Quality Assurance Project Plan

Evapotranspiration and Floodplain Aquifer Storage Capacity in Yakima Tributaries

March 2023

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Studies funded by the Washington State Department of Ecology (Ecology) must have an approved Quality Assurance Project Plan (QAPP). This plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completing the study, Ecology will post the final report of the study to the Internet.

This Quality Assurance Project Plan is available via Ecology's publications database and upon request. The Ecology publication number for this Quality Assurance Project Plan is 23-12-006.

Field data collected for this project will be uploaded to Ecology's Environmental Information Management (EIM) database under Study ID: CWUEVAP_001. This QAPP is valid through April 30, 2028.

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COVER PHOTO: Taneum Creek flooplain, photographed in June 2021. PHOTO BY CAREY GAZIS.

Quality Assurance Project Plan

Evapotranspiration and Floodplain Aquifer Storage Capacity in Yakima Tributaries

Contract No. C2100177

by Lisa Ely and Carey Gazis

Published March 2023

Approved by:

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2.0 Abstract

Several stream restoration projects underway in the Yakima River watershed have the potential to increase groundwater storage in shallow floodplain aquifers during spring high-flow periods for in-stream release later in the summer. A principal knowledge gap related to this topic is the net annual recharge benefit (or loss) of floodplain aquifer storage, especially the extent to which the increasing evapotranspiration losses under increased floodplain connectivity might counteract the gains in groundwater storage. This project will assess and estimate how much and for how long water can be reasonably stored in Yakima River headwater tributary watersheds, and to evaluate the net gain/loss and timing of floodplain aquifer recharge. The water budget will refine previous estimates by taking into account factors such as the floodplain stratigraphy, geometry of the hydrogeologic units and various parameters of inflow and outflow, including floodplain infiltration, channel discharge, evapotranspiration from floodplain vegetation, and modeling of the seasonal timing of groundwater discharge from the shallow aquifers.

The objectives of the project are 1) quantify sediment composition and storage capacity of the floodplain aquifers in the study sites; 2) critically evaluate the role of evapotranspiration loss in the water budget for a tributary floodplain system; 3) assess the timing of seasonal flow in shallow floodplain aquifers under various conditions; 4) combine the measured variables above into a water budget for floodplain aquifers under different projected scenarios of climate change management strategies.

The study sites include the Teanaway River and Taneum Creek watersheds where existing monitoring wells and previous studies provide data to constrain the aquifer geometry, evapotranspiration, and changes in the water budget parameters over time. These watersheds each contain restoration projects such as large wood installations, which can be compared with unrestored reaches. The results from these example sites will be extrapolated to generate estimates for other similar tributaries in the Yakima basin. We will identify areas that are promising for shallow floodplain aquifer recharge, as well as those where it might be less effective.

3.0 Background

3.1 Introduction and problem statement

Enhancing groundwater storage is a practical strategy to increase late-summer water supplies within the Yakima River watershed. Through the collaboration of multiple stakeholders, recent stream restoration projects have placed large wood into multiple tributaries of the Yakima River to increase sedimentation in channels and divert more water onto adjacent floodplains. The intended hydrologic effect of wood emplacement is to increase groundwater recharge and storage in alluvial aquifers during spring high flows, resulting in a natural release of water into streams during the drier summer months. Benefits of wood restoration in streams for aquatic and riparian habitats are well documented (Roni et al., 2015). However, the impact of wood restoration on groundwater storage is not yet well understood or quantified (Nash et al., 2018; Boylan, 2019). Relatively few long-term, field measurements of this approach to enhance groundwater recharge and storage have been completed.

Groundwater storage in shallow alluvial aquifers of headwater basins could augment late-summer water supplies within the Yakima Basin by increasing groundwater recharge during spring high flows on tributaries. To apply these strategies most effectively and responsibly requires 1) a characterization of the geometry of the floodplain aquifers, 2) assessment of the surface water–groundwater interaction and 3) quantification of the overall water budget. This project will establish the baseline conditions and assess the potential of the restoration of large wood in channels as a strategy for realizing the Yakima Basin Integrated Plan (YBIP) goals of enhanced aquifer storage and recovery.

The major goal of this project is to quantify how much and for how long water can be reasonably stored in tributary watersheds, and to evaluate the net gain/loss and timing of floodplain aquifer recharge. The water budget will refine previous estimates by taking into account factors such as the geometry of the hydrogeologic units and various parameters of inflow and outflow, including floodplain infiltration, channel discharge, evapotranspiration from floodplain vegetation, and modeling of the seasonal timing of groundwater discharge from the shallow aquifers.

The study sites include the Teanaway River and Taneum Creek watersheds where existing monitoring wells and previous studies provide data to constrain the aquifer geometry, evapotranspiration, and changes in the water budget parameters over time. These watersheds each contain restoration projects such as large wood installations, which can be compared with unrestored reaches. The results from these example sites will be extrapolated to generate estimates for other similar tributaries in the Yakima basin. We will identify areas that are promising for shallow floodplain aquifer recharge, as well as those where it might be less effective.

The project aligns with the following priority ***Knowledge Gaps*** as described in the 2021 Summary of Findings of the Knowledge Gap Subgroup of the YBIP Groundwater Storage Subcommittee:

- Sediment and aquifer properties that can store and release groundwater to increase in-stream flow during the post-storage control period
- Evaluate transverse and horizontal groundwater flow gradient conditions and seasonal interaction with the stream
- Evaluate evapotranspiration losses associated with shallow floodplain aquifers.
- Identify floodplain aquifer storage sites in the basin
- Estimate the size and volume of groundwater storage

3.2 Study area and surroundings

The Yakima River, located in central Washington (Fig. 1), runs 345 km from Lake Keechelus and other reservoirs near the crest of the Cascade Mountains to the Columbia River and drains an area of 15,940 km^2. The climate in the Yakima River basin is variable, with annual precipitation ranging from around 270 cm on the Cascade crest to 15 cm in central Washington (Washington Climate Summaries, 2019). Because of the strong precipitation gradient, the Cascade Mountains are the source of the majority of precipitation input for the Yakima River basin, which falls mostly as snow during the winter months and recharges the soil water, groundwater and surface water systems as snowmelt during the spring and summer. The majority of the watershed lies in the arid rainshadow of the Cascades where the natural landscape is dominated by a shrub-steppe ecosystem.

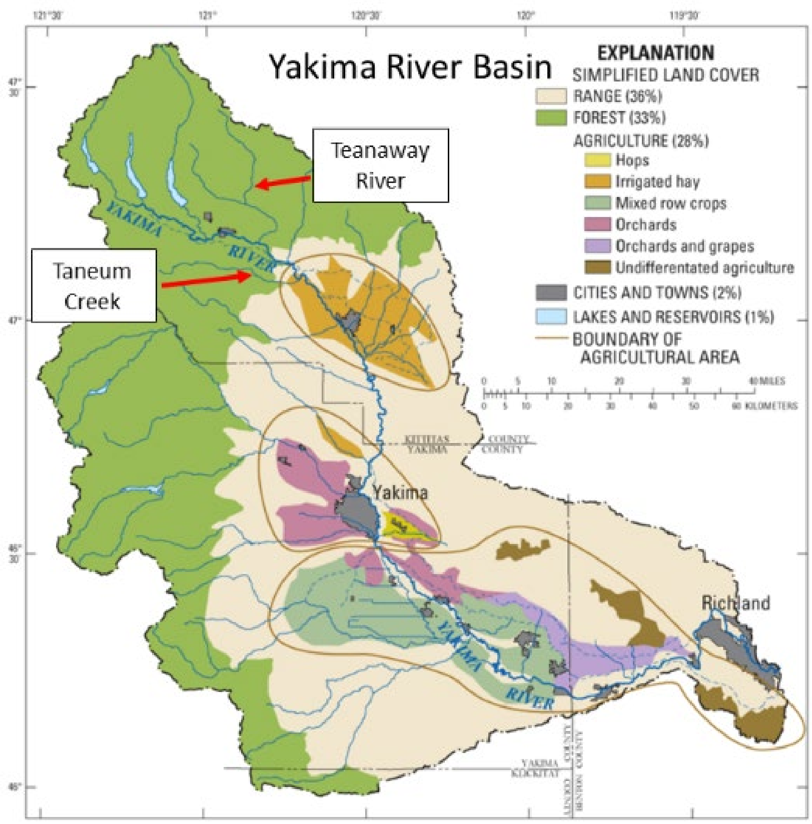

Figure 1. Locations of Teanaway River and Taneum Creek study sites in the Yakima Basin.

Teanaway River

The Teanaway River is a tributary of the upper Yakima River Basin, upstream of the Kittitas Valley (Figs. 1 and 2). The upper forks of the river, where the floodplains are predominantly managed by state or federal agencies, drain approximately 500 square kilometers. The Teanaway and its tributaries have undergone significant channel erosion, partly due to early 20th century log drives. The middle and west forks of the Teanaway River have incised an average of 2 meters (6 ft.) since ca. AD 1900, decreasing the active floodplain of the river by up to 53% in some areas (Schanz et al., 2019). Restoration projects in the last five years have emplaced large wood (LW) into multiple Teanaway tributaries and the main channel to enhance habitat and potentially slow runoff and increase water retention in floodplain aquifers. This project will incorporate the stratigraphy within the area of the floodplain aquifers (Fig. 2) into a refined estimate of aquifer storage.

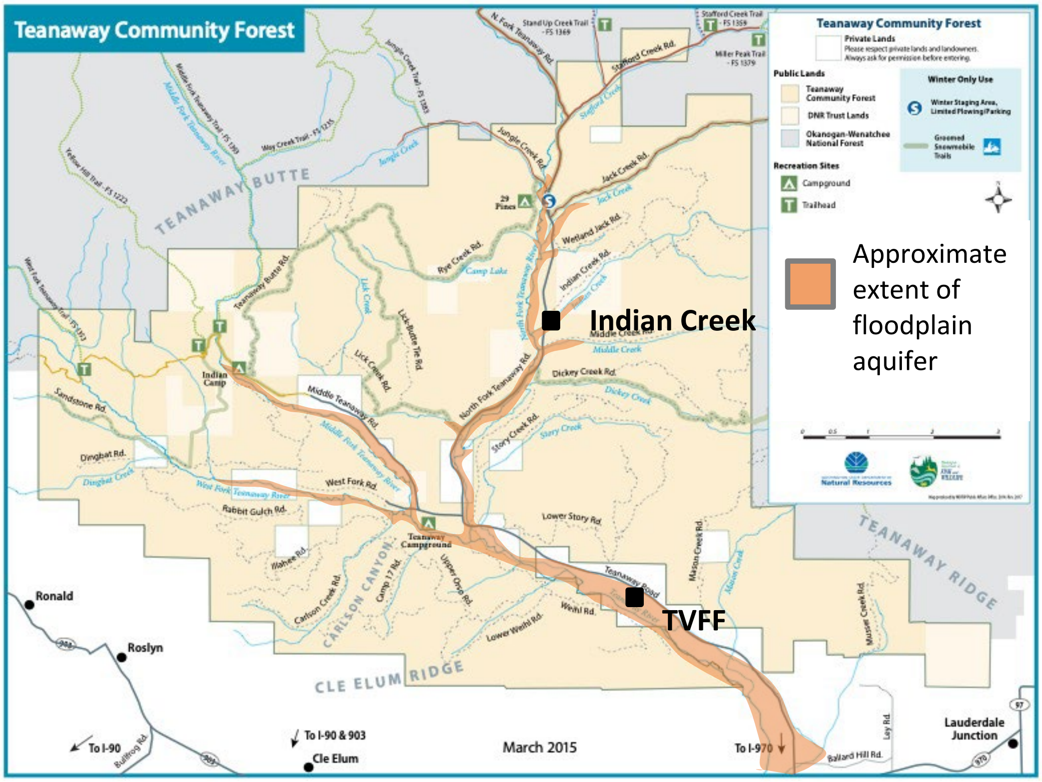

Figure 2. Approximate extent of floodplain aquifer in the Teanaway River basin. Squares mark locations of Teanaway Valley Family Farm (TVFF) and Indian Creek, where there are existing monitoring wells.

The Teanaway Valley Family Farm (TVFF) is an 85-hectare parcel located at River Mile 8 on the Teanaway River (Fig. 2). The property is located in a region where the river flows from WNW to ESE and cuts directly into bedrock on the southern side of the floodplain, which is approximately 1 km wide. TVFF was used for conventional hay farming prior to 2016, when it was acquired by the Washington Department of Fish and Wildlife for conservation purposes, including floodplain and meadow restoration (Washington Bureau of Reclamation, 2017). A desirable consequence of floodplain restoration is enhancing groundwater seepage into streams. As part of this conservation effort, 10 groundwater monitoring wells were installed by Mid-Columbia Fisheries Enhancement Group in 2018 (Gazis, 2021).

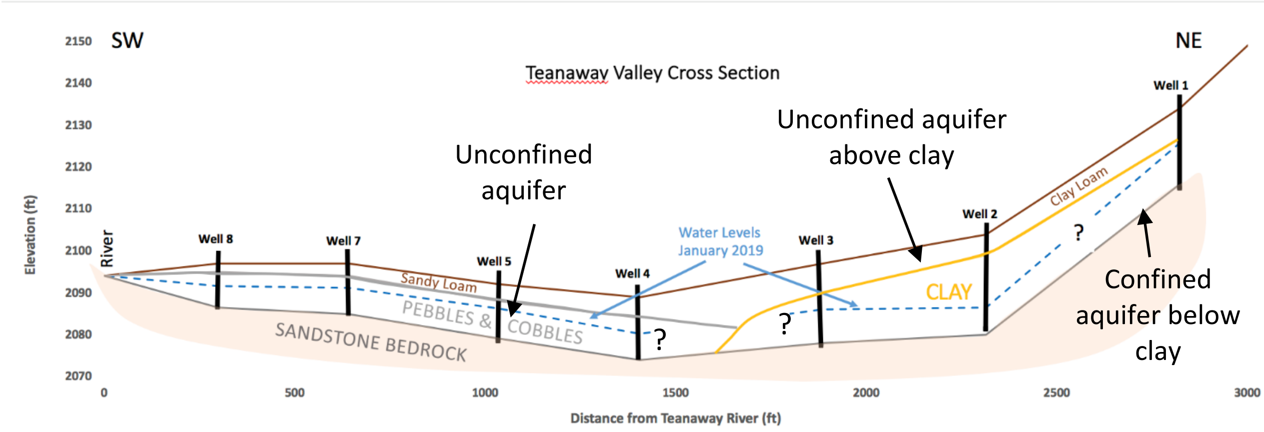

Figure 3. Cross section of stratigraphy and groundwater levels at the Teanaway Valley Family Farm study site, from Well 1 to the Teanaway River beyond Well 8.

A cross-section diagram of piezometer depths and materials encountered at TVFF (Fig. 3) is representative of the general stratigraphy of this section of the Teanaway River valley and its tributaries, including Indian Creek. An unconfined alluvial aquifer of pebbles and cobbles directly overlies the bedrock in Wells 4-8 near the river. A thick clay layer in the valley margins and tributaries separates a confined aquifer between the bedrock and the base of the clay, and the unconfined aquifer in the sediment overlying the clay. The clay layer influences the water levels in Wells 1-3. The widespread clay layer could significantly affect groundwater storage and flow. A similar clay layer occurs at Indian Creek and other sites in the Teanaway valley and upper Yakima River Basin (Tabor et al, 1982; Bartlett, 2022).

<u>Taneum Creek</u>

Taneum Creek is a lower elevation tributary that drains approximately 200 square kilometers and joins the Yakima River in the southwestern Kittitas Valley (Fig. 4). It is one of the earliest large wood (LW) channel restoration areas in the Yakima River Basin, with LW emplacement beginning in 2008. A large flood in 2011 mobilized LW and channel sediment, inducing significant channel change and floodplain connectivity in reaches where LW had been added. Taneum Creek provides ideal test sites for this project, as floodplain aquifer capacity and evapotranspiration can be compared between reaches with channel-floodplain connectivity and reaches with a single incised channel.

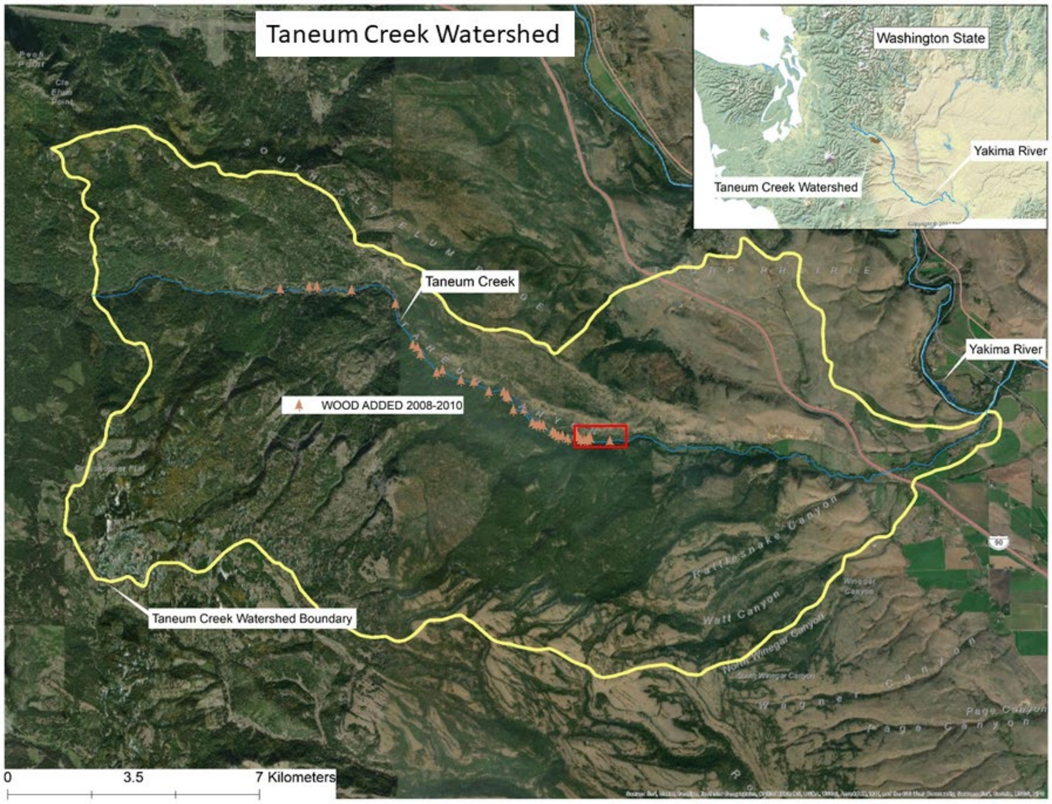

Figure 4. Taneum Creek watershed. Triangles mark sites where large wood was added to the channel in 2008-2010. Red box outlines the area of the detailed field investigation.

3.2.1 History of study area

Historically, the Teanaway River and its tributaries have been severely impacted by human uses, including removal of natural log jams, construction of splash dams and a railroad for logging, agriculture and irrigation in the floodplains, and grazing. The main river and most of the tributaries are deeply incised and disconnected from the floodplain. Several agencies and organizations, including Washington DOE, WDFW, and DNR, the Yakama Nation, and the Kittitas Conservation Trust (KCT) have engaged in channel restoration efforts within the Teanaway River watershed, most notably on Indian Creek beginning in 2014. Additional large wood (LW) installations have continued up to the present on the main river and tributaries. The goals of the restoration efforts were to improve fish habitat, connect the floodplain to the channel, and increase groundwater storage (Boylan, 2019) to emulate the natural conditions of wood historically found in streams in this region (Russell, 1898; Shanz et al., 2019; Stock et al., 2005).

The TVFF property was acquired and transferred to WDFW ownership in 2017 for conservation of fish and wildlife habitat and public enjoyment on foot. The lower floodplain and alluvial fan below Teanaway Road were farmed until July 2018 by the former landowner. Both tributaries in the project area are ditched below Teanaway Road and disconnected from the floodplain in the project area. The downstream tributary was moved to its present location along the property boundary approximately 30 years ago. Irrigation shifted from flood irrigation using surface water diversions to pivot irrigation pumped from shallow wells in approximately the year 2000, and on neighboring properties as well. The shallow (<12 ft) wells that fed this irrigation are located approximately 300 feet from the Teanaway River on the TVFF property and the adjacent downstream property. The upstream neighbor uses water from a pond to irrigate. An irrigation schedule that ends annually in July has been used by the landowners for approximately 14 years. Irrigation on the TVFF property was discontinued as of July 2018. Late season water rights on adjacent properties are now owned by Washington Water Trust. Restoration of floodplain vegetation is underway below Teanaway Road.

Restoration on Taneum Creek has included removing dams and irrigation screening diversions, building fish passage, and adding large wood (Monk, 2015). Initial large wood was emplaced in 2008-2010 (Fig. 4). A large flood in 2011 increased channel complexity, side-channel flow onto the floodplain, beaver ponds and possibly floodplain greenness values in reaches where large wood had been added (Fixler, 2022). The Kittitas Reclamation District (KRD) has installed four deep monitoring wells in a downstream parcel of the Taneum Creek floodplain as part of a pilot project for floodplain inundation and aquifer recharge, which further supports the use of Taneum Creek as an example tributary for detailed analysis.

3.2.2 Summary of previous studies and existing data

Large wood restoration projects on the mainstem Teanaway River and tributaries, including Indian Creek, began in 2014 and on Taneum Creek in 2008. An initial study was conducted in Indian Creek to discern whether any measurable temporal and spatial changes in groundwater levels could be detected in the groundwater piezometers (Fig. 2) since the installation of large wood in the channel (Boylan, 2019; Boylan and Campana, 2019). The results showed little change in water table elevation and groundwater baseflow, and a slight increase in groundwater storage volume in one location, which could have been attributable to other processes. The study by Boylan (2019) provided baseline data and a conceptual model, but did not quantify the alluvial aquifer geometry or stratigraphy, nor relate the groundwater recharge potential to the seasonal stream discharge. A subsequent investigation at Indian Creek by Bartlett (2022) confirmed that the groundwater levels in the floodplain piezometers did not show a consistent difference before and after the major addition of large wood into the channel in 2016. This study also documented laterally extensive glacial clay, gravel and silt layers within the stratigraphy at Indian Creek, which probably affect the storage capacity and retention time in the floodplain aquifer.

To better understand surface-water/groundwater interactions along the Teanaway River, Petralia (2022) conducted a study of water levels and stable isotope compositions for water in the ten Teanaway Valley Family Farm wells. The aquifer stratigraphy is similar to that of Indian Creek, with an low permeability glacial clay overlain by a shallow aquifer of gravel, sand and fine sediment (Fig. 3). This glacial clay lacustrine unit has been mapped elsewhere in the Teanaway valley and adjacent Yakima River (Tabor et al., 1982), and could affect the depth and storage capacity of the alluvial aquifers at sites of channel wood installations throughout the headwaters of the Yakima Basin. Petralia (2022) found that groundwater in the region is recharged in late January to February and begins declining to summer levels before the peak in streamflow. At this time, water enters the aquifer from the local hillslopes. For much of the rest of the year, groundwater flows roughly parallel to the river, mixing extensively with river water in the riparian zone beside the river. Changes in irrigation patterns that include pumping from an upstream pond have drawn down the groundwater levels near the river in the summer and contributed to the die-off of cottonwood trees on the TVFF property.

Natural Systems Design conducted a LW restoration project on the Teanaway River with the goals of slowing vertical incision rates and increasing channel meandering and floodplain recharge within the Teanaway River Watershed. They calculated a floodplain groundwater storage capacity within the Teanaway River Watershed assuming a uniform sandy floodplain stratigraphy and the potential for the river to aggrade the currently incised channels to reconnect with the floodplains (Dickerson-Lange and Abbe, 2019). A general study of groundwater in the upper Yakima River basin that includes the Teanaway River basin was conducted by the USGS in 2014 (Gendaszek at el., 2014). That study includes groundwater level contours, at 50-ft intervals, in the first approximately 7 miles of the Teanaway River based on water levels in wells open to the unconsolidated sediment unit, collected in spring 2011.

At Taneum Creek, a recent study has tracked the decadal-scale effects of large wood restoration on channel changes and floodplain vegetation (Fixler, 2022). Large wood was restored to several reaches of Taneum Creek in 2008-2010, followed by a large flood in 2011. The flood mobilized the wood and channel sediments, increased the incidence of multi-threaded channels, and created numerous side channels across the floodplain. Floodplain greenness was quantified using a normalized difference vegetation index (NDVI) on satellite imagery from 2006-2019. The results suggest possible increased summer moisture retention in the floodplain in the reaches with the large wood restoration following the flood, perhaps due to the side-channels.

The Kittitas Reclamation District (KRD) has installed four deep monitoring wells in a downstream parcel of the Taneum Creek floodplain as part of a pilot project for floodplain inundation and aquifer recharge. That project is currently in progress.

3.2.3 Parameters of interest and potential sources

The parameters of interest in this study are:

- Aquifer stratigraphy in relation to groundwater levels, aquifer storage capacity, and groundwater flow
- Evapotranspiration and its role in the floodplain water budget
- Stable isotope geochemistry as a tracer of evaporation amounts

3.2.4 Regulatory criteria or standards

The study objectives do not inclue an assessment of regulatory compliance status.

3.3 Water quality impairment studies

Not applicable

3.4 Effectiveness monitoring studies

Not applicable

4.0 Project Description

The problem to be addressed in this project is to quantify how much and for how long water can be reasonably stored in Yakima Basin tributary watersheds, and to evaluate the net gain/loss and timing of floodplain aquifer recharge. The water budget will refine previous estimates by taking into account factors such as the geometry of the hydrogeologic units and various parameters of inflow and outflow, including floodplain infiltration, channel discharge, evapotranspiration from floodplain vegetation, and modeling of the seasonal timing of groundwater discharge from the shallow aquifers.

Several stream restoration projects underway in the Yakima River watershed have the potential to increase groundwater storage in shallow floodplain aquifers during spring high-flow periods for in-stream release later in the summer. One goal of the large wood restorations in the Teanaway and Taneum Creek tributary basins is to increase the connectivity of the channel and floodplain. Principal knowledge gaps related to this topic include 1) the net annual recharge benefit (or loss) of floodplain aquifer storage, especially the extent to which the increasing evapotranspiration losses under increased floodplain connectivity might counteract the gains in groundwater storage, and 2) the affect of the floodplain stratigraphy on the aquifer storage capacity.The anticipated study outcomes include an improved understanding of the floodplain water budget parameters in the two example tributaries, which will provide a basis on which to assess the application of this strategy for other headwater streams in the Yakima basin. The combined data from the selected field sites will quantify the potential for aquifer recharge and storage under different scenarios of channel restoration and evapotranspiration.

4.1 Project goals

The overall goal of this project is to quantify how much and for how long water can be reasonably stored in tributary watersheds, and to evaluate the net gain/loss and timing of floodplain aquifer recharge. We will use restoration sites on Taneum Creek and the Teanaway River as example study sites. Specific questions that this project will address are:

1. Quantify the geometry and storage potential of the alluvial aquifer through field observations of subsurface stratigraphy, including bedrock, alluvium and a possible regional confining layer of glacial clay; well logs; maps; and previous studies.
2. Critically evaluate the role of evapotranspiration loss in the water budget. Floodplain inundation and increased groundwater storage can result from channel wood restoration, beaver dams and other natural or human causes. However, vegetation growth and increased transpiration could negate some of the gains from the increased infiltration of surface water.

3. Combine the measured variables above into an estimated water budget for floodplain aquifers under different projected scenarios of climate change and management strategies within the tributary basins.
4. Construct a conceptual model of the potential for seasonal groundwater storage in alluvial aquifers under existing conditions of wood restoration and aquifer geometry.

4.2 Project objectives

The project objectives are to:

1. Measure and describe floodplain aquifer geometry and subsurface stratigraphy in two study areas: 1) the locations of wood restoration and subsequent channel changes during the 2011 flood on Taneum Creek (Fig. 5; Fixler, 2022), and 2) floodplains of the Teanaway River and its tributaries within the Teanaway Community Forest (Fig. 2).
2. Use ArcGIS Pro to determine the elevations of the described stratigraphic sections and the confining glacial clay layer and to map the spatial extent of the glacial clay layer.
3. Create topographic transects of the floodplain at the locations of the stratigraphic descriptions in Taneum and Teanway watersheds using existing imagery such as LiDAR, Google Earth and possibly existing drone imagery to determine the shallow aquifer storage capacity above the confining clay layer.
4. Construct a water budget model of groundwater recharge, loss and storage potential under the existing conditions of wood installations and aquifer geometry.
5. Use field and remote sensing methods to estimate evapotranspiration on the Taneum Creek floodplain. Field measurements will include pan evaporation, soil moisture, soil temperature, wind speed, solar radiation. Remote sensing methods include application of models such as METRIC (Measuring Evapotranspiration with Internalized Calibration, Allen et al., 2007). Several models will be accessed and compared using the OpenET data portal.
6. Measure stable isotope compositions of waters from beaver ponds, side channels and Taneum Creek to quantify evaporation by an independent means.
7. Determine the effect of stream restoration efforts on the role of evapotranspiration within the overall water budget by comparing available historic data and estimates to the new, calculated water budget. Determine whether these efforts have decreased or increased the availability of water for irrigation agriculture during the dry season.

4.3 Information needed and sources

Data that will be generated through the study are:

- Stable isotope geochemical data of samples collected from main stem, side channels, beaver ponds, marshy areas, and evaporation pan at site on Taneum Creek.
- Descriptions and measurements of floodplain stratigraphy in Taneum Creek and

Teanaway River.

Data that will be gathered through other sources are:

- River stage and flow data from the flow monitoring station 39P080 on Taneum Creek at Brain Ranch, which posts data at https://apps.ecology.wa.gov/ContinuousFlowAndWQ/StationDetails?sta=39P080#StationDataTabs
- River stage and flow data from the flow monitoring site on the Teanaway River at Red Bridge Road operated by the DOE, which posts data at https://fortress.wa.gov/ecy/eap/flows/station.asp?sta=39D110#block2.
- Yakima Basin Hydromet station Teanaway River at Forks (TNAW1) operated by the Bureau of Reclamation (Bureau of Reclamation 2019, which posts data at https://www.usbr.gov/pn/hydromet/rtgraph.html?list=tnaw%20q&daily=tnaw%20qd

4.4 Tasks required

Specific tasks planned for the study are:

1. Acquire streamflow data from Taneum Creek gaging station.
2. Describe floodplain stratigraphy in Taneum and Teanaway watersheds; document locations and elevations of stratigraphic profiles.
3. Measure sediment grain-size distribution of representative stratigraphic units to estimate transmissivity of different stratigraphic layers.
4. Map floodplain within Taneum and Teanaway study areas in ArcGIS and incorporate thickness and extent of stratigraphic layers to estimate floodplain aquifer volume.
5. Install Class A evaporation pan at site on the floodplain of Taneum Creek and measure evaporation until freezing temperatures occur.
6. Install equipment to meaure soil moisture, soil temperature, wind speed, and solar radiation at the same site.
7. Collect water samples from the main channel, side channels, beaver ponds, and marshes at a site on the floodplain of Taneum Creek.
8. Determine stable isotope ratios of oxygen and hydrogen in water samples using a Picarro cavity-ring-down spectrometer in the laboratory.
9. Prepare data analysis report to assess the groundwater recharge and storage potential under the existing conditions of wood installations and aquifer geometry in Indian Creek.

4.5 Systematic planning process

The QAPP is the systematic planning process for this project.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

This QAPP was prepared by Lisa Ely and Carey Gazis for Central Washington University (CWU). Dr. Ely, a professor in the Department of Geological Sciences at CWU, is the Project Manager and Principal Investigator; Dr. Gazis, a professor in the Department of Geological Sciences at CWU is the co-Principal Investigator. Much of the project work will be undertaken by Emily Polizzi and Edward Vlasenko, M.S. graduate students at CWU, as part of their thesis research. The Principal Investigators and graduate students at CWU will communicate regularly with Scott Tarbutton, grant project manager, at the Department of Ecology and other members of the Groundwater Storage Subcommittee of the Yakima Basin Intergrated Plan.

Table 1 shows the responsibilities of those who will be involved in this project.

Table 1. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Lisa Ely Geological Sciences Dept. Central Washington Univ. Phone: 509-963-2177	Project Manager/ Principal Investigator	Writes the QAPPs. Oversees reporting and project budget. Collaborates on QA review of data. Oversees analysis and interpretation of stratigraphic, topographic and geomorphic data. Prepares final report in collaboration with Carey Gazis, with assistance from Emily Polizzi and Edward Vlasenko.
Carey Gazis Geological Sciences Dept. Central Washington Univ. Phone: 509-963-2820	Co-Principal Investigator	Collaborates on writing the QAPPs. Oversees field sampling and transportation of samples to the laboratory. Oversees field sampling and transportation of samples to the laboratory. Collaborates on QA review of data. Oversees analysis and interpretation of geochemical and groundwater data. Collaborates on preparation of final report with Lisa Ely, with assistance from Emily Polizzi and Edward Vlasenko.
Emily Polizzi Geological Sciences Dept. Central Washington Univ.	Graduate Student Researcher	Collects samples and records field information. Conducts field measurements, topographic surveys, and sediment analyses. Compiles data and enters into EIM database. Works with Dr. Ely and Dr. Ely to interpret data and prepare report.
Edward Vlasenko Geological Sciences Dept. Central Washington Univ.	Graduate Student Researcher	Collects samples and records field information related to evapotranspiration. Conducts field measurements and geochemical laboratory analyses. Compiles data and enters into EIM database. Works with Dr. Gazis and Dr. Ely to interpret data and prepare report.
Scott Tarbutton Office of Columbia River WA Dept. of Ecology Phone: 509-454-4242	Grant Project Manager	Manages the project grant and provides oversight of project, approves the budget. Provides internal review of the QAPP, approves the final QAPP.
Scott Tarbutton Office of Columbia River WA Dept. of Ecology Phone: 509-867-6534	OCR Quality Assurance Coordinator	Reviews and approves the draft QAPP and the final QAPP

QAPP: Quality Assurance Project Plan
NEP: National Estuary Program
WQX: Water Quality Exchange

5.2 Special training and certifications

Graduate students Emily Polizzi and Edward Vlasenko will receive training from Dr. Ely and Dr. Gazis in field measurement, field sampling and data processing protocols. Individuals performing project tasks will be trained in and experienced with the SOPs being used for pan evaporation measurements, data logger (weather, soil moisture) installation and downloading; and data interpretation.

Mr. Vlasenko will receive training in laboratory safety, sample preparation, and use of the Picarro water isotope analyzer. These trainings will be given by Dr. Gazis and an engineering technician at Central Washington University. Ms. Polizzi will receive training in laboratory safety, sample preparation and use of the CAMSizer and Mastersizer sediment particle-size analyzers from Dr. Lisa Ely at Central Washington University.

5.3 Organization chart

Not applicable – See Table 1.

5.4 Proposed project schedule

Tables 2 – 4 list key activities, due dates, and lead staff for this project.

Table 2. Schedule for completing field and laboratory work.

Task	Due date	Lead staff
Field work	August 2023	Ely and Gazis
Laboratory analyses	August 2023	Gazis
Contract lab data validation	NA	NA

NA: Not Applicable

Table 3. Schedule for data entry.

Task	Due date	Lead staff
EIM data loaded	January 2024	Gazis
EIM QA	January 2024	Gazis
EIM complete	January 2024	Gazis

WQX: Water Quality Exchange; NA: Not Applicable

Table 4. Schedule for final report.

Task	Due date	Lead staff
Draft report	Dec.1, 2023	Ely and Gazis
Final report	Jan 31, 2024	Ely and Gazis

5.5 Budget and funding

This project is funded by the Department of Ecology Office of Columbia River contract C2200177, as recommended by Groundwater Storage Subcommittee under the Yakima Basin Integrated Plan . Funding covers summer and academic-year salary, benefits, and tuition costs for the two CWU graduate students, Emily Polizzi and Edward Vlasenko; partial summer salary for principal investigators, Dr. Gazis and Dr. Ely; travel for field measurements, observations and sample collection; field supplies, including evaporation pan, soil and meteorological data loggers; groundwater modeling software; and stable isotope analyses of 120 water samples. The remainder of Dr. Gazis's and Dr. Ely's effort toward this project is funded by Central Washington University.

Tables 5 and 6 show project and laboratory budget details.

Table 5. Project budget and funding.

Cost Category	Cost ($)
Salary, benefits	$57,540
Supplies and software	$7000
Travel	$1120
Graduate student tuition	$19,146
Laboratory (See Table 6 for details.)	$2817
DAHP permitting and site visit	$1000
Indirect cost of 52.5% on salaries	$23,649

Table 6. Laboratory budget details.

Parameter	Number of Samples	Number of QA Samples	Total Number of Samples	Cost Per Sample ($)	Lab Subtotal ($)
Surface water samples					
O and H isotopes	100	20	120	$15	$1800
Radiocarbon analysis	3			$339	$1017

6.0 Quality Objectives

6.1 Data quality objectives [1]

The main data quality objectives (DQO) for this project are as follows:

1) Collect continuous evaporation measurements from a site on the floodplain of Taneum Creek using a Class A Evaporation Pan.

2) Measure the following other parameters at the same site using data loggers: soil moisture and temperature at depths of 10 and 60 cm, wind speed, solar radiation, air temperature.

3) Collect 100 surface water samples from a site on the floodplain of Taneum Creek and analyze their hydrogen and oxygen stable isotope geochemistry. The analyses will use standard methods to obtain stable isotope data that meet the (MQOs) that are described below and are comparable to previous study results.

6.2 Measurement quality objectives

The measurements in this project are land surface elevations and locations, elevation of surface water bodies (creek and river), depth of stratigraphic units below land surface, and stable isotope chemistry of water samples.

Land surface and water body locations will be documented using a handheld Garmin GPS. These will be plotted and mapped using existing topographic layers in ArcGIS Pro. For the Teanaway River we will use Teanaway 2015 lidar from the Puget Sound LiDAR Consortium. Projection: Washington State Plane South, Horizontal Datum: NAD83, Vertical Datum: NAVD88 (GEOID03) (QSI Environmental, 2015), see Table 7.

For Taneum Creek we will use Kittitas Creeks 2010 lidar from the Puget Sound LiDAR Consortium. Projection: Washington State Plane South FIPS 4602, Horizontal Datum: NAD83, Vertical Datum: NAVD88 (GEOID03) (Watershed Sciences, 2010), see Table 7.

Depth of stratigraphic units below land surface will be measured directly with a standard tape measure.

The MQOs for the use of the isotopic data for hydrogeologic characterization are based on precision, bias, and sensitivity, and will be used to assess data quality. Laboratory MQOs for the isotopic analyses are summarized in Table 9.

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[1] DQO can also refer to ***Decision*** Quality Objectives. The need to identify Decision Quality Objectives during the planning phase of a project is less common. For projects that do lead to important decisions, DQOs are often expressed as tolerable limits on the probability or chance (risk) of the collected data leading to an erroneous decision. And for projects that intend to estimate present or future conditions, DQOs are often expressed in terms of acceptable uncertainty (e.g., width of an uncertainty band or interval) associated with a point estimate at a desired level of statistical confidence.

6.2.1 Targets for precision, bias, and sensitivity

The MQOs for project results, expressed in terms of acceptable precision, bias, and sensitivity, are described in this section and summarized in the tables below.

Table 7. Measurement quality objectives for land-surface locations.

MQO →	Precision		Bias	Sensitivity
Parameter	**Duplicate Measurements or Sensor Resolution**		**Based on reported accuracies**	**Minimum Measurement**
	Relative Percent Difference (% RPD)	in measurement units	in measurement units	in measurement units
Land surface position (Garmin handheld GPS)	NA	3 m	N/A	NA
Teanaway 2015 LiDAR	N/A	0.67 m	N/A	N/A
Kittias Creeks 2010 LiDAR (for Taneum Creek)	N/A	0.15 m	N/A	N/A

Table 8. Specifications of weather station and soil data loggers.

	Measurement	Range	Accuracy	Resolution/ Sensitivity	Response Time (90%)	Stability (Drift)
Novalynx Class A Evaporation Pan with Stilling Well	Evaporation		≈0.1 in			
Hukseflux HFP01 Heat Flux Plate	Heat Flux	-2000 to +2000 W/m^2		$60x10^{-6}$ $V/(W/m^2)$		-
Onset Hobo S-SMD-M005 Soil Moisture Smart Sensor	Soil Volumetric Water Content	0 to $0.570 m^3/m^3$	+/-0.033 m^3/m^3 (+/-3.3%)	0.0008 m^3/m^3 (0.08%)		-

	Measurement	Range	Accuracy	Resolution/ Sensitivity	Response Time (90%)	Stability (Drift)
Onset Hobo TMC6-HD Air/Water/Soil Temperature Sensor	Temp.	-40°C to 50°C	1°C	0.10°C	5 min	0.1°C per yr
Novalynx Modular Weather Station	Wind Speed	0 to 125 mph	1 mph	>0.1 mph	2 sec	
	Solar Radiation		3%	75µA per 1000 W/m^2		
	Relative Humidity	10 to 90%	+/-3% at 20°C			2% over 2 yr

Table 9. Measurement quality objectives for laboratory analyses of water samples.

MQO →	Lowest Concentration of Interest	Duplicate Samples	Matrix Spikes	Matrix Spike-Duplicates	Check Standard (QC)
Parameter	mg/L	Relative Percent Difference	Recovery Limits	Relative Percent Difference	Recovery Limits
Oxygen-18	NA	0.1 per mil	NA	NA	0.1 per mil
Deuterium	NA	1 per mil	NA	NA	1 per mil

6.2.1.1 Precision

In documenting the location of land-surface points for mapping the floodplain aquifer, precision is based on the quality and number of satellites acquired with the GPS unit.

See Table 8. For specifications for the monitoring equipment that will be used to measure evaporation and soil parameters.

See Table 9. Precision for the laboratory analyses of stable isotopes will be determined based on laboratory measurements of duplicate samples. Duplicates will include both field duplicates (two different bottles collected in the field, collected every 20 samples) and laboratory duplicates, two runs from a single sample bottle. For stable isotope analyses, measurements are of ratios that are expressed in delta notation* (per mil units). For these analyses, in addition to measuring duplicate samples, the laboratory method includes multiple injections and measurements of each sample (typically ten). The first three injections are discarded because of memory effects. The reproducibility of the remaining analyses provides another determination of the precision of the method. Both the duplicate sample measurements and the multiple analyses of the same sample should meet the MQOs for stable isotopes, 0.1 per mil for oxygen-18 and 1 per mil for deuterium.

6.2.1.2 Bias

Bias for surveyed locations, elevations and stratigraphic depths is based on the readability of measurement scales and irregularities in the ground surface and stratigraphic contacts.

Bias for laboratory analysis of the stable isotope geochemistry will be determined based on measurement of quality control (QC) standards of known isotopic composition. These QC samples are independent from the calibration standards for each measurement. For stable isotope analyses, these QC standards should measure within 0.1 per mil (oxygen-18) and 1 per mil (deuterium) from their known value.

6.2.1.3 Sensitivity

See Tables 7, 8 and 9. Sensitivity estimates represent field instrument minimum measurements. For the laboratory analysis, stable isotopes of hydrogen and oxygen are major constituents of water, so sensitivity, defined as a measure of the capability of a method to detect a substance, is not an issue of concern.

6.2.2 Targets for comparability, representativeness, and completeness

6.2.2.1 Comparability

Comparability is the degree to which data can be compared directly to similar studies. The use of benchmarks, standardized sampling procedures, analytical methods with comparable sensitivity, and units of reporting, and quality control procedures and standards ensure comparability of data. For comparability with existing data, particularly for stable isotope analyses, standards of known concentration will be analyzed and those analyses will either serve as the basis for the measurement calibration or as a check (quality control) standard for the calibration.

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* $\delta = \left(\frac{R_{sam}-R_{std}}{R_{std}}\right) * 1000, \textit{where } R_{sam} \textit{ and } R_{std} \textit{ are the isotope ratios } \left(\frac{^{18}O}{^{16}O} \textit{ for } \delta^{18}O, \frac{D}{H} \textit{ for } \delta D\right)$ *of the sample and the standard, respectively.*

Standard sampling and field measurement procedures will be used as described in this document and informed by the following SOPs:

Procedure for Evaporation Pan installation and measurement:

https://s.campbellsci.com/documents/us/manuals/255-100.pdf

Collection, Processing, and Analysis of Stream Samples
https://fortress.wa.gov/ecy/publications/documents/1703207.pdf

6.2.2.2 Representativeness

Evaporation pans are known to lose water through evaporation at a higher rate than nearby lakes and reservoirs because of their small size, shallow depth, and the increase circulation of air around them. As a result, pan coefficients are used to convert to lake evaporation. In addition, they are dependent on the local conditions (shade, wind, temperature, humidity) in small area where they are placed. In this case, the pan will be placed in a partly shaded area near the Taneum Creek that is chosen to represent an intermediate case among the wide range of conditions that exist in the floodplain.

The streamflow gages on the Teanaway River at Red Bridge Rd (39D110) and Taneum Creek at Brain Ranch (39P080) operated by the WA Dept. of Ecology will provide continual flow measurements that are representative of the surface water fluctuations at the study sites. Representativeness of the water and sediment samples collected is ensured by adherence to the field sampling protocols and standard laboratory protocols.

6.2.2.3 Completeness

To ensure data completeness, only properly calibrated and maintained equipment will be used. Data logger measurements will be compared to measurements (soil moisture) or nearby data (weather data) and any data logger that is not collecting high quality complete data will be replaced. Problems occasionally arise during sample collection that cannot be controlled; thus, a completeness of 95% is acceptable. Example problems are flooding, site access problems, measurement drift, or equipment failure. For the laboratory analyses, a complete or valid result will include sample documentation and a laboratory analysis report. Greater than 95% completeness is expected for samples collected as part of this project.

6.3 Acceptance criteria for quality of existing data

The stable isotope data of water samples collected at the Taneum site will be compared with existing unpublished data by Dr. Gazis from that site and nearby sites (Teanaway River) for consistency. Much of the existing Teanaway River data was collected under an existing project QAPP (Contract No. C2100007) and has undergone the same QA/QC procedures as those described here. Precision is based on reproducibility of multiple injects of a single sample, replicate analyses and QC standards. Accuracy is ensured by periodic measurement of international isotope standards as well as interlaboratory comparisons of internal laboratory standards.

6.4 Model quality objectives

N/A

7.0 Study Design

7.1 Study boundaries

The general study area is shown in Figure 1. The boundaries of the two specific study sites, Taneum Creek and Teanaway River floodplains, are shown in Figures 2 and 3.

7.2 Field data collection

Water samples will be measured and collected from surface water sites at locations at a site on the lower Taneum Creek floodplain shown in Figures 5. Data from an evaporation pan, weather sensors, and soil moisture sensors will be collected from the same site (Fig. 5). The focus of the groundwater storage portion of the project is to assess the potential physical storage capacity of the shallow floodplain aquifer adjacent to large wood restoration sites in the stream channel. Because monitoring groundwater levels is not within the scope or objectives of this project, we will not drill any new monitoring wells. We will examine the physical characteristics of the uppermost units of the stratigraphy to determine whether they could serve as potential aquifer storage, and if so, what is the feasible capacity. Stratigraphic profiles will be described in locations of vertical streambank exposures along Taneum Creek and Teanaway River, to be identified during field reconnaissance. We will incorporate existing stratigraphic descriptions from existing well logs, previous projects such as the C2100007 grant from the Washington Department of Ecology to Carey Gazis (2020), and Master's theses by Bartlett (2022) and Petralia (2022) in the Teanaway watershed.

There are no groundwater monitoring wells in the Taneum Creek study area. To augment the stratigraphy from the streambank exposures and the transect shown in Figure 5, we will hand auger additional cores across the floodplain of Taneum Creek at locations identified after the initial stratigraphy has been described. The stratigraphy obtained in this study will be compared with well logs from the Ecology database and from monitoring wells installed by the Kittitas Reclamation District on Taneum Creek approximately 4 km downstream of our study site in Figure 5.

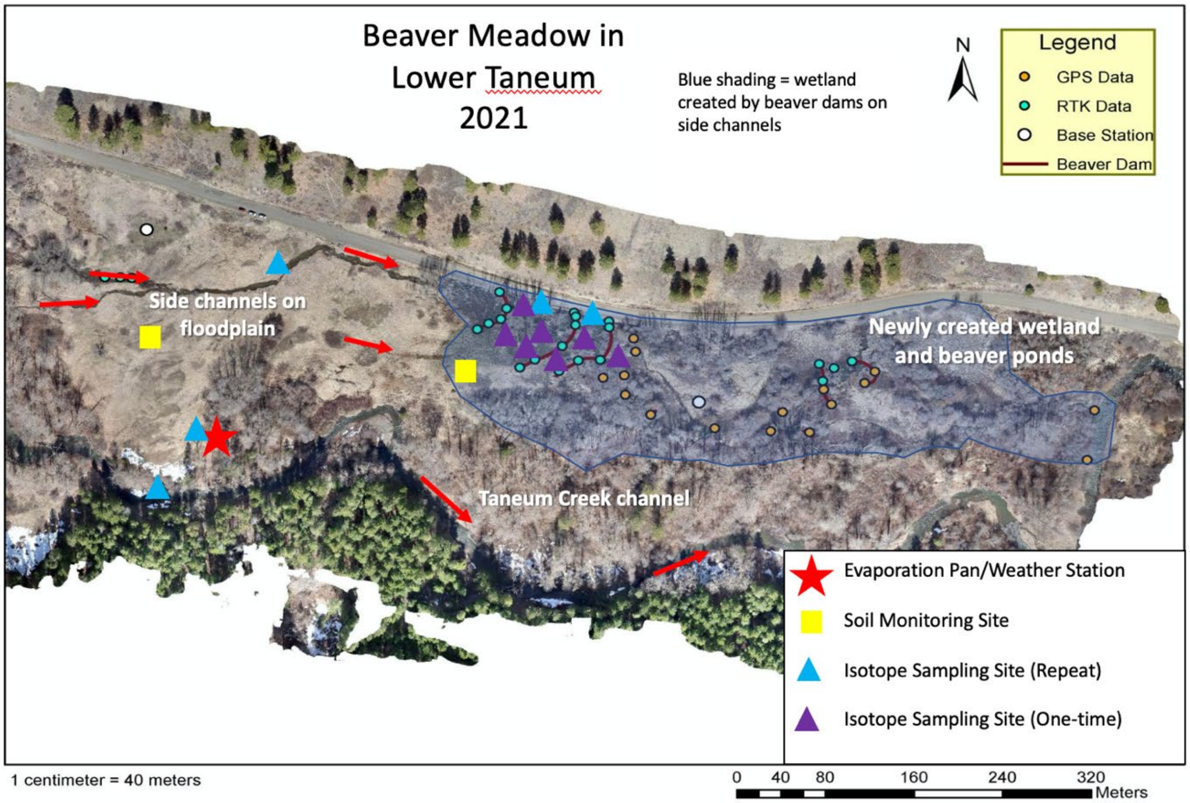

Figure 5. Location of focused study area on Taneum Creek , Section 35, T 19 N, R 16 E. Wetland area from beaver dams is shown with blue shading. Symbols identify sites of field data collection (star and squares) and water sample collection (triangles).

7.2.1 Sampling locations and frequency

Water samples for stable isotope analysis will be collected from Taneum Creek, a side channel, and two beaver pond sites every week throughout the summer. In addition, water from the evaporation pan will be collected at these sampling times. On one sampling date in July, additional samples will be collected from seven additional sites throughout the main beaver pond area. After these samples have been analyzed sample locations will be adjusted as needed to ensure that they are representative of evaporated water within the beaver pond. Water samples are collected as grab samples from a location that appears to be well mixed with the water body that is being sampled and stored in tightly capped high density polyethylene (HDPE) bottles. There is existing stable isotope data from the Taneum River (Gazis, unpublished data) that will be added to the data from these samples to produce a longer term data set.

The aquifer stratigraphy will be examined at multiple locations along the banks of Taneum Creek and Teanaway River within the study areas so as to represent, as much as possible, a range of typical stratigraphic characteristics that could affect the shallow groundwater storage capacity. Stratigraphy will also be described in a transect across the lower Taneum Creek floodplain near the evaporation pan, as delineated by the yellow squares in Figure 5. We will hand auger additional cores across the floodplain to augment the stratigraphy acquired at these locations in Taneum Creek. The stratigraphy obtained in this study will be compared with well logs in the Ecology database and from monitoring wells installed by the Kittitas Reclamation District approximately 4 km downstream.

In the Teanaway River watershed, we will incorporate the stratigraphy at existing monitoring wells in the Indian Creek tributary, auger cores excavated as part of Project C2100007 in the vicinity of Indian Creek, existing stratigraphic descriptions (Bartlett, 2022; Petralia, 2022) and streambank exposures in other tributaries of the Teanaway River.

For both Taneum Creek and the Teanaway River, well logs from the Department of Ecology database will be examined and used to assist with the stratigraphic analysis when appropriate.

7.2.2 Field parameters and laboratory analytes to be measured

Environmental parameters to be measured:

- Subsurface stratigraphy
- Pan evaporation
- Meteorological data: windspeed, solar radiation, humidity, precipitation
- Soil heat flux
- Soil moisture and water content

In the laboratory at CWU, collected water samples will be analyzed for:

- Oxygen isotope ratio (oxygen-18/oxygen-16)
- Hydrogen isotope ratio (deuterium/hydrogen)

7.3 Modeling and analysis design

7.3.1 Analytical framework

Not applicable

7.3.2 Model setup and data needs

Not applicable

7.4 Assumptions of study design

The study is based on the following assumptions:

- There is the potential for a connection between the groundwater and surface water in the adjacent channel, at least seasonally (Petralia, 2022).
- The stratigraphy of the floodplain affects the groundwater storage and flow in that different sedimentary units have different properties of transmissivity (Bartlett, 2022).
- The evaporation measured in the field is representative of the study area.
- The stable isotope values of the surface water is affected by the water source and degree of evaporation.

We will evaluate these assumptions as we analyze the data, looking for evidence of perched aquifers or confined aquifers, particularly beneath clays. The previous stable isotope dataset and water levels from the observation wells at TVFF and Indian Creek on the Teanaway River will assist in this analysis and interpretation (Boylan, 2019; Bartlett, 2022; Petralia, 2022).

7.5 Possible challenges and contingencies

In general, the sites are accessible from mid-spring through late fall via well maintained county roads. Snow cover limits access to the field sites during the winter, typically from November through mid-March. There are no significant physical or chemical hazards.

7.5.1 Logistical problems

The evaporation pan might not be completely installed until fall of 2022. We will collect what we can before winter and will reinstall it in spring 2023 to collect a full spring and summer season of data in 2023.

7.5.2 Practical constraints

If the evaporation pan or data loggers fail or sustain damage, we will repair or replace the failed equipment as soon as possible. We do not currently have funds to purchase contingency equipment. There are two operational isotope ratio mass spectrometers in the geochemistry laboratory at CWU that can be used for stable isotope analyses of water if the Picarro water isotope analyzer breaks down.

7.5.3 Schedule limitations

If deployment of the evaporation pan is delayed due to QAPP development and review or due to requirements by the Department of Natural Resources, we will rely on evapotranpiration estimates for this area on the OpenET evapotranspiration website, as well as the stable isotope and water chemistry values. The main people involved in accomplishing the tasks of this study are Emily Pollizi and Edward Vlasenko, both graduate students at CWU. Inasmuch as this research constitutes their thesis projects, it will be their top priority. The research stipends that are funded in this project will allow them to devote their time to this research.

Restrictions imposed by COVID-19 safety precautions should not impede the schedule for field data collection. All field and laboratory procedures will follow the COVID-19 safety and sanitation protocols established by Central Washington University, which in turn observe the state and county guidelines. All researchers must read and sign the CWU COVID-19 safety protocol, acknowledging that they understand the safety procedures.

8.0 Field Procedures

8.1 Invasive species evaluation

SOP EAP070, Version 2.2 (Parsons et al 2018) will be followed to minimize any chance of spreading of invasive species.

8.2 Measurement and sampling procedures

Standard sampling and field measurement procedures will be used as described in this document and informed by the following SOPs:

Procedures for topographic and ground-penetrating radar surveys are given in:

- Standard Operating Procedure for Determining Global Positioning System coordinates (Janisch, 2006)

Procedures for collecting and analyzing water samples for stable isotopes are given in:

- Collection, Processing, and Analysis of Stream Samples https://fortress.wa.gov/ecy/publications/documents/1703207.pdf

Procedures for soil/sediment sampling and description:

- ASTM Standard Practices for Description and Identification of Soils (Visual-Manual Procedures). International Standard, Designation D2488-17

8.3 Containers, preservation methods, holding times

Table 10. Sample containers, preservation, and holding times.

Parameter	Minimum Quantity Required	Container	Sample Handling and Preservation	Holding Time
Stable isotopes (O and H)	2 ml	30 ml HDPE bottle sealed with tape	Tightly sealed to prevent evaporation	NA

8.4 Equipment decontamination

It is unlikely that any sample will contain high levels of contaminants or organic materials. In the event that in does, the following SOP will be used to decontaminate equipment:

SOP EAP090, *Decontamination of Sampling Equipment for Use in Collecting Toxic Chemical Samples*

8.5 Sample ID

Sample identification will be based on a format that includes the overall project and year, the site, the type of water, and a sample number. The format will be as follows: TC22-site-type#, where TC22 is this project designation and year, the site ID will be the location on Taneum Creek, the type is either G (groundwater) or S (surface water), and the number (#) is the numbering for the water sample in the order that they are collected. For each sampling location/date, the following information will be recorded in a field log:

- Sample identification number

- Sample location
- Sampling date and time
- Sampler's name and names of other field personnel present
- QA samples collected
- Any other relevant information (field conditions, details of how sample was collected).

Sample bottles will be labeled using self-adhesive labels, which will be completed in indelible ink.

Following completion of each sampling trip, the principal investigator will review the field logs recorded by the samplers for completeness, accuracy, and clarity. The principal investigator will retain a copy of all documentation.

8.6 Chain of custody

Samples will remain within the custody of Carey Gazis and Edward Vlasenko at Central Washington University throughout the project. They will be stored on project-designated shelves in a refrigerator in the Stable Isotope Laboratory in the Geological Sciences Department.

8.7 Field log requirements

Field data will be recorded by field personnel at the time of measurement, sampling or observations in a field notebook (log). Data to be entered into field notebooks includes

- names of field personnel
- date and location
- site or data logger identification and description
- environmental conditions
- sequence of events
- dates and times of measurement, sampling or other activity
- appropriate field measurement values and units of measure
- field measurements of surface water level on stage recorders in stream
- any observations or unusual circumstances that might affect interpretation of results. This should include observations of surface water use and hydrology (water in tributaries, irrigation on neighboring properties, etc.)
- stratigraphic descriptions and GPS locations
- locations and subjects of photographs
- detailed notes on any deviations from prescribed procedures

8.8 Other activities

In addition to the standardized procedures described previously in Section 8, the following additional steps will be taken to ensure an adequate level of quality control during sampling:

- Accurate field notes will be maintained that describe field procedures, record values for measured field parameters, track sample identification, and note any variation from the planned procedure.
- Field instruments will be calibrated and/or checked in accordance with the manufacturer's instructions on a daily basis at the beginning of each sampling day, and as needed during the day.
- All non-dedicated, non-disposable field equipment coming into contact with sample water will be cleaned between uses at subsequent sampling locations to prevent cross-contamination of samples. Prior to collection of samples, a rinsing with deionized water followed by rinsing with sample water shall be considered sufficient.
- Samples will be labelled clearly and in multiple places.

Samples will remain in the custody of Edward Vlasenko or Carey Gazis from the time of sample collection through delivery to and storage in the laboratory. Samples will be stored in a refrigerator at 4 degrees C until analysis. Five milliliters of each sample will be archived in break-seal glass ampules.

9.0 Laboratory Procedures

9.1 Lab procedures table

The standard laboratory quality control procedures in place at CWU are adequate to estimate laboratory precision and accuracy. Laboratory quality control samples will include duplicates and check standards (QC standards). Duplicates will be used to estimate overall bias due to the combination the analytical procedure and any sample-specific interferences. Check standards will be used to verify analytical precision, to test for instrument drift, and to provide an estimate of bias due to calibration. Because stable isotope analyses are measurements of ratios, not concentrations, there is no need for measurements of blanks or determinations of detection limits.

Table 11 presents a summary of the types and minimum frequency of field and laboratory quality control samples for this project. If QC results regularly fall outside of the acceptable limits defined in this table, the investigators will review the sampling and/or analytical methods to determine an appropriate course of action to obtain the desired data quality. Any changes in procedure will be submitted for approval Ecology.

There will be no measurements of samples in the field.

Table 11. Measurement methods (laboratory).

Analyte	Sample Matrix	Samples (Number/ Arrival Date)	Expected Range of Results	Detection or Reporting Limit	Sample Prep Method	Analytical (Instrumental) Method
Oxygen-18	water	95/Oct 2022	-5 to -25‰	NA	Filter 0.45 μm	Cavity Ring-down Spectroscopy
Deuterium	water	95/Oct 2022	-30 to -170‰	NA	Filter 0.45 μm	Cavity Ring-down Spectroscopy

9.2 Sample preparation method(s)

For stable isotope analysis, water sample is collected directly into a clean, dry 30 mL HDPE bottle, filling it almost to the top, and capping it tightly. The main objective is to protect the sample from evaporation and exchange with atmospheric water vapor. Samples that contain visible particulate matter are filtered with a 0.45 micron polypropylene filter. Samples are stored in a refrigerator in the Stable Isotope Laboratory at CWU.

9.3 Special method requirements

Not applicable.

9.4 Laboratories accredited for methods

Stable isotope analyses is a specialized type of geochemical analysis that does not have EPA accreditation criteria. Dr. Gazis's laboratory in the Geological Sciences Department has been performing this type of analyses for over twenty years, including over 400 analyses for an Ecology-funded project in the Columbia Basin Groundwater Management Area (Vlassopoulos, 2008) and past projects awarded to Gazis by the DOE through the YBIP Groundwater Storage Group, which used stable isotopes to decipher surface water/groundwater interactions at potential groundwater storage locations in the Yakima River Basin.

10.0 Quality Control Procedures

The quality control procedures for field and laboratory measurements are outlined above. Field notebooks and field data will be reviewed after each sampling trip. Laboratory results will be reviewed immediately to ensure that quality control standards are within accepted range and that there are no problems with the blanks, duplicates, or matrix spikes. One of the co-principal investigators, Carey Gazis or Lisa Ely, will meet weekly with the graduate student researchers to review quality control results and discuss any problems that have arisen and will accompany them regularly to the field sites.

The quality control procedure for documenting the stratigraphic locations will be to compare the relative elevations and locations with landmarks and benchmarks from aerial photographs and satellite imagery.

10.1 Table of field and laboratory quality control

Table 12 presents a plan for frequency and types of quality control samples.

Table 12. Quality control samples, types, and frequency.

Parameter	Field		Laboratory			
	Blanks	Replicates	Check Standards	Method Blanks	Analytical Duplicates	Matrix Spikes
Oxygen-18	NA	1/20	1/6	NA	1/6	NA
Deuterium	NA	1/20	1/6	NA	1/6	NA

10.2 Corrective action processes

If there is a problem with a single sample or a set of samples, a series of steps will be taken to correct any faulty data:

- A series of standards will be run through the instrument to ensure that it is running.
- If there is a problem with the instrument, the instrument technicians at CWU will help with any trouble-shooting to solve the problem.
- Once the instrument is running properly, the samples will be rerun and checked again for quality of analysis.
- If necessary, samples will be recollected in the method described in this QAPP.

For data logger measurements, the following corrective actions will be taken:

- Data will be compared between nearby loggers (soil moisture) and nearby National Weather Service weather stations (wind speed, solar radiation, humidity) and unreasonable or inconsistent results will be rejected.
- Any faulty data logger will be replaced if there is evidence of mid-deployment failures.
- If there is evidence that a sensor is not working, it will also be replaced if possible.

For field data collection with handheld GPS, the following steps will be take to correct any faulty data:

- If there is a problem with the instrument or software, the instrument technicians at CWU will help with any trouble-shooting to solve the problem, which could include replacing the instrument.
- Once the instrument is running properly, the affected portion of the survey will be recalculated or resurveyed as appropriate using the method described in this QAPP.

11.0 Data Management Procedures

11.1 Data recording and reporting requirements

All field data will be recorded in a field notebook. Field notebooks will be checked for missing or improbable measurements before leaving each site. Field-generated sampling and survey data will be entered into Excel spreadsheets or other instrument-specific formats as soon as practical after returning from the field. Data entry will be checked by the field staff against the field notebook data for errors and omissions. Missing or unusual data will be brought to the attention of the project manager for consultation.

Laboratory-generated data will be managed by the Laboratory Information Management Systems (LIMS) at CWU and backed up on the Geological Sciences Department's server. In addition to sample results, the laboratory data package will include all relevant calibration standards and QC results needed for data validation. Following evaluation of the analytical data against the project data quality objectives, the investigators will incorporate the results into a master Excel spreadsheet database. For each sample, the spreadsheet database will record station identification, coordinates, sampling date, and associated field and laboratory analytical data. The documentation for each sampling location will include the completed field notebook (log) entry, a copy of the analytical results, as well as analytical results for associated field and laboratory QC samples. Full documentation for all samples will be compiled and stored at the investigator's office at CWU.

Results of quality control checks and calibrations will be recorded on electronic forms to allow for quality assurance review. Quality assurance records will be saved on CWU computers until Ecology's final approval of the project report so they may be accessed for post-project analysis and audits.

11.2 Laboratory data package requirements

The laboratory data will initially be transferred into an Excel workbook and sorted into the following worksheets:

1. Raw data
2. Results for calibration standards and calibrations
3. Results for QC standards with graph of results with time and comparison to quality control thresholds
4. Results of duplicates and any other QC samples and comparison with expected values
5. Corrected sample results

11.3 Electronic transfer requirements

Data will be transferred to Ecology's EIM system according to the timeline approved for this project per online submittal guidelines. Only applicable project data, verified through the project QA process, will be uploaded into EIM.

11.4 Data upload procedures

Data will be transferred to Ecology's EIM system according to the timeline approved for this project per online submittal guidelines. Only applicable project data, verified through the project QA process, will be uploaded into EIM. The EIM data coordinator will be consulted if data submittal problems arise. The graduate student researchers will complete EIM training offered by Ecology and follow all existing Ecology business rules and the EIM User's Manual for loading, data quality checks, and editing.

11.5 Model information management

NOT APPLICABLE

12.0 Audits and Reports

12.1 Audits

Not applicable.

12.2 Responsible personnel

See Table 1 in Section 5.1.

12.3 Frequency and distribution of reports

The data collected under this project will be summarized in a formal peer-reviewed report that includes results, methods, and data quality assessment. This final report will be submitted in January, 2024.

12.4 Responsibility for reports

Carey Gazis, Lisa Ely, Emily Polizzi and Edward Vlasenko will co-author the final report.

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

All data collected are subject to review by the principal investigator to determine if the data meet QAPP objectives. Decisions to reject or qualify data are made by the principle investigator in conjunction with the other investigators. Data may be rejected because of inadequate or deficient documentation or because the QC sample results fail to meet the MQOs identified in Section 4.

13.2 Laboratory data verification

All laboratory data will undergo an initial quality assurance review by Edward Vlasenko to verify that laboratory quality control samples met acceptance criteria as specified in the laboratory's standard operating procedure for that method. The co-principal investigator, Carey Gazis, will provide a follow-up quality assurance review. Appropriate qualifiers will be attached to results that do not meet requirements. An explanation for the data qualification will be attached with the data package.

13.3 Validation requirements, if necessary

Not applicable.

13.4 Model quality assessment

13.4.1 Calibration and validation

Not applicable

13.4.1.1 Precision

Not applicable

13.4.1.2 Bias

Not applicable

13.4.1.3 Representativeness

Not applicable.

13.4.1.4 Qualitative assessment

Not applicable

13.4.2 Analysis of sensitivity and uncertainty

Not applicable

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

After all field data are verified, the field lead or project manager will thoroughly examine the data to determine if MQOs have been met. The project manager will examine the data to determine if all the criteria for MQOs, completeness, representativeness, and comparability have been met. If the criteria have not been met, the project manager will decide if affected data should be qualified or rejected. The project manager will decide how any qualified data will be used in the technical analysis.

Upon receipt of the verified laboratory data, the principal investigator will determine if the results meet the MQOs for bias, precision, and accuracy for that sampling episode. Precision will be estimated by calculating standard deviations for multiple measurements of a single sample and the difference between results for duplicate pairs. All should lie within the MQOs of 0.1 per mil for delta-18O and 1 per mil for delta-D. These values provide an indication of the degree of random variability introduced by sampling and analytical procedures. Analytical bias is assumed to be within acceptable limits if laboratory quality control limits are met for quality control and check standards. Sampling bias will be checked by verifying that the correct sampling and handling procedures were used.

14.2 Treatment of non-detects

Not applicable.

14.3 Data analysis and presentation methods

Stratigraphic data will be correlated and plotted in geologic cross sections. Surveyed locations and elevations of stratigraphic sites will be presented in tabular form, plotted on channel and geologic cross sections, and mapped. Floodplain aquifer extent will be presented in maps and topographic cross sections.

Stable isotope data will be analyzed by a variety of means. The relationship between dD and d18O, characterized by the deuterium excess will be calculated for each sample:

d-excess = $\delta D - 8*\delta^{18}O$

This value gives an indication of the relative importance of kinetic fractionation through evaporation versus equilibrium fractionation between water and vapor. To obtain a view of variations between, stable isotope data will be displayed on a plot of delta-18O versus delta-D. In addition, data at each location will be plotted versus time (delta-18O versus time, delta-D versus time, deuterium excess versus time). Data will be further evaluated using mass balance considerations and methods described in Brooks et al. (2014) in order to evaluate the relative rates of inflow and outflow (and thus residence time) versus evaporation.

14.4 Sampling design evaluation

The sampling design is based on existing information, and the actual conditions at the site may be more complex than indicated. The spatial distribution of the water sampling locations is based on the location of the stream, side channel and beaver ponds at the study sites. The evaporation pan site was chosen to be representative of an intermediate level of shade within the study area and also to be accessible and yet not visible from the road. A representative from Washington Department of Fish and Wildlife (WDFW), the land manager, was present with us when the site was selected. The soil monitoring sites are chosen to represent a wet location where soil moisture remains high throughout the summer and a dry location, where the is minimal soil moisture in the hot summer months. We are working with WDFW to gain permits to install the soil heat flux plates and moisture/temperature sensors at these locations. If we identify deficiencies in our sampling design, we will evaluate the potential consequences on the project. We may recommend additional work or activities to resolve such problems.

The stable isotope sampling design includes approximately 100 samples, including five surface water samples collected each week for approximately four months. From our experience analyzing stream water in the past, this will be an appropriate interval to characterize the variation throughout the summer.

14.5 Documentation of assessment

The project manager will include a section in the final technical report summarizing the findings of the data quality assessment. This summary will be included in the data quality section of the report.

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16.0 Appendices

Appendix A. Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

Ambient: Background or away from point sources of contamination. Surrounding environmental condition.

Anthropogenic: Human-caused.

Bankfull stage: Formally defined as the stream level that "corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels (Dunne and Leopold, 1978).

Baseflow: The component of total streamflow that originates from direct groundwater discharges to a stream.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Critical condition: When the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or designated water uses. For steady-state discharges to riverine systems, the critical condition may be assumed to be equal to the 7Q10 flow event unless determined otherwise by the department.

Designated uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each water body or segment, regardless of whether or not the uses are currently attained.

Diel: Of, or pertaining to, a 24-hour period.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Dilution factor: The relative proportion of effluent to stream (receiving water) flows occurring at the edge of a mixing zone during critical discharge conditions as authorized in accordance with the state's mixing zone regulations at WAC 173-201A-100.
http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-020

Diurnal: Of, or pertaining to, a day or each day; daily. (1) Occurring during the daytime only, as different from nocturnal or crepuscular, or (2) Daily; related to actions which are completed in the course of a calendar day, and which typically recur every calendar day (e.g., diurnal temperature rises during the day, and falls during the night).

Effluent: An outflowing of water from a natural body of water or from a human-made structure. For example, the treated outflow from a wastewater treatment plant.

Existing uses: Those uses actually attained in fresh and marine waters on or after November 28, 1975, whether or not they are designated uses. Introduced species that are not native to Washington, and put-and-take fisheries comprised of non-self-replicating introduced native species, do not need to receive full support as an existing use.

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform bacteria are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100 mL).

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10 to 10,000 fold over a given period. The calculation is performed by either: (1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

Hyporheic: The area beneath and adjacent to a stream where surface water and groundwater intermix.

Load allocation: The portion of a receiving water's loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

Loading capacity: The greatest amount of a substance that a water body can receive and still meet water quality standards.

Margin of safety: Required component of TMDLs that accounts for uncertainty about the relationship between pollutant loads and quality of the receiving water body.

Near-stream disturbance zone (NSDZ): The active channel area without riparian vegetation that includes features such as gravel bars.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Point source: Source of pollution that discharges at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites where more than 5 acres of land have been cleared.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Reach: A specific portion or segment of a stream.

Riparian: Relating to the banks along a natural course of water.

Salmonid: Fish that belong to the family *Salmonidae*. Species of salmon, trout, or char.

Sediment: Soil and organic matter that is covered with water (for example, river or lake bottom).

Streamflow: Discharge of water in a surface stream (river or creek).

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Synoptic survey: Data collected simultaneously or over a short period of time.

System potential: The design condition used for TMDL analysis.

System-potential channel morphology: The more stable configuration that would occur with less human disturbance.

System-potential mature riparian vegetation: Vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

System-potential riparian microclimate: The best estimate of air temperature reductions that are expected under mature riparian vegetation. System-potential riparian microclimate can also include expected changes to wind speed and relative humidity.

System-potential temperature: An approximation of the temperatures that would occur under natural conditions. System potential is our best understanding of natural conditions that can be supported by available analytical methods. The simulation of the system-potential condition uses best estimates of *mature riparian vegetation, system-potential channel morphology, and system-potential riparian microclimate* that would occur absent any human alteration.

Thalweg: The deepest and fastest moving portion of a stream.

Total suspended solids (TSS): Portion of solids retained by a filter.

Turbidity: A measure of water clarity. High levels of turbidity can have a negative impact on aquatic life.

Wasteload allocation: The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. Wasteload allocations constitute one type of water quality-based effluent limitation.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

1-DMax or 1-day maximum temperature: The highest water temperature reached on any given day. This measure can be obtained using calibrated maximum/minimum thermometers or continuous monitoring probes having sampling intervals of thirty minutes or less.

7-DADMax or 7-day average of the daily maximum temperatures: The arithmetic average of seven consecutive measures of daily maximum temperatures. The 7-DADMax for any individual day is calculated by averaging that day's daily maximum temperature with the daily maximum temperatures of the three days before and the three days after that date.

7Q2 flow: A typical low-flow condition. The 7Q2 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every other year on average. The 7Q2 flow is commonly used to represent the average low-flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q2 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

7Q10 flow: A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every ten years on average. The 7Q10 flow is commonly used to represent the critical flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

90th percentile: An estimated portion of a sample population based on a statistical determination of distribution characteristics. The 90th percentile value is a statistically derived estimate of the division between 90% of samples, which should be less than the value, and 10% of samples, which are expected to exceed the value.

Acronyms and Abbreviations

BMP	Best management practice
DO	Dissolved oxygen
DOC	Dissolved organic carbon
e.g.	For example
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others
FC	Fecal coliform
GIS	Geographic Information System software
GPS	Global Positioning System
i.e.	In other words
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
NAF	New Approximation Flow
NPDES	National Pollutant Discharge Elimination System
NSDZ	Near-stream disturbance zones
NTR	National Toxics Rule
PBDE	Polybrominated diphenyl ethers
PBT	Persistent, bioaccumulative, and toxic substance
PCB	Polychlorinated biphenyls
QA	Quality assurance
QC	Quality control
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation

SOP	Standard operating procedures
SRM	Standard reference materials
TIR	Thermal infrared radiation
TMDL	Total Maximum Daily Load
TOC	Total organic carbon
TSS	Total suspended solids
USFS	United States Forest Service
USGS	United States Geological Survey
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WQA	Water Quality Assessment
WRIA	Water Resource Inventory Area
WSTMP	Washington State Toxics Monitoring Program
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cfu	colony forming units
cms	cubic meters per second, a unit of flow
dw	dry weight
ft	feet
g	gram, a unit of mass
kcfs	1000 cubic feet per second
kg	kilograms, a unit of mass equal to 1,000 grams
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters
L/s	liters per second (0.03531 cubic foot per second)
m	meter
mm	millimeter
mg	milligram
mgd	million gallons per day

mg/d	milligrams per day
mg/kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mg/L/hr	milligrams per liter per hour
mL	milliliter
mmol	millimole or one-thousandth of a mole
mole	an International System of Units (IS) unit of matter
ng/g	nanograms per gram (parts per billion)
ng/kg	nanograms per kilogram (parts per trillion)
ng/L	nanograms per liter (parts per trillion)
NTU	nephelometric turbidity units
pg/g	picograms per gram (parts per trillion)
pg/L	picograms per liter (parts per quadrillion)
psu	practical salinity units
s.u.	standard units
µg/g	micrograms per gram (parts per million)
µg/kg	micrograms per kilogram (parts per billion)
µg/L	micrograms per liter (parts per billion)
µm	micrometer
µM	micromolar (a chemistry unit)
µmhos/cm	micromhos per centimeter
µS/cm	microsiemens per centimeter, a unit of conductivity
ww	wet weight

Quality Assurance Glossary

Accreditation: A certification process for laboratories, designed to evaluate and document a lab's ability to perform analytical methods and produce acceptable data (Kammin, 2010). For Ecology, it is defined according to WAC 173-50-040: "Formal recognition by [Ecology] that an environmental laboratory is capable of producing accurate and defensible analytical data."

Accuracy: The degree to which a measured value agrees with the true value of the measured property. USEPA recommends that this term not be used, and that the terms *precision* and *bias* be used to convey the information associated with the term *accuracy* (USEPA, 2014).

Analyte: An element, ion, compound, or chemical moiety (pH, alkalinity) which is to be determined. The definition can be expanded to include organisms, e.g., fecal coliform, Klebsiella (Kammin, 2010).

Bias: Discrepancy between the expected value of an estimator and the population parameter being estimated (Gilbert, 1987; USEPA, 2014).

Blank: A synthetic sample, free of the analyte(s) of interest. For example, in water analysis, pure water is used for the blank. In chemical analysis, a blank is used to estimate the analytical response to all factors other than the analyte in the sample. In general, blanks are used to assess possible contamination or inadvertent introduction of analyte during various stages of the sampling and analytical process (USGS, 1998).

Calibration: The process of establishing the relationship between the response of a measurement system and the concentration of the parameter being measured (Ecology, 2004).

Check standard: A substance or reference material obtained from a source independent from the source of the calibration standard; used to assess bias for an analytical method. This is an obsolete term, and its use is highly discouraged. See Calibration Verification Standards, Lab Control Samples (LCS), Certified Reference Materials (CRM), and/or spiked blanks. These are all check standards but should be referred to by their actual designator, e.g., CRM, LCS (Kammin, 2010; Ecology, 2004).

Comparability: The degree to which different methods, data sets and/or decisions agree or can be represented as similar; a data quality indicator (USEPA, 2014; USEPA, 2020).

Completeness: The amount of valid data obtained from a project compared to the planned amount. Usually expressed as a percentage. A data quality indicator (USEPA, 2014; USEPA 2020).

Continuing Calibration Verification Standard (CCV): A quality control (QC) sample analyzed with samples to check for acceptable bias in the measurement system. The CCV is usually a midpoint calibration standard that is re-run at an established frequency during the course of an analytical run (Kammin, 2010).

Control chart: A graphical representation of quality control results demonstrating the performance of an aspect of a measurement system (Kammin, 2010; Ecology 2004).

Control limits: Statistical warning and action limits calculated based on control charts. Warning limits are generally set at +/- 2 standard deviations from the mean, action limits at +/- 3 standard deviations from the mean (Kammin, 2010).

Data integrity: A qualitative DQI that evaluates the extent to which a data set contains data that is misrepresented, falsified, or deliberately misleading (Kammin, 2010).

Data quality indicators (DQI): Commonly used measures of acceptability for environmental data. The principal DQIs are precision, bias, representativeness, comparability, completeness, sensitivity, and integrity (USEPA, 2006).

Data quality objectives (DQO): Qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions (USEPA, 2006).

Data set: A grouping of samples organized by date, time, analyte, etc. (Kammin, 2010).

Data validation: The process of determining that the data satisfy the requirements as defined by the data user (USEPA, 2020). There are various levels of data validation (USEPA, 2009).

Data verification: Examination of a data set for errors or omissions, and assessment of the Data Quality Indicators related to that data set for compliance with acceptance criteria (MQOs). Verification is a detailed quality review of a data set (Ecology, 2004).

Detection limit (limit of detection)**:** The concentration or amount of an analyte which can be determined to a specified level of certainty to be greater than zero (Ecology, 2004).

Duplicate samples: Two samples taken from and representative of the same population, and carried through and steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variability of all method activities including sampling and analysis (USEPA, 2014).

Field blank: A blank used to obtain information on contamination introduced during sample collection, storage, and transport (Ecology, 2004).

Initial Calibration Verification Standard (ICV): A QC sample prepared independently of calibration standards and analyzed along with the samples to check for acceptable bias in the measurement system. The ICV is analyzed prior to the analysis of any samples (Kammin, 2010).

Laboratory Control Sample (LCS)/LCS duplicate: A sample of known composition prepared using contaminant-free water or an inert solid that is spiked with analytes of interest at the midpoint of the calibration curve or at the level of concern. It is prepared and analyzed in the same batch of regular samples using the same sample preparation method, reagents, and analytical methods employed for regular samples. Monitors a lab's performance for bias and precision (USEPA, 2014).

Matrix spike/Matrix spike duplicate: A QC sample prepared by adding a known amount of the target analyte(s) to an aliquot of a sample to check for bias and precision errors due to interference or matrix effects (Ecology, 2004).

Measurement Quality Objectives (MQOs)**:** Performance or acceptance criteria for individual data quality indicators, usually including precision, bias, sensitivity, completeness, comparability, and representativeness (USEPA, 2006).

Measurement result: A value obtained by performing the procedure described in a method (Ecology, 2004).

Method: A formalized group of procedures and techniques for performing an activity (e.g., sampling, chemical analysis, data analysis), systematically presented in the order in which they are to be executed (USEPA, 2001).

Method blank: A blank prepared to represent the sample matrix, prepared and analyzed with a batch of samples. A method blank will contain all reagents used in the preparation of a sample, and the same preparation process is used for the method blank and samples (Ecology, 2004; Kammin, 2010).

Method Detection Limit (MDL): The minimum measured concentration of a substance that can be reported with 99% confidence that the measured concentration is distinguishable from method blank results (USEPA, 2016). MDL is a measure of the capability of an analytical method of distinguished samples that do not contain a specific analyte from a sample that contains a low concentration of the analyte (USEPA, 2020).

Minimum level: Either the sample concentration equivalent to the lowest calibration point in a method or a multiple of the method detection limit (MDL), whichever is higher. For the purposes of NPDES compliance monitoring, EPA considers the following terms to be synonymous: "quantitation limit," "reporting limit," and "minimum level" (40 CFR 136).

Parameter: A specified characteristic of a population or sample. Also, an analyte or grouping of analytes. Benzene and nitrate + nitrite are all parameters (Kammin, 2010; Ecology, 2004).

Population: The hypothetical set of all possible observations of the type being investigated (Ecology, 2004).

Precision: The extent of random variability among replicate measurements of the same property; a data quality indicator (USGS, 1998).

Quality assurance (QA): A set of activities designed to establish and document the reliability and usability of measurement data (Kammin, 2010).

Quality Assurance Project Plan (QAPP): A document that describes the objectives of a project, and the processes and activities necessary to develop data that will support those objectives (Kammin, 2010; Ecology, 2004).

Quality control (QC): The routine application of measurement and statistical procedures to assess the accuracy of measurement data (Ecology, 2004).

Relative Percent Difference (RPD): RPD is commonly used to evaluate precision. The following formula is used:

$$RPD = [Abs(a-b)/((a + b)/2)] * 100\%$$

where "Abs()" is absolute value and a and b are results for the two replicate samples. RPD can be used only with 2 values. Percent Relative Standard Deviation is (%RSD) is used if there are results for more than 2 replicate samples (Ecology, 2004).

Relative Standard Deviation (RSD): A statistic used to evaluate precision in environmental analysis. It is determined in the following manner:

$$RSD = (100\% * s)/x$$

where s is the sample standard deviation and x is the mean of results from more than two replicate samples (Kammin, 2010).

Replicate samples: Two or more samples taken from the environment at the same time and place, using the same protocols. Replicates are used to estimate the random variability of the material sampled (USGS, 1998).

Reporting level: Unless specified otherwise by a regulatory authority or in a discharge permit, results for analytes that meet the identification criteria (i.e., rules for determining qualitative presence/absence of an analyte) are reported down to the concentration of the minimum level established by the laboratory through calibration of the instrument. EPA considers the terms "reporting limit," "quantitation limit," and "minimum level" to be synonymous (40 CFR 136).

Representativeness: The degree to which a sample reflects the population from which it is taken; a data quality indicator (USGS, 1998).

Sample (field): A portion of a population (environmental entity) that is measured and assumed to represent the entire population (USGS, 1998).

Sample (statistical): A finite part or subset of a statistical population (USEPA, 1992).

Sensitivity: In general, denotes the rate at which the analytical response (e.g., absorbance, volume, meter reading) varies with the concentration of the parameter being determined. In a specialized sense, it has the same meaning as the detection limit (Ecology, 2004).

Spiked blank: A specified amount of reagent blank fortified with a known mass of the target analyte(s); usually used to assess the recovery efficiency of the method (USEPA, 2014).

Spiked sample: A sample prepared by adding a known mass of target analyte(s) to a specified amount of matrix sample for which an independent estimate of target analyte(s) concentration is available. Spiked samples can be used to determine the effect of the matrix on a method's recovery efficiency (USEPA, 2014).

Split sample: A discrete sample subdivided into portions, usually duplicates (Kammin, 2010).

Standard Operating Procedure (SOP): A document which describes in detail a reproducible and repeatable organized activity (Kammin, 2010).

Surrogate: For environmental chemistry, a surrogate is a substance with properties similar to those of the target analyte(s). Surrogates are unlikely to be native to environmental samples. They are added to environmental samples for quality control purposes, to track extraction efficiency and/or measure analyte recovery. Deuterated organic compounds are examples of surrogates commonly used in organic compound analysis (Kammin, 2010).

Systematic planning: A step-wise process which develops a clear description of the goals and objectives of a project, and produces decisions on the type, quantity, and quality of data that will be needed to meet those goals and objectives. The DQO process is a specialized type of systematic planning (USEPA, 2006).

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