Hydrological Study of Connaught Creek, Glacier National Park, British Columbia;

Changes in stage, discharge, and sedimentation over a 43 hour period

Blake Rose, Tyson Bancroft, and Noah Edwards

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1.0 Introduction

The Balu valley is located near Rogers Pass in Glacier National Park, British Columbia. Previous studies have been conducted on neighboring Asulkan and Illecillewaet glacier fed channels (Linton and DeWolff, 2009), however none have been conducted on the Balu valley watershed. The valley is drained by Connaught Creek, which is supplied by a number of sources including precipitation, as well as snowpack and glacier meltwater. During a September field trip to the study area, over a 43 hour period a number of measurements were conducted; these included data on the stream's discharge, sediments and dissolved solid load. A number of factors influence these variables, including time of year, frequency and duration of precipitation events, and temperature amongst others (Warburton, 1990; Williams et al. 1996). From the data, conclusions can be reached as to; the source of the streams flow and total values for the study period can be determined to provide an inventory of this freshwater resource.

2.0 Purpose/Objective of Experiment

This project is an investigation of the Balu valley watershed and its main drainage channel, Connaught Creek. It will explore how various inputs including precipitation, ground water, snow and glacial melt influence stream discharge, temperature, suspended sediment load, conductivity and total dissolved solids over a 43 hour study period. This data, supplemented with hydrological literature from past studies will yield a better understanding of how these processes are affecting Connaught Creek. The Balu valley drainage basin provides the historic Rogers Pass area with its drinking water, and an inventory of the fresh water resource available from the stream could be of use if the area is to be further developed.

3.0 Study Area: Balu Pass Watershed

The Balu valley watershed is located near Rogers Pass in Glacier National Park, British Columbia (figure 1) and is part of the Selkirk Mountain Range in the Columbia Mountains. Rogers Pass is located between the interior British Columbia communities Revelstoke and Golden. Balu Pass is prime bear habitat, and got its name from the Indian word "baloo", meaning bear (Parks Canada). The mountains on the North side of the valley are called Ursus Major and Ursus Minor (Ursus means bear in Latin), and are also known as the Grizzly Mountains (Parks Canada). Connaught Creek found in Balu valley was the focus for the study, and is very important to the Rogers Pass community, as it is their main source of fresh water (Parks Canada). Connaught Creek is one of the main tributaries in the eastern central part of Glacial National Park, and feeds water into the Columbia River system (Achuff et al., 1984).

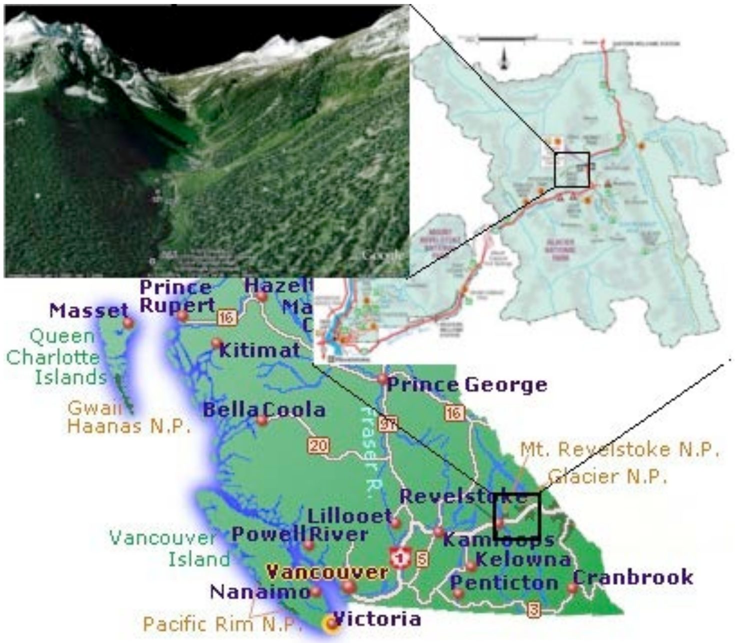

Figure 1: Map of Study area showing the location of Balu valley in Glacier National Park and the Parks Location In relationship in the province as well as a view looking up the Balu valley.

The Selkirk Mountain Range is one of four mountain ranges that make up the Columbia Mountains (Wheeler and Parker, 1912). It is approximately 300 miles long and is orientated north south running from the Northern United Stated to Southern Canada (Achuff et al., 1984). The Selkirk Mountains are geographically older than the Rocky Mountains and are composed of folded and faulted metamorphic rock that was uplifted by orogenic deformation (Wheeler and Parker, 1912, Achuff et al., 1984). The highest peak in the Selkirk Mountains, located north of Rogers Pass is Mount Sir Sandford rising to a height of 3,522 meters (Selkirk Mountains, 2010).

Balu Pass is located in the Interior Wetbelt region of British Columbia (Parks

Canada). Two main converging air masses provide it with its climatological characteristics: moisture rich Maritime Pacific air mass moving in from the west, and the drier, colder Continental air mass from the Northeast. The Continental air mass results in dryer colder air in the winter and warmer air in the summer. The Maritime Pacific air mass is brought inland by weather systems traveling eastwards, and when it hits the Selkirk Mountains is forced upwards releasing orographic precipitation in the form of rain or snow (Loukas et al., 2002; Parks Canada). Elevation plays an important role on the form of precipitation, as approximately 60 -80% of the precipitation falls as snow depending on the elevation (Loukas et al., 2002). The amount of precipitation in the area is from a low of 950mm/yr in Revelstoke, situated at 443 m.s.l. to a maximum of 2160mm/yr at the Glacier Mount Fidelity station, situated at 1875 m.s.l. (Loukas et al., 2002).

The area has very steep valleys that have been eroded by fluvial and glacial processes over millions of years. The majority of the valley is vegetated, only the high elevation areas are not vegetated. (Achuff et al., 1984). There are three different ecoregions that are present in the Rogers Pass area. These three ecoregions are the Interior Cedar Hemlock ecoregion, the Engelmann spruce – sub alpine fir ecoregion and the alpine ecoregion (Achuff et al., 1984). The interior cedar hemlock ecoregion is located in the lowest elevation it is the warmest and driest it receives between 1000 and 1700mm of precipitation a year (Achuff et al., 1984). The Engelmann spruce – sub alpine fir ecoregion is located at higher elevations below the tree line receives more precipitation with a range of 1700 to 2100 mm per year (Achuff et al., 1984). The Alpine ecoregion is located above the timber line and this region receives the coldest conditions and harsh weather (Achuff et al., 1984).

3.1 Site Description

The study site was located 1,403 m.s.l. the latitude and longitude coordinates were N51^{o}18’06”, W117^{o}31’45”. Our study area on Connaught Creek was located approximately 150 meters above the water collection point for the Rogers Pass town site. A number of factors were taken into consideration when choosing the study site; these will be discussed in the methodology section of the paper. A photograph of the study site can be seen in Figure 2. At the sampling site, the creek was 4.95 meters across and had a maximum depth of 1.2 meters. The water that was flowing through this bounded channel was moving quite rapidly, which created turbid flow. A graph showing the depth profile of Connaught Creek can be seen in figure 7.

Figure 2: Photograph of Team collecting data from the study site on Connaught Creek

4.0 Processes: Evaporation/tree cover

Vegetation plays a large role in the hydrological cycle. In Connaught Creek vegetation diminishes the amount of water that enters the drainage regime of Balu valley through interception (Ward and Robinson, 2000). Interception is the evaporation of water from the surface of vegetation's foliage, stems and branches. Water that falls on a plant may be evaporated in whole or in part before it runs down the plant to the ground as stemflow or falls through the plants canopy to the ground as throughfall (Ward and Robinson 2000). Once the moisture infiltrates the soil it can still be removed from the hydrological inventory of the valley by uptake from vegetation's roots (Emanuel et al. 2010). In an alpine/subalpine environment such as the Balu valley snowfall is the most important annual precipitation input (Stottlemyer and Troendle, 2001). In the subalpine area of our study area the thick forest canopy can intercept some of this snowfall, sublimating it back into the atmosphere. This high degree of sublimation, up to a third of the snowfall in southern Rockies, may be lessened by the moist climate of Rogers Pass (Stottlemyer and Troendle, 2001). Snowpack is an important input for the total dissolved solids in the creek (Stottlemyer and Troendle, 2001). This is due to the cations that are present in a snowpack therefore a greater snowpack will result in more total dissolved solids being transported by the creek (Stottlemyer and Troendle, 2001). Although snow is an important input to the hydrological regime of Balu valley rainfall also plays an important role. Balu valley and the Rogers Pass area is part of the Interior Cedar Hemlock, Engelmann Spruce-Subalpine Fir, and Alpine ecoregions (Achuff et al. 1984). In these an inland rainforest zones annual precipitation can reach up to 2100mm (Achuff et al. 1984). Although rainfall may be high Interception still plays a large role as interception rates for liquid water is greater than rate for snow Interception lessens the amount of water that makes it to the creek; this process is much more applicable to rainfall than it is to snow fall (Ward and Robinson 2000).

The type of canopy is a controlling factor for both snow and rain interception. The vegetation of our study site varied according to both elevation and the local geomorphological disturbance processes occurring; avalanche tracks, glacier erosion and debris/rock falls. The dominant tree types are spruce and subalpine fir in the higher subalpine and Cedar and Hemlock in the lower subalpine (Achuff et al. 1984). In wooded areas coniferous cover allows for greater interception than deciduous, 25-35% of the precipitation compared with 15-25% for the latter (Ward and Robinson 2000). The lower elevations of Balu valley was dominated by coniferous forest cover which we would expect to intercept a significant amount of rainfall. Lower stands were permeated by disturbance corridors created by avalanche run out tracks. These corridors were dominated by dense alder growth which function as a closed canopy deciduous forest (Figure 3). However alder's multitude of branches, stems and lower boughs create a situation where as much as 55% of the precipitation in a wet environment like Balu valley may be re-evaporated (Ward and Robinson 2000). Alder is not in full leaf year round so its effect will be significantly less when the plant is defoliated. In the alpine region of the valley the ground is either bare or covered in low moss and grass vegetation. Grasses and low brush have lower interception rates than tall multi stemmed plants like the trees in the subalpine, however the higher wind velocities in the high areas of the valley will boost the interception values in this area (Ward and Robinson 2000).

The precipitation that isn't intercepted or taken up by the vegetation's roots will either be put into storage as snow or ice or will enter the drainage of the valley. This drainage will manifest itself as overland flow or infiltrate the ground to become groundwater or throughflow.

Figure 3: Photograph of a Glacier fed tributary with alder growing on the avalanche slope

4.1 Overland flow

Overland flow is the portion of runoff that flows over ground to the stream channel as either a laminar sheet flow or more commonly as small streams (Ward and Robinson 2000). Overland flow's counterpart is throughflow (shallow subsurface flow) and groundwater flow (deep subsurface flow). Both of these terms cover water that infiltrates the ground and continues as underground to the stream channel, this process is covered in another section. Precipitation will fail to or be less likely to infiltrate the ground and become subsurface flow if the rainfall is of high intensity, the ground has a low infiltration capacity (ie solid rock or frozen ground, or if the ground is already saturated) (Ward and Robinson 2000). The Balu valley contained many steep, scree slops, exposed bedrock and in the upper alpine a thin soil (Achuff et al. 1984). These factors will lessen the delay between a precipitation event in the valley and an increase in streamflow (Brown and Hannah, 2006).

Overland flow in poorly vegetated areas like the high alpine of Balu valley is more likely to entrain sediments into the stream (Godt and Coe, 2006). An exploration of the valley found a variety of small channels where overland flow was occurring above the tree line and entraining into larger streams (figure 4). In figure 4 the water is comprised of both meltwater from the visible snowpack and from the rain which has fallen shortly before this photo was taken. While overland flow does entrain sediments it is not responsible for much of the dissolved solids which are usually the product of upwelling groundwater, or melting snowpack or glaciers (Jenkins et al. 1993, Kumar et al. 2008,).

Figure 4: Photograph of small tributary feed by snowpack melt and rain fall.

4.2 Glacial Melt, Snow Melt and Climate Pertaining to Streamflow

Balu valley is more akin to the continental climate; however the air from the Pacific does have some effect. The influx of moist Pacific air maintains temperatures slightly higher than continental mountain valleys to the east of the park during the winter, and creates high precipitation levels similar to a coastal rainforest (Achuff et al. 1984). The maximum precipitation levels occur in the winter creating large snowpacks and adding material to glaciers which provide meltwater during warmer months.

The temperature and precipitation regime in the Connaught Creek watershed controls whether water enters the stream through overland and throughflow or if it is stored as glaciers, snow and ice (Ward and Robinson 2000). Frozen stored water will eventually be melted and enter the stream as overland flow or groundwater flow (Ward and Robinson 2000). During cooler years water discharge in a basin may be less than the total precipitation whereas in warmer years release of thermally stored water may allow for a larger total discharge than total precipitation (Ward and Robinson 2000).

Glaciers in the Balu valley also contribute to water flowing through Connaught Creek (figure 3). Meltwater from snow and ice are a major contributor to the dissolved ions present in a stream. The products of weathered rocks in glaciers can be dissolved as cations in the glacial melt water (Jenkins et al. 1993, Kumar et al. 2008). Valley glaciers are also a source of suspended sediments, as they erode the landscape the material and debris is moved toward the tongue of the glacier and is deposited on the land to be moved downstream by overland flow (Sharp 1985).

Snowmelt can influence the geochemical load in a distinct manner. As snow crystals refreezes within the snowpack they can concentrate ion into specific layers of snow (Lilbaek and Pomeroy 2008**)**. As these ion rich layers melt a spike in the geochemical readings will be present followed by a decrease to the normal level for that stream (Lilbaek and Pomeroy 2008)

5.0 Methodology

A number of factors needed to be taken into account when choosing an appropriate location for the various stream monitoring processes. The study site was chosen at a section of stream where the banks were constrained on both side to ensure that there was only one channel that the water was flowing down and accurate discharge measurement could be taken. An ideal sampling site consists of a straight channel, of uniform slope and cross section. It should also consist of defined stream banks, and be of sufficient depth (Department of Geography, No date). Unfortunately due to the mountainous terrain of the study area not all of these conditions could be met, however the site chosen met as many of these factors as possible. The site used was in a relatively straight section of the channel; its banks were enclosed by bedrock and was of sufficient depth. It also featured a small sheltered section of stream where the stage recorder could be placed.

The stage recorder was used in order to obtain a continuous record of stream flow for the duration of the study (figure 5). The instrument was placed on a stilling well so as to minimize interference in the readings caused by turbulent stream flow. A float and counterweight pulley system was used in conjunction with a rotating drum and chart paper in order to record changes in stage. As the float rose and fell with the stream, the drum would rotate and a pen recorded the relative heights of the water. The stage recorder was set to a 24 hour recording interval, and was reset 1 day into the study.

A cross section of the stream was conducted at the point where depth and velocity measurements were collected. Being a smaller alpine stream, the standard 25 channel measuring sites used with bigger channels was deemed unnecessary, and the channel was divided into 9 evenly spaced stations(Department of Geography, No date). A section of rope was strung over the width of the stream, and marked at these intervals in order to obtain some uniformity between samplings. Once the site was fully set up, a Pygmy meter and a wading rod were used to obtain instantaneous velocity and depth measurements. Due to the relatively shallow depth of the channel (0.20 m at some points) velocity was measured at 60 percent depth from the surface, as opposed to the standard at 20% and 80% used by studies in larger channels.

The study area was visited a total of 7 times in order to collect enough data to accurately model stream flow over the 43 hour time period. Each time the site was visited, a number of other measurements were collected. These included air temperature (°C), and conductivity (µS/cm**)**, Total dissolved solids (mg/L), and stream temperature (°C) which were measured with a Hach Model 44600 Conductivity/TDS Meter. Suspended sediment load was measured using a wading type sediment sampler and glass bottles which had a capacity of 500 ml. Each sample was collected so as to obtain an even amount of sample across the whole stream profile. The instrument was slowly lowered into the water down to the stream bead and lifted back up at a uniform speed so that when the bottle reached the surface it was filled. Samples were stored in glass containers until they could be processed in the lab at the University of Victoria.

Once the samples reached the laboratory, they were processed using a small manually operated vacuum filtration pump. Each sample was poured into a graduated cylinder in order to measure its exact volume. These were then passed through pre-weighed filters, which were subsequently dried and weighed in order to ascertain the amount of sediment in each sample. These weights were compared with the respective volumes, yielding the concentration of suspended sediment for each sample.

In order to further investigate the various sources of inputs in the drainage basin, GPS points were taken from the junction of the two main tributaries feeding Connaught Creek and at various smaller tributaries heading down river towards the study site. Notes speculating the sources of water were recorded and photos taken at several of these smaller streams. These were loaded onto a map showing their locations on Balu Pass which can be seen in figure 14.

6.0 Data

Tables 1-7 below, show the data that was collected in the field and in the lab. Each table represents the different study times when the sampling was done. This data was used to create the figures that are found in the results section. The points where measurements were taken across the creek were labeled A1- A9 right to left looking down the creek.

Table 1: Sample 1, measurements from September 15 2010 at 10:25 on Connaught Creek

Measurement 1									
Station	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
Depth (m)	0.24	0.65	0.7	0.9	0.3	0.92	0.96	0.07	0.17
Velocity (m/s)	0.07	0.1	0.18	0.13	0.07	0.11	0.13	0.36	0.29
Segment	A1- A2	A2- A3	A3- A4	A4- A5	A5- A6	A6- A7	A7- A8	A8- A9	
Segment Discharge	0.0234	0.0584	0.0766	0.0371	0.0339	0.0697	0.0780	0.0241	
Total Discharge	0.401206								
Section Width	0.618								
Date and Time	9/15/2010 10:25								
TDS (mg/L)	23.4								
Conductivity (μS/cm)	46.3								

Suspended Sediments (g/L)	N/A								
Water Temp (^{o}C)	6.2								
Air Temp (^{o}C)	11								
Weather	Light rain switching to overcast								
Total Distance (m)	4.95								

Table 2: Sample 2, measurements from September 15 2010 at 16:44 on Connaught Creek

<u>Measurement 2</u>									
Station	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
Depth (m)	0.12	0.6	0.7	0.91	0.94	0.9	1.05	0.07	0.17
Velocity (m/s)	0.07	0.18	0.18	0.24	0.13	0.13	0.15	0.34	0.44
Segment	A1- A2	A2- A3	A3- A4	A4- A5	A5- A6	A6- A7	A7- A8	A8- A9	
Segment Discharge	0.02781	0.072306	0.104473	0.105755	0.073913	0.084357	0.08479	0.028922	
Total Discharge	0.582326								
Section Width	0.618								
Date and Time	9/15/2010 16:44								
TDS (mg/L)	18.7								
Conductivity (µS/cm)	37.5								
Suspended Sediments (g/L)	0.053								
Water Temp (^{o}C)	10.5								
Air Temp (min/max ˚C)	9.5 / 10.0								
Weather	Currently raining moderately 4:30-5:45 pm								
Total Distance (m)	4.95								

Table 3: Sample 3, measurements from September 15 2010 at 20:02 on Connaught Creek

<u>Measurement 3</u>									
Station	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
Depth (m)	0.1	0.65	0.73	0.93	0.93	0.9	0.97	0.12	0.2
Velocity (m/s)	0.05	0.09	0.13	0.15	0.07	0.2	0.24	0.15	0.49
Segment	A1- A2	A2- A3	A3- A4	A4- A5	A5- A6	A6- A7	A7- A8	A8- A9	
Segment Discharge	0.016223	0.046906	0.071812	0.063221	0.076338	0.127123	0.065678	0.031642	
Total Discharge	0.498942								
Section Width	0.618								
Date and Time	9/15/2010 20:02								
TDS (mg/L)	21.6								

Conductivity (µS/cm)	44.4								
Suspended Sediments (g/L)	0.045								
Water Temp (^{o}C)	6.8								
Air Temp (min/max ˚C)	7.5/10.0								
Weather	light rain, overcast 0.5~1mm								
Total Distance (m)	4.95								

Table 4: Sample 4, measurements from September 16 2010 at 06:10 on Connaught Creek

Measurement 4									
Station	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
Depth (m)	0.11	0.65	0.74	0.93	0.95	1.06	0.97	0.09	0.2
Velocity (m/s)	0.4	0.15	0.11	0.11	0.13	0.13	0.04	0.44	0.38
Segment	A1- A2	A2- A3	A3- A4	A4- A5	A5- A6	A6- A7	A7- A8	A8- A9	
Segment Discharge	0.064581	0.055836	0.056763	0.06971	0.080742	0.053318	0.07861	0.03674	
Total Discharge	0.496300								
Section Width	0.618								
Date and Time	9/16/2010 06:10								
TDS (mg/L)	17.8								
Conductivity (µS/cm)	36.6								
Suspended Sediments (g/L)	0.069								
Water Temp (^{0}C)	6.2								
Air Temp (min/max ˚C)	7.0/7.2								
Weather	light rain 1~2mm in collection pot								
Total Distance (m)	4.95								

Table 5: Sample 5, measurements from September 16 2010 at 12:03 on Connaught Creek

Measurement 5									
Station	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
Depth (m)	0.12	0.65	0.75	0.93	1	1.12	1.1	0.12	0.23
Velocity (m/s)	0.02	0.04	0.18	0.09	0.18	0.24	0.18	0.53	0.47
Segment	A1- A2	A2- A3	A3- A4	A4- A5	A5- A6	A6- A7	A7- A8	A8- A9	
Segment Discharge	0.007138	0.047586	0.070081	0.08051	0.137567	0.144056	0.133828	0.054075	
Total Discharge	0.674841								

Section Width	0.618								
Date and Time	9/16/2010 12:03								
TDS (mg/L)	23.9								
Conductivity (µS/cm)	48.7								
Suspended Sediments (g/L)	0.087								
Water Temp (^{0}C)	7.8								
Air Temp (min/max ˚C)	7.2/10.0								
Weather	cloudy no rain in collection container								
Total Distance (m)	4.95								

Table 6: Sample 6, measurements from September 16 2010 at 16:00 on Connaught Creek

Measurement 6									
Station	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
Depth (m)	0.12	0.65	0.72	0.85	0.87	0.98	1	0.16	0.22
Velocity (m/s)	0.09	0.18	0.09	0.13	0.39	0.27	0.25	0.47	0.33
Segment	A1- A2	A2- A3	A3- A4	A4- A5	A5- A6	A6- A7	A7- A8	A8- A9	
Segment Discharge	0.032121	0.05715	0.053364	0.138185	0.188645	0.159073	0.129038	0.046968	
Total Discharge m3/sec	0.804543								
Section Width	0.618								
Date and Time	9/16/2010 16:00								
TDS (mg/L)	24.7								
Conductivity (µS/cm)	50.4								
Suspended Sediments (g/L)	0.039								
Water Temp (^{0}C)	8.4								
Air Temp (min/max ˚C)	8.9/10.0								
Weather	(no notes, do we have a pictures?)3mm precipitation in trap								
Total Distance (m)	4.95								

Table 7: Sample 7, measurements from September 16 2010 at 20:20 on Connaught Creek

Measurement 7									
Station	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
Depth (m)	0.16	0.71	0.74	0.98	1	1.2	1.17	0.17	0.3

Velocity (m/s)	0.13	0.04	0.11	0.05	0.07	0.44	0.24	0.53	0.33
Segment	A1- A2	A2- A3	A3- A4	A4- A5	A5- A6	A6- A7	A7- A8	A8- A9	
Segment Discharge	0.022851	0.033604	0.042518	0.036709	0.173349	0.248992	0.159413	0.062449	
Total Discharge (m3/sec)	0.779885								
Section Width	0.618								
Date and Time	9/16/2010 20:20								
TDS (mg/L)	21.8								
Conductivity (µS/cm)	44.6								
Suspended Sediments (g/L)	0.209								
Water Temp (^{0}C)	6.2								
Air Temp (min/max ˚C)	6.0/9.0								
Weather	0.5-1mm in trap								
Total Distance (m)	5.00								

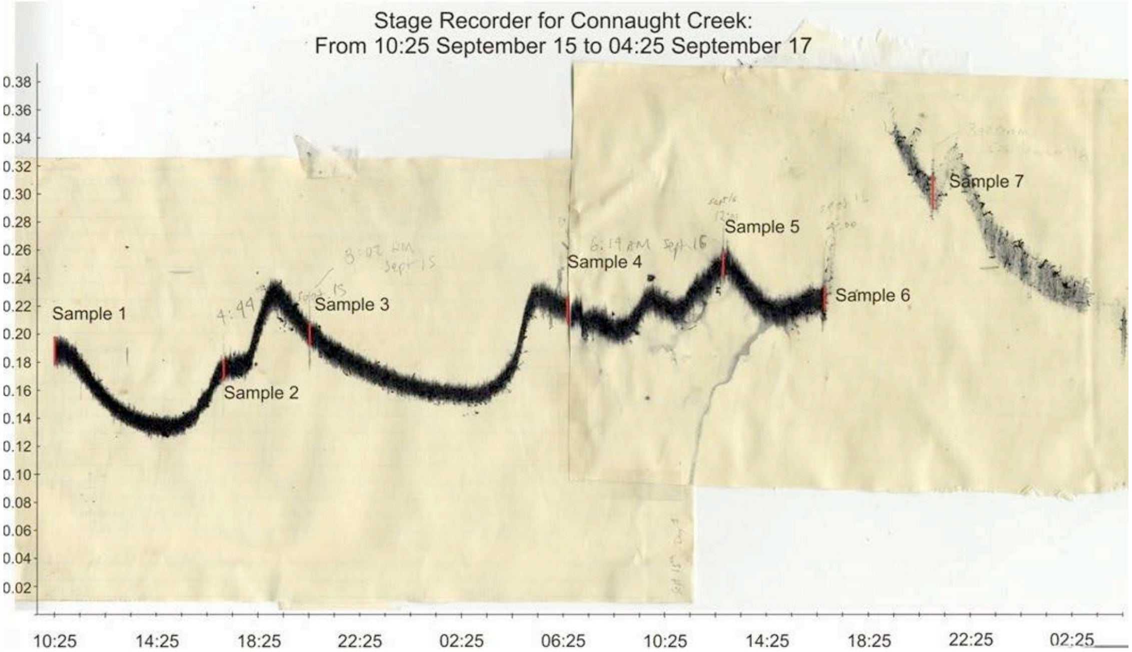

Figure 5: Output from Stage recorder with scale bar for time and depth of station A9 of the 43 hour study.

Table 8: Sediment data from water samples collected using the wading type sediment sampler

	Dish #	Filter (g)	Volume (L)	Dry Weight (g)	Weight of Sediment (g)	Concentration (g/L)
Sample 1	No data	No data	No Data	No Data	No Data	No Data
Sample 2	270	*0.077	0.480	0.102	0.025	0.053
Sample 3	372	*0.077	0.455	0.097	0.020	0.045
Sample 4	279	0.074	0.465	0.106	0.032	0.069
Sample 5	249	0.076	0.425	0.113	0.037	0.087
Sample 6	477	0.075	0.485	0.094	0.019	0.039
Sample 7	405	0.078	0.455	0.173	**0.095	**0.209
Average			0.461		0.038	0.083

*Filter weight for sample 1 and 2 was obtained by averaging the weight of 10 filters
**Visually much more suspended sediment in sample

Table 9: Total discharge calculation table data from hydrograph recorded on the stage recorder

Time	Number	N	Depth (m)	Discharge (m^3/s)	Discharge (m^3/h)
10:25	96.6	62.7	0.21	0.599645555	2158.724
11:25	92.9	59	0.20	0.56843172	2046.354193
12:25	85.2	51.3	0.17	0.501795628	1806.464263
13:25	80.7	46.8	0.16	0.46180326	1662.491736
14:25	78.7	44.8	0.15	0.44378043	1597.609548
15:25	79.2	45.3	0.15	0.448300471	1613.881695
16:25	85.8	51.9	0.17	0.507069464	1825.450072
17:25	93	59.1	0.20	0.569282217	2049.415983
18:25	100.5	66.6	0.22	0.631980173	2275.128622
19:25	108.2	74.3	0.25	0.694113314	2498.807929
20:25	100.6	66.7	0.22	0.632801621	2278.085836
21:25	96	62.1	0.21	0.594619399	2140.629837
22:25	93	59.1	0.20	0.569282217	2049.415983
23:25	90.5	56.6	0.19	0.547905122	1972.45844
0:25	88.2	54.3	0.18	0.528027208	1900.89795
1:25	86.8	52.9	0.18	0.515828613	1856.983008
2:25	86.3	52.4	0.17	0.511453817	1841.23374
3:25	87.1	53.2	0.18	0.518448905	1866.416056
4:25	93.3	59.4	0.20	0.571831416	2058.593096
5:25	109.6	75.7	0.25	0.705166773	2538.600384
6:25	106.8	72.9	0.24	0.682984939	2458.745779
7:25	104.1	70.2	0.23	0.661311513	2380.721446
8:25	101.5	67.6	0.23	0.640177456	2304.638842
9:25	106.3	72.4	0.24	0.678992363	2444.372508
10:25	107.1	73.2	0.24	0.685375897	2467.353229

11:25	109.5	75.6	0.25	0.704379725	2535.767009
12:25	116.2	82.3	0.27	0.756266875	2722.560751
13:25	113.2	79.3	0.26	0.733245956	2639.685441
14:25	106.6	72.7	0.24	0.681389055	2453.000599
15:25	106.9	73	0.24	0.683782307	2461.616305
16:25	108.8	74.9	0.25	0.698859684	2515.894862
17:25	152.3	118.4	0.39	1.006309804	3622.715294
18:25	157.3	123.4	0.41	1.037014463	3733.252066
19:25	148.4	114.5	0.38	0.981696824	3534.108568
20:25	138	104.1	0.35	0.913220014	3287.59205
21:25	138.2	104.3	0.35	0.914575862	3292.473104
22:25	133.5	99.6	0.33	0.882309227	3176.313218
23:25	121.7	87.8	0.29	0.797578452	2871.282427
0:25	117.3	83.4	0.28	0.764621688	2752.638078
1:25	113.2	79.3	0.26	0.733245956	2639.685441
2:25	109.7	75.8	0.25	0.705953439	2541.432382
3:25	107.2	73.3	0.24	0.686172119	2470.219627
4:25	100	66.1	0.22	0.627867198	2260.321912
				Total Discharge m^3	103604.0333
				Average m^3/h	2409.396123

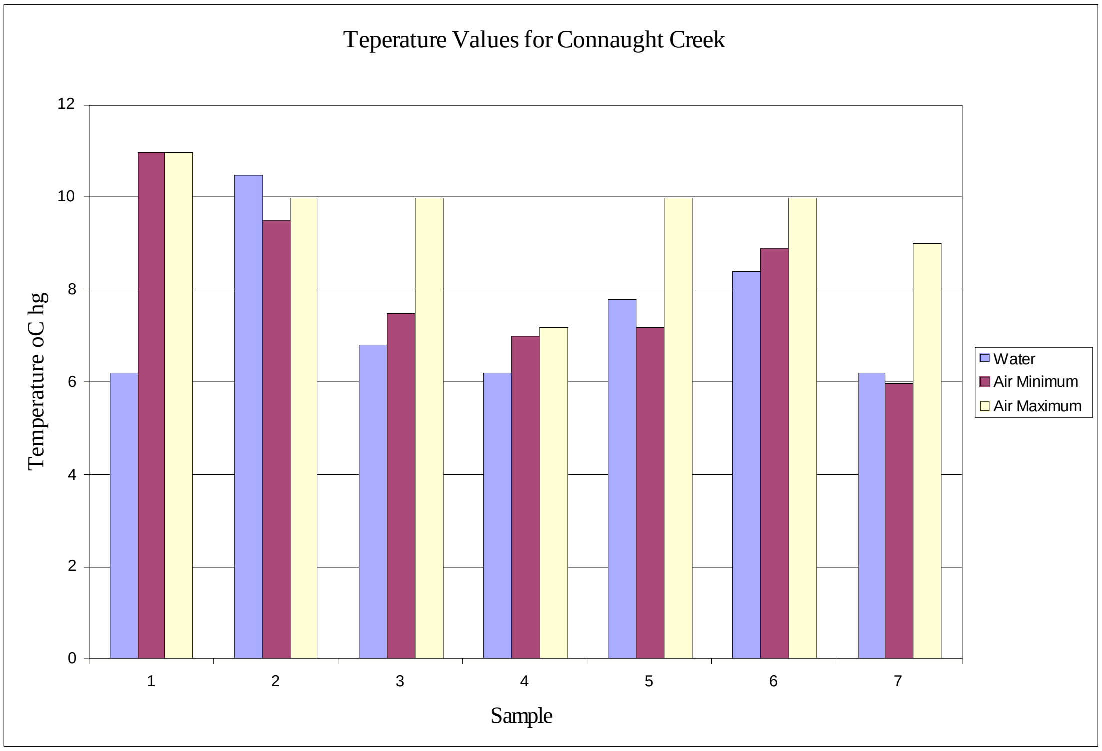

Figure 6: Graph comparing temperature of water at the sample times with the max and min air temperature between the sample times

7.0 Results

Figure 7 shows the variation in the depth profile of the creek over the seven sample times.

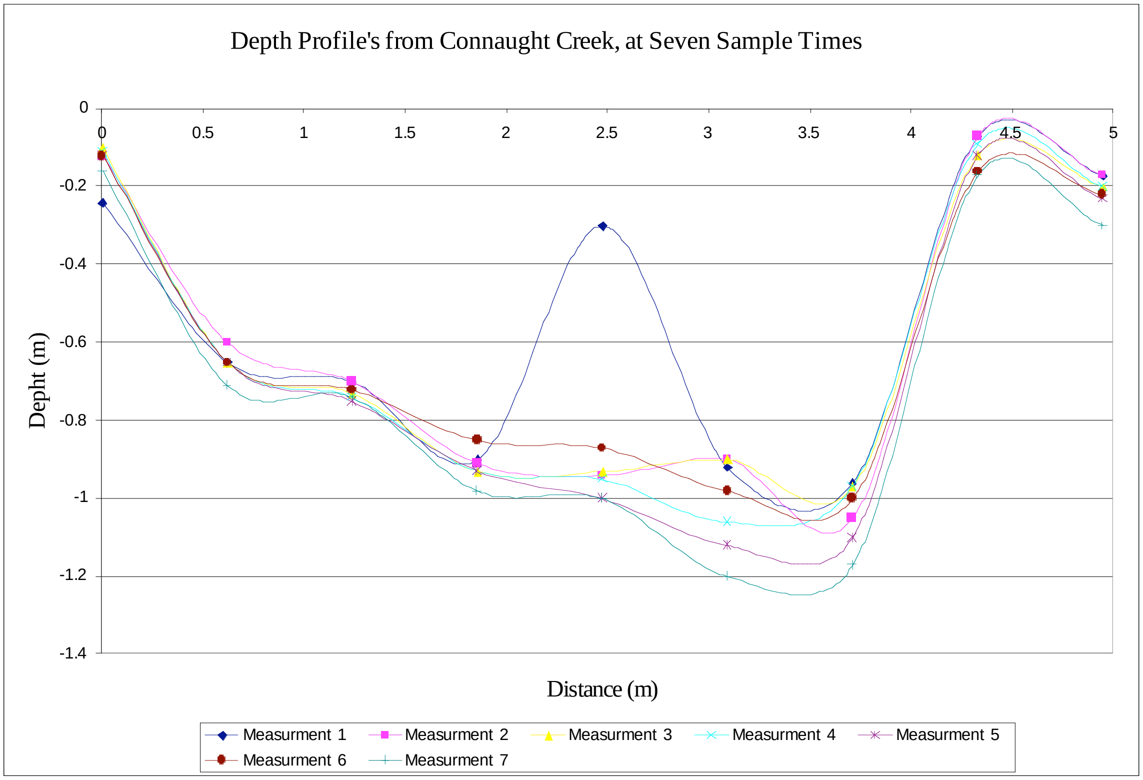

Figure 7: Depth profile for Connaught Creek

In figure 8 below, of the stream rating curve allows for the values on the stage recorder to be used and converted into discharge value to determine the total discharge for the creek over the study period.

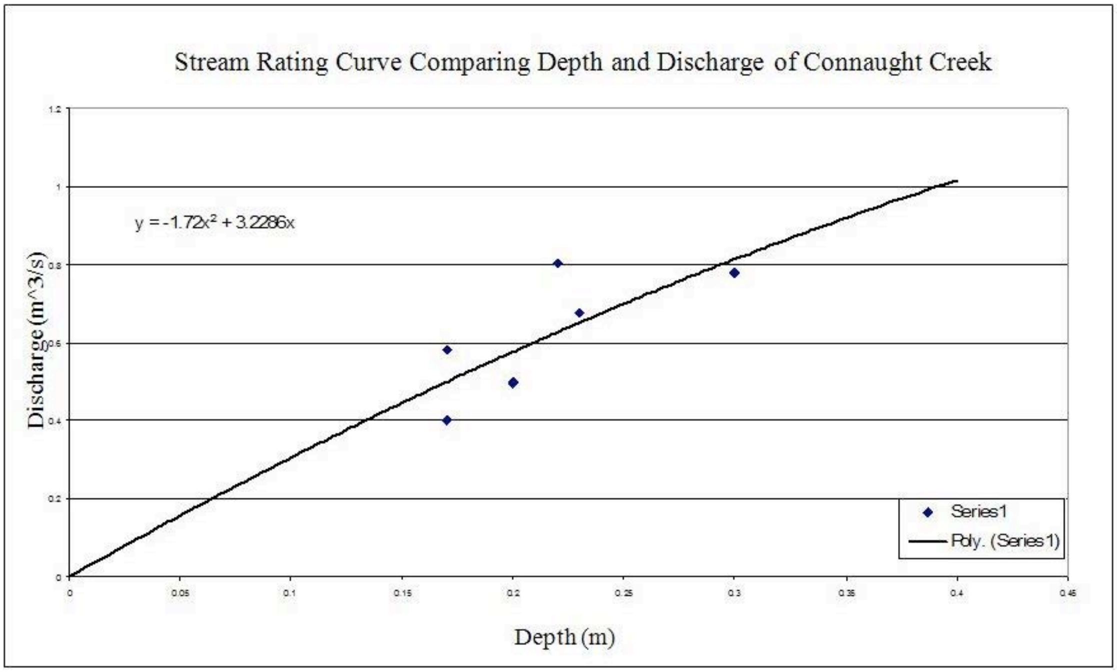

Figure 9: Steam rating curve compiled from the data collected from site A9 over the seven sample times.

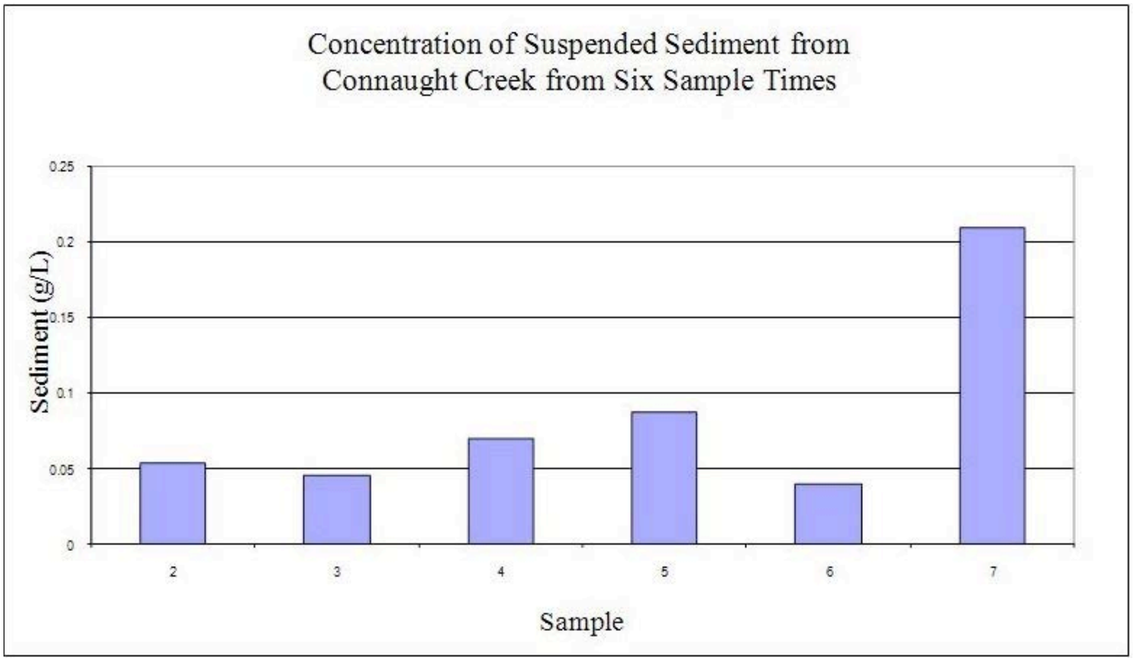

Figure 10: Graph of concentration for suspended sediment from six sample times.

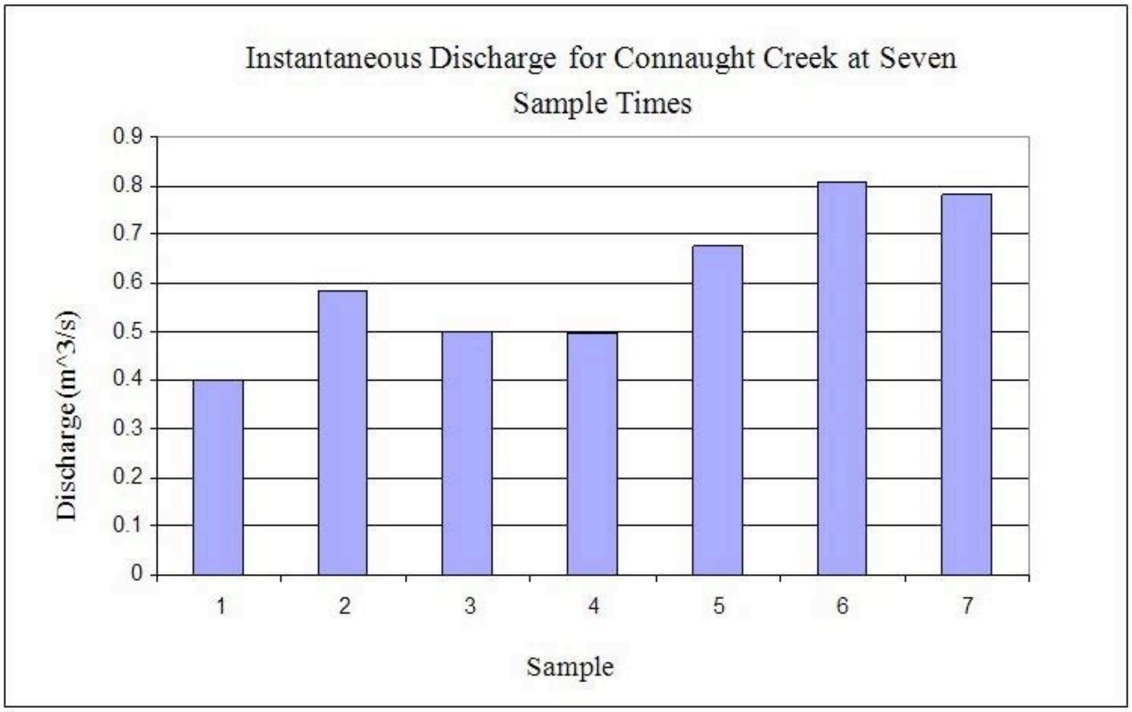

Figure 11: Graph of Instantaneous discharge for seven sample times calculated form depth and velocity values

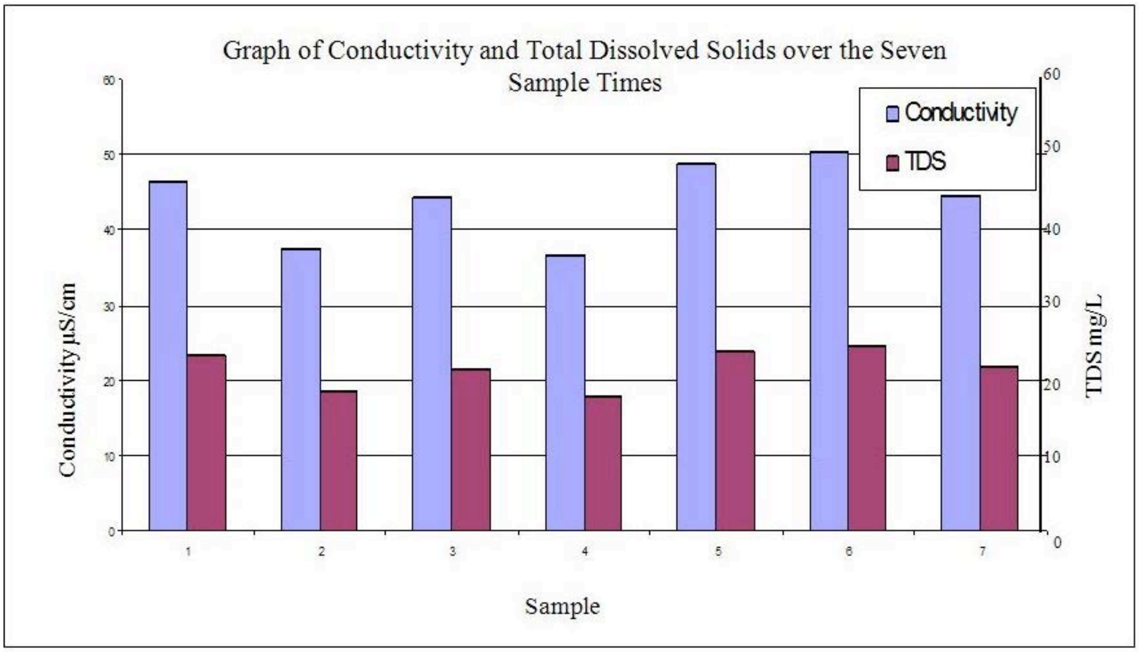

Figure 12: Graph show the Concentration and total dissolved solids in the water for the seven sample times

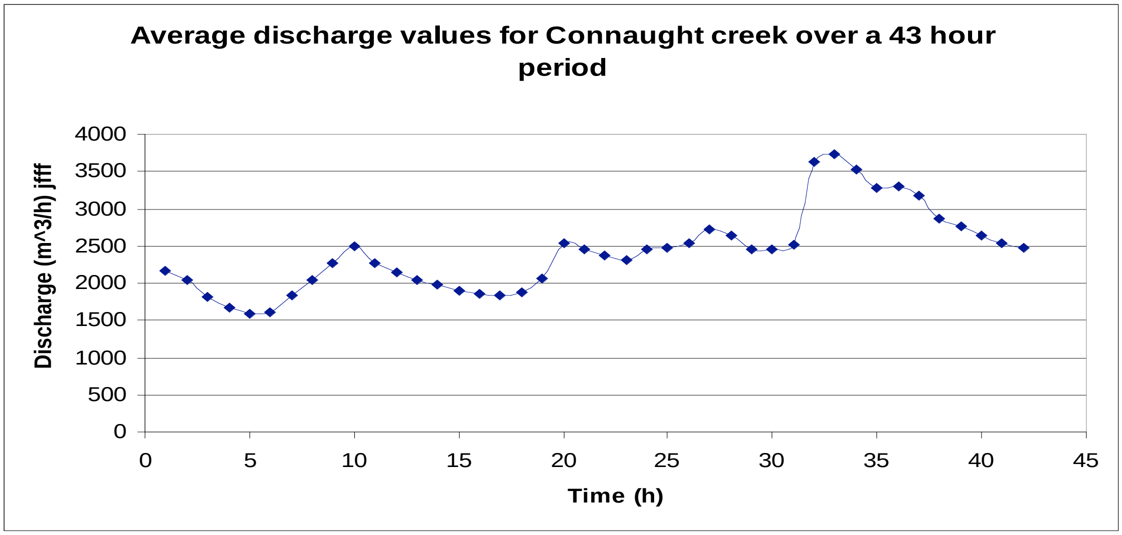

Figure 13: Average discharge for Connaught Creek calculated using the stage recorder and the stream rating curve.

Table 10: Total TDS and suspended sediment values for the 43 hour study period

Sample	Conductivity	TDS (mg/L)	Suspended Sediment (g/L)
1	46.3	23.4	
2	37.5	18.7	0.053
3	44.4	21.6	0.045
4	36.6	17.8	0.069
5	48.7	23.9	0.087
6	50.4	24.7	0.039
7	44.6	21.8	0.209
Average	44.1	21.7	0.084
Total for 43 in (Kg)		2248.2	8668.201

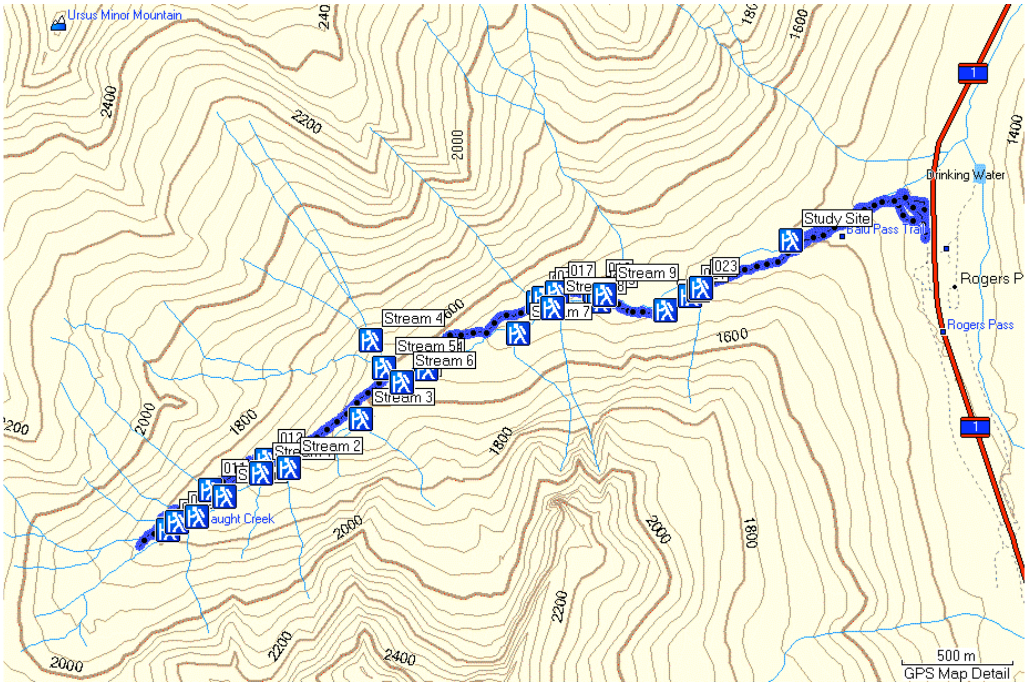

Figure 14: GPS points for tributaries feeding into Connaught Creek

8.0 Discussion

Instantaneous discharge for each sample site was derived from the velocity and depth values recorded across channel during the acquisition of each sample. (Refer to Table 1through 7 for velocity and depth values recorded during each sample) These values were derived using the Mean Section Method equation, seen in figure 15, where v1 is the velocity of station 1 and v2 is the velocity of station 2, etc. Stream discharge

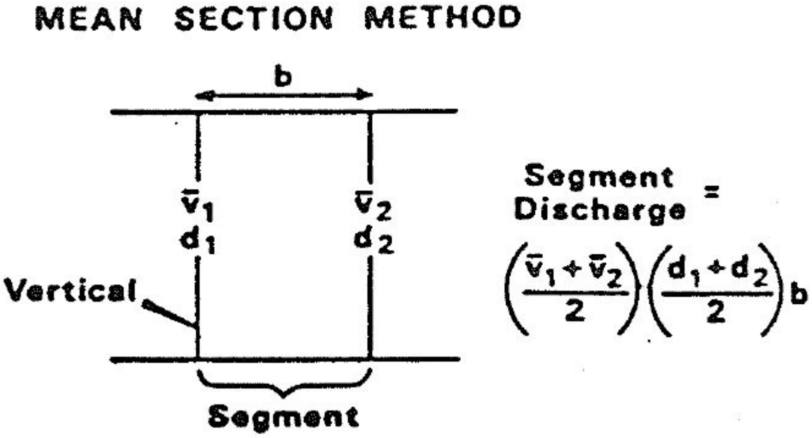

Figure 15: Calculation used for determining instantaneous discharge for section of the creek from Techniques Manual.

can be seen in figure 11 illustrating a degree of correlation with the values recorded by the hydrograph. Samples 6 and 7 were problematic, as sample 7 had a greater depth than sample 6, but a lower recorded velocity, leading to an apparent drop in discharge. This can be attributed to the methodology used to acquire velocity readings.

The narrow channel of Connaught Creek required velocity measurements at only 0.6 channel depth instead of the 0.2 and 0.8 depth measurements required for larger channels. More measures at different heights in the water column would have limited error due to back eddies and provided a more realistic measurement of the streams velocity and discharge and provided a large number of sample velocities. A hybrid measurement system may have yielded more meaningful results from this experiment. This system would have only taken one velocity measurement at 0.6 channel depth in the shallow portions of the stream while the comparatively deeper sections of the stream would be measured twice (ie points greater then 0.5m), at 0.2 and 0.8 depth. This improved strategy might have accounted for the rapid surface flow observed at the site during high discharge, and yielded a more accurate discharge value for the duration of the study, most notably samples 6 and 7.

These discharge values were used to create a Stream Rating Curve for Connaught Creek, which can be seen in figure 9. Station A9 was used for the depth values as this showed the closest relationship between samples when compared with the hydrograph values. This was because A9 had the least variation between readings as the stream bottom was bedrock, and it was relatively shallow. The scatterplot results were not as linear as one would expect, however the apparently weak correlation between discharge and depth values can be partially attributed to the aforementioned methodological source of error. The results yielded a positive relationship between discharge and depth; as depth increased, so did discharge. A polynomial line of best fit was used to create the Stream Rating Curve, which was used to extrapolate discharge values for the duration of the study using the hydrograph.

The hydrograph was produced using a Stage Recorder, and can be seen in figure 5. There are several pronounced peaks and troughs that can be seen throughout the 43 hour study period. Many of these appear to have a sharp increase in stage height, followed by a gradual decrease. These changes are characteristic of rainfall-runoff events (Ward and

Robinson 2000), which was the primary source of input for our stream. On smaller time scales like that of this 43 hour study an increase in the melt water portion of stream discharge can be caused by a warm period of increased melt, a period of prolonged high intensity precipitation during the warmer parts of the day, or by the sudden release of liquid water stored in the glacier known as a *jokulhlaump.* Likely none of the spikes in the hydrograph created by this experiment are the result of *jokulhlaumps* but are due to rainfall; however meltwater was a constant contributor to the steam's discharge. In figure 3 we can see the snowpack and toe of a small glacier which is contributing to the stream.

The high velocity nature of the alpine stream caused turbulence to disturb the stilling well and added variation to the hydrograph data. These vibrations were translated to the hydrograph's line which made it considerably thicker than was expected, and introduced a degree of error into the data. After Sample 6, there is a large gap in the data, as well as a sudden apparently increase in stage height. One possible explanation for this increase could be the occurrence of a high output precipitation event; however without access to a rain gauge it is difficult to be certain how rainfall was influencing the hydrograph. The gap in the data was most likely due to a mechanical failure which caused the pen attached to the stage recorders to malfunction. This problem seemed to fix itself as before the next monitoring sample the pen recovered and began recording information again.

Evapotranspiration and interception by vegetation in the valley reduced the precipitation that entered Connaught Creek during our study period. If a regime of rain gauges were set up in both cleared area and beneath trees an estimate of how much of a role interception played in reducing the flow of Connaught Creek could be determined. The time and resources necessary to set up such a monitoring system were beyond the scope of this experiment. Evapotranspiration, uptake by tree roots can cause root zone in soil to become water deficient later in the growing season, ie during the September study period. However rain throughout the week probably negated this process, providing abundant groundwater (Emanuel et al. 2010).

Water temperate stayed relativity consistent for the duration of the study. Large storm events can depress the temperature of an alpine stream up to a 7.5 ^{o}C, however the weather during out study period was relatively constant, rainy, overcast, and air temperature remained stable (Figure 6) (Brown and Hannah 2006).

Suspended sediment load was at its highest during the end of the study period at sample time 7 (Figure 10). Suspended sediments in the stream correlate to increased rainfall after the peak seen in hydrograph. This increased overland flow would have entrained more suspended sediment into the stream flow; this is consistent with the data we collected. Over the 43 hour period the average total suspended sediment was 8668.2kg.

The total dissolved solids and conductivity values recorded over the study period showed strong correlation. Overall the concentration of dissolved solids stayed stable and low for the study period. In an alpine valley like the Balu valley dissolved solids are sourced from meltwater (Lilbaek and Pomeroy, 2008). Because the study took place in mid September meltwater contributions to stream would be nearing their annual low and cation levels would also be low. The average totals dissolved solids transported during the 43 hour period was 2248.2kg.

The geology of the Balu valley played an important role in the geochemical load of the creek. Balu valley is mostly underlain by metamorphosed rock, possibly schist and shales (Achuff et al., 1984). In a geologic setting such as this the expected the total dissolved solids are generally less than 100mg/liter (Ward and Robinson, 2000). This is due to the impermeability of the rocks present and the temperate environment of the study area (Ward and Robinson 2000). However large amounts of available moisture and weathering by hot cold/freeze thaw cycles provide weathered product to be entrained as suspended and dissolved sediments (Ward and Robinson 2000). The suspended sediments measured in the study were carried by overland flow and sourced from weather material and glacial processes (Sharp 1985).

Safe drinking requirements set out by the US Environmental Protection Agency state that drinking water must not have greater than 500mg/L TDS (Kent and Belitz 2004). Connaught Creek fell well under this concentration ceiling and is considered "very soft" (ITT Analytics 2010). However the type of dissolved solid is important to determine weather or not the water is safe for consumption as some may be toxic. Analyzing the varying dissolved ions present in the stream may be an important future topic for study.

9.0 Experimental Limitations

During the course of the experiment sources or error were noted. The nature of field work presents a variety of challenges to experimental observations, one such obstacle was the choice of monitoring site. The site selection was limited by natural features, an ideal location for monitoring the stream discharge would have been a permanent man made monitoring station with a v-shaped weir. (figure 16) A location similar to that shown in the figure 16 did exist with a rectangular weir however drinking water for the Rogers Pass area was being drawn from the reservoir behind the weir and would have influenced the experiments results. The experimental location chosen did naturally constrain the creek with bedrock on either side of the stream however not as uniformly as a weir would have. The depth of the chosen study site presented some challenges while making measurements of stream discharge. Acquiring measurements of depth and velocity in the deeper sections of the stream channel required wading in swift flowing 6°C chest deep water with only thigh high waders. This presented a safety concern and time spent in the water was kept to a minimum for safety and comfort.

Figure 16: A man made weir for stream flow measurments

Sampling the suspended sediments required dipping the collection jar through the entire height of the water column at a constant rate ensuring that the bottle filled completed during one return trip from the surface to stream bed. This leaves room for human error in the dip rate and required trail and error to ensure the bottle filled completely. Visibility in the stream was poor and samples were often collected in the dark, making determinations on whether the bottle had filled or not even more difficult.

In an effort to keep measurements uniform samples were collected from the same point in the stream for each measurement. However collection of samples from a variety of locations across the stream would have provided a more detailed view of total suspended sediments across the stream channel and may have shown fluctuations in sediment load in different portions of the stream. Suspended sampling was overlooked during the initial setup and a sample was not collected for the September 15th 10:25 sampling time. Due to a limited supply of water sample collection bottles it was necessary to transfer the collected sample to another glass container for storage and transport from Rogers Pass back to the lab at the University of Victoria. In the laboratory the sample had to once again be transferred to a graduated cylinder to obtain a more precise volume measurement, and then the sample was transferred to the vacuum filter apparatus. Each of these three transfers presented an opportunity for sediments to be left in the previous container creating greater uncertainty in the final dried sample weights. Ideally the collection bottles would allow for precise volumetric measurements and would also be sued for transport, eliminating the need for two of the transfers.

The environment and scale of the study site dictated that a degree of error be induced by the environment. It was not possible in this experiment to account for water that may have been percolating beneath the stream bed and banks. The Bedload of the stream and the shifting of cobbles on the stream bed may have affected the accuracy of our depth measurements. Station A5 during measurement period 1 could have been influenced by an object on the streambed which shifted downstream during subsequent measurements, without monitoring the bed load it is difficult to ascertain if measurements where being influenced by shifting bed load or not. During observations of the various tributaries of Connaught Creek it was not possible to account for groundwater flow. Time constraints and the delicate nature of the park dictated that people refrain from deviating from marked trails and exploring more of the drainage basin. Ideally traverses of both the north and south ridges of the valley would have given better insight to the glaciers and snow pack present.

Access to a rain gauge would have provided a clearer picture of how rainfall was influencing the hydrograph produced by the experiment. This would have also created a better distinction between what portion of the streams discharge were from precipitation, glacial melt, and groundwater. An attempt was made to collect observations of the precipitation using containers to catch rainfall however these observations are only qualitative and have little scientific value for inferring meaningful climatic results.

10.0 Conclusion

This study provided experience and insight into the hydrological techniques employed to investigate small alpine streams such as Connaught Creek and the processes operating in a typically glacial alpine valley like Balu valley. For the 43 hour study period the average discharge was 2409.4 m^3/hr and the total discharge was 103,604.03 m^3. Average total suspended sediment load over the 43 hour study period was 8668.2kg was and the average total dissolved solid load was 2248.2kg.

The investigation into Connaught Creek leads to the conclusion that the stream derived its water primarily from precipitation as well as snowpack, and very small amounts of glacier meltwater during the period of the study. Changes in stage over the 43 hour monitoring period can be attributed to precipitation events, which were mostly rainfall due the season in which the study took place. Further investigation into the separation of runoff, groundwater, and meltwater sources and the relative contributions of each source to the stream could provide additional insight into this important watershed. Investigations into the amount of bedload carried by the stream and fluctuations in sediment discharge could also be further investigated, ideally over a longer period of study. A more complete understanding of this stream and its seasonal fluctuations in the both sources and characteristics could be provided by a long term study or by the installation of a monitoring site on the stream.

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