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Project Summary

Keywords

Rocky Mountain National Park, periglacial, groundwater seeps, water quality, heavy metals, and nitrogen deposition.

Abstract

Alpine environments are highly vulnerable to climatic change. Nitrogen deposition, climatic change, snowmelt, and biological communities are just a few factors that influence the hydrology of alpine environments. Specific parameters have not been tested to further the understanding of alpine groundwater seeps and their water chemistry, especially on periglacial slopes where melting ground ice can contribute to baseflow. These seeps are significant because they are in a federally protected location in a watershed that contributes to the Big Thompson River. This study establishes baseline parameters for future trend analysis. Alpine seeps in Colorado's Rocky Mountain National Park were tested for temperature, dissolved oxygen, chloride, total dissolved solids, pH, nitrates, nitrite, ammonium, calcium, alkalinity, and various heavy metals. Some of the seeps emerge from the ground, flow across the surface, and disappear under the surface. These sites were sampled at their emergence and exit points. Additional samples were collected extending to tree line in a section where water has been visible on the surface for and extended distance. Additional studies and data collection are necessary to determine long-term and short-term seasonal change in the hydrology in alpine environments.

Number of students participating in this project:

- 30 undergraduate students
- The report was written by students and later edited by Dr. Janke.

Lessons Learned from this project:

- The pH of groundwater seeps range from 5 to 7 on periglacial slopes
- The water contains minimal concentration of heavy metals, with the exception of iron.
- One of the most significant concentrations is that of calcium which averaged about 13 mg/L.
- Alkalinity decreased about 2 ppm as water excited and re-entered the ground.
- TDS was greatest at higher elevations along the slope.
- Chloride concentration averaged about 34 mg/L.
- Nitrogen readings suggest soil microbes are fixing nitrogen, although it is difficult to quantify their contribution to the water.

An analysis of water quality from groundwater seeps on periglacial slopes in Rocky Mountain National Park

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Introduction

Alpine environments are delicate ecosystems in which unique, adapted plants or animals find hospitable to live. As the climate changes, the alpine environment, which is sensitive to small disturbances, will be one of the first environments to respond. The mountains along the Front Range in Colorado are in close proximity to populated areas and are therefore subject to anthropogenic influences. Alpine groundwater seeps can be found in high elevations of Rocky Mountain National Park in Colorado. These seeps supply water to urban areas and provide habitat in the form of streams and rivers farther downstream. A seep, is a water supply located underground that reaches the surface in the form of small waterholes or wet spots along hillsides or along the banks of rivers. The source of the water can come from joints or fissures in solid rock, small openings in porous ground, or melting ground ice. Seeps generally have a lower flow than springs and typically do not have a large enough discharge to generate a perennial stream. However, the amount of water and flow can vary depending on the geology of the site and the water pressure below the ground surface. Relatively little is known about the water chemistry of alpine seeps. Data collection and water testing are necessary to evaluate ecosystem health for alpine environments and to monitor and maintain their integrity for the future. Here, we intend to establish baseline parameters in an alpine environment to use in future studies. Tracking the change inflicted to sensitive alpine ecosystems is essential for an understanding the impacts of human development and climate change in those environments.

Literature Review

There is a need for long-term monitoring of the watersheds in National Parks to determine the health of ecosystems. Establishing baseline data over time allows for detection of both spatial and temporal changes in the environment. Concerns involving these changes were first officially described by the National Park System in 1987, "it is the policy of the National Park Service to assemble baseline inventory data describing the natural resources under its stewardship, and to monitor those resources forever – to detect or predict changes that may require intervention, and to provide reference points to which comparisons with other, more altered parts of the home of mankind may be made" (Hermann and Stottlemyer, 1991).

In recent years, researchers have developed a strong interest in the response of mountain terrestrial and aquatic ecosystems to external drivers of change, especially climate change and atmospheric deposition of nitrogen. Numerous laboratory experiments and field observations have been conducted to explore the consequences of increasing temperatures as well as atmospheric nitrogen deposition and its effects on alpine and subalpine watersheds of Rocky Mountain National Park. Their findings and suggestions are reviewed here to provide background into this baseline study.

Burns (2004) conducted a study between 1992 and 1996 to evaluate the effects of current levels of nitrogen deposition on high elevation ecosystem function in the central Rocky Mountains of North America. They used an empirical approach to determine critical loads for inorganic nitrogen deposition. There has been rising concern that the present levels of wet nitrogen deposition are causing disturbances in the nitrogen cycle and are affecting ecosystem health. Some of the negative environmental problems included reduced drinking water quality, toxic effects on freshwater biota, disruption of nutrient recycling, and increased soil acidification.

Williams and Tonnessen (2000) sought to determine critical loads for nitrogen deposition in the central Rocky Mountains using an empirical approach. To accomplish this task, they used published data and original data to: (1) estimate emissions and deposition amounts of inorganic N; (2) determine hydrochemical changes in surface waters at present deposition levels of inorganic N as wetfall; (3) evaluate the spatial extent of N leakage as the result of inorganic N in atmospheric deposition using synoptic data; and (4) recommend critical loads for inorganic N deposition to high-elevation catchments of the central Rocky Mountains.

This analysis concluded that "the largest amounts of inorganic nitrogen in wetfall for all tested sites in the five-state region were at high-elevation sites located on the east side of the Colorado Front Range: Niwot Ridge, Loch Vale in Rocky Mountain National Park, and the Glacier Lakes, Wyoming" (Williams and Tonnessen, 2000). This study was significant because it justified the need to establish a regional threshold for critical loads of organic nitrogen deposition to prevent large scale-resource damage. However, this threshold should be refined in the future as more data from sensitive ecosystems is collected. A more restrictive target load can then be enacted to protect ecosystems from changes caused by inorganic nitrogen deposition.

Baron et al. (2009) focused on the consequences of warming temperatures and the effects that stream nitrates could have on subalpine and alpine watersheds in the Colorado Front Range. These watersheds have been receiving elevated amounts of atmospheric nitrogen deposition. Baron et al. (2009) concluded that "the mean annual stream nitrate concentrations since 2000 are higher by 50% than an earlier monitoring period of 1991-1999" (Mast et al., 1990). In this study, Baron et al. (2009) observed that stream nitrogen increases in the watershed are a result of climate change, in particular, warmer summer and fall temperatures. This is causing an increase in the melting of ice contained within glaciers and periglacial landforms such as rock glaciers, talus, or blockfields. It was determined that increased levels of nitrogen in high mountain aquatic ecosystems can be linked to nitrogen that has been flushed from microbial disturbed sediments. This study is important because the phenomenon observed may be indicative of N releases from ice features such as permafrost or frost affected soils. Future studies are necessary to determine whether climate change is also affecting nitrogen loads within other areas of Rocky Mountain National Park. The baseline study presented here will provide an analysis of the current nitrate situation within the groundwater seeps.

Objectives

The objective of this study is to establish baseline data and determine how water quality characteristics vary at different locations along the slope, at pointes where water exits and later-re-enters the ground. To date, there is minimal information about these high alpine seeps and the complex system dynamics associated with them. The area's geology, vegetative cover, and climate can play a significant role in determining the water chemistry of the seeps found at Rocky Mountain National Park. This study hopes to gather data and create baseline data that will further the understanding of these complex systems. These seeps have great importance since they form at the headwaters of major hydrological systems for wildlife and humans. A wealth of data may help shed light on some of the complexities of the biological, geological, and chemical systems. Testing aimed at delivering consistent data needs to be a major component of this continued study if it is to lead to quality results and further understanding.

Study Area

Rocky Mountain National Park is located in the north-central region of Colorado and contains snow-covered peaks which rise above subalpine valleys and numerous lakes (Figure 1). One-third of the park is above tree line and consists of vast alpine tundra. The vegetation is short due to harsh winds and extreme weather. It consists of grasses, mosses, and sedges that are established in regions of melted snowpack. Trail Ridge Road extends across a periglacial climate that is exposed to extreme weather patterns. Because of the range of elevations, temperatures and other weather conditions vary greatly and change rapidly.

A limited soil horizon with exposed bedrock and short growing seasons limit vegetation growth and diversity in the region (Benedict et al., 2013). Cold, water-saturated soils that encompass this alpine tundra play important biogeochemical roles and involve a diverse working environment. However, the bacterial microflora in the soil and water in this alpine environment remain relatively unstudied.

The Rocky Mountain National Park represents the culmination of many geologic events. The remnants of the most ancient rocks in the park can be located along Trail Ridge Road which rests on a Tertiary surface. These rocks are recognizable by the marbled gray, white, and black bands of minerals in biotite gneiss and the darker, finer grained schist. Silver Plume Granite has been intruded upward into the metamorphic rocks and is recognized by its gray-tan and pink-red coloration and for the prominent feldspar crystals (Lillie, 2005). Dissolution of these bedrock minerals, including biotite, plagioclase, pyrite, and microcrystalline calcite influence surface water chemistry in Rocky Mountain National Park (Mast et al., 1990).

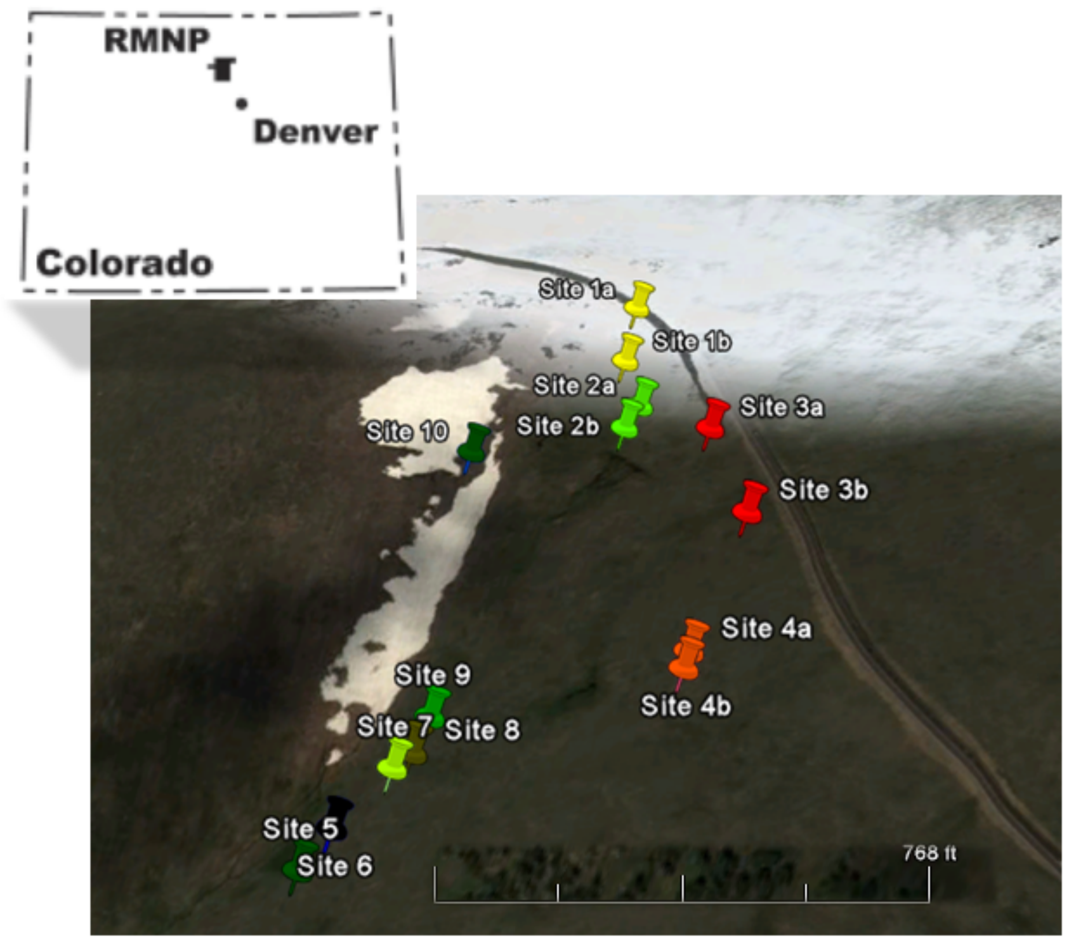

Figure 1: Study area and location of the sampling sites along Trail Ridge Road

Methods

Sample collection

Water samples were collected from approximately 12,030 feet to treeline where the seeps were no longer traceable. Fourteen samples from ten different sites were collected manually as grab samples on September 6, 2013. Collection bottles were sterilized prior to sampling. Seeps were selected based on their location, characteristic vegetation, and the geology of the area. The first four seeps had enough flow to allow collection at the head (water exiting the ground) and toe (water re-entering the ground) of the seep. Samples collected at the head of the seep were designated as "A" samples, whereas the samples collected at the foot of the seep were designated as "B" samples. Samples 5 through 10 (highest elevation) were taken along a continuous surface flow that emerged from a seep. The bottles were stored in a refrigerator (35 to 38 °F) for further laboratory analysis after collection.

Field parameters

Immediately after collection, a YSI Professional Plus handheld multiparameter meter was used to test temperature, dissolved oxygen, chloride, total dissolved solids, salinity, pH, nitrate, and SPC (specific conductivity). Time was given for the probe to acclimate in each sample to ensure accurate readings of all parameters. Site characteristics were recorded for each of the 10 sites including vegetative cover, water flow, soil, and turbidity.

Laboratory analysis

A Vernier Probe was used to test ammonium and calcium concentrations within the water samples. The alkalinity was tested using a LaMotte direct reading titrator. The Ion-Selective Electrode (ISE) on the testing system was calibrated prior to data collection by soaking it in a High Standard Solution for approximately 30 minutes before obtaining a reading. After calibrating, the end of the ISE was rinsed off and blotted dry with a paper towel. The tip of the ISE was inserted into each of samples being tested and ammonium, calcium, and alkalinity readings were recorded. The calcium ISE was used to determine the concentration of aqueous Ca^{2+} ions, in the range of 1.8 to 40,000 mg/L. Concentrations of ammonium were expressed in units of mg/L NH^{4+}.

Using the Lamotte titrator, alkalinity was tested by filling a titration tube with 5 mL of the water sample and one BCG-MR Indicator Tablet was added to the sample water. The titration tube was capped and swirled until the tablet was dissolved. At this time, the solution had turned blue-green in color. A direct reading titrator was filled with an alkalinity reagent containing 0.1% sulfuric acid and was inserted into the test tube cap. While gently swirling the tube, the plunger was slowly pressed until the solution had changed from blue-green to purple and an alkalinity endpoint color chart was used to assess the color. The test results were recorded as ppm total alkalinity as a measurement of ppm Calcium Carbonate ($CaCO_3$).

The samples were submitted to a professional laboratory in Golden, Colorado on October 9, 2013 and were analyzed for concentrations of aluminum, cadmium, copper, iron, lead, manganese, and zinc. At this certified lab, the samples were prepared for total trace metal samples and were preserved as soon as possible by acidifying with concentrated nitric acid to a pH of < 2 or a concentration of 1%. After acidifying, the samples were stored in a refrigerator at 4^{o} C to prevent evaporation. The samples were then run through a Varian Vista MPX Axial ICP-OES following the standard operating procedures for the machine

Results and Discussion

The pH levels yielded some interesting results (Figure 2). The water at the head of the seeps was slightly acidic (6.0 on average), while the water at the toe of the slope remained relatively neutral (7.0 on average); pH increases about 1 to 2 units after exiting the seeps. Given that this environment is highly complex, there could be a multitude of reasons that the pH could raise before re-entering the ground. There is a possibility that this is caused by increased mircrobial activity; however, this finding is inconclusive without further testing (Green and Tarre, 2004).

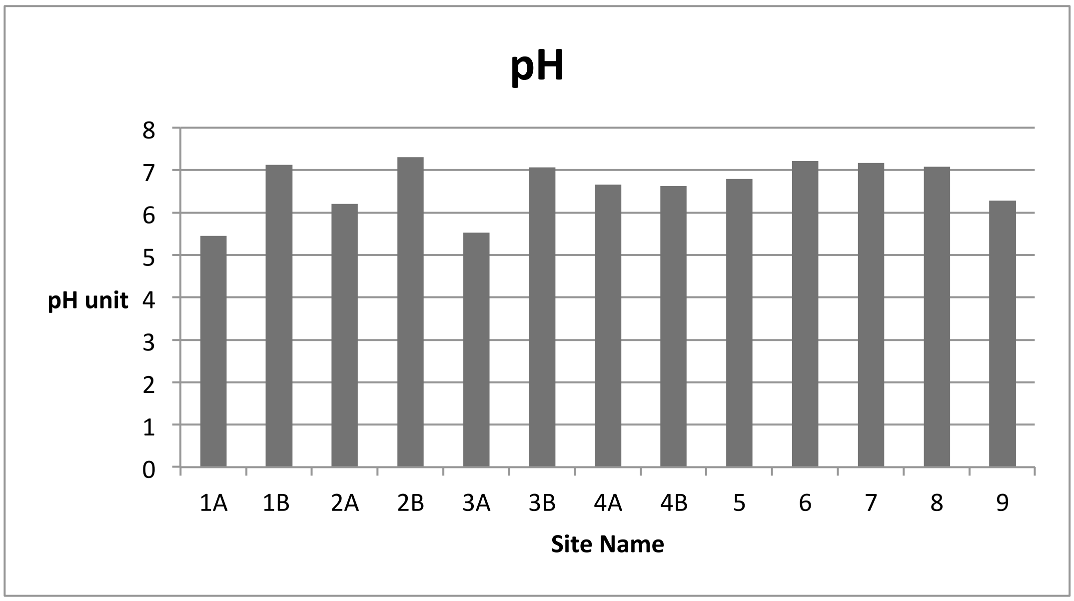

Figure 2: pH results for each site

The presence of metals in the water, particularly iron, is likely coming from chemical weathering of the surrounding geology (Figure 3). Sites 2a and 4a contained the greatest

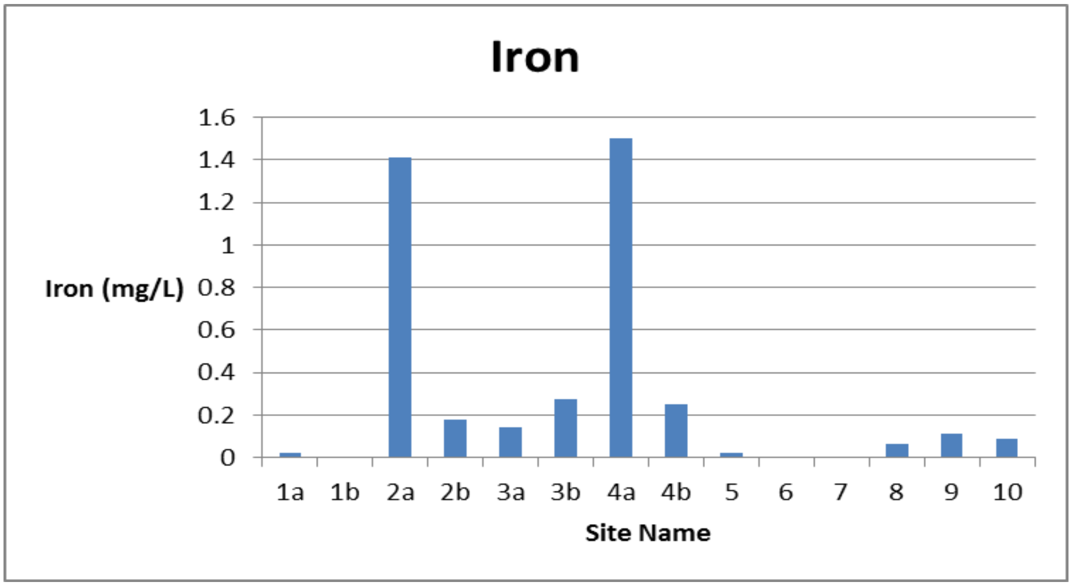

Figure 3: Iron results for each site

concentration of iron, which are probably due to high iron content in the subsurface geology. Slopes comprised of sand, clay, and loose rock cover most of the tundra environment and frequently influence the alpine hydrology (Burns, 2004). According to the ICP-OES analysis, insignificant amounts of aluminum, cadmium, copper, iron, lead, manganese, and zinc were found.

Temperature, calcium, and alkalinity do not appear to show any consistent patterns. As individual parameters, they have relevance for future studies, but additional data are needed to establish a baseline trend study. Temperature ranged from 3 to 23° C. Water exiting the seeps had a mean temperature of 11.7° C, whereas water entering a new seep had a mean temperature of 15.2° C. This pattern of increasing water temperature after exiting seeps, however, was not consistent at all sites (Figure 4).

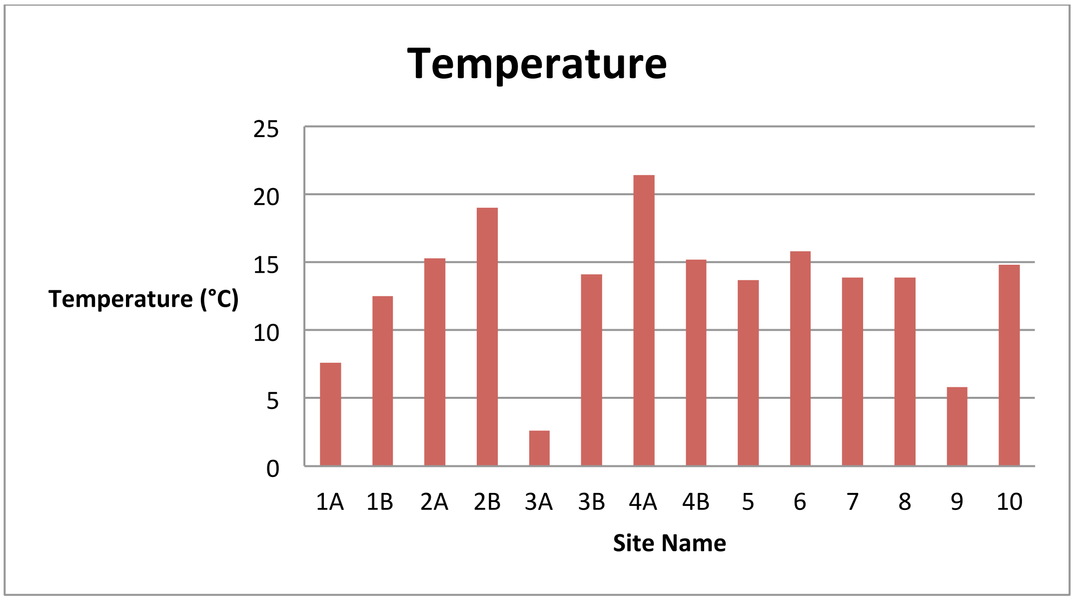

Figure 4: Temperature results for each site

Calcium cation concentration was greatest at sites 3a and 4b at about 20 mg/L (Figure 5). These sites were located farther to the south in comparison with other sites, which suggests that local geology may be impacting the results. Average values were 13.6 mg/L for water exiting seeps and an average of 12.2 mg/L for water entering seeps.

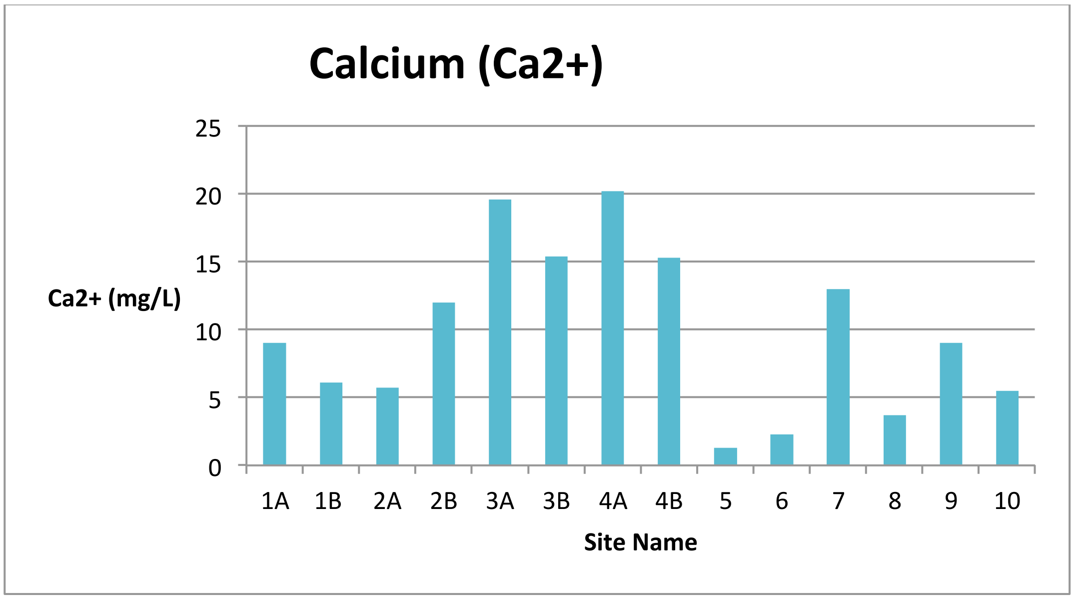

Figure 5: Calcium results for each site

Alkalinity ranged from 3 ppm to 14 ppm for all sites (Figure 6). A maximum of 14 ppm was recorded at site 2a. Alkalinity for water exiting the seeps averaged 8.8 ppm and decreased to 6.5 ppm as the water entered another seep. In general, alkalinity showed a slight decrease downslope for sites 5 through 10.

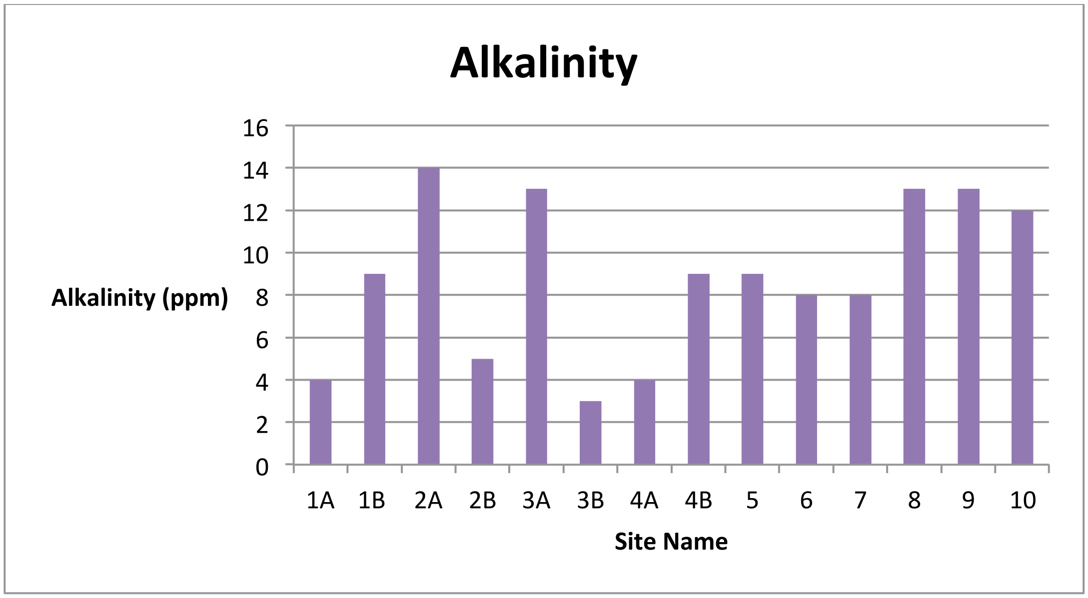

Figure 6: Alkalinity results for each site

Total Dissolved Solids (TDS) ranged from 10 to 42 mg/L. Average values for TDS exiting the seeps was 30.9 mg/L, which decreased to 25.8 mg/L as water re-entered the ground, although there was not a consistent exiting/entering pattern among seeps (Figure 7). At lower elevation sites, TDS decreased, possibly because of dilution with other water sources.

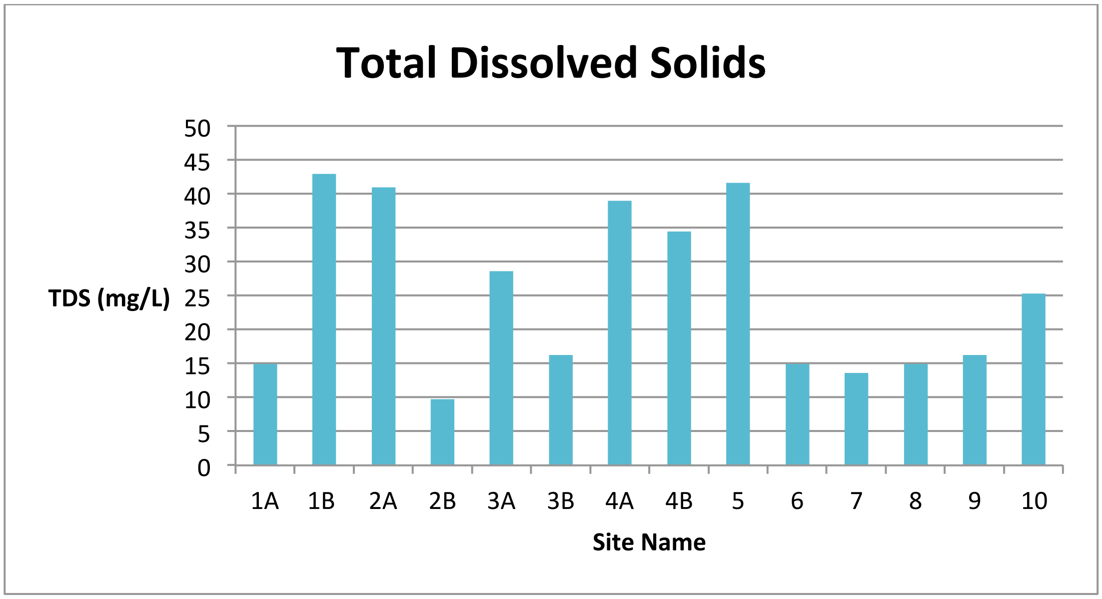

Figure 7: Total Dissolved Solids (TDS) results for each site

Chloride concentrations ranged from 12 to 55 mg/L. Water exiting seeps had an average value of 37.3 mg/L, whereas water entering the seeps had an average of 32.4 mg/L (Figure 8). Concentrations were lower downslope at sites 6 through 9. Total Dissolved Solids and chloride are interrelated because chloride accounts for a dissolved solid. Conductivity, or how well the water conducts an electrical current, is greater with additional ions that are dissolved in the water. As expected, these parameters increase and decrease together. For site 1, values increase as water exits and later enters another seep. For sites 2, 3, and 4, values decrease after a seep is exposed at the surface.

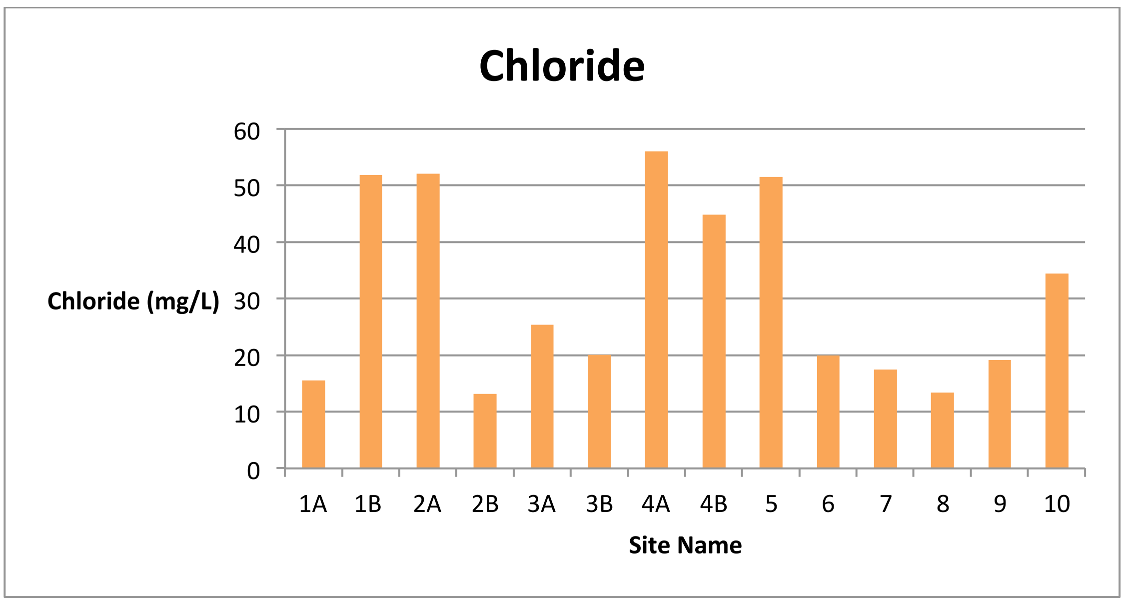

Figure 8: Chloride results for each site

Dissolved oxygen ranged from 10 to 85%. Values showed a slight decrease from 56% to 48% after the water exited a seep (Figure 9). This is odd because one would think that exposure to the atmosphere would increase oxygen content.

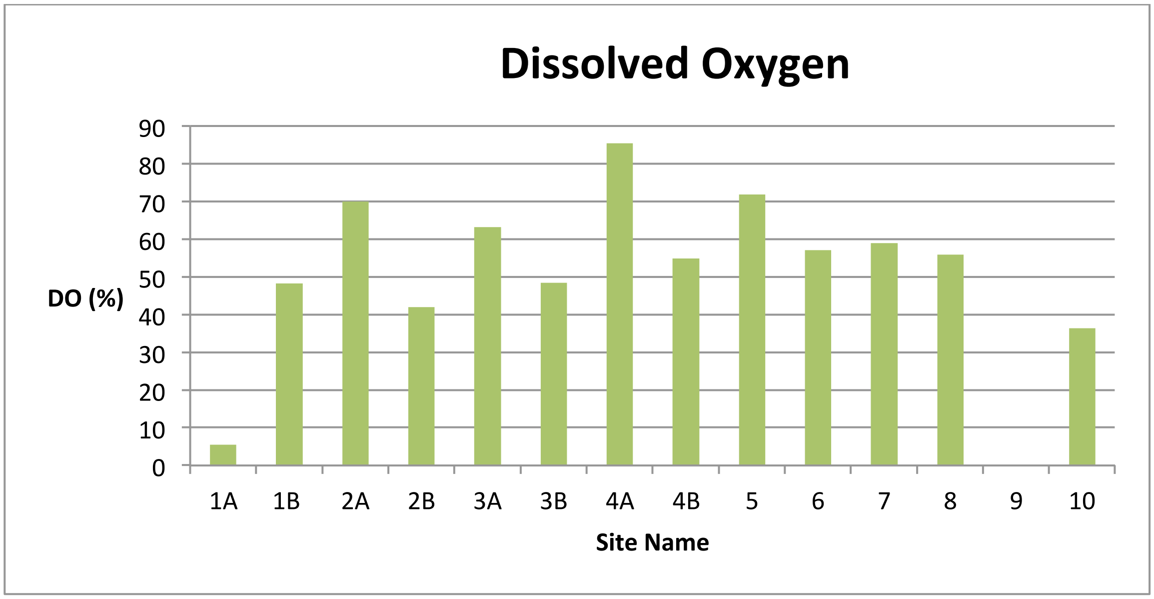

Figure 9: Dissolved oxygen results for each site

Ammonium showed a slight increase from exiting to entering seeps (Figure 10). Values ranged from 0.1 to 0.9 mg/L. Ammonium also decreased farther downslope. Nitrate values averaged about 0.08 mg/L. Site 4a had the greatest nitrate concentration at 0.2 mg/L (Figure 11). Nitrate values decreased with distance downslope. Nitrite values decreased from exiting (3475 ppm on average) to entering a seep (2200 ppm on average) (Figure 12). Given these values, it is reasonable to assume that nitrogen fixation is occurring. It is possible that biological processes, such as microbes contained within soil or water, influence these parameters. Further testing need will need to be conducted in order to determine the nutrient fluctuations and the organisms responsible. Given the complexity of the environment, there are likely many different variables that play a role in determining the water chemistry.

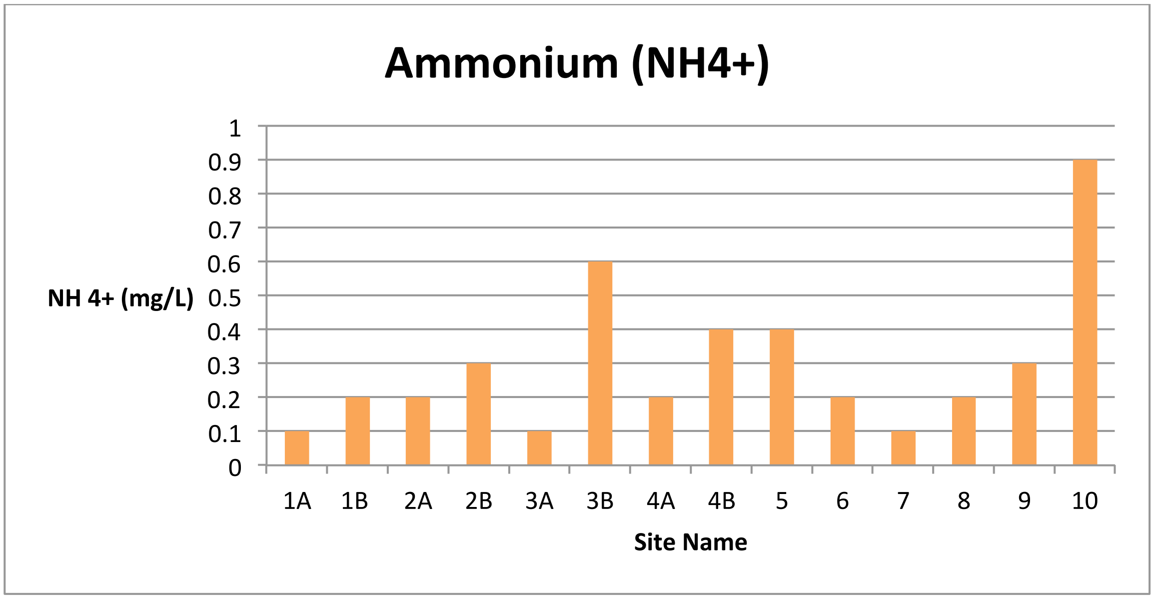

Figure 10: Ammonium results for each site

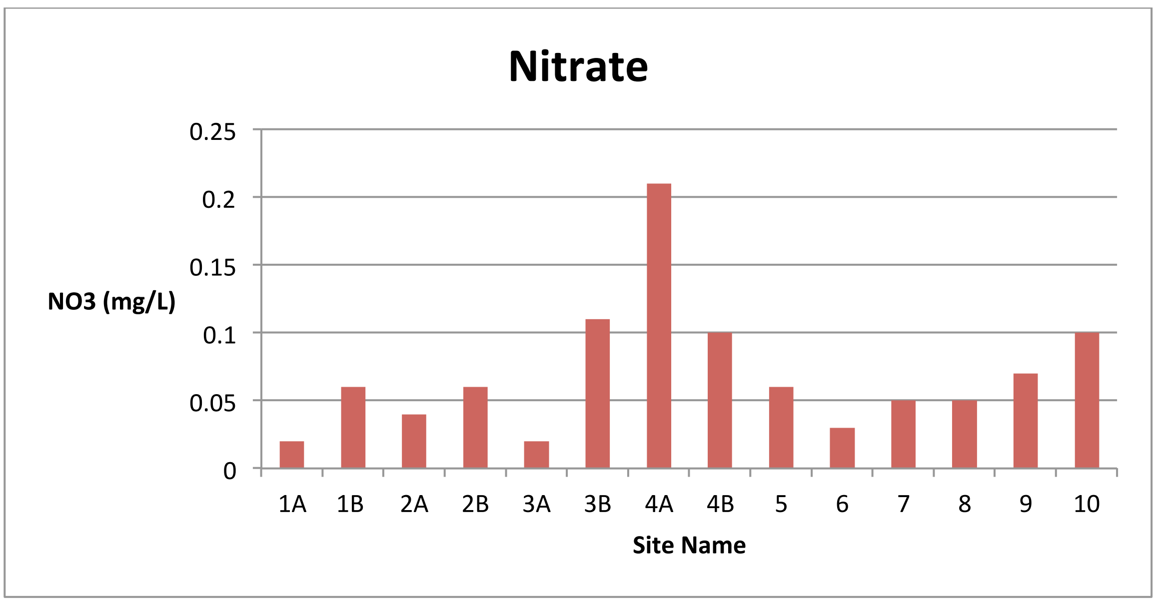

Figure 11: Nitrate results for each site

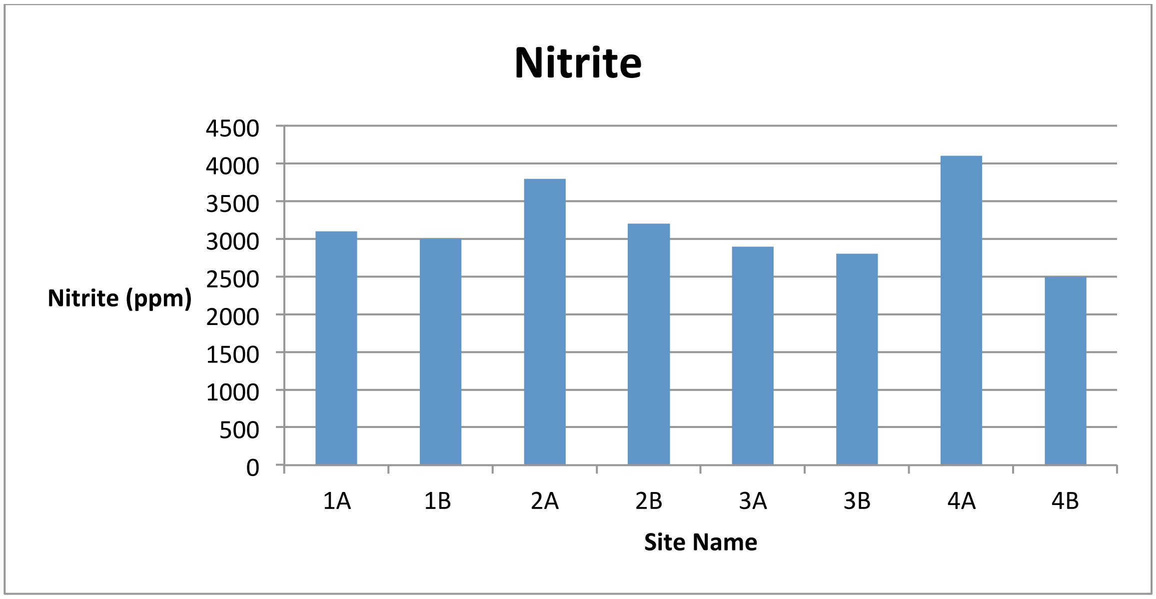

Figure 12: Nitrate results for each site

Understanding the high alpine seeps located in Rocky Mountain National Park are of great significance. This is not only because it is federally protected land, but it is also the source of drinking water for numerous communities living downstream. The complex interactions between the geological, biological, atmospheric, and chemical systems of the area make it difficult to identify the influencing variables. The importance of an ongoing seasonal trend study is also amplified due to the changing climate. Slight fluctuations in the environment may have drastic impacts on this sensitive ecosystem, furthering the need for frequent monitoring.

Conclusions

Baseline studies provide critical background information for detecting ecological change. By establishing study areas and baseline parameters, scientists will be able to use this data in future studies. Streams which are vulnerable to nitrogen loading as a result of human development and climate change are subjects of interest for Colorado and other alpine environments. When water emerged from underground, the pH was slightly acidic, but increased to neutral when it re-entered the ground. Some samples were saturated with iron at emergence points, which was likely the product of local geologic factors. The water chemistry analysis did not indicate any significant amounts of other heavy metals. Some calcium concentrations reached a maximum value of 20 mg/L. Total Dissolved Solids (TDS) were higher when emerging from slopes. Chloride and TDS decreased toward the treeline. The data also suggests soil microbes are fixing nitrogen, which may be affecting the water chemistry. Continual data collection in this area will be vital for assessing ecosystem health and integrity in the future. One possible study could assess seasonal changes of nutrient loads in sample collection and include an evaluation of water quality and quantity prior to and following snow melt in the area. A climate change study could be conducted with temperature recorded at each site to evaluate the consequences of warming temperatures and amounts of atmospheric nitrogen deposition. Another possible study could involve DNA sequencing to investigate specific bacterial microflora in the soil and water and their biogeochemical roles in this alpine environment. These additional studies will help evaluate growing climatic pressures and their influence on alpine environments.

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