Catchment scale observations at the Niwot Ridge Long-Term Ecological Research site

Nels Bjarke[1], Ben Livneh[2], Sarah Elmendorf[2], Noah Molotch[2], Eve-Lyn Hinckley[2], Nancy Emery[2], Pieter Johnson[2], and Katherine Suding[2]

[1]University of Colorado Boulder
[2]University of Colorado at Boulder

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Abstract

The Niwot Ridge and Green Lakes Valley (NWT) long-term ecological research (LTER) site collects environmental observations spanning both alpine and subalpine regimes. The first observations began in 1952 and have since expanded to nearly 300 available datasets over an area of 99 km2 within the north-central Colorado Rocky Mountains that include hydrological (n = 101), biological (n = 79), biogeochemical (n = 62), and geographical (n = 56) observations. The NWT LTER database is well suited to support hydrologic investigations that require long-term and interdisciplinary data sets. Experimentation and data collection at the NWT LTER are designed to characterize ecological responses of high-mountain environments to changes in climate, nutrients, and water availability. In addition to the continuation of the many legacy NWT datasets, expansion of the breadth and utility of the NWT LTER database is driven by new initiatives including (a) a catchment-scale sensor network of soil moisture, temperature, humidity, and snow-depth observations to understand hydrologic connectivity and (b) snow-albedo alteration experiments using black carbon to evaluate the effects of snow-disappearance on ecosystems. Together, these observational and experimental datasets provide a substantial foundation for hydrologic studies seeking to understand and predict changes to catchment and local-scale process interactions.

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Full Text

1. Introduction

The Niwot Ridge and Green Lakes Valley (NWT) long-term ecological research (LTER) site encompasses several catchments spanning alpine and subalpine zones in the Southern Rocky Mountains. Such catchments provide a vital natural reservoir for mountain source waters and snowmelt generated runoff (Cayan, 1996; Mote, 2006; Mote et al., 2018). High elevation regions are among the most sensitive to climate change and present a valuable testbed for evaluating climate impacts on hydrology and ecology (Barnett et al., 2005; Cayan, 1996; Clow, 2010; Livneh et al., 2015; Livneh & Badger, 2020; Pepin & Losleben, 2002; Sexstone et al., 2018; Vano, 2020), but comprehensive in situ observations in these extreme environments are rare. Hydrologically relevant observations collected at the NWT LTER include: 68 years of daily and hourly observations of meteorology, 30+ years of snow depth and distribution observations, multiple surveys of soil characteristics, a spatially dense sensor array of collecting sub-hourly observations of catchment soil moisture and temperature, stream gauge observations, and several experiments designed to evaluate the drivers and consequences of long-term ecological and biogeochemical trends. The unique spatiotemporal density of hydrological and ecological observations paired with multi-decadal climate records make the data collected at the NWT LTER particularly well suited for research that seeks to understand catchment-scale ecohydrological processes in alpine and subalpine environments.

2. Site Description

The NWT LTER site is located in the Southern Rocky Mountains of North America (40.05°N, 105.59°W) (Figure 1). The sub-alpine Niwot Ridge Saddle catchment (Area: 0.6 km^2; Elevation: 3528 m), located 5.6 km east of the continental divide, receives a majority (˜80%) of its approximately 1035 mm of annual precipitation as snow (Bowman et al., 2001; Caine, 1995; Greenland, 1989; Jennings et al., 2019). The alpine Green Lakes Valley catchment (Area: 2.3 km^2; Elevation: 3745 m) receives slightly more annual precipitation than the Saddle catchment, 1200 mm, which feeds into the Green Lakes and Lake Albion (Jennings et al., 2019). Average daily temperatures of -8.8 in the winter season and -0.5 in the summer season (Jennings et al., 2019) support persistent snowpacks in the NWT LTER catchments through much of the year and a short growing season for the alpine vegetation (1-3 months) (Jones et al., 2001). Annual records of daily gauged streamflow begin each year with the onset of snowmelt in the mid to late spring and extend back nearly 40 years.

3. Available Datasets

Hydro-climate observations were first collected at the NWT LTER in 1952 and have since expanded to nearly 300 available datasets over an area of 99.125 km^2 within the Southern Rocky Mountains that include hydrological (n = 101), biological (n = 79), geographical (n = 56), and biogeochemical (n = 62) observations (Figure 2). Here we emphasize active datasets identified as being the most spatio-temporally unique and relevant to hydrological catchment research, but encourage exploration and use of the hundreds of current and legacy datasets collected and stored on the publicly accessible NWT LTER database (*https://nwt.lternet.edu/data-catalog*). Emphasized hydrological datasets and other major datasets relevant to catchment hydrology are described briefly in Table 1.

3.1 Stream Discharge and Chemistry

Gauged stream observations of discharge are collected at daily resolution for four major streams (Albion, Green Lake 4, Martinelli, and Saddle) in the NWT LTER alongside weekly or monthly observations of water chemistry. These long records of stream observations are valuable for the validation of the performance hydrological (Biondi et al., 2012; Du et al., 2014) and hydrochemical (Molotch et al., 2008) model simulations interested in alpine and sub-alpine catchment behavior. Furthermore, the combination of chemical and volumetric streamflow observations has been used to understand changes to the contribution of glacial melt to surface runoff (Barnes et al., 2014; Leopold et al., 2011) and changes in carbon respiration and nitrification (Barnes et al., 2014; Blanken et al., 2009; Knowles et al., 2015; Liu et al., 2004) for alpine tundra under a changing climate.

3.2 Long-Term Climate Observations

Daily observations of precipitation and temperature are available from 1952 to present for the D1 meteorological station that is located at the head of the Green Lakes Valley catchment and the C1 sub-alpine meteorological station located below tree-line. In addition to the raw observations, temporally infilled and continuous records of daily temperature (Kittel et al., 2019a, 2019b) and precipitation (Kittel et al., 2019c, 2019d) following methods described in (Kittel, 2009) are available on the NWT LTER data catalog. Daily precipitation and temperature observations beginning in 1981 for the Saddle meteorological station, located at the head of the Niwot Ridge Saddle catchment, were updated to hourly frequency in 2009. Continuous observations of relative humidity, wind speed and direction, atmospheric pressure, and solar radiation are available at daily or hourly frequencies at the aforementioned meteorological stations in addition to more recently developed sites (Table 1).

4. High-Resolution Observations

Within the last five years, two high-resolution observation arrays have been established and produce observations relevant to catchment-scale hydrology research: the Saddle Catchment Sensor Array and the Green Lake 4 Sensor Array. These datasets are highlighted here due to the uniquely high spatial and temporal density of observations collected as part of the research framework.

4.1 Saddle Catchment Sensor Array

A high-density array of sensor nodes, installed in 2017, collects observations of soil moisture and temperature within the Niwot Ridge Saddle catchment at a 10-minute frequency. Sixteen sensor nodes are each equipped with a three-part transect of sensors that measures soil temperature and moisture at 5 cm and 30 cm depths, for a total of six observation points at each node, following methods outlined in (Kerkez et al., 2012). These high spatiotemporal resolution soil observations in the Saddle catchment can help constrain uncertainties in the distribution of subsurface water (Grayson et al., 1997; Western et al., 2004) and can be used to further understand the role of catchment-scale soil moisture variability as it relates to runoff generation and hydrologic connectivity (Western et al., 2004; M. W. Williams et al., 2015).

4.2 GL4 Lake Sensor Array

To better document spatial and temporal variation in alpine lake systems, both within and among seasons (including under ice), an instrumented buoy line was deployed with sensors at fixed depths in Green Lake 4 (Figure 1) in early summer 2018. The sensor line was positioned in the area of deepest depth and contained eight RBR soloT sensors to record water temperature, three PME miniDOT sensors to record dissolved oxygen, one PME miniPAR sensor to record photosynthetically available radiation (PAR) and a Cyclops 7 from Turner Designs to optically measure in situ chlorophyll-a. Available data from summer 2018 and winter 2018-2019 have revealed the establishment and erosion of stratification in GL4, which previous 'snapshot' sampling did not detect. Given that alpine lakes such as GL4 are typically frozen for >200 days per year, this depth-stratified sensor array provides high-resolution limnological data and valuable insights into lake temporal dynamics during a period often difficult to sample directly.

5. Extended Summer Experiments

Plot scale experiments, established in 2018, are conducted annually at the NWT LTER to evaluate the hydrologic and ecologic impacts of accelerated snowmelt and warmer alpine temperatures driven by climate change. Modulations of albedo and organic composition are applied to snow/ice located at several terrestrial and aquatic sites, paired with high-resolution observations of soil characteristics, snow depth, and biological composition.

5.1 Terrestrial Snowmelt Timing Manipulations

Beginning in 2018, "black sand" experiments were conducted to reproduce and observe the effects of changing snow albedo on snowmelt timing and subsequent soil moisture by applying varying volumes of black sand to snow-covered plots equipped with soil moisture sensors (Blankinship et al., 2014; Bueno de Mesquita, 2019). Hourly observations of soil moisture, soil temperature, and electrical conductivity are collected at four locations for each of the five habitat sites along with sub-weekly (˜ every 3 days) observations of snow depth for each of the sites. These terrestrial experiments are motivated in part by observed changes in snow albedo associated with dust-on-snow events, resultant from human activities (Neff et al., 2008), shown to impact the timing of peak snowmelt in the Western US (Deems et al., 2013; Livneh et al., 2015; T. H. Painter et al., 2010; Thomas H. Painter et al., 2012; Skiles et al., 2012).

5.2 Mesocosms: Experimental manipulation of ice cover and dissolved organic matter

In September 2019, an experimental array of 20 large-volume (2,600-liter) mesocosms were positioned at a high-elevation site in Boulder Watershed (10,800 feet above sea level). This represents the highest established mesocosm experiment and provides an aquatic analog to the Black Sand experiments that are conducted in the terrestrial plant communities. Half of the mesocosms are made of a plastic, light in color (control), while half are black (warmed), creating an albedo difference that is expected to drive variation in both ice-off date and water temperature (based on pilot experiments). The experiment also manipulates dissolved organic material (DOM) through the addition of willow-leaf packs, thereby mimicking forecasted advances in terrestrial vegetation around alpine lakes—which is expected to help mitigate the extreme UV effects common to such high-elevation environments. Each of the four treatments (light vs. dark tanks, enhanced vs. ambient DOM) are replicated five times in all factorial combinations (i.e., a 2 x 2 manipulation with five replicates per condition = 20 mesocosms). Mesocosms were seeded with lake sediment and zooplankton and are intended to run for two years. It is expected that higher temperatures, longer growing seasons, and higher DOM will function to 'soften' the harsh abiotic limitations inherent to alpine systems, leading to greater planktonic production (chl-a and zooplankton biomass) and lower water clarity. Additionally, mesocosm experiments are designed to observe expected shifts in zooplankton community composition and body size with warmer water and lessened UV stress, although whether these will be additive or interactive is uncertain.

6. Data Availability Statement

The data collected at the Niwot Ridge and Green Lakes Valley is stored and publicly accessible through the Niwot Ridge LTER data catalog (*https://nwt.lternet.edu/data-catalog*). All datasets include documentation of data collection practices, instrumentation, collection site information, and quality control information. In addition to the raw data, multiple temporally infilled and quality-control filtered datasets exist alongside documentation of the methods used to generate those datasets.

7. Acknowledgements

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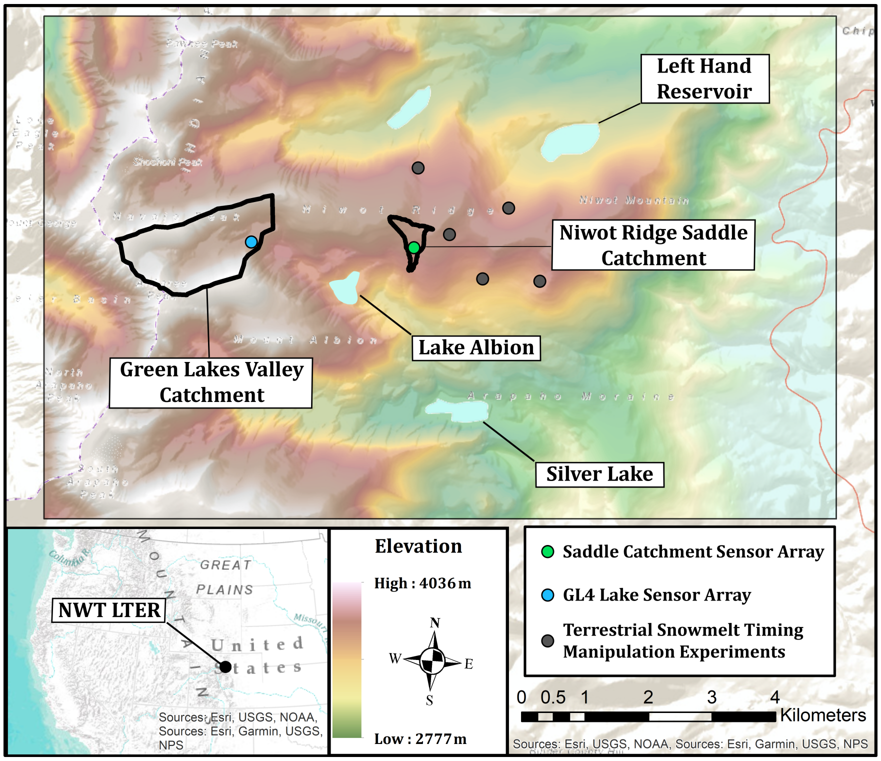
`Table 1.xlsx` available at https://authorea.com/users/363272/articles/484110-catchment-scale-observations-at-the-niwot-ridge-long-term-ecological-research-site


Left Hand Reservoir
Niwot Ridge Saddle Catchment
Lake Albion
Green Lakes Valley Catchment
Silver Lake
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Sources: Esri, USGS, NOAA, Sources: Esri, Garmin, USGS, NPS
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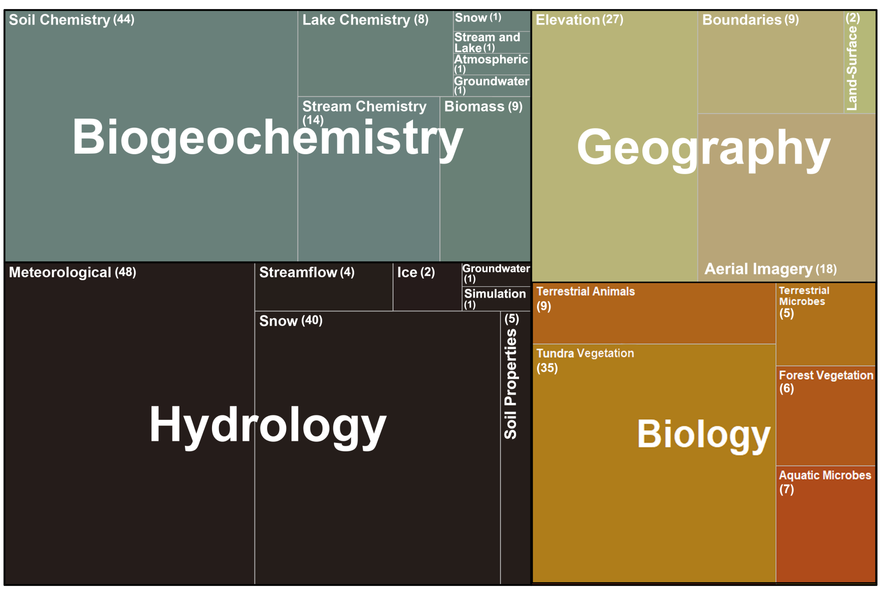
Soil Chemistry (44)
Lake Chemistry (8)
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Stream and Lake (1)
Atmospheric (1)
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Stream Chemistry (14)
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Biogeochemistry
Elevation (27)
Boundaries (9)
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Streamflow (4)
Ice (2)
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Simulation (1)
Snow (40)
(5) Soil Properties
Hydrology
Terrestrial Animals (9)
Terrestrial Microbes (5)
Tundra Vegetation (35)
Forest Vegetation (6)
Biology
Aquatic Microbes (7)