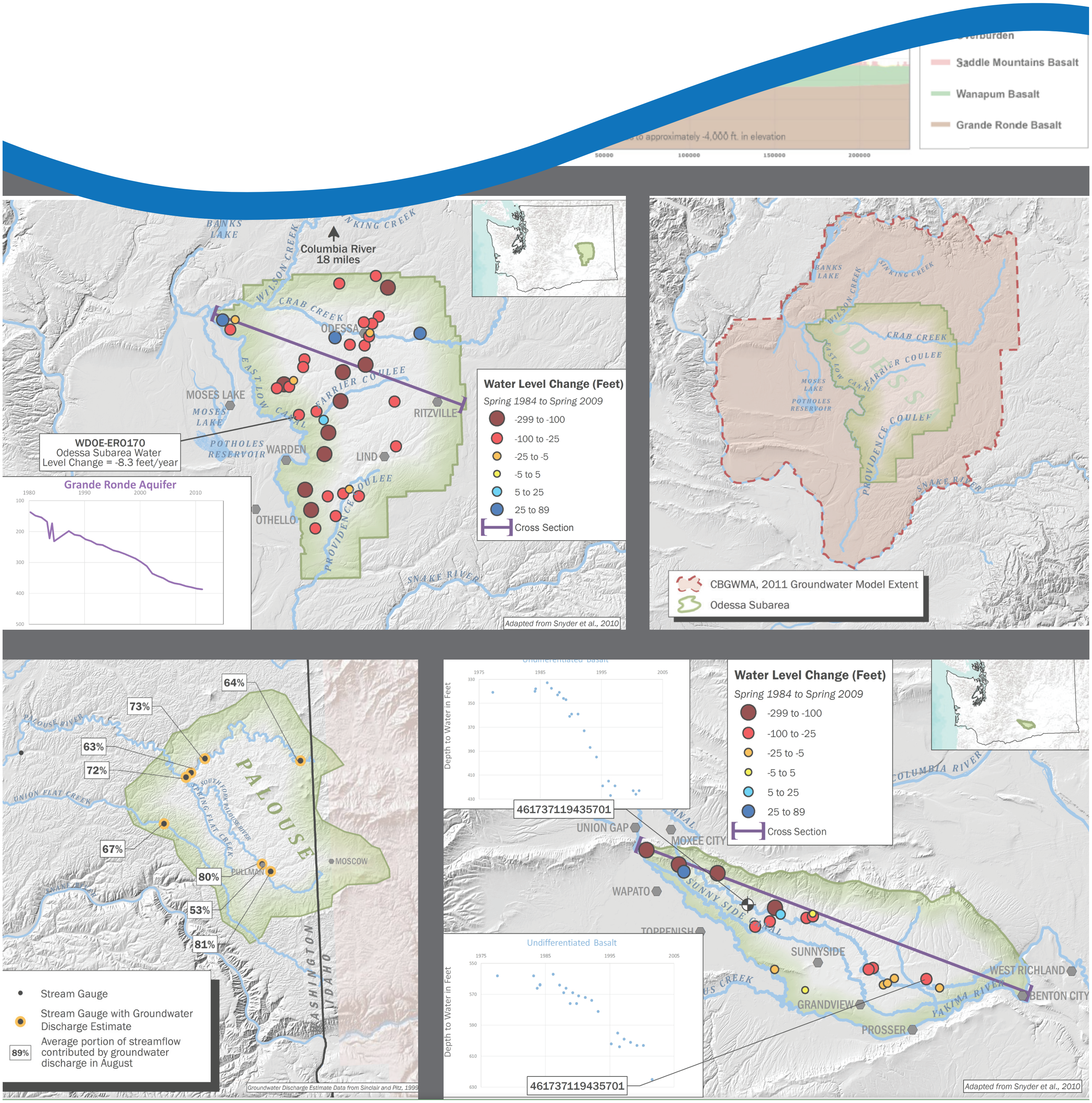
MODULES
TO INFORM KEY POLICY ISSUES

TABLE OF CONTENTS

Integrating Declining Groundwater Areas into Supply and Demand Forecasting



Introduction

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:

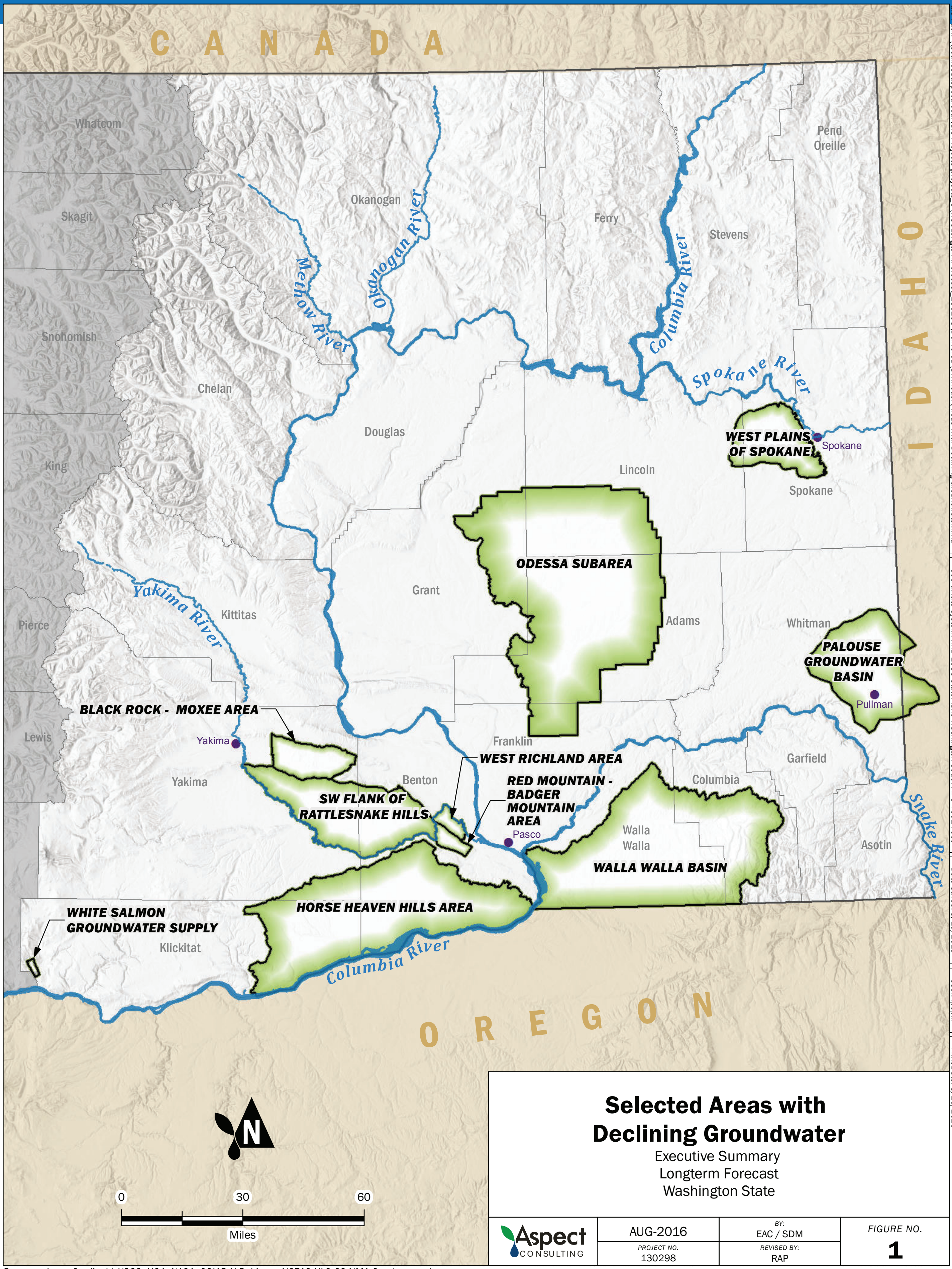
1. Emerging areas of increased regulation either at the groundwater subbasin scale through closures, or targeted efforts through interviews with Ecology water masters.
2. County and State health jurisdiction efforts to ensure reliable public water supplies.
3. Assessments of priority-schemes in each 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.

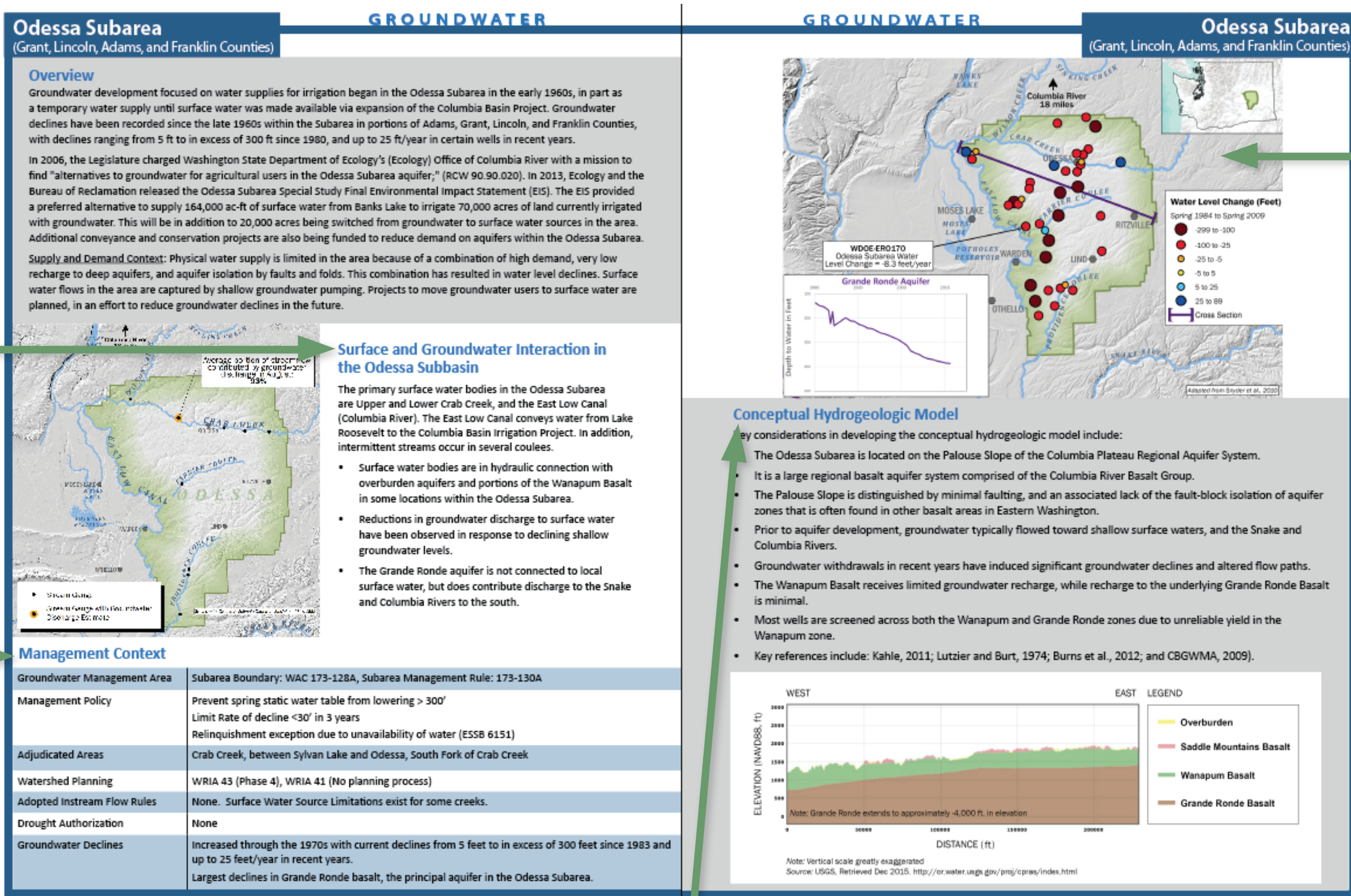
Additional groundwater development is already limited in all areas in Washington where there are regulated or closed surface water bodies. The current focus on documented areas of decline is therefore a first step towards identifying the places where is it critical to integrate groundwater sup-ply modeling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



Selected Areas with Declining Groundwater
Executive Summary
Longterm Forecast
Washington State

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

How to Read the Groundwater Pages



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

GROUNDWATER

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' Limit Rate of decline <30' in 3 years 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. 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).

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.

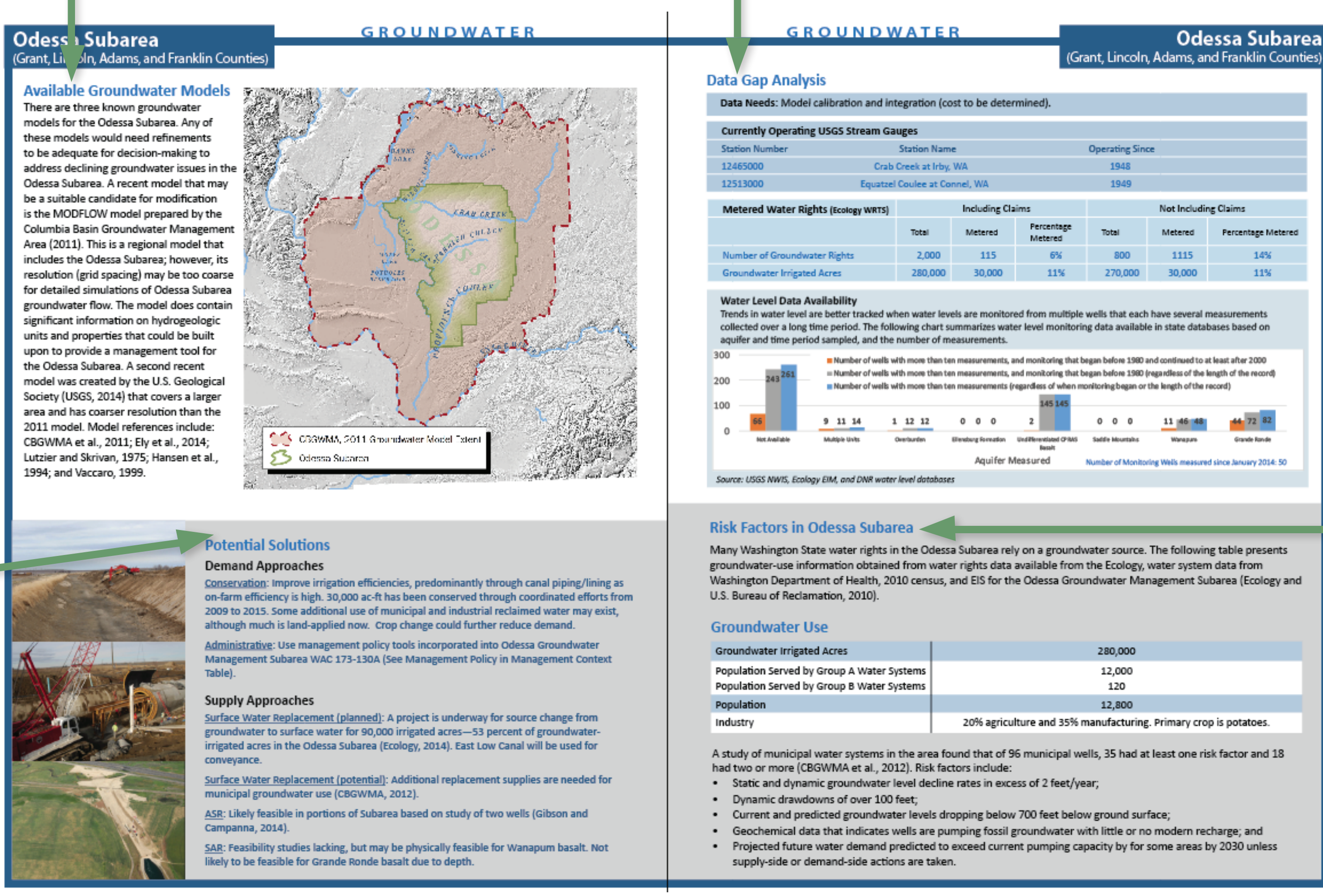
This section summarizes water supply or demand solutions that may be feasible, being planned or being implemented in each area. Supply side solutions include switching to new sources of water or storage. Demand oriented solutions work to decrease water use through measures such as conservation.

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 Population Served by Group B Water Systems	12,000 120
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

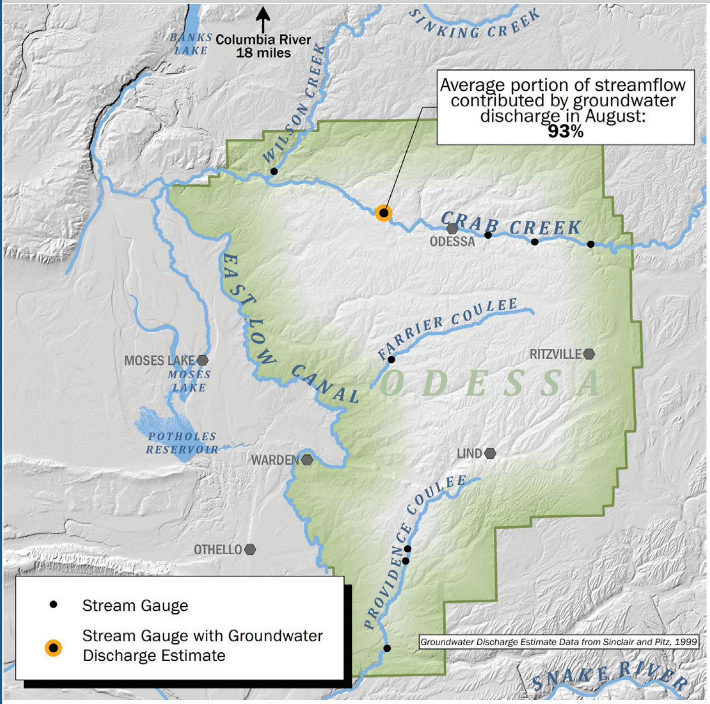
(Grant, Lincoln, Adams, and Franklin Counties)

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.

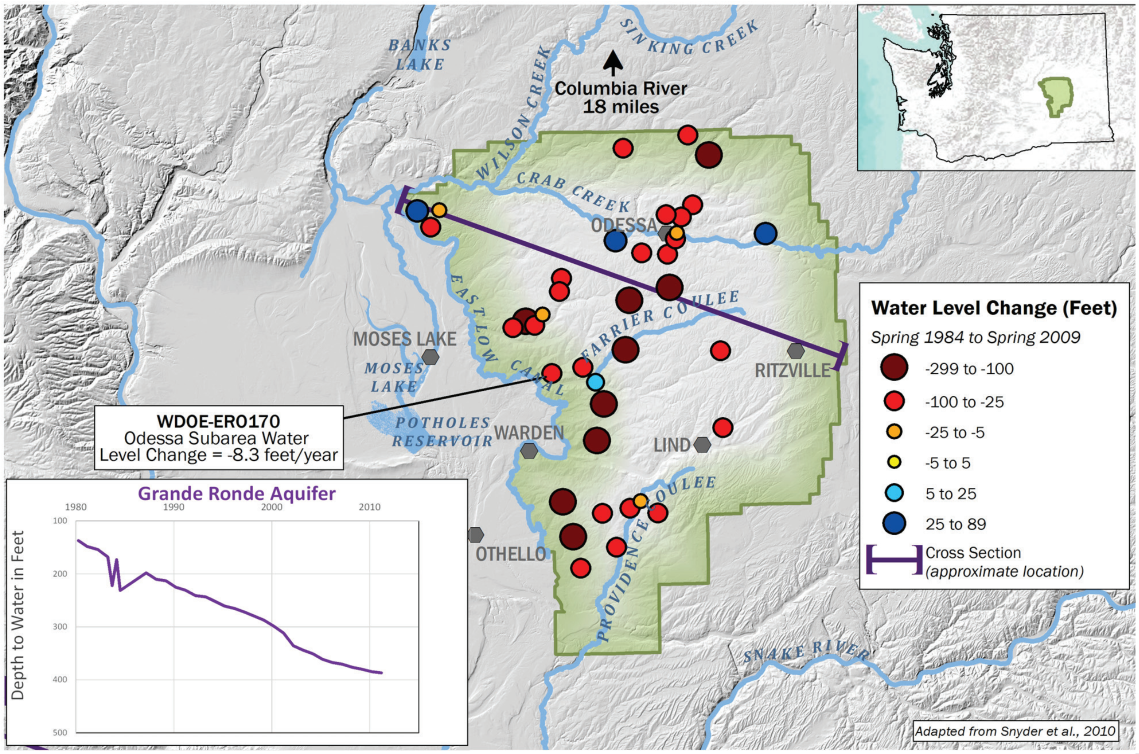
- Surface water bodies are in hydraulic connection with overburden aquifers and portions of the Wanapum Basalt in some locations within the Odessa Subarea.
- Reductions in groundwater discharge to surface water have been observed in response to declining shallow groundwater levels.
- The Grande Ronde 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' Limit Rate of decline <30' in 3 years 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. Largest declines in Grande Ronde basalt, the principal aquifer in the Odessa Subarea.

Odessa Subarea

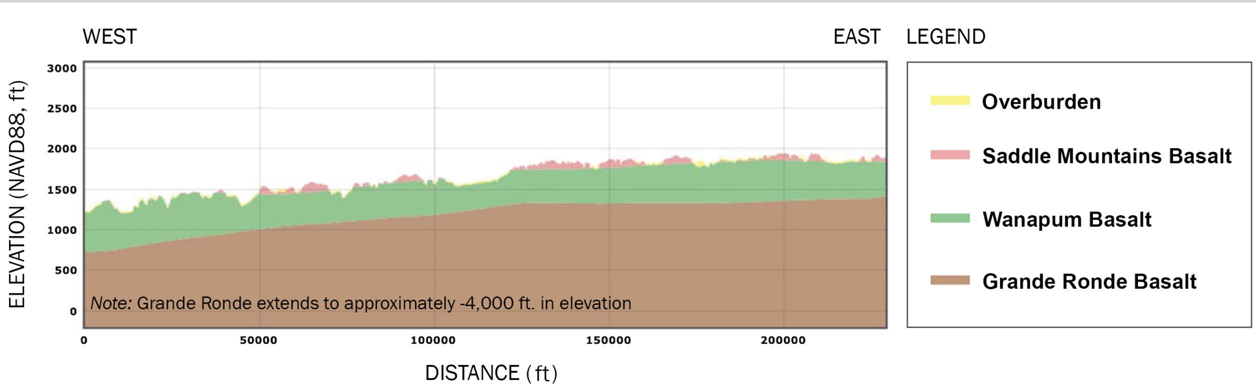
(Grant, Lincoln, Adams, and Franklin Counties)



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).



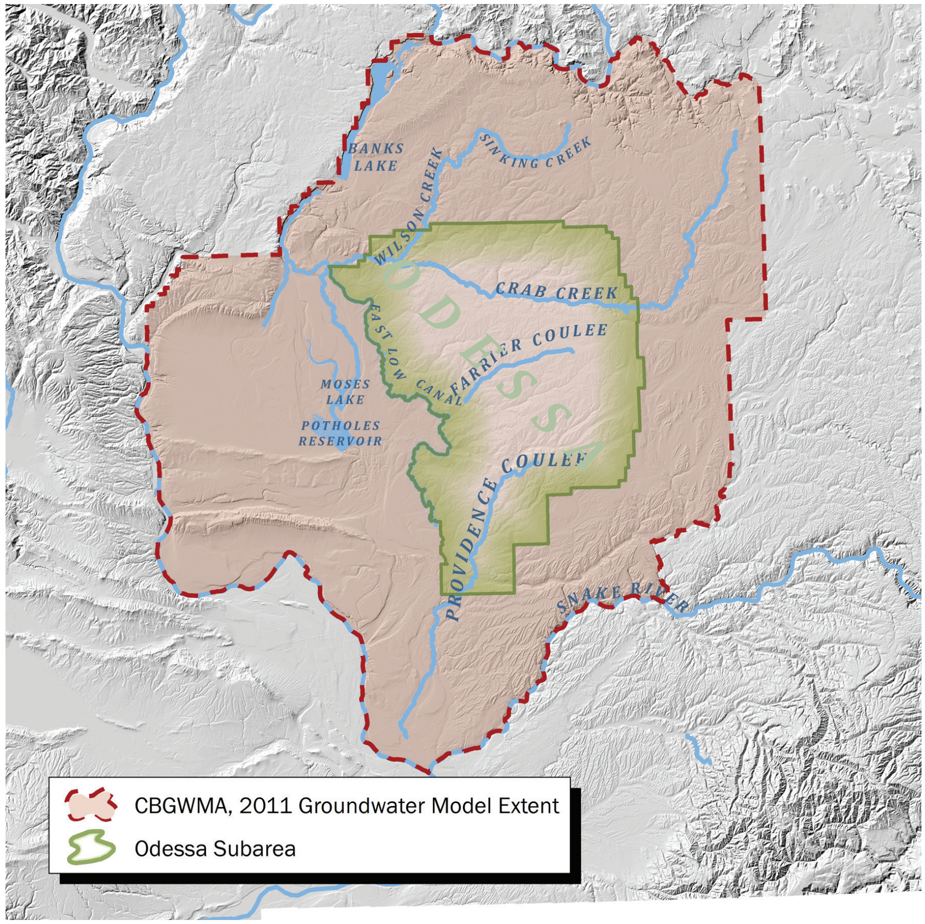
Note: Vertical scale greatly exaggerated
Source: USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

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.

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

Data Gap Analysis

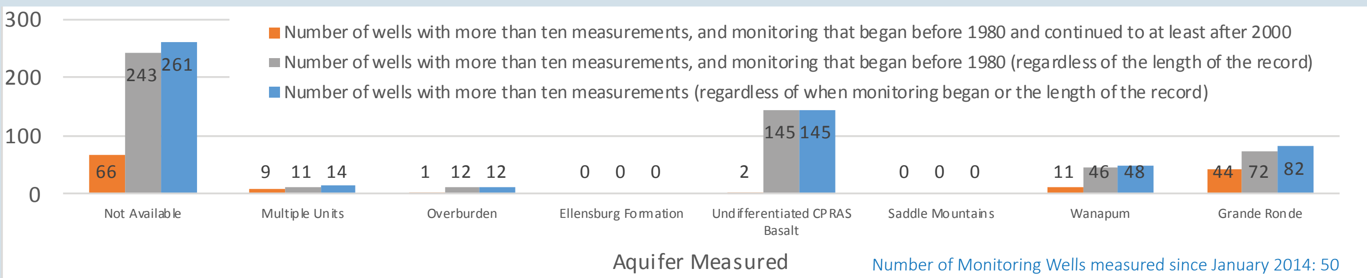
Data Needs: Model calibration and integration [estimated costs yet to be determined].

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	12,000
Population Served by Group B Water Systems	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.

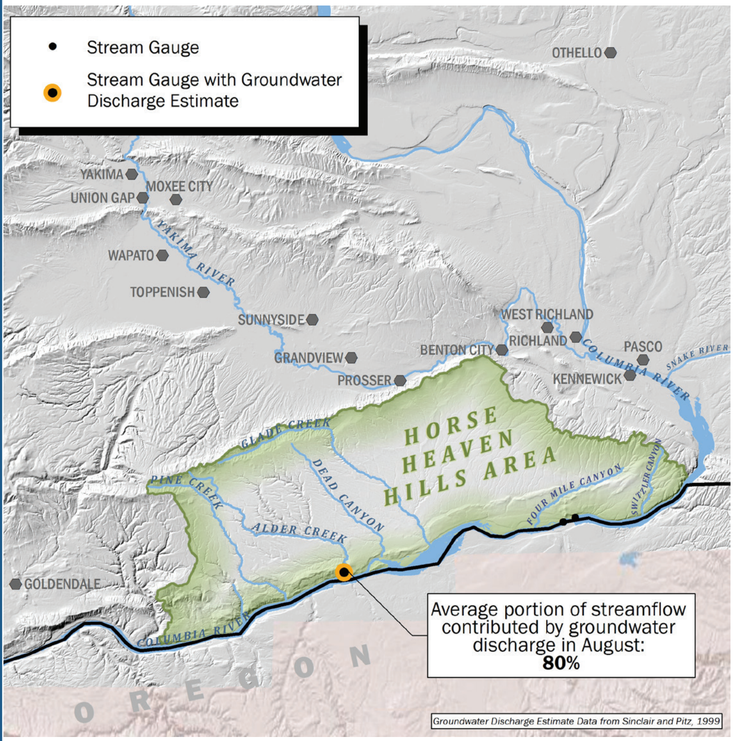
Horse Heaven Hills Area
(Klickitat and Benton Counties)

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

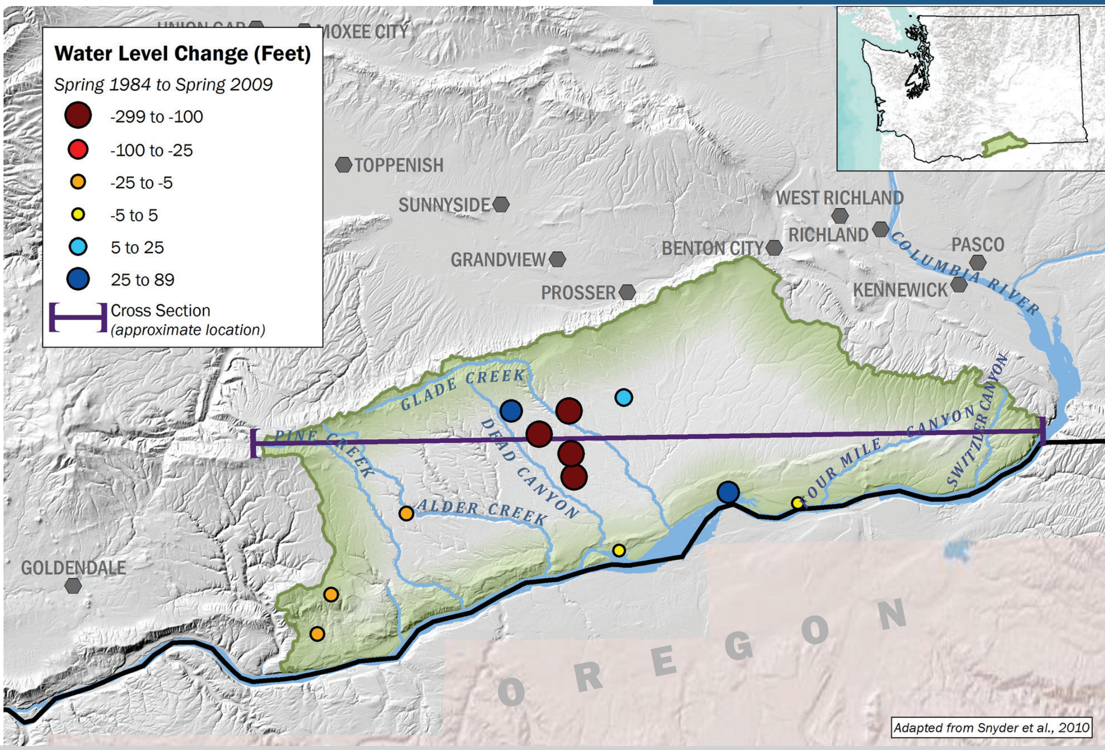
The primary surface water drainages in the Horse Heaven Hills Area are Wood Gulch, Pine, Alder, Dead, Glade, Four Mile, and Switzler Canyons, all of which drain to the Columbia River.

- 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.

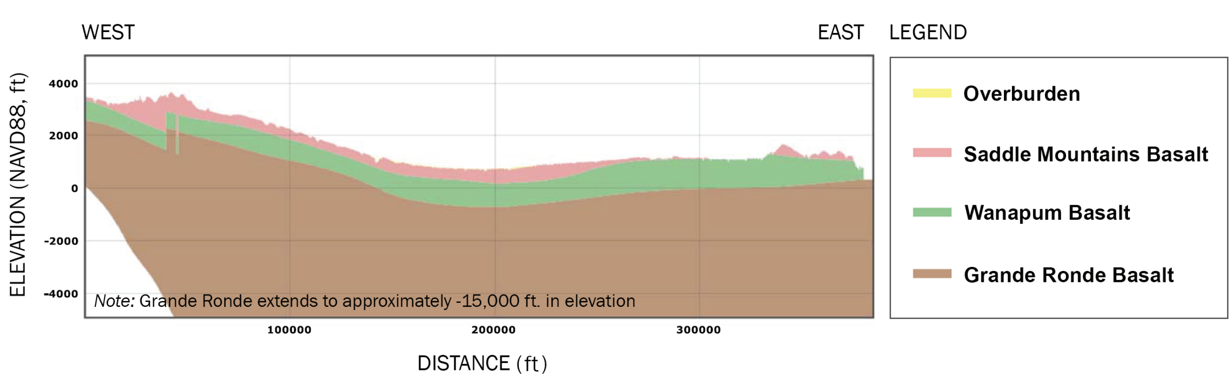
Horse Heaven Hills Area
(Klickitat and Benton Counties)



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.

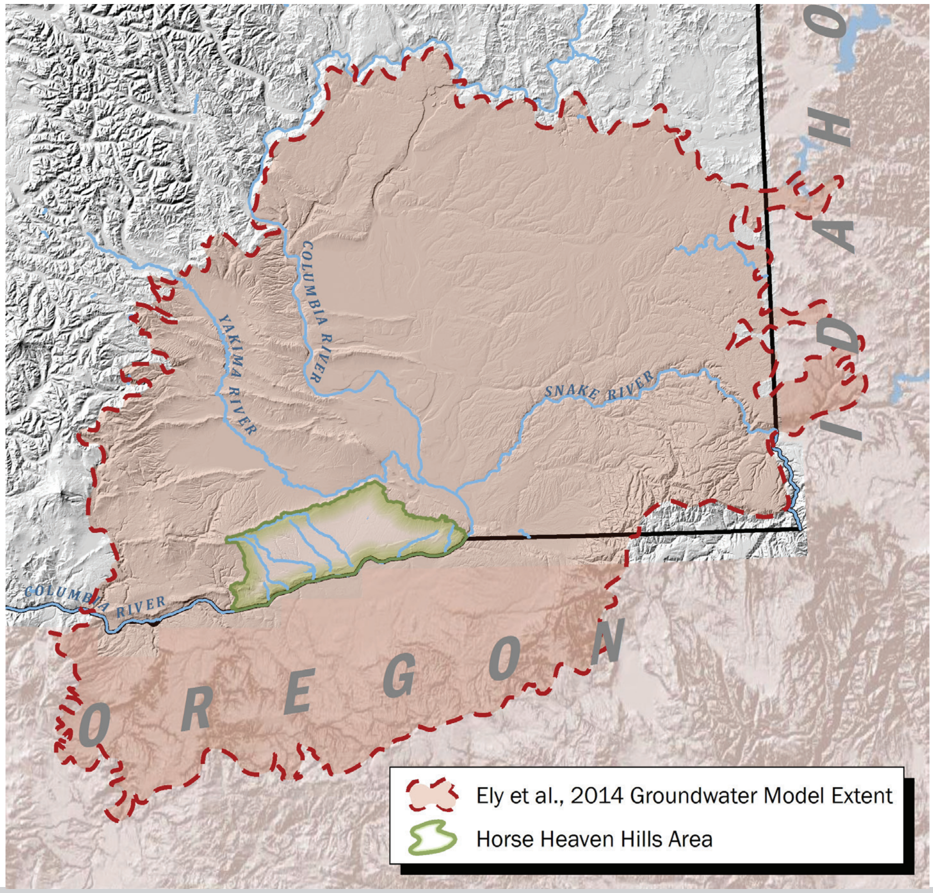


Note: Vertical scale greatly exaggerated
Source: USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

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

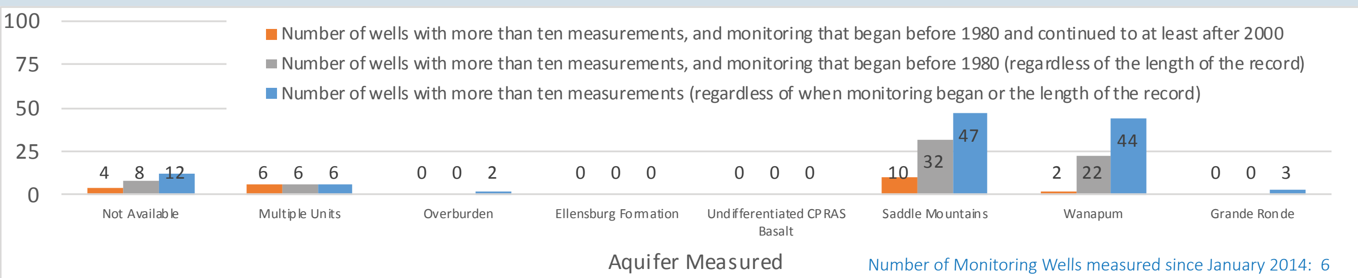
Data Needs: Aquifer testing to investigate geological structural controls, groundwater monitoring (particularly in all aquifers on the east side and in Grande Ronde), drilling exploration of the Grande Ronde, investigation of connectivity between basalt aquifers and Columbia River [estimated costs yet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

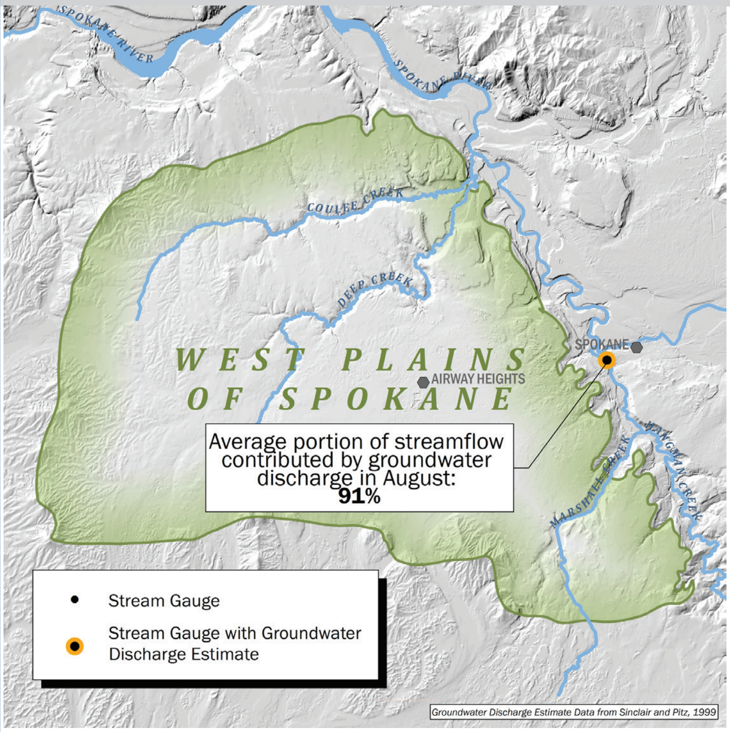
Groundwater Irrigated Acres	39,000
Population Served by Group A Water Systems Population Served by Group B Water Systems	760 240
Population	1,570
Industry	Primarily Agriculture: food processing, vegetable farming, and wineries; Roosevelt Landfill

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

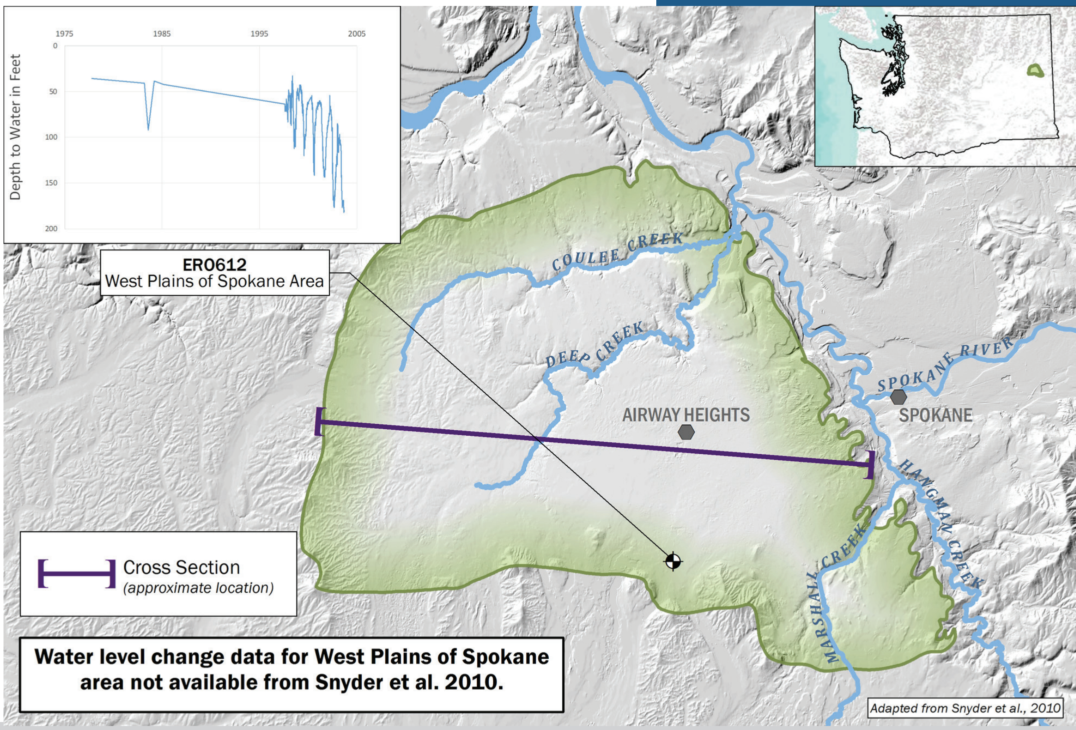
Surface water bodies that drain the West Plains of Spokane Area eventually discharge to the Spokane River. These tributaries include Coulee Creek and Deep Creek, which flow directly into the Spokane River, and Marshal Creek, which drains into Hangman Creek.

- 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).

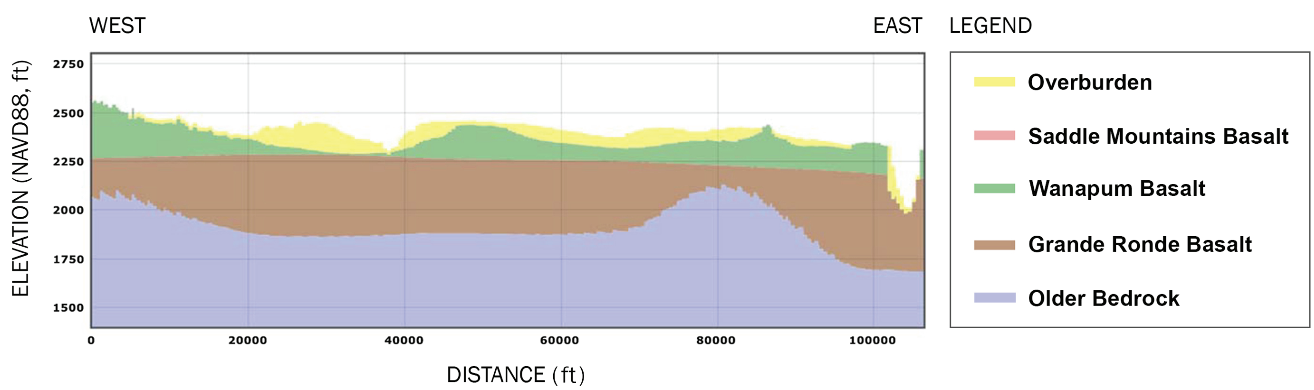
West Plains of Spokane
(Spokane County)



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.



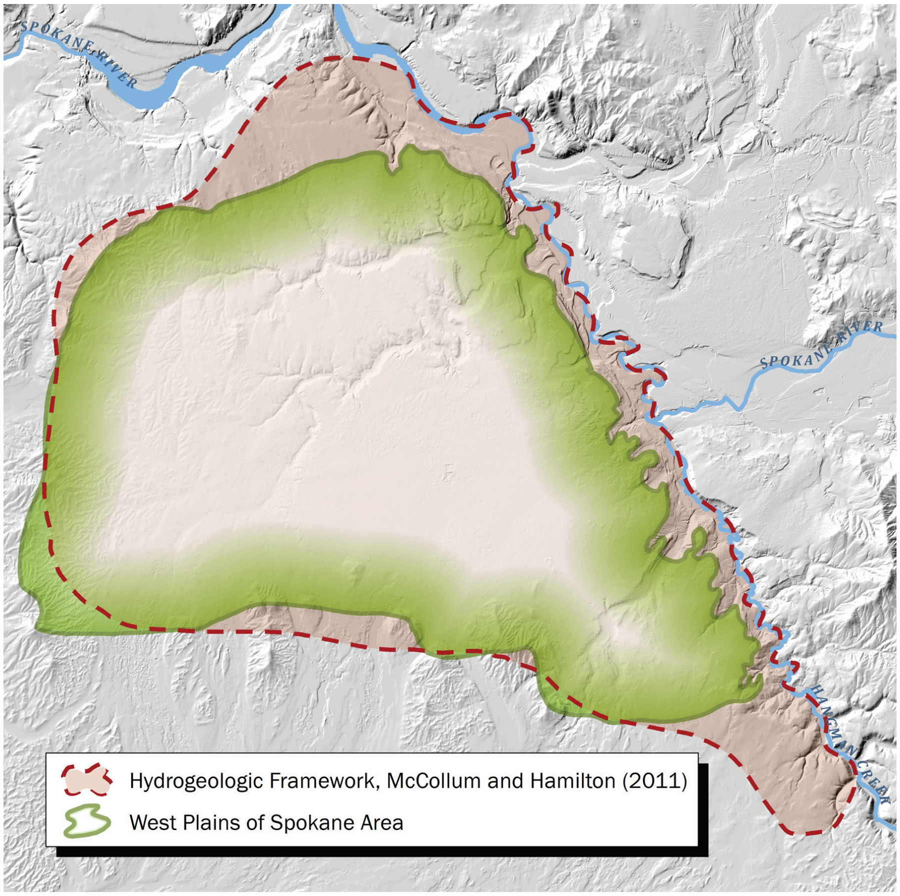
Note: Vertical scale greatly exaggerated

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]

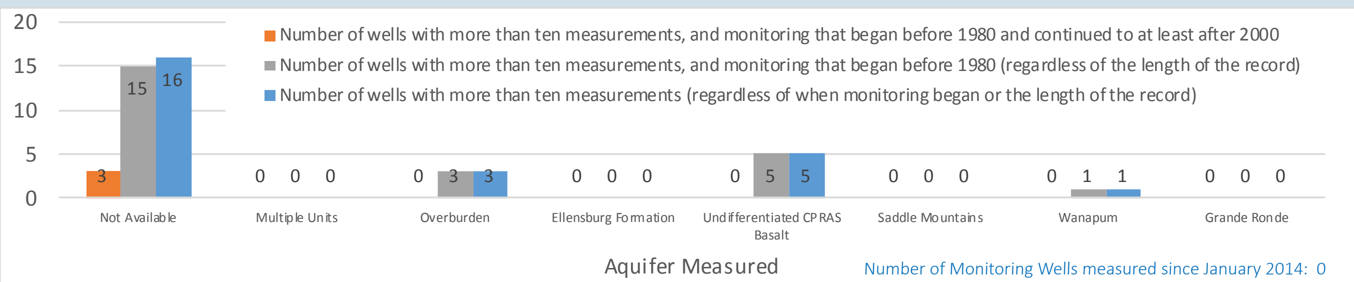
Currently Operating USGS Stream Gauges

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: Fairchild Air Force Base, Spokane International Airport, Airway Heights, City-operated Golf Course, correctional facility, and small industry.

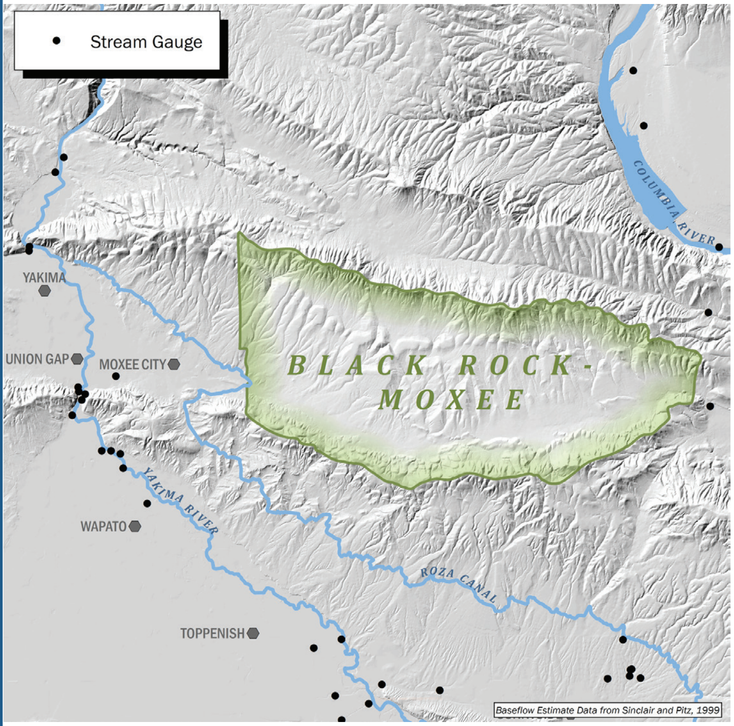
Black Rock - Moxee Area
(Yakima County)

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

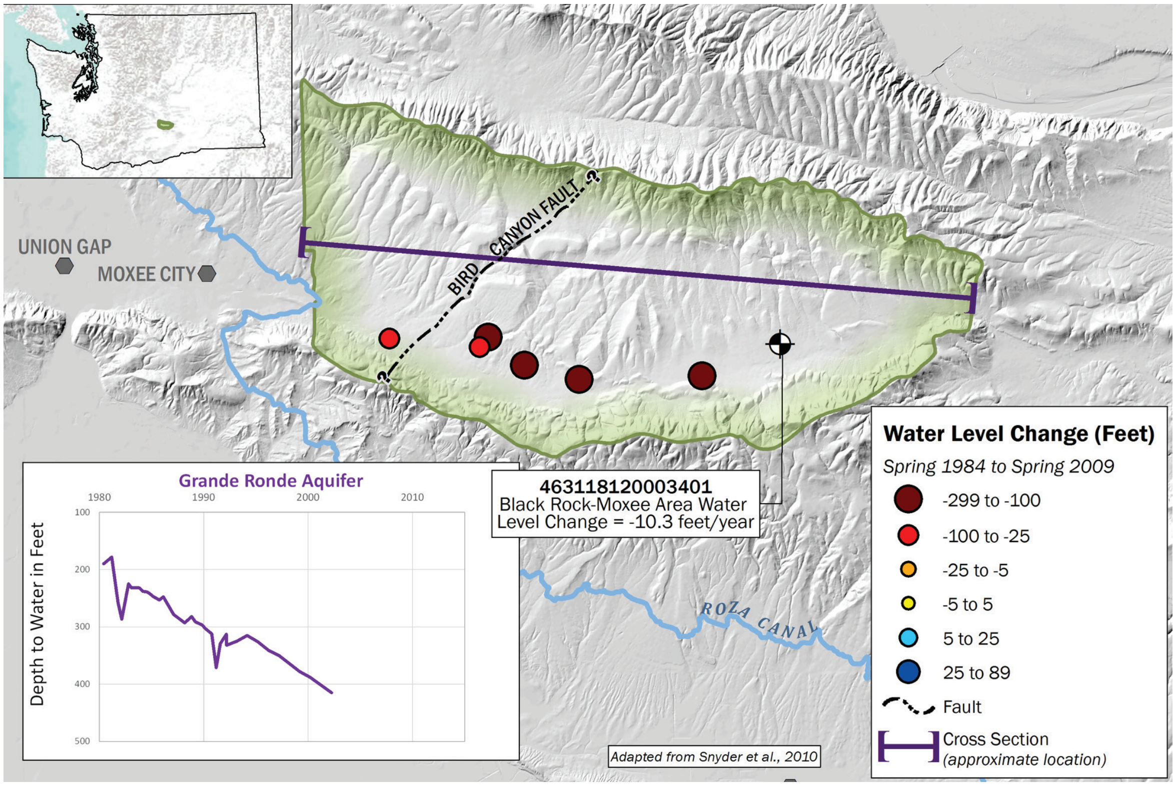
There are no perennial streams in the Black Rock/Moxee Area. The nearest major surface water bodies include the Yakima and Columbia Rivers, located several miles to the south and north of the area, respectively.

- 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).

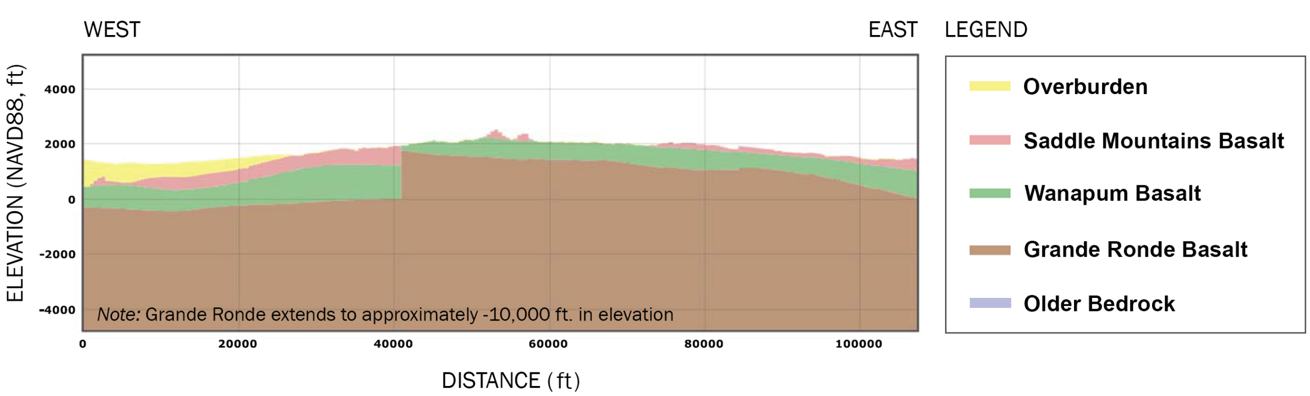
Black Rock - Moxee Area
(Yakima County)



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.

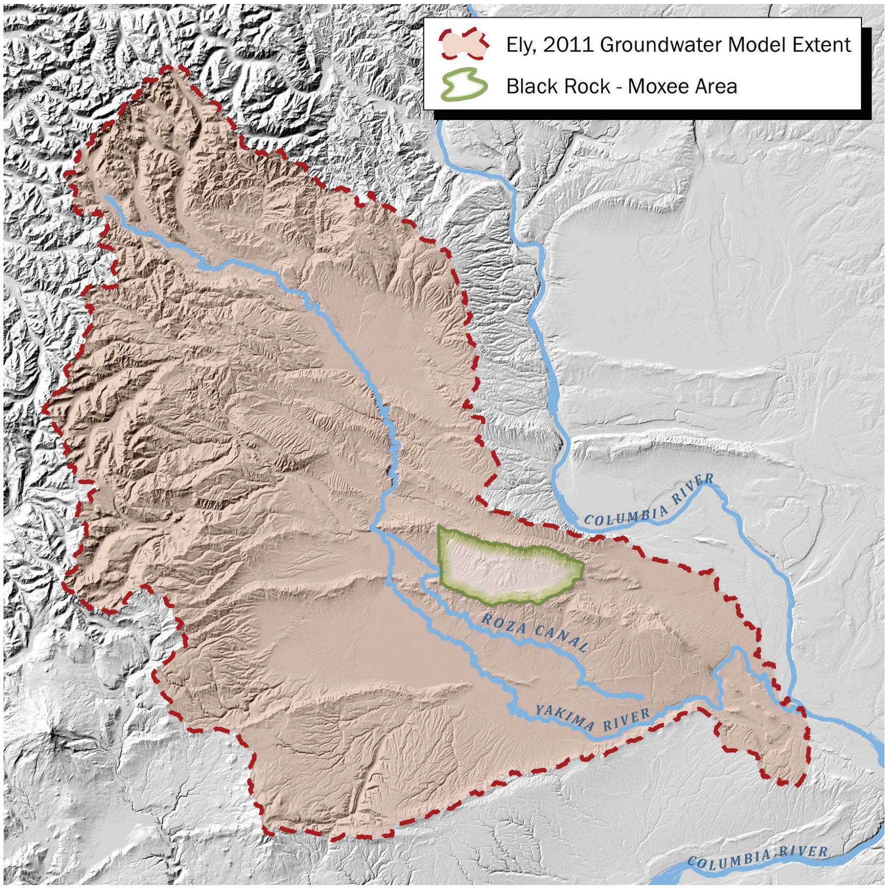


Note: Vertical scale greatly exaggerated
Source: USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

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

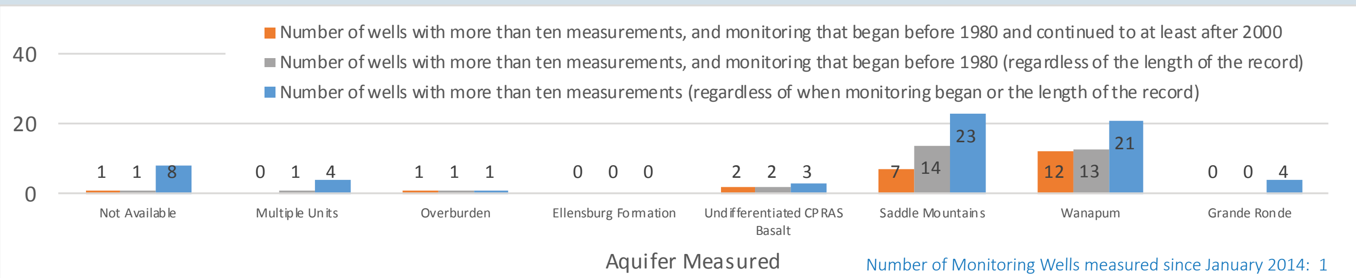
Data Needs: Model calibration and integration, augmenting historic long term groundwater monitoring [estimated costs are yet to be determined] and a feasibilty study on water supply solutions [estimated cost is $50,000].

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

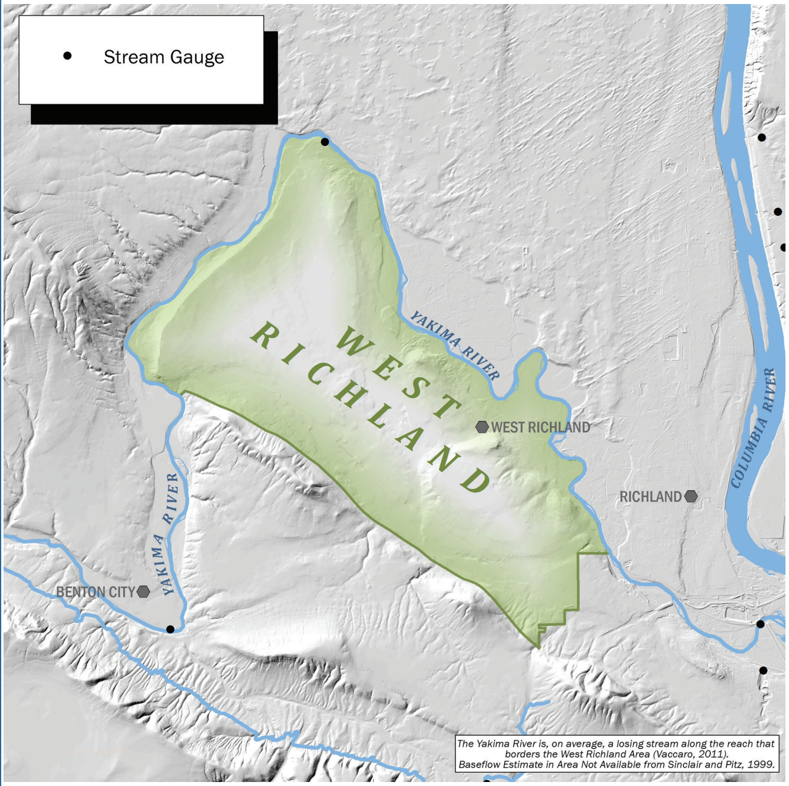
West Richland
(Benton County)

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.



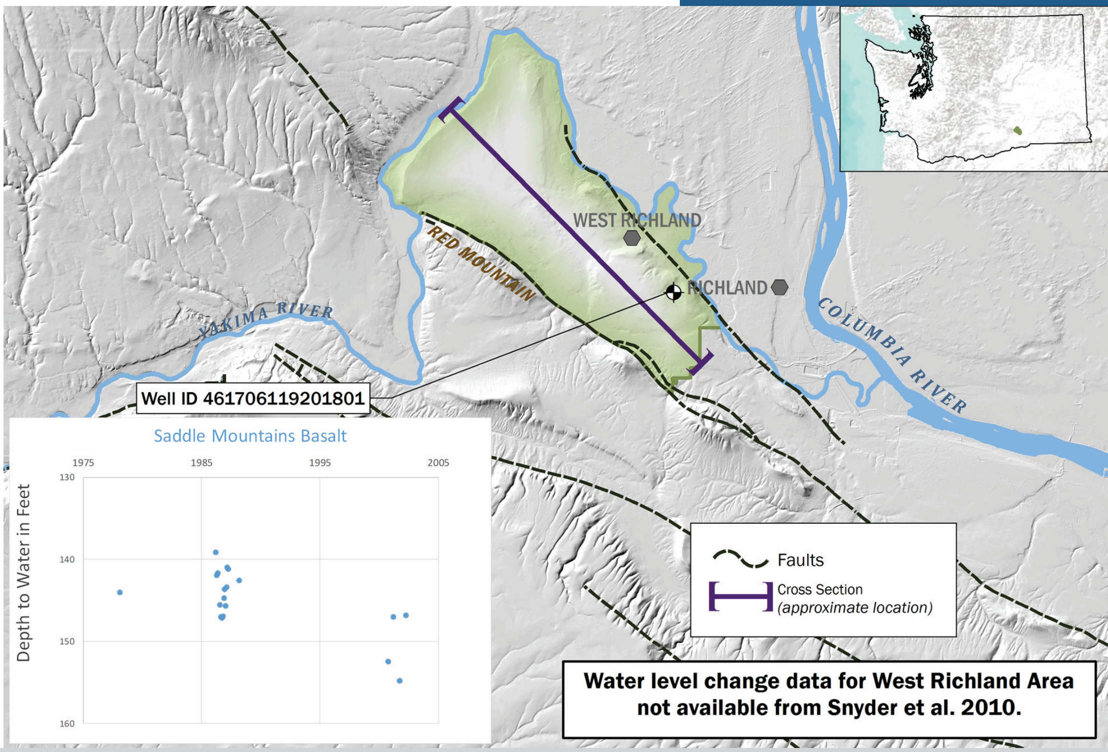
Surface and Groundwater Interaction in the West Richland Area

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.

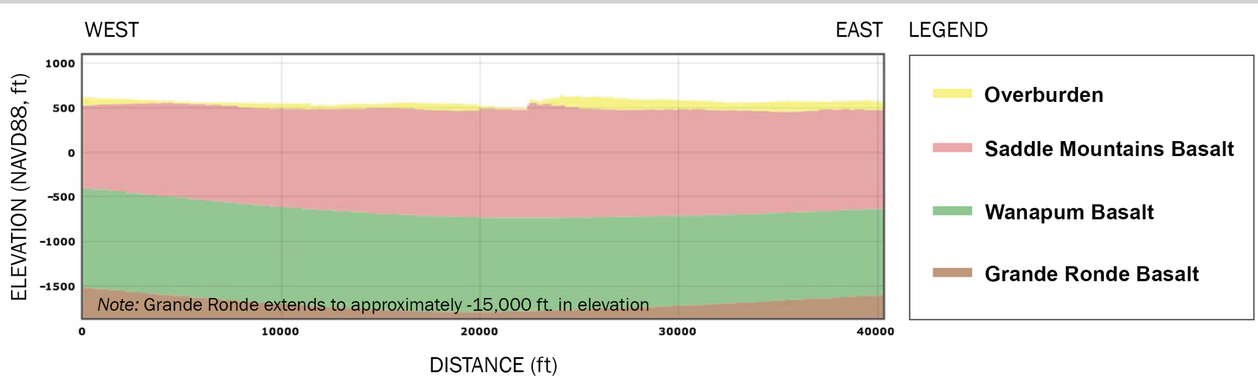
West Richland
(Benton County)



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).

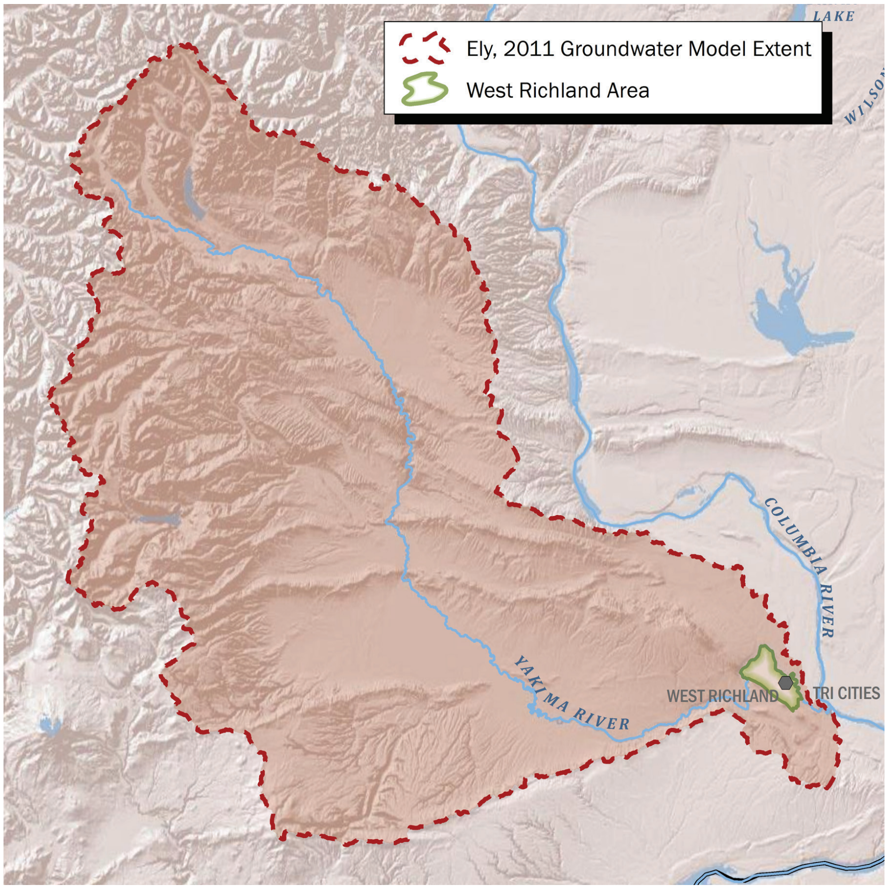


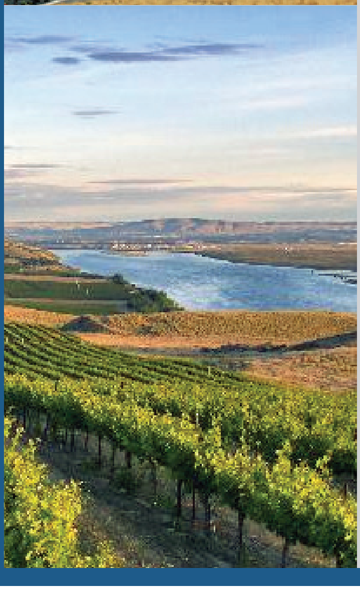
Note: Vertical scale greatly exaggerated
Source: USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

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

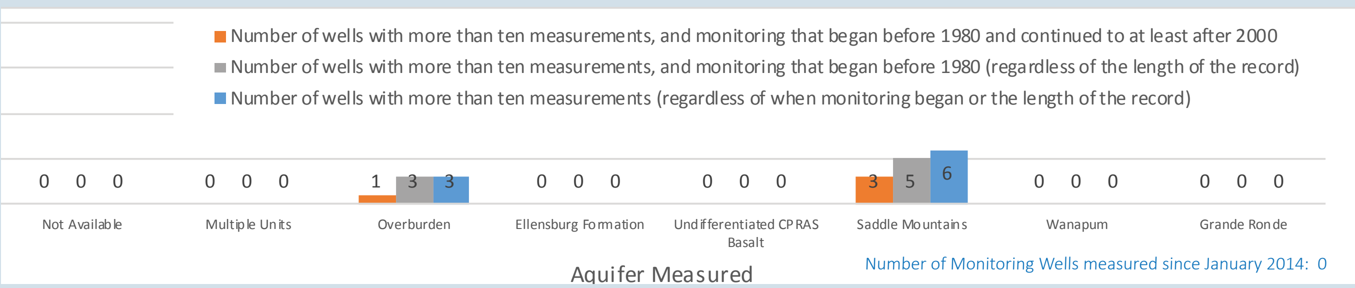
Data Needs: Available groundwater models require hydrostratigraphic refinement in the area. Also, adding the City water system water level data to the Ecology database is needed. [estimated costs are yet to be determined] .

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 Population Served by Group B Water Systems	12,400 403
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

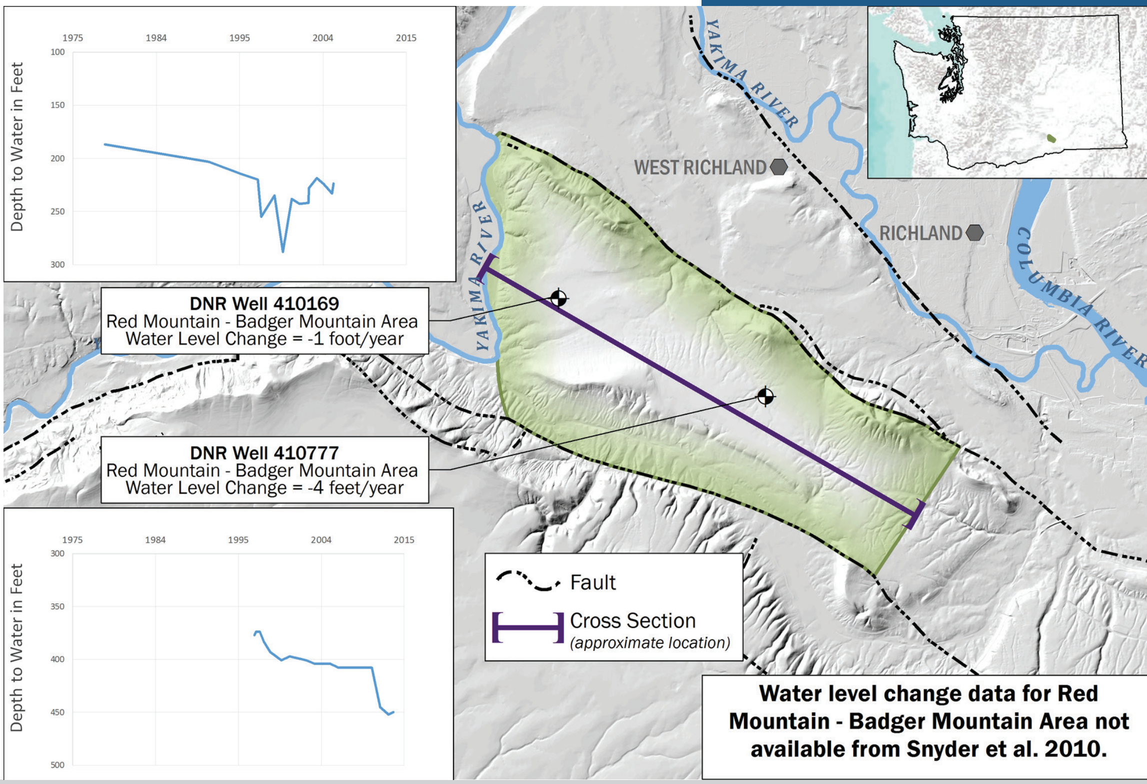
The only major surface water body in the Red Mountain/Badger Mountain Area is the Yakima River, which flows along the northwestern edge of the area.

- 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.

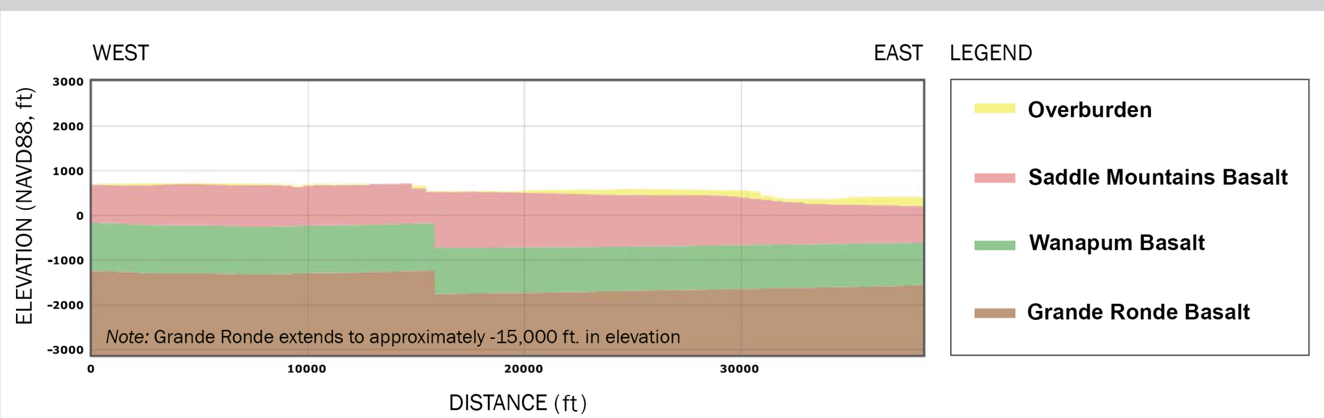
Red / Badger Mountain Area
(Benton County)



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.

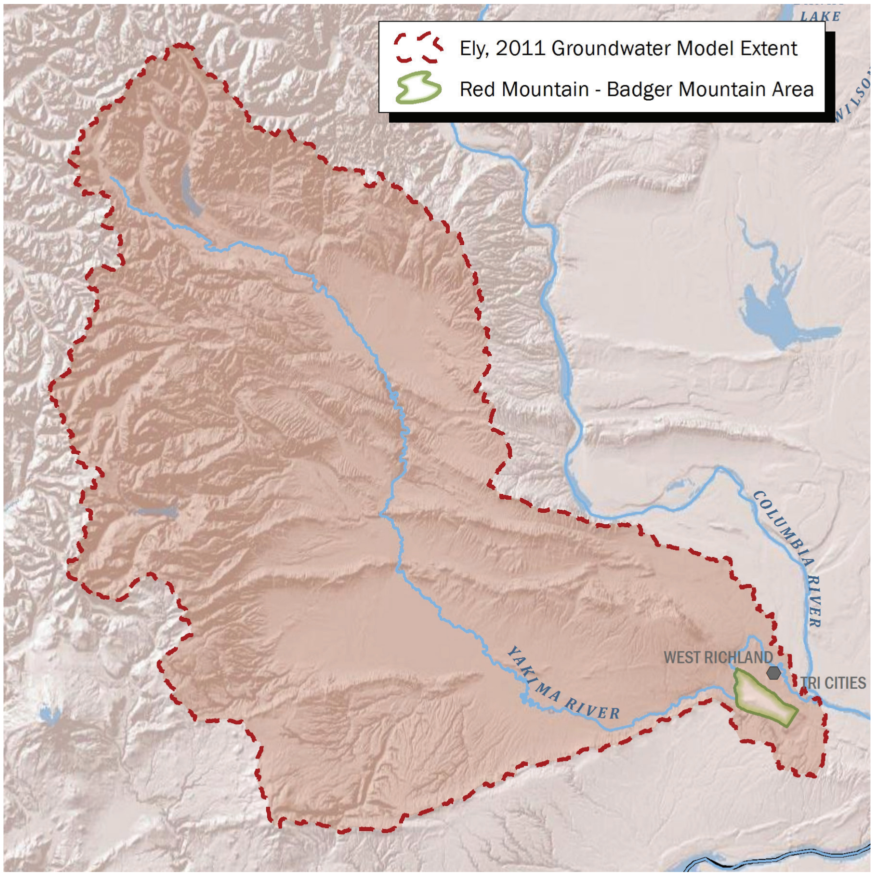


Note: Vertical scale greatly exaggerated
Source: USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

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.

Red / Badger Mountain Area
(Benton County)

Data Gap Analysis

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

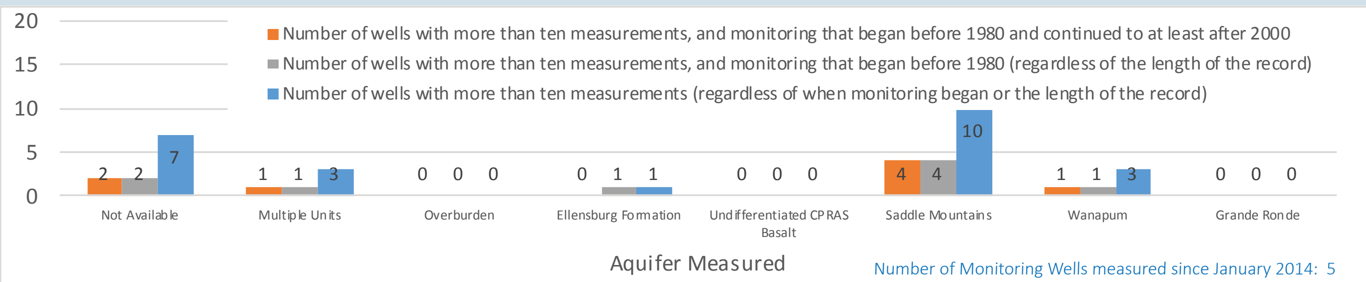
Currently Operating USGS Stream Gauges

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)

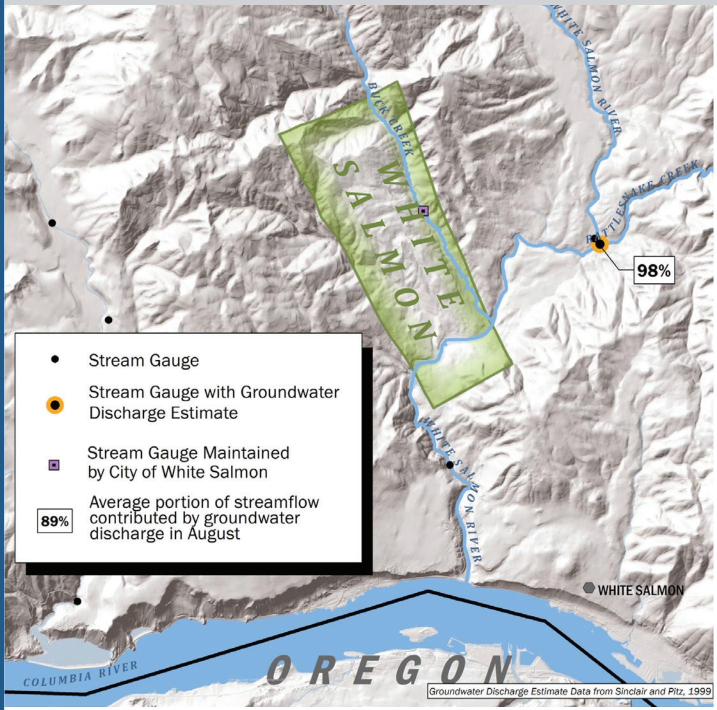
White Salmon Area
(Klickitat County)

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.



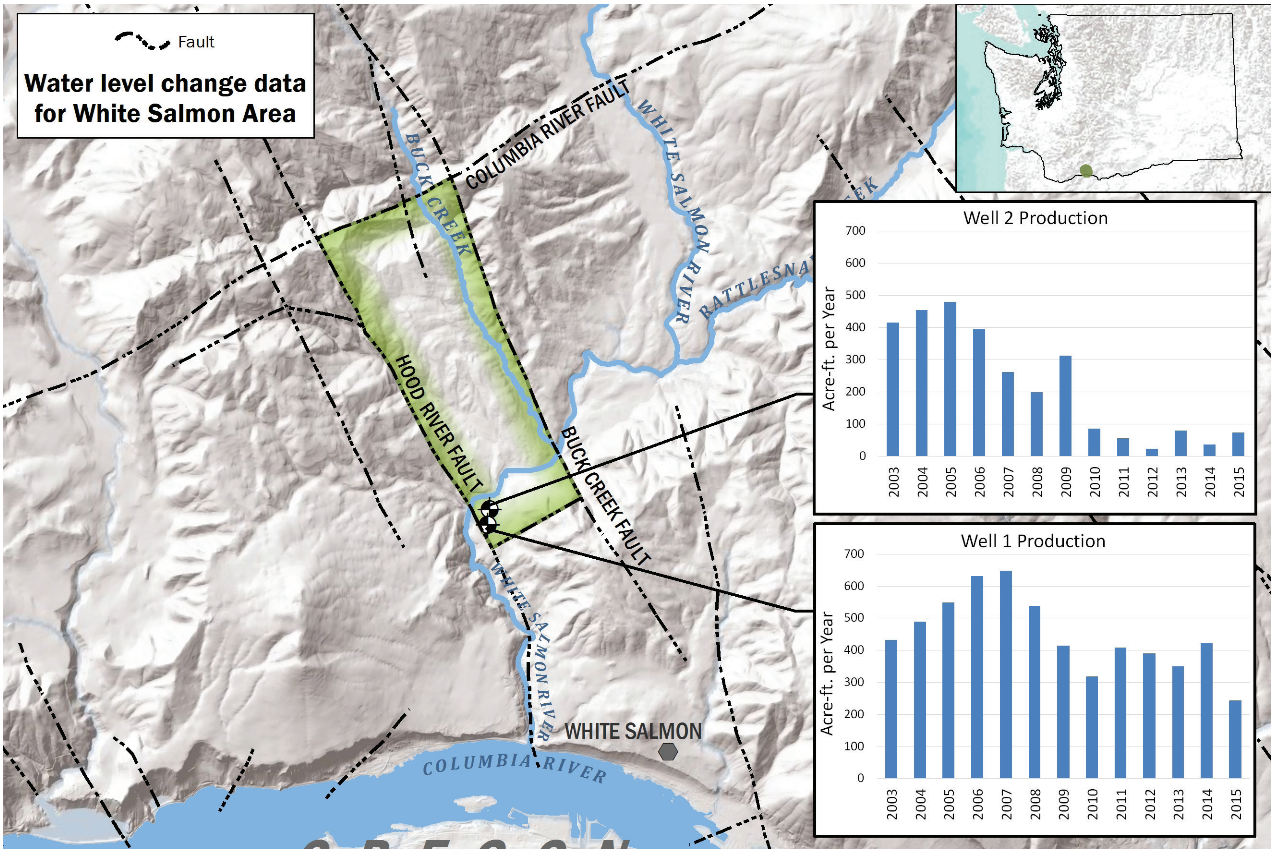
Surface and Groundwater Interaction in the White Salmon Area

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).

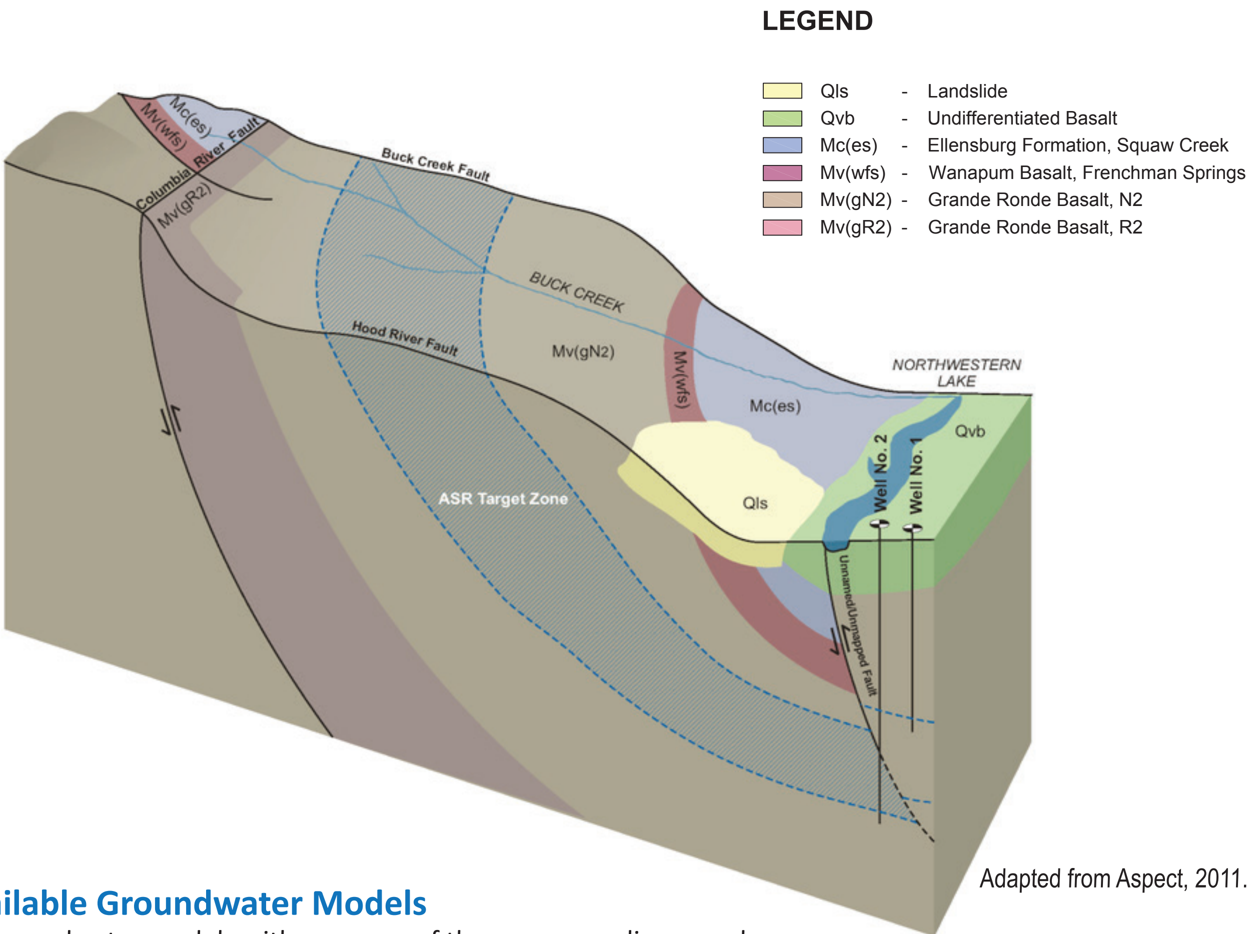


Conceptual Hydrogeologic Model

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 (Note: water systems serve a population outside the area.)
Population	650
Industry	Unmanned aeronautics manufacturing, agriculture, and outdoor recreation/tourism

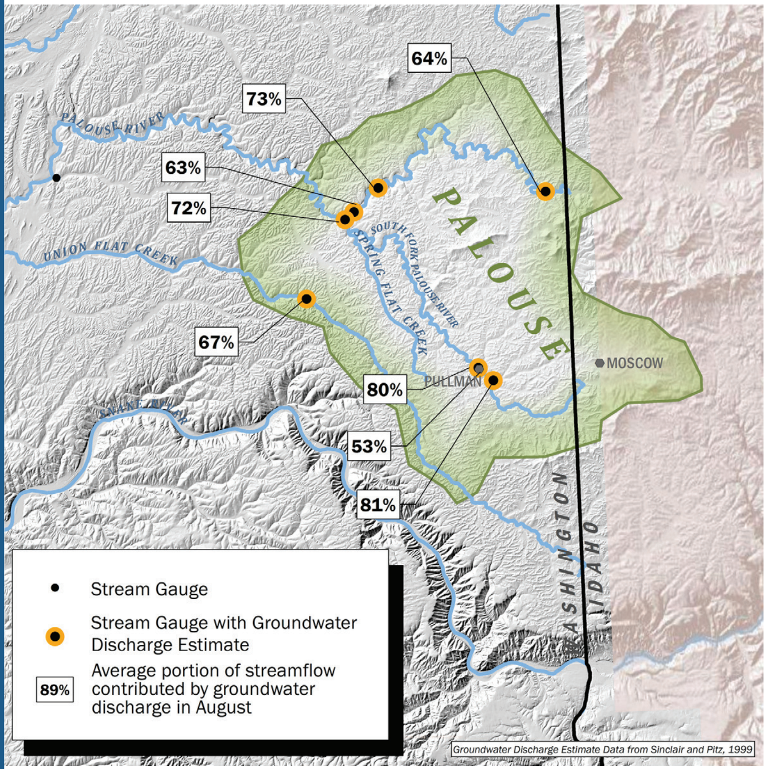
Palouse Groundwater Basin
(Whitman County)

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

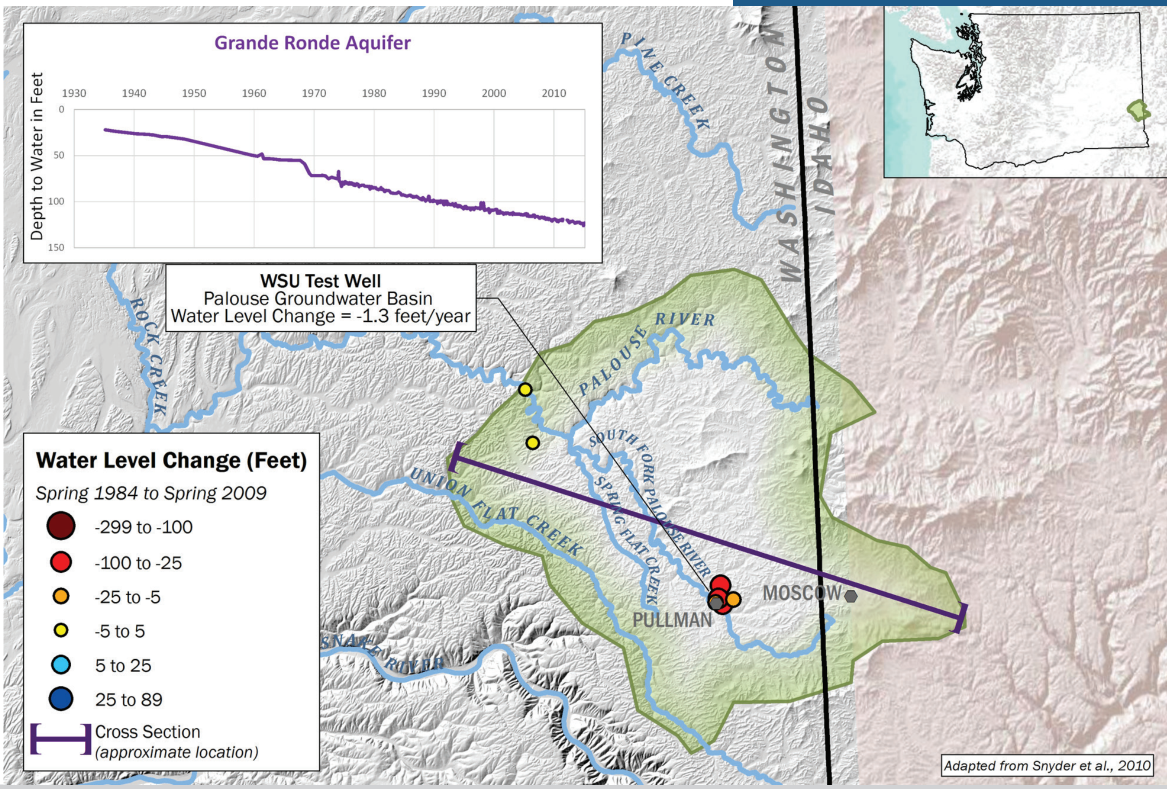
The primary surface water bodies in the Palouse Groundwater Basin include Union Flat Creek, and the South Fork of the Palouse River and its tributaries: Spring Flat Creek and Fourmile Creek.

- 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.

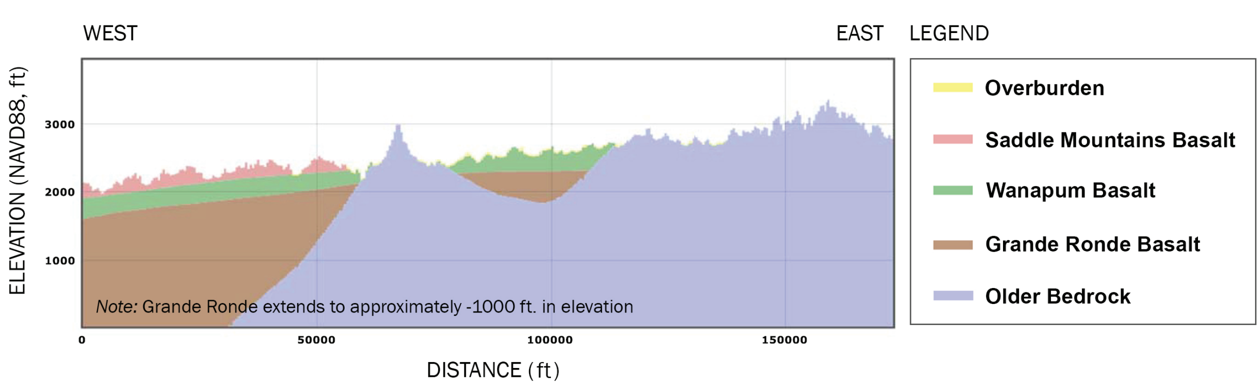
Palouse Groundwater Basin
(Whitman County)



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.

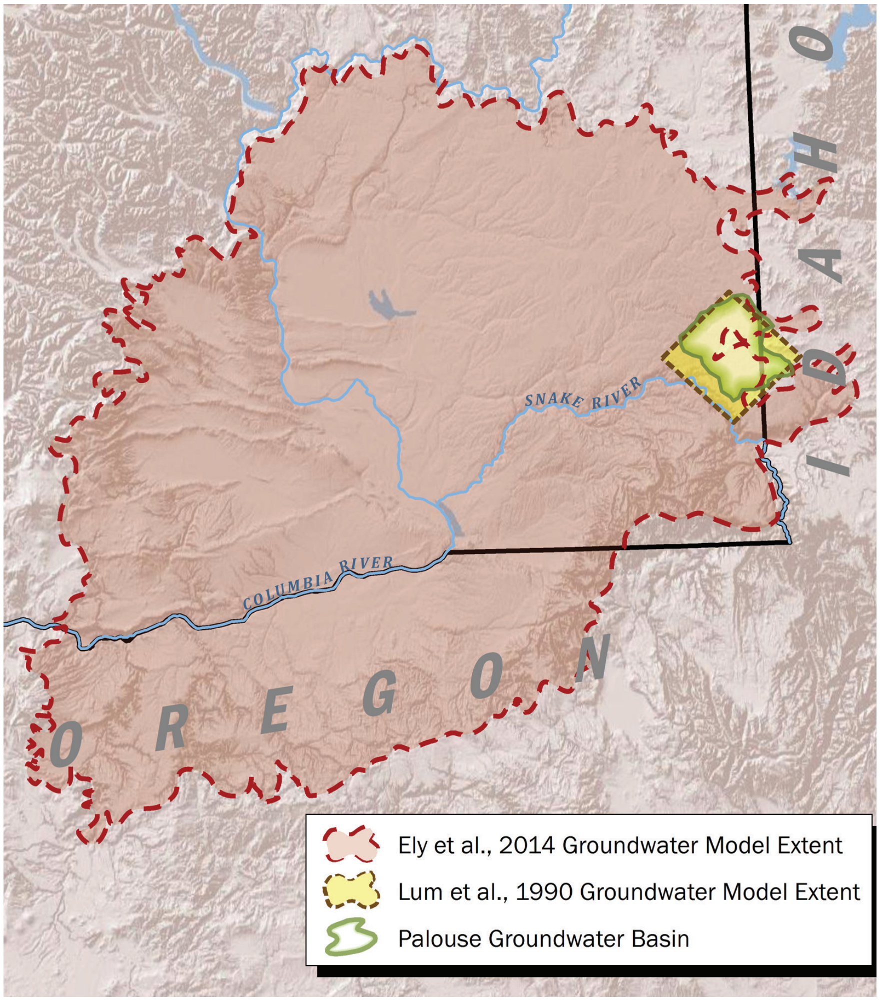


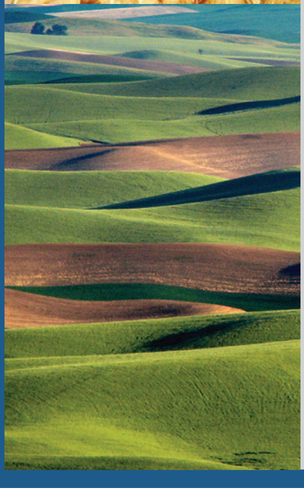
Note: Vertical scale greatly exaggerated
Source: USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

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.

Palouse Groundwater Basin
(Whitman County)

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].

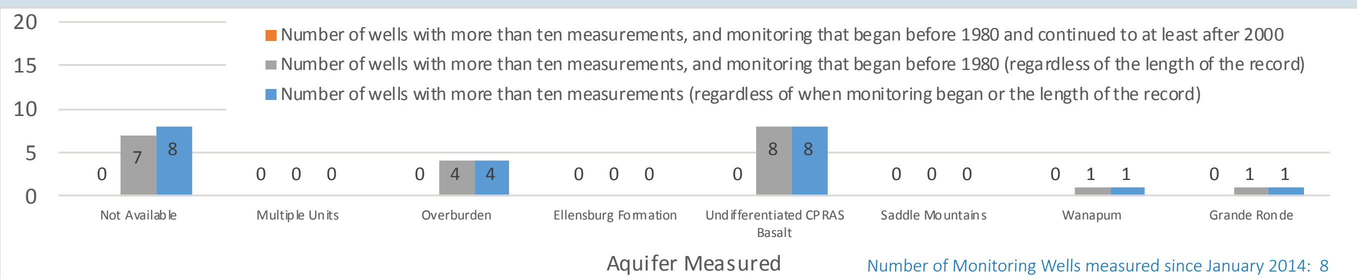
Currently Operating USGS Stream Gauges

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

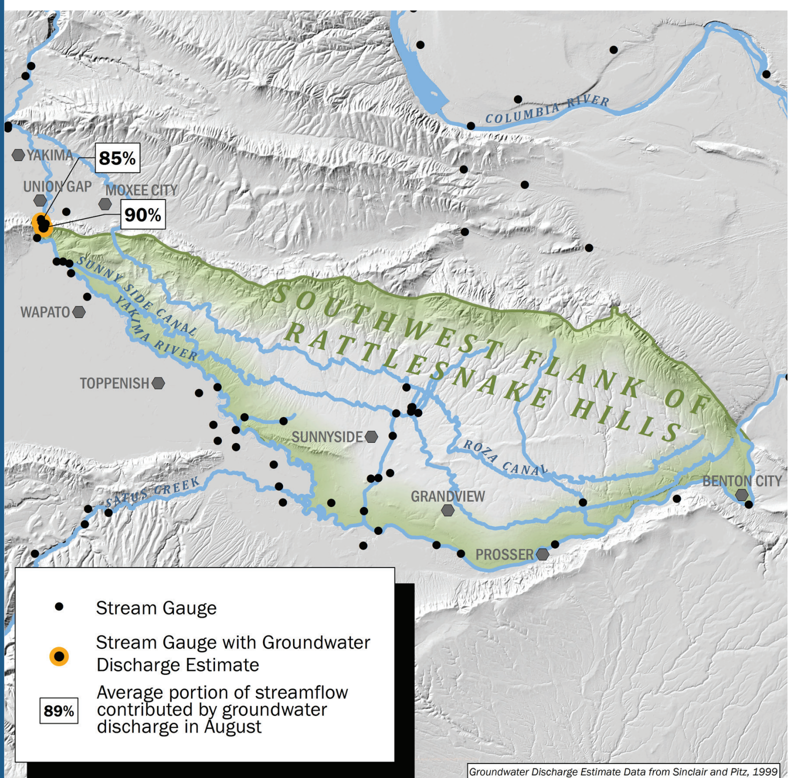
Groundwater Irrigated Acres	11,000
Population Served by Group A Water Systems	36,000
Population Served by Group B Water Systems	170
Population	38,000
Industry	Washington State University; Mostly agriculture: barley, wheat, dry peas, and lentils

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

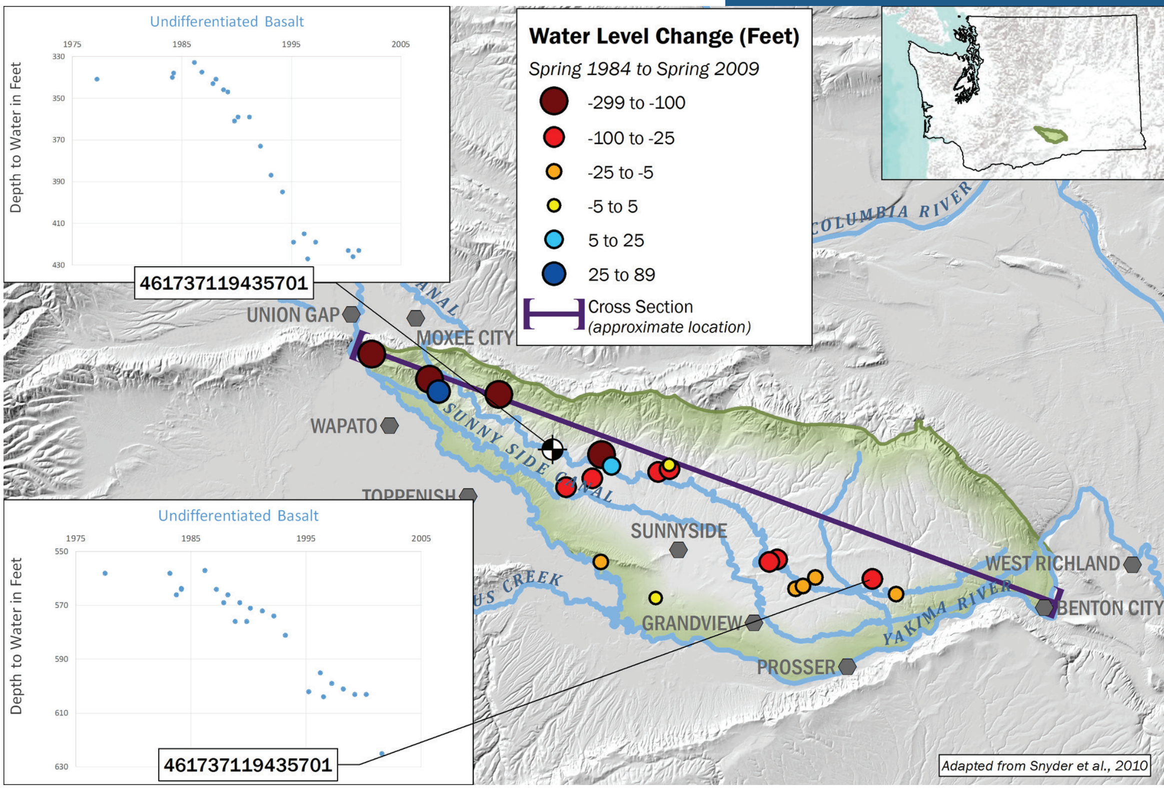
The primary surface water bodies in the Rattlesnake Hills include the Yakima River, and the Roza and Sunnyside Canals that supply Yakima River water to those respective irrigation districts.

- 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.

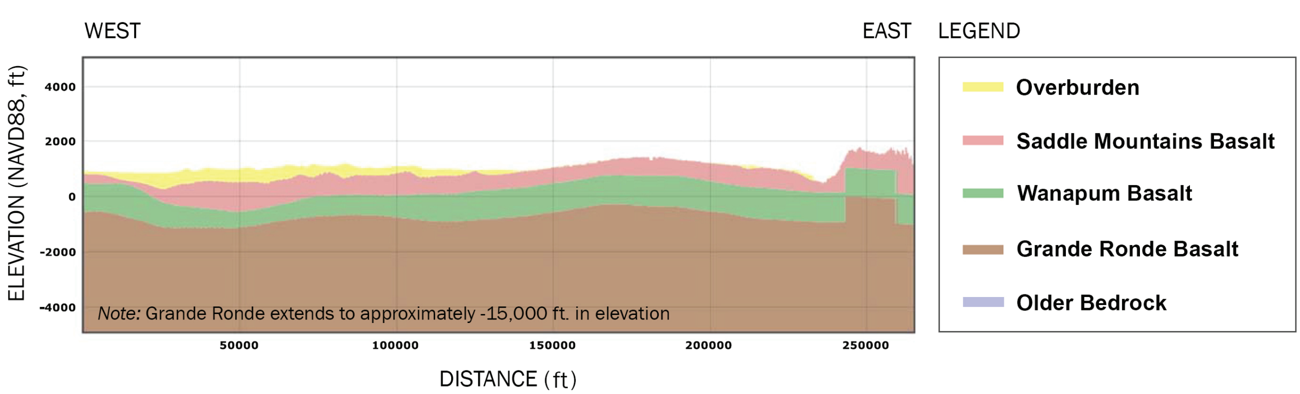
SW Flank of Rattlesnake Hills
(Yakima and Benton Counties)



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.

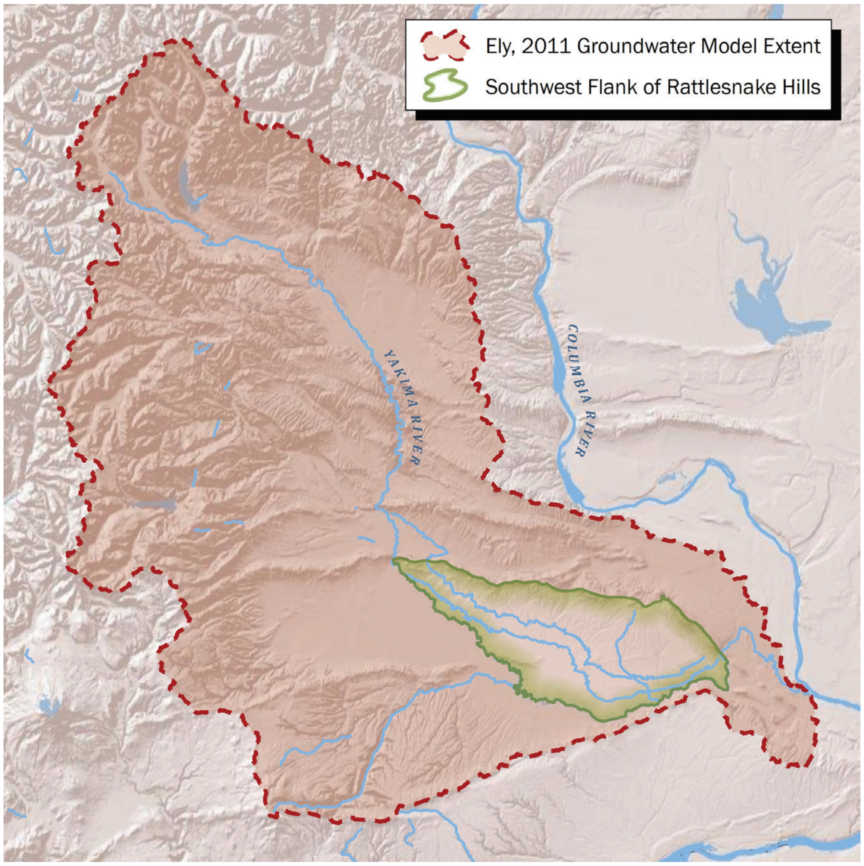


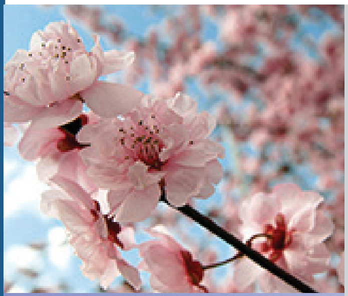
Note: Vertical scale greatly exaggerated
Source: USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

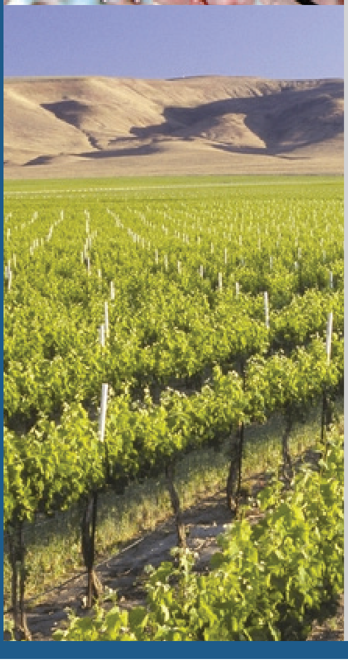
SW Flank of Rattlesnake Hills
(Yakima and Benton Counties)

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.

SW Flank of Rattlesnake Hills
(Yakima and Benton Counties)

Data Gap Analysis

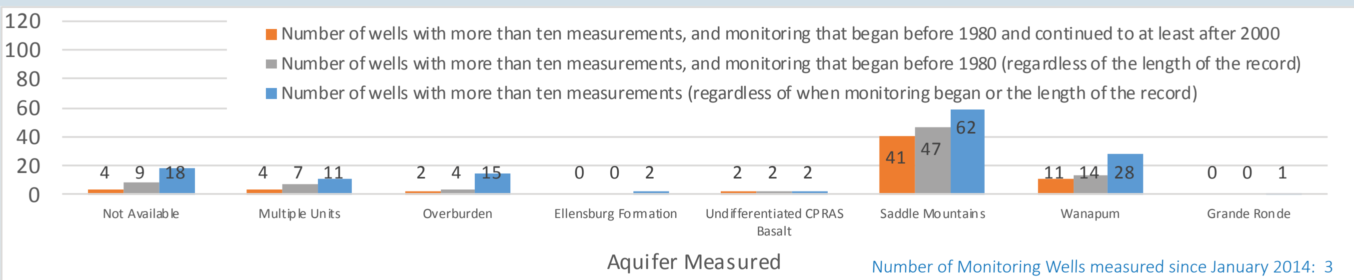
Data Needs: Continue historic groundwater modeling, and ASR/SAR pilot studies are planned [estimated costs are yet to be determined].

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 Population Served by Group B Water Systems	45,000 1,700
Population	67,000
Hatcheries	Prosser Hatchery (Falll Chinnook and Coho Salmon
Industry	Agriculture includes orchards, grapes, and mixed row crops

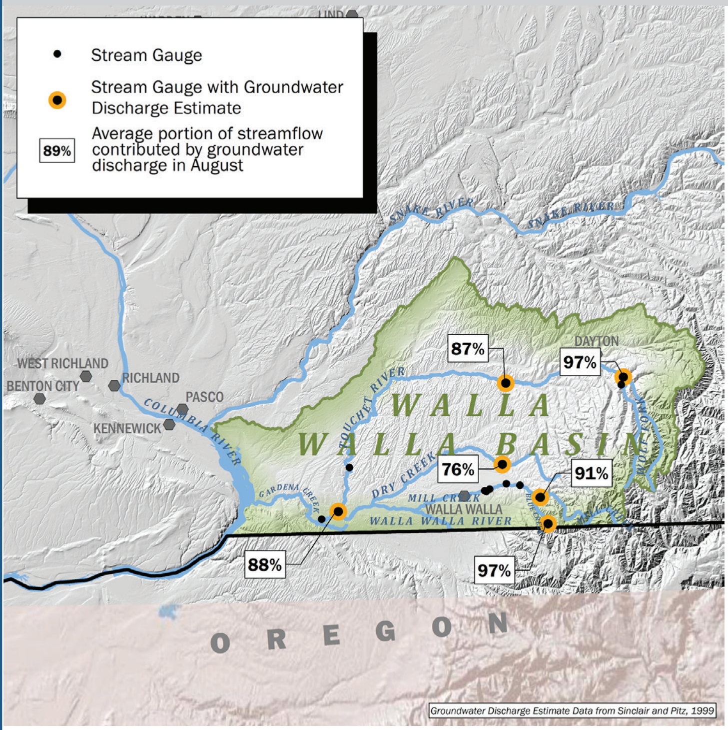
Walla Walla Basin
(Walla Walla and Columbia Counties)

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

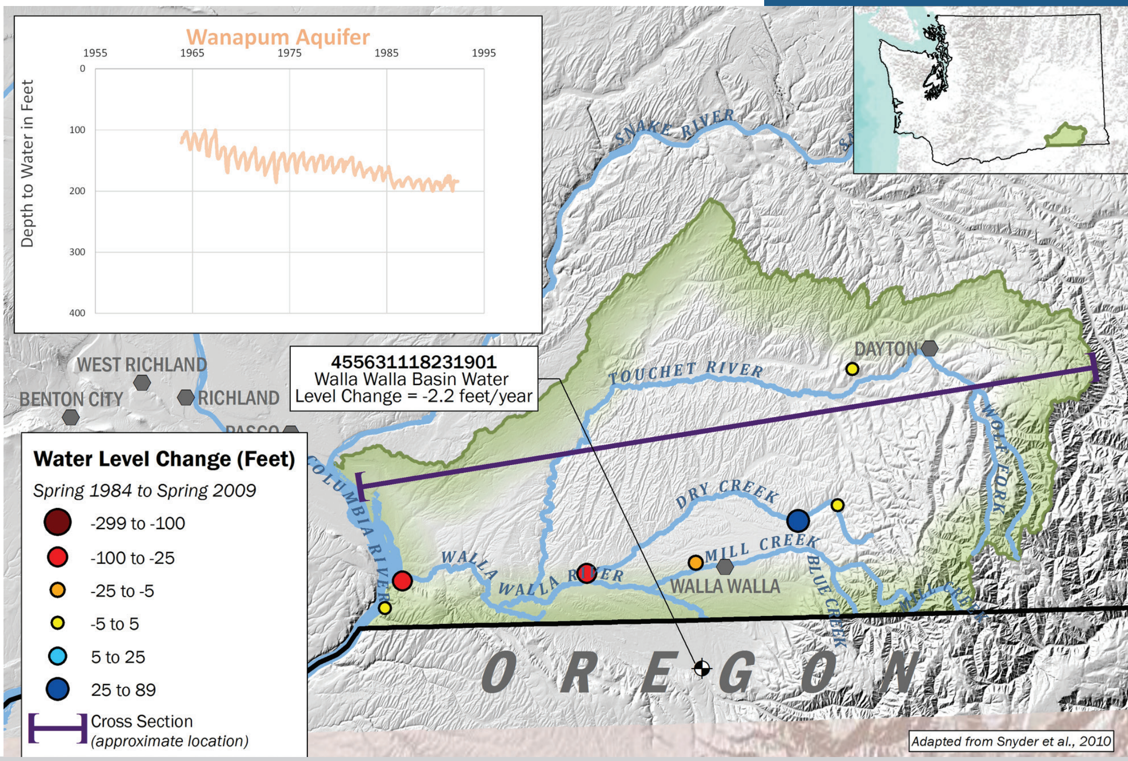
Major surface water bodies in the Walla Walla Basin include the Walla Walla River, Mill Creek, the Touchet River, and the North Fork of the Touchet River.

- 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).

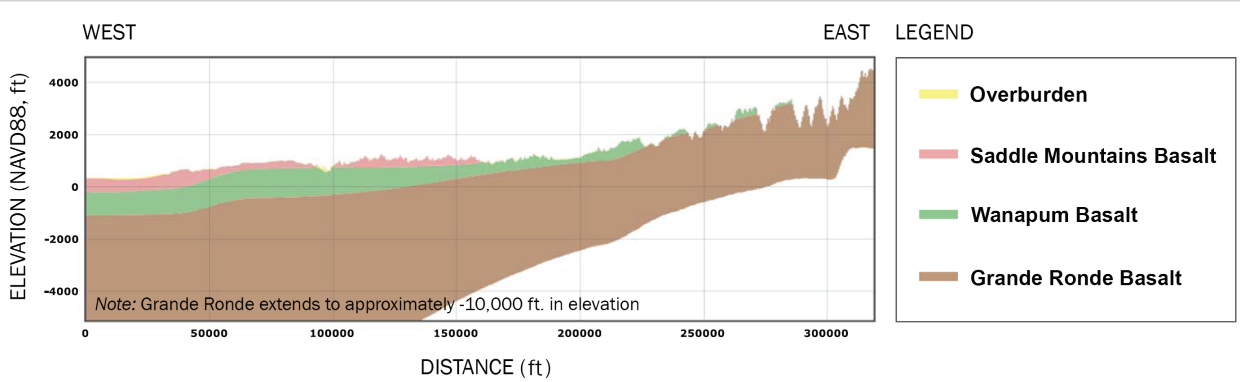
Walla Walla Basin
(Walla Walla and Columbia Counties)



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.

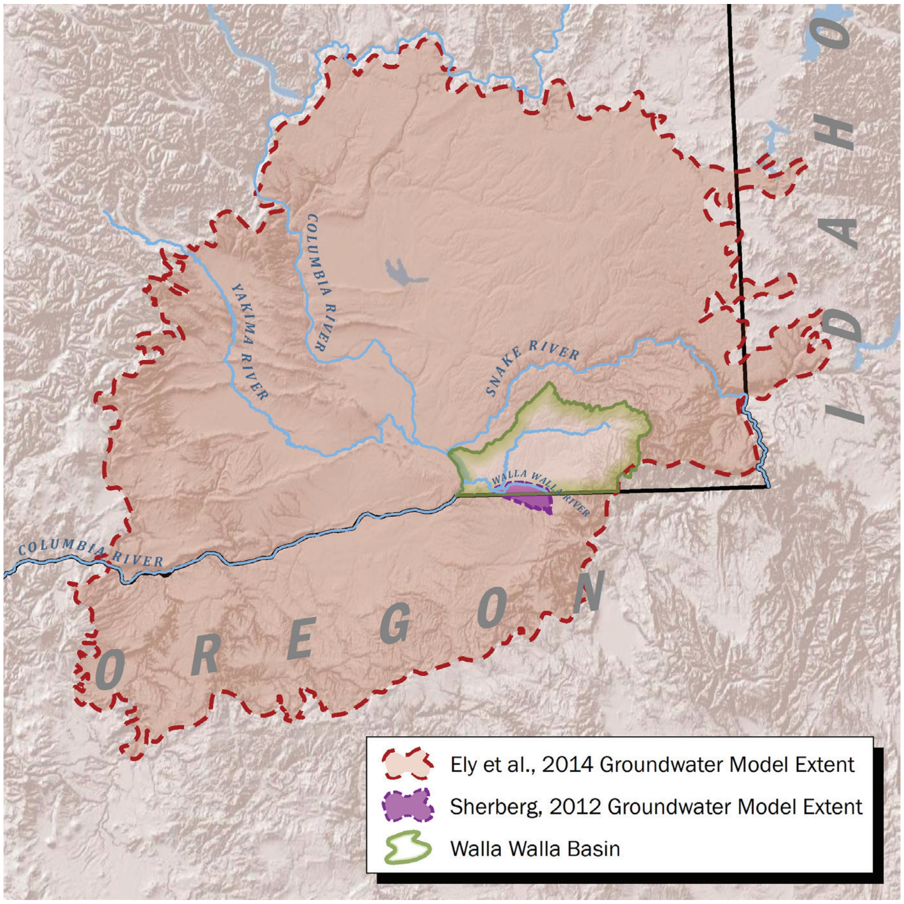


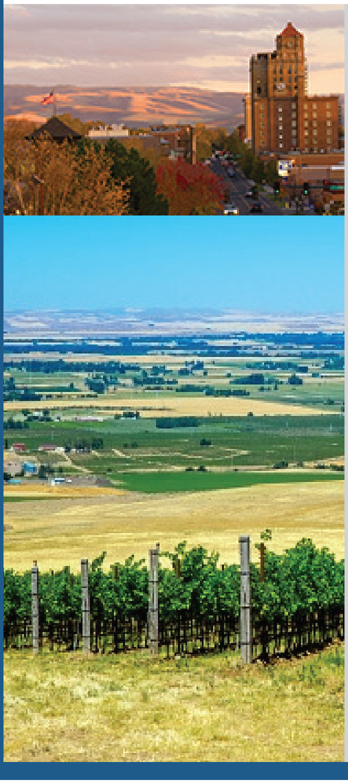
Note: Vertical scale greatly exaggerated
Source: USGS, Retrieved Dec 2015. http://or.water.usgs.gov/proj/cpras/index.html

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].

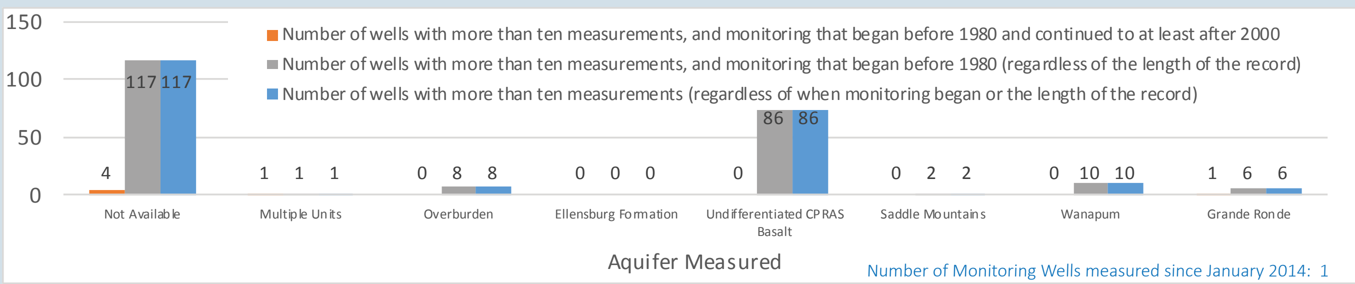
Currently Operating USGS Stream Gauges

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

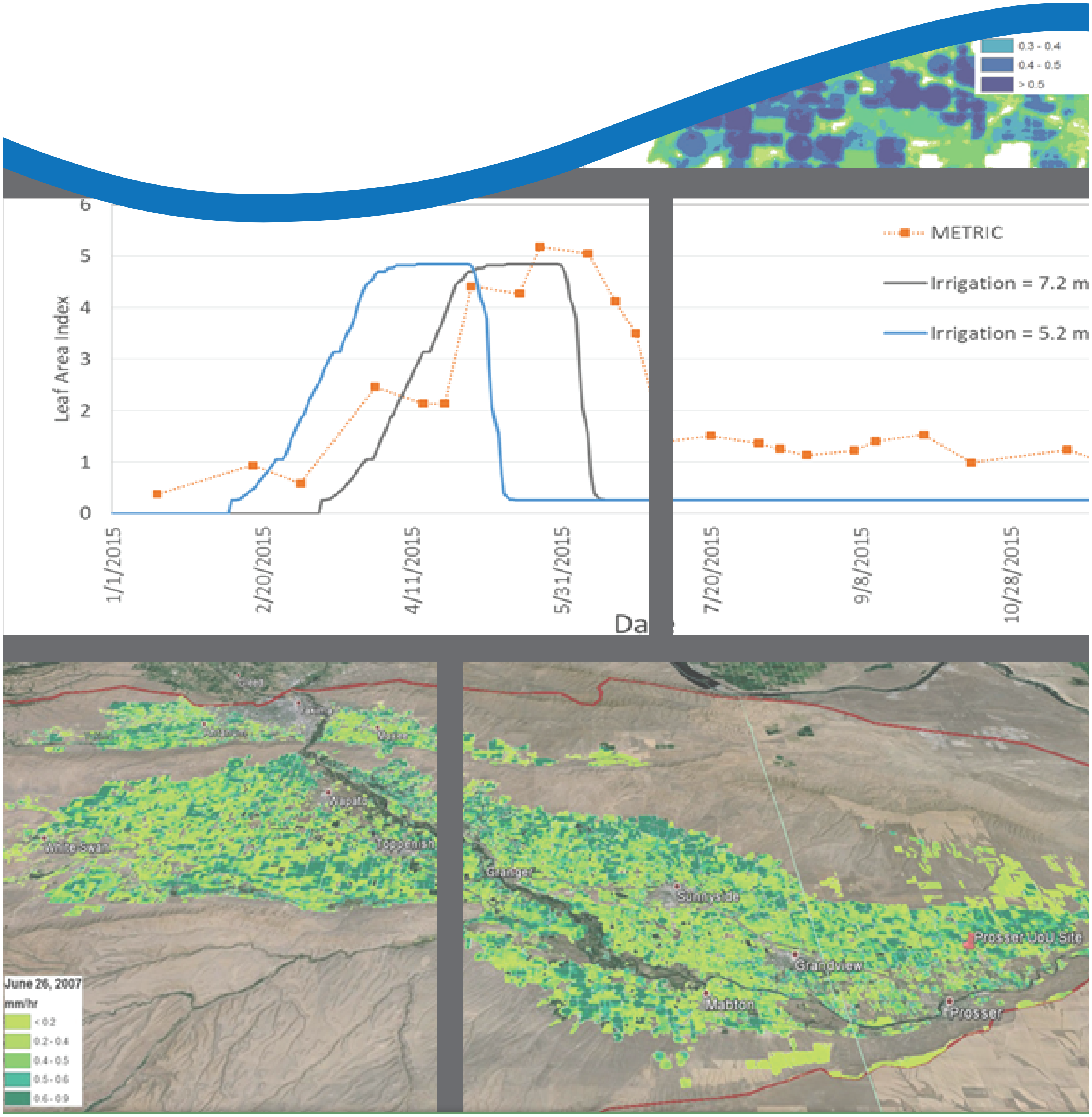
Risk Factors in the Walla Walla Basin

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



Remote Sensing of Evapotranspiration to Estimate Agricultural Water Use (Why METRIC?)

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) 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.

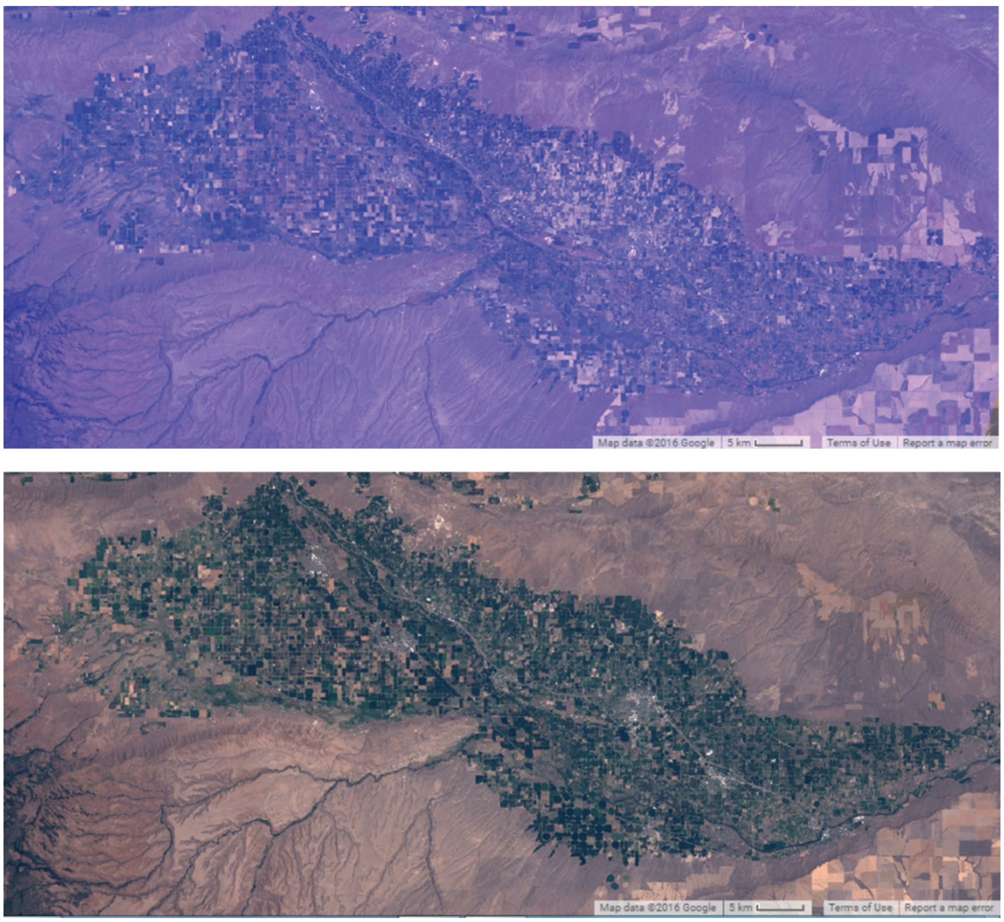


Figure 1: Satellite Images of Yakima watershed (Top) Landsat 5 image on June 19, 1993 (Bottom) Landsat 8 image on July 14, 2014. Satellite imaging of land surfaces has improved in quality so remote sensing approaches to manage agricultural water use is getting popular.

Policy Considerations of METRIC (Where Can it Be Used / Where Has it Been Used?)

- METRIC has been used in water rights evaluations and adjudications in Idaho courts
- METRIC has provided water use data which compliments metering data on a seasonal scale
- Researchers have used METRIC to identify areas of crop stress
- METRIC has assisted in studies of aquifer depletion and ground-water modeling

Objectives of This Module

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).

Development and Calibration of METRIC

Basis of METRIC (Surface Energy Balance)

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. 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.

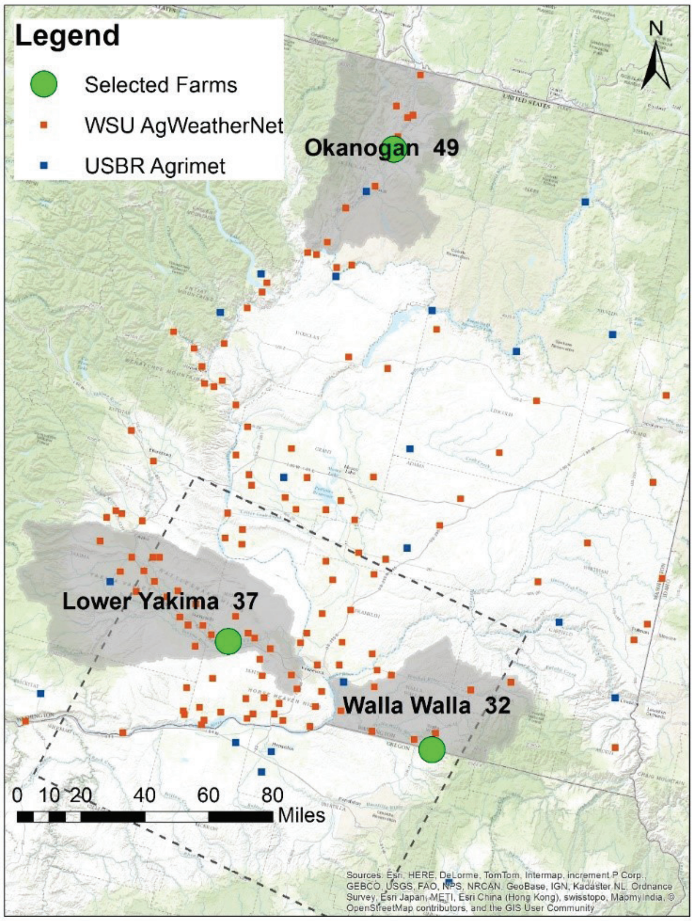


Figure 2: Location of three selected watersheds for study. WSU Agweathernet and USBR Agrimet make up a dense network of weather stations in Eastern Washington which makes use of METRIC easier in this region.

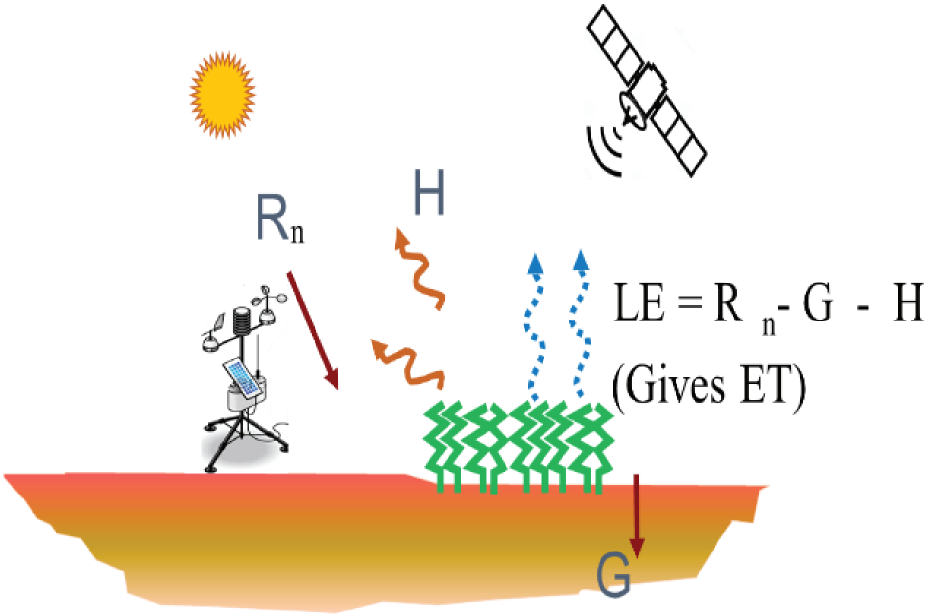


Figure 3: Scientific Basis of METRIC. METRIC uses satellite imagery with weather data to estimate consumptive use using surface energy balance method.

Application of METRIC Algorithm

METRIC was initially developed by Richard G. Allen in University of Idaho. The model's algorithm is available in published literature but the application of this model, as a software, has not been provided by the authors. According to the literature, METRIC had been developed by the authors using proprietary image processing software, 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 has made the model easier and cheaper for users interested in water use in Washington.

Features added:

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 more easier.

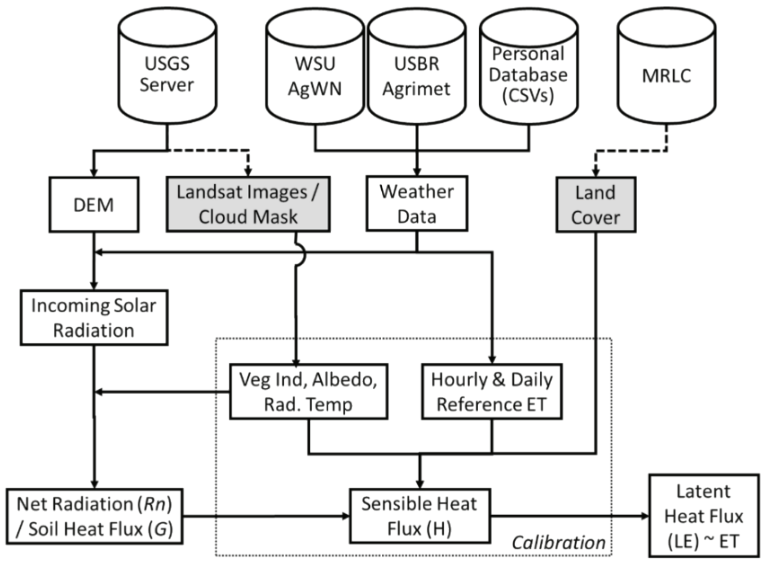


Figure 4: Formulation of METRIC. Dashed arrows and gray boxes indicate that these processes have not yet been automated. Calibration has also been automated but the detailed steps are not shown here.

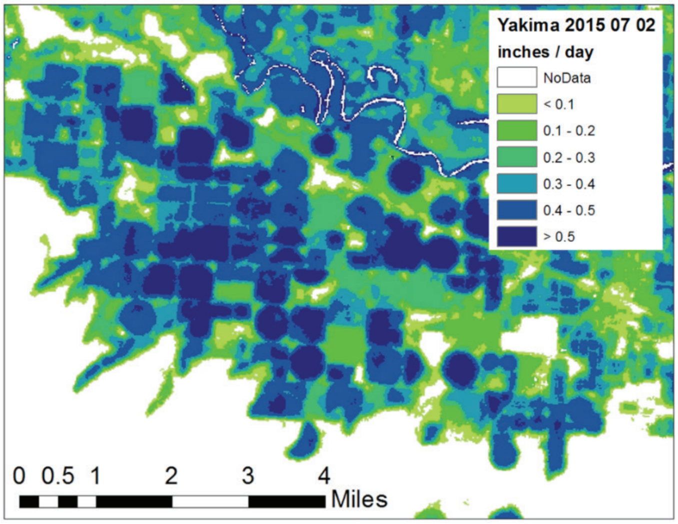


Figure 5: METRIC can produce high resolution consumptive use maps. This is METRIC result for an area west of Prosser, Yakima. The reference (alfalfa) evaporation rate for this day using the nearest available station (WSU AgWeatherNet station - Mabton East) was 0.42 inches per day.

METRIC Application Results for Eastern Washington

METRIC was applied to the three watersheds – Lower Yakima, Walla Walla and Okanogan using satellite images for 2015. Cloud-free image days were selected to present the results of METRIC. Our confidence in consumptive use in croplands is higher than other land covers since the model was calibrated using agricultural land use data.

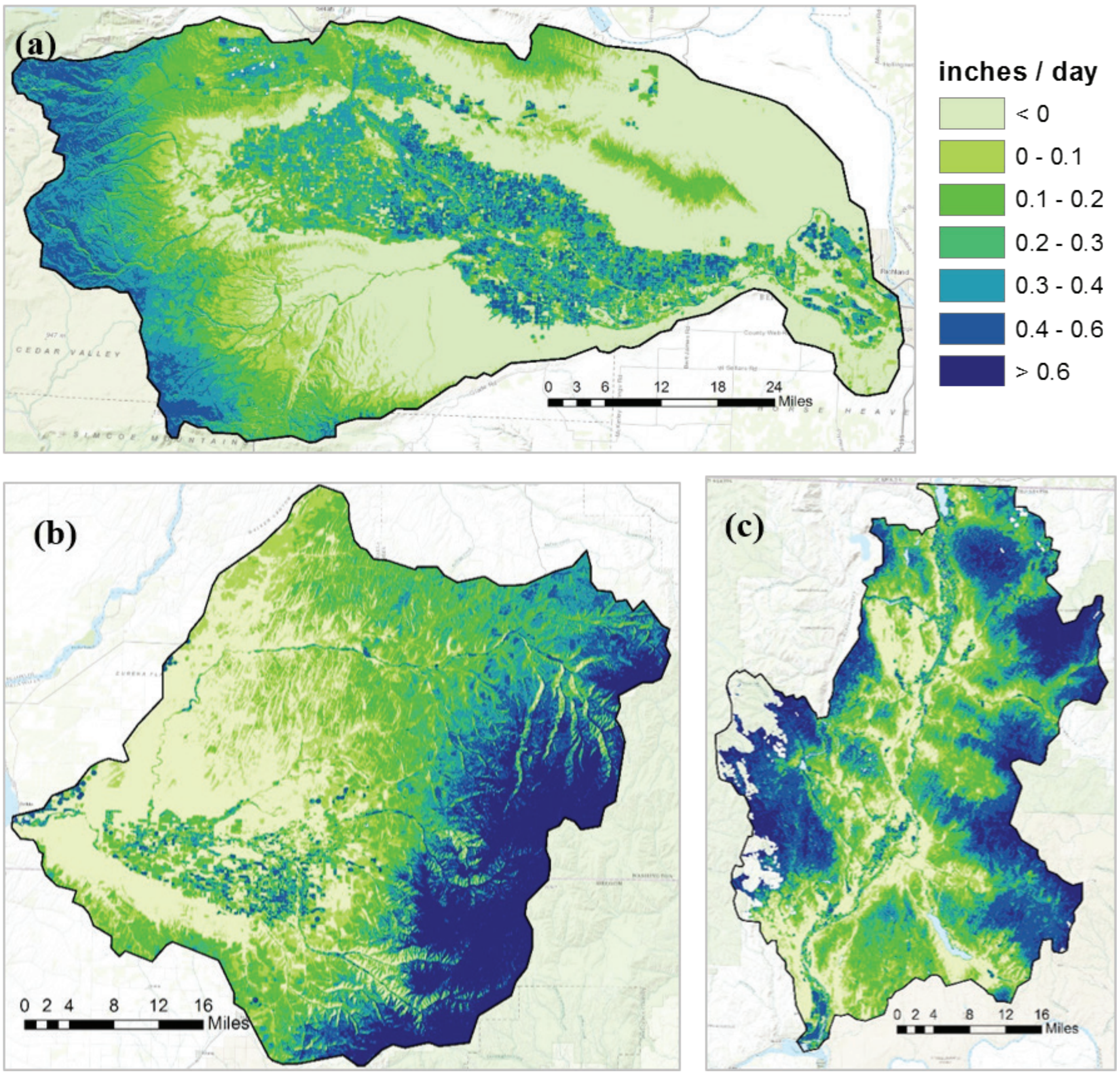


Figure 6: Results of METRIC - daily consumptive use for (a) Lower Yakima on Aug 19, 2015 (b) Walla Walla on Aug 05, 2015 (c) Okanogan on July 18, 2015.

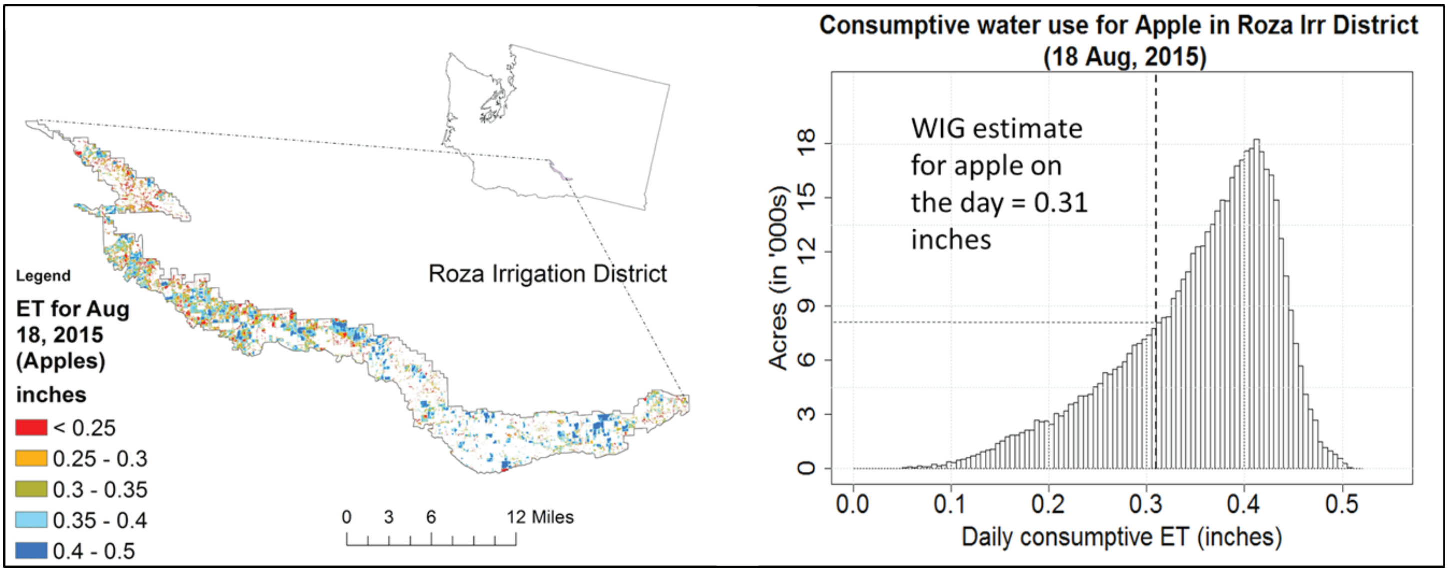


Figure 7: Variability in ET estimates from METRIC could help in identifying differences in water use patterns for similar crops. Comparison with WIG estimates show that about two-thirds of apple orchards in Roza use more water than recommended by WIG.

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 (WIG, 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 7 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.

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). CropSyst is a daily crop simulation model which is the crop production model used in this Forecast.

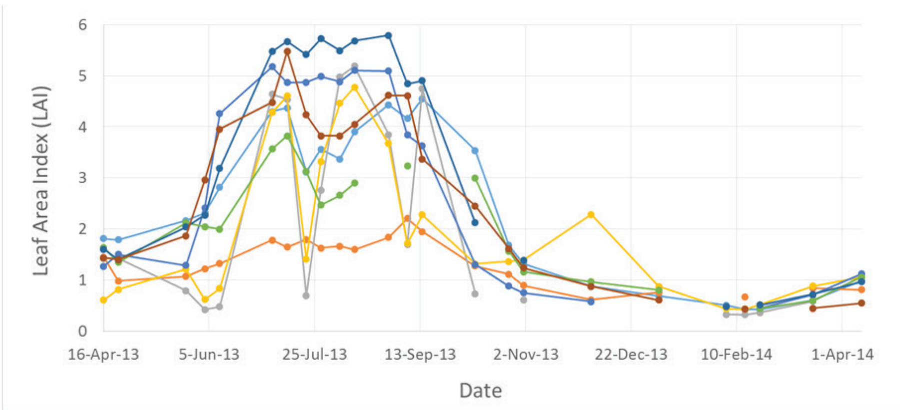


Figure 8: Leaf Area Index (estimate of crop growth) of 10 selected orchards in Walla Walla showed high variability. A single parameter is used in crop model for a single crop but growth and water use can vary for the same crop in a watershed.

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.

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. This application has provided insights into the development of an algorithm to use satellite-based models to parameterize crop models.

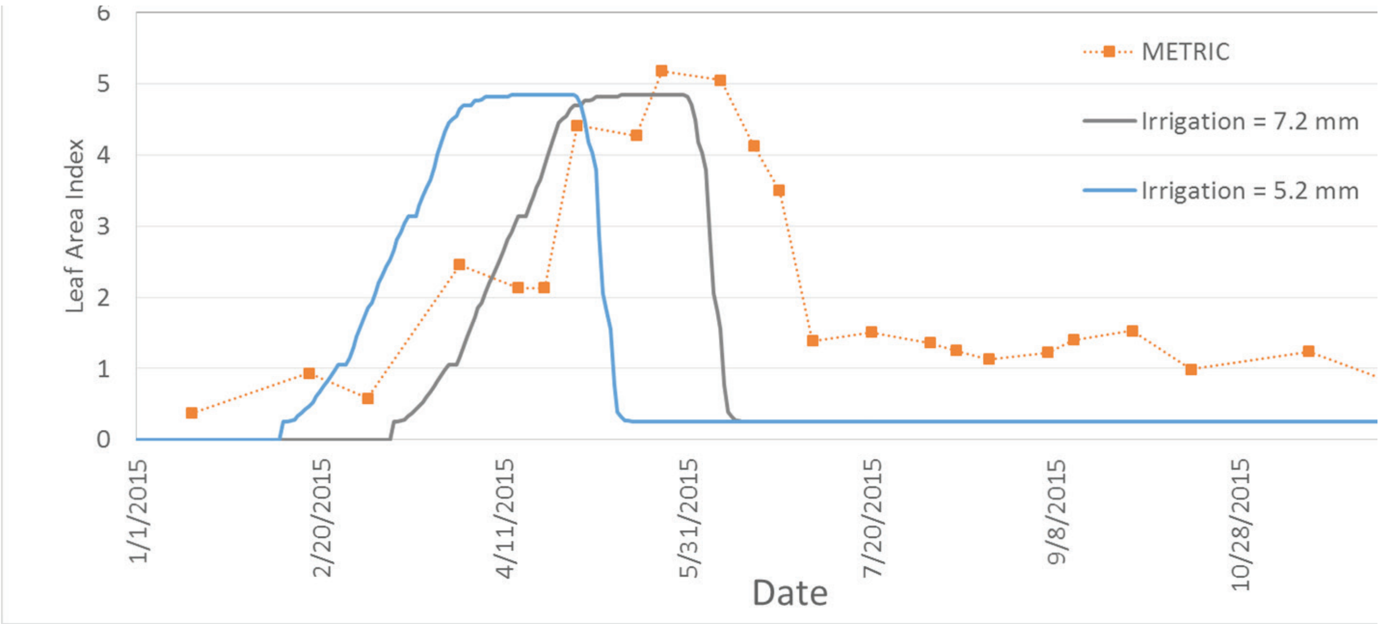


Figure 9: Comparison of METRIC's and CropSyst's leaf area index (LAI) estimates for a grape vineyard in Walla Walla. Irrigation rate specified by the irrigator was 0.2 inches / week which when used in the crop model, did not produce same LAI as provided by METRIC which uses satellite imagery. When irrigation rate was increased to 0.3 inches/week, the distribution of LAI from CropSyst was replicated by CropSyst.

Conclusions and Future Work

1. **Development of Model**

   Development and formulation of METRIC for three watersheds in Washington has paved the way for application of METRIC at a larger scale, spatially as well as temporally. The removal of platform dependence from the original model with use of freely or more generally available software and automation of various processes involved has made METRIC easier to use in Washington.

   As a next step, in terms of model development, the group is working to make the model user-friendly, find model sensitive parameters for this region, and reduce and report uncertainties of the model.

2. **Application of METRIC**

   Application of METRIC to the pilot watersheds in Washington provided the variability of water use for similar crops. Comparison of METRIC results with previous measures of consumptive use, such as WIG estimates for a watershed, showed that there can be considerable differences in water use, even within a region inside watershed.

   As next step, in terms of application of METRIC, comprehensive modeling of major crops in the selected watersheds will be performed and crop water use patterns and trends in these watersheds will be identified. The results of this work can assist in identifying areas where additional storage projects would be needed, quantifying amounts of water needed based on location within the WRIA and complementing water demand forecasts.

3. **Coupling METRIC with Crop Model**

   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.

Water Banking Trends in Washington and Western States

Introduction

Water banking is an institutional mechanism used to facilitate the legal transfer and market exchange of water (Clifford et. al. 2004). Knowledge of water banking helps clarify how water rights will move 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).


Yakima Canyon

Purpose of Water Banking

Water banking is process used to transfer water to new uses (MacDonnell, 1995). The overall goal of a water bank is to facilitate water transfers using market forces. In Washington, the legislature has identified additional goals of water banking in RCW 90.42.100, which include:

- Making water supplies available when and where needed during times of drought;
- Improving streamflows and preserve instream values during fish critical periods;
- Reducing water transaction costs, time, and risk to purchaser;
- Facilitate 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 has varied from state to state, and within Washington.

Water Banking Defined

Water banking is facilitated by an institution (the water bank) that operates as a broker, clearinghouse, or market-maker. 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. In Washington, many of these actions are defined in the Trust Water Right Agreement (TWRA) between the water bank and Ecology.

Washington State Market Activity and Participation

This chapter discusses Washington's water allocation framework, water banking policy, water banking programs, and compares the water banking models.

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”. Water banking provides a market-based approach to solve this problem by allowing senior water to be reallocated for new uses.

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 actions and water bank need, and ability of Ecology and counties to agree on the standards for legal water availability and physical availability. The operational structures include:

1. Public: State, County, City, or other local governments. Hybrid banks result when a public entity contracts with a third party to perform the non-regulatory functions.
2. Quasi-Government: Quasi-government organizations are considered to be entities formed by the legislature (i.e., Irrigation Districts, Walla Walla Watershed Management Partnership).
3. Nongovernmental Organizations (NGO): Nongovernmental Organizations (NGO) are considered to be entities operating under IRS tax code 501(c)3 (i.e. Washington Water Trust).
4. Private: Private entities are considered for-profit organizations incorporated under State and Federal Law. Currently, private water banks only operation in the Yakima Basin where Groundwater Rule WAC 173-539A requires mitigation of all new groundwater uses.

Summary of Washington Water Banking Metrics

Comparing Water Banks

Water banks transact quantities of water for a variety of purposes and quantities. To compare water banks’ activity, we will compare “units of mitigation” and acre-foot consumptive. A unit of mitigation is the quantity of water a water bank does business in. To standardize reporting across different bank metrics, we have quantified water conveyed by the residential unit, and water conveyed by the acre-foot, to the acre-foot consumptive equivalent (Figure 1).

Water Bank Activity and Prices

Price, or the amount of money paid for one unit (not including fees) is highly variable between these different models, as shown in Table 1 and Figure 1. Our research also indicates the number or units transacted is highly variable between models, as illustrated in Figure 2.

Private banks appear to be the most expensive to participate in, having both the highest average unit price and price per consumptive acre-foot. Quasi-Governmental/NGO has the second highest price, with public banks having the lowest price. The price difference 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 banks also appear to be most active. Private banks have issued 827 mitigation credits compared to 53 for non-profit/quasi-governmental, and 381 for public water banks. This is likely related to locations and markets served, as well as regulatory requirements for water banking. Figure 2 show how many units have been transacted by banking model.

Water Banking in the Western U.S.

Water banking approaches and activity varies substantially across the western United States. This section provides a summary of water transactions, prices, water bank structures, and other characteristics of water banks and their activities across the 11 western states of Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, and Wyoming since 2004. This summary is not comprehensive, but provides a synopsis of the basic characteristics of water banking in these states as an update to the report by Clifford and Larsen-Hayden (2004) written for the Department of Ecology (http://www.ecy.wa.gov/pubs/0411011.pdf).

Arizona

All water banking activity in Arizona is governed by the Arizona Water Banking Authority (AWBA) to provide water supplies to municipal, industrial, and other users though the Central Arizona Project (Arizona Water Banking Authority (AWBA), 2014). Between 1997 and 2015, a total of about 3.4 million acre-feet (averaging 187 thousand acre-feet/year) were purchased through AWBA, at prices ranging from a low of $32/acre-foot in 1997 (2014 dollars) to a high of $177/acre-foot in 2014. These purchases represent storage credits that can be banked across years.

California

Water banking began in the state after the droughts of 1980s and early 1990s and has grown substantially since (Hanak and Stryjewski 2012). A number of groundwater banking programs have developed for active aquifer storage and recovery. Examples include several related water banks in Kern County including Semitropic, among the largest water banking operations in the world (Semitropic, 2015), and the Metropolitan Water District of Southern California (MWDSC). By 2003, over 2 million acre-feet have been committed for sale or lease annually in the state, with about 1.3 million acre feet of completed transactions in any given year (Hanak and Stryjewski 2012).

Colorado

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. It allowed for one year leasing programs for stored water within the Arkansas River Basin and its tributaries. Low market participation led to restructuring in 2003 and a 2006 statute made the water bank permanent (Scanga 2013). Some of the changes included expedited transaction timeline and more authority to the water bank operator. However, these modifications have not resulted in any trading activity through the bank, and the bank is currently not active (personal communication with Upper Arkansas Water Conservancy District. December, 2015).

Idaho

Water banks in Idaho are separated onto two categories by the Idaho Department of Water Resources Board (IWRB) as water supply banks and local rental pools (IWRB 2014, Van Bussum 2011). The IWRB water supply bank handles water rights-related cases for all surface and groundwater throughout Idaho. The filing fee to lease a water right to the bank is between $250 and $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 (Idaho Department of Water Resources Board 2014). The number of lease and rental applications has ranged from 250 in 2010 to 491 in 2014. Besides IWRB's water bank, there are five state managed rental pools in Idaho. Rental pools are governed by various committees appointed by the IWRB Information on the water banking activities of these rental pools were not readily available by completion of this report.

Montana

No state water banks are in operation in the state of Montana. However, a private company named Grass Valley French Ditch Co. 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.

Nevada

The Southern Nevada water authority (SNWA) is currently engaged in three different water banking projects that accounts for nearly six years' worth of Nevada's allocation of the Colorado River water; among them is the Southern Nevada Water Bank (SNWA 2015). 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. The SNWA has about 600,000 acre-feet of water stored in Arizona's aquifers at a cost to SNWA of about $200 per acre-foot, among other trading arrangements with California (Personal communication with Mack Bronson, Southern Nevada Water Authority. December 15, 2015).

New Mexico

There is no coordinated water banking program operating in New Mexico at present, however, there are some local water banks present in New Mexico. For example, The Middle Rio Grande Conservancy District (MRGCD) manages the

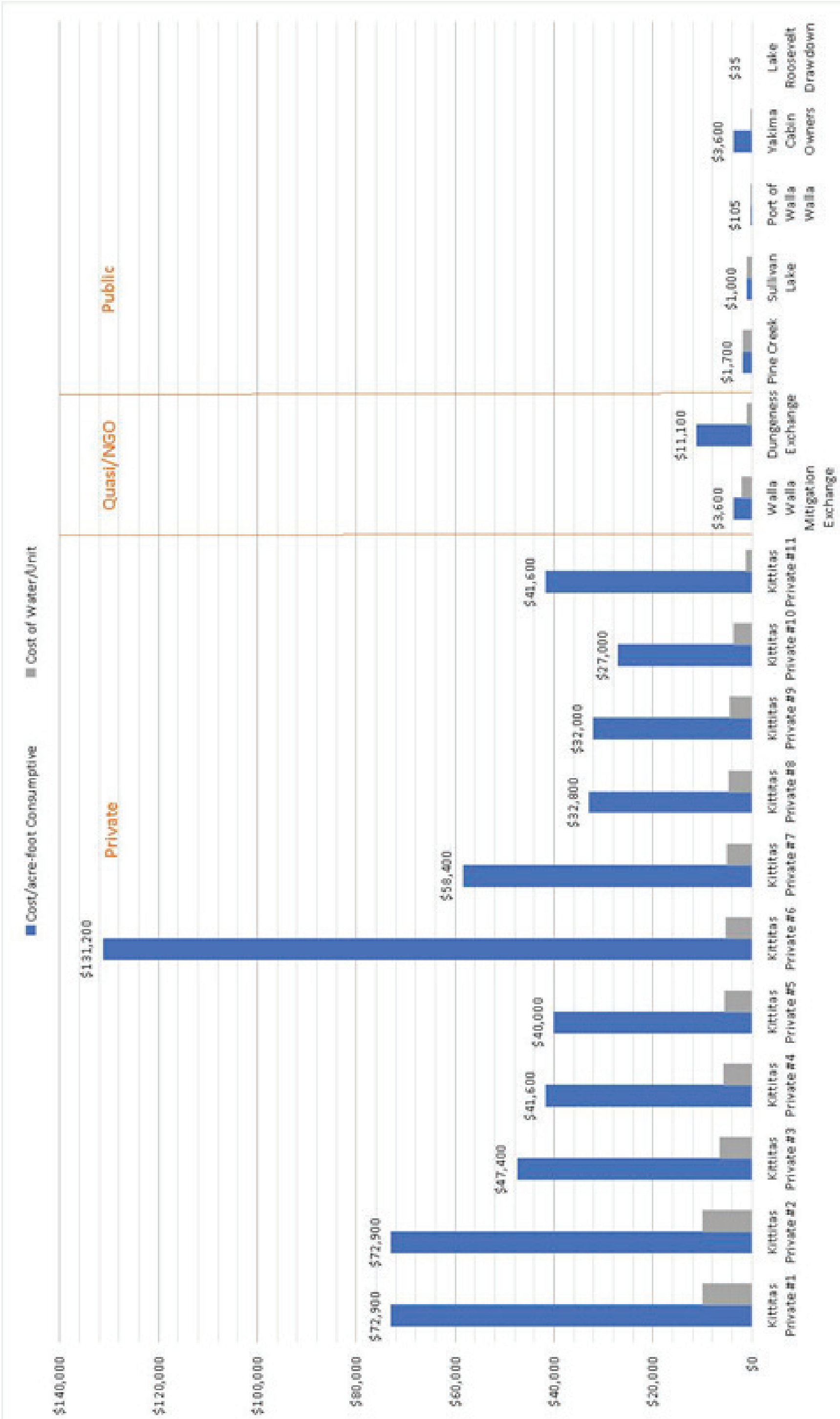


Figure 1: Comparing Price of Different Water Bank Models

Table 1. Summary of Price of Water Charged by Public/Private Water Banks

	Cost of Water/Unit	Cost/acre-foot con-sumptive
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: Excludes annual rate programs and lease programs
Excludes transactional fees
Data collected through spring 2015

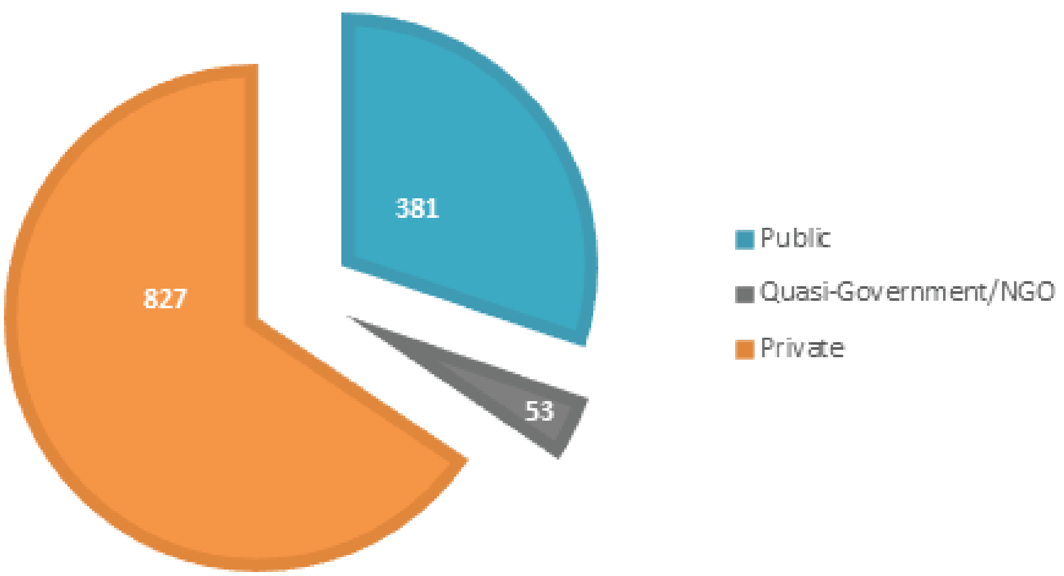


Figure 2: Units Transacted by Banking Model

MRGCD water bank for leasing this irrigation district's water (mrgcd.com). Water trading does occur on a regular basis in New Mexico, but much of it is handled through the New Mexico Office of the State Engineer (NMOSEISC 2011, Oat and Paskus 2013). The Water Bank (waterbank.com) is operated out of Albuquerque, NM, but is a brokerage firm, rather than a water bank per se.

Oregon

As of 2012 there were 18 water market developments in Oregon designed to facilitate trading to address quantity and quality concerns (Oregon Institute for Water and Watersheds 2012). Of these, all designated water banks are in the Deschutes basin. The Deschutes Water Alliance Water Bank (DWA: http://www.deschutesriver.org/ DWA-Water-Bank.pdf) facilitates trades primarily among agricultural irrigators, municipalities, and for instream flows, and the Deschutes Groundwater Mitigation Program provides a means to mitigate groundwater use by lease and purchase of water rights. As of 2012, 95 groundwater rights had been mitigated.

Texas

The Texas Water Bank (est. 1993) to facilitate the temporary or permanent transfer, sale, or lease of water and water rights throughout the state (TWDB 2015). 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 the price negotiations between potential buyers and sellers. See http://www.twdb.texas.gov/waterplanning/waterbank/bank/index.asp for more details. Surface water rights deposited in the bank are protected from relinquishment while on deposit in the bank for an initial 10-year period and for an ensuing 10 years. The TWDB may charge as much as 1 percent of the value of the water or water right received into or transferred from the water bank to cover its administrative expenses. One can also choose to post their water right sale or lease offers to the TWDB website without depositing it through the application process. No fees are charged for such seller postings but are not protected by the water bank rules. The Texas Water Trust is a program administered within the Texas Water Bank. It is designed specifically to acquire water rights through donations, sale or purchase for environmental purposes. All deposits made to the trust are exempt from any fees from the TWDB.

Utah

Although there are bills and statutes in the state legislature to allow for the creation of water banking programs in Utah, there are apparently no formal water banks in operation in Utah (Flint 2013).

Wyoming

There are no water baking programs in place in the State of Wyoming. Currently, there is no legislation under consideration to help facilitate water banking actives

Washington Water Banking Barriers and Improvements

This section summarizes water banking barriers and improvements identified through stakeholder surveys. This section includes our outreach approach, survey questions, and responses.

Outreach Approach and Survey

In order to identify issues, obstacles and improvements for water banking in Washington, we surveyed 12 water bank managers and stakeholders[1]. Surveys were generally conducted over the phone. Water bank managers were asked to answer questions about specific bank operation, and questions about their working relationship with Ecology. Water bank managers provided a variety of responses to the survey, ranging from concern over metering requirements to out-of-WRIA transfers. However, there were some common themes that emerged from the survey. Barriers identified during the surveys are discussed below and in the Alternative Models and Recommendations section.

1 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.

Summary of Barriers to Water Banking Identified in Surveys

Regulatory

The water bank surveys revealed several 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[2] wells are appropriate for development and when a water right permit is required. Some interviewees cited the permit requirement from Campbell and Gwinn made it more difficult to provide mitigation water to domestic uses because permits require an impairment analysis.

Funding

Funding was another commonly cited banking barrier. 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.). The cost of bank formation and limited funding both impedes bank development and creates high costs for bank participation.

Operational Barriers

The two main operational barriers to water banking cited by interviewees were public buy-in and 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 for water banking. Without groundwater modeling and studies, it is difficult for bank managers to determine appropriate mitigation and creates uncertainty around availability and ESA impacts.

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.

Metering Issues

Concern over metering requirements was raised during our water bank surveys. 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 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.

2 A permit exempt well is a well that meets that stator exemption for a permit under RCW 90.44.050.

Additionally, this metering standard raises the cost to participate in water banking. Beyond just increasing 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.** 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.

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 to the overall water cost and value of the water right. However, for small domestic uses, CWRE costs as a fraction of permitting/water right value is high. 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[3] 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.

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.

Out-of-WRIA Transfers

Out-of-WRIA transfers are a concern for 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). This system creates pressure for downstream marketing, which will eventually limit the pool of available rights 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[4]. In addition to keeping the current process, there are several legislative and policy options that could be used to address out-of-WRIA transfers:

3 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".

4 Protecting Local Economies (2008), http://www.ecy.wa.gov/programs/wr/wrac/images/pdf/wa_local_econ_web.pdf.

- **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.** The Legislature could require county consultation on local bank formation policies. RCW 90.03.380(9)(a) requires electronic notice to the county of origin on transfers, 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.
    - 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.

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 alternatives:

- **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.

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 could be done by Ecology, USGS, or via a privatization model (e.g. using contractors to measure or model groundwater declines).

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.

Funding Inequities

Legislative funding for water bank development comes in many forms: 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 on the funding process and help create a sense of equity in the funding system.

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.

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

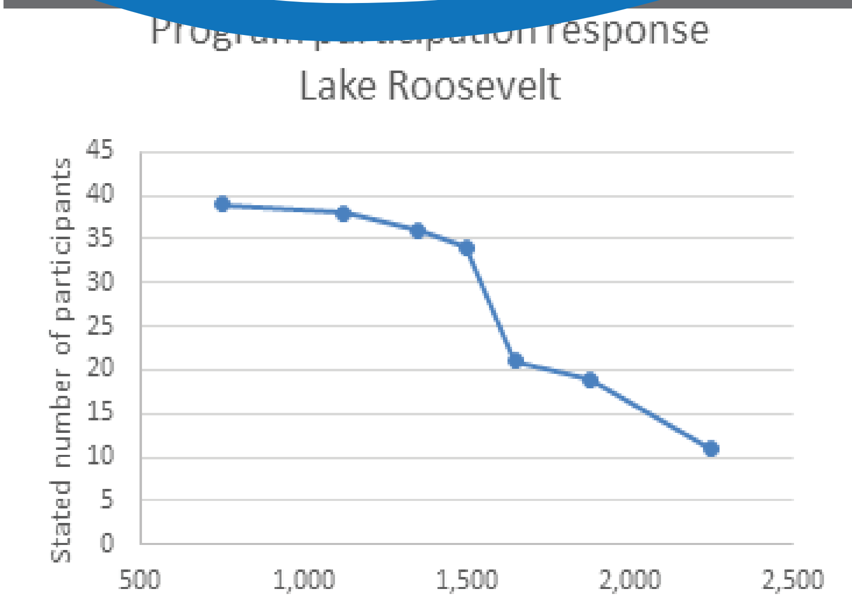
Tomkins, C., Weber, T., Freyberg, D.L., Sweeney, J.L, Thompson, B.H., 2008, Option Contracts in Practice: Contractual and Institutional Design for California Water Transfers. Policy Brief.

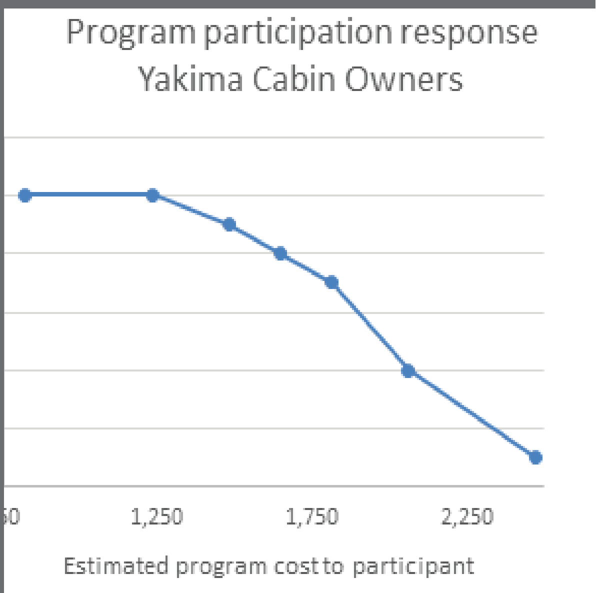
Tomkins, C., & Weber, T., 2009, Option contracting in the California water market. J Regul Econ Journal of Regulatory Economics, 37(2), 107-141.

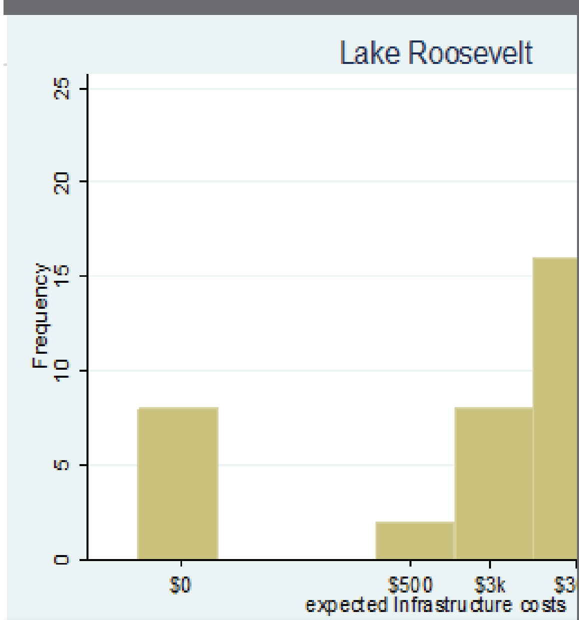
Van Bussum, M, 2011, The Board's Water Supply Bank. Retrieved from the Idaho Water Resource Board Website : https://www.idwr.idaho.gov/files/water-supply-bank/Basics-of-the-Bank.pdf

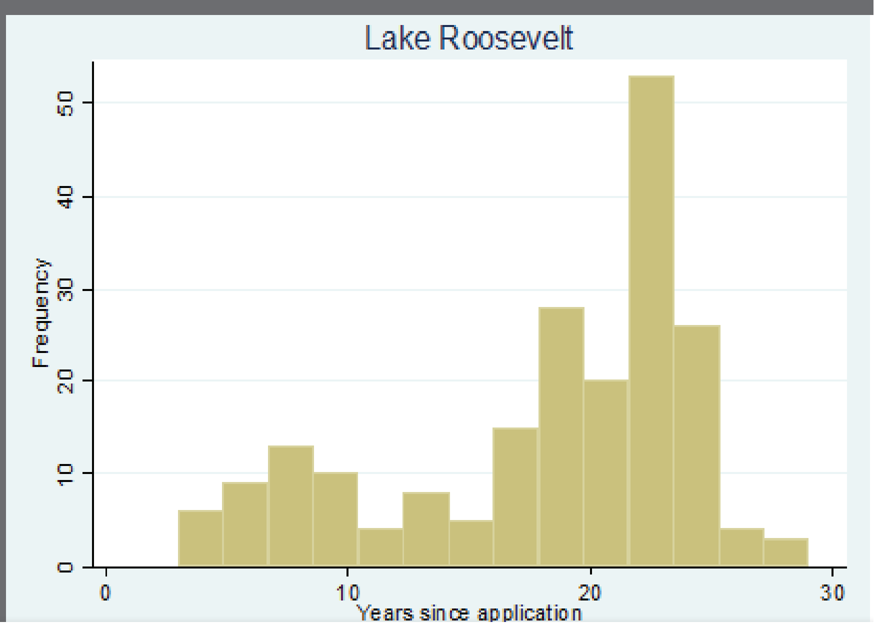
Yoskowitz, D.W., 1999, Spot Market for Water along the Texas Rio Grande: Opportunities for Water Management. Natural Resources, 39(2), 345-355

Effects of User-Pay Requirements on Water Permitting









Water Service Programs:
The Effects of Price and Other Factors on Participation

Introduction

When the Department of Ecology (Ecology) and its predecessor agencies' mission 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 application processing to approval was the norm. Today, however, application filing fees are around $50/acre-foot, priority processing fees are around $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 where the administrative and transactional fees have increased, more applicants have declined water when made available, and 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 conditioned Ecology funding levels for permit staffing on 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 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. Variations include: paying for processing a water right permit application, paying for the cost of water supply development; paying an annualized fee versus one-time cost; and paying a specified cost versus requiring individualized mitigation without a specified cost.

To better understand program variation and user reactions to it, WSU developed a survey and delivered it to water rights applicants who were associated with these programs in Ecology applicant databases. The analysis and evaluation of survey responses includes a broad set of sample summary statistics of survey responses for each program.

In summary, WSU concluded that the change in applicant circumstances during long waiting periods since the application was submitted, the costs incurred by applicants to pay for Ecology's cost recovery, and uncertainty about applicant's family or business situations were the primary reasons for non-participation.

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. WSU 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.

The surveys were designed to evaluate the reasons that people chose either to participate in the various programs offered or not to participate. The survey design was based on standard economic methods to assess program participation decisions. It focuses on collecting information that is likely to be related to expected benefits and costs of participating in the program from the applicants' perspective. WSU 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. Surveys were developed by the WSU 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 useable 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.

Table 1 provides the initial sample sizes and response rates by program. Response rates ranged from 8.1 % to 64.8%, with an average of almost 30%.

Table 2 provides information on program participation within our sample of survey respondents.

Table 1: 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**

Table 2: 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 Selected Individual Programs

Table 1 shows that sample sizes vary substantially by program. For this brief report we focus on just two of the programs from which we can make the broadest inferences: The Lake Roosevelt and Yakima Cabin Owners programs. The technical report includes analysis of data associated with each of the six programs.

Lake Roosevelt Incremental Storage Releases Program (LR)

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%. 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. 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 were more likely to have responded to the survey.

Figure 1 provides a graphical illustration of how stated participation in the program among survey respondents would change as program cost changes. The pattern is a classic downward sloping demand curve: as prices increase, the number of respondents who claim would participate declines. 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 1 represent these 20-year total costs.

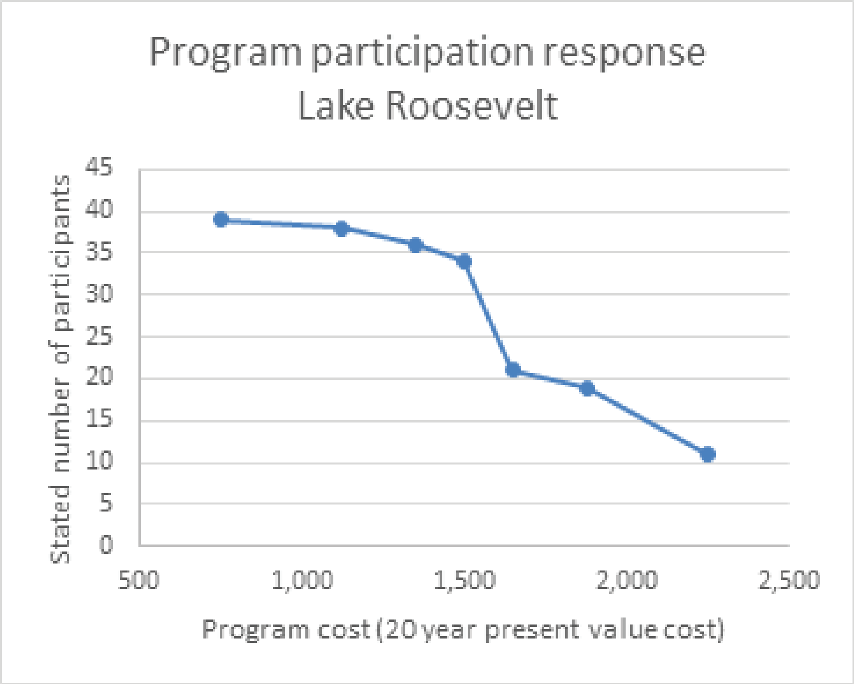


Figure 1: Program participation demand as a function of price.

The average elasticity of demand (the percentage change in participation resulting from a percent 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, 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, its magnitude should be considered as tentative.

Table 3 below show the number of respondents answering yes to 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 3: stated reasons for maintaining application on hold.

Reason	# Responding
Uncertain about the need or value of the use of water applied for	2
Uncertain about the total cost of program participation	3
Waiting for other unrelated family or business issues to be resolved before committing	4
Some other reason	4

Table 4 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 4: Stated reasons for non-participation (decline to participate) in the LR program.

Reasons	# respondents indicating "important" or "somewhat important"
Sold the Property	1
Less or no need for the water due to land use change or other reason	4
The price per unit volume or the for water service contract is too high	1
Cost of water contract, application processing and public notice is too high	1
Cost of required infrastructure investments to use the water is too high	1
Cost of acquiring mitigation right if required by the contract is too high	3
Program or contract terms are unclear	2
Inability to complete project on Ecology's timeframe requirement	1
Other factors	1

Figures 2 and 3 show that infrastructure costs and application processing delays can be substantial for this program. Regression analysis (see technical report) suggests (weakly) 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, permitting.

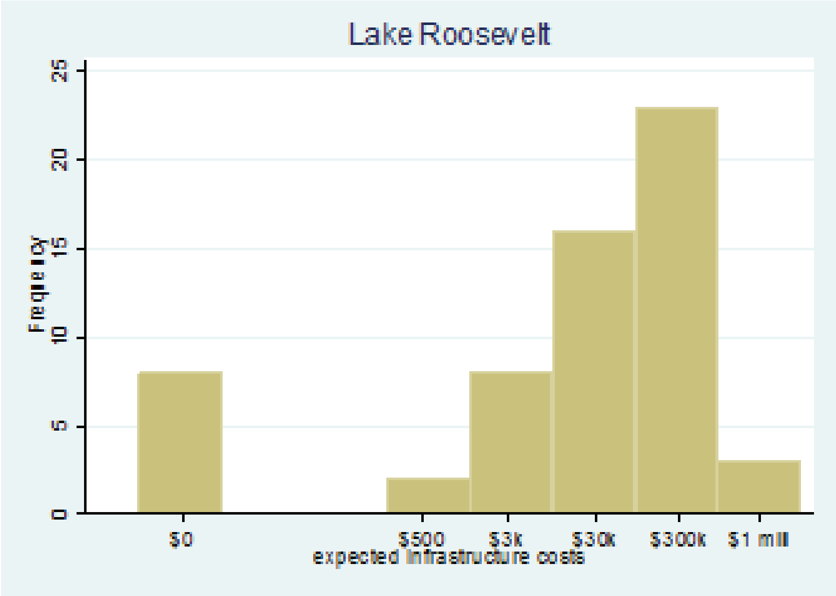


Figure 2: Expected infrastructure costs to use water.

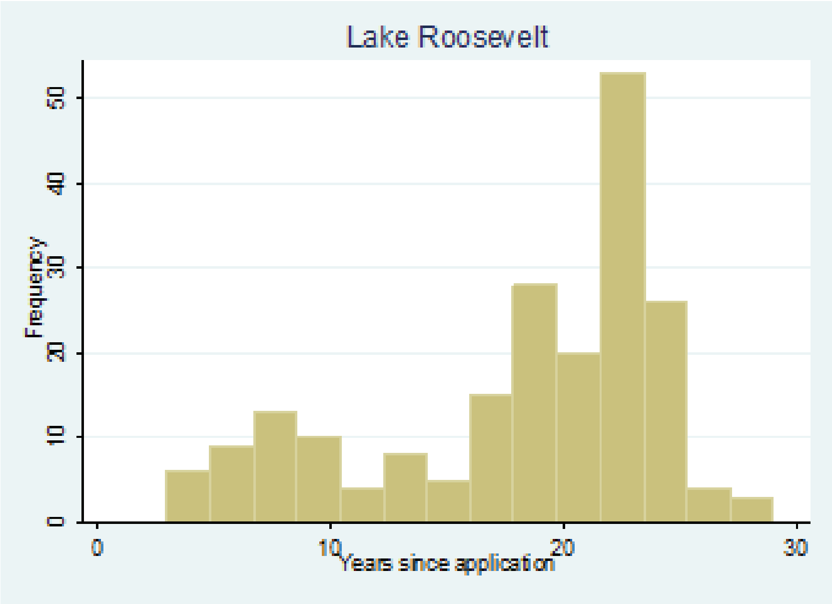


Figure 3: Time since priority date of application.

Yakima Basin Cabin Owners Mitigation Program

Ecology's database had a total of 37 unique applications for which contact information was available and to which surveys were sent. 24 surveys were returned with at least some of the questions answered, for a response rate of 64.8 %. 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 were more likely to have responded to the survey. The survey asked questions of respondents who declined participation about their reasons for declining. However, there are no observations in the dataset for these question for the Yakima Cabin Owners Mitigation Program. Figure 6 provides a graphical illustration of stated program participation demand as a function of estimated program mitigation costs and fees per applicant.

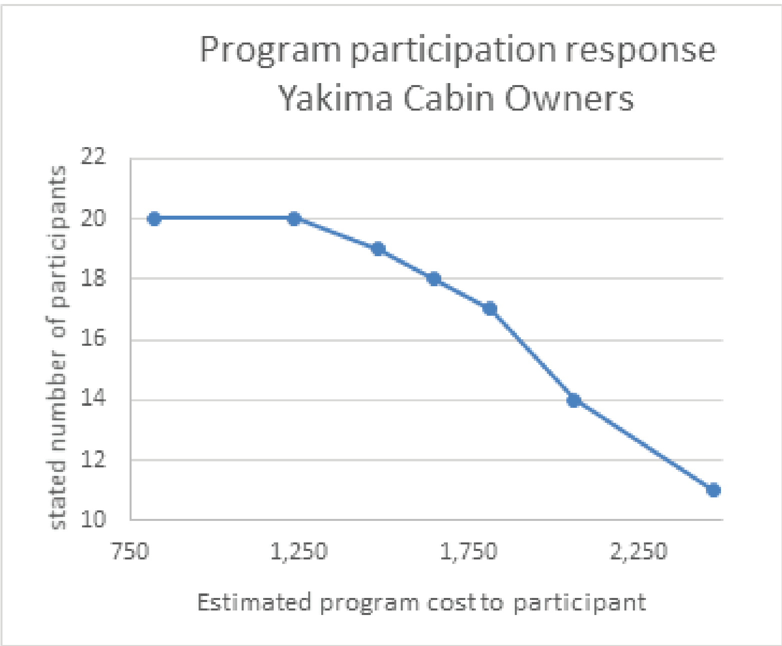


Figure 6: Yakima Cabin owner program participation demand

As for the Lake Roosevelt respondents, we can calculate an elasticity of demand, 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 for why the 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 without program participation, under a Court order from the Acquavella Adjudication, their formerly firm water right would be reclassified as interruptible during times of drought, which may affect their price responsiveness. Expected infrastructure costs for users of the water range from zero to about $30,000, with a mode of $0. This is a smaller cost range than the Lake Roosevelt distribution of infrastructure costs. In any case, 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.

Comparison of Ecology 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. The purpose of this section is to compare the bonding authority mechanisms used in Washington with those evaluated in other states. 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.

Various other states have contracting/bonding finance mechanisms for water rights. The most common finance mechanism 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 obligation bonds have been extensively used to fund various water related projects in California in the last few decades.

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 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 is a program 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 within the New Mexico Finance Authority (NMFA) is 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 the decision 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 the applicant to expedite the processing of water rights application or other regulatory action (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).

Summary and Policy Implications

Although there are many possible reasons why individuals may choose not to participate, we find evidence of three primary categories of reasons for program participation decisions for the six Ecology programs that we examine:

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 of program costs or benefits, with the intent of resolving the decision when uncertainty is better resolved. There is also no cost or penalty to keeping an application on file, so there is no impetus not to simply leave it there even if it no longer represents a viable project.

It is important to note that these results 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. Our results do suggest that these factors affect outcomes, and that it therefore 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 issues, but an understanding that waiting times, cost effects, and program uncertainty have impacts on participation rates and hold-times can be 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 hydrogeological 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 or more 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 more timely processing would result.
- Ecology (by policy choice) currently allows applicants who are offered water or 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, we 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 about 30 percent on average. While response rates this low or lower are common in survey-based social science research, it limits the statistical power of our 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 we report 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 for 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. Our results suggest that an emphasis on duration since application, price concerns, and program uncertainty are topic areas such analysis can focus on to estimate 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.

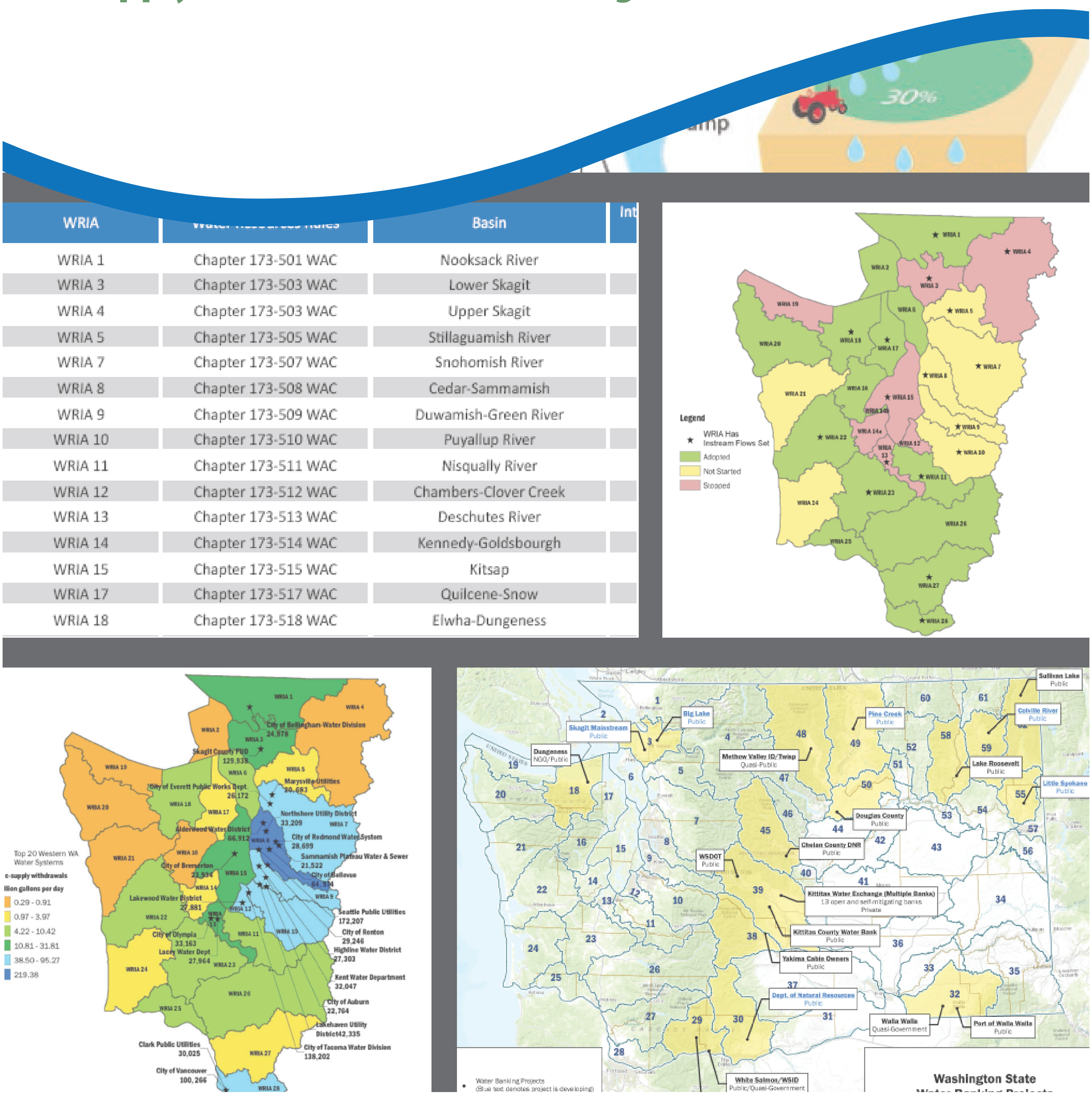
Dillman, Don A., Jolene D. Smyth, and Leah Melani Christian. Internet, phone, mail, and mixed-mode surveys: the tailored design method. John Wiley & Sons, 2014.

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

Western Washington Supply and Demand Forecasting



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	

Overview of Western WA 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.

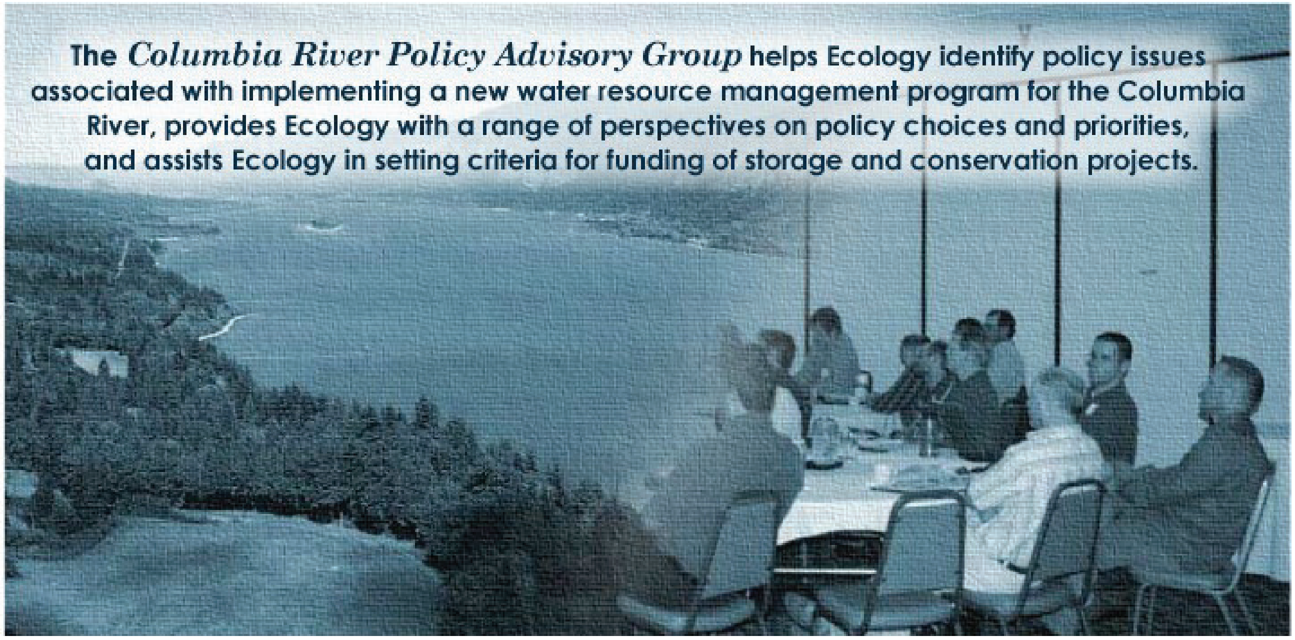


Figure 1. Columbia River Policy Advisory Group

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.

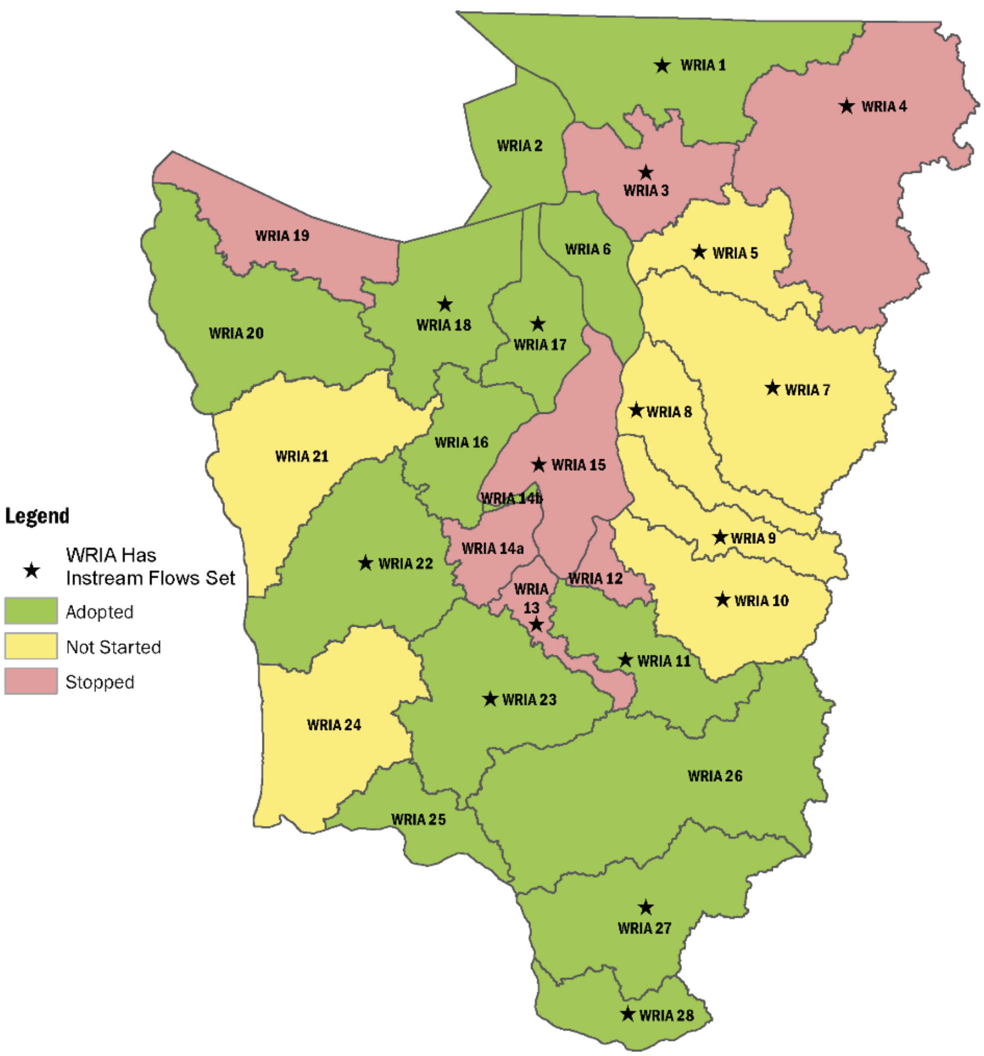


Figure 2. Western Washington WRIAs and Watershed Planning Status

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.

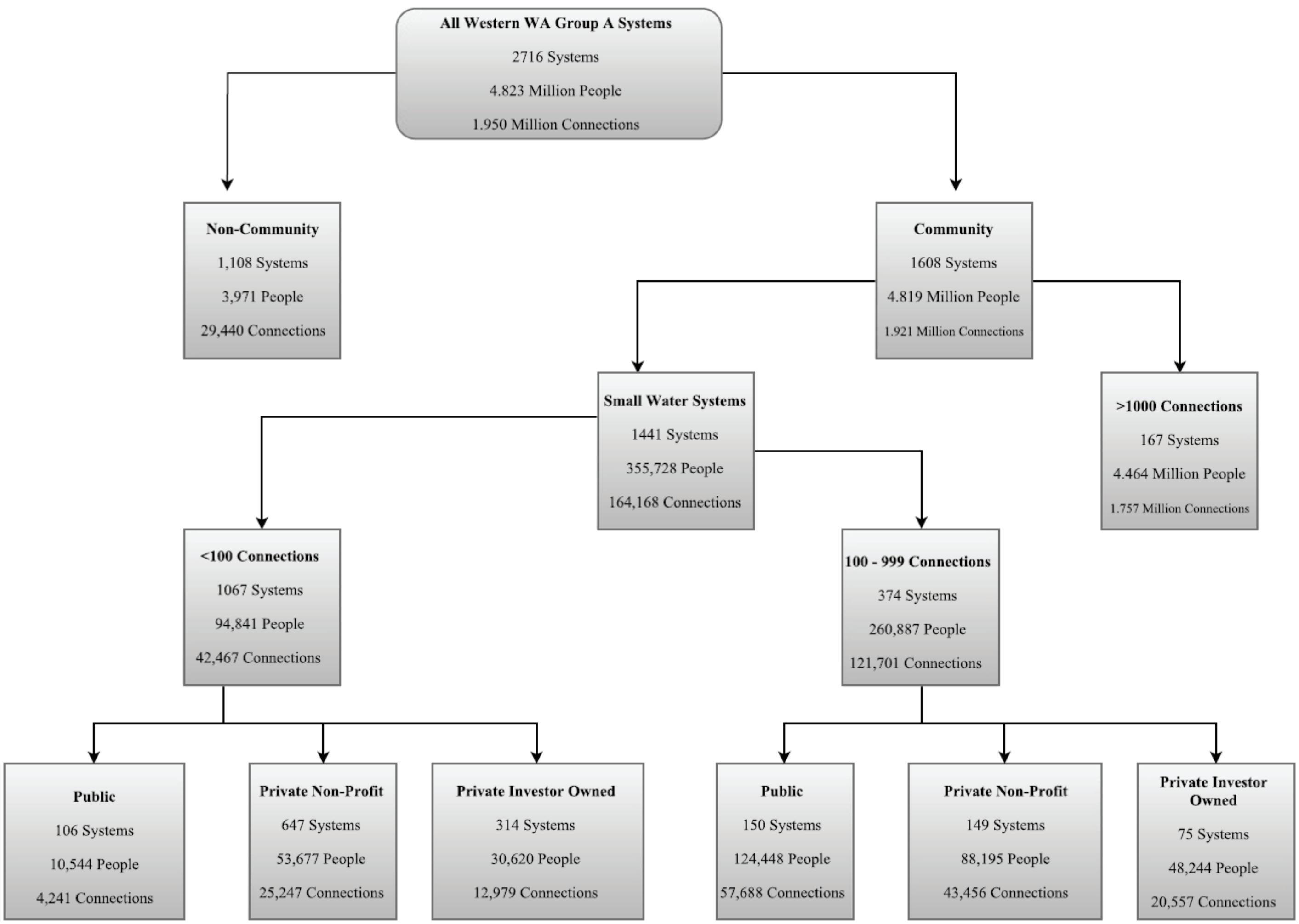


Figure 3. Summary of Water Systems in Western Washington

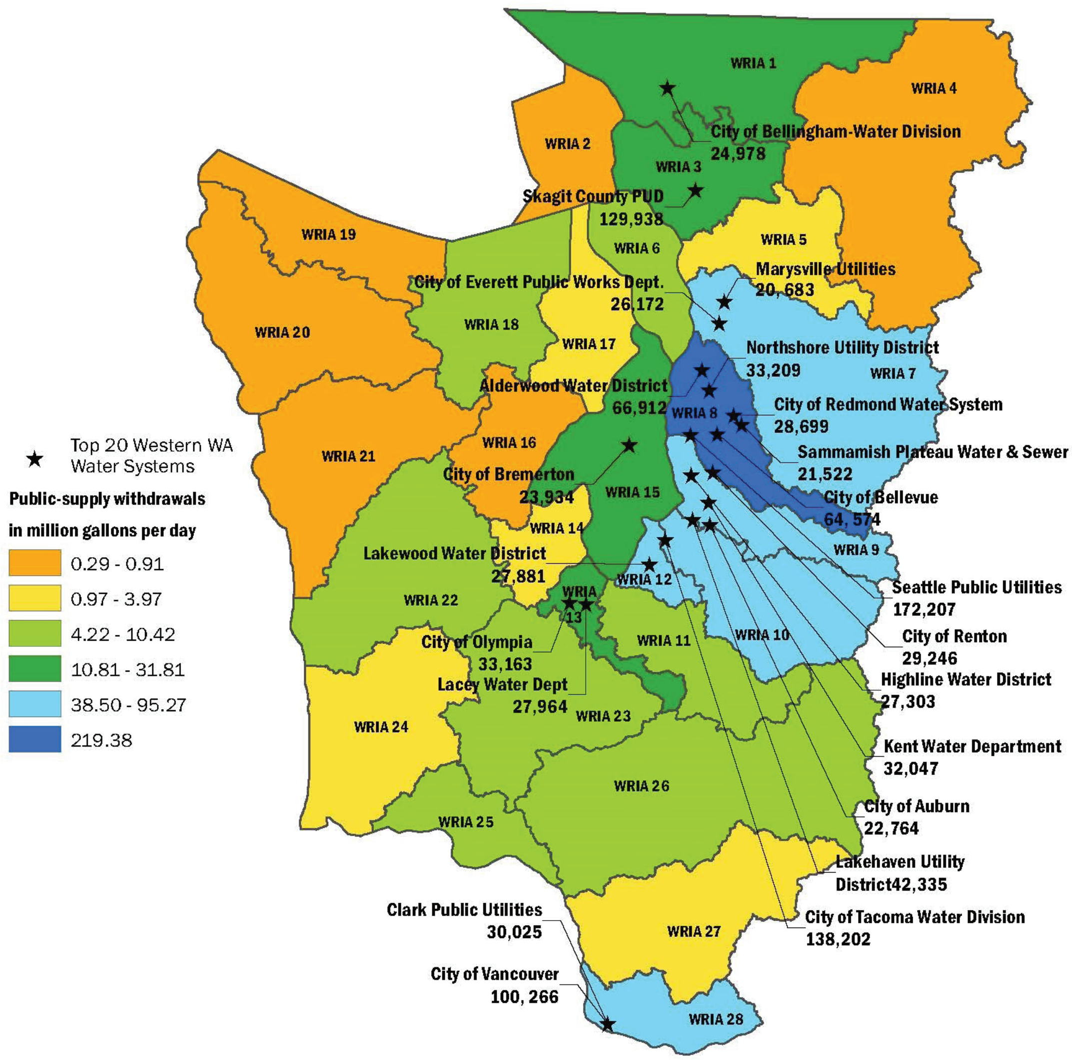


Figure 4. Estimated Public Water System Use and Top 20 Systems in Western Washington

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.

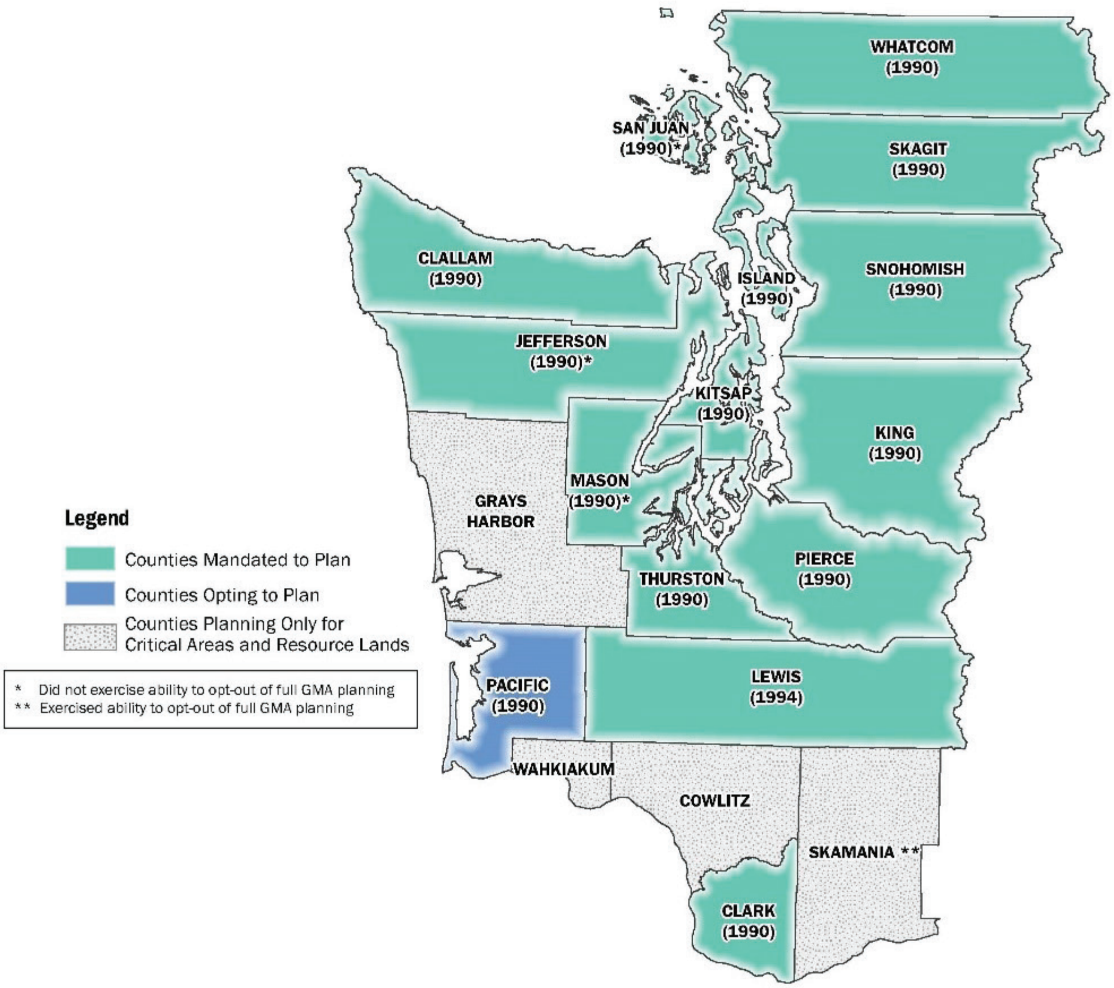


Figure 5. Growth Management Planning in Western Washington

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.

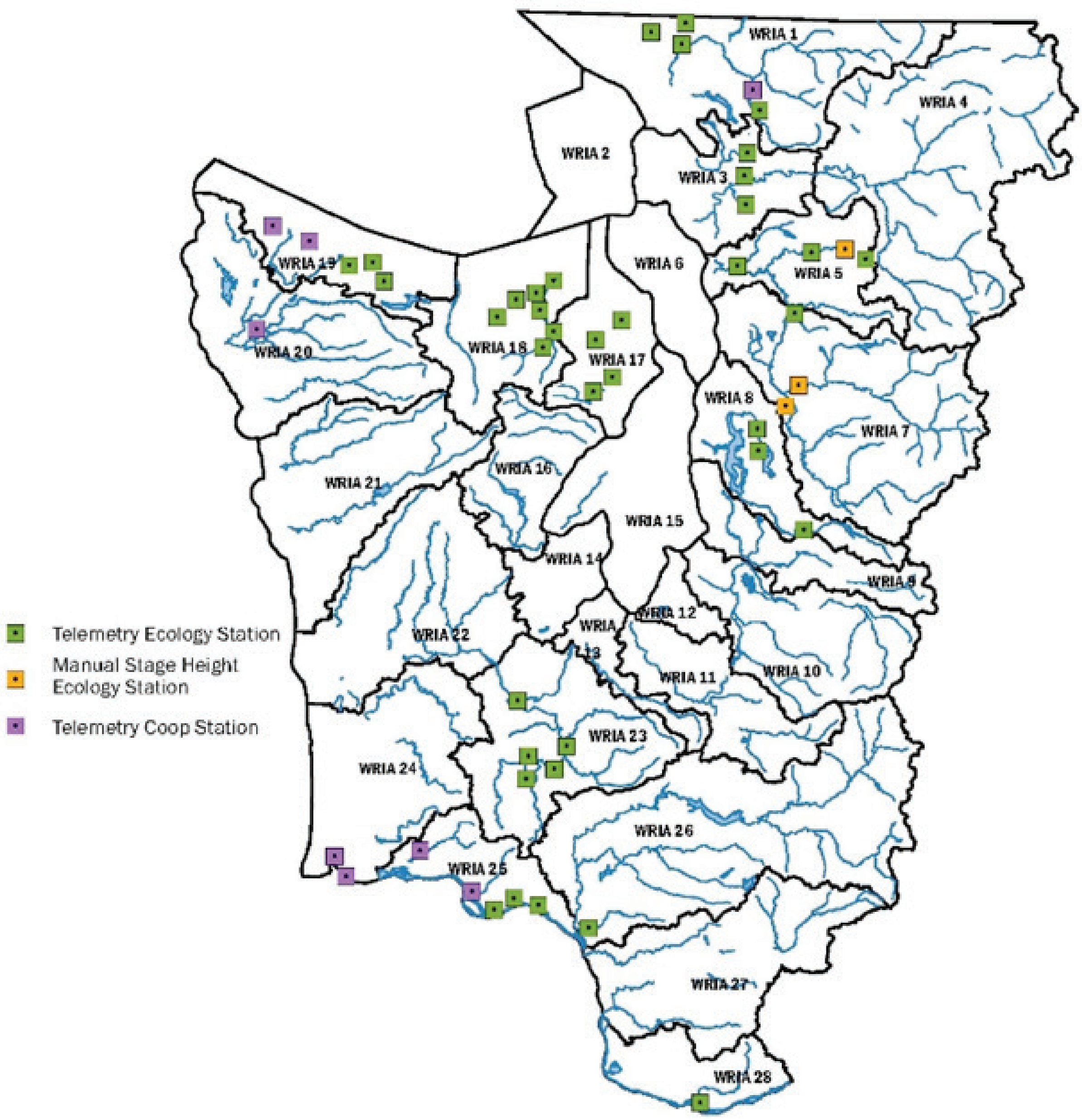


Figure 6. Ecology Stream Gage Network

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.

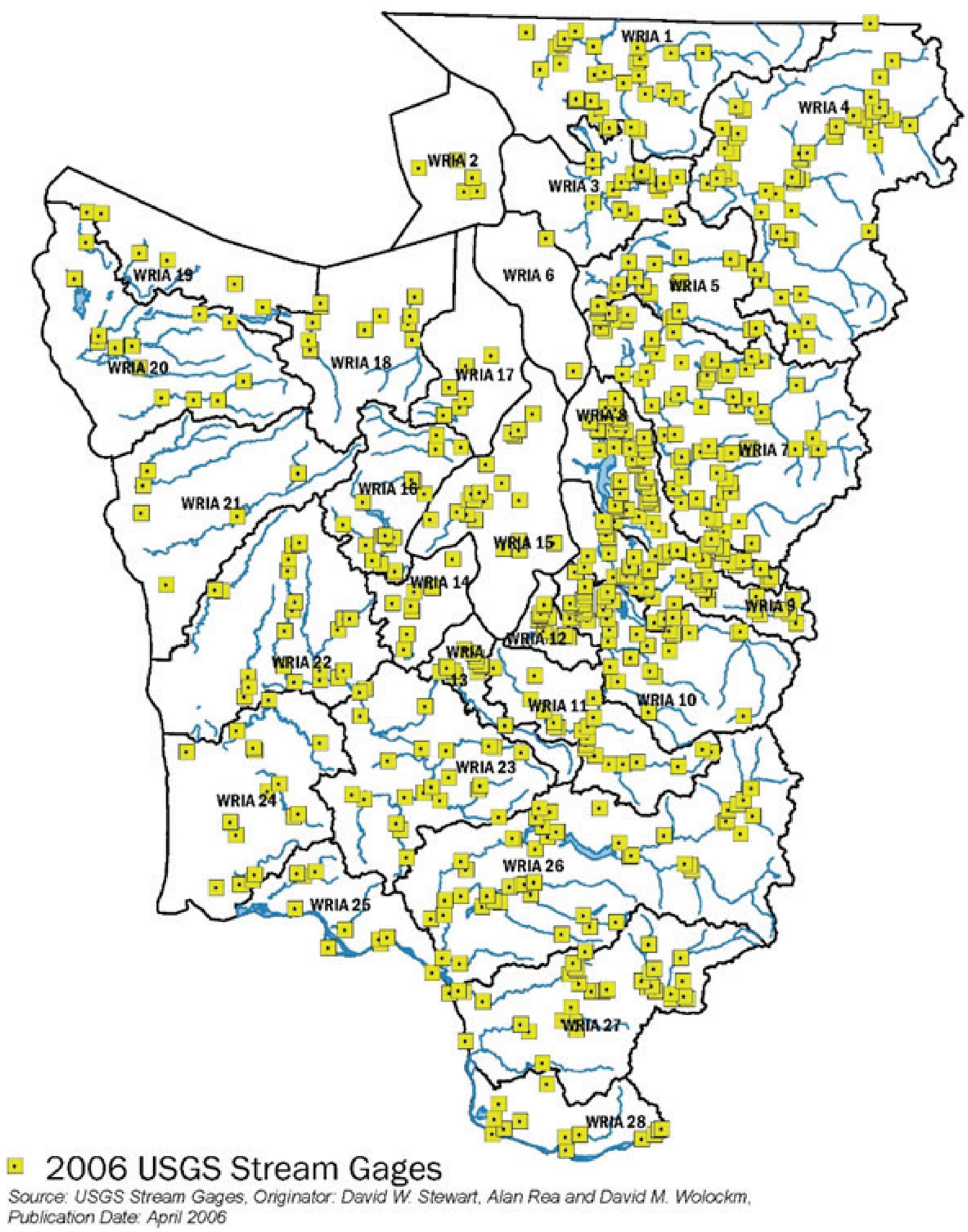


Figure 7. USGS Stream Gauges in Western Washington

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.

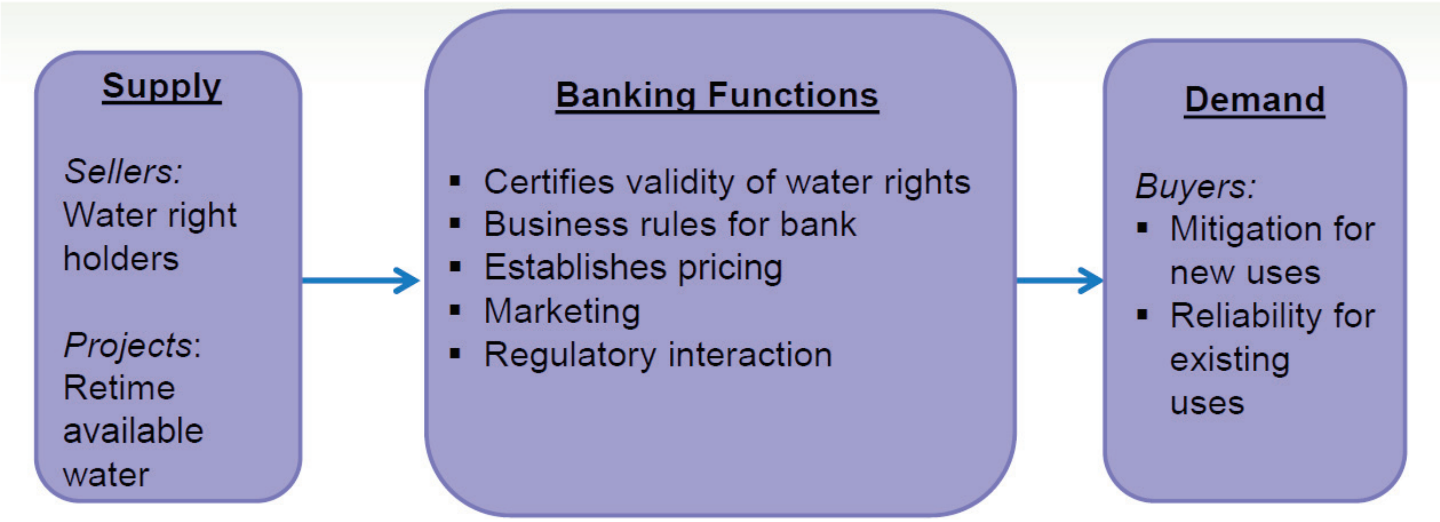


Figure 8. Water Bank Process Diagram

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:

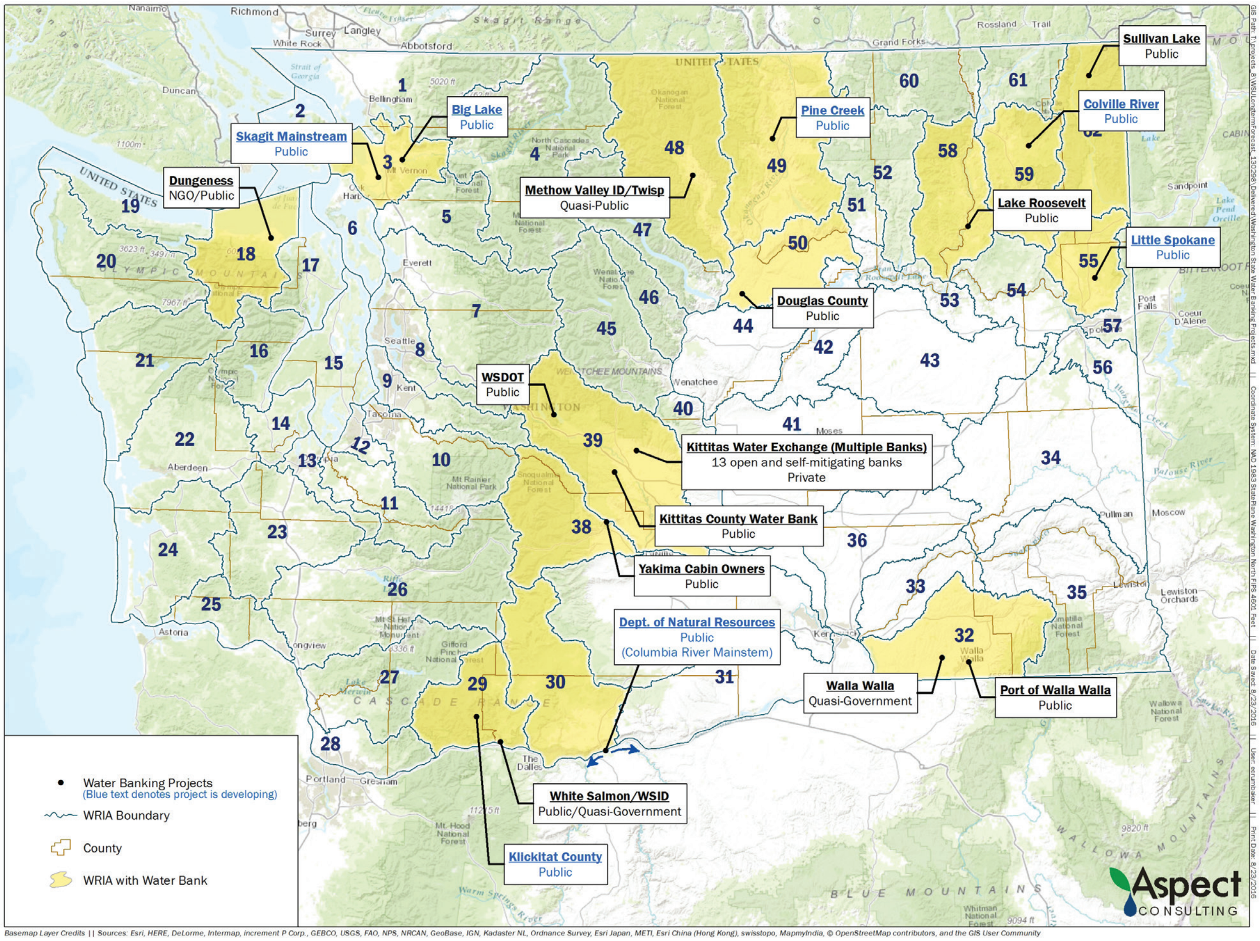


Figure 9. Water Banking in Washington.

- 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 Outdoor 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.
- Irrigation efficiency improvements can include:
  - Canal lining and pipe replacement
  - On-farm efficiency programs (drip, microspray sprinklers)
  - Automation to reduce spills
  - Re-regulation reservoirs

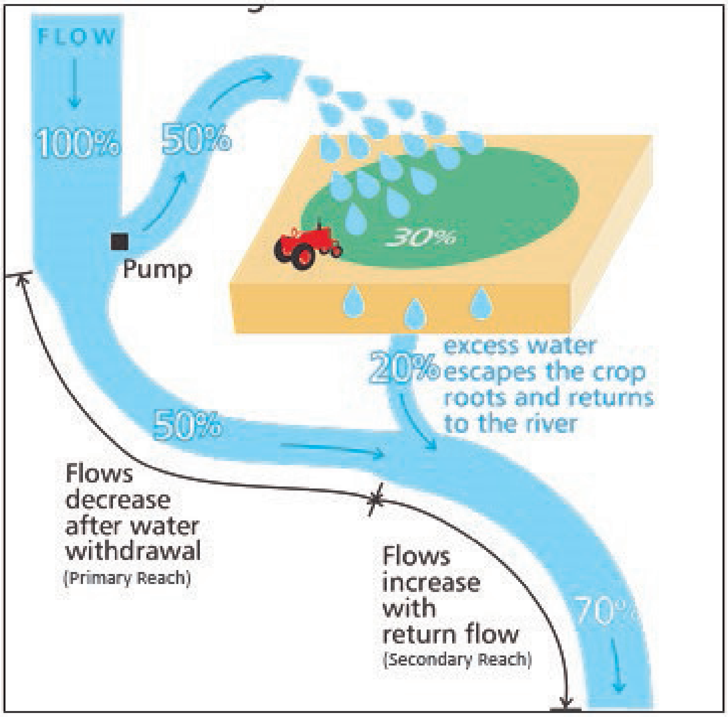


Figure 10: Conservation Benefits for Instream Flows

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.

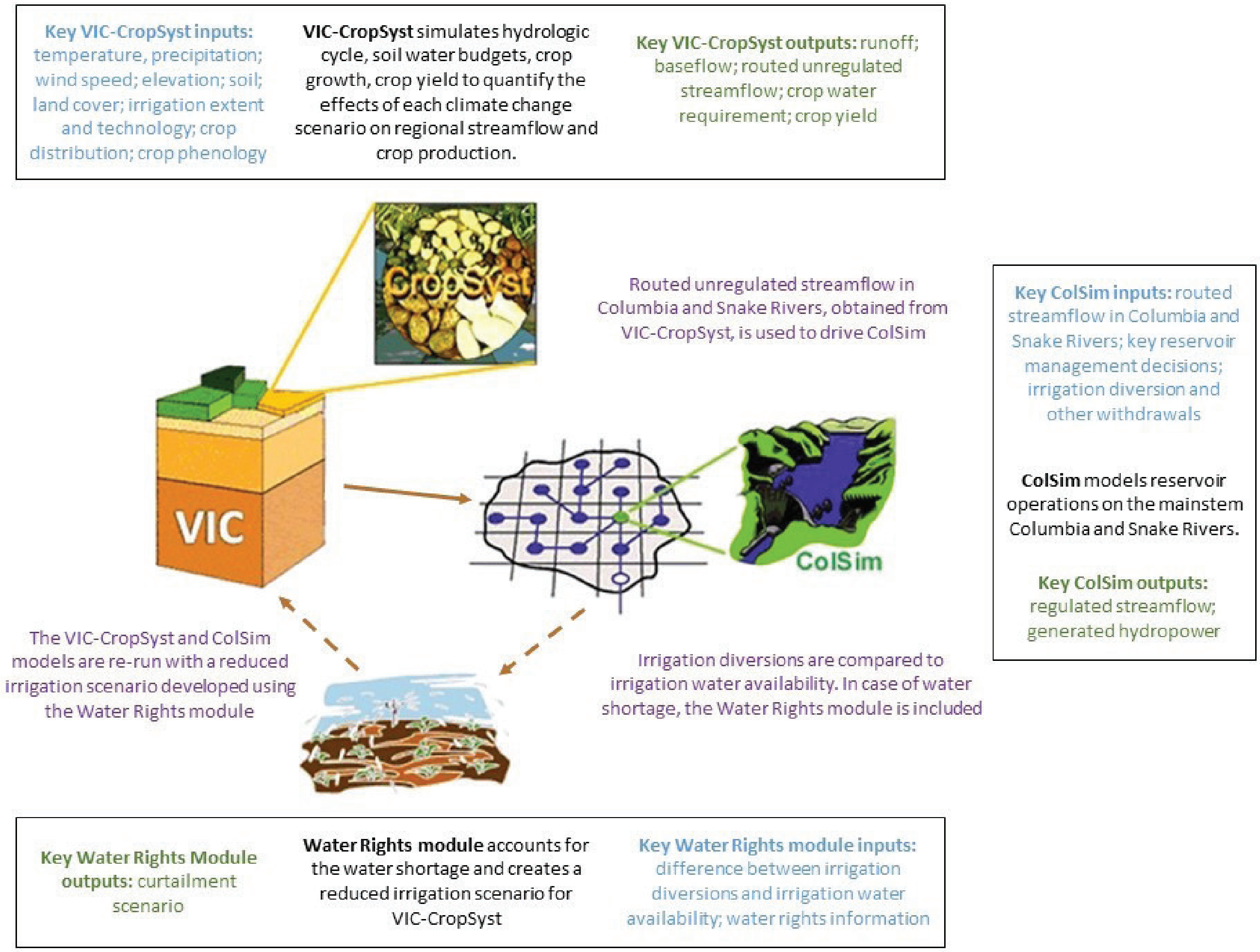


Figure 11: Overview of 2016 Water Supply and Demand Forecast Modeling

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 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 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 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 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 https://www.cga.ct.gov/2013/rpt/2013-r-0159.htm	
Rhode Island	Y	http://www.planning.ri.gov/statewideplanning/land/water.php 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.