Water Temperature and pH Measurements on Gulkana Glacier and Phelan Creek, Alaska

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Abstract

Brought together on the Gulkana Glacier through the Inspiring Girls* Expeditions: Girls* on Ice Alaska, three students examined how the physical location of glacial meltwater affects water temperature and pH. Their objective: to measure and compare the pH and water temperature of glacial meltwater in various locations on and near the Gulkana Glacier. Four locations on the Gulkana Glacier and one on Phelan Creek were sampled over two days with a Hanna Meter probe utilizing GLOBE Hydrosphere water temperature and pH protocols. It was hypothesized that the water temperatures would be highest at a pond at the glacier's base and lowest at the most elevated site. A higher pH further up the glacier and a lower pH towards the bottom were also hypothesized. The highest elevation sites recorded the lowest temperatures. The single, standing water site (Glacier Pond) recorded the highest temperature and lowest pH. Measurements suggest that downstream flow and aquifer recharge for local Coho Salmon habitat are mostly within the preferred salmon range for pH (7-8). Physical location (elevation, ice formation, type of sediment/rock) affected the pH and water temperature of the meltwater sample. Exposure to solar radiation, friction, and kinetic energy from flow are also possible factors. Measuring pH in glacial meltwaters is challenging due to the cold, slow response of equipment and the remoteness of fieldwork. Continued and additional research is needed to determine the effect of Gulkana Glacier's meltwater on salmon dependent on the rivers and aquifers it replenishes.

Keywords: Gulkana Glacier, water temperature, pH

Research Questions

Question 1

How does the physical location of the water sample collected at Gulkana Glacier affect pH?

Question 2

How does the physical location of the water sample collected at Gulkana Glacier affect water temperature?

As moisture patterns, known as atmospheric rivers, flow over already melting glaciers, more meltwater pools are formed on top of the ice. These glacial pools are exposed to solar radiation, heating the pool which increases the melting of the ice it sits on (Wisconsin-Madison, 2023). Typically, when water temperature increases, pH decreases (Atlas, 2023). When examined with the increased human-driven levels of carbon dioxide (CO_2) dissolving into the water, pH decreases. Glacial rivers, influenced by sediment weathering reactions, become CO_2 sinks and can continue absorbing CO_2 26 miles downstream (Pierre et al., 2019). The Gulkana Glacier meltwaters flow (on the surface and basal levels) into the Tanana Valley watershed (Tanana Valley Watershed Association, n.d.), where they could potentially have lasting effects on many ecosystems, yet very little data was found pertaining to pH for the area.

The study was student-driven and exploratory in nature. One member of the student research team had multiple years of experience collecting data from water quality samples using GLOBE Hydrology protocols. Implementation of previous programming of the Girls* On Ice Alaska expedition resulted in research question selection with a randomized group of three students during one hour of brainstorming on Gulkana Glacier. Preplanning was not completed prior to leaving for the glacier due to a lack of student awareness of the scientific research portion of the expedition. Thus, necessary research equipment was limited, which required the student researchers to make do with what was available in their packs or at base camp. Access to GLOBE Hydrosphere protocol field guides or a GLOBE teacher was also unavailable while on the glacier.

Scientific research was related to different physical locations on and near Gulkana Glacier that were deemed safe to study by the expedition lead glaciologist and mountaineer. It was hypothesized that further up the glacier, in elevation, would have a higher pH, and further down would measure a lower pH. Our thinking was based on how glacial drinking water is advertised and sold as the world's best drinking water because of its alkalinity, whereas river water has had more opportunities to be filtered. For water temperature it was hypothesized to be highest at the small Glacial Pond site, towards the bottom of the glacier, and lowest at the Upper Mid-Moraine Stream site. This was because the Glacial Pond site had no motion or ice and received the most solar radiation out of all the sites; the upper moraine was enclosed, with little to no solar radiation and more ice.

Introduction and Review of Literature

In June of 2023, nine high school students between the age of 16-18 were selected for the Inspiring Girls* Expeditions: Girls* On Ice Alaska (GOIA) program. The twelve-day expedition is composed of a physical, art, and science component and led by a professional mountaineer, glaciologist, and artist on Gulkana Glacier. Deep in the eastern Alaska Range, Phelan Creek originates from the Gulkana Glacier and is part of the vast Tanana Valley watershed in interior Alaska (Tanana Valley Watershed Association, n.d.). Glaciers are a significant part of the water cycle. During summer, there is a substantial increase of meltwater on a glacier from the ablation zone or the lower portion, where more snow is lost than accumulates (Ashford, n.d.). As moisture patterns, known as atmospheric rivers, flow over already melting glaciers, more meltwater pools are formed on top of the ice. These glacial pools are exposed to solar radiation, heating the pool and increasing the melting of the ice it sits on (Wisconsin-Madison, 2023).

Streamflow measurements have been collected near the head of Phelan Creek since 1966 by the United States Geological Survey (USGS, n.d.), and a two-year climate study was conducted on the West Gulkana Glacier and surrounding area in 1986-87 (Marcus & Reynolds, 1988); however, little research has been found regarding water quality. Research of the glacierized Lake Hazen watershed in Nunavut, Canada, demonstrated glacial rivers' amazing ability to absorb CO_2 over 26 miles downstream through sediment weathering chemical reactions at rates twice as high as the Amazon Rainforest (Pierre et al., 2019). Basically, turning meltwaters into CO_2 sinks. At the bottom of the glacier, a portion of the meltwater (called basal meltwater) filters through the rocky layer to recharge the aquifer, replenishing local ground-fed streams and rivers (Liljedahl et al., 2017).

The Delta Clearwater River, the largest known producer of Coho Salmon in the Yukon River Drainage, is 11 miles away, and groundwater is fed from these glacial basal meltwaters. Currently, it provides a consistent flow and temperature year-round with a thriving aquatic insect and fish population (Parker, 2005). The Delta Clearwater River is capable of supporting millions of juvenile Coho Salmon as long as it stays within the salmon's preferred water temperature of >15ºC (Scannell, n.d.) and a pH between 7-8 (Howk, n.d.).

A literature review did not reveal pH measurements in our area of study. Our objectives were to measure and compare pH and water temperature in glacial meltwater in various locations on and near the Gulkana Glacier.

Research Methods

Study Site

This project was conducted on Ahtna Nenn', the traditional lands of the Ahtna people, at C'ulc'ena' Luu,' 'cutting stream glacier,' also known in English as Gulkana Glacier (Pittas, 2023). Deep in the eastern Alaska Range, the Gulkana Glacier is known as a world climate "reference glacier" because of its relatively easy accessibility and long-term data sets (Gulkana Glacier, n.d.). Meltwater from the Gulkana Glacier flows from Phelan Creek to the Delta River to the Tanana River to the Yukon River and empties into the Bering Sea. Gulkana and surrounding glacial meltwater is also transported by basal flow to underground aquifers, recharging ground fed salmon spawning streams (Liljedahl et al., 2017).

Prior to setting out on our expedition, we did not know that a science project was going to be conducted. While on the glacier, we were split into groups of three and given an hour to brainstorm a scientific study. Our group decided on water quality since one of the group members, Teslin Brannan, had experience in this area from previous GLOBE studies. As a group of three student researchers, we loaded up our day packs and started hiking up, on, and around the glacier looking for features we thought would be best to measure while remaining safe. This resulted in a few different ideas. The first sites considered were pools of water on the glacier, crevasses, and moulins. Unfortunately, they were deemed too extreme and dangerous by our lead glaciologist and mountain guide, so we regrouped and started looking for streams and more minor features. Basic aspects of land cover on the glacier moraine included no trees, very little vegetation, and lots of snow, ice, and rock. As we approached Phelan Creek there was an increase of shrubs present.

Figure 1

Local Gulkana Glacier Watershed - Google Earth

Figure 2

Collection Site Locations - Google Earth Pro

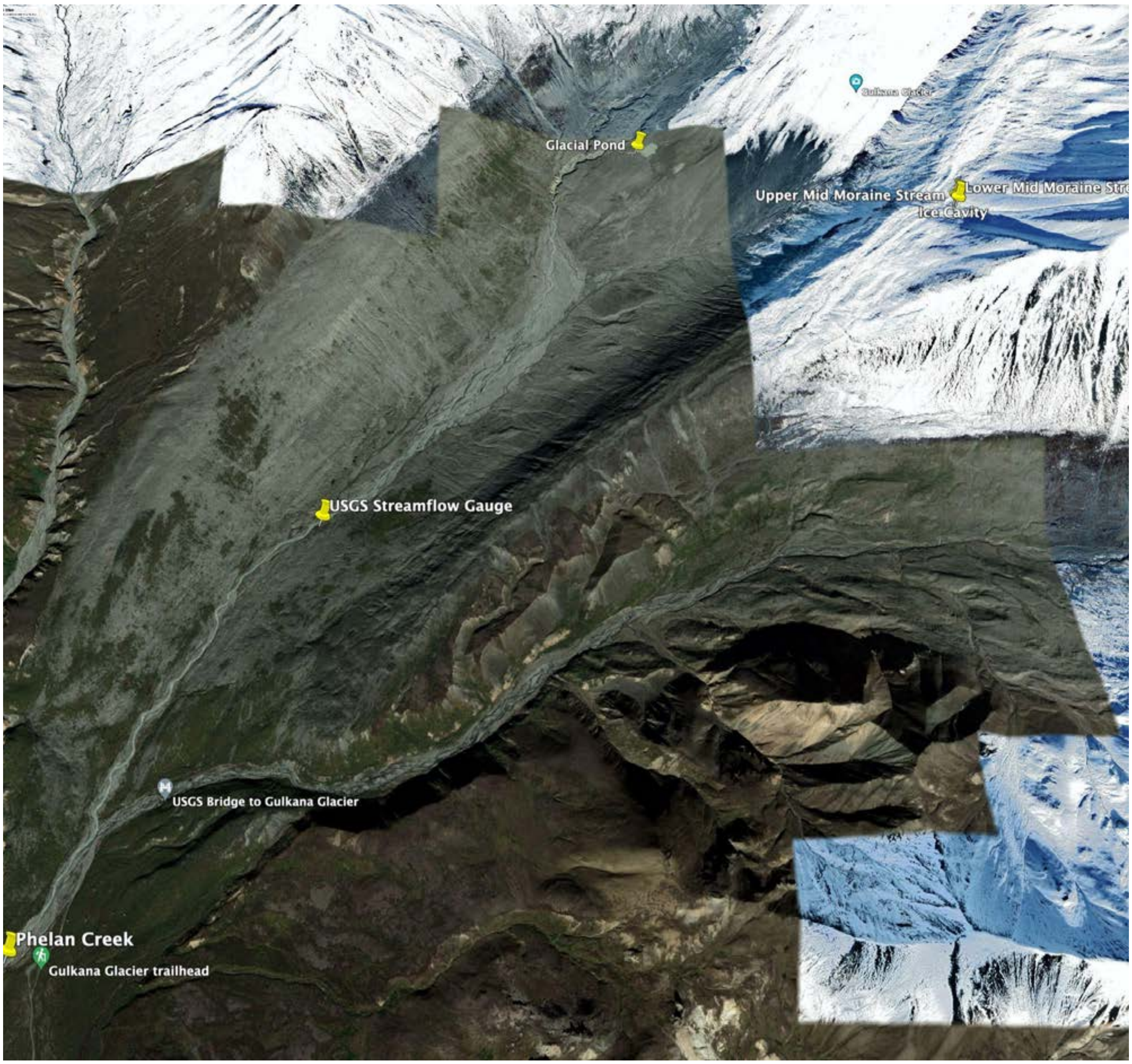


Figure 3

Highest Gulkana Elevation Collection Sites - Google Earth Pro

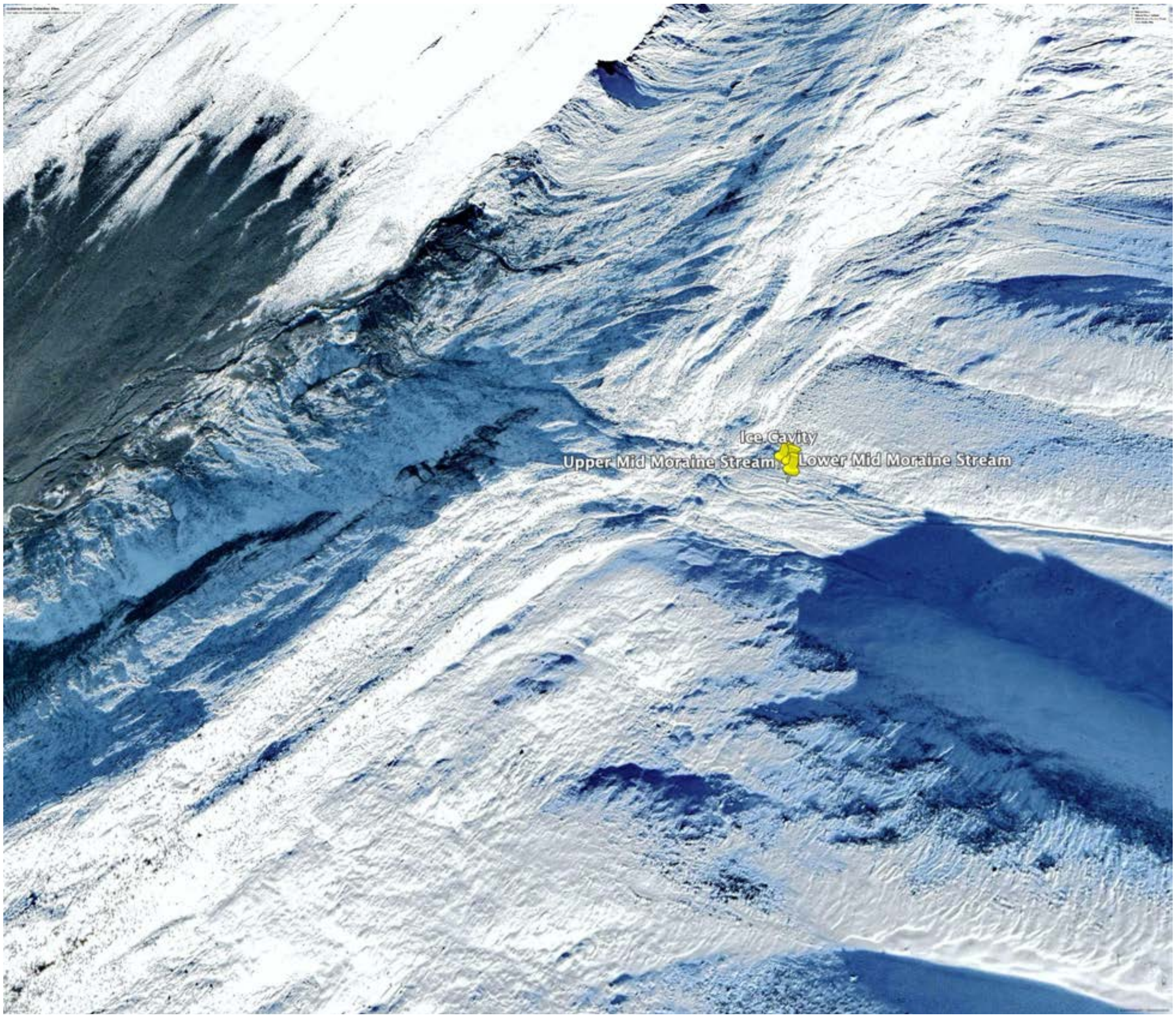


Table 1

Collection Site Names and Locations

Site Name	Site Coordinates Decimal	Site Coordinates DMS	Elevation
Upper Mid Moraine Stream	63.2517222 -145.4188806	63º 15’ 6.20” N 145º 25’ 7.97” W	1438.8 m
Lower Mid Moraine Stream	63.2516528 -145.4188806	63º 15' 5.95" N 145º 25' 7.97" W	1440.1 m
Ice Cavity	63.2517750 -145.4189667	63º 15' 6.39" N 145º 25' 8.28" W	1436.5 m
Glacial Pond	63.25614 -145.44382	63° 15' 22.104" N 145° 26' 37.752" W	1230.4 m
Filtered Glacial Pond (not included in data)	63.25614 -145.44382	63° 15' 22.104" N 145° 26' 37.752" W	1230.4 m
Phelan Creek	63.2268024 -145.4849106	63° 13' 36" N 145° 29' 05" W	1072.6 m

Location Descriptions

The clear flowing Upper and Lower Mid-Moraine Streams sites were connected; the Upper site was a small but steady stream of water through the ice, creating a narrow tunnel or crack about one to two feet deep before disappearing into the ice. The Lower Mid-Moraine Stream site was slightly downstream from the Upper site where the stream reappeared and created a small pool against the snow and rock before returning to its icy tunnel. The Ice Cavity site was a cave-like hole in the ice very close to the Mid-Moraine Stream sites, where water could be seen pooling in rocky sediment. We were unsure where the Ice Cavity site water went as we couldn't physically see its end and did not climb inside due to safety concerns. We were able to lean over the edge of the Ice Cavity site to sample the small amount of water. Glacial Pond and Filtered Pond sites were from the same location near our base camp, which was located on an empty glacial lake bed with a small, shallow, unflowing glacial pond of water nearby. This is also where we got our drinking water, the Filtered Glacial Pond site, which we did not include in our data analysis due to the change in the sample from artificial filtering. Lastly, on our hike out from the glacier expedition, we approached Phelan Creek which accumulates glacial melt from the Gulkana and College Glaciers. The Phelan Creek collection site was heavy with sediment and glacial silt, had a strong flow (appearing more like a river), and braided as it travels across rock and gravel with very little topsoil. This site was chosen as a location to gather additional water quality data at the bottom of the glacier.

Data Collection

One sample was collected at each site between June 16-18, 2023. The order in which we hiked to and took samples was Lower Mid-Moraine Stream, Ice Cavity, Upper Mid-Moraine Stream, Glacial Pond, Filtered Glacial Pond (filtered Glacial Pond water for drinking), and Phelan Creek. The weather changed regularly throughout the trip between rain, hail, full cloud cover, and snow, with rarely clear sky, but fortunately, it stayed consistent with wind and mostly clear sky the two days we collected data.

Yi Lou, from San Francisco, California used the Hana Meter probe, and Lydia Patterson, from Richmond, Texas, operated the Garmin eTrex Global Position System (GPS) unit to record the site coordinates. The Hanna Meter provided by GOIA on-site only collected pH and water temperature and we did not have access to salt, known buffering solutions, GLOBE Hydrosphere protocol field guides, or an electrical conductivity meter. Teslin Brannan supervised the instrument use and GLOBE Hydrosphere protocols: water temperature (2022) and pH (2022). All three student researchers recorded the data, presenting the initial findings to an audience of scientists and family at the University of Alaska Fairbanks as a conclusion to the expedition. Teslin Brannan further researched the topic as part of her interest in hydrology and salmon for an Introduction to Watershed Management class, comparing water temperature to pH by elevation at the collection site.

Figure 4

GLOBE Site Entry

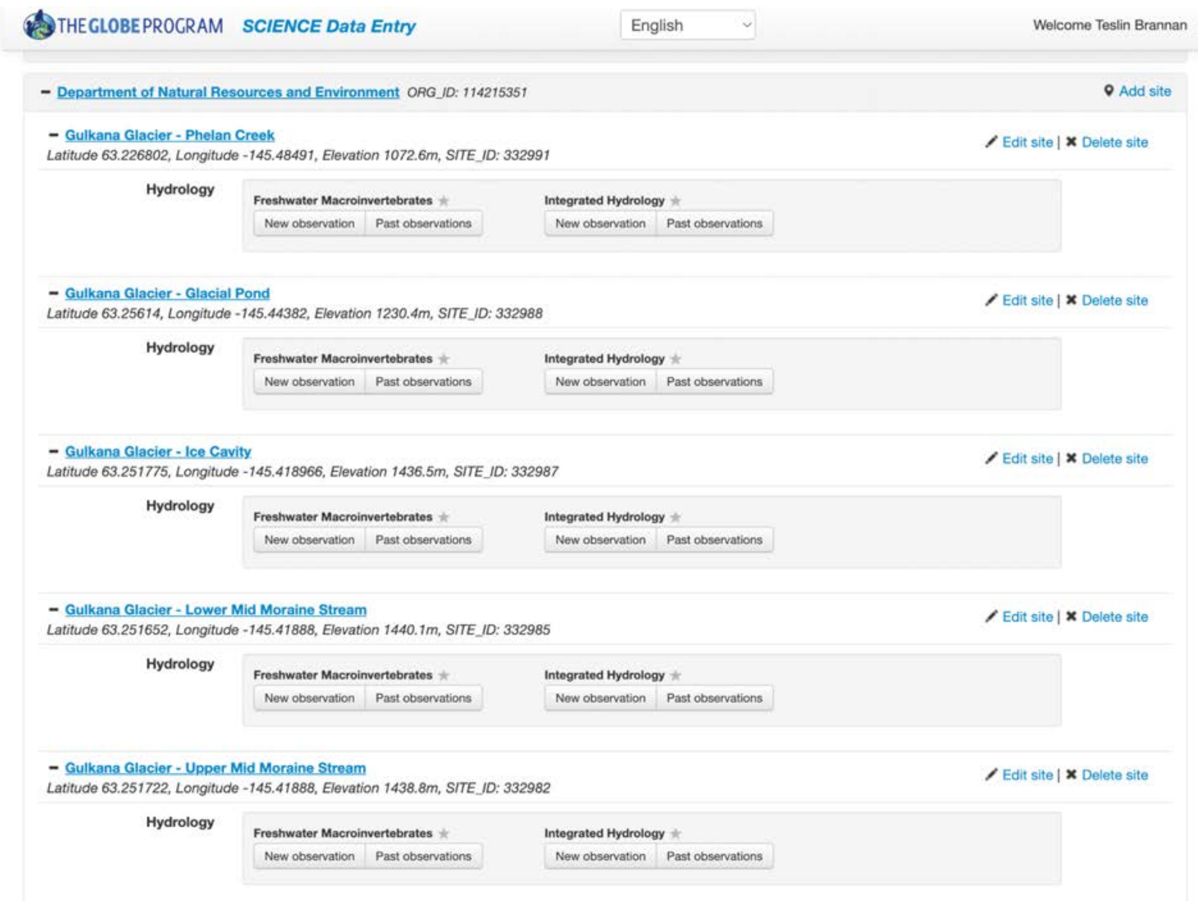
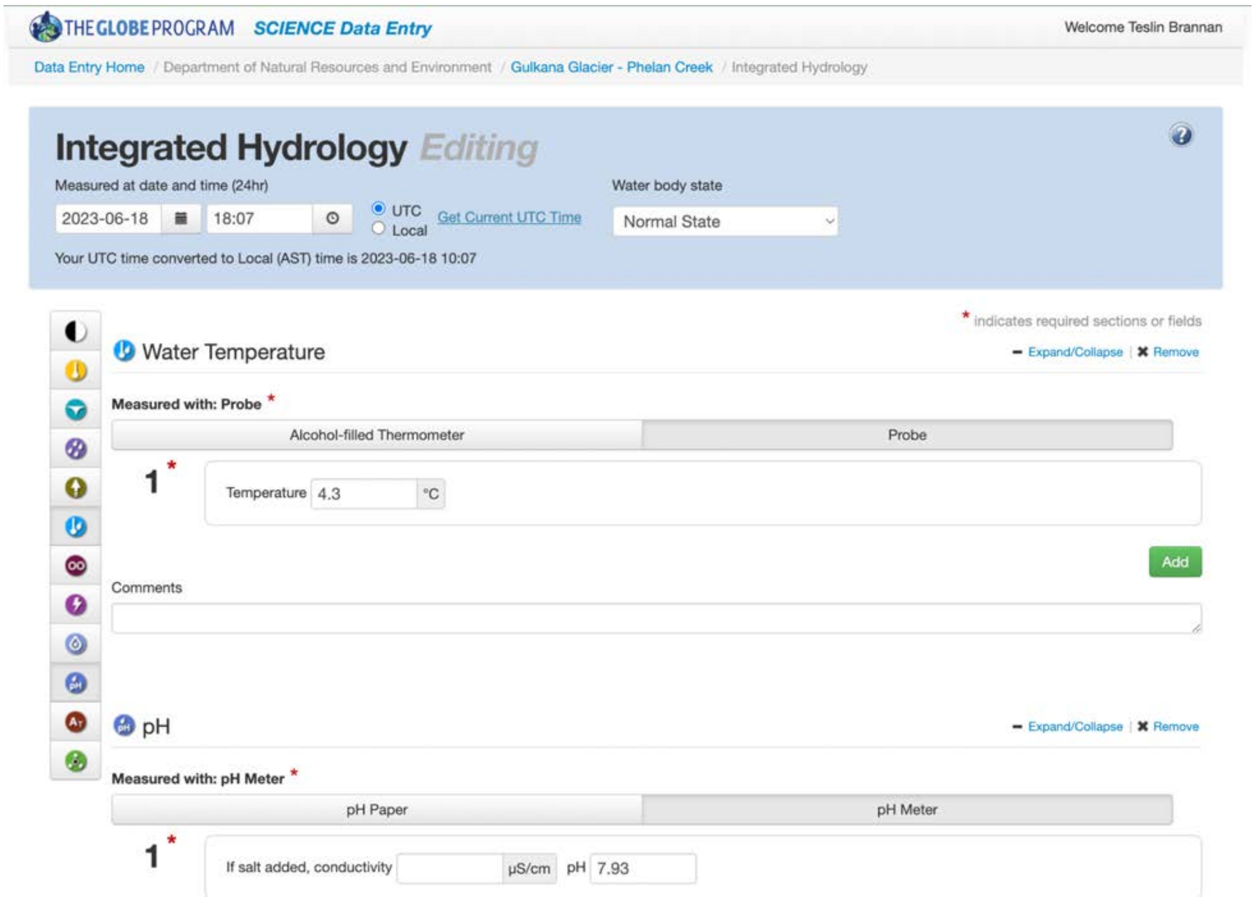


Figure 5

GLOBE Data Entry: Gulkana Glacier - Phelan Creek



Results

Results indicated that the highest water temperature was at the lowest elevated site still on the glacier, Glacial Pond (1,230.4 m), at 12.7ºC. The coolest temperature was recorded at the highest elevated site, Lower Mid-Moraine Stream (1,440.1 m), at 0.4ºC. The Upper Mid-Moraine Stream (1,438.8 m), our second most elevated site, recorded the highest pH (8.3) while the Glacial Pond site (1,230.4 m), which was also our warmest water temperature, recorded the lowest pH (7.19) of our glacial sites. Interestingly, our lowest elevation site, Phelan Creek (1,072.6 m) had the second highest water temperature (4.3ºC) and pH (7.93).

Table 2

Comparison of pH and Water Temperature by Site

Site Name	Elevation	Date/Time	pH	Water Temperature
Upper Mid Moraine Stream	1438.8 m	June 16, 2023 16:16	8.3	0.5º C
Lower Mid Moraine Stream	1440.1 m	June 16, 2023 15:56	7.27	0.4º C
Ice Cavity	1436.5 m	June 16, 2023 16:06	7.75	1.4º C
Glacial Pond	1230.4 m	June 16, 2023 17:47	7.19	12.7º C
Filtered Glacial Pond (Basecamp)	1230.4 m	June 16, 2023 17:57	7.32	12.4º C (measure at basecamp and not pond)
Phelan Creek	1072.6 m	June 18, 2023 10:07	7.93	4.3º C

Figure 6

GLOBE Visualization: pH

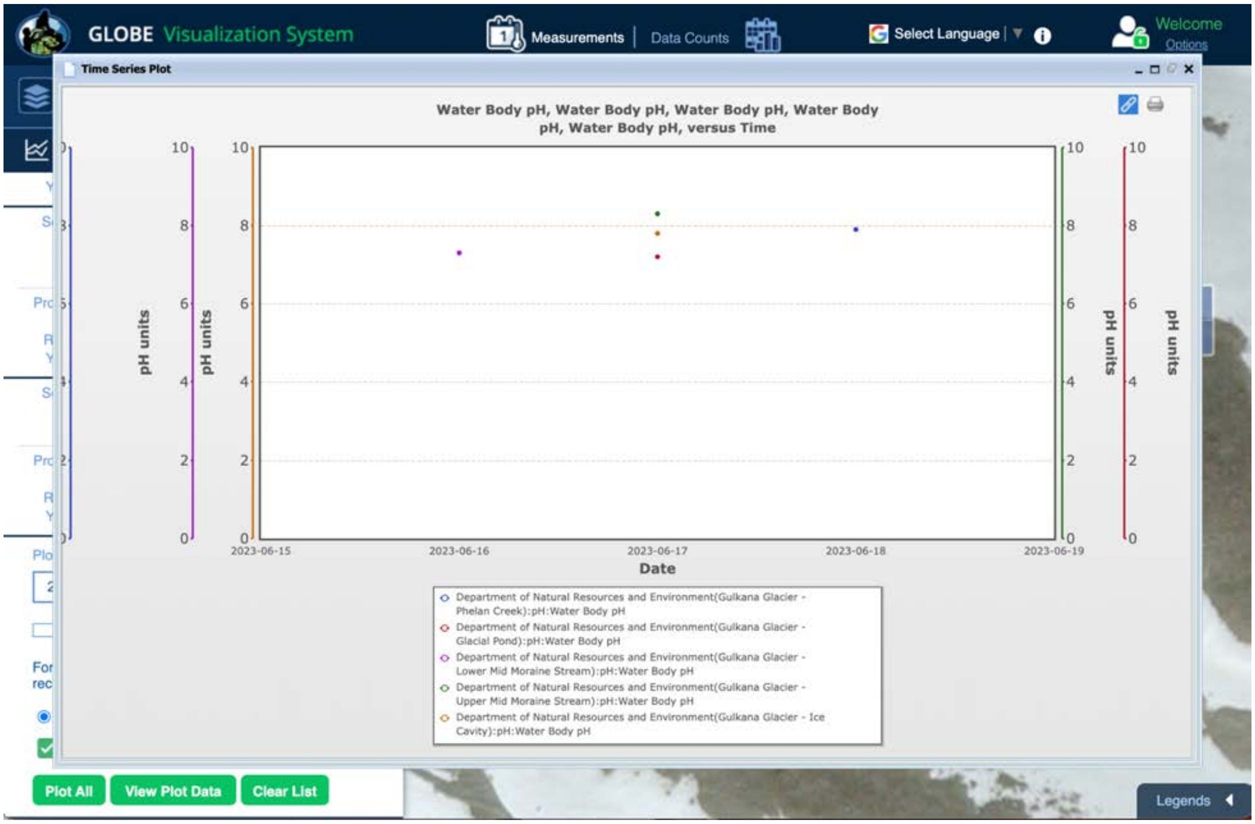


Figure 7

GLOBE Visualization: Water Temperature

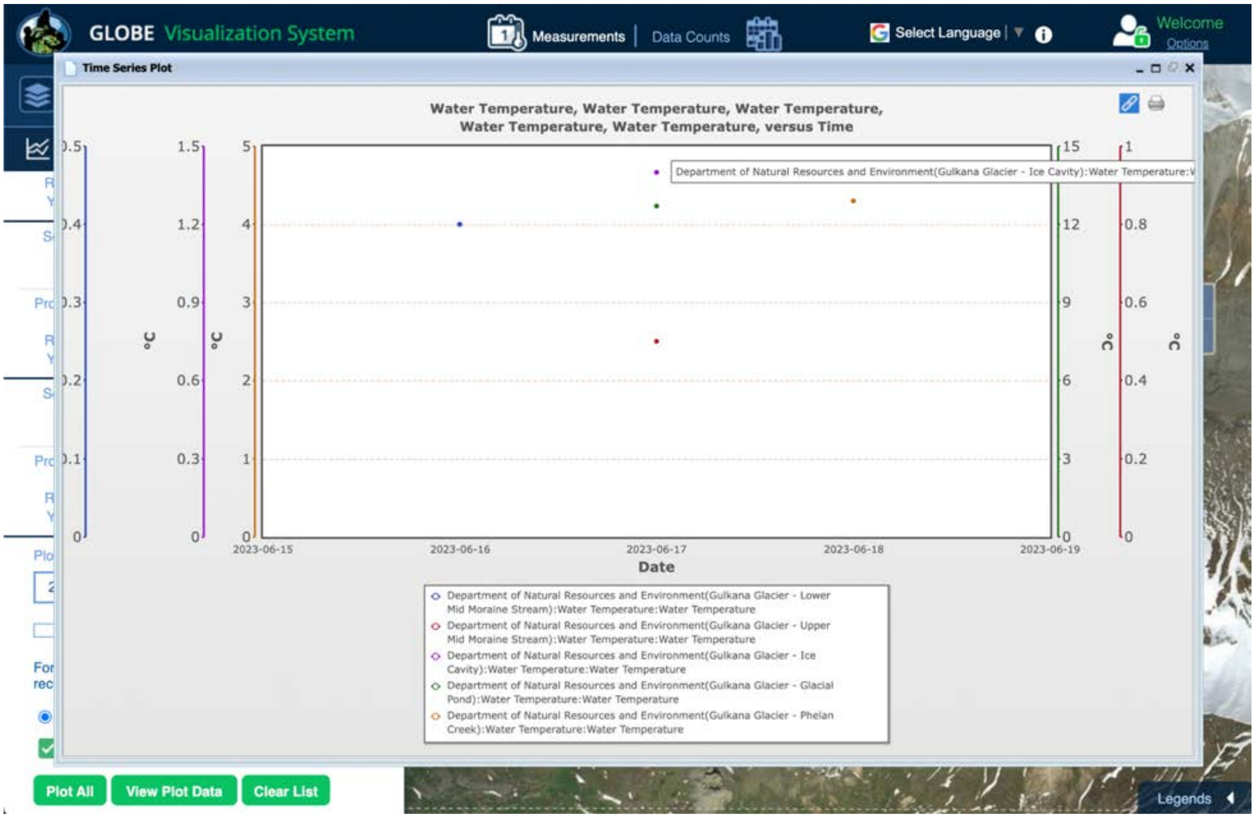
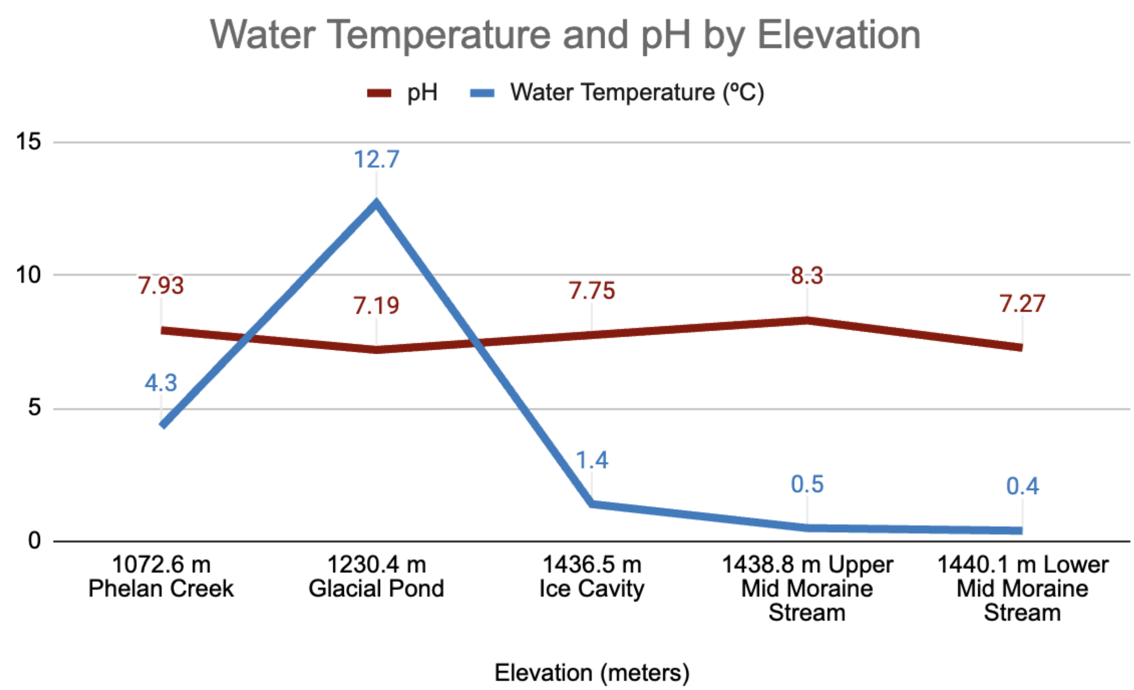


Figure 8

Water Temperature and pH by Elevation



Discussion

We hypothesized that the water temperatures would be highest in the Glacial Pond and lowest in the Upper Mid-Moraine Stream. Our reasoning was based on each location's physical features and conditions. The Glacial Pond was shallow standing water with no movement, leaving it more open to the effects of solar radiation. At the same time, the other sites, except for the Ice Cavity, had consistently flowing water. The Upper Mid-Moraine Stream was a small stream flowing on ice through a crack but not reached by the sun, so we hypothesized that this was the coldest even though it was not the highest being 1.3 meters lower in elevation than the Lower Mid-Moraine Stream site. The data collected shows that the highest temperature was in the small Glacial Pond site at the base of the glacier, and the coolest temperature was at the Lower Mid-Moraine Stream, which, although different than we hypothesized, made sense as it was not far off in distance or elevation from the Upper and carried the same stream of water, just different conditions. At the bottom of the glacier, Phelan Creek had the second-highest water temperature, which could be caused by the meltwater (called basal meltwater) heating up due to friction (Aschwanden, 2012).

Making a hypothesis on pH was more difficult as we didn't have as much background knowledge on it at the time. We hypothesized that further up the glacier would have a higher pH and further down the glacier would measure a lower pH. Our data showed that our hypothesis of the higher sites up the glacier having the highest pH was mostly correct, with all three of the sites clustered above 1,435 meters (Upper Mid-Moraine Stream, Lower Mid-Moraine Stream, and Ice Cavity) recording higher pH levels than the Glacial Pond site. The Phelan Creek site recorded the second-highest pH measurement. However our hypothesis on the site with the lowest pH would be correct if considering only the sites on the glacier itself with the Glacial Pond site recorded the lowest pH. Temperature plays a key role in pH measurements. When temperature levels increase, the pH level drops (Atlas Scientific, 2023). This explains our data at the Glacial Pond site, which was heating due to its larger surface exposure to solar radiation, increasing its CO_2 absorption, and, in turn, decreasing its pH. Gulkana Glacier's landscape is also in an area containing lots of limestone. The glacier's runoff picks up chemicals, such as calcium carbonate ($CaCO_3$), from the rock, raising the water's pH and alkalinity, which could explain the increased pH at Phelan Creek (*Alkalinity and Water,* n.d.). Recent research on the glacierized Lake Hazen watershed in Nunavut, Canada, demonstrated glacial rivers' amazing ability to absorb CO_2 over 26 miles downstream through sediment weathering chemical reactions in combination with exposure to carbon dioxide in the atmosphere (Pierre et al., 2019).

Possible Sources of Error

Measuring pH in glacial meltwaters brings a few challenges with it, such as the response time for the probe being a lot longer than it would be elsewhere due to the cold (Bagshaw et al., 2021). The remoteness of the study area also plays a huge part. One of the most challenging portions of this project was making the best of what we had with little planning beforehand. In the backcountry, you can only use what you have with you. We had a Hanna Meter probe, Garmin eTrex GPS, and whatever was in our packs for our time on the expedition. We were not able to test electrical conductivity and determine if salt was needed for an accurate pH measurement because we did not have that piece of equipment or salt. We also did not test against buffers of a known pH because we didn’t have any with us up on the glacier. This meant we needed to be creative while also as valid as possible, in conducting our GLOBE protocols, which took some trial and error.

In GLOBE Hydrosphere water sampling protocols, all sites are measured three times. Due to time constraints, the probe response time was much slower on the cold glacier. For safety considerations, only one measurement for water temperature and pH was collected at each site. Per GLOBE water sampling protocols, a bucket is used to retrieve water at a site. We were not provided a bucket, but we did have our Nalgene water bottles. The only problem was our Nalgene's were holding a hydration fluid called Liquid I.V.. We rinsed a water bottle out the best we could before collecting our water. Because we were still determining if this would skew the readings, we collected data from all the glacial sites by holding the Hana Meter in the water before taking a reading on a water sample in the Nalgene bottle on the last glacial site only. This ensured that we still had a baseline. Our readings in the Nalgene bottle sample was significantly different from the reading in the same water straight from the source. The Phelan Creek site measurements were conducted two days after the Nalgene water bottle probe measurements, which may also account for the high pH reading lower in the glacial valley. Unfortunately, we only completed one reading at each site due to weather, materials, training, and other contributing factors. Working in a randomized group with limited resources and varying degrees of subject knowledge was challenging, especially when only one student researcher had been trained in GLOBE with no GLOBE teacher present for consultation.

Conclusion

We concluded that the physical location of our water sample collection sites did affect meltwater temperature. Our water temperature data led us to consider if the Lower Mid-Moraine Stream site was cooler because of its exposure; it was more open and accessible to weather changes. The Upper Mid-Moraine Stream site, though lower in elevation, was insulated by the enclosed ice and, depending on where its source was, may have absorbed heat from solar radiation in a surface meltwater pool (Wisconsin-Madison, 2023), latent heat sources, or is giving off heat from kinetic energy or friction as it travels downstream (Aschwanden, 2012). The cluster of three highest elevation sites (Lower Mid-Moraine Stream, Upper Mid-Moraine Stream, Ice Cavity) exhibited the three lowest water temperatures.

We concluded that the physical location of our water sample collection sites did affect meltwater pH. Geologic study shows that Gulkana Glacier sits in an area containing lots of limestone (Bond, n.d.). The glacier's runoff picks up chemicals, such as calcium carbonate ($CaCO_3$), from the rock, raising the water's pH and alkalinity (*Alkalinity and Water,* n.d.). Phelan Creek exhibited the second highest pH level, which may speak more to the limestone deposits in the area, while the lowest pH reading at the Glacial Pond site may have resulted from the surface meltwater's exposure time to the atmosphere through solar radiation and increased absorption of carbon dioxide (Wisconsin-Madison, 2023). The cluster of three highest elevation sites (Lower Mid-Moraine Stream, Upper Mid-Moraine Stream, Ice Cavity) exhibited the highest levels of pH on the glacier itself when excluding Phelan Creek.

In researching how pH will affect the local communities downriver from Phelan Creek, it's important to consider where the Gulkana Glacier's meltwater flows, whether through surface flow as shown in Fig. 1 or basal flow. In Alaska, many of our population have a vested and cultural interest in salmon. Our data did show that the pH is mostly within the acceptable range (7-8) for salmon (Howk, n.d.); however, due to the limited nature of the study (locations, equipment), there is not enough data to come to an informed conclusion on the impacts

Gulkana Glacier meltwater could have on the Delta Clearwater Coho Salmon and other species and communities within its watershed.

After a review of research literature, we realized there needs to be more research conducted around Gulkana Glacier's water quality. Suggested next steps for continuing the study of the Gulkana Glacier and surrounding watershed would include: repeated water temperature and pH measurements of the established sites, incorporating new protocols at these same sites, such as turbidity, conductivity, dissolved oxygen, air temperature, cloud and land observations, and adding more sites along the glacier and the rivers the meltwater flows into. This could be best done utilizing the same Girls* On Ice Alaska expeditions, which happen annually in June. GOIA staff could receive training in GLOBE protocols and in turn, teach new cohorts of student researchers each year. This helps ensure the proper research equipment is available, protocols are followed (I suggest laminated field guides), and multiple data measurements are gathered over time. Considering the Gulkana Glacier is classified as a world climate "reference glacier" by the World Glacier Monitoring Service (Gulkana Glacier, n.d.), the inclusion of regular monitoring of additional GLOBE protocols could be significant to current and future scientists worldwide, as well as the rivers and communities it flows through.

None of the information in this study would have been possible if not for our mentors. Project mentor brings knowledge, experience, and guidance, allowing mentees to enhance their understanding of scientific concepts, research methodologies, and problem-solving techniques. On the Girls* On Ice Alaska expedition, the guides helped us take our brainstormed ideas and narrow them down for the most efficient use of time and safety measures while also giving us experience and deeper understanding. Mentors come in many different forms. Although the expedition guides were some of the most critical mentors for this project in the field, I also realized that a mentor can be anyone who provides valuable feedback and constructive criticism on experimental designs, data interpretation, and research conclusions, which the collaborators and GLOBE Teacher all contributed to.

References

Alkalinity and Water | U.S. Geological Survey. (n.d.). Www.usgs.gov. https://www.usgs.gov/special-topics/water-science-school/science/alkalinity-and-water#:~:text=If%20the%20landscape%20is%20in

Aschwanden, A. (2012). *Thermodynamics of Glaciers McCarthy Summer School 2012*. https://glaciers.gi.alaska.edu/sites/default/files/Notes_thermodynamics_Aschwanden.pdf

Ashford, M. A. 55210 238th A. E., & Us, W. 98304 P. 360 569-2211 C. (n.d.). *Glacier Features - Mount Rainier National Park (U.S. National Park Service)*. Www.nps.gov. Retrieved November 22, 2023, from https://www.nps.gov/mora/learn/nature/glacier-features.htm?fullweb=1#:~:text=The%20ablation%20zone%20is%20the

Atlas Scientific. (2023, January 12). *Does Temperature Affect pH?* Atlas Scientific. https://atlas-scientific.com/blog/does-temperature-affect-ph/#:~:text=Temperature%20plays%20a%20key%20role

Bagshaw, E. A., Wadham, J. L., Tranter, M., Beaton, A. D., Hawkings, J. R., Lamarche-Gagnon, G., & Mowlem, M. C. (2021). Measuring pH in low ionic strength glacial meltwaters using ion selective field effect transistor (ISFET) technology. *Limnology and Oceanography: Methods*, *19*(3), 222–233. https://doi.org/10.1002/lom3.10416

Bond, G. (n.d.). *GEOLOGY OF THE RAINBOW MOUNTAIN-GULKANA GLACIER AREA, EASTERN ALASKA RANGE, WITH EMPHASIS ON UPPER PALEOZOIC STRATA Stratigraphy, structure, petrology, and sedimentology of late Paleozoic and Tertiary rocks in the Rainbow Mountain-Gulkana Glacier area*. Retrieved November 30, 2023, from https://dggs.alaska.gov/webpubs/dggs/gr/text/gr045.pdf

Gulkana Glacier, Alaska – World Glacier Monitoring Service. (n.d.). https://wgms.ch/products_ref_glaciers/gulkana-glacier-alaska/

Howk, L. (n.d.). *Pebble Mine Report, Chapter 5: Potential Effects of the Pebble Mine on Salmon*. Wild Salmon Center. Retrieved November 30, 2023, from https://wildsalmoncenter.org/resources/pebble-mine-report-chapter-5/

Liljedahl, A. K., Gädeke, A., O'Neel, S., Gatesman, T., & Douglas, T. (2017). *Glacierized headwater streams as aquifer recharge corridors, subarctic Alaska*. *44*(13), 6876–6885. https://doi.org/10.1002/2017gl073834

Marcus, M., & Reynolds, W. (1988). Glacier and Climate Studies: West Gulkana Glacier and Environs, Alaska. *Arizona State University, Department of Geography, Publication Series No. 4., & United States Military Academy, Department of Geography and Computer Science, Research Paper No. 1,* https://apps.dtic.mil/sti/pdfs/ADA206992.pdf

Parker, J. (2005, April). *Coho in the Delta Clearwater River, Alaska Fish & Wildlife News.* Alaska Department of Fish and Game. Alaska.gov. https://www.adfg.alaska.gov/index.cfm?adfg=wildlifenews.view_article&articles_id=138

pH - Hydrosphere - GLOBE.gov. (2022). Globe.gov. https://www.globe.gov/web/hydrosphere/protocols/ph

Pierre, K. A. S., Louis, V. L. S., Schiff, S. L., Lehnherr, I., Dainard, P. G., Gardner, A. S., Aukes, P. J. K., & Sharp, M. J. (2019). Proglacial freshwaters are significant and previously unrecognized sinks of atmospheric CO2. *Proceedings of the National Academy of Sciences*, *116*(36), 17690–17695. https://doi.org/10.1073/pnas.1904241116

Pittas, M. (2023, June 9). *Gulkana Glacier Land Acknowledgement* [Oral Presentation *Gulkana Glacier Land Acknowledgement*].

Scannell, P. (n.d.). *INFLUENCE OF TEMPERATURE ON FRESHWATER FISHES: A LITERATURE REVIEW WITH EMPHASIS ON SPECIES IN ALASKA*. Retrieved November 30, 2023, from http://www.adfg.alaska.gov/static/home/library/pdfs/habitat/91_01.pdf

Tanana Valley Watershed Association. *Tanana Valley Watershed* Map (n.d.). Retrieved November 22, 2023, from https://www.tvwatershed.org

USGS 15478040 PHELAN C NR PAXSON AK. (n.d.). Waterdata.usgs.gov. Retrieved November 22, 2023, from https://waterdata.usgs.gov/ak/nwis/inventory/?site_no=15478040&agency_cd=USGS

Water Temperature - Hydrosphere - GLOBE.gov. (2022). Globe.gov. https://www.globe.gov/web/hydrosphere/protocols/water-temperature

Wisconsin-Madison, U. of. (2023, May 9). *Sky-High Melting Menace: Atmospheric Rivers Linked to Melting Greenland Ice Sheet*. SciTechDaily. https://scitechdaily.com/sky-high-melting-menace-atmospheric-rivers-linked-to-melting-greenland-ice-sheet/

GLOBE Badge Descriptions/Justifications

I am a student researcher: My science journey started as a kindergartener in elementary school, learning authentic, place-based science, the fundamentals of GLOBE protocols, and the impact such student-led research can have. Since then, I have been a part of multiple studies as a student researcher and have been internationally published through publications such as this.

I am a collaborator: I was the only one on the Girls* On Ice expedition who knew about GLOBE protocols; thus, I was able to share my knowledge of it with others in my study group and expedition team. Since this study was also within the Tanana Valley watershed, I was able to continue my collaboration with the Tanana Valley Watershed Association, with whom I've conducted fieldwork before, introducing GLOBE protocols. It is my hope that I positively influence the other expedition team members and the Inspiring Girls* Expeditions program to incorporate GLOBE into their future practices.

I make an impact: Gulkana Glacier is classified as a world climate "reference glacier" by the World Glacier Monitoring Service (Gulkana Glacier, n.d.). However, not much data has been recorded on water quality. The addition of regular monitoring in protocols not normally measured could potentially be used by current and future scientists worldwide. The members of the 2023 Girls* On Ice Alaska expedition have also now been introduced to the GLOBE program, increasing its opportunity for growth as they return to their schools, work, and homes all across the United States.