# Upper Walla Walla River Base flow Assessment 2023 Project Report

WALLA WALLA BASIN
WATERSHED COUNCIL

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BONNEVILLE POWER ADMINISTRATION

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## Record of Document Revision

| Version | Date | Responsible Party | Summary of Changes |
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| Original Version | January 2024 | WWBWC | |
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## Purpose

The purpose of this assessment was to locate, map, and describe groundwater resources (springs and seeps) that provide critical summer streamflows in the upper Walla Walla River. An updated inventory of spring locations is needed to document existing conditions, track future trends, help determine vulnerability to projected climate change impacts, and support Forest Service efforts to protect water resources. Source water information will also inform fisheries managers working to protect and enhance habitat for vulnerable aquatic populations. In addition, the groundwater inventory provides basin partners with information to promote water conservation and increase community resilience to changes in water supply.

## Background

Figure 1 shows the project area, which covers the upper Walla Walla Watershed located within the Umatilla National Forest (UNF) and, immediately above the Harris Park trailhead, land managed by the Bureau of Land Management. The elevation of the project area ranges from about 2,000 ft at the South Fork Walla Walla River trailhead above Harris Park to 5,750 ft at the upper watershed boundary. Figure 2 shows the water year 2023 hydrograph for the Walla Walla River at Milton-Freewater. The South Fork watershed provides about 90% of summer base flow to the Walla Walla River.

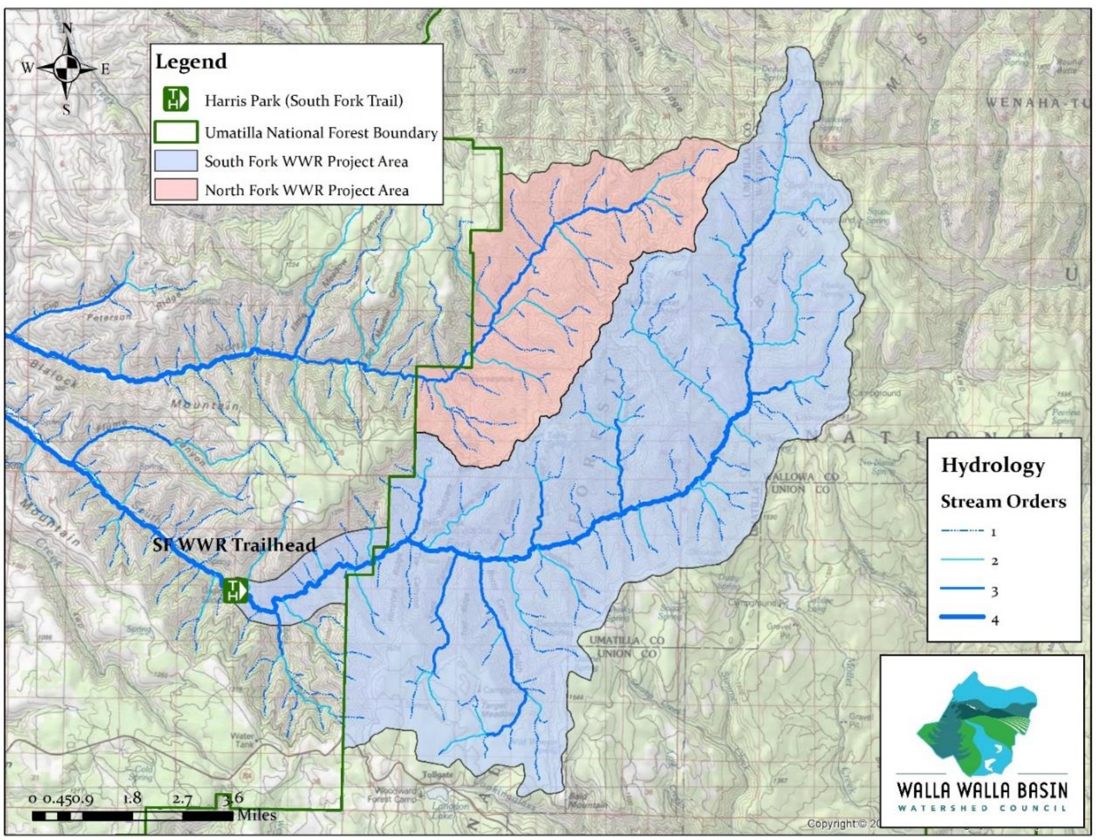
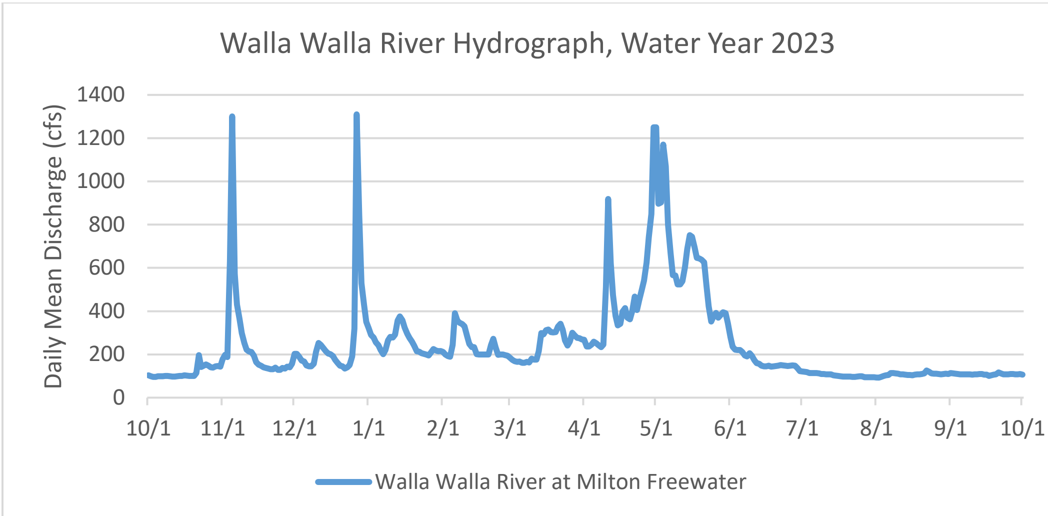



*Figure 1. Spring inventory project area. The inventory covered the upper Walla Walla Watershed located within the Umatilla National Forest and a smaller area of Bureau of Land Management lands.*



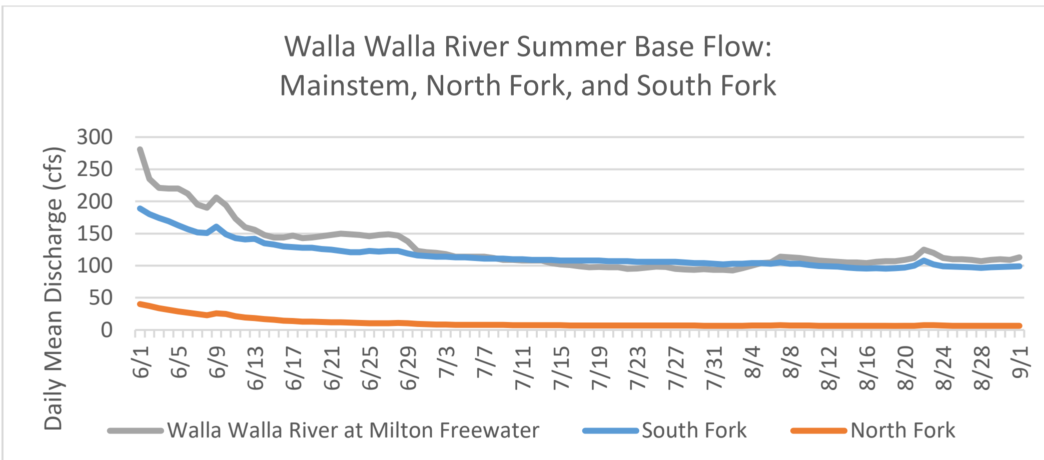




*Figure 2. Hydrograph showing Walla Walla River stream flow during water year 2023 (above). Relative contributions of flow from the North and South Forks of the Walla Walla River during the summer months (below). Data source: https://apps.wrd.state.or.us/apps/sw/hydro_near_real_time/. Station numbers 14010000, 14010800, and 14012000.*

Numerous springs emerging from basalt aquifers in the Blue Mountains provide the summer base flow in the Walla Walla River. The location and status of groundwater resources in the watershed are not well documented. A previous UNF study in 2008 was limited to mapped springs in the upper watershed (Johnson and Clifton, 2008). Baseline data describing the current conditions of groundwater resources in the upper Walla Walla Watershed are needed to protect groundwater-dependent ecosystems, determine climate-related impacts on water supplies, protect existing watershed functions, and guide efforts to reduce the impact of predicted climate changes on ESA-listed native fish and aquatic life.

Climate models predict changing temperature, precipitation and infiltration patterns in the Blue Mountains will impact water storage and reduce spring discharge in the coming decades (Holofsky and Peterson, 2017). Snowpack is the main source of groundwater recharge, feeding the basalt aquifers of our region. Climate models predict a shift from snow-dominated to rain-dominated hydrologic regime, potentially impacting the timing and rate of infiltration to the basalt aquifer, particularly in the mid-elevations of the Blue Mountains (Dwire et al, 2018). Reduced infiltration will likely affect the quantity of spring-derived inputs to the river, exacerbating existing low flow and high water temperature conditions during the summer months.

Findings from the 2008 UNF inventory also indicate that groundwater supply in the upper Walla Walla watershed is likely vulnerable to changing climate patterns. In their Spring Inventory Report, Johnson and Clifton (2008) suggest that the low conductivity and low pH values measured in the springs could indicate their proximity to the top of the infiltration zone. If the spring water has a relatively short residence time in the basalt aquifer before being discharged to the river, shifting precipitation regimes and reduced groundwater infiltration is likely to impact groundwater supply and correspondingly instream flows and water temperature.

## Impacts to Threatened and Endangered Species

ESA-listed bull trout, mid-Columbia River steelhead, and reintroduced Spring Chinook Salmon utilize the Walla Walla River and its headwater tributaries. The Umatilla National Forest Plan identifies the Middle South Fork and Upper South Fork Walla Walla River subwatersheds as ESA critical habitat. While the upper watershed offers high-quality habitat, conditions are less favorable downstream. Two major factors limiting the success of native fish species are a lack of in-stream flow and high summertime water temperatures on the valley floor.

Figure 3 shows the cool summer water temperatures in the South Fork Walla Walla as it emerges from the mountains onto the valley floor.

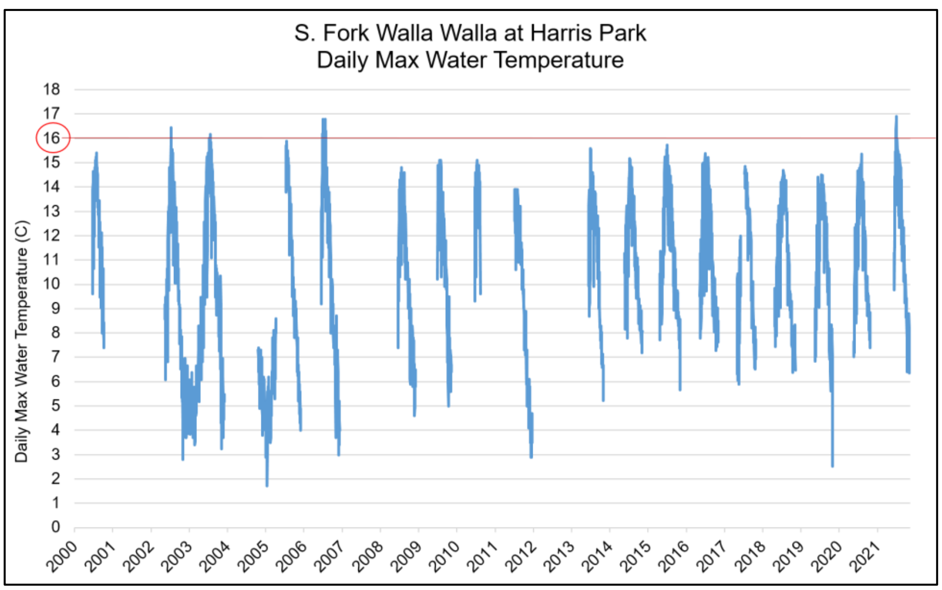



*Figure 3. Water temperature collected by WWBWC in the S. Fork Walla Walla at Harris Park as it leaves the mountains.*

Figure 4 shows summer water temperature in the Walla Walla near Milton Freewater and at the lower levee near the OR/WA state line. The red line shows the year-round core cold water habitat criterion for that reach described in the Walla Walla Subbasin Stream Temperature TMDL (ODEQ, 2005). At the lower levee site, the river exceeds the temperature standard for much of the summer.

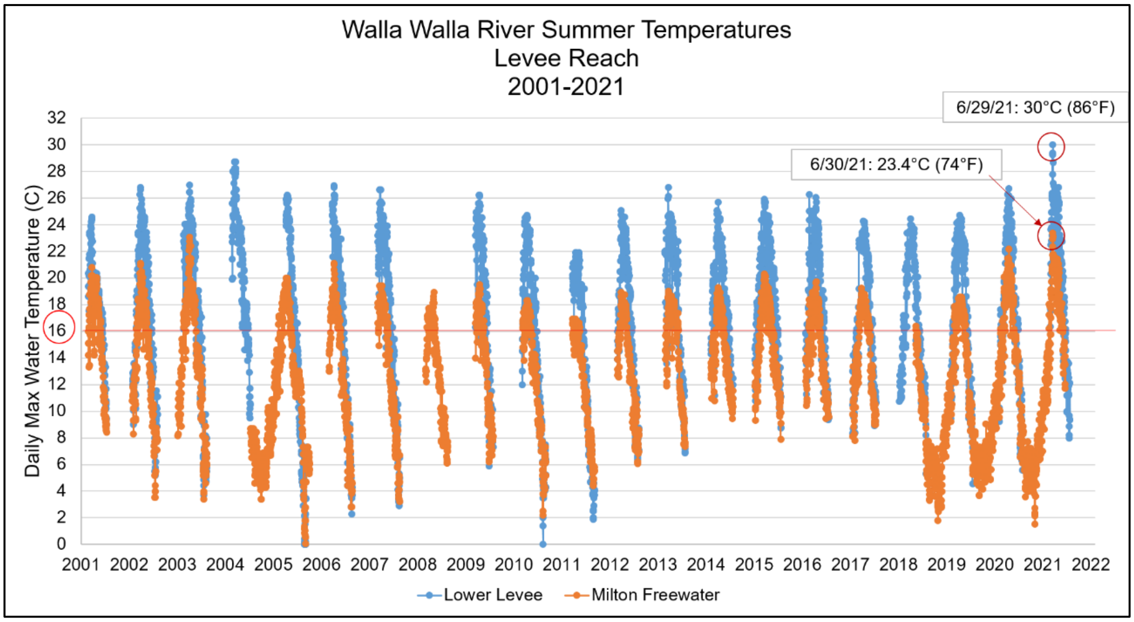



*Figure 4. Summer water temperature collected by WWBWC in the Walla Walla River at MIlton Freewater and downstream near the OR/WA state line (approx. 17 miles downstream of Harris Park).*

Since the Walla Walla River is impaired for both summertime flow and water temperature, groundwater inputs during the dry season are an invaluable component of habitat function. As climate impacts reduce the rate of cool groundwater inputs upstream, the already inadequate downgradient river conditions will worsen.

The project aims to benefit bull trout, spring Chinook salmon, and Mid-Columbia steelhead by providing resource managers with the data needed to understand, plan for, and adapt to climate-related impacts on water supply, instream habitat, and water temperature in the Walla Walla River. Reduced supply of the cool, clean water provided by upgradient basalt springs would exacerbate the seasonal water temperature and low flow impairments documented by the Walla Walla Subbasin Plan (NPCC, 2004) and state and federal regional recovery plans for bull trout and steelhead (ODFW, 2010; NMFS, 2009; USFWS, 2015). Findings concerning the status and condition of the watershed's groundwater sources will allow local managers to monitor trends and, as needed, develop resiliency plans to reduce the climate change impacts on native fish species in the Walla Walla River.

The baseline data describing the status of groundwater sources supplying the Walla Walla River summertime base flows will support trend monitoring to determine the vulnerability of water supply to climate changes. Significant investments of time and funding are being made downstream to improve conditions for aquatic species. The success of those efforts depends on an ongoing supply of cool, clean water from the upper watershed. Data-driven strategies are needed to plan for and mitigate climate-related impacts on summertime flow and water temperature. A clearer understanding of source water status and trends is vital as local partners, state, and federal agencies work to protect existing ecosystem functions and reduce limiting habitat factors for species of concern in the Walla Walla Watershed.

## Project Partners

Walla Walla Basin Watershed Council (WWBWC) is a non-profit organization whose mission is to collaborate with the local community and natural resource managers to enhance, restore, and protect our native aquatic populations, watersheds, and habitat while maintaining a healthy economy.

The project area is located on BLM land (Baker District) and the UNF, which is managed by the Walla Walla Ranger District. The land was ceded in 1855 by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR). The Walla Walla Watershed is ecologically and culturally significant to the Tribes, serving an integral role in CTUIR's First Foods and River Vision.

Funding was provided by the Oregon Watershed Enhancement Board, the EPA's 319 program administered by the Oregon Department of Environmental Quality[1], and the Bonneville Power Administration.

# Methods

WWBWC received approval from the BLM and coordinated with UNF staff to obtain a special uses permit to conduct the LiDAR flight and field inventory of groundwater-dependent ecosystems (GDEs) on the national forest. WWBWC hired Eagle Mapping, Inc. to collect LiDAR data covering 126 square miles of the upper Walla Walla watershed. Data were analyzed to produce high-resolution topographic maps of the project area and were shared with project partners.

To locate previously undocumented spring sources, WWBWC staff used the National Hydrography Dataset (NHD), DOGAMI and USGS geology maps (Figure 5), high-resolution topographic maps created from the LiDAR data, and location data from WWBWC's 2021 aquatic habitat inventory. In the office, we identified target areas for reconnaissance, and field staff then traveled to the potential spring

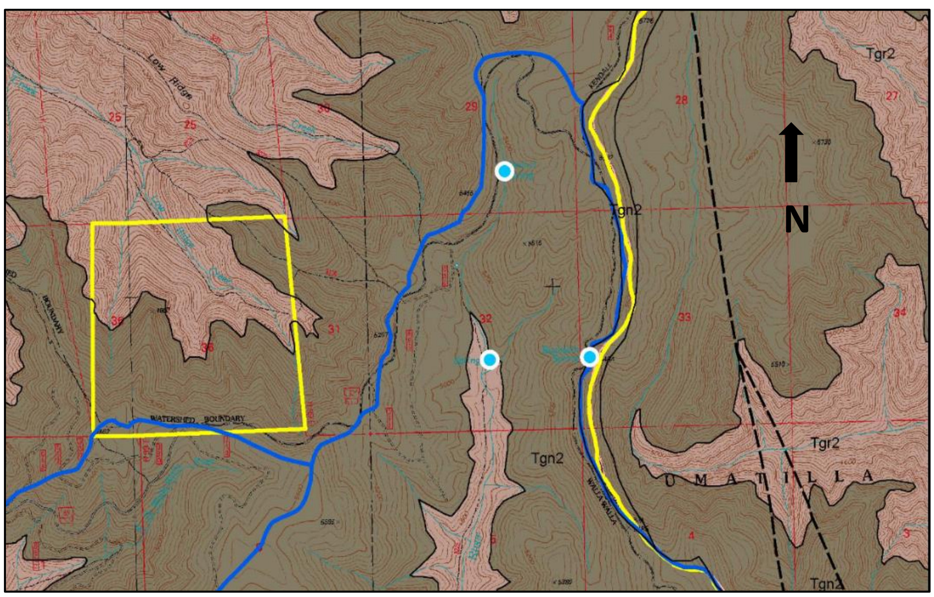



*Figure 5. Geologic map showing the watershed boundaries (solid blue lines), geologic units (colored areas), contacts (solid black lines), faults (dashed lines), and previously mapped springs (blue dots) in the uppermost portion of the upper Walla Walla watershed.*

[1] This Project has been funded wholly or in part by the United States Environmental Protection Agency under a federal grant issued under Section 319(h) of the Clean Water Act. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

sites. The upper watershed boundary is accessible by Forest Service roads, but most of the interior is accessible only on foot.

Field teams documented spring locations using iPhone GPS and double-checked with a handheld Garmin eTrex 22x. Springs were characterized using methods described in the Forest Service document Groundwater-Dependent Ecosystems: Level 1 Inventory Field Guide (USDA, 2012 and an update in 2022). WWBWC field staff learned how to apply the protocol by attending training events hosted by Forest Service staff. These USFS methods are intended to document the location, size, and basic characteristics of ecosystems where groundwater emerges on the ground surface (springs and groundwater-dependent wetlands). The following information was collected: type of groundwater-dependent ecosystem (GDE), geologic structure type, vegetation, flow rate and pattern (Figure 6), water quality (water temperature, specific conductance, pH, and dissolved oxygen), disturbance and water use. Inventory data were collected from July to October to minimize the influence of precipitation and snowmelt on groundwater measurements.

WWBWC field staff entered and submitted the inventory data using an ArcGIS Online form developed by the Forest Service. Forest Service staff created a partner account for WWBWC so we could see and review our data in the USFS ArcGIS Online GDE Level 1 Inventory layer. At the end of each field season, USFS staff submitted data from the GDE data layer to the national data repository, which is the Springs Online Database hosted by the Springs Stewardship Institute (www.springsdata.org). Water quality data collected at spring sources were submitted to ODEQ's water quality database.

*Figure 6. Field teams used plastic sheeting to channel spring water for a volumetric flow measurement.*

## Springs Classification by Source Geomorphology

The 2012 USDA Level 1 GDE Inventory Field Guide uses the classification of spring types described in Springer and Stevens (2009). Between our 2021 and 2022 field seasons, the Forest Service released an update to the GDE Inventory Field Guide (USDA, 2022) that references a slightly modified classification system based on a 2021 Springer et al article called "Springs Ecosystem Classification." Both the 2009 and 2021 Springer articles classify springs based on the source geomorphology of each spring type. Figure 7 shows the six lentic spring types, and Figure 8 shows the six lotic spring types. Note in Figure 8, hillslope springs are subdivided into floodplain hillslope, called hillslope rheocrene on the data entry forms, and upland hillslope, which is simply called "hillslope" in the forms

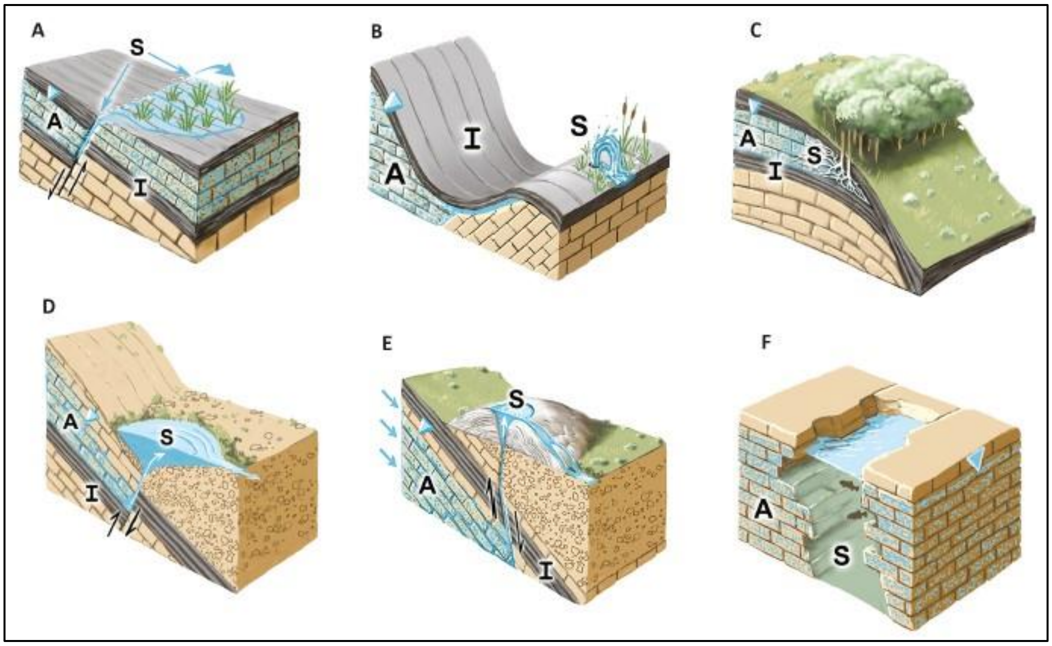



*Figure 7. Lentic spring types from Springer et al, 2021. (A) helocrene, (B) fountain, (C) hypocrene, (D) limnocrene, (E) mound-forming, and (F) semi-lotic fountain springs. A on each figure stands for aquifer; I, impermeable infiltration barrier; S, surface groundwater expression (springs source).*

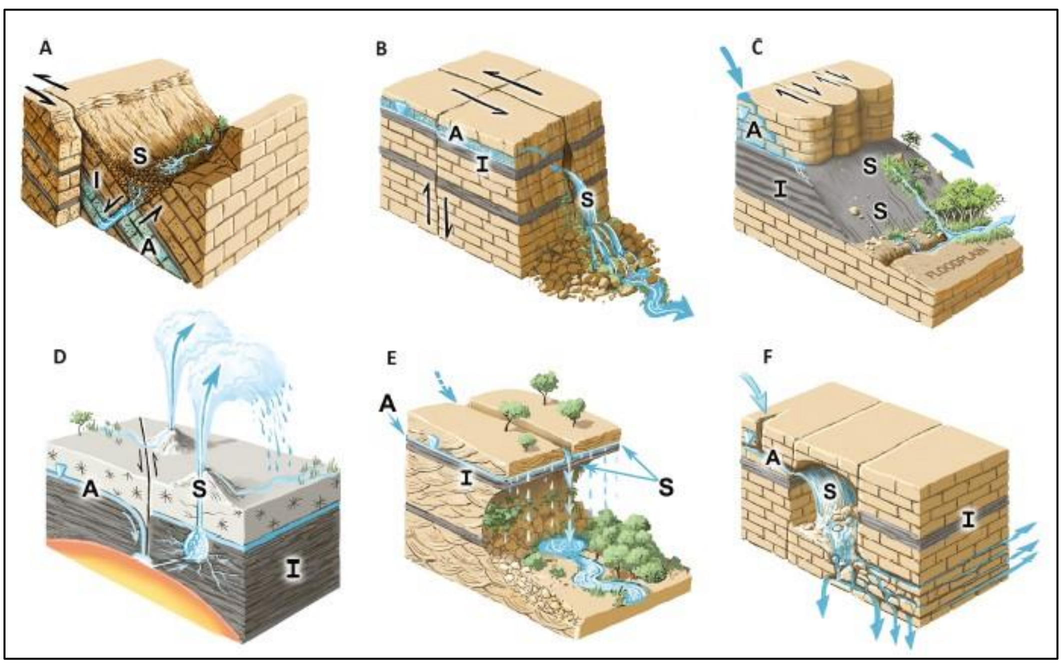



*Figure 8. Lotic spring types from Springer et al 2021. (A) rheocrene, (B) gushet, (C) floodplain vs. upland hillslope, (D) guyser, (E) hanging gardens, and (F) cave springs. A on each figure stands for aquifer; I impermeable infiltration barrier; S, surface groundwater expression (springs source).*

# Results and Discussion

## LiDAR

LiDAR data were collected at an average density of 16 pulses per meter and used to produce a high-resolution digital terrain model for 126 square miles of the upper Walla Walla Watershed (Figure 9). The resulting detailed surface topography was used in conjuction with geologic maps to identify potential unmapped springs. The front page of the LiDAR collection report from Eagle Mapping is attached in Appendix A. The complete report and LiDAR data are available from WWBWC upon request.

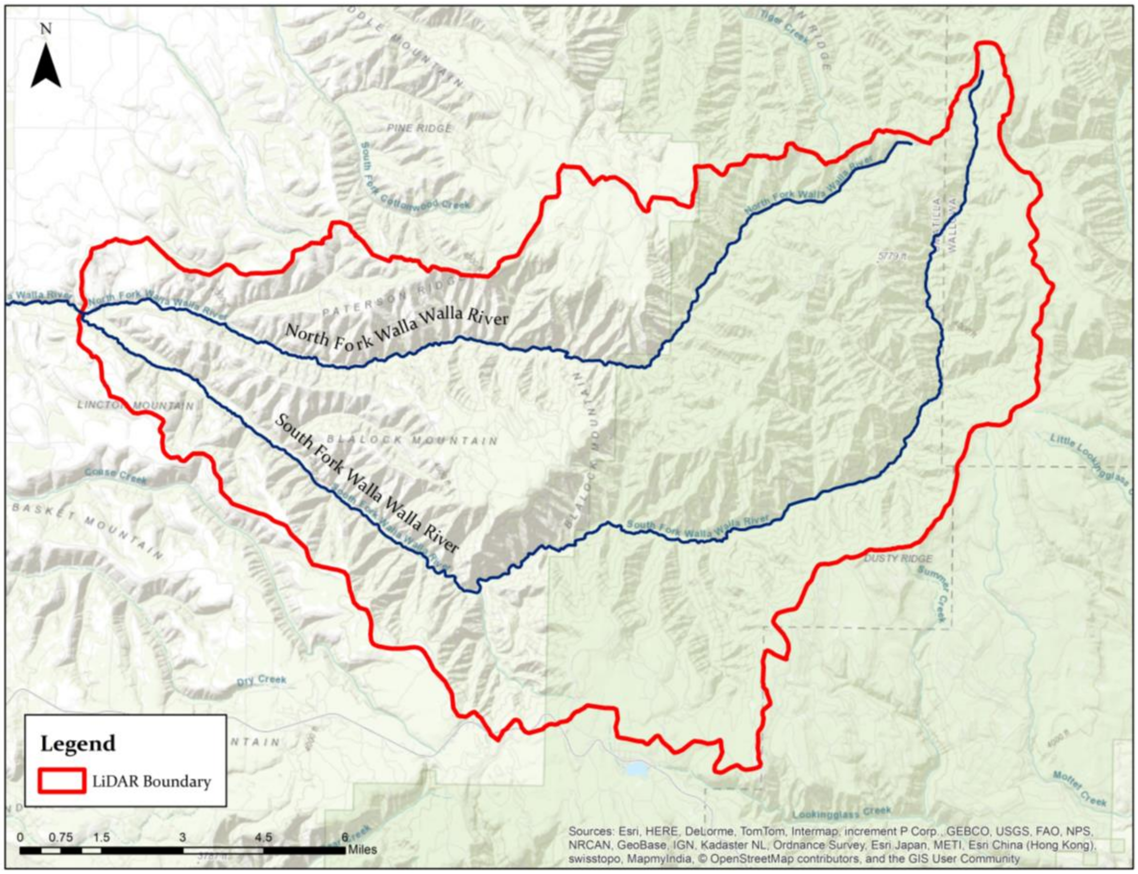



*Figure 9. LiDAR boundary covering 126 sq miles of the upper Walla Walla River Watershed.*

## Springs Inventory Results

Walla Walla River base flow is provided by hundreds of springs and seeps emerging from the basalt aquifer in the middle and upper watershed. WWBWC field teams mapped and inventoried 130 springs within the upper portion of the Walla Walla Watershed (Figure 10). Most of the springs were found in the South Fork subbasin (110 springs).

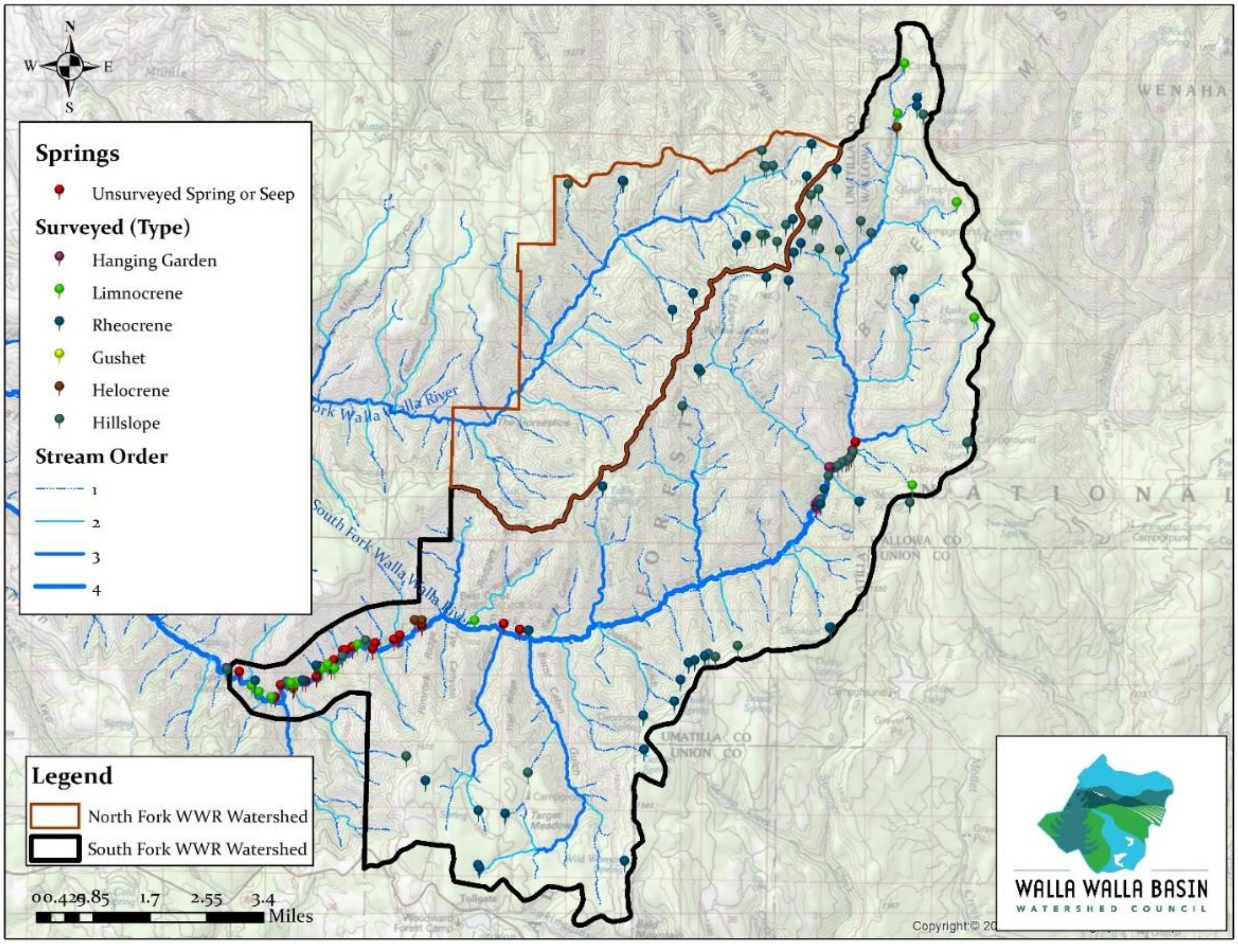



*Figure 10. Map showing the surveyed spring locations and types.*

## Geology

Figure 11 shows the surveyed springs overlaid on the geologic map of the project area. Most springs were associated with geologic unit contacts and structural faults.

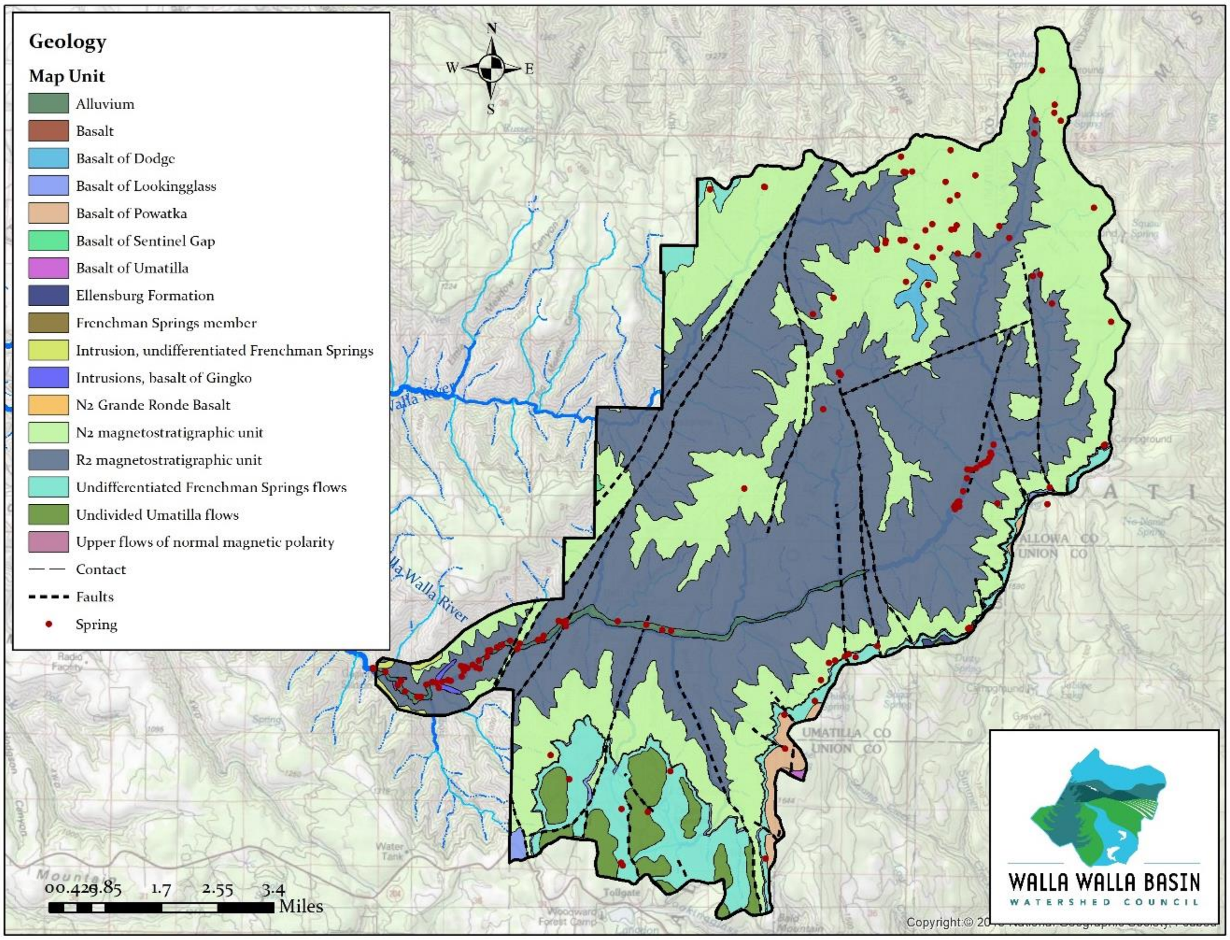



*Figure 11. Spring locations are overlaid on a geologic map of the project area.*

The upper Walla Walla Watershed is composed largely of the N2 and R2 units of Grande Ronde Basalt (light green and purple). Springs were located in each of these units as well as near the contacts with Frenchman Springs basalt flows near the watershed rim. These high-elevation springs were mostly hillslope and limnocrene springs (Figure 12). In the lower portion of the project area, over 40 surveyed springs were located near the contact of the hillslope unit Tgr2 (the R2 unit of Grande Ronde Basalt) and the South Fork's river alluvium/floodplain terrace. Springs types on the toe slope and floodplain terrace included hillslope, rheocrene, and limnocrene ponds.

*Figure 12. A spring-fed limnocrene pond near the watershed rim.*

Another area of notable spring emergence is the reach above and below the mouth of Reser Creek, located at the bottom of the Rough Fork Trail, which starts on the watershed rim near Mottet Campground. Field teams walked in the South Fork channel and observed numerous large-volume springs emerging from the steep hillslopes. Downstream of the Rough Fork Trail, the South Fork flows through a narrow basalt canyon covered with hanging gardens, gushets, and hillslope springs (Figure 13).

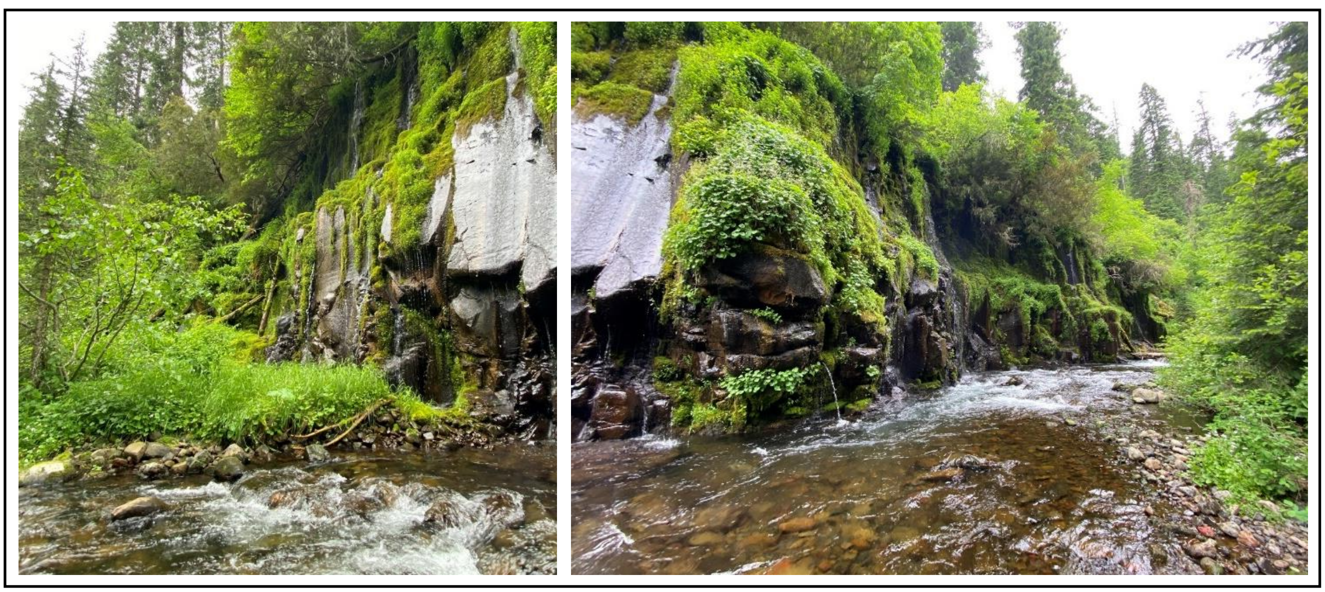


*Figure 13. Springs from a large complex of hillslope and hanging gardens flow into the S. Fork Walla Walla upstream of the Rough Fork Bridge and Reser Creek confluence.*

## Spring Locations and Source Geomorphology

Springs were present across the watershed, emerging near the upper ridges, mid-elevation hillslopes, and in the valley bottoms where the hillslope meets the floodplain terraces. The elevation of spring locations ranged from 2,083 to 5,561 feet.

Springs were classified according to their source geomorphology. Table 1 shows the springs inventoried in the North and South Fork subwatersheds grouped by geomorphic type.

*Figure 14. A limnocrene pond near the upper rim of the watershed.*

*Table 1. Surveyed springs were classified according to source geomorphology. Note that some of the rheocrene springs surveyed in 2021 may be classified as hillslope or hillslope-rheocrene according to the 2022 field guide.*

| Spring Type | Description | Subwatershed | | Total Number Surveyed |
|---|---|---|---|---|
| | | North Fork | South Fork | |
| Hillslope | Emerges from an upland hillslope | 5 | 14 | 19 |
| Hillslope-Rheocrene | Emerges on a floodplain hillslope | 7 | 20 | 27 |
| Rheocrene | Emerges in a draw | 8 | 32 | 40 |
| Hanging Garden | Diffuse flow from vertical bedrock cliff | 0 | 21 | 21 |
| Limnocrene | Forms open pool | 0 | 15 | 15 |
| Gushet | Focused spring flow from bedrock cliff | 0 | 5 | 5 |
| Helocrene | Wet meadow | 0 | 3 | 3 |
| | TOTAL | 20 | 110 | 130 |

## Spring Discharge

Measured flow at spring sites ranged widely from just a trickle to almost two cubic feet per second. Most spring flow measurements were less than five gallons per minute (gpm). The second most common flow range was from 5-50 gpm. Table 2 shows the number of springs in five different categories of flow rate. The average flow rate (48 gpm) was much higher than the median flow rate (5.5 gpm) because the 15 highest flowing springs produce a disproportionately high quantity of water compared with the majority of springs surveyed.

The highest flow rate we measured was from a complex of springs located at the toe of the south-facing hillslope north of the mouth of Burnt Cabin Creek. The spring complex was named Umpteen Springs and emerges from multiple, diffuse sources located near the geologic contact where R2 Grande Ronde Basalt meets the river alluvium on the floodplain terrace. Field crews measured 1.98 cfs (889 gpm) downstream of the confluence of several spring sources before the spring brook flowed into the South Fork Walla Walla. The measurement could have been influenced by recent precipitation. The College Place weather station recorded 0.23 inches of rain the day before we surveyed Umpteen Springs.

*Table 2. Summary of spring flow rates in the project area.*

| Flow Rate | Subwatershed North Fork | Subwatershed South Fork | Total Number Surveyed |
|---|---|---|---|
| > 1 cfs (~450 gpm) | 0 | 4 | 4 |
| 50 gpm – 1 cfs (~450 gpm) | 0 | 11 | 11 |
| 5 – 50 gpm | 5 | 43 | 48 |
| < 5 gpm | 11 | 46 | 57 |
| Too diffuse to measure | 4 | 6 | 10 |
| | North Fork | South Fork | |
| Average Flow Rate | 4 gpm | 55 gpm | 48 gpm |
| Median Flow Rate | 2.4 gpm | 6.5 gpm | 5.5 gpm |
| Total Flow Rate of Surveyed Springs | 63 gpm (0.1 cfs) | 5,610 gpm (12.5 cfs) | 5,673 gpm 12.6 cfs |

Of the four springs with the greatest flow rates, two were located in the Tgr2 (R2 unit of Grande Ronde Basalt), and two were found at the contact of Tgr2 and the river alluvium. All four of these were located in close proximity to a fault.

## Water Quality

In general, the spring water sampled was cool, clear, and had a neutral pH.

Table 3 shows the range, average, and median water quality values. The spring water chemistry was similar to measurements taken in the South Fork Walla Walla River. Figure 15 shows WWBWC staff collecting data.

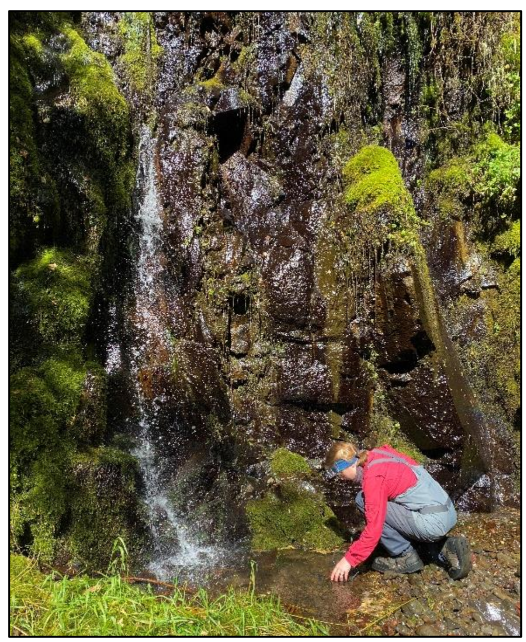


*Figure 15. Left: WWBWC staff collect water from a gushet spring. Right: Staff place water quality sensors directly into a spring-fed pond to measure water temperature, conductivity, pH, and dissolved oxygen.*

*Table 3. A summary of water quality measurements from spring sources and the S. Fork Walla Walla River.*

| Parameter | Range | Average Value | Median Value | South Fork Walla Walla River* |
|---|---|---|---|---|
| Specific conductance | 9.9-121 µs/cm | 56.4 µs/cm | 57.1 µs/cm | 65.2 µs/cm |
| Water temperature | 2.6-19.0 °C | 7.4 °C | 6.6 °C | 10.0 °C |
| pH | 5.4-8.5 | 7.0 | 7.1 | 7.3 |
| Dissolved oxygen | 1.1-11.5 mg/l | 8.7 mg/l | 9.5 mg/l | 10.0 mg/l |

* Measurements taken in July and August 2021

## Historical Data Comparison

At six spring locations, we were able to compare current conditions to UNF data collected in 1979 and 2008. Tables 4 and 5 provide a comparison of the datasets. Flow measurements in 2021-22 were notably higher than in 2008 and, at 4 of 6 sites, higher than the 1979 measurements. Two of the sites are developed springs, and in both cases the development occurred prior to 1979. The reason for the observed flow variation is uncertain. Historical snowpack records show higher April 30 snow water equivalent in 2008 compared with 2021 and 2022. Stream flow data in the South Fork Walla Walla River show higher summer flows in 2008 and 2021 and lower in 1979 and 2021 (Figure 16). More data are need in order to identify time-dependent groundwater patterns.

With the exception of Whisky Spring, conductivity measurements were similar. Variarions at Whiskey and Wild Woman could be due to the influence of recent snow melt on the measurements taken in June 2021 (Table 5). At five out of six sites, water temperature was higher in 2021-22 than in 2008. Measurements of pH did not vary widely between the 2008 and 2021-22 inventories.

*Table 4. Comparison of measurements taken in 2021-22 to data collected in 1979 and 2008.*

| | Flow Rate (l/s) | | | Sp Conductance (µs/cm) | | Water Temp (°C) | | pH | |
|---|---|---|---|---|---|---|---|---|---|
| | 1979 | 2008 | 2021-22 | 2008 | 2021-22 | 2008 | 2021-22 | 2008 | 2021-22 |
| Deadman Spring* | 0.57 | 0.06 | 0.2 | 33 | 32 | 4.6 | 3.8 | 6.5 | 6.1 |
| Gabriel Spring | 0.25 | 0.01 | 4.8 | 32 | 22 | 8.9 | 12.5 | 7.0 | 6.0 |
| Husky Spring | 0.13 | 0.06 | 0.8 | 47 | 31 | 2.5 | 3.0 | 6.3 | 6.8 |
| Skookum Spring | 0.19 | 0.03 | 0.5 | 37 | 41 | 2.3 | 4.4 | 7.3 | 7.7 |
| Whiskey Spring | 0.06 | 0.03 | 0.5 | 95 | 22 | 3.2 | 5.6 | 5.8 | 5.8 |
| Wild Woman Spring* | 0.06 | 0.01 | 0.04 | 80 | 24 | 6.0 | 6.6 | 5.7 | 6.1 |

* Indicates a developed spring

*Table 5. Survey dates of springs visited both in 2008 and in 2021-22.*

| Site Name | 2008 Survey Date | 2021-22 Survey Date |
|---|---|---|
| Deadman Spring | 10/1/08 | 6/28/21 |
| Gabriel Spring | 10/1/08 | 6/8/21 |
| Husky Spring | 10/22/08 | 8/9/22 |
| Skookum Spring | 10/22/08 | 7/27/22 |
| Whiskey Spring | 10/22/08 | 6/28/21 |
| Wild Woman Spring | 10/1/08 | 6/28/21 |

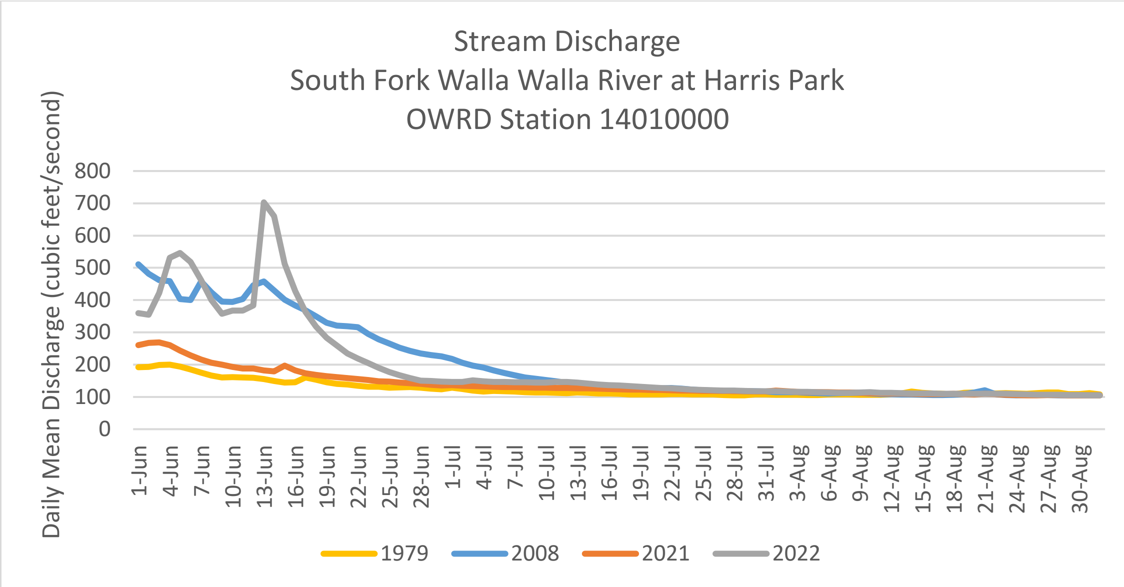



*Figure 16. Daily mean discharge in the South Fork Walla Walla River at Harris Park during the summers of 1979, 2008, 2021, and 2022. Data source: https://apps.wrd.state.or.us/apps/sw/hydro_near_real_time/display_hydro_graph.aspx?station_nbr=14010000.*

## Groundwater Age and Climate Change Impacts

In collaboration with USGS, WWBWC collected 18 water samples at spring sources and downgradient spring brooks for water dating using stable isotope analysis. Results will be published with the Walla Walla Basin Groundwater Study report produced by USGS, Oregon Department of Water Resources and Washington Department of Ecology. Field measurements of specific conductance can provide a clue about groundwater residence time. Much depends on aquifer geology, but water that has been underground for a longer time period will often have a higher conductivity due to mineral dissolution over time. Overall, the conductivity of spring water in the upper Walla Walla Watershed is relatively low, suggesting that the groundwater supplying the springs has had a short residence time underground.

Figure 17 shows the relationship between spring elevation and the specific conductivity measured in the field using a handheld meter. Although wide variation exists, the higher elevation springs we surveyed have a lower specific conductance than springs emerging lower in the watershed. These findings are consistent with data from the 2008 Spring Inventory Report

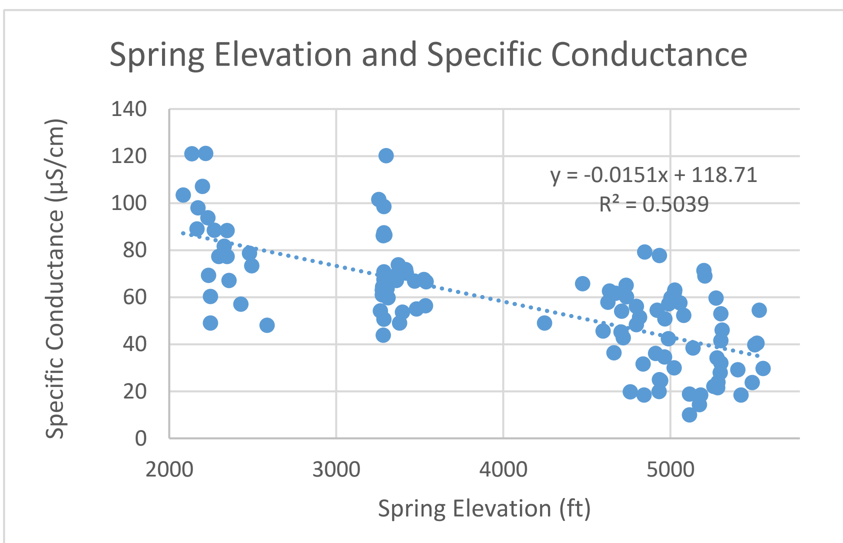



*Figure 17. Relationship of specific conductivity and the elevation of springs in the project area. Most springs emerging above 4,000 ft have lower specific conductivity compared to springs in the lower elevations of the project area.*

(Johnson and Clifton), which suggested the low conductance and pH values they measured could indicate a close proximity to the infiltration zone.

Forthcoming data about the age of spring water will inform climate change resilience planning for the Walla Walla Basin. Stream gage data from the North and South Forks of the Walla Walla show about 100 cfs of summertime flow, largely fed by groundwater springs. If indeed, the spring water is only a couple decades old, shifting precipitation regimes and reduced groundwater infiltration are likely to impact groundwater supply and correspondingly instream flows and water temperature within the next several decades.

## Tributary Flow Measurements

In addition to the springs inventory, field teams measured tributary flow in 30 spring-fed creeks. These flow measurements ranged from 0.01-15.8 cfs. For the subwatersheds producing substantial quantities of water, WWBWC produced catchment maps showing the drainage area and geologic features of each. Figure 18 shows the five drainage areas included in the analysis.

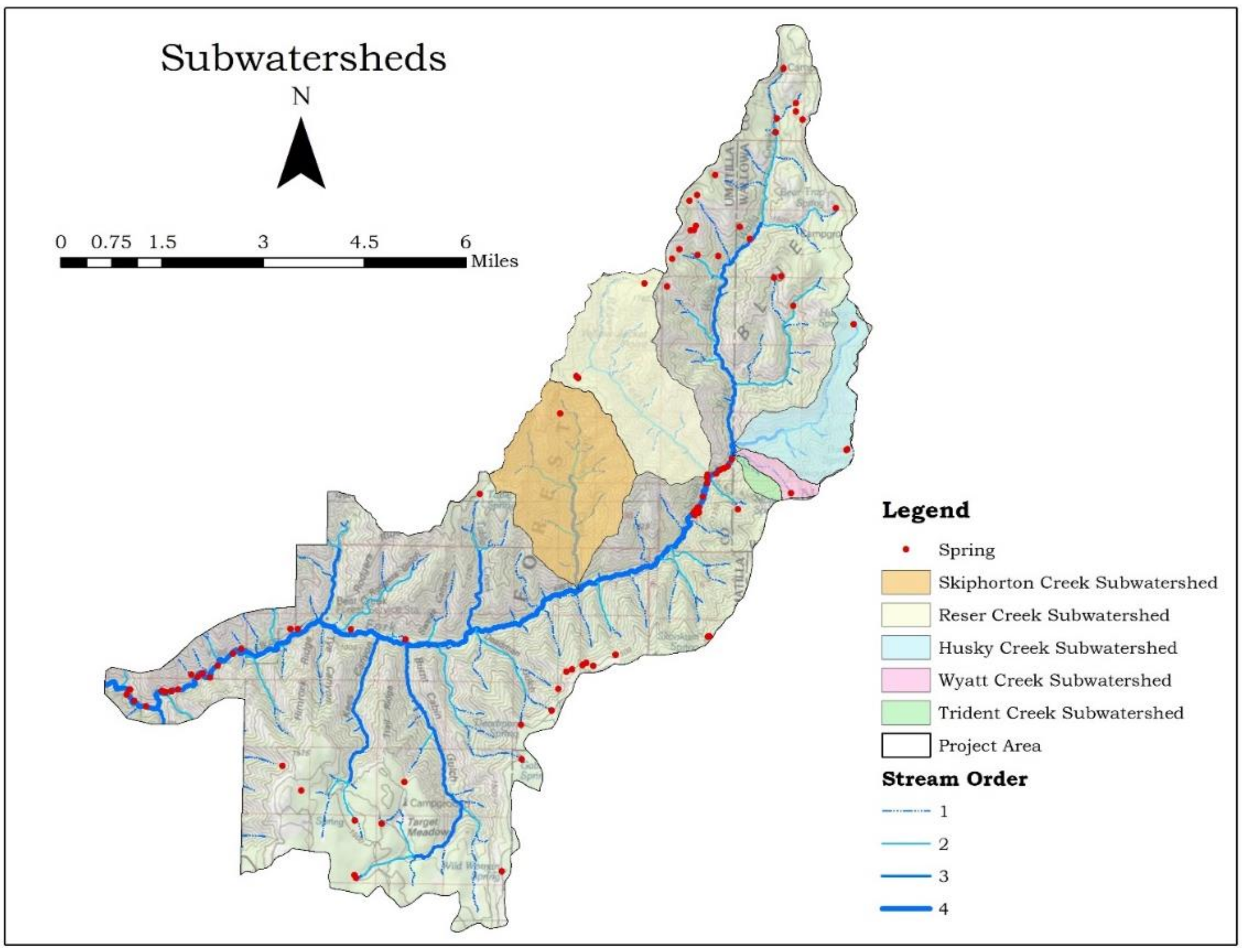



*Figure 18. Five subwatersheds contributing notably high tributary flows to the S. Fork Walla Walla River.*

Figure 19 shows the Skiphorton Creek subbasin, which is underlain largely by the R2 Grande Rhonde basalt unit. The one surveyed spring contributes just a trickle, but tributary flow near the mouth was measured at almost 16 cfs. Further inventory efforts are likely to identify numerous springs along the contacts and faults in this drainage. For this continually flowing streams like Skiphorton, identifying discrete areas of groundwater inputs along the stream bottom may not be possible or practical.

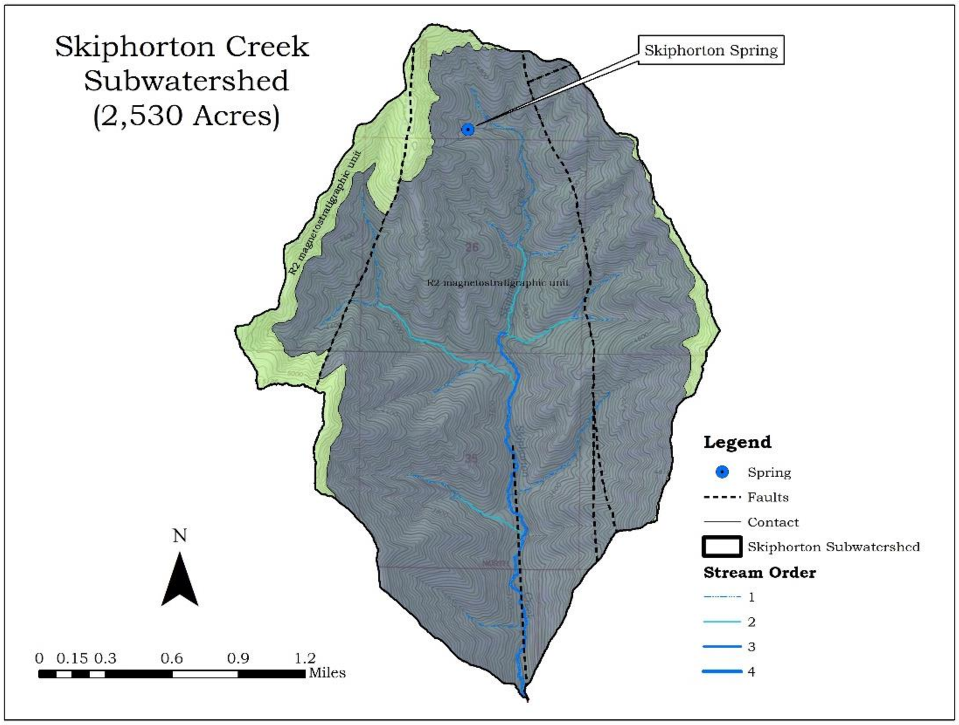



Figure 19. Skiphorton Creek watershed.

The Reser Creek subwatershed provides the second largest tributary flow, measured near the mouth at 5.2 cfs. Figure 20 shows the surveyed springs along with the two types of Grande Ronde basalt, the R2 and N2 units, and faults present in the subbasin.

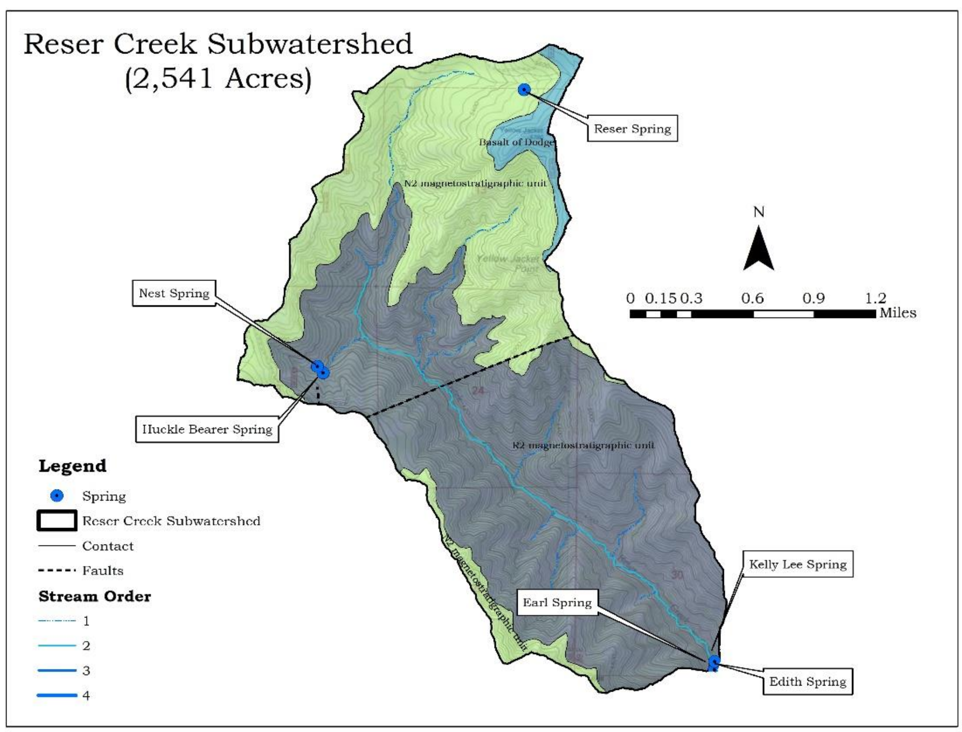



Figure 20. Reser Creek subwatershed.

Trident Creek subwatershed is a small drainage with steep topography. On the USGS quad map it is an unnamed tributary but, for the purpose of this project, field staff named it Trident Creek. We didn't survey springs within this subbasin, but included it in the catchment analysis because of the 2.1 cfs flow rate measured just above its confluence with the S. Fork Walla Walla. Figure 21 shows the geologic units and a fault within the Trident Creek subwatershed.

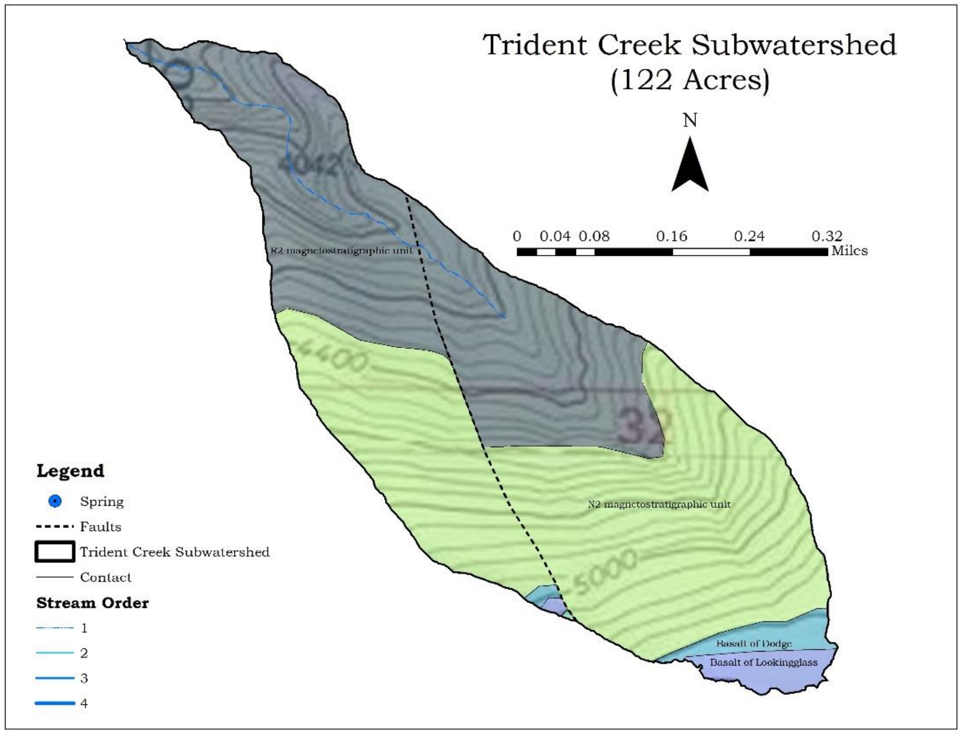



*Figure 21. Trident Creek subwatershed.*

The Wyatt Creek subwatershed is another unnamed tributary that we named for the purpose of data organization and analysis (Figure 22). It is a small drainage area that contributes a lot of spring-fed flow to the upper Walla Walla River. Field staff measured 3.71 cfs in Wyatt Creek just upstream of its confluence with the South Fork.

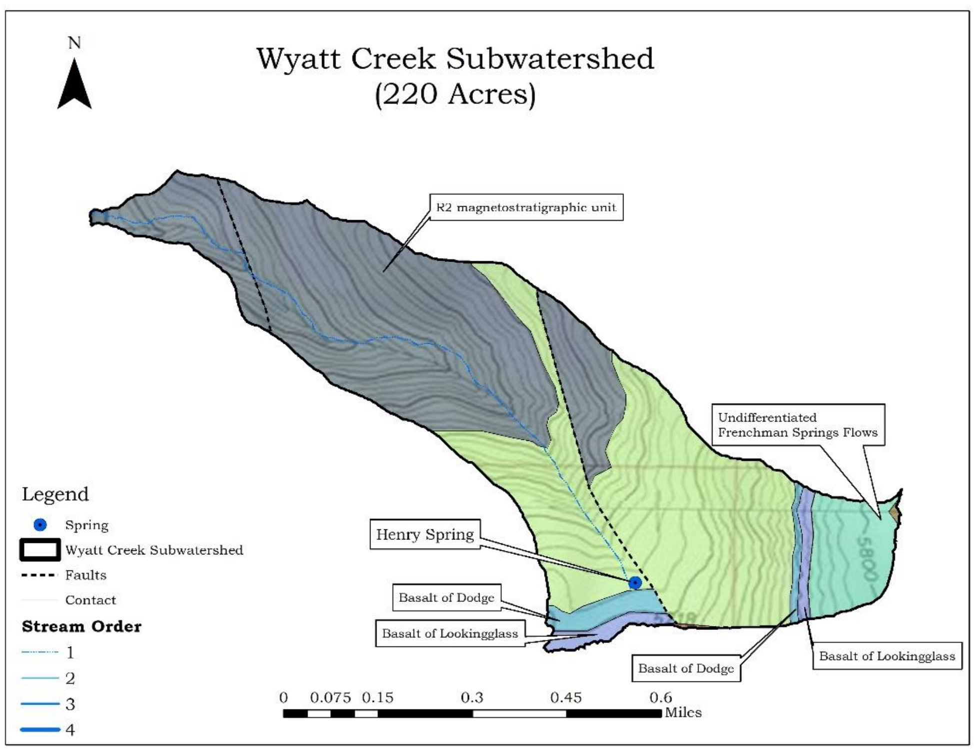



*Figure 22. The Wyatt Creek subwatershed is another small subbasin that contributes a significant amount of base flow to the South Fork Walla Walla.*

The fifth drainage in our catchment analysis is Husky Creek, which had a measured flow of 4.85 cfs near the mouth. Figure 23 shows a map of the subbasin with geologic layers, faults, and the two recently located and one previously mapped springs surveyed, all of which are located near the upper boundary of the drainage. We suspect additional springs may be found near one or both of the faults in the lower half of the Husky Creek subwatershed.

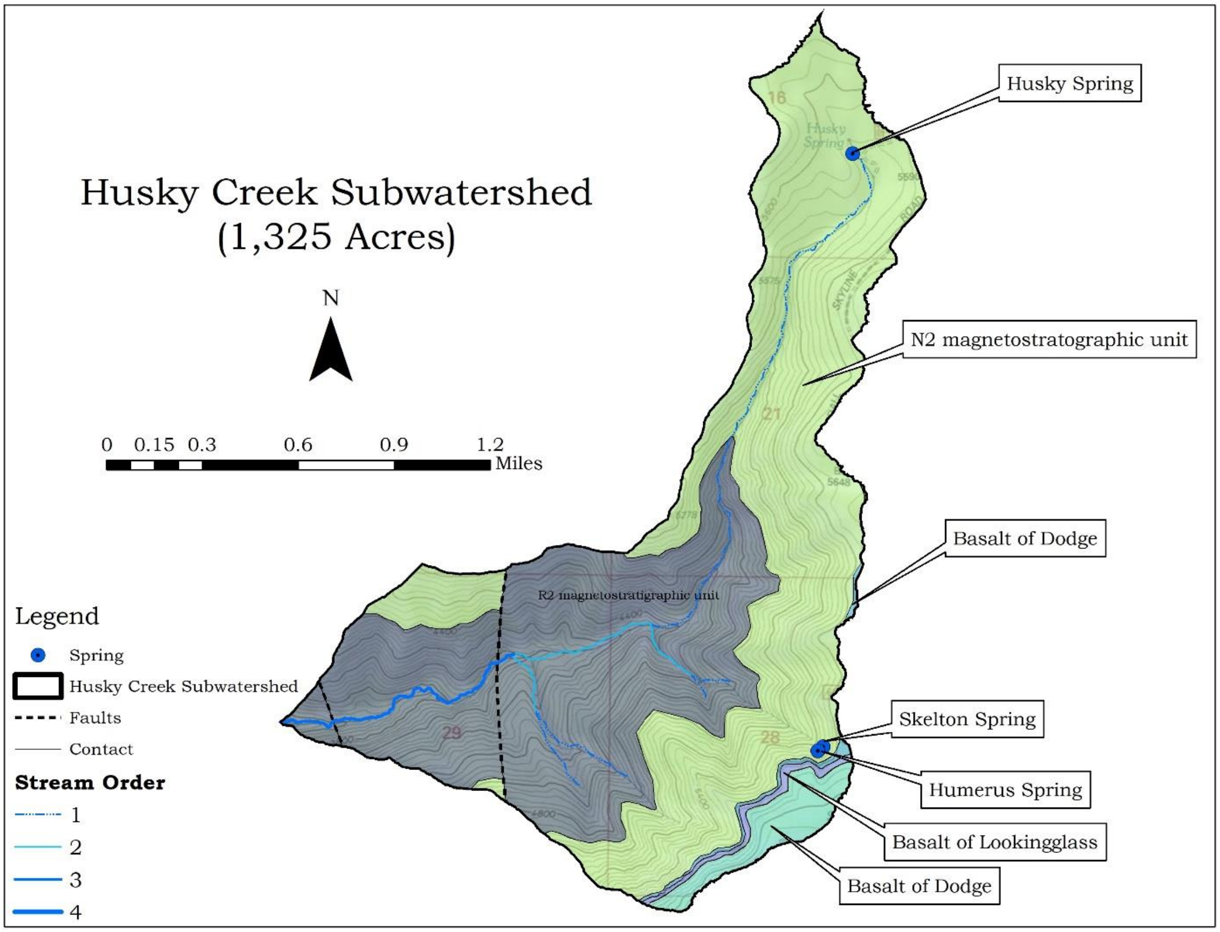



*Figure 23. A map of the Husky Creek subwatershed, which contributes 4.85 cfs of spring-fed flow to the South Fork Walla Walla.*

## Summary and Future Work

This baseflow assessment builds on previous US Forest Service work in the upper Walla Walla Watershed to catalog groundwater sources. The project documented many previously unmapped groundwater sources with the majority hillslope (35%) rheocrene (31%), and hanging garden (16%). The use of Lidar in conjuction with geologic mapping supported the location and survey of unmapped springs. Springs were associated with geologic unit contacts and structural faults. Conductivity differences suggest shorter residence time in higher elevations. The tributary flow measurements, however, suggest the need for additional work to produce a complete inventory of groundwater sources providing base flow to the Walla Walla River. Future work should focus on locating and surveying springs in the Skiphorton, Reser, Trident, Wyatt, and Husky subbasins. Stream survey data show additional unsurveyed springs in the upper North Fork drainage.

The USGS age-dating and groundwater study report and collaboration with the UNF and CTUIR will help to determine the time interval between infiltration (snowmelt/precipitation) and emergence as surface flow in the upper Walla Walla watershed. Future work could include a project to evaluate the proportion of snowmelt and rainful in the project area emerging locally as springs versus percoloating to deeper groundwater and recharges the basalt aquifer underlying the Walla Walla Valley.

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# Appendix A: LiDAR Acquisition Report

EAGLE MAPPING

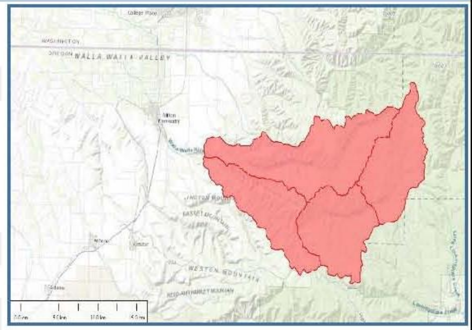
REPORT

EM #: 21-028

WALLA WALLA BASIN

**Client Name:** Walla Walla Basin Watershed Council

**Client Address:** 810 S. Main Street
Milton-Freewater, OR 97862
P.O. Box 68



**Specifications:**

| | |
|---|---|
| **LiDAR:** | 8 pulses/m² |
| **Imagery:** | none |
| **AOI:** | ~ 327 sq. km |

MAP PROJECTION

| | |
|---|---|
| **Projection:** | UTM 11N |
| **Horizontal Datum:** | NAD83(2011) |
| **Vertical Datum:** | NAVD88 |
| **Geoid:** | GEOID18 |
| **Units:** | meters |
| **EPSG:** | 6340 |

PRODUCT DELIVERABLES

| Product | Resolution/Type | Delivered As | File Format |
|---|---|---|---|
| Full Point Cloud | ≥ 8 ppm | prj tiles | LAZ v1.4 (.laz) |
| DTM | 1.0 m | prj tiles | ERDAS Imagine (.img) |
| DSM | 0.5 m | prj tiles | ERDAS Imagine (.img) |
| Intensity Rasters | 0.5 m | prj tiles | ERDAS Imagine (.img) |
| Metadata | FGDC compliant | per deliverable | HTML (.html) |
| Trajectory Files | txyzrpy | per swath | ASCII (.txt) |
| Tile Layout | 1000 m | USGS Index | ESRI Shapefile (.shp) |
| Boundary | | per area | ESRI Shapefile (.shp) |

ACQUISITION DETAILS

| | |
|---|---|
| **Flight Date(s):** | June 13, 2021 |
| **Aircraft:** | PA31 Piper Navajo |
| **Flight Altitude:** | 1700 m (AGL) |
| **Flight Speed:** | 150 knots |

**Sensor Settings**

| | | | |
|---|---|---|---|
| **LiDAR Unit:** | Riegl VQ-1560II | **Swath Width:** | ~ 1900 m |
| **Scan Rate:** | 2 x 600 kHz | **Footprint Diameter:** | ~ 0.32 m |
| **Field of View:** | 58° | **Wavelength:** | 1064 nm |
| **Overlap:** | 55% | | |

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*Figure 24. First page of LiDAR acquisition report. The entire report is available for download. WWBWC is happy to share the LiDAR data upon request.*