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FINAL GROUNDWATER MONITORING REPORT

FALL CITY FLOODPLAIN RESTORATION, FALL CITY, WASHINGTON

Prepared for: Snoqualmie Tribe

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1 Well Installation

1 Introduction and Background

The Snoqualmie Tribe is a federally-recognized sovereign tribe and a signatory to the Treaty of Point Elliott of 1855 in which it reserved to itself certain rights and privileges and ceded certain lands to the United States. As a signatory to the Treaty of Point Elliot, the Tribe specifically reserved to itself, among other things, the right to fish at usual and accustomed areas and the "privilege of hunting and gathering roots and berries on open and unclaimed lands" off-reservation throughout the modern-day state of Washington (Treaty of Point Elliot, art. V, 12 Stat. 928). In 2021, the Snoqualmie Tribe applied for and received a Cooperative Watershed Management Grant from the King County Flood Control District, which is allocated by the Snoqualmie Watershed Forum. This grant supported the Fall City Floodplain Shallow Groundwater Well Monitoring project, for which this report is the final technical report. Abundant, cool, clean stream flows in the Snoqualmie River system are vitally important to the Snoqualmie Tribe, and in support of that, the goal of the Fall City Floodplain Shallow Groundwater Well Monitoring project, as described in the grant application, "…is to help improve understanding of how floodplain reconnection projects in the Snoqualmie Valley may influence local groundwater-surface water interactions, and potentially support streamflow." In particular, the Groundwater Monitoring project was designed to investigate some types of effects of the planned Fall City Floodplain Restoration Project.

The King County Water & Land Resources Department (WLRD) began construction on the Fall City Floodplain Restoration Project ("Restoration Project") in the summer of 2022 and construction was completed in the fall of 2023. The Restoration Project location and major elements are shown on Figure 1. This project included removal of the Barfuse Levee and the Haffner Revetment, excavation of new side channels, rock removal, addition of large wood and engineered log jams (ELJ's), regrading, construction of a setback revetment to project the new alignment of Neal Road SE, and other elements.

The purpose of the Restoration Project is to help address recovery goals for four species listed under the Endangered Species Act. Chinook salmon, bull trout, and steelhead trout are threatened and the Puget Sound Southern Resident Orca population is endangered. These species are part of northwest heritage and important for the culture, economy, and food sources of local tribes. This project and previously-implemented projects, such as the McElhoe Pearson Restoration Project and the Lower Tolt Restoration Project are addressing the habitat needs for Chinook recovery identified in the Snohomish River Basin Salmon Conservation Plan. The 2005 plan was supported by 14 local jurisdictions, one tribe, business representatives, citizen groups and various non-profit organizations. The plan was approved by the federal government in 2007.

The Restoration Project restored almost one-half mile of river edge habitat, restored the connection of the river to approximately 134 acres of floodplain, constructed an estimated 2,500 feet of floodplain side channel, controlled invasive weeds, and restored native plants on more than 80 acres. Setback facilities on both sides of the river will protect farmland and infrastructure that are outside the project footprint.

The Snoqualmie Tribe's Fall City Floodplain Shallow Groundwater Well Monitoring project conducted groundwater monitoring before and after construction of the Restoration Project in order to help improve understanding of how floodplain reconnection projects in the Snoqualmie may influence groundwater-surface water connections and affect

streamflow and river temperatures. Water level and temperature data were collected before and after construction of the Restoration Project to determine if there are significant changes resulting from the project and evaluate if floodplain restoration can increase streamflow and decrease river temperatures during low flow periods in late summer and fall.

The groundwater monitoring study includes installation of shallow groundwater wells within and near the Restoration Project and collection of groundwater elevation data for a period of two years, starting in October 2021 and ending in November of 2023. This report provides a summary and analysis of the data. The effects of the Restoration Project are not fully apparent at this time, and it is intended that King County WLRD will take responsibility for continued collection of groundwater data and evaluation of the data into the future.

2 Precipitation Data

Precipitation data was reviewed for two nearby King County rain gages. The Fall City rain gage is located a half mile south of the site at Latitude 47.56529 North and Longitude 121.89455 West at an elevation of 113 ft. The North Bend rain gage is located approximately 10.5 miles southeast of the Restoration Project location at Latitude 47.4854 North and Longitude 121.7158 West at an elevation of 740 ft.

Cumulative rain totals recorded at these location for the water years 2021 through the early part of 2024 are provided on Table 1 and illustrated on Figure 2. (Water years begin on October 1 of the previous year.) The Fall City rain gage provides a reasonably good estimate of the amount of precipitation at the Restoration Project location. The cumulative precipitation is considerably higher at the North Bend rain gage than the Fall City gage because it is higher in elevation and closer to the crest of the Cascades. The North Bend data are likely a good representation of average rainfall across the basin upstream of the Restoration Project.

Table 1: Summary of Precipitation Data

Water Year	Fall City Gage (in.)	North Bend Gage (in.)
2021	47	71
2022	60	92
2023	42	57
2024 (thru 12/8/23)	16	23

3 Timing of Construction Activities

Based on information provided by King County, left bank side channel excavation started on roughly July 28, 2022. The outlet was connected on August 11, 2022, and the inlet connections to the river were cut on August 23-26, 2022. The sandbag cofferdams across the outlet were progressively removed throughout September and the sandbag dams at the inlets were removed on October 18, 2022.

Construction on the right bank began in early June. A summary of activities is provided below:

6/5/23: Side channel excavation begins in middle and downstream portions of site. Side channel was separated into three cells by earthen plugs with groundwater seepage only visible in the upstream most cell.

7/3/23: 5 dewatering wells initiated to drawdown groundwater in vicinity of setback revetment. Pumped water discharged to Snoqualmie following treatment. Removal of the middle segment of the existing revetment begins.

7/10/23: Side channel outlet connected (dry connection). Setback revetment excavation begins near Neal Road

7/17/23: Diversion dam placed to mostly dewater downstream third of existing revetment. Diversion channel excavated around left split of mid-channel bar. Removal of downstream revetment segment begins. Removal of plug between downstream 2 cells of side channel (dry connection). Two dewatering pumps decommissioned.

7/22/23: Removed the diversion dam on this day which caused the water level in the river to drop below the “natural” level. The deep dredge to remove revetment toe rock significantly increased conveyance through that riffle section and would have lowered the pool elevation upstream by some amount. This may have contributed to the disconnection of the left back side channel around that same time.

7/24/23: Bank deflector log structure assembly begins. This involved a large (>5 ft) and sudden rise in water level in the excavation due to deep placement of logs and large rocks. Revetment removal begins in upstream segment of existing revetment.

7/26/23: 4 of 5 dewatering wells decommissioned with bentonite on this day.

7/31/23: Final dewatering well decommissioned. Deflector structure assembly and setback revetment construction continues.

8/7/23: Deflector structure construction completed.

8/14/23: Completion of the final (upstream) zone of existing revetment removal

8/28/23: Final earthen plug in right-bank channel removed. Groundwater in low flow channel drains downstream and infiltrates into lower portion of side channel. Side channel inlet excavation complete. Short sand-bag dam at inlet prevents surface flow water from entering the side channel. Water seeped into the channel and was present from the upstream (southern) end of the side channel north to a point about 150 feet north of MW-5. North of that point there was no surface flow.

9/21/23: The sandbag berm was removed and the channel flowed all the way to the outlet.

After construction the following observations were reported:

- At river flows of roughly 6,000 cfs at the Snoqualmie Gage, the right-bank side channel rises to a level where there is surface flow from the side channel to the oxbow near MW-1.
- Since construction was completed, the right-bank side channel has widened and deepened along the northern ~800 feet.
- Following the December 5, 2023 flood that peaked at about 23,000 cfs, log jams in the right-bank channel resulted in sediment deposition within the channel.

4 Groundwater Data Collection

Details of the well installation, including well logs, are provided in Appendix A. Locations of groundwater monitoring wells are shown on Figure 3. Dataloggers that measure water pressure and temperature were installed in the 12 wells and have collected hourly readings since installation. The dataloggers are Model 3001 Levelogger 5 Junior with a 33 ft range and are manufactured by Solinst Canada Ltd.

The water level elevations and temperature data are shown on Figures 4 and 5 for each of the wells. Figure 4 shows the data for the wells on the northeast side of the river (right bank) and Figure 5 shows the data for the wells on the southwest side of the river (left bank). The graphs for each well are laid out on the figure to generally represent their relative locations in the field, approximately arranged in relative location to each other.

Transducers were installed in MW-1, MW-2, and MW-5 on October 23, 2021, before a significant rainfall event began on October 28, 2021 and were able to record groundwater elevations typical of late fall before the rainy season. The remaining transducers were installed on October 29 or 31, 2021 after a significant rise in groundwater elevations due to heavy rainfall and flooding.

The dashed lines on the graphs indicate the ground surface elevation at the well locations. It is evident from the figures that multiple flooding events have occurred since the transducers were installed, including: October 29, 2021, a double peak flood in early November 2021, January 13, 2022, March 1, 2022, and November 5, 2022. Groundwater levels rose above the ground surface during all of these flooding events at MW-1, MW-2, MW-4, and MW-5, MW-10, and MW-11.

The biggest flood since monitoring was initiated occurred on March 1, 2022. Groundwater levels during this flooding event rose above the ground surface at all the wells except MW-8 and MW-9. The highest groundwater elevations (>90 ft above NAVD88) were observed at MW-7, MW-3, MW-10, and MW-11.

Between the middle of January 2022 and the end of February 2022, water levels declined continuously, indicating a period of winter drought with no significant groundwater recharge and minimal fluctuations in the river level.

Groundwater elevations were relatively constant during the spring of 2022, with a small decline during late April and a peak during the middle of June. June was uncharacteristically cool and wet in 2022. Between the middle of June and the end of October 2022, groundwater elevations dropped continuously with a total decline of approximately 5 to 6.5 feet. This summer/fall drought ended in early November 2022 with a significant precipitation/flooding event. This flood resulted in groundwater elevations in wells near the river that were as high as the March 2022 flood.

From November 2022 through March 2023, groundwater elevations were relatively stable, with one significant precipitation event in late December 2022. Groundwater elevations during the winter of 2023 are 1-2 feet lower than the winter of 2022. This is likely due to the much lower precipitation in 2023 compared with 2022.

In April and May 2023, groundwater elevations on the southwest side of the river and in MW-5 on the northeast side of the river rose about 2-3 feet relative to winter water levels, likely reflecting snowmelt from the mountains. Other than MW-5, the groundwater rise on the northeast side of the river has been less than 1 foot during the same period.

Groundwater elevations began falling at the end of May 2023 in all the wells, approximately one month earlier that in 2022. This difference was likely due to the hot dry weather in May of 2023 followed by a normal June and the cool and wet weather in June of 2022. Groundwater elevations continued to drop during the summer and by the end of the summer drought (September 19, 2023) the water level in most of the wells were slightly lower (about 0.5 ft) than the summer of 2022, even though the summer drought in 2022 lasted for another month. This difference may reflect the lower cumulative precipitation during water year 2023 compared with water year 2022.

5 Data Analysis

5.1 Groundwater Elevation Cross-Sections

Figure 6 shows groundwater cross-sections for six dates: February 26, 2022 (winter drought conditions), March 1, 2022 (highest flood), October 16, 2022 (end of summer drought), November 5, 2022 (flood), February 20, 2023 (typical winter conditions), and September 20, 2023 (end of summer drought). The locations of the cross-sections are shown on Figure 3. Cross-sections A-A' and B-B' are perpendicular to the river and show that groundwater was flowing away from the river during flood conditions and back towards the river during dry and normal periods. Cross-section C-C' shows that the groundwater gradient parallel to the river is generally relatively flat during flood conditions and steeper during dry and normal periods.

As shown on the C-C' cross section, the November 2022 flood was unusual because groundwater elevations were lower in the upgradient wells (MW-6 and MW-7) than the downgradient wells (MW-4 and MW-1). This is likely because the flood did not rise above the ground surface at MW-6 and MW-7 during this flood.

5.2 Groundwater Elevation Contours

Figures 7 shows groundwater contours on February 26, 2022, towards the end of the winter drought. Groundwater is flowing downstream parallel to the river and towards the river during this winter dry period.

Figure 8 shows groundwater contours on March 1, 2022, during a flood. Groundwater is flowing away from the river with a steeper gradient on the southwest side of the river and a flatter gradient on the northeast side of the river. This difference may be due to the greater extent of flooding on the northeast side of the river (MW-8 and MW-9, located on the southwest side of the river, were the only wells that were not flooded on this date).

Figure 9 shows groundwater contours on August 11, 2022 during the typical summer drought. Comparison of the water levels on this date with February 2022 (end of the winter drought) indicates that the hydraulic gradient is lower in the summer than in the winter and the groundwater gradient is more parallel to the river than towards the river. This difference may reflect the lower groundwater recharge rates in summer compared with winter conditions. Alternatively, the difference may reflect that August 11, 2022 is eight weeks into the drought while February 26, 2022 was about five weeks into the drought.

Figure 10 shows groundwater contours during a flood on November 5, 2022. Comparison with Figure 8 shows that the groundwater flow pattern during the November 2022 flood is different than the March 2022 flood. In March 2022, the groundwater gradient on the northeast side of the river is relatively flat. In November 2022, the groundwater gradient in the vicinity of MW-5, MW-4, and MW-1 is still relatively flat but the gradient in the vicinity of MW-6 and MW-7, as well as the gradient between MW-1 and MW-2, is significantly steeper. Furthermore, the groundwater gradient on the west side of the river is significantly steeper during the November 2022 flood than the March 2022 flood. As

discussed in the next section, the water levels in MW-6 and MW-7 peaked several hours after the water levels in MW-1 and MW-4. This steeper groundwater gradients in November 2022 may reflect that the pre-flood groundwater elevations were 3-4 ft lower in November 2022 than in March 2022 and tended to buffer the flood flows.

Figures 11 shows groundwater contours on February 20, 2023, following a period of typical winter precipitation without any recent flooding events. The water levels and flow patterns are similar to February 2022, which was a winter drought.

Figures 12 shows groundwater contours on September 20, 2023, at the end of the summer drought. Similar to October 2022, the hydraulic gradient is lower on this data than in the winter and the groundwater gradient is more parallel to the river than towards the river compared with winter conditions.

5.3 Comparison of Groundwater Elevations in Select Wells

Figure 13 shows comparisons of selected wells parallel to the river (MW-1, 4, 6, & 7) for the entire monitoring period, the March 1, 2022 flood, and the November 5, 2022 flood. Groundwater elevations generally decreased down-valley, but the water table was flat between MW-1 and MW-4 during both floods. During the November 5, 2022 flood, the water level in MW-7 eventually rose as high as in MW-1 and MW-4, but the peak in both MW-7 and MW-6 occurred several hours later than in the downgradient wells.

Figure 14 shows comparisons of selected wells perpendicular to the river (MW-9, 11, 12) on the west side of the river. Before July 2022, these hydrographs demonstrate that groundwater generally flows towards the river with a very flat gradient between MW-11 and MW-12. Starting in July 2022 (slightly before excavation of the left bank side channel) the water level in MW-11 began to deviate from the water level in MW-12 and by October, the water level in MW-11 was approximately a foot higher than in MW-12 and was actually slightly higher than the water level in MW-9. Following the onset of winter rains, the groundwater elevations in MW-11 and MW-12 began to merge and tracked closely all winter. A similar pattern was observed during the summer and fall of 2023. These water levels suggest that MW-12 may be completed in a very permeable zone that is connected with the new side channel on the left-bank. This only makes sense if the water level in the side channel is lower than the main stem in the summer (perhaps because it dries up in places) and at the same elevation in the winter when it is free running.

Figure 15 also shows comparisons of selected wells perpendicular to the river (MW-3, 8, 10) on the west side of the river. These hydrographs demonstrate that groundwater generally flows towards the river in this region of the site, except during floods, when it flows away from the river.

Figure 16 also shows comparisons of selected wells perpendicular to the river (MW-1, 2, 5) on the east side of the river. These hydrographs demonstrate that groundwater generally flows towards the river in this region of the site. During floods, the groundwater table is relatively flat, likely due to flood water rising above the ground surface at all three wells during floods. Groundwater elevations in MW-5 are

significantly more variable (i.e., “spikey”) than MW-1 and MW-2, likely due to closer proximity to the river.

5.4 River Stage Data

River stage data for SNO_03 was obtained from King County and is shown on Figure 17 from July 23, 2020 through November 12, 2023. As shown on Figure 3, SNO_03 is located near MW-11 on the opposite side of the river. The winter of 2021/2022 had higher floods than the winters of 2020/2021 and 2022/2023, consistent with the higher precipitation for that year, as shown in Figure 2.

As shown on Figure 17, the water level in MW-11 is usually slightly higher than SNO_03 through the dry season in 2022, suggesting a slight hydraulic gradient towards the river. Since that time however, the water level in MW-11 has generally tracked the water level in the river. During periods of flooding, the river stage has been generally higher than the water level in MW-11, indicating flow away from the river.

It is anticipated that the Restoration Project will change the elevation of the river bed and stage over time due to sediment deposition and expansion of the flow cross section. Figure 17 shows river stage as a function of river flow for different times of the year and different years. River flow is based on average daily flow at the USGS river gage[1] located just downstream of Snoqualmie Falls at 47.545102 North and 121.84234 West approximately 3 miles southeast of the Restoration Project. River stage is the average daily stage at SNO_03, located near the Restoration Project.

The relationship between stage and flow in the river can be affected by the recent precipitation and groundwater elevations in the floodplain. This is evident in Figure 17, where the lower flow data generally follows a tight linear trend with little scatter because it is less affected by precipitation events. More scatter is evident at higher flow rates which are more likely to be affected by precipitation events. Furthermore, stage versus flow data for August and September indicate that stage was significantly higher in 2020 and 2021 than in 2022 and 2023 for similar flow rates. A similar difference was observed for the October stage versus flow data. The flow data for these months indicate that 2020 and 2021 had numerous days with average flows greater than 1,500 cfs, which was not the case for 2022 and 2023. These data demonstrate that the stage-flow relationship can be affected by recent precipitation.

The February and March stage data suggests that the river stage was higher in 2021 and 2022 than 2023 for similar flow rates. This may reflect that 2021 and 2022 had higher precipitation than 2023.

The relationship between flow and stage appears to be significantly affected by recent precipitation history. It is anticipated that late summer flow and stage data, which is generally less affected by precipitation events, will provide the best indication of how river elevation changes over the years.

[1] https://waterdata.usgs.gov/nwis/dv/?site_no=12144500&agency_cd=USGS&referred_module=sw

5.5 Floodplain Gradients

Because it will spread out the river across the floodplain, it is expected that the floodplain restoration will reduce the hydraulic gradient of the river. Since groundwater responds to the water level in the river, it is likely that the Restoration Project will also reduce the hydraulic gradient in groundwater parallel to the river flow. Figure 18 shows the groundwater gradient between MW-12 and MW-3 and between MW-9 and MW-10 on the left bank of the river and between MW-7 and MW-1 on the right bank of the river. All three sets of wells demonstrate that the gradient becomes relatively flat (close to zero) during flooding events, due to flood water spreading across the floodplain.

The groundwater gradient between MW-12 and MW-3 fluctuated significantly during the rainy season before construction in the summer of 2022. This may reflect that MW-3 was closer to the river than MW-12 and groundwater levels responded more quickly in MW-3 than MW-12 as the river stage rose and fell. After construction, the left-bank side channel was much closer to MW-12 than the main channel and it appears that the groundwater levels in MW-12 and MW-3 are more synchronized. In addition, the gradient between the wells drops from an average of 10-12 ft/mile before construction to an average of 7-10 ft per mile after construction. The gradient has risen significantly since the end of July 2023, which did not occur in the summer and fall of 2022 until the beginning of October. This rise appears to coincide with the water level in MW-12 dropping below an elevation of about 77 ft, which occurred much earlier in 2023 than in 2022. It may be that the side channel near MW-12 becomes disconnected from the main stem of the river at this elevation.

The groundwater gradient between MW-9 and MW-10 is higher in the winter and spring and lower in the summer. Compared with the gradient in 2022, the gradient in 2023 between these wells appears to have less seasonal variability perhaps because MW-9 is better connected to the river since the left-bank side channel was constructed.

The groundwater gradient between MW-7 and MW-1 illustrates significantly less fluctuation than the gradients between MW-12 and MW-3 and MW-9 and MW-10, likely because MW-7 and MW-1 are further from the river. The groundwater gradient on these right-bank wells appears to be slightly less in 2023 compared with previous years, which may reflect the Restoration Project, or the lower precipitation in the 2023 water year.

5.6 Temperature Data Analysis

As shown on Figures 4 and 5, groundwater temperatures have generally ranged from 48°F to 58°F. Since monitoring began, most of the wells experienced a steady temperature decline from the beginning of the year through late spring, and temperature rising during the summer through late fall. Most of the wells have low temperatures in the range of 50°F to 52°F and high temperatures in the range of 53°F to 54°F.

MW-3 and MW-10 on the southwest side and MW-6 on the northeast side exhibited less seasonal variability (less than 1.5°F fluctuation) than the other wells. This pattern may reflect upward seepage from a deeper aquifer with no seasonal variability in temperature.

Some of the wells exhibited distinct temperature perturbations during floods (MW-5, MW-6, MW-7, and MW-10), generally spiking higher during the November floods and lower during the March 2022 flood. As shown in Figure 19, these perturbations do not reflect river temperatures at the time of the flood but can be explained by ground temperatures in the unsaturated zone. These perturbations may be due to vertical percolation of flood water flowing through relatively warm ground in November and relatively cold ground in March before reaching the saturated zone.

River temperature data was obtained from King County and is provided in Figure 19. Temperature data from site MS_06 is shown from September 8, 2021 through October 5, 2023. MS_06 is located at the Neal Road Boat Launch (also known as Richter's Boat Landing) approximately 1.25 miles north -northeast of the site. The river temperature varies significantly more than the groundwater temperatures, ranging from a low of 35°F in the winter to a high of 74°F in the summer of 2023. River temperature generally tracks with air temperature and is lowest in January/February and highest in July/August. In contrast, the temperatures provided in Figures 4 and 5 indicate that groundwater temperatures in most of the wells are lowest in June-July and highest in December-January, illustrating almost a six-month delay compared with river and air temperatures. This delay in groundwater temperatures compared with river temperatures can be explained by heat storage in the subsurface sediments.

Figure 19 compares river temperatures with groundwater temperatures in MW-02, MW-05, and MW-11. These wells have the largest seasonal variability. The temperature in MW-11 dropped 2-3 degrees more in the spring of 2023 than the spring of 2022 and can be explained by the construction of the left-bank side channel in the summer of 2022 and flow of river water between the side channel and the main stem. The river water is cooler than the subsurface in the winter and spring and warmer than the subsurface in the late summer and early fall. Since July 20th 2023, the temperature in MW-5 has climbed much faster than the same period in 2022. Similar to MW-11, this warming is likely due to the opening of the right-bank side channel and initiation of flow between the main channel and the side channel.

The seasonal low temperature in MW-2 was significantly lower in 2023 (~48°F) than 2022 (~51°F). MW-2 is not located between the main stem and a side channel and changes in the seasonal temperature fluctuation cannot be explained by the Restoration Project. The reason for the large temperature decline in MW-2 during the spring of 2023 is uncertain, but it is downgradient of a marshy oxbow to the east and there may be changes in flow through the oxbow that caused more surface water to enter groundwater upgradient of MW-2 in 2023.

The lowest temperature in MW-7 was 2 degrees warmer in 2023 compared with 2022. Similar to MW-2, there is an oxbow located up gradient from MW-7 and there may be changes in flow through the oxbow that caused the warmer temperatures in 2023. In the case of MW-7, the temperature increase is likely due to less surface water entering groundwater.

6 Summary

Twelve groundwater monitoring wells were installed to monitor groundwater elevations and temperatures before and after construction of the Restoration Project. The wells ranged in depth from 20 to 35 ft below the ground surface and were constructed with 10 to 20 ft of 2-inch diameter PVC slotted screen.

The geology at the site consists of fine-grained alluvium over coarse-grained alluvium. The coarse-grained alluvium was encountered at depths of 6 to 16 ft below the ground surface corresponding to an elevation range of 73.7 to 93.0 ft above NAVD88.

Water level and temperature data was collected at hourly interval in the 12 wells from the end of October 2021 to May 2023. The patterns observed to date and associated hypotheses include:

1. Five flooding events occurred during the monitoring period and many of the wells were flooded during these events.
2. Groundwater flow is away from the river during floods with a steeper groundwater gradient on the southwest side of the river and a flatter gradient on the northeast side of the river. This difference may reflect the larger spread of flood water on the northeast side of the river.
3. During normal river stages, groundwater flows downstream and towards the river.
4. Groundwater elevations during the 2023 water year were generally lower than in the 2022 water year, likely due to the significantly lower precipitation during water year 2023 compared with water year 2022.
5. The late summer/early fall river stage was almost a foot lower in 2022 and 2023 than in 2020 and 2021. This difference appears to be due to lower precipitation during these months in 2022 and 2023.
6. The groundwater gradient parallel to the river appears to have decreased slightly from 2021 to 2023. It’s possible that this decrease is due to the addition of two side channels that allow the river to spread out across the floodplain. Or it may be due to the lower precipitation in 2023 compared with 2022.
7. Groundwater temperatures have ranged from 48°F to 58°F. Flooding can cause groundwater temperatures to spike both up and down, depending on the season.
8. River temperatures have ranged from a low of 35°F to a high of 74°F and are generally lowest in December-February and highest in July-August.
9. Other than spikes due to floods, temperatures in most of the wells were lowest in June-July and highest in December-January, illustrating almost a six-month delay compared with river and air temperatures. This delay in groundwater temperatures compared with river temperatures can be explained by heat storage in the subsurface sediments.

10. MW-3 and MW-10 on the southwest side and MW-6 on the northeast side exhibited less seasonal variability (less than 1.5°F fluctuation) than the other wells. This pattern may reflect upward seepage from a deeper aquifer with no seasonal variability in temperature.
11. Following construction of the side channels, the temperatures in MW-11 and MW-5 exhibit significantly more seasonal variability than the other wells. The reason for this difference can be explained by the flow of river water between the side channels and the main stem. The river water is cooler than the subsurface in the winter and spring, and warmer than the subsurface in the late summer and early fall.

7 Conclusions and Recommendations

The Snoqualmie Tribe, with funding from a King County Flood Control District Cooperative Watershed Management grant, conducted groundwater monitoring before and after construction of the Fall City Floodplain Restoration project. The goal of this groundwater monitoring study was to improve understanding of how floodplain reconnection projects in the Snoqualmie may influence groundwater-surface water connections and affect streamflow and river temperatures. Groundwater data collection began in October 2021 and construction of the Floodplain Restoration project was conducted in the summers of 2022 and 2023.

Based on the analysis of the data collected to date, it is apparent that the Restoration Project has improved the connection between surface water and groundwater. This connection is best illustrated by the two wells, MW-11 and MW-5, located between the main stem of the river and the new side channels. The groundwater temperatures in these two wells are exhibiting significantly greater seasonal variability, likely due to groundwater flux between the side channels and the main stem.

Other than MW-11 and MW-5, it is unclear if the Restoration Project has significantly changed groundwater elevations. Evaluating change in groundwater elevations at this time is complicated by the fact that the precipitation in water year 2022 was much greater than in water year 2023 and we have not yet collected a full year of data since the Restoration Project was complete.

Although it is expected that the Restoration Project will result in more floodplain storage during floods and reduce peak river flows, this result cannot be parsed from the data due to the differences in flood flows and ambient groundwater elevations at the times of the various floods. It is also unclear at this time if the Restoration Project increased river flow during late summer and early fall when water levels are lowest. Future monitoring of water elevations and river flows may help to address these questions regarding flood attenuation and changes in summer low flows. However, it’s also possible that the effects may be too small to measure. Numerical modeling of the hydrologic system before and after the Restoration Project could evaluate how the project had affected flood flows and late summer low flows.

The most important observation from this study is that seasonal changes in groundwater temperatures tend to lag river and air temperatures by approximately six months due to the heat storage provided by subsurface sediments. Furthermore, creating groundwater flow between surface water channels can increase heat exchange between the river and the subsurface, as illustrated in Wells MW-11 and MW-5. Because of the six-month lag in subsurface temperatures, this heat exchange will reduce river temperatures in the summer and increase river temperatures in the winter.

The actual temperature impact on the river due to the increased heat exchange will be difficult to measure given the limited size of the Restoration Project. However, it may be possible to document the process by collecting temperature measurements along the river channel banks where groundwater is flowing into surface water. In addition, numerical

modeling of groundwater and heat transport could be conducted to quantify the temperature impacts.

The results of this study to date indicate that floodplain restoration projects that create increased groundwater flow between side channels and the main stem can reduce river temperatures during summer and late fall.

Additional years of groundwater data collection and analysis will provide much better information regarding the impacts of the Restoration Project on river flows and temperatures. This study was only funded for two years, but it covered the significant costs of monitoring well and transducer installation. Based on discussions with King County WLRD staff, it is intended that King County WLRD will take responsibility for continued collection of groundwater data at the site, and evaluation of the data into the future.

Figures

Natural Area

Neal Rd SE

Fall City-Carnation Rd SE (SR 203)

SE Redmond-Fall City Rd (SR 202)

Fall City

Existing Wetlands
OHWM
Project Area
Haffner Revetment Removal
Barfuse Levee Removal
Side Channel Excavation
Floodplain Swale
Large Wood and ELJs
Rock Removal
Impervious Area Removal
Setback Revetment
Hummocks
Flank Protection
Neal Road Realignment
Deflector ELS
Floodplain Roughening
LB Grading
RB and LB Embankments
Buried Log Structures

N

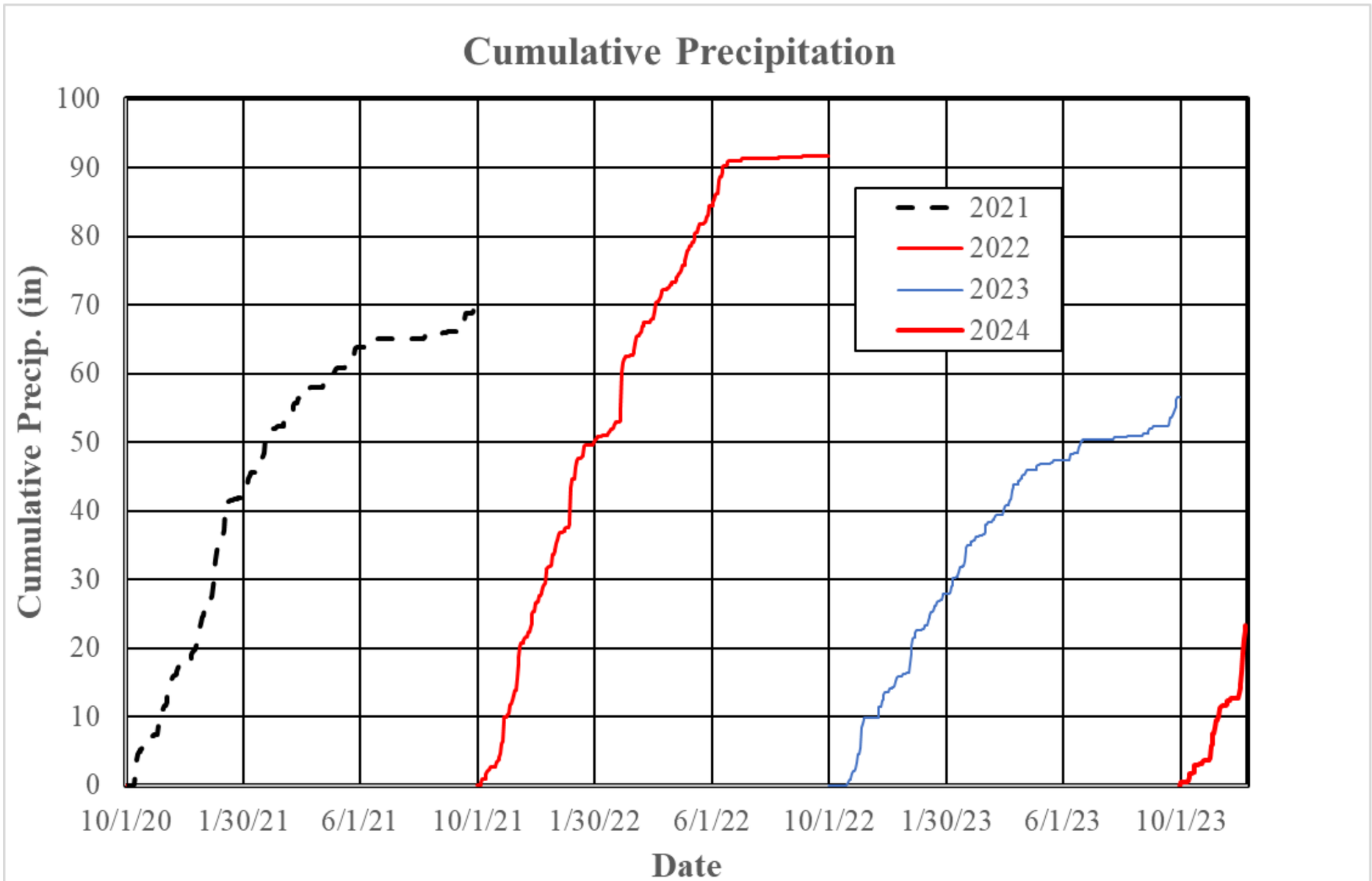
0 500 1,000 2,000 Feet

Fall City Floodplain Restoration Project

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	1
2/17/22	



Cumulative Precipitation

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	2
12/21/22	

Well Locations

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
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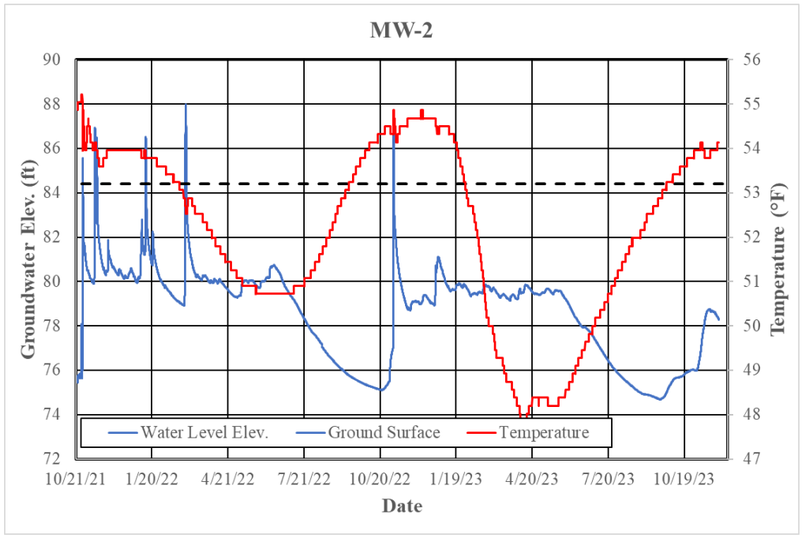
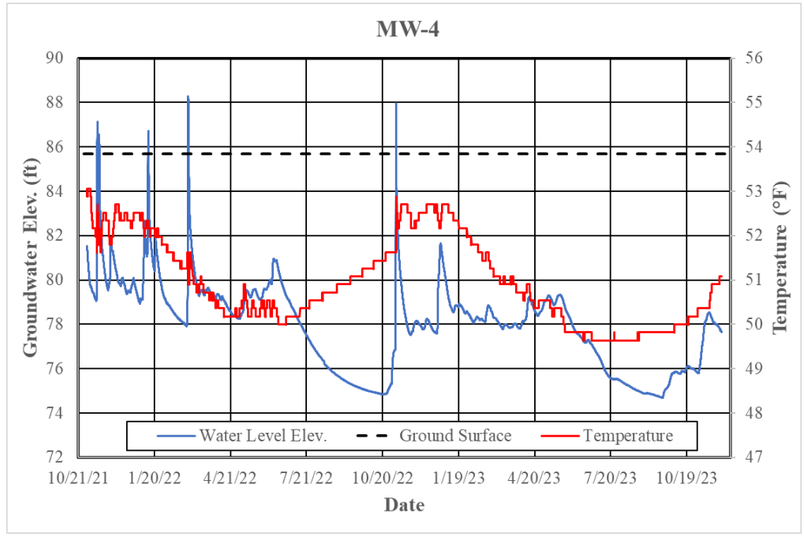
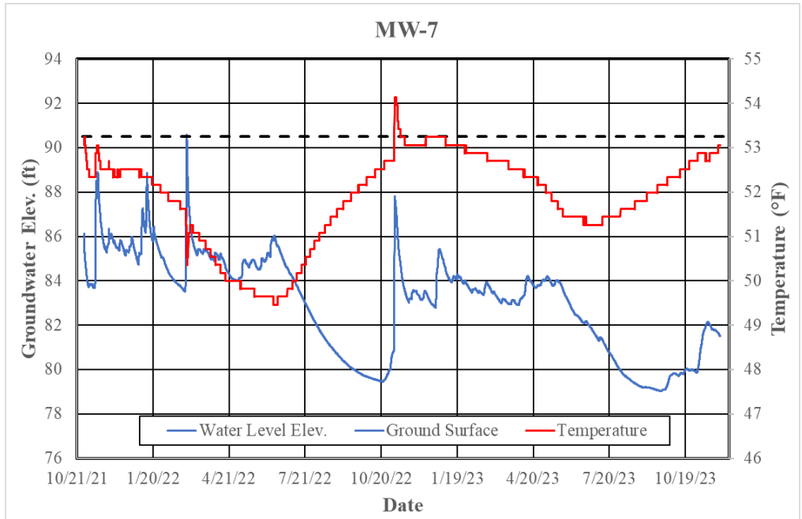
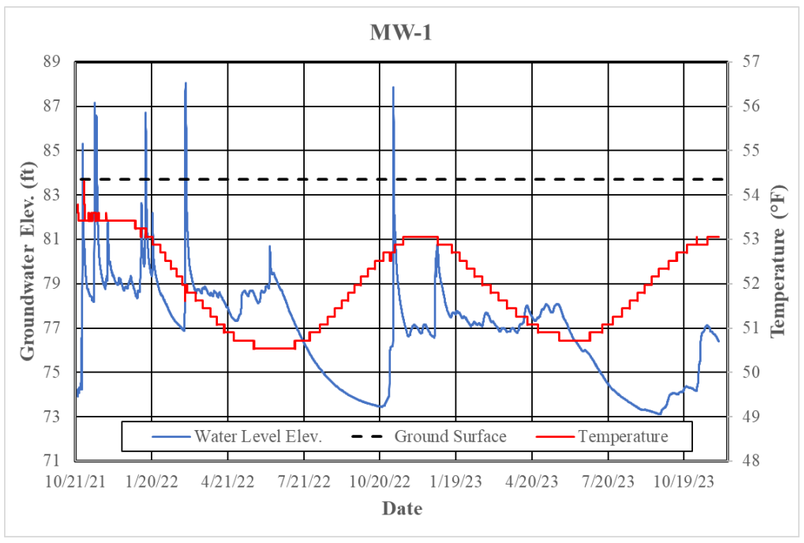
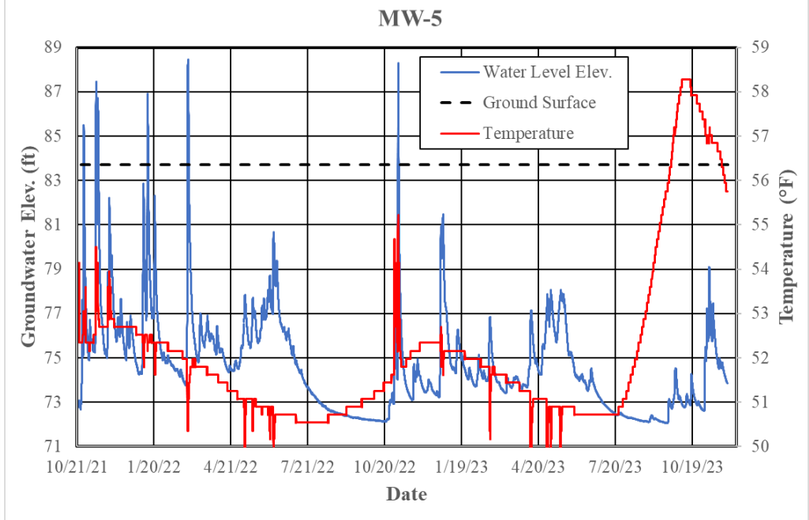
5/28/22	

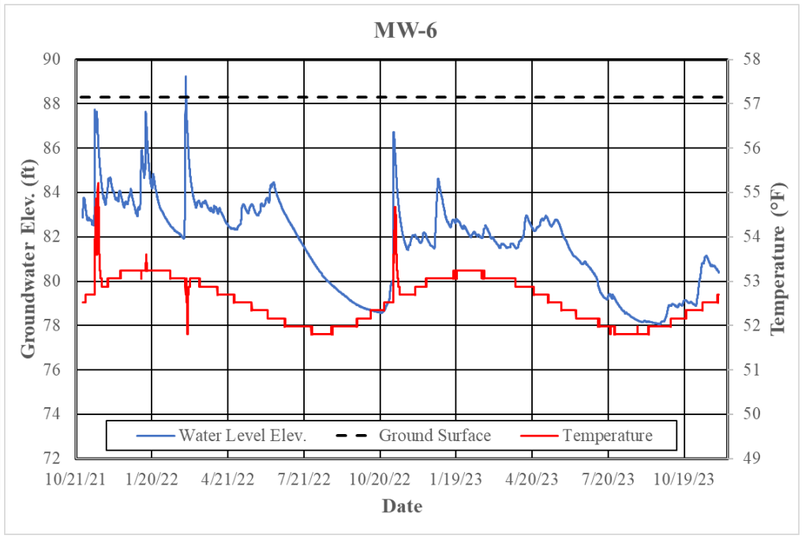










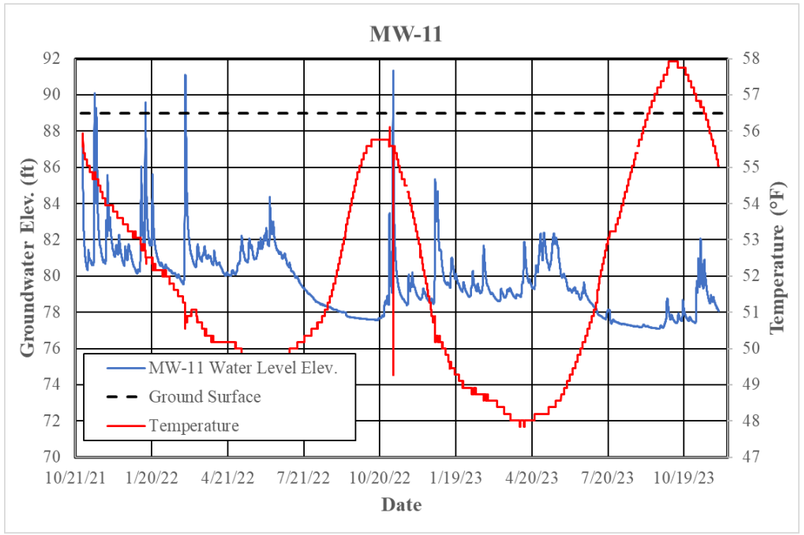


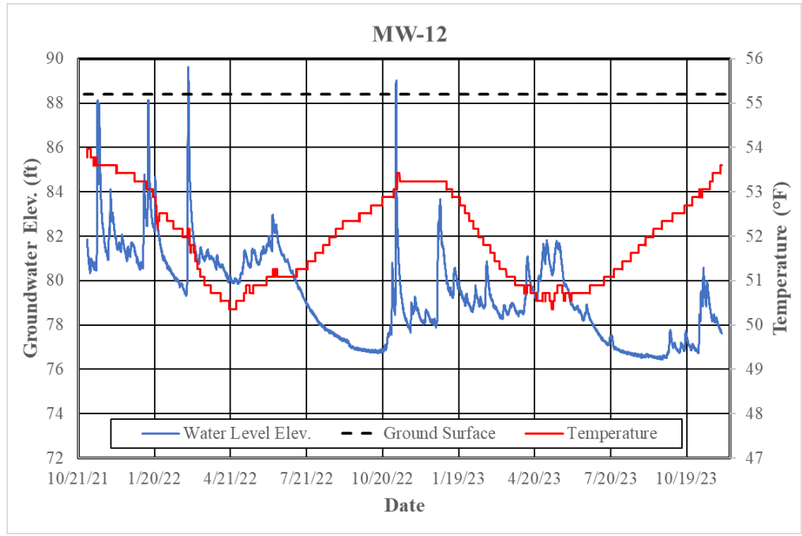
Groundwater Elevations and Temperatures - NE Side

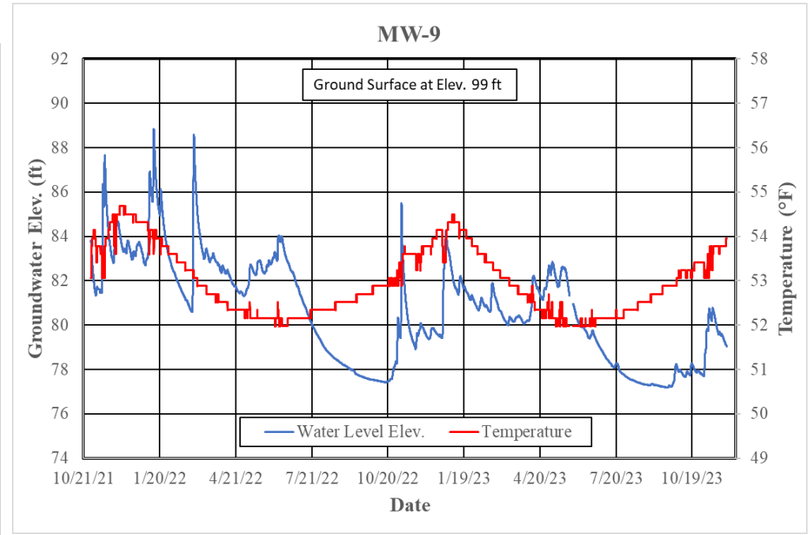
Fall City Groundwater Monitoring, Fall City

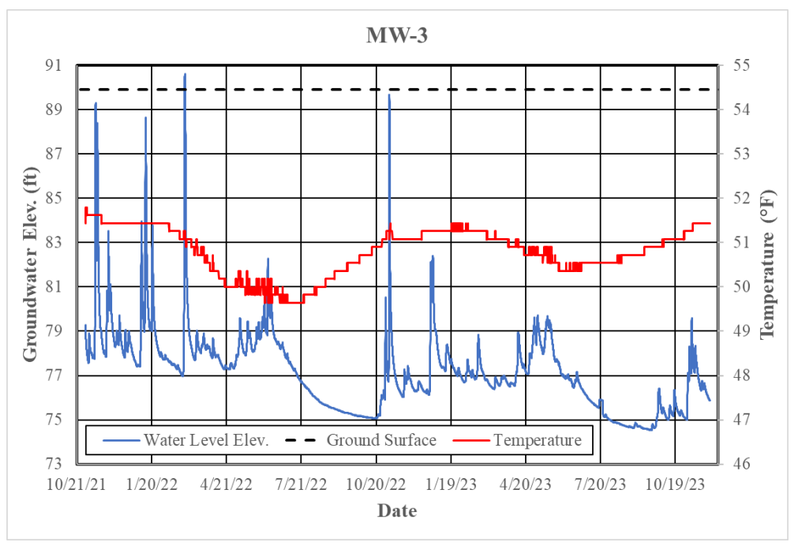
Kindred Hydro

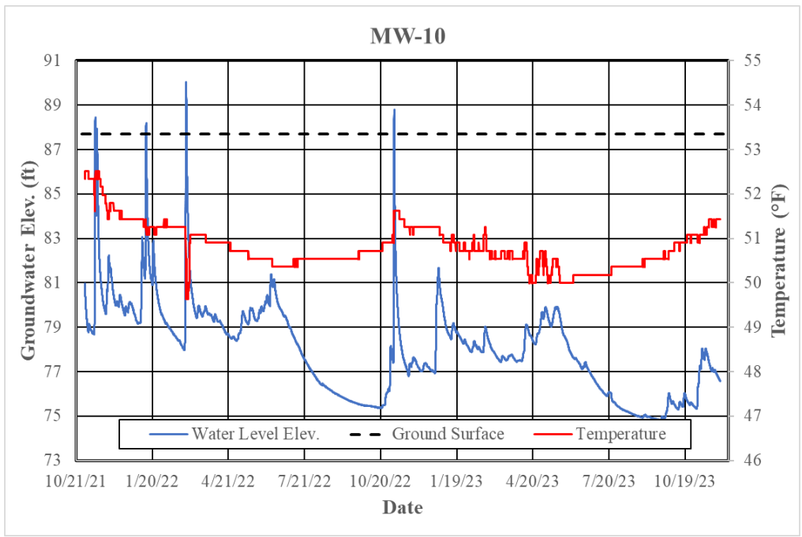
Project Number	Figure No.
SNO-21-2	4
12/20/23	

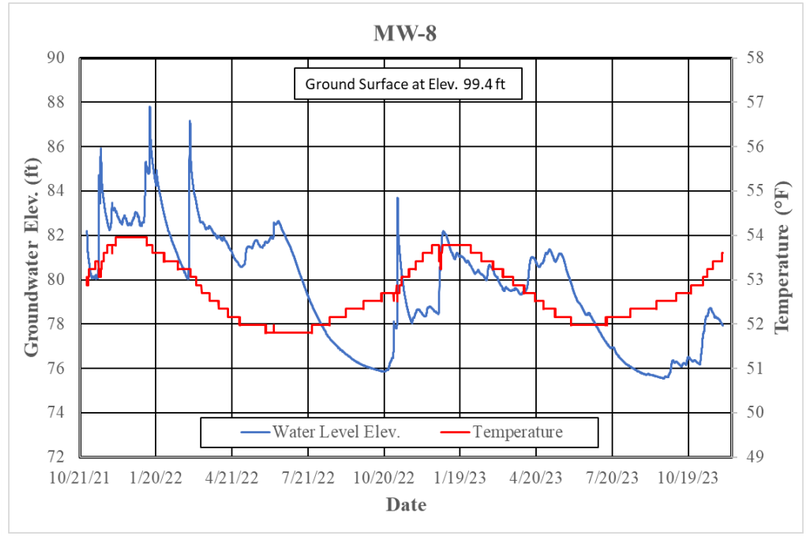












Groundwater Elevations and Temperatures - SW Side

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
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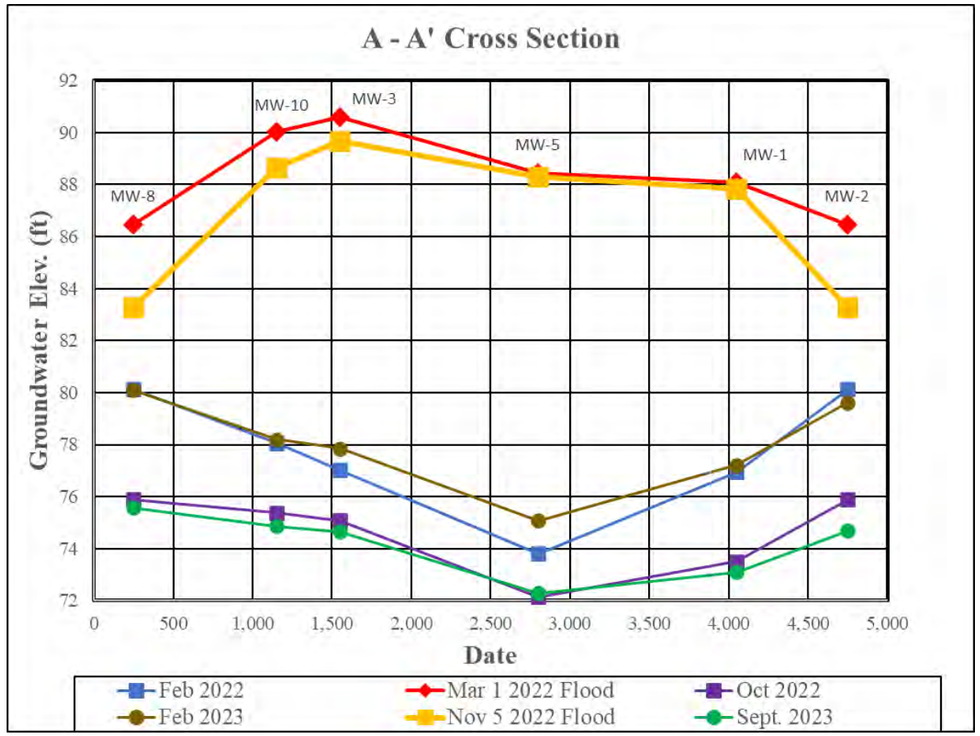
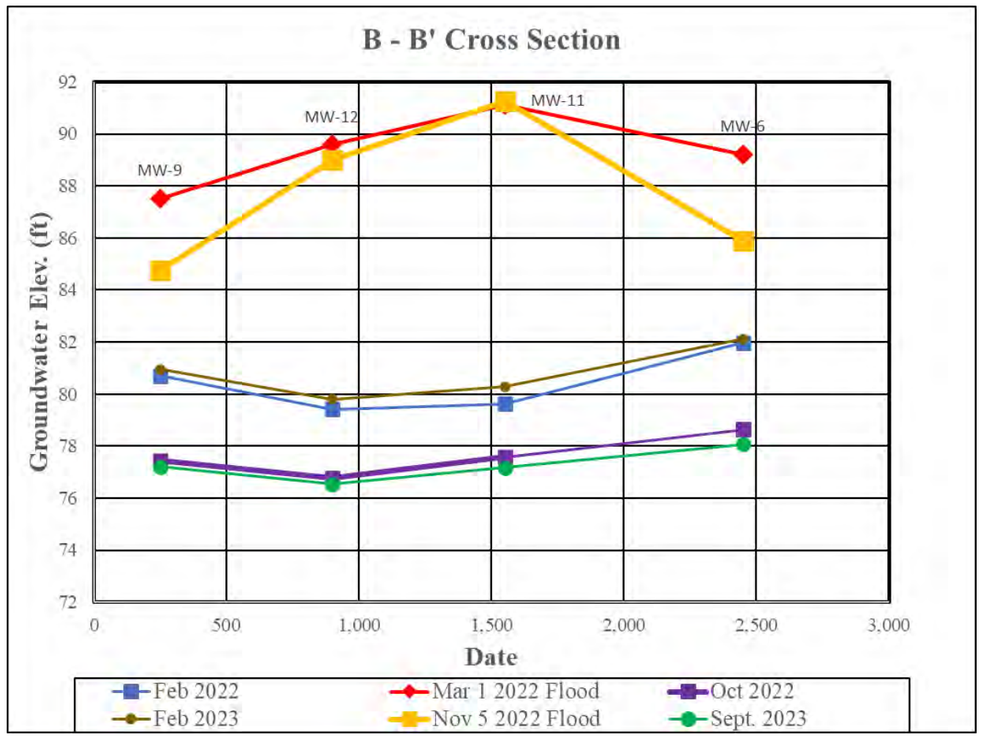
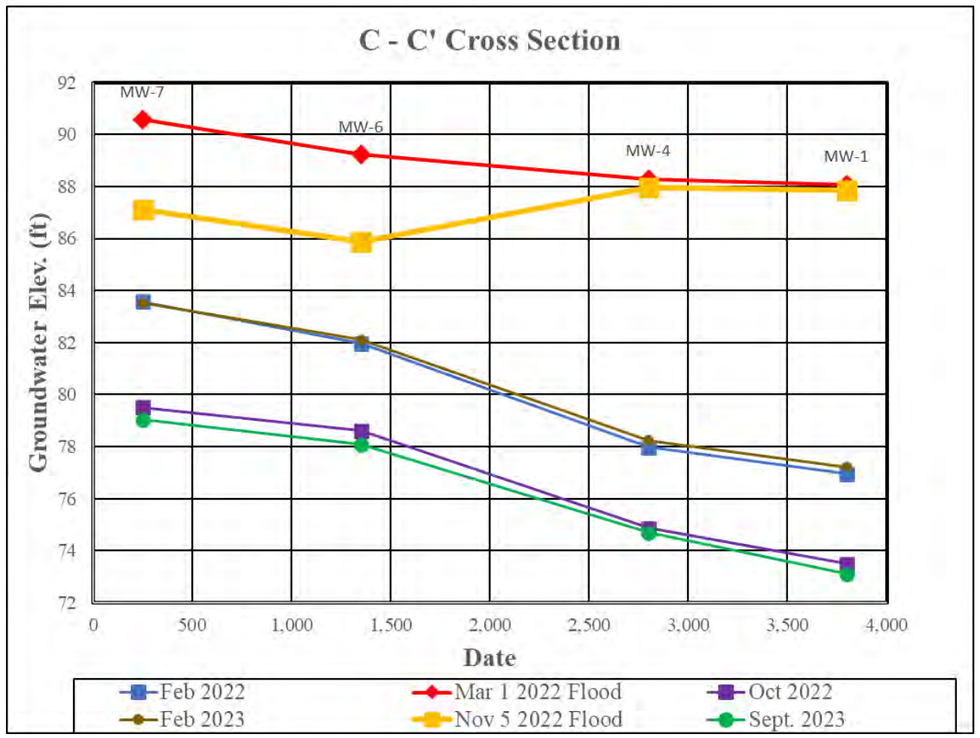
12/20/23	







Groundwater Cross-Sections for Selected Dates

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	6
12/20/23	

MW-2
(80.1)

MW-1
(77.0)

MW-4
(78.0)

MW-5
(73.8)

MW-6
(82.0)

MW-7
(83.6)

MW-3
(77.0)

MW-10
(78.1)

MW-11
(79.6)

MW-12
(79.4)

MW-8
(80.1)

MW-9
(80.7)

N

0 500 1,000 2,000 Feet

Groundwater Contours – February 26, 2022 Winter Low

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	**7**
5/28/22	

Groundwater Contours – March 1, 2022 Flood

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	8
5/28/22	

MW-2
(77.1)

MW-1
(75.0)

MW-5
(72.8)

MW-4
(76.3)

MW-6
(80.3)

MW-7
(81.5)

MW-3
(75.9)

MW-10
(76.4)

MW-11
(78.4)

MW-12
(77.9)

MW-8
(77.6)

MW-9
(78.7)

N

0 500 1,000 2,000 Feet

Groundwater Contours – August 11, 2022

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	9
8/12/22	

MW-2
(83.3)

MW-1
(87.8)

MW-4
(87.9)

MW-5
(88.3)

MW-6
(85.9)

MW-7
(87.1)

MW-3
(89.7)

MW-10
(88.6)

MW-11
(91.3)

MW-12
(89.0)

MW-8
(83.3)

MW-9
(84.8)

84 85 86 87 88 89 90 91

N

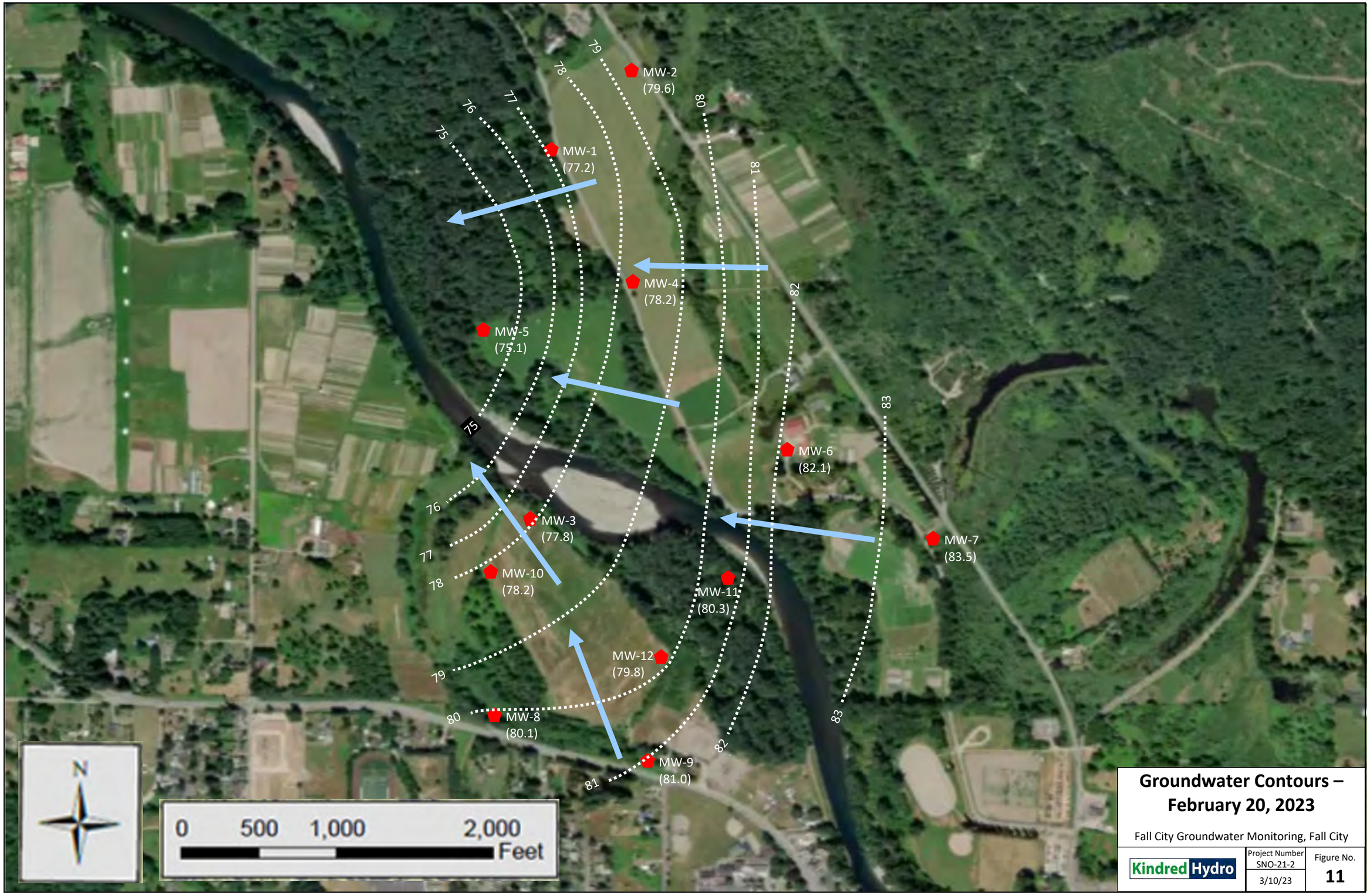
0 500 1,000 2,000 Feet

Groundwater Contours – November 5, 2022 Flood

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	10
10/30/22	

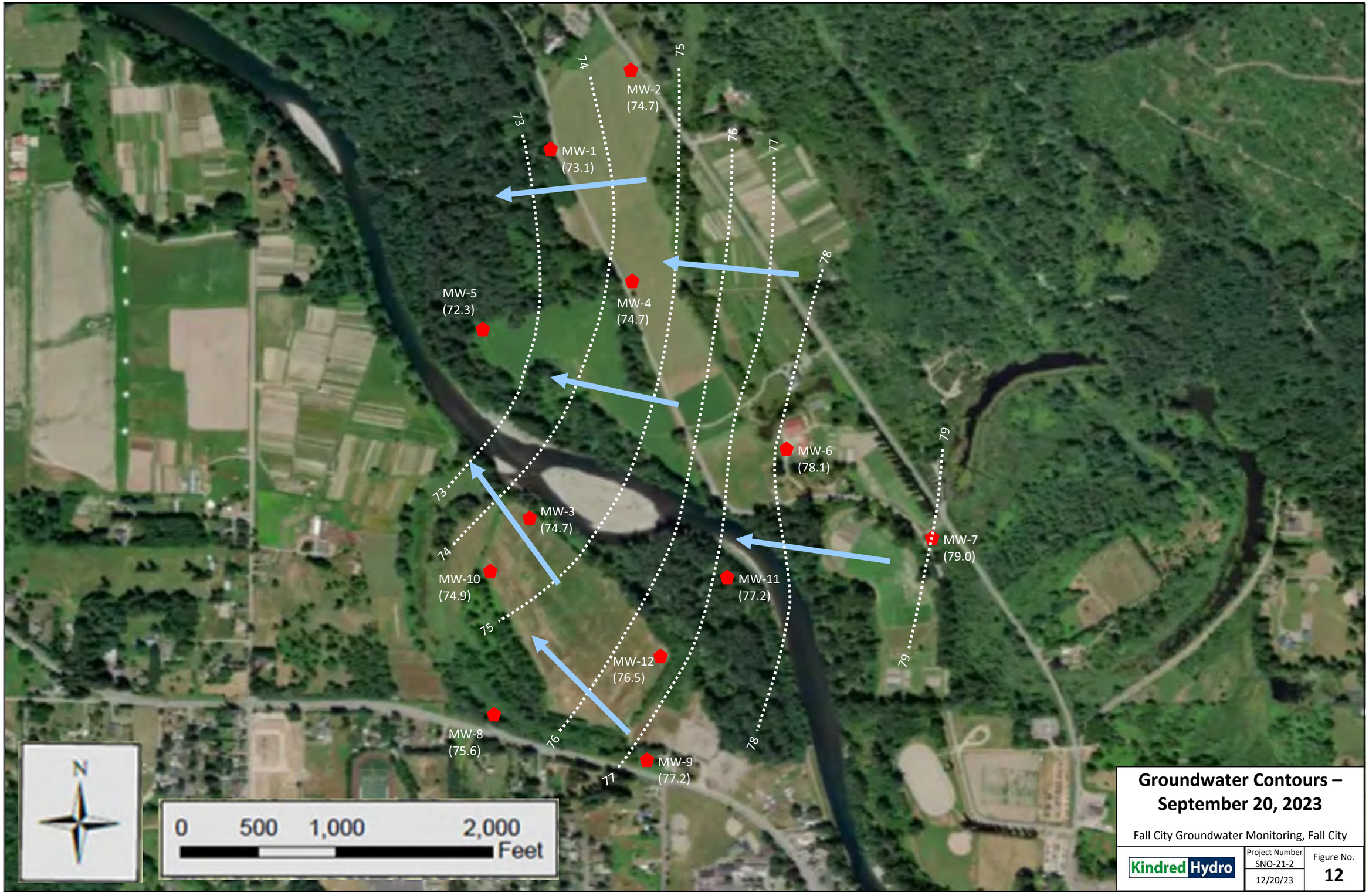


Groundwater Contours – February 20, 2023

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	11
3/10/23	



Groundwater Contours – September 20, 2023

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
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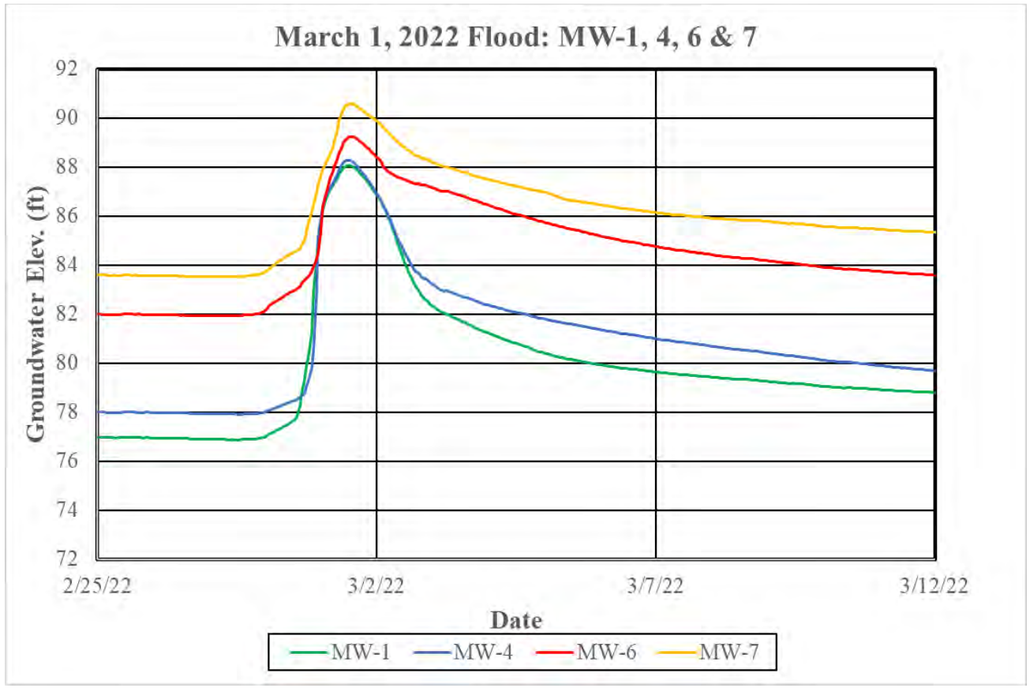
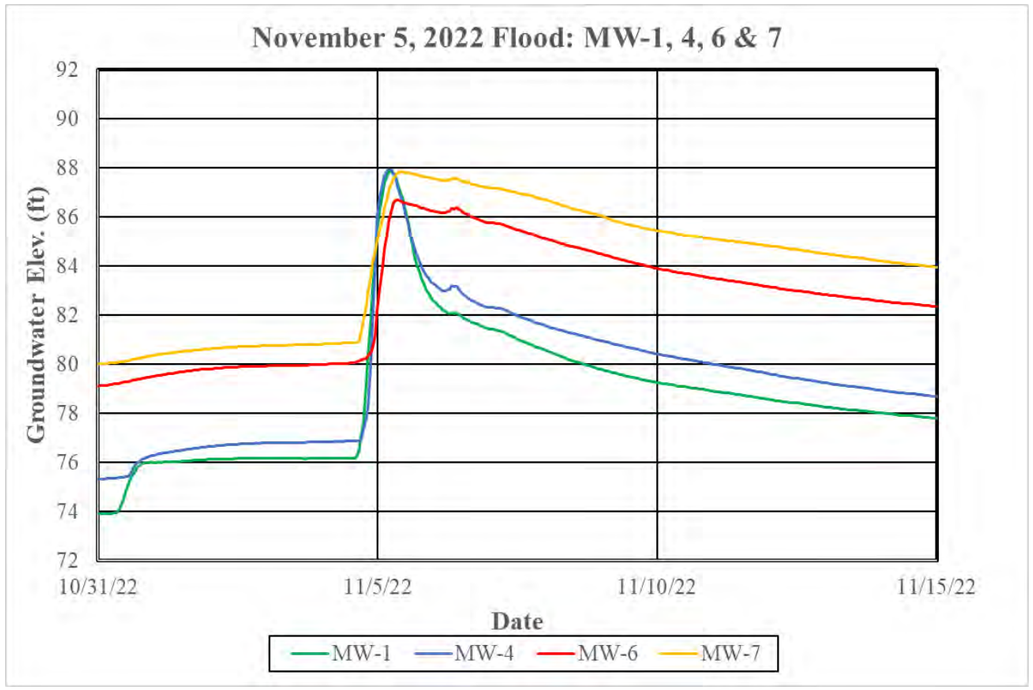
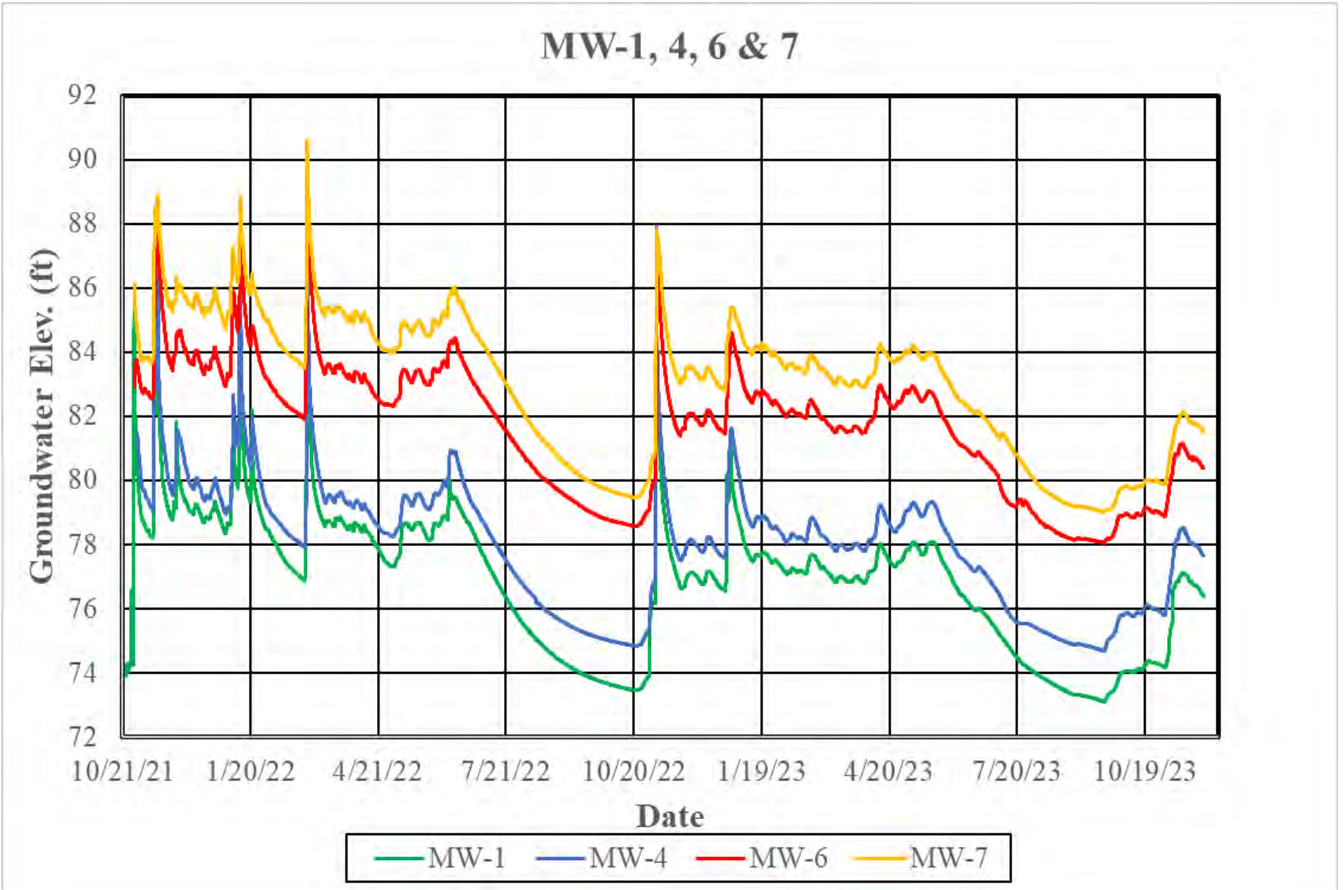
12/20/23	







Comparison of MW-1, 4, 6, & 7 Hydrographs

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
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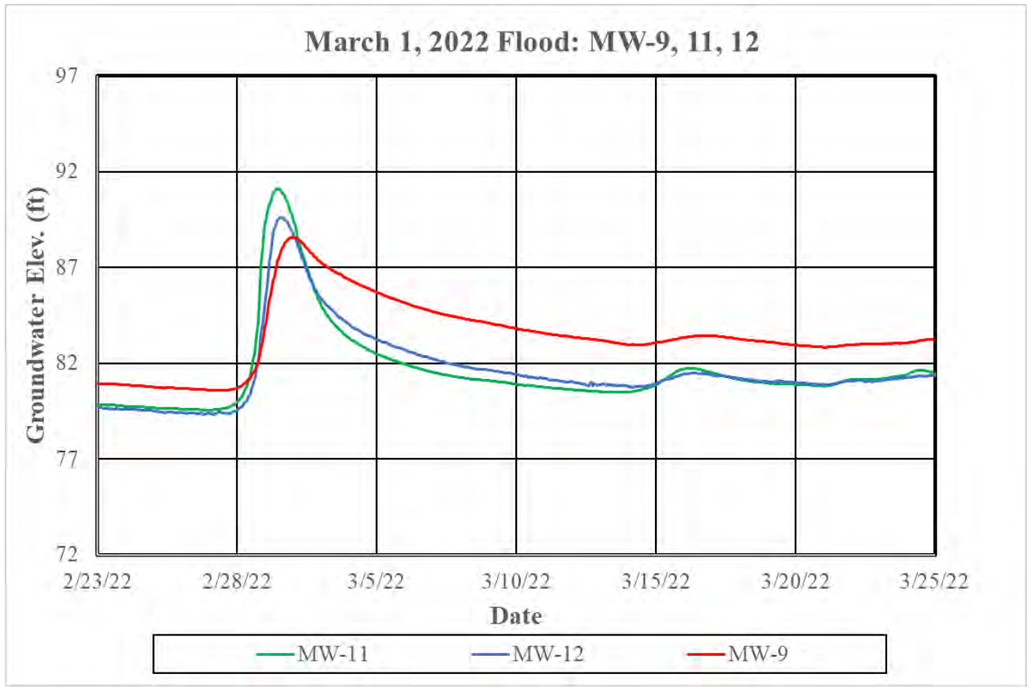
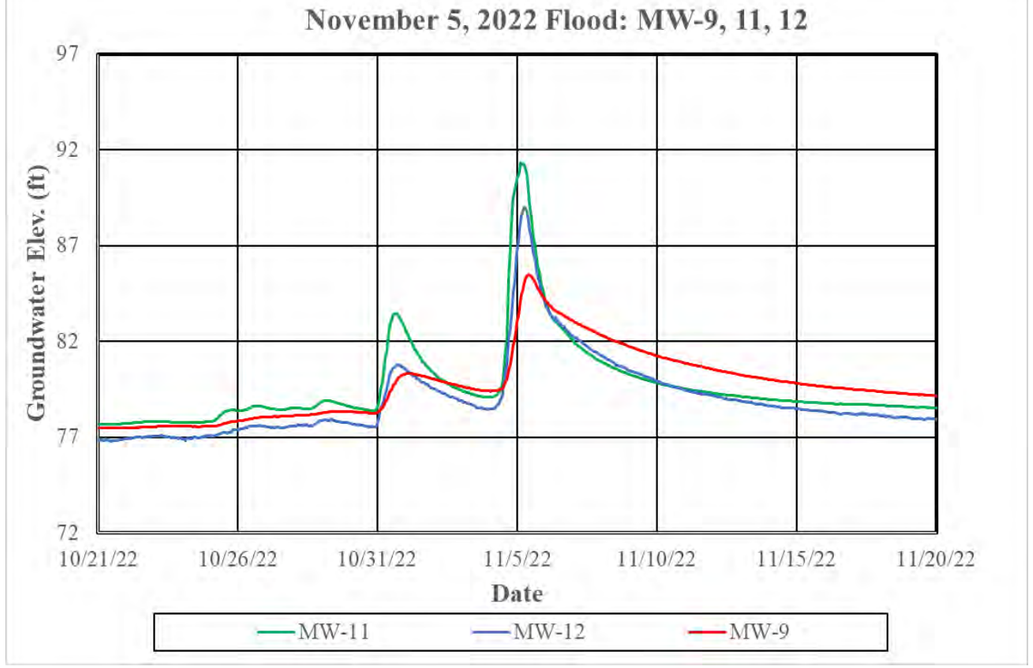
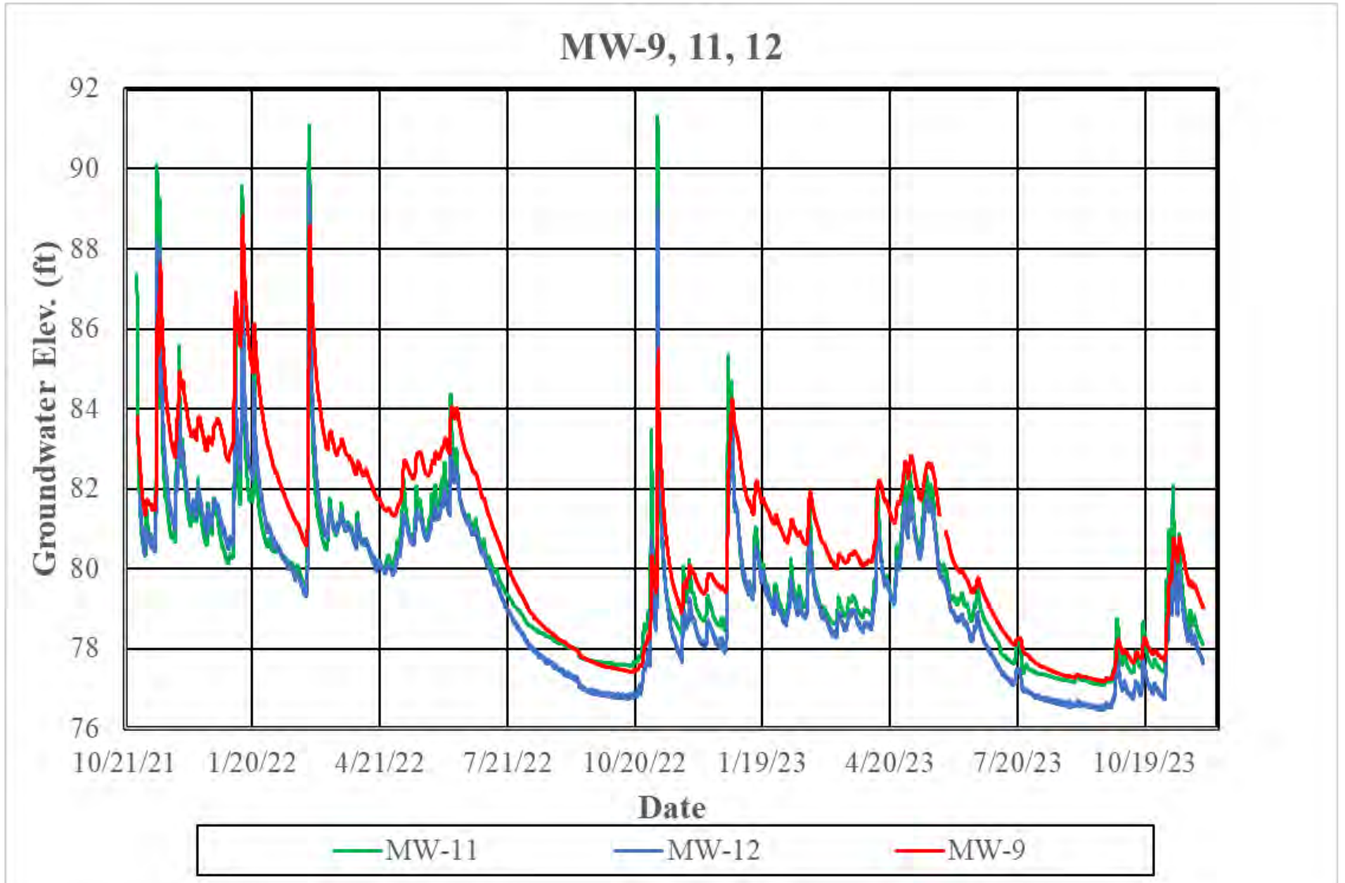
12/20/23	





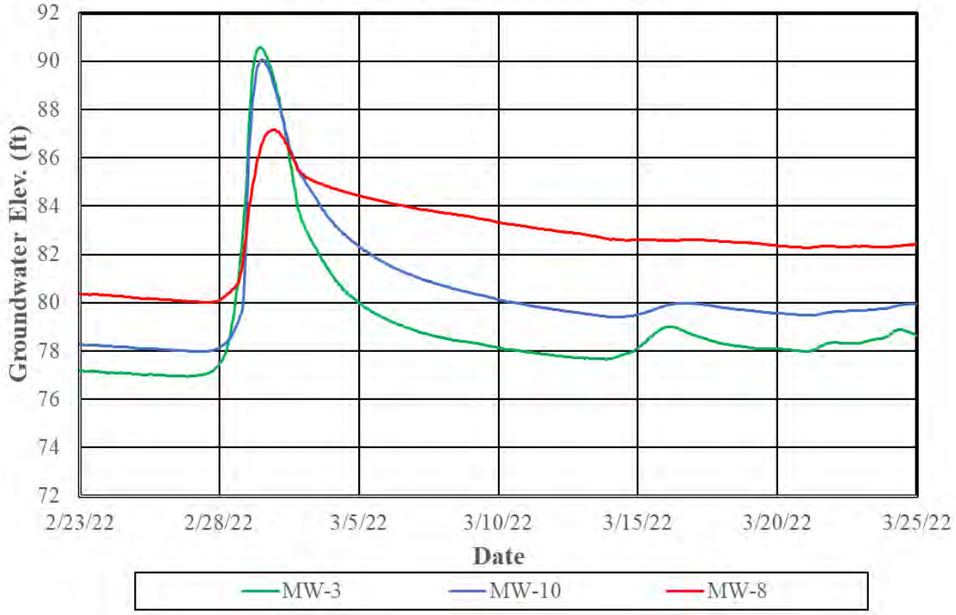


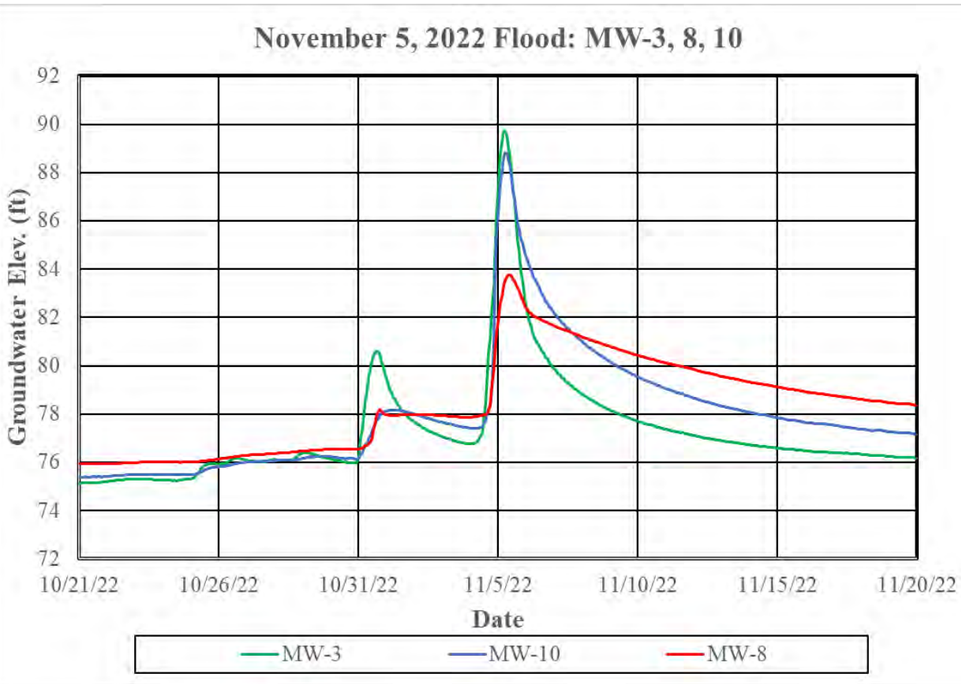
Comparison of MW-9, 11, 12 Hydrographs

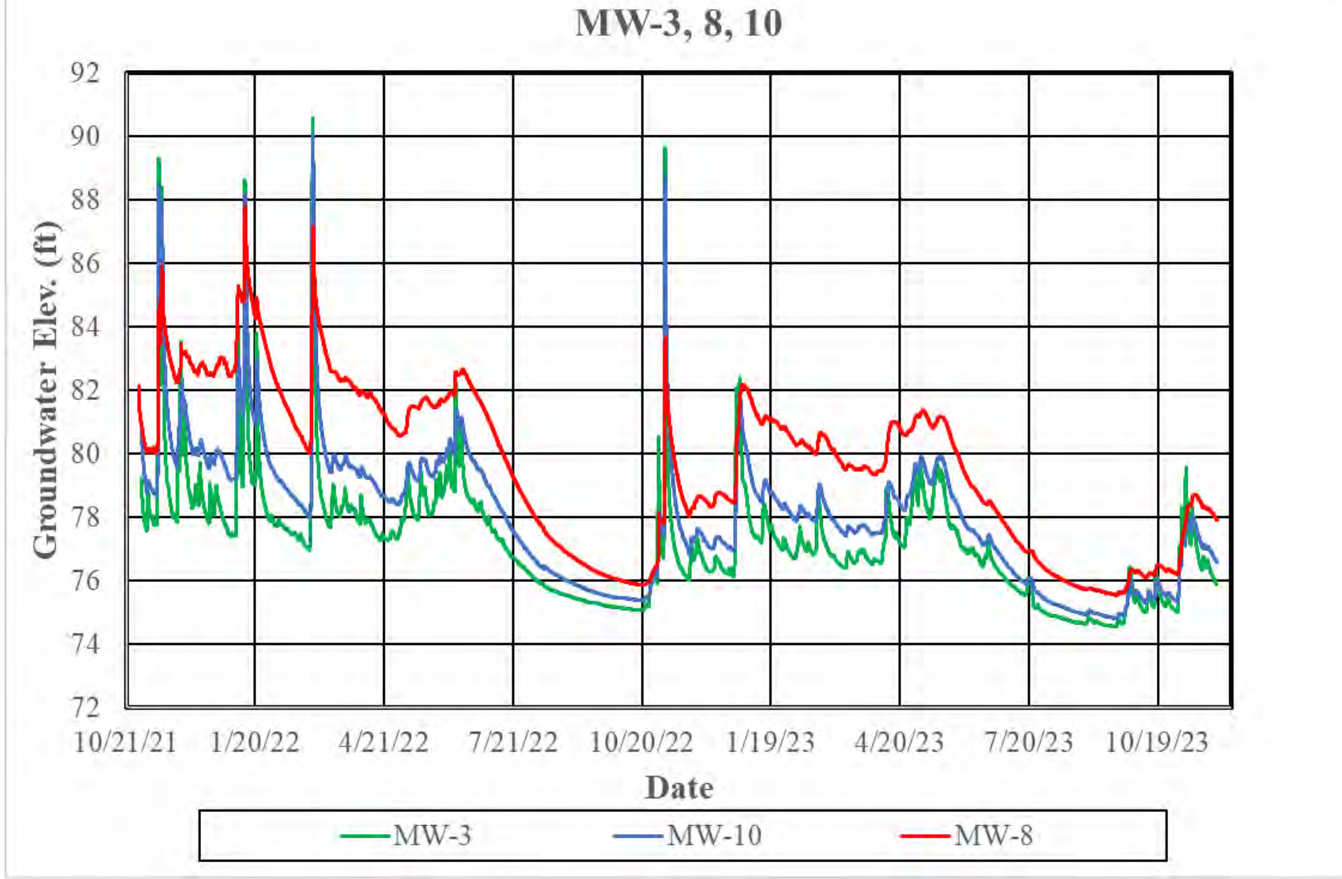
Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	14
12/20/23	





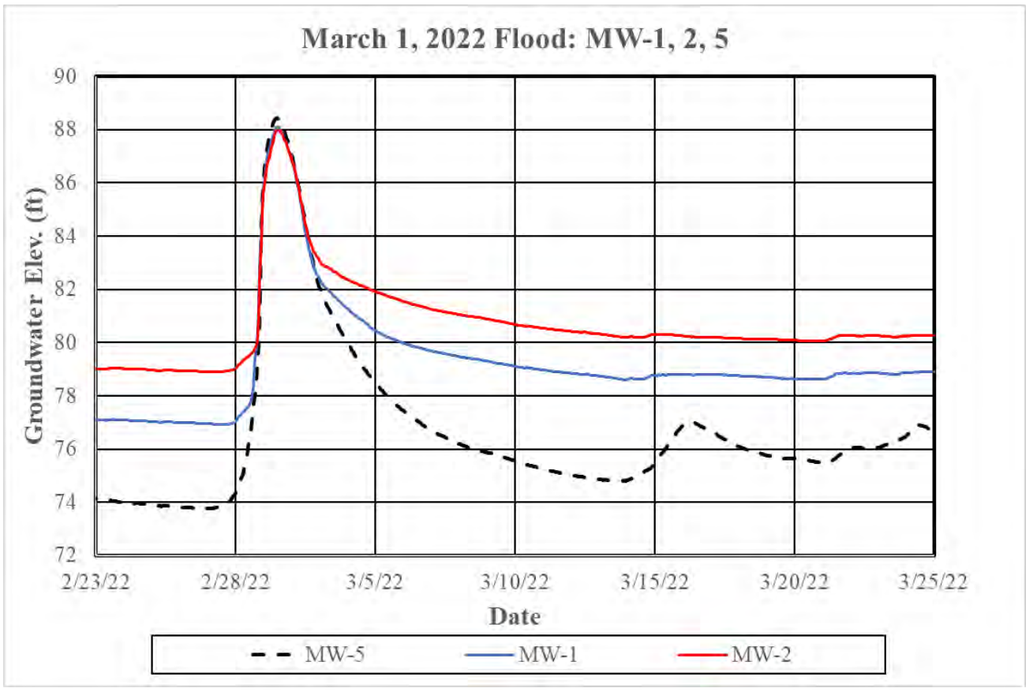


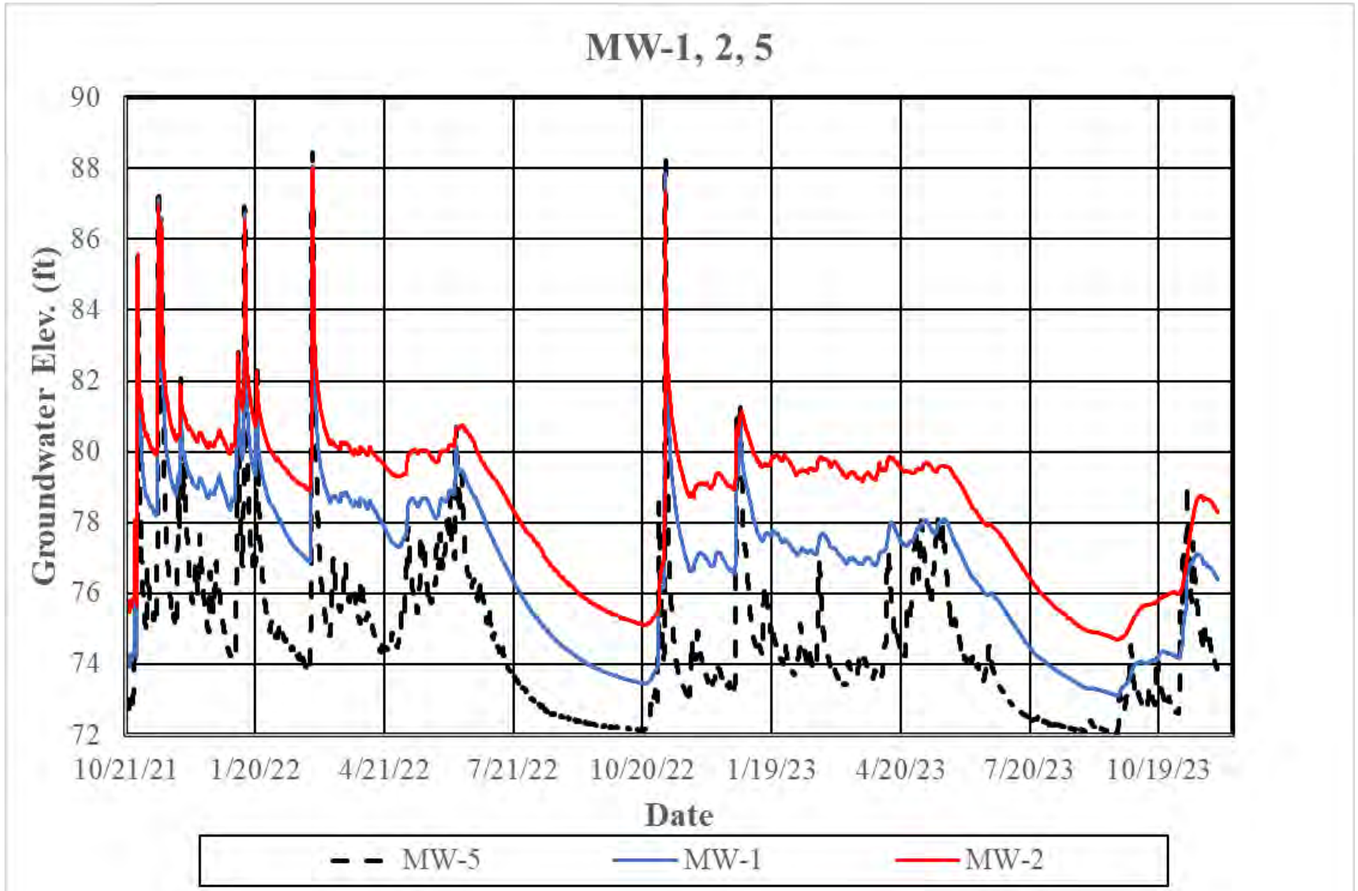
Comparison of MW-3, 8, & 10 Hydrographs

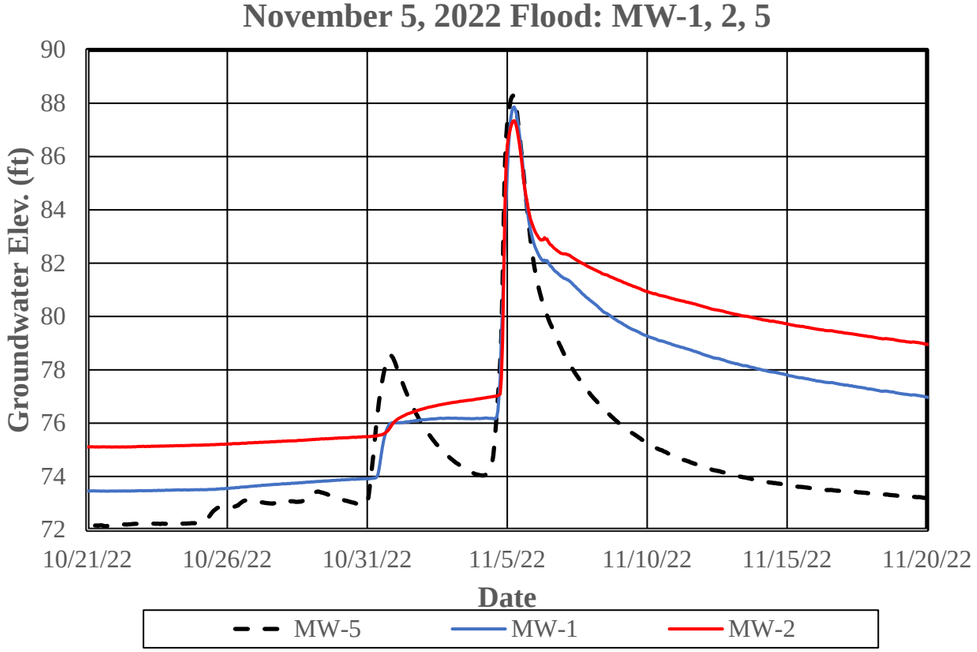
Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	15
12/20/23	





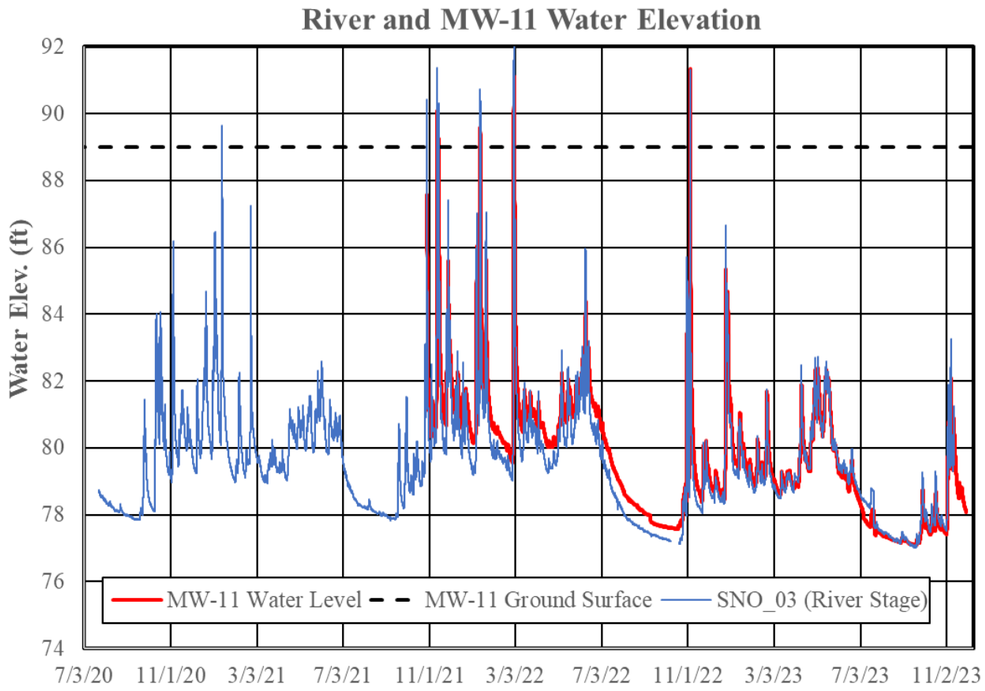


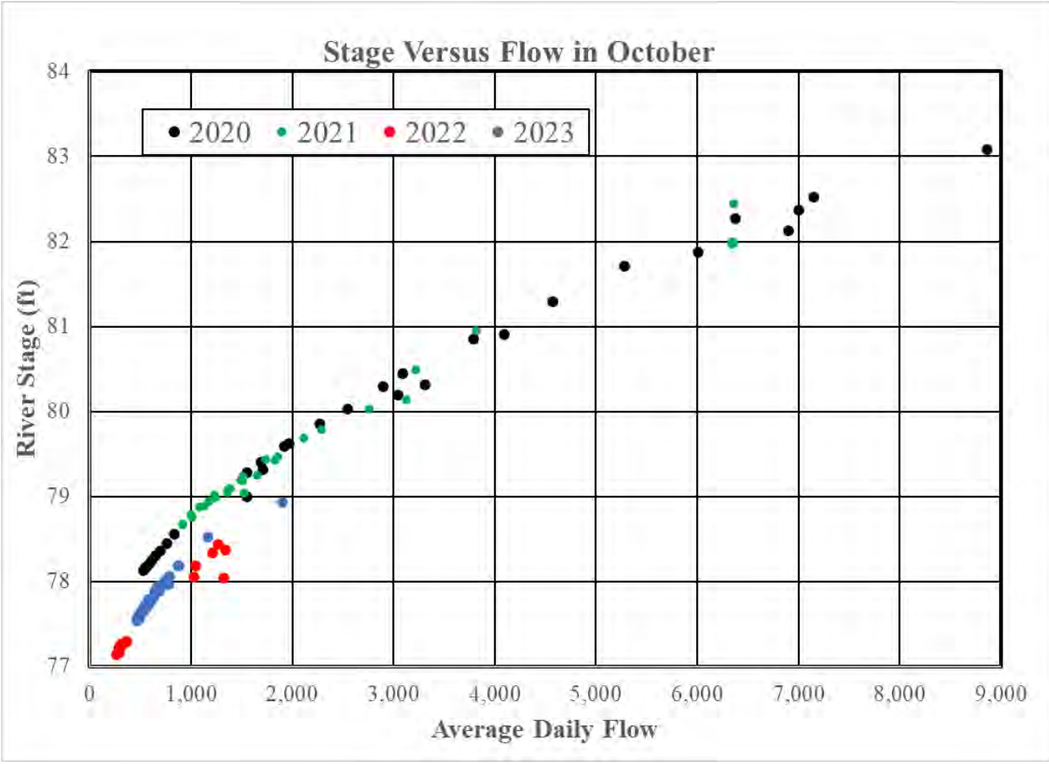
Comparison of MW-1, 2, & 5 Hydrographs

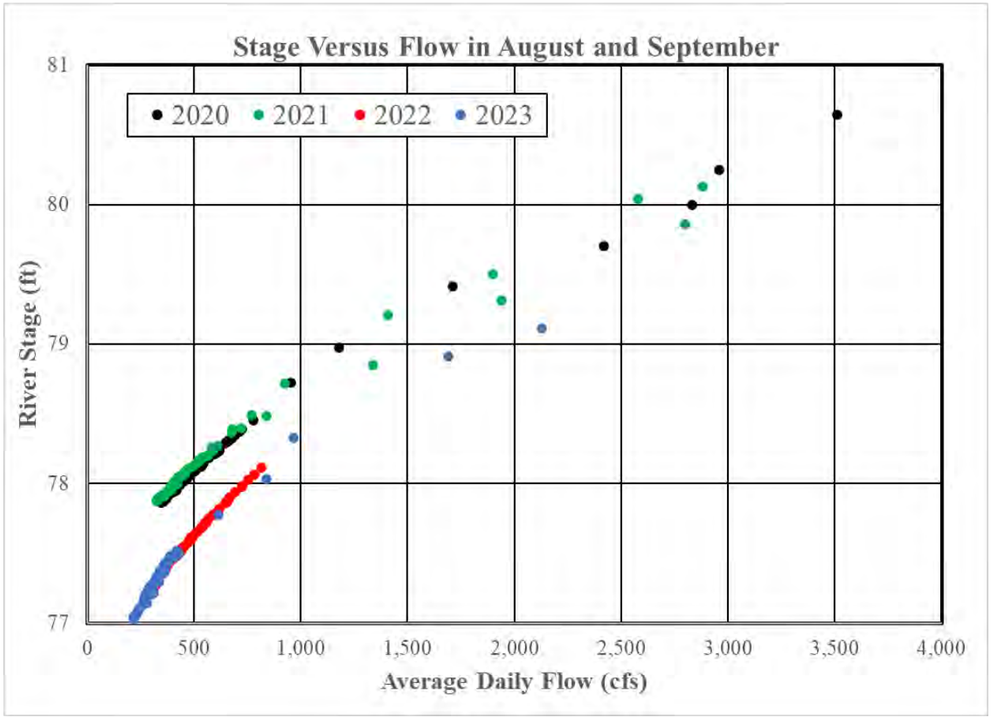
Fall City Groundwater Monitoring, Fall City

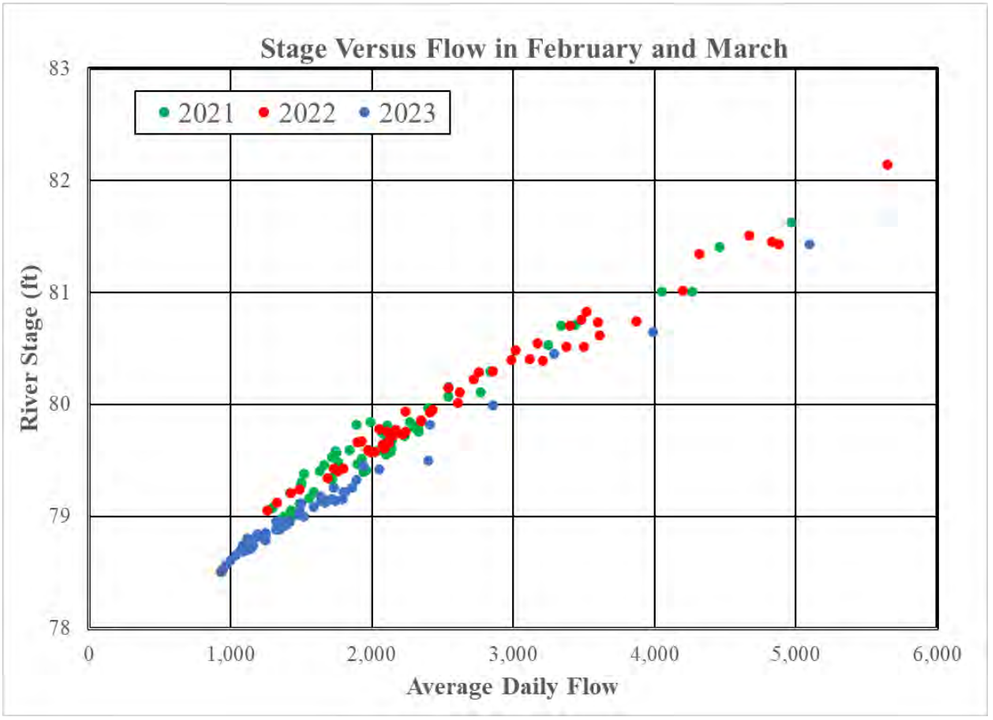
Kindred Hydro

Project Number	Figure No.
SNO-21-2	16
12/20/23	









River Stage and Flow

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
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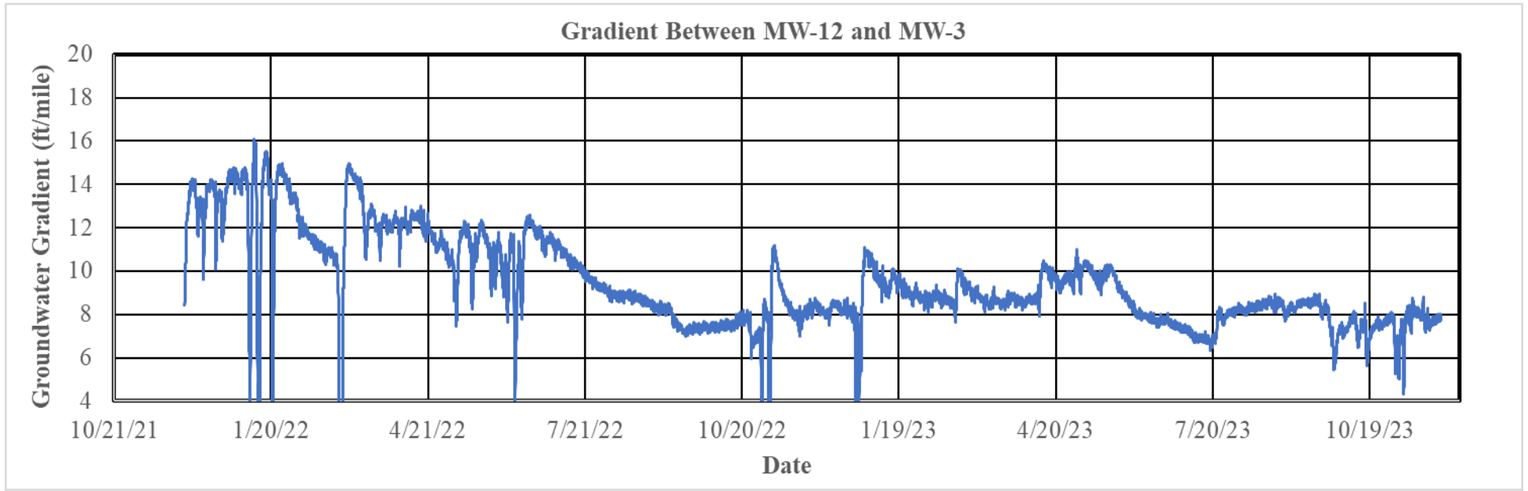
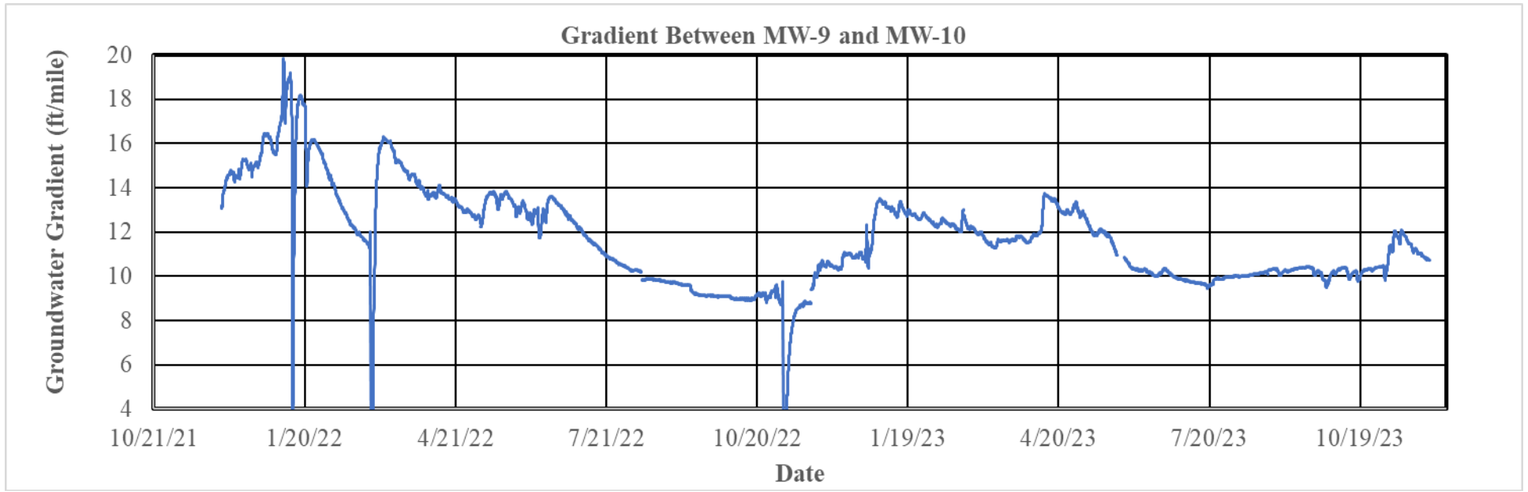
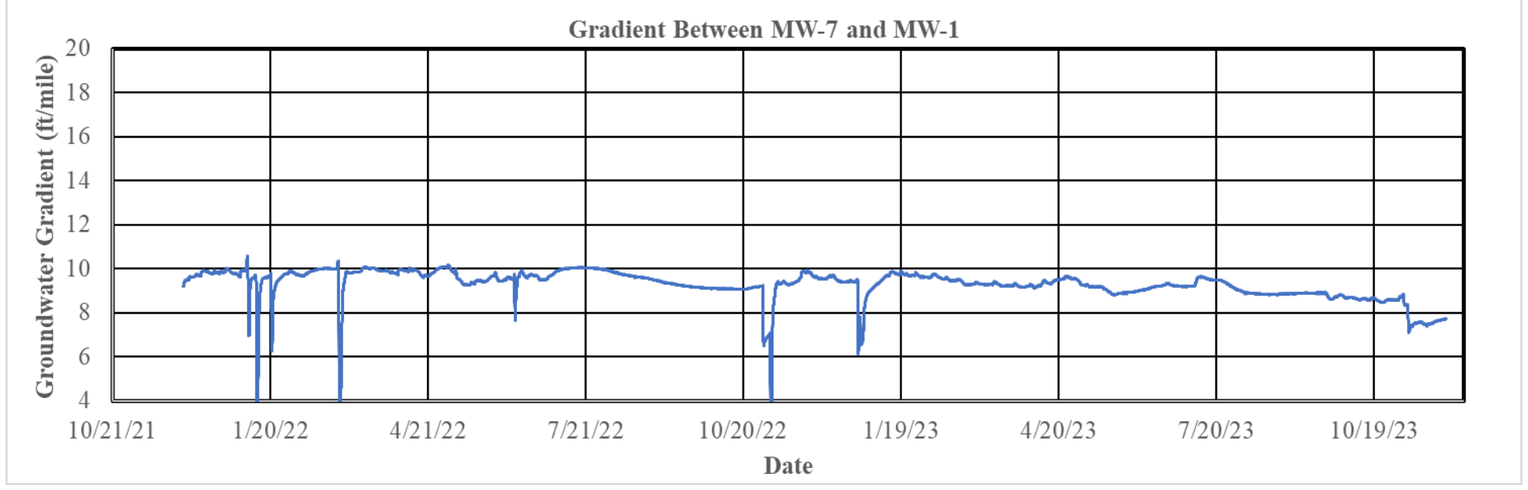
12/20/23	





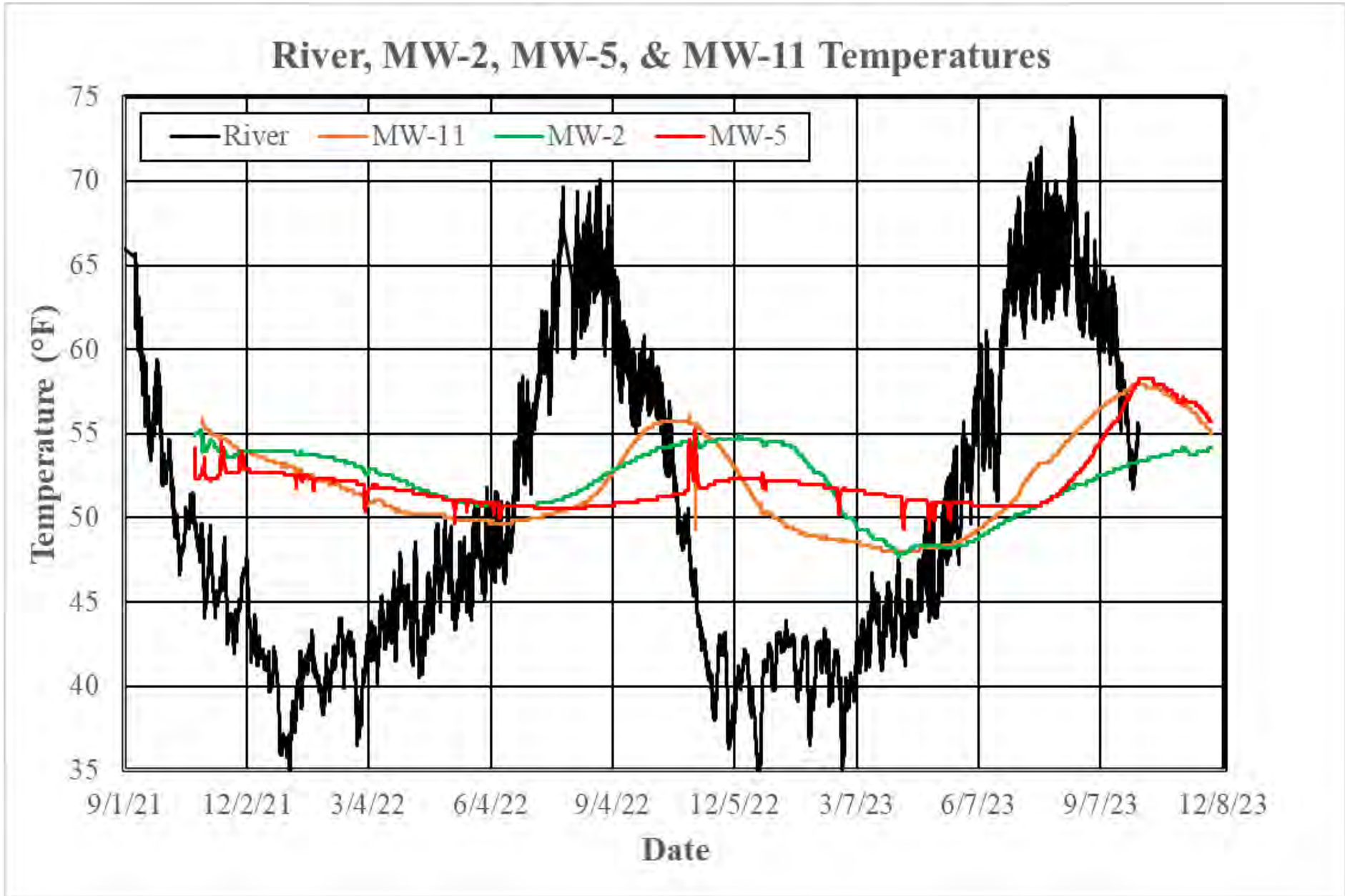


Groundwater Gradients

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	18
12/20/23	



River and Select Well Temperatures

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	19
12/21/23	

Appendix A: Well Construction

Kindred Hydro

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WELL INSTALLATION
FALL CITY FLOODPLAIN RESTORATION, FALL CITY, WASHINGTON

Prepared for: Snoqualmie Indian Tribe

Project No. SNO-21-2 • December 21, 2023

Kindred Hydro, Inc.

J. Scott Kindred, PE
scottk@kindredhydro.com

State of Washington
Hydrogeologist
3343
Licensed Geologist
J. SCOTT KINDRED

https://netorg82711-my.sharepoint.com/personal/scottk_kindredhydro_com/Documents/Projects/Fall City/Report Drafts/Final Report/Fall City Well Installation - Final.docx

7204 91st Avenue SE • Mercer Island, WA 98040
206-660-5417

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2.2 Geology.... 3

2.3 Well Development and Transducer Installation 3

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Attachment A: Well Installation Methods and Exploration Logs....A-1

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1 Well Completion Details and Depth to Coarse Alluvium (ft)

2 Survey Results (ft)

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1 Well Locations

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A Well Installation Methods and Exploration Logs

1 Introduction and Background

The Fall City Restoration Project will restore almost one-half mile of river edge habitat, restore the connection of the river to approximately 134 acres of floodplain, construct an estimated 2,500 feet of floodplain side channel, control invasive weeds, and restore native plants on more than 80 acres. Setback facilities on both sides of the river will protect farmland and infrastructure that are outside the project footprint. This groundwater monitoring project is intended to observe and evaluate the effects of the floodplain restoration project on groundwater flow. This document summarizes the installation of 12 groundwater monitoring wells for the project.

2 Well Drilling and Installation

This section summarizes the drilling and installation of the monitoring wells, installation of the pressure transducers, and surveying of wellhead locations and elevations.

2.1 Well Installation

Kindred Hydro, Inc. observed the installation of 12 groundwater monitoring wells between September 30 and October 22, 2022. Details of the drilling and well construction are provided in Attachment A and the locations of the wells are shown on Figure 2. Well drilling and installation was conducted by Holocene Drilling, based out of Puyallup, Washington. Drilling of MW-11, MW-9, and MW-8 was initially attempted on September 30, 2022 using a truck-mounted hollow-stem auger drilling rig. The hollow stem auger rig drills an 8-inch-diameter borehole and soil samples were collected every 5 feet using the standard penetration test method. Loose cobbles and gravels encountered at 7 to 17 ft were very difficult to penetrate due to caving and the large diameter of the cobbles. Although MW-11 was installed, drilling was terminated at 7.5 ft in MW-9 and at 17 ft in MW-8 and the holes were abandoned.

Holocene Drilling returned on October 20, 2022 with a track-mounted Sonic drilling rig that was better equipped to drill through the cobbles and maintain an open hole. The Sonic drilling rig uses a vibrating inner core barrel and outer casing and is capable of penetrating large cobbles. It also allows collection of a continuous core that facilitates more complete documentation of soil characteristics.

The boreholes were completed as 2-inch diameter polyvinyl chloride (PVC) wells with slotted screen. The screen was 10 to 20 ft long and the annular space around the casing was usually filled with clean sand to provide a good connection with the native soils. MW-11 had significant caving issues during well construction and no sandpack was placed around the screen. Rather, the native formation collapsed around the well screen. The annular space above the screen was backfilled with bentonite chips to create a surface seal. The wellheads were protected with either a surface monument flush with the ground surface or an above-ground monument. Well logs, describing subsurface

conditions and well completion details are provided in Attachment A. Details for each well are summarized in Table 1.

Table 1: Well Completion Details and Depth to Coarse Alluvium (ft)

Well	Borehole Depth[a]	Sandpack Interval[a]	Well Screen Interval[a]	Ground Surface Elevation[b]	Depth to Coarse Alluvium[a]	Top of Coarse Alluvium Elevation[a]
MW-1	20	8 - 20	10 - 20	83.7	10	73.7
MW-2	25	8 - 24	9 - 24	84.4	8	76.4
MW-3	30	7 - 29.5	9.25 - 29.25	89.9	16	73.9
MW-4	25	8 - 25	10 - 25	85.7	10	75.7
MW-5	25	8 - 25	10 - 25	83.7	7	76.7
MW-6	25	8 - 24.5	9.5 - 24.5	88.3	7	81.3
MW-7	20	8 - 20	10 - 20	90.5	7.5	83.0
MW-8	35	18 - 35	20 - 35	99.4	15	84.4
MW-9	35	18 - 35	20 - 35	99.0	6	93.0
MW-10	25	8 - 25	10 - 25	87.7	9.5	78.2
MW-11	20.75	Caving	10.75-20.75	89.0	10	79.0
MW-12	25	8 - 26	11 - 26	88.4	12	76.4

Notes:
a) Depths intervals are measured from the ground surface.
b) Elevations referenced to North American Vertical Datum 88 (NAVD88).

2.2 Geology

Most of the wells encountered fine-grained alluvium over coarse grained alluvium. The transition between the fine-grained alluvium and the coarse-grained alluvium occurred between 6 and 16 ft below the ground surface, as shown on Table 1. The fine-grained alluvium predominately consisted of fine sand with trace silt, slightly-silty to silty fine sand, and silt. The coarse-grained alluvium predominately consisted of sandy gravel with various amounts of silt and cobbles and occasional layers of sand and gravelly sand.

As shown on Table 1, the depth to the coarse alluvium ranged from 6 ft in MW-9 to 16 ft in MW-3. The top of the coarse-grained alluvium ranged from a high elevation of 93 ft above NAVD88 at MW-9 to a low elevation of 73.7 ft above NAVD88 at MW-1.

2.3 Well Development and Transducer Installation

Wells were developed using a submersible pump with a maximum flow rate of 3.8 gpm. The pump was moved up and down through the well screen interval to flush water into and out of the sandpack around the well screen. Most of the wells were developed for 20 to 30 minutes, until the water was running relatively clear. All the wells with a sandpack produced did not run dry during development. MW-11, which didn't contain a sandpack around the screen, did run dry during development and did not clean up as well. Although the absence of a sandpack in this well could be an issue for collection of water samples for chemical testing, it should be suitable for measuring water levels in the aquifer.

Pressure transducers with build-in data loggers were installed in the bottom of all the wells on October 29 and 30, 2021. The transducers were programed to measure head elevations and temperature on an hourly schedule.

2.4 Surveying

The well locations and elevation were surveyed by Encompass Engineering and Surveying based out of Issaquah, Washington during January and February 2022. The master benchmark used for the survey is King County Benchmark GP17202*56 with an elevation of 104.318 ft. The results are summarized in Table 2.

The above-ground monument for MW-11 was knocked over by a floating tree during the Nov. 1, 2022 flood. The monument was removed and replaced by a flush monument on December 7, 2022. The PVC casing was cut down to near ground level and the new casing elevation was estimated by subtracting the amount of casing removed from the original PVC casing elevation.

Table 2: Survey Results (ft)

Well	Northing[a]	Easting[a]	Ground Surface Elevation[b]	PVC Casing Elevation[b]	Monument Elevation[b]
MW-1	214195.254	1376920.334	83.7	86.40	86.61
MW-2	214824.957	1377362.358	84.4	87.95	88.09
MW-3	211903.802	1376676.605	89.9	90.96	91.77
MW-4	213307.965	1377420.986	85.7	88.85	89.09
MW-5	213041.08	1376468.897	83.7	86.71	87.09
MW-6	212262.279	1378389.406	88.3	88.21	88.46
MW-7	211746.148	1379299.224	90.5	93.34	93.52
MW-8	210618.474	1376427.761	99.4	101.20	101.56
MW-9	210287.458	1377650.598	99.0	98.93	99.08
MW-10	211547.775	1376488.186	87.7	90.29	90.46
MW-11 (original)	211315.498	1378182.699	89.0	91.90	92.25
MW-11 (post 12/7/22)[c]	211315.498	1378182.699	89.0	89.40	Not measured
MW-12	210962.803	1377652.754	88.4	92.15	92.31

Notes:

a) Locations referenced to horizontal datum NAD 83-2011
b) Elevations referenced to North American Vertical Datum 88 (NAVD88).
c) Above-ground monument fs knocked over by floating tree on Nov. 1, 2022. Replaced by flush monument and PVC casing cut down to near ground level on December 7, 2022. Casing elevation based on amount of casing cut off.

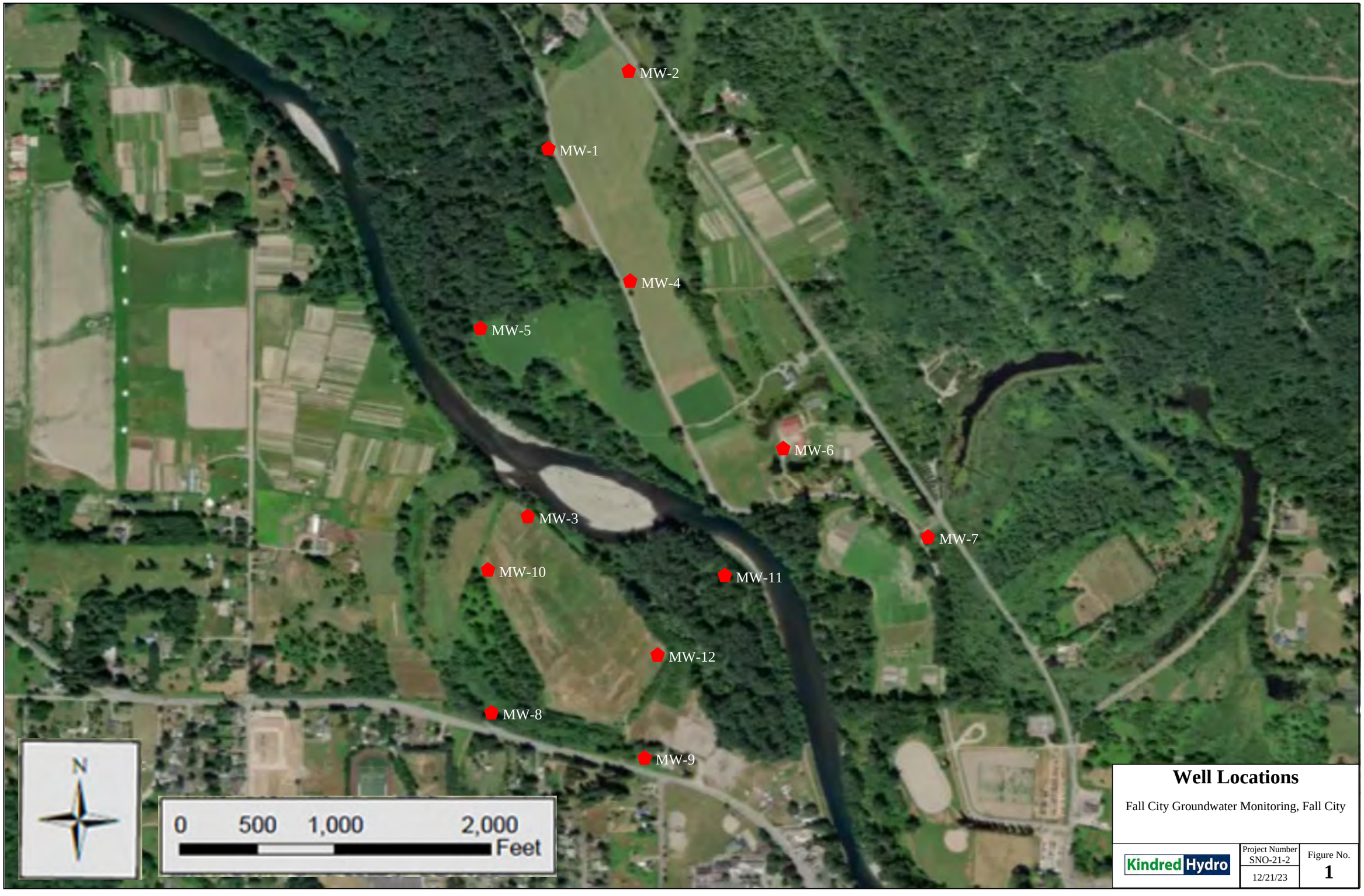
3 Conclusions

Twelve groundwater monitoring wells were installed to monitor groundwater elevations and temperatures before and after construction of the Restoration Project. The wells ranged in depth from 20 to 35 ft below the ground surface and were constructed with 10 to 20 ft of 2-inch diameter PVC slotted screen.

The geology at the site consists of fine-grained alluvium over coarse-grained alluvium. The coarse-grained alluvium was encountered at depths of 6 to 16 ft below the ground surface corresponding to an elevation range of 73.7 to 93.0 ft above NAVD88.

Transducers were installed to measure water level and temperature data at hourly interval.

Figures



Well Locations

Fall City Groundwater Monitoring, Fall City

Kindred Hydro

Project Number	Figure No.
SNO-21-2	1
12/21/23	

ATTACHMENT A: Well Installation Methods and Exploration Logs

A.1. Utility Locate

The proposed areas for drilling were marked in the field and utility locates were called before excavation began. Drilling locations were selected to avoid utilities.

A.2. Well Drilling and Installation

The wells were drilled using either hollow-stem auger drilling or Sonic drilling methods by Holocene Drilling out of Puyallup, Washington on September 30 and October 20-22, 2021.

MW-11 was drilled using a track-mounted hollow-stem auger rig with an 8-inch diameter auger. Soil samples were collected every 5 feet using the standard penetration test. Initially, the sampling device consists of an 18-inch long, 1.5-inch inside diameter split-spoon barrel driven with a 140-pound downhole hammer. The number of blow-counts in the last 12 inches provides an estimate of the density of the soil, referred to as the "n-value". If 50 blows results in less than 6 inches of penetration, the n-value is recorded as the number of inches penetrated in 50 blows. Observed soil conditions were documented and representative soil samples were placed in chip trays.

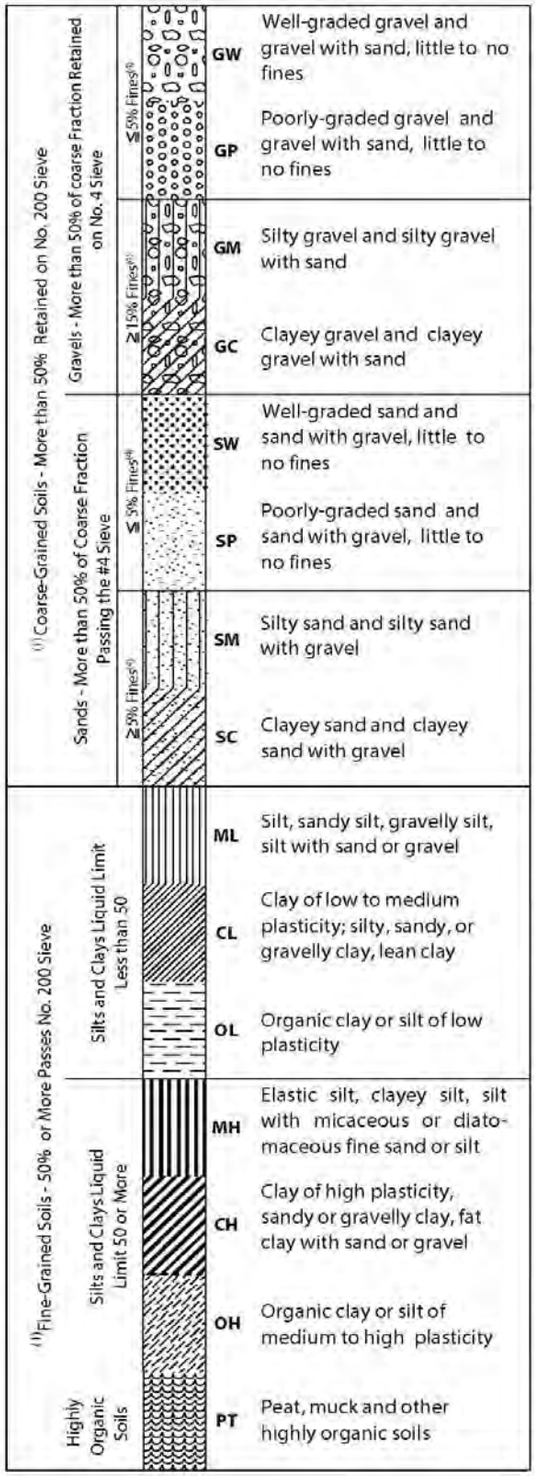
Th remaining wells were drilled using a track-mounted Sonic rig with a 4-inch inside-diameter coring barrel and a 6-inch outside-diameter casing barrel. Continuous core samples were collected every 5 feet and vibrated into plastic bags. Observed soil conditions were documented and representative soil samples were placed in chip trays.

Once the total borehole depth was achieved, either a monitoring well or an infiltration test well was installed in the borehole. The monitoring/test wells were constructed using polyvinyl chloride (PVC) well screen and solid well casing. The screen was 10-20 feet of flush-threaded 2-inch diameter slotted PVC 10-slot screen and a threaded cap was placed on the bottom of the screen. Solid flush-threaded 2-inch diameter PVC pipe was attached to the screen and extended to just below or above the ground surface. A filter pack consisting of #12-20 Colorado silica sand was place in the annular space around the screen to approximately 2 feet above the top of the screen. Bentonite chips were placed in the annular space to within 5 to 10 feet of the ground surface and concrete was placed the remainder of the annular space to within 6 inches of the ground surface. Two of the wells (MW-6 and MW-9) were completed using a 12-inch diameter flush-mounted steel monument placed around the wellhead and set in concrete. The remaining wells were completed with an above-ground monument, consisting of 6 to 8-inch diameter steel casing that extended at least 2 feet into the ground and at least 2 feet above the ground and set in concrete. Three steel bollards were installed around the casing, set in concrete, and filled with sand and concrete.

Scott Kindred from Kindred Hydro, Inc. observed the soil and groundwater conditions in the explorations during vactoring and drilling. Descriptive logs of the exploration and well construction details are provided in this attachment.

A.3. Soil and Groundwater Description

Scott Kindred from Kindred Hydro, Inc. was present throughout the field exploration program to observe the explorations, note groundwater conditions, conduct soil sampling, and prepare descriptive logs of the exploration. Soils were classified in general accordance with ASTM D-2488, *Standard Practice for Description and Identification of Soils (Visual-Manual Procedure*, and ASTM D-2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System*). The exploration logs provided in this attachment represent our interpretation of the contents of the field logs. A key to the symbols and terms used in the boring logs is also found in this attachment. The stratigraphic contacts shown on the individual summary logs represent the approximate boundaries between soil types; actual transitions may be more gradual. The subsurface conditions depicted are only for the specific date and locations reported, and therefore, are not necessarily representative of other locations and times. Exploration ground surface elevations and top of casing elevations are provided on the logs. Ground surface elevations were surveyed to the nearest 0.1 feet and top of casing elevations were surveyed to the nearest 0.01 ft.



Terms Describing Relative Density and Consistency

Coarse-Grained Soils		Fine-Grained Soils	
Density	SPT(2) (blows/ft)	Consistency	SPT(2) (blows/ft)
Very Loose	0 to 4	Very Soft	0-2
Loose	4-10	Soft	2-4
Medium Dense	10 to 30	Medium Stiff	4-8
Dense	30-50	Stiff	8-15
Very Dense	>50	Very Stiff	15-30
		Hard	>30

Component Definitions

Descriptive Term		Size Range and Sieve Number
Boulders		Larger than 12"
Cobbles		3" to 12"
Gravel	Coarse	3" to 3/4"
	Fine	3/4" to No. 4 (4.75 mm)
Sand	Coarse	No. 4 (4.75 mm) to No. 10 (2.00 mm)
	Medium	No. 10 (2.00 mm) to No. 40 (0.425 mm)
	Fine	No. 40 (0.425 mm) to No. 200 (0.075 mm)
Silt and Clay		Smaller than No. 200 (0.075 mm)

Estimated Percentage(3) (by weight)

Percent	Modifier	Percent	Secondary Modifier
<5	Trace	<5	Trace
5-15	Slightly (sandy, silty, clayey, gravelly)	5-10	Few
15-30	Sandy, silty, clayey, gravelly	15-25	Little
30-49	Very (sandy, silty, clayey, gravelly)	30-45	Some

Moisture Content

Dry - Absence of moisture, dusty,dry to the touch
Slightly Moist - Perceptible moisture
Moist - Damp but no visible water
Very Moist - Water visible but not free draining
Wet - Visible free water, usually from below water table

Water Levels

At time of drilling (ATD):
Static water level (date):
Seepage:

(1) Percentage by dry weight
(2) Standard Penetration Test (ASTM D-1586)
(3) In General Accordance with Standard Practice for Description and Identification of Soils (ASTM D-2488)
(4) Combined USCS symbols used for fines between 5% and 15% as estimated in General Accordance with Standard Practice for Description and Identification of Soils (ASTM D-2488)
BGS = below ground surface
BOH=Bottom of hole
CAL=California Sampler

Classifications of soils in this report are based on visual field and/or laboratory observations, which include density/consistency, moisture condition, grain size, and plasticity estimates and should not be construed to imply field or laboratory testing unless presented herein. Visual-manual and/or laboratory classification methods of ASTM D-2487 and D-2488 were used as an identification guide for the Unified Soil Classification System.

Kindred Hydro

Exploration Log Key

Kindred Hydro

Well Log: MW-1

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 83.7 NAVD-88 Surveyed

Start/Finish Date: Oct. 22, 2021

Exploration Method: Sonic

Depth to Water (ft BGS): 9.3 (after drilling)

Sampling Method: Coring

Monument: Aboveground

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
		Core			OL	2-inch Dia. PVC Solid Casing / Bentonite Chips	**Sod/Topsoil**
							dark brown SILT with organics
1	82.7				ML		**Fine-grained Alluvium**
							brown, moist, SILT
2	81.7						
3	80.7				SM		brown, moist, slightly silty fine SAND
4	79.7						
5	78.7	Core					
6	77.7						
7	76.7						
8	75.7				SP		brown, moist, fine SAND, trace silt
9	74.7			10/22/2021			wet
10	73.7	Core			SM		**Coarse-Grained Alluvium**
							brown, wet, silty medium-coarse SAND
11	72.7						
12	71.7						
13	70.7						

Well Log: MW-1

Project Name: Fall City Groundwater

Depth (ft)		Sample Type/I.D.		Water	USCS Class	Well Const.	Description
13	70.7	Core			GM-GW		brown, wet, slightly silty sandy GRAVEL
14	69.7						
15	68.7						
		Core					
16	67.7						
17	66.7						
18	65.7						
19	64.7						
20	63.7						
							BOH at 20 ft

2-inch Dia. 20-slot PVC Well Screen

#12-20 Colorado Silica Sand

Kindred Hydro

Well Log: MW-2

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 84.4 NAVD-88 Surveyed

Start/Finish Date: Oct. 22, 2021

Exploration Method: Sonic

Depth to Water (ft BGS): 8.7 (after drilling)

Sampling Method: Coring

Monument: Aboveground

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
		Core			SM	2-inch Dia. PVC Solid Casing / Bentonite Chips	**Sod/Topsoil**
							dark brown, slightly moist, silty fine SAND, with organics
1	83.4				SM		**Fine-grained Alluvium**
							tan brown, dry, silty fine SAND
2	82.4						
3	81.4				SM-SP		olive brown, slightly moist, slightly silty fine SAND
4	80.4						
5	79.4	Core					
6	78.4						
7	77.4						
8	76.4				GM-GW		**Coarse-Grained Alluvium**
							gray, wet, sandy GRAVEL, trace to slightly silty
9	75.4			10/22/2021			
10	74.4						
11	73.4						
12	72.4						3-5 feet of sample falls out of core barrel
13	71.4						

Well Log: MW-2

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
13	71.4	Core			GM-GW		gray, wet, sandy GRAVEL, trace to slightly silty
							3-5 feet of sample falls out of core barrel
14	70.4						
15	69.4						
		Core					
16	68.4						
17	67.4						
18	66.4						
19	65.4						
20	64.4						
		Core					likely lost 1-3 ft of material out of core barrel
21	63.4						
22	62.4						
23	61.4						
24	60.4						
							heave up to 24 ft
25	59.4						
							BOH @ 25 ft

2-inch Dia. 20-slot PVC Well Screen

#12-20 Colorado Silica Sand

Kindred Hydro

Well Log: MW-3

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 89.9 NAVD-88 Surveyed

Start/Finish Date: Oct. 20, 2021

Exploration Method: Sonic

Depth to Water (ft BGS): 12.0 (after drilling)

Sampling Method: Coring

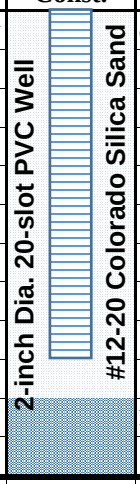
Monument: Aboveground

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
		Core			SM	2-inch Dia. PVC Solid Casing / Bentonite Chips	**Sod/Topsoil**
							dark brownm moist, slightly silty-silty fine SAND with organics
1	88.9						
2	87.9						
					SP-SM		**Fine-grained Alluvium**
							dark brown, slightly moist, slightly silty fine SAND
3	86.9						
4	85.9						
5	84.9						
		Core					
6	83.9						
7	82.9						
8	81.9				SM		olive brown, miost, silty fine SAND
9	80.9						
10	79.9						
		Core					
11	78.9						
12	77.9			10/20/2021			wet
13	76.9						

Well Log: MW-3

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
13	76.9	Core			ML	2-inch Dia. 20-slot PVC Well Screen / #12-20 Colorado Silica Sand	olive brown, wet, SILT
14	75.9						
15	74.9	Core					
16	73.9				SP		**Coarse-Grained Alluvium** gray, wet, medium sand, trace silt
17	72.9						
18	71.9						
19	70.9						gray, wet, gravelly SAND, trace silt
20	69.9	Core					
21	68.9						
					GM-GW		olive brown, wet, slightly silty sandy GRAVEL
22	67.9						
23	66.9						
24	65.9						
25	64.9	Core					
26	63.9						
27							

Well Log: MW-3							Project Name: Fall City Groundwater
		Sample Type/I.D.		Water	USCS Class	Well Const.	Description
27		Core			GM-GW		olive brown, wet, slightly silty sandy GRAVEL
28	61.9						
29	60.9						
							heave up to 29.5 ft
30	59.9						
							BOH @ 30 ft

Well Log: MW-4

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 85.7 NAVD-88 Surveyed

Start/Finish Date: Oct. 21-22, 2021

Exploration Method: Sonic

Depth to Water (ft BGS): 10.0 (after drilling)

Sampling Method: Coring

Monument: Aboveground

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
		Core			ML	2-inch Dia. PVC Solid Casing / Bentonite Chips	**Sod/Topsoil**
							dark brown sandy SILT with organics
1	84.7				ML		**Fine-grained Alluvium**
							dark brown, slightly moist, SILT, trace sand
2	83.7						
3	82.7				SM		brown , moist, silty fine SAND
4	81.7						
5	80.7	Core					
6	79.7						
7	78.7						
8	77.7						
9	76.7						4-inch layer of moist silt with mottling
10	75.7	Core		10/22/2021	SM		**Coarse-Grained Alluvium**
							brown, wet, silty fine-medium SAND
11	74.7				GM-GW		gray, wet, sandy GRAVEL, trace to slightly silty
12	73.7						
13	72.7						

Well Log: MW-4

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
13	72.7	Core			GM-GW	2-inch Dia. 20-slot PVC Well Screen / #12-20 Colorado Silica Sand	gray, wet, sandy GRAVEL, trace to slightly silty
14	71.7						
15	70.7						
		Core					
16	69.7						
					SP		gray, wet, medium-coarse SAND, trace silt
17	68.7						
18	67.7						
19	66.7						
					GM-GW		sandy gravel, slightly silty
20	65.7						
		Core			SP		gray, wet, medium SAND, trace silt
21	64.7						
22	63.7						
23	62.7						
24	61.7						
					GM-GW		slightly silty sandy GRAVEL
25	60.7						
							BOH @ 25 ft

Kindred Hydro

Well Log: MW-5

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 83.7 NAVD-88 Surveyed

Start/Finish Date: Oct. 22, 2021

Exploration Method: Sonic

Depth to Water (ft BGS): 10.6 (after drilling)

Sampling Method: Coring

Monument: Aboveground

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
		Core			ML	2-inch Dia. PVC Solid Casing / Bentonite Chips	**Sod/Topsoil**
							dark brown sandy SILT with organics
1	82.7				ML		**Fine-grained Alluvium**
							brown, slightly moist, SILT
2	81.7						
3	80.7						
4	79.7				SM		gray, slightly moist, trace to slightly silty fine SAND
5	78.7	Core					
6	77.7						
7	76.7				GW-SP		**Coarse-Grained Alluvium**
							gray, moist, sandy GRAVEL to gravelly SAND, trace silt
8	75.7						
9	74.7				GW		gray, wet, sandy GRAVEL, trace silt
10	73.7	Core					
				10/22/2021			
11	72.7						
12	71.7						
13	70.7						

Well Log: MW-5

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
13	70.7	Core			GW	2-inch Dia. 20-slot PVC Well Screen; #12-20 Colorado Silica Sand	gray, wet, sandy GRAVEL, trace silt
14	69.7						
15	68.7						lost most of sample from 15-25 ft, likley sandy GRAVEL
16	67.7						
17	66.7						
18	65.7						
19	64.7						
20	63.7						
21	62.7						
22	61.7						
23	60.7						
24	59.7						
25	58.7						
							BOH @ 25 ft

Well Log: MW-6

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 88.3 NAVD-88 Surveyed

Start/Finish Date: Oct. 21, 2021

Exploration Method: Sonic

Depth to Water (ft BGS): 9.0 (after drilling)

Sampling Method: Coring

Monument: Flush Mount

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
		Core			SM	2-inch Dia. PVC Solid Casing / Bentonite Chips	**Sod/Topsoil**
					SM		**Fine-grained Alluvium**
							dark brown, moist, silty fine SAND with gravel and organics
1	87.3						
2	86.3						
					ML		brown, very moist, slightly sandy SILT
3	85.3						
4	84.3						
5	83.3						
		Core					
6	82.3						
					SM		olive brown, very moist, very silty, fine SAND
7	81.3						gradual transition
					SP		**Coarse-Grained Alluvium**
							gray, slightly moist, medium-coarse SAND, trace silt
8	80.3						
9	79.3			▼ 10/21/2021			
10	78.3						
		Core					changes to wet
11	77.3						
12	76.3						
13	75.3						

Well Log: MW-6

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
13	75.3	Core			SP	2-inch Dia. 20-slot PVC Well Screen / #12-20 Colorado Silica Sand	gray, wet, medium-coarse SAND, trace silt
							red staining from 13.5-14.5 ft
14	74.3						
15	73.3						
		Core			GW		transitions to sandy GRAVEL
16	72.3						
17	71.3						
18	70.3						
					GW		olive gray, wet silty sandy GRAVEL
19	69.3						
20	68.3						
		Core			SM		dark gray, wet, fine-medium SAND
21	67.3						
					SP		trnasitioning to medium-coarse SAND, trace silt, some gravel
22	66.3						
23	65.3						
24	64.3						
							heave up to 24.5 ft
25	63.3						
							BOH @ 25 ft

Well Log: MW-7

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 90.5 NAVD-88 Surveyed

Start/Finish Date: Oct. 21, 2021

Exploration Method: Sonic

Depth to Water (ft BGS): 10.0 (after drilling)

Sampling Method: Coring

Monument: Aboveground

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
		Core			ML	2-inch Dia. PVC Solid Casing / Bentonite Chips	**Sod/Topsoil**
							dark brown, moist, slightly sandy SILT with organics
1	89.5						
					ML		**Fine-grained Alluvium**
							brown, slightly moist, SILT, trace sand, fine layering
2	88.5						
3	87.5						
4	86.5						
5	85.5						
		Core					
6	84.5						
					SM		brown slightly moist, silty fine SAND
7	83.5						
					SM		**Coarse-Grained Alluvium**
8	82.5						olive brown, moist, silty gravelly SAND, cobble at 7.5 ft
9	81.5						
10	80.5			10/21/2021			
		Core					
					GW		gray, wet, slightly silty sandy GRAVEL
11	79.5						
12	78.5						
13	77.5						

Well Log: MW-7

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
13	77.5	Core			GW	2-inch Dia. 20-slot PVC Well Screen / #12-20 Colorado Silica Sand	gray, wet, slightly silty sandy GRAVEL
14	76.5						
15	75.5	Core					
16	74.5						
17	73.5						
18	72.5						
19	71.5						
20	70.5						
							BOH at 20 ft

Well Log: MW-8

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 99.4 NAVD-88 Surveyed

Start/Finish Date: Oct. 21, 2021

Exploration Method: Sonic

Depth to Water (ft BGS): 22.4 (after drilling)

Sampling Method: Coring

Monument: Aboveground

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
		Core			SM	2-inch Dia. PVC Solid Casing / Bentonite Chips	**Sod/Topsoil**
							dark brown, slightly moist, silty fine SAND with organics
1	98.4						
					SM		**Fine-grained Alluvium**
2	97.4						brown, dry, silty SAND
3	96.4						
					ML		brown, dry, SILT with fine layering
4	95.4						
5	94.4						
		Core					
6	93.4						
7	92.4						
8	91.4						
							changes to slightly moist
							mottling from 8 to 10 ft
9	90.4						
10	89.4						
		Core					
11	88.4						
12	87.4						
13	86.4						moist and mottling from 13-14 ft

Well Log: MW-8

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
13	86.4	Core			ML	2-inch Dia. PVC Solid Casing / Bentonite Chips	brown, moist, SILT, mottling from 13-14 ft
14	85.4				SM		tan, slightly moist, fine SAND, trace silt
15	84.4	Core			GM-GW		**Coarse-Grained Alluvium**
16	83.4						gray, slightly moist, slightly silty, sandy GRAVEL, with numerous cobbles
17	82.4						
18	81.4						
19	80.4						
20	79.4	Core					
21	#REF!				GM		olive brown, moist, slty sandy GRAVEL
22	#REF!			10/21/2021			
23	#REF!						
24	#REF!						
25	#REF!	Core				2-inch Dia. 20-slot PVC Well Screen / #12-20 Colorado Silica Sand	wet
26	#REF!						
27							

Well Log: MW-8

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
27	72.4				GM	2-inch Dia. 20-slot PVC Well Screen / #12-20 Colorado Silica Sand	olive brown, moist, slty sandy GRAVEL
28	71.4						
29	70.4						
30	69.4	Core			SP		olive brown, wet, medium SAND, trace silt
31	68.4						
32	67.4						
33	66.4						
34	65.4						
35	64.4						
							BOH @ 35 ft

Well Log: MW-9

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 99.0 NAVD-88 Surveyed

Start/Finish Date: Oct. 20-21, 2021

Exploration Method: Sonic

Depth to Water (ft BGS): 20.2 (after drilling)

Sampling Method: Coring

Monument: Flush Mount

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
		Core			SM	2-inch Dia. PVC Solid Casing / Bentonite Chips	**Sod/Topsoil**
							dark borown, slightly moist, silty fine SAND with organics
1	98						
					ML		**Fine-grained Alluvium**
2	97						brown, dry, silty sandy SILT
3	96						
4	95						
5	94	Core					
6	93				GW		**Coarse-Grained Alluvium**
							gray, dry, sandy GRAVEL, with numerouls cobbles
							unknown water and silt content due to grinding of cobbles and heating
7	92						
8	91						
9	90						
10	89	Core					
11	88						
12	87						
13	86						

Well Log: MW-9

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
13	86	Core			GW	2-inch Dia. PVC Solid Casing / Bentonite Chips	gray, sandy GRAVEL, with numerous cobbles
14	85						
15	84	Core					
16	83						
17	82						
18	81						
19	80						
20	79	Core		10/21/2021			
21	78						
22	77						wet
23	76						
24	75						
25	74	Core				2-inch Dia. 20-slot PVC Well Screen / #12-20 Colorado Silica Sand	
26	73						
27	72						

Well Log: MW-9

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
27	72				GW		gray, sandy GRAVEL, with numerous cobbles
28	71						
29	70						
30	69	Core					
31	68						
32	67						
33	66						
34	65						
35	64						
							BOH @ 35 ft

2-inch Dia. 20-slot PVC Well Screen

#12-20 Colorado Silica Sand

Well Log: MW-10

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 87.7 NAVD-88 Surveyed

Start/Finish Date: Oct. 20, 2021

Exploration Method: Sonic

Depth to Water (ft BGS): 11.3 (after drilling)

Sampling Method: Coring

Monument: Aboveground

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
		Core			SM	2-inch Dia. PVC Solid Casing / Bentonite Chips	**Sod/Topsoil**
							dark brown, silty fine SAND with organics
1	86.7						
					SM-SP		**Fine-grained Alluvium**
							dark brown, slightly moist, slightly silty fine-medium SAND
2	85.7						
3	84.7						
							brown, slightly moist to moist, slightly silty, fine SAND
4	83.7						
5	82.7						
		Core					
6	81.7						
7	80.7						
8	79.7				ML		brown, moist, SILT
9	78.7						
							Coarse-Grained Alluvium
10	77.7						gray, moist, slightly silty fine-medium SAND
		Core			SM		
11	76.7						
				10/20/2021			
12	75.7						
					GM-GW		gray, wet, slightly silty sandy GRAVEL
13	74.7						

Well Log: MW-10

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
13	74.7	Core			GM-GW	2-inch Dia. 20-slot PVC Well Screen / #12-20 Colorado Silica Sand	gray, wet, slightly silty sandy GRAVEL
14	73.7						
15	72.7						
		Core			GM		gray, wet, silty, sandy GRAVEL
16	71.7						
17	70.7						
18	69.7						
19	68.7						
20	67.7						
		Core					
21	66.7						
22	65.7						
23	64.7						
24	63.7						
25	62.7						
							BOH @ 25 ft

Well Log: MW-11

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 89.0 NAVD-88 Surveyed

Start/Finish Date: Sept. 30, 2021

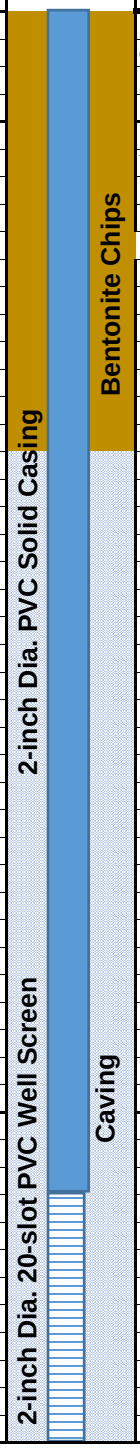
Exploration Method: Hollow Stem Auger

Depth to Water (ft BGS): 11.0 (after drilling)

Sampling Method: Standard Penetration Test (STP)

Monument: Aboveground

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
					SM		**Sod/Topsoil**
							dark brown, silty fine SAND with organics
1	88						
					SM-SP		**Fine-grained Alluvium**
							brown, slightly moist to dry, slightly silty fine SAND
2	87						
3	86						
4	85						
5	84						
		STP	9				
			10				
6	83						
			16				
7	82						
8	81						
9	80						
10	79						
		STP	13		GM		**Coarse-Grained Alluvium**
							gray, wet, silty sandy GRAVEL
			25				
11	78						
			47				
				9/30/2021			
12	77						
13	76						



Well Log: MW-11

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Well Const.	Description
13	76				GM	2-inch Dia. 20-slot PVC Well Screen / Caving	gray, wet, silty sandy GRAVEL
14	75						
15	74						
		STP	50/5"				gray, wet, sandy GRAVEL
16	73						
17	72						
18	71						
19	70						
20	69						
		STP	31				gray, wet, sandy GRAVEL
			50/3"				
21	68						BOH @ 20.75 ft, cave around screen

Well Log: MW-12

Project Name: Fall City Groundwater

Project #: SNO-21-2

Logged by: Scott Kindred

Location: Fall City, WA

Driller: Holocene Drilling

Ground Surface Elevation: 88.4 NAVD-88 Surveyed

Start/Finish Date: Oct. 20, 2021

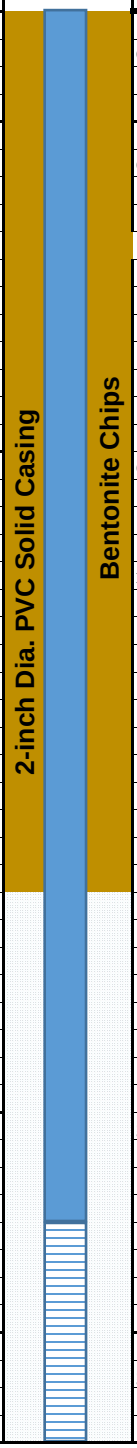
Exploration Method: Sonic

Depth to Water (ft BGS): 11.3 (after drilling)

Sampling Method: Coring

Monument: Aboveground

Depth (ft)	Elev (ft)	Sample Type/I.D.	Blow Counts	Water	USCS Class	Description
		Core			SM	**Sod/Topsoil**
						dark brown, silty fine SAND with organics
1	87.4					
					ML	**Fine-grained Alluvium**
						olive brown, slightly moist, SILT with fine layering
2	86.4					
3	85.4					
4	84.4					
					SM	olive brown, slightly moist, silty fine SAND
5	83.4					
						no recovery 5-10 ft
6	82.4					
7	81.4					
8	80.4					
9	79.4					
10	78.4					
		Core			ML	gray, wet, SILT
				10/20/2021		
11	77.4					
12	76.4					
					GW	**Coarse-Grained Alluvium**
						gray, wet, sandy GRAVEL, trace silt
13	75.4					



Well Log: MW-12

Project Name: Fall City Groundwater

Depth (ft)	Elev (ft)	Sample Type/I.D.		Water	USCS Class	Well Const.	Description
13	75.4	Core			GW	2-inch Dia. 20-slot PVC Well Screen / #12-20 Colorado Silica Sand	gray, wet, sandy GRAVEL, trace silt
14	74.4						
15	73.4	Core					
16	72.4				GM-GW		gray, wet, slightly silty, sandy, GRAVEL
17	71.4						
18	70.4						
19	69.4						
20	68.4	Core					
21	67.4						
22	66.4				GW		gray, wet, slightly sandy GRAVEL, trace silt
23	65.4						
24	64.4				GM-GW		gray, wet, slightly silty, sandy GRAVEL
25	63.4						
26	62.4						BOH @ 26 ft