Appendix H: Groundwater Monitoring Report 2019-2024

Overview.and.Methods

The project team installed a set of seven groundwater wells in Faith Valley July 22-26, 2019. They are two inches in diameter and installed to a depth of up to 10 feet using the method developed by Amy Merrill PhD at Stillwater Sciences. The wells were installed in three transects roughly perpendicular to flow, near transects previously surveyed by Waterways Consulting (Figure 1). Faith Valley (FV) Groundwater Well (GW) 6 and 7 are located at the upstream end, FV GW 1 and 2 are in the middle and FV GW 3-5 are at the downstream end of the project reach (Figure 1). The project design originally proposed work in the vicinity of the upper transect (wells 6-7), but was refined to only include work well downstream, so this transect can act as a control for evaluating the effects of project activities. Each well is equipped with a pressure transducer collecting one-hour depth data. The site is equipped with one barometric pressure transducer to correct for atmospheric pressure. Wells were visited roughly monthly during the spring-fall 2019-2024. Manual groundwater depth measurements were taken along with data downloads and used to calibrate the data. All wells were surveyed by Waterways Consulting during summer 2023, allowing data to be expressed as the elevation of the groundwater table at each well. This allows for more robust comparisons between wells in transects.

Faith Valley meadow has multiple active beaver colonies whose dams affect the groundwater locally in multiple parts of the meadow (See Beaver Inventory in Appendix F for details). Figure 1 shows the results of beaver monitoring 2016-2024 in relation to the groundwater well locations to facilitate comparisons between beaver dam locations and groundwater data. A layered PDF of this map, where specific years of data can be toggled on and off, is included as Appendix F.1. BDAs installed in 2022, 2023, and 2024 were included in the beaver survey and are included in this figure. During the duration of groundwater monitoring 2019-2024, beaver activity has been most concentrated at the upstream and downstream ends of the project area. The lower transect (wells 3-5) was affected by a large natural dam for several years through spring 2024, while the upper transect (wells 6 and 7) has been more intermittently beaver-affected. The middle transect (wells 1 and 2) has generally had less beaver influence and is close to several beaver dam analogues (BDAs) installed during the project. As a result, the middle transect is the most useful for examining project effects, while the upstream and downstream cross sections can act as references to some degree. Groundwater levels in the upper transect were affected by a beaver dam during and after phase 1 implementation in fall 2022, but this dam blew out in spring 2023 and was not rebuilt before phase 2 implementation in fall 2023. As a result, the upper transect is useful for examining how BDA construction affects groundwater levels relative to a natural beaver dam (2022) and relative to a reach without a beaver dam (2023). In contrast, the lower transect provides an example of a water table that has been affected by large beaver dams for most of the monitoring period. Groundwater levels in the lower transect may also be affected by the grade control structure installed at the lower end of the meadow in fall 2022.

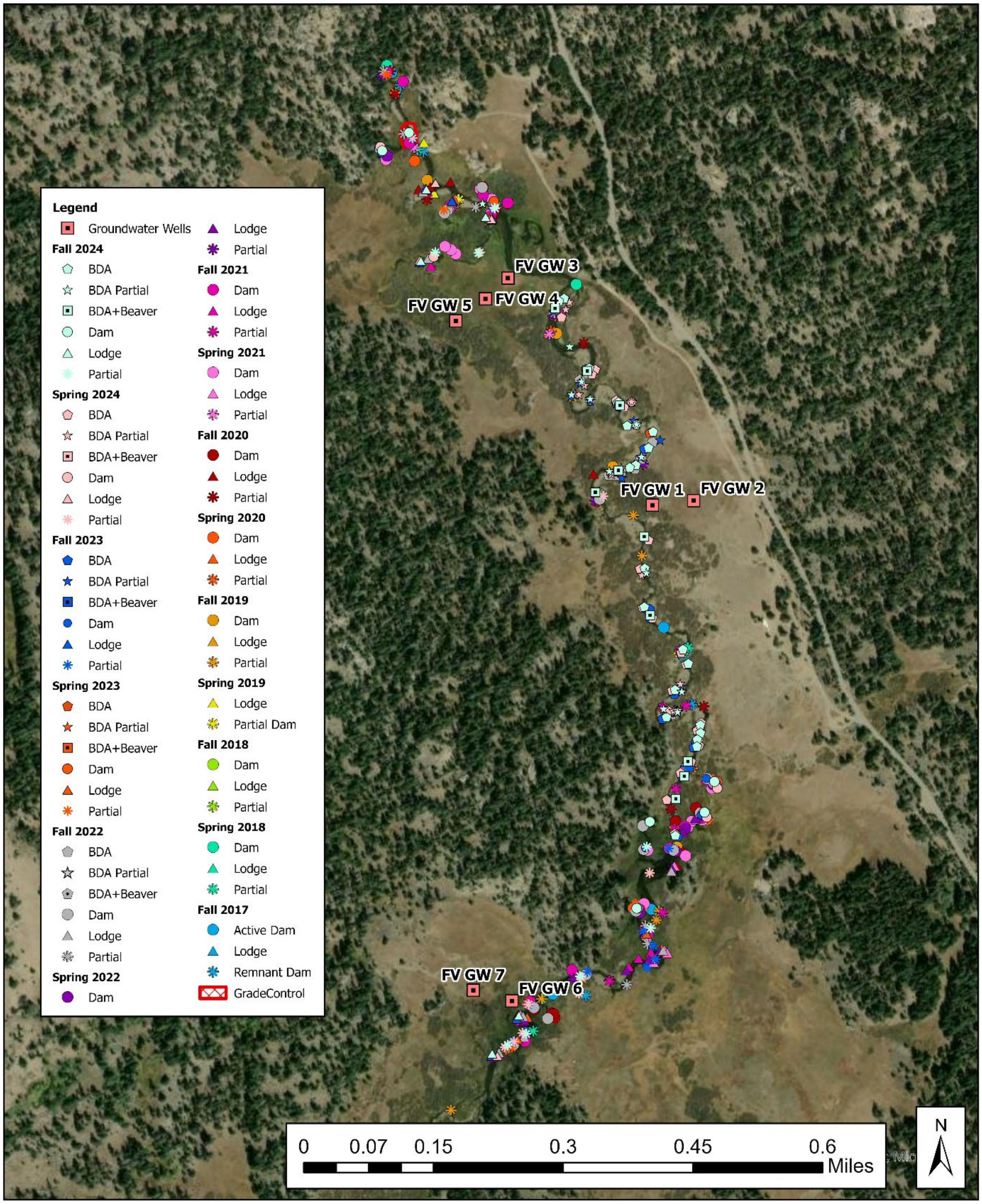

Figure 1. Map showing the locations of groundwater monitoring wells in Faith Valley Meadow along with beaver structure monitoring data from 2016-2022. Wells are arranged in three transects roughly perpendicular to the channel: one above the project area (FV GW 6&7), one mid-meadow in the project reach (FV GW 1&2), and one at the bottom of the project reach (FV GW 3, 4, & 5). For an interactive version of this map where data from different years can be toggled on and off, see Appendix F.1

Hydrologic context

As with most stream systems in the Sierra Nevada, both streamflow in the West Fork Carson River and groundwater levels in Faith Valley Meadow are tightly linked to snowpack. The Snowpack in the headwaters upstream from Faith Valley has varied from below average to well above average between 2019 and 2024 (Figure 2), with 2022 being the driest and 2023 the wettest year of record. 2020 and 2021 both had below average snowpack as well, while 2019 and 2024 were the only other years with average or above average snowpack during the monitoring period (Figure 2). In lieu of any other factors (e.g. summer rainfall, beaver activity), groundwater levels in Faith Valley would be expected to track with snowfall patterns and be lower than average in 2020-2022 and average or higher than average in 2019, 2023, and 2024. For a more complete discussion of snowpack and streamflow conditions in Faith Valley, see Appendix G – Streamflow Monitoring Report.

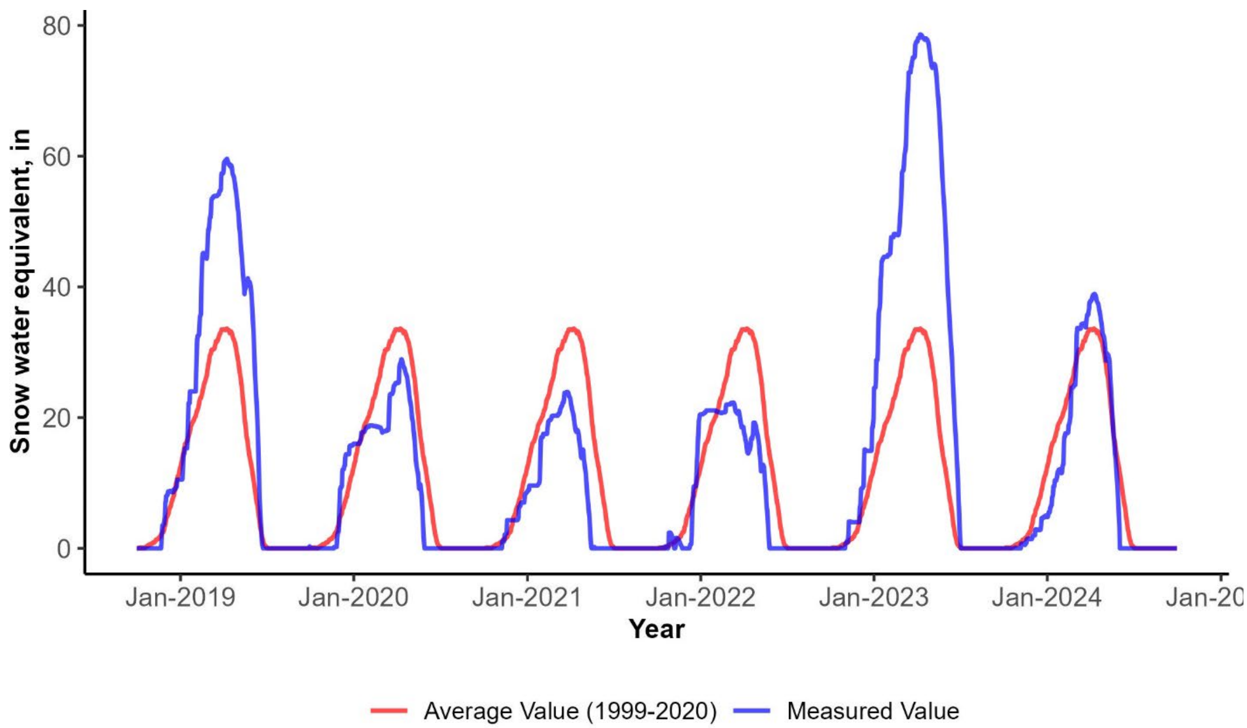

Figure 2. Snow Water Equivalent for water years (WY) 2019-2024 at the NRCS Forestdale Creek SNOTEL station located just west of Faith Valley Meadow. For the purposes of this report, we used October 1st-September 30th to define water years. WY 2019 and 2023 were well above average and WY 2024 was approximately average, while WY 2020-2022 were below average. 2023 was the wettest year, while 2022 was the driest. Data exported from the NWCC Report Generator (*https://wcc*.sc.egov.usda.gov/reportGenerator/).

Monitoring.Data

Expected and observed patterns

As stated above, annual fluctuations in groundwater levels in the Sierra Nevada are snowmelt-driven. This usually manifests as a large increase in groundwater levels during snowmelt (approximately April-June) followed by a gradual decrease into the late summer and fall. This overall pattern is often interrupted by summer and fall thunderstorms, which can produce intense local precipitation and drive substantial short-term increases in groundwater table elevations. On the broader scale of multiple years, groundwater levels would generally be expected to be higher following winters with larger snowpacks and lower after winters with smaller snowpacks.

In general, groundwater monitoring data for 2019-2024 follows the expected pattern discussed above, with peaks during snowmelt and lower water table elevations in the spring/fall (Figure 3 and Figure 4). In all three transects, the highest water table elevations are usually recorded in May, while the lowest elevations generally occur between July-November, depending on the year (Figure 3). The main exceptions to these patterns are presumably precipitation-driven peaks that are visible in all three transects. The most obvious of these occurred in November 2021 and is visible in the data from all seven wells (Figure 3). Monitoring data also generally follow the expected pattern of higher maximum water table elevations in years with larger snowpacks. Almost all wells recorded their highest water table levels in spring 2023 (Figure 3) following the largest snowpack recorded during the monitoring period (Figure 2). In addition, all wells exhibited a delayed lowering of the water table after snowmelt in 2023 compared to previous years (Figure 4).

While some of the expected patterns occur in the monitoring data, some data does not conform to this framework. These patterns become more pronounced when directly comparing data from different years (Figure 4). These discrepancies are most likely due to the influence of beaver, who construct dams that raise the surface water elevation in the stream channel and increase ponded and wetted areas adjacent to the channel, as well as the BDA and grade control features constructed by the project (described below). For example, between November 2020 and May 2022, the groundwater table elevation at the lower transect was relatively steady – snowmelt peaks still exist, but the difference between the maximum and minimum groundwater table elevations in these years is small when compared to the variability in the middle transect during the same period (Figure 3, Figure 4). This difference is likely due to the influence of a large natural beaver dam that was built just downstream of the lower transect between the spring and fall beaver surveys in 2020, which kept the water table higher during the summer months as compared to the non-beaver affected middle transect. Despite 2019 being an above average snow-year, the lowest groundwater elevations from 2019 and the first half of 2020 are much lower than subsequent years, especially during the driest part of the year (Figure 4), demonstrating the influence of the adjacent beaver dam. This dam blew out in spring of 2024, causing a rapid decline in water table elevations in the lower transect (Figure 3, Figure 4). However, water table elevations in the lower transect rebounded to nearly the same level as before the large dam blew out, likely due a new beaver dam built on the downstream grade control structure and repairs to the series of BDAs just upstream of this transect in fall 2024(Figure 4). The upper transect also shows evidence of beaver activity, with fairly consistent water table elevations between November 2021 and November of 2022 coinciding with a large beaver dam built near the transect that persisted from fall of 2020 through spring of 2023. The high late-season water table in the upper transect during 2021 and 2022 (Figure 4) provides another example of beaver influence.

There are also several periods both during spring snowmelt and during these beaver-affected periods where groundwater wells were flooded above the ground surface, resulting in groundwater table readings above the ground surface (Figure 3, Figure 4). The data also generally show small increases around the time when the Carson Water Subconservancy District (CWSD) releases water upstream associated with their water right around the first week of October each year. Finally, there are a few periods of missing data due to logger issues (e.g. wells 4 and 5 between July and November of 2022; Figure 3).

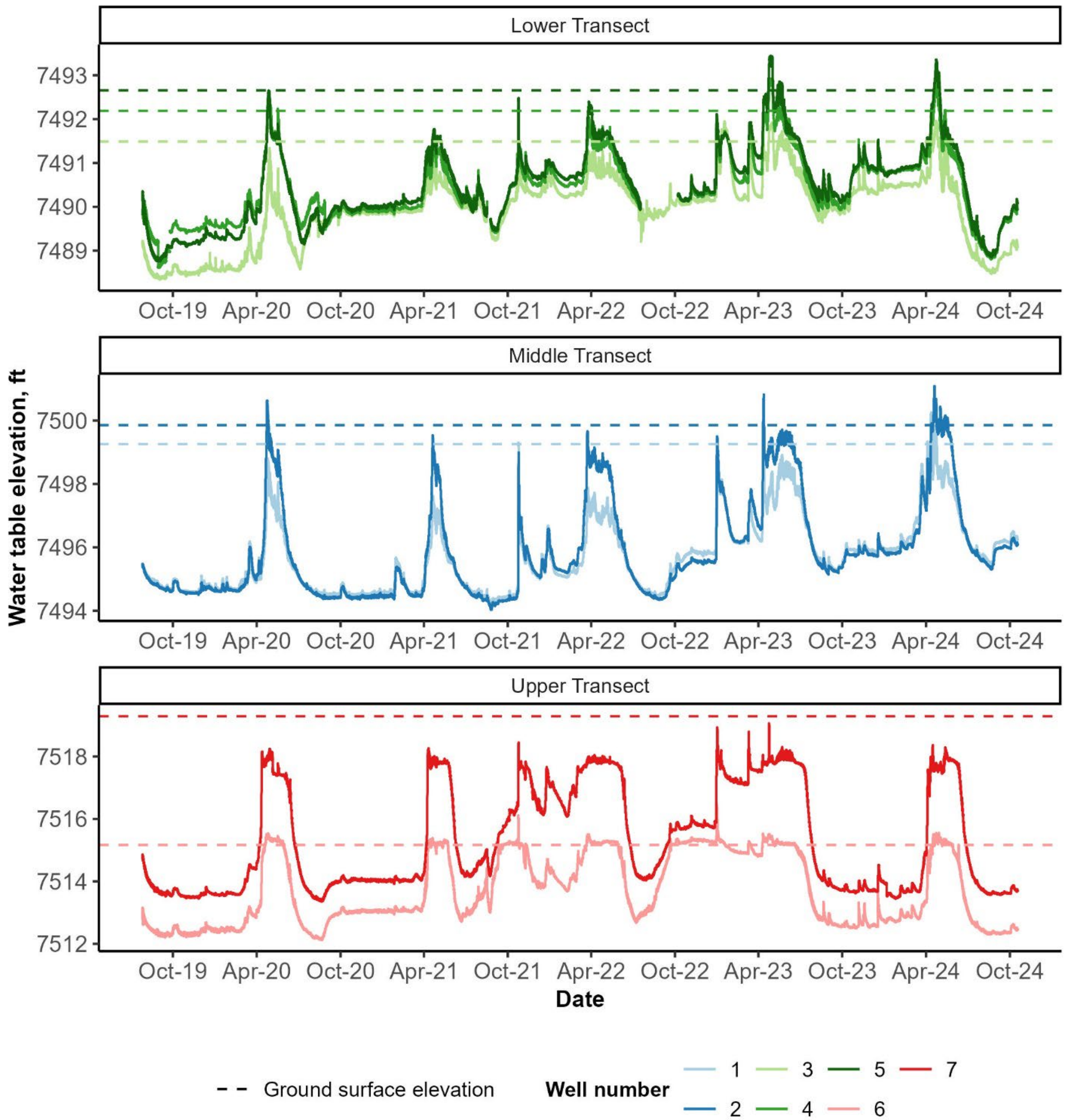

Figure 3. Line graph showing the elevation of the groundwater table at each well in each transect. Horizontal dashed lines show the elevation of the ground surface elevation at each well. Within each transect, wells closer to the channel are

represented by lighter colors, while wells farther from the channel are represented by darker colors. Values above the ground surface elevation are due to flooded conditions from high flow or beaver ponds.

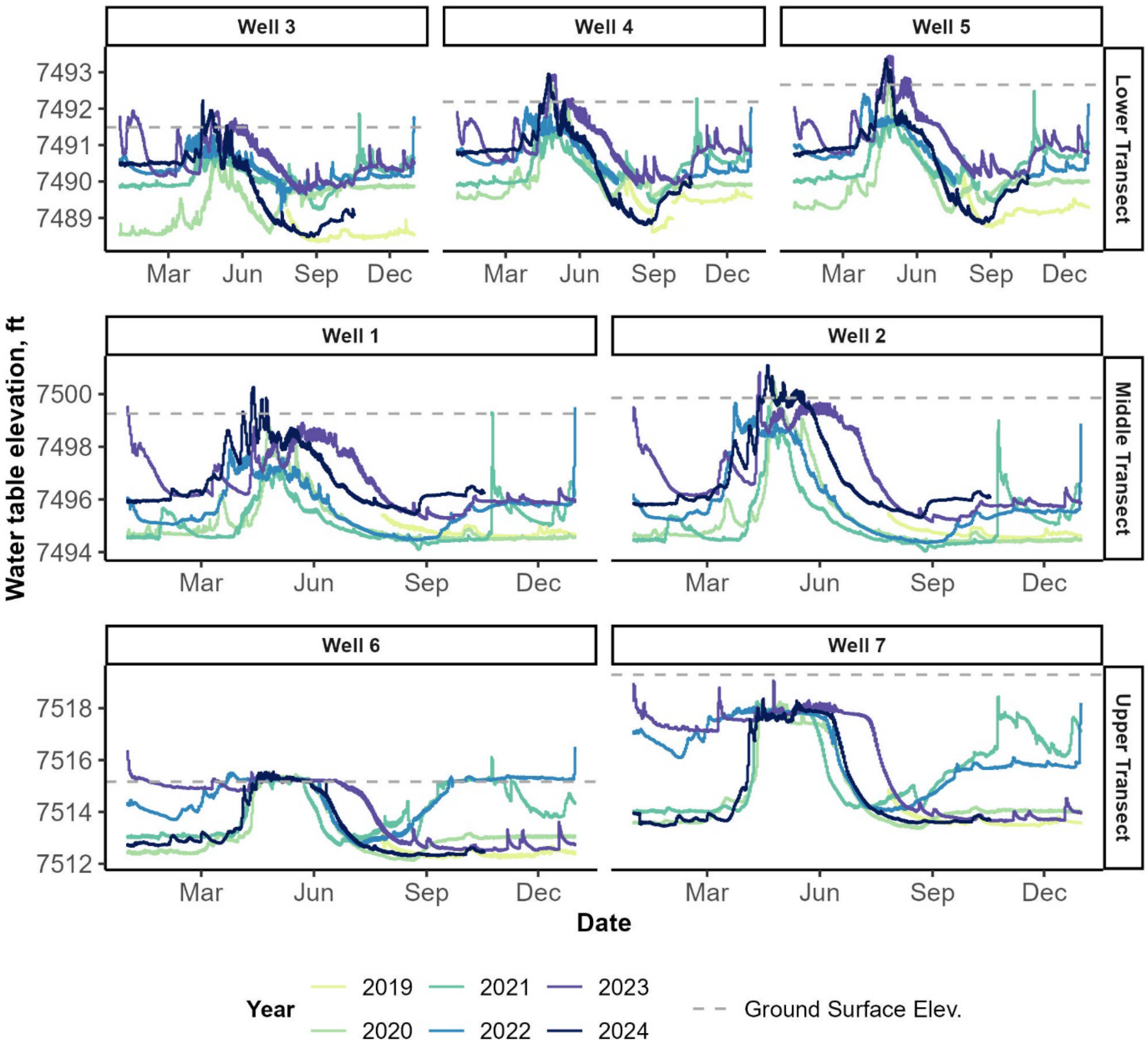

Figure 4. Year-over-year comparisons of groundwater elevations in each well. Lighter colored lines represent earlier years, while darker lines represent more recent years. Horizontal dashed lines represent the ground surface elevation at each well. Wells on the left side of the figure are closer to the channel, while wells on the right side of the figure are farther from the channel. All data represent the actual elevation of the water table in each well.

Comparison with manual measurements

All well logger data were calibrated using manual water depth measurements, which were collected approximately once monthly during the late spring-fall throughout the monitoring period.

For quality control purposes, all manual measurements are shown plotted against calibrated logger data in Figure 5. All points fall on the calibrated logger data as expected.

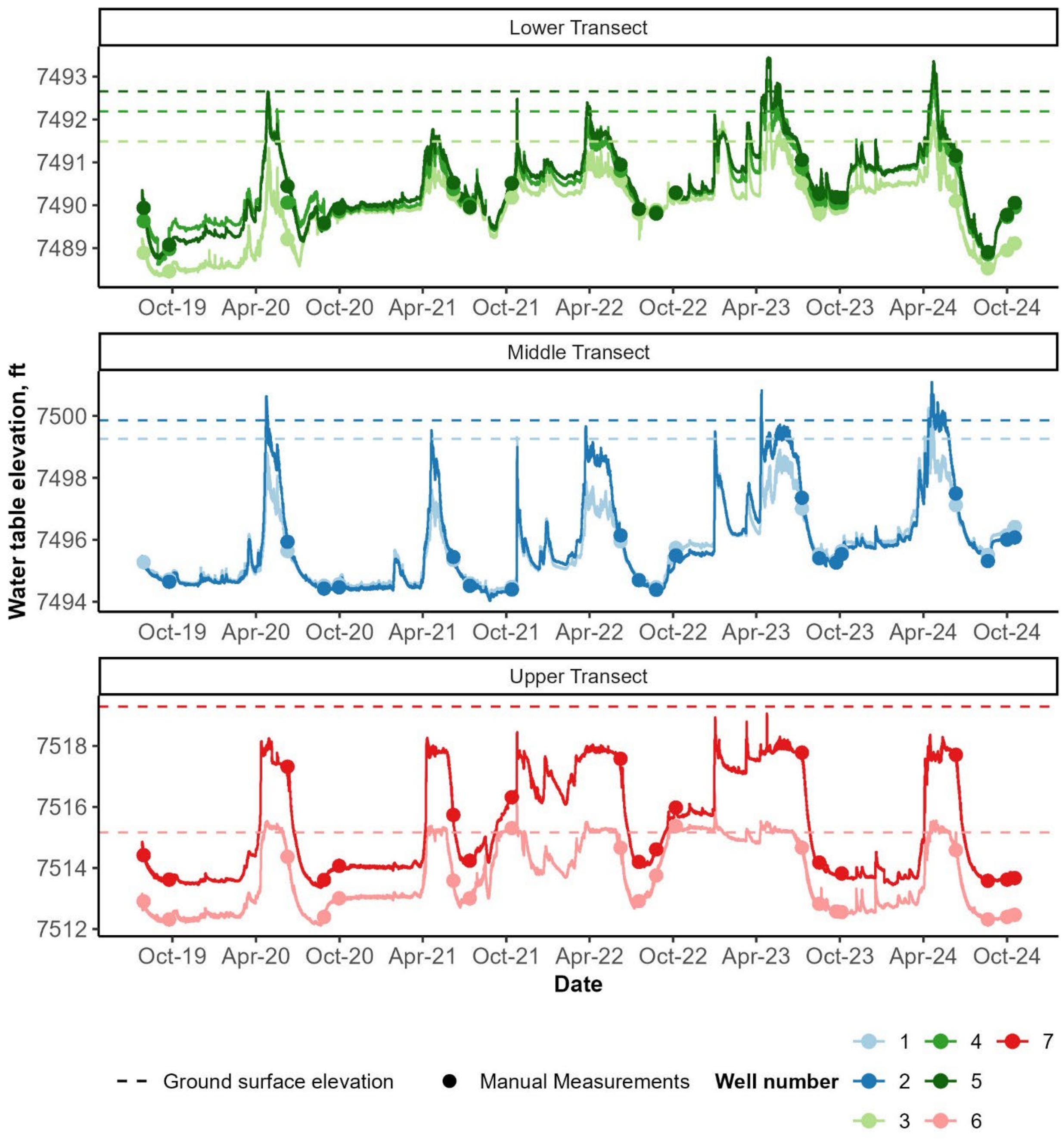

Figure 5. Line graph showing logger data from all wells, with points denoting manual measurements conducted approximately monthly during the late spring-fall throughout the monitoring period. Within each transect, lighter colors denote wells closer to the channel, while darker colors represent wells farther from the channel.

Project.Effects

As stated in the project monitoring plan, major project objectives included increasing groundwater table elevations locally and establishing a trend towards raising the water table to within three feet of the meadow surface in the lower and middle transects during late spring-fall (June-November). To evaluate progress towards these goals, we used two different methods. First, to examine whether groundwater table elevations in Faith Valley Meadow have increased over time, we calculated average, maximum, and minimum groundwater table elevations between June 1st and November 30th for each well for each year of the monitoring period (2019-2024) and fit basic linear models to the resulting points. Second, to specifically evaluate project affects and progress towards raising the groundwater table to within three feet of the meadow surface, we conducted basic analyses of variance (ANOVAs) comparing groundwater levels before and after project implementation. It should be noted that both approaches have implicit biases due to: A) the limited amount of data available for post-implementation, and B) the fact that post-implementation data was collected during average (2024) or well above average (2023) water years (Figure 2). In combination, these factors make it difficult to separate project effects from the effects of the natural fluctuations in snow pack. Additional years' worth of monitoring data would be necessary to definitively separate these effects, but the data available at present can provide some initial insight on current progress towards the project objectives.

Evidence for change in local water table elevation over time

After adding data for 2024, linear models of minimum, average, and maximum groundwater table elevations between June 1st and November 30th show that average groundwater table elevations have significantly increased ($p<0.05$) in the middle transect between 2019-2024, but not in the upper or lower transects (Figure 6). These findings differ from a similar analysis conducted in 2023, which showed a significant increase in average and minimum groundwater table elevations in the lower transect, but *not* in the middle transect. This difference can be attributed to two factors: First, the loss of the large beaver dam near the lower transect in spring 2024, and second, the influence of BDAs constructed near the middle transect. As previously discussed, the large beaver dam that had elevated groundwater levels in the lower transect between 2020-2024 blew out during spring runoff in 2024, leading to a substantial drop in groundwater levels in the lower transect during summer 2024. This decline is likely responsible for the lack of a significant trend in groundwater elevations in the lower transect (Figure 6).

However, the significant increase in average groundwater elevations between June 1st and November 30th in the middle transect provides strong evidence that the project is progressing towards its goal of raising water table elevations. Prior to implementation, there was little to no beaver activity near the middle transect, but numerous BDAs were constructed near the transect during the project. As such, the middle transect is best situated to evaluate how BDA construction has affected the local water table elevation. After adding data from summer 2024, both wells in the middle transect had a significant ($P<0.05$) increase in dry season water table elevations between 2019-2024 (Figure 6), suggesting that BDAs installed during the project are functioning as planned and raising the local water table. There were substantial increases in average June-November groundwater table elevations in both 2023 and 2024 relative to previous years in both wells in the middle transects (Figure 6, Figure 7), which are notably absent in the upstream "reference" transect that is not affected by project or current beaver activity. During the same time period, average groundwater table elevations in the upper transect decreased relative to previous years (Figure 6). Furthermore, while groundwater table elevations did drop in the lower transect after the large natural beaver dam blew out in spring 2024, they remain higher than all but one year pre-implementation (2019/20). This suggests that a combination of the grade control structure at the downstream end and the most downstream BDA series (series 12) are elevating groundwater levels in the lower meadow.

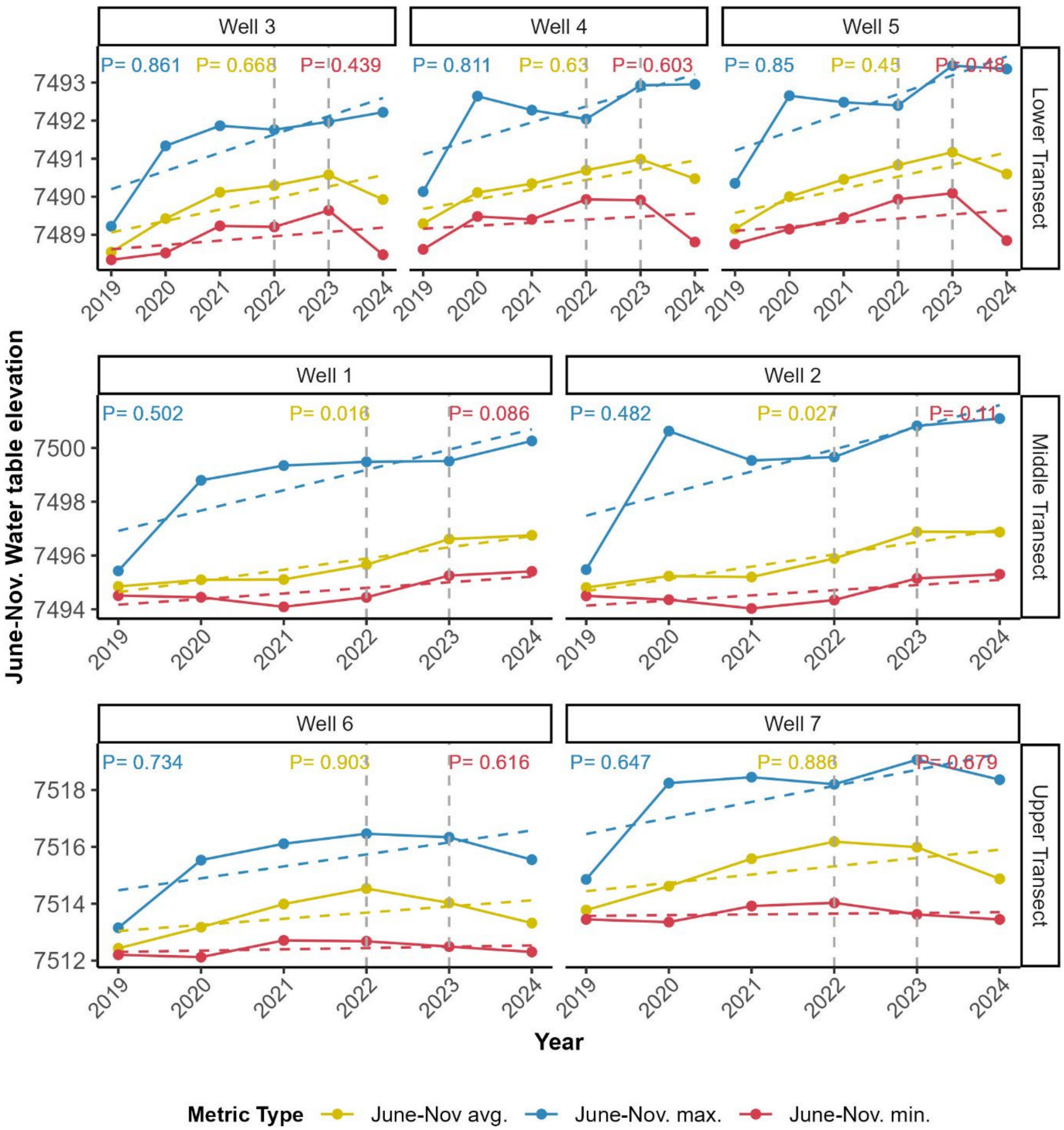

Figure 6. Line graph showing average, maximum, and minimum groundwater table elevations in each well between June 1st-November 30th for each year of the monitoring period. Colored dotted lines show linear trends, and p-values are based on a simple linear regression of average/maximum/minimum water table elevation over time. Grey dotted vertical lines

denote phases of implementation; Initial implementation was conducted in 2022, and full implementation in 2023. Average groundwater table elevations increased significantly in the middle transect (indicated by P values <0.05) but did not in the upper or lower transects.

Overall, monitoring data from 2019-2024 provide convincing evidence that the project is making progress towards its stated objective of increasing the elevation of the groundwater table in Faith Valley Meadow. The middle transect shows clear increases in late summer groundwater table elevations relative to pre-project years (Figure 7), and the lower transect has maintained consistently higher groundwater table elevations post-implementation despite losing a large natural beaver dam in Spring 2024. Additional years of monitoring data would be helpful in determining how large and persistent these increases are, but the data available clearly demonstrate that the project is performing as planned.

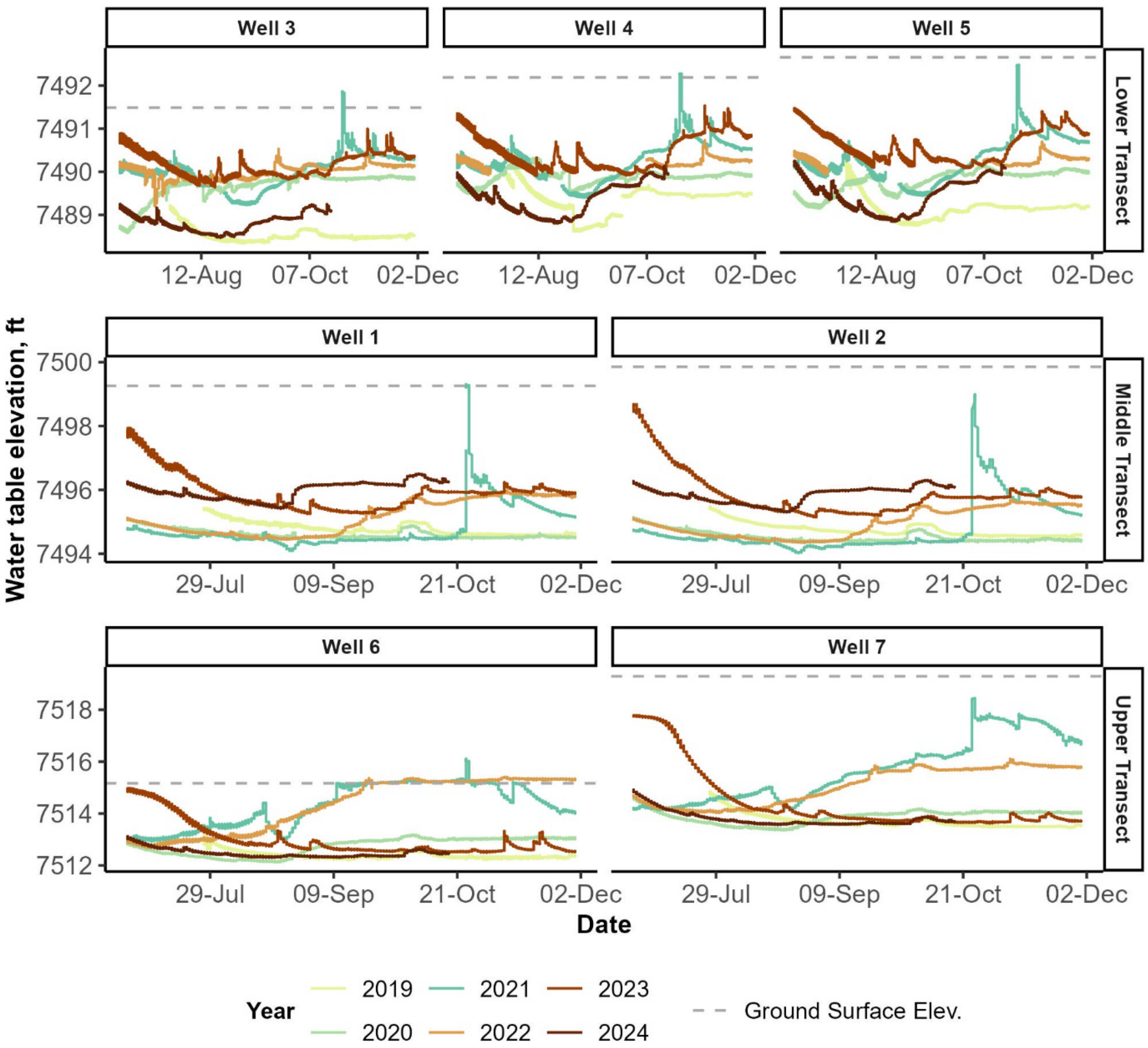

Figure 7. Line graph showing June-November groundwater levels in each well, with different colors denoting different years. Green/blue colors represent pre-project years (2019-2021), while brown colors represent post-project years (2022 and 2023). Dashed grey lines mark the ground surface elevation at each well.

Evidence for progress towards raising and maintaining water table elevations to within 3 ft of meadow surface

Basic ANOVA comparing the depth to the water table surface during June-November before and after project implementation show the water table has been significantly closer to the meadow surface post-project in all wells (Figure 8, $p<0.001$). In the lower transect, the average water table depth has been less than three feet below the meadow surface in all three wells post-project (Figure 8, Figure 9). While the average groundwater table depth was still greater than three feet below the surface post-project in the middle transect, the water table has been significantly closer to the meadow surface than it was pre-project (Figure 8) and is very near three feet at the well closest to the channel. In combination, these results indicate significant progress towards the stated project objective of raising and maintaining the water table to within three feet of the meadow surface in the lower and middle transects. With that said, this analysis includes the data from the historically wet winter of 2023 in the post-project data, which likely skews the post-project results. To evaluate the effect of the 2023 data, we re-ran the ANOVA analysis with the 2023 data omitted to allow for comparison of results (Figure 10). Although this analysis is limited due to only one season of post-project data (2024), it is helpful to evaluate trends without the exceptionally high 2023 water year. This second basic ANOVA comparing the depth to the water table surface during June-November before and after project implementation with 2023 data omitted shows similar results. It shows that the water table has been significantly closer to the meadow surface post-project in all wells (Figure 10, $p<0.001$). The mean is still within 3 feet of the meadow surface in all wells in the lower transect. In the middle and upper transects, the water table is still significantly closer to the meadow surface than it was pre-project (Figure 10) and is very near three feet at the well closest to the channel in the middle transect. The similar results when 2023 data are omitted help to confirm that these results of the pre- and post-project comparison, indicating progress toward the project objectives. Overall, additional years of post-project data would be needed to determine the persistence of the observed effects.

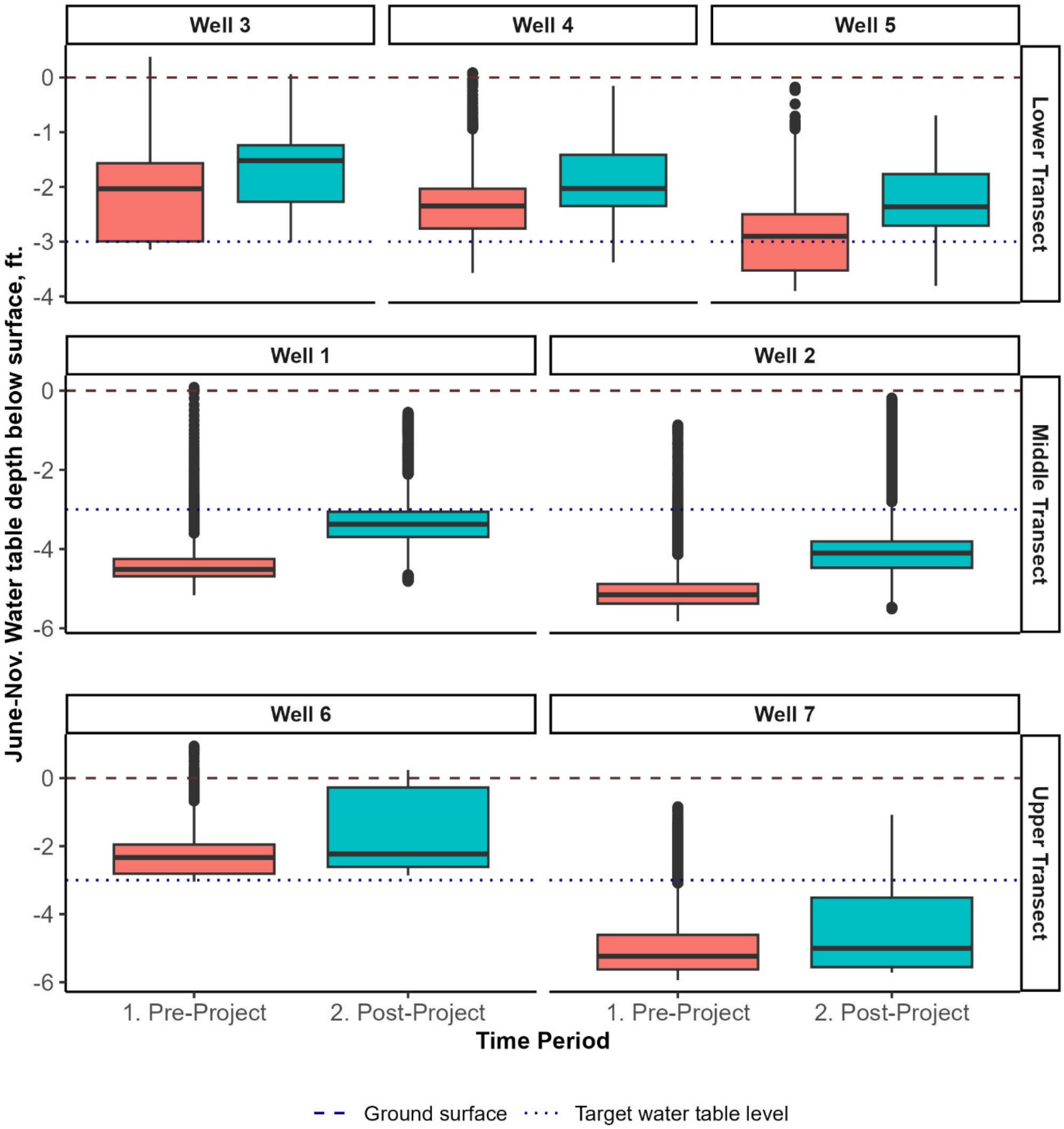

Figure 8. Box plots comparing summer/fall (June-November) water table depth below surface for pre project (before August 15, 2023 – before 2023 Phase 2 implementation) and post project (after August 15, 2023) in each well. For all wells, average groundwater table depths during June-November were significantly closer to the surface after project implementation (ANOVA, p<0.001). However, much of this difference can likely be attributed to the much higher than average snowpack during winter 2022-2023, which resulted in elevated stream flow and presumably groundwater table depth during June-November 2023.

Until more post-project data is available, a subjective comparison between the middle and upper transects can also help tease out how BDA installation near the middle transect has affected the depth to the water table surface. As discussed in the previous section, average groundwater table elevations in the middle transect have increased significantly relative to pre-project after BDA construction (Figure 6, 7). This increase raised the water table surface closer to the target depth of three feet in both post-project years (Figure 9). Notably, this decrease in depth to the water table in late summer/fall 2023 and 2024 occurred during periods when the depth to water table was increasing in the upper transect (Figure 9), indicating that the project improved conditions relative to the control conditions of the upper transect. A similar comparison cannot be made for 2022, as the upper transect was affected by a beaver dam during and after phase 1 implementation. Overall, both subjective and quantitative evaluations of changes in water table depth indicate that the project has made substantial progress towards the stated goal of raising water table elevations to within three feet of the meadow surface in the lower and middle transects.

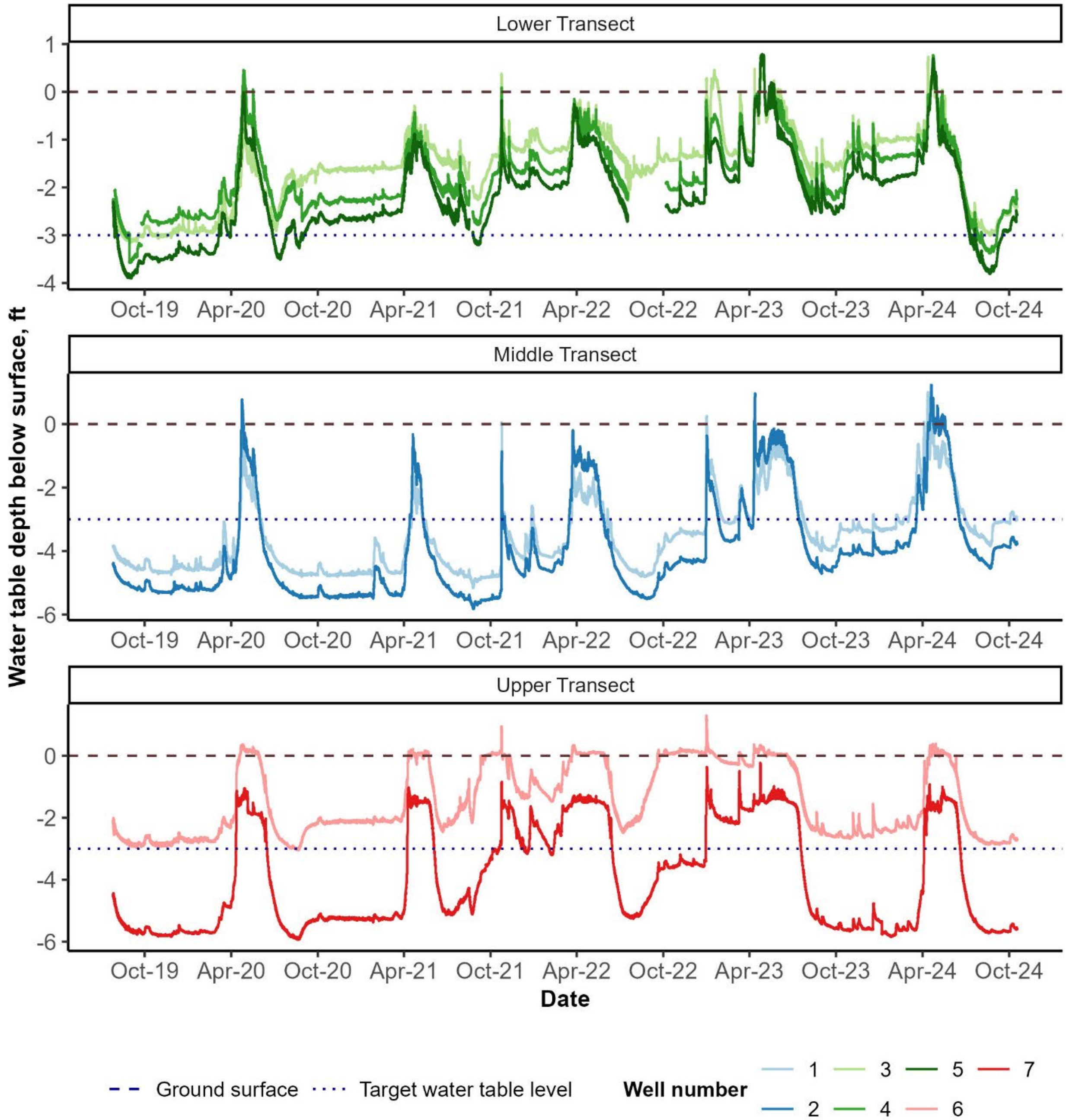

Figure 9. Line graph showing the water table depth below the surface for each well for the entire monitoring period. Dashed horizontal lines represent the ground surface (0ft) in each panel, while dotted blue lines represent the stated target groundwater table elevation of 3ft below the meadow surface. Within each transect, lighter colors represent wells closer to the channel while darker colors represent wells farther from the channel. Although the middle transect does not maintain groundwater elevation within 3 ft of the meadow surface, it does show improvement toward decreasing the depth to groundwater table in post-project years while the upper transect (which acts as a partial control) does not.

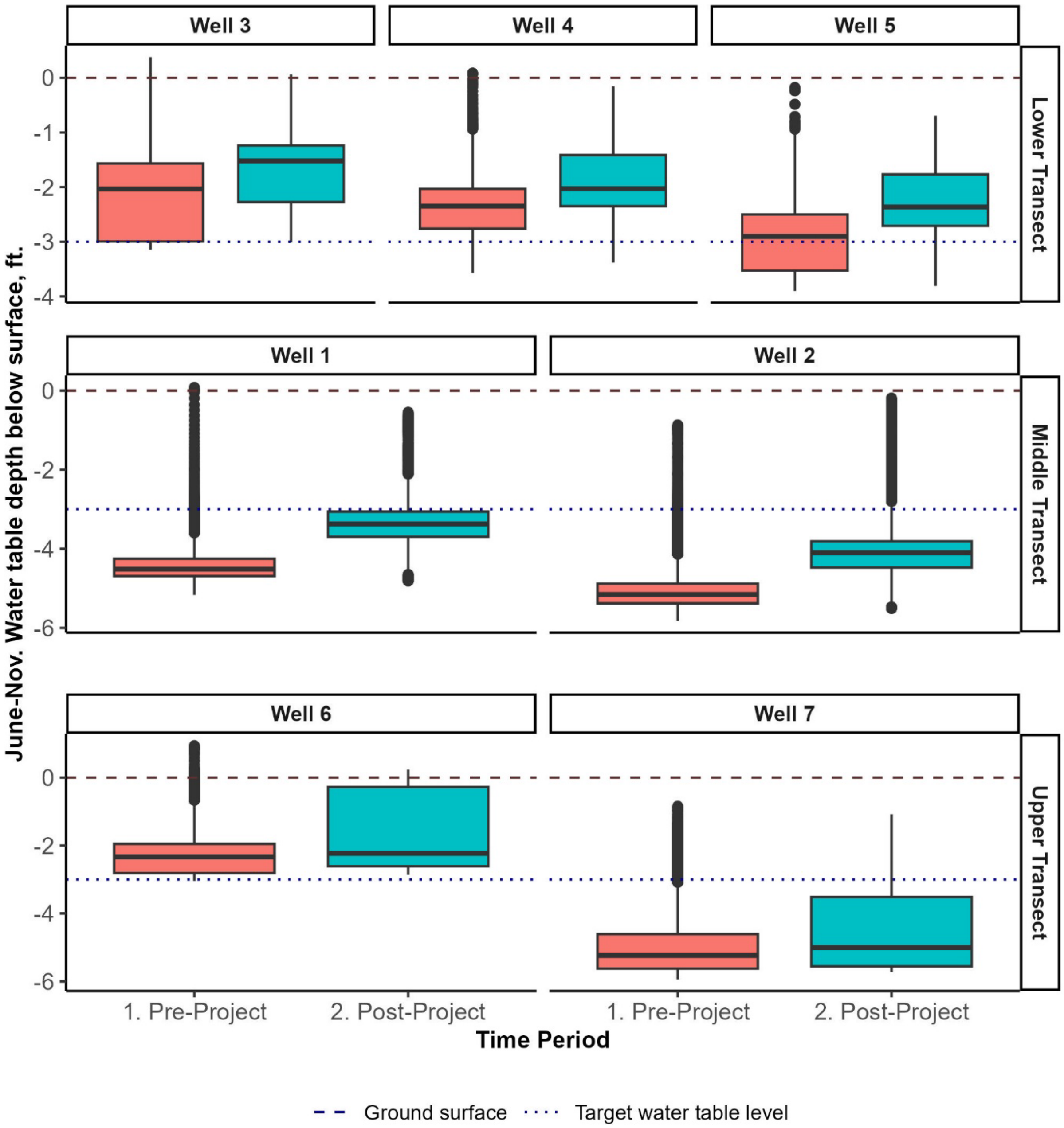

Figure 10. Box plots comparing summer/fall (June-November) water table depth below surface for pre project (before Phase 2 implementation in August 15, 2023) and post project (after August 15, 2023) in each well. For all wells, average groundwater table depths during June-November were significantly closer to the surface after project implementation (ANOVA, $p<0.001$).

Conclusions

Groundwater monitoring data from 2019-2024 shows that groundwater in Faith Valley Meadow is tightly linked to snowmelt and that beaver activity also strongly influences fluctuations in groundwater storage throughout the meadow. The data demonstrate that persistent beaver dams at the lower transect maintain consistently elevated water table elevations, highlighting the importance of increasing the persistence of beaver dams for achieving the project objectives. In addition, groundwater data show that BDA installation has significantly increased local water table elevations during summer/fall and that the project has raised the water table surface closer to the targeted depth of three feet below the meadow surface over baseline. The grade control structure installed in 2022 (and subsequent natural beaver dam built on it) and the furthest downstream series of BDAs may also have buffered the effects of the loss of the large natural beaver dam adjacent to the lower transect in spring 2024, as groundwater table elevations in that transect rebounded to almost to the same levels as 2023 by October 2024. Overall, groundwater monitoring data provide strong evidence that restoration has significantly increased groundwater storage in Faith Valley Meadow as intended.