Surficial geology and hydrology of Pearl Creek: effects on anion concentration

Rose Lauck
Whitman College, 200 Broyer St., Walla Walla, WA 99362
Faculty sponsor: Berry Goldstein, University of Puget Sound

Vionette De Choudens
University of Puerto Rico, Mayagüez, P.O. Box 5000, Mayagüez, PR 00681

INTRODUCTION

This study's goal is to determine how the extensive logging of the headwater catchments and the fire increase the release rate of NO_3 into the water. It has been determined that burning of organic material significantly increases concentrations of nitrates into the system (Robert Newton, 1996). To do this effectively, six water catchments were studied and compared. Cougar Creek, Trail Creek, Lemah Creek and Pearl Creek are used to determine the effects of burn, specifically the concentration of nitrates added. The Dead Horse Creek watershed has been only logged and was used to determine the effects of logging in relation to nitrate concentration. Deep Creek has not been significantly effected by either fire nor logging and serves as the control for the study. By comparing geological, chemical, and hydrological characteristics of each of the watersheds concentrations of nitrates in the water can be determined.

This paper will concentrate on the Pearl Creek watershed study. The Pearl Creek watershed is the only catchment to be logged, burned, and logged again. The geology of the area was consistent through out each of the watersheds; each had been glaciated and were underlayed with bedrock which was a portion of the Atlantic Batholith. It is expected that the nitrate levels of this catchment would be the highest because of the compounded effects of logging and burning. To determine this, measurements of nitrate, sulfate, chloride, acid neutralizing capacity, pH, and specific conductance will be taken. In addition, the surficial geology will be mapped to determine the effect of water storage capacity. Discharge and stage readings will also be used to obtain an idea of the hydrology of the areas. The chemical and hydrological data combined, will enable a means to determine concentration of chemicals and the rate at which they empty into the Payette system.

METHODS

The discharge of the creek was determined by creating a rating curve based on the relationship between the stage of the creek and the corresponding velocities. This was significant in determining the rate at which the water was leaving the catchment. Daily fluctuations in discharge were recorded with a data logger with a pressure transducer.

A well was established to monitor the ground water. First a deep hole was dug, followed by auguring down further. This produced a well of 3.8 feet in depth. A screened PVC pipe, with a conic end piece was pounded in to the hole serving as the encasement for the well. From this, the permeability and porosity of the till could be observed by bailing out the well and measuring the recovery time. Measurements of the depth of the well were taken over the four week period and then related to the stage of the creek..

The surficial geology was mapped. The mapping was conducted over a three week period by visual observation. The percentage of burned areas were also mapped because of its impact upon run-off. The thickness of surficial sediment was estimated in the field and then confirmed using seismic refraction methods.

ANC, the measure of the acid neutralizing capability of the water, was determined by using the Gran Titration method. Along with this, the Specific Conductance was measured. This information further supports the findings of the levels of ANC.

The concentrations of anions: nitrate, sulfate, and chloride were measured with an ion chromatography. This process determined the concentrations of nitrate, chloride, and sulfate.

Quality assurance/quality control was conducted by doing split measurements of the same water samples. These margins of error determined the validity of the data that was collected.

water has a high residence time, such as Buck Lake (fig. 3). Decreased values occur when water is diluted by runoff and snow melt. There is no significant source of either chloride or sulfate in the Lemah Creek watershed; therefore, we conclude that chloride and sulfate enter the system through precipitation.

ANC values in the catchment correlate with groundwater residence time, size of groundwater reservoir, and rock type. For example, more severe weathering produces higher ANC values. Later in summer when the groundwater level is not recharged by runoff, ANC levels drop, possibly due to organic acids infiltrating the soil instead of being washed off or diluted by runoff. Bedrock runoff does not significantly increase ANC because the water is in contact with only a small surface area for a short time.

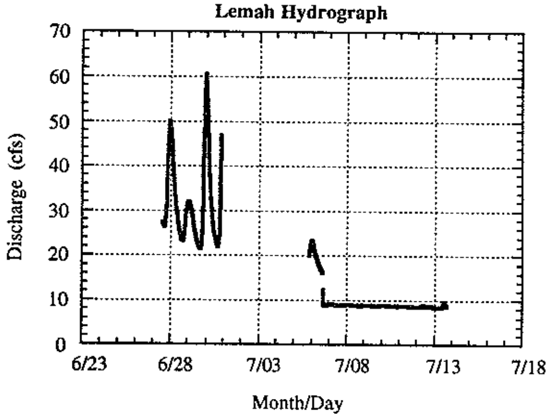

Fig. 2. Hydrograph of snowmelt and base-flow conditions.

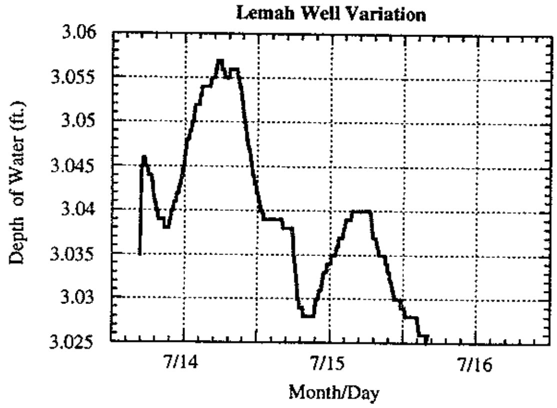

Fig. 4. Well cycle during base flow of Lemah Creek.

Sample Description	Sample Code	lab pH	Spec. Cond. (μ mhos)	ANC (μ eq)	Cl- (mg/L)	NO3- (mg/L)	SO4-- (mg/L)	IC Run Code
snowmelt dilution	LC6191400-g	5.43	10.20	77.14	0.556	1.250	0.820	1
sample after rain (6/24)	LC6241445-g	6.50	8.50	63.63	0.368	0.857	0.700	2
midnight - high flow	LC7012400-g	6.56	8.00	60.08	0.500	0.451	0.560	A
low flow	LC7051600-g	6.72	8.10	84.08	0.623	0.539	0.651	A
saddle pond	LC6251310-1	6.42	9.70	89.11	0.885	0.000	0.768	B
south saddle rivulet	LC6281300-2	6.44	13.20	110.95	0.835	0.404	0.979	B
Buck Lake outlet	LC6261330-3	6.64	7.70	59.54	0.863	1.201	0.741	2
pool at site 12	LC6251335-4	6.66	16.20	187.44	1.019	0.000	0.521	2
Squaw Lake inlet	LC7011435-5	6.33	6.20	36.33	0.510	0.226	0.438	A
Squaw Lake outlet	LC7011450-6	6.31	7.60	48.19	0.596	0.266	0.475	B
ash sample	LC6251400-7	ND	ND	ND	1.82	0.000	2.866	NC
Well-S1	LC6221130-w1	5.83	23.60	287.96	1.261	0.046	1.844	1
Well-S2	LC7051610-w2	6.06	21.30	233.67	1.252	0.000	1.166	NC
Well-S3	LC7101215-w3	5.93	19.50	218.19	2.157	0.000	0.947	NC
Well-S3 replicate	LC7101215-w3	6.14	27.2	236.13	ND	ND	ND	NC

ND = no data collected
NC = no run code

Fig. 3. Geochemistry data for the Lemah Creek watershed. Sample codes refer to date, time, and place of collection. The characters after the dash refer to the gaging station (-g), upper catchment (-#), and the well (-w). Sites referred to under "Sample Description" are located on figure 1.

RESULTS

Geology. The Pearl Creek watershed contains three major units: thick till, bedrock, and thin till. The major composition of the bedrock is tonalite, constituted of K-feldspar, orthoclase and hornblende phenocrysts. There are granitic dikes that intrude the tonalite, composed of quartz, K-feldspar, orthoclase, and biotite. These were the result of the Challis volcanism during the Eocene period (Alt and Hyndman, 1995). Some of the dikes were pegmatitic, with large crystals of quartz and K-feldspar. In this study, the differentiation between the tonalite and the granite is based on the presence of either hornblende or biotite. Mapping of the catchment determined that the top 20.9% of Pearl watershed is completely bedrock.

The Pearl Creek catchment was formed by glaciation. The moving ice moved over the bedrock mountains, rounding the tops and creating two saddles in the bedrock headwall. The northeast saddle seemingly is the main access for the flow ice. Striations were left in the pegmatite dikes, oriented N86E-N70W which is orientated in the direction of the main saddle in the bedrock. In the east part of the water shed, there are a series of lateral, oriented in the same direction as the striations, also in line with the saddle in the bedrock. In addition, there are streamlined glacial ridges, primarily composed of bedrock with thin till on top, with the same orientation. Based on these findings, it was determined that the glacier was moving from the east toward the west. On the southeast boundary of the catchment, there is one long lateral moraine, defining the boundary of the catchment.

The topography is terraced, typical of a glaciated area. In the areas of low relief, there are thick deposits of unstratified sediments and organic material, creating wetlands. Interspersed between these areas of wetlands are large boulders, thin till, and bedrock outcrops. Thin till is defined as glacial deposits with a depth of 2.5 meters or less. This thin till and bedrock, with areas of wetlands, colluvium and stratified sediments makes up 55.2% of the total area of the catchment.

The head wall of the east portion of the watershed is comprised of bedrock. It forms a bowl like feature typical of a cirque. But, at the north end of this head wall, the ice has crested the boundary of the watershed, creating a col-like feature. Bedrock ridges have been observed at the edge of the lake. The thick till surrounding the area may have been deposited by the retreating ice which may have also formed lateral moraines. The bedrock was plucked out by the glacier, creating the lake bottom. These two lakes compose .6% of the watershed area.

The west portion of the watershed is only comprised of thick till. This unit is defined as unsorted, unstratified glacial sediment, with a depth of 3 meters or greater, which was deposited by the end margin of the glacier. Thick till makes up 39.4% of the total area of the catchment, most of this unit is centered at the bottom. With in these areas there are ten large till ridges. They are oriented perpendicularly to the lateral moraines and the creek.

Hydrology. A discharge/stage curve relation was determined by plotting the discharge as a function of stage. The pearl Creek discharge follows an exponential curve, with an equation y=.0093472*e^(1.6064x). This was necessary because of the inconsistency on data points over numerous days.

The initial plot using manual data points represents the Pearl Creek's large response to the hydrologic events and snow melt. The first peak of the graph correlates with increasing air and stream temperatures--some of water stored in the snow pack began to significantly melt. The second peak also represents a large snow melt event--this event was in response to both warmer temperatures during the day and in correlation with some precipitation. It is possible that the precipitation may have increased the rate of melting. The highest peak represents the major hydrologic event with a discharge of 91.73 CFS. The discharge of that day was the highest reported during the four weeks of field work. The measure of discharge was manually taken during the height of the storm. During this forty five minute period, the stage increased from 5.65 to 5.7. From approximately day June 27th until July 6th shows the rate of snow melt decreasing, leading to the baseflow measured with the data logger.

Data from the well was also collected. The depth of the well was measured three times during the course of the study. The depth of the well began at 2.32 feet, from the ground down to the water level on June 22nd. Between this date and the 24th of June, the well raised to the depth of 1.89 feet. The last measurement of the well yielded 3.19 feet from the top of the well to the surface of the water.

Chemistry. Water samples were taken at various places throughout the watershed to assesses representative contributors of water to the main outlet of Pearl Creek. Two samples where taken at the well and at the gauge station. The rest of the samples were taking at different locals to determine the effect of the chemical composition of the Pearl tributaries.

The initial sampling of the gauge station yielded a specific conductance of 11.4 µmhos, a relatively low amount of total amount of dissolved solids in comparison to the other five catchments. The ANC was measured as 97.20 µeq, which is a moderate amount of basic anions. The concentration of chloride, nitrate, and sulfate values were .539 mg/L, 1.188 mg/L, and .0923 mg/L respectively. On the conclusion of the study; the value for total amount of dissolved solids was determined to be 13.1 μmhos, higher than the initial sample. The acid neutralizing capacity was also higher, measured as 104.42 μeq. The concentration of chloride, nitrate, and sulfate were .784 mg/L, .264 mg/L, and .712 mg/L respectively.

Two samples of the well were taken to ascertain the change of the concentrations as the creek and ground water supply dropped. Each of the measurements increased from the first sampling to the next.

Various samples from burned areas and one unburned areas were taken. The sample representative of the unburned area generally had the lowest results throughout all of the chemical testing. The samples taken in burned areas, especially the groundwater samples had the highest results.

The measurements of the anions of chloride, nitrate, and sulfate of the tributary running into the lake were also lower than most of the other samples taken. The concentration of chloride was found to be .579 mg/L. The highest levels of chloride were discovered in the second sampling of the well, a concentration of 1.086 mg/L. This concentration was not extremely high when compared to other levels within the other catchments.

The nitrate level within this unburned area was determined to be .176 mg/L. This too was the lowest concentration found within the watershed. The highest levels of nitrate were found in a stream fed by ground water. The concentration of nitrate in this area was measured to be 3.191 mg/L, the highest levels found in this study. Finally, the level of sulfate found in the unburned area was .713 mg/L. This was not an anomalous low measure, nor is it high. The anion bar graph on figure 1 correlates the anion concentration of each sample, and at the same time shows the amount of each anion of each sample.

DISCUSSION

Hydrology. The hydrology of the Pearl Creek catchment has a significant response to hydraulic events and snow melt. In the study, it was ascertained that the catchment was comprised of more than seventy percent of bedrock and thin till. Hence the permeability of these materials is low. The amount of bedrock and surficial geology seemingly is responsible for this dramatic response. Some water may be stored in fractures but is a small volume in respect to the entire catchment. In addition, the ground water reservoir is not expansive, and becomes saturated rapidly. As a result, snow melt and precipitation flows directly into the creek rather than being stored in ground water reservoirs or in lakes. In areas of thick till, the ground water reservoir is completely saturated. Hence, any additional water must run-off into the stream because of the lack of storage space.

Another factor of the thick till is the permeability and porosity of the material. This leads to slow recharge of the ground water reservoir. In addition, the water leaving the system must also flow slowly out of the system because of the retarded nature of the flow through this unit. In times when the reservoir is not full, large percentage run-off and snow melt, in areas of high relief, can more easily move in overland flow than permeate into the soil. As the stream relies more on baseflow and less on snow melt, the oscillations decrease. Therefore, the daily snow melt was running into the creek directly affecting the stage of the creek. As baseflow comprises a larger percentage of the creek's flow, the change between days and daily peaks has decreased.

Chemistry (ANC). The surface geology has a large effect on the water chemistry of the catchment. In the areas of thick till, the water resides longer because of the poor porosity and permeability of the unit. The till in Pearl Creek seems to have a large residence time than other areas of the watershed, this is observed with the amount of time that the well recuperated its water level when compared to the overland flow in areas of thin till. Groundwater moves relatively slow through the till. Hence, water leaving the system must also leave in a comparable rate. This residence time gives to the water an opportunity to interact with weathering reaction products within the soil. Long residence time explains the high ANC levels found in the initial and final well samples (162.0 μeq and 137.01 μeq respectively). The well location is on a thick till, an area where the slow recovery of the water level was observed. A slow recovery rate was also observed in the ANC results of the Deep Creek well sample, yielding 647.24 μeq. Both of these wells were imbedded in thick till.

When a comparison between the ANC levels in the Pearl tributaries and the ANC levels of the main Pearl stream is made, the main stream results are higher. Pearl tributaries are located in a thin till with bedrock. This area does not have a large ground water reservoir and the water tends to run over the surface, without providing time for weathering reactions to be absorbed by the water. As a result, the main flow of water in the tributaries comes from snow melt. This surficial flow does not have enough contact with the soil and has lower ANC levels than groundwater flow. The main stream gauge station is located in an area of thick till. It receives the water from the tributaries plus the baseflow from the thick till. The flow of ground water has a higher ANC and when it comes into the stream raise up the ANC levels.

Specific Conductance. The Specific Conductance is controlled by the residence time of the water in the soil. The water in the ground water reservoir has more time and comes in contact with more of the dissolved solids. In contrast, the surface flow moves more rapidly out of the water shed and has less surface area of the water in contact with the soil. When a comparison between the well samples the streams samples is made, the well sample results are higher than the stream. The main stream shows variation on the S.C. during high flow and low flow. The main stream during high flow is mostly comprised of snow melt, while low flow has high percentages of baseflow. The stream S.C. changed from 11.4, during high flow to 13.1 during low flow. The variation on the main stream S.C. is explain by the change on the stream water sources. The specific conductance is higher in the ground because of the extended amount to time in contact with the thick till.

Nitrates. Based on the various samples taken throughout the study, several observations were made. First, as the water level in the well dropped, the concentration of nitrates increased. Second, when the creek stage dropped, levels of nitrate decreased. Third, the levels of nitrate in snow, unburned areas and bedrock were lower than those in burned areas (approximately) . Finally, nitrate levels in open areas (which coincided with burned and logged) yielded higher concentrations of nitrate. The highest levels of nitrate were measured in an pocket of thick till with a high percentage of organic material incorporated within the soil.

The NO_3 concentration increased in burned and logged areas. The canopy in this area has been removed, thus decreasing the amount of shade. The sun then beats down on the soil and increases the temperature. This increase on temperature on the soil (by the sun) increases the activity of the nitrogen-using bacteria. This bacteria uses the nitrogen from the air and then alters it into nitrate, thus increasing the concentration of the NO_3 within the soil. In addition, there is an absence of vegetation that utilizes the NO_3 created by the bacteria, further increasing the concentrations. This was demonstrated in the area of highest nitrate levels. The area had been burned, decimating the canopy.

The well is located in a burned and logged open area with direct sunlight. Here the nitrogen bacteria can produce a lot of NO_3 and the only consumer is the grass that is growing in the area. The NO_3 goes into ground water system by infiltration into the thick till and burned vegetated areas. They move slowly because the till has a high level of impermeability and act as a filter as the water table goes down. In other words, when the ground water table is saturated they move fast through the area into the stream in a more diluted solution, hence the levels are lower per volume of water. But when the ground water table decreases, the concentration per volume goes up because is more difficult move through the area.

The NO_3 levels in the stream at the end of the study, decreased because it had less surficial flow coming in from the stream. The water that is coming from the ground water table has been filtered as it goes through the thick till and into the stream. The nitrites in the ground are also absorbed by the plants that grow on the riverside, lowering the nitrate concentration.

Levels of chloride and sulfate seem to be related and respond to the same variables. The highest levels of these ions was found in the second sampling of the well, note that this was discovered in the ground water. These anions are present in the precipitation. As this water is incorporated into the ground water reservoir the anions are dissolved into this body. While the ground water moves through the reservoir, plants utilize the water, evaporation takes place, leaving behind the anions in a smaller volume of water. Therefore, though the anions do not increase in volume while moving through the ground water reservoir, the concentration becomes stronger because of the removal of water from the system. This is demonstrated in the increased levels of both chloride and sulfate in the well between the first sampling and the second. The ground water represented in the second sample had higher concentrations of these anions because more water had been removed from the reservoir than the initial sample.

CONCLUSION

Pearl Creek had the highest concentrations of nitrate in comparison to the other five catchments. This catchment was logged, extensively burned, and then logged again. Because of this, there is little canopy to shade the soil from the sun. This increases the temperature of the soil which speeds up the bacteria's rate of nitrate production. In addition to this, there is only low-lying grass to consume the nitrates. These plants cannot compensate for the large concentrations produced initially by the fire.

From this study, logging seemingly did not have a large impact on the concentrations of nitrate. Dead Horse Creek, the only catchment that was not burned, but was extensively logged demonstrates the lowest concentrations of nitrates. Data collected throughout the study suggests that the fire had a larger effect than logging, but because there was not a control in the study, impacts of logging cannot be determined. Though Pearl Creek catchment produced the highest concentrations of nitrate. It cannot be determined the specific effect logging had on nitrate concentrations .

Though Pearl Creek does not have a large percentage of thick sediment, the little amount of thick till that it does have, has a large impact on the concentrations of the chemical constituents. This is due to the poor porosity and permeability this unit has. These factors decrease the rate of water flow through the ground water reservoir and makes infiltration of the water into the soil slow. Water does not easily permeate into the ground water reservoir and also moves slowly through the unit. Hence, the water that is trapped in the system must leave the ground reservoir slowly. This indicates a long residence time of the water, allowing the water more time to be effected by the weathering of the soil and absorption of the anions, specifically nitrate.

The surficial geology directly effects the response of catchments. The catchments with lots of bedrock and thin till will reflect a fast response and the catchments with lots of thick till will present a slow response to the same events. A larger percentage of bedrock in the catchment produces a larger response because it is impermeable. Thick sediments provide a reservoir for the water, hence catchments with a large percentage of thick sediments do not experience large fluctuations in discharge.

Figure 1: