CWC's Interdisciplinary Climate Change Expedition (ICCE): Measuring Black Carbon, Water Quantity, and Water Quality in the Dinwoody Cirque

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Abstract

The effects of ongoing climate change provoke glacial recession in Wyoming's high alpine environment, specifically the Dinwoody Cirque. This study investigates the impacts of water quality, seasonal water flow, and snow albedo on the alpine ecosystem and local communities. There are two prior seasons of CWC research data associated with water contamination and snow albedo, but this is the first data set to include flow data. Black carbon, a powerful, light-absorbing particle, is the strongest contributor in snow albedo reduction. Using field sampling and laboratory analysis methods provided by Dr. Carl Schmitt (National Center for Atmospheric Research), 22 samples were collected from glacial terrain and nearby snowfields. The results for effective black carbon (eBC) amounts for 2016 contrast sharply across years. Samples from 2014 and 2015 revealed an average value of 30ng/g of eBC, whereas the 2016 results indicated an average of 193 ng/g. The reason for this increase is still being explored. The 2016 water flow measurements were taken below the Dinwoody Cirque and ranged from .81 to 1.63 cubic meters per second (cms). These initial seven points provide comparable data to analyze the rate of future glacial melt**.** The 2016 analysis for *E. coli* -- a surface bacterial indicator organism--revealed negative presence in all ten surface water samples, identical to the 2015 results. Additional water quality, flow measurements, and black carbon sampling will be performed to document and assess the hydrological and ecological changes associated with glacial recession due to climate change.

Introduction

Global climate change is proving to have significant impact on alpine glaciers, especially those in the Wind River Range. These glaciers currently show an earlier spring snowmelt by 20 days compared to the mid-20th century (Moss 2015). Since much of the Wyoming is comprised of high elevation semi-desert and desert basins, monitoring water sources is critical. Climate change threatens one of our most valuable water reservoirs--glaciers. Estimates suggest that 75% of the world's freshwater supply comes from these frozen masses and associated seasonal streamflow, providing essential water for municipal and agricultural uses (Maloof *et al.* 2014). The Wind River Range contains 63 of the 80 glaciers in Wyoming and glacial melt provides water for agricultural and ranching opportunities across the state (Moss 2015). Human-influenced factors demonstrate a key contribution to the increased glacial melt in the Wind River Range, specifically in the Dinwoody Cirque. Black carbon increases snow albedo; therefore increasing the rate of light absorption and effectively accelerating the glacier's melt rate (Schmitt *et al.* 2015). Black carbon is the result of incomplete combustion of organic matter commonly formed from residential and transportation emissions. This combustion forms particulate matters that absorbs a million times more solar energy than carbon dioxide ("Black Carbon" n.d.). Minimal sampling for black carbon has occurred in the Wind River Range and the continuation of sample collections will help assess the impacts of carbon particulate matter (Greenwald, Tomme, Klancher, & Schmitt). Black carbon is not the only study source for glacial melt research in the Wind River Range.

In addition to capturing and analyzing black carbon, measuring flow in the Dinwoody Creek provides an indicator of melt rates and a baseline for future studies. Wyoming residents rely heavily on glaciers for water since 4-10% of water flows in July-October come directly from glacial melt water. Approximately 70% of western US residents use snowmelt for water supply (Moss 2015, Hall *et al.* 2012). Wyoming's high elevation ecoregions experience low temperatures and minimal rainfall. Agricultural production seasons rely on late-summer and early-fall waterflow (Cheesbrough *et al.* 2009). If glacial mass balance declines due to increased temperatures due to climate change, snowmelt may occur earlier in the season and eventually lead to less available surface water in summer months. A concentrated assessment of hydrologic flow in the Dinwoody Creek can provide field-based data on time of peak flow and associated discharge.

Gannett Peak attracts many visitors to the Dinwoody Cirque. Increased traffic consequently implies an increase of human waste, specifically fecal matter. The popular camping sites are located near the lateral moraine where large boulders monopolize the terrain. This terrain has little to no soil leaving a deficit in soil depth for human waste burial (Chase, Kennedy, & Klancher). In this case, *E.coli* is tested from various water bodies below the main campsites to assess for surface water contamination. Since this is a well-trafficked area, not only is there a good deal of human waste production, but wilderness travelers rely on the surface water from nearby streams for drinking. If water is not properly purified, there is potential for gastrointestinal diseases. Incubating water samples for *E.coli* growth is used as a means for assessing whether the Dinwoody Cirque contains harmful pathogens indicative of other pathogenic contamination.

A collective assessment of the factors that impact glacial melt, and subsequently affect water quantity and quality in the Dinwoody Cirque are of contemporary interest to land use managers, ecologists and wilderness travelers.

Study Area

Wyoming is home to the largest number of glaciers in the lower 48, with the majority of these glaciers residing in the Wind River Range (Cheesbrough *et al.* 2009). This belt of mountains spans about 210 km along the Continental Divide Trail, allowing runoff from the snow and glaciers to flow into two key drainage systems. Runoff from the western slopes flows into the Colorado River basin, and ultimately into the Gulf of California. Runoff from the eastern slopes flows into the Missouri River basin and then into the Gulf of Mexico. The Dinwoody Cirque, located in the northern half of the Wind River Range contains one of the largest glaciers in the continental United States. Due to its proximity to Gannett Peak, Wyoming's highest summit, this is a highly trafficked area and potentially vulnerable to the impacts of backcountry travelers. This research targeted key sampling sites within the Dinwoody Cirque for black carbon sampling, water flow measurements, and surface water sampling and analysis for *E.coli.* The Dinwoody Glacier is located approximately 21 miles south-southwest of the Trail Lakes trail head in the Fitzpatrick Wilderness Area and can only be accessed by foot or horseback.

In 2016, 22 snow samples were collected from 12 glacial and periglacial permanent snow field sites to measure black carbon particulate. Each sample was collected from snow and ice, clean to the naked eye, at a depth of approximately six inches. Two samples per site were retrieved, excluding sites 7, 8 and 11 where only one sample was taken. Sample sites 1 and 2 were taken from snowfields high on the glacier near the moat. Sample site 3 was taken from a snowfield below the moat. Sample sites 4, 5, 6, 7, 8, 9 and 10 were taken from various permanent snowfields in and around the boulder field. Sample site 11 and 12 were taken below the entrance of the Heap Steep glacier.

Flow measurements were collected from 6 different locations within the Dinwoody Creek. Site 1 was taken from the Dinwoody Glacier tarn, site 2 and 3 were taken below the first site at the tarn's peninsula, and sites 4-6 were taken below the terminal moraine of the Dinwoody Cirque.

10 surface water samples for water quality and *E.coli* were collected from several different bodies of water including the Dinwoody Creek, the tarn immediately below the glacier, and stillwater ponds. Parameters of interest for water quality were pH, dissolved oxygen, salinity and temperature.

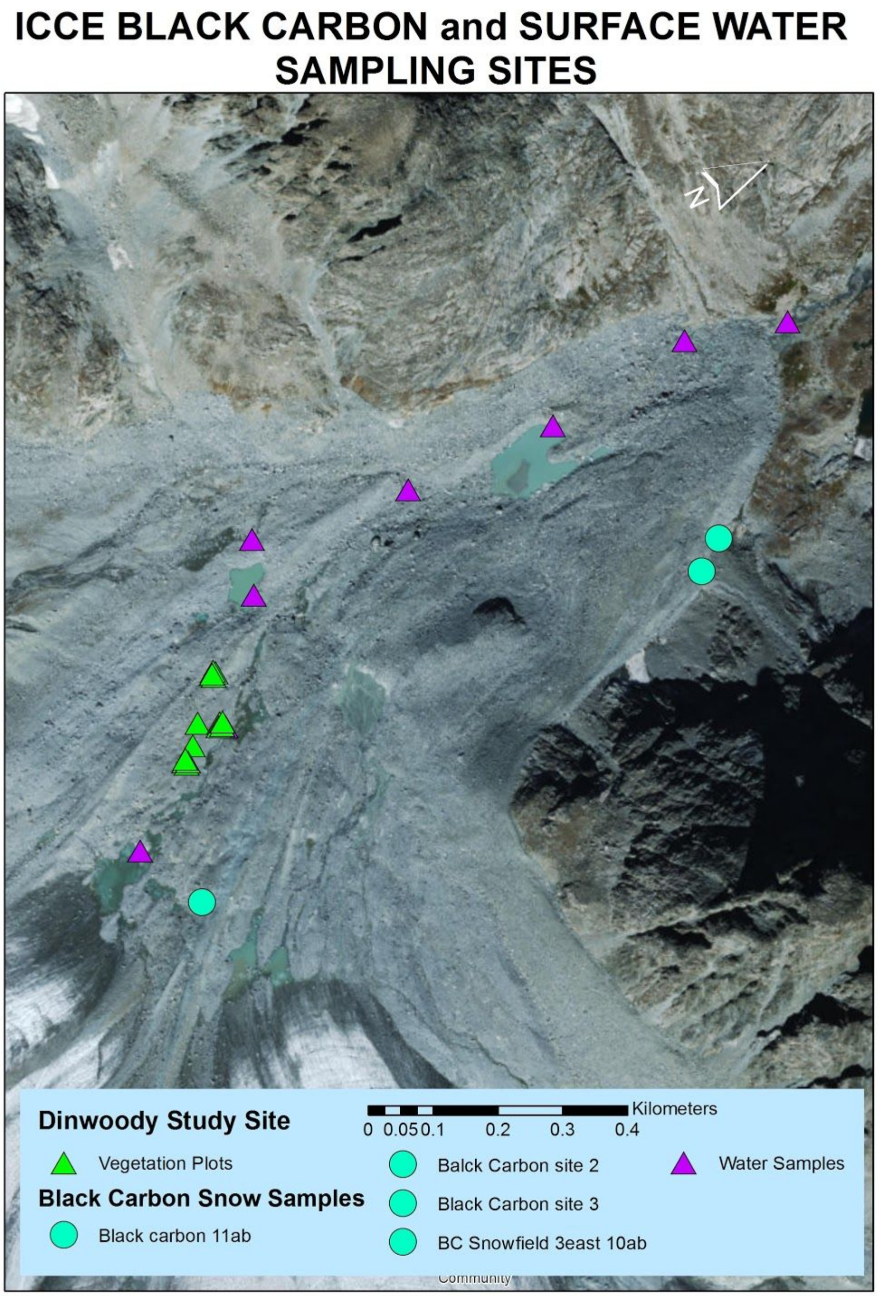

Figure 1: Map of different study sites around the Dinwoody Glacier

Methods

In order to effectively track our study areas, we utilized various methods for each field of study. The black carbon field kit included one-gallon Ziploc bags, membrane filters, plastic filter holders, and 60 ml syringes. 10 sites were sampled above and below the Dinwoody Glacier terminus. Two samples per site were taken excluding sites 7, 8, and 11 where only one sample was taken. Additionally, two more samples were taken from a snow field below the Heap Steep Glacier, an adjacent glacier to the Dinwoody. All samples were collected by hand with the help of a designated trekking pole. The hard top snow was broken up and samples were taken from at least six inches below the surface insuring that the snow samples were cleaner with less surface dirt contamination. Snow samples were taken to the field lab two miles below the sampling sites and melted in a sterilized Jetboil stove. Then the melted water was filtered through a syringe. As the water pushed through the filter, the filter collected the particles turning the white filter to brown. Each filtration process aimed to receive 360 ml of water; however in all of the samples, the filters were too congested with particles. In that case, the amount of filtered water was documented. All filters were encased in a plastic case and stored until they were sent to Dr. Carl Schmitt's lab for his Light Heat Absorption Method (LAHM) analysis.

Figure 2: Collecting snow samples for black carbon analysis

The water quantity field kit used included a HACH FH950 Portable Velocity Meter, a measuring rod, EM950 Sensor, and a measuring tape. Flow readings were taken at various points below the terminus of the glacier-- the start of Dinwoody Creek. To measure the flow, the width of the river was taken with a measuring tape and measurements were recorded at regular intervals from one side of the stream to the other. The EM950 Sensor used a pressure transducer to assess river depth and velocity. These measurements provided a river profile to help visualize the flow of a specific point in the river.

Figure 3: Measuring the flow in the Dinwoody Creek

The water quality field kit included various equipment: a YSI probe, 100 ml Whirl-Paks, live *E. coli* for the positive control, test tubes with phenol red lactose broth, 3M petrifilm plates, sterile pipets, a Still Air Incubator Item #9300 Little Giant brand, Nomad 20 and Sherpa 50 Goal Zero Solar panels, and Goal Zero Yeti 150 generators. Water samples for *E. coli* analysis were taken from ten sites adjacent to, above and below the Dinwoody Glacier terminus and included sites above and below the main camp. At each sample site a Whirl-Pak was filled with 100 ml of water for sampling. Every sample site also had a YSI probe analysis to measure pH, temperature (°C), dissolved oxygen (DO-%L), and salinity (PSU) which determines overall water quality. With samples back at the field lab, a positive *E. coli* control was prepared using live *E. coli.* The control was placed into lactose tubes and on the 3M plates for controlled colony growth. 1 ml of water from each sample location was deposited into two test tubes and two 3M plates. The test tubes and 3M plates were immediately placed into the incubator. Due to the Goal Zero generator batteries dying and limited solar radiation, samples were not kept at exactly 37 °C for 24 hours straight. Using solar panels to charge the generator, the samples were incubated for 48 hours as close to 37°C as possible.

Figure 4: Phenol red lactose broth test tubes with *E.coli* water samples in them

Results

The previous 2014 and 2015 results for black carbon yielded an average of 30 ng/g eBC, whereas the recent 2016 results yielded a higher average of 193.1 ng/g eBC (Greenwald *et al*). The saturated and discolored filters represented obvious dirt particle presence. The reason for this increase is still being explored with various factors to consider.

Samples	Syringes Used	Milliliters of Sample	eBC ng/g
1A	6	360	111.4
1B	3	180	186.6
2A	5.5	330	66.5
2B	5.5	330	70.4
3A	2	120	57.3
3B	1.66	100	235.5
4A	0.66	40	247.1
4B	3	180	61.7
5A	2	120	101.6
5B	1	60	304
6A	2.25	135	317.8
6B	2	120	339.8
7A	6	360	67.8
8A	5	300	123.5
9A	2.5	150	309.8
9B	4	360	110.3
10A	1.66	100	461.1
10B	2	120	316.1
11A	5.66	340	96.1
11B	2	120	335.6
12A	5	300	128.9
12B	3	180	198.3
Average	3.245	200.227	**193.054**

Table 1: Black carbon values for 2016

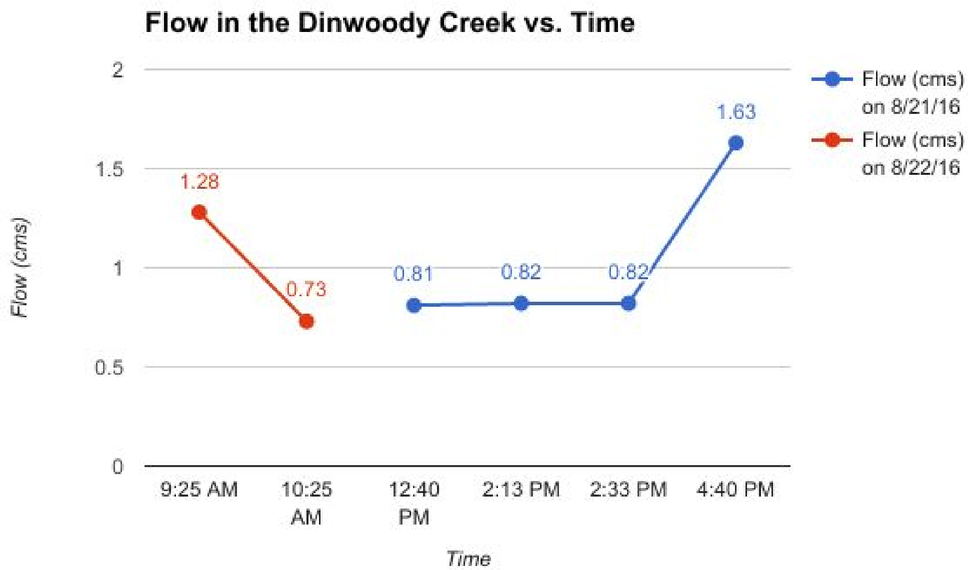

Figure 5: Graph of the Dinwoody Creek flow vs. Time

Figure 2 shows a line graph of the Dinwoody Creek flow relative to time during the day. The figure shows a general pattern of higher flows during evening hours, after daytime warming, and lower flows measured early in the day. The 2016 study year was the first time flow was captured using the Hach FH950 and EM950 instruments and the results will be used as comparative data for measurements obtained in 2017.

The 2016 *E. coli* analysis revealed negative presence in all 10 water samples. The controlled *E. coli*-positive test tubes and petri films expectantly revealed a positive result which supports the accuracy of the incubation and testing methods on the sample test tubes and petri films. However, these results are not fully compliant with FDA regulations because the incubation took 48 hours instead of the water surface method standard of 24 hour incubation.

Water Sampling Location	Time (PM)	PH	Dissolved O_2 (%Liter)	Salinity (PSU)	Temperature °C
1	12:20	8.12	95.2	0	1.7
2	1:00	7.64	98.6	0	2.5
3	1:16	7.5	94.8	0.01	8.8
4	1:33	7.2	100.5	0	7.1
5	1:47	7.17	96.4	0	8.2
6	2:04	7.2	100.2	0	4.3
7	2:21	7.11	97.1	0	3.9
8	2:41	7.17	97.6	0	3.9
9	3:10	7.31	98.5	0.01	7.1
10	3:34	7.11	98.8	0.01	9.7

Table 2: Water quality measurements from various bodies of water near and around the Dinwoody Cirque

Discussion

The 2016 study showed an increased average of 161ng/g eBC compared to 2015 which could be attributed to different factors: human error, modification in data calibration and environmental changes. Environmental field research holds more potential for error since the tests are not in a controlled setting. In this case, handling and storing the filters deemed most problematic because snow was dug by hand and a trekking pole. Although dirt particles do not affect black carbon analysis, it does limit the amount of water filtered with the syringes since the filters saturate more quickly. Another variable to consider is the recalibration of Dr. Schmitt's LAHM methods (Schmitt, personal communication, April 25, 2017). This is only a consideration and should not have resulted in the drastic increase. The environmental variables most likely contributed to the increased black carbon values. In the 2016 summer various parts of Wyoming endured large forest fires including Lava Mountain. The Lava Mountain forest fire spanned across 14,644 acres 20 miles northwest of Dubois, approximately 40 miles from the study site ("Lava Mountain Fire" 2016). Forest fires emit carbon therefore emitting black carbon. So far, the analysis has not been filtering out anthropogenic black carbon and natural black carbon which means the higher values could have been from forest fires. Theoretically, the 2017 summer should yield lower black carbon values in the case of no nearby forest fires.

The results from the flow research are a good baseline for future flow studies. The 2016 snow year was very heavy and this past season was an exceptional year for precipitation. This potentially affects the flow rates. In the 2017 summer, flow will be taken from the exact location and time as 2016 to see if anything changes in the river profiles, velocity, rate and depth.

The negative presence in all 10 *E. coli* samples poses as good news for land managers and outdoor guides. Land managers and outdoor guides attempt to uphold classic Leave No Trace (LNT) methods to ensure minimal impact on the environment. If the *E. coli* samples were to result in a positive, this creates issues within their LNT practices. As of now, it is still safe to practice traditional LNT ethics for human waste disposal--burying. Since *E. coli* is an indicator organism, there is no immediate concern for presence of other harmful pathogens.

Along with the *E. coli* water samples, at each location water quality was also measured. These measurements are imperative baseline indicators of healthy water. These samples were taken at the headwaters of the Dinwoody Cirque and should have pristine quality. If there were to be geological substrate changes, various ecological factors have to be considered. For example, as ice and snow melt and more granitic exposure occurs, will this raise the pH levels? If the overall water temperature increases, will this affect the organisms in the water, and will this affect the dissolved oxygen levels? The hotter the water, the greater the potential for a decrease in dissolved oxygen. These are questions that must be asked if there are any changes in water quality. These parameters matter and indicate whether or not the water systems are healthy for not only the immediate environment, but also to the surrounding human communities dependent on this water.

Conclusion

This study revealed the presence and rise of black carbon quantities in the Dinwoody glacier and surrounding snowfields. The presence of black carbon corresponds with the rate at which the glacier is receding, the higher the black carbon levels the quicker the glacier will recede. Fortunately there was a negative result of *E. coli* for all samples in 2016. In 2017, the same experiments will be repeated in the same locations to collect comparable data. The water flow data collected will serve as a benchmark for measurements taken in 2017. This coming season, the ICCE expedition would like to expand its resources by acquiring Dr. Schmitt's methods and equipment so analysis can be done by the students themselves. The possible absence of forest fires and recent shut down of Kemmerer coal mine could contribute to potentially lower black carbon values. This research will be continued in the future to track the consequences global warming poses on the Dinwoody Cirque.

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