Sediment Transport and Deposition in Fishercap Lake and the Swiftcurrent Valley, Glacier National Park, Montana, USA

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Abstract

In alpine valley systems with paternoster lakes, lake sediment cores reflect both changing environmental conditions and the complexities of spatial sediment transport and deposition. A sequence of lakes within two major valleys in the Many Glacier region of Glacier National Park, Montana, have multiple sediment sources which include glacial erosion, hillslope processes, and fluvial transport between lakes. We focus on a downlake transect of cores from Fishercap Lake in the Swiftcurrent Valley to better understand sediment transport and records of environmental change in the basin. Additionally, we measured suspended sediment concentrations as well as acquired bathymetric data from Fishercap and Redrock Lakes, which provide preliminary insights into sediment sources and sinks within the valley.

Fishercap Lake is relatively shallow (~1 m) and uniform in depth, with a slightly deeper upvalley region containing a greater accumulation of organic material. Fine sediment accumulation in the lake is generally massive, with organic content averaging 15%. There is a dense gravel layer below the sediment-water interface that appears to be uniform across the basin, suggesting past desiccation of the lake. The fine-grained sediment above the gravel is thickest at the upvalley end of the lake (85 cm) and grades to 40 cm at the downvalley end of the lake. Preliminary total suspended solids (TSS) data show TSS is higher at the outlets than at the inlets of Redrock and Fishercap lakes, suggesting that the lakes are not currently efficient sediment traps and may be sources of material for Swiftcurrent Lake. Comparison of sediment concentrations from Swiftcurrent and Grinnell Valleys suggests that Swiftcurrent Valley transports more sediment than Grinnell Valley into Swiftcurrent Lake. This has implications for our interpretations of climate and environmental change from cores that receive sediment and water from both valleys.

Introduction and Field Site

Glacier National Park, Montana (Figure 1) is sensitive to climate change as observed through glacial retreat (e.g., Key et al., 2002) and ecosystem adjustments (e.g., Klasner and Fagre, 2002), and there is widespread interest in the effects of future climate change in this unique and public space. Our research in the Park over the past decade is broadly aimed at understanding environmental and climate change variability in a near-pristine alpine basin in North America, with the goal of collecting data that is relevant to the debate about landscape response to climate change in the northern Rockies since the Last Glacial Maximum, including anthropogenic change, fire history, and historical land use impacts in the area. In summer 2018, as part of the undergraduate Keck Geology consortium, eight students (seven undergraduates just completing their first year in college, and one near-peer mentor completing her sophomore year) with an interest in STEM fields participated in the project (Figure 2). Field work in the Many Glacier region (Figures 3,4) took place July 15-25, 2018, followed by two weeks of lab work at the LacCore laboratory at the University of Minnesota.

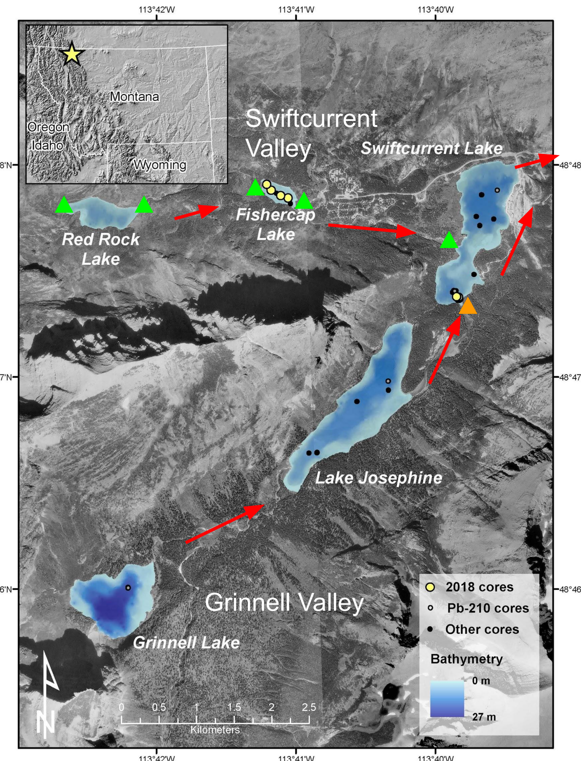


Fig. 1 (above). *Inset:* Glacier National Park, Montana is located near the U.S./Canadian border on the eastern edge of the Rocky Mountains. *Main:* Overview of the two valleys and chains of lakes of the study area. Bathymetry shown in blue shading, and locations of coring sites shown as dots. Yellow dots represent coring sites from summer 2018; green triangles show TSS sampling sites. Orange triangle is water discharge and TSS sampling site. Flow direction of water shown in red arrows; cores from the southern subbasin of Swiftcurrent Lake receive water and sediment from Grinnell Valley only.

Fig. 2 (above). Eight undergraduate research students at Logan Pass, Continental Divide, Glacier National Park, MT. Left to right: Etienne Chenevert, Joshua Stephenson, Liza Moore, Diala Abboud (peer mentor), Jacob Watts, Bonnie Page, Liz Atalig, and Anna Pearson.

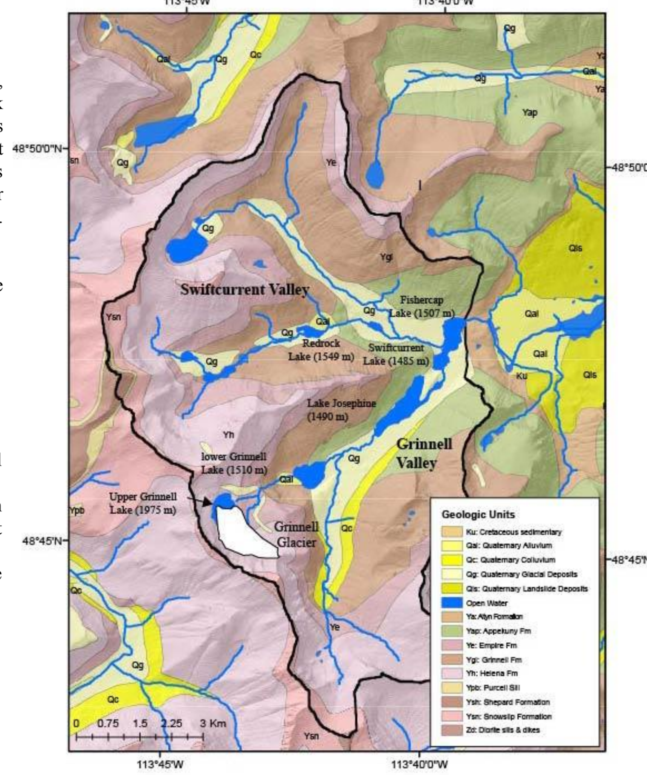


Fig. 3 (right). Geologic map of the Swiftcurrent and Grinnell valley systems, with basins outlined in black. Note pink colors represent carbonate rocks (primarily dolomite) in the highest elevations, with siliciclastic argillites dominating the valley floors and lower elevations. Lake elevations noted on map. Grinnell Valley is 36 km^2 in size, and Swiftcurrent Valley is 44 km^2. Both valleys supply water and sediment into the northern subbasin of Swiftcurrent Lake.

Fig. 4 (left). View from near Grinnell Glacier cirque basin in Grinnell Valley, with lower Grinnell Lake in foreground and Lake Josephine in middle view (Swiftcurrent Lake not visible). Yellow colored rocks are carbonates (dolomite), and pink are argillites.

Methods

Our work focused on collecting a) bathymetric data on Fishercap and Redrock Lakes, b) a down valley transect of sediment cores, c) water discharge entering Swiftcurrent Lake, and d) suspended solids/sediment at several sites in the valleys. Charcoal from Fishercap cores was picked in September 2018 to determine average sedimentation rates.

- Piston cores taken in a transect along Fishercap Lake
- Geotek Multi-Sensor Core Logger (MSCL) logged density, magnetic susceptibility, and non-contact resistivity
  - Cores split, one half archived and the other cleaned and imaged
  - Descriptions of color, texture, and grain size
  - Smear slide analysis
  - Loss on ignition (LOI) analysis at 2 cm intervals
- Water discharge measured between Swiftcurrent and Josephine Lakes using Q = velocity * channel area. Velocity was estimated using the float method. Seven measurements were made over the course of two days
- Total Suspended Sediment (TSS) data collected upstream and downstream on the streams between Redrock and Fishercap and between Fishercap and Swiftcurrent Lakes
  - A small number of samples were collected (44 total)
  - 2L of water collected from the surface of the stream
  - Suspended sediments filtered, dried, and weighed
- Bathymetric data collected on Fishercap and Redrock Lakes

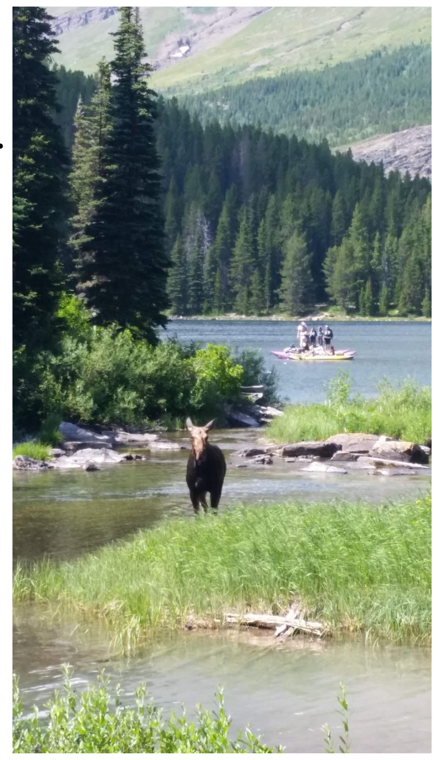
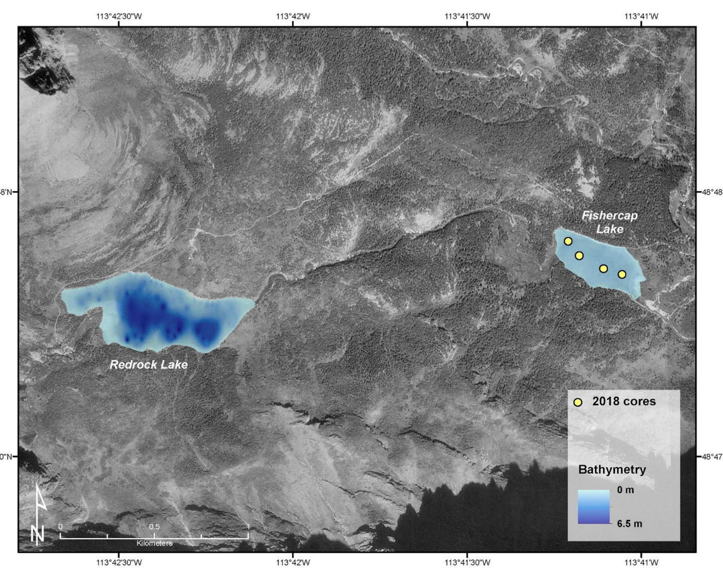



Fig. 5 (near right). Moose near water discharge site, with coring craft in Swiftcurrent Lake in background
Fig. 6 (middle right). Filtering water samples for TSS
Fig. 7 (far right, top). Preparing Livingston corer on craft
Fig. 8 (far right, bottom). Conducting core descriptions and additional analyses at LacCore.



Bathymetry

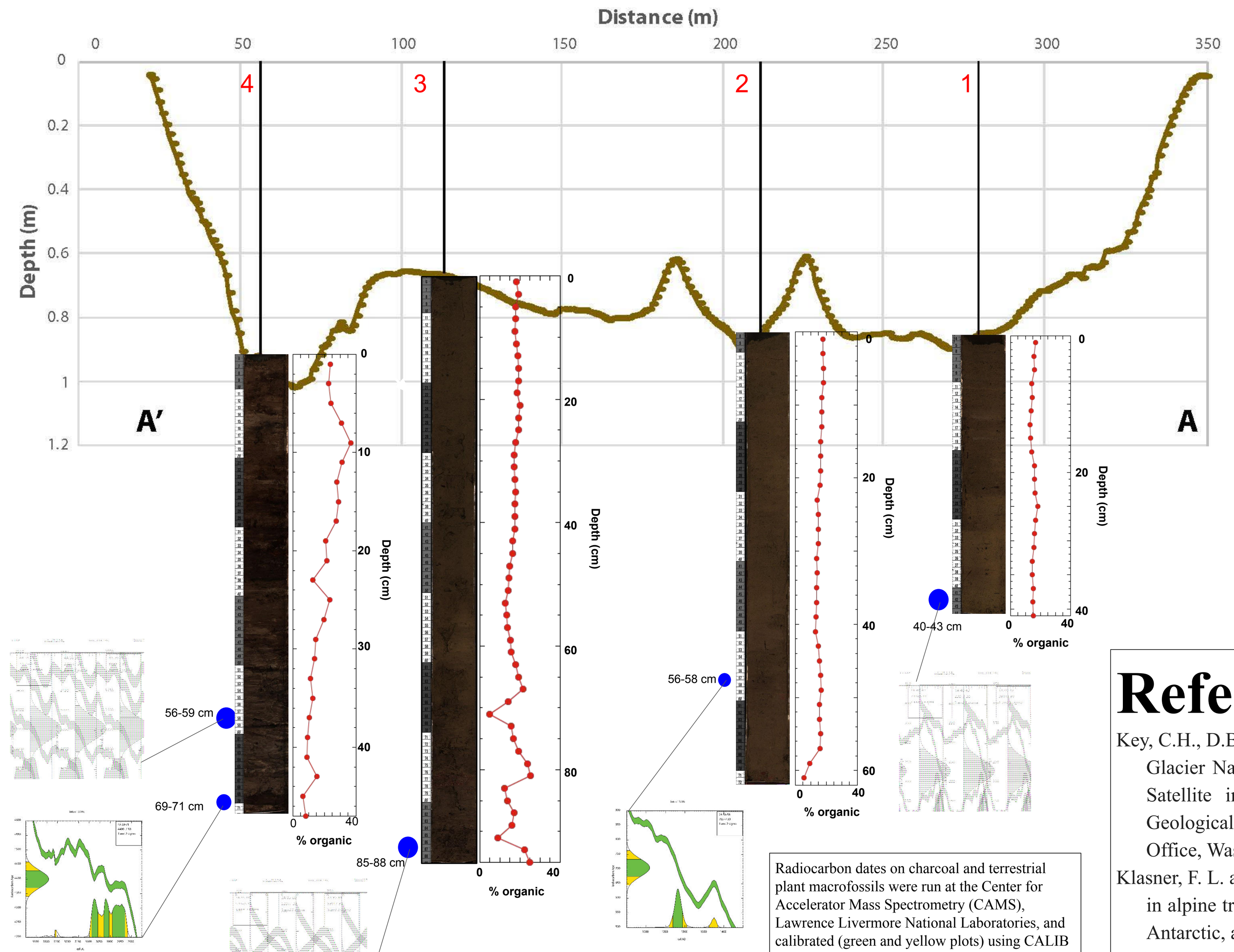
- Redrock Lake had a maximum water depth of ~6.5 m, with the deepest water on the southern side (Figure 9)
- Fishercap Lake was uniformly shallow with an average water depth of ~0.8 m
- We observed frequent moose grazing in the lake, suggesting macro bioturbation of lake sediments (Figure 5)
- Key finding: Fishercap is significantly more shallow than any lake in the Grinnell Valley, and is therefore unlikely to be an important sediment trap for material moving down the Swiftcurrent Valley.

Fig. 9 (left). Bathymetry of Redrock and Fishercap Lakes. Coring sites from 2018 noted by yellow dots. Note Fishercap is shallow and relatively uniform.

Fig. 10 (left). Fishercap Lake, looking toward outlet stream and Swiftcurrent Lake. Students are making bathymetric measurements of lake bottom from an inflatable raft.

Fishercap Cores

- A transect of four cores was collected, ranging from 42-96 cm in length
- All cores hit refusal in a coarse silty gravel layer
- Sediments in cores 1-3 show minimal lamination and are predominantly massive, while core 4 (most upstream) shows distinct laminations
- Percent organic carbon (derived from loss-on-ignition) range from 5-40%, with little down core variability in cores 1 and 2 and generally decreasing % organic matter with depth in core 4
- Basal charcoal radiocarbon ages for cores 1-3 are somewhat difficult to interpret based on their young (more recent) ages (Figure 12)
  - Core 1: 230±30 radiocarbon years (modern, 1790, or 1660 AD)
  - Core 2: 705±30 radiocarbon years (1280 AD)
  - Core 3: 530±30 radiocarbon years (1415 AD)
  - Average sedimentation rates:
- Located in a slightly deeper part of the lake and away from the lake inlet, core 4 has a basal age of 4400±30 radiocarbon years, with a sample ~12 cm higher of 3355±30 radiocarbon years
- Basal gravels suggest either a period of dessication/lower lake levels, when portions of the basin may have acted as a streambed and created a winnowed gravel layer
- Basal ages for cores 2 & 3 are near the likely termination of the Medieval Climate Anomaly, when drier and possibly warmer conditions prevailed
- Sedimentology and radiocarbon ages for core 4 suggest the upstream end of the basin was accumulating lake sediments during a possible MCA drying of the rest of the lake



Radiocarbon dates on charcoal and terrestrial plant macrofossils were run at the Center for Accelerator Mass Spectrometry (CAMS), Lawrence Livermore National Laboratories, and calibrated (green and yellow plots) using CALIB 7.1 online (Stuiver, M., Reimer, P.J., and Reimer, R.W., 2018, CALIB 7.1 at http://calib.org, accessed 2018-10-31)

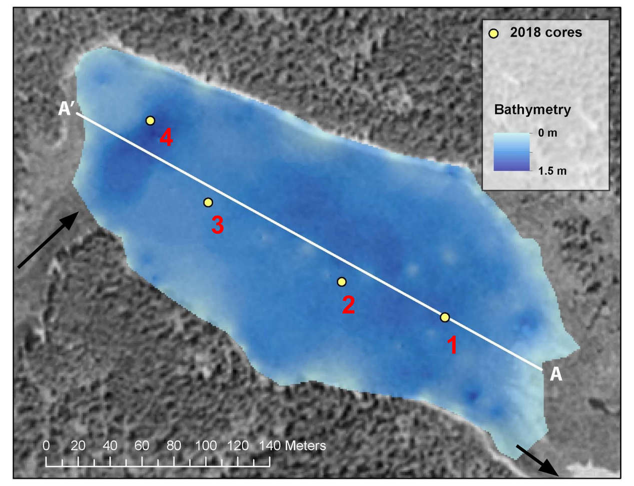


Fig. 11 (above). Fishercap Lake showing shallow, fairly uniform water depths and the locations of coring transect from down lake (core 1; A) to upvalley (core 4; A') . Inlet and outlet streams shown with arrows.
Fig. 12 (left). Water depth along transect A'-A (down lake) shown in brown, with coring sites labeled (black lines, red numbers). Core images shown alongside % organic (red dots). Radiocarbon sample locations shown by blue dots; dot height reflects core interval used in charcoal picking.
Inset figures: Radiocarbon calibration for all samples. Age analysis provided by LLNL (Tom Guilderson). Note laminations are present only in core 4, which also has the oldest basal age.

References

Key, C.H., D.B. Fagre, R.K. Menicke. 2002. Glacier retreat in Glacier National Park, Montana. In R.S. Williams and J.G. Ferrigno, eds., Satellite image atlas of glaciers of the world: North America. U.S. Geological Survey Professional Paper 1386-J, U.S. Government Printing Office, Washington D.C. p 365-381.

Klasner, F. L. and D. B. Fagre. 2002. A half century of change in alpine treeline patterns at Glacier National Park, Montana, U.S.A.Arctic, Antarctic, and Alpine Research. 34(1):53-61.

Stuiver, M., Reimer, P.J., and Reimer, R.W., 2018, CALIB 7.1 at http://calib.org accessed 2018-10-31

Water Discharge and Sediment Transport

Cores from Swiftcurrent Lake spanning at least the past ~14 ka show higher overall sedimentation rates in the northern subbasin, which is contributed by both the Grinnell and Swiftcurrent Valleys, compared to the southern subbasin, which receives sediment from only the Grinnell Valley. To begin to test the relative contributions of Swiftcurrent and Grinnell Valleys to the northern subbasin of Swiftcurrent, we collected a small number of surface water samples (1-2 at each site) from inlet and outlet sites of Redrock and Fishercap Lakes (Figures 1, 13)

- TSS concentrations at the sampling sites were low, ranging from 0-4 mg/L
- TSS values were higher at the lake outlets than inlets (Fig. 13, below), suggesting the lakes could be temporary sediment sources or that shoreline and/or hillslope processes also contribute sediment into the lakes
- TSS values were higher at the Swiftcurrent Lake inlet (from Swiftcurrent Valley) than the Fishercap Lake outlet, suggesting the stream channel (or surrounding area, including development in the Park) is a sediment source
- More intensive sampling over the entire summer is needed to quantify sediment fluxes through the system

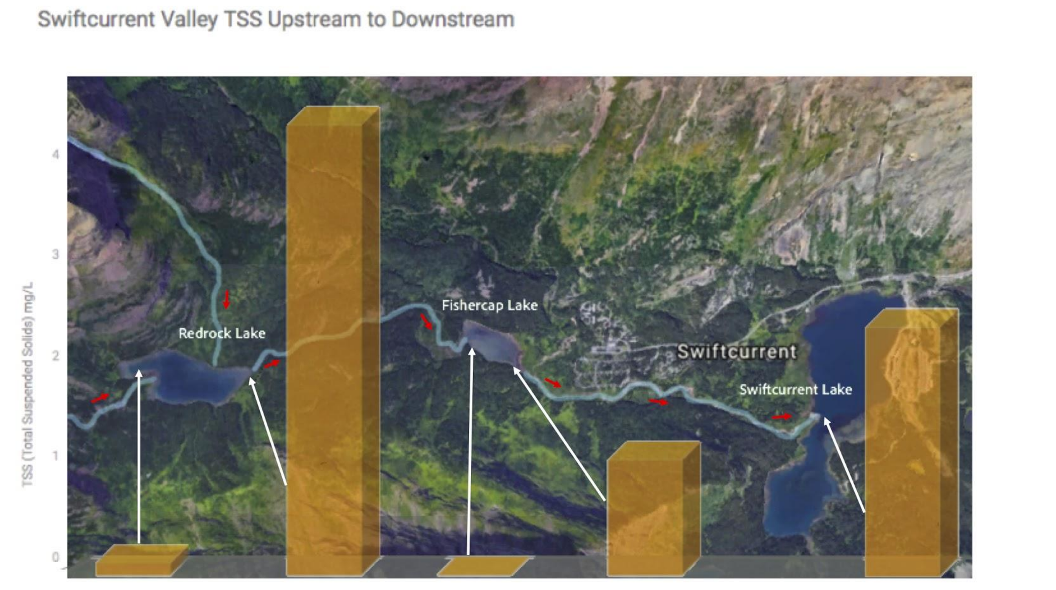


Fig. 13 (above). Total Suspended Sediment measurements throughout the Swiftcurrent Valley System. Note the higher levels of suspended sediments in the outlets of both Redrock and Fishercap Lakes, suggesting that they act largely as sediment sources for Swiftcurrent Lake.

To better understand modern water and TSS inputs into Swiftcurrent Lake from Grinnell Valley, we made water discharge and TSS measurements between July 20-24, 2018 (Figure 14 below)

- Measured water discharge used surface water velocity data, overestimating actual water discharge
- Water discharge was consistently higher than USGS measurements at the Swiftcurrent Lake outlet, confirming our measurements as overestimates by ~50%, based on observations of water flow at the inlet stream from Fishercap Lake (Figure 14)
- Gaging station data at the outlet of Swiftcurrent Lake had no diurnal pattern during the period of measurement
- TSS varied between 0-8 mg/L, with an average of ~2.5 mg/L. There was no measurable diurnal pattern

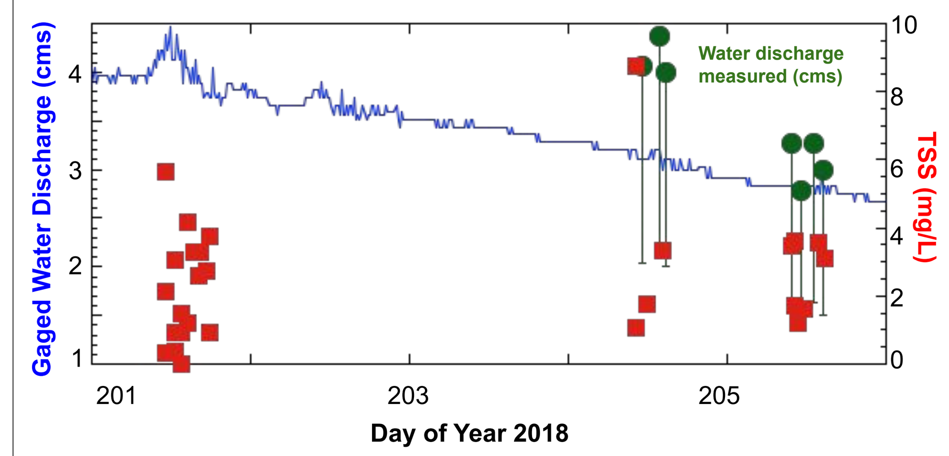


Fig. 14 (left). Water discharge reported at the USGS gaging station 05014500 (blue line), measured in the field (green dots, showing 50% uncertainty based on our velocity measurements), and TSS (red squares)

Fig. 15 (below). Photo of students measuring channel cross section to determine water discharge in the stream flowing from Lake Josephine into Swiftcurrent Lake

Discussion

- Fishercap Lake is significantly more shallow that other lakes in Grinnell and Swiftcurrent Valleys, and has a continuous coarse gravel layer less than a meter below the sediment/water interface. The age of this surface is variable, but is generally coincident with the end of the Medieval Climate Anomaly
- One of the cores from Fishercap records >4000 years of sedimentation, suggesting part of the basin was continuously accumulating sediment
- Preliminary TSS measurements suggest lakes are not always sediment sinks in Swiftcurrent Valley, but additional monitoring is needed to better understand water and sediment transport in the valleys
- Future work: higher resolution TSS and water discharge measurements across summer melt season, analysis of diatom concentration and diversity, comparison with upstream lake systems, charcoal content and grain size in conjunction with recent fires as well as the larger climate history

Acknowledgements

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