Impacts of Lowered Baselevel on the Hydrology of Van Norden Meadow

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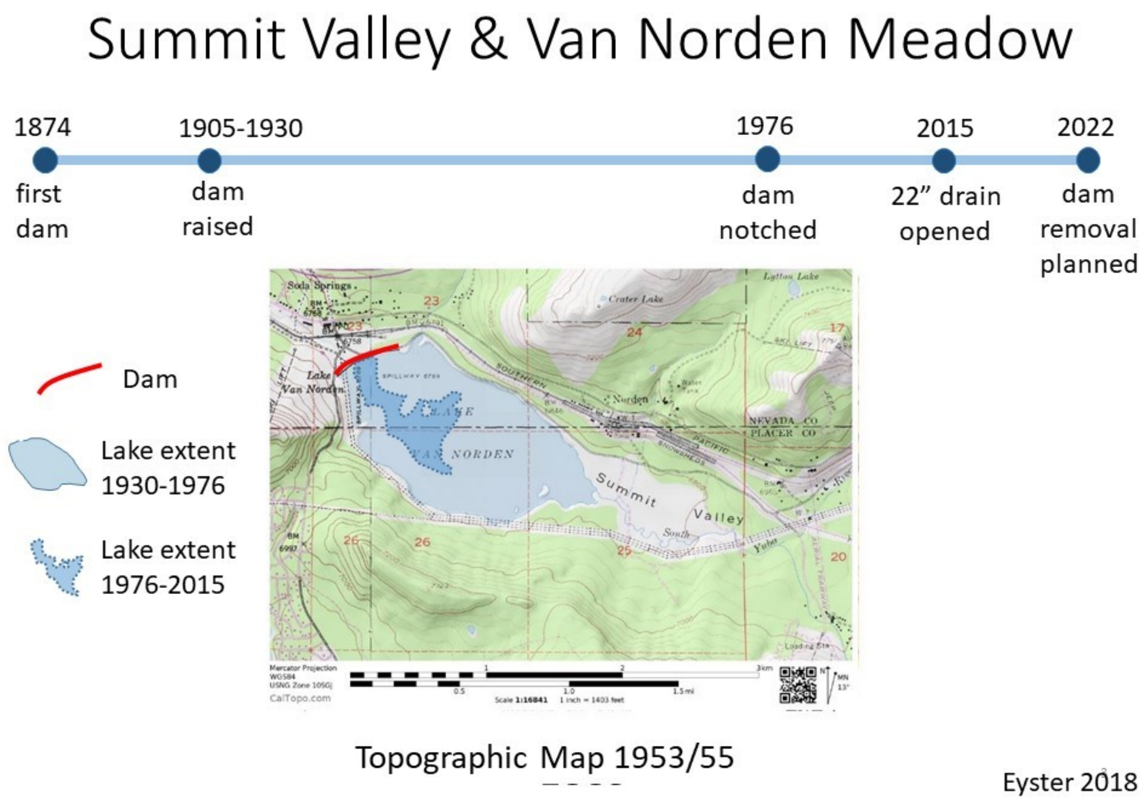
1-BACKGROUND

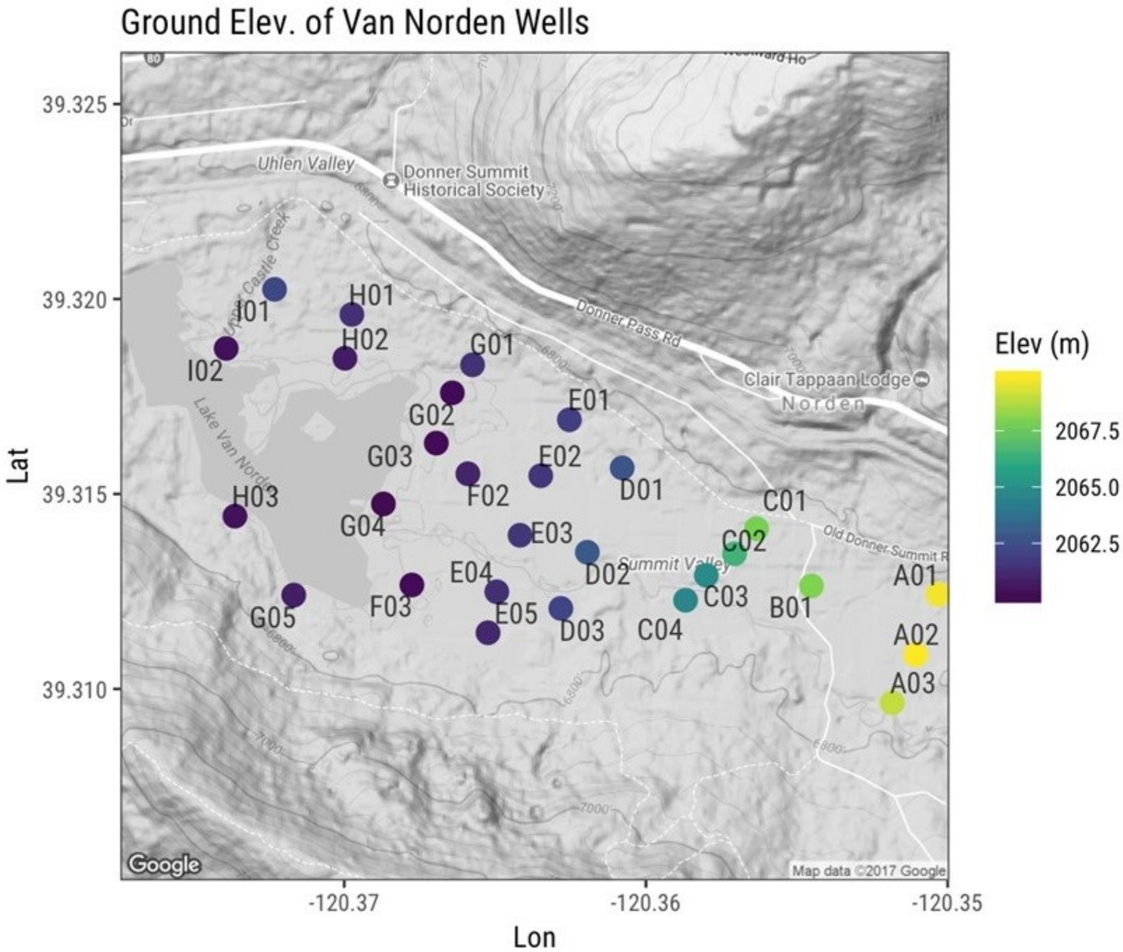
One of the largest sub-alpine meadows on the west slope of the Sierra Nevada range in California, Van Norden meadow has been degraded since the late 1800s by over-grazing and road development. A dam was built at the meadow outlet resulting in variable reservoir conditions for over 100 years.



Following an initial notching of the dam in 1976 for safety concerns, local stakeholders began restoring the meadow in October 2015 by unearthing and opening an old low level 22 inch outlet to drain the reservoir, effectively lowering the meadow's hydrologic baselevel by more than 1 meter.

2-GROUNDWATER MONITORING

A network of 30 wells were installed in 2014 along 9 transects across the meadow to monitor groundwater elevations.



Manual water depth measurements were taken every 2 weeks during the spring and summer from 2014-2019 and converted to groundwater elevations at each well using RTK-GPS surveyed elevations.

Groundwater elevations were plotted at each well through time for each year to determine groundwater level declines across the spring and summer seasons.

The groundwater data was also compiled in ArcGIS and interpolated to create monthly groundwater maps across the meadow for each summer.

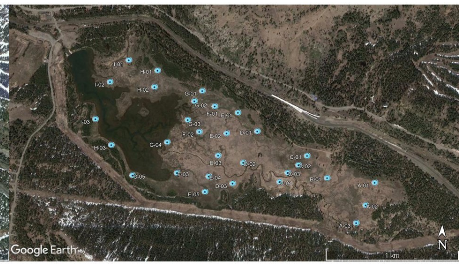
3-SURFACE WATER CONDITIONS

Google Earth imagery of Van Norden meadow prior to and following opening of the low level outlet in late 2015 shows varying reservoir conditons post-2015. The dam impounds snowmelt runoff in spring to the elevation of the spillway when inflows exceed maximum outflow through the low level outlet; however, the open outlet allows the reservoir to drain by mid-summer each year. Outside the reservoir footprint, surface water is largely limited to the stream channels running through the meadow.

April 2014

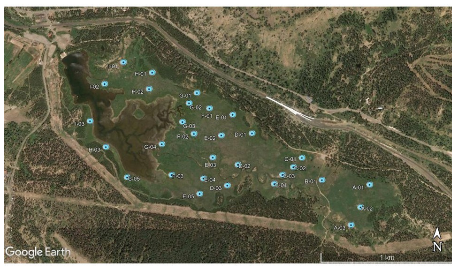
Pre-drain opening

April 2015



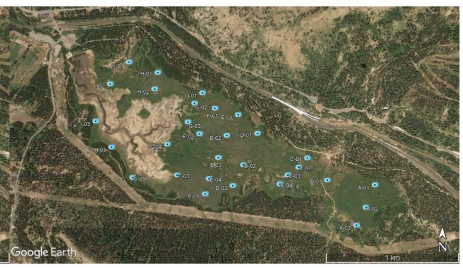
Pre-drain opening

June 2016



Post-drain opening

July 2016

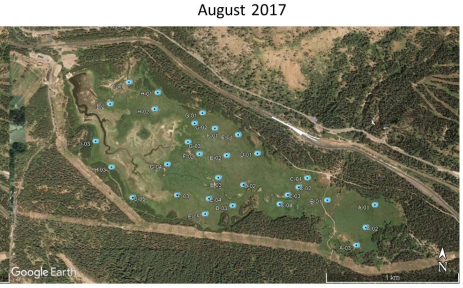


Post-drain opening

June 2017

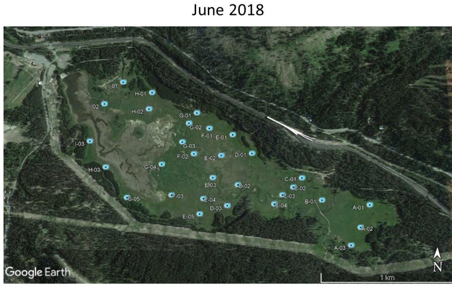
Post-drain opening

August 2017



Post-drain opening

June 2018



Post-drain opening

September 2019

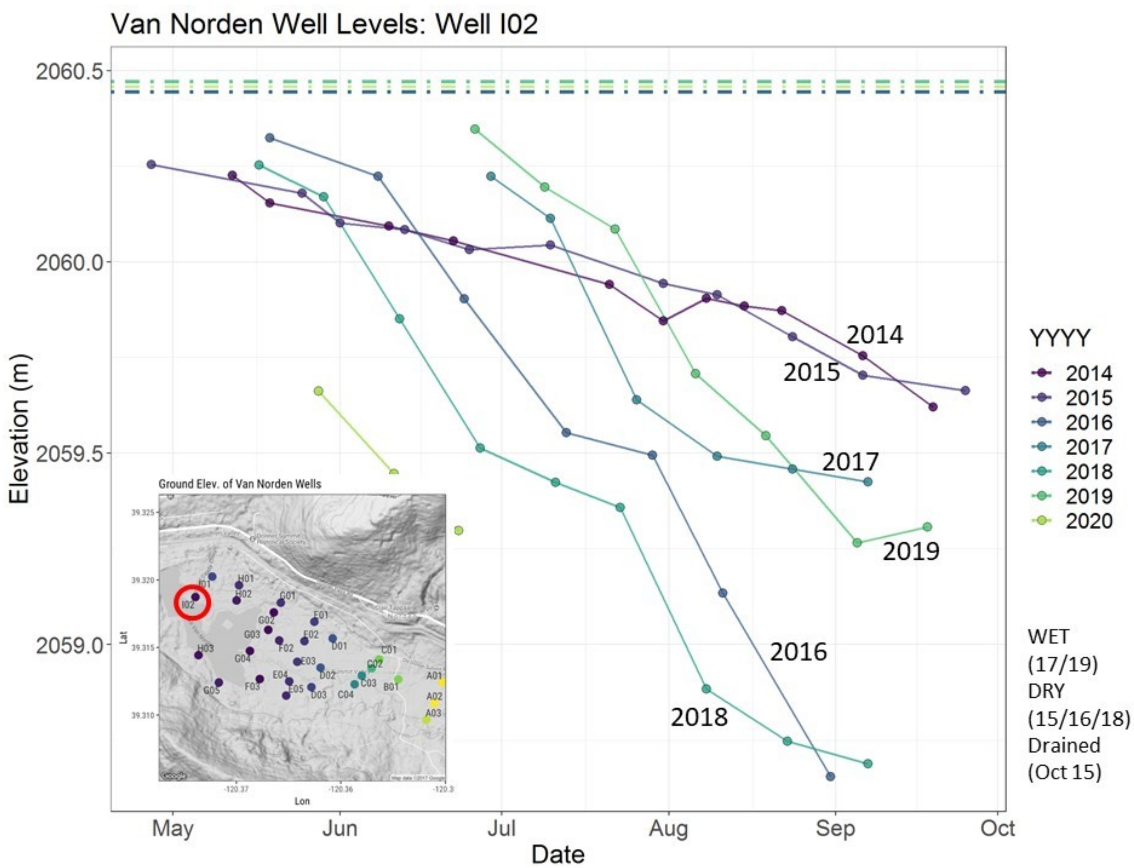
Post-drain opening

4-GROUNDWATER CONDITIONS

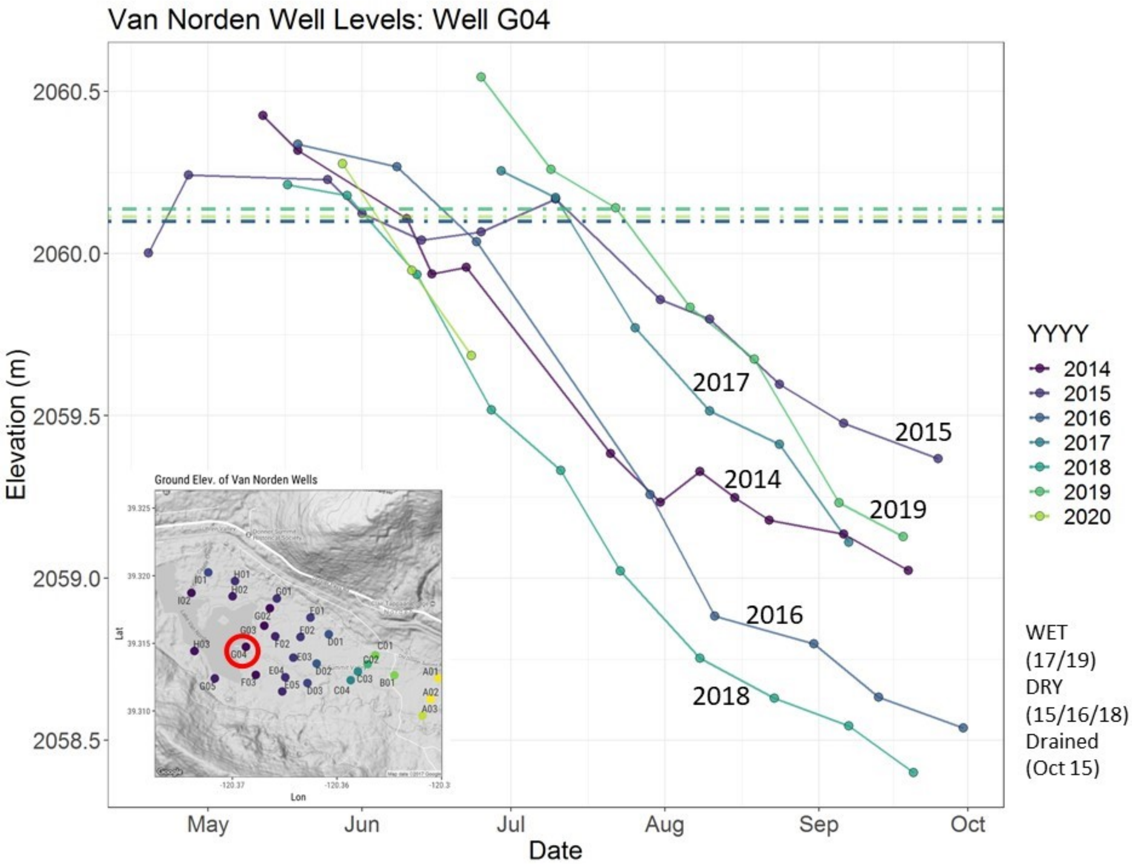
Throughout the meadow in all years, groundwater remained near the surface in early spring when snowmelt runoff was high, then declined through the summer season.

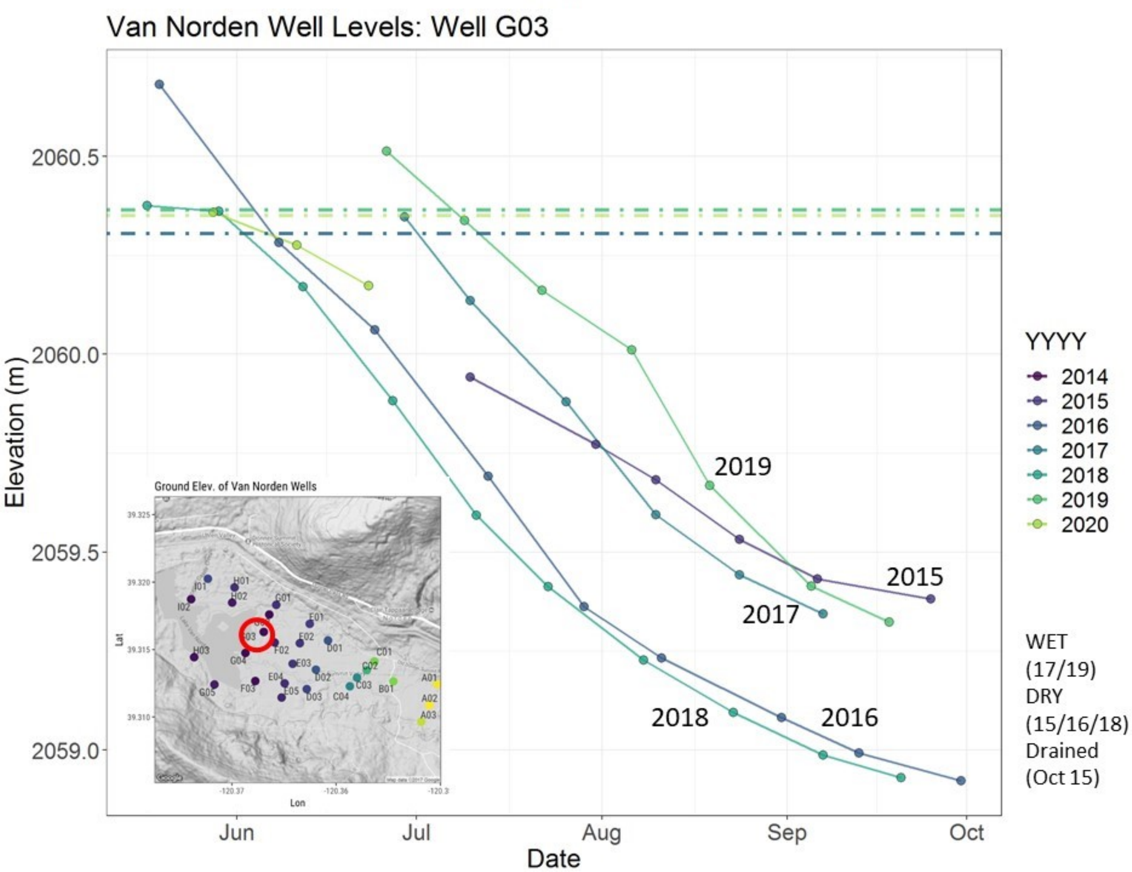
Climate conditions were wet with high snow levels and prolonged runoff in 2017 and 2019, but very dry with low snow levels in 2014, 2015, 2016, and 2018. 2015 was the driest year of the 2012-2015 drought.

At the lower end of the meadow near the dam, groundwater levels were highest prior to the reservoir draining in 2014 and 2015. Groundwater levels decreased by about 0.5 m in wet years (2017, 2019) and 1.0 m in dry years (2016, 2018) by late summer following draining of the reservoir.

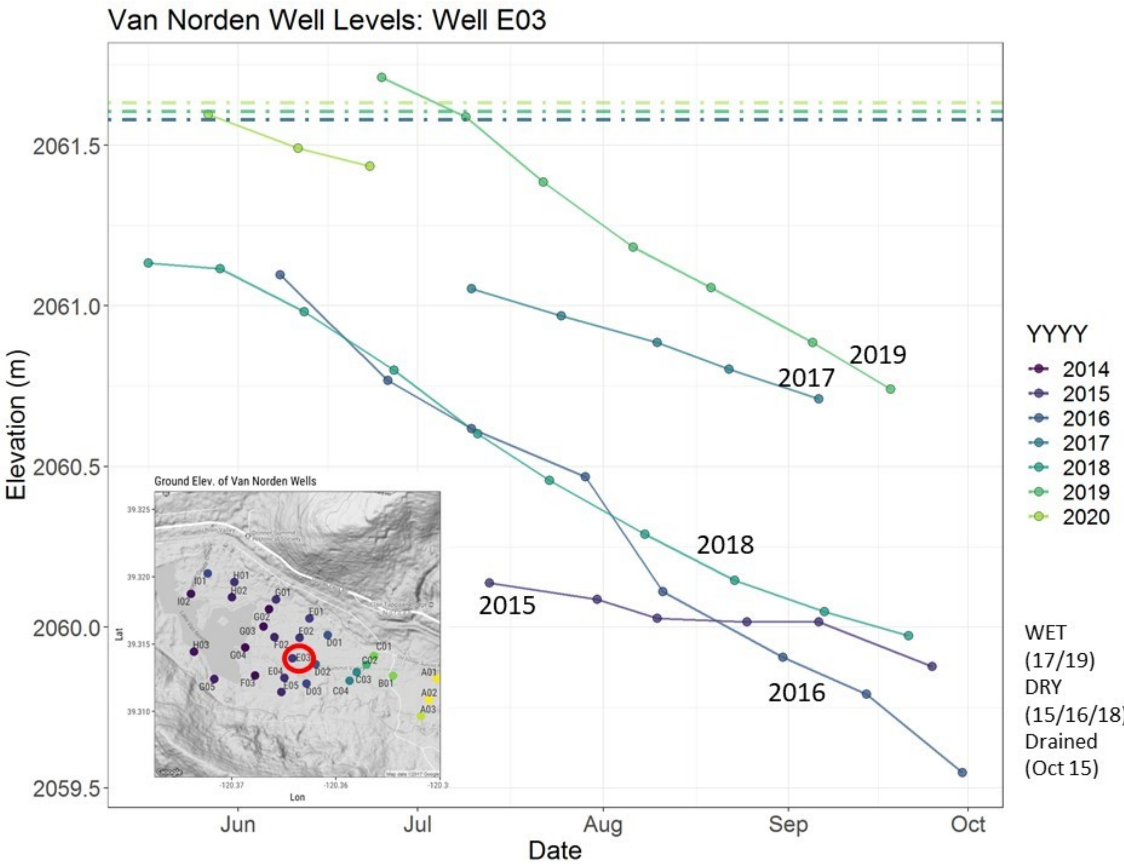


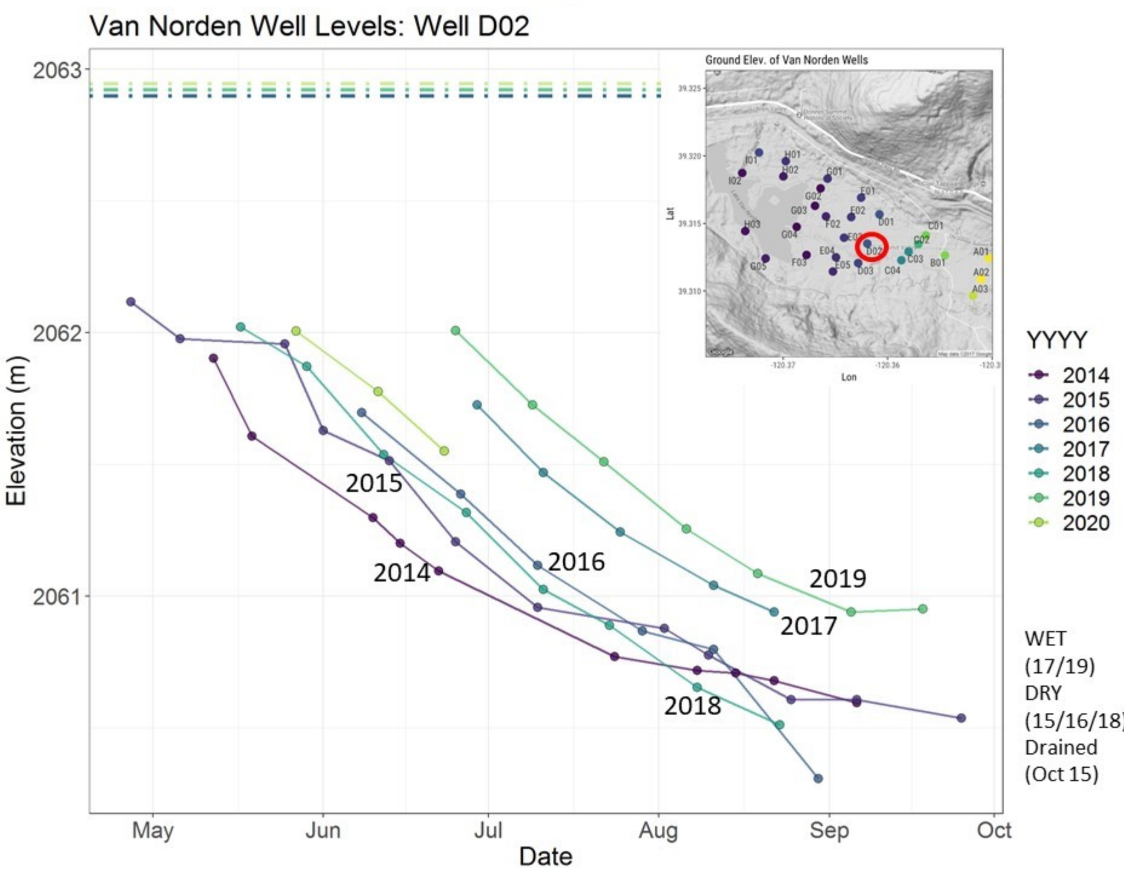
Near the upper end of the reservoir footprint at transect G, groundwater levels were highest in wet years (2017, 2019) and in 2014 and 2015 prior to the reservoir draining. Groundwater levels were approximately 0.5 m lower in dry years after draining of the reservoir (2016, 2018).

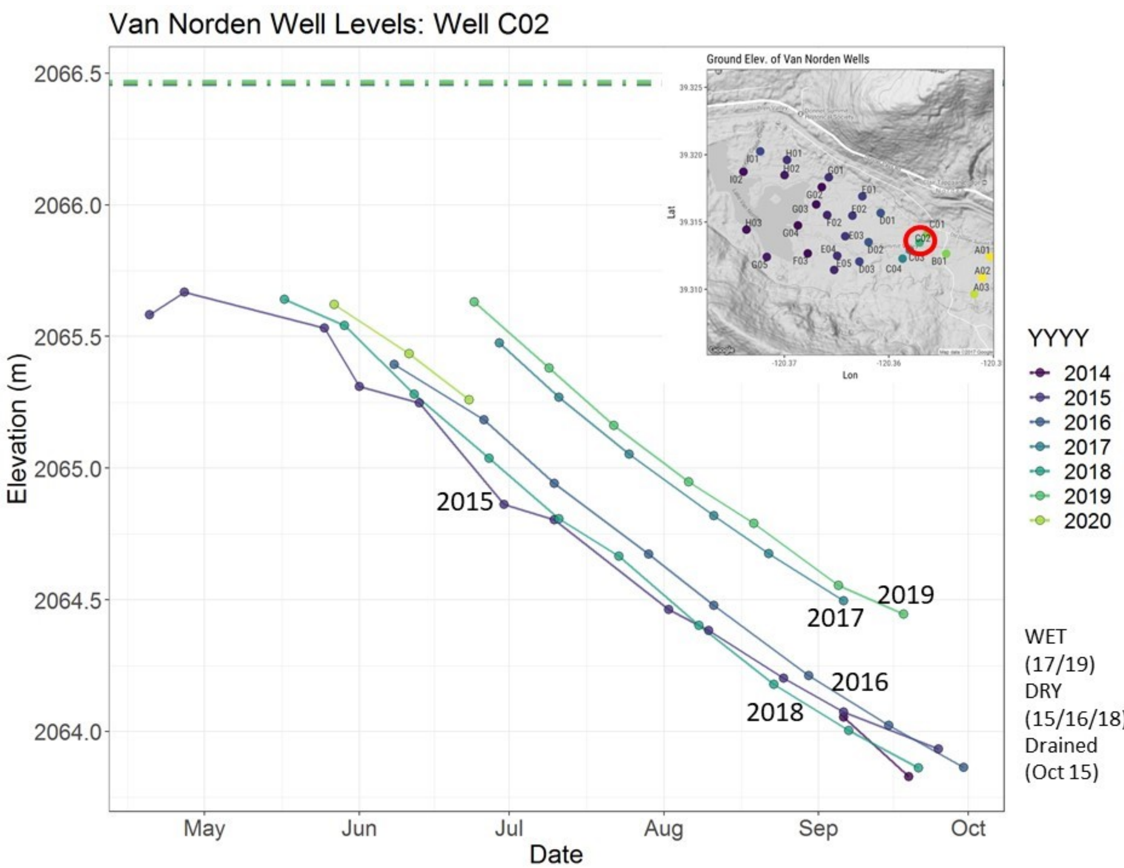




In the middle and upper portion of the meadow, groundwater levels were highest in wet years (2017, 2019) and lowest in dry years. In 2014 and 2015 prior to the reservoir draining, groundwater levels were similar to the other dry years of 2016 and 2018, suggesting the influence of the dam did not extend to these portions of the meadow.

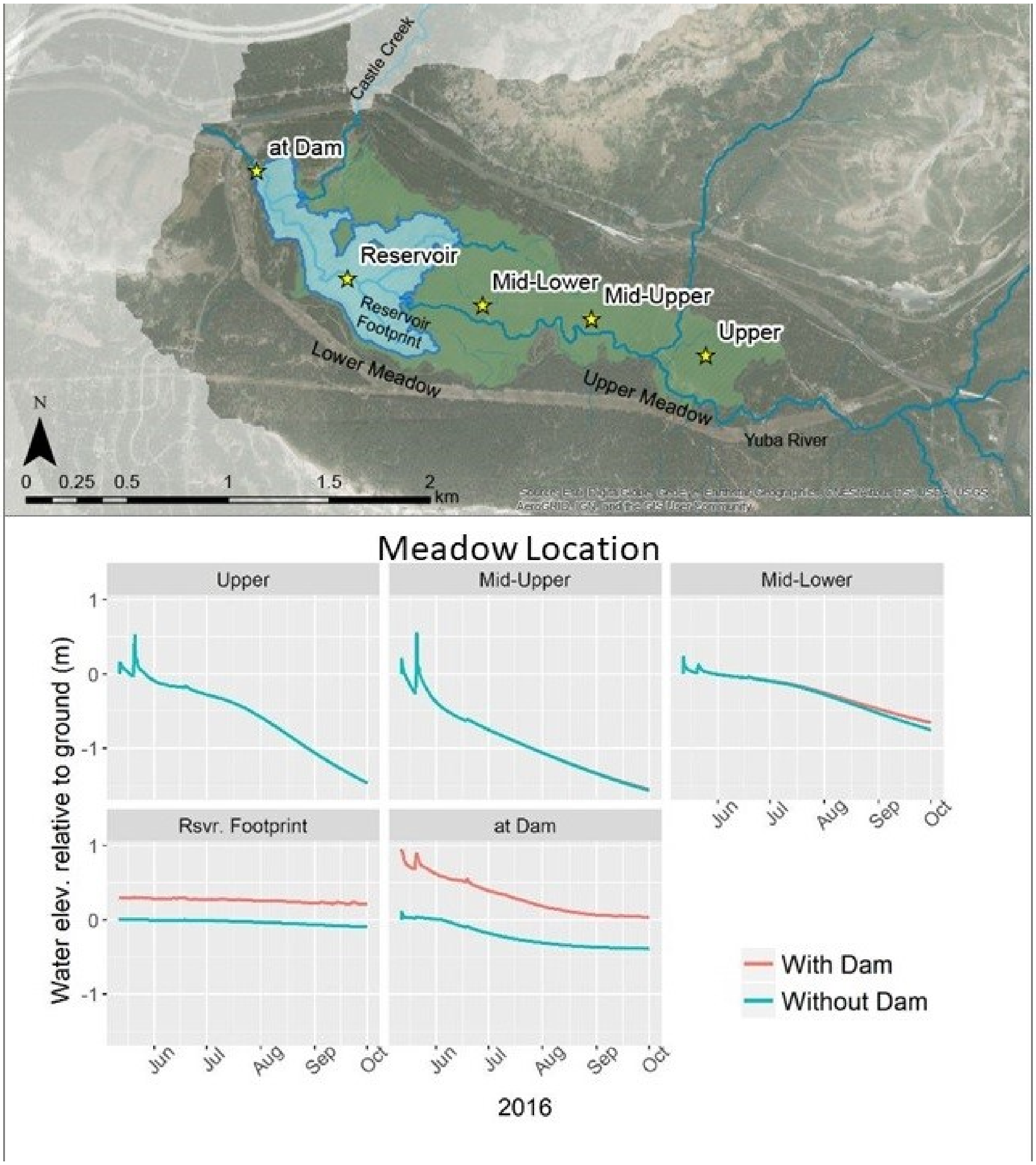





Van Norden Well Levels: Well C02
Ground Elev. of Van Norden Wells
Elevation (m)
Date
2066.5
2066.0
2065.5
2065.0
2064.5
2064.0
May
Jun
Jul
Aug
Sep
Oct
YYYY
2014
2015
2016
2017
2018
2019
2020
2015
2017
2019
2016
2018
WET
(17/19)
DRY
(15/16/18)
Drained
(Oct 15)

5-MODELED DAM REMOVAL

These field observations correlate with and support modeled results of the predicted impacts of dam removal on groundwater elevations. A groundwater model developed in MODFLOW for Van Norden showed likely impacts of a 1.5 meter reduction in dam height and hydrologic baselevel were constrained to the lower portion of the meadow near the reservoir (Eyster 2018).



Predicted changes in depth to groundwater over the length of the summer season were largely confined to the reservoir footprint, with small changes to groundwater levels predicted in the middle portion of the meadow late in the season (Eyster 2018). The field observations of groundwater elevations showed similar increases in depth to groundwater near the reservoir (transects G and I as shown in figures in panel 4), but did not show decreases in groundwater depth in the middle portion of the meadow (transect E) as predicted.

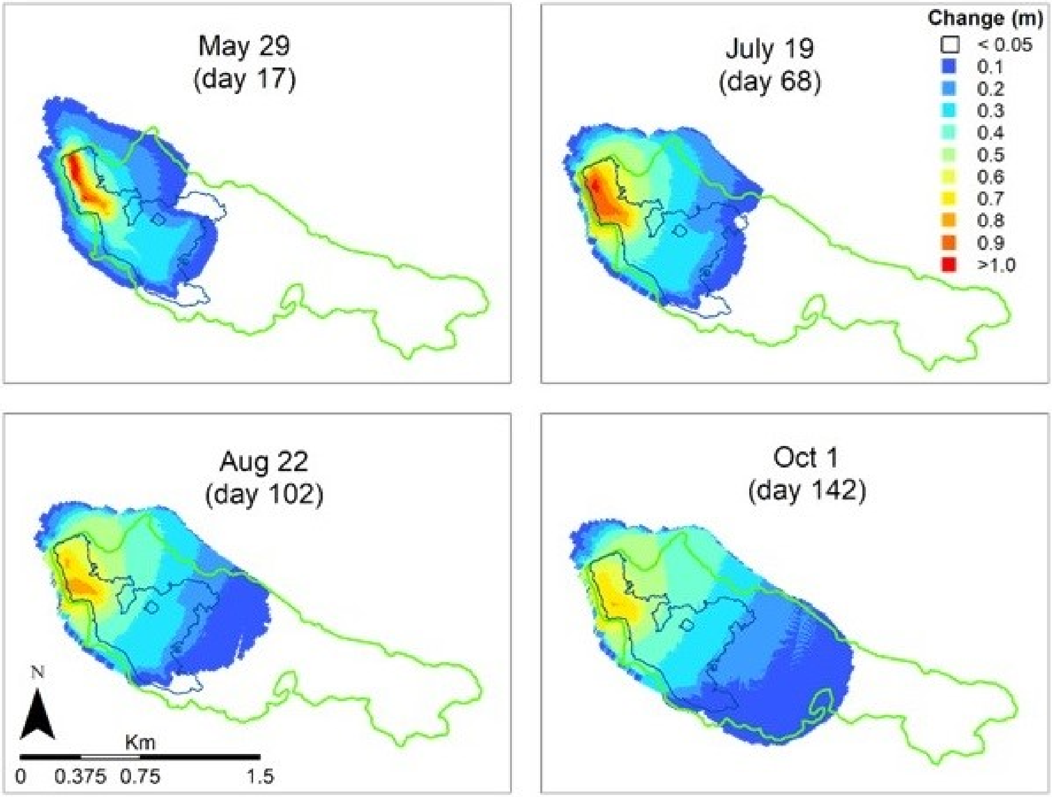


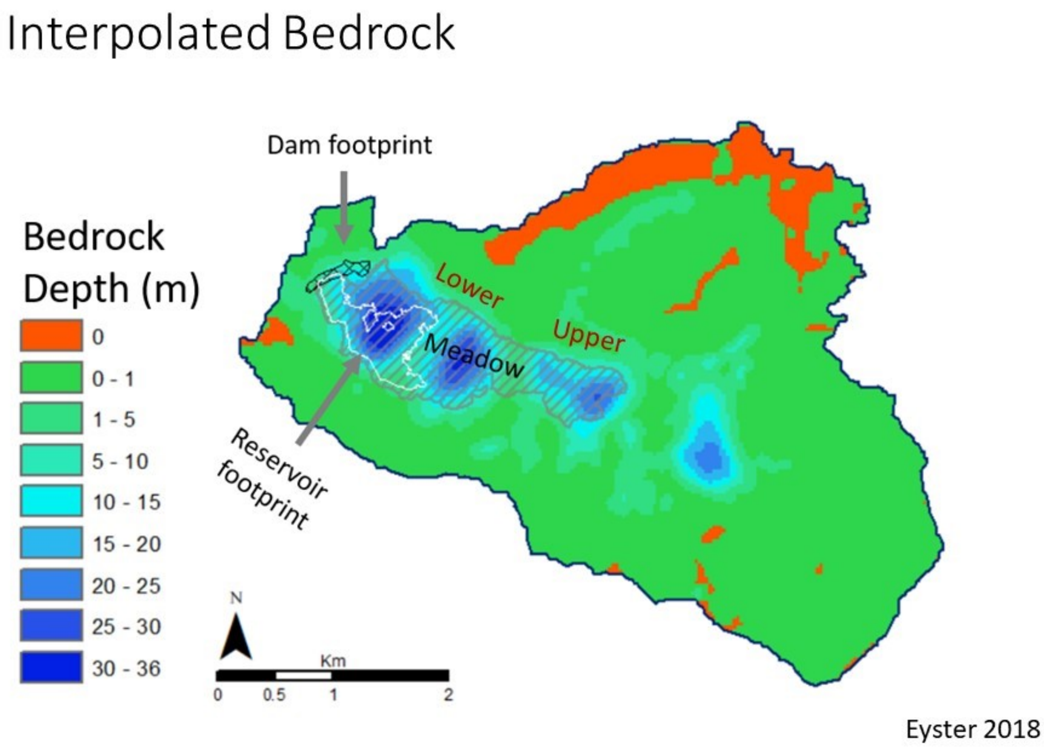
Figure 4.4 Modeled change in depth to groundwater after dam removal. Simulated with data from the summer of 2016. The difference between the base case and the dam removal case ranges from 0 to about 1.1 m. The water table is lowered by the largest magnitude in the early season, but, as the season progresses, the magnitude lessens while the extent spreads.

Underlying geologic conditions likely constrain the impacts of changes in baselevel to the lower portion of the meadow.

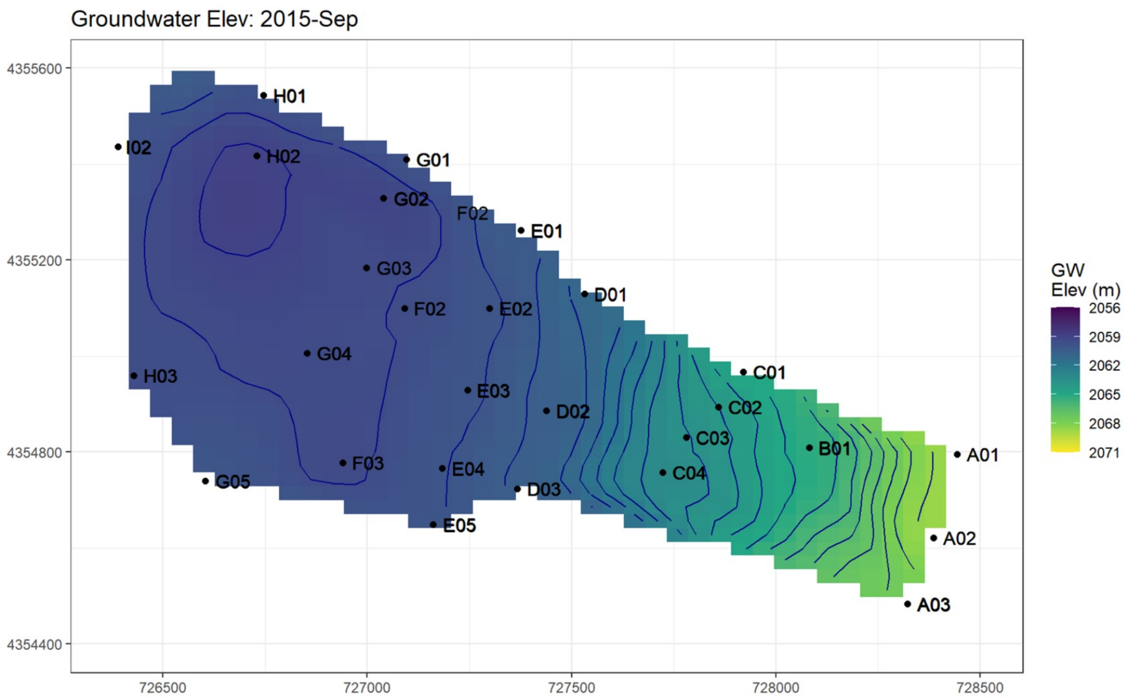
6-SUBSURFACE GEOLOGIC CONDITIONS

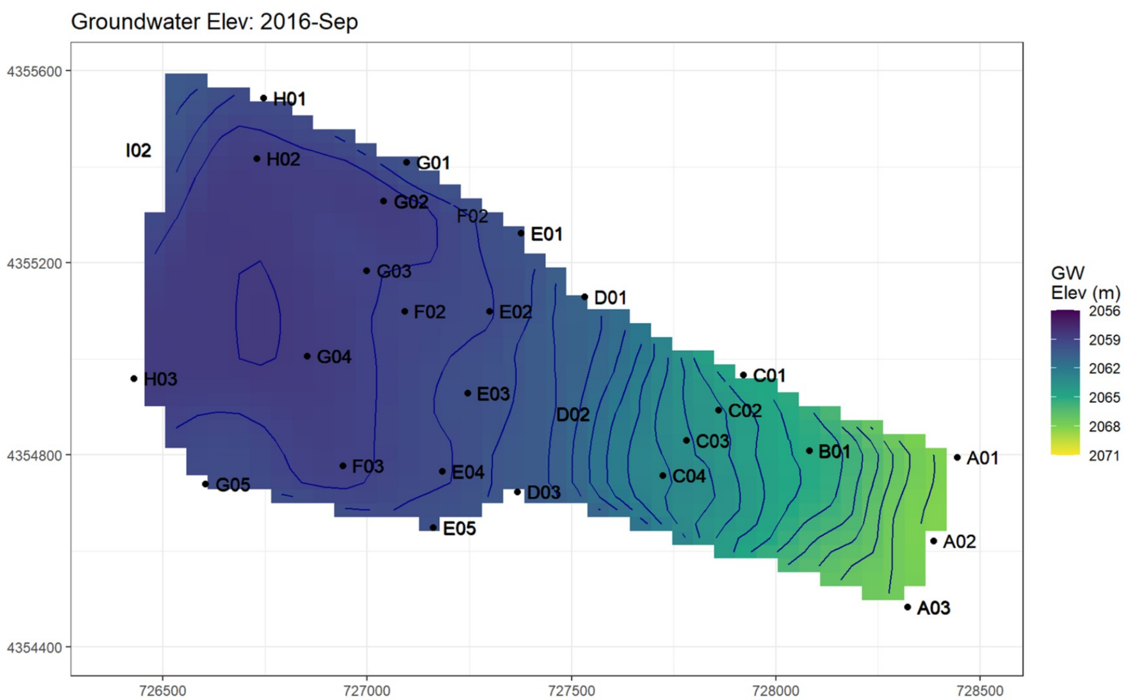
Given the low elevational change (slope) across the meadow (10m/2700m), we would expect to see lowered groundwater elevations of ~0.5m at transect E (middle meadow) under uniform subsurface sediments and hydrologic connectivity. However, groundwater decreases were limited to the lower meadow, suggesting subsurface conditions limit the effect of baseflow changes.

Interpolation of the bedrock conditions from adjacent hillslopes and geologic conditions suggest variations in bedrock depth are likely providing subsurface controls on water movement. A subsurface bedrock ridge in the lower meadow appears to provide a local independent baselevel for the upper meadow disconnecting the influence of the dam baselevel from upper hydrologic conditions.



Spatial mapping of groundwater elevations across the meadow before (2015) and after (2106) opening of the valve supported these indications. Changes in groundwater gradient were limited to the lowest portion of the meadow near the dam. Following opening of the valve, the groundwater gradient remained consistent upstream of transect F where a bedrock ridge is approximately located. A second bedrock ridge and associated glacial morraine upstream of transect D likely provides a local baselevel control for the uppermost portion of the meadow.





In CONCLUSION, consideration of subsurface geologic conditions in meadow assessments are key to understanding hydrologic functioning and potential impacts of changes in baselevel, such as from dam removal or installation of grade control structures in restoration efforts.

AUTHOR INFORMATION

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[3]Tahoe National Forest, USDA

ABSTRACT

One of the largest sub-alpine meadows on the west slope of the Sierra Nevada range in California, Van Norden meadow has been degraded since the late 1800s by over-grazing and road development. In addition, a dam was built at the meadow outlet resulting in variable reservoir conditions for over 100 years. In fall 2015, following an initial notching of the dam in 1976, local stakeholders began restoring the meadow by partially draining the reservoir, lowering the baselevel by more than 1 meter. In fall 2019, the dam was further notched to maintain this new baselevel and permanently reduce previously impounded water volumes, and the dam is proposed for full removal in 2022-2023.

In 2014, we began monitoring the meadow hydrology in collaboration with restoration project partners. A total of 30 monitoring wells were installed along 9 transects to measure groundwater levels. Water levels were manually measured from 2014-2019 every 2-3 weeks from late spring through early fall. Following partial draining of the reservoir, groundwater levels near the dam and previous reservoir footprint decreased by up to 1 m as expected due to the lowered baselevel. However, groundwater levels upstream of the reservoir footprint were minimally impacted, such that levels remained unchanged in the upper two-thirds of the meadow. Based on field observations of glacial moraine deposits and adjacent hillslope topography, we surmise that changes in stratigraphy and underlying bedrock topography create a shallow subsurface ridge that impedes groundwater flow. The ridge effectively creates an independent baselevel for the upper meadow disconnecting the influence of the dam baselevel from upper hydrologic conditions. Coincident hydrologic modeling efforts support this assertion, but additional geophysical research is needed to quantify the underlying geologic conditions. These results suggest that while restoration is likely needed to offset impacts of decreased groundwater levels on vegetation in the lower meadow, additional efforts to limit further incision due to decreasing the dam baselevel are not needed in the upper meadow. We suggest subsurface geologic conditions should be taken into account when seeking to understand meadow hydrologic functions and the potential impacts of changes in baselevel conditions during restoration efforts.

REFERENCES

Eyster, T. 2018. Modeling Dam Removal in a Mountain Meadow with MODFLOW-NWT. Master's Thesis. University of British Columbia,Vancouver.