07-06

Contemporary Climate History and Climate Change Impacts in Great Basin National Park

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1. Introduction

Changing climate including drought is likely to occur in Great Basin National Park (GBNP). A recent study has provided convincing evidence from climate model simulations that up to 60% of the climate related trends in river discharge, winter air temperature, and snow pack between 1950 and 1999 are human-induced (Barnett et al. 2008). Research on past climate using tree rings has shown that droughts occurring over the past 1200 years were much larger than the recent multi-year dry periods (Cook et al. 2004), implying that any trends towards warmer temperatures could result in much drier conditions (Seager et al. 2007).

Reconstructing the regional and sub-regional responses of Great Basin hydrology to climate dynamics over the late Holocene (last 2000 years) will provide valuable insight into the nature of future local responses to climate change. Understanding the magnitude and range of past climate variability is vital for predicting future water availability and secondary ecological responses to climate change. The increases in surface temperature that are projected to occur as a result of global warming will greatly impact the chemical and physical limnology of high-altitude lakes, as well as the biota currently present in these lakes (Holzapfel & Vinebrooke 2005), and other biophysical and hydrological systems of the Park. However, alpine lakes, due to their remoteness, tend to be poorly monitored with limited faunal distributional data collected and little or no instrumental climate records available. Using a paleolimnological approach to study the modern distribution of aquatic fauna in these high-elevation sites will help establish 'baseline' conditions against which the effects of projected warming in these regions can be evaluated.

2. Research Objectives, Methodology and Design

We began our work in GBNP in 2005 and 2006, establishing a field site to survey climate variability and learn about physical geography and environmental issues with our graduate and undergraduate Geography students from Ohio State University (OSU). After sharing preliminary observations from shallow sediment cores of changing lake biota over the past 10 years with GBNP staff, we were invited to propose this one-year educational research project to WNPA comprising three components: (1) development of a multi-node (N > 20) meteorological network to assess recent climate variability over the elevation range of the Park; (2) collection of lake sediment cores to develop a long-term climate history; and (3) an evaluation of climate impacts to hydrology using hydrochemical and temperature sampling of surface waters and digital photogrammetry of rock glaciers.

Our specific research objectives were to:

1. quantify seasonal and interannual variability of temperature and humidity across the range of elevation and bio-physical systems in the Park;
2. analyze biological and physical characteristics of lake sediments to reconstruct multi-century thermal and hydrological variations;
3. use daily temperature records and geochemistry to trace the seasonal contribution of different waters sources (snowpack, groundwater, glacier/permafrost) to stream flow;
4. obtain repeat metric photographs of rock glaciers on Wheeler Peak to derive motion and glacier water budgets;
5. measure evaporation from sub-alpine lakes in GBNP using detailed energy budget measurements;
6. train undergraduate and graduate students in bio-physical field research design and methods.

3. Results

3.1 Topoclimate Network

We have established and maintained an "embedded sensor network" of 26 Lascar USB EL-2 temperature/humidity sensors (Fig.1) hung discretely, in 15 cm diameter aluminum shields, in trees and on wooden posts spanning a 2329 m elevation range from the Great Basin Visitor Center (GBVC) (1629 m) to the summit of Wheeler Peak (3958 m). Measurements of surface air temperature (T) and dew-point temperature (Td) are made hourly by the sensors, situated 1.3-2.0 m (130-200 cm) above the ground. During our data analysis, Td is converted to absolute humidity (Q), having units of grams water vapor per kg air (g/kg). Annual, seasonal, monthly, and daily averages of hourly samples are made and have been posted with documentation on a publicly available web site: http://bprc.osu.edu/~jbox/GBNP/data/ESN/.

Our sensor network recorded minima in surface air temperature of - 29.5°C at Wheeler Peak and -16.0°C in the valley at the GBVC. Summer minima were -8.0°C at Wheeler Peak and -4.5°C at the GBVC. Winter maxima were 2.0°C at Wheeler Peak and 27.0 °C at the GBVC. Summer maxima were 23.5°C at Wheeler Peak and 39.0°C at the GBVC. In winter, temperatures are more uniformly cold and are probably the result of cold air pooling in the valley, as indicated by temperature inversions aloft during calm and clear weather conditions. The maximum valley to summit temperature differential is found in April and May, suggesting that valley warming leads the timing of summit warming. The August decrease in lapse rate, we suspect, is the result of less vigorous atmospheric circulation and the annual maximum vertical mixing. The maximum seasonal temperature range is 50.0°C, occurring in winter in the valley. Winter weather, evidently, can be either warm or extremely cold. At the highest elevations, the winter temperature range is 29.5°C. In winter, the air is more consistently cold at high altitudes. The summer temperature range with altitude is small, 31.0°C in the valley and 34.5°C at Wheeler Peak.

Absolute humidity decreases with elevation. The decrease is greatest in summer, when annual maximum absolute humidity occurs in valley air. In winter, humidity values as low as 1.3 g kg^{-1} are observed at and above treeline. Maximum observed summer humidity is 14.9 g kg^{-1}.

Future work will involve: mining the "mountain topo-climate" baseline data set we have created to facilitate higher precision and accuracy in climate studies in Great Basin National Park; using seasonal and elevation-based surface climate statistics to better calibrate quantitative climate reconstructions from lake sediment cores; and maintaining the network to create a longer record to better quantify interannual variability. As the duration of this record increases, the ability to reconstruct surface climate using longer-term records from Mather Peak and elsewhere within the park will increase, enhancing the data resources and applications of the park.

3.2 Lake Studies

Short sediment cores recovered from Baker Lake were analyzed for organic matter content and midge community composition in order to elucidate changes in the hydroclimatic conditions that have occurred in the Park during the 20th and 21st centuries. Chronological control was provided using ^{210}Pb and undertaken by MyCore Scientific Incorporated (Dunrobin, Ontario, Canada). The midge community in Baker Lake currently consists of a total of 12 taxa; however, the midge community was relatively depauperate in the early 20th century with only 8 taxa present until ~ 1940 AD (See Fig. 3). The midge community experiences notable compositional change in the uppermost sediment, with dramatic increases in several genera. Application of midge-based inference model for July temperature (Porinchu et al. 2007) to the sub-fossil midge remains present in the sediment core recovered from Baker Lake provided a detailed high resolution record of thermal variability spanning the 20th century. A plot of the deviations of surface water temperature from the average chironomid-inferred surface water temperatures for Baker Lake and Stella Lake for the period ~ AD 1900 – 2005 is depicted in Fig. 4. Deviations of summer air temperature data for Nevada's Climate Division 2 (CD-2) are also illustrated. This diagram reveals that the air temperatures for the early to mid-20th century were characterized by an extended period of below average temperature and that the last two decades have seen a dramatic increase in air temperature at Stella and Baker lakes. Longer ice free seasons resulting from the later onset and earlier ice-off will lead to stronger thermal stratification and enhanced nutrient suspension. This in turn may increase lake productivity and potentially facilitate the invasion/introduction of non-native species and may limit the ability of native fish to survive in Baker Lake.

We propose to expand this research and incorporate mid-Holocene sediment in our analyses. Extending these records further into the past, i.e. the mid-Holocene, will enable reconstruction of Great Basin paleohydrology over a longer time-scale, put contemporaneous changes into context and increase our understanding of the linkage between these localized changes and regional climate dynamics.

3.3 Hydrology

During the summer of 2007, twenty-one water samples were collected from surface waters (streams, lakes and springs) in the Lehman and Baker watersheds. These samples complement others taken in 2005 and 2006, and provide a means to characterize both the different surface water end-members and interannual variability. All samples were analyzed for stable isotopes of hydrogen (^2H) and oxygen (^{18}O). Values of $\delta^{18}O$ and δ^2H were measured with a mass spectrometer (Finnigan MAT coupled to a HDO water equilibrator) in the Ice Core Paleoclimatology Lab at the Byrd Polar Research Center at The Ohio State University, Columbus Ohio.

The $\delta^{18}O$ and δ^2H values measured for water samples collected in 2005-2007 are provided in Table 1. These data contribute valuable information on the nature of the water in GBNP, and have already contributed to an M.S. thesis tracing mammalian usage of riparian resources with water isotopes by park staff (Bryan Hamilton, Biologist GBNP). The relative magnitude of isotope values reflects certain processes such as evaporation. For example, the least negative (most enriched) sample for all years was from Brown Lake (3314 m) in 2007, which is generally a very shallow (< 1 m) water body with no stream inflow or outflow. Also, the springs and stream samples generally show much less interannual variability than the lakes, implying less evaporation.

The averaged isotopic values for the three years are plotted on a bi-variant plot according to the groups from Table 1 (Fig. 5). This perspective confirms that most springs derive from precipitation that has not experienced evaporation during recharge, while the lakes demonstrate the most intense evaporation. The amount of evaporative enrichment and slope of the evaporation line for the lakes is slightly higher but consistent with observations from the only other isotopic survey of Great Basin NP waters (Acheampong, 1992). Also, all the lakes show a consistent trend to higher isotopic values (Fig. 5, inset). This probably reflects the fact that 2005 was a very wet year (300% normal precipitation), and consistently drier conditions and more intense evaporation are suggested for the subsequent 2006 and 2007 years. In contrast, Teresa Lake shows the least amount of interannual variability, as it features a more consistent spring-sourced inflow of more depleted water, possibly rock glacier melt.

Waters from different source regions also show systematic differences in isotope values (Fig. 6). The data show that springs in the Lehman catchment are recharged from either higher elevations or more rock glacier meltwater, while springs in the Baker catchment are likely to be recharged by water from snow pack at slightly lower elevations, and/or less rock glacier melt. These initial results confirm our stream temperature recordings that show lowest values and least diurnal to seasonal variability in spring fed streams.

More work remains, especially to monitor hydrological changes unfolding over time in the park beyond the single year of this project. With our established educational research protocol, we propose to analyze dissolved ion concentrations (measured for each isotope sample) and continue ongoing hydrological sampling in collaboration with GBNP staff to refine a hydrochemical mixing model and test how the hypothesized source waters change over time. Limited resources and personnel during our 2008 field visit prevented measuring evaporation using detailed lake energy budgets (objective 5), but our isotopic evaluation reinforces this as an important future goal.

4. Other Products of Research

WNPA funding supported M.S. student Scott Reinemann and undergraduate student Adam Herrington. Scott received training in processing the Stella Lake core and presented analyses of the data as lead author at the Association of American Geographers national meeting in Boston, MA, April 2008. He has completed his master's thesis, entitled "A chironomid-based paleolimnological study of recent and mid-Holocene changes in mean July air temperature in the Great Basin m Nevada, USA", under the supervision of D.F. Porinchu. Two related manuscripts are currently in preparation for submission to peer-reviewed journals. Adam received training in computer programming Interactive Data Language (IDL) to process the embedded sensor data, a skill he is utilizing to complete an honors thesis under the guidance of J. Box. Additional OSU undergraduate students (Erica Harris, Patrick Burns and Tyler Serafini) and one M.S. student (Karin Bumbaco) have been involved in field research in 2006 and 2008. Our analyses of the topo-climate network data are currently being developed into a manuscript for submission to the journal *Arctic, Antarctic and Alpine Research.*

Data from our project has broader impact to related research and educational outreach activity in GBNP and beyond. Our rock glacier photography and differentially-corrected GPS control points (research objective 4) will provide a valuable baseline for future change monitoring and will be used to assess glacial flow and melt volumes with future repeat surveys. We have been introduced (email via Gretchen Baker, Ecologist GBNP) with other researchers interested in our data, including Franco Biondi (University of Nevada, Reno) and Alice Chung-MacCoubrey, the NPS Mojave Desert Network Inventory and Monitoring Coordinator. Finally, we have put together a poster summarizing our work, and also established communication with the educational outreach personnel for GBNP, both Betsy Duncan-Clark, Chief of Interpretation, and Brandi Roberts, Educational Specialist.

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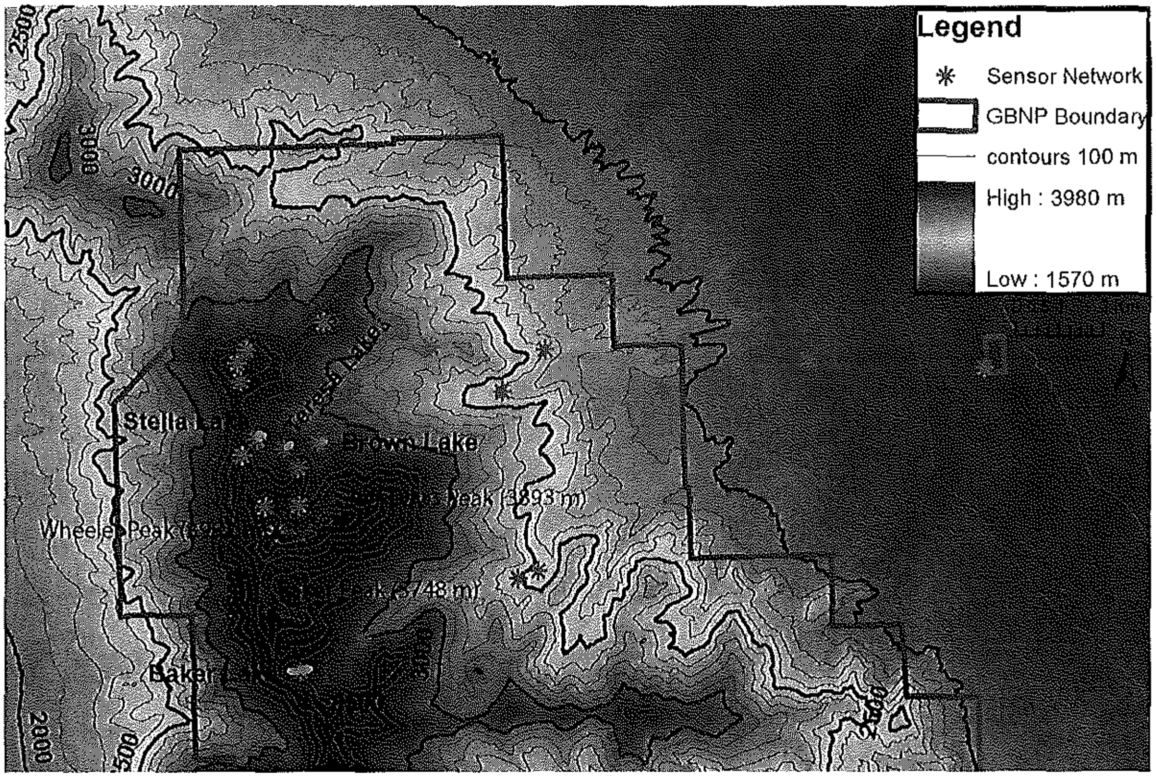

Figure 1: Location map with sensor Locations

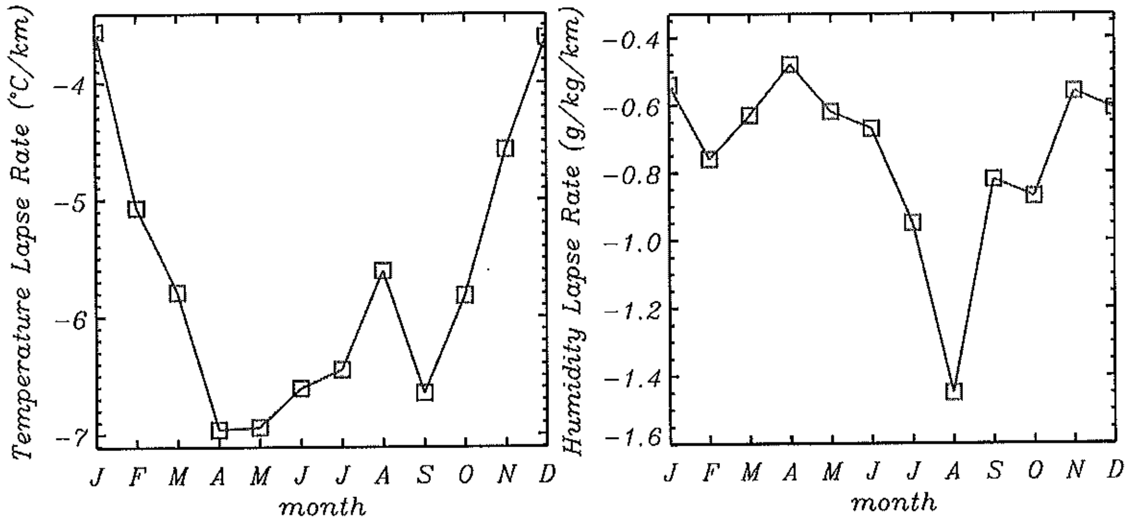

Figure 2: Annual cycles of the monthly average surface air temperature (left) and absolute humidity (right) elevation gradients based on 20+ small sensors hung in trees and on posts throughout Great Basin National Park.

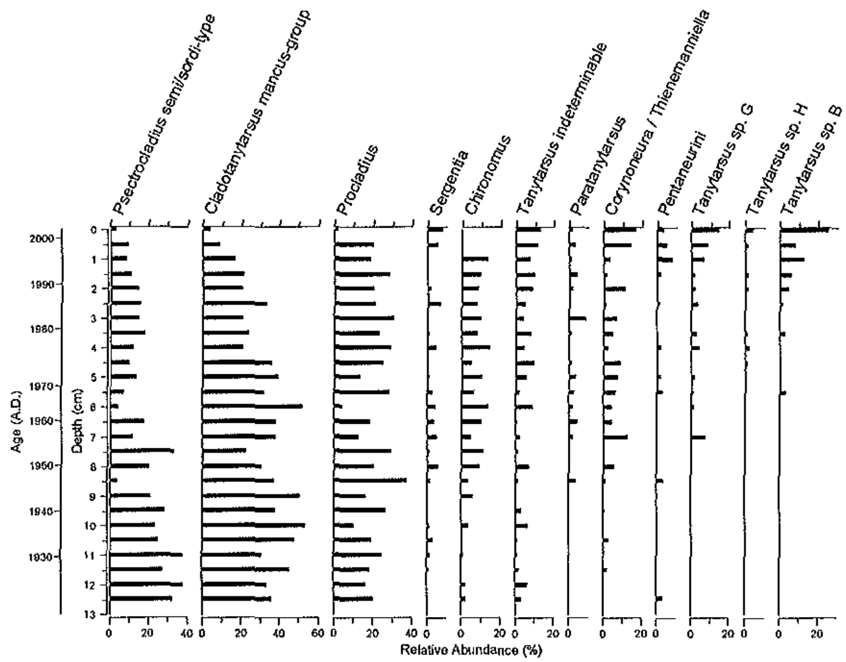

Figure 3: Chironomid stratigraphy for Baker Lake.

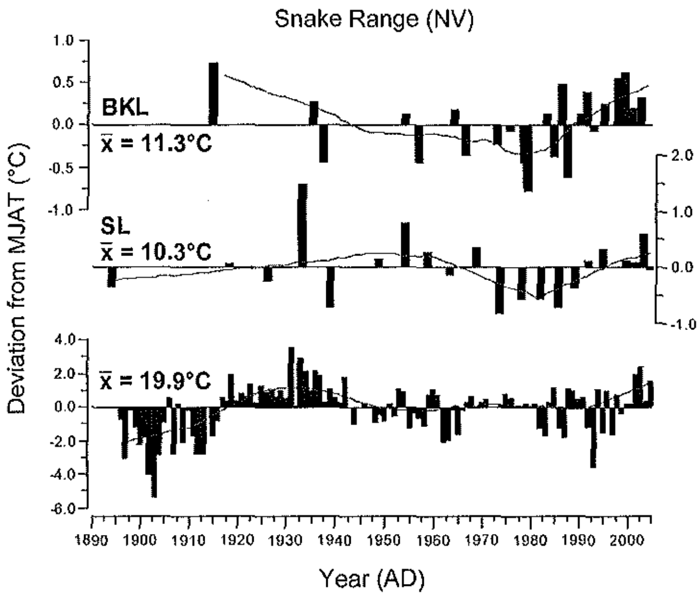

Figure 4: Deviations of the chironomid-based surface water temperature from the average surface water temperature for a) Baker Lake, b) Stella Lake and c) deviations of air temperature from long-term average air temperature for Climate Division-2, Nevada. This diagram reveals the last two decades have seen a dramatic increase in air temperature at Stella and Baker Lake.

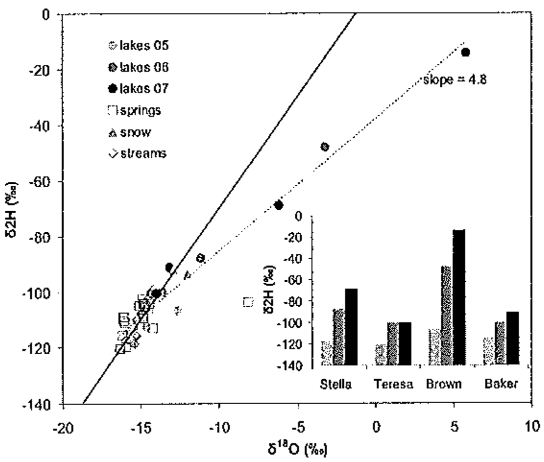

Figure 5: Relationship of $\delta^{18}O$ and $\delta^{2}H$ for all water samples taken 2005-2007, classified by water type (springs, lakes, streams or snow), each with different symbols. Lakes are shaded by year. (Inset): Annual $\delta^{2}H$ values for named lakes, with same shading pattern by year (2005-2007). The isotopic data provides valuable information on the hydrologic balance and precipitation:evaporation ratios for the study lakes.

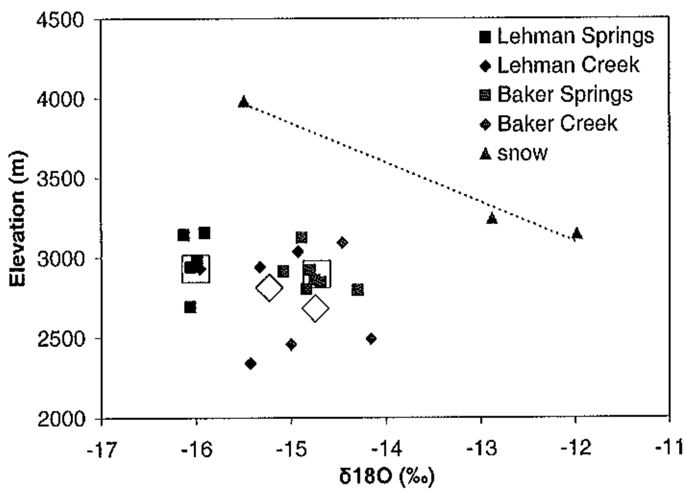

Figure 6: $\delta^{18}O$ of spring and stream samples plotted with elevation. Samples are color-coded by watershed, showing Lehman samples in black and Baker samples in red. Values of snow also plotted by elevation, showing linear decrease in $\delta^{18}O$ with elevation (dashed line, with slope of 4 ‰ km^{-1}). The more negative ("lighter") isotope values for springs in the Lehman watershed suggest recharge from higher elevations and/or more rock glacier melt than in Baker watershed.

Table 1: Isotope samples from Lehman and Baker Creek catchments (2005-2007).

Sample	type	lon (dd)	lat (dd)	elev (m)	$\delta^{18}O^{*}$ (‰) 2005	$\delta^{18}O^{*}$ (‰) 2006	$\delta^{18}O^{*}$ (‰) 2007	$\delta^{2}H$ (‰) 2005	$\delta^{2}H$ (‰) 2006	$\delta^{2}H$ (‰) 2007
Stella Lake	lake	-114.3187	39.0051	3170	-15.78	-11.14	-6.16	-117.58	-87.84	-68.91
Dead Lake	lake	-114.2741	38.9359	2903	-14.6			-112.61		
Teresa Lake	lake	-114.3114	39.0028	3159	-16.34	-14.32	-13.98	-120.9	-100.56	-100.52
Brown Lake	lake	-114.3021	39.0038	3114	-12.65	-3.24	5.77	-106.78	-48	-14.21
Baker Lake	lake	-114.3094	38.9574	3241	-15.87	-13.59	-13.14	-115	-100.19	-91.13
Snow above Teresa	snow	-114.3125	39.0022	3145	-11.98			-93.41		
Wheeler snow	snow	-114.3133	38.9861	3982	-15.49			-118.13		
Baker snow	snow	-114.3128	38.9574	3243		-12.88			-92.02	
Stella Spring	spring	-114.3185	39.0069	3157	-15.6			-116.85		
Brown Spring	spring	-114.2968	39.0093	2980	-15.91	-8.12	-14.19	-119.81	-103.69	-113.13
Ter-spring	spring	-114.3125	39.0022	3142	-16.29	-14.83	-14.39	-120.46	-104.21	-104.14
Lehman Spring 1	spring	-114.2970	39.0141	2942		-15.99	-16.06		-110.97	-110.35
Lehman Spring 2	spring	-114.2925	39.0150	2692		-16.13	-16.06		-115.45	-108.99
Nort Fork-Baker	spring	-114.2813	38.9690	2845		-14.69			-105.17	
Bak-up snow course	spring	-114.2870	38.9673	2921			-14.89			-102.6
Bak-mor-spring	spring	-114.2975	38.9575	3123			-15.08			-105.04
Bak-NFS1	spring	-114.2849	38.9683	2912			-14.84			-108.65
Bak-NFS2	spring	-114.2800	38.9698	2859		-14.75	-14.8		-104.34	-109.56
Bak-NFS4	spring	-114.2735	38.9736	2802			-14.3			-102.49
Bak-NFS5	spring	-114.2732	38.9739	2796			-14.49			-106.19
Lehman B4 confl	stream	-114.2961	39.0113	2929		-15.33	-15.24		-115.56	-115.66
Lehman aft confl	stream	-114.2952	39.0120	2939	-15.96	-14.93	-14.59	-117.53	-107.71	-105.86
Lehman-up-camp	stream	-114.3072	39.0097	3035		-15.43	-15.41		-112.78	-118.53
Lehman-lower-camp	stream	-114.2540	39.0129	2339		-15.22	-14.97		-109.59	-107.64
Up Baker Stream	stream	-114.2971	38.9591	3093		-14.46	-14.16		-102.05	-98.89
Baker Creek Low	stream	-114.2454	38.9762	2457		-15	-14.85		-108.43	-104.21
Bak-L-low	stream	-114.2488	38.9756	2493			-15.25			-110.12

*Stable isotopes results are reported using the δ-notation reported relative to the Vienna-Standard Mean Ocean Water (VSMOW) standard, with an accuracy of ± 0.1‰ for $\delta^{18}O$ and ± 3 ‰ for δ