A Hydrologic Study of the Fifteenmile Creek Basin Groundwater System, Oregon

A proposal prepared by the Technical Services Division of the Oregon Water Resources Department

Prepared by:

Jonathan La Marche

Josh Hackett

Aaron Orr

Laurel Stratton Garvin

Mukesh Mehata

Aaron Fellows

Kara Morris

Graham Thomas

For

Justin Iverson and Jordan Beamer, Project Sponsors

Amanda Lowe, Project Manager

Version 1.0

Date: 05/07/2026

OREGON
WATER RESOURCES
DEPARTMENT

Draft Document – Content Subject to Change
Version May 2026

A hydrologic study work plan should be treated as a living document that evolves throughout the course of the project. As new data needs emerge, additional questions arise, community concerns surface, or unforeseen issues develop, the plan may require updates to remain accurate and effective. Flexibility also ensures the work can adapt to changes in department priorities and available resources. By keeping the work plan dynamic, the study can better respond to real-time information and continue to meet community and project goals. Groundwater studies support the Oregon Integrated Water Resources Strategy by providing the scientific data needed to understand local water availability, identify resource challenges, and guide sustainable water-management decisions across the state; these goals will remain consistent throughout the life of the workplan.

Contents

Summary

Purpose and Use of This Workplan

This workplan is a technical document that describes the scope, objectives, approach, major work tasks and deliverables for the Fifteenmile Creek groundwater study. It is intended to guide both project management and technical execution of the study. The document is written for multiple audiences, including OWRD administrators and managers; technical staff in the Surface Water and Groundwater Hydrology Sections, Field Services Division staff; and technical staff with any external partners involved in the study such as universities, tribes, watershed councils and other agencies and cooperators.

For managers and decision-makers, the workplan defines the hydrologic problems, study objectives, primary tasks, and expected products. It provides a basis for prioritizing resources, coordinating with related efforts, and communicating planned work. For technical staff and collaborators, it serves as a roadmap linking methods and datasets to overarching study objectives.

The workplan also supports transparency and defensibility of the study. As work progresses, it may be updated under an adaptive management approach to incorporate new information, adjust priorities, or refine methods, while maintaining a clear record of the original scope and any subsequent modifications.

Study Motivation

Groundwater levels in the basalt aquifers of the Fifteenmile Creek watershed in north-central Oregon have been declining since the 1990s, with several wells exceeding the threshold for “declined excessively” as defined in OAR 690-008-0001(5). Surface water resources are also over-appropriated, and there is evidence of groundwater–surface water interactions in the basin. Over the past two decades, the mainstem of Fifteenmile Creek has experienced extreme low flows and, in some years, localized desiccation in its lower reaches.

Although these conditions are well documented, the relative contributions of various potential drivers remain uncertain. Potential causes include increased groundwater pumping, inter-aquifer commingling wells, climate-driven reductions in recharge and discharge to baseflow, increased surface water withdrawals due to climate-driven increases in crop evapotranspiration, increases in riparian evapotranspiration, and other hydrologic processes. A comprehensive study is therefore warranted to characterize the hydrologic system and provide the scientific foundation for future water-policy and management decisions.

Objectives and Scope

To address these uncertainties, the study will:

(1) Develop a foundational conceptual groundwater model that integrates existing and new data to describe the hydrostratigraphy, groundwater budget, groundwater-flow directions, and zones of recharge and discharge, including groundwater/surface-water interactions. This conceptual model will provide a coherent framework for interpreting groundwater levels and streamflow behavior.

(2) Evaluate the causes of groundwater-level declines in CRBG aquifers, focusing on the relative roles of groundwater pumping, inter-aquifer commingling wells, and climate-related changes in recharge and discharge. The study will produce lines of evidence that clarify whether observed declines are consistent with known stresses and hydraulic characteristics of the aquifer system(s).

(3) Assess subsurface and other hydrologic contributions to periodic stream desiccation and low flows in Fifteenmile and Eightmile Creeks, including stream/well hydraulic connections, structural and stratigraphic controls on groundwater flow that influence the extent and magnitude of pumping impacts on connected stream reaches, riparian evapotranspiration losses, and climate-driven declines in stream flow (including baseflows). The study will evaluate how these processes influence the timing, magnitude, and spatial patterns of low flows, losing reaches and episodic stream desiccation.

Taken together, these objectives are intended to answer questions such as:

- How is groundwater moving through the CRBG aquifers, and where are the main recharge and discharge areas, including where (if) stream reaches are hydraulically connected to which CRBG aquifers?
- Are groundwater-level declines and streamflow losses consistent with estimated groundwater pumping stresses, commingling wells, riparian ET estimates, and (or) climate variability?
- Which parts of the groundwater system are most sensitive to changes in groundwater use or climate?
- How does riparian ET influence streamflow in losing reach(s)?

The study area will encompass the entire Fifteenmile Creek watershed. Ancillary studies, data, and comparative analyses from adjacent or hydrologically analogous watersheds such as Mosier Creek, Tygh Creek, and Threemile Creek may also be included. The temporal scope will be guided by climate and hydrologic data availability and is anticipated to span at least the period of observed groundwater declines (1990s to present day).

Relevance and Benefits

The study will provide a scientific foundation for water management and policy decisions, including a potential Groundwater Administrative Area designation. It will refine understanding of the groundwater-flow system and groundwater/surface-water interactions and contribute to the broader knowledge base of Columbia River Basalt Group (CRBG) hydrogeology. The study will support local communities, water users, conservation organizations, and natural resource agencies by providing foundational information for development of sustainable water-management strategies. The study will generate published datasets, analyses, and reports that will be publicly accessible online.

General Approach

The study is organized so that all major tasks contribute to developing, testing, and refining a conceptual groundwater model of the basin. This model will define the principal aquifers and confining units, describe their geometry and compartments, and identify the main groundwater flow paths, head gradients, and recharge and discharge areas. It will also integrate groundwater budget and flow-system analyses to explain observed groundwater level declines and assess groundwater-pumping contributions (if any) to low and zero-flow conditions in Fifteenmile Creek. Work will proceed along three overlapping tracks: (1) compiling and synthesizing existing information and identifying data gaps (Task 1); (2) collecting targeted new data to address identified data gaps (Task 2); and (3) performing the three core analytical tasks—Hydrogeologic Framework Development (Task 3), Groundwater-Budget Assessment (Task 4), and Flow-System Evaluation (Task 5). Tasks 1 and 2 focus on compilation, new data collection, and supporting analyses, while Tasks 3-5 integrate these inputs into a coherent interpretation of the groundwater system (the updated conceptual groundwater model) and address the study objectives.

Hydrogeologic Framework: The hydrogeologic framework (Task 3) will identify the principal aquifers and confining units; characterize their hydrologic properties; and map their three-dimensional geometry and the structural features that create aquifer compartments and influence groundwater flow. This framework establishes the physical template of the conceptual groundwater model by describing feasible groundwater-flow pathways and the degree of hydraulic connectivity between compartments. It supports the flow-system evaluation and water-budget analysis by identifying likely areas, mechanisms, and scales of recharge and discharge. It also guides mapping of potentiometric surfaces and vertical gradients in the flow-system evaluation and indicates where additional data (e.g., seepage runs, streambed-temperature profiling, borehole geophysics) should be collected to support both the flow-system evaluation and water-budget work. Task 3 directly supports the study's objectives of developing an accurate, internally consistent, conceptual groundwater model and providing the structural and stratigraphic context needed to evaluate how groundwater withdrawals can influence streamflow.

Groundwater Budget Assessment: The groundwater-budget assessment (Task 4) will quantify recharge, discharge, and changes in storage within the study area. This includes numerical estimates of recharge from precipitation, stream losses and gains, groundwater withdrawals, spring discharge, and phreatophyte evapotranspiration. These flux estimates are central to the conceptual model and must be consistent with both the hydrogeologic framework and observed system behavior. For example, if the budget indicates substantial baseflow contributions to a stream reach, the hydrogeologic framework should show plausible upgradient recharge areas, mapped hydraulic gradients should indicate groundwater flow toward the stream network, and geologic mapping and cross sections should identify units and structures that allow this movement. Any inconsistencies will trigger reassessment of either the budget estimates or aspects of the hydrogeologic framework. This task directly supports the evaluation of groundwater-level declines and streamflow depletion by quantifying how water enters, leaves, and is stored in the groundwater flow system.

Flow-System Evaluation: The flow-system evaluation (Task 5) will use groundwater elevations, vertical and horizontal gradients, age and chemical tracers, seepage runs, and streambed-temperature profiling to characterize how groundwater moves through the system. This work will delineate flow paths between recharge and discharge areas, identify or refine the degree of hydraulic connection between units or compartments, and confirm the direction, magnitude, and time frame of fluxes estimated in the water budget assessment. The results will be interpreted within the context of the hydrogeologic framework and groundwater budget and will be used to refine compartment boundaries, recharge and discharge zones, and estimated fluxes. Where age distributions, head gradients, or discharge/recharge patterns diverge from expectations, the conceptual model will be revised, and additional data collected as needed. For example, the groundwater age distributions should agree with plausible recharge mechanisms and magnitudes suggested by the hydrogeologic framework and water-budget analysis; or if groundwater head-gradients diverge from expectations, investigation of possible unmapped structures may be needed to revise the hydrogeologic framework.

Integration Across Tasks: These core analytical tasks (Tasks 3-5) are interrelated and must remain internally consistent to ensure an accurate conceptual model of the hydrologic system. New data collection (Task 2) is designed to support the analytical tasks and reduce uncertainty in the linkages between them. When inconsistencies arise, the team will first evaluate the existing datasets and analytical results before prioritizing additional targeted data collection (e.g., repeat seepage runs) and updating the working conceptual model. Through this iterative process, each major component of the study constrains and informs the others, enabling a cross-validated and hydrologically coherent conceptual model of the basin's hydrologic system designed to meet the study's objectives.

Introduction and Background

The Fifteenmile Creek watershed, located in north-central Oregon, drains the eastern slopes of the Cascade Range to the Columbia River near The Dalles and encompasses approximately 369 square miles (Figure 1). It is bounded by Surveyors Ridge to the west, Tygh Ridge to the south, Summit Ridge to the east, and the Columbia River to the north. Fifteenmile Creek originates near Lookout Mountain (~ 6,525 feet above mean sea level, amsl) and flows northeast from forested uplands into lower-elevation agricultural lands before entering the Columbia River at approximately 85 feet amsl. The watershed occupies a transitional climate zone influenced by both the humid maritime climate of western Oregon and the arid continental climate of eastern Oregon. Precipitation is strongly influenced by elevation and the orographic effects of the Cascade Range. Higher elevations near the headwaters in the western portion of the watershed receive greater precipitation (65-80 inches; WCSWCD-FCG, 2004), including seasonal snowpack that contributes to streamflow through the spring and early summer. In contrast, most of the watershed lies below the transient-snow zone (approximately 3,000 feet) and receives less precipitation (~ 13 inches per year near Dufur; WWRC, 2025), primarily as rainfall. Streamflow in Fifteenmile and Eightmile Creeks follows a seasonal pattern, with high flows during winter rainfall events and elevated flows in spring from snowmelt. By mid-summer, streamflow frequently falls below consumptive demand, prompting regulation of junior surface water right holders by the Watermaster. Near its mouth, Fifteenmile Creek flows have ranged from less than 1 cubic foot per second (cfs) to over 1,000 cfs on rare occasions. Typical summer flows often drop below 5 cfs, while winter and early spring flows commonly exceed 100 cfs.

Low streamflows in the basin are especially concerning given the presence of threatened salmonid species listed under the Endangered Species Act (ESA). Reduced summer streamflows have been linked to elevated water temperatures and degraded habitat conditions for these species (ODFW, 2019). Efforts to restore degraded channel conditions, improve water quality, improve watershed health, and restore fisheries have been underway in the watershed since the early 1990s. These efforts have resulted in the establishment of riparian buffers along approximately 90 percent of the perennial stream miles on privately held land in the watershed (OWEB, 2019). However, given recent episodes of stream desiccation in the lower reaches there has been growing concern within the community that these efforts may be inadvertently contributing to stream desiccation.

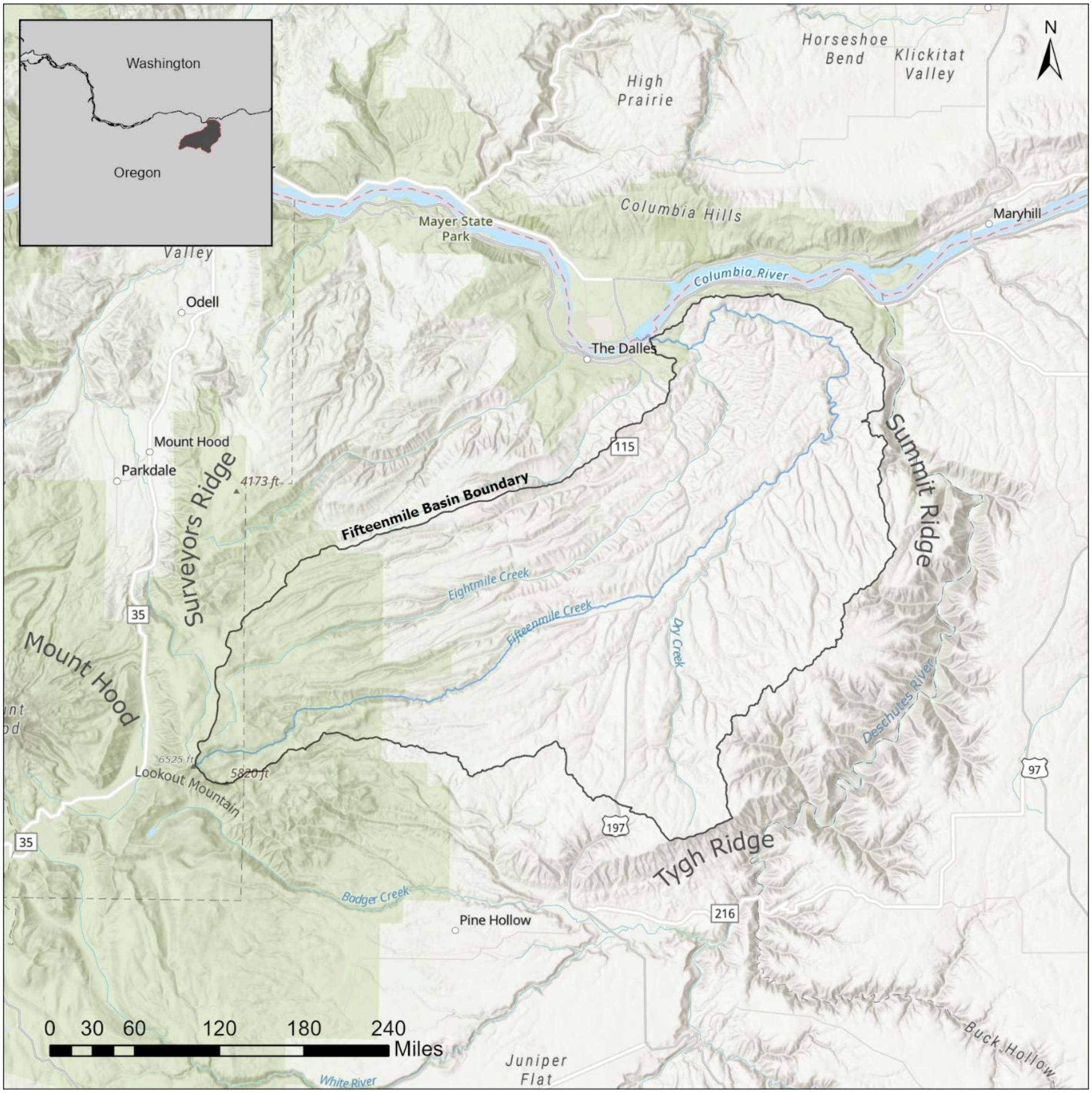

Figure 1: Fifteenmile Study Area

Land cover and land use broadly follow the underlying climate and elevation gradients. At higher elevations in the western portion of the basin, dense coniferous forests dominate, transitioning downslope through mixed conifer-oak woodlands into oak savanna, shrub-steppe and grasslands at lower elevations. Land use reflects these patterns: commercial and non-commercial forestry is the primary use in the upper watershed, while dryland wheat and rangelands represent about 60-70 percent of the watershed area, concentrated across much of the drier mid- and lower watershed (WCSWCD, 2004; OWEB, 2019). Floodplain areas, mostly in the valley above Dufur, are irrigated for pasture and forage crops. Outside the floodplain, mostly on hillsides in the lower watershed, groundwater irrigated areas of orchards and vineyards have been developed over time. The OWRD Water Rights Information System (WRIS) database indicates that total surface water irrigation rights in the study area are approximately 6,100 acres. Total groundwater irrigation rights are approximately 11,000 acres (OWRD, WRIS), with 3,000 of those acres being supplemental rights. Actual irrigated acres for both surface water and groundwater sources are thought to be less than these totals due to mapping inaccuracies/limitations in the WRIS database, land idling, and some water rights not yet developed.

Soils in the watershed generally consist of loess-derived silt loams developed over dissected hillslopes underlain by Columbia River Basalt Group (CRBG) and Dalles formation, with locally shallow stony soils in the steeper uplands to the south and southeast and younger alluvial soils along the valley bottoms. Approximately 63 percent of the basin is classified as hydrologic class group “B” soils, generally described as deep silt-loams with moderate infiltration rates (NRCS, 2009). However, class group “D” soils are also abundant and represent the slowest infiltration rates predominately in the uplands of Dry Creek as well as mid elevations of Fivemile, Eightmile and Fifteenmile Creeks (Clark, 2003).

The geologic setting exerts a strong control on groundwater resources and streamflow in the watershed. The area is underlain predominantly by the CRBG—a thick sequence of more than 300 Miocene flood-basalt flows that exceed 10,000 feet in thickness in the Pasco Basin (Tolan et al., 1989) and more than 2,000 feet locally. Individual flows are laterally extensive, commonly covering hundreds to thousands of square miles, and are typically tens to hundreds of feet thick, with an average thickness of about 100 feet. Each flow generally exhibits a three-part internal structure: a dense, low-permeability flow interior (≈80-90% of total thickness), bounded by much thinner, more permeable flow top and flow bottom. Flow interiors transmit water poorly, whereas flow tops and bottoms have higher permeability created by interactions with the land surface during emplacement (flow bottoms) and effects of degassing and irregular cooling (flow top).

When sufficient time elapsed between eruptions, sediments accumulated on flow tops and were subsequently buried by the next flow. Together, the flow top, sedimentary interbed, and overlying flow bottom form an interflow zone (IFZ). These IFZs constitute the primary aquifers within the CRBG. The sharp contrast in permeability between IFZs and flow interiors creates laterally extensive, but vertically isolated aquifers, often with limited hydraulic connection across flow interiors (Johnson, et al. 2024).

Post depositional tectonic deformation has folded and faulted the basalt sequence, producing broad structures such as the Tygh Ridge anticline and The Dalles–Umatilla syncline, which influence both surface drainage and groundwater-flow patterns. In the region, CRBG units are overlain unconformably by volcanic and sedimentary rocks of the upper Miocene to lower Pliocene Dalles Formation. Both units are locally overlain by younger Pliocene volcanic and volcaniclastic rocks that partially fill paleochannels incised into the underlying formations (McClaughry and others, 2021). Faults and folds exert additional control on groundwater flow, acting as either barriers or conduits depending on their geometry and material properties. Geologic mapping has identified several structural features within the study area; for example, a fault near Boyd is interpreted to impede groundwater flow and contribute to observed aquifer compartmentalization. The hydrologic character of the CRBG—thin, transmissive IFZs separated by thick, low-permeability flow interiors—tends to limit vertical infiltration of precipitation and produce a vertically stratified sequence of confined aquifers.

Many earlier studies of recharge to CRBG aquifers have identified exposed IFZs as plausible pathways for water to reach deeper aquifers suggesting that recharge is proportional to precipitation (U.S. Department of Energy 1988; Johnson et al. 1993; Reidel et al. 2002; Pischel et al. 2018). In contrast, Johnson et al. (2024) found that in the upper Umatilla Basin, recharge to CRBG aquifers is extremely slow, highly localized, and much smaller than previously estimated. Their results indicate that recharge rates are largely independent of modern precipitation gradients and that recharge occurs primarily through slow, vertical infiltration through the low-permeability interiors of CRBG flows. This study will investigate these contrasting recharge mechanisms to identify the dominant process affecting groundwater recharge in the study area.

These combined conditions—high horizontal permeability within IFZs and extremely low vertical permeability through flow interiors, and the low storage capacity typical of confined CRBG aquifers—make the system particularly sensitive to groundwater development. Sustained pumping has been shown to cause large water-level declines in CRBG aquifers across the region (Sceva, 1966; McCall, 1975; Bartholomew, 1975; Grady, 1983; Norton and Bartholomew, 1984; Lite and Grondin, 1988). A well-documented nearby example is the CRBG aquifer underlying the city of The Dalles ("The Dalles Ground Water Reservoir"), which was declared a "critical groundwater area" by the state engineer in 1959 following continued groundwater-level declines.

Detailed Problem Statement

Since the late 1990s, groundwater levels in the CRBG aquifers of the Fifteenmile Creek watershed have shown widespread declines, particularly in the central part of the basin, with some wells exceeding 100 feet and surpassing the "excessive decline" threshold as defined by OAR 690-008-0001. The cause(s) of these declines remain unclear; however, over that same period, groundwater related irrigation development expanded from less than 5,000 permitted acres in 1990 to over 10,000 acres by 2010 (see Figure 2).

Documented evidence indicates that groundwater pumping for irrigation has interfered with springs (Norton, 1999), identifying a mechanism by which groundwater development can affect streamflow. Because surface-water resources are over-appropriated, this raises concern that junior groundwater rights may adversely affect senior surface water rights. Additionally, prior work has identified a significant losing reach in the lower mainstem of Fifteenmile Creek (LaMarche and Wood, 2011), which may be further impacted by groundwater withdrawals if hydraulic connections exist with the stream network. Collectively, current water use in the watershed is a plausible contributor to perennial streams experiencing localized desiccation in their lower reaches over the last two decades, raising significant ecological concerns for threatened salmonid species listed under the Endangered Species Act (NOAA, 1999).

While factors such as groundwater pumping, commingling wells, riparian evapotranspiration, and climate variability are all suspected contributors to declining groundwater levels and stream desiccation, their individual impacts, spatial distributions, and seasonal patterns remain unquantified. The work tasks below are designed to characterize the groundwater-flow system and provide a scientific basis for effective water policy and management decisions aimed at addressing the continuing decline of groundwater and surface water resources in the watershed.

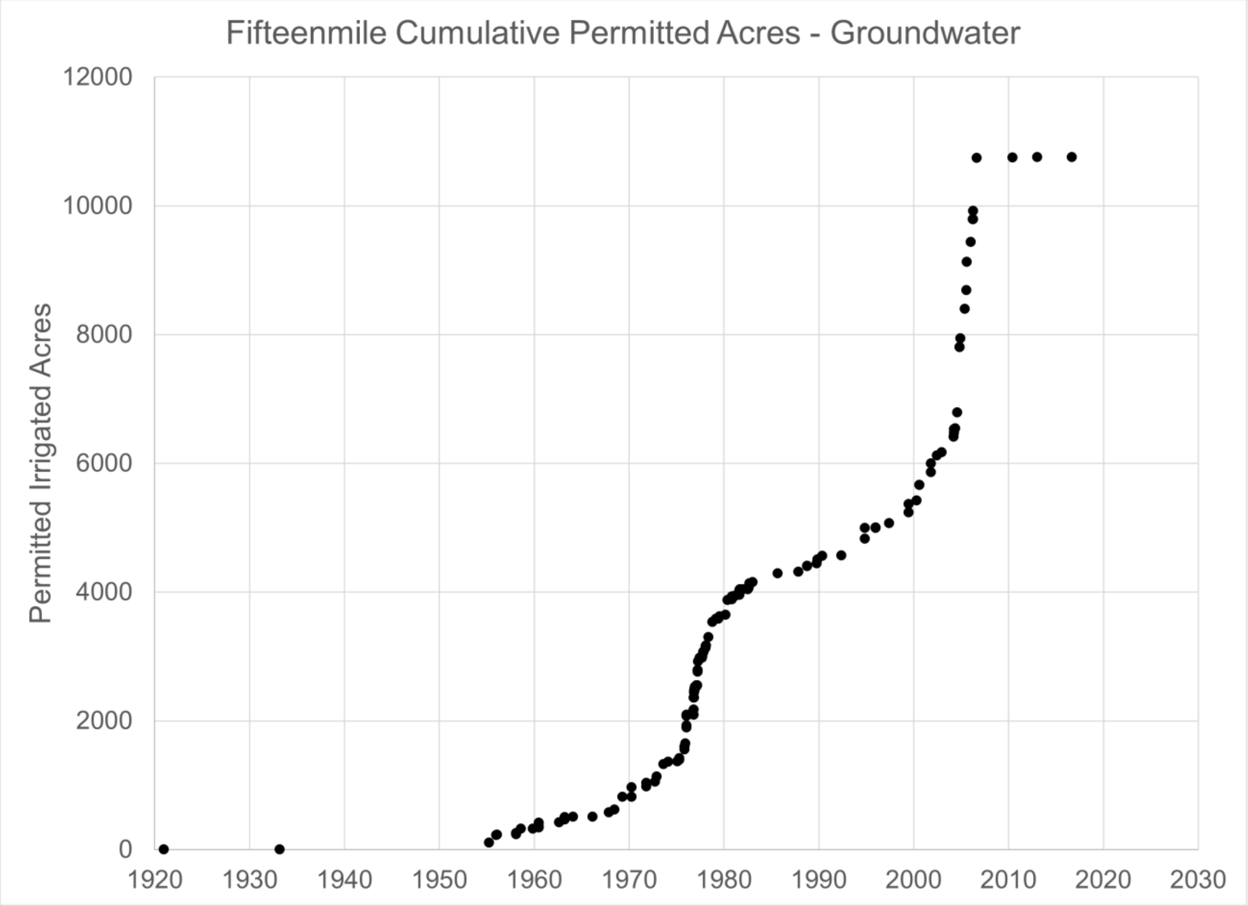

Figure 2. Cumulative acreage permitted for irrigation with groundwater.

Work Tasks

This study will address the currently unquantified contributions of pumping, commingling, riparian evapotranspiration and climate on groundwater and streamflow by,

(1) develop a foundational conceptual groundwater model that integrates existing data and new analyses to describe hydrostratigraphy, groundwater-flow directions, and key areas of recharge and discharge, including groundwater interactions with the stream network.

(2) investigate the causes of groundwater-level declines in CRBG aquifers (pumping, inter-aquifer leakage due to commingling wells, and climate-related changes in recharge/streamflow), and

(3) assess subsurface contributions to periodic creek desiccation and low flows, including structural/stratigraphic controls, riparian ET, and climate variability/trends.

General tasks consist of: (i) literature review, data compilation, and data-gap analysis; (ii) targeted new data collection to supplement/close gaps and support the three main technical tasks; (iii) hydrogeologic framework development; (iv) water-budget assessment; and (v) flow-system evaluation.

Task 1.0: Literature Review and Data Compilation

A thorough review of existing data and literature on the geology, hydrogeology, hydrology, water use, land cover, climate, and vegetation in the watershed will be performed. This will also include information pertaining to nearby areas with similar climate and geologic settings. Sources will include government reports, academic investigations, consultant documents, and publicly available databases. Hydrological data will be compiled in digital database format as detailed in the data management plan. Similarly, spatial data will be managed and stored in GIS compatible formats according to the data management plan. This information will be used to build a baseline understanding of the hydrologic setting, water resources, and water use in the basin. This task will also inform data collection efforts in Task 2.0 by identifying known data gaps.

Task 1.1: General Hydrologic Data Compilation

Previously published and unpublished hydrologic data for the watershed will be compiled to develop a foundational understanding of the basin's hydrology, with emphasis on groundwater systems. This effort will support the identification of data gaps and guide the design of new data collection efforts (Task 2) aimed at refining the hydrogeologic framework and improving characterization of groundwater–surface water interactions. Task 1.1 focuses on inventorying and quality-checking existing datasets, observations, analyses, and general information from previous published and unpublished studies to support subsequent analysis.

Most of the hydrologic data compilation from previous studies will occur in 2026, although additional information will continue to be reviewed and incorporated throughout the duration of the study. The initial compilation phase will help identify spatial and temporal data gaps, and those gaps will be used to inform Task 2 priorities. Emphasis will be placed on compiling and synthesizing existing hydrologic observations across the watershed. In addition to quantitative datasets, this task will compile relevant qualitative and observational information (e.g., documented reports or accounts of historical stream desiccation, seasonal drying patterns, spring emergence or loss, land-use or irrigation practice changes, and other field observations) that inform interpretation of hydrologic conditions and change over time. Priority will be given to data that enhances understanding of recharge and discharge patterns, aquifer compartmentalization, and zones of hydraulic connectivity between surface water and groundwater.

Local datasets, including those provided by landowners, watershed councils, and other agencies or organizations, will also be reviewed for potential inclusion in the study. Any data selected will be evaluated for consistency with Oregon Water Resources Department (OWRD) data collection and quality standards. Selection criteria will include documented data collection methods, data consistency, and publication or validation history.

Major categories of existing data to be compiled include streamflow data, spring locations and discharge, groundwater levels, and relevant climatological and landscape datasets. Data on hydraulic properties of aquifer units (e.g., transmissivity, hydraulic conductivity, specific yield, and specific storage) will be obtained from prior studies, aquifer tests, and specific capacity data.

Climatological data will be compiled from public datasets, including gridded products such as PRISM, GridMET, and Daymet, as well as point measurements from the Global Historical Climatology Network, AgriMet, and SNOTEL or Snow Course sites, where available. Additional spatial data (including vegetation, soils, and land cover) will be compiled as needed to support the watershed-scale hydrologic characterization.

Task 1.2: Geologic and Hydrogeologic Frameworks

Existing geologic maps (Anderson, J.L., 2026a, 2026b, 2026c; McClaughry et al., 2021, 2024;), geologic reports (Newcomb, 1969; Piper, 1932), stratigraphic picks from rock chips collected during well drilling, borehole geophysical survey logs, drillers' reports, geothermal and oil and gas exploration logs, and other well records will be compiled. Nearby watersheds with similar hydrogeologic settings will also be reviewed for context and comparisons. Unpublished data and mapping will also be considered. Compilation under Task 1.2 will focus on assembling and organizing existing framework inputs (e.g., unit descriptions, correlations, and structural features) and documenting key uncertainties and information gaps to support interpretation under Task 3.

Task 1.3: Geochemistry

Groundwater chemistry data and isotopic studies in the study area and in other CRBG aquifer systems will be summarized (Grady, 1983; GWMA 2009d, Johnson et al., 2024; Jones, 2016; OWRD, 2013). Unpublished data from OWRD (e.g., miscellaneous SC readings) and other sources will also be considered. This synthesis will document existing chemistry/isotope information, summarize key interpretive findings from prior work, and identify gaps relevant to groundwater sources, recharge mechanisms, and groundwater–surface water interactions in CRBG settings.

Task 1.4: Water Use and Associated Datasets

Water rights, water-use, and water management information will be compiled to provide context and inputs for historic estimates of both surface and groundwater-use components of the water budgets. Diversion and delivery records (e.g., flow meters and other regulation/accounting datasets compiled by the watermaster) will be organized and summarized to support estimates of historic surface water budgets and stream baseflows. Crop consumptive use (CU) and ET products used to develop new estimates of historical crop ET and natural-vegetation ET (for recharge constraints) are addressed under Task 2.10, rather than under Task 1.4, because those estimates rely on new analyses developed as part of this study.

Task 2.0: New Data Collection and Compilation

Task 2 will address priority data gaps and information needs identified under Task 1 through targeted new data collection, subject to funding availability and landowner access. Activities under Task 2 are intended to refine the hydrogeologic framework, improve characterization of groundwater–surface water interactions, and strengthen the datasets needed to support subsequent analyses (e.g., Tasks 3–5). Data collection priorities, locations, parameters, and frequencies will be informed by the Task 1 compilation and gap assessment, with emphasis on collecting information that improves understanding of recharge and discharge patterns, aquifer compartmentalization, and zones of hydraulic connectivity between surface water and groundwater.

Task 2.1: Groundwater-Level Measurements

Groundwater-level measurements will be collected from existing observation wells and supplemented with new monitoring points if necessary. Measurements will be collected at various frequencies, including continuous logging and manual seasonal readings. These data will be used to assess seasonal and long-term trends, map potentiometric surfaces, and evaluate groundwater flow directions and gradients. Where feasible, proximal wells screened in different units will be measured to evaluate vertical gradients and aquifer connectivity.

Task 2.2: Streamflow and Specific Conductance Monitoring

Continuous streamflow data will be collected and processed to mean daily flow (MDF) values using standard USGS/OWRD procedures at established gaging stations throughout the watershed. The MDF will be used to evaluate surface water balances, assess seasonal groundwater-surface water fluxes between gaging stations, and estimate stream baseflows.

Miscellaneous discharge measurements and concurrent spot SC readings will be collected at roughly six index locations across the basin—for example, the upper reaches of Fivemile, Eightmile, and Fifteenmile Creeks, and key tributaries such as Pine Creek and Fivemile Creek near the mouth. Measurements will be timed opportunistically around periods when routine gage measurements occur (not as synoptic seepage runs) to support development of empirical relationships between index sites and nearby gages within key seasonal windows. Together, these data increase the spatial resolution of streamflow variability across the watershed and provide defensible constraints on water-balance and recharge estimates (baseflows) away from gaged sites, at substantially lower cost and staffing than establishing additional continuous gages. Data collection will follow established OWRD protocols.

Continuous SC monitoring at three stream gages will support hydrochemical hydrograph separation techniques to improve baseflow estimation. Handheld meters will be used to collect additional discrete measurements of SC and temperature data from springs, wells, and other miscellaneous measurement and stream gaging sites throughout the watershed. For gaging and measurement sites, these parameters will be measured whenever discharge measurements are made.

All data will be subjected to routine quality checks and managed in accordance with the study's QA/QC plan. Periodic data reviews will be conducted to ensure consistency with study goals, adherence to accuracy targets, and to support interim analyses.

Task 2.3: Seepage Runs

Quarterly seepage runs (synoptic flow measurements) will be conducted along the mainstems of Fifteenmile and Eightmile Creeks for four years to identify and quantify seasonal groundwater/surface-water exchanges. General measurement locations will be selected (and modified) based on the evolving hydrogeologic framework and flow-system evaluation, and in close coordination with Hydrographics and Field Services staff to ensure/obtain site access and optimal channel/flow conditions.

Flow measurements will proceed in river order from upstream to downstream within a defined same-day window for each reach to limit travel-time and diurnal effects. Measurements will occur under hydrologically stable conditions (i.e., relatively steady-state flow and water management conditions). At each mainstem site, discharge will be measured multiple times using USGS/OWRD standards to reduce measurement uncertainty. All inflows and diversions will also be measured and documented, including tributaries with observed zero flow. Additionally, SC readings (μS/cm) will be made at all measurement locations to support interpretation of neutral, gaining, or losing reaches. All data will be collected, reviewed, processed, and archived according to OWRD protocols.

Synoptic flow measurement locations and the quarterly schedule will be refined based on results from early seepage runs, streambed-temperature monitoring, geochemical sampling results, and hydrogeologic framework development. Site maps and seepage run plans will be updated as needed to maintain or improve analysis of key segments while improving efficiency and interpretability.

Task 2.4: Streambed Temperature Profiling

Streambed temperature profiling will be conducted using composite rods equipped with 6 self-contained logging thermometers, spaced at regular intervals (~5-10 cm) along the rod and vertically embedded into the streambed such that the top thermometer monitors water temperature (Briggs et al., 2014; Irvine et al., 2017). A variety of locations will be selected for monitoring to complement the seepage run segments, with 40-50 rods deployed to form short longitudinal arrays of a quarter to a mile immediately upstream and downstream of target sites. Exact placement will depend on streambed composition and site accessibility. Loggers will record data at hourly or shorter intervals and will be installed seasonally, for one to three weeks per deployment depending on logging intervals and data storage constraints. Before and after each deployment, temperature sensors calibration will be checked using a two-point temperature test with ice bath (~32°F) and ambient air temperature (~ 70°F) checked against an independent temperature reading. Field notes will document location, date/time of deployment and removal, burial depth, exposure, and hydraulic conditions.

The resulting vertical temperature profiles will be analyzed for diel amplitude damping and phase shift to infer the direction and relative magnitude of groundwater exchange with surface water, providing an independent line of evidence to interpret seepage-run results and refine the evolving hydrogeologic framework (Hatch et al., 2006; Keery et al., 2007; McCallum et al., 2012; Luce et al., 2013; Gordon et al., 2012). Data will be screened for sensor drift or exposure, noise and archived under OWRD data-management protocols.

Task 2.5: Springs Assessment and Mapping

Springs (i.e., spring vents including seeps with mappable, perennial or seasonally persistent discharge) will be inventoried using multiple sources, such as the USGS National Hydrography

Dataset (U.S. Geological Survey - NHD, 2019), USGS 7.5’ topographic quadrangle maps, aerial/satellite imagery, published and unpublished reports, landowner surveys/outreach, and field reconnaissance. Each feature will include a minimum: latitude/longitude coordinates, elevation, feature type (spring/seeps), persistence (perennial/intermittent/ephemeral), estimated or measured discharge (date stamped), discharge methods, water temperature and SC, photos, site access notes, and general geologic/topographic context (e.g., bedrock at bottom of north cliff face).

Measured/estimated discharge will be paired with geologic mapping to relate spring occurrence and discharge to hydrostratigraphic units and structures, improving the conceptual model of groundwater–surface water interactions in the watershed and informing both surface water and groundwater budgets.

All spring measurements and estimates will include method and uncertainty metadata and will be stored in a dedicated Springs schema (e.g., *Springs_Sites*, *Springs_Q_Measured*, *Springs_Q_Estimated*) with versioned exports and an accompanying data dictionary. Quarterly reviews will check temporal consistency, reconcile duplicate features and records from multiple sources, verify linkages to hydrogeologic units, and ensure integration with the hydrogeologic framework and basin water-budget analyses. All data will be archived under OWRD data management and publication protocols.

Task 2.5.1: Spring Discharge Measurements

For accessible springs suitable for standard techniques, discharge will be measured directly under USGS/OWRD procedures (e.g., volumetric/timed-fill, portable weir/flume where feasible, wading discharge measurement). Concurrent field parameters (e.g., temperature, specific conductance) will be recorded to support source characterization. Measurements will be targeted quarterly across four years, with visits scheduled within key seasonal windows (low-flow autumn, winter baseflow, spring high flow and spring recession/, and the irrigation season) to capture variability and enable annualized discharge estimates. Field notes will document site conditions (ponded vs channelized flow, vegetation/ice effects), evidence of management influence, measurement location, and any connectivity to surface channels.

Task 2.5.2: Spring Discharge Estimates

Where direct measurement is infeasible, discharge will be estimated using remote-sensing approaches and desktop methods. Primary emphasis will be on ET-based water-balance approaches (e.g., delineating riparian/phreatophytic polygons, obtaining seasonal ET values from OpenET or comparable sources, subtracting effective precipitation, and adjusting for upland runoff contributions) following methods adapted from analogous studies (e.g., Beamer et al., 2013; Moreo et al., 2020). Assumptions, coefficients, and polygon delineations will be documented and archived. Sensitivity checks will be performed to inform uncertainty estimates. Estimated discharges will be reconciled with seepage run evaluations where appropriate surface hydraulic connection occurs.

Task 2.6 Hydraulic Tests in Wells

Opportunities to conduct aquifer tests will be evaluated to improve estimates of hydraulic properties of CRBG aquifer units (i.e., the hydrostratigraphic units that function as aquifers in the study area) and to identify groundwater flow boundaries, including recharge or no-flow boundaries. The specific need for new testing will be determined after a comprehensive review of existing aquifer test data, driller's test records, and previously derived estimates of hydraulic parameters for the principal hydrogeologic units.

The study anticipates conducting approximately 2 to 5 multiple-well aquifer tests, contingent on-site availability and resource constraints. Additional testing opportunities may be identified as the project progresses. For example, production wells used for public supply or irrigation may serve as test wells if located near suitable observation wells, such as non-pumping irrigation wells. These configurations would support controlled multi-well test configurations that improve the spatial resolution and reliability of aquifer hydraulic- property estimates.

Results from these tests will provide key hydraulic property estimates for the hydrostratigraphic units and aquifer compartments defined in Task 3.3 and incorporated into Task 3.6. Together, Tasks 2.6 and 3.6 support refinement of aquifer-compartment geometry and hydraulic properties, as well as identification of groundwater flow boundaries. These elements are critical for interpreting groundwater level responses to pumping and for meeting Objective (1), development of a robust conceptual model, and Objective (2), evaluation of the causes of groundwater-level declines.

Task 2.7 Geochemical Data

Geochemical and isotopic data will be collected to support interpretations of groundwater age, recharge areas, and groundwater flow paths. These data are essential for understanding the timing and connectivity of groundwater systems and their interaction with surface water. A network of wells, springs, and stream sites will be sampled for general water chemistry (major cations and anions) and isotopic tracers, including stable isotopes of water (deuterium and oxygen-18), tritium, and radiocarbon. The sampling strategy aims to provide approximately 100 samples for general chemistry and stable isotopes, and a smaller subset (estimated 30-50) of samples each for tritium and carbon-14 analyses. Wells selected for isotope sampling will be dependent on a combination oh, of results of general chemistry data from an initial round of sampling and hypothesized structural controls on groundwater flow in the basin. Actual sample numbers may vary depending on landowner access, field conditions, evolving project priorities, and available funding.

Repeat samples at select wells, streams, and springs will also be collected to assess the interannual variability of water stable isotope values.

Task 2.8 Borehole Geophysical Surveys

Borehole geophysical surveys will be conducted in study area wells to support development of the hydrogeologic framework. Surveys are limited to wells without pumping equipment installed—currently less than 10 have been identified; of those, 3-5 wells located in areas with limited subsurface information have been targeted to be surveyed. These surveys — consisting of electrical resistivity, spontaneous potential, natural gamma, caliper, flowmeter, and temperature logs — will provide high-resolution vertical profiles of subsurface physical properties, aiding in the identification of lithologic contacts, aquifer boundaries, and confining units. The surveys will be particularly valuable in areas with limited lithologic information or where significant stratigraphic complexity is anticipated.

Task 2.9 Flow Metering & Diversion Data

Flow metering data are critical for quantifying surface water and groundwater use in the basin, and for developing an accurate groundwater budget and conceptual model of the groundwater system. This task will inventory all irrigation and municipal water use in the watershed, identify sites with and without working flow meters, and implement comprehensive metering for groundwater and surface water diversions within the study area. Work will proceed in close coordination with the Watermaster, assistant Watermaster, and Field Services Division's North Central Region staff (FSD-NCR) and will be consistent with applicable statutes and rules.

Using the WRIS database as a base layer, all irrigation-related surface water Points of Diversion (PODs), groundwater Points of Appropriation (POAs), and Places of Use (POUs) will be compiled and preliminarily mapped. This desktop inventory will be refined with on-the-ground knowledge from the Watermaster's office and FSD-NCR input to produce a current map and list of all active (generally defined as used within the last five years) PODs along the main stems of Fifteenmile and Eightmile Creeks, and all active irrigation and municipal groundwater POAs in the watershed.

Next, all PODs and POAs with operational flow meters will be inventoried through field surveys. For users lacking flow meters, the Department will communicate the intent to require measurement devices consistent with ORS 540.045(1)(a), ORS 540.310(2) and OAR 690-250-0060, and will provide information about the Water Measurement Cost Share Program to help offset costs. The type and configuration of the measurement device will require Watermaster approval and will be installed and maintained according to manufacturer specifications.

Each mapped POA, POD (and the corresponding flow meters) will be linked to the corresponding POUs using WRIS attributes, field knowledge from the Watermaster's office, and field verification surveys conducted during this study. Prior to field surveys, the POU boundaries and acreage will be refined using remote-sensing-derived-field boundaries (Task 2.10). These steps are necessary to attribute metered withdrawals (Task 2.9) to the correct irrigated acres/POUs and associated remote-sensing-derived ET datasets (Task 2.10): actual evapotranspiration (ETa), consumptive use (CU), and applied water (AW).

Each POA and POD will be assigned an OWRD groundwater (for POAs) or surface water (for PODs) location identification (LID) that links the site to the landowner and its latitude and longitude. Meter readings will be collected prior to the growing season (or at the end of the previous growing season), and then near the end of each month to align with remote sensing ET data. For each reading, the following will be recorded: the LID, landowner name, date and time, volumetric reading and instantaneous rate (including units for both), Meter Identification (e.g., serial number), power meter reading (kilowatt hours), and the instantaneous power demand.

Comprehensive metering of municipal and irrigation groundwater withdrawals is necessary for accurate estimation of groundwater discharge due to pumping and is the basis for estimating historical withdrawals (Task 2.10) used in subsequent water-use analyses (Tasks 4.2.1 and 5.1).

Similarly, comprehensive surface water metering supports quantification of seasonal groundwater/surface water exchanges based on surface water balance calculations delineated by the stream gaging network (Tasks 2.2-2.4, and 4.1.2). Existing metering data from the Watermaster's office collected for regulation activities will also be incorporated into this effort.

Power meter usage will be collected with flowmeter records for irrigation water use. Power meter information supports flowmeter data collection by: (1) allowing for quality assurance checks, (2) confirming instances where a flowmeter "rolls over" and (3) gap-filling missing flowmeter records where statistical relationships between flowmeter and power meter use can be established.

Task 2.9 focuses on establishing and operating the metering program and producing comprehensive withdrawals datasets that support ET–based historical withdrawal estimates under Task 2.10.

Task 2.10 Evapotranspiration, Consumptive Use, and Applied Water Estimates

Remote sensing derived ET datasets (Huntington et al., 2025) will be used to estimate groundwater and surface water withdrawals for irrigated crops when flowmeter records are not available (see Task 2.9). These ET datasets will be paired with concurrent metered withdrawal datasets (Task 2.9) during the intensive metering period (2026-2029) to develop ET–meter relationships for estimating historical groundwater and surface water withdrawals, and for filling gaps for non-metered withdrawals over the study period. ETa, CU and AW estimates for irrigated agriculture will be obtained from Oregon's Statewide ET remote sensing datasets. This information will be produced (or summarized) at monthly, seasonal, and annual time steps to quantify spatial and temporal patterns in subsequent trend and water balance analysis. Data summaries will include surface water and groundwater analyses, or as otherwise specified by the study. For surface water analyses, summaries will also be aggregated spatially between gaging locations. For groundwater, spatial aggregation will be based on aquifers and/or aquifer compartments identified in Task 3.3.

Currently, Oregon's Statewide ET data time series for irrigated agricultural is available from water year 1985 through 2024. However, this dataset will need to be extended through the end of the comprehensive flow-metering data-collection effort ending in October of 2029. Further dataset refinements will include a review of agricultural field mapping, source water attribution, understanding supplemental groundwater use in fields irrigated with both surface and groundwater sources, and irrigation methods using a combination of desktop reviews and field surveys. The field surveys will be used to confirm agricultural field mapping and field attributes such as irrigation status and irrigation system types that are used for calculating remote sensing-based AW. These dataset refinements will be incorporated into the Statewide ET data to assure and possibly improve AW estimates.

ETa–meter and AW–meter relationships will be developed for all irrigated field boundaries (or POUs) over the study's intensive data collection period (2026-2029). Using these relationships, historical surface and groundwater diversion estimates will be generated over the full ETa record (1984-present) where metering data are unavailable. Key shifts in irrigation practices will be assessed based on literature reviews and interviews with watershed council, NRCS, soil and water conservation districts, and Watermaster personnel and incorporated into the estimates. Historical withdrawals estimates will support trend analysis, the development of the groundwater budget, and interpretation of groundwater declines and stream desiccation. Changes in irrigated areas, cropping patterns, and crop types over time will also be evaluated to support causal analysis of groundwater declines.

Development of ETa–meter and AW–meter relationships requires paired observations of metered withdrawals (Task 2.9) and ETa/CU/AW estimates for mapped irrigated areas and attributes (e.g., acreage, irrigation status, irrigation system type), supported by field mapping and verification. Where water for a given field boundary is applied from multiple sources (e.g., surface water primary with supplemental groundwater), both sources will be metered and attribution will be addressed explicitly to estimate source fractions and improve historical groundwater-withdrawal and surface-water diversion estimates over the ET record.

This task will also include a water rights analysis that informs water use. Water rights data (PODs, POAs, and POUs) and associated attributes will be compiled in GIS (Task 1.4), then field-verified to relate water-rights and irrigated acreage to water-use data as described in Task 2.9. Core attributes will include the LID (assigned in Task 2.9), irrigated acreage, stated (paper) diversion rate and duty limits. Additional attributes will include the reach designation delineated by the gaging network for PODs (e.g., upper, middle, and lower for mainstem of Fifteenmile creek) or aquifer/aquifer-compartment assignments for POAs (per the hydrogeologic framework analysis in Task 3.3).

Additionally, non-irrigated landscape ETa (e.g., dryland wheat, sagebrush/grassland, oak/forest, evergreen forest) will be estimated from remote sensing to provide zonal and basin-wide temporal ET fluxes from the natural landscape. These estimates will inform the hydrologic modeling and specifically inform the groundwater recharge estimate using the Precipitation-Runoff Modeling System (PRMS) or a similar approach.

Task 2.11 Riparian Vegetation Assessment

This task will inform the impact of riparian water use and ET on observed stream losses and periodic desiccation in the lower mainstem of Fifteenmile Creek, a concern raised by water users in the basin following two decades of restoration activities. Prior studies show that riparian ET can affect reach-scale water balances in some hydrologic settings (Culler et. al., 1982). This work will specifically test whether stream reaches with stronger late-season riparian vigor/ET systematically coincide with larger measured losses.

Statistical analysis will relate riparian vegetation to streamflow characteristics and explore causal factors for stream losses by stream reach and seasonal drying. Indicators of vegetation condition will be compiled at reach scale, including: (a) greenness/cover metrics (e.g., NDVI/EVI quantiles), (b) phenology (spring peak vs late-summer persistence), and (c) riparian ETa. For this work, riparian ET and water use will be determined by (1) delineating riparian extent using existing datasets, aerial imagery, and targeted field investigations and (2) estimating riparian ET rates and volumes (Beamer et al., 2013, Nagler, OpenET). Similar remote-sensing approaches of this type have been used to quantify riparian water use and relate vegetation dynamics to hydroclimate along western river corridors (Nagler et al. 2005; 2013). These indicators will be summarized for reaches independently classified as neutral, gaining, or losing from seepage runs, streambed temperature profiling, and specific-conductance interpretations (Tasks 2.2-2.4), and compared across seasons.

Limited field checks (photo points and possible a few short belt-transects at representative gaining, neutral, and losing segments) may be used to validate desktop indicators. Published values of riparian ET in similar settings will be used to qualitatively cross-check the assessment.

Task 3.0: Hydrogeologic Framework Development

The hydrogeologic framework will synthesize current understanding of the basin's stratigraphy, aquifer geometry, and structural controls on groundwater movement. This work proceeds from compilation of surface geologic mapping (Task 3.1) and subsurface lithologic data (Task 3.2) to delineation of aquifer compartments and hydrostratigraphic units that describe the basin's principal groundwater bearing units (Task 3.3). Geologic cross sections (Task 3.4) and potentiometric surface mapping (Task 3.5) will further clarify subsurface geometry and flow patterns, while estimates of hydraulic properties (Task 3.6) will support evaluation of groundwater connectivity and aquifer behavior. Together, these tasks establish a coherent understanding of the basin's hydrogeologic system and form the foundation for conceptual model development and any future numerical groundwater-flow analyses.

Task 3.1: Develop comprehensive geologic map of study area.

The framework development will begin by compiling published Department of Geology and Mineral and Mineral Industries (DOGAMI) geologic maps (McClaughry et al., 2021; McClaughry et al., 2024), a thesis map (Powell, 1982), and unpublished U.S. Geological Survey (USGS) geologic maps that cover the study area. Post-Columbia River Basalt Group (CRBG) surficial deposits will be generalized, and adjacent map boundaries will be matched to produce a seamless regional compilation. This comprehensive geologic map will provide the foundation for interpreting subsurface conditions and for developing an integrated understanding of the watershed's geologic setting. It will also provide the primary spatial framework for defining hydrostratigraphic units and aquifer compartments in Task 3.3.

Task 3.2: Develop subsurface stratigraphy database.

Subsurface stratigraphy will be interpreted using surficial geologic maps, LiDAR, and lithologic information from well reports. Where available, whole-rock geochemical data will be incorporated to refine stratigraphic interpretations and improve unit correlations. This integrated approach will enhance understanding of the relationships between geologic units and groundwater occurrence and flow and will support the delineation of hydrostratigraphic units that function as aquifers or confining units within each aquifer compartment (Task 3.3).

Task 3.3: Define Aquifer compartments and hydrostratigraphic units

Aquifer compartments will be delineated to describe the major structural and hydraulic subdivisions of the groundwater flow system. These compartments represent areas where groundwater flow is relatively well connected internally but restricted by structural or stratigraphic boundaries such as faults, folds, pinchouts, or dense flow interiors. Delineation will rely on the integration of geologic structures, water-level data, and geochemical and isotopic tracers that indicate hydraulic connection or isolation between zones.

Within each compartment, hydrostratigraphic units will be defined to represent the principal water-bearing and confining layers that control vertical and lateral groundwater movement. Determination of these units will draw on lithologic data from well logs, borehole geophysical surveys, aquifer test results, water chemistry and isotopic composition, and trends in groundwater levels. Interpreting hydrostratigraphic units in the context of defined compartments will allow for a clearer understanding of how geologic structure and stratigraphy jointly influence groundwater occurrence and flow.

The resulting framework will provide a detailed picture of aquifer and confining-unit geometry, connectivity, and heterogeneity across the study area. It will form the foundation for conceptual model development and establish the technical basis for any future numerical groundwater-flow modeling, should such modeling be pursued.

Task 3.4: Develop Geologic Cross Sections

Geologic cross sections will be constructed in multiple orientations—along strike, down dip, across stream valleys, and through major structural features—to highlight features that influence groundwater flow. Each section will integrate mapped geology (Task 3.1), well lithology and stratigraphy, and driller logs (Task 3.2), available borehole geophysics (Task 2.8), and hydrostratigraphic interpretations (Task 3.3). These sections will delineate structural controls, the three-dimensional extent and thickness of hydrostratigraphic units, aquifer extents, and stratigraphic variations that define the hydrogeologic framework. Cross sections will be iteratively refined to remain consistent with geochemical and age-dating results (Task 5.2), potentiometric surface mapping (Task 3.5), and water-budget constraints (Task 4.0).

Task 3.5: Develop Potentiometric Surface Maps.

Potentiometric surface maps will be developed for major hydrogeologic units in the study area. At least two maps are anticipated: one representing water levels in shallow CRBG wells that define the local flow system, and another representing deeper wells that characterize the regional flow system. These maps will provide key insights into groundwater gradients and flow directions.

Task 3.6: Estimate hydraulic properties and interconnection of hydrostratigraphic units

Aquifer hydraulic properties—including hydraulic conductivity (K), transmissivity (T), and storativity (S)—will be determined using both existing datasets and new field testing. Data sources will include published literature, well records, specific capacity analyses, borehole geophysical logs (Task 2.8) and results from pump and interference tests (Task 2.6). Priority for new aquifer testing will be given to wells that offer the greatest insight into system behavior, such as high-capacity irrigation wells completed within distinct productive zones. Where possible, testing will focus on well pairs completed within the same stratigraphic interval or at comparable depths on opposite sides of major geologic structures, enabling evaluation of hydraulic connectivity across these boundaries.

Estimated hydraulic properties will be assigned to water-bearing hydrostratigraphic units and aquifer compartments defined in Task 3.3, providing a foundation for interpreting groundwater flow dynamics within and between compartments. Coupled with the hydrogeologic framework and observed groundwater level measurements, these properties will support water-budget assessments (Task 4) by enabling the translation of observed changes in hydraulic head into corresponding volumes of water. For example, estimates of storativity and compartment geometry (from Task 3.3), combined with observed groundwater level changes (Task 2.1) and estimated groundwater discharge (Task 2.9) will allow calculation of effective recharge needed to account for observed storage changes over specified time intervals and facilitate comparison with basin-scale recharge estimates from Task 4.1 when data permit.

Hydraulic-property estimates will also inform the flow-system evaluation outlined in Task 5. By enabling the conversion of head gradients and aquifer geometries into groundwater velocities, travel times, and fluxes, these estimates help distinguish well-connected flow pathways from barriers or weakly connected compartments. In coordination with Task 2.6, Task 3.6 offers an independent physical approach to compare with isotopically and chemically derived groundwater ages. For instance, age-tracer results can be evaluated against calculated travel times and hydraulic connections within and between compartments to evaluate consistency or help confirm the existence of barriers implied from aquifer pump tests. Similarly, observed stream gains or losses can be assessed in relation to the hydraulic properties of aquifers interacting with the stream network, determining whether observed values reflect the physical capacity of those units. Ultimately, Task 3.6 reinforces the conceptual groundwater model (Objective 1) and supports the evaluation of whether groundwater-level declines and streamflow losses are consistent with pumping stresses and aquifer capacity (Objective 2).

Task 4.0: Water Budget Development

The water budget (also referred to as the groundwater budget) development is a core building block of the conceptual groundwater model described in Study Objective (1). Water-budget estimates will be developed at two primary spatial scales: a watershed-scale budget for the entire Fifteenmile system and nested budgets for individual aquifers or aquifer compartments. This approach provides important linkage between basin-wide conditions and local problem areas identified in the Detailed Problem Statement.

The water budget will be developed from a groundwater-focused perspective, quantifying recharge, discharge, and changes in aquifer storage at spatial and temporal scales supported by both existing and new data collection efforts. Surface water fluxes will be analyzed primarily where they help constrain groundwater components. For example, total (potential) upland recharge to the CRBG aquifers will be estimated as the residual of the surface water budget—that is, the portion of precipitation remaining after accounting for observed runoff, stream baseflows (where hydrologically appropriate) and estimated landscape ET. Similarly, groundwater recharge from stream losses will be estimated as the residual of reach-scale surface-water balances.

The analysis will begin with an assessment of available data for each groundwater budget component, guiding the selection of appropriate periods of record (POR) for different spatial scales—such as basin-wide, sub-basin, or individual aquifer compartments. Instead of relying on a uniform period of record across all components and locations, the study will identify the most defensible periods and areas for estimates, while ensuring a clearly documented temporal framework so that recharge, discharge, and storage estimates can be accurately interpreted within the context of potentially different PORs and varying hydrologic and water-use conditions.

Water budget development will be informed by the Hydrogeologic Framework (Task 3) and the groundwater Flow-System Evaluation (Task 5). For example, in areas of significant baseflows, the hydrogeologic framework should indicate plausible upgradient recharge areas and hydraulic connections with the stream network. Groundwater budget estimates, interpreted alongside the hydrogeologic framework, will serve as key inputs to the flow system evaluation (Task 5), where they will be integrated with groundwater level, streamflow, and geochemical data to assess how hydrologic stresses correspond to observed groundwater declines and streamflow losses. This integrated methodology ensures that recharge and discharge estimates remain consistent with both the hydrogeologic framework and the conceptual understanding of the groundwater flow system.

By quantifying how inflows, outflows, and storage change over time and across locations, Task 4 directly addresses the Detailed Problem Statement and supports Objective (2) (evaluating causes of groundwater-level declines) and Objective (3) (assessing the contributions of subsurface processes to low flows and stream desiccation).

Task 4.1: Groundwater Recharge

Groundwater recharge will be quantified from four primary sources: infiltration of precipitation, stream channel losses, irrigation-related recharge and, where applicable, fluxes resulting from commingling wells. The Hydrogeologic Framework (Task 3) and the Flow-System Evaluation (Task 5) tasks will play a key role in constraining and validating these recharge estimates by providing essential context, including aquifer stratigraphy, hydraulic gradients, and the geometry and boundaries of major aquifer compartments. Collectively, these recharge estimates will serve as crucial evidence for developing the conceptual groundwater model (Objective 1) and for distinguishing between climate-driven recharge variations and pumping-induced stresses when analyzing observed groundwater-level declines (Objective 2).

Recharge will be estimated at two spatial scales. At the watershed scale, Tasks 4.1.1–4.1.3 will evaluate recharge contributions from individual sources: precipitation, streams, and irrigation. These estimates will primarily inform the magnitude and spatial distribution of potential recharge to the entire CRBG aquifer system. Recharge from precipitation will be estimated using PRMS (or a similar surface-water budgeting tool) for the entire CRBG aquifer system (i.e., bulk recharge not delineated by aquifer compartment). Recharge from stream losses will be estimated using streamflow analyses, including seepage runs, in reaches connected to CRBG aquifers. For irrigation-related recharge, applied irrigation water balances for the irrigated lands will be developed. Together, these analyses will provide an overall estimate of potential recharge to the CRBG system at the watershed and sub-watershed scale. These results will be further refined using chemistry, isotope, and age-dating analyses (Task 2.7). These macro-scale recharge values will provide constraints (i.e., upper bounds) for evaluating recharge at the aquifer compartment-scale inferred from storage changes (Task 4.3) and discharge estimates (Task 4.2). The watershed scale recharge estimates will also be compared with groundwater-level trends and low-flow/desiccation patterns to assess whether changes in recharge alone can plausibly explain observed conditions.

At the aquifer compartment scale, recharge from all sources will be estimated as a lumped value using a water-balance approach. In this approach, recharge sources (e.g., precipitation, stream losses, irrigation losses) are not explicitly separated. Recharge is estimated from change in groundwater storage and discharge (i.e., recharge = change in storage + discharge). Groundwater storage changes will be derived from groundwater levels and hydraulic properties (see Task 3.6). Discharges (e.g., pumping, spring discharge, stream gains) will be measured or estimated (Task 2.2-2.5, 2.9, 2.10). These compartment-scale estimates will be evaluated against watershed-scale estimates, climate variability, pumping histories, commingling fluxes, and riparian ET demands to ensure consistency across scales and to partition the relative impact of different drivers on groundwater-level declines and low flows (Objectives 2 and 3). Recharge estimates will integrate historical data (Task 1.0), new data (Task 2.0), and geochemical and isotope analyses, following similar methodologies as Johnson (202X) in the Walla Walla Basin, and Johnson et al. (2024) in the upper Umatilla Basin. Isotopic and chemical tracers—including tritium, carbon-14, water stable isotopes (^{2}H and ^{18}O), and major ion chemistry—will be used to infer recharge rates, groundwater ages, residence times, source areas, and flow paths. These analyses will enhance understanding of the timing and spatial distribution of recharge, and connectivity between recharge areas, aquifer compartments, and discharge zones.

Task 4.1.1: Recharge from precipitation.

Watershed-scale recharge from precipitation will be estimated using a watershed modeling approach (also referred to as a precipitation-runoff model). Watershed models simulate a range of physiographic, hydrogeologic, and ecohydrologic conditions and processes to apportion precipitation and snowmelt to “reservoirs” (or buckets) representing the soil zone, the groundwater reservoir, streamflow, and other components of the hydrologic cycle. Local aquifer recharge can be modeled as the residual of the surface water budget (including observed baseflows, when appropriate, based on the hydrogeologic framework). “Excess” recharge can be attributed to potential deep groundwater recharge to CRBG aquifers, where supported by other hydrogeologic evidence.

Recharge from precipitation will be modeled using a gridded configuration of the Precipitation-Runoff Modeling System (PRMS) that is scaled to capture recharge processes in the basin. Scope for the model construction, calibration, evaluation, and integration with the larger project are detailed in a separate internal scoping document, “Development and Application of a Precipitation-Runoff Modeling System (PRMS) Model for the Fifteenmile Creek Basin Groundwater Study.” The model will be built in partnership with experts from the Desert Research Institute under an intergovernmental agreement (IGA) to support model development and review. The IGA will be executed according to a second scoping document, “Modeling Support for Development and Application of a Precipitation-Runoff Modeling System (PRMS) Model for the Fifteenmile Creek Basin Groundwater Study.”

Model-based watershed-scale recharge estimates will be informed by (or evaluated against) multiple lines of evidence, including stream baseflow estimates (when hydrologically appropriate, Task 2.2), remote-sensing estimates of natural landscape ET (e.g., Nassar et. al., 2025), chemical signatures (Task 2.7), and the sum of independent recharge estimates for aquifer units derived from storage changes (using groundwater elevations from Task 2.1 and hydraulic properties from Task 3.6) plus measured aquifer outflows (Task 2.3, 2.5, and 4.2). Natural and non-irrigated landscape ET will be estimated using remote sensing (e.g., OpenET) for various land cover types, including dryland wheat, sagebrush and grassland areas, forests, and transitional zones (Task 2.10). This information will be used to ensure alignment between the conceptual model and the hydrologic model.

Both steady-state and transient recharge estimates will be developed, covering periods with available climate data. These estimates will be compared with groundwater-level trends and hydroclimatic analyses (Task 5.1) to determine how climate-driven recharge changes relate to the magnitude and timing of observed groundwater-level declines (Objective 2).

Task 4.1.2: Recharge from streams

Recharge from stream channels will be assessed using (i) surface water balance analyses between gaged locations, (ii) seasonal seepage runs, and (iii) streambed temperature monitoring. These analyses will be supported by water chemistry, isotopic tracers, and carbon-14 dating to confirm the occurrence and spatial extent of stream losses. Results will be interpreted within the context of the hydrogeologic framework (e.g., whether mapped CRBG units and structures provide plausible pathways for stream losses) and the riparian vegetation assessment (Task 2.11) to evaluate whether observed temporal and spatial patterns of losses are consistent with riparian ET demands, recharge to CRBG aquifers, or both.

Monthly or seasonal surface water balances between gaged sites will be developed from streamflow records and measurements of all surface water withdrawals from Eightmile and Fifteenmile Creeks. Withdrawals will be measured by flow meters (for direct pump withdrawals) or temporary gages (for significant ditches) and combined with historical monitoring of diversions and irrigation practices observed by the watermaster. Withdrawal measurements will be integrated with consumptive use estimates from OpenET and data from the Riparian Vegetation Assessment (Task 2.11) to identify and quantify groundwater recharge from stream losses at the gage-network scale. Quarterly seasonal seepage runs will provide a higher spatial resolution snapshots of these exchanges.

Streambed temperature profiling will be used to evaluate vertical thermal gradients, providing additional estimates of the direction and magnitude of surface water-groundwater exchanges, following established methods (Hatch et al., 2006; Constantz, 2008; Irvine et al., 2017). Seasonal deployments of one to three weeks will be conducted quarterly. The resulting profiles will complement seepage-run data and improve understanding of vertical exchange processes.

Together, these analyses provide reach and watershed-scale estimates of stream-derived recharge and help clarify where and how stream losses may contribute to CRBG aquifer(s) recharge. They will also directly inform Objective (3) by distinguishing stream losses primarily recharging CRBG aquifers from those more closely associated with riparian ET, thus clarifying the subsurface contribution to low flows and episodic desiccation in lower Fifteenmile Creek.

Task 4.1.3: Recharge from irrigation

Given the current understanding of the hydrogeologic framework, it is unlikely that irrigation activities contribute significant recharge to the CRBG aquifers. Nevertheless, irrigation-related recharge (see Task 2.10) will be evaluated by analyzing the difference between measured surface water diversions (or pumped groundwater volumes) and crop water use, with the residual partitioned among (i) wind drift, (ii) shallow irrigation returns (to surface water), and (iii) deep percolation to groundwater. Partitioning will be informed by streamflow data from gages and seepage runs, and specific conductance (SC) data. Water chemistry, isotopic tracers, and age dating will further distinguish deep percolation (item iii) between shallow (basin-fill and near-surface CRBG) and deep CRBG groundwater recharge. Results will be interpreted in the context of the hydrogeologic framework (e.g., stratigraphic units and associated hydraulic properties from Tasks 3.3 and 3.6).

At the watershed scale, these analyses will help constrain the potential contribution of irrigation related recharge. At the aquifer compartment scale, they will provide context for interpreting lumped recharge estimates where irrigated areas intersect permeable zones of specific aquifer units. By assessing the magnitude and pathways of irrigation-related recharge (and return flows), this task will clarify whether changes in irrigated agriculture (Task 2.10) could be contributing to groundwater-level declines and streamflow changes (Objectives 2 and 3).

Task 4.1.4: Recharge from commingling wells

Commingling wells can vertically redistribute groundwater between aquifers and aquifer compartments, serving as a source of recharge to some units and a source of discharge from others. At the watershed scale, commingling fluxes primarily represent internal redistribution within the CRBG system, rather than new recharge from outside the groundwater system. Therefore, commingling wells will not be explicitly evaluated at the watershed scale water budget.

At the aquifer-compartment scale, commingling fluxes can be a significant recharge (for “receiving” units) or discharge (for “donor” units) term in water balances. This recharge into a receiving aquifer from a donor aquifer is implicitly included in the lumped recharge term (see aquifer scale description in Task 4.1). Therefore, commingling wells will be addressed in Task 4.2.5 (as a discharge mechanism from donor aquifers), with those results incorporated into compartment-scale recharge estimates (Task 4.1) and groundwater-level trend analyses (Task 5.1).

Task 4.2: Groundwater Discharge

Groundwater discharge in the study area occurs through four primary mechanisms: pumping withdrawals, discharge to streams and springs, direct use by phreatophytes, and internal redistribution via commingling wells. Both steady state and transient (time series) estimates of these discharges will be developed for periods that match the available data sets.

Groundwater discharge will be evaluated at both the watershed and aquifer (or aquifer compartment) scales. At the watershed scale, Tasks 4.2.1-4.2.4 will quantify discharge by mechanism (pumping, streams, springs, and phreatophyte ET). This will complement recharge estimates from Task 4.1 and help close the basin-scale groundwater budget. These data, when interpreted alongside the hydrogeologic framework (Task 3) and the hydraulic-property estimates (Task 3.6), will also be used to calculate discharge from individual aquifers, and where, feasible aquifer compartments. To avoid double counting, the phreatophyte discharge term (Task 4.2.4) will be constructed to exclude locations where phreatophyte ET is already used as a proxy for spring discharge (Task 4.2.3 and Task 2.5.2). Compartment-scale discharge estimates will be combined with compartment-scale storage changes (Task 4.3) to infer compartment-scale recharge.

To identify discharge areas and quantify groundwater discharge, the study will rely on groundwater flow metering data and derived pumping estimates, baseflow calculations from gaged streams, identification of gaining reaches through seepage runs and streambed temperature profiling (Task 1.4 and 2.0). As with groundwater recharge quantification (Task 4.1), geochemical and isotope analyses (Task 2.7) will be incorporated to aid interpretation, as detailed in the following sub tasks. The hydrogeologic framework and flow-system evaluation tasks will provide essential supporting information—such as aquifer stratigraphy and hydraulic gradients—to help constrain and validate the location and volume of groundwater discharge.

Together with recharge estimates (Task 4.1), these independently derived discharge terms will be used to construct groundwater budgets at both the watershed and aquifer (or aquifer compartment) scales, directly linked to observed changes in groundwater levels. The budget analysis will assess the relative impact of pumping, commingling (at the compartment scale), discharge to streams and springs, and phreatophyte ET—together with recharge estimates—on groundwater level changes and highlight areas where additional data or revisions to the conceptual model may be necessary. In this way, Task 4.2 helps refine the conceptual groundwater model (Objective 1) and connects specific discharge mechanisms to the groundwater-level declines and streamflow depletion described in the Detailed Problem Statement (Objectives 2 and 3).

Task 4.2.1: Estimate discharge from groundwater use

Water-use data will be collected to quantify groundwater withdrawals for irrigated agriculture and municipal purposes across the watershed (see Task 2.9). This information will be integrated with remote sensing–based ET estimates to support water budget development and enable spatially distributed estimates of pumping and consumptive use.

Withdrawals will be estimated using both historical flow meter data (from a subset of historically monitored irrigation wells) and current data from a comprehensive deployment of new flow meters on all irrigation wells in the study area during the study period (Task 2.9). Data collection will occur monthly to quarterly to characterize major extractions across the groundwater flow system. At the watershed scale, these records will provide total pumping discharge from CRBG aquifers. At the compartment scale, wells will be assigned to aquifer compartments defined in Task 3; so that pumping can be allocated to individual compartments for compartment water balances.

Evapotranspiration from irrigated agriculture will be derived from remote sensing datasets and methods such as those developed by Huntington et al. (2025). The ET time series, spanning 1984 to the present, will be used to analyze both spatial and temporal patterns of consumptive use.

These detailed pumping estimates serve as a primary stressor in the groundwater system and will be compared against groundwater-level trends (Task 5.1) and storage changes (Task 4.3) to evaluate the relationship between groundwater use and the magnitude, timing, and spatial distribution of groundwater-level declines (Objective 2) and to assess the contribution of groundwater use to low-flow and dry-reach conditions in Fifteenmile and Eightmile Creeks (Objective 3).

Task 4.2.2: Estimate discharge to streams

Groundwater discharge to streams will be quantified using the same methods as the recharge-from-stream analysis (Task 4.1.2), but with a focus on gaining reaches and baseflow contributions. Efforts to quantify baseflow using multiple methods will be made to help estimate the magnitude and variability of baseflow contributions to streamflow, providing an indicator of groundwater discharge to the stream network upstream of gages. Continuous specific conductance (SC) monitoring at three gaging sites—two in the upper watershed and one near the mouth of Fifteenmile Creek—will be collected and analyzed for baseflow using endmember mixing analysis. PRMS (or an equivalent approach) will be used to estimate baseflows in ungaged basins and to extend baseflows estimates in gaged basins beyond the observed record, making discharge estimates available for various analysis periods. Additional SC and temperature readings will be collected from springs, wells, and other stream gaging and measurement sites throughout the watershed, supplementing continuous data and providing broader spatial coverage for interpreting baseflow contributions and seasonal groundwater discharge and recharge patterns.

To differentiate groundwater discharge to streams originating from CRBG versus other sources (such as Dalles Formation or quaternary alluvial sources), analyses will be interpreted in the context of the hydrogeologic framework (Task 3.0) and SC, major-ion chemistry, isotopic signatures, and age-tracer data (task 2.7). A broader synthesis of flow paths, residence times, and connectivity using these datasets will be conducted in the Flow-System Evaluation (Task 5.0).

At the watershed scale, these analyses will quantify total groundwater discharge to streams. At the compartment scale, analyses will be apportioned to aquifer units (or compartments) as determined by the flow-system evaluation and hydrogeologic framework. In combination with Tasks 5.1–5.4, these discharge-to-stream estimates will directly support Objective (3) by quantifying how much of the observed low-flow behavior, including losing reaches and episodic desiccation, can be attributed to changes in groundwater contributions from CRBG aquifers versus other sources.

Task 4.2.3: Estimate discharge to springs

Discharge from springs, though generally low in CRBG terranes, will be assessed as outlined in New Data Collection Tasks 2.5.1 and 2.5.2. Results will be summarized in tables showing average annual groundwater discharge to springs for each aquifer compartment (see Task 2.5 and 3.6). These estimates will inform both watershed-scale and, when integrated with the hydrogeologic framework, compartment-scale water balances.

The relationship between measured discharge and spring-adjacent phreatophyte ET from remote sensing sources (e.g., OpenET) over the study period will be used to estimate historical spring discharge prior to the study period. Phreatophyte ET associated with discrete spring-fed areas (e.g., hillslope phreatophytes clearly tied to mapped spring vents) will be included in the spring-discharge term, not as a separate phreatophyte-discharge component (see Task 4.2.4), to prevent double counting in the groundwater budget.

Historical investigations will also be reviewed and synthesized to provide estimates of historic spring discharge, including work by Grady (1983), Piper (1932), Newcomb (1960s), OWRD seepage runs (LaMarche and Wood, 2011), water chemistry sampling by OWRD and ODEQ (2013), and records from the Neal Spring interference complaint (Norton, 1999). Due to historic complaints and observations involving springs (e.g., Norton, 1999), these reconstructions are especially important for evaluating groundwater contributions to baseflow in lower Fifteenmile Creek and for testing whether reductions in estimated spring discharge are consistent with documented groundwater-level declines (Objectives 2 and 3).

Task 4.2.4: Estimate discharge to phreatophytes

Groundwater discharge from CRBG aquifers via evapotranspiration is another component of the budget, though the spatial extent is expected to be limited. The study area lacks extensive wetland complexes; most phreatophytes are found (i) in discreate patches along hillslopes near individual spring vents, or (ii) as narrow riparian corridors along stream channels.

Phreatophyte ET associated with known springs is captured by spring discharge methods. Therefore, Task 4.2.4 will focus on phreatophyte zones (e.g., riparian corridors, hillside phreatophytes not located near mapped spring vents) where geologic mapping suggests CRBG discharge is occurring

For riparian phreatophytes, groundwater discharge from CRBG aquifers is expected only where CRBG interflow zones are mapped at or near land surface (Task 3.0). In other reaches, riparian vegetation is likely sustained by local shallow alluvium or surface water rather than deep CRBG units. Reaches where riparian ET could be plausibly supported by CRBG discharge will be identified using information from geologic mapping (Task 3.0), the flow-system evaluation (Task 5), and seepage, temperature, and chemistry analyses.

Monthly riparian ET will be estimated using remote sensing and other methods within delineated stream reaches (see Task 2.11). Reaches will be categorized as gaining, neutral, or losing. Vegetation type and density within these reaches will be characterized using datasets such as NAIP and LANDFIRE, and field-verified where feasible and resources allow. These data will support estimates of riparian consumptive use supported by groundwater (CRBG aquifers), quantifying the corresponding groundwater-discharge term in the water budget and evaluating its contribution to reach-scale streamflow depletion.

At the watershed scale, riparian ET will be treated as a discharge component from the CRBG system where the hydrogeologic framework, flow-system evaluation, and riparian vegetation assessment (Task 2.11) indicate groundwater is the dominant water source. At the aquifer compartment scale, phreatophyte discharge will be included in water balances only where the hydrogeologic framework confirms a plausible hydraulic connection between CRBG aquifers and mapped phreatophyte zones. By distinguishing phreatophyte-supported discharge from CRBG aquifers from shallow-alluvial or surface-water–supported ET, this task will help assess stakeholder concerns that riparian restoration and increased riparian ET may be contributing to reach-scale losses and desiccation (Objective 3).

Task 4.2.5: Estimate discharge from commingling wells

At the watershed scale, commingling wells represent internal water redistribution rather than net discharge from or recharge to the CRBG groundwater system. Therefore, commingling wells do not constitute a separate external discharge term in the basin-wide budget (see Task 4.1.4).

At the aquifer-compartment scale, however, these fluxes can be an important discharge term for “donor” aquifers. Since recharge into receiving aquifers is already implicitly captured in the lumped recharge term derived from compartment-scale water-balance analyses (Task 4.1), the primary focus here is on additional discharge from donor aquifers resulting from inter-aquifer leakage through commingling wells.

Where feasible, the study will (i) identify potential commingling wells from construction records and water-level behavior, (ii) evaluate vertical head differences and possible cross-borehole flow using targeted water-level logging and, where possible, borehole geophysics, and (iii) develop screening-level estimates of net inter-unit flux attributable to commingling. Additionally, geochemical and age-dating information (Task 2.7) will support interpretations of vertical mixing between aquifers connected by commingling wells.

The resulting commingling-discharge estimates will be explicitly incorporated as a discharge component for donor aquifers in compartment-scale water budgets under Task 4.2 and used alongside compartment-scale storage changes (Task 4.3) and groundwater-level trends (Task 5.1). This will determine whether inter-aquifer leakage through commingling wells is a plausible driver of the “excessive declines” identified in the Detailed Problem Statement (Objective 2), and assess its importance to declines relative to pumping, climate-related recharge changes, and other discharge mechanisms.

Task 4.3: Groundwater Storage Changes

Changes in groundwater storage will be estimated from water-level measurements and aquifer properties within defined aquifer units (Task 3.6). Storage changes provide a quantitative bridge between groundwater-level trends (Task 5.1) and the recharge and discharge terms of the water budget (Tasks 4.1 and 4.2).

Where data allow, storage changes will be delineated by aquifer compartment and used with groundwater discharge (measured and estimated) to infer recharge (recharge = change in storage + discharge). Compartment-scale storage estimates will be summed and compared to watershed-scale CRBG recharge and discharge estimates (Tasks 4.1 and 4.2) to evaluate general consistency in magnitudes. Given the compartmentalized nature of typical CRBG systems, these comparisons will serve as a coarse consistency check and be interpreted within the context of the hydrogeologic framework and flow-system evaluation, including geochemistry, age-dating, and isotope analyses.

Storage changes link directly to the observed groundwater-level declines described in the Detailed Problem Statement. In this way, Task 4.3 plays a central role in addressing Objective (2).

Additionally, by testing whether inferred recharge and discharge patterns align with observed storage changes, Task 4.3 helps refine the conceptual groundwater model (Objective 1).

Task 5.0 Flow-System Evaluation

The groundwater flow system will be evaluated through an integrated approach that combines groundwater elevation and hydroclimatic time-series data, geochemical and isotopic analyses, interpretations of both vertical and horizontal hydraulic gradients, and assessments of groundwater–surface water interactions. This comprehensive methodology will characterize basin-wide groundwater behavior, quantify key flow pathways, and identify influential factors thereby advancing the conceptual groundwater model outlined in Study Objective (1). Together with the hydrogeologic framework (Task 3) and groundwater-budget assessment (Task 4), this work will clarify how groundwater moves through the subsurface, interacts with surface water, and responds to both natural and anthropogenic influences.

Findings from the flow-system evaluation will be interpreted alongside those from the hydrogeologic framework (Task 3) and groundwater budget assessment (Task 4),and will be used to: (i) determine if observed head patterns, age distributions, and flow paths align with estimated recharge, discharge, and storage changes; (ii) identify where structural or stratigraphic features create distinct aquifer units or compartments; and (iii) assess the impacts of pumping, climate variability, and other stressors on groundwater levels and streamflow depletion. In this way, Task 5.0 serves as a key integrative step to evaluate the relative roles of groundwater development, climate variability, and natural hydrologic processes in driving aquifer responses and streamflow depletion (Objectives 2 and 3).

Task 5.1: Groundwater Level and Hydroclimatic Trends

This task will analyze how groundwater levels across various aquifer units or compartments (defined in Task 3.3) respond seasonally, annually, and over multiple years to factors such as precipitation, snowmelt, total potential CRBG groundwater recharge (as estimated from PRMS or similar approach), evapotranspiration or atmospheric evaporative demand, streamflow (including baseflows), and pumping patterns. These insights will help distinguish natural fluctuations from anthropogenic impacts on groundwater levels throughout the watershed.

Results from this task will guide the selection of analysis periods for the groundwater-budget (Task 4.0), support calculations of storage changes (Task 4.3), and provide a direct link between observed groundwater-level declines (highlighted in the Detailed Problem Statement) and the stressors analyzed in Tasks 4.1, 4.2, and 4.2.5. Thus, Task 5.1 directly supports Objective (2) by evaluating how hydroclimate variability relates to observed groundwater declines.

Task 5.2: Geochemistry and Groundwater Age Dating

The study will evaluate isotopic tracers, age-dating indicators, and major chemical constituents in both groundwater and surface water (Task 2.7). These data, interpreted in the context of the hydrogeologic framework (Task 3.0), will provide estimates of aquifer residence times, constrain possible recharge locations, and inform delineation of groundwater flow paths. This deeper understanding will reveal how water moves through and is stored within the hydrogeologic framework.

Comparisons of age distributions with inferred recharge rates (Tasks 4.1 and 4.3), and discharge pathways (Tasks 4.2.2–4.2.5) will test the accuracy of the conceptual groundwater model (Objective 1) and the hypothesized causes of declines and streamflow depletion (Objectives 2 and 3) against independent geochemical evidence. For example, if age-dating indicates minimal or no modern water in an aquifer, then changes in modern recharge are unlikely to explain observed declines, making pumping and/or inter-aquifer leakage more probable contributors. Additionally, estimates of recharge from precipitation (Task 4.1.1) should be interpreted with respect to age distributions, and any mapped potential groundwater pathways from recharge areas (identified in Task 3.0) should be reexamined where they conflict with geochemical results.

Task 5.3: Assess Vertical and Horizontal Flow Direction

Groundwater occurrence and movement will be further characterized using potentiometric surface maps (developed in Task 3.5), which illustrate vertical and horizontal hydraulic gradients and flow directions within and between hydrostratigraphic units and across structural or stratigraphic boundaries. These interpretations will help identify recharge and discharge areas, as well as potential barriers or conduits within the aquifer system.

In combination with hydraulic-property estimates from Task 3.6, these gradient analyses will be used to estimate the direction and relative magnitude of groundwater fluxes between compartments, supporting the compartment-scale water-budget analyses (Tasks 4.1 and 4.3). Task 5.3 thereby connects the structural and stratigraphic framework (Task 3.0) with quantitative groundwater-budget estimates (Task 4.0), refining the conceptual model (Objective 1) and clarifying the pathways along which pumping stresses and inter-aquifer leakage propagate (Objective 2).

Task 5.4: Evaluate Groundwater/Surface-water Interactions

As introduced in Task 4.0, groundwater–surface water interactions will be assessed through a multi-faceted approach that integrates hydrologic, geochemical, and temperature-based methods to analyze the spatial and temporal variability of hydraulic connectivity throughout the watershed. This evaluation will utilize streamflow and spring monitoring, water-use data, seepage runs, streambed temperature profiling, and water chemistry analyses.

By synthesizing these complementary datasets, the study will characterize gaining and losing stream reaches, identify the direction and magnitude of groundwater–surface water exchanges, and quantify the potential impacts of groundwater withdrawals on streamflow. The analysis will be strengthened by integrating stratigraphic and structural information from the hydrogeologic framework (Task 3.1–3.4), which will help pinpoint reaches hydraulically connected to underlying aquifers and reveal potential barriers or conduits to exchange. Additionally, information from the water-budget development (Tasks 4.1–4.2), and riparian vegetation assessment (Task 2.11) will provide context, helping to constrain the plausible magnitude and timing of discharge to and from the stream network. Collectively, these analyses will clarify where and when CRBG aquifers support baseflow, where stream losses likely recharge CRBG aquifer units, and where riparian ET or shallow alluvial processes dominate, directly supporting Objective (3) and illuminating subsurface contributions to low flows and episodic desiccation described in the Detailed Problem Statement.

Project Coordination, Data Management, & Quality Assurance

Project Coordination

Roles and responsibilities will primarily follow the Department's organizational structure but will be refined to reflect each team member's training, expertise, experience, and interests. Responsibilities for each task and sub-task will be captured in a RACI (Responsible, Accountable, Consulted, and Informed) matrix maintained and tracked alongside the project Gantt table/chart. Each task will have a single Accountable owner, with Responsible staff clearly identified and Consulted and Informed parties listed to ensure timely input and communication.

To execute the work efficiently, the project will organize functional sub-teams aligned with the major tasks described in this plan (e.g., ET and Water Use, Hydrogeologic Framework, Water Budget Development, Field Data Collection, etc.). Sub-teams will meet regularly to coordinate field and analytical activities, monitor progress against milestones, manage dependencies, and adapt to evolving analyses, priorities, and constraints. Action items, owners, and due dates will be documented in a shared tracker, and significant decisions will be recorded in a project decision log.

A Project Management Team (PMT) will be formed consisting of groundwater hydrology, surface-water hydrology, and field services leads; the Groundwater Manager, Surface Water Assistant Manager, and the FSD-NCR Manager; and the Senior Water Advisor and Community Engagement Coordinator from the Planning, Collaboration, and Investments Section. The PMT will meet bi-weekly during the first 6-9 months, then less frequently under an adaptive management approach. The PMT will set and refine project scope, objectives, and deliverables; allocate staff and budget; manage risks and issues; and approve major changes to the study. The Project Manager will be the Senior Water Advisor and will be accountable for overall project delivery. Technical leads will be responsible for the quality and integration of the various deliverables of their respective workstreams.

Project-wide team meetings will also be scheduled to support cross-team coordination and communication of recently completed work, upcoming tasks, and strategic planning needs. These meetings will initially occur monthly and be adjusted as needed under adaptive management principles.

Project outreach to tribal government(s), local communities, landowners, organizations, and partner agencies will be coordinated by the Community Engagement Coordinator in collaboration with the PMT and the Hood River Basin (District 3) Watermaster and Assistant Watermaster. For outreach to individual landowners regarding data-collection activities, the PMT will coordinate with the Watermaster and Assistant Watermaster—who will lead those contacts when appropriate. The district 3 Watermasters will always be informed of the purpose, timing, and locations of any field data collection-activity before it occurs.

Quality Assurance / Quality Control (QA/QC)

The purpose of QA/QC in this study is to ensure that all measurements, samples, analyses and model results are accurate, traceable, and reproducible. Procedures will promote consistent accepted methods across locations and seasons; quantify and communicate uncertainty for key estimates (e.g., discharge, baseflows, groundwater elevations, head gradients); and maintain a transparent audit trail from raw observations to published results.

QA/QC governance and roles will follow the project's organizational structure. Staff designated as Accountable for individual tasks are responsible for method-specific QA/QC within their workflows, with Responsible staff executing procedures as documented. Core documentation will include method-specific SOPs or internal memos, instrument calibration and maintenance logs, sampling plans, data dictionaries and metadata templates, and field/processing checklist. All materials will be stored and archived per the data management plan.

Measurement of stage and discharge at gaging stations will be conducted according to OWRD operating procedure and USGS Techniques and Methods, Book 3, Chapters A7 & A8 (Turnipseed and Sauer, 2010) and USGS Water-Supply Paper 2175 (Rantz et al., 1982). These methods require the maintenance of a permanent vertical gage datum by levels to ensure accuracy of primary and auxiliary gages for routine comparison with the stage sensor. If the stage sensor is found to be outside of acceptable error tolerance when compared to the primary gage, corrections will be applied to the stage record at the date and time of observation and prorated between site visits. When measuring discharge, check measurements will generally be required when the rating table indicates an abnormally large shift or more specifically, an indicated shift of greater than the uncertainty of the discharge measurement (generally, 5%) that does not follow the recent trend of departures from the rating. Discharge ratings and time series will be computed using established OWRD methods and from USGS Techniques and Methods, Book 3, Chapter A10 and A13 (Kennedy, 1983; Kennedy, 1984).

The target data-quality rating for all published streamflow records is "good", which estimates that 95% of the values are within 10% of the true value (Rantz et al., 1982). Deviations will be noted and discussed in a timely manner with Accountable staff and addressed with corrective actions whenever possible. Chronic deviations from the accuracy target will be elevated for discussion with the study leads and reviewed in the context of the monitoring and analysis objectives.

For seepage runs, measurements will be conducted from upstream to downstream with travel times considered to minimize effects of unforeseen flow variations or water management changes. Zero-flow observations in tributaries and return ditches will be documented on standard measurement forms, with latitude and longitude locations recorded to fifth decimal place and processed per standard measurement workflow. Diversions, if on, will be measured using flow meters or other appropriate techniques and documented on standard measurement forms. For miscellaneous and gage site measurements, USGS/OWRD protocols will be used with a target single-measurement uncertainty of +/- 5% whenever channel and flow conditions allow.

Departures and causes of deviations (e.g., narrow channels, poor velocity distribution, macrophyte growth, etc.,) will be recorded on standard measurement forms.

For continuous SC monitoring, guidance from USGS Techniques and Methods 1-D3 and USGS Techniques and Methods 9-A6.3 will be applied. SC meters at gaging sites (i.e., "SC site-meters" will be checked for calibration error before deployment with multiple calibration standards that cover the expected range of known SC values. If SC meters are found to be outside of +/- 5 µS/cm for readings below 100 µS /cm or greater than +/- 3-percent for readings above 100 µS/cm, a one-point calibration will be required using the calibration standard closest to the expected value and followed by a two-point calibration check in two additional solutions. Routine monthly inspections will be made to compute calibration drift and fouling corrections following methods described in OWRD SOP (being drafted) and USGS Techniques and Methods 9-A6.3 and 1-D3. Similarly, manual readings using hand-held SC meters will be made at all miscellaneous following protocols describe in OWRD SOP (being drafted). All hand-held meters will be checked against calibration standards before making readings.

Streambed temperature sensors will be checked to ensure they are in working order and sensors will be set to a future start to ensure recording happens after deployment. A brief memo will be written describing the methods of streambed heat tracing using diurnal temperature signals along with details on installing temperature sensors into rods, rod deployment, data extraction and processing. It will also summarize the analytical approaches (e.g., amplitude-ratio and phase-shift methods) used to infer vertical groundwater–surface water exchange from temperature time-series data. A formal reference to this memo will be included in the final project documentation once completed.

QA/QC for general chemistry and isotope sampling will follow a written sampling plan that specifies sampling methods, bottle types, preservatives, filtration, and handling. Field duplicates, blanks, and equipment rinsates will be collected at defined frequencies recommended by contracted laboratories to assess precision and contamination risks. Chain-of-custody forms will accompany all samples to accredited laboratories, and laboratory QA documentation, detection limits, and qualifiers will be preserved with the analytical results. Field measurements of temperature, SC, and pH will be recorded with each sample to aid data validation and mass-balance checks. If necessary, collected samples will be stored at conditions required to preserve analytes before they can be sent to laboratories. For example, water samples for alkalinity, water stable isotopes, and radiocarbon dating will be kept at approximately 4 °C until analysis (Johnson et al., 2024).

Quality control for stable isotope sampling will follow procedures outlined in the supporting information document for Johnson et al., 2024. This includes collecting field replicates at select sites during each sampling round and evaluating the absolute difference and relative percent differences of samples submitted to contracted laboratories.

The PRMS (or equivalent watershed model) will be built, calibrated, and documented according to modeling community best practices. Because recharge from precipitation is difficult to quantify, the "true" value remains unknown. As a result, accurate simulation of other key water budget components is critical for building confidence in recharge estimates produced by a watershed model. Simulated groundwater discharge will be evaluated against available baseflow estimates using standard hydrologic goodness-of-fit metrics. Runoff will be similarly evaluated against available stream gaging data. Simulated ET and snow metrics (SWE, covered area, or similar) will be evaluated using available gridded datasets (e.g., OpenET) that have been vetted against available observational station data (e.g., weather station, Eddy-covariance towers, SNOTEL sites). Finally, modeled recharge estimates will be evaluated against independent estimates of recharge from existing studies, gridded datasets, and empirical estimation methods to assess the reasonableness of the modeled values. Other calibration and evaluation methods may also be used depending on input from expert modelers.

Both quantitative and qualitative goodness-of-fit metrics will be documented to report the accuracy of model results and discuss any inherent limitations or areas for future improvement. Where feasible, ensemble runs will be used to identify influential parameters (sensitivity analysis) and to characterize the range of uncertainty in model outputs given the range or reasonable parameters provided to the optimization algorithm (uncertainty analysis). The calibrated model, all supporting data, and any model scenario runs (e.g., scenarios modeled to evaluate the effect of different climate conditions on recharge) will be archived such that model runs are independently reproducible.

Remote-sensing ET from OpenET will be reviewed and compared with meter-based data to assess uncertainty and reasonableness. All ETa, CU and AW estimates will undergo routine QA/QC checks, including manual or automated screening for inconsistencies, comparisons to field knowledge and landowner practices, bias checks against metered data, and comparisons to published benchmarks for similar landscapes, crops, and irrigation methods. NDVI/EVI will provide phenology baselines and context to support QC of ETa. Data will be archived under OWRD data-management and publication protocols.

Uncertainty will be quantified and reported at each step, in units appropriate to the method. Seepage-run reach balances, chemical hydrograph separation and water-budget components will include propagated uncertainties whenever possible so that comparisons and management decisions reflect realistic confidence intervals. When quantitative analyses are not possible, qualitative assessments will be made. Outliers will be flagged but not deleted and any exclusions from analyses will be documented with the appropriate objective criteria.

QA/QC reporting will be integrated into project management. Routine reviews will be conducted by Accountable staff at appropriate agreed-upon intervals to ensure protocols are being followed and accuracy goals are being met, and corrective actions are taken in a timely manner. Accountable staff will communicate results from the review to the team leads and PMT. Major technical deliverables will undergo an internal peer review that checks methods, assumptions, and uncertainty characterizations. Staff training on SOPs, calibration, chain-of-custody, and note-keeping/documentation will be covered before data collection activities begin and prior to the start of the main work tasks identified in this plan.

The QA/QC program is designed to be practical and proportionate. It emphasizes consistent techniques, clear documentation, and routine reviews and communications to PMT that directly supports the study's analytical tasks.

Peer Review

All documents produced during this study (reports, memoranda, journal articles, etc.) will be reviewed according to applicable departmental guidance for peer review. Additionally, an individualized review plan for all products from this report will be developed and adhered to. Reports and memoranda will receive, at minimum, two peer reviews by independent scientists with the appropriate expertise to evaluate and contextualize the methods, assumptions, interpretations, and conclusions of each product. Highly interpretive and/or highly impactful products will also be subject to external peer review according to the process laid out in the project's review plan.

Data Management Plan

A data management plan (DMP) serves to identify and organize project needs and products and to promote the reproducibility of project analyses. A DMP works to ensure that all data collected, compiled, and generated for the study are consistently organized, documented, stored, published, and preserved so they can be traced from raw measurements to published products and analysis, and reused in future analyses.

A **detailed DMP will be developed as the project details are finalized**. The descriptions below are a draft, abbreviated, summary of data types and products that will be addressed by the DMP. what will be included in this plan.

Data Types

Data to be utilized in the project include data originating from within OWRD and data from external sources, as well as primary and secondary data. Anticipated data types include:

- Hydrologic time series data: streamflow, stage, specific conductance, water and streambed temperature, groundwater levels, and stream gage derived gain/loss calculations.
- Discrete hydrologic data: streamflow, stage, specific conductance, water temperature, groundwater levels, and seepage run derived gains/losses
- Water-use data: flowmeter records, water-rights and related attributes, ET spatial and time series estimates including effective precipitation; ETa; consumptive use and applied water.
- Geologic and hydrogeologic data: geologic maps, well logs, borehole geophysics, aquifer-test results, hydrostratigraphic interpretations.
- Geochemical and isotopic data: major ions, tracers, stable isotopes, tritium, carbon 14
- Spatial (GIS) datasets: springs and site locations, riparian mapping, aquifer compartments, reach delineations, static-watershed parameters (e.g., land cover, soils, etc.)
- Watershed analysis data: water-budget calculations, baseflow estimates, regression and other statistical analysis.
- Project documentation: field notes, SOPs, QA/QC records, decision logs, draft/final figures and tables.
- Modeling datasets (inputs, outputs, associated model code, model runs)

Data organization and storage

Working data will be organized and stored into established existing databases where appropriate (e.g., continuous streamflow data will be stored in WISKI). For data that does not fit into existing databases, the data will be organized into a shared directory structure on OWRD's SharePoint network with permissions aligned with project assigned roles. The structure will distinguish raw data (e.g., from the field or from external sources), processed data (QA/QC'd, transformed, aggregations, disaggregation, modeled inputs, etc.), derived products (seepage runs, model outputs, maps/figures), and documents (methods, metadata, data dictionaries, change/decisions logs, QA/QC logs). The main structure will generally follow the data types described above. A README will be created for each main sub-directory by the assigned Responsible team member describing the directory structure, data types, version control, and metadata.

Naming conventions and identifiers

Consistent naming conventions will be used for fields, fields, and feature classes to support integration across tasks. Key elements include:

- Unique location identifies for flow meters, monitored wells (elevations), springs, gaging, miscellaneous measurements, and other spatial observations consistent with OWRD conventions.
- Standardize field names for key attributes (e.g., site_id, datetime, parameter, value, units, methods, qualifiers, field notes, etc.)
- File names reflect content, version, and date (e.g., Fifteenmile_SeepageRunV2_12.04.2025)
- Specialized schemas will be documented

Archive and publication

All study data, documentation, and model artifacts will be archived in a manner that preserves data from raw observations to published products and enables long-term reuse following any applicable OWRD file management and archival guidelines and guided by USGS Scientific Data Management Policies (Conn and others [2019] and in USGS Instructional Memos 2015.1 through 2015.4 [USGS, 2015a-d] for work not covered under OWRD policies. Archiving will follow the project's directory and metadata conventions described above and will be coordinated by the Accountable lead for each task, with final review by the appropriate study lead (GW, SW, or FSD) and the Data Management lead.

Project Deliverables, Timeline, and Resources

Products

The Fifteenmile Watershed Groundwater Study will produce a suite of reports, technical memoranda, fact sheets, data releases, maps, and outreach materials. Together, these products are intended to (1) document methods and results in a transparent, reproducible way; (2) provide a defensible basis for management and policy decisions; and (3) make core datasets and interpretations readily usable by OWRD staff and external partners.

The list below represents a preliminary assessment of the reports and/or memoranda that may be necessary to adequately document the study and make the results useable and available to interested parties. It may be revised as the study progresses, reflecting new information, emerging complexities, or shifts in study focus under an adaptive management strategy. As appropriate to enhance the credibility, longevity, and visibility of project results, some products may be published as journal articles. Final decisions on product type and publication venue will be made in coordination between primary authors, project managers, and project sponsors.

Reports

Conceptual Groundwater Model Report (Integrated Final Report)

The Conceptual Model Report serves as the study's final report which will synthesize results from the Hydrogeologic Framework (Task 3), Water Budget Development (Task 4), and Flow-System Evaluation (Task 5) into a single basin-wide conceptual groundwater model. The report will:

- Describe hydrostratigraphy, compartment geometry, hydraulic properties, and groundwater flow paths.
- Summarize recharge, discharge, and storage changes at watershed and aquifer (compartment) scales.
- Integrate geochemistry, age dating, and GW/SW interaction results
- Synthesize the assessment of hydroclimatic variability and trends, including groundwater recharge, groundwater elevations, streamflow, crop and natural ET, and baseflows.
- Explicitly address Study Objectives (1)-(3) and the Detailed Problem Statement, including clear discussion of the relative roles of pumping, commingling, climate, and riparian ET in driving groundwater-level declines and streamflow depletion.

This will be the primary technical basis for any subsequent management or policy decisions (e.g., Groundwater Administrative Area).

Hydrogeologic Framework Report

Documents the development of the hydrogeologic framework (**Tasks 1.2, 2.8, 3.0-3.6**). The report provides the physical template that the water-budget and flow-system analyses must honor. It includes:

- Compiled and interpreted geology, stratigraphy, aquifer, and confining units.
- Aquifer compartment boundaries and rationale.
- Geologic cross sections and potentiometric surface maps.
- Estimated hydraulic properties and inferred connectivity between compartments.

Water Budget Report

Summarizes the groundwater-focused water budget (**Tasks 1.4, 2.2–2.11, 4.0–4.3**). This report directly supports Objectives (1)– (3) and underpins the integrated conceptual model. It includes:

- Watershed-scale recharge, discharge, and storage changes.
- Nested budgets for key aquifers and aquifer compartments.
- Methods and uncertainty for recharge from precipitation, streams, irrigation, and commingling wells, as well as discharge via pumping, springs, streams, and phreatophytes.
- Evaluation of whether observed groundwater-level declines and streamflow losses are consistent with the quantified stresses.

Flow System Evaluation Report

Presents the integrated flow-system analysis (**Tasks 2.1–2.5, 2.7, 3.5, 4.2.2–4.2.5, 5.0–5.4**), including:

- Groundwater level and hydroclimatic trends.
- Vertical and horizontal gradients and inferred fluxes between compartments.
- Geochemical and age-dating interpretations of residence times, recharge areas, and flow paths.
- Groundwater–surface water interaction results, including gaining/losing reaches and timing/magnitude of GW contributions to streamflow.

The report will focus on whether head patterns, flow paths, and age distributions are internally consistent with the hydrogeologic framework and water budget.

Water Use Report

Summarizes groundwater and surface-water use in the basin (**Tasks 2.9–2.11, 4.2.1, 4.1.3**) including:

- Spatial and temporal patterns in irrigation and municipal use.
- ETa, consumptive use, and applied water estimates (remote sensing + meters).
- Reconstruction of historical groundwater and surface-water withdrawals over the ET record.
- Discussion of how water-use patterns relate to observed groundwater-level declines and streamflow behavior.

PRMS Modeling: Historic and Current Streamflow and Groundwater Recharge Estimates

- Recharge estimates, baseflow estimates for ungaged areas
- Results from scenario runs
- Published model (**Tasks 4.0, 4.1.1, 5.1**).
- Publicly accessible code
- Model development report documenting data, model configuration, calibration and uncertainty analysis, and performance metrics
- (Potential) Model interpretation report documenting output

Technical Memoranda

These memos will document methods, interim results, and detailed analyses that feed into the major reports. They may be published as standalone OWRD technical products, or appendices to the main reports, or combined (where appropriate) and made into a new main report and added to the list above.

- **GW/SW Interactions: Seepage Runs & Streambed Temperature Analysis**
  Methods, site selection, QA/QC, reach-by-reach gains/losses, vertical flux interpretation, and implications for recharge/discharge patterns (**Tasks 2.3, 2.4, 4.1.2, 4.2.2, 5.4**).
- **Hydroclimate Variability and Trends: Climate, Groundwater Levels, ET, and Streamflow**
  Statistical analysis of climate indices, ET, streamflow, and groundwater trends; evaluation of climate-related contributions to declines and low flows (**Tasks 1.1, 2.1, 2.10, 5.1**).

- **Geochemistry & Isotope Analysis: Groundwater Age, Recharge Rates, and Flow Path Inferences**
  Sampling design, lab methods, QA/QC, age distributions, recharge elevations/areas, mixing patterns, and consistency checks against storage and recharge estimates (**Tasks 2.7, 5.2**).
- **Riparian ET Assessment**
  Methods and results from the riparian vegetation and ET assessment, linkage to gains/losses and desiccation in lower Fifteenmile Creek (**Tasks 2.11, 4.1.2, 4.2.4, 5.4**).
- **Springs Assessment**
  Springs inventory, discharge measurements/estimates, compartment attribution, and implications for baseflow and groundwater budgets (**Tasks 2.5, 4.2.3, 5.4**).
- **Commingling Wells Assessment**
  Inventory of commingling wells, head differences, cross-borehole flow interpretations, flux estimates, and evaluation of their contribution to observed declines (**Tasks 2.6, 2.7, 3.3, 3.6, 4.1.4, 4.2.5, 5.1, 5.3**).

Additional shorter internal memos may document specific methods (e.g., streambed temperature analysis, PRMS QA/QC) as needed.

Fact Sheets

Short (2–3 page) accessible summaries for non-technical audiences. Develop in coordination with the Community Engagement Coordinator (from the OWRD PCI group). Likely topics include:

- **Flow System Evaluation and GW/SW Interactions**
  Where and how groundwater supports baseflow or contributes to stream losses and desiccation.
- **Hydrogeologic Framework**
  Basic explanation of CRBG aquifers/compartments, flow paths, and why the system is sensitive.
- **Water Budget**
  "Where the water comes from and where it goes" at watershed and compartment scales.
- **Water Use**
  Summary of irrigation and municipal water use trends and their relationship to declines.
- **Geochemistry and Groundwater Age**
  What geochemistry and age dating say about recharge rates and travel times.

Presentations

- **Interim Annual Progress Presentations (Years 1–4)**
  Internal and external updates on data collection, preliminary interpretations, and course corrections.
- **Topical Technical Presentations**
  Targeted talks on the hydrogeologic framework, water budget, flow-system evaluation, GW/SW interactions, commingling wells, and riparian ET—tailored for OWRD leadership, local stakeholders, and technical conferences.

- **Conceptual Groundwater Model / Final Synthesis Presentation**
  Integrated presentation summarizing the final conceptual model, key lines of evidence, and management implications (e.g., potential GAA designation).

Data Products and Releases

Data products will be compiled, QA/QC'd, and released in formats consistent with the project's data management plan, OWRD's data management and publication standards, including metadata and data dictionaries. Anticipated products include:

- Groundwater-level datasets (wells, time series, QA flags).
- Spring database (site table; measured and estimated discharge; methods; uncertainty).
- Seepage-run database (sites, conditions, measurements, uncertainty).
- Streambed-temperature datasets and associated processed flux estimates.
- Stream gage and specific conductance/temperature time-series extracts used in the analyses.
- Water-use and metering datasets (POD/POA/LID, monthly volumes, QA flags).
- Remote sensing ETa/CU/AW summaries and GIS layers for the basin.
- Flowmeter-based AW and remote sensing AW comparison
- PRMS (or equivalent) recharge outputs and model configuration files for defined periods of record.
- Geochemistry datasets (major ions, isotopes, age tracers, sampling metadata).
- GIS layers: aquifer compartments, hydrostratigraphic units, geologic cross sections, gaining/losing reaches, riparian ET zones, spring locations, and key monitoring sites.

Maps & Models:

- **Maps:**
    - Surficial geologic and hydrogeologic maps.
    - Aquifer compartment maps.
    - Potentiometric surface maps (local vs regional systems).
    - Gaining/losing reach maps and spring discharge maps.
    - Riparian ET/vegetation condition maps by reach.
- **Models:**
    - Calibrated PRMS (or comparable) watershed model(s), including selected input/output datasets and documentation (published)
    - Any additional simple analytical tools or spreadsheets developed for water-budget or flow-system evaluation (e.g., compartment-scale budget calculators).

General Timeline & Milestones

The project is anticipated to proceed through four main overlapping phases as shown in Table 1 below. A more detailed Gantt table is provided in the accompanying workbook, including RACI assignments and quarterly timelines.

Phase	Approx. Year	Primary Focus	Key Milestones / Deliverables
Phase 1 – Compilation, Initial Framework, and Monitoring Build-Out	26-27	Data compilation, initial hydrogeologic framework, monitoring and metering network build-out	•Finalize Workplan. •Complete literature and data compilation from previous studies (Tasks 1.0–1.4). • Establish/verify monitoring networks (Tasks 2.1–2.4, 2.9–2.11). • Complete initial geologic compilation and subsurface stratigraphy database (Tasks 3.1–3.2). • Draft aquifer-compartment and hydrostratigraphic-unit definitions (Task 3.3 – preliminary). • Initiate PRMS (or similar) set-up and preliminary calibration. • Finish stream gaging network buildout • Interim Progress Presentation #1. • Begin flow metering collection, seepage runs, streambed temperature monitoring, springs assessment, and riparian vegetation assessment. • Finalize water rights assessment, POD/POU mapping & relationships, field verification, initial SW & GW ETa data summaries, initial estimates of landscape ET.
Phase 2 – Hydrogeologic Framework & Intensive Data Collection	27-29	Complete framework, continue intensive data collection, begin budget and flow-system analyses	• Complete geologic cross sections, updated compartment mapping, and potentiometric surfaces (Tasks 3.3–3.5). • Initial hydraulic-property estimates compiled/refined (Tasks 2.6, 3.6). • First 2–3 years of seepage runs, streambed temperature, spring measurements, geochemistry, and metering data collected and QA'd (Tasks 2.2–2.7, 2.9–2.11). •Finalize riparian vegetation assessment • Technical Memos (draft): Riparian Vegetation Assessment, GW/SW Interactions – early results, Hydroclimate Trends – preliminary. • Hydrogeologic Framework Report – Draft. • Interim Progress Presentations #2–3 with emphasis on framework and early GW/SW findings.
Phase 3 – Water Budget & Flow-System Evaluation	28-30	Develop and refine groundwater budgets and flow-system interpretation; evaluate causes of declines and low flows	• Complete PRMS (or equivalent) calibration and core recharge/baseflow estimates (Task 4.1.1; PRMS Modeling Scope). • Watershed- and compartment-scale recharge and discharge estimates completed (Tasks 4.0–4.2). • Storage-change estimates by compartment completed (Task 4.3). • Flow-system evaluation tasks (5.1–5.4) completed and internally consistent with framework and budget. • Complete ET/WU-pumping & diversions relationships and historical estimates, • Technical Memos (draft): Springs Assessment, • Technical Memos: GW/SW Interactions (complete), PRMS Modeling, Hydroclimate Trends, Geochemistry & Isotopes, Riparian ET, Commingling Wells Assessment. • Water Budget Report – Draft. • Flow-System Evaluation Report – Draft. • Water Use Report – Draft. • Interim Progress Presentation #4 focusing on recharge/discharge/decline causality and GW/SW linkages.
Phase 4 – Integration, Synthesis, and Final Products	30-31	Integration of all lines of evidence into conceptual model; communication and policy support	• Integrate framework, budget, and flow-system results into coherent conceptual model (Objective 1). • Evaluate and document relative roles of pumping, commingling, climate, and riparian ET in declines and streamflow depletion (Objectives 2 and 3). • Conceptual Groundwater Model Report – Draft → Final. • Finalization of fact sheets and data releases (GW levels, springs, seepage, ET/ AW, geochemistry, GIS layers, PRMS outputs). • Final stakeholder / policy presentations summarizing key findings, uncertainties, and implications for potential management actions (e.g., GAA considerations, mitigation strategies). • Archiving of data, models, and documentation per the Data Management Plan.

Table 1: General Timeline and Milestones

References

Anderson, J.L., 2026a, Geologic map of the Emerson 7.5 minute quadrangle, Oregon, University of Hawaii, Hilo, Scale 1:24,000, unpublished map.

Anderson, J.L., 2026b, Geologic map of the Petersburg 7.5 minute quadrangle, Oregon, University of Hawaii, Hilo, Scale 1:24,000, unpublished map.

Anderson, J.L., 2026c, Geologic map of The Dalles South 7.5 minute quadrangle, Oregon, University of Hawaii, Hilo, Scale 1:24,000, unpublished map.

Bartholomew, W.S., 1975, Ground-water conditions and declining water levels in the Butter Creek area, Morrow and Umatilla Counties, Oregon: State of Oregon Water Resources Department Ground Water Report No. 24, 102 p., 5 pl.

Beamer, J. P., Huntington, J. L., Morton, C. G., & Pohll, G. M., 2013, Estimating annual groundwater evapotranspiration from phreatophytes in the great basin using landsat and flux tower measurements. JAWRA Journal of the American Water Resources Association, 49(3), 518-533. https://doi.org/10.1111/jawr.12058

Briggs, M. A., Lautz, L. K., Buckley, S. F., & Lane, J. W., 2014, Practical limitations on the use of diurnal temperature signals to quantify groundwater upwelling. *Journal of Hydrology, 519*, 1739–1751. https://doi.org/10.1016/j.jhydrol.2014.09.030

Clark, J.S., 2003, Fifteenmile Watershed Assessment. Prepared for Wasco County Soil and Water Conservation District. Accessed 11/24/2025. https://digitalcollections.library.oregon.gov/nodes/view/306180

GWMA, 2009a, A summary of Columbia River Basalt Group geology and its influence on the hydrogeology of the Columbia River Basalt aquifer system, Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties, Washington: Consultant report prepared for Columbia Basin GWMA, prepared by GSI Water Solutions, Inc., June 2009.

GWMA, 2009d, Groundwater geochemistry of the Columbia River Basalt Group aquifer system: Columbia Basin ground water management area of Adams, Franklin, Grant, and Lincoln Counties, Washington: Consultant report prepared for Columbia Basin GWMA, prepared by S.S. Papadopoulos & Associates, Inc. and GSI Water Solutions, Inc., June 2009.

Conn, K.E., Mastin, M.C., Long, A.J., Dinicola, R.S., and Barton, C., 2019, Data management plan for the U.S. Geological Survey Washington Water Science Center: U.S. Geological Survey Open-File Report 2019-1049, 23 p., https://doi.org/10.3133/ofr2019-1049.

Constantz, J., 2008, Heat as a tracer to determine streambed water exchanges. Water Resources Research, 44(4), W00D10. https://doi.org/10.1029/2008WR006996

Culler R. C., Hanson R. L., Myrick R. M., Turner R. M., and F. P. Kipple, 1982, Evapotranspiration Before and After Clearing Phreatophytes, Gila River Flood Plain, Graham County, Arizona. Geological Survey Professional Paper 655-P. 81 pages

Grady, S.J., 1983, Ground-water resources in the Hood Basin, Oregon: U.S. Geological Survey Water-Resources Investigations Report 81-1108, 68 p., 2 pl., scale 1:62,500.

Gordon, R. P., Lautz, L. K., Briggs, M. A., & McKenzie, J. M., 2012, Automated calculation of vertical pore-water flux from field temperature time series using the VFLUX method and computer program. Journal of Hydrology, 420–421, 142–158. https://doi.org/10.1016/j.jhydrol.2011.11.053

Hatch, C. E., Fisher, A. T., Revenaugh, J., Constantz, J., & Ruehl, C., 2006, Quantifying surface water–groundwater interactions using time series analysis of streambed thermal records: Method development. Water Resources Research, 42(10), W10410. https://doi.org/10.1029/2005WR004787

Huntington, J., Minor, B., Bromley, M., Pearson, C., Beamer, J., Ingwersen, K., Carrara, K., Atkin, J., Brito, J., Morton, C. and Dunkerly, C., 2025. *Crop evapotranspiration, consumptive use, and open water evaporation for Oregon*. Division of Hydrologic Sciences, Desert Research Institute. Available at: https://s3-us-west-2.amazonaws.com/webfiles.dri.edu/Labs/Huntington/owrd/Huntington_et_al_2025_DRI_Report_41306.pdf

Irvine, D. J., Briggs, M. A., Cartwright, I., Scruggs, C. R., & Lautz, L. K., 2017, Using diurnal temperature signals to infer vertical groundwater–surface water exchange. Groundwater, 55(1), 10–26. https://doi.org/10.1111/gwat.12459

Johnson, V.G., Graham, D.L., and Reidel, S.P.,1993, Methane in Columbia River Basalt aquifers: isotopic and geohydrologic evidence for a deep coal-bed gas source in the Columbia Basin, Washington. AAPG American Association of Petroleum Geologists Journal, 77(7), 1192-1207.

Johnson, H.M., Ely, K. and Maher, A.T., 2024, Timing and source of recharge to the Columbia River Basalt groundwater system in Northeastern Oregon. Groundwater, 62(5), 761-777. https://doi.org/10.1111/gwat.13404

Jones, C.B., 2016, Groundwater — Surface Water interactions near Mosier, Oregon [M.S. thesis]: Portland, Oregon, Portland State University, 170 p.

Keery, J., Binley, A., Crook, N., & Smith, J. W. N., 2007, Temporal and spatial variability of groundwater–surface water fluxes: Development and application of an analytical method using temperature time series. Journal of Hydrology, 336(1–2), 1–16. https://doi.org/10.1016/j.jhydrol.2006.12.003

Kennedy, E. J., 1983, *Computation of continuous records of streamflow*. US Department of the Interior, Geological Survey.

Kennedy, E. J., 1984, *Discharge ratings at gaging stations* (Vol. 3). US Government Printing Office.

LaMarche, J.L., and Wood, R.L., 2011, Groundwater and surface water interactions in Fifteenmile Creek Watershed, Oregon—results and analysis from the 2008 seepage run: State of Oregon Water Resources Department Open File Report SW 11 – 01, 46 p.

Lite, Kenneth E. Jr., and Grondin, G.H., 1988, Hydrogeology of the Basalt Aquifers Near Mosier, Oregon: A Ground Water Resource Assessment. Salem, Oregon: State of Oregon Water Resources Department Ground Water Report No. 33, 119 p.

Luce, C. H., Tonina, D., Gariglio, F., & Applebee, R., 2013, Solutions for the diurnally forced advection–diffusion equation to estimate bulk fluid velocity and diffusivity in streambeds from temperature time series. Water Resources Research, 49, 488–506. https://doi.org/10.1029/2012WR012380

McCall, W.B., 1975, Ground-water conditions and declining water levels in the Ordnance Area, Morrow and Umatilla Counties, Oregon: State of Oregon Water Resources Department Ground Water Report no. 23, 134 p.

McCallum, A. M., Andersen, M. S., Rau, G. C., & Acworth, R. I., 2012, A 1-D analytical method for estimating surface water–groundwater interactions and effective thermal diffusivity using temperature time series. Water Resources Research, 48, W11532https://doi.org/10.1029/2012WR012007

McClaughry, J.D., Herinckx, H.H., Niewendorp, C.A., Azzopardi, C.J.M., Hackett, J.A., 2021, Geologic map of the Dufur area, Wasco County, Oregon. Oregon Department of Geology and Mineral Industries, Geological Map Series GMS 127, 209 p., 3 pl., scale 1:24000

McClaughry, J.D., Niewendorp, C.A., Azzopardi, C.J.M., Herinckx, H.H., Webb, B.M., 2024, Geologic Map of the Mill Creek area, Hood River and Wasco Counties, Oregon. Oregon Department of Geology and Mineral Industries, Geological Map Series GMS 128, 203 p., 3 pl., scale 1:24000

Nagler, P. L., Cleverly, J., Glenn, E., Lampkin, D., Huete, A., & Wan, Z., 2005, Predicting riparian evapotranspiration from MODIS vegetation indices and meteorological data. *Remote sensing of environment*, *94*(1), 17-30. https://doi.org/10.1016/j.rse.2004.08.009

Nagler, P. L., Glenn, E. P., Nguyen, U., Scott, R. L., & Doody, T., 2013, Estimating riparian and agricultural actual evapotranspiration by reference evapotranspiration and MODIS enhanced vegetation index. *Remote Sensing*, *5*(8), 3849-3871. https://doi.org/10.3390/rs5083849

Nassar, A., Tarboton, D., Anderson, M., Yank, Y., Fisher, J.B., Purdy, A.J., Baig, F., He, C., Gochis, D., Melton, F., & Volk, J., 2025, Intercomparison of the U.S. National Water Model with OpenET over the Bear River Basin, U.S., Journal of Hydrology, 656,132826., https://doi.org/10.1016/j.jhydrol.2025.132826

National Marine Fisheries Service (NMFS), *Endangered and Threatened Species; Threatened Status for Two ESUs of Steelhead in Washington, Oregon, and California; Final Rule.* Federal Register 64(57): 14517–14528. March 25, 1999.

Natural Resources Conservation Service (NRCS), 2009, *National Engineering Handbook (NEH), Part 630—Hydrology, Chapter 7: Hydrologic Soil Groups.* U.S. Department of Agriculture, Washington, DC.

Newcomb, R.C., 1969, Effect of tectonic structure on the occurrence of groundwater in the basalt of the Columbia River Group of The Dalles area, Oregon and Washington: U.S. Geological Survey Professional Paper 383-C, 33 p., 1 pl., scale 1:62,500.

National Oceanic and Atmospheric Administration. (1999, March 25). *Endangered and threatened species: Threatened status for two ESUs of steelhead in Washington and Oregon*. *Federal Register, 64*(57). https://www.govinfo.gov/content/pkg/FR-1999-03-25/pdf/99-6817.pdf

Norton, M. A., and Batholomew, W.S., 1984, Update of Ground Water Conditions and Declining Water Levels in the Butter Creek Area, Morrow and Umatilla Counties, Oregon. Salem, Oregon: State of Oregon Water Resources Department Groundwater report No. 30, 203p.

Norton, M.A., 1999, A groundwater investigation to determine interference between a well and several springs on Eightmile Creek, Wasco County, Oregon: State of Oregon Water Resources Department Open File Report No. 99-01, 20 p.

Oregon Department of Fish and Wildlife (ODFW), 2019, Oregon Middle Columbia Steelhead Conservation and Recovery Plan Implementation Report for 2010 – 2016. Prepared by A.W. Averett. Oregon Department of Fish and Wildlife, East Region, La Grande, Oregon.

Oregon Watershed Enhancement Board (OWEB) and partners. n.d. *Fifteenmile Creek: A Whole Watershed Restoration Approach.* Oregon Watershed Enhancement Board, Salem, Oregon Accessed March 2025. https://www.oregon.gov/oweb/Documents/CEP-15Mile.pdf

Oregon Water Resources Department (OWRD) Water Rights Information System (WRIS) database, Accessed April 14, 2026.

OWRD, 2013, Water chemistry analysis of streams, springs, and wells in the Fifteenmile Creek Watershed [Unpublished raw data], State of Oregon Water Resources Department, Salem, Oregon.

Piper, A.M., 1932, Geology and groundwater resources of The Dalles region, Oregon: U.S. Geological Survey Water-Supply Paper 659-B, p. 107–189, 2 pl., scale 1:62,500.

Pischel, E.M., Johnson, H.M., Gingerich, S.B., 2018, Deep aquifer recharge in the Columbia River Basalt Group, upper Umatilla River Basin, northeastern Oregon: U.S. Geological Survey Scientific Investigations Report 2018-5110, 23 p., https://doi.org/10.3133/sir20185110.

Powell, J.E., 1982, Geology of the Columbia Hills, Klickitat County, Washington. M.S. Thesis, University of Idaho, 56 p.

Rantz, S. E., 1982, Measurement and computation of streamflow (Vol. 2175). US Department of the Interior, Geological Survey.

Reidel, S.P., Johnson, V.G., and Spane, F.A., 2002, Natural gas storage in basalt aquifers of the Columbia Basin, Pacific Northwest USA: a guide to site characterization: Richland, Wash., Pacific Northwest National Laboratory, 277 p.

Sauer, V. B., & Turnipseed, D. P., 2010, *Stage measurement at gaging stations* (No. 3-A7). US Geological Survey.

Sceva, J. E., 1966, A brief description of the ground-water conditions in the Ordnance area, Morrow and Umatilla counties, Oregon: State. of Oregon Water Resources Department Ground Water Report no. 11, 43p.

Tolan, T., Lindsey, K., and Porcello, J., 2009, A summary of Columbia River Basalt Group Geology and its influence on the hydrogeology of the Columbia River Basalt Aquifer System: Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties. June 2009. Prepared by the Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties. 65 p.

Tolan, T.L., Reidel, S.P., Beeson, M.H., Anderson, J.L., Fecht, K.R., and Swanson, D.A., 1989, Revisions to the estimates of the areal extent and volume of the Columbia River Basalt Group, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 1-20.

Turnipseed, D. P., & Sauer, V. B., 2010, *Discharge measurements at gaging stations* (No. 3-A8). US Geological Survey.

U.S. Department of Energy (USDOE),1988, Site characterization plan, Reference Repository Location, Hanford Site, Washington - consultation draft: Washington, D.C., Office of Civilian Radioactive Waste Management, DOE/RW-0164, v. 1 - 9.

U.S. Geological Survey, 2015a, Instructional Memorandum OSQI 2015-01—Scientific data management foundation: accessed September 26, 2016 at http://www.usgs.gov/usgs-manual/im/IM-OSQI-2015-01.html.

U.S. Geological Survey, 2015b, Instructional Memorandum OSQI 2015-02—Metadata for scientific data, software, and other information products: accessed September 26, 2016 at http://www.usgs.gov/usgs-manual/im/IM-OSQI-2015-02.html.

U.S. Geological Survey, 2015c, Instructional Memorandum OSQI 2015-03—Review and approval of scientific data for release: accessed September 26, 2016 at http://www.usgs.gov/usgs-manual/im/IM-OSQI-2015-03.html.

U.S. Geological Survey, 2015d, Instructional Memorandum OSQI 2015-04—Preservation requirements for digital scientific data: accessed September 26, 2016 at http://www.usgs.gov/usgs-manual/im/IM-OSQI-2015-04.html.

U.S. Geological Survey, 2015e, Office of Groundwater Technical Memorandum 2015.02—Policy and guidelines for archival of surface-water, groundwater, and water-quality model applications: accessed September 26, 2016 at http://water.usgs.gov/admin/memo/GW/gw2015.02.pdf.

U.S. Geological Survey, 2019, Specific conductance: U.S. Geological Survey Techniques and Methods, book 9, chap. A6.3, 15 p., https://doi.org/10.3133/tm9A6.3. [Supersedes USGS Techniques of Water-Resources Investigations, book 9, chap. A6.3, version 1.2.]

U.S. Geological Survey, 2019, National Hydrography Dataset (ver. USGS National Hydrography Dataset Best Resolution (NHD) for Hydrologic Unit (HU) 4 - 2001 (published 20191002)), accessed

October 23, 2025 at URL https://www.usgs.gov/national-hydrography/access-national-hydrography-products

Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006, Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods 1–D3, 51 p. + 8 attachments; accessed April 10, 2006, at http://pubs.water.usgs.gov/tm1d3

Wasco County Soil and Water Conservation District (WCSWCD) and Fifteenmile Coordinating Group (FCG), 2004, *Fifteenmile Subbasin Plan*. Prepared for the Northwest Power and Conservation Council (NWPCC), The Dalles, Oregon. Available at the Northwest Power and Conservation Council website. Accessed 11/24/2025. https://www.nwcouncil.org/sites/default/files/EntirePlan_3.pdf

Western Regional Climate Center (WRCC), Cooperative Climatological Data Summaries, Dufur Cooperative Site. Accessed 11/24/2025. https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?or2440