Correlation Between Stream Discharge and Dissolved Oxygen Concentration at Salish Creek, Vancouver Pacific Spirit Park

Daphne Chiu, Harsimran Grewal, Melody Lan, Niyusha Zahedimazandarani

Abstract

Stream discharge and dissolved oxygen (DO) concentration are important abiotic factors for salmon. The existence of a linear correlation between these two abiotic factors could bear significance to the salmon ecosystem. In this study, we examined the existence of a linear correlation, or the lack thereof, between these two variables with our alternative hypothesis being that there is a linear correlation between the two variables. To do this, we measured DO concentration and stream discharge at 3 ripple water sites and 3 still water sites from upper Salish Creek. Stream discharge was calculated using the wetted depth, the wetted channel width, and the stream velocity. The correlation coefficient was found to be -0.516, suggesting a moderate negative trend. Using the Pearson's Product Moment Correlation test, *P*-value was found to be 0.296, and at a significance level of 0.05, *P*-value > 0.05. Thus, we failed to reject the null hypothesis. This may be due to the increased amount of organic matter leading to greater biochemical oxygen demand (BOD) caused by the mixing of the water column at ripple water sites, and a greater BOD would result in a lower DO. We conclude that there was not enough statistical evidence to indicate that there is a linear correlation between stream discharge and DO concentration.

Introduction

In Pacific Canada, low stream discharge poses serious problems for spawning salmon population. Low stream discharge results in reduction in food sources, available habitats, and water quality, and can enhance the effect of river ice (Bradford & Heinonen, 2008). Stream discharge is defined as the volume of water moving down a stream per unit of time (USGS Water Science School, 2013).

Low stream discharge also slows down the turnover of nutrients and wastes. Accumulation of these nutrients and wastes in streams can then be reflected in the fluctuations of measured dissolved oxygen (DO) concentration, which is vital to the survival of all aerobic aquatic organisms (Sergeant et al., 2017). Alabaster and Lloyd (2013) studied the effect of different levels of DO on the hatching success of salmon eggs. The usual DO range for successful hatching of salmon embryos is 2-3 mg/L. DO concentrations higher than 3 mg/L reduce the hatching success rate (Alabaster & Lloyd, 2013).

To compensate for oxygen deficiency in their surrounding environment, fish change their behavior in multiple ways (Britwell & Kruzynski, 1989). These responses include increased use of surface water for aquatic respiration, reducing their activity, changing their habitat, and changes in their avoidance behavior (Britwell & Kruzynski, 1989). These responses, however, can have negative consequences on their fitness and survival.

We propose a biological model for the relationship between stream discharge, DO concentration, and salmon population based on existing research. Stream discharge delivers important nutrients and oxygenated water to salmon spawning areas (Bradford & Heinonen, 2008). Spawning population require oxygen for metabolic activity, swimming performance and migration and will in turn cause a depletion in DO concentration (Fellman et al., 2015). Together, these two variables tightly regulate the survival and fitness of salmon population.

In this study, we are interested in examining whether there is a linear correlation between stream discharge and DO concentration. Our null hypothesis (H_0) is that DO concentration and stream discharge are not linearly correlated. Our alternate hypothesis (H_A) is that DO concentration and stream discharge are linearly correlated. We predicted that there is a positive linear correlation between stream discharge and DO concentration. This prediction is supported by the fact that slow flowing water has little to none surface turbulence, and there is minimal oxygen mixing taking place (Morten, 2005). Furthermore, in a study done by Fellman et al. (2018), low DO concentration was observed during mid-summer when stream discharge was low.

The purpose of this study is to investigate the presence of a linear correlation between stream discharge and DO concentration. It's an important topic to study because keeping both abiotic factors within salmon's tolerance range is vital to the survival of spawning salmons. In doing so, we will also strive to refine the existing research on the correlation between stream discharge and DO concentration and provide empirical evidence for their effectiveness. Finally, we will highlight the significance of this correlation, or lack thereof, to the salmon-related ecosystem of the Pacific Northwest.

Methods

Data Collection

On November 2nd, determined the most suitable creek for data collection among the 3 creeks we had permit for: Salish, Canyon, and Musqueam. We wanted to collect data from 3 distinct still water and 3 distinct ripple water sites all being from one creek only, in order to be to keep other abiotic factors constant. We found Salish Creek to be the most suitable of the 3 creeks because it had 3 distinct still water sites and more than 3 distinct ripple water sites and it also had good accessibility to the sites.

We wanted to collect data on only one day to keep other abiotic factors such the amount of precipitation, that may vary on different days, constant. On November 4th, we collected data at 6 sites of upper Salish Creek, as we did not have access to lower creeks. Still water sites, those with low stream discharge, and rapid water sites, those with high stream discharge, were classified in comparison to each other, by qualitatively examining the stream velocity. We recorded the GPS coordinates of each site using a mobile app called My GPS Coordinates. We had 3 still water sites: site A (49.27396 N and 123.23845 W), site B (49.27378 N and 123.23834 W), and site C (49.27398 N and 123.23844 W), and 3 ripple water sites: site D (49.27398 N and 123.23842 W), site E (49.26978 N and 123.23994 W), and site F (49.27142 N and 123.23839 W).

At each site, we took 5 pseudoreplicates of stream discharge, then averaged the values to get one value for each site (Figure 3). To calculate stream discharge, we calculated stream cross-sectional area, which is the product of the stream wetted channel width (measured with a measuring tape) and wetted depth (measured with a meter stick) (Figure 1) (Morten, 2005).

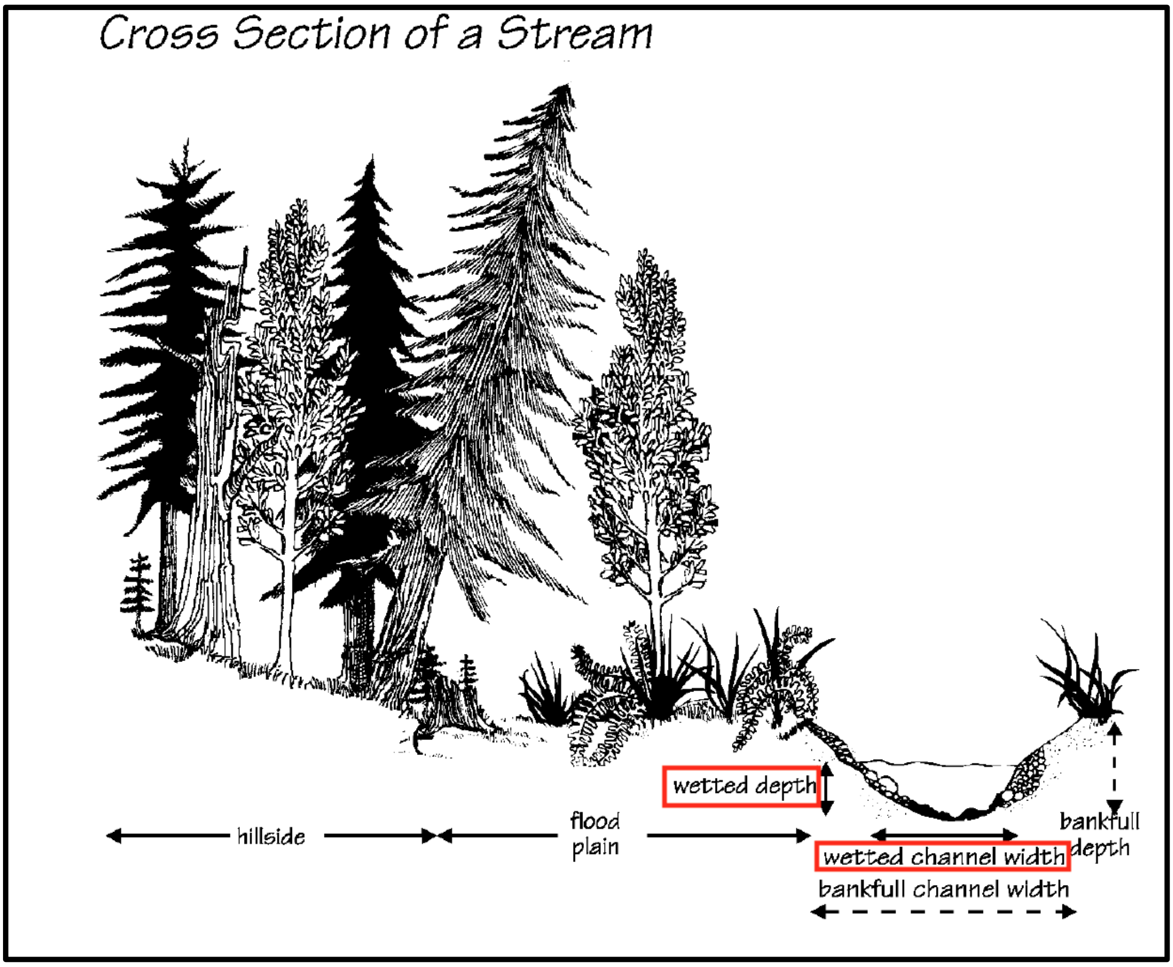

Figure 1. A diagram of stream wetted channel width and wetted depth outlined in red. Other lengths are shown in comparison to these two (Morten, 2005).

To measure stream velocity, we dropped a tennis ball in the stream from an initial position and let it travel for 10.00s, after which it was stopped with a stick, so not to disturb the gravel. We measured the distance the ball had travelled during the 10.00s and calculated the stream velocity (Figure 2a & b). We repeated this 5 times for each site. The tennis ball sometimes got stuck while travelling down the stream.

To solve this problem, we picked up the ball using a stick and repeated the measurement.

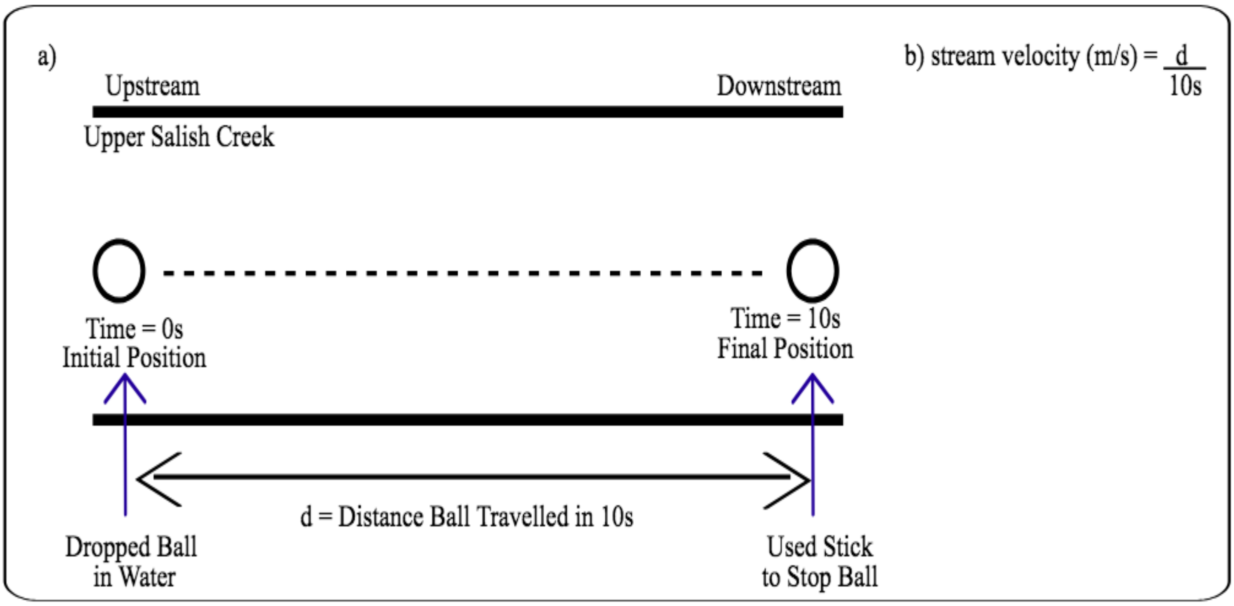

Figure 2. (a) Tennis ball strategy used for measuring stream velocity. (b) Equation used to calculate stream velocity.

To calculate the stream discharge, we used the equation below, where 0.8 is the correction factor (Morten, 2005):

stream discharge (m^3/s) = velocity (m/s)×area (m^2)×0.8

For DO measurements, we took 5 pseudoreplicate measurements at each site, and to ensure consistency, we collected all water samples from the surface. We then calculated their average to get one DO concentration for each site (Figure 3). To be consistent, the same oxygen probe was used for all measurements. We connected the oxygen probe to a TI-84 graphing calculator and submerged the probe into the water samples collected in plastic cups, and waited until the number on the calculator stabilized. The probe was rinsed with distilled water before and after each use.

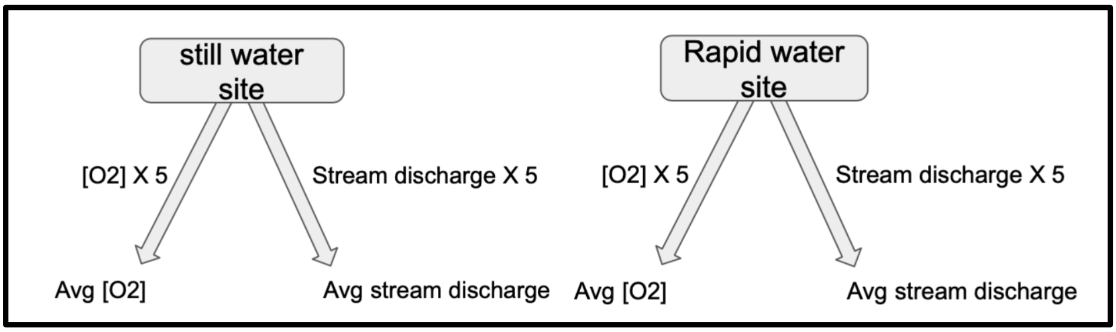

Figure 3. A flowchart of the measurements taken at Upper Salish Creek. There were 3 distinct still water sites (sites A, B, and C) and 3 distinct ripple sites (sites D, E, and F). At each site, we took 5 measurements of stream discharge and 5 measurements of DO concentration. The average of the 5 pseudoreplicates was calculated to give one stream discharge and one DO concentration measurement for each site.

Data Analysis

Based on our original question and hypotheses, we conducted a correlation statistical test. Because this was a correlation test, there was no distinction made between the explanatory and response variables. The most commonly used parametric correlation test is the Pearson's Product Moment Correlation test. Our data fit the assumptions of this test, which were: at least one of the continuous variables has a normal distribution, the ranges of data used are not truncated, there are no outliers in the data, and that the bivariate relationship is linear and homoscedastic. For this reason we were able to conduct the parametric correlation test using two online calculators, instead of the non-parametric equivalent, the Spearman's Rank Correlation test (Stangroom, n.d.; Arcidiacono, n.d.).

We conducted an outliers test using an online calculator called GraphPad and found that there were no outliers in our data (Motulsky, n.d.).

Results

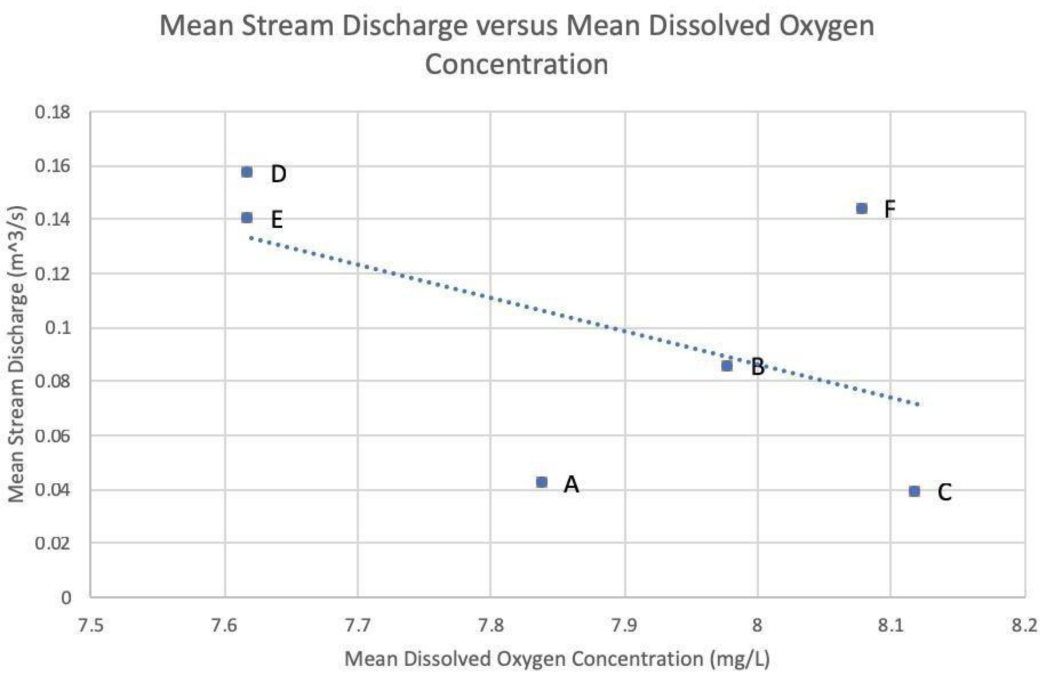

Figure 4. A scatterplot showing the relationship between mean stream discharge and mean dissolved oxygen concentration. Sites A, B, and C are still water sites and sites D, E, and F are fast running water sites. There were no outliers in the data. The specific sites are indicated to the right of the corresponding data point. The dotted line represents the linear best-fit line. *P*-value was found to be 0.296. The correlation coefficient (R) was -0.516 (suggesting a moderate negative trend), the coefficient of determination (R^2) was 0.266, and sample size (n) was 6. The degrees of freedom were n-2=4.

Because we found our *P*-value to be 0.296, which is greater than our significance level (alpha) of 0.05, our results were not statistically significant. Moreover, because a correlation test does not imply causation, we did not include the equation of the best-fit line in Figure 4. Our correlation coefficient (R) of -0.516, suggests a moderate negative trend between mean stream discharge and mean DO concentration (Figure 4). This means that as one variable increases, the other would decrease.

Figure 5. Upper Salish Creek where we collected data. The vegetation cover included ferns and shrubs and several tree types.

The fast running water sites were generally cloudier compared to the still water sites. Furthermore, still water sites were more level compared to the fast running water sites, which usually had a slight downwards slope. The wetted depth almost equaled the bankfull depth, probably due to rain on the previous days. The vegetation cover of the stream banks were similar for all six sites and included shrubs, ferns, and different species of trees (such as Douglas fir, Western Red Cedar, Red Alder, Big Leaf Maple, ...) (Figure 5). During our data collection, the weather was cloudy and there was no rainfall, keeping the conditions the same during all of our measurements. The water temperature was around 12°C during the time we were collecting the data at different sites, making water temperature roughly constant among the 6 sites.

Discussion

Based on the statistical analysis, setting the significance level (alpha) at 0.05, and a P-value of 0.296 ($P > 0.05$), our results were not found to be significant.

Therefore, we fail to reject the null hypothesis that there is a linear correlation between stream discharge and DO concentration. The biological model we proposed between stream discharge, DO and salmon population is not supported by the results. There is not sufficient evidence to suggest whether there is a relationship between these two variables, and how they may affect salmon. In addition, these results are not consistent with the findings from previous studies such as the study conducted by Fellman et al. (2015) that indicated oxygen depletion was greatest when stream discharge was low and salmon population was abundant. Our results were possibly affected due to confounding variables such as rain and pH that were present in this field study and the introduction of errors.

One of the limitations of the study was that it was difficult to control for external variables in the field such as rainwater, temperature and pH. Fellman et al. (2015) found that these variables also have an effect on DO concentration. These variables along with stream discharge may have confounded the result of observed DO concentration present at each site, and therefore, it may be important to consider that stream discharge itself may not be a sufficient factor to compare DO concentration between sites. Specifically, for this study, it rained the day before the results were obtained. Rainwater may have caused more runoff of organic matter from river banks into the stream. Thus, coastal rainwater may have affected DO by increasing dissolved organic matter (DOM) in relation to the biological oxygen demand (BOD) of organisms in the stream water (Bao et al., 2018). Ripple sites were also composed of more sediments, meaning that running water of greater velocity may have increased the amount of organic matter reaching the surface of the waters from the bottom. BOD and DO are inversely related, so an increase in BOD would mean a decrease in DO (Gupta et al., 2004). With increased organic matter, and the presence of oxygen in the water, organisms can oxidize organic matter for energy, thus, lowering the levels of oxygen (Krevs & Kucinskiene, 2012). This may explain lower levels of DO in the rapid water sites versus still water sites.

An additional limitation was the availability of still and ripple water sites. Although the still and rapid water sites selected for this study were distinct sites, they are geographically close in distance and were obtained from one area of Salish Creek, rather than multiple areas. Consequently, this may have contributed to the insignificant differences found between the sites. Stream discharge may not vary as much between replicates within one site (upper creek) as it would be between two creeks that are separated with greater distance. Fellman et al. (2015), specifically, studied two sites that were at different elevations, one of which was labelled as a glacial site and the other as a forested site. The sites chosen also varied qualitatively in terms of forestation and glaciation. Thus, one of the reasons the results of our field study may have been inconsistent with the results of the study conducted by Fellman et al. (2015), was the difference in design with regards to site selection. Accordingly, an effective way to improve the study would be to increase the number of sampling sites which would reduce sampling error, and to select sites that are further geographically separated in terms of elevation or distance.

Another way to improve the study would be to measure stream discharge on different times of day, seasons of the year and on several days with presence/absence of rain to account for variance. Multiple factors such as pH, dissolved carbon dioxide concentration, and temperature can be measured to determine the extent to which they affect DO concentration in stream water.

Future research can study the direct effect of stream discharge and DO concentration on the growth and development of salmon once they hatch. Research can also look at the effect of stream discharge and DO concentration on the salmon returning from the ocean to spawn.

Conclusion

Our results fail to reject the null hypothesis, and therefore, fail to provide support for the alternative hypothesis that there is a linear correlation between stream discharge and DO concentration in the water. We conclude that there was not enough statistical evidence to show that there is a linear correlation between these two variables. However, these results do highlight the importance of considering and studying additional factors, such as temperature and pH, and their relation to the DO concentration in stream water.

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Appendix

Trials	Stream wetted channel width (m)	Wetted depth (m)	Cross-sectional area (m^2)	Distance (m) ball travelled in 10.00s	Velocity (m/s) (distance (from previous column)/ 10.00s)	Stream discharge (m^3/s)
1	3.320	0.445	1.4774	0.350	0.0350	0.0413672
2	3.310	0.376	1.24456	0.446	0.0446	0.0444059
3	3.320	0.393	1.30476	0.480	0.0480	0.05010278
4	3.310	0.371	1.22801	0.200	0.0200	0.01964816
5	3.320	0.382	1.26824	0.533	0.0533	0.05407775
Average						0.0419

Table 1. Site A (still water) stream discharge data. GPS coordinates of the site were a latitude of 49.27396 and a longitude of -123.23845. The values in this table are not rounded as they are intermediate values except for the final stream discharge value (average of the 5 stream discharge values calculated at this site) is rounded to the correct number of significant digits to be shown in the tables.

Trials	Stream wetted channel width (m)	Wetted depth (m)	Cross-sectional area (m^2)	Distance ball (m) travelled in 10.00s	Velocity (m/s) (distance (from previous column)/ 10.00s)	Stream discharge (m^3/s)
1	1.700	0.265	0.4505	1.900	0.1900	0.068476
2	1.800	0.213	0.3834	2.900	0.2900	0.0889488
3	1.800	0.295	0.531	2.600	0.2600	0.110448
4	1.750	0.276	0.483	1.500	0.1500	0.05796
5	1.820	0.270	0.4914	2.600	0.2600	0.1022112
Average						0.0856

Table 2. Site B (still water) stream discharge data. GPS coordinates of the site were a latitude of 49. 27378 and a longitude of -123.23834. The values in this table are not rounded as they are intermediate values except for the final stream discharge value (average of the 5 stream discharge values calculated at this site) is rounded to the correct number of significant digits to be shown in the tables.

Trials	Stream wetted channel width (m)	Wetted depth (m)	Cross-sectional area (m^2)	Distance (m) ball travelled in 10.00s	Velocity (m/s)(distance (from previous column)/ 10.00s)	Stream discharge (m^3/s)
1	2.350	0.256	0.6016	0.850	0.0850	0.0409088
2	2.320	0.241	0.55912	0.660	0.0660	0.02952154
3	2.300	0.325	0.7475	0.730	0.0730	0.043654
4	2.300	0.260	0.598	0.900	0.0900	0.043056
5	2.330	0.242	0.56386	0.850	0.0850	0.03834248
Average						0.0391

Table 3. Site C (still water) stream discharge data. GPS coordinates of the site were a latitude of 49.27398 and a longitude of -123.23844. The values in this table are not rounded as they are intermediate values except for the final stream discharge value (average of the 5 stream discharge values calculated at this site) is rounded to the correct number of significant digits to be shown in the tables.

Trials	Stream wetted channel width (m)	Wetted depth (m)	Cross-sectional area (m^2)	Distance (m) ball travelled in 10.00s	Velocity (m/s)(distance (from previous column)/ 10.00s)	Stream discharge (m^3/s)
1	2.920	0.152	0.44384	3.400	0.3400	0.12072448
2	2.900	0.120	0.348	5.800	0.5800	0.161472
3	2.950	0.130	0.3835	5.550	0.5550	0.170274
4	2.890	0.135	0.39015	5.620	0.5620	0.17541144
5	2.910	0.125	0.36375	5.370	0.5370	0.156267
Average						0.157

Table 4. Site D (rapid water) stream discharge data. GPS coordinates of the site were a latitude of 49.27398 and a longitude of -123.23842. The values in this table are not rounded as they are intermediate values except for the final stream discharge value (average of the 5 stream discharge values calculated at this site) is rounded to the correct number of significant digits to be shown in the tables.

Trials	Stream wetted channel width (m)	Wetted depth (m)	Cross-sectional area (m^2)	Distance (m) ball travelled in 10.00s	Velocity (m/s)(distance (from previous column)/ 10.00s)	Stream discharge (m^3/s)
1	1.775	0.180	0.3195	0.930	0.0930	0.0237708
2	1.780	0.212	0.37736	5.600	0.5600	0.16905728
3	1.765	0.170	0.30005	7.600	0.7600	0.1824304
4	1.790	0.184	0.32936	7.840	0.7840	0.206574592
5	1.785	0.160	0.2856	5.200	0.5200	0.1188096
Average						0.140

Table 5. Site E (ripple water) stream discharge data. GPS coordinates of the site were a latitude of 49.26978 and a longitude of -123.23994. The values in this table are not rounded as they are intermediate values except for the final stream discharge value (average of the 5 stream discharge values calculated at this site) is rounded to the correct number of significant digits to be shown in the tables.

Trials	Stream wetted channel width (m)	Wetted depth (m)	Cross-sectional area (m^2)	Distance (m) ball travelled in 10.00s	Velocity (m/s)(distance (from previous column)/ 10.00s)	Stream discharge (m^3/s)
1	1.700	0.228	0.3876	5.000	0.5000	0.15504
2	1.900	0.188	0.3572	5.500	0.5500	0.157168
3	1.850	0.107	0.19795	5.300	0.5300	0.0839308
4	2.000	0.202	0.404	5.750	0.5750	0.18584
5	2.000	0.152	0.304	5.600	0.5600	0.136192
Average						0.144

Table 6. Site F (ripple water) stream discharge data. GPS coordinates of the site were a latitude of 49.27142 and a longitude of -123.23839. The values in this table are not rounded as they are intermediate values except for the final stream discharge value (average of the 5 stream discharge values calculated at this site) is rounded to the correct number of significant digits to be shown in the tables.

Trials / Sites	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
A (still water)	8.3	7.8	7.8	7.7	7.6	7.8
B (still water)	8.1	8.0	7.9	8.0	7.9	8.0
C (still water)	8.2	8.1	8.0	8.1	8.2	8.1
D (ripple water)	8.0	7.4	7.5	7.7	7.5	7.6
E (ripple water)	7.7	8.0	7.5	7.5	7.4	7.6
F (ripple water)	8.0	8.1	8.2	8.0	8.1	8.1

Table 7. Concentration of dissolved oxygen (mg/L) for all six sites. The average of the 5 oxygen concentration measurements at each site are shown in the last column.

sites	GPS coordinates	Mean dissolved oxygen concentration (mg/L) from Table 7.	Mean stream discharge (m^3/s)
A (still water)	Latitude: 49.27396 N Longitude: 123.23845 W	7.8	0.0419
B (still water)	Latitude: 49. 27378 N Longitude: 123.23834 W	8.0	0.0856
C (still water)	latitude: 49.27398 N longitude: 123.23844 W	8.1	0.0391
D (ripple water)	latitude: 49.27398 N longitude: 123.23842 W	7.6	0.157
E (ripple water)	latitude: 49.26978 N longitude: 123.23994 W	7.6	0.140
F (ripple water)	Latitude: 49.27142 N Longitude: 123.23839 W	8.1	0.144

Table 8. Summary table showing the GPS coordinates, mean dissolved oxygen concentration and mean stream discharge for each site.

Sample calculations:

Site A trial 1

Measured values:

Stream wetted channel width (m): 3.320 m

Wetted depth (m): 0.445 m

Distance (m) ball travelled in 10.00s: 0.350 m

Calculated values:

Stream cross-sectional area = stream wetted channel width (m)×wetted depth (m) →
Stream cross-sectional area= (3.320 m)×(0.445 m) = 1.4774 m^2

stream discharge (m^3/s) = velocity (m/s)×area (m^2)×0.8→
stream discharge (m^3/s) = (0.0350 m/s)×(1.4774 m^2)×0.8 = 0.0414 m^3/s

velocity=delta d/delta t → velocity= (0.350 m)/10.00s = 0.0350 m/s