A cooperative study of the Walla Walla River Basin groundwater system, Oregon-Washington

A proposal prepared by the U.S. Geological Survey for the Washington Department of Ecology Central and Eastern Offices and the Oregon Water Resources Department

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Summary

Problem

Groundwater levels in the Walla Walla River Basin (WWRB) have been declining since the 1940s (Newcomb, 1965). The largest demand on groundwater is from irrigated agriculture. Surface water is over appropriated, and groundwater declines reduce summer streamflow required for fish populations, including several listed as threatened under the Endangered Species Act (ESA). The WWRB spans the state boundary of Oregon and Washington, adding to the challenge of managing the basin's water resources. A comprehensive transboundary study to characterize and quantify the groundwater-flow system will inform water management plans at a basin-wide scale.

Objectives and Scope

The objective of this study is to develop a three-dimensional quantitative and conceptual understanding of the groundwater-flow system bounded by the areal extent of the WWRB, with emphasis on the interaction of groundwater and surface water and related hydrogeologic controls.

Relevance and Benefits

The proposed study results will provide local communities, conservation groups, and natural resource and regulatory agencies with the information necessary to characterize current conditions and assess impacts of human activities in the WWRB. The study is consistent with the goals of the USGS Water Availability and Use Science Program (WAUSP) that assists in the determination of water that is available for human and ecological uses now and in the future, and includes evaluating the quantity and quality of water, identifying long-term trends in water availability, and developing an improved ability to forecast water availability for economic and environmental uses. The study will generate published reports, datasets, and models that will be publicly accessible online.

Approach

The approach consists of assembling existing data and collecting new data, including borehole geologic logs, groundwater levels, streamflow, springflow, and geochemistry. On the basis of these data, a hydrogeologic framework will be developed, which will consist of a surficial hydrogeologic map, a three-dimensional digital hydrogeologic model of the subsurface, potentiometric maps of the hydrogeologic units therein, and estimates of the units' hydraulic properties. A groundwater budget will be estimated, which will include evapotranspiration, groundwater recharge, exchanges of groundwater and surface water, groundwater use, and interbasin groundwater flow. A flow-system evaluation will bring the results of all project components together to describe the groundwater system conceptually and quantitatively.

Introduction and background

The 1,777 mi^2 Walla Walla River Basin (WWRB) spans the state boundary of Washington and Oregon and drains into the Columbia River on the east side of the Cascade Mountains (fig. 1). Groundwater levels in the Walla Walla River Basin (WWRB) have been declining since the 1940s (Newcomb, 1965; Vaccaro and other, 2015). These declines of as much as 150 feet suggest that groundwater use exceeds natural recharge (Oregon Water Resources Department, 2018). Irrigated agriculture accounts for the largest groundwater use but groundwater also supplies industrial, municipal, domestic, and livestock needs. Groundwater is well connected to streams in the WWRB (Newcomb, 1965; MacNish and others, 1973), and groundwater declines result in streamflow decreases during the dry summers.

Meeting the needs of rural and urban growth in the basin while maintaining sufficient instream flows for fish is a challenge (Washington Department of Ecology, 2020). Affected fish include several listed as threatened under the Endangered Species Act (ESA). Litigation settlements under the ESA have resulted in irrigators in Oregon and Washington limiting their water use (McPherson, 2020). Further complicating the issue, water resources in the basin have been "over-appropriated" in Washington for decades, meaning that if all water-rights holders used their full allotments, streams would run dry (Walla Walla Watershed Management Partnership, 2018).

Water resources in the WWRB are available from deep basalt aquifers (Columbia River Basalt Group), the overlying basin-fill aquifer, streams, and springs. Although these hydraulically connected components of the WWRB have been investigated across multiple scales, a basin-wide understanding of the integrated system is limited. For example, basalt units in some parts of the WWRB exhibit limited connectivity with adjacent basalt units due to complex folding and faulting related to uplift of the Blue Mountains and the Yakima Fold and Thrust Belt (Golder Associates, 2007). Ely and others (2014) and Vaccaro and others (2015) described groundwater flow in these complex basalt aquifers and the basin-fill aquifer for 33,000 mi^2 of the Columbia River Basin, which is 18 times the size of the WWRB. While these studies help to understand groundwater resources in the context of the larger Columbia River Basin, they don't include the detail desired for management at the WWRB scale.

The Oregon Water Resources Department (OWRD) has taken steps to mitigate groundwater declines by (1) closing the Oregon part of the basin to additional groundwater development, (2) requiring meters on all permitted wells accessing the basalt aquifer system to better quantify withdrawals, and (3) initiating a public forum to discuss voluntary and regulatory options to reduce water use (Oregon Water Resources Department, 2019). Washington State Department of Ecology (Ecology) recently established a new strategic planning effort known as *Walla Walla Water 2050* that enlists water users, conservationists, and private citizens along with representatives from tribal, federal, state, and local governments and agencies to help plan the watershed’s future (Washington State Department of Ecology, 2020). One such group is the Confederated Tribes of the Umatilla Indian Reservation (CTUIR), which maintains treaty rights to fish within the WWRB.

Walla Walla Water 2050 extends and builds on ten years of work done by the Walla Walla Water Management Partnership that focused on water rights, flow issues, and a bi-state flow study which supports restoration of ecological functions to support spring Chinook and ESA-listed steelhead and bull trout.

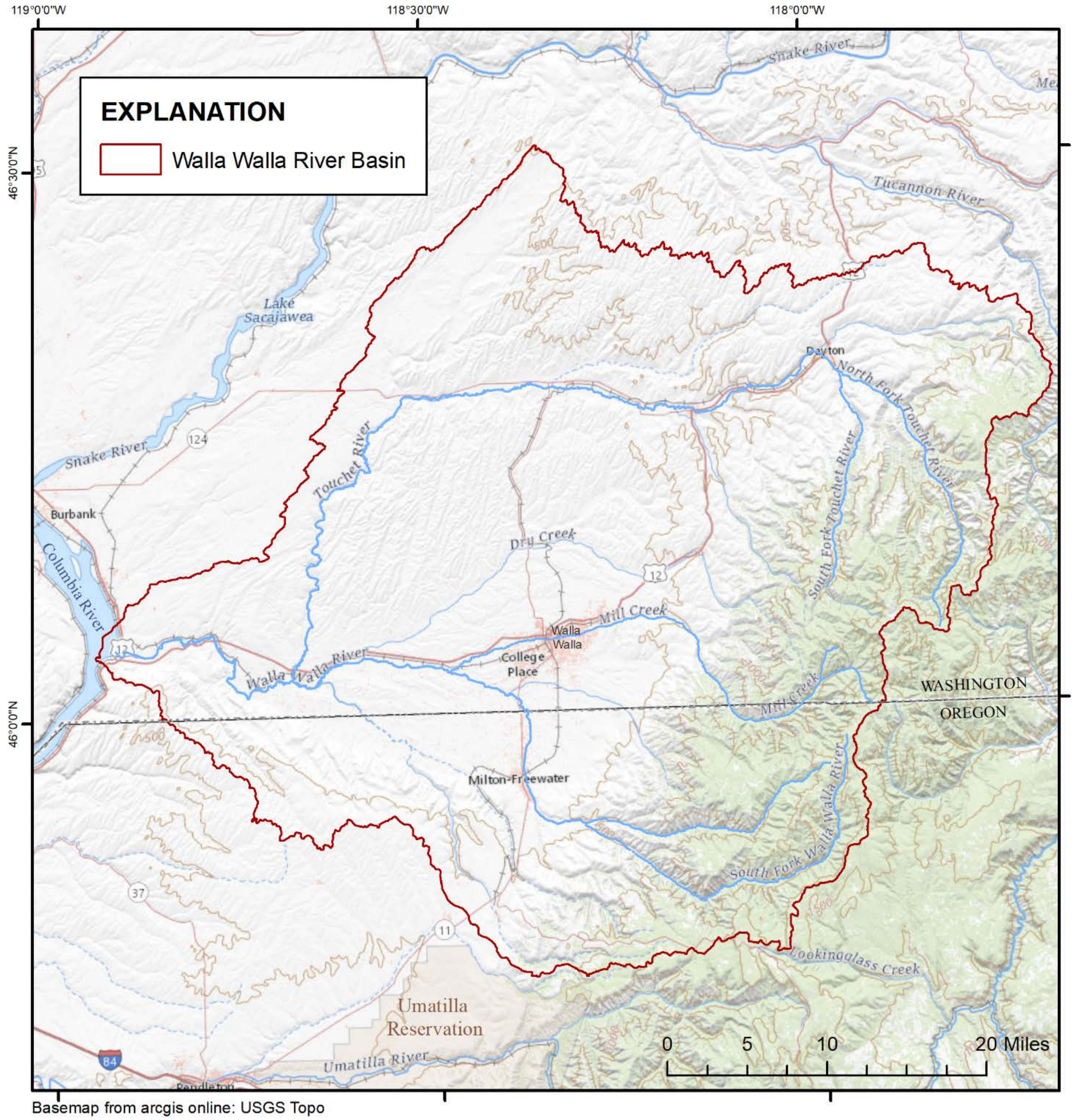

Figure 1. Study area, showing the Walla Walla River Basin.

Problem

Decades of declining groundwater levels in the WWRB described by Newcomb (1965) and Vaccaro and others (2015) are affecting instream flows and water availability for competing interests. OWRD and Ecology recognize the significance of the problem and have begun management and planning efforts to stabilize groundwater levels across the WWRB and restore instream flows. In concert with these efforts, OWRD and Ecology recognize the need for a comprehensive transboundary study to characterize the groundwater-flow system in the WWRB to inform planning and water management decisions at a basin-wide scale.

Objectives, scope, and tasks

The objective of this study is to develop a quantitative and conceptual understanding of the WWRB groundwater-flow system. The scope will consist of the estimation of the rates and distribution of groundwater recharge and discharge throughout the basin, quantification of the interaction of groundwater and surface water, identification of major hydrogeologic units, characterization of the geologic controls on groundwater flow, and estimation of potentiometric surfaces and groundwater-flow paths. This work plan comprises Phase I of the groundwater study. A future phase of the study, Phase II, will focus on developing a simulation tool, such as a numerical groundwater-flow model, to assess the conceptualization of the flow system and simulate effects of potential future water-use scenarios on groundwater and surface-water resources in the basin. Tasks for Phase I consist of the following:

1. Conduct a literature review, compile existing data, and define data gaps
2. Collect new data where necessary to fill priority data gaps.
3. Develop and describe the hydrogeologic framework. This will consist of defining important hydrogeologic units, developing a three-dimensional surface and subsurface digital model of the units, a summary of the hydraulic properties of each unit, and potentiometric maps of selected units.
4. Estimate the groundwater budget composed of inflows, outflows, and storage changes in the WWRB.
5. Describe the integrated groundwater-flow system, including groundwater flow and trends, geochemistry and groundwater age, and groundwater/surface-water interactions.
6. Select an appropriate tool to simulate the flow-system scenarios and develop a workplan to build this tool for Phase II of this study.
7. Document study findings in peer reviewed reports and provide data in publicly available databases and clearinghouses.

This study is a collaboration primarily between the U.S. Geological Survey (USGS), Ecology, and OWRD, with input from the Confederated Tribes of the Umatilla Indian Reservation (CTUIR), which maintains treaty rights to fish within the WWRB. Project tasks are described in detail in the body of this document, with a summary in the Timeline section. This work plan describes how tasks will be carried out among the USGS Oregon Water Science

Center (USGS-OR), the USGS Washington Water Science Center (USGS-WA), Ecology, and OWRD.

Relevance and benefits of the study

The proposed study results will provide local communities, conservation groups, tribes, and natural resource and regulatory agencies with the information necessary to characterize current conditions and assess impacts of human activities in the WWRB. The study is consistent with the goals of the USGS Water Availability and Use Science Program (WAUSP) that assists in the determination of water that is available for human and ecological uses now and in the future, and includes evaluating the quantity and quality of water, identifying long-term trends in water availability, and developing an improved ability to forecast water availability for economic and environmental uses. The study will generate published reports, datasets, and models that will be publicly accessible online.

Literature review and data compilation

General material

Existing information related to wells, springs, stream and canal flow, surface-water management, climate, soils, water-use, and other geohydrologic data will be gathered with special attention given to assessing the accuracy and reliability of the information. Available information will be obtained from published reports, government agencies, public utilities, and other sources. Published reports contain information on wells used to assess geology, water levels, hydraulic properties, water use, and streamflow characteristics and include maps of geology, soils, land use, water tables, and other geohydrologic features. The OWRD and Ecology maintain well information that can be used to help describe geology, water levels, hydraulic properties, and water use. All hydrogeologic data will be stored in digital format. Map data will be acquired and stored in GIS format whenever possible.

Compile and assess existing data

Previously published hydrologic data for the WWRB will be compiled and used as a baseline for understanding the groundwater system and identifying gaps in understanding. On this basis, an analysis of data gaps will guide plans for new data collection including data types and locations. Existing data will be compiled primarily in FY2021 with less intense efforts likely continuing throughout the study duration. Any additional data collection will seek to improve spatial and temporal coverage of water levels, streamflow, and geochemical data. Additional data will be collected as funding permits.

The CTUIR and Walla Walla Basin Watershed Council (WWBWC), among other stakeholders, have collected hydrologic data for several years and have shared a wealth of information through reports and personal contacts. Local hydrologic datasets will be considered in the data compilation component of the study and those selected for inclusion will be quality checked and assured using standard protocols developed by the USGS and OWRD. Data selection criteria will be based, in part, on documented data collection procedures and data publication.

General hydrologic data

Major categories of data to be compiled include the following:

- groundwater levels, including continuous and discrete measurements, from USGS, OWRD, Ecology, and other stakeholders
- geologic borehole logs, drillers' reports, oil and gas borehole logs, and geothermal logs
- streamgage data, including continuous and discrete measurements of flow and stage, from USGS, OWRD, Ecology, and other stakeholders
- spring locations and measured flows
- geochemical data from USGS, OWRD, Ecology, peer-reviewed technical literature, consultant reports, and academic theses and dissertations
- hydraulic properties of hydrogeologic units consisting of transmissivity, hydraulic conductivity, specific yield, and specific storage. Data will be obtained from results of previous studies, aquifer testing, and specific capacity data
- climatological datasets from publicly available sources, including raster data from PRISM, GridMET, or Daymet; and point measurements from Global Historical Climatology Network, AgriMet, SNOTEL, and Snow Course Data if available

Geologic and hydrogeologic frameworks

Three-dimensional geologic and hydrogeologic framework models and groundwater-flow models of the WWRB will be compiled. Several geologic and hydrogeologic framework models have been developed over the last 40 years such as Drost and others (1986), Whiteman and others (1994), Burns and others (2010), and Kahle and others (2009, 2011).

Water budgets and associated datasets

Previous estimates of the groundwater and surface-water budgets for the WWRB will be compiled from published sources and used to guide a refined and updated estimate of the groundwater budget. These include simulated water budgets from groundwater models (Petrides Jimenez, 2012; Ely and others, 2015; Scherberg and others, 2018) as well as earlier estimates (Newcomb, 1965; Barker and MacNish, 1976; MacNish and Barker, 1976; Bauer and Vaccaro, 1990).

Water use and management data, including surface-water routing and surface-water and groundwater irrigation data, will be compiled to provide a basis for estimating water-use components of the water budget. Existing information on the current and historical routing of surface water and extent of irrigated land will be compiled from available sources such as OWRD, Ecology, Washington Department of Agriculture, and the Walla Walla Irrigation District. Available managed aquifer recharge data for both sediment and basalt aquifers will be compiled.

New data collection

Groundwater-level measurements

Groundwater-level measurements will be used for mapping potentiometric surfaces, understanding seasonal and long-term effects of pumping, and assessing recent changes in groundwater level. When possible, previously monitored wells will be selected for new measurements to facilitate long-term trend analysis.

Existing network

Groundwater-level measurements by OWRD and USGS-WA have been ongoing in the WWRB. OWRD's annual winter-synoptic well network consists of 185 wells in Oregon, 125 of which are completed in basalt and 60 of which are completed in basin fill. OWRD's quarterly measurement network consists of about 12 wells completed in basin fill or basalt; basalt wells are equipped with continuous recorders. USGS-WA has been measuring a winter-synoptic well network of 25 basalt wells since 2018 and visited an additional 53 basin-fill wells with the WWBWC during January 2020.

Future plans

OWRD and USGS-WA are actively working to increase the number of wells in their synoptic and quarterly networks in the basin. OWRD plans to expand the annual synoptic network in Oregon to include approximately 10 additional basalt wells in upland areas near the southern basin boundary (fig. 1) and 10 additional basin-fill wells in lowland areas. USGS-WA plans to expand the Washington synoptic network to include 20-30 of the 53 basin-fill wells visited in 2020 and an additional 80-120 basin-fill and basalt wells in the Washington part of the WWRB to ensure sufficient areal and depth coverage in basin-fill and basalt units. Particular emphasis will focus on including wells in the Touchet subbasin. The well inventory and network expansion by the USGS-WA is supported by a Fiscal Year (FY) 2020 agreement that was delayed because of the COVID-19 pandemic and will commence in 2021. The total synoptic well network in Washington will then be 125-175 wells. The synoptic networks for Oregon and Washington will be measured during winter of FY22 and FY23 as part of Phase 1 data collection.

Quarterly well networks will be expanded to include 50 wells in Washington and as many as 40 wells in Oregon as part of this Phase I workplan. Quarterly networks will represent a subset of synoptic well networks and will be focused on measuring static water-level conditions. Quarterly networks will be measured about every 3 months starting in April 2022 and ending in July 2024. These quarterly network measurements will follow directly after the quarterly measurements planned for 2021 as part of the FY 2020 agreement previously mentioned. Also, the winter synoptic well network that began in 2018 will be repeated in February 2021 and 2022.

Wells with continuous water-level recorders are important to track groundwater-system responses to variable pumping and recharge patterns. Currently, 19 WWRB wells are equipped with continuous transducers—7 wells in Oregon operated by OWRD and 12 wells in Washington operated by Ecology. Oregon recorder wells are completed in basalt units, whereas the Washington wells are completed in basin-fill. As many as five additional transducers will be deployed by OWRD in synoptic wells in Oregon during this study. In Washington, USGS will install water-level recorders in eight wells, contingent upon finding suitable wells that are not pumped and obtaining access permission.

Conduct seepage runs

Streams and irrigation canals in the WWRB gain and lose water through exchange with the groundwater system. Quantifying the volume and location of the gain or loss is important for a groundwater budget. A seepage run consists of streamflow measurements at multiple locations along a stream and its tributaries. The purpose is to quantify stream gains and losses for the reaches between measurement points. A seepage run was conducted for the Walla Walla River, the Touchet River, and Mill Creek during August 2020 (fig. 2), which consisted of 64 measurement stations in Washington and 22 stations in Oregon. Agricultural diversions and outflows from water treatment plants were measured. Return flows from agricultural diversions were assumed minimal during this time. USGS and Ecology made the Washington measurements, and ORWD made the Oregon measurements. The August 2020 seepage run will be repeated four times: twice annually during periods of low irrigation.

Monitor streamflow

Continuous streamflow data are valuable for analyzing groundwater flow patterns and discharge, because baseflow and seepage can be estimated from these records to assess groundwater gains and losses. Thirteen real-time streamgages currently are operating within the WWRB by USGS (5 stations), Ecology (4 stations) and OWRD (4 stations) (fig. 2). The Walla Walla River, Touchet River, and Mill Creek each host three stations, and the North Fork and South Fork Walla Walla River each host one station. Two additional stations, operated by USGS under a separate agreement, are to be installed during this study: Mill Creek at Last Chance Road and Walla Walla River at 15th Street Bridge, Milton-Freewater. The CTUIR and WWBWC operate several additional streamgages in the WWRB.

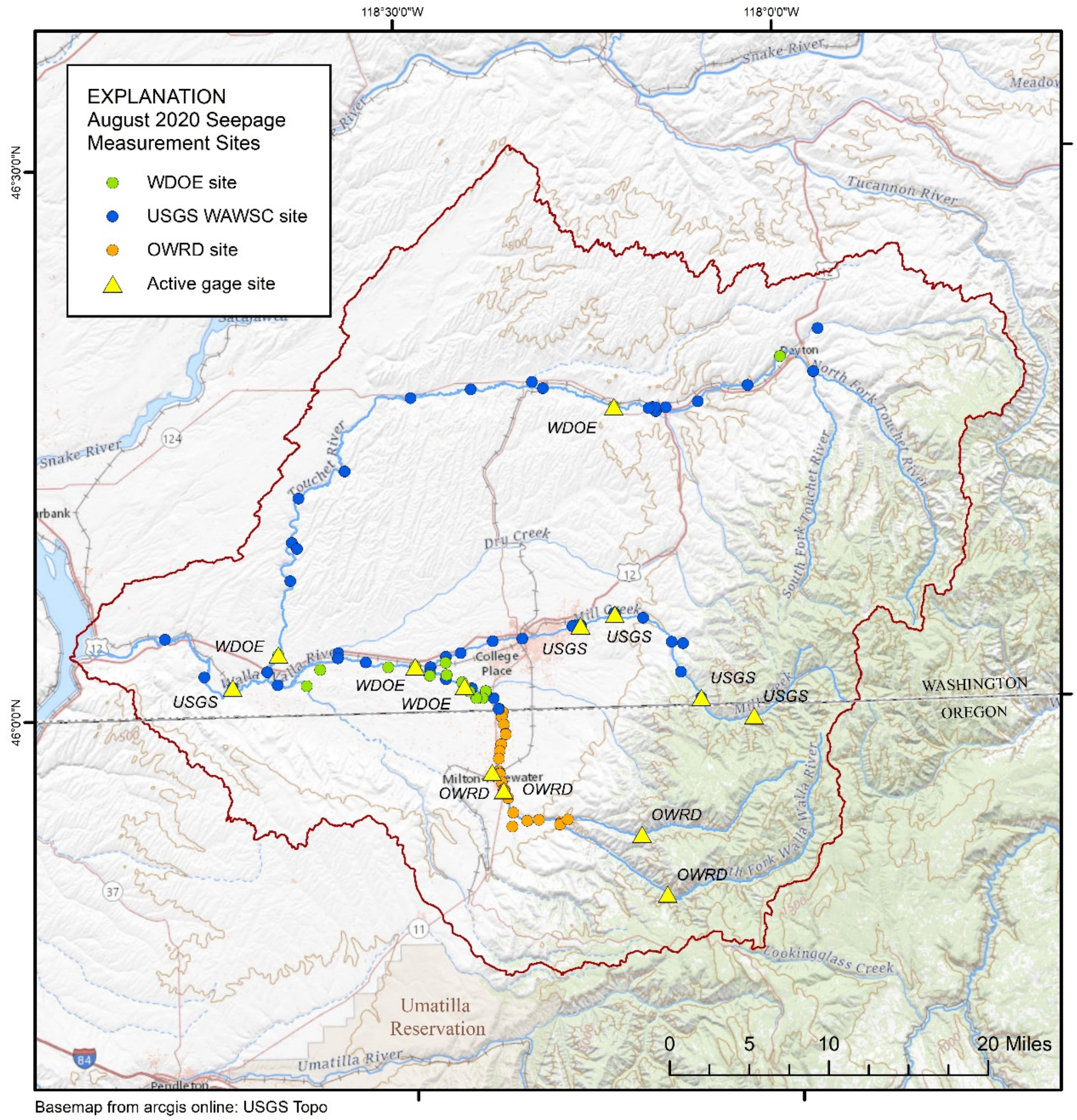

Figure 2. August 2020 seepage run measurement locations.

Petrides Jimenez (2012) noted that the largest sources of uncertainty in simulated basin-fill water budgets were ungaged streams discharging onto basin-fill sediments and canal diversions. Miscellaneous, historical measurements are available for some currently ungaged sites and diversions along the Little Walla Walla and Mud creek are actively being measured by the WWBWC. Additionally, annual seepage runs will provide a discharge measurement for a single point in time. To improve the temporal coverage at ungaged streams and irrigation canals, several options are being considered to estimate (1) annual discharge and (2) gains and losses, including:

- quarterly discrete streamflow measurements at approximately 30 ungaged sites; this network could include many additional sites to observe and document the presence or absence of flow,
- installation of additional continuous streamgages that monitor stage but not flow, which are less costly than full streamgages,
- installation of cameras to document the presence or absence of flow, and
- deployment of pressure transducers or temperature sensors to document the presence or absence of flow.

One or more of these, or similar, options will be employed; selection criteria will be guided by previous publications, field reconnaissance, consultation with project partners, and available funding and staff to install and maintain gaging stations and process data.

Conduct hydraulic tests in wells

Opportunities for aquifer tests will be pursued by OWRD to improve estimates of hydraulic properties in basalt and basin-fill units. These may include slug tests, single-well aquifer tests, and (or) multiple-well aquifer tests. The necessity will be determined after reviewing available aquifer-test and drillers' test data and existing and derived estimates of hydraulic properties for major hydrogeologic units. OWRD plans to conduct approximately 2 multiple-well aquifer tests during the first two years of the study. During Phase I, additional hydraulic testing opportunities will be evaluated by USGS and OWRD. For example, production wells used for public water supply or irrigation that are within adequate proximity to potential monitoring wells, such as non-pumping irrigation wells, will be identified. Opportunities for this type of multiple-well test and other similar opportunities will be pursued during Phase II and included in the Phase II workplan.

Collect new geochemical data

Geochemical tracers will be used to quantify the residence time of groundwater, elucidate flow paths, and help identify recharge areas. Tracers to be used include stable isotopes of water (^{2}H and ^{18}O), tritium (^{3}H), sulfur hexafluoride (SF_6), carbon-14 (^{14}C), and dissolved gases. A summary of the budgeted number of samples of each type is provided in table 1, but the actual number of each type of sample will depend on access, sampling conditions, and project needs. Adjustments to sample types and sample number will be made within the constraints of a fixed sampling budget. Water samples from 50-60 synoptic wells in Washington, completed at a range of depths, will be sampled for analysis of stable isotopes of water (^{2}H and ^{18}O) and tritium (^{3}H), as part of the 2020 funded work that was delayed because of the COVID-19 pandemic.

Table 1. Budgeted number of geochemical tracer samples.

Analysis	Number of samples	Analytical lab
Stable isotopes of water	300	USGS Stable Isotope Lab, Reston, VA
Tritium	100	USGS Tritium Lab, Menlo Park, CA *or* University of Miami Tritium Lab, Miami, FL
Sulfur hexafluoride	50	USGS Groundwater Dating Lab, Reston, VA
Carbon-14	50	National Ocean Sciences Accelerator Mass Spectrometry Facility at Woods Hole Oceanographic Institution, Woods Hole, MA
Dissolved gases	50	USGS Groundwater Dating Lab, Reston, VA *or* USGS Noble Gas Lab, Denver, CO

Continuous measurements of specific conductance will be used to estimate baseflow in Mill Creek, NF Walla Walla River, and SF Walla Walla River using an end-member mixing chemical hydrograph separation method. Conductivity sondes will be deployed at or near gaging stations on the three rivers. The sonde on Mill Creek will be deployed and maintained by USGS staff, and the sondes on NF Walla Walla River and SF Walla Walla River will be deployed and maintained by staff from OWRD. Measurements of specific conductance and temperature will be made opportunistically from wells and streams throughout the basin using handheld meters.

Measure spring discharge

Springs with published measurements and other notable unmeasured springs will be inventoried and measured where possible. Piper and others (1933) and Newcomb (1965) reported about 30 sizable springs each discharging more than 100 gallons per minute, most of which issued from stream-channel walls on the alluvial fan and valley lowlands. A subset of these springs has been monitored by the WWBWC since about 2005. As of 2017, 5 of the springs monitored each discharged more than 600 gallons per minute (Cobb and Keller, 2019). Barker and MacNish (1976) identified five spring discharge zones on the WWRB alluvial fan and lowlands where coarse sediment intersects clay and silt. Spring locations will be compiled from existing datasets such as the USGS National Hydrography Dataset (NHD; U.S. Geological Survey, 2019) and previous reports and selected sites will be field inventoried. A subset of 10 – 15 major springs will be measured twice per year to obtain an estimate of annual discharge and evaluate temporal variability in discharge. Where springs discharge into stream channels within the seepage run network, discharges will be quantified from the seepage data.

Hydrogeologic framework development

The hydrogeologic framework will be constructed using information from borehole geologic logs, drillers' reports, geologic maps, land-surface altitudes, and previous investigations. The horizontal extent of the framework will extend beyond the WWRB to include an area that can potentially influence groundwater flow within the boundaries of the WWRB. Knowledge will be gained from the hydrogeologic framework developed for the Columbia Plateau Regional Aquifer System (CPRAS; Ely and others, 2015). The new framework will be at a higher spatial resolution than the CPRAS framework and will include more recent borehole data, geologic maps, and land-surface data. The spatial distribution, continuity, and hydrologic properties of major hydrogeologic units in the basin will be determined and processes used to identify and combine geologic units with similar hydrologic properties will be described. Structural controls on groundwater flow also will be identified and described.

Define hydrogeologic units

Hydrogeologic units for the WWRB will be defined using hydraulic properties, surficial geologic mapping, interpretation of subsurface lithology from driller's well reports, and rock geochemistry. The geologic and hydraulic characteristics of each hydrogeologic unit will be described and summarized. If there are sufficient data, the spatial distribution of one or more hydraulic properties may be developed for one or more hydrogeologic units.

Develop a surficial hydrogeologic map

A surficial hydrogeologic map will be developed from published geologic mapping and hydrologic interpretation of those units. The first step in creating the hydrogeologic map will be to create a simplified geologic map depicting surficial exposures of geologic units and major structural features on the basis of published geologic mapping in the region. Existing geologic maps cover different parts of the basin and will be used to create one seamless map. To the extent possible, the new basin-wide map will resolve discrepancies in mapping by different authors to provide a unified understanding of the geology across the study area, particularly across the state line. As needed, study personnel will consult with geologists from Oregon Department of Geology and Mineral Industries (DOGAMI) and Washington Department of Natural Resources (DNR) to ensure consistent geologic interpretation and incorporate new information from recent mapping in the area. The next step will be to combine geologic units of similar hydraulic properties, spatial continuity, or other geologic characteristics into hydrogeologic units defined to meet the objectives of this study.

Define the three-dimensional geometry of hydrogeologic units

The three-dimensional geometry of the subsurface hydrogeology will be defined using lithology, mineralogy, and geochemistry from drilling programs, lithologic information interpreted from drillers' well reports, geophysical surveys, and any other source of subsurface information. Top and bottom elevations and thickness of hydrogeologic units will be produced as raster datasets. Where the hydrogeologic units crop out, the land surface will define the unit top. These datasets will be published in a data release as GIS layers.

Develop potentiometric maps

Potentiometric surface maps will be developed for major hydrogeologic units underlying WWRB. The extent and number of maps will be determined once the hydrogeologic units have been developed and after an evaluation of available data to constrain the potentiometric surfaces. It is expected that at least two maps will be developed—one representing hydraulic heads in basin fill and one or more representing those of the basalt. The ability to define more than one basalt unit as part of the hydrogeologic framework and develop associated potentiometric maps will depend on data availability. The potentiometric surface maps will be produced as geospatial datasets and published along with the final hydrogeologic framework report.

Estimate hydraulic properties and evaluate connectivity of hydrogeologic units

Estimates of hydraulic conductivity (K), transmissivity (T), specific storage (S_s), and specific yield (S_y) will be compiled from the literature and calculated from new or existing specific capacity, pump-test, or slug-test data. New, calculated values will be derived from analytical and (or) simple numerical models, or empirical methods.

Hydraulic connectivity between surface water and groundwater will be evaluated through seepage runs and evaluation of groundwater levels in response to seasonal changes in streamflow. Connectivity among subsurface units will be evaluated using previously published aquifer tests and ongoing isolated pumping that can be monitored and used to evaluate hydraulic connections.

Groundwater budget estimation

The groundwater budget in the WWRB will be estimated and evaluated over multiple decades. The budget period will be determined after evaluating data availability. Groundwater budget components consist of recharge, discharge, and changes in groundwater storage. Recharge or inflow occurs through infiltration of precipitation, stream channel losses, irrigation losses from canals and beneath fields, artificial aquifer recharge, and potentially, interbasin groundwater flow. Discharge or outflow occurs through stream baseflow, springs, lakes, groundwater pumpage, evapotranspiration (ET), and potentially, interbasin groundwater flow. Changes in groundwater storage represent differences between groundwater recharge and discharge. Estimates of sub-area water budget components made in this study will be compared with estimates from previous studies such as those from the CPRAS model (Ely and others, 2015).

Recharge

Infiltration of precipitation

Groundwater recharge from infiltration of precipitation will be estimated using tools such as the Deep Percolation Model (Bauer and Vaccaro, 1986, 1990), the Soil-Water-Balance (SWB) Model (Westenbroek, 2010), or Precipitation Runoff Modeling System (PRMS; Markstrom and others, 2015). Water balance tools will be informed using many types of spatial and temporal data including land use and cover, soils, and climate among others. Estimates of recharge from precipitation will be constrained using local and regional groundwater discharge estimates.

Stream channel and irrigation canal losses

Recharge from stream channel and irrigation canal losses will be estimated using a surface-water balance incorporating streamflow, irrigation and management diversions, crop water use, groundwater levels, and existing canal loss data. Water exchange between streams and canals and the groundwater system will be evaluated using existing streamgage data, seepage run measurements, and nearby groundwater-level measurements. Elevation differences between shallow wells near streams and stream stage will be used to assess the groundwater response to stream and canal losses. The complexity of natural groundwater and surface-water exchanges coupled with exchanges related to irrigation activities might preclude distinguishing recharge from stream channel losses, from surface-water irrigation losses beneath canals and fields, and from losses related to managed aquifer recharge. Recharge estimates along stream reaches will represent the sum of gains and losses.

Infiltration of irrigation water

Recharge from infiltration of irrigation water will be assessed using estimates of irrigation application volumes and crop water use. The difference between crop water use and water application estimates is referred to as efficiency losses. Efficiency losses can be attributed to runoff, return flow to the stream, wind losses, evaporation, or recharge. Efficiency losses will be apportioned to these components based on published estimates for similar crop and soil types. Water application estimates will be based on groundwater use (see Groundwater use section) and surface-water application data and published irrigation efficiency estimates based on crop type, irrigation application method, and soil type (Washington State Department of Ecology, 2005).

Estimates of stream, canal, and field irrigation losses to the groundwater system can be refined using field measurements within streams and canals, and beneath irrigated crops. Temperature profiling coupled with two-dimensional numerical models can be used to estimate seepage losses beneath channels (Metcalf, 2003; Naranjo and Smith, 2016). Irrigation losses beneath crops can be refined with unsaturated-zone water flux estimates based on soil-water potential measurements. USGS will pursue discussions with OWRD, Ecology, and Washington State University Extension to evaluate the potential for field measurements and applicable sites.

Artificial aquifer recharge

Artificial aquifer recharge estimates will be based on existing data. Managed aquifer recharge (MAR) in WWRB provides a notable input into shallow basin fill and basalt units. As of Fall 2020, 18 MAR sites have been equipped to recharge the shallow basin fill, 15 of which are currently being used (Cobb and Keller, 2019). The basin-fill MAR sites are comprised of infiltration basins and subsurface perforated pipes, typically operate during winter and spring, and are supplied by diverted surface water. The 18 MAR sites have the capacity to contribute nearly 10,000 acre-ft of aquifer recharge annually if fully operational during November–May. The city of Walla Walla operates an aquifer storage and recovery (ASR) program where surface water is diverted during winter months and injected into deeper basalt units for use during water-limited periods.

Discharge

Seepage and baseflow to streams

Groundwater discharge to streams as baseflow through springs and seeps will be estimated using previously published measurements and new streamflow measurements made during this study. Seepage-run data will be used to estimate stream gains and losses to groundwater in different stream reaches and in selected canals. This analysis will be compared with previous seepage runs conducted by the WWBWC (2014). Graphical and chemical hydrograph separation methods and (or) low-flow measurements will be used to estimate baseflow from streamgage records where available. Estimates in ungaged watersheds or those in data-limited areas will be estimated from hydrologically similar gaged watersheds. Existing shallow wells near perennial streams will be used to determine elevation differences between groundwater and the streams, and to assess groundwater response to stream elevation.

Springs, evapotranspiration, and seepage to lakes

Spring discharge historically represented a considerable portion of groundwater discharge in the WWRB (Piper and others, 1933; Newcomb, 1965; Barker and MacNish, 1976). Springs discharge groundwater from basin fill on the flanks of lowland areas and from the basalt aquifer in upland areas of the basin. Most spring discharge occurs in stream channels near the interface of higher and lower permeability hydrogeologic units, and through cliff walls where groundwater moving downward encounters a low permeability unit. Historical and new measurements of discharge will be aggregated and compared where possible to evaluate current discharge and potential changes in discharge related to climate and water management. Where springs discharge diffusely into stream channels, discharge will be accounted for in baseflow estimates.

Groundwater discharge by evapotranspiration (ET) from wetland, riparian, and phreatophyte areas, and from areas where shallow groundwater is with a few feet of land surface, historically represented a notable portion of groundwater discharge (Piper and others, 1933; Barker and MacNish, 1976). Land use change from wetlands and phreatophytes to irrigated land

and declining water levels in the shallow unconfined aquifer likely have reduced natural groundwater discharge by ET to minimal volumes. Groundwater discharge by ET will be estimated as ET minus precipitation and any surface-water inputs within mapped groundwater discharge areas.

Groundwater-lake exchanges likely comprise a minor component of the groundwater budget because few lakes, ponds, and reservoirs (hereafter generally referred to as lakes) exist within the WWRB. Groundwater-lake exchanges will be evaluated by considering surface-water inflows and outflows and hydraulic gradients between groundwater and lake stage if this component of the water budget is found to be important.

Groundwater Use

Groundwater use in the WWRB includes irrigation, livestock, domestic, municipal, and industrial. Rates of groundwater use in Washington and Oregon are not tracked to the degree of accuracy and spatial resolution needed for this project and therefore will be estimated indirectly. Non-irrigation water use data will be evaluated using population density from the US Census, public water-supply data from the Washington Department of Health, Ecology and OWRD water-use records, land-cover data, and USGS water use assessments. Irrigation water use will be estimated from ET estimates from irrigated fields with available groundwater pumpage data. ET of applied irrigation water will be estimated by OWRD and USGS using a remote-sensing based ET model such as SSEBop (calibrated to regional ET measurements from agricultural fields), precipitation data and mapped agricultural field boundaries. OWRD will provide all associated estimates during 2016–2020 as part of a separate state-wide study, and OWRD and USGS will provide at least 10 years of estimates during 1990-2015 using complimentary methods. The number of years within this 26-year period will depend on cloud cover. Reported pumpage data and water-source type (groundwater, surface water, or both) will be evaluated using mapped field boundaries, OWRD and Ecology water-rights information, user reported pumpage volumes from OWRD and Ecology water-use reporting databases, and surface-water diversion records. For fields irrigated with groundwater and surface water, ET will be apportioned by water source using diversion and pumpage records, where available and coupled, and local knowledge. Where pumpage data is limited, relations between available pumpage data and crop ET estimates can be used to estimate pumpage for similar crop types and irrigation methods.

A decision support tool for water-use estimation such as Bright (2020) might be incorporated with agricultural and domestic water use estimates to determine the horizontal and vertical distribution of groundwater extraction. Although the volume of groundwater use for irrigation can be spatially distributed using remote-sensing based methods, irrigated fields might not be linked to individual wells. Also, the depths of some irrigation, livestock, and domestic wells and the aquifer they draw from might not be included in the available data.

Interbasin groundwater flow

Previous studies indicate groundwater in the basalt aquifer likely flows across the boundaries of the WWRB (Ely and others, 2015). Upgradient inflows serve as a source of groundwater recharge to the basin and downgradient outflows are a source of groundwater discharge. An initial estimate of interbasin groundwater flow will be provided by the CPRAS model and used as a basis for improving estimates. Project estimates of interbasin groundwater flow will be evaluated using Darcy's Law and simplifying assumptions about subsurface geometry through which groundwater flows. Hydraulic gradients determined from mapped groundwater levels, transmissivity estimates of hydrogeologic units, and the hydrogeologic framework will be used to estimate groundwater fluxes across basin boundaries.

Flow-system evaluation

Groundwater-level trends

Groundwater-level trends will be evaluated using qualitative and (or) statistical methods. Time-series of groundwater levels can highlight seasonal recharge and discharge patterns and long-term stresses on the flow system. Well-construction data, nearby surface-water features, precipitation patterns, land use (such as agriculture or MAR), and groundwater-flow paths will be considered when evaluating groundwater levels.

Geochemistry and age dating

The compiled and newly collected geochemical data will be synthesized to provide insight into relationships among water in the WWRB. The distribution of age and isotopic tracers in groundwater and surface water will provide information on groundwater flowpaths, recharge locations, and residence time of groundwater.

Groundwater occurrence and flow

Groundwater occurrence and flow will be described using a compilation of potentiometric surface maps, subsurface hydraulic property and connectivity evaluations, and geochemical data. Assessments of groundwater occurrence and flow include identification of confined and unconfined conditions, horizonal and vertical hydraulic gradients, flow directions within and between major hydrogeologic units, apparent structural controls, and proximity to recharge and discharge features. Possible changes in groundwater flow directions resulting from water use and management, and the effects of these changes on interbasin flow, if any, will be assessed.

Groundwater/surface-water interactions

The interaction of groundwater and surface water will be evaluated on the basis of data from seepage runs, water-budget estimates of stream gains and losses, canal losses, and MAR coupled with groundwater-flow directions, groundwater-level trends, and water-chemistry data. Rates, locations, and timing of groundwater/surface-water interactions along stream reaches, canals, and at spring complexes will be described. Seasonal and annual groundwater/surface-water exchanges will be summarized and individual and combined physical and anthropogenic factors affecting these exchanges will be evaluated where sufficient data exists. Hydrograph separation methods will be applied to streamgages with daily records to estimate daily baseflow.

Workplan development for Phase II—simulation tool

A descriptive workplan for Phase II of the study will be developed near the completion of Phase I. The Phase II workplan will describe the development of a hydrologic simulation tool, such as a three-dimensional groundwater flow model or another appropriate tool. The approach taken to build this tool will be decided before the conclusion of Phase I and will be guided by discussions with project partners and other WWRB stakeholders. This tool will simulate forward-looking scenarios for prediction of hydrologic outcomes, which will assist in informing water-management decisions.

Project coordination

The magnitude and scope of this study requires good coordination among cooperating agencies directly involved in the proposed work and with other State and Federal agencies involved in land- and/or water-management issues in the basin, Tribal governments, local governments, and other local stakeholders. Meetings among cooperating agencies (USGS, Ecology, and OWRD) and other stakeholders will occur regularly throughout the study. The USGS maintains a SharePoint site for sharing documents, such as this workplan, among the cooperating agencies. Another document at this site is a study team coordination plan that describes the structured meeting schedule, progress reports, and other communication. Staff from USGS-OR and USGS-WA will hold project meetings every 1-2 weeks to share progress and coordinate tasks. Quarterly meetings among technical staff and managers of cooperating agencies that have been ongoing since July 2019 will continue during the study. USGS will participate in annual stakeholder meetings organized by state agencies.

Quality assurance / quality control

USGS Quality Assurance Plans for groundwater, surface-water, and water-quality activities in Oregon and Washington will be used to guide the collection and review of groundwater data, surface-water data, and water-quality data during the study (Kozar and Kahle, 2013; Conn and others, 2017; Mastin, 2019). OWRD protocols for measuring water levels, discharge, and water quality were developed from USGS guidance, and data are comparable to USGS measurements, ensuring comparability across the Washington-Oregon state line.

Quality control for geochemistry will consist of blank and replicate samples. One field blank sample will be collected for major ions. Blank samples are not possible for the other sample types. All samples for noble gases, dissolved gases, and SF6 will be collected and analyzed in replicate. Five percent of samples for stable isotopes, tritium, carbon-14, and major ions will be collected and analyzed as replicates.

Data management plan

In accordance with the USGS-OR and USGS-WA data management plans and USGS fundamental science practices, all data associated with the project will be stored in appropriate, publicly accessible databases and clearinghouses. Data collection will be shared among USGS, OWRD, and Ecology. Overall, this will be a coordinated effort, but each agency will largely manage staffing and tasks independently. The data collection agency will also serve the data publicly from the following sources:

1. USGS National Water Information System (NWIS): https://waterdata.usgs.gov/nwis
2. USGS National Spatial Data Infrastructure (NSDI) node: http://water.usgs.gov/lookup/getgislist
3. OWRD data portal: https://www.oregon.gov/OWRD/pages/index.aspx
4. OWRD near real-time data: https://apps.wrd.state.or.us/apps/sw/hydro_near_real_time/
5. Environmental Information Management System (EIM): https://apps.ecology.wa.gov/eim/search/
6. Streamflow data from Ecology – https://fortress.wa.gov/ecy/eap/flows/regions/state.asp

Reviewed and approved data and metadata not released through one of the listed sources will be made available online through USGS ScienceBase or other appropriate USGS, Ecology, or OWRD data clearinghouses. USGS data management will follow USGS Scientific Data Management policies and requirements described in Conn and others (2019) and in USGS Instructional Memos 2015.1 through 2015.4 (USGS, 2015a-d)

Continuous and discrete streamflow, water-level, and chemical data collection by USGS will be checked, reviewed, and approved at approximately quarterly intervals according to USGS Continuous Records Processing policy. All data collected by USGS will be made available to the public via the National Water Information System (NWIS; http://waterdata.usgs.gov/or/nwis/) or through OWRD or Ecology online databases.

Spatial datasets such as maps and other datasets constructed for the study will be documented with all appropriate metadata and made available through the NSDI node or through the appropriate USGS data release or other appropriate USGS, Ecology, or OWRD geospatial data clearinghouses following guidelines of the Open Data Initiative.

Any models used or aquifer tests analyses performed during the study will be documented and archived according to USGS policy (USGS, 2015e) and the Open Data Initiative. A copy of any models will be available to the public through an approved USGS repository such as ScienceBase. Aquifer-test analyses and associated modeling will be quality assured through project reviews as well as through the aquifer-test and model-review process and made publicly available.

Products

Reports planned include a USGS Scientific Investigations Report (SIR) that provides a quantitative conceptual model of the WWRB groundwater-flow system and documents the basin hydrogeology and water budget. One or more products summarizing the study results, such as a USGS Factsheet, or a USGS Geo-Narrative—an online story map—will be published. Other USGS products will include data releases containing the geospatial datasets defining the hydrogeologic framework, recharge model, groundwater budget, and water-use estimates. Other data including streamflow, groundwater levels, and geochemical data will be available in NWIS or in publicly available OWRD or Ecology databases. An SIR or data-series report will document the results of seepage runs. The number of reports and their topics may change as the study develops; any changes to report products will be discussed with and approved by the cooperating agencies. A workplan describing development and documentation of a hydrologic simulation tool for the WWRB (Phase II) also will be developed. All USGS-authored products will be peer reviewed following standard USGS protocols (U.S. Geological Survey, 2016).

Cooperating agencies also might provide open-file reports (OFRs) documenting results associated with specific study tasks. Possible OFRs include documentation of results from aquifer or slug tests conducted by OWRD and documentation of methods and results pertaining to irrigation water use including crop ET and irrigation pumpage estimates made by OWRD.

Timeline

Table 2. Project tasks and timeline

[Washington Department of Ecology, Ecology; Oregon Department of Water Resources, OWRD; USGS Washington Water Science Center; USGS-WA; USGS Oregon Water Science Center, USGS-OR. The first agency listed for each task will lead the effort. General “USGS” indicates tasks will be equally shared.]

Project task	Fiscal year				Agency assigned to
	21	22	23	24	
Project management					
Team meetings	x	x	x	x	All
Stakeholder meetings	x	x	x	x	All
Literature review and data compilation					
General material	x	x			USGS
Compile and assess existing data and estimates					USGS
General hydrologic data	x				USGS
Geologic and hydrogeologic frameworks	x	x			USGS
Groundwater budget estimates and associated datasets	x	x			All
Data collection					
Groundwater-level measurements	x	x	x		USGS-WA/OWRD
Conduct seepage runs	x	x			USGS-WA/OWRD/Ecology
Streamflow monitoring	x	x	x		USGS-WA/OWRD
Conduct pump or slug tests in wells		x	x		OWRD
Collect new geochemical data	x	x	x		USGS-OR/USGS-WA/OWRD
Spring discharge measurements	x	x			USGS-WA/OWRD
Hydrogeologic framework					USGS-WA/USGS-OR/OWRD
Define hydrogeologic units	x				USGS-WA/USGS-OR/OWRD
Develop a surficial hydrogeologic map	x				USGS-WA/USGS-OR
Develop a digital hydrogeologic model of the subsurface	x	x			USGS-WA/USGS-OR/OWRD
Develop potentiometric maps		x	x		USGS-WA/USGS-OR
Estimate hydraulic properties and evaluate connectivity of hydrogeologic units	x	x	x	x	USGS-WA/USGS-OR/OWRD
Groundwater budget estimation					USGS-OR/USGS-WA/OWRD
Recharge					
Infiltration of precipitation	x	x	x	x	USGS-OR/USGS-WA
Stream channel and irrigation canal losses	x	x	x	x	OWRD/USGS-OR/USGS-WA
Infiltration of irrigation water	x	x	x		USGS-OR/OWRD/USGS-WA
Managed aquifer recharge	x	x			USGS-OR/OWRD/USGS-WA
Discharge					USGS-OR/OWRD/USGS-WA
Seepage and base flow to streams	x	x	x		USGS-OR/USGS-WA/OWRD
Springs, ET, and seepage to lakes	x	x	x		USGS-OR/OWRD/USGS-WA
Groundwater Use	x	x	x		USGS-OR/OWRD/USGS-WA
Interbasin groundwater flow	x	x	x		USGS-WA/USGS-OR/OWRD
Flow-system evaluation					USGS-WA/USGS-OR
Groundwater-level trends	x	x	x		USGS-OR/USGS-WA
Geochemistry and age dating		x	x	x	USGS-WA/USGS-OR
Groundwater occurrence and flow		x	x		USGS-OR/USGS-WA
Groundwater/surface-water interactions		x	x		USGS-WA/USGS-OR
Workplan development for phase II--simulation tool			x	x	All
Project coordination	x	x	x	x	All
Quality assurance / quality control	x	x	x	x	All
Data management plan (execution of)	x	x	x	x	All

Products					
USGS scientific investigations report(s)			x	x	USGS
Fact sheet/geo-narrative			x	x	USGS
Data releases			x	x	USGS

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