
Hydrogeology and Potential for Groundwater Recharge and Storage on Alluvial Fans in the Yakima Basin

Part 1: Hydrogeochemical Characterization of the Ahtanum Alluvial Fan for Managed Aquifer Recharge

Lisa L. Ely, Brook M. Bauer, and Carey A. Gazis



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Department of Geological Sciences
Central Washington University

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EXECUTIVE SUMMARY

Securing the future water supply for agriculture, domestic use, instream flow and habitat in the Yakima Basin is the focus of coordinated efforts under the Yakima Basin Integrated Plan (YBIP). Managed aquifer recharge (MAR) is a sustainable and cost-effective approach to store water underground for recovery or supplementation of instream flows during seasonal dry periods or drought. This project characterized the hydrogeology, aquifer stratigraphy, and geochemistry of two large alluvial fan aquifers in the Yakima Basin to assess their potential for groundwater recharge and storage (Fig. 1).

We analyzed the physical characteristics and hydrology of the Ahtanum Creek alluvial fan in the Yakima Valley and Manastash Creek alluvial fan in the Kittitas Valley to provide the foundation for an informed decision about the implementation of MAR projects. We combined existing data from wells logs, maps and reports with new data on sediment characteristics, water levels and geochemistry to identify areas with suitable permeability rates, head space and surface water penetration into the unconfined aquifer.

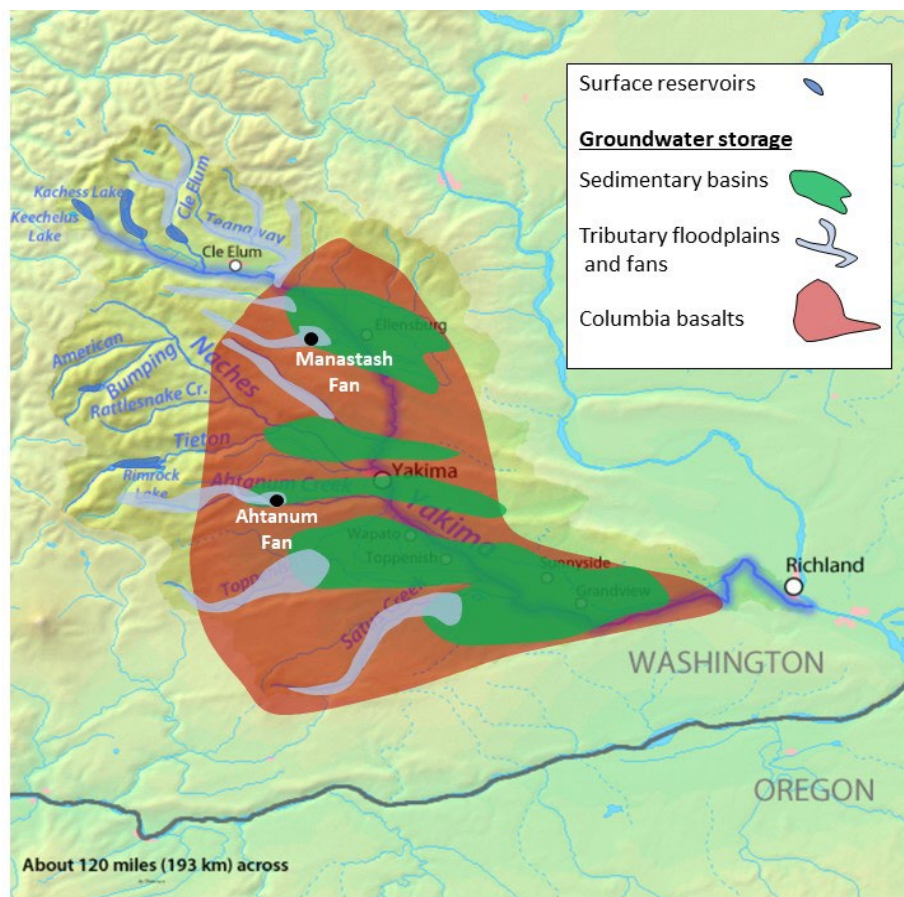


Figure 1. Map of alluvial fans and sedimentary basins in the Yakima River Basin. Schematic map of potential groundwater storage reservoirs in alluvial fans and sedimentary basins in the Yakima River Basin. The Ahtanum and Manastash Creek alluvial fans are labeled.

The two chapters of this report cover the potential for MAR and the locations of promising recharge sites on each of the alluvial fans by addressing the following:

- The effects of the physical properties of the alluvial fan and the human-built water infrastructure on groundwater recharge and storage.
- The use of geochemistry to interpret general patterns of infiltration and mixing of surface water with groundwater.
- Identifying locations for potential storage at different points on the alluvial fans and estimating the travel time of stored water to nearby streams.

Part 1 (this volume). Hydrogeochemical Characterization of the Ahtanum Alluvial Fan for Managed Aquifer Recharge

Part 1 of this project report (this volume) evaluates the recharge potential of the Ahtanum Creek alluvial fan within the lower Ahtanum Sub-Basin by integrating geologic, hydraulic, and geochemical data. Four main hydrogeologic units (unconsolidated, semi-consolidated, consolidated basin-fill deposits, and Columbia River Basalt aquifers) were identified from stratigraphic analysis of well logs across seven transects spanning the active fan surfaces and elevated alluvial terraces of the alluvial fan.

Stable isotope ($\delta^{18}\text{O}$, δD) and major ion analyses of 25 groundwater and eight surface-water samples defined six hydrochemical groups (A-F) exhibiting various degrees of surface-water and groundwater interaction. Groups A, B, D, and E show heavy to moderate isotopic and nitrate (NO_3^-) signatures indicative of some modern surface-water recharge. Group A, located in the active floodplain, is associated with highly transmissive unconsolidated to semi-consolidated units and well-drained soils, supporting both rapid infiltration and long-term storage. Groups B and D, in semi-consolidated and consolidated units and well-drained soils along the anticlinal ridges, offer moderate infiltration and extended retention potential. Group E, near the fan apex in shallow fractured basalt units overlain by excessively drained soils, presents characteristics suitable for distribution of flow and long-term storage.

Groups C and F display isotopically lighter and chemically evolved chemistries, indicating minimal recharge from surface water at present. Group C, located in the mid-to-downstream sections of the active alluvial fan, includes consolidated aquifer units overlain by poorly drained soils. Group F includes wells in two deep, sedimentary interbeds within the Columbia River Basalt bedrock in the upstream reaches of the elevated alluvial terrace.

The results highlight the upstream reaches of the active fan and the mid-fan aquifer units along the northern and southern slopes of the anticlinal ridges as optimal regions for surface-water infiltration recharge through MAR, while deeper consolidated units are more appropriate for long-term groundwater storage. Units C and E are less suitable for recharge through passive infiltration but may present opportunities for long-term storage through alternative recharge methods.

Part 2 (see Volume 2 of the Project Report). Assessing Potential for Managed Aquifer Recharge on the Manastash Alluvial Fan: A Geochemical Analysis

Part 2 of this project report (see Volume 2) evaluates the Manastash alluvial fan located west of Ellensburg, Washington as a potential region for two MAR methods: Shallow Aquifer Recharge (SAR) and Aquifer Storage and Recovery (ASR). Six subsurface lithologic cross-sections were developed from well logs and geologic maps to characterize hydrogeologic relationships. Water levels within Manastash Creek and two unused wells were monitored using in situ devices to identify surface/groundwater level correlations. Major ion, trace element, and stable isotope geochemistry of 22 groundwater and nine surface water samples were analyzed to further support surface water/groundwater interactions and classify groundwater groupings.

Three groundwater hydrochemical groups were identified: Group 1 has high to medium sodium values suggesting older waters; Group 2 is from sedimentary wells with light isotopic signatures suggesting little-to-no influence from surface water; and Group 3 has intermediate to heavy stable isotope signatures indicating influence from surface water diverted from the Yakima River and Manastash through irrigation canals. Sedimentary wells with evidence of strong surface-water influence (Group 3) were combined with soil infiltration and drainage data, tax parcel information, and estimated seepage velocity calculations to identify four suitable locations for SAR along the outer fan boundary. Wells in the southeastern part of the fan and near Manastash Creek also showed evidence of surface-water influence. A region of concentrated basalt wells and tax parcel data were combined to identify one potential location for ASR at the fan apex. A potential barrier to groundwater flow was identified by abrupt changes in hydrochemical groups on either side of a probable fault. Suitability analysis results identified specific locations to be further assessed for MAR on the Manastash alluvial fan.

Part 1. Hydrogeochemical Characterization of the Ahtanum Alluvial Fan for Managed Aquifer Recharge

Lisa L. Ely, Brook M. Bauer and Carey A. Gazis

INTRODUCTION

The Yakima Basin is home to a robust agricultural economy, essential natural resources, the Confederated Tribes of the Yakama Nation, and several municipalities that rely on the consistent quality and supply of water from the Yakima River. Climate change is predicted to bring changing precipitation patterns, which could alter the seasonal distribution of the water supply within the basin. The Yakima Basin Integrated Plan (YBIP) is taking preemptive measures to anticipate these changes and secure water resources through investments in irrigation, conservation, and water storage (Yakima Basin Integrated Plan, 2023). Enhancing groundwater storage through application and infiltration of excess surface water during the non-irrigation season is one strategy to increase late-summer water supplies or instream flow within the Yakima River watershed. Managed Aquifer Recharge (MAR) is a form of facilitated aquifer replenishment aiming to maintain, enhance, and secure groundwater systems under stress by water managers (Dillon et al., 2019).

Part 1 of this report on the Ahtanum alluvial fan (this volume) is based on the Master's thesis research at Central Washington University by Brook Bauer (2024). The chapter assesses aquifer storage capacity and recharge potential within the Ahtanum alluvial fan in the Lower Yakima Basin. The Ahtanum fan is one of the larger alluvial fans within the Yakima River basin (Fig. 1), and thus represents a potentially expansive groundwater storage capacity. Ahtanum Creek provides a natural source of surface water onto the fan. The study provides a comprehensive assessment of the physical properties of the sedimentary aquifer units within the Ahtanum alluvial fan. We used stable isotopes and geochemistry to quantify mixing of surface water and groundwater and thus the potential degree of surface water infiltration in different shallow aquifer units. The analysis here is based only on the physical and hydrological characteristics of the alluvial fan. Implementation of MAR would also have to account for additional non-geological factors necessary to acquire and deliver surface water to specific recharge sites, such as water rights, delivery mechanisms, source, and land ownership.

Ahtanum Alluvial Fan Study Site

The 6,200 square miles composing the Yakima River Basin consists of sedimentary basins separated by a series of anticlines and synclines of the Yakima fold and thrust belt (Fig. 1; Ely et al., 2011). The Yakima basin headwaters originate on the eastern slopes of the north to south trending Cascade Mountains, with a mean annual precipitation of 270 cm, which decreases to 15 cm at the Yakima River confluence with the Columbia River (Ely et al., 2011).

The Ahtanum Creek sub-basin, one of the largest tributaries to the Yakima River, covers approximately 440 km² in a continental semi-arid climate characterized by sagebrush, desert shrubs, grasses, and cottonwood willows (Foxworthy, 1962). The lower Ahtanum valley contains

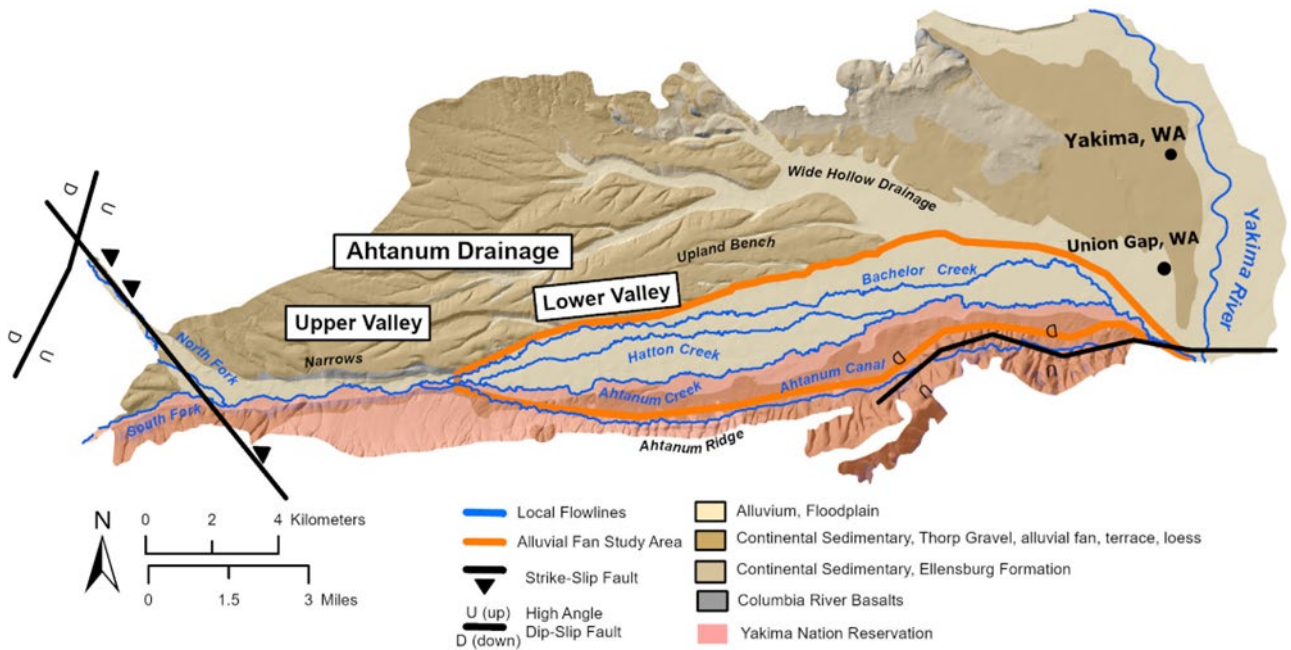


Figure 2. Ahtanum sub-basin surficial geology. The map indicates study area extent (orange) and key topographic and geologic features influencing the hydrogeologic characteristics of the drainage. (Basemap sources: WDNR, 2023; USGS TNM, 2023).

a broad alluvial fan 1.6 to 4 km wide, that spans 23 km from the point where the creek exits a narrow canyon at the base of the Cascade Mountains to its confluence with the Yakima River at Union Gap (Fig. 2). Upstream of the alluvial fan, the channel runs through the bedrock-confined Narrows and the North and South Forks of Ahtanum Creek, which define the upper valley. The upland bench forms the northern boundary of both the lower and upper valleys, extending eastward past the Narrows and merging with terrace remnants that separate the lower Ahtanum valley and alluvial fan from Wide Hollow (Foxworthy, 1962; Yakima County, 2012).

The portion of the study area south of Ahtanum Creek lies within the Yakama Nation (Fig. 2). North of Ahtanum Creek, the alluvial fan is divided among private landowners. Surface water from the Ahtanum drainage currently supports (1) the Yakama Nation Wapato Irrigation Project (WIP), (2) in-stream flow managed by the Yakama Nation to support fisheries, and (3) off-reservation agricultural irrigation, primarily north of Ahtanum Creek. Groundwater is also utilized for domestic uses and to augment irrigation. Water allocation within the drainage is influenced by seasonal water availability and water right priorities.

This study examines the hydrogeologic properties of the alluvial fan area within the lower valley. As it emerges from the Upper Valley, Ahtanum Creek divides into four flowlines through the alluvial fan: Bachelor Creek, Hatton Creek, Ahtanum Canal, and Ahtanum Creek (Foxworthy, 1962; Fig. 3). Both Ahtanum and Hatton Creek are perennial flowlines, while Bachelor Creek and the Ahtanum Canal experience intermittent flow, primarily as a function of regulated flow diversions located at the fan apex (Fig. 4). The alluvial fan study area is defined by the active alluvial fan floodplain in the north and the elevated alluvial terrace in the south (Fig. 3).

Groundwater flow in the lower valley of the Ahtanum Basin is influenced by precipitation, surface water, irrigation, and deeper aquifer inputs (Golder, 2004). Precipitation and snowpack vary annually and are monitored by two United States Geological Survey (USGS) stream gages on the North Fork and South Fork tributaries of Ahtanum Creek (Foxworthy, 1962). Current delineations identify groundwater recharge in the upstream sections of the alluvial fan study area, a mid-fan transition zone, and groundwater discharge to surface water in the downstream section (Sandison, 2005).

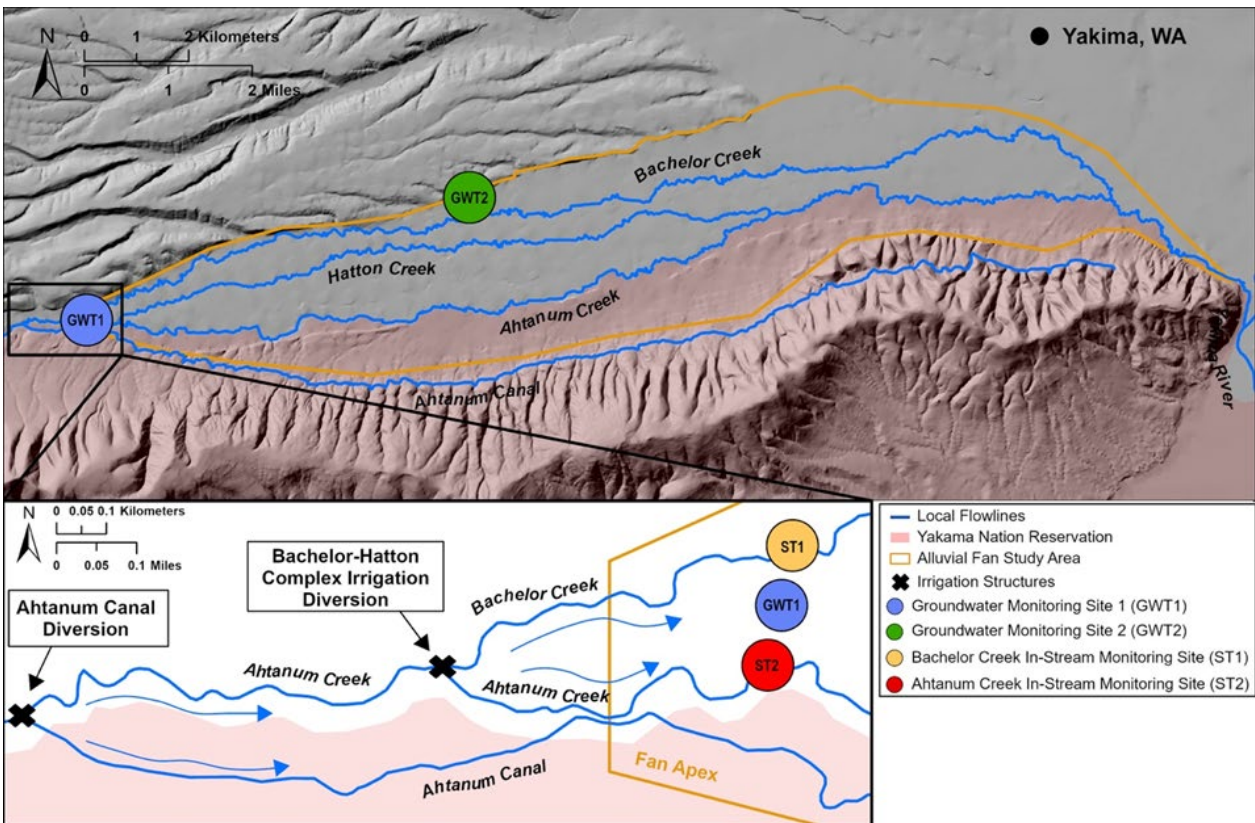


Figure 3. Ahtanum alluvial fan monitoring sites and infrastructure. Basemap source: U.S. Geological Survey National Map, Digital Elevation Model (USGS TNM, 2023).

Previous studies have documented flooding in the upstream and downstream sections of the alluvial fan and adjacent Wide Hollow, linked to slightly perched water table conditions (Golder, 2004; Yakima County, 2012). Mid-fan, surface water recharges alluvial aquifers annually, while downstream recharge primarily occurs during summer months. Deeper groundwater contributions to streamflow, particularly in the lower valley of the Ahtanum drainage, increases during high-flow events (WA Ecology, 2005; Golder, 2004).

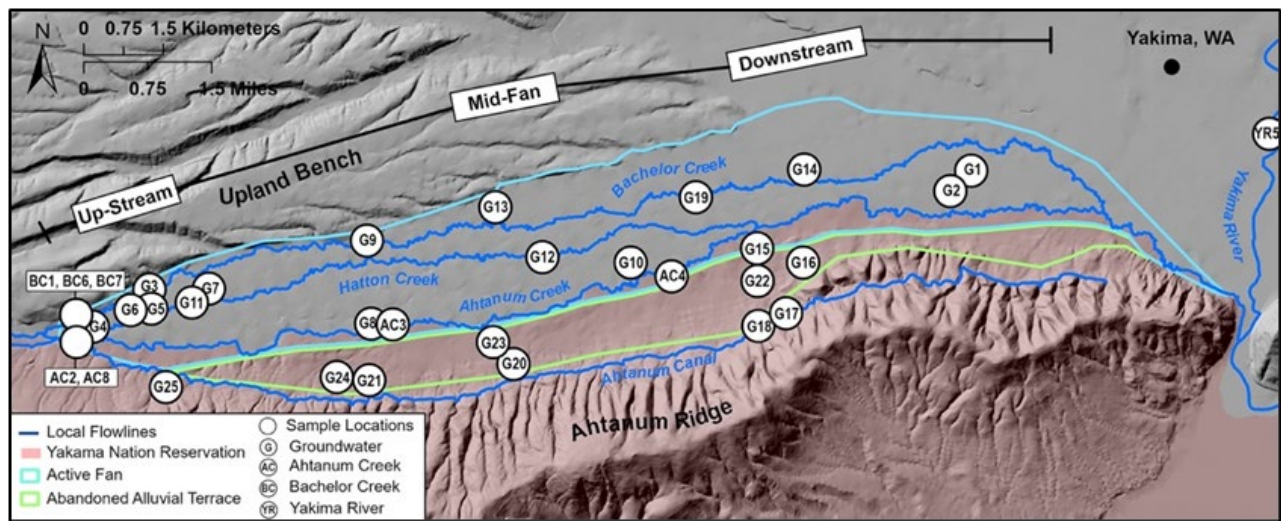


Figure 4. Ahtanum alluvial fan study area and sampling sites. The map indicates fan anatomy, local topography, Yakama Nation boundaries, and a summary of locations where samples were collected from groundwater (G), Ahtanum Creek (AC), Bachelor Creek (BC), and the Yakima River (YR). Basemap sources: USGS TNM, 2023.

Hydrogeology of the Ahtanum sub-basin alluvial fan

The suitability of sites for Managed Aquifer Recharge was determined based on the ability of regional geologic units to yield and transmit water. Previous geologic characterization of the Ahtanum lower valley indicate the occurrence of four hydrogeologic units: (1) unconsolidated alluvium; (2) semi-consolidated continental sediments associated with Thorp Gravels, terrace, alluvial fan, and loess deposits; (3) consolidated continental sediments associated with the Ellensburg Formation; and (4) basalt aquifers (Foxworthy, 1962; Vaccaro et al, 2009; WA Ecology, 2005; Fig. 5).

The unconsolidated alluvium (Unit 1; Fig. 5) forms a relatively thin, erodible stratigraphic layer, largely in the modern floodplain of the different channel flowlines (Fig. 3) across the Ahtanum alluvial fan. In the upper sections of the alluvial fan, deposits consist of both sorted and unsorted gravel, sand, and silt (Foxworthy, 2062; Sandison, 2005). Most of the gravel is composed of basalt fragments eroded from the semi-consolidated sedimentary Unit 2. In the middle and downstream sections of the fan, the alluvium transitions into fine silt and clay (Foxworthy, 1962). This alluvium unit reaches a thickness of up to approximately 9 m (Foxworthy, 1962).

The semi-consolidated sedimentary aquifer (Unit 2; Fig. 5) is commonly found under the unconsolidated alluvium unit and overlying the older, more consolidated, sediment of the Ellensburg Formation (Unit 3) and the Columbia River Basalt Group (Unit 4) (Foxworthy, 1962; Fig. 5). Unit 2 consists primarily of moderately to well-rounded basalt gravels and pebbles, which make up about 75% of the unit (Foxworthy, 1962). The fine-grained matrix accounts for the remaining 25% and is predominantly angular in shape. The gravels are composed mainly of cemented basaltic material with minimal sand, silt, and clay occurring in discontinuous layers throughout the unit (Foxworthy, 1962). This unit is associated with the semi-consolidated Thorp Gravel, alluvial fan, terrace, and loess deposits (Foxworthy, 2962; Vaccaro et al., 2009).

The Ellensburg Formation in Unit 3 (Fig. 5) is a sedimentary aquifer unit composed of consolidated silt, sand, clay, and gravel deposited by streams, lakes, or ponds during the early Pliocene, as indicated by fossil evidence (Foxworthy, 1962; Vaccaro et al., 2009). This formation typically overlies basalt and is characterized by a high water-holding capacity, with 85% to 95% consisting of clay, silt, and sand, and 5% to 15% small gravels (Foxworthy, 1962; Taylor and Gazis, 2014). The finer fractions are composed of pumice, volcanic ash, quartz, feldspar, and hornblende, while the gravel component includes tuffaceous hornblende andesite, diorite, quartzite, and granitic and metamorphic gravels (Foxworthy, 1962).

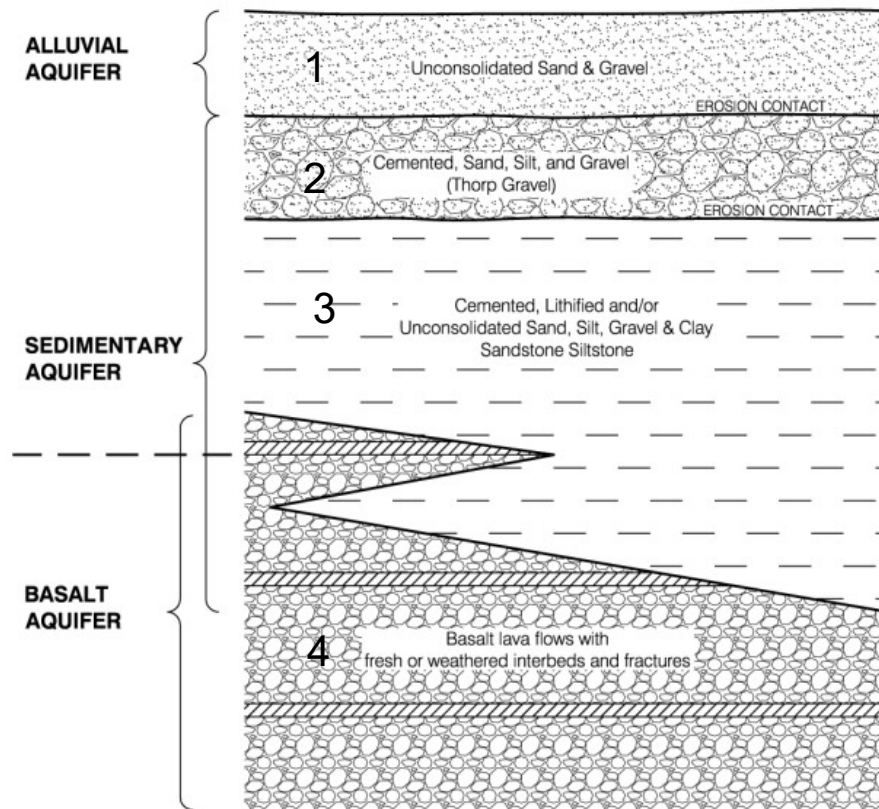


Figure 5. Stratigraphic column of hydrogeologic units in the Ahtanum Lower Valley. Numbers indicate the four hydrogeologic units referred to in the text. Modified from Sandison (2005).

The Ellensburg Formation tends to accumulate in the lower Ahtanum valley, where synclinal topography forms sediment traps (Fig. 2). Previous studies of the groundwater in this formation in different areas of the Yakima River basin found that it contains high concentrations of HCO_3^- , Ca^{2+} , and Mg^{2+} , with variable levels of SO_4^{2-} and Cl^- , attributed to mineral weathering and precipitation reactions (Taylor and Gazis, 2014). The isotopic signatures of the Ellensburg Formation groundwater were heavier than those of the Columbia River Basalt Group, yet more depleted than surface water (Vaccaro et al., 2009; Taylor and Gazis, 2014).

METHODS

Multiple methods were integrated to characterize the hydrogeochemical properties of the alluvial fan aquifers. Sedimentary basin-fill deposits and bedrock stratigraphy were used to distinguish contacts between geologic units and to provide context for laboratory and statistical analyses. Laboratory analyses were used to quantify the hydrogeochemical properties of water samples to interpret mixing, flow patterns and the extent of rock-water interactions. Statistical methods were applied to estimate aquifer controls on groundwater flow within a selected region of the alluvial fan study area, with consideration for MAR applications. Together, these approaches provide an assessment of aquifer properties and identify potential zones suitable for MAR within the study area. All data presented in this report are in metric units; imperial unit equivalents are summarized in Appendix A, Tables A1 through A15.

Mapping, Stratigraphic Descriptions, and Cross-Sections

The extent and topography of the alluvial fan was mapped using LiDAR-derived digital elevation models (DEMs) from the U.S. Geological Survey (USGS) National Map (TNM), which provided a foundation for defining topographic features of the fan (e.g. the elevated alluvial terrace and active fan). The maps were used to guide field data collection to obtain a representative sampling distribution from different hydrogeological units.

The stratigraphy of the Ahtanum alluvial fan study area was delineated using existing historic well logs and existing characterization of aquifer units. Historical well logs were used to distinguish contacts between hydrogeologic stratigraphic units and guide selection of wells for sampling and monitoring. Wells were additionally cataloged by depth, static water level, well type, hydrogeologic unit, completion date, and sampling or deployment date. Well construction details, including screen and perforation intervals, determined which portion of the aquifer was represented by each well.

Sedimentary basin-fill wells were categorized into shallow (0–107 m) and deep (107–561 m), with a separate category for wells drilled into basalt units. Spatially, well types were selected to effectively capture the entire extent of the alluvial fan study area, including the upstream, middle and downstream portions of the active fan and floodplain, the alluvial terrace, and basalt bedrock (Fig. 6). Stratigraphic contacts were interpreted from driller logs. Hydrogeologic units were standardized into four categories: unconsolidated, semi-consolidated, consolidated, and basalt (Fig. 5), informed by previous regional units previously described as Quaternary alluvium, Thorp Gravels, Ellensburg Formation and Columbia River Basalt Group (Foxworthy, 1962; Vaccaro et al., 2009).

We constructed stratigraphic cross-sections to connect the stratigraphic units interpreted from individual wells logs. Locations of the transects were selected based on topography, proximity to creeks and canals, and the availability of well log data from the Washington Department of Ecology (WA Ecology) Well Construction and Licensing database. Cross-sections were developed along east- west and north-south trending transects using well log contacts, surface elevations, and lidar data. The resulting stratigraphic cross-sections along the transects depict the vertical and lateral distribution of hydrogeologic units and informed our interpretations of flow paths and geochemical trends.

Streambank stratigraphy was described at natural exposures at three locations along the stream banks to assess the range of typical surface-sediment characteristics that could influence shallow groundwater infiltration capacity. Two sites were located in the upstream section of the fan, at Bachelor Creek (OC1) and Ahtanum Creek (OC2), while the third site was mid-fan on Ahtanum Creek (OC3) (Fig. 6). Stratigraphic descriptions included average grain size, presence of organics, color, and cementation. Ground-surface elevation measurements were collected at each site.

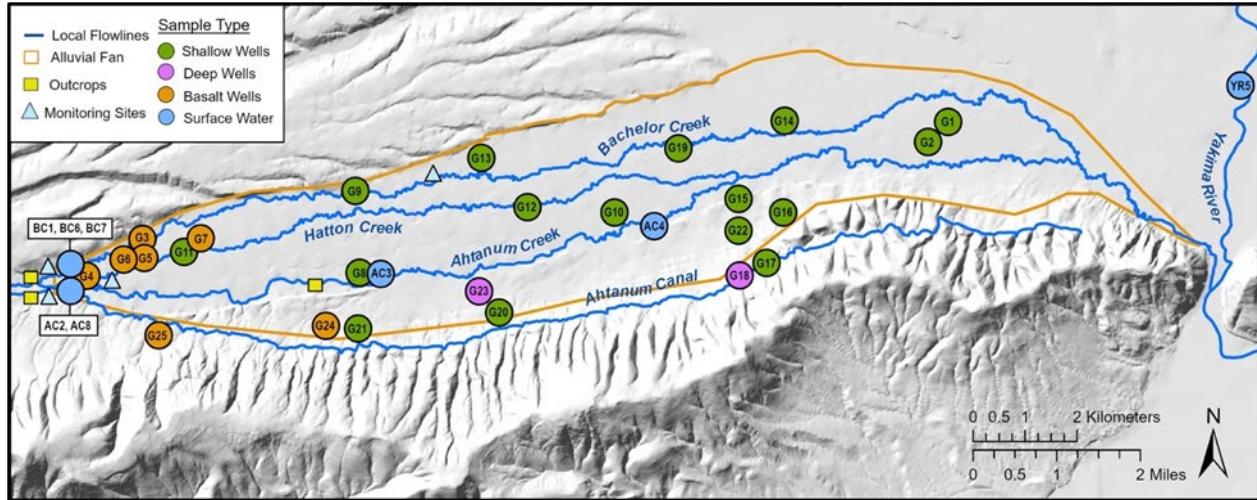


Figure 6. Map of sample types and well depths. Spatial distribution of samples collected from shallow wells (green), deep wells (purple), basalt wells (orange), and surface water sources (blue). Basemap source, : USGS TNM (2023).

Soil infiltration rates were classified and mapped using remote sensing applications in ArcGIS, based on Natural Resources Conservation Service (NRCS) soil survey data (NRCS, 2003). Soils were categorized into four groups based on drainage class occurrence: (1) somewhat excessively drained, (2) well drained, (3) moderately well drained, and (4) somewhat poorly drained.

Groundwater Elevation Measurement

Groundwater and surface water levels and temperatures were continuously recorded by four pressure transducers deployed within the alluvial fan study area. Three transducers (ST1, ST2, and GWT1) were deployed for this study, and one was an existing monitoring site from the Washington Department of Ecology (GWT2) (Fig. 7). Logger measurements were taken at one-hour intervals and downloaded once per month. To ensure accuracy, manual measurements of the depth to groundwater and surface water were also collected once per month using 30 m and 152 m electric tape, with three cumulative trials completed during each well visit to minimize errors (Fig. 7).

The Hanging Cable Length (HCL) method was used to process the transducer datasets (Washington Dept. of Ecology, 2019). This method incorporates the hanging cable length, barometric pressure data, and continuous water pressure recorded by the transducers. Barometric pressure data, obtained from the Yakima Air Terminal McAllister Field (NOAA 2023), was used to correct raw transducer readings by subtracting the raw transducer pressure from the barometric transducer pressure. Subsequently, the depth to groundwater was calculated by subtracting the transducer hanging depth from the barometric compensated pressure, using the following equation:

$$P_c = P_r - P_d$$

Where P_c is the barometric compensated submersible transducer pressure, P_r is the raw transducer pressure, and P_d is the barometric transducer pressure (WA Dept. Ecology, 2019).

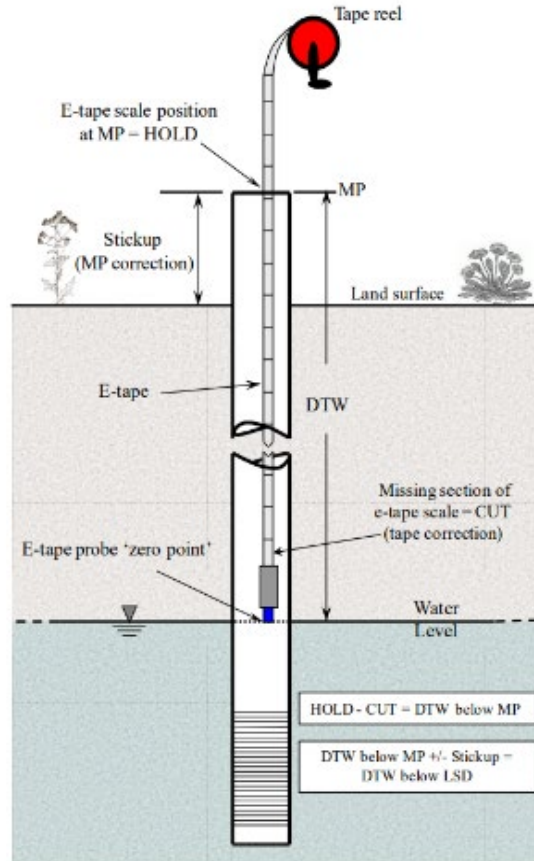


Figure 7. Example of depth-to-water measurements. (WA Dept. of Ecology, 2019).

$$D_{gw} = H - P_c$$

Where D_{gw} is the calculated depth to groundwater below the measuring point and H is the deployment depth of transducer from the measuring point (WA Dept. Ecology, 2019).

Water Sample Collection

Groundwater samples were collected from 25 wells distributed throughout the alluvial fan study area (Fig. 6). Of these, 16 samples originated from shallow wells, 2 from deep, and 7 from wells drilled into basalt (Fig. 6). Sampling was conducted from faucets located proximal to each well. Prior to sample collection, wells were purged for approximately 2 minutes, typically yielding a discharge of approximately 5 L. After purging, a 200 mL beaker was filled for the measurement of field parameters, including temperature, specific conductance, pH, and dissolved oxygen, using calibrated multiparameter probes. Measurements were recorded at three-minute intervals, and sampling proceeded once values stabilized according to the criteria outlined in Table 1.

Surface water samples were collected at five locations along transects, with sampling conducted over multiple time points to capture seasonal and irrigation-related variability. Ahtanum and Bachelor Creeks were sampled during and after the irrigation season to assess the persistence of flow potentially sustained by groundwater discharge. Three samples were collected from Bachelor Creek: one during the irrigation season (9 July 2024) and two post-season (6 January 2025 and 10 February 2025). Ahtanum Creek was sampled once during the irrigation season (9 July 2024) and three times afterward (24 July 2024, 7 August 2024, and 10 February 2025). A single surface water sample was obtained from the Yakima River near Union Gap to evaluate geochemical differences relative to Ahtanum and Bachelor Creeks (Fig. 6).

Well water samples designated for laboratory analysis were collected in four bottles: (1) a 30 mL polyethylene bottle for stable isotope analysis, filtered through a 0.45 μm polyethylene filter and tightly sealed to prevent evaporation; (2) and (3) two 60 mL polyethylene bottles for cation and anion analysis, both filtered using a 0.45 μm polyethylene filter; and (4) a 250 mL high-density polyethylene bottle for alkalinity analysis, filled directly from the faucet without filtration. Prior to collection, all bottles were rinsed three times with deionized water to prevent contamination.

Surface water samples collected from the thalweg of Bachelor and Ahtanum Creeks followed the same preparation protocol as the well samples. For the Yakima River, the sample was collected from the bank in an area of flow continuity with the thalweg.

Table 1. Well purging stabilization criteria.

Parameter	Stabilization Criteria
Temperature	$\pm 0.1^{\circ}\text{C}$
pH	$\pm 0.1^{\circ}\text{C}$ standard units
Specific conductance (EC)	$\pm 10\ \mu\text{ohms/cm}$ for values $< 1000\ \mu\text{ohms/cm}$ $\pm 20\ \mu\text{ohms/cm}$ for values $> 1000\ \mu\text{ohms/cm}$
Dissolved oxygen (DO)	$\pm 0.1\ \text{mg/L}$ for values $< 1.0\ \text{mg/L}$ $\pm 0.2\ \text{mg/L}$ for values $> 1.0\ \text{mg/L}$

Geochemical Analysis

All geochemical analyses were conducted on instruments in the Murdock Laboratory in the Department of Geological Sciences at Central Washington University. Water samples were prepared for laboratory analysis of major cations within 28 days of collection. Ten mL of a water sample was transferred by pipette into a 15 mL vial and acidified with 50 μL HCl and 100 μL HNO₃. Anion samples were stored in tightly sealed 1.5 mL tubes for up to six months to minimize evaporation. Stable isotope samples were filtered in the field, transported in 30 mL HDPE bottles, transferred into 1.5 mL tubes in the laboratory, and tightly sealed to minimize evaporation.

Analytical standards were prepared bi-monthly by diluting commercial stock solutions with deionized water. The Dionex Six Cation-II Standard was used for cation analysis (Na^+ , NH_4^+ , K^+ , Mg^{2+} , Ca^{2+}), and the Dionex Five Anion Standard was used for anion analysis (Cl^- , NO_3^- , SO_4^{2-}).

Major cations were quantified using an Agilent 8900 Triple Quadrupole inductively coupled plasma mass spectrometer. Anion concentrations, including F^- , Cl^- , SO_4^{2-} , NO_3^- , PO_4^{3-} , and NO_2^- , were measured using a Dionex ICS-5000 DP ion chromatograph (Fig. 13). Alkalinity was determined via titration by adding 0.01 M HCl in 1 mL increments to 100 mL of sample. pH was monitored using an Orion Model 420A pH probe until the solution reached a pH of 3.0 (Fig. 15). Alkalinity values were used to calculate HCO_3^- concentrations and assess the carbonate buffering capacity of the system. Charge balance errors were calculated based on the measured concentrations of major cations, anions, and HCO_3^- (Appendix C; Table C1).

Stable isotopes of oxygen ($\delta^{18}\text{O}$) and hydrogen (δD) were analyzed using a Picarro G/L2 cavity ring-down spectrometer. Each sample underwent multiple injections, with replicate analyses performed to evaluate analytical uncertainty. Quality control procedures included field duplicates, laboratory duplicates, blanks, matrix spikes, and certified standards to assess instrument precision, accuracy, and drift, following established procedures (Taylor and Gazis, 2014).

Detection limits for major ions range from 0.05 to 0.1 mg/L. Stable isotope results are reported in per mil (‰) notation relative to Vienna Standard Mean Ocean Water (VSMOW) and are not subject to concentration-based detection limits (Table 2), through the following equation:

$$\delta = \left(\frac{R_{sam} - R_{std}}{R_{std}} \right) \times 1000$$

Where δ is the isotopic delta value, R_{sam} is the isotopic ratio in the sample, and R_{std} represents the isotopic ratio within the standard.

Table 2. Study analytes, detection limits and laboratory methods.

Analyte	Detection Limit	Analytical (Instrumental) Method
Alkalinity (HCO_3^- and CaCO_3)	10 mg/L	pH Probe & Titration
Chloride (Cl^-)	0.1 mg/l	ICS-5000
Fluoride (F^-)	0.1 mg/l	ICS-5000
Sulfate (SO_4^{2-})	0.1 mg/l	ICS-5000
Nitrate (NO_3^-)	0.1 mg/l	ICS-5000
Phosphate (PO_4^{3-})	0.05 mg/l	ICS-5000

Analyte	Detection Limit	Analytical (Instrumental) Method
Calcium (Ca ²⁺)	0.05 mg/l	ICP-MS
Magnesium (Mg ²⁺)	0.05 mg/l	ICP-MS
Potassium (K ⁺)	0.05 mg/l	ICP-MS
Sodium (Na ⁺)	0.05 mg/l	ICP-MS
Oxygen-18 ($\delta^{18}\text{O}$)	NA	Picarro
Deuterium (δD)	NA	Picarro

Statistical Analysis

Principal component analysis (PCA) is a widely used multivariate statistical technique for identifying variation and similarity patterns within complex datasets. In this study, four PCA subsets were developed and analyzed in R-Studio to determine dominant hydrogeochemical associations among chemical constituents in surface water and groundwater samples.

Subset A included major ion and stable isotope data for all groundwater samples. Subset B employed similar input parameters but excluded two samples (G24 and G25) originating from basalt wells to better isolate sedimentary basin-fill aquifer groupings. Combined, Subsets A and B were instrumental in distinguishing six distinct hydrochemical groups, as described in detail in the Results section of this report. Subset C incorporated major ion data from both groundwater and surface water sources, enabling cross-comparison between aquifer and stream chemistry. Subset D expanded this approach by including major ions, stable isotopes, and in situ field parameters (i.e., dissolved oxygen, hydraulic conductivity, and pH) from both water sources. Given the smaller sample sizes in Subsets C and D, results were considered exploratory but useful in defining potential hydrogeochemical groupings with greater specificity. Additional information about the subsets is in Appendix D (Tables D1-D2; Figs. D1-D2).

Laboratory data for each subset were normalized prior to analysis to standardize units and enable meaningful comparison. Components with eigenvalues greater than 0.7 were extracted, as these represented the greatest contribution to dataset variance. A correlation matrix was used to assess the relationships (both positive and negative) among samples. PCA results were expressed in terms of component loadings (representing dominant chemical contributors) and score data (indicating sample distribution along the principal components). The PCA outputs, when paired with geochemical data, well metrics, and spatial position within the study area, were effective in delineating distinct hydrogeochemical groupings.

Hydrogeological Properties

Seepage velocity calculations were applied to three distinct aquifer units identified within the alluvial fan study area to estimate the hydraulic characteristics of the hydrogeologic framework, defined by lateral groundwater flow regimes (Vaccaro et al., 2009). Seepage velocity represents the rate at which a water molecule moves through a porous medium (Fetter, 1988) and is useful for estimating the transit time of water through different stratigraphic units. This approach assumes that the aquifer is a homogeneous and isotropic porous medium and does not account for preferential flow pathways (Fetter, 1988).

Seepage velocity (S_v) is derived from Darcy's Law and is calculated using the equation:

$$S_v = (-K / n_e) h l$$

where K is hydraulic conductivity (L/T), n_e is effective porosity (dimensionless), and dh/dl is the hydraulic gradient (dimensionless).

Hydraulic conductivity (K) describes the rate at which water can move through a permeable medium and is typically expressed in units of length per time (e.g., m/day). Porosity (n) refers to the ratio of void space to total volume in a geologic unit, while effective porosity (n_e) represents the interconnected pore space available for fluid flow (Groundwater Project, 2023). Study values for K and n_e (Table 5) were derived from previously published hydrogeologic assessments of aquifer properties in or near the Ahtanum, Washington area (Tables 3 and 4).

Table 3. Hydraulic conductivity estimates.

Unit	Minimum (m/sec)	Mean (m/sec)	Max (m/sec)	Model Derived (m/sec)	Source
Alluvium	-	-	-	87	Golder Associates, 2002; WA Ecology, 2008
Alluvium, unconsolidated	204	4	245	-	Foxworthy, 1962
Alluvium, Ellensburg Formation (upper)	-	-	-	23	Golder Associates, 2002; WA Ecology, 2008
Ellensburg Formation (upper)	-	-	-	2.3	WA Ecology, 2008
Ellensburg Formation (middle)	0.2	4	690	-	Golder Associates, 2002
Ellensburg Formation (middle)	-	-	-	0.02	WA Ecology, 2008
Ellensburg Formation (lower)	-	-	-	0.001	Golder Associates, 2002
-	12	18.2	29.2	-	Golder Associates, 2002
-	-	-	-	2.4	Golder Associates, 2002
-	-	-	-	0.3	Golder Associates, 2002

Unit	Minimum (m/sec)	Mean (m/sec)	Max (m/sec)	Model Derived (m/sec)	Source
Ellensburg Formation (lower)	-	-	-	0.003	Golder Associates, 2002
-	-	-	-	2.3	WA Ecology, 2008
-	-	-	-	0.03	WA Ecology, 2008
-	-	-	-	0.01	WA Ecology, 2008

Table 4. Effective porosity estimates.

Unit	Value	Source
Sedimentary basin-fill units	0.1	Vaccaro et al., 2009
CRBG	0.04	Vaccaro et al., 2009
Older bedrock	0.01	Vaccaro et al., 2009
Gravel	0.13-0.44	Woessner and Poeter, 2020
Coarse Sand	0.18-0.43	Woessner and Poeter, 2020
Medium Sand	0.16-0.46	Woessner and Poeter, 2020
Fine Sand	0.01-0.46	Woessner and Poeter, 2020
Silt, Loess	0.01-0.39	Woessner and Poeter, 2020
Clay	0.02-0.18	Woessner and Poeter, 2020

Table 5. Hydraulic conductivity and effective porosity estimates of stratigraphic units.

Unit	Description	Effective Porosity	Hydraulic Conductivity (m/day)
Unit 1: Unconsolidated alluvium (Vaccaro et al., 2009)	Sorted and unsorted gravel, sand, silt, semi consolidated silt and clay (Foxworthy, 1962)	0.3	244
Unit 2: Semi-consolidated Thorp Gravels, alluvial fan, loess, terrace (Vaccaro et al., 2009)	75% gravel and 25% sand (Foxworthy, 1962)	0.1	23
Unit 3: Consolidated Ellensburg formation and undefined continental sediments (Vaccaro et al., 2009)	85% to 95% semi consolidated clay, silt, sand, and 15% gravel (Foxworthy, 1962)	0.2	2

The hydraulic gradient (dh/dl) was determined as the difference in hydraulic head between two monitoring wells divided by the linear distance separating them. This calculation was performed

along sections five transects: along two west to east trending transects, two north to south trending transects, and between groundwater monitoring wells GWT1 and GWT2.

Discharge Modeling and Calculations

Cross-sectional and manual surface water elevation data for Bachelor Creek (Fig. 4) were collected during summer 2024 in preparation for surface water hydraulic modeling using HEC-RAS. These data were used to calculate flow conditions within and following the irrigation season. Each cross-section included measurements of horizontal distance along the cross section, channel depth, calculated channel elevation, and distance between cross sections. Channel elevation was standardized using a fixed right-bank reference elevation measured in June 2024 (Fig. 8). Elevation at each point was determined by subtracting the measured depth from the reference elevation.

Additional input data included water surface elevation (WSE) and data from an in-stream transducer within a PVC pipe housing, which was monitored monthly from June 2024 through April 2025 (Fig. 8).

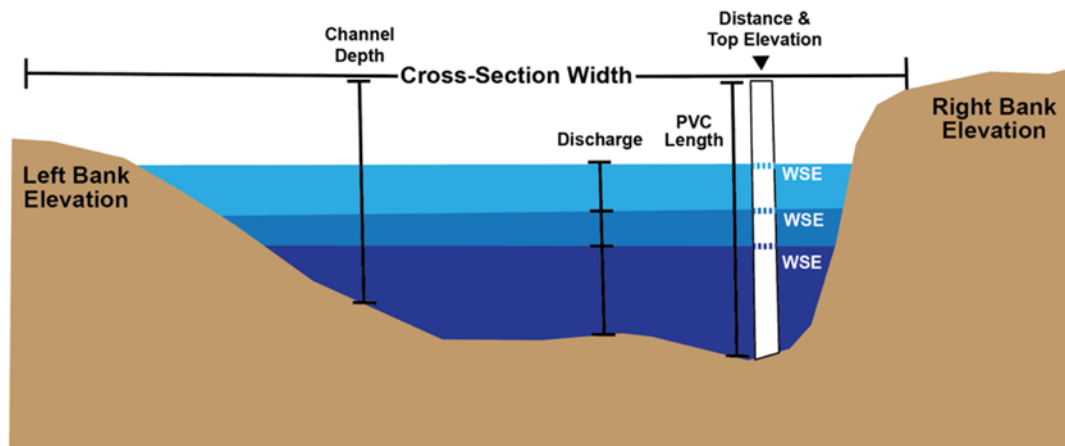


Figure 8. Schematic illustration of measured input parameters for HEC-RAS model.

Discharges for Bachelor Creek were calculated using the HEC-RAS hydraulic model Version 6.5 (Hydrologic Engineering Center, 2024). Input parameters include cross-sectional geometry, channel elevations, distances between cross-sections, and assigned Manning's n roughness coefficients for both the main channel and adjacent overbanks.

Geometric data were entered into the HEC-RAS Geometry Data Editor. Monthly flow conditions were calibrated using manually collected WSE data on 25 June, 8 August, and 5 October 2024. These measurements represent seasonal discharge variability during the irrigation diversion period. The model was iteratively adjusted to align simulated WSE with field observations.

Model outputs included seasonal WSE, discharge rates, and four-dimensional cross-sectional renderings of Bachelor Creek during and after the irrigation season. Temporal variations in WSE and discharge were plotted across return events, and rating curves were generated by plotting WSE versus discharge for each cross-section.

RESULTS

This section provides a comprehensive summary of hydrogeologic, chemical, and hydraulic datasets pertaining to the characterization and assessment of the Ahtanum alluvial fan study area (Fig. 5; Table 6). All results in this section are tabulated in metric format. Imperial values can be found in Appendix A, Tables A1 through A15.

Table 6. Summary characteristics of wells used for stratigraphy and water samples. Well logs are in Appendix F.

ID ¹	WA Well ID Tag ²	Well Depth (m)	Well Depth (ft)	SWL ³ (m)	SWL ³ (ft)	Type ⁴	Unit ⁵	Drill Date	Sample Date
G1	BJA153	78	257	5	15	Shallow	SC	2016	7/2/24
G2	BJA153	78	256	5	15	Shallow	SC	2016	7/2/24
G3	BJB961	87	285	25	82	Basalt	BI	2016	7/2/24
G4	BIF858	45	147	29	94	Basalt	BI	2021	7/2/24
G5	-	46	152	6	19	Basalt	BI	1989	7/17/24
G6	-	43	140	5	16	Basalt	BI	1993	7/17/24
G7	BPX077	119	390	75	245	Basalt	BI	2023	7/17/24
G8	AAM007	69	227	27	90	Basalt	C	1994	7/17/24
G9	ABW767	52	170	23	75	Shallow	C	1995	7/17/24
G10	BJB975	91	298	35	115	Shallow	C	2016	7/23/24
G11	BIF240	38	125	9	29	Shallow	C	2014	7/23/24
G12	BIF067	73	239	26	85	Shallow	C	2014	7/23/24
G13	BHT862	76	250	40	130	Shallow	SC	2013	7/24/24
G14	BBJ244	47	155	17	56	Shallow	C	2012	7/24/24
G15	AFE168	67	220	18	60	Shallow	C	2001	7/24/24
G16	-	39	129	25	82	Shallow	SC	1977	7/31/24
G17	APG332	154	505	76	250	Deep	C	2007	7/31/24
G18	APG333	26	85	4	13	Shallow	SC	2007	7/31/24
G19	BJB995	61	200	8	25	Shallow	C	2017	7/31/24
G20	AGM847	47	153	14	46	Shallow	SC	2002	7/31/24
G21	BJA230	68	223	41	135	Shallow	C	2017	7/31/24
G22	ALF784	98	322	34	113	Shallow	C	2006	8/7/24
G23	-	215	705	12	39	Deep	SC	1957	8/7/24
G24	-	326	1069	281	922	Basalt	BI	1973	8/7/24
G25	-	282	925	72	235	Basalt	BI	1985	8/7/24
GWT1	BAF733	32	100	18	60	Basalt	BI	2009	6/4/24
GWT2	-	126	413	34	112	Shallow	SC	1978	6/4/24

ID ¹	WA Well ID Tag ²	Well Depth (m)	Well Depth (ft)	SWL ³ (m)	SWL ³ (ft)	Type ⁴	Unit ⁵	Drill Date	Sample Date
Table 6 notes: ¹ ID = sample identification number ² WA State Dept. of Ecology Well Log ID Tag Number. Well logs are in Appendix F and available at https://ecology.wa.gov/regulations-permits/guidance-technical-assistance/well-report-gateway ³ SWL = static water level ⁴ Shallow wells (0-107 m deep), deep wells (107-244 m deep), and wells drilled into basalt. ⁵ Hydrogeologic unit from which the well receives groundwater inflows. SC = semi-consolidated (Unit 2), C = consolidated units (Unit 3, BI = basalt interbeds (Unit 4) Units are defined in Fig. 5.									

Stratigraphy

The stratigraphy of the Ahtanum alluvial fan was delineated using historical well logs and prior hydrogeologic characterizations, enabling detailed interpretation of unit contacts and spatial variations in composition across the drainage (Sandison, 2005; Foxworthy, 1964; Jones et al., 2009). Relevant well data are tabulated in Table 6; well logs are in Appendix F.

Seven transects of the alluvial fan stratigraphy were constructed, with three trending west to east (Fig. 9), and four trending north to south (Fig. 10). The cross-sectional stratigraphy was divided into four primary hydrogeologic units: (1) unconsolidated alluvium, (2) semi-consolidated deposits, (3) consolidated deposits, and (4) basalt, based on the general basin stratigraphic units described in previous studies (Foxworthy, 1962; Vaccaro et al., 2009; Fig. 5).

Regional stratigraphic patterns indicate that at higher elevations, wells encounter impermeable and fractured basalt units nearer the surface, often with interbedded sedimentary units forming confined aquifers (Figs. 9 and 10). These sedimentary interbeds are laterally continuous throughout much of the study area and consist of sand, shale, clay, and sandstone, resembling the consolidated sedimentary basin-fill deposits. The contact with basalt occurs at shallower depths in the upstream portion of the fan and at greater depths downstream, with depths from 282 to 330 m (Table 7).

Transects A, B, and C illustrate the west–east trending stratigraphy across the Ahtanum alluvial fan. Transect A reveals moderate thickness of unconsolidated and semi-consolidated units, with the greatest thickness of consolidated deposits among the three transects (Fig. 9). The maximum depth to the basalt contacts along Transect A is 330 m, occurring at the fan toe, whereas the shallowest contact is observed at 55 m near the fan apex, as indicated by stratigraphic data from supplemental well X and well G4 (Table 8).

Transect B, which follows the central axis of the active alluvial fan, exhibits the deepest alluvium deposits at the fan apex (as indicated by stratigraphy near well G11), with intermediate thicknesses of semi-consolidated and consolidated deposits relative to Transects A and C (Fig. 9). The deepest identified basalt contact along Transect B occurs mid-fan at a depth of 265 m. No well logs were available to define the basalt contact at the fan toe; the shallowest basalt contact, again occurring at 55 m, is inferred from wells near the fan apex (supplemental well X and G4) (Table 8).

Transect C traverses the elevated alluvial terrace in the study area and shows minimal alluvium thickness, along with the greatest cumulative thicknesses of semi-consolidated and consolidated

units compared to Transects A and B (Fig. 9). The deepest contact with basalt occurs mid-fan at 326 m, while the shallowest contact is observed at 282 m near the fan apex (Table 8). As with Transect B, no basalt contact was identified in the downstream section due to a lack of well control; thus, depth estimates to basalt in the distal portions of Transects B and C rely on stratigraphic correlations with wells at the fan apex along Transect A.

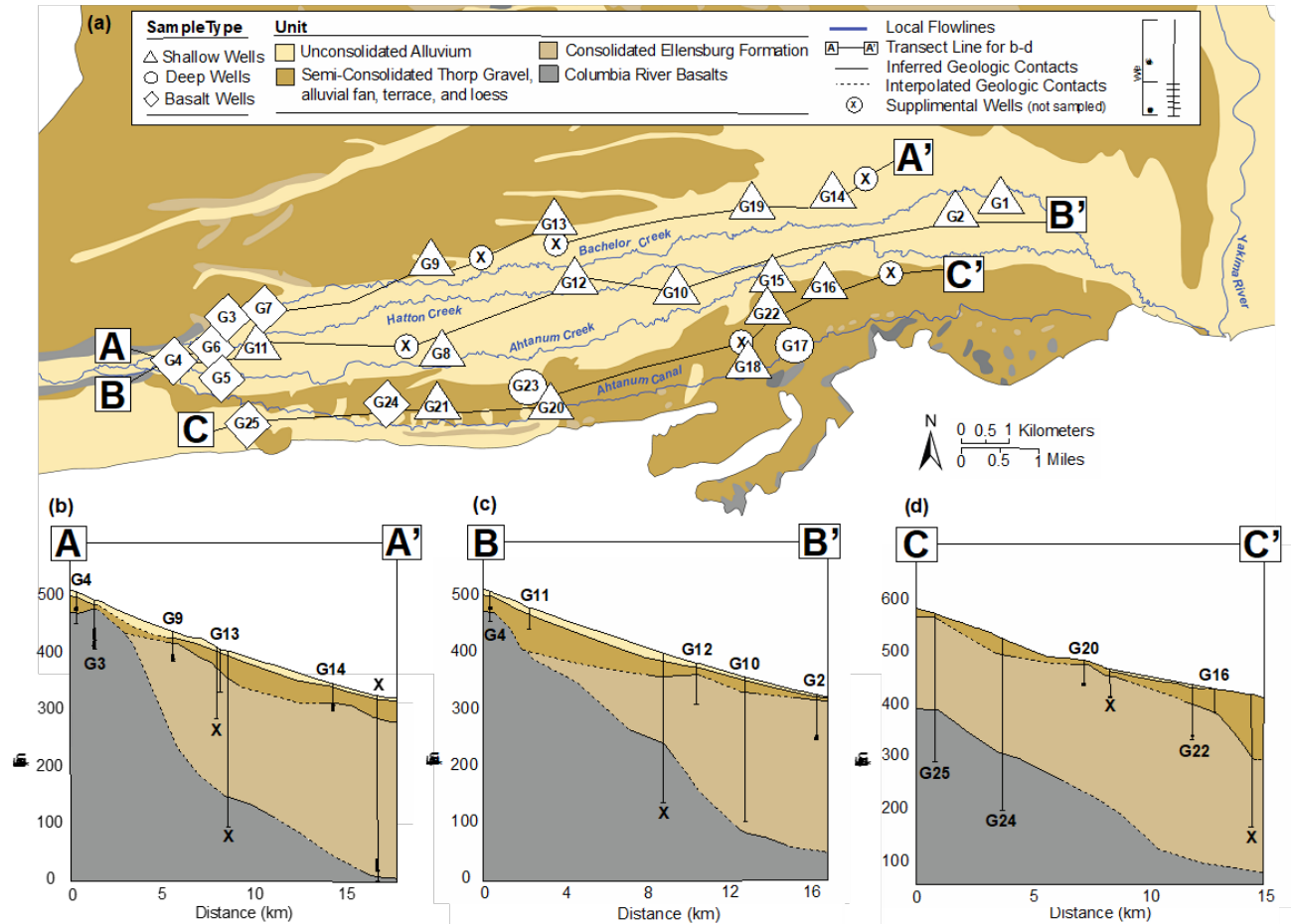


Figure 9. Ahtanum west to east transect stratigraphy. Simplified surficial geology map of the lower valley of the Ahtanum basin, a subsurface stratigraphy, as shown along west to east trending transects A, B, and C. Basemap source: WA Dept. Natural Resources, 2023.

An additional four transects (D, E, F, and G) were constructed trending north to south across selected upstream and mid-fan portions of the Ahtanum alluvial fan to evaluate the vertical extent of stratigraphy in the study area (Fig. 10). Transect D, located in the upstream region of the fan, exhibits the greatest thickness of alluvium and the least thickness of semi-consolidated and consolidated units compared to Transects E, F, and G (Table 9). Depth to the basalt contact along Transect D ranges from 84 m in the northernmost section along the upland bench to 79 m along the southern margin near Ahtanum Ridge (Fig. 10).

Progressing downstream through Transects E, F, and G, the thicknesses of sedimentary basin-fill units increase, while the depth to the basalt contact generally decreases (Table 9). As with Transect

D, the basalt contact in Transects E, F, and G is present at relatively higher elevations near the north and south ridges of the upland bench and Ahtanum Ridge. These

transects indicate sedimentary basin-fill units reaching thicknesses of 68 m to over 98 m in the vertical sections of the middle and lower parts of the fan (Table 9; Fig. 10).

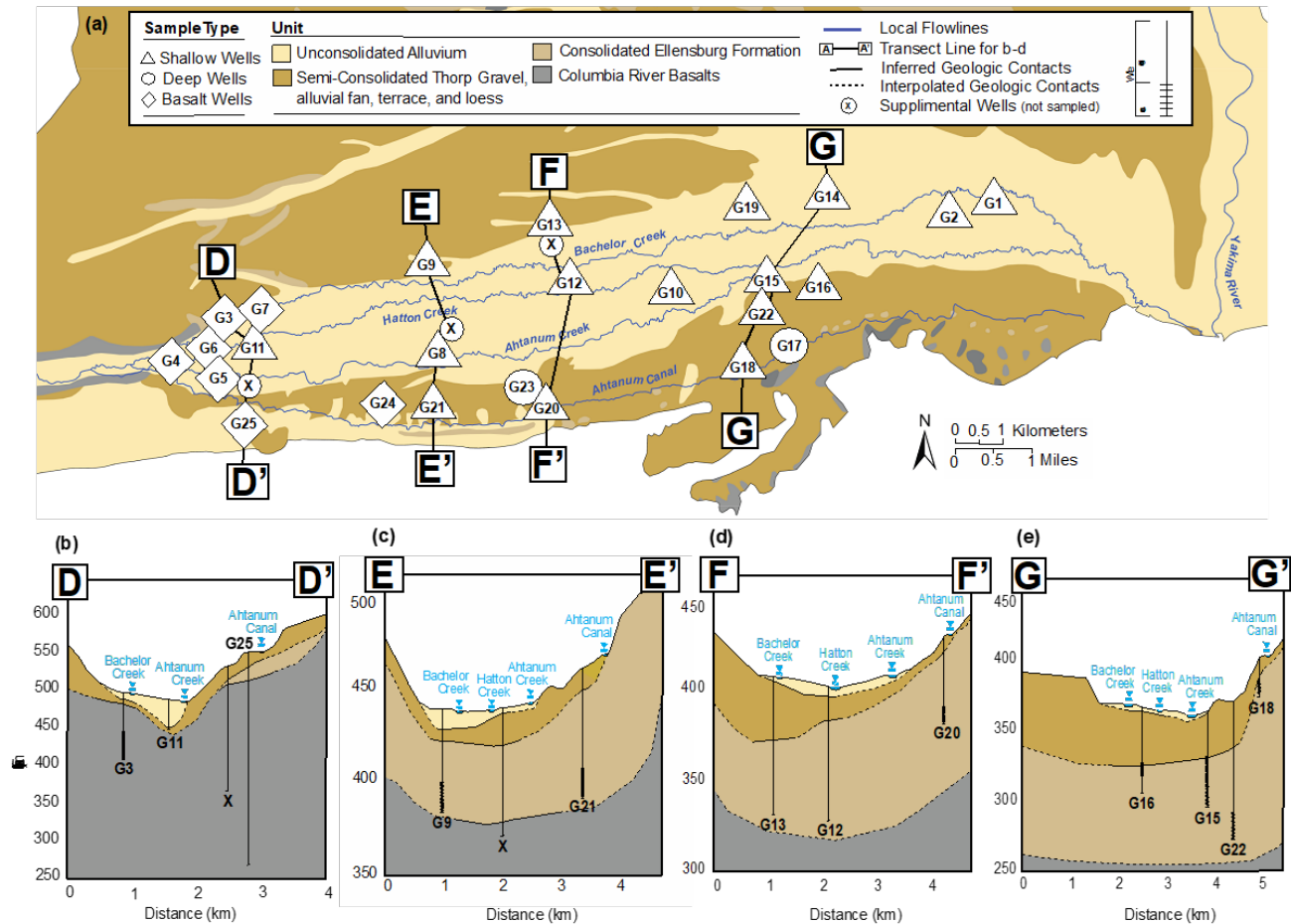


Figure 10. Ahtanum north to south stratigraphy. Simplified surficial geologic map of the Ahtanum Sub-Basin, and subsurface geology, as shown along transects D—G in the north to south trending cross-sections. Basemap source: WA Dept. Natural Resources, 2023.

Table 7. Maximum depth of hydrogeologic units on the Ahtanum alluvial fan.

Hydrogeologic Unit	Upper Fan	Mid-Fan	Lower Fan
Unit 1: Unconsolidated	37 m	11 m	2 m
Unit 2: Semi-consolidated	38 m	61 m	166 m
Unit 3: Consolidated	39 m	254 m	250 m
Unit 4: Basalt	282 m	326 m	330 m

Table 8. Maximum depth to units along west-east transect.

Transect	Unit 1: Unconsolidated	Unit 2: Semi-consolidated	Unit 3: Consolidated	Unit 4: Basalt
A-A'	11m	61 m	254 m	330 m
B-B'	11m	43 m	157 m	91 m
C-C'	2 m	116m	250 m	326 m

Table 9. Maximum depth to units along north-south transects.

Transect	Unit 1: Unconsolidated	Unit 2: Semi-consolidated	Unit 3: Consolidated	Unit 4: Basalt
D-D'	27 m	27 m	39 m	282 m
E-E'	11 m	55 m	68 m	67 m
F-F'	5 m	61 m	76 m	N.D.
G-G'	29m	75 m	98 m	N.D.

Note: N.D. = not detected

Supplemental near-surface stratigraphic observations were obtained from three in situ streambank outcrops: one located in the upstream reach of Bachelor Creek and two situated in upstream and mid-fan sections of Ahtanum Creek. These exposures provide additional insight into the composition of alluvial units in the upper fan that could influence surface-water infiltration. For example, the bankside stratigraphy observed in Ahtanum Creek outcrop 2 (OC2) reveals a thin layer of consolidated sand and fine gravel transitioning at a depth of approximately 39 cm into coarser gravels embedded within a sand and silt matrix (Fig. 11).

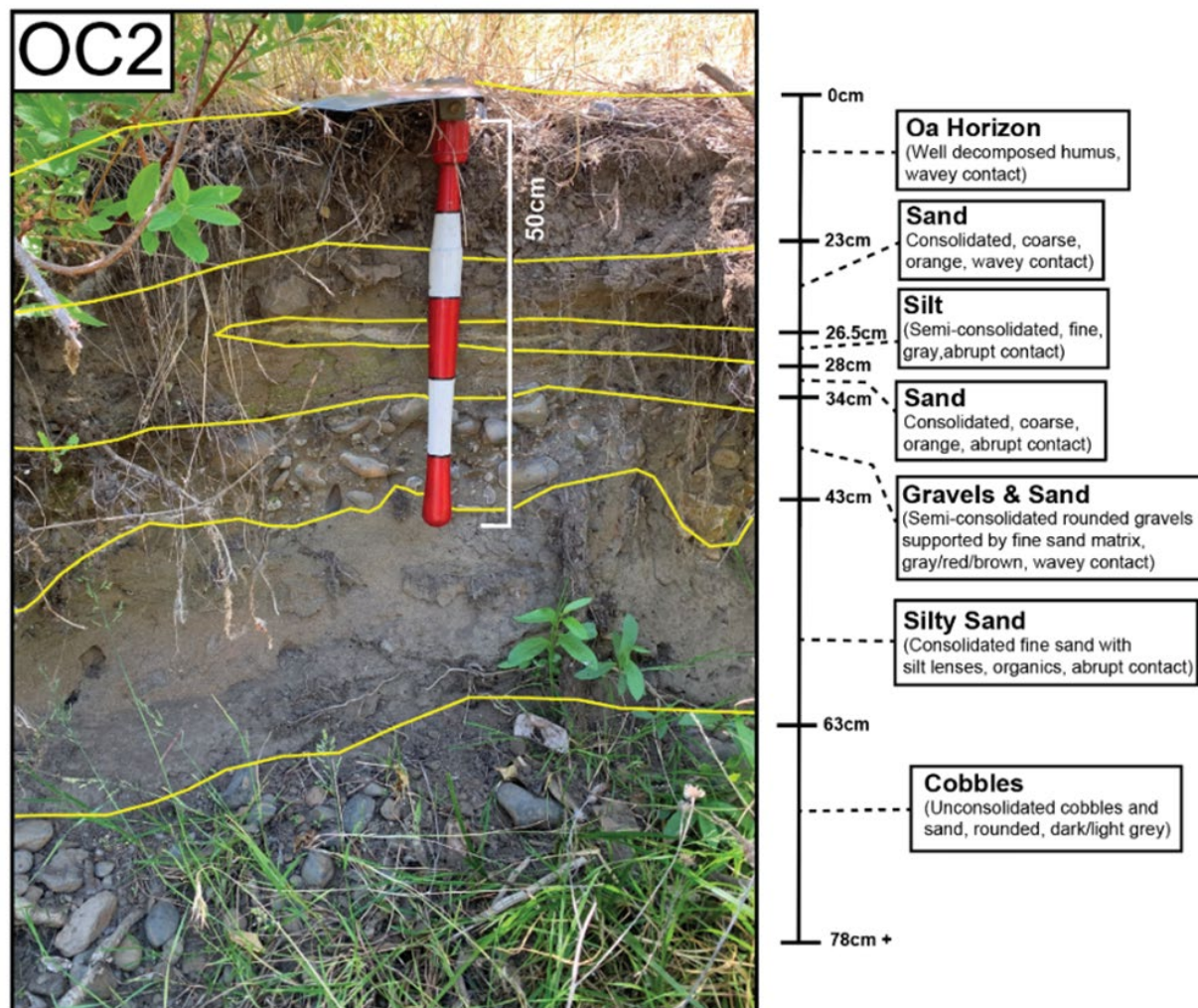


Figure 11. Stratigraphy of Ahtanum Creek streambank exposure.

Soil Drainage

Soil drainage classes vary spatially throughout the Ahtanum alluvial fan study area (Fig. 12). The drainage classes that occur in the study area are somewhat excessively drained, well drained, moderately well drained, and somewhat poorly drained soils, derived from data from the National Resource Conservation Service (NRCS, 2003). Somewhat excessively drained soils are composed of gravely fine sandy loam, located in the upstream portion of the alluvial fan. Slightly over half of the study area consists of well-drained soils of silt loam and cobbly loam. Most of these soils are in the alluvial terrace south of Ahtanum Creek or in the active alluvial fan section. Moderately well-drained soils of silt loam comprise less than 1% of the soils in the study area. Somewhat poorly drained soils composed of silt loam are mainly concentrated in the mid- to downstream sections of the alluvial fan.

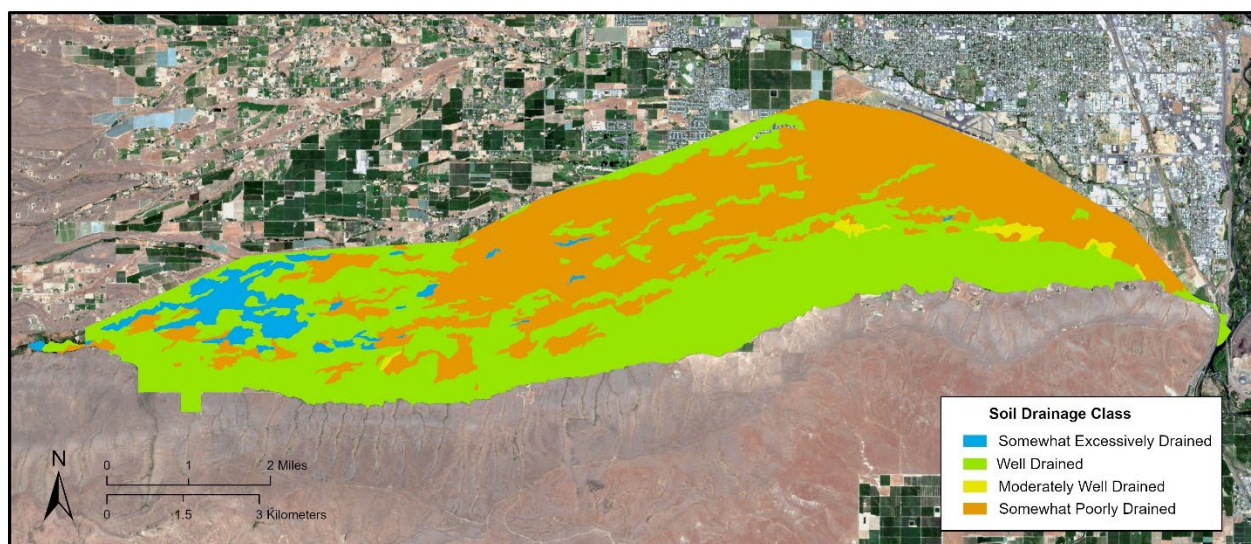


Figure 12. Ahtanum alluvial fan soil drainage classes. Data from National Resources Conservation Service (2003).

Groundwater Elevation

Changes in surface-water and groundwater levels observed during the study period reflect the influence of irrigation management operations associated with the Bachelor–Hatton Complex, particularly the annual opening (April 15) and closure (July 10) of the headgate (Table 10; Figs. 13 and 14).

Table 10. Change in surface-water elevation relative to start of measurements, June 26, 2024.

	ST1		ST2	
Date	Surface Water Elevation (m)	Change from Start (m)	Surface Water Elevation (m)	Change from Start (m)
6/2024	513.18	0.00	513.68	-0.02
7/2024	512.96	-0.21	513.64	-0.05
8/2024	512.87	-0.31	513.65	-0.05
9/2024	512.87	-0.31	513.62	-0.07
10/2024	512.86	-0.32	513.63	-0.06
11/2024	512.90	-0.28	513.67	-0.02
12/2024	512.93	-0.25	513.70	0.00

	ST1		ST2	
Date	Surface Water Elevation (m)	Change from Start (m)	Surface Water Elevation (m)	Change from Start (m)
1/2025	512.93	-0.25	N.D.	N.D.
2/2025	512.91	-0.27	N.D.	N.D.
3/2025	512.92	-0.26	N.D.	N.D.
4/2025	512.99	-0.22	N.D.	N.D.
5/2025	513.22	0.04	N.D.	N.D.
6/2025	513.20	0.02	N.D.	N.D.

Note: N.D. = not detected.

Data from location ST1 indicate that surface-water flow in Bachelor Creek ceases after the headgate closure, with relatively stable levels until the system reactivated in April 2024 (Fig. 14). ST2 data for Ahtanum Creek show an initial decline in surface water elevation between June and August, followed by an increase from September to December 2024 (Table 10). This transducer dataset was discontinued after it washed downstream in December (Fig. 13).

Groundwater elevation data were collected from two monitoring wells: GWT1 (located near the fan apex) and GWT2 (located mid-fan) (Fig. 14). GWT1 is 32 m deep with basalt contact at 32.6 m. Groundwater levels at GWT1 dropped 1.07 m between June and July 2024, then remained relatively stable through April 2025 with a total decline of just 0.01 m after July (Table 11).

The GWT2 well, 126 m deep and screened in multiple sedimentary units, exhibited a 4.0 m drop in groundwater elevation from June—August, 2024. A recharge period followed, with an increase of 11 m through April 2025. Most of this rise (8.2 m) occurred October—November, 2024 (Table 11; Fig. 14), underscoring the delayed recharge response following the diversion closure.

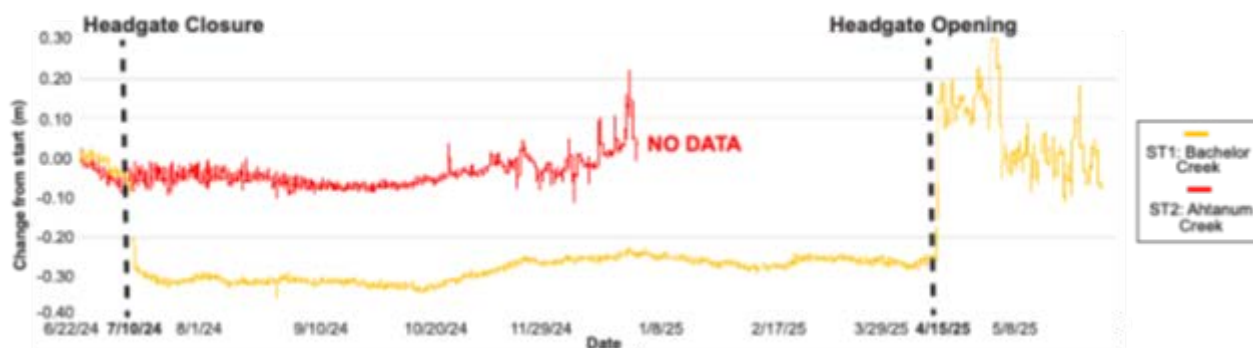


Figure 13. Change in surface water elevation during the study period. Change is relative to starting date on June 22, 2024.

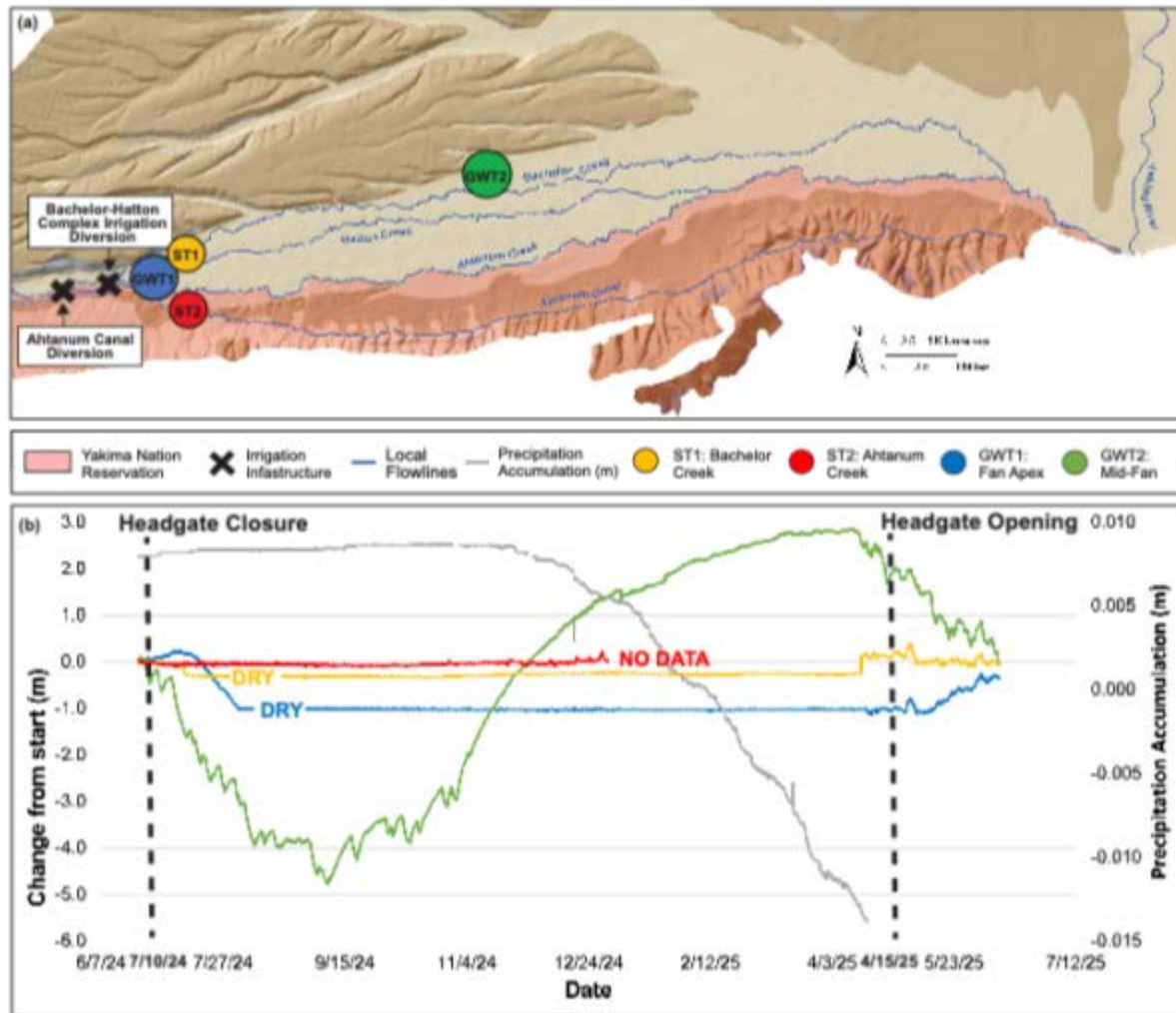


Figure 14. Changes in groundwater and surface-water elevation and precipitation. Change is relative to starting date of June 7, 2024. Yellow=ST1, red=ST2, blue=GWT1, green=GWT2, gray=precipitation accumulation. Basemap source: Washington Geologic Information Portal, 1:100,000 Surface Geology (WA Dept. of Natural Resources, 2023).

Table 11. Change in groundwater elevation from start of measurements on June 4, 2024.

	GWT1		GWT2	
Date	Groundwater Elevation (m)	Change from Start (m)	Groundwater Elevation (m)	Change from Start (m)
6/2024	490.52	0.05	391.14	-0.15
7/2024	490.34	-0.13	389.58	-1.72
8/2024	489.45	-1.01	387.61	-3.68
9/2024	489.45	-1.02	387.25	-4.04
10/2024	489.44	-1.02	388.02	-3.27
11/2024	489.44	-1.03	390.30	-0.99
12/2024	489.44	-1.03	392.11	0.81
1/2025	489.44	-1.03	392.94	1.65
2/2025	489.44	-1.03	393.60	2.30
3/2025	489.44	-1.02	394.00	2.71
4/2025	489.44	-1.02	394.05	2.76
5/2025	489.44	-1.02	492.43	1.13
6/2025	490.11	-0.36	491.77	0.48

Surface Water Flow

The HEC-RAS instream hydraulic model was used to analyze monthly changes in discharge at monitoring site ST1 in Bachelor Creek (ST1). Measured water-surface elevations and modeled discharge express a decline in both WSE and discharge after the diversion period along three cross-sections within the select reach in Bachelor Creek (Fig. 14). Following the closure of the diversion, WSE and discharge stabilized and slightly declined, but the creek did not go completely dry.

The data express a cumulative discharge reduction of 0.85 m³/s along the reach between June and October 2024. The significant decline of 0.77 m³/s from June 25 to August 2, 2024, corresponds to the transition from active to inactive surface-water diversion into Bachelor Creek, which is marked by the Bachelor-Hatton Complex headgate closure on July 10th every year. Following the headgate closure, on August 2, 2024, discharge declined by only 0.08 m³/s (Table 12), indicating stabilized discharge levels after the upstream diversion ended on July 10. These patterns highlight the influence of diversion timing on discharge dynamics within the reach.

Table 12. HEC-RAS modeled discharge values.

Cross-Section	Month	Discharge (m3/sec)	WSE (m)
Cross-Section 1	June	1.2	512.13
	August	0.43	511.96
	October	0.35	511.94
Cross-Section 2	June	1.2	512.26
	August	0.43	512.08
	October	0.35	512.06
Cross-Section 3	June	1.2	512.45
	August	0.43	512.32
	October	0.35	512.31

Groundwater Flow Properties

Seepage velocity was calculated for five scenarios to evaluate groundwater flow: one within the upstream reach of the alluvial fan study area, two from the fan apex to the Yakima River along the active fan and alluvial terrace, and two from the southern and northern valley walls to Ahtanum

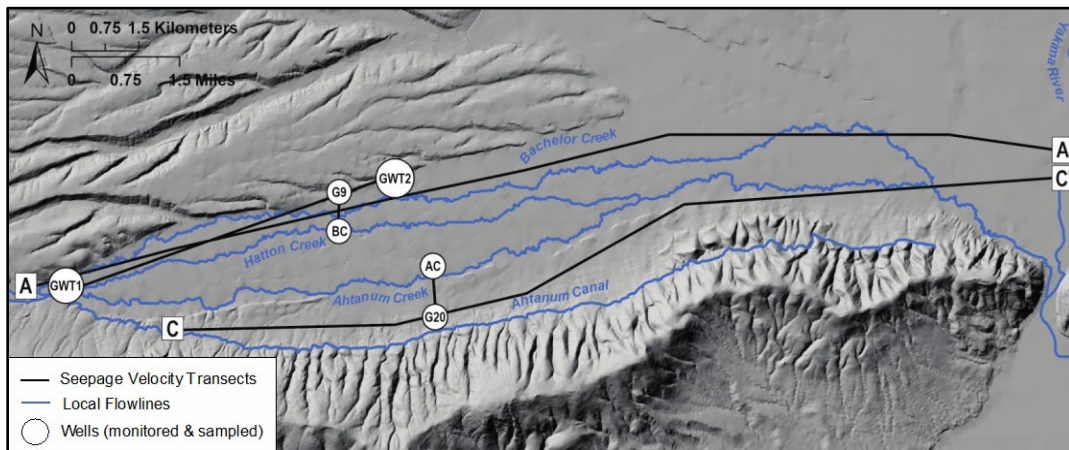


Figure 15. Seepage velocity cross-sections. Transects A and C align with hydrogeologic cross sections, with slight modification and extension to Yakima River; GWT1 to GWT2 spans two monitoring wells from the up-stream to the mid-fan extent of the study area; G9 to BC extends from the northern border to the active alluvial fan to Bachelor Creek; G20 to AC extends from a well in the southern extent of the elevated alluvial terrace to Ahtanum Creek. Wells G9 and G20 align with hydrogeologic cross-section E. (basemap sources: USGS TNM, 2023).

and Bachelor Creeks, respectively (Fig. 15). Hydraulic conductivity (K) and effective porosity (ne) were derived from previous investigations (Golder Associates, 2002; WA Ecology, 2008; Foxworthy, 1962; Vaccaro et al., 2009).

Monitoring wells GWT1 and GWT2 (Fig. 15) are spaced 7.2 km apart in the upstream and middle sections of the fan. The hydraulic gradient between these wells was 0.014 m during the irrigation season, when the highest amount of surface-water and groundwater flux occurs. Seepage velocities for the different hydrologic/stratigraphic units (Fig. 5) are shown in Table 13.

Table 13. Estimated seepage velocities for the upper alluvial fan.

Unit	Hydraulic Gradient (m) ($\Delta h/\Delta l$)	Hydraulic Conductivity (m/day)	Effective Porosity	Seepage Velocity (m/day)	Distance per month (km)
Unit 1: Unconsolidated	0.014	244.4	0.3	11.3	0.34
Unit 2: Semi-Consolidated	0.014	22.9	0.4	0.8	0.02
Unit 3: Consolidated	0.014	2.3	0.2	0.2	0.005

In determining the hydraulic properties of aquifers located within the active alluvial fan and the alluvial terrace, it is assumed that the water table runs parallel to the topographic extent of transect A and transect C (Fig. 15), with hydraulic gradients of 0.01 m along transect A and 0.0105 m along Transect C (Tables 14 and 15).

Table 14. Estimated seepage velocities along Transect A in the lower alluvial fan.

Hydrogeologic Unit	Hydraulic Gradient (m) ($\Delta h/\Delta l$)	Hydraulic Conductivity (m/day)	Effective Porosity	Seepage Velocity (m/day)	Distance in a month (km)
Unit 1: Unconsolidated	0.01	244.4	0.3	7.1	0.2
Unit 2: Semi-consolidated	0.01	22.9	0.4	0.5	0.01
Unit 3: Consolidated	0.01	2.3	0.2	0.1	0.003

Estimates of seepage velocities along Transect C-C' (Fig. 15) in the alluvial terrace section of the study area from the upstream section of the fan to the Yakima River are shown in Table 15. This section of Transect C is dominated by the semi-consolidated sediment of stratigraphic Unit 2 (Fig. 5), which is estimated to yield a seepage velocity of 0.6 m a day and 0.02 km/month (Table 15).

Table 15. Estimated seepage velocities for Transect C on the alluvial terrace.

Hydrogeologic Unit	Hydraulic Gradient (m) ($\Delta h/\Delta l$)	Hydraulic Conductivity (m/day)	Effective Porosity	Seepage Velocity (m/day)	Distance per month (km)
Unit 1: Unconsolidated	0.0105	244.4	0.3	8.5	0.3
Unit 2: Semi-consolidated	0.0105	22.9	0.4	0.6	0.02
Unit 3: Consolidated	0.0105	2.3	0.2	0.1	0.004

Seepage velocity was also estimated for sections along the north-south Transect E-E' (Fig. 15), indicating flow characteristics from the stratigraphy located on the valley ridges flanking Ahtanum and Bachelor Creeks. Well G22 and G9 were selected due to their upstream location within the alluvial fan study area and semi-consolidated and consolidated hydrogeologic units. The south-north hydraulic gradient between Well G22 and Ahtanum Creek is 0.4 (Table 16). The north-south hydraulic gradient from Well G9 to Bachelor Creek is 0.004 (Table 17).

Table 16. Estimated seepage velocities from south to north along Transect E.

Hydrogeologic Unit	Hydraulic Gradient (m) ($\Delta h/\Delta l$)	Hydraulic Conductivity (m/day)	Effective Porosity	Seepage Velocity (m/day)	Distance per month (km)
Unit 2: Semi-consolidated	0.4	22.9	0.4	2.3	0.07
Unit 3: Consolidated	0.4	2.3	0.2	0.5	0.01

Table 17. Estimated seepage velocities from north to south along Transect E.

Hydrogeologic Unit	Hydraulic Gradient (m) ($\Delta h/\Delta l$)	Hydraulic Conductivity (m/day)	Effective Porosity	Seepage Velocity (m/day)	Distance per month (km)
Unit 1: Unconsolidated	0.004	244.4	0.3	4	0.11
Unit 2: Semi-consolidated	0.004	22.9	0.4	0.2	0.01
Unit 3: Consolidated	0.004	2.3	0.2	0.05	0.001

Geochemical Field Measurements

Groundwater and surface-water chemistry properties measured in the field are summarized in Table 18. Basalt wells had the highest conductivity levels, and the shallow sedimentary wells expressed higher conductivity levels than deeper sedimentary wells. Basalt wells had higher pH values than sedimentary wells. The ranges of dissolved oxygen concentrations were comparable among the different types of wells. (Table 18).

Table 18. Summary of geochemical measurements taken in the field.

	Sample ID	EC (μS/cm)	pH	DO (mg/L)	Temperature (°C)
Shallow Sedimentary Wells	G1	542	6.77	6.88	16.1
	G2	241	6.92	7.52	14.3
	G8	45.6	6.92	5.67	13.9
	G9	63.6	6.88	7.97	18.2
	G10	112	6.67	5.08	17.4
	G11	83.6	7.04	2.72	16.2
	G12	56	7.07	4.15	18.4
	G13	89.3	7.28	9.9	15
	G14	63.3	6.95	4.99	19.0
	G15	155	6.92	9.25	17.8
	G16	119	7.29	10.2	18.5
	G17	92	7.4	12.9	18.9
	G19	62.7	7.41	9.86	20.1
	G20	65.7	7.03	11	14.9
	G21	125	6.87	9.91	15.6
	G22	134	7.03	7.46	17.7
Deep Sedimentary Wells	G23	51.8	7.2	5.75	26.2
	G18	90.33	7.31	14.71	19.5
Basalt Wells	G3	188	7.73	6.17	15.9
	G4	190	7.76	8.19	21.3
	G5	88.3	7.45	6.31	16.2
	G6	80.3	6.94	9.73	13.9
	G7	140	7.26	1.5	19.3
	G24	73.5	8.09	5.33	24.6
	G25	72.7	8.05	2.81	24.2
Surface Water	BC1	65.8	7.36	9.42	20.3
	AC2	89.5	7.65	9.35	22.6
	AC3	37	7.88	10.74	16.5
	YR4	35.5	7.69	10.3	21.7

Shallow Sedimentary Wells	Sample ID	EC ($\mu\text{S}/\text{cm}$)	pH	DO (mg/L)	Temperature ($^{\circ}\text{C}$)
	G1	542	6.77	6.88	16.1
	G2	241	6.92	7.52	14.3
	G8	45.6	6.92	5.67	13.9
	G9	63.6	6.88	7.97	18.2
	G10	112	6.67	5.08	17.4
	G11	83.6	7.04	2.72	16.2
	G12	56	7.07	4.15	18.4
	G13	89.3	7.28	9.9	15
	G14	63.3	6.95	4.99	19.0
	G15	155	6.92	9.25	17.8
	G16	119	7.29	10.2	18.5
	G17	92	7.4	12.9	18.9
	G19	62.7	7.41	9.86	20.1
	G20	65.7	7.03	11	14.9
	G21	125	6.87	9.91	15.6
	G22	134	7.03	7.46	17.7
	AC5	44.3	7.91	10.63	20
	BC6	32.4	6.42	6.86	6.43
	BC7	35.6	6.55	8.37	3.1
	BC8	22.1	6.97	12.9	0.5

Stable Isotopes

Isotopic analysis of groundwater and surface water samples reveals distinct variations in $\delta^{18}\text{O}$ and δD signatures across the Ahtanum alluvial fan (Fig. 16; Table 19). Overall, surface-water samples display heavier isotopic values than groundwater. Minimal seasonal variation was observed in samples collected during and after the irrigation season.

Two shallow groundwater samples (G10 and G11), located in middle and downstream portions of the active fan, display heavy isotopic signatures similar to surface water samples from Ahtanum and Bachelor Creeks (e.g., AC2, AC3, AC4, BC6, BC7). Several samples from basalt wells in the upstream active fan (G3–G6) also exhibit relatively heavy isotopic signatures, overlapping with one Ahtanum Creek sample (AC8). The isotopically lightest samples in the dataset are from two deep basalt wells (G24 and G25) in the southern fan. Groundwater samples from other shallow sedimentary wells across the fan and one basalt well show moderate stable isotope values between the two end members.

Table 19. Summary of stable isotope data.

Sample	Location/Type	$\delta^{18}\text{O}$	δD
G1	Shallow Basin-Fill	-16.43	-122.3
G2	Shallow Basin-Fill	-16.50	-122.7
G8	Shallow Basin-Fill	-16.64	-122.3
G9	Shallow Basin-Fill	-16.27	-120.4
G10	Shallow Basin-Fill	-15.56	-114.5
G11	Shallow Basin-Fill	-15.43	-115.8
G12	Shallow Basin-Fill	-16.64	-122.2
G13	Shallow Basin-Fill	-16.12	-123.9
G14	Shallow Basin-Fill	-16.58	-122.0
G15	Shallow Basin-Fill	-15.96	-119.5
G16	Shallow Basin-Fill	-16.37	-122.1
G18	Shallow Basin-Fill	-17.01	-125.5
G19	Shallow Basin-Fill	-16.90	-123.0
G20	Shallow Basin-Fill	-16.42	-119.7
G21	Shallow Basin-Fill	-16.34	-120.0
G22	Shallow Basin-Fill	-16.23	-118.3
G17	Deep Basin-Fill	-16.53	-124.7
G23	Deep Basin-Fill	-16.29	-120.6
G3	Basalt	-16.02	-118.3
G4	Basalt	-15.96	-117.3
G5	Basalt	-15.90	-116.9
G6	Basalt	-15.78	-115.8
G7	Basalt	-16.53	-125.1
G24	Basalt	-17.67	-133.2
G25	Basalt	-18.15	-136.3
BC1	Bachelor Creek	-15.81	-115.3
AC2	Ahtanum Creek	-15.80	-114.9
AC3	Ahtanum Creek	-15.83	-115.2
AC4	Ahtanum Creek	-15.73	-114.9
YR5	Yakima River	-13.98	-101.8
BC6	Bachelor Creek	-15.78	-115.9
BC7	Bachelor Creek	-15.80	-115.5
AC8	Ahtanum Creek	-15.92	-116.9

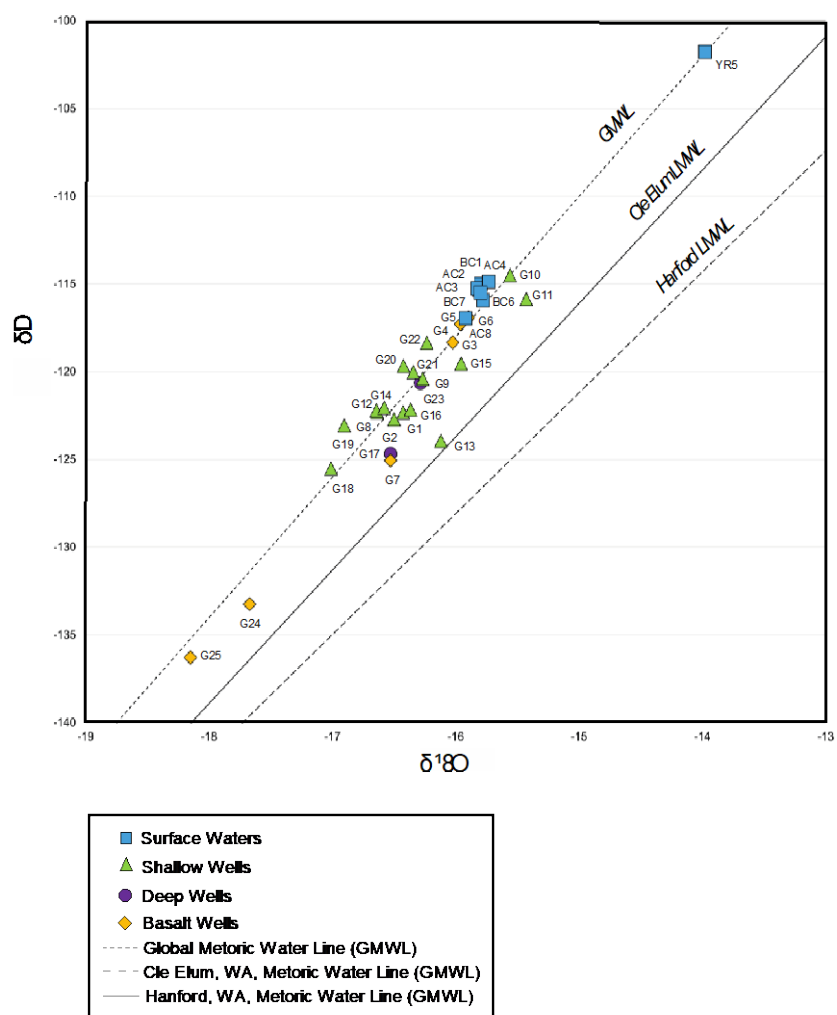


Figure 16. Stable isotope plot of surface water and groundwater samples.

Major Ion Geochemistry

Major ion concentrations (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , F^- , Cl^- , SO_4^{2-} , NO_3^- , PO_4^{3-} , HCO_3^- , and CaCO_3) were used to evaluate geochemical relationships among groundwater and surface water samples. The piper diagram (Fig. 17) shows five sample groupings reflecting variations in ion composition and degree of interaction between groundwater and surface water.

A total of 14 groundwater samples (five basalt, one deep, and eight shallow wells) displayed strong chemical similarity to surface water samples collected during the irrigation season from Ahtanum and Bachelor Creeks (Fig. 17). These samples were dominated by HCO_3^- and exhibited elevated SO_4^{2-} and PO_4^{3-} concentrations. Sample G1, though showing slightly higher HCO_3^- , was included in this group due to overall geochemical similarity. The elevated bicarbonate may be attributed to minor field contamination.

Five groundwater samples (four shallow and one deep) and one surface water sample from the

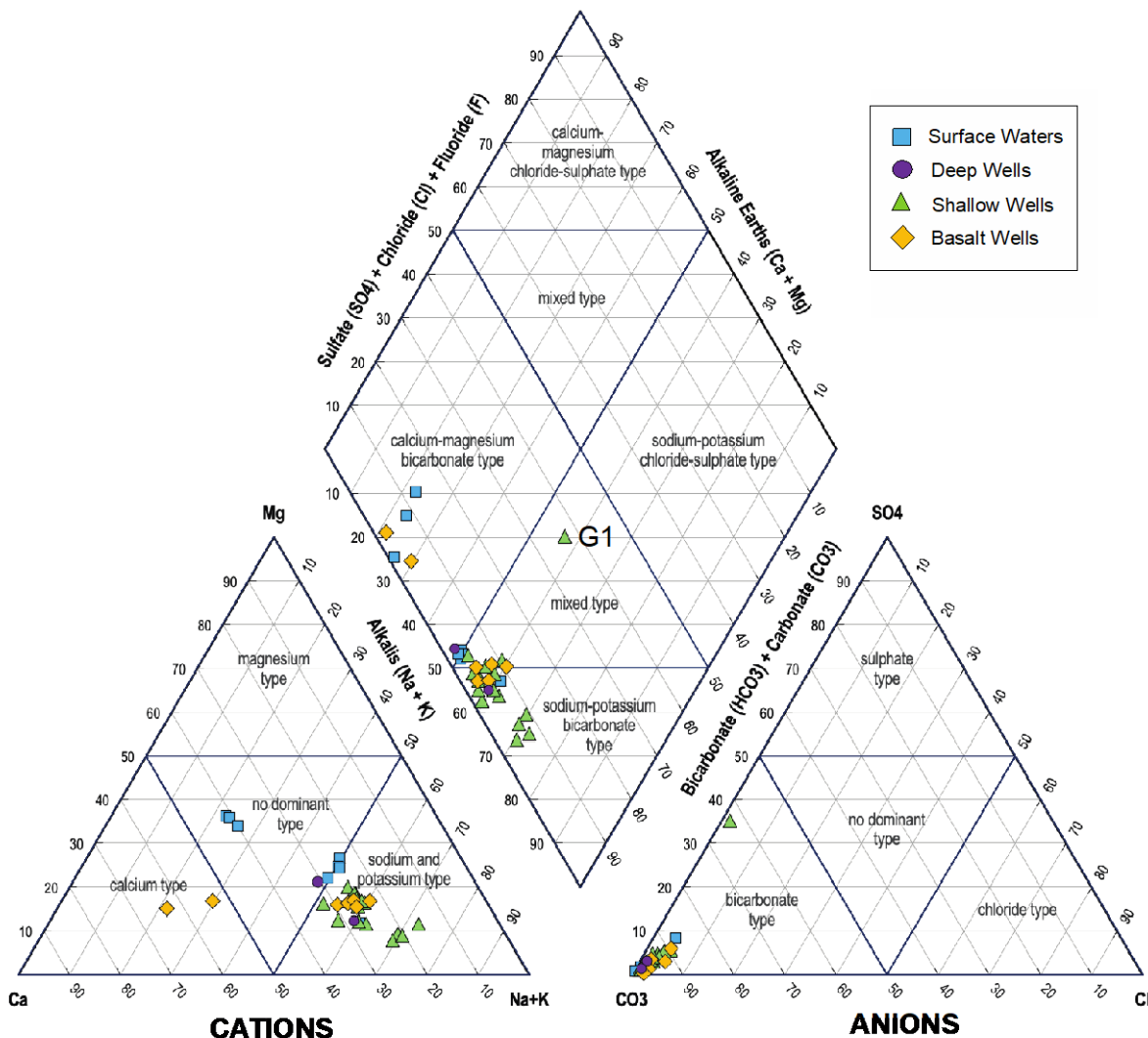


Figure 17. Piper diagram of major ion geochemistry of groundwater and surface water. Triangles are averages for wells in sedimentary stratigraphy; diamonds are averages for wells in basalt; squares are surface water averages.

Yakima River near Union Gap exhibited moderate Na^+ , K^+ , and HCO_3^- concentrations, with minimal similarity to local Ahtanum Creek water. Four additional shallow wells showed elevated Na^+ and K^+ and weak correspondence with surface-water chemistry, indicating geochemical evolution distinct from surface water influence.

Two deep basalt wells located on the alluvial terrace exhibited the most chemically evolved signatures. These samples were characterized by high concentrations of Ca^{2+} , Mg^{2+} , and HCO_3^- , consistent with confined groundwater flow paths through deeper units such as the Ellensburg Formation or Columbia River Basalt Group, as identified in previous studies (Taylor and Gazis, 2014).

Surface-water chemistry showed seasonal variation. Samples collected during or near the irrigation season (April 15–July 10, 2024; BC1, AC2, AC3, YR4, AC5) were dominated by bicarbonate and aligned closely with groundwater chemistry from the alluvial fan. In contrast, samples collected outside the irrigation season (BC6, BC7, AC8) were enriched in Ca^{2+} and Mg^{2+} as well as HCO_3^- , suggesting contributions from groundwater discharge to surface flow. These results indicate seasonal shifts in surface water composition and reinforce evidence of hydrologic connectivity between surface and groundwater systems within the Ahtanum alluvial fan (Table 20; Fig. 17).

Table 20. Summary of major ion geochemical data from groundwater and surface water.

Sample	Ca^{2+} (ppm)	Mg^{2+} (ppm)	Na^+ (ppm)	K^+ (ppm)	Cl^- (ppm)	SO_4^{2-} (ppm)	CaCO_3 (ppm)	HCO_3^- (ppm)	F^- (ppm)	NO_3^- (ppm)	PO_4^{3-} (ppm)
G1	7.45	3.4	14.6	8.65	2.52	3.81	76.1	46.4	0.3	0.4	0.0
G2	6.88	2.12	15.3	3.62	3.14	3.95	73.6	44.9	0.27	0.36	0.0
G3	6.19	2.64	8.19	9.23	1.95	6.73	89.9	54.9	0.34	2.61	0.19
G4	7.3	1.16	10.5	9.28	1.95	3.98	100	60.9	0.32	2.61	0.0
G5	8.49	1.35	11.1	9.28	2.64	3.71	85.9	52.4	0.28	2.49	0.0
G6	8.35	1.25	9.38	6.67	2.59	6.69	77.9	47.2	0.29	1.92	0.0
G7	7.18	3.14	9.51	5.9	2.14	5.21	79.0	47.9	0.28	2.04	0.0
G8	7.23	2.83	8.39	6.3	2.79	4.63	77.9	47.0	0.29	3.17	0.0
G9	10.6	3.93	16.7	3.99	3.6	4.22	71.7	43.6	0.36	3.19	0.0
G10	4.55	2.3	6.94	6.3	3.93	4.26	90.4	55.1	0.41	3.17	0.0
G11	5.18	2.53	5.45	4.58	2.74	5.6	81.8	49.8	0.33	3.19	0.0
G12	7.84	4.23	9.48	4.0	3.88	6.62	75.9	46.0	0.26	3.02	0.0

Sample	Ca ²⁺ (ppm)	Mg ²⁺ (ppm)	Na ⁺ (ppm)	K ⁺ (ppm)	Cl ⁻ (ppm)	SO ₄ ²⁻ (ppm)	CaCO ₃ (ppm)	HCO ₃ ⁻ (ppm)	F ⁻ (ppm)	NO ₃ ⁻ (ppm)	PO ₄ ³⁻ (ppm)
G13	5.0	1.97	6.35	4.33	1.86	4.23	84.0	51.5	0.23	2.0	0.0
G14	5.88	3.22	12.6	4.61	3.01	4.36	72.5	44.6	0.31	1.96	0.0
G15	6.53	2.78	14.9	6.0	3.17	4.13	77.0	47.4	0.31	1.96	0.0
G16	6.15	3.21	15.6	4.47	3.59	4.13	70.1	43.1	0.32	1.99	0.0
G17	5.89	2.98	11.83	7.16	3.9	6.87	65.1	40	0.4	1.99	0.0
G18	6.5	2.28	12.7	4.45	2.95	5.44	76.3	47.1	0.33	1.92	0.0
G19	5.28	1.88	8.27	5.33	3.17	4.36	79.8	49.1	0.28	1.9	0.0
G20	2.24	1.33	4.14	8.89	0.63	1.16	66.7	41.6	0.29	1.79	0.0
G21	3.63	2.01	10.9	7.67	2.88	6.09	76.4	47.6	0.27	2.45	0.0
G22	3.11	1.64	11.3	7.89	2.99	4.91	66.4	41.5	0.31	1.99	0.0
G23	3.4	1.36	10.3	8.17	2.64	4.89	77.2	48.3	0.34	1.77	0.0
G24	7.0	2.93	15.6	10.7	3.74	4.91	69.8	43.6	0.34	3.01	0.0
G25	7.94	4.06	8.78	8.32	1.66	5.5	101.4	61.8	1.02	0.0	0.0
BC1	3.94	2.67	7.5	3.4	1.16	1.47	40.1	24.5	0.1	0.44	0.0
AC2	4.82	2.8	9.33	4.43	2.71	3.26	49.9	30.5	0.21	0.32	0.0
AC3	4.45	2.8	8.65	3.95	2.01	1.47	56.7	34.5	0.22	0.29	0.0
YR4	2.47	1.91	8.89	3.73	0.88	2.03	45.5	27.6	0.2	0.32	0.0
AC5	4.23	3.55	8.99	5.0	1.11	3.21	43.7	26.5	0.28	0.29	0.0
BC6	4.15	2.9	6.88	5.0	0.88	2.71	49.1	30.4	0.26	0.22	0.0
BC7	3.75	2.98	6.88	3.63	0.84	2.81	47.9	29.6	0.2	0.29	0.0
AC8	4.89	4.37	5.14	2.09	0.38	0.71	49.7	30.3	0.04	0.12	0.0

Principal Component Analysis

The Principal Component Analysis (PCA) was conducted on five data subsets: A) major ion and stable isotope data from all groundwater samples, (B) groundwater major ion and stable isotope data excluding two samples indicative of old, evolved groundwaters (G24 and G25), (C) the full major ion dataset including both groundwater and surface water samples, (D) the major ion, stable isotope, dissolved oxygen (DO), conductivity (EC), and hydrogen (H⁺) in-situ measurements for groundwater and surface water samples collected within the irrigation season, and (E) the major ion dataset for the groundwater samples. In distinguishing distinct hydrochemical groups, subset A and B provided the greatest insights into the units and are therefore emphasized in this section, with scores, eigenvalues, and loadings tabulated in Table 21 and 22. Complete statistical results and descriptions for subsets C and D can be found in Appendix E (in Tables E1-E2 and Figs. E1-E2), including sample scores and component loadings.

Table 21. Principal Component Analysis Subset A and B eigenvalues and loadings.

	A1	A2	A3	A4	B1	B2	B3	B4
Eigen Values	5.41	3.08	1.22	0.84	6.18	2.23	1.02	0.93
Variance (%)	45.12	25.68	10.17	7.02	51.51	18.55	8.52	7.73
Ca ²⁺	-0.31	0.88	0.19	0.16	0.94	-0.16	-0.01	-0.15
Mg ²⁺	0.18	0.50	0.70	0.02	0.94	-0.14	0.01	-0.04
Na ⁺	0.84	0.24	0.03	0.45	0.77	0.19	-0.52	-0.10
K ⁺	0.92	0.12	-0.04	0.34	0.58	0.54	0.09	-0.24
Cl ⁻	0.72	0.30	-0.31	0.32	0.76	-0.28	0.13	0.33
SO ₄ ²⁻	0.91	0.23	-0.32	0.01	0.89	-0.36	0.13	0.17
HCO ₃ ⁻	0.75	0.47	0.14	0.11	0.88	0.02	-0.10	-0.05
F ⁻	-0.63	0.70	0.04	0.03	-0.40	0.23	-0.52	0.68
NO ₃ ⁻	0.79	0.10	-0.25	0.22	0.72	-0.17	0.33	0.44
PO ₄ ³⁻	-0.35	-0.56	-0.20	0.54	-0.71	-0.15	0.47	0.11
δ ¹⁸ O	0.63	-0.58	0.43	0.19	0.37	0.86	0.21	0.16
δD	0.54	-0.68	0.43	0.01	0.16	0.89	0.23	0.08

Table 22. Principal Component Analysis Subset A and B sample scores.

Subset A				Subset B			
Sample	A1	A2	A3	Sample	B1	B2	B3
G1	0.56	-0.04	-0.06	G1	0.84	0.35	0.04
G2	0.19	1.16	-0.28	G2	0.95	0.30	0.13
G3	-0.10	1.11	-0.54	G3	0.99	0.25	0.07
G4	-0.12	1.26	-0.27	G4	0.83	0.34	0.02
G5	-0.04	0.79	-0.42	G5	0.87	0.28	0.03
G6	-0.21	0.65	-0.29	G6	0.84	0.26	0.09
G7	-0.44	0.30	-0.23	G7	0.74	0.16	-0.08
G8	-0.72	0.04	0.13	G8	0.73	0.11	-0.01
G9	-0.88	-0.03	0.14	G9	0.68	0.11	0.07
G10	-0.63	-0.22	0.20	G10	0.66	0.10	0.00
G11	-0.51	-0.40	0.20	G11	0.63	0.02	-0.02
G12	-0.52	-0.42	0.16	G12	0.61	0.02	0.04
G13	-0.66	-0.60	0.28	G13	0.57	-0.05	-0.02
G14	-0.46	-0.48	0.24	G14	0.55	-0.05	-0.01
G15	-0.63	-0.69	0.17	G15	0.51	-0.04	-0.01
G16	-0.28	-0.43	0.12	G16	0.48	-0.08	-0.01
G17	-0.22	-0.23	0.00	G17	0.45	-0.12	0.03
G18	-0.16	-0.31	-0.02	G18	0.40	-0.14	-0.03
G19	0.12	-0.43	0.00	G19	0.36	-0.19	-0.03
G20	0.23	-0.50	-0.04	G20	0.30	-0.22	-0.04
G21	0.47	-0.62	-0.19	G21	0.27	-0.30	-0.08
G22	0.66	-0.91	-0.51	G22	0.23	-0.36	-0.06
G23	0.71	-1.00	-0.46	G23	0.20	-0.39	-0.04
G24	1.16	-1.14	-0.65	G24	0.15	-0.42	-0.02
G25	-5.06	-0.96	-2.07	G25	-1.90	-0.91	-0.46

The scores and loadings illustrate the degree of correlation with each component, with eigenvalues greater than 0.70 indicating strong contributions to the overall variance in the dataset. Subset A, representing groundwater samples G2 through G25 major ion and stable isotope data, generated four components (A1, A2, A3, A4) that cumulatively represent 88% of the variance within the dataset (Table 21; Fig. 18).

- Component A1 (45% of variance) contains samples from 7 shallow and 1 deep well, and expresses high loadings of NO_3^- , and varying concentrations of K^+ , SO_4^{2-} , Na^+ , HCO_3^- , Cl^- , Mg^{2+} , with moderate $\delta^{18}\text{O}$ and δD signatures.
- Component A2 (26% of variance) is characterized by 2 groundwater samples collected from deep basalt wells located in the southern alluvial terrace section of the study area, with light $\delta^{18}\text{O}$ and δD signatures, and varying loadings of HCO_3^- , Ca^{2+} , Na^+ , K^+ , and Mg^{2+} .

- Component A3 (10% of variance) contains 6 groundwater samples originating from 5 basalt wells and from one from a shallow sedimentary well with heavy $\delta^{18}\text{O}$ and δD signatures, and variations in loadings of Mg^{2+} , Ca^{2+} , HCO_3^- , F^- , and Na^+ .
- Component A4 (7% of variance) contains samples from 7 shallow and 1 deep well and correlates with high loadings of PO_4^{3-} , and variations in Na^+ , K^+ , Ca^{2+} , HCO_3^- , and expresses light $\delta^{18}\text{O}$ and δD signatures (Table 20).

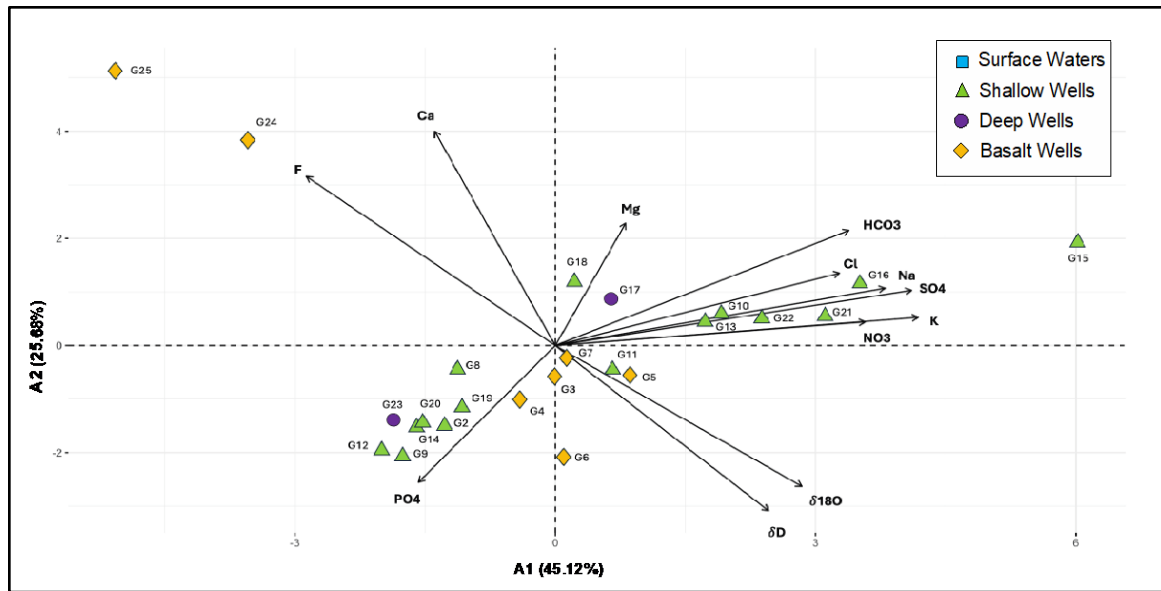


Figure 18. Principal component Subset A plot.

Subset B, groundwater major ions and isotopes excluding two distinct wells (G24 and G25), generated four components (B1, B2, B3, B4) that represent 78% of the variance within the dataset (Table 21; Fig. 19).

- Component B1 (52 % of variance) has high loadings of NO_3^- , and varying concentrations of Mg^{2+} , Ca^{2+} , SO_4^{2-} , HCO_3^- , Na^+ , Cl^- , K^+ , with moderate $\delta^{18}\text{O}$ and δD signatures, similar to component A1.
- Component B2 (18.5% of variance) is isotopically heavy, K^+ , F^- , Na^+ , and HCO_3^- loadings, indicating signatures of surface waters and groundwaters of basalt origins (Taylor et al, 2014).
- Component B3 (8.5%) has the highest PO_4^{3-} loadings of the subset, with moderate NO_3^- and $\delta^{18}\text{O}$ and δD values, with some variations of SO_4^{2-} , Cl^- , K^+ , and Mg^{2+} .
- Component B4 (8% of variance) had intermediate chemistry with moderate NO_3^- , and low PO_4^{3-} , Cl^- , and $\delta^{18}\text{O}$ and δD values.

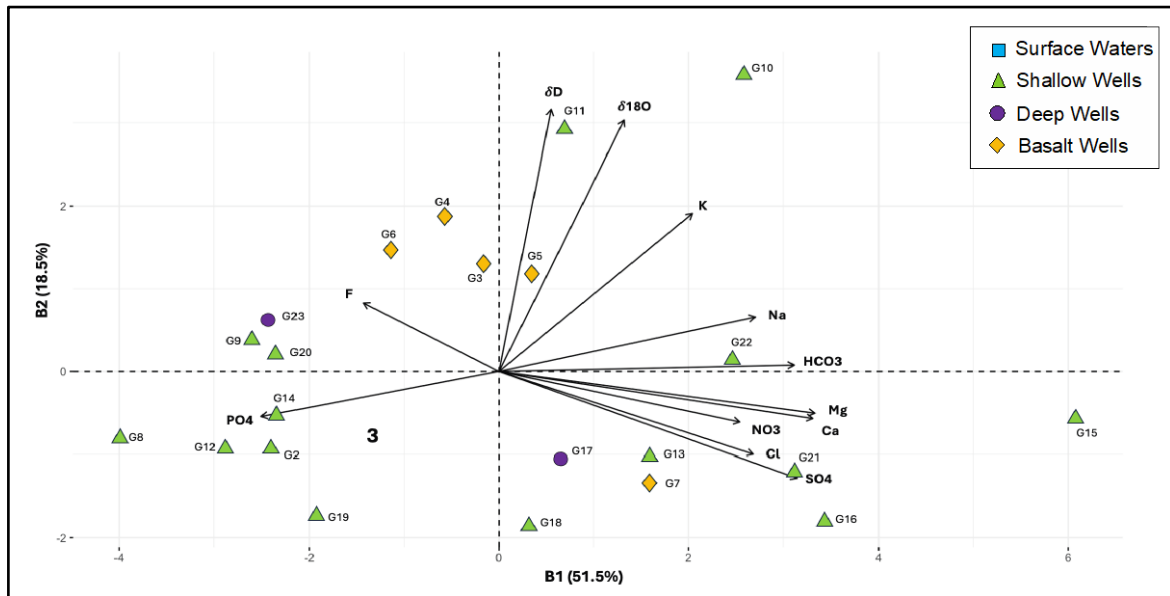


Figure 19. Principal component Subset B plot.

DISCUSSION

The results were interpreted by combining the stratigraphic characteristics of hydrogeologic units with the identification of hydrochemical groups based on analysis of major ions and stable isotopes. Changes in surface-water and groundwater elevation were examined as a function of seasonal and irrigation temporal variations and paired with the geochemical results, providing insights into surface-groundwater interactions, specifically in the up-stream portion of the fan. Estimates of aquifer hydraulic properties, paired with previous estimates for hydraulic conductivity and effective porosity, were used to make general calculations about aquifer capability to store and transmit water.

Hydraulic Conductivity of Stratigraphic Units

Stratigraphy of the study area reveals a progressive deepening of the basalt contact from the apex to the mid-fan region, with shallow basalt units occurring within 4 to 5 km of the fan apex, typically containing sedimentary interbeds which appear in seven of the sampled wells (Figs. 9 and 10). Sedimentary basin-fill units have accumulated above the basalt between the Ahtanum Ridge anticline in the south and an upland bench in the north, consisting of unconsolidated, semi-consolidated, and consolidated sedimentary basin-fill units (Vaccaro et al, 2009; Fig. 5).

Overlying the basalt is the Ellensburg Formation and similar continental sediments (Unit 3, Fig. 5), exhibiting semi-consolidated properties near the surface and more consolidated properties at depth, composed mainly of cemented sand, silt, clay, and minor gravels, with low estimated hydraulic conductivity and permeability (Table 5) (Vaccaro et al, 2009 & Foxworthy, 1962).

Above Unit 3, the Thorp Gravel, terrace, alluvial fan, and loess deposits dominate the stratigraphy, largely composed of gravels with some fine-grained interbeds of silt, sand, and clay (Unit 2, Fig.

5). Unit 3 is characterized as semi-consolidated due to the stratigraphic variation in cementation in the gravel-dominated stratigraphy and is likely to exhibit moderate permeability and hydraulic conductivity (Table 5). The uppermost deposits (Unit 1, Fig. 5) consist of Holocene floodplain alluvium of unconsolidated silt, sand, and gravel, which transitions downstream into finer-grained silty sand. Unit 1 has the highest hydraulic conductivity (Table 5).

Soil Drainage and Surface-Water Infiltration

Soil drainage class distributions across the Ahtanum Sub-Basin provide insight into the spatial variability of infiltration potential and groundwater recharge capacity within alluvial fan sedimentary basin-fill aquifer units. South of Ahtanum Creek, where approximately 84% of soils are classified as well drained, the subsurface conditions appear favorable for vertical percolation and groundwater recharge (NRCS, 2003). These well-drained soils are indicative of higher permeability, which is consistent with areas less impacted by anthropogenic disturbance and more conducive to water transmission through unsaturated zone pathways. In contrast, the active alluvial fan area north of Ahtanum Creek is dominated by somewhat poorly drained soils (65%), with only 29% well drained and 7% somewhat excessively drained (NRCS, 2003; Fig. 12), suggesting increased soil compaction or finer-grained sediment. These soils could reduce infiltration and transmissivity from the surface to subsurface stratigraphy (Sandison, 2005). The somewhat excessively drained soils in both areas, though limited in extent, may correspond to coarser-grained alluvial deposits that allow for rapid percolation but potentially limit water retention.

Collectively, soil drainage class distributions suggest that the portions of the alluvial terrace on the southern side of the Ahtanum alluvial fan offer greater potential for recharge, while the northern portions of the active fan may have lower hydraulic connectivity between the surface soil layers and subsurface sedimentary basin-fill aquifer units.

Hydrochemical Groupings

The stratigraphic and geochemical datasets of the Ahtanum alluvial fan reveal spatial patterns in the subsurface geology and the extent of interaction between surface water and groundwater. This section discusses the groupings identified in the stable isotope, major ion, and principal component analyses that were used to identify six distinct hydrochemical groupings within the study area.

Stable Isotope Groups

Five groups were identified within the $\delta^{18}\text{O}$ and δD stable isotope data from surface water and groundwater samples (Fig. 20). The wells drilled into deep, confined, basalt aquifers in the upstream southern extent of the alluvial terrace express the lightest (most negative) $\delta^{18}\text{O}$ and δD signatures among the samples. Isotopically light water in basalt aquifers has been observed throughout the Yakima basin and into the Columbia plateau and has been interpreted to represent older waters, up to ten thousand years old, that were recharged in a different climatic and hydrologic setting that had isotopically lighter surface waters (Miller, 2009; Taylor and Gazis, 2014; Gazis, 2023).

Stable isotope groups 1, 2, 3 and 4, including wells drilled into both sedimentary stratigraphy and shallow basalt, indicate varying degrees of similarity to the surface water samples (Table 19; Fig. 20).

Group 1 contains two samples (G10 and G11) that represent the isotopically heaviest end members of the groundwater dataset. The close correlation of these samples with surface water from Ahtanum and Bachelor Creeks suggests recharge and mixing with surface water at the locations of these wells in the middle and downstream portions of the active fan (Figs. 6 and 20).

Group 2 contains four samples from basalt wells that also indicate relatively close correlation with surface water samples, suggesting a mixture of modern surface water and older groundwater within this unit (Fig. 20). This group shows close correlation with one surface water sample (AC8), which was collected upstream from the sampled wells outside of the irrigation season. This sample could reflect temporal variation in groundwater contributions to Ahtanum Creek, shifting to higher groundwater contributions in surface flow during the dry season.

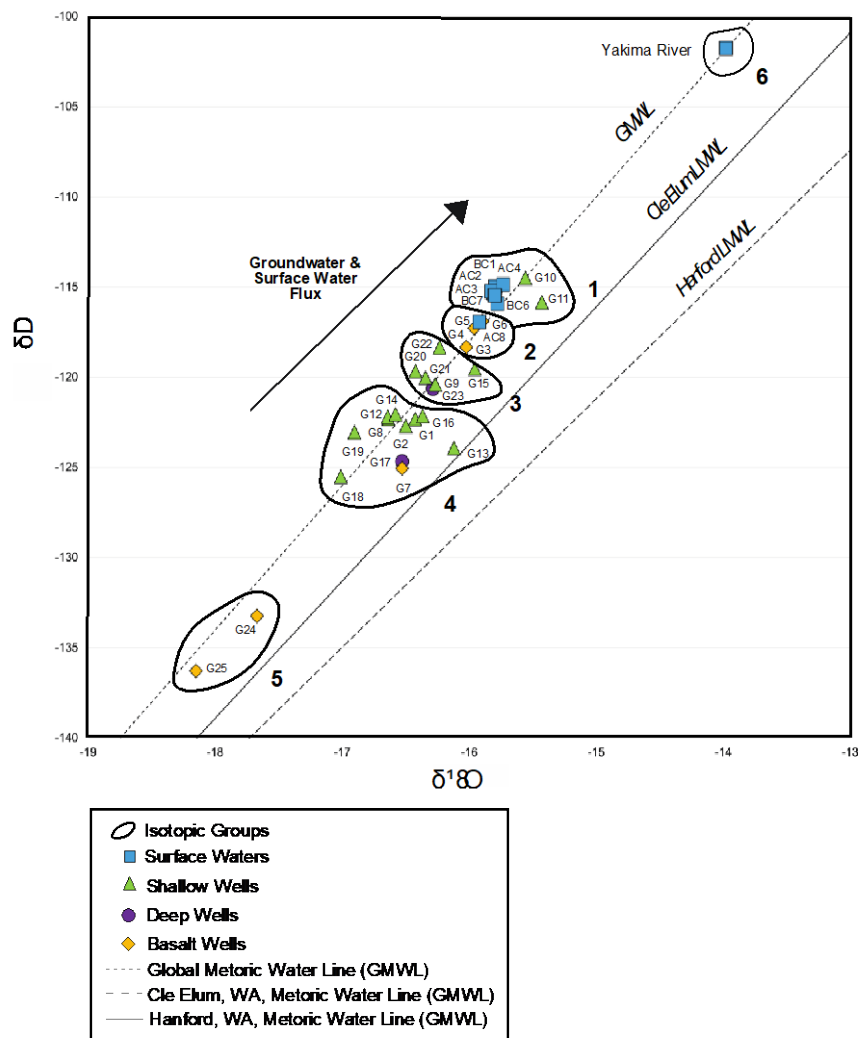


Figure 20. Plot of stable isotope groups.

Groups 3 and 4 largely consist of isotopically moderate to light signatures (Fig. 20). Group 3 contains five shallow wells and one sample from a deep sedimentary basin-fill well. These samples are primarily located on the flanks of the northern bench and southern Ahtanum Ridge anticline (Fig. 4). The isotopic signatures are likely attributed to limited surface-water recharge. Group 4 contains samples from nine shallow, one deep, and one basalt well located throughout the alluvial fan. The moderate to light $\delta^{18}\text{O}$ and δD values suggest that very little recharge occurs at these well locations.

Group 5 is the Yakima River (YR5), which has the heaviest isotopic values due to its source region in the northwestern Yakima Basin (Fig. 20). None of the groundwater samples collected from the Ahtanum fan display a Yakima-River isotopic signature because Yakima River water is not used for irrigation in the study area. In contrast, some groundwater samples are isotopically similar to samples from Ahtanum (AC2, AC3, AC4, AC8) and Bachelor Creeks (BC1, BC5, BC6), which flow through the Ahtanum fan and are used for irrigation. Surface waters from these creeks have distinctly lighter isotopic signatures than the Yakima River, as their water source originates from the southern and eastern Cascades (Fig. 20).

Major Ion Groups

Analysis of the major ions revealed five groups (A-E) that provided insight into aquifer unit hydrogeologic and hydraulic properties within the Ahtanum alluvial fan study area. The concentration of cations (Figs. 17 and 21) allowed differentiation between unconsolidated units with high porosity, characterized by mixed ionic types and strong correlation with surface waters, and more consolidated units with lower porosity and higher dissolved solids.

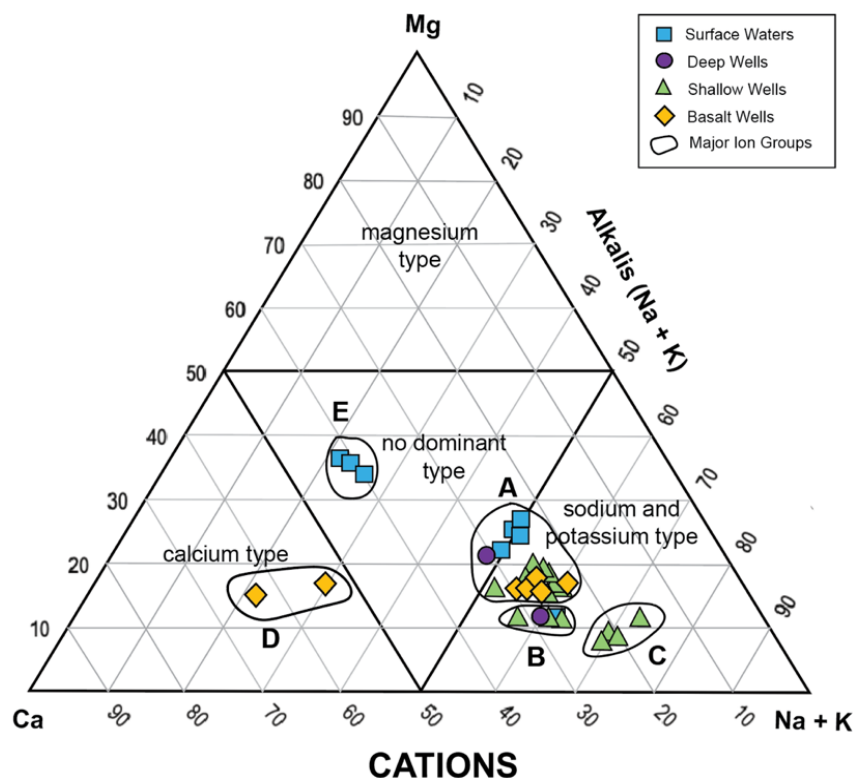


Figure 21. Plot of cation groups.

Group A includes both shallow and deep sedimentary wells and basalt wells with mixed dominant cations and varying degrees of correlation with surface water samples (Fig. 21). These samples were collected within or shortly after the irrigation season (April 15th to July 10th). Group A is the dominant groundwater chemistry in the region and is interpreted to represent “resident” sedimentary groundwater, intermediate in age, with some surface water influence .

Group B has lower proportional Mg^{2+} and slightly higher proportional Na^+ and K^+ cations than Group A (Fig. 21), suggesting moderate porosity and partial interaction with surface waters of semi-consolidated units. Notably, one surface water sample (AC8), collected outside of the irrigation season, aligns with Group B, implying that Ahtanum Creek may receive increased groundwater contributions during these periods, as similarly indicated by stable isotope Group 2 (Fig. 20).

Group C includes groundwater samples from four shallow wells and exhibits lower proportional Ca^{2+} and Mg^{2+} and higher proportional Na^+ and K^+ than Group B (Fig. 21). Group C also has higher proportional SO_4^{2-} (Fig. 17). This group is associated with more consolidated units with greater cementation, low porosity and limited surface water interaction (Fig. 29).

Group D comprises two chemically distinct deep wells drilled into basalt (G24 and G25 in Fig. 9) inferred to be confined with consolidated interbeds, characterized by elevated Ca^{2+} cation and HCO_3^- anion concentrations (Figs. 17 and 21). Previous studies in the Yakima Basin observed variations of Ca^{2+} , Mg^{2+} , and Na^+ in groundwater samples to determine age from mineral precipitation within older groundwaters (Miller, 2009). In this process, waters undergo ionic exchange where Ca^{2+} and Mg^{2+} undergoes an ionic reduction reaction causing for Na^+ concentrations to increase (Steinkempff and Hearn, 1996; Taylor and Gazis, 2014).

Group E includes three surface water samples collected outside the irrigation season, each exhibiting mixed chemistries, with higher proportional Ca^{2+} and Mg^{2+} than surface water samples in Group A (Fig. 21). The chemical composition of this group suggests higher groundwater contributions to surface water flows within the winter months outside of the irrigation season.

Spatial Trends in Stable Isotopes and Nitrate

Spatial patterns in $\delta^{18}O$ and NO_3^- concentration are assessed in this section as environmental tracers to determine trends in groundwater flow pathways and land use influence (Figs. 22 and 23). In the Yakima Basin, shallow groundwater tends to exhibit isotopically heavy $\delta^{18}O$ signatures due to recent interaction with modern surface waters. Confined groundwater exhibits lighter signatures, indicative of older, more isolated water (Taylor and Gazis, 2014). Nitrate (NO_3^-) ion concentrations can reveal impacts of land use and irrigation on groundwater quality. Elevated NO_3^- often indicates areas where irrigation water infiltrates into aquifer units (Gazis, 2023).

The spatial distribution of stable isotope $\delta^{18}O$ signatures across the Ahtanum alluvial fan reveals four distinct groundwater flow regimes shaped by interactions with surface water (Fig. 22). Heavier $\delta^{18}O$ values in the upstream fan closely resemble surface water from Ahtanum and Bachelor Creeks, indicating strong recharge influence. In contrast, the mid-fan region exhibits much lighter $\delta^{18}O$ values, reflecting a diminished connection to surface water sources and suggesting the presence of older or regionally sourced groundwater. Toward the eastern portion of the fan, $\delta^{18}O$ values become isotopically heavier again, aligning with nearby surface waters and indicating renewed surface water influence, probably from irrigation. Finally, the downstream fan

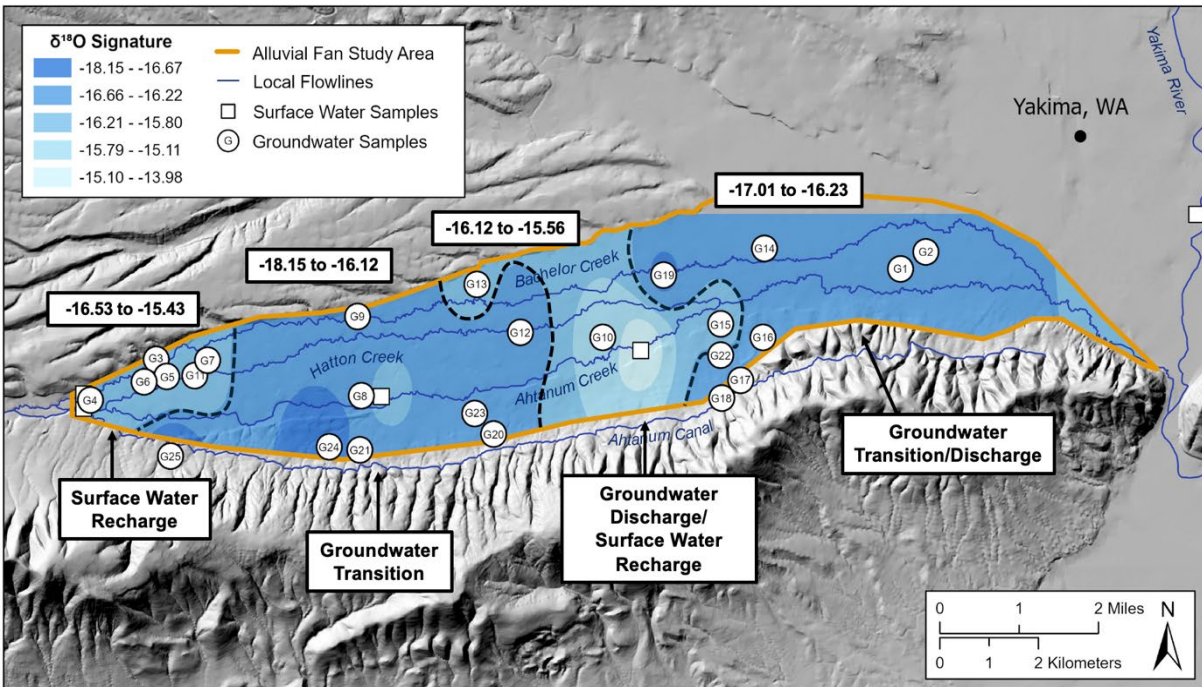


Figure 23. Spatial distribution of stable isotope $\delta^{18}\text{O}$ values. Heavy $\delta^{18}\text{O}$ values (less negative) indicate a greater influence of surface water. Light blue=heavier $\delta^{18}\text{O}$, dark blue=lighter $\delta^{18}\text{O}$.

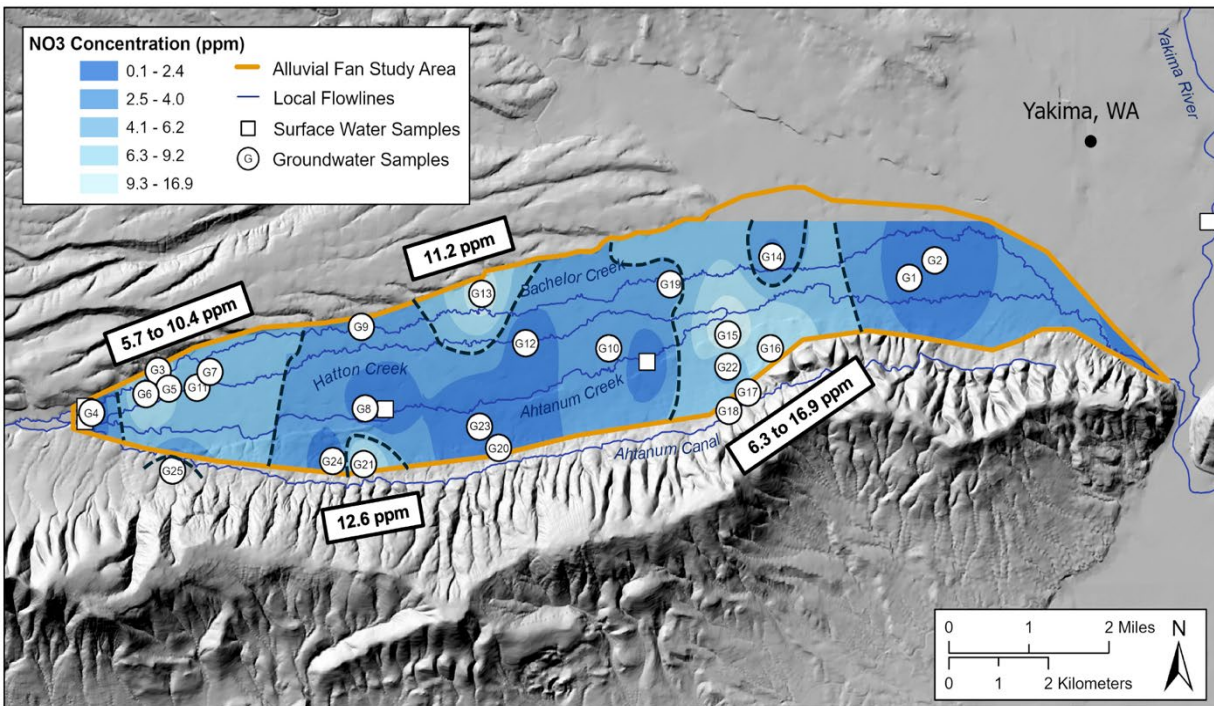


Figure 22. Spatial distribution of nitrate (NO_3^-) concentration (ppm). Higher nitrate values indicate greater influence of irrigation water. Light blue=high nitrate concentration; dark blue=low nitrate concentration.

shows another shift to lighter $\delta^{18}\text{O}$ values, further indicating a complex mix of surface-water recharge and groundwater discharge zones. These findings support a nuanced understanding of

groundwater flow dynamics, where structural controls, topography, and localized recharge processes govern spatial variability in isotopic composition.

Complementary to the isotope data, NO_3^- concentrations further delineate zones of recharge influenced by land use and irrigation. Elevated nitrate levels in the upstream and downstream fan regions, contrasting with much lower concentrations in adjacent surface waters, suggest significant input from agricultural return flows rather than direct stream infiltration (Fig. 23). The highest groundwater nitrate concentrations (up to 16.9 ppm) occur where $\delta^{18}\text{O}$ data also indicate surface-water recharge, most likely from irrigation water.

Principal Component Analysis of Stable Isotopes and Major Ions

Principal Component Analysis (PCA) Subsets A and B (Figs. 24 and 25; Tables 21 and 22) provide insights into interactions between aquifer units and surface waters through analyzing the major ion (Table 20) and stable isotope (Table 19) datasets. Subset A includes stable isotope and major ion data for all groundwater samples, except for one outlier well (G1) to avoid offset from elevated SO_4^{2-} concentrations. Subset B did not include samples G24 and G25, which form component A2 in Subset A and are responsible for much of the geochemical variation in the Subset A data set. The PCA analysis of Subset B provides additional insight into the sedimentary basin-fill aquifer units.

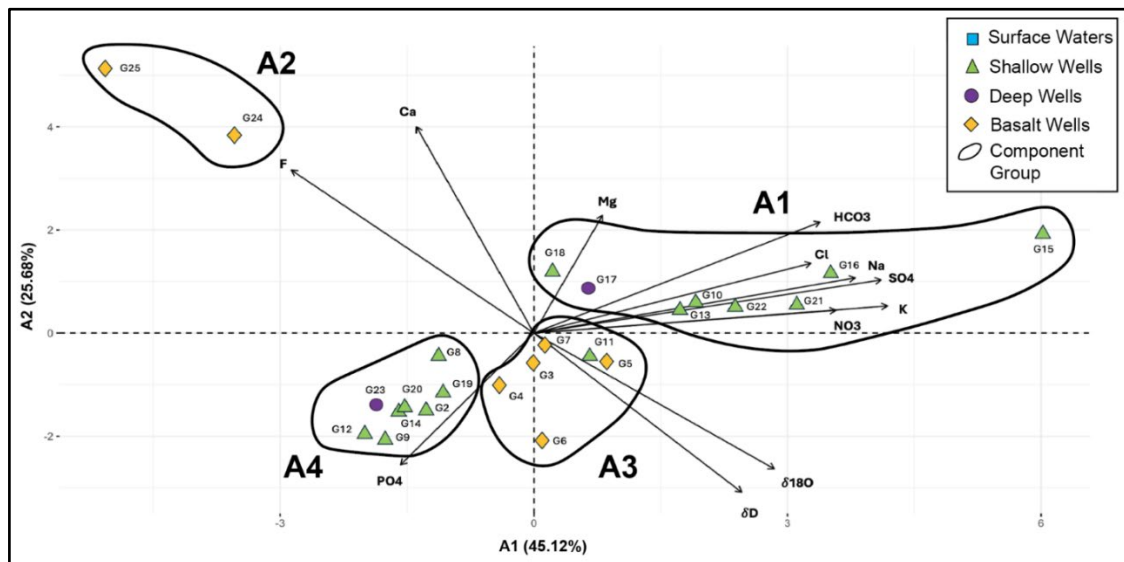


Figure 24. Principal Component Analysis Subset A groups.

Subset A distinguishes four components indicative of (A1) semi-consolidated units with moderate recharge from surface waters, probably from irrigation sources, (A2) deep confined units with little to no recharge from surface waters, (A3) semi-consolidated and shallow basalt units with high recharge from surface water and (A4) consolidated units indicating low correlation with surface water, with some contributions from irrigation sources (Fig. 24).

Subset B reveals five groups (Fig. 25). Two groups are similar to Subset A, indicating correlation with semi-consolidated units recharged by irrigation waters (component B1), and consolidated

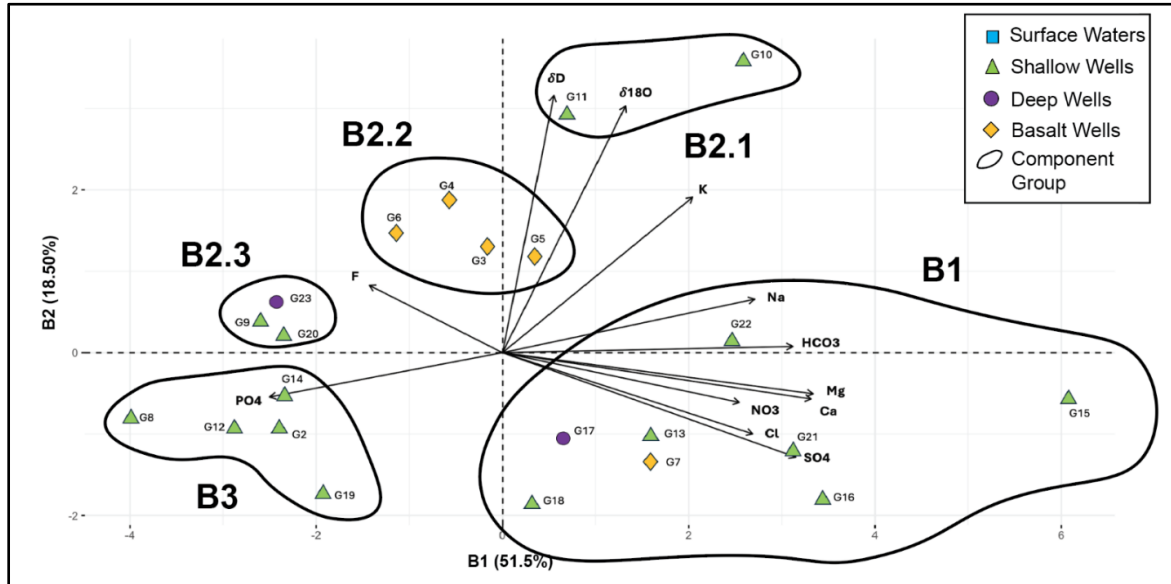


Figure 25. Principal Component Analysis Subset B groups.

units with minimal recharge from surface waters (component B3). Component B2 is similar to component A3, but is further divided into subgroups B2.1—sedimentary units with high influence of surface waters, B2.2—shallow basalt units with high recharge from surface waters, and B2.3—consolidated sedimentary units that experience moderate recharge from surface waters and show evidence of contributions from older, evolved groundwater sources.

Summary of Hydrochemical Groups in Relation to Stratigraphy and Surface Water

Six final hydrochemical groups were distinguished by combining the results of PCA subsets A and B, major ion and stable isotope geochemistry, and hydrogeologic units. Hydrochemical group details and correlation to other datasets is outlined in Table 23. The stratigraphic context and spatial distribution of the hydrochemical groups are illustrated in Figures 26 and 27.

The following hydrochemical groups were derived: Group A) unconsolidated and semi-consolidated units exhibiting high flux with surface water, Group B) semi-consolidated units exhibiting moderate to low recharge from irrigation waters, Group C) consolidated units with low recharge from irrigation waters, Group D) consolidated units with moderate recharge from surface water and mixing with old evolved groundwaters, Group E) shallow fractured basalt units with high recharge from surface waters, and Group F) deep confined basalt groundwaters with very little recharge with surface waters (Fig. 26).

Group A is characterized by heavy $\delta^{18}\text{O}$ and δD signatures and intermediate major ion and NO_3^- compositions. These properties are typical of hydrogeologic unconsolidated units, such as coarse gravels, that experience high flux with surface waters. Group A correlates with PCA subset B, component B2, which contains three subgroups (B2.1, B2.2, B2.3). The variance in component B2 is primarily due to elevated $\delta^{18}\text{O}$ and δD loadings compared to the other components in this subset.

Hydrochemical Group A correlates with major ion Group A (Fig. 17) and represents the most common water type, characterized by intermediate proportional major ion signatures. These waters

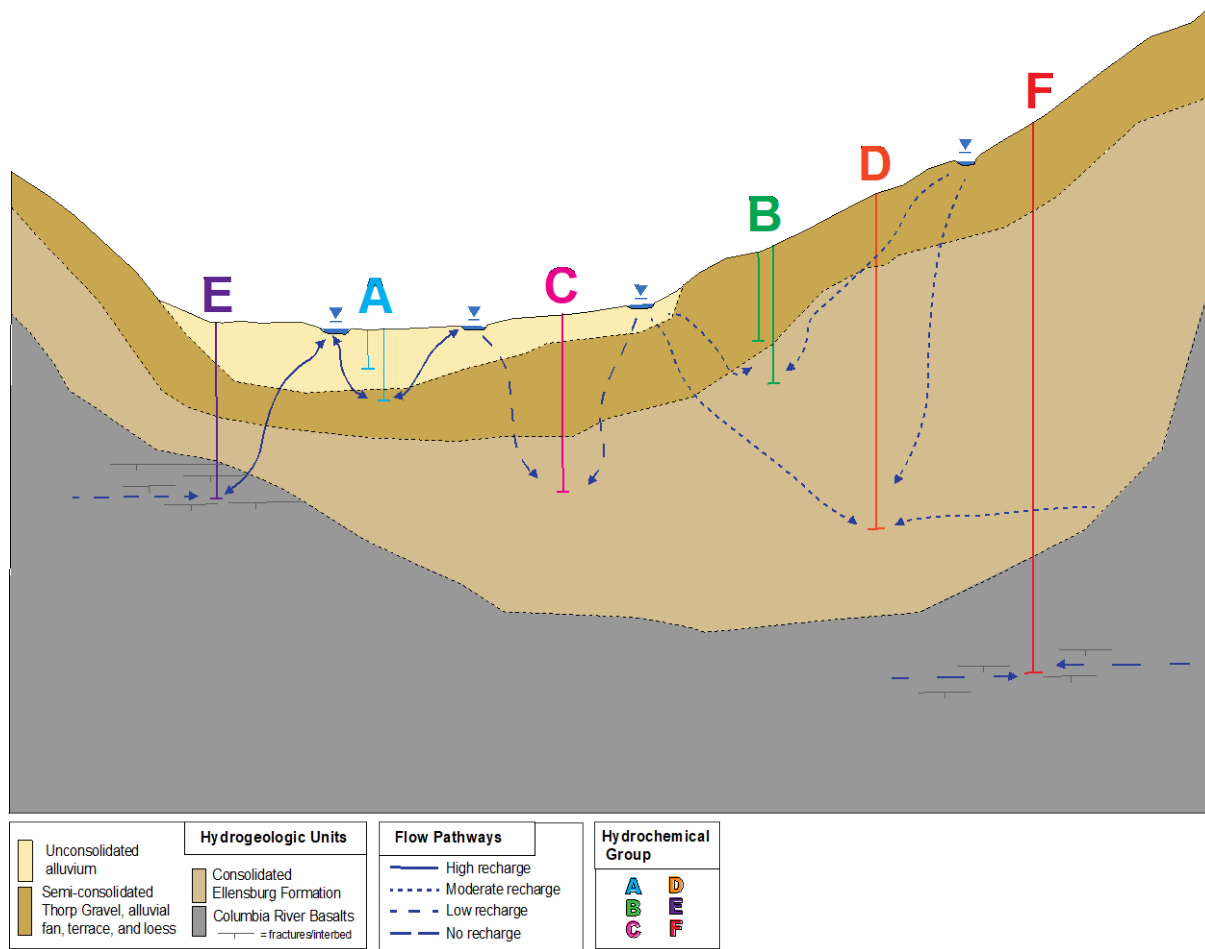


Figure 26. Cross section of stratigraphic and surface water sources associated with hydrochemical groups.

closely resemble modern surface water chemistry, indicating significant recharge from surface sources with minimal subsequent chemical evolution.

Two shallow wells, G10 and G11, exemplify this group. Well G11, at a depth of 38 m, is in cemented gravels of the semi-consolidated unit in the upstream fan, possibly terrace or paleochannel remnants. This suggests perched aquifer conditions with restricted flow and enhanced interaction with surface water. Sample G10 is from a 91-m deep well located in the mid-fan area in consolidated sand and clay overlain by coarse-grained gravels and sand and cemented gravels. This stratigraphy may also indicate perched conditions due to cementation, promoting preferential flow pathways that could facilitate flux with surface water (Fig. 26).

Group B is defined by high NO_3^- concentrations and moderate $\delta^{18}\text{O}$ and δD values compared to Group A, indicating moderate recharge from surface waters, likely originating from irrigation sources. This group is defined based on PCA components A1 and B1. These PCA groups both exhibit high scores for the first principal component, indicating that they collectively describe most of the variation in the data set. NO_3^- accounts for some of this variance, and as a common byproduct of fertilizers, it is likely that recharge originates from irrigation within these units (Taylor & Gazis, 2014). Hydrochemical Group B corresponds to major ion Groups A, B, and C (Fig. 21), which are intermediate in composition and variable. The variable proportions of ions suggest varying

amounts of water-rock interaction and limited interaction with surface water. Isotope signatures are moderate to light for this hydrochemical group, in stable isotope Groups 3 and 4 (Fig. 20). Overall, Group B includes eight samples, six from shallow sedimentary wells, one deep sedimentary, and one basalt well, primarily located north and south of the anticlinal ridges in the lower Ahtanum Valley. Sample G15 is an outlier in the group, with the highest NO_3^- (16.9 ppm) and HCO_3^- (121.9 ppm) concentrations and a lighter isotopic signature.

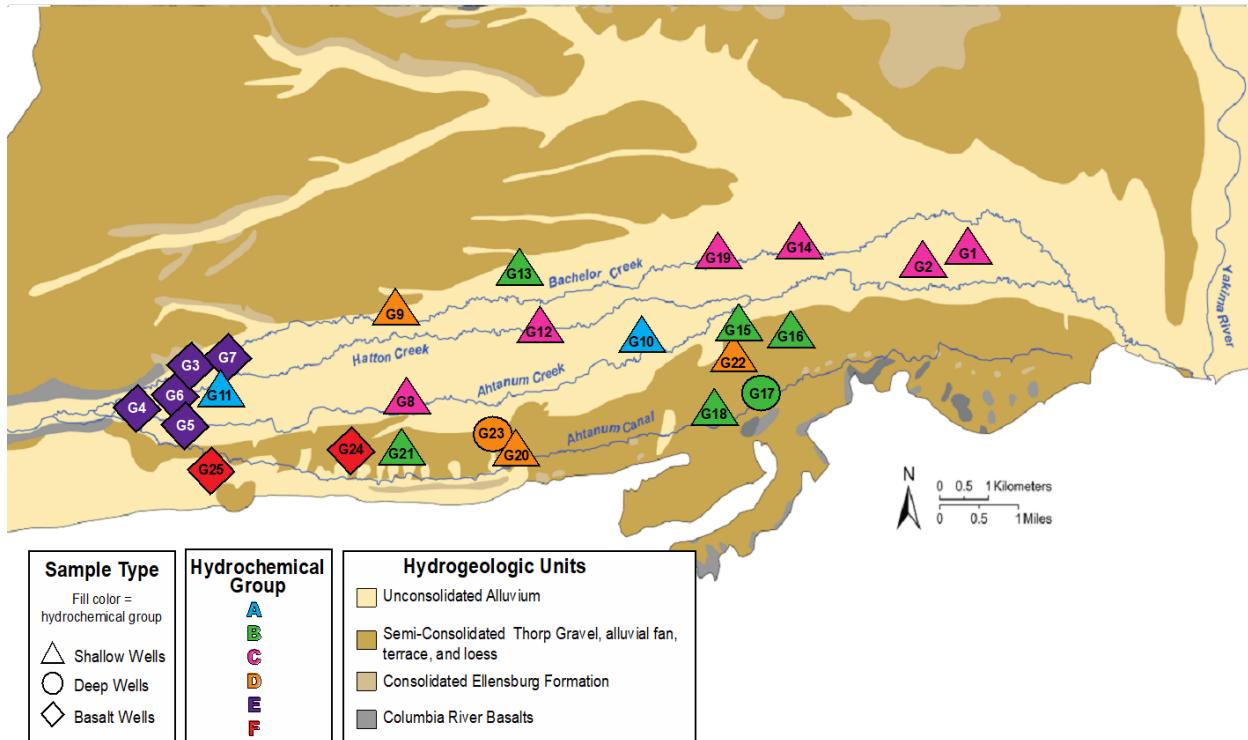


Figure 27. Spatial distribution of hydrochemical groups. Basemap source: Washington Geologic Information Portal, 1:100,000 Surface Geology (WDNR, 2023).

Hydrochemical Group C includes five shallow wells (G1, G2, G8, G12, G19) located in the mid-downstream alluvial fan near active creeks or canals. Group C consists of semi-consolidated and consolidated hydrogeologic units that correlate with PCA component B3 (Fig. 25) and experience limited recharge. The samples exhibit intermediate chemistry, light isotopic signatures and correlate with major ion groups A and B (Fig. 21), like the Ellensburg Formation wells in the Kittitas Valley (Taylor & Gazis, 2014). These units may have undergone slight compaction through enhanced mineral precipitation, reducing porosity and permeability. The presence of PO_4^{3-} in this group may derive from either mineral weathering or agricultural runoff, given the proximity to irrigated areas. Sample G1 is an outlier due to elevated detected SO_4^{2-} (88.31 ppm) concentrations, potentially from sample contamination or increased sulfate dissolution.

Hydrochemical Group D is associated with semi-consolidated units and represents a mixture of modern recharge and older evolved groundwater. This group includes three shallow wells (G9, G20, G22) and one deep well (G23) that are mainly in PCA subgroup B 2.3 (Fig. 25). Samples in this group have low scores for the first principal component in the group and have low concentrations of the variables that define that component. Hydrochemical Group D correlates

with the isotopically moderate stable isotope Group 3 (Fig. 20), suggesting limited surface water interaction. Samples in Group D were collected from wells along anticlinal ridges bordering the lower valley, near underlying basalt formations. These wells tap into the higher elevations of the consolidated clay, sand, and gravels of the Ellensburg Formation and similar continental sediments. Sample G23, a deep well with no detectable NO_3^- or PO_4^{3-} , likely reflects minimal irrigation input. G22, also NO_3^- absent, shows isotopic and ionic evidence of mixing between modern and evolved waters. Despite these outliers, Group D samples are compositionally consistent.

Hydrochemical Group E consists of groundwater from four shallow basalt wells (G3, G4, G5, G6) located in the upstream section of the active fan, which experience high recharge from surface water. Well logs indicate fracturing within the basalt aquifer and the presence of sedimentary interbeds. This group correlates with moderately heavy $\delta^{18}\text{O}$ and δD signatures and moderate NO_3^- concentrations, suggesting contributions and mixing from both surface water and evolved basalt groundwater. This group correlates with PCA subgroup B2.3 (Fig. 25), the isotopically heavy signatures in stable isotope Group 2 (Fig. 20), and the mixed chemistries of major ion Group A (Fig. 21). Sample G6 is an outlier within this group due to its high NO_3^- and PO_4^{3-} concentrations, comparatively light isotopic signature, and lower HCO_3^- concentrations, suggesting that this well might be located in a more unconsolidated unit than the other wells in Group E.

The stratigraphic units associated with Hydrochemical Group E could be remnants of the upward warping and subsequent incision from the cross-flexure, which formed the narrow ridges above the fan apex (Foxworthy, 1964). The fractured aquifer units characterized by this hydrochemical group might also experience seasonal variation in geochemistry due to the relative proximity to intermittent and managed surface flows of Bachelor Creek (see next section for a more detailed discussion of temporal variations). However, surface water contributions to these units may continue outside of the irrigation season due to their proximity to the perennial Hatton and Ahtanum Creeks and underscores the need for further investigation to determine the extent of recharge in this unit.

Hydrochemical Group F consists of two deep basalt wells (G24, G25) on the upstream alluvial terrace. These groundwaters express low NO_3^- and PO_4^{3-} (Fig. 17) and isotopically light $\delta^{18}\text{O}$ and δD signatures (Fig. 20), suggesting minimal surface water recharge. Prior studies in the Yakima Basin attribute high Mg^{2+} , Ca^{2+} , and HCO_3^- in the Ellensburg Formation to weathering, while elevated Na^+ in confined basalt aquifers reflects older groundwater (Taylor and Gazis, 2014). These geochemical patterns indicate mineral precipitation processes, evolved groundwater and no modern recharge.

Table 23. Characteristics of hydrochemical groups.

Hydro-chemical Group	Sample	Well Depth (m) ¹	Well Type	Piper Group	Isotope Group	PO ₄ ³⁻ (ppm)	NO ₃ ⁻ (ppm)	Subset A	Subset B	Hydrogeologic Unit ²	Geography ³
A	G10	91	Shallow	A	1	0	3.79	A1	B2.1	Semi-consolidated	Mid-Fan, Active, Center
A	G11	38	Shallow	A	1	0	4.47	A3	B2.1	Semi-consolidated	Up-Stream, Active Fan, North
B	G13	76	Shallow	A	4	0	11.16	A1	B1	Consolidated	Mid-Fan, Active, North
B	G15	52	Shallow	C	3	0	16.88	A1	B1	Consolidated	Mid-Fan, Alluvial Terrace, South
B	G16	39	Shallow	C	4	0	9.77	A1	B1	Consolidated	Mid-Fan, Alluvial Terrace, South
B	G17	154	Deep	B	4	0	6.26	A1	B1	Consolidated	Mid-Fan, Alluvial Terrace, South
B	G18	26	Shallow	B	4	0	6.94	A1	B1	Semi-consolidated	Mid-Fan, Alluvial Terrace, South
B	G21	68	Shallow	C	3	0	12.61	A1	B1	Consolidated	Mid-Fan, Alluvial Terrace, South
C	G1	78	Shallow	A	3	0	0.40	-	-	Consolidated	Downstream, Active Fan, Center
C	G2	78	Shallow	A	3	0.31	2.42	A4	B3	Consolidated	Downstream, Active Fan, Center
C	G8	69	Shallow	B	4	0.25	1.15	A4	B3	Consolidated	Mid-Fan, Active, South
C	G12	73	Shallow	B	4	0.14	0.64	A4	B3	Consolidated	Mid-Fan, Active, Center
C	G14	47	Shallow	A	4	0.16	1.79	A4	B3	Consolidated	Downstream, Active Fan, North
C	G19	61	Shallow	A	4	0.19	3.52	A4	B3	Consolidated	Mid-Fan, Active, North
D	G9	52	Shallow	A	3	0.16	3.37	A4	B2.3	Semi-consolidated and consolidated	Mid-Fan, Active, North

Hydro-chemical Group	Sample	Well Depth (m) ¹	Well Type	Piper Group	Isotope Group	PO ₄ ³⁻ (ppm)	NO ₃ ⁻ (ppm)	Subset A	Subset B	Hydrogeologic Unit ²	Geography ³
D	G20	47	Shallow	B	3	0.22	0	A4	B2.3	Consolidated	Mid-Fan, Alluvial Terrace, South
D	G22	56	Shallow	C	3	0	0	A1	B2.3	Consolidated	Mid-Fan, Alluvial Terrace, South
D	G23	215	Deep	A	3	0	0	A4	B2.3	Consolidated	Mid-Fan, Alluvial Terrace, South
E	G3	87	Basalt	A	2	0	6.10	A3	B2.2	Basalt Interbed	Up-Stream, Active Fan, North
E	G4	45	Basalt	A	2	0	2.61	A3	B2.2	Basalt Interbed	Up-Stream, Active Fan, Center
E	G5	43	Basalt	A	2	0	7.79	A3	B2.2	Basalt Interbed	Up-Stream, Active Fan, North
E	G6	46	Basalt	A	2	0.25	10.42	A3	B2.2	Basalt Interbed	Up-Stream, Active Fan, North
E	G7	55	Basalt	A	2	0	5.04	A3	B1	Basalt Interbed	Up-Stream, Active Fan, North
F	G24	326	Basalt	D	5	0	0	A2	-	Basalt Interbed	Mid-Fan, Alluvial Terrace, South
F	G25	282	Basalt	D	5	0	0	A2	-	Basalt Interbed	Up-Stream, Alluvial Terrace, South

¹ Shallow wells (0-107 m deep), deep wells (107-244 m deep), and wells drilled into basalt.

² Hydrogeologic unit into which the sampled well was drilled and screened, derived from well logs (Appendix F).

³ Location of samples in the alluvial fan study area (Fig. 27).

Groundwater Level Responses to Management Practices

The hydrology of the Ahtanum drainage is predominantly influenced by seasonal water management practices, particularly the operation of the Bachelor-Hatton Complex headgate, which opens annually on April 15 and closes on July 10, diverting water from Ahtanum Creek for irrigation purposes (Fig. 14). These diversion operations exert strong control over both surface water and groundwater levels within the study area.

Hydrographs from in-stream pressure transducers (ST1 and ST2) show that the closure of the headgate on July 10, 2024, triggered an immediate decline in surface water levels in both Bachelor and Ahtanum Creeks (Fig. 14). In Bachelor Creek, modeled outputs from the HEC-RAS application confirm that the channel ceases in surface flow following the diversion cutoff, with residual flow likely derived from groundwater or minor leakage through the headgate (Table 26). Ahtanum Creek, after the headgate closure on July 10th, receiving redirected flows previously split between channels, showed an increase in surface-water levels after the diversion, followed by a relative stabilization of levels (Fig. 14).

Bachelor Creek remained largely dry until the headgate reopened on April 15, 2025, when surface water levels increased, marking the start of the new irrigation season. This response in levels in Bachelor Creek indicates the immediate influence of diverted surface-water flows on the upstream portion of the active alluvial fan study area. Groundwater levels, derived from pressure transducers installed in two monitoring wells (GWT1 and GWT2), also reflect the influence of the diversion timeframe and related groundwater pumping (Fig. 14).

The well located near the fan apex (GWT1), surrounded by unconsolidated sediments overlying basalt, exhibited the most significant groundwater decline (1.07 m) between June and August 2024, ultimately going dry (Fig. 14). The mid-fan well (GWT2), which is 126 m deep and surrounded by unconsolidated to consolidated basin-fill sediment, showed a more delayed response, with groundwater elevation declining steadily through September and then recharging between late September and early December 2024 (Fig. 14). The continued decline and fluctuations in groundwater elevation in well GWT2 likely represent nearby pumping for irrigation use when surface water is not available. This delayed recharge response, compared to Bachelor Creek (ST1) and the fan apex well (GWT1), likely reflects deeper sedimentary basin-fill pathways that support more consistent, perennial recharge, whereas upstream units near GWT1 rely on intermittent recharge from irrigation diversions into Bachelor Creek (Figs. 13 and 14).

In-stream surface water data from Ahtanum Creek (ST2) showed relatively stable conditions, with only minor fluctuations (Table 10; Fig. 22). Minor declines occurred from June to July and again from August to September 2024, potentially related to redistribution of diverted flows. These were followed by gradual increases into the winter months, likely a function of increase in seasonal precipitation and snowmelt runoff. A similar pattern was observed in Bachelor Creek (ST1), with minimal increase in flow between October and December 2024, likely attributed to groundwater recharge under dry channel conditions.

Collectively, the water-level data highlight the dynamics of surface water and groundwater interactions in response to managed diversion practices. The timing and duration of the Bachelor-Hatton Complex headgate operation control both streamflow and aquifer conditions across the alluvial fan, especially in shallow unconfined aquifers. These findings underscore the need for integrated management practices in the drainage that consider not only surface flow but aquifer recharge and response time during drought-prone periods.

Groundwater Seepage Velocities

Seepage velocities were estimated across the hydrogeologic units in both the upstream and mid-fan sections of the Ahtanum drainage, including the active fan and alluvial terrace (Table 23; Fig.

15). Quantifying seepage velocity provides insight into the hydraulic properties of the sedimentary basin-fill units and helps to assess potential areas for Managed Aquifer Recharge. For this analysis, aquifer units are assumed to behave as continuous, homogeneous porous media, with hydraulic gradient defined as a function of surface topography. These estimates provide a first-order approximation of the ability of an aquifer unit to transmit and store water and do not account for preferential flow paths. As such, they likely provide minimum estimates of seepage velocity.

Hydrochemical Groups A, C, and D show evidence of contributions from older evolved groundwaters and modern surface waters, emphasizing the likelihood of connectivity between unconsolidated, semi-consolidated, and consolidated hydrogeologic units. Hydrochemical signatures suggest that there are interactions between these units through preferential flow paths such as fractures that are not effectively characterized in seepage estimates. Additional uncertainty in the calculated seepage velocities may arise from differing regional estimates of hydraulic conductivity and effective porosity derived from previous investigations, which may not fully represent the nuances and heterogeneity of the hydrogeologic characteristics of units within the Ahtanum Sub-Basin (Golder Associates; Jones et al., 2009; Tables 4 and 5).

Five seepage velocity scenarios were modeled using representative transects (Fig. 14) across the alluvial fan system to evaluate the capability of the distinct hydrogeologic units defined in this study to store and transmit water. These scenarios characterize the relative hydraulic behavior of unconsolidated, semi-consolidated, and consolidated units, offering insight into the spatial variability of groundwater flow and storage potential.

Table 24. Annual seepage velocities for transects across Ahtanum fan shown in Fig. 14.

Hydrogeologic Unit	Seepage Velocity (m/yr)				
	Upper fan, longitudinal (GWT1-GWT-2)	Active fan, longitudinal (A-A')	Alluvial terrace, longitudinal (C-C')	Across southern fan (E-E')	Across northern fan (F-F')
Unconsolidated	4.1	2.4	3.6	N.A.	1.3
Semi-consolidated	0.24	0.12	0.24	0.84	0.1
Consolidated	0.06	0.04	0.05	0.12	0.01

Note: N.A. = not applicable.

Results consistently show that unconsolidated units exhibit the highest seepage velocities across all scenarios (Table 24; Figs. 28 and 29). Consequently, these units are likely to contribute the most to dynamic groundwater flow systems, particularly in proximal and mid-fan regions. However, their high transmissivity implies shorter residence times and reduced potential for long-term water storage.

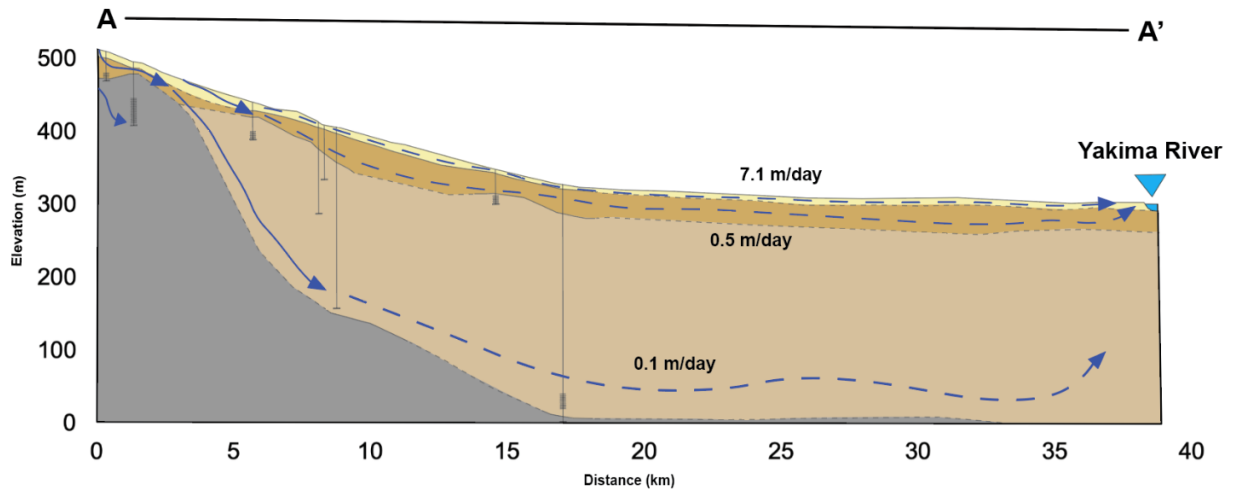


Figure 28. Seepage velocities of hydrogeologic units down the fan. Transect A-A' extends from the apex of Ahtanum alluvial fan to the Yakima River (Figs. 9 and 14). Stratigraphic units are described in Fig. 5. Yellow=unconsolidated alluvium, dark tan=semi-consolidated sediment, light tan=consolidated sediment, gray=basalt.

Semi-consolidated units demonstrate moderate seepage velocities. Their composition, which includes cemented sands and gravels with partial lithification, yields lower permeability compared to unconsolidated materials but still allows for appreciable groundwater movement. These units represent a transitional zone with dual roles: facilitating slower recharge and acting as intermediate-term storage zones, particularly where unconsolidated units are thin or absent.

The consolidated unit of cemented sand, clay, silt, and fine gravels have the slowest seepage velocities. This unit is associated with low permeability, a likely barrier to groundwater flow, suggesting that water entering this unit may remain stored for extended periods. These deeper and occasionally confined aquifers may serve as long-term aquifer storage reservoirs with minimal connectivity to surface processes.

Seepage velocities along transects A and C (Figs. 14 and 28), which follow relatively steep hydraulic gradients, illustrate the direct relationship between gradient and groundwater flow velocity. Even under these conditions, the consolidated units remain the most restrictive to flow. In contrast, seepage velocities along transect E, which includes gently sloping sections of the fan, emphasize the capacity of lower-gradient environments to promote prolonged storage, particularly in semi-consolidated and consolidated units (Figs. 14 and 29).

Collectively, these scenarios underscore the importance of characterizing hydrogeologic units to effectively understand the controls on groundwater flow and evaluating locations suitable for MAR. Unconsolidated units have low groundwater residence times, yielding water at a faster rate

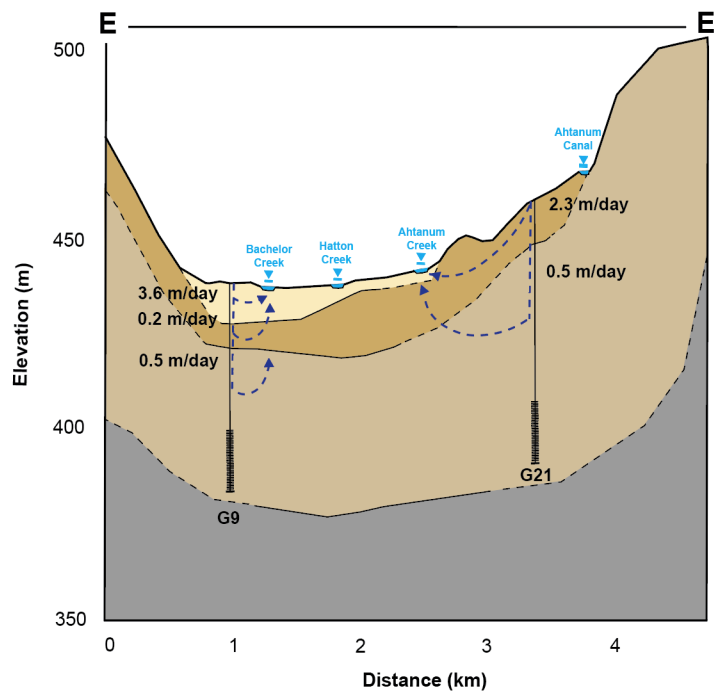


Figure 29. Seepage velocities of hydrogeologic units across the fan. Transect E-E' extends across the southern part of the fan (Figs. 10 and 14). Stratigraphic units are described in Fig. 5. Yellow=unconsolidated alluvium, dark tan=semi-consolidated sediment, light tan=consolidated sediment, gray=basalt.

than the other units. The semi-consolidated and consolidated units have longer residence times, providing opportunities for long-term storage, especially in areas with lower hydraulic gradients, such as the active alluvial fan. The elevated alluvial terrace exhibits steeper hydraulic gradients located within dominantly well-drained soils, posing optimal conditions for groundwater recharge, coupled with deep semi-consolidated and consolidated units exhibiting moderate to long residence times.

Summary of Managed Aquifer Recharge Assessment

The study area includes both the elevated alluvial terrace and the active fan, which display different relationships between hydrochemical groupings and soil drainage characteristics. The alluvial terrace along the southern side of the valley lies at a higher elevation than the active floodplain and streams, and it exhibits a steeper hydraulic gradient. It is largely composed of well-drained soils that would be conducive to infiltration. It is dominated by the semi-consolidated sediment of hydrogeological Unit 2 (Fig. 30) that slows seepage rates and thus could be conducive to longer-term storage. The active fan and floodplain in the lower-elevation central and northern portions of the valley consist of somewhat poorly drained fine sediment at the surface (Fig. 30), with a variety of sedimentary units at different depths. The middle and lower portions of the active fan are not conducive to infiltration and recharge, and thus are not favorable for MAR as has been observed in previous studies (Gibson and Campana, 2018; WA Ecology, 2005). The well-drained gravel and fractured basalt near the fan apex have higher infiltration rates and could have potential for deep penetration of surface water and long-term storage through MAR (Fig. 30).

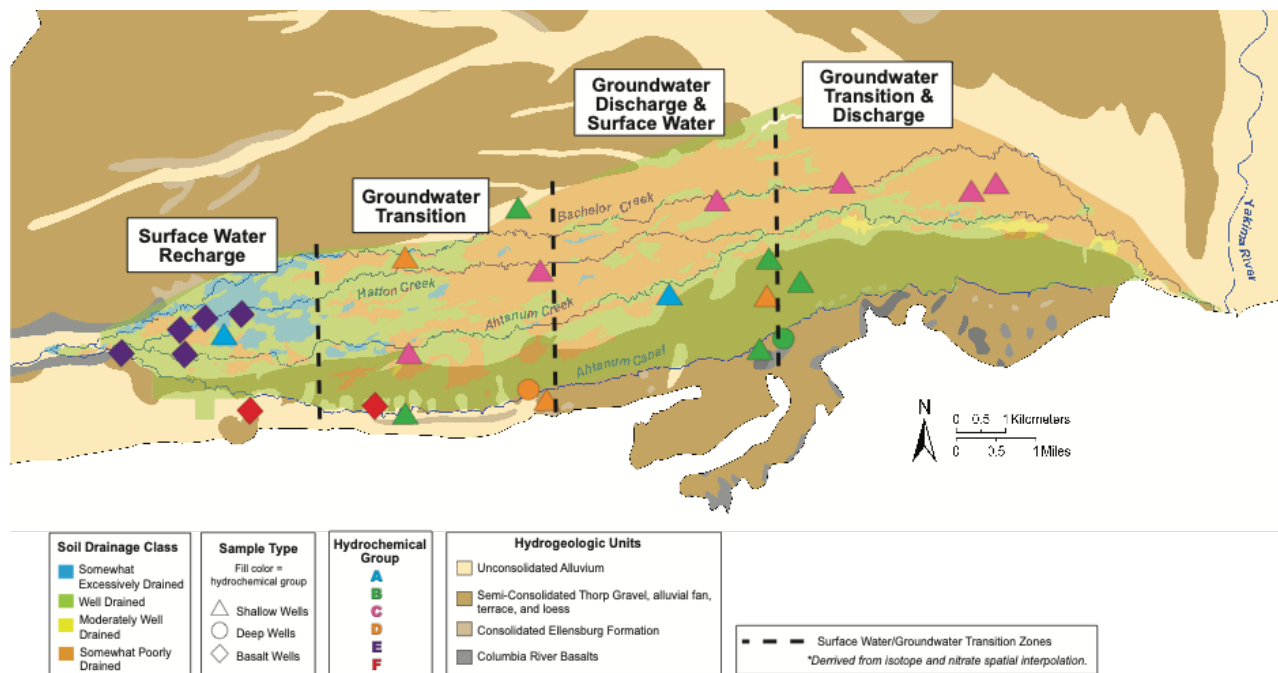


Figure 30. Map of Locations Conducive to Managed Aquifer Recharge. The locations of hydrochemical groups A, B, D and E exhibit the physical and hydrological characteristics most conducive to MAR. Hydrochemical groups C and F show less potential for MAR.

The suitability of each group for MAR is summarized below and in Figure 30:

Group A is associated with unconsolidated to semi-consolidated hydrogeologic units that exhibit high interaction with surface water and are predominantly located within the active floodplain. These units are found in well-drained soils and are characterized by high transmissivity and storativity, making them favorable for transmitting infiltrated water to downgradient aquifers capable of both transmitting and storing water over longer timescales.

- Group B includes semi-consolidated units with moderate to low recharge potential, typically occurring along anticlinal ridges and the alluvial terrace in well-drained soils. These areas exhibit steep hydraulic gradients and may be suitable for moderate infiltration and storage, with the added benefit of potential long-term retention.
- Group C in the active floodplain has a lower potential for recharge and long-term storage because of poorly drained soils and thicker layers of unconsolidated alluvium that could rapidly transmit shallow groundwater the short distances to surface streams.
- Group D is found in consolidated units located on steep slopes of the anticlinal ridges and the alluvial terrace, also under well-drained soil conditions. These units exhibit moderate recharge potential and could transmit water more slowly, supporting long-term storage.
- Group E is located near the fan apex and includes shallow fractured basalt. Geochemical evidence suggests contributions from surface water, and the presence of well-drained soils indicates potential for both short- and long-term recharge. The fractured basalt zones may facilitate broader distribution of infiltrated water throughout the basin.
- Group F is basalt bedrock, with low to no surface-water infiltration.

In summary, hydrochemical groups A, B, D, and E are the most suitable for Managed Aquifer Recharge (Fig. 30). These groups are located on the elevated alluvial terrace on the southern flank of the Ahtanum valley and at the apex of the fan. They exhibit a moderate to high potential for recharge and deep infiltration of surface water, as well as potential for longer-term subsurface storage. Hydrochemical group C in the low-elevation central and northern parts of the alluvial fan is less suitable for MAR due to poor soil drainage, low potential recharge rates, and possibly low storage retention. Group F is the basalt bedrock, which has low recharge potential through passive infiltration and thus low suitability for MAR.

CONCLUSIONS

Alluvial fans show potential for recharge and storage of water in shallow aquifers, due to their relatively permeable sediment, adequate infiltration rates, and accessible source of surface water. Investigating the most promising locations for Managed Aquifer Recharge (MAR) requires a wholistic assessment of shallow sedimentary basin-fill aquifer characteristics and associated capabilities to recharge, store and transmit water.

This study provides a recommendation for optional locations for on the Ahtanum alluvial fan in the Yakima River basin through an analysis of (1) the seasonal variations in the amount and distribution of surface water to the alluvial fan, (2) the hydrogeologic properties of alluvial fan sedimentary basin-fill aquifers and soils in the lower Ahtanum valley to assess their capacity for infiltration, transmission and storage, and (3) the water chemistry to quantify infiltration and mixing of surface water and groundwater.

Seasonal variations in surface water and groundwater elevation reveal that recharge of the sedimentary basin-fill aquifers on the alluvial fan of the lower Ahtanum fan is largely driven by surface water irrigation, which diverts flows into Bachelor Creek, facilitating aquifer recharge from April 15th to July 10th since 2019. Ahtanum Creek and wells in the mid-fan area also receive recharge from seasonal runoff, beginning around November.

The primary aquifer hydrogeologic units properties were derived from previous literature (Foxworthy, 1962; Vaccaro et al, 2009), yielding four units: (1) unconsolidated alluvium, (2) semi-consolidated Thorp Gravels, alluvial fan, terrace and loess deposits, (3) consolidated continental sediments exhibiting characteristics associated with the Ellensburg Formation, and (4) impermeable and fractured basalt aquifer units. These stratigraphic units were correlated throughout the subsurface of the alluvial fan using well logs.

Geochemical analysis of stable isotopes and major ions was used to create six hydrochemical groups based on the interaction between surface water and groundwater in the four hydrogeologic units. The hydrochemical groups results are (A) unconsolidated and semi-consolidated units exhibiting high flux with surface waters, (B) semi-consolidated units with moderate to low surface water recharge, (C) consolidated units with low recharge from irrigation surface water, (D) consolidated units exhibiting moderate recharge from both surface water and more evolved groundwaters, (E) shallow consolidated sedimentary fractured basalt interbeds exhibiting high surface water recharge, and lastly (F) deep basalt aquifer confined sedimentary interbeds with minimal interactions with modern surface waters.

When paired with soil infiltration data and calculated estimates of groundwater seepage velocities, we conclude that the portions of the Ahtanum alluvial fan represented by hydrochemical groups A, B, D, and possibly E, exhibit combination of moderate to high surface-water infiltration and potential for long-term storage that would be optimal for Managed Aquifer Recharge. These groups are mainly located on the elevated alluvial terrace along the southern boundary of the alluvial fan, on the northern edge of the upper and middle fan, and in the gravel and fractured basalt near the fan apex. Regions represented by hydrochemical Groups C and F in the floodplain of the active alluvial fan and the bedrock basalt exhibit low infiltration rates and are not as readily suitable for MAR.

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APPENDIX A. Imperial Units Data Tables

Table A1. Summary of catalogued well characteristics (ft).

Rating	Depth	Unit Contacts	Year of Drilling
1	n.r.	poor	<1990
2	< 560 m (1840 ft)	somewhat detailed	1990-2000
3	< 609 m (2000 ft)	detailed	>2000

Note: N.R. = not recorded.

Table A2. Stabilization criteria for well purging (°F).

Parameter	Stabilization Criteria
Temperature	±0.1°C (32°F)
pH	±0.1°C (32°F) standard units
Specific conductance	±10 µohms/cm for values < 1000 µohms/cm ±20 µohms/cm for values > 1000 µohms/cm
Dissolved oxygen	±0.1 mg/L for values < 1.0 mg/L ±0.2 mg/L for values > 1.0 mg/L

Table A3. Summary of previous estimates for horizontal hydraulic conductivity (ft).

Unit	Minimum (m/sec)	Mean (m/sec)	Max (m/sec)	Model Derived (m/sec)	Source
Alluvium	-	-	-	87 (284 ft/day)	Golder Associated, 2002 & Ecology, 2008
Alluvium, unconsolidated	204 (668 ft/day)	4 (13 ft/day)	245 (803 ft/day)	-	Foxworthy, 1962
Alluvium, Ellensburg Formation (upper)	-	-	-	23 (75 ft/day)	Golder Associated, 2002 & Ecology, 2008
Ellensburg Formation (upper)	-	-	-	2.3 (7.5 ft/day)	Ecology, 2008
Ellensburg Formation (middle)	0.2 (0.6 ft/day)	4 (13 ft/day)	690 (2265 ft/day)	-	Golder Associates, 2002
Ellensburg Formation (middle)	-	-	-	0.02 (0.05 ft/day)	Ecology, 2008
Ellensburg Formation (lower)	-	-	-	0.001 (0.002 ft/day)	Golder Associates, 2002
-	12 (38 ft/day)	18.2 (60 ft/day)	29.2 (96 ft/day)	-	Golder Associates, 2002
-	-	-	-	2.4 (8 ft/day)	Golder Associates, 2002
-	-	-	-	0.3 (0.1 ft/day)	Golder Associates, 2002
Ellensburg Formation (lower)	-	-	-	0.003 (0.01 ft/day)	Golder Associates, 2002
-	-	-	-	2.3 (7.5 ft/day)	Ecology, 2008
-	-	-	-	0.03 (0.1 ft/day)	Ecology, 2008
-	-	-	-	0.01 (0.03 ft/day)	Ecology, 2008

Table A4. Estimates of effective porosity and hydraulic conductivity of hydrogeologic units (ft).

Unit	Description	Effective Porosity	Hydraulic Conductivity (ft/day)
Unit 1: Unconsolidated alluvium (USGS, 2009)	Sorted and unsorted gravel, sand, silt, semi consolidated silt and clay (Foxworthy, 1964)	0.3	802
Unit 2: Semi-consolidated Thorp Gravel, alluvial fan, terrace, and loess (USGS, 2009)	75% gravel and 25% sand. (Foxworthy, 1964)	0.1	75
Unit 3: Consolidated Ellensburg formation and undefined continental sediments (USGS, 2009)	85% to 95% semi consolidated clay, silt, sand, and 15% gravel. (Foxworthy, 1964)	0.2	7.5

Table A5. Alluvial fan maximum depth of hydrogeologic unit (ft).

Hydrogeologic Unit	Upper Fan	Mid-Fan	Lower Fan
Unit 1: Unconsolidated	37 m (121 ft)	11 m (36 ft)	2 m (6.6 ft)
Unit 2: Semi-consolidated	38 m (125 ft)	61 m (200 ft)	166 m (381 ft)
Unit 3: Consolidated	39 m (128 ft)	254 m (833 ft)	250 m (820 ft)
Unit 4: Basalt	282 m (925 ft)	326 m (1070 ft)	330 m (1082 ft)

Table A6. Maximum depth to hydrogeologic unit for west-east trending transect (ft).

Transect	Unit 1: Unconsolidated	Unit 2: Semi-consolidated	Unit 3: Consolidated	Unit 4: Basalt
A-A'	11m (35ft)	61 m (200 ft)	254 m (833 ft)	330 m (1082 ft)
B-B'	11m (35ft)	43 m (140 ft)	157 m (516 ft)	91 m (1082 ft)
C-C'	2 m (7ft)	116m (821 ft)	250 m (821 ft)	326 m (1069.5ft)

Table A7. Maximum depth to hydrogeologic units for north-south trending transect (ft).

Transect	Unit 1: Unconsolidated	Unit 2: Semi-consolidated	Unit 3: Consolidated	Unit 4: Basalt
D-D'	27 m (90 ft)	27 m (90 ft)	39 m (127 ft)	282 m (925 ft)
E-E'	11 m (35 ft)	55 m (179 ft)	68 m (223 ft)	67 m (221 m)
F-F'	5 m (15 ft)	61 m (200 ft)	76 m (250 ft)	N.D.
G-G'	29m (95 ft)	75 m (247 ft) _	98 m (332 ft)	N.D.

Note: N.D. – not detected

Table A8. Summary of changes in surface water elevation from starting date (ft).

	ST1 (Bachelor Creek)				ST2 (Ahtanum Creek)			
	Surface Water Elevation		Change From Start		Surface Water Elevation		Change From Start	
Date	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
6/2024	513.18	1683.75	0.00	0.00	513.68	1685.37	-0.02	-0.05
7/2024	512.96	1683.04	-0.21	-0.70	513.64	1685.25	-0.05	-0.16
8/2024	512.87	1682.73	-0.31	-1.01	513.65	1685.28	-0.05	-0.15
9/2024	512.87	1682.72	-0.31	-1.02	513.62	1685.20	-0.07	-0.23
10/2024	512.86	1682.69	-0.32	-1.06	513.63	1685.23	-0.06	-0.20
11/2024	512.90	1682.83	-0.28	-0.92	513.67	1685.36	-0.02	-0.07
12/2024	512.93	1682.91	-0.25	-0.83	513.70	1685.44	0.00	0.02
1/2025	512.93	1682.91	-0.25	-0.83	-	-	-	-
2/2025	512.91	1682.86	-0.27	-0.89	-	-	-	-
3/2025	512.92	1682.90	-0.26	-0.84	-	-	-	-
4/2025	512.99	1683.11	-0.22	-0.72	-	-	-	-

Table A9. Summary of changes in groundwater elevation from starting date (ft).

	GWT1 (Fan Apex)				GWT2 (Mid-Fan)			
	Groundwater Elevation		Change From Start		Groundwater Elevation		Change From Start	
Date	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
6/2024	490.52	1609.40	0.05	0.18	391.14	1283.32	-0.15	-0.51
7/2024	490.34	1608.79	-0.13	-0.42	389.58	1278.20	-1.72	-5.63
8/2024	489.45	1605.90	-1.01	-3.32	387.61	1271.75	-3.68	-12.08
9/2024	489.45	1605.89	-1.02	-3.33	387.25	1270.56	-4.04	-13.27
10/2024	489.44	1605.86	-1.02	-3.36	388.02	1273.09	-3.27	-10.74
11/2024	489.44	1605.85	-1.03	-3.37	390.30	1280.59	-0.99	-3.24
12/2024	489.44	1605.84	-1.03	-3.37	392.11	1286.50	0.81	2.67
1/2025	489.44	1605.84	-1.03	-3.37	392.94	1289.24	1.65	5.41
2/2025	489.44	1605.84	-1.03	-3.38	393.60	1291.39	2.30	7.56
3/2025	489.44	1605.86	-1.02	-3.36	394.00	1292.71	2.71	8.88
4/2025	489.44	1605.87	-1.02	-3.35	394.05	1292.88	2.76	9.05

Table A10. HEC-RAS modeled discharge and change in elevation (ft) for Bachelor Creek.

Cross-Section	Month	Discharge (cfs)	WSE (ft)
Cross-Section 1	June	42.38	1680.30
	August	15.19	1679.74
	October	12.36	1679.68
Cross-Section 2	June	42.38	1680.73
	August	15.19	1680.13
	October	12.36	1680.07
Cross-Section 3	June	42.38	1681.35
	August	15.19	1680.92
	October	12.36	1680.89

Table A11. Summary of seepage velocity values (ft) for Scenario 1.

Unit	Hydraulic Gradient (ft) ($\Delta h/\Delta l$)	Hydraulic Conductivity (ft/day)	Effective Porosity	Seepage Velocity (ft/day)	Distance in a month (ft)	Distance in a month (miles)
Unit one: Unconsolidated	0.0138	802	0.3	37	1109	0.2
Unit two: Semi-Consolidated	0.0138	75	0.4	3	78	0.01
Unit three: Consolidated	0.0138	7.5	0.2	1	16	0.003

Table A12. . Summary of seepage velocity values (ft) for Scenario 2.

Unit	Hydraulic Gradient (ft) ($\Delta h/\Delta l$)	Hydraulic Conductivity (ft/day)	Effective Porosity	Seepage Velocity (ft/day)	Distance in a month (ft)	Distance in a month (miles)
Unit 1: Unconsolidated	0.0087	802	0.3	23	698	0.1
Unit 2: Semi-consolidated	0.0087	75	0.4	2	49	0.01
Unit 3: Consolidated	0.0087	7.5	0.2	0.3	10	0.002

Table A13. Summary of seepage velocity values (ft) for Scenario 3.

Unit	Hydraulic Gradient (ft) ($\Delta h/\Delta l$)	Hydraulic Conductivity (ft/day)	Effective Porosity	Seepage Velocity (ft/day)	Distance in a month (ft)	Distance in a month (miles)
Unit 1: Unconsolidated	0.0105	802	0.3	28	839	0.2
Unit 2: Semi-consolidated	0.0105	75	0.4	2	59	0.01
Unit 3: Consolidated	0.0105	7.5	0.2	0.4	12	0.002

Table A14. Summary of seepage velocity values (ft) for Scenario 4.

Unit	Hydraulic Gradient (ft) ($\Delta h/\Delta l$)	Hydraulic Conductivity (ft/day)	Effective Porosity	Seepage Velocity (ft/day)	Distance in a month (ft)	Distance in a month (miles)
Unit 2: Semi-consolidated	0.03 (0.03 ft)	75	0.4	7.7	231.2	0.04
Unit 3: Consolidated	0.03(0.03 ft)	7.5	0.2	1.5	46.3	0.01

Table A15. Summary of seepage velocity values (ft) for Scenario 5.

Unit	Hydraulic Gradient (ft) ($\Delta h/\Delta l$)	Hydraulic Conductivity (ft/day)	Effective Porosity	Seepage Velocity (ft/day)	Distance in a month (ft)	Distance in a month (miles)
Unit 1: Unconsolidated	0.004	244.4	0.3	11.7	350.2	0.07
Unit 2: Semi-consolidated	0.004	22.9	0.4	0.8	24.6	0.005
Unit 3: Consolidated	0.004	2.3	0.2	0.2	4.9	0.001

Table A16. Cataloged well characteristics (imperial and metric units).

ID	Depth (m)	Depth (ft)	SWL (m)	SWL (ft)	Well Type	Unit	Drill Date	Sample/Deployment Date
G1	78	257	5	15	Shallow	SC	2016	7/2/24
G2	78	257	5	15	Shallow	SC	2016	7/2/24
G3	87	285	25	82	Basalt	BI	2016	7/2/24
G4	45	147	29	94	Basalt	BI	2021	7/2/24
G5	43	140	5	16	Basalt	BI	1989	7/17/24
G6	46	152	6	19	Basalt	BI	1993	7/17/24
G7	119	390	72	235	Basalt	BI	2023	7/17/24
G8	69	227	27	90	Basalt	C	1994	7/17/24
G9	52	170	23	75	Shallow	C	1995	7/17/24
G10	91	298	35	115	Shallow	C	2016	7/23/24
G11	38	125	9	29	Shallow	C	2014	7/23/24
G12	73	239	26	85	Shallow	C	2014	7/23/24
G13	76	250	40	130	Shallow	SC	2013	7/24/24
G14	47	155	17	56	Shallow	C	2012	7/24/24
G15	52	172	18	59	Shallow	C	2001	7/24/24
G16	39	129	25	82	Shallow	SC	1977	7/31/24
G17	154	505	76	250	Deep	C	2007	7/31/24
G18	26	85	4	13	Shallow	SC	2007	7/31/24
G19	61	200	8	25	Shallow	C	2017	7/31/24
G20	47	153	14	46	Shallow	SC	2002	7/31/24
G21	68	223	41	135	Shallow	C	2017	7/31/24
G22	56	185	34	113	Shallow	C	2006	8/7/24
G23	215	705	12	39	Deep	SC	1957	8/7/24
G24	326	1069	281	922	Basalt	BI	1973	8/7/24
G25	282	925	72	235	Basalt	BI	1985	8/7/24
GWT1	30	100	18	60	Basalt	BI	2009	6/4/24
GWT2	126	415	34	110	Shallow	SC	1978	6/4/24

APPENDIX B. Supplemental Stratigraphic Descriptions

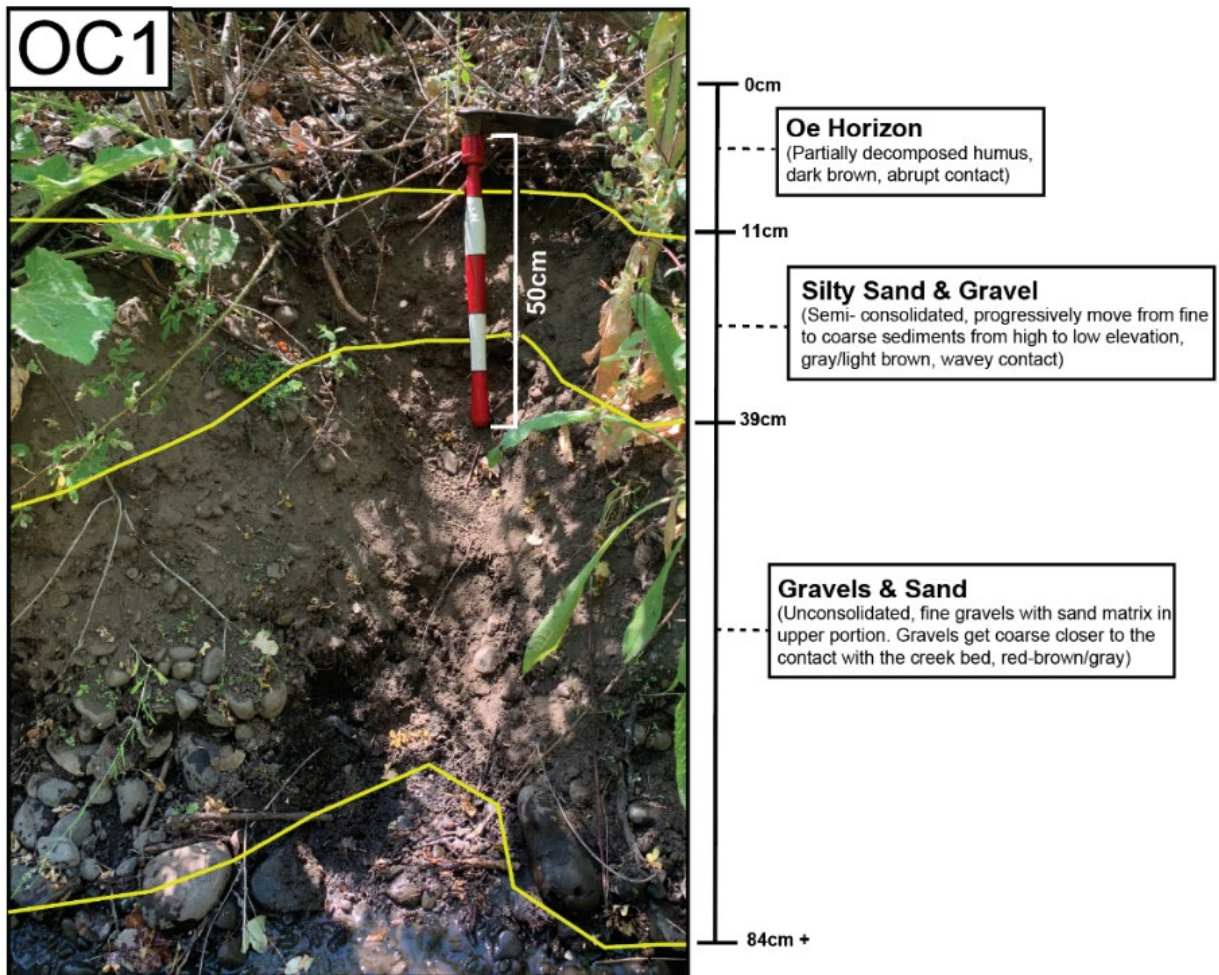


Figure B1. Bachelor Creek streambank stratigraphic description.

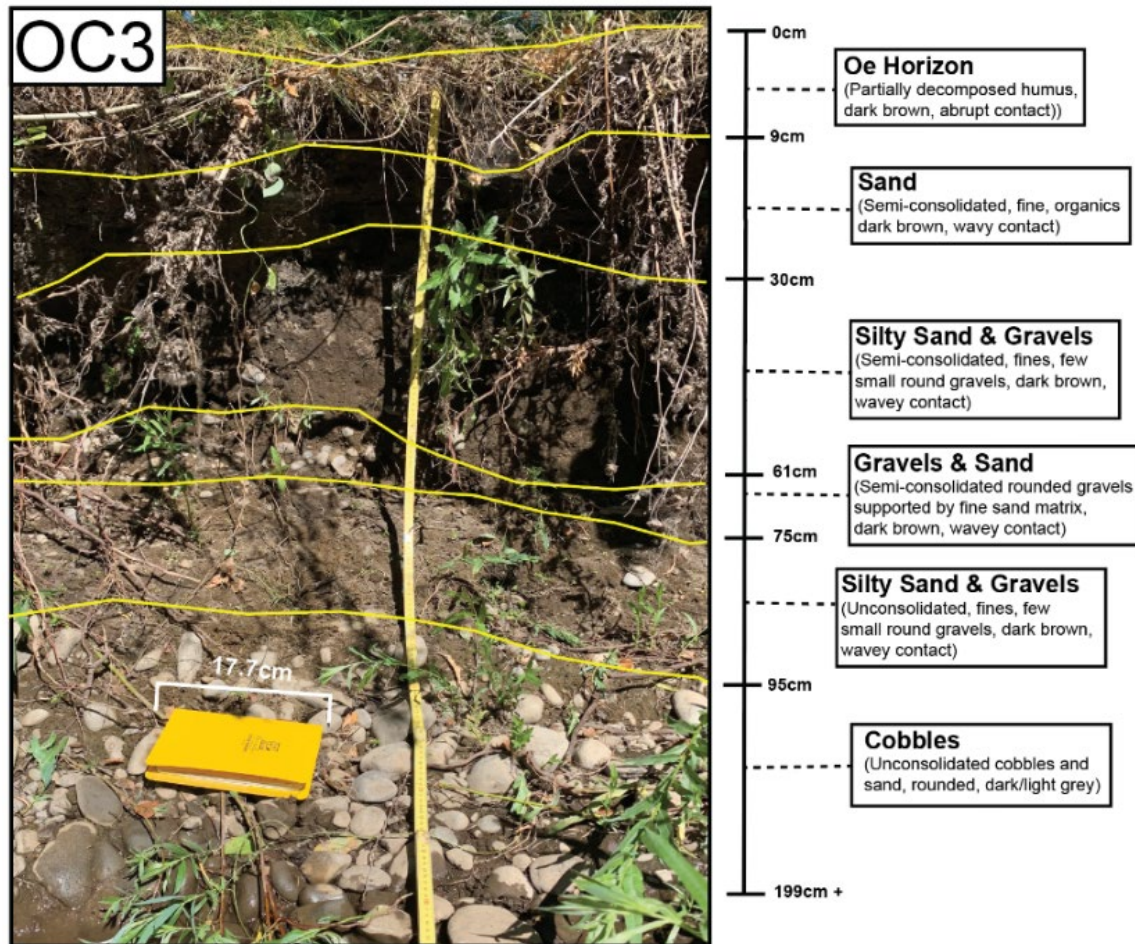


Figure B2. Mid-fan Ahtanum Creek streambank stratigraphic description.

APPENDIX C. Supplemental Major Ion Data

Table C1. Major ion charge balance.

Note: % CBE = Charge balance error percentage.

	Na	K	Ca	Mg	Cation Total	F	Cl	SO ₄	NO ₂	PO ₄	HCO ₃	Cation- Anion	
Sample	meq/L	meq/ L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/ L	meq/L	meq/L	% CBE
G1	0.35	0.09	0.76	0.75	1.94	0.02	0.07	1.84	0.08	0.00	1.52	-1.60	-29.13
G2	0.29	0.08	0.66	0.65	1.68	0.01	0.09	0.12	0.08	0.01	1.45	-0.12	-3.54
G3	0.46	0.09	0.86	0.80	2.21	0.01	0.06	0.13	0.09	0.00	1.92	-0.10	-2.22
G4	0.46	0.09	0.81	0.80	2.17	0.01	0.06	0.08	0.09	0.00	2.00	-0.11	-2.56
G5	0.38	0.08	0.83	0.85	2.15	0.02	0.22	0.14	0.10	0.00	1.99	-0.44	-9.31
G6	0.31	0.08	0.79	0.79	1.97	0.01	0.06	0.13	0.09	0.01	1.55	-0.05	-1.17
G7	0.61	0.10	1.53	1.06	3.30	0.01	0.17	0.22	0.08	0.00	1.54	1.20	22.15
G8	0.20	0.06	0.46	0.40	1.12	0.02	0.05	0.07	0.06	0.01	1.01	-0.11	-4.87
G9	0.29	0.07	0.57	0.58	1.51	0.01	0.04	0.06	0.08	0.01	1.43	-0.17	-5.43
G10	0.58	0.16	1.33	1.11	3.17	0.01	0.10	0.13	0.11	0.00	3.00	-0.26	-3.88
G11	0.55	0.10	0.85	0.86	2.35	0.02	0.08	0.15	0.09	0.00	2.43	-0.50	-9.64
G12	0.25	0.06	0.62	0.56	1.50	0.01	0.03	0.04	0.08	0.00	1.50	-0.17	-5.27
G13	0.43	0.09	0.96	0.94	2.42	0.01	0.22	0.27	0.08	0.00	1.98	-0.32	-6.20
G14	0.30	0.08	0.67	0.66	1.71	0.01	0.04	0.05	0.08	0.00	1.78	-0.28	-7.53
G15	0.46	0.12	2.10	1.85	4.53	0.01	0.25	0.44	0.12	0.00	4.00	-0.56	-5.78
G16	0.48	0.08	1.57	1.49	3.61	0.01	0.25	0.39	0.11	0.00	3.00	-0.30	-4.02
G17	0.50	0.08	1.05	1.01	2.63	0.02	0.10	0.20	0.10	0.00	2.97	-0.85	-13.86
G18	0.51	0.08	1.12	1.02	2.73	0.02	0.10	0.19	0.09	0.00	2.47	-0.25	-4.40
G19	0.29	0.07	0.69	0.67	1.73	0.01	0.11	0.15	0.08	0.01	1.54	-0.22	-6.05
G20	0.42	0.06	0.74	0.73	1.94	0.02	0.06	0.10	0.08	0.01	1.85	-0.17	-4.08
G21	0.53	0.07	1.60	1.49	3.68	0.01	0.11	0.34	0.11	0.00	3.06	-0.17	-2.19
G22	0.51	0.08	1.75	1.63	3.97	0.01	0.11	0.22	0.12	0.00	3.58	-0.08	-0.97
G23	0.33	0.08	0.52	0.47	1.40	0.01	0.03	0.04	0.07	0.00	1.11	0.14	5.40
G24	1.01	0.11	0.62	0.31	2.05	0.04	0.09	0.06	0.08	0.00	2.02	-0.23	-5.32
G25	1.22	0.10	0.44	0.30	2.06	0.05	0.05	0.01	0.09	0.00	2.03	-0.17	-3.90
BC1	0.17	0.07	0.37	0.28	0.89	0.01	0.03	0.03	0.05	0.00	0.80	-0.03	-1.79
AC2	0.17	0.06	0.36	0.27	0.86	0.01	0.02	0.03	0.05	0.00	0.78	-0.03	-1.85

	Na	K	Ca	Mg	Cation Total	F	Cl	SO ₄	NO ₂	PO ₄	HCO ₃	Cation- Anion	
Sample	meq/L	meq/ L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/ L	meq/L	meq/L	% CBE
AC3	0.20	0.07	0.41	0.32	1.00	0.01	0.02	0.03	0.05	0.00	1.06	-0.18	-8.08
YR4	0.19	0.03	0.43	0.31	0.96	0.00	0.09	0.07	0.06	0.00	0.86	-0.12	-5.92
AC5	0.26	0.07	0.47	0.38	1.18	0.01	0.02	0.05	0.06	0.00	1.22	-0.17	-6.89
BC6	0.28	0.08	0.65	0.57	1.58	0.01	0.14	0.27	0.05	0.03	1.32	-0.29	-8.44
AC7	0.31	0.07	0.65	0.57	1.61	0.00	0.15	0.13	0.08	0.00	1.44	-0.19	-5.58
AC8	0.22	0.05	0.42	0.36	1.06	0.00	0.01	0.01	0.02	0.00	0.99	0.02	0.77

APPENDIX D. Supplemental Principal Component Analyses

Table D1. Subset C and D eigenvalues and loadings.

	C1	C2	C3	D1	D2	D3	D4	D5
Eigen Values	5.40	2.26	0.85	5.83	3.68	1.61	1.31	0.74
Variance (%)	54.01	22.60	8.59	38.85	24.56	10.73	8.72	4.96
Ca ²⁺	0.95	-0.12	-0.01	0.95	0.11	0.00	-0.05	-0.05
Mg ²⁺	0.94	-0.21	0.06	0.95	0.20	-0.07	-0.01	-0.03
Na ⁺	0.37	0.90	0.05	0.36	-0.87	0.22	-0.05	-0.02
K ⁺	0.53	0.56	0.00	0.53	-0.40	0.19	-0.54	-0.07
Cl ⁻	0.83	-0.13	0.04	0.82	0.05	0.06	0.22	-0.05
SO ₄ ²⁻	0.93	-0.27	0.08	0.93	0.21	-0.04	0.22	-0.01
HCO ₃ ⁻	0.90	0.16	0.03	0.90	-0.10	0.07	-0.03	-0.09
F ⁻	-0.04	0.91	0.31	-0.03	-0.93	0.01	0.08	0.00
NO ₃ ⁻	0.81	-0.26	0.19	0.81	0.22	-0.06	0.20	-0.02
PO ₄ ³⁻	-0.41	-0.30	0.84	-0.33	0.13	-0.86	-0.03	0.13
δ ¹⁸ O	-	-	-	-0.08	0.81	0.41	-0.33	0.005
δD	-	-	-	-0.20	0.84	0.34	-0.29	0.01
EC	-	-	-	0.55	-0.01	-0.14	-0.28	0.77
DO	-	-	-	0.06	0.48	0.11	0.71	0.14
H ⁺	-	-	-	-0.38	-0.38	0.68	0.31	0.32

Table D2. Subset C and D sample scores.

Subset C				Subset D					
Sample	C1	C2	C3	Sample	D1	D2	D3	D4	D5
G1	-1.29	-0.96	2.08	G1	-0.28	0.31	-2.94	-0.92	2.76
G2	0.17	0.30	-0.50	G2	0.36	-0.25	0.95	-0.87	1.91
G3	-0.29	0.60	-0.65	G3	-0.09	-0.19	1.17	-0.71	2.09
G4	1.13	-0.08	-0.19	G4	0.90	0.24	0.90	0.12	-0.28
G5	-0.37	-0.93	1.97	G5	-0.27	1.44	-1.53	-0.05	-0.16
G6	1.87	0.09	-0.49	G6	2.04	-1.07	-0.08	-1.24	0.12
G7	-2.55	-0.82	1.47	G7	-2.43	0.05	-2.36	-0.08	-0.77
G8	-1.67	-0.35	0.74	G8	-1.53	0.38	-1.40	-0.20	-0.62
G9	2.23	1.47	-0.58	G9	2.35	0.10	0.62	-3.28	-1.02
G10	0.69	0.87	-0.41	G10	0.57	-0.05	0.70	-2.02	-0.95
G11	-2.07	-0.83	0.18	G11	-2.02	0.01	-1.41	-0.54	-0.76
G12	2.25	-0.59	-0.15	G12	2.18	0.38	0.38	1.14	-0.35
G13	-1.47	-0.44	0.56	G13	-1.36	-0.09	-1.55	-0.72	-0.78
G14	6.60	-0.95	0.40	G14	6.75	1.26	0.12	-0.04	-0.17
G15	4.11	-1.05	0.02	G15	4.10	0.67	0.23	1.53	-0.01
G16	1.44	0.22	-0.25	G16	1.43	-0.26	0.41	1.65	0.00
G17	1.37	0.28	-0.19	G17	1.44	-0.47	0.07	2.17	0.01
G18	-0.75	-0.93	1.03	G18	-0.79	0.06	-1.20	1.26	-0.10
G19	-1.36	-0.08	1.40	G19	-1.25	0.20	-1.50	0.77	-0.25
G20	3.44	-1.10	-0.03	G20	3.63	1.12	-0.40	0.90	-0.20
G21	2.66	-0.13	-0.61	G21	2.81	0.42	0.12	-0.68	-0.08
G22	-1.94	0.14	-1.06	G22	-2.04	-0.18	0.19	-0.64	-0.84
G23	-0.45	4.09	0.07	G23	-0.67	-5.35	1.04	0.39	0.02
G24	-0.98	5.70	0.65	G24	-1.12	-7.30	0.66	0.26	-0.10
G25	-2.62	-0.80	-1.33	G25	-2.77	1.37	0.73	0.02	-0.09
BC1	-3.00	-0.89	-0.19	BC1	-3.11	1.19	0.29	0.18	0.82
AC2	-2.48	-0.71	-1.32	AC2	-2.97	1.16	1.57	0.75	-0.08
AC3	-2.51	-1.65	-1.33	AC3	-2.94	1.84	1.12	1.55	-0.21
YR4	-2.17	-0.49	-1.29	YR4	-2.91	3.03	3.11	-0.69	0.06
AC5	-1.29	-0.96	2.08	AC5	-0.28	0.31	-2.94	-0.92	2.76
BC6	0.17	0.30	-0.50	BC6	0.36	-0.25	0.95	-0.87	1.91
BC7	-0.29	0.60	-0.65	BC7	-0.09	-0.19	1.17	-0.71	2.09
AC8	1.13	-0.08	-0.19	AC8	0.90	0.24	0.90	0.12	-0.28

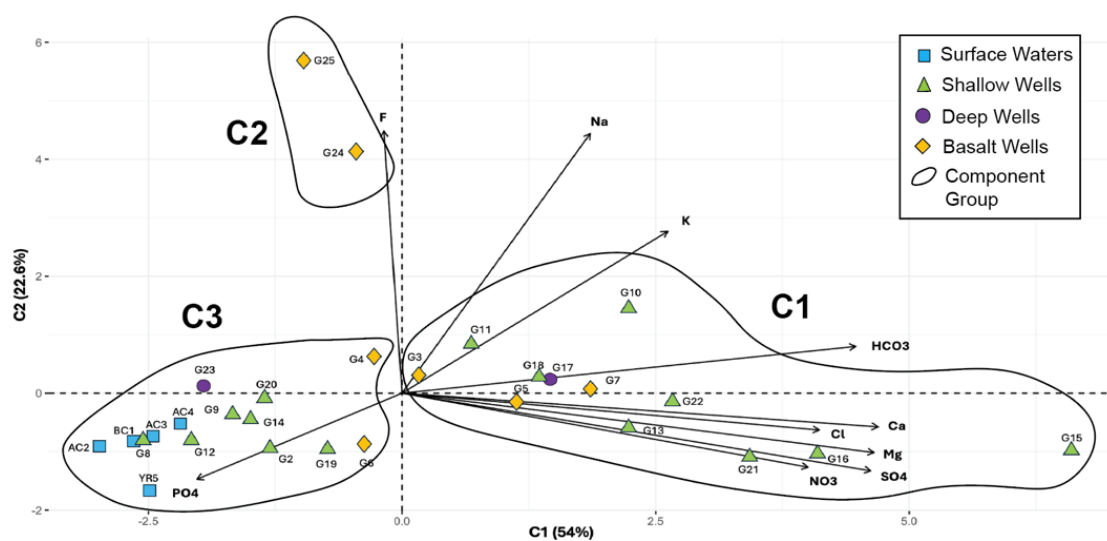


Figure D1. Principal Component Subset C Plot.

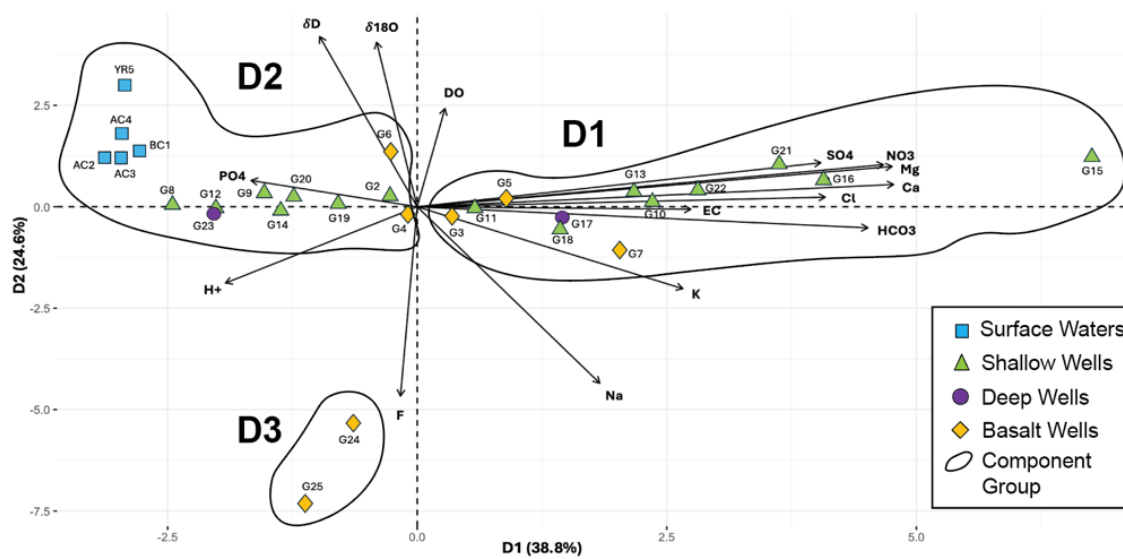


Figure D2. Principal Component Subset D Plot.

APPENDIX E. Supplemental Hydrochemical Group Data

Table E1. Detailed hydrochemical group parameters

Group	Description	PCA Variance	PCA Loadings	PCA Subset	Stable Isotope Group	Piper Group	Samples	Outliers
B	Semi-consolidated gravels, high surface water, likely irrigation influence	NO ₃ : 0.72, Isotopes: 0.53	High HCO ₃ , SO ₄ , Cl, Na, Mg	Subset B1 (51.5% variance), correlates w/ Subset A	Group 3 & 4, mix w/ Group E	Groups A, B, C; Na-K-HCO ₃ type	6 shallow (G22, 18, 16, 13, 21, 15), 1 deep (G17)	G22: no NO ₃ , possibly not irrigated; G15: highest NO ₃ (16.88 ppm), light isotopes
A	Unconsolidated units, high recharge, basalt signatures	Isotopes: 1.75	Moderate NO ₃ , SO ₄ , Mg, Cl, F; High HCO ₃ , Na, K, Ca; no PO ₄	Subgroup B2.1, from A1 & A2	Group 1 (isotopically heavy)	Closest to SW (BC1, AC2, AC3, AC5); mixed ionic	2 shallow (G10, G11), 5 SW (BC1, AC2, AC3, BC6, BC7)	None
E	Basalt units, high surface water recharge	Isotopes: 1.75	High Na, K; low HCO ₃	Subgroup B2.2	Group 2 (isotopically heavy)	Group A (Na-K-HCO ₃ type)	5 basalt (G3, G4, G5, G6, G7)	G6: high NO ₃ , PO ₄ ; light isotopes; lower HCO ₃
D	Consolidated units; mix of basalt & basin-fill recharge	Isotopes: 1.75	High Na, K; low HCO ₃	Subgroup B2.3	Group 3 (isotopically moderate)	Groups B & C (Na-K-HCO ₃ type)	3 shallow (G9, G20, G22), 1 deep (G23)	G23: deep, no NO ₃ /PO ₄ ; G22: overlaps with Group A, but likely not irrigated
C	Semi-consolidated; moderate surface water, likely irrigation	PO ₄ : 0.47 NO ₃ : 0.33 Isotopes: 0.44	Moderate SO ₄ , Cl, K, Mg	Negative correlation to B2	Group 4 (lighter isotopes, low recharge)	Groups A & B (moderate Na-K-HCO ₃)	6 shallow (G2, G1, G8, G12, G14, G19)	G1: high SO ₄ (88.31 ppm), likely sampling contamination
F	Deep confined basalt, minimal surface water interaction	PO ₄ : -0.56, Isotopes: -1.26, NO ₃ : 0.1	High Ca, Na, HCO ₃	Group A2 from Subset A	Group 5 (very light isotopes)	Group D (Ca-Mg-HCO ₃ type)	2 basalt (G24, G25)	G25: shallower, lighter isotope signal

APPENDIX F. Well logs for sampled wells and stratigraphic cross sections

The following pages contain copies of the original well logs for wells used to create the stratigraphic cross sections and collect water samples analyzed for stable isotopes and major ion geochemistry. See Table 6 for summary of well characteristics and Figure 4 for mapped locations of wells. The well ID numbers used in this study (e.g. G1, G2, etc.) are written at the top of each well log in this appendix. Well logs were obtained from the Washington Department of Ecology Well Construction and Licensing Map at <https://ecology.wa.gov/regulations-permits/guidance-technical-assistance/well-report-gateway>



DEPARTMENT OF
ECOLOGY
State of Washington

WATER WELL REPORT

Original & 1st copy - Ecology, 2nd copy - owner, 3rd copy - driller

Construction/Decommission ("x" in circle)

☒ Construction

☐ Decommission *ORIGINAL INSTALLATION*

Notice of Intent Number

PROPOSED USE: ☐ Domestic ☐ Industrial ☐ Municipal
☐ DeWater ☒ Irrigation ☐ Test Well ☐ Other

TYPE OF WORK: Owner's number of well (if more than one) _____

☒ New well ☐ Reconditioned Method: ☐ Dug ☐ Bored ☐ Driven
☐ Deepened ☐ Cable ☒ Rotary ☐ Jetted

DIMENSIONS: Diameter of well 8 inches, drilled 257 ft.

Depth of completed well 257 ft.

CONSTRUCTION DETAILS

Casing ☒ Welded 8 " Diam. from +2 ft. to 244 ft.

Installed: ☐ Liner installed _____ " Diam. from _____ ft. to _____ ft.

☐ Threaded _____ " Diam. From _____ ft. to _____ ft.

Perforations: ☐ Yes ☒ No

Type of perforator used _____

SIZE of perfs _____ in. by _____ in. and no. of perfs _____ from _____ ft. to _____ ft.

Screens: ☒ Yes ☐ No ☒ K-Pac Location 241

Manufacturer's Name Allow Machine & Johnson

Type Stainless Model No. _____

Diam. 7 Slot size .080 from 241 ft. to 257 ft.

Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Gravel/Filter packed: ☐ Yes ☒ No Size of gravel/sand _____

Materials placed from _____ ft. to _____ ft.

Surface Seal: ☒ Yes ☐ No To what depth? 18+ ft.

Material used in seal Bentonite

Did any strata contain unusable water? ☐ Yes ☒ No

Type of water? _____ Depth of strata _____

Method of sealing strata off _____

PUMP: Manufacturer's Name _____

Type: _____ H.P. _____

WATER LEVELS: Land-surface elevation above mean sea level _____ ft.

Static level 15 ft. below top of well Date 4/18/16

Artesian pressure _____ lbs. per square inch Date _____

Artesian water is controlled by _____ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? ☐ Yes ☒ No If yes, by whom? _____

Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____

CURRENT

Notice of Intent No. WE23295

Unique Ecology Well ID Tag No. BJA153

Water Right Permit No. G4-30182P(A)

Property Owner Name Borton & Sons Inc.

Well Street Address Ahtanum Road

City Yakima County Yakima

Location SW1/4-1/4 NW1/4 Sec 02 Twn 12 R 18 EWM ☒

(s, t, r Still REQUIRED)

Or
WWM ☐

Lat/Long

Lat Deg _____

Lat Min/Sec _____

Long Deg _____

Long Min/Sec _____

Tax parcel No. (Required) 18120232003

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Silt	0	4
Silty Sand & Gravels	4	22
Cemented Sand & Gravels	W.B. 22	251
Sandstone (Brown w/Black)	W.B. 251	257

Start Date 4/6/16 Completed Date 4/18/16

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) Michael Robinson

Driller/Engineer/Trainee Signature _____

Driller or trainee License No. 1544

IF TRAINEE: Driller's License No. _____

Driller's Signature: _____

Drilling Company Robinson Drilling & Development, Inc.

Address 4902 Viewland Drive

City, State, Zip Yakima, WA, 98908

Contractor's

Registration No. ROBINDD9380E

Date 4/29/16

ECY 050-1-20 (Rev 02-2010) To request ADA accommodation including materials in a format for the visually impaired, call Ecology Water Resources Program at 360-407-6872. Persons with impaired hearing may call Washington Relay Service at 711. Persons with speech disability may call TTY at 877-833-6341.



Gutierrez, Erin (ECY)

* AE36245/Borton & Sons
Correction to 1/4-1/4 should be NW/SW

S2
T12
R18E

From: Richardson, Avery (ECY)
Sent: Friday, January 06, 2017 10:52 AM
To: Gutierrez, Erin (ECY)
Subject: Well report changes

Hi Erin,

Mike Robinson and I reviewed two well reports and need to change the locations slightly. AE36245 for Borton and Sons should be NW of the SW. WE23295 for Borton and Sons should be NW of SW.

Thank you, *

Avery Richardson and Mike Robinson



Original & 1st copy – Ecology, 2nd copy – owner, 3rd copy – driller

Construction/Decommission ("x" in circle)☒ Construction☐ Decommission *ORIGINAL INSTALLATION*

Notice of Intent Number **W308652**

PROPOSED USE:
☒ Domestic
☐ Industrial
☐ Municipal
☐ DeWater
☐ Irrigation
☐ Test Well
☐ Other

TYPE OF WORK:
Owner's number of well (if more than one)
☒ New well
☐ Reconditioned
Method:
☐ Dug
☐ Bored
☐ Driven
☐ Deepened
☐ Cable
☒ Rotary
☐ Jetted

DIMENSIONS:
Diameter of well 6 inches, drilled 28.5 ft.
Depth of completed well 28.5 ft.

CONSTRUCTION DETAILS
Casing
☒ Welded
6" Diam. from +2 ft. to 43 ft.
Installed:
☒ Liner installed
4.5" Diam. from 25 ft. to 28.5 ft.
☐ Threaded
" Diam. From ft. to ft.

Perforations:
☒ Yes
☐ No
Type of perforator used
Skillsaw
SIZE of perfs
1/4 in. by 12 in. and no. of perfs
72 from 165 ft. to 28.5 ft.
Screens:
☐ Yes
☒ No
☐ K-Pac
Location
Manufacturer's Name
Type
Diam.
Slot size
from
ft. to
ft.
Diam.
Slot size
from
ft. to
ft.

Gravel/Filter packed:
☐ Yes
☒ No
Size of gravel/sand
Materials placed from
ft. to
ft.

Surface Seal:
☒ Yes
☐ No
To what depth?
18 ft.
Material used in seal
Bentonite
Did any strata contain unusable water?
☐ Yes
☒ No
Type of water?
Depth of strata
Method of sealing strata off

PUMP:
Manufacturer's Name
Type:
H.P.

WATER LEVELS:
Land-surface elevation above mean sea level
ft.
Static level
82 ft. below top of well
Date
4/16/16
Artesian pressure
lbs. per square inch
Date
Artesian water is controlled by
(cap, valve, etc.)

WELL TESTS:
Drawdown is amount water level is lowered below static level
Was a pump test made?
☐ Yes
☒ No
If yes, by whom?
Yield:
gal./min. with
ft. drawdown after
hrs.
Yield:
gal./min. with
ft. drawdown after
hrs.
Yield:
gal./min. with
ft. drawdown after
hrs.
Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test
Bailer test
gal./min. with
ft. drawdown after
hrs.
Airstest
40 gal./min. with stem set at 28.4 ft. for 1 hrs.
Artesian flow
g.p.m. Date
Temperature of water
Was a chemical analysis made?
☐ Yes
☒ No

CURRENT

Notice of Intent No. W308652

Unique Ecology Well ID Tag No. **BJB-961**

Water Right Permit No.

Property Owner Name Jake Petty

Well Street Address 122 Lynch Rd

City Yakima County Yakima

Location **SW** 1/4 - **SE** 1/4 Sec **7** Twn **12** R **17**

(s, t, r Still REQUIRED)

EWM ☒

Or
WWM ☐

Lat/Long Lat Deg _____ Lat Min/Sec _____

Long Deg _____ Long Min/Sec _____

Tax Parcel No. (Required) 171207-43409

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

[illegible]

Start Date 4/15/16 Completed Date 4/16/16

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) Justin Wamsley

Driller/Engineer/Trainee Signature Justin Wamsley

Driller or trainee License No. 4 2973 0

Driller's Signature: _____

Director's Signature:

Drilling Company **Water Wells Drilling, INC**

Address P.O. Box 908

City, State, Zip Selah, WA, 98942

Contractor's
Registration No. **WATERWD112QB** Date **4/18/16**

Requisition No. 70-1987

File Original and First Copy with
Department of EcologySecond Copy—Owner's Copy
Third Copy—Driller's CopyG-6
WATER WELL REPORTStart Card No. W 27395

STATE OF WASHINGTON

UNIQUE WELL I.D. #

Water Right Permit No.

(1) OWNER: Name Bud & Donna CrawfordAddress 6509 Englewood(2) LOCATION OF WELL: County YakimaNW NE NE Sec. 18 T. 12 N. R. 17 W.M. B(2a) STREET ADDRESS OF WELL (or nearest address) 366 Lynch Rd.(3) PROPOSED USE: ☒ Domestic ☐ Industrial ☐ Municipal ☐
☐ Irrigation ☐ Test Well ☐ Other ☐
☐ DeWater(4) TYPE OF WORK: Owner's number of well
(if more than one)Abandoned ☐ New well ☒ Method: Dug ☐ Bored ☐
Deepened ☐ Cable ☐ Driven ☐
Reconditioned ☐ Rotary ☐ Jetted ☐(5) DIMENSIONS: Diameter of well 6 inches.
Drilled 140 feet. Depth of completed well 140 ft.

(6) CONSTRUCTION DETAILS:

Casing installed: 6 " Diam. from 0 ft. to 24 ft.
Welded ☒ 4 1/2 " Diam. from -5 ft. to 140 ft.
Liner installed ☐
Threaded ☐ " Diam. from _____ ft. to _____ ft.Perforations: Yes ☒ No ☐Type of perforator used DrillSIZE of perforations 1/8 in. by 1/8 in.
80 perforations from 100 ft. to 140 ft.
_____ perforations from _____ ft. to _____ ft.
_____ perforations from _____ ft. to _____ ft.Screens: Yes ☐ No ☒

Manufacturer's Name _____

Type _____ Model No. _____

Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Gravel packed: Yes ☐ No ☒ Size of gravel _____

Gravel placed from _____ ft. to _____ ft.

Surface seal: Yes ☒ No ☐ To what depth? 18 ft.Material used in seal BentoniteDid any strata contain unusable water? Yes ☐ No ☒

Type of water? _____ Depth of strata _____

Method of sealing strata off _____

(7) PUMP: Manufacturer's Name _____

Type: _____ H.P. _____

(8) WATER LEVELS: Land-surface elevation above mean sea level _____ ft.

Static level 16 ft. below top of well Date 7-28-93

Artesian pressure _____ lbs. per square inch Date _____

Artesian water is controlled by _____ (Cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? Yes ☐ No ☐ If yes, by whom? _____

Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

" " " " " "

" " " " " "

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time Water Level Time Water Level Time Water Level

75 GPM W/stem set at 120 ft.Date of test 7-28-93

Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.

Airstest 75 gal./min. with stem set at 140 ft. for 1 hrs.

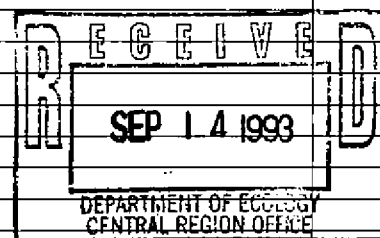
Artesian flow _____ g.p.m. Date _____

Temperature of water 56 Was a chemical analysis made? Yes ☐ No ☒

(10) WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

MATERIAL	FROM	TO
Topsoil	0	2
Boulders	2	16
Cement gravel	16	18
Med. brown basalt	18	26
Med. mustard color shale	26	28
Med. black basalt w/mustard shale	28	63
Hard black basalt	63	68
Med. black basalt	68	72
Hard grey basalt	72	108
Med. soft brown basalt	108	109
Med. brown basalt	109	112
Med. grey basalt laced w/brn. basalt fracture	112	125
Hard grey basalt	125	140

Work started 7-27, 19. Completed 7-28, 19 93

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

NAME Bach Well Drilling Company

(PERSON, FIRM, OR CORPORATION)

(TYPE OR PRINT)

Address 2111 Birchfield Rd. Yakima, Wa.(Signed) Jim Bach License No. 021

(WELL DRILLER)

Contractor's

Registration

No. BACHWDC137NU Date August 2, 19 93

(USE ADDITIONAL SHEETS IF NECESSARY)

G 8

File Original and First Copy with
Department of Ecology
Second Copy — Owner's Copy
Third Copy — Driller's Copy

WATER WELL REPORT

STATE OF WASHINGTON

Water Right Permit No.

Start Card No. W 36487UNIQUE WELL I.D. # AAM 007

(1) OWNER: Name Fred Hine Address 132 Sec 12 Rd Yakima Wash 98903
(2) LOCATION OF WELL: County Yakima S10 1/4 NW 1/4 Sec 15 T. 12 N. R. 17 WM.
(2a) STREET ADDRESS OF WELL (or nearest address) _____

(3) PROPOSED USE: ☒ Domestic ☐ Industrial ☐ Municipal ☐
☐ Irrigation ☐ Test Well ☐ Other ☐
☐ DeWater ☐ Rotary ☐ Jetted ☐

(4) TYPE OF WORK: Owner's number of well (if more than one) _____
Abandoned ☐ New well ☒ Method: Dug ☐ Bored ☐
Deepened ☐ Cable ☐ Driven ☐
Reconditioned ☐ Rotary ☒ Jetted ☐

(5) DIMENSIONS: Diameter of well 10" 6" inches.
Drilled 227 feet. Depth of completed well 227 feet.

(6) CONSTRUCTION DETAILS:

Casing installed: 6" Diam. from +2 ft. to 125 ft.
Welded ☒ Y-spur Diam. from -27 ft. to 227 ft.
Liner installed ☒
Threaded ☐ Diam. from _____ ft. to _____ ft.

Perforations: Yes ☒ No ☐
Type of perforator used SKILL SAW
SIZE of perforations 6" long in. by 5/8" wide in.
220 perforations from -180 ft. to 227 ft.
_____ perforations from _____ ft. to _____ ft.
_____ perforations from _____ ft. to _____ ft.

Screens: Yes ☐ No ☒
Manufacturer's Name _____
Type _____ Model No. _____
Diam. _____ Slot size _____ from _____ ft. to _____ ft.
Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Gravel packed: Yes ☐ No ☒ Size of gravel _____
Gravel placed from _____ ft. to _____ ft.

Surface seal: Yes ☒ No ☐ To what depth? 20' ft.
Material used in seal Bentonite
Did any strata contain unusable water? Yes ☐ No ☒
Type of water? _____ Depth of strata _____
Method of sealing strata off _____

(7) PUMP: Manufacturer's Name _____
Type: _____ H.P. _____

(8) WATER LEVELS: Land-surface elevation above mean sea level _____ ft.
Static level 90' ft. below top of well Date _____
Artesian pressure _____ lbs. per square inch Date _____
Artesian water is controlled by _____ (Cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? Yes ☐ No ☐ If yes, by whom? _____
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
" " " " " "
" " " " " "

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level
<u>Approx</u>	<u>42 gpm</u>				

Date of test Air Lift

Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.
Airtest _____ gal./min. with stem set at _____ ft. for _____ hrs.
Artesian flow _____ g.p.m. Date _____
Temperature of water _____ Was a chemical analysis made? Yes ☐ No ☐

(10) WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

MATERIAL	FROM	TO
top soil	0	8
Dark Gravel cobbles	8	14
Cemented Gravel cobbles	14	22
Cemented Gravel cobbles	22	28
Cemented Gravel cobbles	28	43
Cemented Gravel clay	43	51
Cemented Gravel sandstone	51	62
Cemented Gravel white clay	62	76
Cemented Gravel cobbles	76	112
Cemented Gravel sandstone	112	158
Cemented Gravel tan clay	158	167
Sandstone mottled color	167	175
Sandstone with clay shale	175	179
Sandstone brown clay	179	215
Sandstone	215	227

Work Started 4/12/94 19. Completed 4/15/94 19.

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

NAME Will Willys wells
(PERSON, FIRM, OR CORPORATION) (TYPE OR PRINT)

Address 6520 Postma Rd Yakima wa 98901

(Signed) Steve Mills License No. 1335
(WELL DRILLER)

Contractor's Registration No. Willwyw1068244 Date 4/18/94 19

(USE ADDITIONAL SHEETS IF NECESSARY)

G9

36676

WATER WELL REPORT

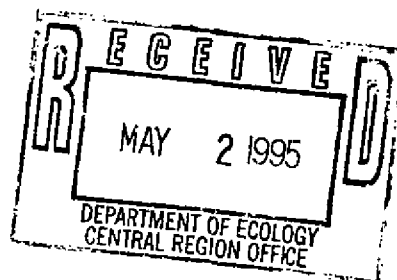
STATE OF WASHINGTON

Start Card No. WA0121

Unique Well I.D. # ABW767

Water Right Permit No.

(1) OWNER: Name GERDES, STEVE M.		Address 3324 STANTON YAKIMA, WA 98908-	
(2) LOCATION OF WELL: County YAKIMA		- SW 1/4 NW 1/4 Sec 10 T 12 N., R 17E WM	
(2a) STREET ADDRESS OF WELL (or nearest address),			
(3) PROPOSED USE: DOMESTIC		(10) WELL LOG	
(4) TYPE OF WORK:	Owner's Number of well (If more than one) Method: ROTARY	Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change in formation.	
NEW WELL			
(5) DIMENSIONS:	Diameter of well 6 inches		
Drilled 170 ft.	Depth of completed well 170 ft.		
(6) CONSTRUCTION DETAILS:			
Casing installed: 6 " Dia. from +2 ft. to 88 ft.			
WELDED 4 " Dia. from -5 ft. to 170 ft.			
	" Dia. from ft. to ft.		
Perforations: YES			
Type of perforator used SKILL SAW			
SIZE of perforations 1/8 in. by 6 in.			
144 perforations from 130 ft. to 170 ft.			
perforations from ft. to ft.			
perforations from ft. to ft.			
Screens: NO			
Manufacturer's Name			
Type	Model No.		
Diam. slot size from ft. to ft.			
Diam. slot size from ft. to ft.			
Gravel packed: NO			
Gravel placed from ft. to ft.			
Surface seal: YES	To what depth? 20 ft.		
Material used in seal BENTONITE			
Did any strata contain unusable water? NO			
Type of water? Depth of strata ft.			
Method of sealing strata off OVERBONE			
(7) PUMP: Manufacturer's Name	H.P.		
Type			
(8) WATER LEVELS:	Land-surface elevation		
	above mean sea level ... ft.		
Static level 75 ft. below top of well	Date 04/13/95		
Artesian Pressure lbs. per square inch	Date		
Artesian water controlled by			
(9) WELL TESTS: Drawdown is amount water level is lowered below static level.			
Was a pump test made? NO	If yes, by whom?		
Yield: gal./min with ft. drawdown after hrs.			
Recovery data			
Time Water Level Time Water Level Time Water Level			
Date of test / /			
Bailer test gal/min. ft. drawdown after hrs.			
Air test 30 gal/min. w/ stem set at 170 ft. for 1 hrs.			
Artesian flow g.p.m. Date			
Temperature of water Was a chemical analysis made? NO			
Work started 04/12/95		Completed 04/13/95	
(9) WELL TESTS: Drawdown is amount water level is lowered below static level.		WELL CONSTRUCTOR CERTIFICATION:	
Was a pump test made? NO		I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.	
Yield: gal./min with ft. drawdown after hrs.			
Recovery data			
Time Water Level Time Water Level Time Water Level			
Date of test / /			
Bailer test gal/min. ft. drawdown after hrs.			
Air test 30 gal/min. w/ stem set at 170 ft. for 1 hrs.			
Artesian flow g.p.m. Date			
Temperature of water Was a chemical analysis made? NO			
NAME PIONEER DRILLING		(Person, firm, or corporation) (Type or print)	
ADDRESS E 6010 BROADWAY			
[SIGNED] <i>Paul H. Hall</i>		License No. 2227	
Contractor's			
Registration No. PU-ND-EI#248JL		Date 04/17/95	



CRD



DEPARTMENT OF
ECOLOGY
State of Washington

NOTICE OF INTENT TO CONSTRUCT A WATER WELL

This form and fee **must be received** by Ecology
at least 72 hours before well construction.

Notice of Intent
Number

W 355708

This is a notice, not a permit, certificate, or application for a water right.

This document serves as your notification to Ecology that you intend to construct a water well in compliance with all applicable laws and regulations and, if you are a licensed well driller, that you intend to meet the conditions of your current license. This does not represent approval or permission to use water from the well.

Submit one form and the required fee (check or money order) for each well that you intend to construct. (*) Indicates a *required* field. Your notice of intent may be returned if it is not complete or if it contains incorrect data. The return of an incomplete or incorrectly filled out form could delay construction of your well. Mail completed form to: Department of Ecology, Cashiering Unit, PO Box 47611, Olympia, WA 98504-7611.

Well Owner or Agent

Organization Name: _____
or
Last Name: Adams First Name: Jason
Email Address: jasona@helliesenlumber.com
Mailing Address: _____ City: _____ State: _____ ZIP: _____
Agent (if different from above): _____
Mailing Address: _____ City: _____ State: _____ ZIP: _____



Well Location

Township 12 Range 17 E or W Section 17 in the NW 1/4 of NW 1/4
Well Site Street Address (No PO Box or mailing address, cross streets are okay):
Rutherford Rd
City: Yakima County: Yakima
Tax Parcel Number: 171217-22001

Well Use

☐ Commercial/Industrial ☒ Domestic ☐ Group Domestic/Number of homes to be served: _____
☐ Irrigation ☐ Stockwater ☐ Test Well ☐ Other _____
Does this well require a water right? ☐ Yes (Copy of Water Right permit attached) ☐ No

Type of Work

☐ Alteration ☐ Deepened Well ☐ Hydrofracturing ☒ New ☐ Replacement ☐ Other _____
Estimated Start Date: 7-8-14

Driller Information

Well Drilling Company Name: Apple Valley Well Drilling *Phone Number: (509) 697-6605
*Well Driller Name: Cary Lydin Licensed Well Driller Number: 1023

DEPT. OF ECOLOGY
FISCAL & BUDGET
JUN 11 10:47



DEPARTMENT OF
ECOLOGY
State of Washington

WATER WELL REPORT

Original & 1st copy - Ecology, 2nd copy - owner, 3rd copy - driller

Construction/Decommission ("x" in circle)

☒ Construction CR
☐ Decommission ORIGINAL INSTALLATION

Notice of Intent Number

CURRENT

Notice of Intent No. WE19325

Unique Ecology Well ID Tag No. BIF067

Water Right Permit No. _____

Property Owner Name Millie Clift

Well Street Address 10108 Meadowbrook Rd

City Yakima County Yakima

Location NE1/4-1/4 SW1/4 Sec 12 Twn 12 R 17
(s, t, r Still REQUIRED)

EWM ☒
Or
WWM ☐

Lat/Long Lat Deg _____ Lat Min/Sec _____

Long Deg _____ Long Min/Sec _____

Tax Parcel No. (Required) 17121231401

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Silt	0	7
Sand & Gravel (coarse)	7	15
Cemented Sand & Gravel	15	62
Clay (Brown)	62	70
Cemented Sand & Gravel	70	101
Clay / Sandstone (Brown)	101	125
Sand & Gravel	125	153
Clay / Sandstone (Brown)	153	157
Cemented Sand & Gravel	157	170
w/ Clay (Tan)	170	217
Shale/Clay w/Sandstone (Tan/Brown)	217	225
Sandstone (Gray & Brown) W.B.	225	232
Multi Colored Sandstone w/ Gravel W.B.	232	239

Start Date 09/24/2014 Completed Date 09/26/2014

PROPOSED USE: ☒ Domestic ☐ Industrial ☐ Municipal
☐ DeWater ☐ Irrigation ☐ Test Well ☐ Other _____

TYPE OF WORK: Owner's number of well (if more than one) _____
☒ New well ☐ Reconditioned Method: ☐ Dug ☐ Bored ☐ Driven
☐ Deepened ☐ Cable ☒ Rotary ☐ Jetted

DIMENSIONS: Diameter of well 6 inches, drilled 239 ft.
Depth of completed well 239 ft.

CONSTRUCTION DETAILS
Casing ☒ Welded 6 " Diam. from +2 ft. to 238 ft.
Installed: ☐ Liner installed _____ " Diam. from _____ ft. to _____ ft.
☐ Threaded _____ " Diam. From _____ ft. to _____ ft.

Perforations: ☐ Yes ☒ No
Type of perforator used _____
SIZE of perfs _____ in. by _____ in. and no. of perfs _____ from _____ ft. to _____ ft.

Screens: ☐ Yes ☒ No ☐ K-Pac Location _____
Manufacturer's Name _____
Type _____ Model No. _____
Diam. _____ Slot size _____ from _____ ft. to _____ ft.
Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Gravel/Filter packed: ☐ Yes ☒ No Size of gravel/sand _____
Materials placed from _____ ft. to _____ ft.

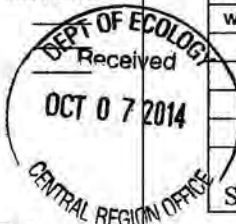
Surface Seal: ☒ Yes ☐ No To what depth? 18 ft.
Material used in seal Bentonite
Did any strata contain unusable water? ☐ Yes ☒ No
Type of water? _____ Depth of strata _____
Method of sealing strata off _____

PUMP: Manufacturer's Name _____
Type: _____ H.P. _____

WATER LEVELS: Land-surface elevation above mean sea level _____ ft.
Static level 85 ft. below top of well Date 09/26/2014
Artesian pressure _____ lbs. per square inch Date _____
Artesian water is controlled by _____ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? ☐ Yes ☒ No If yes, by whom? _____
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)
Time Water Level Time Water Level Time Water Level

Date of test _____
Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.
Airtest 60 gal./min. with stem set at 237 ft. for 1 hrs.
Artesian flow _____ g.p.m. Date _____
Temperature of water 57 Was a chemical analysis made? ☐ Yes ☒ No



WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) Michael Robinson

Driller/Engineer/Trainee Signature _____

Driller or trainee License No. 1544

IF TRAINEE: Driller's License No: _____

Driller's Signature: _____

Drilling Company Robinson Drilling & Development, Inc.

Address 4902 Viewland Drive

City, State, Zip Yakima, WA, 98908

Contractor's

Registration No. ROBINDD938QE

Date 09/27/2014



Original & 1st copy – Ecology, 2nd copy – owner, 3rd copy – driller

Construction/Decommission ("x" in circle)☒ Construction 484 089Decommission **ORIGINAL INSTALLATION**

Notice of Intent Number W362775

CURRENT

Notice of Intent No. W362775

Unique Ecology Well ID Tag No. BHT- 8602

Water Right Permit No.

Property Owner Name Donald Penuef

Well Street Address 11305 Ahtanum Rd

City Yakima County Yakima

Location SW 1/4 SE 1/4 Sec 02 Twn 12 R

(s, t, r Still REQUIRED)

Lat/Long Lat Deg _____ Lat Min/Sec _____

Long Deg _____ Long Min/Sec _____

Tax Parcel No. (Required) 171202-43011

[illegible]

Start Date 5/1/13

Completed Date 5/3/13

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) Justin Wamsley

Driller/Engineer/Trainee Signature Justin Amato

Driller or trainee License No. 2973

IF TRAINEE: Driller's License No:

Driller's Signature: _____

Drilling Company **Water Wells Drilling Inc.**

Address 2241 N Wenas Rd

City, State, Zip **Selah, WA, 98942**

Contractor's

Registration No. **WATERWD112QB** Date **5/4/13**



WATER WELL REPORT

Original & 1st copy - Ecology, 2nd copy - owner, 3rd copy - driller

Construction/Decommission ("x" in circle)

☒ Construction 463327
☐ Decommission ORIGINAL INSTALLATION Notice
 of Intent Number W300129

G 14

CURRENT

Notice of Intent No. W300129

Unique Ecology Well ID Tag No. BB5244

Water Right Permit No. _____

Property Owner Name Alma Mendoza

Well Street Address 2514 S 53rd Ave

City Yakima County Yakima

Location SE 1/4-1/4 NW 1/4 Sec 04 Twn 12 R 18 ☒ WWM ☐ circle one

Lat/Long (s, t, r) Lat Deg _____ Lat Min/Sec _____

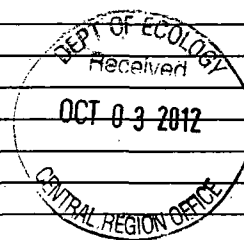
Still REQUIRED) Long Deg _____ Long Min/Sec _____

Tax Parcel No. 181204-24403

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Top Soil	0	5
Br. Clay & Gravel	5	25
Conglomerate	25	91
Brown Clay	91	105
Gravel, Sand, Water	105	120
Br. Sandstone & Clay	120	141
Br. Sandstone, Gravel, & Water	141	155



Start Date 9/3/12 Completed Date 9/3/12

PROPOSED USE: ☒ Domestic ☐ Industrial ☐ Municipal
☐ DeWater ☐ Irrigation ☐ Test Well ☐ Other _____

TYPE OF WORK: Owner's number of well (if more than one) _____
☒ New well ☐ Reconditioned Method: ☐ Dug ☐ Bored ☐ Driven
☐ Deepened ☐ Cable ☒ Rotary ☐ Jetted

DIMENSIONS: Diameter of well 6 inches, drilled 155 ft.
 Depth of completed well 155 ft.

CONSTRUCTION DETAILS:
 Casing ☒ Welded 6" Diam. from 43 ft. to 122 ft.
 Installed: ☒ Liner installed 4 1/2" Diam. from 43 ft. to 135 ft.
☐ Threaded _____ Diam. from _____ ft. to _____ ft.

Perforations: ☒ Yes ☐ No
 Type of perforator used SKILLSAW
 SIZE of perfs 1/4 in. by 12 in. and no. of perfs 36 from 15 ft. to 155 ft.

Screens: ☐ Yes ☒ No ☐ K-Pac Location: _____
 Manufacturer's Name _____
 Type _____ Model No. _____
 Diam. _____ Slot-size _____ from _____ ft. to _____ ft.
 Diam. _____ Slot-size _____ from _____ ft. to _____ ft.

Gravel/Filter packed: ☐ Yes ☐ No ☐ Size of gravel/sand _____ ft.
 Materials placed from _____ ft. to _____ ft.

Surface Seal: ☒ Yes ☐ No To what depth? 20 ft.
 Material used in seal Bentonite
 Did any strata contain unusable water? ☐ Yes ☒ No
 Type of water? _____ Depth of strata _____
 Method of sealing strata-off: _____

PUMP: Manufacturer's Name _____
 Type: _____ H.P. _____

WATER LEVELS: Land-surface elevation above mean sea level _____ ft.
 Static level 5'6 ft. below top of well Date 9/3/12
 Artesian pressure _____ lbs. per square inch Date _____
 Artesian water is controlled by _____ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level
 Was a pump test made? ☐ Yes ☒ No If yes, by whom? _____
 Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
 Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
 Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
 Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

 Date of test _____
 Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.
 Airtest 100 gal./min. with stem set at 150 ft. for 1 hrs.
 Artesian flow _____ g.p.m. Date _____
 Temperature of water _____ Was a chemical analysis made? ☐ Yes ☐ No

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) Justin Wamsley
 Driller/Engineer/Trainee Signature Justin Wamsley
 Driller or trainee License No. 2973

Drilling Company Water Wells Drilling
 Address 5503 Antanum RD
 City, State, Zip Yakima WA 98903
 Contractor's _____
 Registration No. WaterWells Date 9/3/12

If TRAINEE,

Driller's Licensed No. _____

Driller's Signature _____

Ecology is an Equal Opportunity Employer.

WATER WELL REPORT

Application No. _____

File: Final and First Copy with
 Depa: ent of Ecology
 Second Copy - Owner's Copy
 Third Copy - Driller's Copy

STATE OF WASHINGTON

Permit No. _____

(1) OWNER: Name EARL T. MORTON Address 3201 SO. 62ND AVE.
 (2) LOCATION OF WELL: County YAKIMA - NE 1/4 SW 1/4 Sec 9 T. 12 N. R. 12 W.
 and distance from section or subdivision corner WELL NO. 1

(3) PROPOSED USE: Domestic ☒ Industrial ☐ Municipal ☐
 Irrigation ☐ Test Well ☐ Other ☐

(4) TYPE OF WORK: Owner's number of well (if more than one) _____
 New well ☒ Method: Dug ☐ Bored ☐
 Deepened ☐ Cable ☐ Driven ☐
 Reconditioned ☐ Rotary ☒ Jetted ☐

(5) DIMENSIONS: Diameter of well 5 inches.
 Drilled _____ ft. Depth of completed well 129 ft.

(6) CONSTRUCTION DETAILS:

Casing installed: 5" Diam. from 0 ft. to 98 ft.
 Threaded ☐ " Diam. from _____ ft. to _____ ft.
 Welded ☒ " Diam. from _____ ft. to _____ ft.

Perforations: Yes ☐ No ☒

Type of perforator used _____
 SIZE of perforations _____ in. by _____ in.
 _____ perforations from _____ ft. to _____ ft.
 _____ perforations from _____ ft. to _____ ft.
 _____ perforations from _____ ft. to _____ ft.

Screens: Yes ☐ No ☒

Manufacturer's Name _____
 Type _____ Model No. _____
 Diam. _____ Slot size _____ from _____ ft. to _____ ft.
 Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Gravel packed: Yes ☐ No ☒ Size of gravel: _____
 Gravel placed from _____ ft. to _____ ft.

Surface seal: Yes ☒ No ☐ To what depth? 18 ft.
 Material used in seal BENTONITE
 Did any strata contain unusable water? Yes ☐ No ☒
 Type of water? _____ Depth of strata _____
 Method of sealing strata off _____

(7) PUMP: Manufacturer's Name _____
 Type: _____ HP _____

(8) WATER LEVELS: Land-surface elevation above mean sea level APP 1220
 Static level 82 ft. below top of well Date 4-20-77
 Artesian pressure _____ lbs. per square inch Date _____
 Artesian water is controlled by _____ (Cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? Yes ☐ No ☒ If yes, by whom? _____
 Yield: 30 gal./min. with _____ ft. drawdown after _____ hrs.
 " WITH AIR " " "

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test _____
 test _____ gal./min. with _____ ft. drawdown after _____ hrs.
 Artesian flow _____ g.p.m. Date _____
 Temperature of water 56 Was a chemical analysis made? Yes ☐ No ☒

(10) WELL LOG:

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of formation.

MATERIAL	FROM	TO
TOP SOIL	0	7
CONGLOMERATE (MED B)	7	20
" (MED B)	20	33
CLAY STONE	33	36
CLAY / FRACTURED BASALT (MED B)	36	45
DETERIORATED BASALT (MED A)	45	56
SANDSTONE / BASALT (MED A)	56	70
SANDSTONE / CLAY (MED A)	70	76
FRACTURED BASALT / CLAY (MED A)	76	78
CONGLOMERATE (MED YELLOW SAND)	78	98
" (LIGHT B) MED	98	100
SILTSTONE (LIGHT YELLOW SAND)	100	111
CLAY (LIGHT B)	111	115
FRAGMENTED BASALT / CLAY (MED A)	115	126
CONGLOMERATE (MED B) MED	126	129

RECEIVED

MAY 3 1977

DEPARTMENT OF ECOLOGY
CENTRAL REGIONAL OFFICE

Work started 4-19, 1977. Completed 4-20, 1977

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME JENSEN'S WELL DRILLING & DRIVING
 (Person, firm, or corporation) (Type or print)

Address 1603 SO. 10TH AVE.

[Signed] Chris B. Jensen
 (Well Driller)

Licenses No. 0217 Date 5-2, 1977

(USE ADDITIONAL SHEETS IF NECESSARY)



Water Well Report

Original - Ecology, 1st copy - owner, 2nd copy - driller

Construction/Decommission

☒ Construction 275228

☐ Decommission *ORIGINAL INSTALLATION Notice*
of Intent Number _____

PROPOSED USE:					
☐ DeWater	☒ Domestic ☐ Irrigation				
☐ Test Well	☐ Industrial ☐ Municipal ☐ Other				
TYPE OF WORK: Owner's number of well (if more than one) _____					
☒ New well	☐ Reconditioned Method: ☐ Dug ☐ Bored ☐ Driven				
☐ Deepened	☐ Cable ☒ Rotary ☐ Jetted				
DIMENSIONS: Diameter of well <u>6</u> inches, drilled <u>500</u> ft. Depth of completed well <u>500</u> ft.					
CONSTRUCTION DETAILS					
Casing	☒ Welded <u>6</u> " Diam. from <u>+1</u> ft. to <u>456</u> ft.				
Installed:	☐ Liner installed _____ ft. to _____ ft.				
	☐ Threaded _____ ft. to _____ ft.				
Perforations: ☐ Yes ☒ No					
Type of perforator used _____					
SIZE of perfs: _____ in. by _____ in. and no. of perfs _____ from _____ ft. to _____ ft.					
Screens: ☒ Yes ☐ No ☐ K-Pac Location <u>458</u> <u>440-500</u>					
Manufacturer's Name _____					
Type <u>PVC</u>	Model No. _____				
Diam. <u>4 1/2</u>	Slot size <u>020</u> from <u>460</u> ft. to <u>500</u> ft.				
Diam. _____	Slot size _____ from _____ ft. to _____ ft.				
Gravel/Filter packed: ☐ Yes ☒ No ☐ Size of gravel/sand _____ Materials placed from _____ ft. to _____ ft.					
Surface Seal: ☒ Yes ☐ No To what depth? <u>25</u> ft.					
Material used in seal <u>Bentonite</u>					
Did any strata contain unusable water? ☐ Yes ☒ No					
Type of water? _____	Depth of strata _____				
Method of sealing strata off _____					
PUMP: Manufacturer's Name _____ Type: _____ H.P. _____					
WATER LEVELS: Land-surface elevation above mean sea level _____ ft. Static level <u>250</u> ft. below top of well Date <u>9/13/07</u> Artesian pressure _____ lbs. per square inch Date _____ Artesian water is controlled by _____ (cap, valve, etc.)					
WELL TESTS: Drawdown is amount water level is lowered below static level					
Was a pump test made? ☐ Yes ☒ No If yes, by whom? _____					
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.					
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.					
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.					
Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)					
Time _____	Water Level _____	Time _____	Water Level _____	Time _____	Water Level _____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
Date of test _____					
Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.					
Airtest <u>60</u> gal./min. with stem set at <u>500</u> ft. for <u>1</u> hrs.					
Artesian flow _____ g.p.m.	Date _____				
Temperature of water _____ Was a chemical analysis made? ☐ Yes ☒ No					

Current

Notice of Intent No. W 255639

Unique Ecology Well ID Tag No. APG332

Water Right Permit No.

Property Owner Name Jeff Sampson

Well Street Address 62nd & S. Ahtanum Rd.

City Yakima County Yakima

Location NW 1/4-1/4 NE 1/4 Sec 17 Twn 12 R 18 EWM ☒ circle
or WWM ☐ one

Lat/Long (s, t, r Lat Deg 46 Lat Min/Sec 53290
still REQUIRED) Long Deg 120 Long Min/Sec 59161

Tax Parcel No. 1812179999 0

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information indicate all water encountered. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Soil	0	10
Soil, Gravel	10	22
Sandstone, Gravel	22	180
Sandstone, Pumice, Gravel	180	215
Hrd Brn Clay	215	225
Lt Brn Clay	225	255
Clay, Sandstone, Trace H ₂ O	255	280
Clay, Gray Sandstone	280	290
Rd Clay, Rd Sandstone, Trace Water	290	302
Clay, Gravel, Sand	302	340
Clay	340	350
Clay, Gravel, Sand	350	370
Silt, Sand, Trace Water	370	385
Gravel	385	390
Silt, Sm Gravel	390	410
Brn Sandstone, Gravel	410	450
Brn Sandstone, Clay, H ₂ O	450	505

Start Date 8/27/07

Completed Date 9/13/07

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

Driller/Engineer/Trainee Name (Print) Charles White

Driller/Engineer/Trainee Signature Charles Wilkins

Driller or trainee License No. 2328Drilling Company Water Wells Drilling Inc.

Address 5503 Ahtanum Rd.

City, State, Zip Yakima, Wa.. 98903

Contractor's

Registration No. WaterWD1120B Date 9/17/07

Ecology is an Equal Opportunity Employer.

ECY 050-1-20 (Rev 2/03)

(If TRAÎNÉE,

Driller's Licensed No.

Driller's Signature



WATER WELL REPORT

Original & 1st copy - Ecology, 2nd copy - owner, 3rd copy - driller

ECOLOGY

Construction/Decommission ("x" in circle)

☒ Construction 306507

☐ Decommission ORIGINAL INSTALLATION Notice of Intent Number

CURRENT

Notice of Intent No. W 255653

Unique Ecology Well ID Tag No. APG 333

Water Right Permit No.

Property Owner Name Holli Mandrell

Well Street Address Wendle Phillips

City Sunnyside County Yakima

Location NE 1/4-1/4 NE 1/4 Sec 9 Twn 9 R22 FWM - circle one

Lat/Long (s, t, r) Lat Deg N46 Lat Min/Sec 28.262

Still REQUIRED) Long Deg W120 Long Min/Sec 06.484

Tax Parcel No. 220909 11416

CONSTRUCTION OR DECOMMISSION PROCEDURE

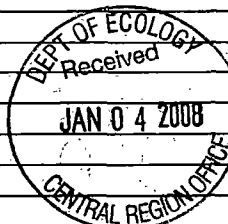
Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Sand, Silt	0	18
Sand, Silt, Water	18	20
Sand, Clay	20	22
Sand, Water	22	68
Sand, Clay	68	70
Gravel, Clay	70	75
Gravel, Water, Sand	75	85

RECEIVED

30-2008

DEPARTMENT OF ECOLOGY - CENTRAL REGIONAL OFFICE



Start Date 10-2-07

Completed Date 10-14-07

PROPOSED USE: ☒ Domestic ☐ Industrial ☐ Municipal
☐ DeWater ☐ Irrigation ☐ Test Well ☐ Other

TYPE OF WORK: Owner's number of well (if more than one) _____
☒ New well ☐ Reconditioned *Method:* ☐ Dug ☐ Bored ☐ Driven
☐ Deepened ☐ Cable ☒ Rotary ☐ Jetted

DIMENSIONS: Diameter of well 6 inches, drilled 85 ft.
 Depth of completed well 85 ft.

CONSTRUCTION DETAILS
 Casing ☒ Welded 6" Diam. from +1 ft. to 80 ft.
 Installed: ☐ Liner installed " Diam. from " ft. to " ft.
☐ Threaded " Diam. from " ft. to " ft.

Perforations: ☐ Yes ☒ No
 Type of perforator used _____
 SIZE of perfs _____ in. by _____ in. and no. of perfs from _____ ft. to _____ ft.

Screens: ☒ Yes ☐ No ☐ K-Pac Location 80
 Manufacturer's Name _____
 Type SS Model No. _____
 Diam. 6 Slot size 020 from 80 ft. to 85 ft.
 Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Gravel/Filter packed: ☐ Yes ☒ No ☐ Size of gravel/sand _____
 Materials placed from _____ ft. to _____ ft.

Surface Seal: ☒ Yes ☐ No To what depth? 25 ft.
 Material used in seal Bentonite
 Did any strata contain unusable water? ☐ Yes ☒ No
 Type of water? _____ Depth of strata _____
 Method of sealing strata off _____

PUMP: Manufacturer's Name _____
 Type: _____ H.P. _____

WATER LEVELS: Land-surface elevation above mean sea level _____ ft.
 Static level 13 ft. below top of well Date 10-14-07
 Artesian pressure _____ lbs. per square inch Date _____
 Artesian water is controlled by _____ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level
 Was a pump test made? ☐ Yes ☒ No If yes, by whom? _____
 Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
 Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
 Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
 Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

 Date of test _____
 Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.
 Airtest 60 gal./min. with stem set at 80 ft. for 1 hrs.
 Artesian flow _____ g.p.m. Date _____
 Temperature of water _____ Was a chemical analysis made? ☐ Yes ☒ No

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☐ Driller ☐ Engineer ☐ Trainee Name (Print) Charles White

Driller/Engineer/Trainee Signature: _____

Driller or trainee License No. 2328

If TRAINEE,

Driller's Licensed No. _____

Driller's Signature _____

Drilling Company Water Wells Drilling Inc.

Address 5503 Ahtanum Rd.

City, State, Zip Yakima, Wa. 98903

Contractor's

Registration No. WaterWD1120b

Date 10-14-07

Ecology is an Equal Opportunity Employer.



Original & 1st copy – Ecology, 2nd copy – owner, 3rd copy – driller

Construction

☐ Decommission *ORIGINAL INSTALLATION*Notice of Intent Number **W308511**

CURRENT

Notice of Intent No. W308511

Unique Ecology Well ID Tag No. **BJB-995**

Water Right Permit No.

Property Owner Name **Sam Weaver**

Well Street Address **2811 S. 74th AVE.**City Yakima

Location SW1/4-1/4 SW1/4 Sec 5 Twn 12 R 18 EWM ☒
(s, t, r Still REQUIRED)

Lat/Long

Lat Deg _____

Long Deg _____

Lat Min/Sec _____

Long Min/Sec _____

Tax parcel No. (Required) **181205-33001**

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) **Justin Wamsley**

Driller/Engineer/Trainee Signature Justin Wamsley

Driller or trainee License No. **2973**

IF TRAINEE: Driller's License No: _____

Driller's Signature: _____

Drilling Company **Water Wells Drilling, INC**

Address **PO Box 908**

City, State, Zip **Selah, WA, 98942**

Contractor's

Registration No. **WATERWD112QB**

Date _____

ECY 050-1-20 (Rev 02-2010) To request ADA accommodation including materials in a format for the visually impaired, call Ecology Water Resources Program at 360-407-6872. Persons with impaired hearing may call Washington Relay Service at 711. Persons with speech disability may call TTY at 877-833-6341.



Construction/Decommission (*x* in circle) 126/83

- Ecology is an Equal Opportunity Employer ECY 050 1 20 (Rev 4/01)



WATER WELL REPORT

Original & 1st copy - Ecology, 2nd copy - owner, 3rd copy - driller

Construction/Decommission ("x" in circle)

☒ Construction

☐ Decommission ORIGINAL INSTALLATION

Notice of Intent Number

PROPOSED USE: ☒ Domestic ☐ Industrial ☐ Municipal ☐ DeWater ☐ Irrigation ☐ Test Well ☐ Other																															
TYPE OF WORK: Owner's number of well (if more than one) _____ ☒ New well ☐ Reconditioned Method: ☐ Dug ☐ Bored ☐ Driven ☐ Deepened ☐ Cable ☒ Rotary ☐ Jetted																															
DIMENSIONS: Diameter of well <u>6</u> inches, drilled <u>223</u> ft. Depth of completed well <u>223</u> ft.																															
CONSTRUCTION DETAILS Casing ☒ Welded <u>6</u> " Diam. from <u>+3</u> ft. to <u>180</u> ft. Installed: ☐ Liner installed _____" Diam. from _____ ft. to _____ ft. ☐ Threaded _____" Diam. From _____ ft. to _____ ft.																															
Perforations: ☐ Yes ☒ No Type of perforator used _____																															
SIZE of perfs _____ in. by _____ in. and no. of perfs _____ from _____ ft. to _____ ft.																															
Screens: ☐ Yes ☒ No ☐ K-Pac Location _____ Manufacturer's Name _____ Type _____ Model No. _____ Diam. Slot size _____ from _____ ft. to _____ ft. Diam. Slot size _____ from _____ ft. to _____ ft.																															
Gravel/Filter packed: ☐ Yes ☒ No Size of gravel/sand _____ Materials placed from _____ ft. to _____ ft.																															
Surface Seal: ☒ Yes ☐ No To what depth? <u>18</u> ft. Material used in seal <u> Bentonite </u> Did any strata contain unusable water? ☐ Yes ☒ No Type of water? _____ Depth of strata _____ Method of sealing strata off _____																															
PUMP: Manufacturer's Name _____ Type: _____ H.P. _____																															
WATER LEVELS: Land-surface elevation above mean sea level _____ ft. Static level <u>135</u> ft. below top of well Date <u>10/11/17</u> Artesian pressure _____ lbs. per square inch Date _____ Artesian water is controlled by _____ (cap, valve, etc.)																															
WELL TESTS: Drawdown is amount water level is lowered below static level Was a pump test made? ☐ Yes ☒ No If yes, by whom? _____ Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs. Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs. Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs. Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level) <table border="1"> <thead> <tr> <th>Time</th> <th>Water Level</th> <th>Time</th> <th>Water Level</th> <th>Time</th> <th>Water Level</th> </tr> </thead> <tbody> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> </tbody> </table> Date of test _____ Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs. Airstest <u>30-35</u> gal./min. with stem set at <u>203</u> ft. for <u>1</u> hrs. Artesian flow _____ g.p.m. Date _____ Temperature of water _____ Was a chemical analysis made? ☐ Yes ☒ No		Time	Water Level	Time	Water Level	Time	Water Level																								
Time	Water Level	Time	Water Level	Time	Water Level																										

CURRENT

Notice of Intent No. W3559746
 Unique Ecology Well ID Tag No. BJA230
 Water Right Permit No. _____
 Property Owner Name Daniel Trenkaush
 Well Street Address Love Dove Lane
 City Yakima County Yakima
 Location SW 1/4-1/4 SW 1/4 Sec 15 Twn R 12 17 EWM ☒
 (s, t, r Still REQUIRED) 12 17 Or WWM ☐
 Lat/Long _____
 Lat Deg _____ Lat Min/Sec _____
 Long Deg _____ Long Min/Sec _____
 Tax parcel No. (Required) 171215-23408

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
topsoil	0	10
to bales / gravel	10	32
sandstone / gravel	32	150
sandstone	150	223

RECEIVED

NOV 30 2017

Dept of Ecology
 Central Region

Start Date 10/4/17 Completed Date 10/11/17

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name Jeremy Bach
 Driller/Engineer/Trainee Signature _____
 Driller or trainee License No. #2536
 IF TRAINEE: Driller's License No. _____
 Driller's Signature: _____

Drilling Company Bach Drilling Company
 Address 3340 Wilson Creek Road
 City, State, Zip Ellensburg, Wa 98926
 Contractor's _____
 Registration No. MIKEBDC942R6 Date 10/11/17

ECY 050-1-20 (Rev 02-2010) To request ADA accommodation including materials in a format for the visually impaired, call Ecology Water Resources Program at 360-407-6872. Persons with impaired hearing may call Washington Relay Service at 711. Persons with speech disability may call TTY at 877-833-6341.

Please print, sign and return to the Department of Ecology

G 22



Water Well Report

Original - Ecology, 1st copy - owner, 2nd copy - driller

Construction/Decommission

☒ Construction☐ Decommission

ORIGINAL INSTALLATION Notice of Intent Number WELL DRILLING UNIT

Current

Notice of Intent No. W208912

Unique Ecology Well ID Tag No. ALF 784

Water Right Permit No. 2005-76

Property Owner Name YIN LAND ENTERPRISE

Well Street Address SITE #3 / T - 2326 & 2326

City YAKIMA

County YAKIMA

Location SE 1/4-1/4 SE 1/4 Sec 8 Twn 12 R 18

EWM
or
WWM

Lat/Long (s, t, r)

Lat Deg

Lat Min/Sec

still REQUIRED)

Long Deg

Long Min/Sec

Tax Parcel No. 62ND AND MEADOWBROOK

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information indicate all water encountered. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
SILT	0	5
SILTY SAND/GRAVEL W/CLAY	5	75
GRAVELS	75	95
CLAY BRN CEMENTED SAND/GRAVELS	95	100
CLAY BRN CEMENTED SAND/GRAVEL W/COB	100	202
SAND	202	210
CEMENTED GRAVELS COARSE	210	223
SAND	223	230
GRAVELS COARSE WB	230	247
SANDSTONE BRW SOFT	247	250
SANDSTONE BRW SOFT W/GRAVEL	250	260
SAND/GRAVEL COARSE WB	260	267
SANDSTONE BRN W/GRAVEL WB	267	275
SAND AND GRAVEL WB	275	282
SAND/GRAVEL W/SANDSTONE	282	287
SAND/GRAVEL COARSE WB	287	290
SANDSTONE WHITE SOFT	290	293
SANDSTONE BROWN W/GRAVEL	293	300
CEMENTED SAND/GRAVEL WB	300	305
SAND AND GRAVEL WB	305	320
SANDSTONE BROWN SOFT	320	322

Screen:

6".020 299 to 304
 6".040 304 to 307
 6".060 307 to 319
 6"Steel blank 319 to 322

Start Date 1/5/06

Completed Date 2/9/06

PROPOSED USE: ☐ Domestic ☐ Industrial ☐ Municipal
☐ DeWater ☒ Irrigation ☐ Test Well ☐ Other

TYPE OF WORK: Owner's number of well (if more than one)

☒ New well ☐ Reconditioned Method: ☐ Dug ☐ Bored ☐ Driven
☐ Deepened ☐ Cable ☒ Rotary ☐ Jetted

DIMENSIONS: Diameter of well 8 inches, drilled 322 ft.

Depth of completed well 322 ft.

CONSTRUCTION DETAILS 6" 319 322

Casing ☒ Welded 10" Diam from +1 ft to 220 ft
 Installed: ☐ Liner installed 8" Diam from +3 ft to 301 ft
☐ Threaded 6" Diam from 293 ft to 299 ft

Perforations: ☐ Yes ☒ No

Type of perforator used

SIZE of perfs in by in and no. of perfs from ft to ft.

Screens: ☒ Yes ☐ No ☒ K-Pac Location 294

Manufacturer's Name ALLOY MACHINE WORK

Type STAINLESS Model No. 76711
 Diam 6" Slot size .020 from 299 ft to 304 ft
 Diam 6" Slot size .040 from 304 ft to 307 ft

Gravel/Filter packed: ☐ Yes ☒ No Size of gravel/sand
 Materials placed from ft to ft.

Surface Seal: ☒ Yes ☐ No To what depth? 220 ft.

Material used in seal

Did any strata contain unusable water? ☐ Yes ☒ No

Type of water? Depth of strata

Method of sealing strata off

PUMP: Manufacturer's Name

Type: H.P.

WATER LEVELS: Land-surface elevation above mean sea level ft.

Static level 113 ft. below top of well Date 2/10/06

Artesian pressure lbs. per square inch Date

Artesian water is controlled by (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? ☐ Yes ☐ No If yes, by whom?

Yield: gal./min. with ft. drawdown after hrs.

Yield: gal./min. with ft. drawdown after hrs.

Yield: gal./min. with ft. drawdown after hrs.

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time Water Level Time Water Level Time Water Level

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WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

Driller/Engineer/Trainee Name (Print) MICHAEL ROBINSON

Driller/Engineer/Trainee Signature Michael Robinson

Driller or trainee License No. 1544

Drilling Company PICATTI BROS

Address 2309 SOUTH 3RD AVE

City, State, Zip UNION GAP, WA. 98903

Contractor's

Registration No. PICATBI033 UC

Date 2/27/06

Ecology is an Equal Opportunity Employer.

ECY 050-1-20 (Rev 2/03)

IF TRAINEE,

Driller's Licensed No.

Driller's Signature

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BORTON & SONS

J. Re BORTON WELL LOG

Reservation well

Started - 4/8/57

Well completed 7/24/57

Well depth - 705 ft.

Location:

Near SE corner of

NW 1/4 of SE 1/4

Sec 14 T12N R17E

CASING

12 inch pipe - 208 feet Perforated 100 ft. - 200 ft.
10 " O.D. - 95/8 I.D. " 170 to 600 ft
8 5/8 " O. D. 8 1/4 I.D. " to 700 ft
5 1/2 "

NW 1/4 SE 1/4

SEC. 14 Township 12

Range 17E

amount	Formations	depth
1 ft.	Soil	1 ft
15 ft.	Gravel	16 ft
7 ft	Cement gravel	23 ft
5 ft	Gravel and clay	28 ft
11 ft	Cement gravel (water)	39 ft
8 ft	Hard pan (water)	47 ft
7 ft.	Clay	54 ft
38 ft.	Brown clay (water)	92 ft
4 ft.	Brown clay	96 ft
14 ft.	Black rock	110 ft
8 ft.	Brown clay	113 ft
9 ft.	Hard and (water)	122 ft
8 ft.	Brown clay	130 ft
28 ft.	Cement Gravel	158 ft
2 ft	Grey clay and Bld.	160 ft
3 ft.	Hard rock and Bld.	163 ft
34 ft.	Cement gravel and Bld.	197 ft
2 ft	Brown clay and Bld.	199 ft
9 ft	Course gravel and clay Bld.	208 ft
12 ft.	Hard pan and Bld. (caving)	220 ft
5 ft.	Loose black sand and gravel (water)	225 ft
20 ft.	Solidified sand and gravel and Bld.	245 ft
4 ft.	Bld. and hard pan	249 ft
11 ft.	Cement gravel ind. of (water)	260 ft
7 ft.	Solidified sand and gravel	267 ft
8 ft.	Hard pan gravel and Bld.	275 ft
10 ft.	Hard pan	285 ft
2 ft.	Grey sandy clay	287 ft
3 ft.	Gravel and Bld. (some water)	290 ft
3 ft	sand rock and some Bld. ... (hard)	293 ft
11 ft.	Cement gravel and Bld.	304 ft
12 ft.	Bld. sand and gravel	321 ft
3 ft.	Brown clay	327 ft
11 ft.	Cement gravel and clay	335 ft
5 ft	Loose Bld.	340 ft
11 ft.	Rock	351 ft
3 ft.	Clay and Bld.	354 ft
12 ft	rock	366 ft
2 ft.	Decomposed rock	368 ft
6 ft.	Solidified sand gravel and some water	374 ft
13 ft	Blue green Decomposed rock and some water	387 ft
21 ft.	Sticky clay conglomerate	403 ft
10 ft.	Gravelly clay	418 ft
42 ft.	Sticky clay	460 ft
5 ft.	Gravel and sand	465 ft
30 ft.	White clay shale	495 ft
5 ft.	Sticky clay	500 ft
60 ft.	Brown clay shale	562 ft
4 ft.	Gravel and bld.	562 ft
9 ft.	Grey sticky clay	573 ft
3 ft	Course sand gravel	576 ft
9 ft	Brown and grey sticky clay	585 ft
15 ft.	Brown sticky clay	600 ft
27 ft.	White clay shale	

25 ft. Clay shale	675 ft
15 ft. Brown sticky clay (water)	690 ft
12 ft. Grey clay and gravel.....	702 ft
8 ft. clay shale.....	710 ft
20 ft. Brown and grey clay shale	730 ft
5 ft. clay shale.....	735 ft
15 ft. Yellow sticky clay	750 ft
5 ft. Clay shale white	755 ft
5 ft. Brown sticky clay	760 ft
10 ft. White clay shale	770 ft
5 ft. Grey clay sticky	775 ft

Mr. John C. Klebe
Well Driller
1503 N. Lanox
Yakima, Washington
Ph. 25004

Land: NW¹/₄ of SE¹/₄, SW¹/₄ NE¹/₄ Sec 14 (12-17)
Well: SE Corner NW¹/₄ of SE¹/₄

Left copy of this report with Mr. Longee for Mr. Taloy
5/20/58 Wapato Irrigation District Office for
registration of the well

Pump. 30 H.P. Lanox Boler Deep Well 500 gpm 177' Lift.
Date started pumping 8/6/57

Also file copy this report at BS Barlow's

Older well

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R

LOG OF BORTON & SONS

DRILLED BY A. A. DURAND & SON

Located SE/4 SE/4 Sec 16-12-17.

<u>From</u>	<u>To</u>	<u>Thickness</u>	<u>Formation</u>
0	5	5	Top Soil
5	8	3	Brown Clay
8	20	12	Brown Clay
20	27	7	Gravel, Clay and Boulders
27	41	14	Gravel, Clay and Boulders
41	62	21	Gravel, Clay and Boulders
62	66	4	Gravel and Boulders
66	72	6	Gravel and Boulders
72	82	10	Gravel
82	86	4	Boulders
86	93	7	Gravel and Boulders
93	98	5	Sand
98	105	7	Sand
105	112	7	Gravel
112	115	3	Coarse Sand
115	125	10	Coarse sand & little gravel
125	133	8	Coarse sand
133	137	4	Cement gravel with clay
137	145	8	Gravel
145	153	8	Gravel
153	156	3	Gravel
156	163	7	Gravel
163	171	8	Gravel
171	177	6	Gravel
177	181	4	Gravel and Boulders
181	189	8	Gravel and little clay
189	197	8	Gravel and Clay
197	201	4	Gravel containing some water
201	203	7	Cement gravel
203	215	7	Gravel and sand
215	225	10	Gravel and some boulders
225	232	7	Some water in gravel
232	247	15	Gravel and boulders
247	257	10	Gravel and boulders
257	262	5	Gravel, little clay
262	267	5	Thin conglomerate
267	283	16	Gravel, boulders, little clay
283	294	11	Gravel, boulders, little clay
294	300	6	Gravel, boulders, little clay
300	304	4	Boulders
304	305	1	Gravel, Boulders, little clay
305	310	5	Sand, Gravel, little clay
310	321	11	Sand, Gravel

<u>From</u>	<u>To</u>	<u>Thickness</u>	<u>Formation</u>
321	326	5	Sand, Gravel and Boulders
326	329	3	Clay
329	332	3	Sand, gravel, boulders (little shale)
332	337	5	Sand, Gravel and Boulders
337	353	16	Clay (some boulders)
353	373	20	Clay
373	385	12	Brown clay
385	390	5	Clay mixed with large gravel
390	400	10	Sticky clay
400	405	5	Clay
405	420	15	Shale
420	434	14	Yellow clay
434	440	6	Yellow clay
440	450	10	Brown sticky clay
450	454	4	White Clay
454	476	22	White Clay
476	480	4	White clay
480	495	15	Brown clay
495	510	15	White clay
510	527	17	Sand stone
527	540	13	Sandstone
540	548	8	Sandstone
548	565	17	Sandstone, some clay
565	576	11	Sandstone
576	585	9	Sandstone
585	590	5	Sandstone
590	599	9	Sandstone
599	602	3	Sandstone
602	617	15	Sandstone
617	619	2	Sandstone
619	631	12	Sandstone
631	636	5	Sandstone
636	639	3	Clay
639	643	4	Sandstone
643	648	5	Unclassified
648	650	2	
650	655	5	Sandstone
655	670	15	Sandstone and sticky clay
670	674	4	Clay with rock mixture
674	676	2	Sandstone
676	691	15	Sandstone and sticky clay
691	702	11	Clay
702	706	4	Sandstone
706	716	10	Blue Basalt
716	723	7	Blue Basalt
723	730	7	Blue Basalt
730	734	4	Blue Basalt
734	737	3	Blue Basalt
737	740	3	Blue Basalt

<u>From</u>	<u>To</u>	<u>Thickness</u>	<u>Formation</u>
740	742	2	Blue Basalt
742	746	4	Blue Basalt
746	753	7	Blue Basalt
753	754	1	Gray Basalt
754	758	4	Gray Basalt
758	760	2	Gray Basalt
760	767	7	Black Basalt
767	776	9	Blue Basalt
776	783	7	Black Basalt
783	786	3	Black Basalt
786	788	2	Black basalt, little sand
788	793	5	Black Basalt
793	801	8	Black Basalt
801	806	5	Black Basalt
806	815	9	Black Basalt, Honeycomb
815	816	1	Black Basalt, Hard
816	818	2	Black Basalt, Hard
818	820	2	Black Basalt, Hard
820	823	3	Black Basalt, Hard
823	827	4	Mixed red and black rock
827	828	1	Hard Black Basalt
828	829	1	Hard Black Basalt
829	831	2	Gray Basalt
831	835	4	Black Basalt
835	836	1	Black Basalt, Hard
836	842	6	Black Basalt and Red Honeycomb
842	846	4	Black Basalt, Honeycomb
846	848	2	Black Basalt, Solid
848	851	3	Black Basalt, Honeycomb
851	853	2	Black Basalt, Hard
853	855	2	Black Basalt, Hard
855	857	2	Black Basalt, Hard
857	861	4	Black Basalt
861	862	1	Black Basalt
862	867	5	Black Basalt
867	876	9	Black Basalt
876	884	8	Black Basalt
884	890	6	Black Basalt
890	896	6	Black Basalt
896	901	5	Granite
901	907	6	Black Basalt
907	910	3	Black Basalt
910	912	2	Black Basalt
912	916	4	Black Basalt
916	918	2	Gray Basalt
918	919	1	Gray Basalt
919	920	1	Hard Granite
920	922	2	Granite (water flowing 10 gal. per minute)
922	924	2	Granite
924	927	3	Granite

SAND
CRUING

<u>From</u>	<u>To</u>	<u>Thickness</u>	<u>Formation</u>
927	930	3	Black Basalt
930	931	1	Granite
931	934	3	Granite
934	940	6	Sand
940	942	2	Black Basalt
942	954	12	Black Basalt
954	960	6	Gray Basalt
960	964	4	Sandstone
964	989	25	Sandstone, considerable water
989	1005	16	Blue Sandstone
1005	1010	5	Blue Sandstone
1010	1015	5	Blue Shale
1015	1028	13	Gray Sandstone
1028	1035	7	Gray Sandstone
1035	1056	22	Black Basalt
1056	1058	2	Sand bearing water
1058	1064	6	Black Basalt
1064	1069	5	Blue Clay

WATER WELL REPORT

Application No. 67-28420

STATE OF WASHINGTON

Permit No.

(1) OWNER: Name BORTON & SONS FRUIT & COLD STORAGE --- Continued ---(2) LOCATION OF WELL: County SE 1/4 SE 1/4 Sec. 18 T. 12 N. R. 17 W.M.Bearing and distance from section or subdivision corner R(3) PROPOSED USE: Domestic ☐ Industrial ☐ Municipal ☐
Irrigation ☐ Test Well ☐ Other ☐(4) TYPE OF WORK: Owner's number of well (if more than one)
New well ☐ Method: Dug ☐ Bored ☐
Deepened ☐ Cable ☐ Driven ☐
Reconditioned ☐ Rotary ☐ Jetted ☐(5) DIMENSIONS: Diameter of well inches.
Drilled ft. Depth of completed well ft.

(6) CONSTRUCTION DETAILS:

Casing installed: " Diam. from ft. to ft.
Threaded ☐ " Diam. from ft. to ft.
Welded ☐ " Diam. from ft. to ft.Perforations: Yes ☐ No ☐Type of perforator used
SIZE of perforations in. by in.
..... perforations from ft. to ft.
..... perforations from ft. to ft.
..... perforations from ft. to ft.Screens: Yes ☐ No ☐Manufacturer's Name
Type Model No.
Diam. Slot size from ft. to ft.
Diam. Slot size from ft. to ft.Gravel packed: Yes ☐ No ☐ Size of gravel:
Gravel placed from ft. to ft.Surface seal: Yes ☐ No ☐ To what depth? ft.
Material used in seal
Did any strata contain unusable water? Yes ☐ No ☐
Type of water? Depth of strata
Method of sealing strata off(7) PUMP: Manufacturer's Name
Type: H.P.(8) WATER LEVELS: Land-surface elevation above mean sea level ft.
Static level ft. below top of well Date
Artesian pressure lbs. per square inch Date
Artesian water is controlled by (Cap, valve, etc.)(9) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? Yes ☐ No ☐ If yes, by whom?
Yield: gal./min. with ft. drawdown after hrs.
" " " " " "
" " " " " "

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m. Date
Temperature of water Was a chemical analysis made? Yes ☐ No ☐

(10) WELL LOG:

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of formation.

MATERIAL	FROM	TO
Hard Black Basalt	595	605
Sandstone & Shale Particles	605	650
Soft Red Basalt (Ap. 500gpm)	650	661
Medium Grey Basalt	661	678
" Black "	678	685
Greenish-Grey Basalt	685	690
Medium Grey "	690	692
" " Fractured Basalt	692	710
" Black Basalt	710	725
" " Fractured "	725	763
Soft " " "	763	782
Medium " " "	782	795
Soft Blk.-Red Basalt-Shale	795	818
Soft Black Basalt	818	827
Medium " " "	827	832
Soft Black Fractured Basalt	832	837
Medium " " "	837	844
Soft Decomposed Black "	844	877
Medium Black Basalt	877	878
Soft Fractured Black Basalt	878	890
Black-Green Fractured "	890	901
Soft Black-Red Basalt	901	922
Medium Black "	922	925

* = Water Bearing Formations

Work started 3-15, 19. 85. Completed 4-12, 19. 85

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME BACH DRILLING COMPANY
(Person, firm, or corporation) (Type or print)Address ROUTE 5 BOX 1010 ELLENSBURG, WA.[Signed]
(Well Driller)License No. 22 Date 4-12-85, 19.

(USE ADDITIONAL SHEETS IF NECESSARY)