COLORADO
Department of Transportation

Applied Research and Innovation Branch

# State Highway 5 (Mount Evans Road) Summit Lake Wetland and Hydrology Study (Summit Lake Wetland Study)

## Interim Report
## June 2018 - June 2019

**Jeremy R. Shaw, PhD**
**David J. Cooper, PhD**

Report No. CDOT-2019-03
June 2019

**Technical Report Documentation Page**

| | | |
|---|---|---|
| 1. Report No.<br>CDOT-2019-03 | 2. Government Accession No. | 3. Recipient's Catalog No. |

| | |
|---|---|
| 4. Title and Subtitle<br>STATE HIGHWWAY 5 (MOUNT EVANS ROAD) SUMMIT LAKE WETLAND AND HYDROLOGY STUDY (SUMMIT LAKE WETLAND STUDY) | 5. Report Date<br>June 2019 |
| | 6. Performing Organization Code |
| 7. Author(s)<br>Jeremy R. Shaw, David J. Cooper | 8. Performing Organization Report No.<br>CDOT-2019-03 |
| 9. Performing Organization Name and Address<br>Colorado State University<br>Department of Forest and Rangeland Stewardship<br>Fort Collins, CO | 10. Work Unit No. (TRAIS) |
| | 11. Contract or Grant No.<br>118.02 |
| 12. Sponsoring Agency Name and Address<br>Colorado Department of Transportation - Research<br>2829 W. Howard Pl.<br>Denver CO, 80204 | 13. Type of Report and Period Covered<br>Interim<br>June 2018 - June 2019 |
| | 14. Sponsoring Agency Code |

| |
|---|
| 15. Supplementary Notes<br>Prepared in cooperation with the US Department of Transportation, Federal Highway Administration |
| 16. Abstract<br><br>Implementation |

| | |
|---|---|
| 17. Keywords<br>Wetlands, Roadside Vegetation, Hydraulics, hydrology, alpine, fen, surface flow, subsurface flow, permafrost. | 18. Distribution Statement<br>This document is available on CDOT’s website<br>http://www.coloradodot.info/programs/research/pdfs |

| | | | |
|---|---|---|---|
| 19. Security Classif. (of this report)<br>Unclassified | 20. Security Classif. (of this page)<br>Unclassified | 21. No. of Pages | 22. Price |

**Form DOT F 1700.7** (8-72) Reproduction of completed page authorized

# Acknowledgements

Thanks go to Aaron Sidder for his help with monitoring well installation, Faith Pranger for processing soil carbon samples, and Mark Pashke for providing laboratory facilities. Special thanks to Nicole Malandri for arranging site access, USFS permits, and providing timely updates on site conditions. We gratefully acknowledge the helpful input and guidance of the Study Manager, Bryan Roeder (CDOT Division of Transportation Development – Research Branch), and the Study Panel: Francesca Tordonato (CDOT Region 1 Senior Biologist); Becky Pierce (CDOT EPB Wetlands Program); Jason Roth (CDOT R4 Wetlands); Steve Harelson (CDOT R1 Hydraulics and West Program Engineer); Bob Finch (Denver Parks Director of Natural Resources); Nicole Malandri (USFS Recreation Arapaho & Roosevelt National Forests); and Tom Bates (USFS Botanist Arapaho & Roosevelt National Forests).

# Executive Summary

Due to concerns that the hydrologic regime of the wetland complex in and around Summit Lake Park has been significantly altered by development of State Highway 5 (SH 5), a field study of the hydrology, soils, and vegetation above and below the roadway was initiated in 2018. The objectives of this study are to investigate the natural hydrologic processes and vegetation up-gradient from SH 5, and how they may be impacted in down-gradient areas. A review and synthesis of the road design elements that mitigate the effects of freeze-thaw and permafrost degradation, as well as minimize hydrologic disruption to adjacent wetlands is also included. This research will identify any areas where surface and subsurface flow paths have been disrupted by SH 5 and quantify potential impacts to wetland vegetation. We will also provide recommendations for road reconstruction to minimize permafrost damage and hydrologic impacts, as well as ways to minimize or restore impacts to alpine wetland ecosystems in the Summit Lake Park area that may be caused by the roadway.

Approximately 150 journal articles, agency reports, and book chapters are being reviewed from cold regions around the world to synthesize current knowledge on mitigating the effects of frost-heave and permafrost thawing on roadway integrity, as well as alternative designs that can minimize hydrologic disruptions to surrounding ecosystems. This review will be completed in 2019.

In 2018, we installed a network of 36 shallow groundwater monitoring wells to characterize water table depth and dynamics across the Summit Lake Park wetland complex. Data are available for part of the 2018 growing season, and groundwater monitoring will continue in 2019. Available data indicate that sheetflow infiltration during summer storms is critical to maintaining shallow groundwater levels during years of low snowpack, and also suggest that SH 5 can impede down-gradient sheetflow movement were no culverts exist. Soil stratigraphy, texture, and organic matter content were characterized at each monitoring well, and plant community composition and structure will be measured during the 2019 growing season.

Differences in water table dynamics and vegetation above and below SH 5 will be integrated with a tracer experiment to document hydrologic flow paths, and the presence of relict organic soils, to determine any areas where SH 5 currently disrupts water movement and impacts vegetation. Roadway design concepts synthesized from available literature and site-specific data will be used to develop specific recommendations to improve or restore hydrologic function within Summit Lake Park wetlands.

# Table of Contents

# Introduction

There is concern that the hydrologic regime of the wetland complex in and around Summit Lake Park has been significantly altered by State Highway 5 (SH 5). Prior to the road construction, surface and groundwater flow to Summit Lake Flats would have followed the valley topography. Sheetflow and shallow groundwater from the flanks of the surrounding peaks provide diffuse inputs along the length of the complex, in addition to outflows from Summit Lake and groundwater movement along the main valley axis. Under current conditions, impermeable road embankments and inboard ditches can intercept and reroute surface and shallow ground water along the roadway, and pass the water under the highway in several culvert crossings. These flow path alterations may have concentrated the formerly uniform distribution of water into discrete flow paths below culvert crossings, while areas not receiving inputs from culvert outfalls may have become drier in the decades since the road was built. The expected impacts of a changing climate such as reduced or more variable winter snowpack, higher summer evapotranspiration rates, and an extended growing season could exacerbate the effects of these hydrologic modifications, and potentially damage the rare alpine wetland ecosystems downstream.

# Objectives

The objectives of this study are to investigate the interaction between the natural hydrologic processes up-gradient from the road, and the roadway which crosses alpine wetland ecosystems, to determine the road effects on downgradient hydrologic regime, soils, soil temperature and permafrost, and vegetation. Long-term goals of this research are to:

(1) Identify options for road reconstruction to minimize permafrost and hydrologic impacts on such roadways.

(2) Minimize or restore impacts to alpine wetland ecosystems in the Summit Lake Park area that may be caused by the roadway.

To accomplish these objectives, we are performing the following tasks:

**Task 1:** Investigate road designs in other frost-heave/permafrost/alpine tundra areas to find relevant roadway designs that are resistant to frost heave and permafrost thawing, and that minimize potential hydrologic alterations to surrounding wetland ecosystems.

**Task 2:** Analyze the hydrologic regime and associated soil and vegetation types of the wetland complex adjacent to SH 5 within Summit Lake Park, to understand the effects of hydrologic variation on alpine wetlands in the central Rocky Mountains.

**Task 3:** Identify past and current impacts to wetland ecosystems within Summit Lake Park caused by hydrologic alterations from SH 5.

**Task 4:** Provide recommendations to improve or restore wetland hydrology and ecosystem function within the Summit Lake Park area that could be implemented in a future road reconstruction project.

**Task 5:** In consultation with the CDOT study panel, summarize and report all findings and recommendations to CDOT and other interested stakeholders.

## Methods

**Task 1:** Approximately 150 journal articles, agency reports, and book chapters are being reviewed from cold regions around the world to synthesize current knowledge on mitigating the effects of frost-heave and permafrost thawing on roadway integrity, as well as alternative designs that can minimize hydrologic disruptions to surrounding ecosystems. The review will summarize the primary processes by which roadways are damaged due to frost-heave and permafrost thawing, and how roadway features can modify local hydrology in alpine settings. We will also describe design features for mitigating road damage and hydrologic disruptions that have been effective in other regions.

**Task 2:** We installed a network of 36 shallow groundwater monitoring wells to characterize water table depth and dynamics across the Summit Lake Park wetland complex (Figure 1). Boreholes were hand augered with a 2 inch auger until bedrock or large boulders were encountered, and wells were cased with slotted 1.5 inch PVC pipe and backfilled with native soil. In each well, groundwater levels are being continuously monitored throughout the growing season (June-September) using Rugged Troll 100 data logging pressure transducers (In-Situ, Fort Collins, CO). Monitoring wells are distributed throughout the study area to capture the range of soil types and topographic settings, and are arrayed along six transects spanning the roadway. Transects are oriented along local topography in order to follow the primary surface and subsurface flow paths. This approach allows for comparison of 'reference' sites up-gradient of SH 5 and potentially impacted areas down-gradient of the road. In addition to recording groundwater depth, the data loggers record water temperature, allowing us to assess any spatial patterns in the thermal regime of Summit Lake Park wetlands. The location and elevation of each well, and the water levels in each well, will be surveyed in 2019 using local bench marks so that we can create flow nets showing ground water flow directions, features that interrupt flow, and the spatially explicit water table depth across the study area. Nested piezometers were installed at depths of 10 and 20 inches below the ground surface next to wells that were adjacent to the road (n = 12). Comparison of vertical pressure head differentials from nested piezometers immediately up-gradient and down-gradient within each transect will help to determine where and when saturated soils are caused by groundwater movement or infiltration of sheetflow, and how this is affected by the roadway. A HOBO RG3 tipping bucket rain gage (Onset, Bourne, MA) was installed onsite to quantify precipitation during the growing season.

At each monitoring well borehole, we recorded soil stratigraphy and characterized soil properties for major horizons. Soil properties included thickness, texture, organic matter content, and the presence of permafrost. Soil texture was determined by the hydrometer method (Gee and Bauder 1986), and organic matter content was determined by loss on ignition. Soil organic matter content and texture will be used to determine the presence of histosols.

At each well location, the abundance and cover of all plant species will be recorded in 1 m radius plots during the 2019 growing season. We will quantify the relationship of vegetation composition to hydrologic, soil and chemical variables using multivariate statistics. We will also analyze relationships between the presence of rare plant species such as leafy stem saxifrage (*Saxifraga foliolosa*), ice grass (*Phippsia algida*), and Iceland purslane (*Koenigia islandica*), and key components of the hydrologic regime if they occur in our study plots. These may include the mean and maximum groundwater depth and temperature, and the rate of groundwater decline throughout the growing season.

**Task 3:** Differences in hydrologic regime and vegetation potentially caused by SH 5 will be identified using data collected from Task 2, a tracer experiment to document hydrologic flow paths associated with the roadway, and the identification of organic soils in areas that do not currently have a water table depth and duration suitable for supporting such soils.

Spatial variation in hydrologic regime components (e.g. mean groundwater depth, seasonal rate of decline), soils, and vegetation measured in Task 2 can provide insights on potential long-term effects of the roadway. For example, deeper water table surfaces and faster groundwater declines in plots down-gradient of the road, after accounting for related factors such as ground slope and aspect, could indicate that SH 5 is diverting or impeding groundwater flow to portions of the Summit Lake Park wetland complex. The presence of histosols in areas that do not currently support wetland vegetation and shallow groundwater would indicate former wetland areas that have been dewatered.

During the 2019 growing season, we will perform a series of field tracer experiments in the well transects established in Task 2 to document any alteration to groundwater flow paths near SH 5. A fluorescent dye tracer (fluorescein) will be injected into wells above the road, and tracer concentrations will be monitored in downstream wells and exfiltrated surface water in roadside ditches. This information will be used to generate a map to illustrate any alterations to subsurface flow paths associated with the roadway, and if tracer recovery is sufficient in down-gradient wells, will allow us to quantify the rates of water movement across the SH 5 corridor. Significant alteration of hydrologic flow paths associated with SH 5 would be apparent if tracer plumes failed to appear in transect positions below the road. We would also be able to follow tracer plumes throughout the site, and identify areas that receive elevated runoff from culvert outfalls.

These tracers have low or negligible environmental toxicity, and have been used to investigate fen hydrology in other regions. The final selection of suitable tracers will depend on initial laboratory testing using soil samples, and approval of project stakeholders. Surface water samples were collected in June 2019 to test for background levels of fluorescent materials, in order to determine the suitability of the proposed tracer.

**Task 4:** We will integrate roadway design concepts identified through Task 1 with site-specific data collected during Tasks 2 and 3 to develop specific recommendations to improve or restore hydrologic function in the Summit Lake Park wetlands. For example, if groundwater interception along the roadway is found to be a significant source of impairment, a porous road base layer may mitigate current impacts. Conversely, if subsurface hydrology is relatively unimpacted by the road corridor but sheetflow concentration below culvert outfalls reduces late summer water availability, increased culvert density may be a viable solution. We will also identify areas where opportunities for wetland restoration exist, based on data from Tasks 2 and 3. Dewatered former wetlands, indicated by relict histosols or reduced wetland vegetation abundance, may be restored by reducing hydrologic disruptions along the roadway.

**Task 5:** After consultation with the CDOT study panel for document review and feedback, we will prepare and provide a final report and presentation to the research study panel and other interested parties. At least one peer-reviewed scientific journal article will be published from this work, so that the findings of this project can support improved management and understanding of alpine wetlands elsewhere.

## Results

**Task 1:** Approximately 150 studies, reports, and book chapters from cold regions around the world have been reviewed. A draft synthesis of current knowledge on mitigating the effects of frost-heave and permafrost thawing on roadway integrity, as well as alternative designs that can minimize hydrologic disruptions to surrounding ecosystems is currently being developed. This review will be completed by October 2019.

**Task 2:** Monitoring of rainfall and groundwater during the 2018 growing season began in late June and concluded on 30 August. Analysis of data from 2018 is ongoing, but selected preliminary observations are presented to illustrate the available data and hydrologic behavior of the study area.

Groundwater levels declined throughout the growing season in transects 1-4, which were located on valley slopes, while groundwater levels in transects 5-6 spanning toe slopes to the valley floor were relative stable (Figure 2). In all but one transect, water table depth was greater in wells below SH 5 than above the roadway. Wells in transect 5 showed the opposite trend, where the water table was shallower below the road, likely due to additional inputs of water from the culvert, and perhaps groundwater flow along the main valley axis away from Summit Lake.

A 17 mm rainfall event on 15 July 2018 (Figure 3) raised the groundwater elevation in most wells, and the magnitude of this response varied among locations likely due to local topography and rainfall distribution (Figure 2). Although no conclusions can be drawn from a single event, comparison of well hydrographs suggests potential sheetflow disruption in some places along SH 5. Both up-gradient and down-gradient wells showed water table rises where culverts exist. Functional culverts at transect 1 and 5 allow surface runoff to cross the roadway, while subsidence of the roadbed allows surface flow across SH 5 where culverts are collapsed or blocked at transects 2 and 4. At transect 3, where no culvert exists, groundwater elevations did not change in the down-gradient well despite an obvious response immediately up-gradient of the road. This event demonstrates that groundwater variation in most parts of the study area respond to sheetflow infiltration during large storms, rather than direct precipitation, and that summer rainfall is critical for maintaining shallow water tables during years of low snowpack. The data also suggest that there are areas where SH 5 can impede the downslope movement of sheetflow and reduce water availability below the roadway. Additional data are necessary to conclusively demonstrate this phenomena.

Data collection has begun for the 2019 growing season, but as of 11 June 2019, over half of the monitoring wells are buried under snow and ice, and all of the accessible wells are frozen within 30 cm of the ground surface. Significant snow cover remains in portions of the study area, although parts of south facing slopes are exposed. Currently, snowmelt is rapidly progressing, and sheetflow and generally saturated soils are present in much of the study area. Vegetation data collection is scheduled for late July 2019.

**Task 3:** Assessment of potential impacts to the hydrologic regime and vegetation of the Summit Lake Park wetland complex will occur once data collection in Task 2 is complete. Hydrologic data collected during the 2018 growing season are not sufficient to assess potential impacts. Delays in site installation due to permitting requirements, and extremely rapid groundwater declines in all wells due to abnormally low snowpack from the previous winter allowed only a partial characterization of the hydrologic regime. We expect that data collected during the 2019 growing season will allow sufficient information to assess the effects of SH 5.

We plan to conduct the tracer experiment using fluorescein dye in late June or July 2019, once all monitoring wells are accessible and thawed. Access to the entire well network is needed in order to follow potential tracer plumes. Surface water samples were collected on 11 June 2019 to test for background levels of fluorescent materials, and soil samples will be collected and analyzed for tracer absorption in mid-June, in order to determine the suitability of the proposed tracer.

Analysis to determine the presence of histosols at monitoring well locations is ongoing. Soil texture and organic matter content has been characterized for samples collected during monitoring well installation (**Table 1**). Most soils were sandy loams or loamy sands. Organic matter content ranged from 1.2 to 35.2%. The presence of organic soils at sampled locations will be compared to hydrologic regime and current vegetation as determined through Task 2 during the 2019 growing season.

**Task 4:** Tasks 1-3 are ongoing and scheduled for completion by October 2019. Integration of roadway design concepts with site-specific data to develop specific recommendations to improve or restore hydrologic function within Summit Lake Park wetlands will take place from November 2019 to February 2020, once data collection is complete.

**Task 5:** The final report and presentation to the research study panel, and at least one peer-reviewed scientific journal article, will be developed following the completion of Task 4. The draft report with recommendations will be submitted for review by the study panel in May 2020, with all revisions completed and the final report submitted by September 2020. A presentation to the study panel will be scheduled in early 2020. Peer-reviewed scientific publications resulting from this work will be submitted by September 2020.

## Conclusions and Recommendations

Data collection began midway through the 2018 growing season and is currently being analyzed, and sufficient information is not yet available to support conclusions or recommendations concerning potential hydrologic impacts to the wetland complex at Summit Lake Park. Similarly, the review and synthesis of existing knowledge concerning road design elements to minimize the impacts of permafrost degradation and hydrologic alteration is ongoing, and recommendations for SH 5 cannot be made at this time.

Because of permitting delays and the rapid decline of groundwater levels below the depths of our observation wells, only limited inferences can be made from the 2018 hydrologic data. The large snowpack from last winter and a complete monitoring network should provide and an excellent characterization of a ‘wet’ year in 2019. However, additional data collection that covers a range of snowpack and climate conditions would allow for a better understanding of potential hydrologic alterations by SH 5. We recommend that the study panel consider supporting hydrologic monitoring for an additional growing season during 2020.

## References

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. *In* Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. Agronomy Monographs 9.

Table 1. Soil texture and organic matter content from 36 monitoring well locations at Summit Lake Park. Samples were not analyzed for some wells located in the ditch (2A3, 3A3, and 4A4), which were completed in saprolite and not actual soils.

| **Well Number** | **Horizon** | **Thickness (cm)** | **Organic Matter (%)** | **Sand (%)** | **Silt (%)** | **Clay (%)** | **Texture** | **Color** |
|---|---|---|---|---|---|---|---|---|
| 1A1 | A | 75 | 2.08 | 52.34 | 42.25 | 5.40 | sandy loam | 10 YR 4/4 |
| 1A2 | A | 88 | 12.36 | 69.70 | 26.71 | 3.59 | sandy loam | 10 YR 2/2 |
| 1A3 | A | 110 | 14.88 | 69.83 | 26.89 | 3.28 | sandy loam | 10 YR 2/2 |
| 1B1 | A | 27 | 11.24 | 52.45 | 39.92 | 7.63 | sandy loam | 10 YR 3/3 |
|  | B | 65 | 2.51 | 63.74 | 30.10 | 6.16 | sandy loam | 10 YR 3/6 |
| 1B2 | A | 31 | 4.69 | 65.17 | 29.00 | 5.83 | sandy loam | 10 YR 3/6 |
|  | B | 44 | 4.62 | 60.41 | 32.50 | 7.09 | sandy loam | 10 YR 3/6 |
| 2A1 | A | 18 | 5.96 | 75.68 | 21.11 | 3.22 | loamy sand | 10 YR 3/4 |
|  | B | 75 | 2.15 | 58.00 | 37.09 | 4.90 | sandy loam | 10 YR 4/6 |
| 2A2 | A | 22 | 13.12 | 75.68 | 21.11 | 3.22 | loamy sand | 10 YR 3/6 |
|  | B | 63 | 3.64 | 68.00 | 27.74 | 4.26 | sandy loam | 10 YR 3/6 |
| 2B1 | A | 16 | 3.93 | 66.19 | 29.26 | 4.55 | sandy loam | 10 YR 3/3 |
|  | B | 28 | 3.18 | 60.59 | 33.97 | 5.44 | sandy loam | 10 YR 3/6 |
|  | C | 18 | 5.97 | 64.44 | 31.12 | 4.44 | sandy loam | 10 YR 2/2 |
| 2B2 | A | 35 | 9.74 | 73.56 | 23.62 | 2.82 | loamy sand | 10 YR 2/2 |
|  | B | 38 | 2.87 | 69.14 | 26.06 | 4.80 | sandy loam | 10 YR 3/6 |
| 3A1 | A | 28 | 13.36 | 75.50 | 22.14 | 2.36 | loamy sand | 10 YR 3/2 |
|  | B | 39 | 2.02 | 60.23 | 34.48 | 5.29 | sandy loam | 10 YR 4/6 |
| 3A2 | A | 22 | 2.41 | 72.60 | 23.87 | 3.53 | sandy loam | 10 YR 3/6 |
|  | B | 40 | 2.40 | 68.11 | 27.07 | 4.82 | sandy loam | 10 YR 3/6 |
| 3B1 | A | 16 | 4.86 | 78.61 | 19.44 | 1.95 | loamy sand | 10 YR 3/2 |
|  | B | 64 | 2.41 | 82.98 | 13.93 | 3.09 | loamy sand | 10 YR 4/3 |
| 3B2 | A | 60 | 18.42 | 69.70 | 19.00 | 11.30 | sandy loam | 10 YR 2/2 |
| 3B3 | A | 25 | 3.37 | 72.81 | 23.31 | 3.89 | sandy loam | 10 YR 3/6 |
|  | B | 35 | 3.43 | 80.14 | 16.92 | 2.94 | loamy sand | 10 YR 3/3 |
| 3B4 | A | 77 | 18.39 | 71.71 | 25.13 | 3.16 | sandy loam | 10 YR 2/1 |
|  | B | 33 | 5.76 | 70.87 | 23.97 | 5.15 | sandy loam | 10 YR 3/3 |
| 4A1-1 | A | 62 | 20.64 | 73.02 | 22.83 | 4.15 | sandy loam | 10 YR 2/2 |
| 4A1.2 | A | 10 | 4.47 | 77.74 | 18.40 | 3.86 | loamy sand | 10 YR 2/2 |
|  | B | 66 | 2.83 | 89.99 | 7.72 | 2.29 | sand | 10 YR 3/6 |
| 4A2 | A | 60 | 26.51 | 58.22 | 36.12 | 5.66 | sandy loam | 10 YR 2/2 |
| 4B1 | A | 62 | 12.00 | 57.96 | 36.32 | 5.73 | sandy loam | 10 YR 2/1 |
| 4B2 | A | 18 | 18.59 | 12.89 | 78.04 | 9.07 | silt loam | 10 YR 3/3 |
|  | B | 27 | 6.60 | 75.86 | 18.95 | 5.19 | loamy sand | 10 YR 2/2 |

| **Well Number** | **Horizon** | **Thickness (cm)** | **Organic Matter (%)** | **Sand (%)** | **Silt (%)** | **Clay (%)** | **Texture** | **Color** |
|---|---|---|---|---|---|---|---|---|
| 4B3 | A | 50 | 2.68 | 76.63 | 21.04 | 2.33 | loamy sand | 10 YR 3/6 |
| 4B4 | A | 60 | 1.16 | 92.67 | 5.93 | 1.40 | sand | 10 YR 3/2 |
| 5A1 | A | 45 | 11.57 | 63.43 | 30.65 | 5.92 | sandy loam | 10 YR 2/2 |
|  | B | 10 | 12.33 | 63.88 | 31.67 | 4.46 | sandy loam | 10 YR 2/2 |
| 5A2 | A | 70 | 12.20 | 71.80 | 25.17 | 3.02 | sandy loam | 10 YR 2/1 |
| 5A3 | A | 99 | 2.03 | 58.38 | 37.46 | 4.16 | sandy loam | 10 YR 3/6 |
| 5A4 | A | 30 | 3.74 | 77.43 | 20.38 | 2.18 | loamy sand | 10 YR 3/3 |
|  | B | 45 | 1.33 | 72.63 | 22.58 | 4.79 | sandy loam | 10 YR 4/3 |
| 5A5 | A | 24 | 35.16 | 36.35 | 57.07 | 6.58 | silt loam | 10 YR 2/2 |
|  | B | 50 | 31.61 | 32.89 | 57.11 | 10.00 | silt loam | 10 YR 2/2 |
| 5A6 | A | 55 | 19.31 | 54.26 | 39.70 | 6.05 | sandy loam | 10 YR 2/2 |
|  | B | 35 | 7.92 | 73.70 | 22.06 | 4.24 | sandy loam | 10 YR 2/2 |
| 5B1 | A | 63 | 5.27 | 79.87 | 16.50 | 3.64 | loamy sand | 10 YR 2/2 |
| 5B2 | A | 15 | 11.80 | 65.10 | 28.35 | 6.55 | sandy loam | 10 YR 2/2 |
| 5B2 | B | 48 | 1.44 | 78.49 | 18.53 | 2.98 | loamy sand | 10 YR 4/3 |
| 5B3 | A | 60 | 4.09 | 83.86 | 14.57 | 1.57 | loamy sand | 10 YR 2/2 |
| 6A1 | A | 35 | 3.12 | 65.10 | 29.95 | 4.95 | sandy loam | 10 YR 3/3 |
| 6B1 | A | 35 | 9.60 | 83.97 | 13.75 | 2.28 | loamy sand | 10 YR 2/2 |
|  | B | 11 | 2.17 | 64.54 | 32.48 | 2.98 | sandy loam | 10 YR 4/3 |
| 7B1 | A | 27 | 2.85 | 82.02 | 15.21 | 2.76 | loamy sand | 10 YR 3/3 |
|  | B | 23 | 31.29 | 55.45 | 41.45 | 3.10 | sandy loam | 10 YR 2/2 |
| 7B2 | A | 36 | 6.64 | 77.99 | 19.02 | 2.99 | loamy sand | 10 YR 2/2 |
|  | B | 29 | 1.54 | 61.31 | 34.63 | 4.07 | sandy loam | 10 YR 3/2 |

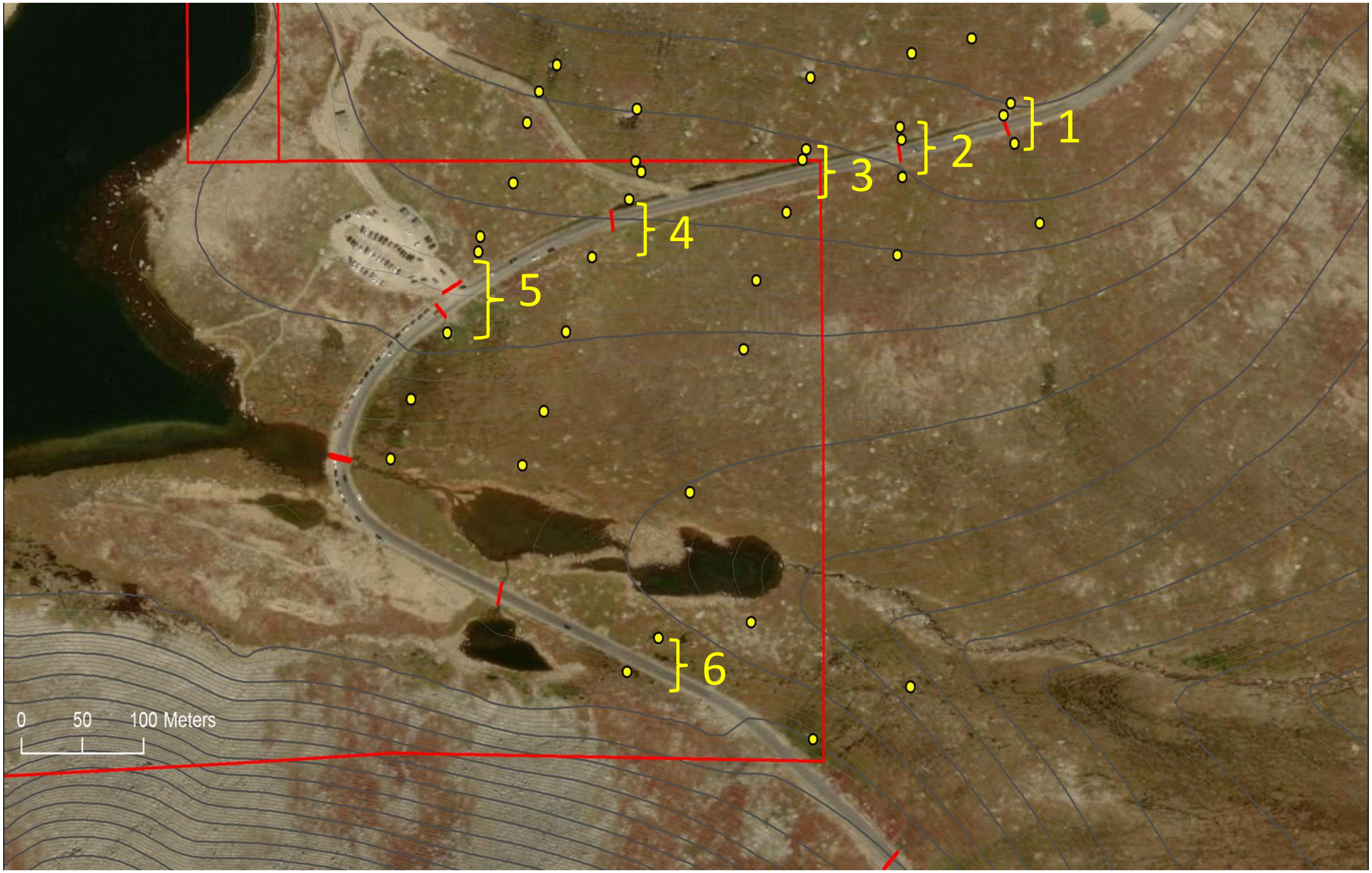

Figure 1. Location of monitoring well transects at Summit Lake Park. Transects are numbered in yellow.

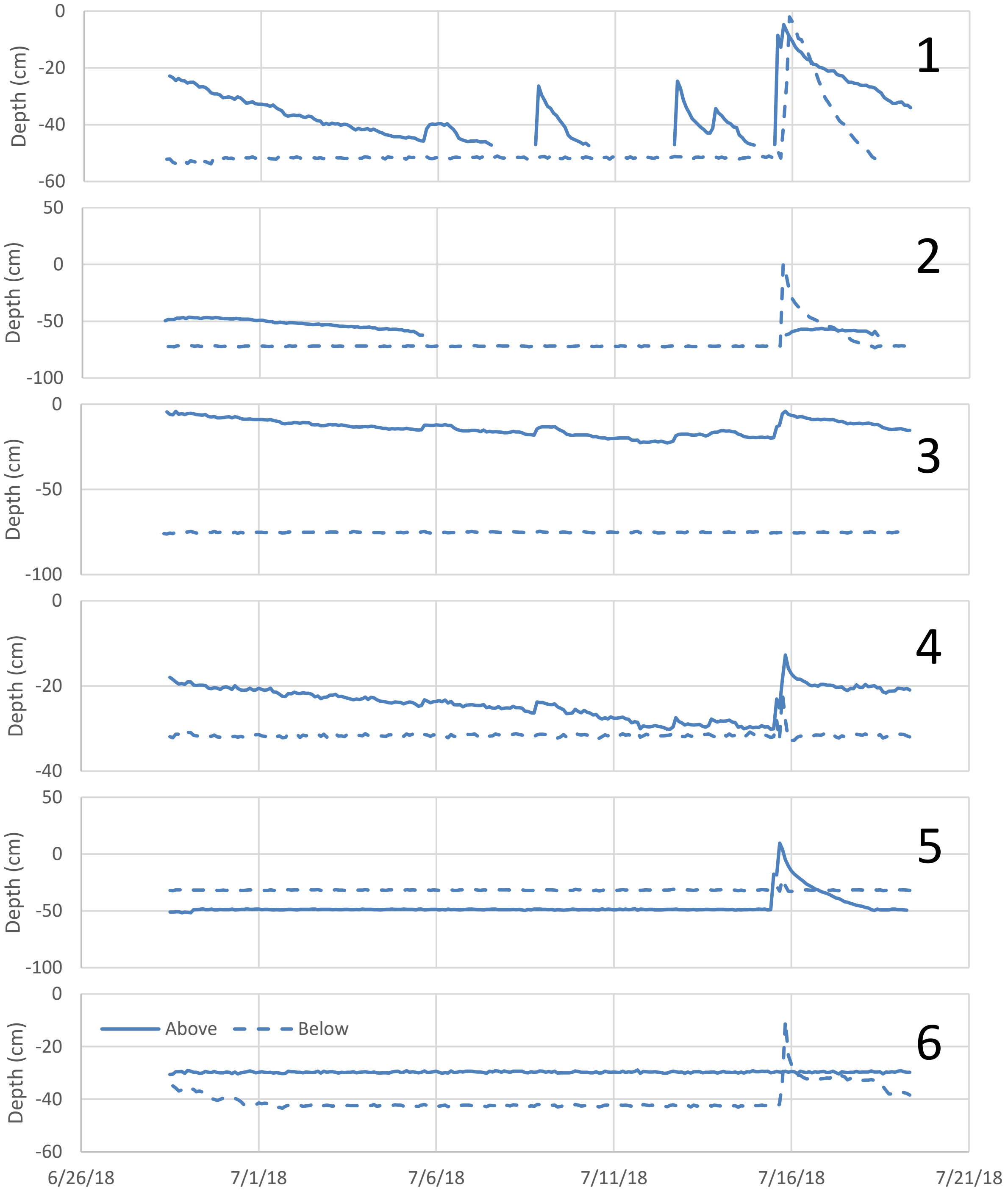

Figure 2. Example groundwater hydrographs from selected monitoring wells at Summit Lake Park during July 2018. Panel numbers indicate transect numbers shown in Figure 1. Above = well immediately up-gradient of SH 5. Below = well immediately down-gradient of SH 5.

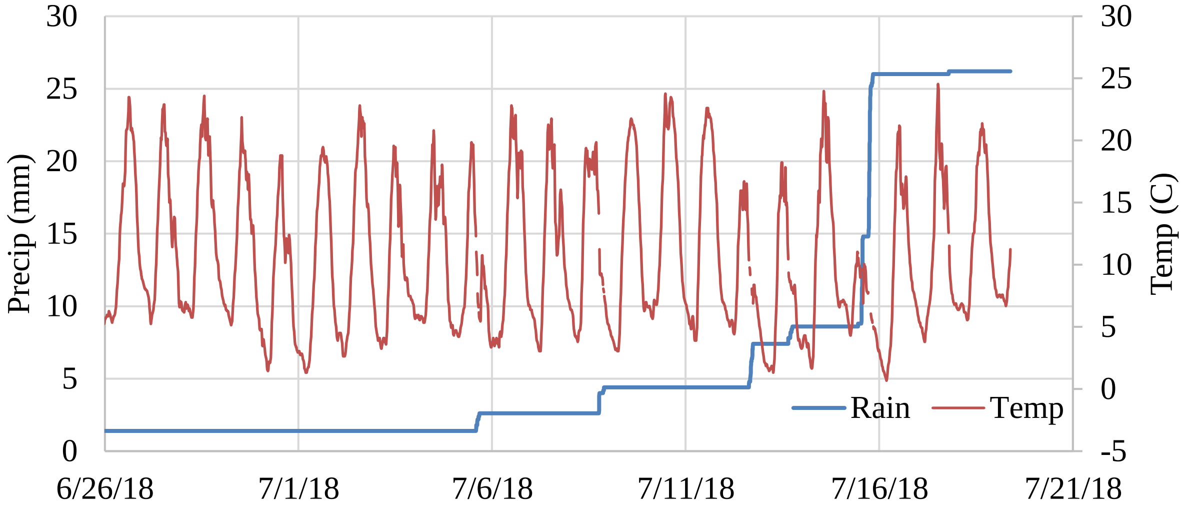

Figure 3. Rainfall and temperature at Summit Lake Park during July 2018.