prorationing | Total of All Diversionary Rights | Total of all Trust (Completed ROEs) | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 22.20 | | 0.045 | 22.150 | | | | |
| MWDA Trust | | 5.81 | | 5.809 | | | | |
| Keach Jensen | 20.50 | | 0.632 | | 5.467 | 1.170 | 1.17 | 1.926 |
| Keach Jensen Trust | 3.39 | 3.39 | 0.975 | | 2.414 | | | |
| Reed | 23.80 | | 7.926 | 4.155 | 1.050 | | 8.217 | 1.985 |
| Hatfield | 2.80 | | | | | | | |
| Totals | 72.485 | 9.198 | 9.578 | 32.114 | 8.931 | 1.170 | 9.387 | 3.911 |

## PRO-RATIONING CALCULATOR

Enter Date Here

29-Apr

Enter Upstream Flow Here

44.88

Calculated diversion rates based on entering creek flow and date to the left

| | Diversion | Trust Water | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 22.20 | | 0.045 | 22.15 | | | | |
| MWDA Trust | | 5.81 | | 5.81 | | | | |
| KJ | 2.58 | | 0.632 | | 1.951 | 0 | 0.000 | 0 |
| KJ Trust | | 1.84 | 0.975 | | 0.86 | | | |
| Reed | 12.46 | | 7.926 | 4.16 | 0.17 | | 0.00 | 0.00 |
| Hatfield | 0.00 | | | | | | | |
| | 37.234 | 7.646 | 9.578 | 32.114 | 3.188 | 0 | 0 | 0 |

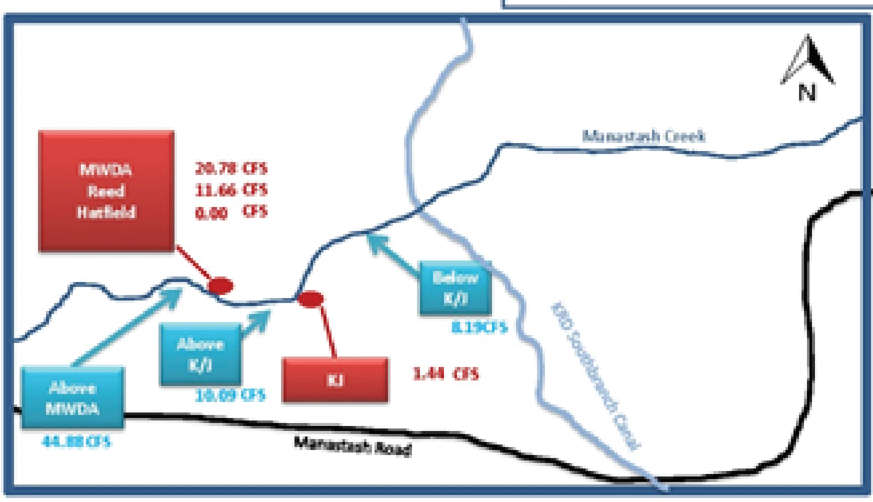
| Flows and Diversion Amounts | CFS at Each Site |
|---|---|
| MCrk Upstream of MWDA | 44.88 |
| MWDA Diversion | 20.78 |
| Reed Diversion | 11.66 |
| Hatfield Diversion | 0.00 |
| MCrk Upstream of KJ | 10.09 |
| KJ Diversion | 1.440 |
| MCrk Downstream of KJ | 8.19 |

*Blue are Creek measurements with Flow Meter*

*Red are measurements with orifice plates at the diversions*

***Variations in actual flow measurements vs. calculated flow rates***

| | |
|---|---|
| -2.35 | *Water unaccounted for from upstream of MWDA to upstream of KJ (what's calculated to be there versus what's actually there)* |
| -0.46 | *Water unaccounted for from upstream of KJ to downstream of KJ (what's calculated to be there versus what's actually there)* |
| -2.81 | *Water unaccounted for from upstream of MWDA to downstream of KJ (what's calculated to be there versus what's actually there)* |



| WATER RIGHTS Before prorationing | Total of All Diversionary Rights | Total of all Trust (Completed ROEs) | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 21.71 | | 0.045 | 21.660 | | | | |
| MWDA Trust | | 6.50 | | 6.299 | | | | |
| Keach Jensen | 19.80 | | 0.632 | | 4.967 | 1.170 | 1.17 | 1.926 |
| Keach Jensen Trust | 3.89 | 3.89 | 0.975 | | 2.914 | | | |
| Reed | 23.80 | | 7.926 | 4.155 | 1.050 | | 8.217 | 1.985 |
| Hatfield | 2.80 | | | | | | | |
| Totals | 71.995 | 10.188 | 9.578 | 32.114 | 8.931 | 1.170 | 9.387 | 3.911 |

PRO-RATIONING CALCULATOR

Enter Date Here

1-May

Enter Upstream Flow Here

42.93

Calculated diversion rates based on entering creek flow and date to the left

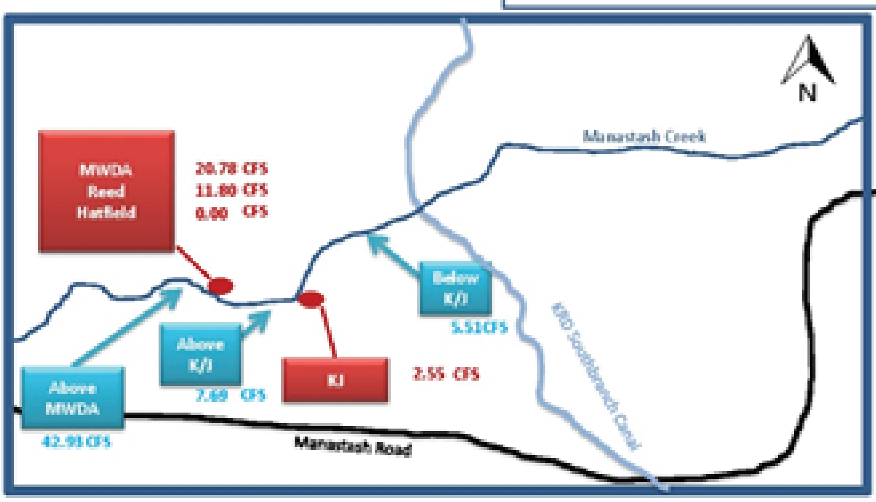
| | Diversion | Trust Water | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 21.71 | | 0.045 | 21.66 | | | | |
| MWDA Trust | | 6.50 | | 6.50 | | | | |
| KJ | 1.32 | | 0.632 | | 0.689 | 0 | 0.000 | 0 |
| KJ Trust | | 1.38 | 0.975 | | 0.40 | | | |
| Reed | 12.23 | | 7.926 | 4.16 | 0.15 | | 0.00 | 0.00 |
| Hatfield | 0.00 | | | | | | | |
| | 35.252 | 7.678 | 9.578 | 32.114 | 1.238 | 0 | 0 | 0 |

| Flows and Diversion Amounts | CFS at Each Site |
|---|---|
| MCrk Upstream of MWDA | 42.93 |
| MWDA Diversion | 20.78 |
| Reed Diversion | 11.80 |
| Hatfield Diversion | 0.00 |
| MCrk Upstream of KJ | 7.69 |
| KJ Diversion | 2.550 |
| MCrk Downstream of KJ | 5.51 |

*Blue are Creek measurements with Flow Meter*
*Red are measurements with orifice plates at the diversions*

***Variations in actual flow measurements vs. calculated flow rates***

| | |
|---|---|
| -2.66 | *Water unaccounted for from upstream of MWDA to upstream of KJ (what's calculated to be there versus what's actually there)* |
| 0.37 | *Water unaccounted for from upstream of KJ to downstream of KJ (what's calculated to be there versus what's actually there)* |
| -2.29 | *Water unaccounted for from upstream of MWDA to downstream of KJ (what's calculated to be there versus what's actually there)* |



| WATER RIGHTS Before prorationing | Total of All Diversionary Rights | Total of all Trust (Completed ROEs) | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| **MWDA** | 21.71 | | 0.045 | 21.660 | | | | |
| MWDA Trust | | 6.30 | | 6.299 | | | | |
| **Keach Jensen** | 19.80 | | 0.632 | | 4.967 | 1.170 | 1.17 | 1.926 |
| Keach Jensen Trust | 3.89 | 3.89 | 0.975 | | 2.914 | | | |
| **Reed** | 23.80 | | 7.926 | 4.155 | 1.050 | | 8.217 | 1.985 |
| **Hatfield** | 2.80 | | | | | | | |
| **Totals** | 71.995 | 10.188 | 9.578 | 32.114 | 8.931 | 1.170 | 9.387 | 3.911 |

## PRO-RATIONING CALCULATOR

Enter Date Here

4-May

Enter Upstream Flow Here

Calculated diversion rates based on entering creek flow and date to the left

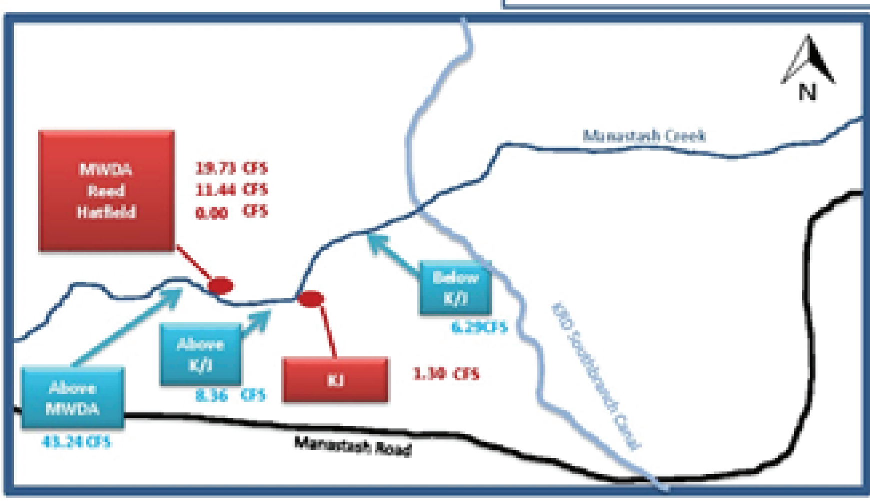
| 43.24 | Diversion | Trust Water | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 21.71 | | 0.045 | 21.66 | | | | |
| MWDA Trust | | 6.30 | | 6.30 | | | | |
| KJ | 1.49 | | 0.632 | | 0.861 | 0 | 0.000 | 0 |
| KJ Trust | | 1.48 | 0.975 | | 0.51 | | | |
| Reed | 12.26 | | 7.926 | 4.16 | 0.18 | | 0.00 | 0.00 |
| Hatfield | 0.00 | | | | | | | |
| | 35.461 | 7.779 | 9.578 | 32.114 | 1.548 | 0 | 0 | 0 |

| Flows and Diversion Amounts | CFS at Each Site |
|---|---|
| MCrk Upstream of MWDA | 43.24 |
| MWDA Diversion | 19.73 |
| Reed Diversion | 11.44 |
| Hatfield Diversion | 0.00 |
| MCrk Upstream of KJ | 8.36 |
| KJ Diversion | 1.300 |
| MCrk Downstream of KJ | 6.29 |

*Blue are Creek measurements with Flow Meter*
*Red are measurements with orifice plates at the diversions*

***Variations in actual flow measurements vs. calculated flow rates***

| | |
|---|---|
| -3.71 | *Water unaccounted for from upstream of MWDA to upstream of KJ (what's calculated to be there versus what's actually there)* |
| -0.77 | *Water unaccounted for from upstream of KJ to downstream of KJ (what's calculated to be there versus what's actually there)* |
| -4.48 | *Water unaccounted for from upstream of MWDA to downstream of KJ (what's calculated to be there versus what's actually there)* |



| WATER RIGHTS Before prorationing | Total of All Diversionary Rights | Total of all Trust (Completed ROEs) | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 21.71 | | 0.045 | 21.660 | | | | |
| MWDA Trust | | 6.30 | | 6.299 | | | | |
| Keach Jensen | 19.80 | | 0.632 | | 4.967 | 1.170 | 1.17 | 1.926 |
| Keach Jensen Trust | 3.89 | 3.89 | 0.975 | | 2.914 | | | |
| Reed | 23.80 | | 7.926 | 4.155 | 1.050 | | 8.217 | 1.985 |
| Hatfield | 2.80 | | | | | | | |
| Totals | 71.995 | 10.188 | 9.578 | 32.114 | 8.931 | 1.170 | 9.387 | 3.911 |

## PRO-RATIONING CALCULATOR

Enter Date Here

6-May

Enter Upstream Flow Here

42.58

Calculated diversion rates based on entering creek flow and date to the left

| | Diversion | Trust Water | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 21.71 | | 0.045 | 21.66 | | | | |
| MWDA Trust | | 6.30 | | 6.30 | | | | |
| KJ | 1.13 | | 0.632 | | 0.494 | 0 | 0.000 | 0 |
| KJ Trust | | 1.26 | 0.975 | | 0.29 | | | |
| Reed | 12.19 | | 7.926 | 4.16 | 0.10 | | 0.00 | 0.00 |
| Hatfield | 0.00 | | | | | | | |
| | 35.016 | 7.564 | 9.578 | 32.114 | 0.888 | 0 | 0 | 0 |

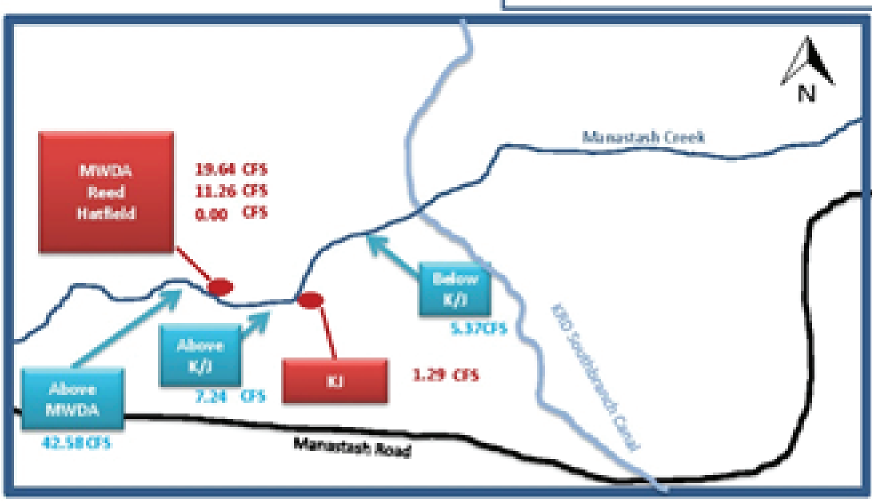
| Flows and Diversion Amounts | CFS at Each Site |
|---|---|
| MCrk Upstream of MWDA | 42.58 |
| MWDA Diversion | 19.64 |
| Reed Diversion | 11.26 |
| Hatfield Diversion | 0.00 |
| MCrk Upstream of KJ | 7.24 |
| KJ Diversion | 1.290 |
| MCrk Downstream of KJ | 5.37 |

*Blue are Creek measurements with Flow Meter*

*Red are measurements with orifice plates at the diversions*

***Variations in actual flow measurements vs. calculated flow rates***

| | |
|---|---|
| -4.44 | *Water unaccounted for from upstream of MWDA to upstream of KJ (what's calculated to be there versus what's actually there)* |
| -0.58 | *Water unaccounted for from upstream of KJ to downstream of KJ (what's calculated to be there versus what's actually there)* |
| -5.02 | *Water unaccounted for from upstream of MWDA to downstream of KJ (what's calculated to be there versus what's actually there)* |



| WATER RIGHTS Before proratoning | Total of All Diversionary Rights | Total of all Trust (Completed ROEs) | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 20.98 | | 0.045 | 20.930 | | | | |
| MWDA Trust | | 7.03 | | 7.029 | | | | |
| Keach Jensen | 19.80 | | 0.632 | | 4.967 | 1.170 | 1.17 | 1.926 |
| Keach Jensen Trust | 3.89 | 3.89 | 0.975 | | 2.914 | | | |
| Reed | 23.80 | | 7.926 | 4.155 | 1.050 | | 8.217 | 1.985 |
| Hatfield | 2.80 | | | | | | | |
| Totals | 71.265 | 10.918 | 9.578 | 32.114 | 8.931 | 1.170 | 9.387 | 3.911 |

**PRO-RATIONING CALCULATOR**

Enter Date Here

8-Jun

Enter Upstream Flow Here

23.76

Calculated diversion rates based on entering creek flow and date to the left

| | Diversion | Trust Water | 1st, 1871 | 2nd, 1872 | 3rd, 1874 | 4th, 1876 | 5th, 1877 | 6th, 1878 |
|---|---|---|---|---|---|---|---|---|
| MWDA | 9.29 | | 0.045 | 9.24 | | | | |
| MWDA Trust | | 3.10 | | 3.10 | | | | |
| KJ | 0.63 | | 0.632 | | 0.000 | 0 | 0.000 | 0 |
| KJ Trust | | 0.98 | 0.975 | | 0.00 | | | |
| Reed | 9.76 | | 7.926 | 1.83 | 0.00 | | 0.00 | 0.00 |
| Hatfield | 0.00 | | | | | | | |
| | 19.681 | 4.079 | 9.578 | 14.182 | 0 | 0 | 0 | 0 |

| Flows and Diversion Amounts | CFS at Each Site |
|---|---|
| MCrk Upstream of MWDA | 23.76 |
| MWDA Diversion* | 12.21 |
| Reed Diversion | 10.09 |
| Hatfield Diversion | 0.00 |
| MCrk Upstream of KJ | 1.00 |
| KJ Diversion | 0.490 |
| MCrk Downstream of KJ | 0.32 |

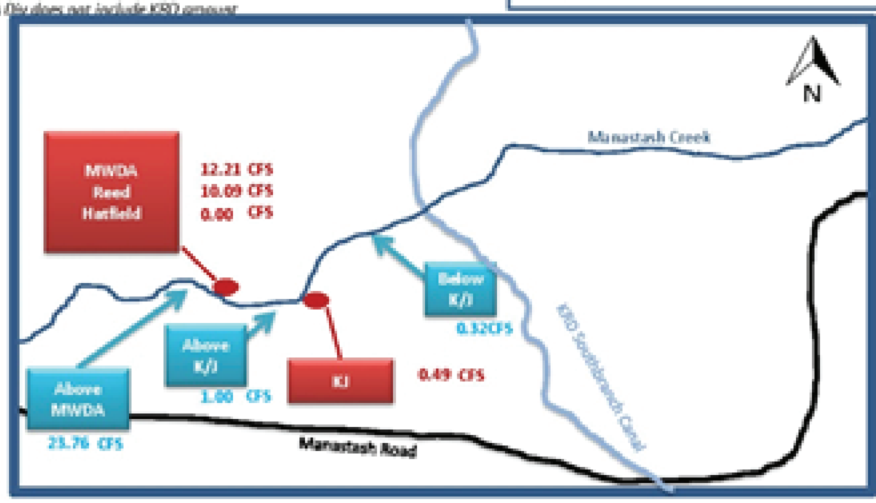
*Blue are Creek measurements with Flow Meter*

*Red are measurements with orifice plates at the diversions*

**MWDA Div does not include KRD amount*

***Variations in actual flow measurements vs. calculated flow rates***

| | |
|---|---|
| -0.46 | *Water unaccounted for from upstream of MWDA to upstream of KJ (what's calculated to be there versus what's actually there)* |
| -0.19 | *Water unaccounted for from upstream of KJ to downstream of KJ (what's calculated to be there versus what's actually there)* |
| -0.65 | *Water unaccounted for from upstream of MWDA to downstream of KJ (what's calculated to be there versus what's actually there)* |



## *Information pertaining to the Eastern Region*

Regulation 2015

### Walla Walla Adjudication

The 2015 water year was extremely low for the Walla Walla River Basin in that many of the smaller streams went dry rapidly so that no curtailment from Ecology was not needed.

### Walla Walla River

Tributary to Colombia River WRIA 32

2015
Starting o the second week of May I was curtail 14 water rights that divert from Yellowhawk Creek that are junior to 1892 (Gardena Farms). There were 4 water right holders upstream of Yellowhawk that were also curtailed.

The water that was available to the 1892 class was limited and they by-passed up to 20cfs to satisfy downstream senior water rights starting May 15th. The river flow had reduced on June 19th to a level that Gardena Farms could not divert water. The flows did not recover until early October 2015.

On a normal year Gardena Farms can divert into early July and then resumes mid Sept.

### Mill Creek

Tributary to Walla Walla River WRIA 32

2015
Water in Mill Creek was flowing in early May at a rate that the Federal, State and Tribal Fish Managers determined to divert any water that was not needed to supply water right holders in Mill Creek be diverted into Yellowhawk Creek to increase flows in the Upper Walla Walla. The Qi needed to insure that water right holders have adequate water a flow of 10cfs is needed downstream of the Yellowhawk diversion

In a normal water year, Mill Creeks flow is adequate to serve the water right holders until July and then returns in Mid Sept.

### Touchet River

Tributary to Walla Walla River WRIA 32

2015
69 water right holders were curtailed on July 9 in favor of a senior water right holders (1882 Touchet Eastside Westside Irrigation District). They were curtailed until August 1st.

These water right holders are curtailed 3 in 10 years. In a normal curtailment year are as short as 1 week and may occur multiple times.

## Tucannon River

Tributary to Colombia River WRIA 35

2015
8 water right were curtailed due to low flows. The water rights are provisioned with a minimum flow rate in the river.

Normal water years the river flow does not get below the minimum flow rate provision.

## Asotin Creek

Tributary to Colombia River WRIA 35

2015
11 water tight holders were curtailed based on low flow provisions on their water rights.

This is the first time that they have been curtailed.

## Cow Creek Adjudication

Tributary to Palouse River WRIA 34

All Classes of diversionary water rights in the "lower basin" curtailed in 2015. Flows did not meet stockwater requirements. Lower Basin is from Sprague Lake to Palouse River

Typically- diversionary water rights curtailed in July on average and wet years.

Many rights in the tributaries of the Palouse River are unadjudicated, but the rights contain individual bypass conditions. Many of these rights were off during 2015 due to lack of water to satisfy diversion. Multiple rights were issue from the Palouse River with July 1-15 cutoff dates (SWSL). Those rights randomly checked by Ecology were off in 2015, voluntary compliance, or have quit irrigating all together.

## Harvey Creek Adjudication

Tributary to Columbia River WRIA 58

All classes below Class 10 regulated in July in 2015 to satisfy stock flows and senior rights.

Typically – regulation of Class 12 and below in late July or August on average and wet years.

## Quillisascut Creek Adjudication

Tributary to Columbia River WRIA 58

All classes of use below Class 1 regulated every year around July 1. Typical all years. Regulation is called by the senior water user and typically does not involve ECY for regulation. Water users are accustomed to the call.

For most all of the small tributaries to the Columbia in WRIA 58, Stevens County were adjudicated early due to lack of flows. Typically there is not sufficient water in these stream to satisfy senior right or stock flows in normal years. Little regulation is required due to the lack of water to fight over.

### Hunters Creek

Open Adjudication – uncompleted
Tributary to Columbia River WRIA 58

Numerous complaints of a dry creek and landowners requesting regulation. Without a completed Adjudication we were unable to regulate. Typical in late summer.

### Hawk Creek

Open Adjudication – uncompleted
Tributary to Columbia River WRIA 58

Numerous complaints over the dry creek. Without a completed adjudication, unable to regulate. Typical in late summer.

### Crab Creek

Partial Adjudications on parts of the creek.
Tributary to Columbia Basin Project.

Creek did not flow in the lower reaches in 2015. Typically insufficient flows in all years to satisfy claimed uses other than spring runoff. In 2015 the spring runoff was insufficient even to saturate the dry creek bed in some areas. Unadjudicated rights cannot be regulated to satisfy adjudicated areas.

# APPENDIX B – Hydropower in the 2016 Long-Term Water Supply and Demand Forecast

## Introduction to Hydropower Demand

Hydroelectric power is extremely important to economic development in the Pacific Northwest, including Washington State. The first hydropower turbines were installed on Columbia River tributaries in the late 1800s, and water power from dams in the Columbia River Basin provided most of the electricity in the Pacific Northwest into the 1960s. As the population became larger and the regional economy grew, demand for electricity surpassed the output of the dams, which gave rise to other types of power plants, including thermal plants fueled by coal, nuclear fission, and natural gas. However, electricity in the Northwest is still dominated by hydropower, which accounts for about two-thirds of the region's supply. Most of the region's hydropower is generated on the Columbia River and its tributaries.

Hydroelectric power consumption in Washington State exceeds other energy sources by a wide margin (U.S. Energy Information Administration; Figure B-1). The figures are even more dramatic if only electricity is considered, with hydropower generating 6,322,000 MWh compared to 973,000 MWh from natural gas-fired facilities, 795,000 MWh from nuclear, and 790,000 from other renewable sources.

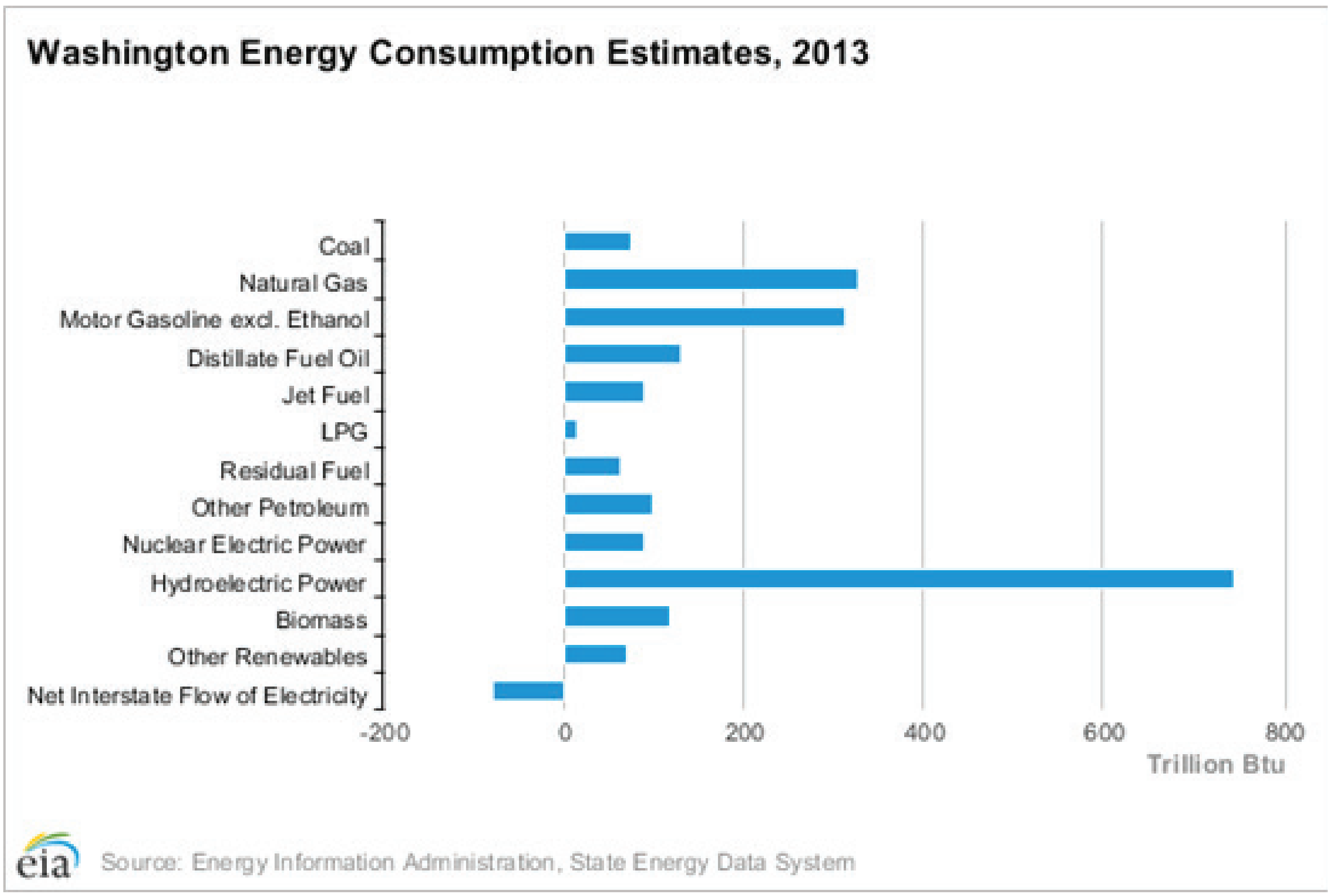



*Figure B-1. Washington State's total energy consumption.*

Water demand for generating hydroelectric power is typically different to water demand for agriculture or for municipal use. Except for evaporation from the impoundment surface, water for hydropower is totally non-consumptive: the water passes through the turbines and is discharged back into the river. While the penstocks and associated piping at some facilities may remove water from certain reaches of the river, for the most part, such distances are relatively short. Furthermore, although many of Washington's hydropower facilities lack meaningful storage, those that do have the ability to store water during high flow events and release it at other times. Power generation is estimated based on effective head, turbine-discharge volume, and efficiency.

Impediments to new traditional dam and power development are related to concerns over migratory fish and lamprey passage, as well as displacement of human activities in upstream reservoir areas, among other technical and economic issues. The potential for innovative hydropower solutions are currently being investigated as understanding of the food-energy-water nexus improves. To inform the 2016 Forecast, the team examined factors related to demand for hydropower in the foreseeable future, to complement the future supply estimates being modeled using VIC-CropSyst and ColSim outputs.

# Forecasting Hydropower Water Demand – Framing Principles

The Northwest Power and Conservation Council (NWPCC) collects data on energy produced by the major hydroelectric dams in the Columbia River Basin. According to the NWPCC (2016a), more than 75 major federal and nonfederal hydroelectric dams in the Columbia River Basin produce upwards of 15,000 annual average megawatts (MWa) of energy, which accounts for approximately 55% of the power generating capacity in the Pacific Northwest (about three quarters of the region's electricity). Power entities in the Northwest regularly carry out extensive forecasting of electricity demand and power-generating capacity. For the 2016 Forecast, the research team reviewed existing projections across the Columbia River Basin with two specific objectives in mind, to:

1. Find out whether regional and state level power entities felt that they would be able to meet anticipated growth in demand over the next 20 years; and

2. Determine the likelihood of any additional hydroelectric storage capacity being built within the Columbia River Basin over the next 20 years.

Available reports that were reviewed included those carried out by the Bonneville Power Administration (BPA), the Northwest Power and Conservation Council, Avista, Idaho Power, Portland General Electric (PGE), Grant County PUD, Chelan County PUD, and Douglas County PUD. British Columbia (BC) Hydro documentation was also reviewed, though their long-term planning documents were general in nature. In addition, newspaper articles and websites were examined for relevant content. It is important to recognize that some information was difficult to evaluate and market conditions and corporate announcements can quickly render some assumptions obsolete. Nevertheless, attempts were made to ensure the most recent information was included. Reviews were supported with conversations with staff at public utility districts in Washington State and Avista Utilities.

## *Hydropower Demands from the Previous 2011 Forecast*

The review of hydropower demand in the 2011 Forecast found that the demand for water storage to supply hydropower facilities across the Columbia River Basin was anticipated to remain essentially unchanged through 2030. Utilities were expected to be able to meet projected steady growth in peak winter and summer energy demands through conservation and integration of other energy sources, including those required under Washington's passage of Initiative 937. However, several power entities and other stakeholders were concerned that climate change, concerns over carbon-based energy, and the possible renegotiation of the international Columbia River Treaty could adversely affect hydropower generation capacity and/or hydroelectric demand.

Thus, the team has re-examined the assumptions made in 2011 as part of the current 2016 Forecast. This re-examination was combined with a review of the Northwest Power and Conservation Council's newly-released 7th Power Plan, to see if any additional information might change the previous assessment.

## *Northwest Power System Overview*

The use of terms such as average, wet, and dry years or flows is standard practice for hydropower forecasting. Average flow year refers to the median point (50th percentile) in the period considered (half of the years were wetter and half were drier) under the middle climate scenario. "Average" by itself, on the other hand, refers to the average value over all climate scenarios and flow conditions, and a 90% confidence interval is provided around that average. In years with normal or average precipitation and runoff, the region's hydroelectric system can provide about 16,000 megawatts of electricity on average. The amounts vary from 12,000 MW during "dry" conditions (20th percentile, with only 20% of years being drier) to 20,000 MW during "wet" conditions (80th percentile, with only 20% of years being wetter).

Electricity load in the Pacific Northwest is expected to grow by about 7,000 megawatts between 2009 and 2030, growing at about 335 average megawatts per year (1.4% per year). The residential and commercial sectors are expected to account for most of the growth. Hydropower is expected to help meet both the base load and peak load under this increasing demand scenario. Base load is the minimum level of electricity demand required over a period of 24 hours. It is needed to provide power to components that keep running at all times. Peak load is the time of high demand, often occurring for only shorter durations. In mathematical terms, peak demand could be understood as the difference between the base demand and the highest demand.

It is unclear whether the increased demand by 2030 will necessitate additional hydropower facilities. Chief Joseph Dam on the mainstem Columbia River, approximately 50 miles downstream of Grand Coulee, is spending nearly $170 million to replace 16 turbine runners. As a result, the facility will produce 6.5% more electricity (an average of 53 megawatts) sometime in 2017 without increasing water demand. This increase is enough to power 39,000 homes and generally qualifies as a renewable source of energy in portfolio standards because it is an upgrade of an existing facility.

## *Emerging Influences on Hydropower Demand*

Recent developments surrounding droughts and water scarcity have focused national and global attention on the interdependent connections between water and energy infrastructure. Several current trends are further increasing the urgency to address the water-energy nexus in an integrated and proactive way. Climate change, population growth, migration, and the introduction of new technologies in the energy and water domains could dramatically shift water and energy demands in the future. Water scarcity, variability, and uncertainty are becoming more prominent, potentially leading to vulnerabilities in the energy system. Market forces and policies continuously shift the mix of future electricity sources. As recently as 2010, the U.S. Energy Information Administration was predicting a steady increase in coal-fired electricity generation through 2035 (Kearney 2010) while their 2016 forecasts present a greater than 50% reduction in this earlier prediction, resulting in opportunities for other sources of energy to fill in the deficit. Because of these interrelated factors, accurately predicting future energy needs and the associated water demands based on hydropower expansion is extremely difficult. As previously mentioned, energy derived from hydropower has a different impact on water resources than fossil-fuel based energy production demands (or agricultural and municipal demands) in that most of the water is passed through the turbines and immediately returned to the river. In that regard, hydropower has some advantages over fossil-fuel based facilities. However, uncertainties surrounding the availability of water to produce power when needed complicate the analysis.

Surface water flows in the Columbia River Basin are dominated by the temperature-sensitive cycle of snow accumulation and melting. During the winter, when the majority of precipitation occurs, snow accumulates in the upper elevations of the Basin, forming a "natural reservoir" that stores water during times when demands are relatively low. Melting snow subsequently provides peak yearly flows in the spring and early summer. This is generally followed by a low-flow period in the late summer and early fall, until late fall flows increase due to rainfall. Operations of major reservoirs have shifted a significant amount of water availability from the winter months to the drier summer months. The United States, however, only directly controls two of the facilities on the Columbia River (Grand Coulee and Libby). Uncertainty related to the operation of the Canadian dams due to ongoing treaty discussions remains high, and thus much of the current analyses assumes status quo. If operations forced additional spill in spring months and provided lower flows in summer, this could impact the demand for additional hydropower.

In addition, the climate in the Pacific Northwest is already changing. Average temperatures are about 0.8°C (1.5°F) higher than they were a century ago, with more warming during the winter than at other times of year. Regional climate change projections suggest that these trends will intensify, with projected temperature changes in the range of 1.1°C to 4.7°C (2 to 8.5°F) over the next 50 years. All models project warming of at least 0.5°C (0.9°F) in every season. This seemingly small amount of warming could fundamentally change the patterns of rain and snowfall in the Columbia River Basin, leading to earlier snowmelt and peak flows, with longer periods of lower flows during the summer. The shift in the annual hydrograph to the left would lead to high flow during winter, most of which would be spilled over dams, and to low flows during summer, which would mean less power generation would be possible when the demand is highest.

There is a general consensus that power demand in summer has been increasing due to warmer temperatures, whereas winter power demand has been increasing due to population growth. Therefore, changes in electricity demand could conceivably surpass changes in future supply, and system-wide power production may shift in the same fashion because it is directly related to stream flow. The drought conditions of 2015, and the market responses to less water during the summer, provided an excellent example of the potential impact of low-flow conditions (Figure B-2). Natural gas use increased significantly to make up for the shortage in hydropower.

The development of an Energy Imbalance Market in the Eastern U.S., and the change in renewable portfolio standards (RPS) in California (from 33% to 50%) could have impacts on hydropower demands in the

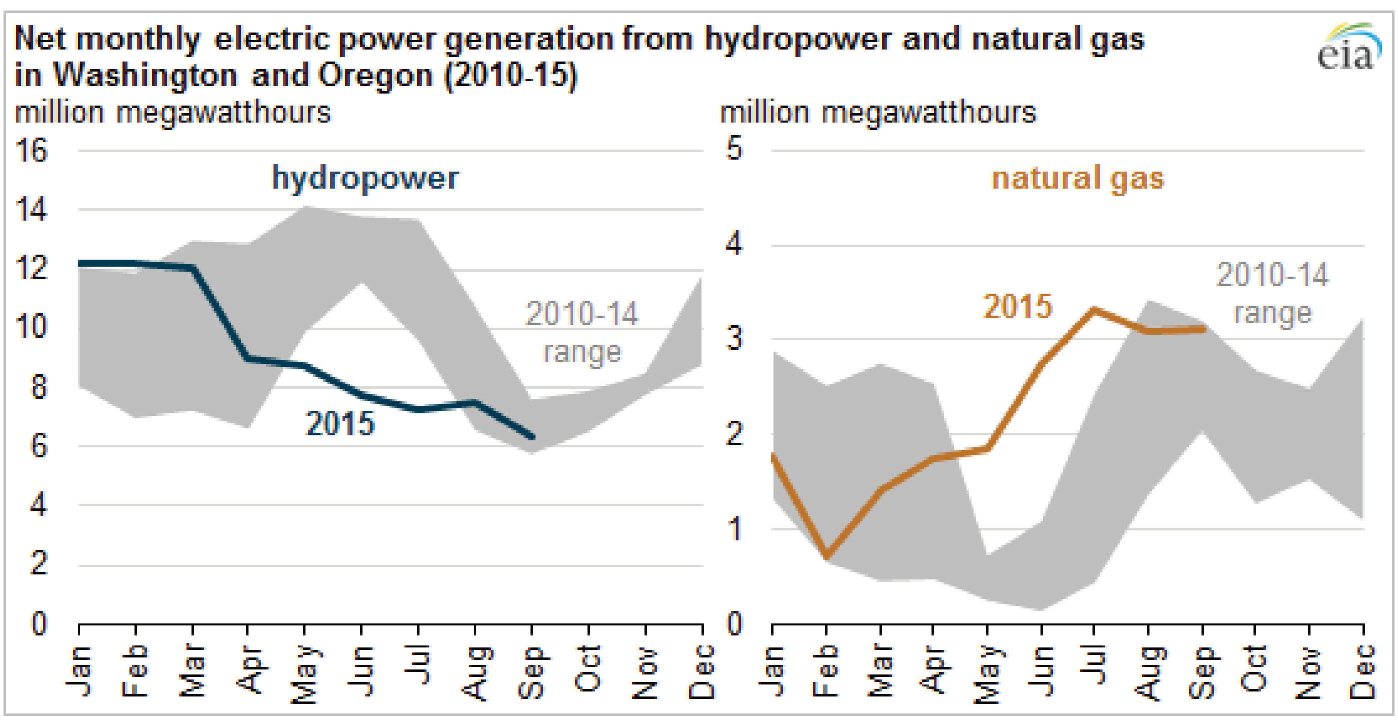



*Figure B-2. Impact of climate variation on the mix of power generation (U.S. EIA 2015).*

Northwest. How market forces and legislative policies will react to such changes is currently being debated. In addition, with very little existing storage capacity, such market forces may warrant new storage projects or the construction of new hydropower sites. Under such scenarios, the concept of the water-energy nexus has become a popular matter of discussion. The water-energy nexus aims to:

- Optimize the freshwater efficiency of energy production, electricity generation, and end-use systems;
- Optimize the energy efficiency of water management, treatment, distribution, and end-use systems;
- Enhance the reliability and resilience of energy and water systems;
- Increase the safe and productive use of non-traditional water sources;
- Promote responsible energy operations with respect to water quality, ecosystem, and seismic impacts; and
- Exploit productive synergies among water and energy systems.

The abovementioned influences on hydropower demand (energy imbalance markets, renewable portfolio standards) have the ability to increase base load (particularly with coal being shut down), and the need for increased peaking facilities. For example, TransAlta, which owns and operates the Centralia Coal Plant, has a net generating capacity of 1,340 MW. In May of 2011, then Governor Gregoire signed legislation that would phase out coal-burning at the facility by 2025. Natural gas production may fill the void caused by this move away from coal, but there may also be an opportunity for increased hydropower demand.

Coal-fired plants within the Columbia River Basin are rare. In fact, Centralia appears to be the only significant coal facility in Washington. Portland General Electric owns a 550 MW facility in Boardman that is scheduled to close by 2020 and replaced by a second gas-fired station. Idaho does not have any coal-fired plants physically located in the state, but it does import electricity generated in neighboring states from coal-burning facilities. Avista, serving northern Idaho, receives coal-generated electricity from Montana's Colstrip Generation Station. Idaho Power has indicated that it may retire its North Valmy Generation Station in Nevada by 2025, but has no timeline for closure of the Jim Bridger Power Plant in Wyoming. PacificCorp, which serves eastern Idaho under the name Rocky Mountain Power, is planning to reduce its reliance on coal by 2,800 MW by 2034 (Ramseth, 2015). Since the closing of the PPL Corette facility in 2015, Montana has four coal-fired facilities, some of which may be technically outside the Columbia River Basin but two still provide electricity to customers within the Bonneville Power Administration's service area. The 2,094 MW Colstrip facility, for example, is located 120 miles southeast of Billings, Montana but is collectively owned by Puget Sound Energy, Talen Energy, Portland General Electric, Avista, PacifiCorp, and NorthWestern Energy. Future Environmental Protection Agency regulations—combined with political and social pressures—could impact the viability of these facilities. It is assumed however that the transition plan for any of these facilities would involve a combination of other energy sources, including hydropower and improvements to generating facilities at existing dams.

Retiring coal plants are not the only potential for increased hydropower needs. However, the likelihood of the region's only nuclear-generating facility closing appears small. While the Columbia Nuclear Generating Station in Benton County, Washington (1,150 MW capacity) receives constant environmental scrutiny, in 2012 Energy Northwest was granted a 20-year license extension for operating the facility from 2023 to 2043. Thus, it was assumed that this facility would remain in operation over the period of analysis of the 2016 Forecast, barring some unforeseeable adverse event.

In 2013 there were 29 states plus the District of Columbia that had mandatory renewable portfolio standards (RPS), and 8 additional states with voluntary targets. In Washington, the Energy Independence Act (I-937) sets RPS targets at 9% in 2016 and 15% by 2020. These types of mandates should create opportunities for

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70 See https://www.bpa.gov/power/pgc/wind/EX_A_BPA_Service_Area.pdf

hydroelectric generation. However, there are a multitude of state policies that govern RPS that makes predicting the economic viability of new hydropower projects very uncertain. While hydropower is typically eligible for RPS status in most states having RPS requirements, there is a wide range of acceptable conditions.

Stori (2013) found restrictions on hydropower in RPS were generally related to capacity, vintage, or technology. Often, large existing facilities are excluded from RPS while small facilities (e.g., < 30MW) are acceptable. Of the 30 locales requiring RPS, 23 allow new hydropower development to be included, while five explicitly prohibit new dams from counting. Some states also allow for efficiency upgrades, even at large facilities, to count. In Washington, incremental electricity generated because of efficiency improvements is acceptable, as is power generated in irrigation pipes and canals; however, new hydropower is not allowed to be counted towards RPS. Unfortunately, RPSs represent relatively new regulatory constraints and the rules are often changing. For example, in 2015 there were four House bills and three Senate bills that were introduced that touched on hydropower and RPS eligibility and requirements.

Need for additional pumped storage may become a necessity as additional renewable energy sources are placed in service. Unlike many coal, gas, or nuclear base-load generating facilities, hydropower generation can quickly be changed in response to fluctuations in wind and solar facilities. In an article on Bonneville Power Administration's website (BPA 2015), it was reported that Chief Joseph has gone from producing 400 MW to 2,400 MW back to 400 MW in just a few minutes as a result of changes in wind generation. Extending this concept even further is the pump storage potential of using excess hydropower and renewable energy supplies to pump water uphill to a storage facility, and releasing it back downhill during peak demand times, like the facility at Grand Coulee and Banks Lake has the potential to do. Yale Environment 360 (2015) reported preliminary planning of a $2.5 billion, 1,200-MW JD Pool Pumped Storage Hydroelectric Project in Washington State, which would site a pair of upper reservoirs between strings of wind turbines on the Columbia Plateau and a lower reservoir, located 2,400 feet down at an abandoned aluminum smelter near the John Day Dam. While projects such as this may only be in the planning phase, the fact that many countries are using or are planning to use pump storage facilities indicates that there is some potential that should be considered.

Low head (typically defined as less than 16 feet) hydropower generation in irrigation canals is another potential for expanding energy production that is being explored. In 2006, the Idaho National Laboratory identified approximately 5,400 sites across the United States where small and low-head power might be feasible. The U.S. Bureau of Reclamation estimated over 365,000 MWh could be generated annually in its canals and conduits located in western states. Gensler and Kinzli (2013) conducted a feasibility study of hydropower generation in New Mexico irrigation systems and found encouraging results. A comprehensive, objective analysis was not found for Washington State. Nevertheless, it would seem that a potential exists that could lead to increased supply.

Battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) currently represent only a small percentage of the automobile industry. Significant increases in BEVs and PHEVs could drive the need for additional power, but it is difficult to find reliable predictions from unbiased sources. Forecasted growth in vehicles sales are plagued with uncertainty surrounding gasoline prices, projections in battery costs, technology adoption rates, national policy initiatives, and hopeful speculation. Bloomberg New Energy Finance (2016) predicted electric vehicles sales will represent 35% of global new car sales by 2040. That would represent a huge increase from the 0.1% of the market currently served by electric vehicles. The Rocky Mountain Institute projects that by 2050, 50% of U.S. vehicles will be electric. Even ExxonMobil projected, in 2015, that hybrid vehicles would represent 50% of the market by 2040, although their forecast for plug-in hybrids and full electric cars was considerably less (about 5% of the global fleet), due to assumptions regarding functional constrains and relatively high costs.

### *Columbia River Treaty*

One of the uncertainties with the Pacific Northwest power supply over the next decade is the fate of the Columbia River Treaty. The Columbia River Treaty between the United States and Canada has the potential to be terminated by either country in 2024, however, notice must be given 10 years prior to this. Currently, Canada operates their facilities on the Columbia River such that the United States can produce hydropower with optimum efficiency. A portion of the power generated in the U.S. as a result of Canadian operations is in turn sent back to Canada. This is known as the Canadian Entitlement, which was laid out in the Columbia River Treaty.

If the Columbia River Treaty continues in its present form, the coordinated operation for power benefits in both countries and the Canadian Entitlement to downstream U.S. power benefits would continue. However, if the treaty is terminated, British Columbia may operate Mica, Arrow, and Duncan as it desires, except that provisions for called-upon flood control storage continue, the Boundary Waters Treaty applies, and the provisions for Libby coordination and Kootenay River diversion options continue. At this point of time, given the flood control and termination provisions, and the changing needs and desires for hydropower, fish, and other water uses, the future of the Columbia River Treaty remains very uncertain.

## Hydropower Water Demand in the Columbia River Basin

The hydropower demand forecast focused on a review of projections carried out by power planning entities throughout the Columbia River Basin. The Northwest Power and Conservation Council (NWPCC 2016a and 2016b) forecasts average regional electricity demand will grow from 19,400 average megawatts in 2013 to somewhere between 20,600 to 23,600 average megawatts by 2035 (NWPCC 2016a) (Figure B-3). In other words, regional demand is expected to increase by anywhere from 1,200 to 3,200 average megawatts over the 2013-2035 timeframe, with the possibilities of these numbers reaching 2,200 to 4,800 average megawatts once distribution and transmission system losses are considered. This represents a relatively modest growth rate of 0.5 to 1.0% per year.

Peak demand is perhaps more important than average demand. The regional peak demand for power, which typically occurs in winter, is forecast to grow from 30,000 to 31,000 megawatts in 2015 to 31,600 to 35,600 megawatts by 2035. Summer-peak demand is forecast to grow faster than winter peak, from 27,000 to 28,000 megawatts in 2015 to 30,600 to 33,600 megawatts by 2035 (NWPCC 2016a). However, the region's hydroelectric system can only produce about 26,000 megawatts of sustained peak over a two-hour period. Over 4-hour and 10-hour periods, the peaking capabilities drop to about 24,000 megawatts and 19,000 megawatts respectively. With a higher average demand growth rate in summer, the gap between summer-peak load and winter-peak load will be narrowed substantially from about 3,000 megawatts to between 1,000 to 2000 megawatts.

In the Canadian portion of the Columbia River Basin, BC Hydro expects that demands may grow as much as 40% across British Columbia. Conservation and transmission improvements will be essential in meeting this anticipated new demand. The construction of the Site C Clean Energy Project (outside the Columbia River Basin, on the Peace River) could provide up to 1,100 MW of capacity, serving 450,000 homes. BC Hydro is currently working to add two new generation units (for a total of six) at the Mica Dam on the Columbia River,

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71 ExxonMobil updates their forecast every year. So while the 2015 forecast is not currently available, their 2017 forecast is available online at: http://corporate.exxonmobil.com/en/energy/energy-outlook

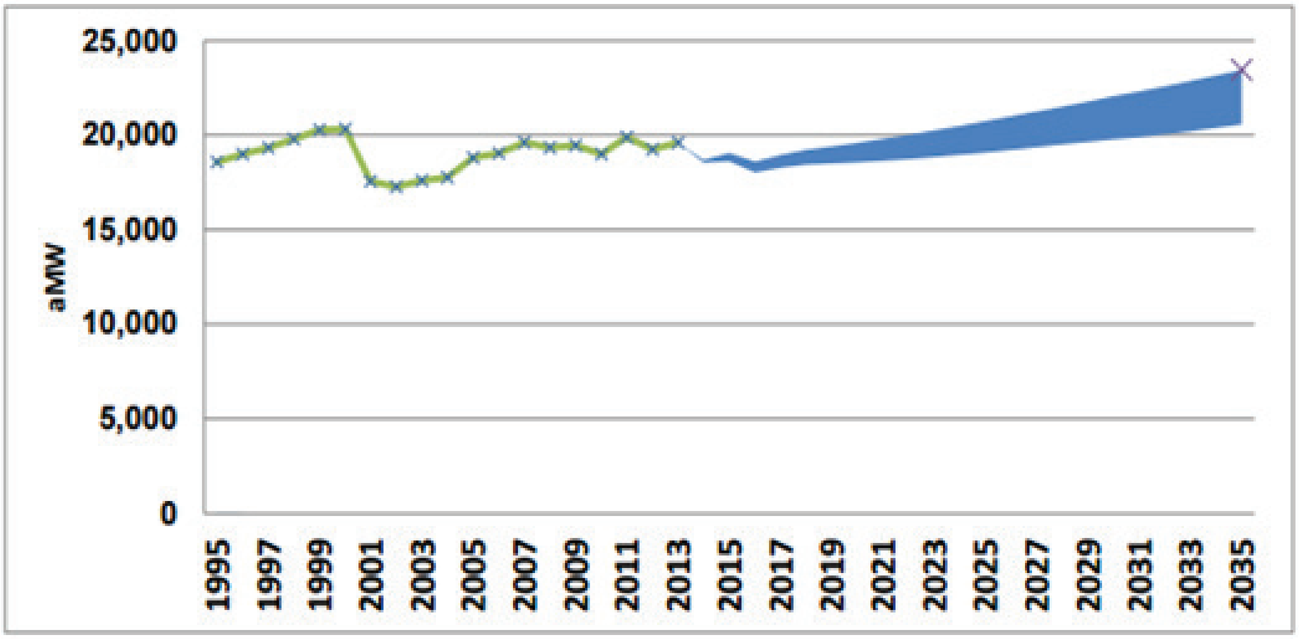


*Figure B-3. Range of NWPCC forecasted electricity demands (aMW) (NWPCC 2016a).*

which will provide additional peak capacity of 1,000 MW. However, this is anticipated to serve only 80,000 homes.

Power entities in the Columbia River Basin feel that new storage reservoir projects may be needed to help meet growing future surface water supply demands. If additional storage projects are built, pumping associated with the storage will likely create additional power demands. This reflects the opinion that the facilities will probably require off-channel storage, as concerns for suitable storage sites on the river given fisheries constraints may force alternative solutions. Several power entities also mentioned concerns about the potential for climate variability and possible renegotiation of the international Columbia River Treaty to disrupt or reduce hydropower generation capacity.

A currently proposed project shows there is at least the potential for new hydropower generation in the Columbia River Basin. The Enloe Hydroelectric Project (owned by the Public Utility District No. 1 of Okanogan County (Okanogan PUD)) on the Similkameen River northwest of Oroville, Washington received a 2013 Federal Energy Regulatory Commission (FERC) license to construct, operate, and maintain generation facilities. The proposed addition to the dam would have a total installed capacity of 9.0 MW. Energy Northwest, a consortium of 27 public power utilities, suggested that the proposed July 2017 start date for construction may not be achievable given uncertainties related to finalizing project costs, equipment purchase timelines, guaranteed participant agreements, and potential environmental challenges.

It is also important to realize that the original FERC application (P-12569) for this project was submitted in January 2005. It has gone through numerous iterations and reviews since then, and construction has yet to start. This partially reflects the timelines of projects involving water resources, but may also indicate the challenges associated with finding cost-effective, environmentally-acceptable solutions in the current energy market.

## Conclusions

A relatively complex and dynamic regulatory environment complicates the question concerning the economic feasibility of additional hydropower supply in the region. An argument can be made for a variety of scenarios ranging from no increase in hydropower to relatively modest increases fueled by climate change, electric cars, renewable energy portfolio standards, and other carbon reducing policies. Site-specific economic analyses will be needed to help determine if a particular project can out-compete other forms of electricity supply. According to the NWPCC, regional demand is expected to increase by anywhere from 1,200 to 3,200 average megawatts over the 2013-2035 timeframe, with the possibility of these numbers reaching 2,200 to 4,800 average megawatts once distribution and transmission system losses are considered.

Converting these 2,200 to 4,800 average megawatts to a demand for water (required acre-feet of storage value) would require knowing what facility (or facilities) would be generating the power, when it would be generated, and where it would be delivered. This is well beyond the current scope of this project. However, using some average flow-production information from Grand Coulee, Rocky Reach, Rock Island and Lake Chelan (all in Washington State), it was estimated that 35,000 to 75,000 acre-feet of water might be necessary.

It seems unlikely that any major on-stream facility will be permitted and constructed in the next 20 years but options for technology upgrades, off-channel pumped storage, and innovative use of existing hydraulic facilities could be developed in the right policy environment. For example, while natural gas is considered a clean fossil-fuel, hydropower generates no emissions, so carbon policies could increase the demand for hydroelectricity.

## References


Bloomberg New Energy Finance, 2016. Electric vehicles to be 35% of global new car sales by 2040. February 25, 2016. Available online at http://about.bnef.com/press-releases/electric-vehicles-to-be-35-of-global-new-car-sales-by-2040/

Bonneville Power Authority (BPA), 2015. Second-largest dam in the nation becomes more powerful, efficient. September 24, 2015. Available online at https://www.bpa.gov/news/newsroom/pages/second-largest-dam-in-the-nation-becomes-more-powerful-efficient.aspx

Gensler, D. and Kinzli, K. 2013. Examining the feasibility of hydropower generation in irrigation canals: Middle Rio Grande Conservancy District. Journal of Irrigation and Drainage Engineering, .139, 405-413. DOI:10.1061/(ASCE)IR.1943-4774.0000548.

Kearney, D. 2010. EIA's outlook through 2035, Surface Transportation Board, March 23, 2010. Available online at https://www.stb.dot.gov/stb/docs/RETAC/2010/March/EIA%20AEO%202010.pdf

Northwest Power and Conservation Council, 2016a. Seventh Power Plan, February 25, 2016. Available online at http://www.nwcouncil.org/energy/powerplan/7/plan/

Northwest Power and Conservation Council, 2016b. Demand Forecast, February 25, 2016. Available online at http://www.nwcouncil.org/media/7149913/7thplanfinal_appdixe_dforecast.pdf

Ramseth, L. 2015. Idaho's energy future: Less coal, uncertain hydro. Post Register, Available online at http://www.idahostatesman.com/news/local/environment/article52010280.html

Stori, V. 2013. Environmental rules for hydropower in state renewable portfolio standards. Clean Energy States Alliance. Available online at http://www.cesa.org/assets/2013-Files/RPS/Environmental-Rules-for-Hydropower-in-State-RPS-April-2013-final-v2.pdf

U.S. Energy Information Administration, 2015. Pacific Northwest electricity mix influenced by weather conditions, El Niño. Available online at http://www.eia.gov/todayinenergy/detail.cfm?id=24012

Yale Environment 360. 2015. For storing electricity, utilities are turning to pumped hydro. November 24, 2015. Available online at http://e360.yale.edu/feature/for_storing_electricity_utilities_are_turning_to_pumped_hydro/2934/