The Relationship Between Stream Discharge and Dissolved Oxygen Levels at Canyon Creek, and Implications Towards Salmon Performance

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Abstract

Dissolved oxygen levels below a critical concentration can have detrimental effects on the performance and proper physiological function of salmon species. It was proposed that stream discharge could be correlated to the concentration of dissolved oxygen present in streams inhabited by salmon. In the current study, the objective was to determine if there was a correlation between stream discharge (m^3/s) and dissolved oxygen levels (mg/L) by obtaining measurements at three ripple-water and three still-water sites on two separate days. A significant positive correlation was determined between stream discharge and dissolved oxygen levels at the West Canyon Creek using the Pearson's r correlation test, with $r=0.7392$ and a p-value of 0.006. These findings can imply that water flow can have an effect on the optimal salmon performance, which can have larger indirect consequences on the surrounding ecosystem.

Introduction

Stream discharge is a mechanism of water flow through the stream and is able to influence environmental conditions such as water temperature, channel morphology, current velocity, as well as habitat and food availability (Durham & Gene, 2006). Depending on how these environmental factors interact with one another, the dissolved oxygen within the stream will differ based on discharge, location, as well as water depth and can range from 1 mg/L to over 20 mg/L (Langland & Cronin, 2003). Stream discharge is a product of stream velocity, wetted depth, and wetted width. Ripple sites along the stream will have a constant discharge allowing for consistent mixing resulting in rich oxygen levels whereas areas of still water will have little flow eventually depleting the site of dissolved oxygen. A study conducted by Wang et al. (2003)

examined two creeks where the stream discharge found was 0.01-0.28 m^3/s and 0.01-0.05 m^3/s at each creek, and found that higher stream discharge resulted in higher readings in oxygen levels.

This dissolved oxygen refers to the level of free oxygen present in water (Fondriest Environmental, 2013) and is vital to the survival of salmon within these streams in order to maintain sufficient oxygen supply for cellular respiration (Kramer, 1987). Generally, the mean dissolved oxygen level requirements for adult salmon is 7 mg/L where stream sites with very low or high dissolved oxygen will result in physiological distress, impaired growth, and lowered survival rates (Armstrong et al., 2003). Salmon swim upstream through stream flows which may include both still water and ripple sites to find optimal habitats to spawn. By investigating different sites, the survivability and habitability of the water along the creek can be deduced.

Stream discharge can possibly influence environmental factors and oxygen levels which may potentially impact the performance of aquatic organisms such as salmon. The relationship between stream discharge and oxygen levels at still and ripple water sites were of interest to identify the effects on salmon populations at Canyon Creek.

The objective of this study was to determine if oxygen levels differed based on stream discharge and how it may affect salmon populations inhabiting still and ripple water sites. The null hypothesis stated that there would be no significant difference in oxygen and stream discharge levels between still and ripple water sites, and that there would be no significant correlation between stream discharge and dissolved oxygen levels. The alternative hypothesis stated that there would be a significant difference in oxygen and stream discharge levels between still and ripple water sites, and a significant correlation between these two variables. As Wang et al. (2003) proposed that higher stream discharge led to higher oxygen readings, it was predicted that ripple sites would have significantly higher dissolved oxygen concentrations than still water sites due to constant replenishment of oxygen. Therefore, it was predicted that there would be a significant positive correlation between dissolved oxygen concentrations and stream discharge.

Methods

Data was measured at the West Canyon Creek near University Hill Elementary School in two sites (still and ripple) on two different days (October 30th and November 8th, 2018). The air temperature on both days was between 8-10^{o}C, and the weather was cloudy, with wet soil due to rainfall but no rain on the days of data collection. The still water site was found following the West Canyon trail about 50 meters from the entrance. The ripple water site was found at the mouth-end of the West Canyon trail.

A 15 metre transect line was laid down through the stream in both still and ripple water sites. Three sites at ripple water and three sites at still water were randomly chosen by a random number generator on each transect line on each of the two days, giving a total of twelve readings.

Measuring Oxygen Levels

An oxygen meter was used to measure the oxygen levels at three sites along the transect line in both still and ripple sites, by attaching a T.I 84 calculator to the Easy Pro link, connected to the oxygen probe. Then, the water samples were collected in plastic cups and the probe was immediately placed in them while gently swirling the sample water the entire time. Oxygen readings (mg/L) were taken once at each site.

Measuring Stream Discharge

The stream discharge is the product of the cross-sectional area of the stream (m^2) and the stream velocity (m/s). At each site, the wetted width of the stream was first measured using the measuring tape. Then, the stream wetted depths at 0.3 metre increments were measured and recorded using a metre stick (Figure 1). The stream cross-sectional area was then calculated at each site by multiplying the wetted stream channel width by the average wetted stream depth.

In addition, the stream velocities were calculated using the "Pooh Stick's Method" by recording the time it took for a tennis ball to travel along the stream before coming to a halt (The Streamkeepers Handbook, 1995). Five trials of velocity measurements were recorded at each of the three sites for both still and ripple waters. Using the five trials, the average velocity for each site was calculated. Finally, the average velocity was multiplied by the cross-sectional area and by the correction factor of 0.8, which calibrates the equation to take into account the characteristics of the tennis ball.

$$\text{Stream discharge} = \text{cross-sectional area} \times \text{average velocity} \times 0.8 \qquad (1)$$

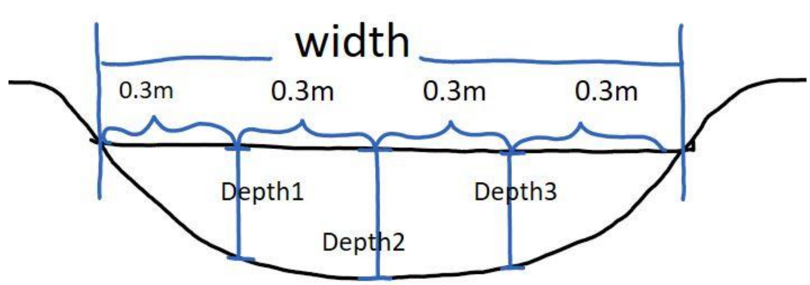

Figure 1. A cross-sectional illustration of a stream showing how measurements were performed to obtain stream discharge.

Statistical Analysis

The mean values of oxygen levels and stream discharge at still-water sites and ripple-water sites were calculated. A 2-sample t-test, p-value and the 95% confidence intervals were then calculated to confirm whether there was a significant difference between oxygen levels and stream discharge values between the two sites.

Additionally, a Pearson R correlation test was performed to determine if there was a correlation between oxygen levels and stream discharge. The Pearson R correlation value, r, and the p-value were calculated to determine if the correlation was positive or negative and if the correlation was significant.

Results

The results obtained from the data compare oxygen levels and stream discharge at still-water sites and ripple-water sites. The results also show the correlation between oxygen levels and stream discharge. Figure 2 compares the mean values of oxygen levels (mg/L) at still-water sites and ripple-water sites. The mean oxygen level at the still-water sites and the ripple-water sites are 7.37 mg/L and 8.65 mg/L, respectively. The 95% confidence intervals are 0.68 for the still-water site and 0.000686 for the ripple-water site, and the standard deviation is 0.86 at the still-water site, and 0.42 at the ripple-water site. The t-value is 3.24, with a p-value of 0.0089. Since $p < 0.05$, the difference between these means is statistically significant, suggesting that oxygen levels are significantly higher at ripple-water sites than still-water sites (Figure 2). Figure 3 compares the mean values of stream discharge (m^3/s) at still-water sites and ripple-water sites. The mean stream discharge at the still-water site is 0.00215 m^3/s and the mean stream discharge at ripple sites is 0.0156m³/s. The 95% confidence intervals are 0.34 at the still-water site and 0.002 at the ripple-water site, while the standard deviation values are 0.00215 for the still-water site and 0.00295 for the ripple-water site. The t-value is 10.67 with a p-value of 0.00001. The difference between these means is statistically significant because $p<0.05$, showing that stream discharge is significantly higher at the ripple-water sites than the still water sites (Figure 3).

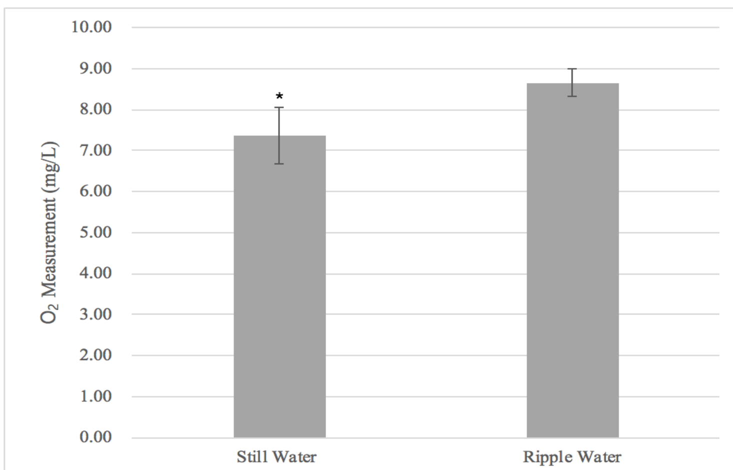

Figure 2. Mean oxygen levels (mg/L) at still water (left) and ripple-water sites (right) (n=6). Error bars represent 95% confidence intervals (0.68 at still water site, 0.000686 at ripple sites), where $p\leq0.05$. The standard deviations for still water and ripple sites are 0.86 and 0.42, respectively. The t-value is 3.24 and p-value is 0.0089.

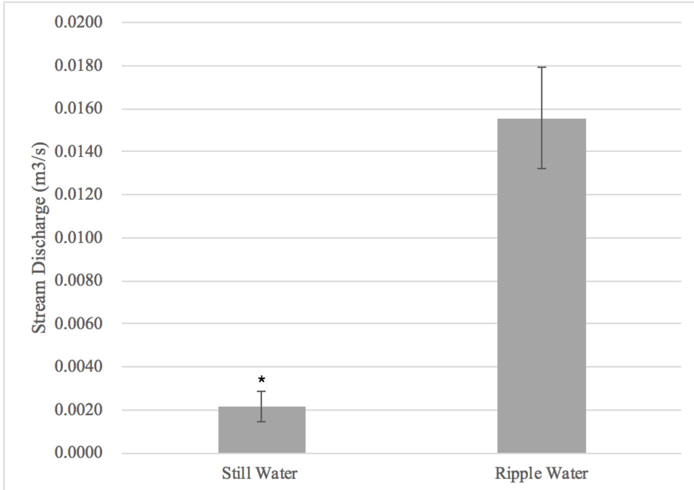

Figure 3. Mean stream discharge (m^3/s) at still water (left) and ripple-water sites (right) (n=6). Error bars represent 95% confidence intervals (0.34 at still water site, 0.002 at ripple site), where $p \leq 0.05$. The standard deviations for still water and ripple sites are 0.00215 and 0.00295, respectively. The t-value is 10.67 and p-value is <0.00001.

Figure 4 displays a scatter plot to show a visual representation of the relationship between oxygen levels and stream discharge. Oxygen levels and stream discharge have a moderate positive correlation, with a correlation value, r, of 0.7392 with p=0.006, and a coefficient of determination, R^2, of 0.5472. Since $p<0.05$, this suggests that the positive correlation between oxygen levels and stream discharge is statistically significant.

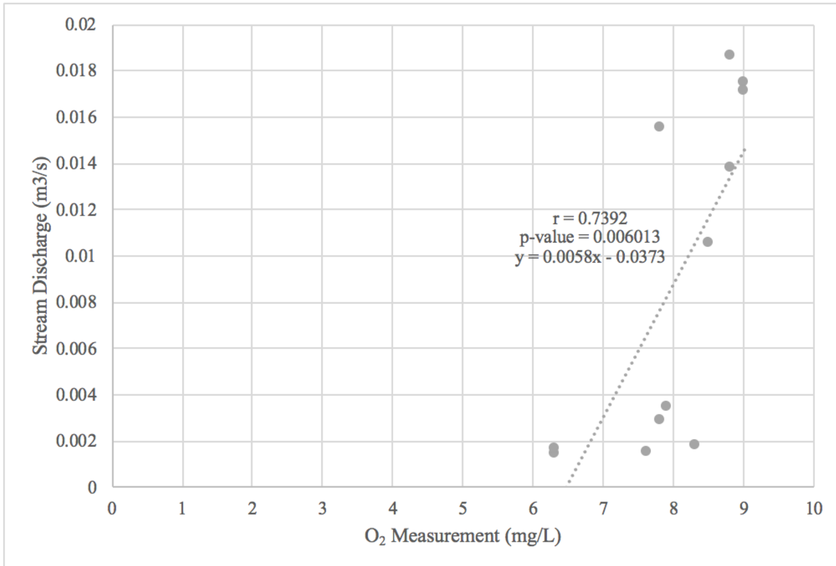

Figure 4. Correlation between oxygen levels (mg/L) and stream discharge (m^3/s) (n=6). Pearson R correlation value, r, is 0.7392 and the p-value is 0.006. The coefficient of determination, R^2, is 0.5472.

Discussion

The aim of this study was to test whether or not stream discharge affects oxygen levels at ripple-water and still-water sites at the West Canyon Creek and to relate our findings to their plausible effects on local salmon populations. In the current study, the null hypothesis was rejected, therefore supporting the alternative hypothesis; Figure 4 shows a correlation between oxygen levels and stream discharge, and the correlation coefficient that was calculated between these two variables, r=0.7392, has a p-value of 0.006, which is less than 0.05, and therefore indicates that there is statistical significance.

As indicated by Figure 2, the mean oxygen levels at the still-water sites and ripple-water sites were significantly different from one another, which is in accordance with our prediction that ripple-water sites would have higher oxygen concentrations. Figure 3 is in agreement with our predictions as well, indicating that stream discharge is significantly higher at the ripple-water sites than the still-water sites. Faster flowing water contains more dissolved oxygen because it has more contact with the air, and it will likely replenish depleted oxygen levels at a specific site along the stream; still-water sites that lack this constant flow of water are unable to replenish depleted oxygen levels, and therefore have lower dissolved oxygen concentrations (Rivers Council, n.d.).

Since a positive r value indicates positive correlation and a negative r value indicates negative correlation, Figure 4 shows a positive correlation between oxygen levels and stream discharge, indicated by the r value of 0.7392. This positive correlation between oxygen levels and stream discharge is statistically significant because the p-value is 0.006 ($p \leq 0.05$). Average oxygen levels at both sites were significantly different from one another and were both above the minimum critical concentration necessary (7 mg/L) for optimal performance in salmon. This suggests that there is no extreme fluctuation in oxygen levels between the two sites, and that neither site would induce physiological stress upon potential salmon populations or embryos inhabiting them.

In order to perform optimally, salmon need a minimum value of dissolved oxygen concentration, and researchers such as Koski (1965) suggest this minimum concentration to be 7 mg/L. At concentrations lower than this, metabolic processes such as swimming performance and growth rate, spawning ability, and embryonic survival can be affected. (Koski, 1965). It has been found that low levels of oxygen concentration are especially detrimental for embryos, as exposure to hypoxic conditions may lead to malformations, slowed growth rate, and premature hatching (Alderdice et al., 1958). Koski (1965) measured the concentration of dissolved oxygen using the standpipe method, where plastic vertical pipes were installed into Coho spawning sites close to where the eggs were deposited. Koski (1965) directly related oxygen concentration levels with embryonic survival, as the higher the dissolved oxygen concentration, the higher the survival rates of the embryos. Additionally, it was found that water velocity, indicative of stream discharge, was positively correlated with embryonic survival, and that it was closely related to dissolved oxygen concentrations, suggesting that streams that have higher stream discharge values would have higher dissolved oxygen concentrations and therefore higher rates of embryonic survival, which agrees with our study (Koski, 1965).

Lower embryonic survival translates to a general decrease in the salmon population, and this has implications in the surrounding ecosystem (Kohler et al., 2007). Nutrients and carbon that salmon take in from marine ecosystems are delivered into freshwater ecosystems once the salmon reach their spawning habitat at the end of their life cycle (Kohler et al., 2007). Marine-derived nutrients such as phosphorus, nitrogen and carbon are released into the ecosystem after the salmon die and decompose, which is vital for the maintenance of trophic productivity (Kohler et al., 2007). The nutrients and carbon are delivered into the forest and surrounding habitats by predators of salmon, which transport the salmon carcasses to these areas (Kohler et al. 2007). A decrease in salmon populations can have severe effects on the ecosystem, as they are keystone species and a main food source to many animals such as black bears, eagles and humans (Kohler et al., 2007). In addition, a decrease in salmon populations will decrease the amount of nutrients delivered to the forest floors, which will decrease overall trophic productivity in the surrounding ecosystems (Kohler et al., 2007).

Further studies are suggested where environmental factors such as weather conditions, gravel composition, water temperature, water murkiness or salinity are taken into account, as these factors may influence the amount of dissolved oxygen present in a stream, and are possible sources of variation. For example, the solubility of oxygen decreases as water temperature increases, resulting in less available oxygen levels (“Water Quality Indicators”, n.d.). It is worth noting that data collection on two separate days may have resulted in increased variation and added extraneous variables to the results. Possible sources of error include the measuring method of the stream velocity. The “Pooh Stick’s” method lacks precision, as the tennis ball got stuck at several sites along the stream such as under logs, leaves, and larger-sized gravel. Future studies should consider the use of more precise equipment like a current meter to obtain more accurate stream discharge readings, and have a larger sample size to verify the presence of a significant correlation between oxygen levels and stream discharge.

Conclusion

The significant difference in oxygen levels and stream discharge values between the still-water and ripple-water sites, and the significant positive correlation between these two variables, suggests that a faster flow of water results in significantly higher oxygen concentrations at West Canyon Creek. These findings agree with our proposed alternative hypothesis and predictions that ripple-water sites would have higher dissolved oxygen levels than still-water sites, and that there would be a positive correlation between stream discharge and oxygen levels. These findings can allow us to determine if a stream has adequate conditions for optimal salmon performance and reproduction.

Acknowledgements

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Appendix

Still water (10.30.18)							
Site (m)	O2 Measurement (mg/L)	Depth (m)	Width (m)	Distance travel (m)	Time (s)	Velocity (m/s)	Stream Discharge (m3/s)
0.4	7.8	0.05	0.8	1.6	34.80	0.046	2.943E-03
		0.12		1.6	47.80	0.033	2.142E-03
		0.13		1.6	29.53	0.054	3.468E-03
				1.6	33.65	0.048	3.043E-03
				1.6	32.95	0.049	3.108E-03
Average	7.8	0.10	0.8	1.6	35.75	0.046	2.941E-03
3.7	8.3	0.04	1.2	1.1	33.77	0.033	1.954E-03
		0.05		1.1	52.50	0.021	1.257E-03
		0.06		1.1	40.90	0.027	1.614E-03
		0.10		1.1	38.39	0.029	1.719E-03
				1.1	48.93	0.022	1.349E-03
Average	8.3	0.06	1.2	1.1	42.90	0.026	1.806E-03
6	7.9	0.09	0.6	3.1	51.83	0.060	3.445E-03
		0.15		2.5	38.45	0.065	3.745E-03
				3.0	42.90	0.070	4.028E-03
				3.0	57.92	0.052	2.983E-03
				2.5	44.02	0.057	3.271E-03
Average	7.9	0.12	0.6	2.8	47.02	0.061	3.495E-03
Total Average	8.00						2.747E-03

Appendix A. Raw Data of Still Water Sites collected on October 30th, 2018

Ripple site (10.30.18)							
Site (m)	O2 Measurement (mg/L)	Depth (m)	Width (m)	Distance travel (m)	Time (s)	Velocity (m/s)	Stream Discharge (m3/s)
4.7	9	0.10	0.5	3.1	6.02	0.515	2.060E-02
				3.1	8.10	0.383	1.531E-02
				3.1	8.58	0.361	1.445E-02
				3.1	5.83	0.532	2.127E-02
				3.1	7.77	0.399	1.596E-02
Average	9	0.10	0.5	3.1	7.26	0.438	1.752E-02
5.9	8.8	0.07	0.5	3.0	6.51	0.461	1.290E-02
				3.0	6.82	0.440	1.232E-02
				3.0	6.73	0.446	1.248E-02
				3.0	5.77	0.520	1.456E-02
				3.0	6.31	0.475	1.331E-02
Average	8.8	0.07	0.5	3.0	6.43	0.468	1.385E-02
4.7	8.5	0.08	0.4	2.5	5.27	0.474	1.214E-02
				2.5	6.04	0.414	1.060E-02
				2.5	7.76	0.322	8.247E-03
				2.5	4.99	0.501	1.283E-02
				2.5	7.05	0.355	9.078E-03
Average	8.5	0.08	0.4	2.5	6.22	0.413	1.058E-02
Total Average	8.77						1.398E-02

Appendix B. Raw Data of Ripple Water Sites collected on October 30th, 2018

Still water (11.8.18)							
Site (m)	O2 Measurement (mg/L)	Depth (m)	Width (m)	Distance travel (m)	Time (s)	Velocity (m/s)	Stream Discharge (m3/s)
0.6	6.3	0.030	1	0.6	36.06	0.017	8.21E-04
		0.080		0.9	24.63	0.037	1.80E-03
		0.075		1.2	33.63	0.036	1.76E-03
				0.7	25.64	0.027	1.35E-03
				0.6	20.00	0.030	1.48E-03
Average	6.3	0.062	1	0.8	27.99	0.029	1.44E-03
3.1	6.3	0.059	0.8	0.7	25.06	0.028	1.83E-03
		0.120		0.7	27.46	0.025	1.67E-03
		0.120		0.7	26.66	0.026	1.72E-03
		0.110		0.7	25.05	0.028	1.83E-03
				0.7	29.72	0.024	1.54E-03
Average	6.3	0.102	0.8	0.7	26.79	0.026	1.67E-03
5	7.6	0.030	1.8	1.3	26.46	0.049	1.50E-03
		0.015		1.3	24.33	0.053	1.63E-03
		0.015		1.3	23.98	0.054	1.65E-03
		0.018		1.3	27.35	0.048	1.45E-03
		0.029		1.3	28.33	0.046	1.40E-03
		0.020					
Average	7.6	0.021	1.8	1.3	26.09	0.050	1.53E-03
Total Average	6.73						1.55E-03

Appendix C. Raw Data of Still Water Sites collected on November 8th, 2018

Ripple site (11.8.18)							
Site (m)	O2 Measurement (mg/L)	Depth (m)	Width (m)	Distance travel (m)	Time (s)	Velocity (m/s)	Stream Discharge (m3/s)
0.5	7.8	0.068	1.3	1	5.82	0.172	1.21E-02
		0.052		1	4.51	0.222	1.56E-02
		0.08		1	6.32	0.158	1.11E-02
		0.07		2	7.12	0.281	1.97E-02
				2	7.22	0.277	1.94E-02
Average	7.8	0.0675	1.3	1.4	6.20	0.222	1.56E-02
4	9	0.12	0.8	1.9	7.45	0.255	1.71E-02
		0.09		1.9	7.83	0.243	1.63E-02
				1.9	7.88	0.241	1.62E-02
				1.9	6.32	0.301	2.02E-02
				1.9	7.36	0.258	1.73E-02
Average	9	0.105	0.8	1.9	7.37	0.260	1.71E-02
5	8.8	0.09	0.6	2	6.00	0.333	1.92E-02
		0.15		2	6.15	0.325	1.87E-02
				2	6.38	0.313	1.81E-02
				2	5.60	0.357	2.06E-02
				2	6.90	0.290	1.67E-02
Average	8.8	0.12	0.6	2	6.21	0.324	1.87E-02
Total Average	8.53						1.71E-02

Appendix D. Raw Data of Ripple Water Sites collected on November 8th, 2018

	Site	O2 Measurement (mg/L)	Stream Discharge (m3/s)
Still water	0.40	7.80	2.94E-03
	3.70	8.30	1.81E-03
	6.00	7.90	3.49E-03
	0.60	6.30	1.44E-03
	3.10	6.30	1.67E-03
	5.00	7.60	1.53E-03
Average		7.37	2.15E-03
Standard Deviations		0.86	8.57E-04
95% Confidence Interval		0.68	6.86E-04
Ripple	4.70	9.00	1.75E-02
	5.90	8.80	1.38E-02
	7.90	8.50	1.06E-02
	0.50	7.80	1.56E-02
	4.00	9.00	1.71E-02
	5.00	8.80	1.87E-02
Average		8.65	1.56E-02
Standard Deviations		0.42	2.95E-03
95% Confidence Interval		0.34	2.36E-03
t-test		-3.24	-10.67
p-value		8.88E-03	<0.00001
Pearson R correlation	0.7392		
p-value (R correlation)	0.006013		

Appendix E. Raw Data of Oxygen Levels and Stream Discharge at Still Water Sites and Ripple Sites with Statistics

Sample calculation for stream discharge (at site 0.4):

Cross-sectional area: 0.1 * 0.8 = 0.08

Velocity: 1.6 / 34.8 = 0.046

Stream Discharge: 0.08 * 0.046 * 0.8 = 0.00294