The hydrology and geochemistry of the Cougar Creek watershed, McCall, Idaho

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INTRODUCTION

The 1996 Idaho Keck Geology Consortium project is a comparative watershed study focusing on the geology, geochemistry, and hydrology of six watersheds which drain into the Payette Lake, the sole source of drinking water for the town of McCall, Idaho. The purpose of the project is to determine the impact of the 1994 Blackwell wildfires and industrial logging on the water quality of the lake. A comparison of the burned, logged, and both burned and logged watersheds will reveal the effects of fire and logging on the nutrient loading of the lake's tributaries. The Cougar Creek watershed was selected to isolate the impact of the 1994 fires on the nutrient loading of the lake. Approximately 45% of the forested area of the Cougar watershed was burned by the fires of 1994. The watershed has not been logged. Four maps were constructed to describe the Cougar Creek watershed: Surficial Geology Map; Forest and Burn Map; Ground Vegetation Map; and Sample Location Map. Cougar Creek flows S35°E into the Upper Payette Lake. The Upper Payette Lake drains, via the North fork of the Payette River, into the Payette Lake.

We hypothesize that the burn residue of the wildfires contains high nitrate levels. However, the top layer of soil in the burned areas has become hydrophobic due to the water-repelling organic waxes released in the burn. We further hypothesize that this inhibits the amount of nitrate that can be absorbed by surface runoff over burned areas of the watershed. Nitrates must be leached down through the top soil into the ground water. Hydrologic data should show that water samples of the stream taken at high flow, where high surface runoff dilutes the high nitrate ground water, will have lower nitrate levels than samples taken at times of low flow, where the primary water source of the tributary is high-nitrate ground water baseflow.

GEOLOGY

The total area of the Cougar watershed is 3.7 sq. miles. The bedrock consists of 97% tonalite, 2% metasedimentary and 1% aplite/pegmatite intrusion. Approximately 26% of the watershed is underlain by bedrock outcroppings. 36% of the watershed is covered with thick till, while 35% of the watershed is covered with thin till. In areas of heavy burn, the till is overlain by a 2-3 inch layer of burned soil. 3% of the watershed is covered with the stratified sediment of a paleolake basin.

The Cougar catchment was carved by the Cougar glacier which advanced from the west, carved out a cirque in the western end of the watershed, and deposited lateral and terminal moraines in the valley. Present day hummocky topography along the walls and basin of the southeastern section of the watershed suggests that, after the glacier retreated, debris landslides slid into the valley, were stabilized by the bedrock knob outcroppings (elevation 6471 ft.), and dammed the meltwater streams. This post-glacial damming formed a lake in which stratified sediments were deposited. Ultimately, the dam and terminal moraines were outwashed by the lake and dissected by meltwater streams.

HYDROLOGY

A well was installed in the lake sediments of the watershed. The ground water level at the well on June 24 was 15 cm below the land surface. By July 10, the ground water level had dropped to 35 cm below the land surface. This suggests that the ground water reservoir is losing water to the gaining stream and is being recharged at a progressively slower rate as the snow pack diminishes. The water level of the well recovered within minutes of bailing; this suggests that the stratified lake sediment in which the well was placed is highly permeable. The stage-discharge relationship for the creek is defined by the second degree polynomial: $y = -23 - 48x + 13x^2$.

The stage (and consequently the discharge) of the creek maintains a daily cycle, which is a function of the daily temperature cycle, yet displays a gradual decrease due to the diminishing snowpack.

CHEMISTRY

Water samples were collected at various locations in the watershed. Sample sites were chosen to show the chemical differences during different phases of flow and infiltration through the watershed. These samples were analyzed for pH, specific conductance, acid neutralizing capacity (ANC), and concentrations of chloride, nitrate, and sulfate ions (figure 2).

Plant decay produces carbonic acid which reacts with minerals in soil and till to produce bicarbonate (HCO_3^-). ANC values of water at Cougar were lower than those at all other watersheds. Since ANC is derived mainly from ground water weathering of thick till, the low ANC values can be attributed to the low percentage of thick till (36%); as opposed to Dead Horse Creek, which had 67% thick till and ground water ANC values of 456 μeq.

The high nitrate concentration in the stream draining a burned area (sample 13, 0.585 mg/L) compared to low concentration in the stream draining an unburned area (sample 12, trace) suggests that nitrates are being acquired from the burned areas of the watershed. The first source of nitrate is the organic matter of the burned soil itself. The second source of nitrates in the burned areas is the nitrogen-fixing bacteria which thrive in the high sunlight of the canopy-free burned areas. The hydrophobic burned soil, combined with the high water table of the watershed, contributes to high surface runoff which can acquire only minimal concentrations of nitrate (sample 2, 0.35 mg/L). The majority of the nitrate is acquired by ground water as the nitrate leaches down into non-hydrophobic soil (sample 8, 0.94 mg/L).

Sulfate and chloride ion concentrations have similar trends throughout the watershed. Sulfate ions within the watershed are acquired through atmospheric reactions of sulfur dioxide, from the burning of fossil fuels, with oxygen and water. The concentration of sulfate ions is nearly equal to that of nitrate ions in almost all samples (figure 2). Properties of the watershed produce variations in concentration of sulfate ions that are similar to those of nitrate ions (figure 3). Thus, watershed properties have a similar effect on concentration of sulfate ions as that of nitrate ions. However, since sulfate ions are not derived from the burning of the forest, sulfate concentrations do not differ greatly in burned and unburned areas (sample 12, 0.623 mg/L ; sample 13, 0.775 mg/L). Chloride ions within the watershed, derived from aerosols of the Pacific Ocean, occur in lesser concentrations than nitrates and sulfates (figure 2). Watershed properties produce chloride concentration variations that are similar to those of nitrate and sulfate. Like sulfate ions, chloride ions are not derived from the burning of trees, so concentrations are not affected by the burning of the forest (sample 12, 1.280 mg/L ; sample 13, 0.800 mg/L). Since fire affects nitrate concentrations but not sulfate or chloride concentrations, it follows that the increase in nitrate concentration in sample 13 can be attributed mostly to the difference in soil compositions that resulted from the fire.

The values of ANC and concentrations of nitrate, sulfate and chloride were greatest at times of low flow of the stream (figure 3). The source of water during low flow is primarily the high-nutrient/ANC ground water (concentrated through subsurface evaporation and evapotranspiration). High percentages of bedrock outcrop (26%) and thin till (35%), hydrophobic soil, a high water table, and relatively steep topographic gradient (figure 1), inhibits soil infiltration and contributes to high surface runoff. Samples collected during times of high flow yielded low nutrient/ANC values, since runoff water has minimal contact with nutrient/ANC sources and effectively dilutes the concentrated ground water baseflow of the stream.

CONCLUSIONS

Geochemical analysis of the Cougar watershed has shown the effect of the fires of 1994 on the nutrient loading of the lake. The ANC of the Cougar Creek watershed was lower than the ANC of less-burned watersheds. This suggests that ANC is independent of the amount of burn affecting the watershed. The nitrate concentrations of the watershed were relatively high. This can be attributed to the high percentage of burn within the watershed. The greatest concentrations of nitrate were found in the ground water. This is due to the high water table and the hydrophobic properties of the topsoil inhibiting the infiltration and subsequent nitrate acquisition from surface runoff. Sulfate and chloride concentrations were consistent with the results of other watersheds. Thus, their concentrations vary solely as a function of the evaporative processes acting within the watershed. The thick till of the watershed contains large ground water reservoirs which subject the ground water to long residence times, thereby increasing the effect of the evaporative processes. This results in high sulfate and chloride concentrations in the areas of thick till and relatively low concentrations in the areas of thin till and bedrock. The inverse proportionality of chemical concentration to discharge is indicative of the dilution process occurring as a result of increased surface runoff during hydrological events.

The study has revealed a slow process of nutrient loading into the lake from the Cougar watershed. Geologic properties (large ground water reservoirs), as well as hydrophobic properties of the soil, currently prevent catastrophic infiltration of nitrates into the lake. More extensive evaluation of the nutrient capacity of the ash and soil is essential for predicting the future duration and magnitude of nutrient loading into the lake. Furthermore, a control watershed, which is neither burned nor logged, is essential to any further scientific inquiry into the extent to which wildfires and industrial logging in the watersheds impact the nutrient loading of the Payette Lake.

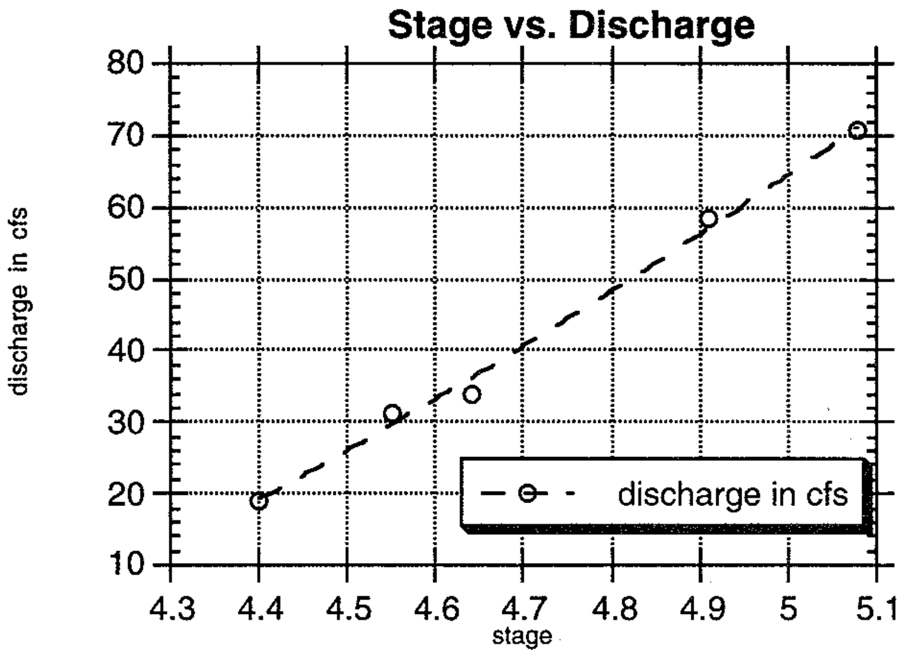

Figure 1. Stage vs. Discharge plot representing $y = -23 - 48x + 13x^2$

Site Description	ANC μ eq	Cl^- mg/L	NO_3^- mg/L	SO_4^{2-} mg/L
Gauge station (1)	75.63	0.342	1.218	0.974
Standing water near well site (2)	136.94	0.681	0.353	0.257
Southern ridge snow (3)	-3.97	n/a	n/a	n/a
Gauge station (4)	60.55	0.280	0.916	0.849
Stream near well site (5)	56.18	0.531	0.814	0.828
Gauge station (6)	61.33	0.491	0.941	0.909
Gauge station (7)	51.11	0.190	0.707	0.701
Well (8)	95.23	1.966	0.940	0.646
Gauge station (9)	46.86	0.344	0.410	0.599
Southern ridge snow (10)	-1.00	0.319	0.000	0.000
Meltwater snow (11)	95.23	0.387	0.736	0.585
SW fork-unburned (12)	52.94	1.280	0.000	0.623
NW fork-partial burn (13)	54.37	0.800	0.585	0.775
Meadow stream (14)	46.22	0.382	0.369	0.721

Figure 2. Chemical analysis of all water samples. The number in parentheses was given to each sample for reference during analysis.

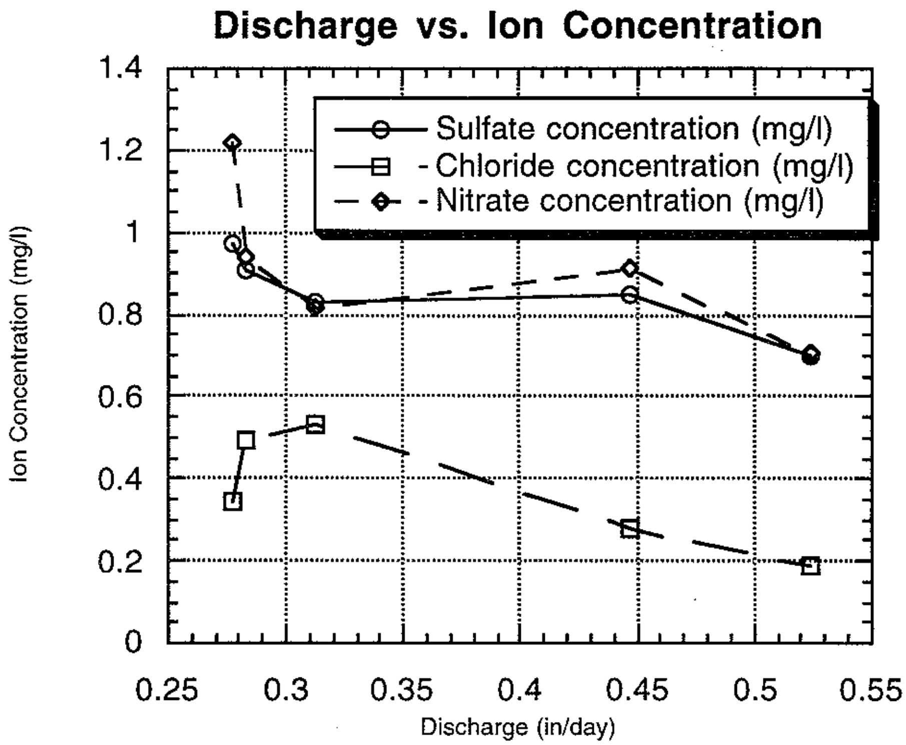

Figure 3. Discharge vs. Ion concentration. The concentrations of nitrate, chloride, and sulfate ions generally decrease with increasing discharge. Sulfate and nitrate ions occur in nearly equal concentrations for each discharge. All samples are from the gauge station.