Streambed composition and its contribution to spawning viability following the completion of the Stoney Creek weir restoration project

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Abstract:

Salmon populations are highly endangered, and in an attempt to restore these populations, habitat restoration projects have become abundant. The Stoney Creek Environment Committee established one such project to enhance salmon spawning conditions at Stoney Creek in Burnaby, BC, by building three weirs. In this report, the streambed composition of the three weirs is analyzed in relation to salmon spawning conditions for the five species of Salmonidea present in Stoney Creek. The result is a number of spawning viability maps ranking spawning conditions in sections of the weirs for each species. Weir 1 contained the smallest amount of undesirable spawning conditions, mainly because the streambed composition was dominated by cobble. Weir 3 contained the most suitable spawning conditions, with smaller gravel sizes and lower sedimentation levels. We provide rationale to explain which factors may have led to the conditions observed. This is followed by a discussion of our method's uncertainties and restrictions as well as suggestions for future research and management.

Introduction

"Salmon have been on a hundred plus year decline [across] the Pacific Northwest." This startling quotation by R. Lackey in 2008 helps to illustrate the dire situation the local salmon populations are facing across this region. Stream restoration projects are a common approach to promoting the recovery of salmon populations. In the Greater Vancouver Region of British Columbia, Canada, numerous streams have been the focus of restoration projects during the last decade (eg. Slaney 1997; Still Creek Rehabilitation and Enhancement Study 2002; FWCP 2011). In particular, Stoney Creek has been the focus of several restoration projects within the last year.

The Stoney Creek watershed runs though sections of Burnaby, Coquitlam and Port Moody in British Columbia. It consists of a main stem and three tributary channels beginning on Burnaby Mountain and discharging to the Brunette River (City of Coquitlam 2013). Stoney Creek provides habitat for five different species of fish from the family Salmonidea: Cutthroat trout, (Oncorhychus clarkii), Chum salmon, (O. keta), Coho salmon, (O. kisutch), Pink salmon, (O. gorbuscha), and Steelhead trout (O. mykiss) (City of Coquitlam 2013) (Appendix 1).

Historically, Stoney Creek has lacked ideal spawning habitat, which has contributed to a decline in the creek's overall fish population (English 2008). The erosion of the streambed down to bedrock led to the destruction of spawning habitat along much of the upper creek (DFO 2001; James 2013). Salmon require deep beds of gravel to successfully lay their eggs (Montgomery 1996). In the fall of 2012, three weirs were built and gravel was added above the weirs to create additional spawning habitat. The aim was to increase salmon abundance by increasing their fecundity (English 2008; James 2013).

Our post project appraisal focused on the artificially created spawning beds above the three man-made weirs. It is important to investigate the effectiveness of this project to evaluate how well it met its objective of increasing the area of spawning habitat and how the site can be further improved. To analyze this, we sampled and mapped the streambed composition above each weir using the mean size of streambed material. Using our data on gravel size and quantity of fine material, we created maps depicting the quality of spawning habitat for each of the five species of Salmonidea that live in Stoney Creek. To our knowledge, no bed composition research has yet been performed for Stoney Creek. This is partially due to the fact that the restoration project occurred very recently. Our study makes a novel contribution to understanding the effectiveness of the restoration project in providing new spawning habitat for Salmonidea in Stoney Creek.

Methods

We sampled and analyzed the streambed composition of each of the three weirs built in the fall of 2012 as part of the restoration project. The weirs are located in the section of Stoney Creek north of Lougheed Highway, where weir 1 is located furthest upstream and weir 3 is located the furthest downstream (Figure 1). Streambed composition was assessed for a ten-meter stretch upstream from each weir. This was accomplished by laying out a 1m x 1m grid over the spawning beds above the weir from bank to bank at the bankfull width (Figure 2). On-site photos of all sampling sites were recorded (Figure 3). The streambed beneath each grid was analyzed using an adaptation of the Wolman pebble count method (Wolman 1954). We chose ten samples of the streambed substrate randomly from each grid. The sampler randomly stepped into the quadrant, reached down in front of his or her foot, and grasped the first stone touched at the toe of the foot, akin to Wolman's 1954 method. Next, we measured and recorded the length, width, height, and embeddedness of each stone. For each quadrant, we visually estimated the percent fines to the nearest ten percent. Using a measuring tape, we took two depth measurements on the middle of the west and east side of each quadrant. Furthermore, we took velocity measurements using a Global Water FP101 flow probe at ¼, ½ and ¾ of the wetted width for every 2m interval beginning at the upstream boundary of each weir.

We used Microsoft Excel to compute and examine the data. For each quadrant of the three gridded weirs, we computed the average size of streambed sample. The majority of plots contained one extreme upper outlier, classified by being beyond two standard deviations of the overall mean of the plot. We excluded the outliers from the averages. Without the exclusion of the outliers, the averages would have led to over-sized classifications of the plot under the Wolman categories (Wolman 1954) and would not have been representative of the majority of material in the quadrant. We classified each square of the grid based on the Wolman Pebble Count classifications (1954) (Table 1). The intermediate width of each sample was the primary dimension used to classify the material category, with length and with being secondary in accordance with the Wolman (1954) method (Figure 4). Using this data, we constructed a spawning viability map of the area above each weir for each of the different species of spawning salmon within Stoney Creek. This resulted in the production of a total of nine spawning viability maps (Figures 5-7). The maps contained three different habitat categories: 'good', 'fair', and 'poor'. 'Good' spawning habitat represented that which contained both an optimal average size of gravel and low amounts of fine material (as determined by average embeddedness and visual percent fines estimates). Habitat classified as 'fair' contained gravel of an appropriate size for spawning but also contained medium or high amounts of fine sediment. 'Poor' material lacked the appropriate size of gravel and/or contained medium or high amounts of sediment. We created separate maps of streambed composition for each of the three weirs (Figure 8). In addition, we produced three graphs of the substrate cumulative streambed distribution for each weir using Excel (Figure 9). To validate the reliability of our data, we tested the sample distributions for each weir against the Normal distribution.

Results

The maps and graphs produced show the differences in spawning viability for each weir. As conditions required for spawning vary among the five different fish species, the production of a separate viability map at each weir for each species helps illustrate the usefulness of the weirs in enhancing the spawning habitat for each individual species. Viability maps for Pink salmon and Cutthroat trout were not produced because the data collected showed that the weirs were not useful in creating viable spawning habitats for these species.

Weir 1

Weir 1 is the most upstream of the three weirs. Maps of streambed viability were produced for Coho salmon, Chum salmon, and Steelhead trout (Figure 5). This section is unique in that the viability maps produced for the three species virtually identical. In general, amongst the three species, weir 1 spawning viability is 'poor' for greater than 50% of the studied weir area. We determined this by looking at the number of grids with a 'poor' classification versus the number with 'fair' and 'good' classifications. Spawning viability improves to 'fair' along the northeastern edge, and the majority of the 'good' spawning sites are found in the centre of the southern portion.

Weir 2

The area above weir 2 is approximately 50% 'poor' spawning viability (Figure 6). The majority of this section that is classified as 'poor' is on the eastern half. The western half has a higher abundance of portions that can be classified as 'fair' or 'good' spawning viability. Spawning viability is greater at weir 2 for Chum salmon. The majority of viable portions for Chum spawning are classified as 'fair,' with a small portion of plots being classified as 'good.' Spawning viability is second highest for Steelhead trout. The distribution of viability is similar to the distribution for Chum salmon with the main difference being a lower number of quadrants classified as 'good.' Finally, spawning viability is lowest at weir 2 for Coho salmon. This is most noticeable in the reduction of quadrants classified as 'fair' or 'good' in comparison with the other two species.

Weir 3

The overall distribution of spawning viability at weir 3 is similar amongst the three fish species (Figure 7). In general, viable areas are located in the southeast and northwest corners of the studied area. The centre of the section, however, is dominated by 'poor' spawning conditions. Streambed conditions are slightly more suitable for Chum salmon than for Steelhead trout. This is due to there being a larger number of 'good' classified regions for Chum salmon than for Steelhead trout. Spawning viability for weir 3 is the lowest for Coho salmon. Streambed conditions are greater than 50% 'poor' for Coho spawning. A small number of viable regions can be classified as 'fair' or 'good' in comparison to the other two salmon species.

The velocities we measured are acceptable for spawning above all three weirs for Coho salmon, Chum salmon and Steelhead trout (Tables 2 and 3). Water velocity above weir 1 is too high for Pink salmon to spawn (Kondolf 1993; Mull 2005). Because there is virtually no streambed material suitable for pink spawning above this weir, this does not change our ranking of the amount of available spawning habitat for this species. The depth above the first two weirs was acceptable for spawning but was close to the species' low end of tolerance (Geist 1998) (Tables 2 and 3). However, depths may be different during the spawning season. (Kondolf 1993).

Discussion

Spawning conditions were of equal viability for all three species for the area above weir 1. The distributions for weirs 2 and 3 are indicative of the differences in viability for each species. For both these weirs, spawning viability is greatest for Chum salmon and lowest for Coho salmon. Spawning viability was intermediate for Steelhead trout. Very little viable spawning habitat was available for Pink salmon and Cuttroat trout. From this, it is evident that the weir-building initiative for Stoney Creek, with the goal of producing more viable spawning habitats for the resident fish species, was the most effective for Chum salmon and the least effective for Pink salmon and Cutthroat trout.

This study of the Stoney Creek restoration project's weirs found that they do not provide as much optimal spawning habitat as possible, based on the streambed composition. Streambed material ranged from sandy fines to medium boulders, with weirs 1 and 2 having an average overall composition of very coarse gravel, in the 3.6-6.4 cm range and the third weir having an overall composition of coarse gravel, in the 1.6-3.2cm range. This larger, very coarse gravel was generally on the upper limits of suitable spawning gravel size for the main species of salmon (Chum and Coho) present in the stream, and vastly too large for the small populations of Cutthroat trout and Pink salmon to utilize (Kondolf 1993). This larger gravel size contributes to the overall poor quality of spawning habitat above weir 1 and 2. Weir 3, on the other hand, had a smaller overall composition of gravel and this in part helped contribute to its better overall suitability for salmon spawning.

Coupled with the issue of poor gravel size is the fact that there has been a large amount of fine sediment depositions in portions of each weir. While all three weirs have noticeable sediment deposits, weir 3 has the largest areas of sand. These large patches of sand have marred and in some cases completely covered areas of ideal sized spawning gravel. One of the main causes for this large sediment build-up in weir 3 is likely the long section of calm water between weir 2 and weir 3 (Table 3), which allows for the current to slow and fines to settle out of the water. These deposited fines impede salmon spawning and egg viability (Jensen 2009).

While the streambed composition is important, many other factors also influence spawning viability. Other main factors include, but are not limited to, water velocity, depth, and temperature (Moscrip 2007; Jensen 2009). Water velocities play a key role in salmon spawning within Stoney Creek and salmon-bearing creeks in general (Jensen 2009). Salmon require certain optimal water velocities to spawn and will actively search out gravel beds with these velocities (Kondolf 1993; Mull 2005). If the velocity is too low, silt can build up between the stones and smother the eggs (Jensen 2009) and if the velocity is too high, the gravel will erode and the eggs will wash away (DFO 2001). Finding the right balance is essential for successful spawning. This balance differs between each species (Table 2). Salmon also require a certain range of depths to spawn (Geist 1998) (Table 2). Depth and water velocity are both factors incorporated into salmon spawning bed selection.

The problem with both of these factors is that they are subject to variance. Rainfall events can dramatically change water depth and velocity, altering the “ideal” spawning conditions found in the stream (Moscrip 2007). This rising and falling of the water levels can lead to salmon spawning on gravel bars with the potential to be exposed by the receding waters, causing the eggs to suffocate (DFO 2001).Increased water levels can also lead to large deposits of silt which can smother salmon eggs and suffocate them (Jensen 2009). Therefore, it is difficult to quantify how depth and velocity affect salmon spawning. For this reason, they were not included in our viability maps, despite the fact that these two important factors were included in our initial measurements.

It is noteworthy that spawning viability improved for all fish species as the study progressed downstream from weir 1 to weir 3. Weir 1 consisted of the least suitable spawning conditions and weir 3 consisted of the most suitable. This variation may be due to the accumulation of larger rocks in weir 1, which are not conducive to spawning for the species studied. This may have occurred due to a faster stream velocity upstream (Table 2). As this occurs, larger cobbles and pebbles are deposited higher upstream because the energy required to carry them is lost (Rubey 1933; Dietrich 1979). Smaller pebbles and fine particles are carried further downstream because less energy is required to move them (Dietrich 1979). This pattern also explains the more uneven distribution of fine particles in weir 3, where most of the fines are deposited. The distribution of appropriate gravel sizes in the streambed may also be partially explained by the formation of eddies, riffles, and other stream velocity phenomena that could alter the deposition of streambed elements after construction of the weir project (Quinn et al. 2007).

Another important spawning condition to consider is water temperature, which directly affects salmon spawning and embryo development (Velsen 1987). Because our research took place in the spring rather than in the spawning season, we were unable to obtain relevant temperature data. However, it should be recognized that water temperature is a very important aspect of spawning viability. Not only does it determine if and when the salmon will spawn, it also determines the incubation period required by the eggs before they hatch (Mull 2005). In colder conditions, Salmonidea eggs take longer to hatch. In warmer water, the eggs hatch more quickly, until a certain point is reached where it is too warm for eggs to survive (Velsen 1987). Therefore, water temperature across these weirs must be considered and acknowledged as an important aspect of spawning.

Overall, the two goals of the weir project were to improve the migration pathway for spawning salmon and to increase the number of spawning habitats (SCEC Funding Application 2012). Based on our data analysis, it appears that the latter goal has been successful. Before the weirs were built, much of this section of streambed was not viable for salmon spawning. Our analysis shows that for three species of Salmonidea (Coho, Chum, Steelhead) the weirs are now approximately 30-50% viable for spawning, as determined by the proportion of quadrants classified as good and fair. Other research (see the Stoney Creek Environment Committee's 2012 Spawner Report) suggests that the first goal of the weir project – to improve migration of salmon across the weirs – has also been successful. Since the completion of the weirs, salmon counts have improved upstream of the weirs and, most significantly, downstream of the weirs as well. This indicates that passage across the section of creek has become more accessible for salmon crossing. In particular, 2012 was a record year for Chum salmon spawning above the weirs (SCEC Spawner Report 2012). Therefore, while not perfect, these weirs are achieving their goals in helping to aid the recovery of the salmon population in Stoney Creek.

Uncertainties and Limitations

Although the gravel sizes we measured followed a Normal distribution (Figure 9), supporting the representativeness of our samples, our measurements and sampling method still contained uncertainties. The measuring tape used to measure out the 1m x 1m grids had an uncertainty of +/- 3 cm. The rulers used to measure the gravel had a 0.1 mm uncertainty and dimensions were estimated to the nearest 0.5 cm to increase efficiency. This should not be a major factor as Wolman's (1954) method is measured to the nearest half-centimeter. Estimates of embeddedness and percent fines had a margin of error of +/- 10% and may have differed subjectively based on which group member was collecting the samples.

We took the water velocity measurements on two separate days throughout the study site. Then we calculated the average velocity above each weir. Had time permitted additional velocity measurements, our sample mean would have been more representative of the true mean velocity.

A large source of uncertainty was the averaging of the streambed material size in each quadrant. While we removed extreme outliers, the averaging of sizes was a generalization which resulted in low resolution data which are not completely representative of the range of material sizes present in each quadrant.

The original plan was to take twenty-five samples per quadrant, but due to time constraints, only ten samples per quadrant were taken. With more data samples collected, a better average of the overall composition could have been obtained. Nevertheless, ten samples provided a fair coverage for a random scatter in the 1m x 1m grid. The fact that our sample resulted in a Normal distribution of material sizes shows that our sample was representative of the true streambed composition.

A more in-depth study could potentially depict the individual effects of water velocity, depth, pH, temperature, salinity, and turbidity – all factors affecting salmon spawning above these weirs. Although we incorporated some of these factors into our final report, a more detailed, longer termed study could provide a broader perspective on the weirs and Stoney Creek as a whole.

Management Recommendations

The restoration project provided a negligible amount of spawning habitat suitable for Pink Salmon and Cutthroat trout, which spawn in a small range of gravel sizes (Table 3). From our analysis of the three weirs, we concluded that the spawning beds above the weirs contained little gravel within these ranges. Instead, the streambed composition was dominated by material in the range of sizes from coarse gravel to fine cobble. This represents material that is 1.6 cm or greater in width, whereas the maximum viable gravel size is 1.1 cm for Pink salmon and 0.8 cm for Cutthroat trout. To provide optimal spawning area for these two species, smaller gravel within the range of 0.2 cm to 1.1 cm in width should be added above the third weir, where water velocities are slowest. Here, there is less chance for the smaller gravel to be eroded by high water velocities. The area above weir 1 is likely unsuitable for holding smaller gravel, as indicated by a high average water velocity (93.9 cm/s) and a streambed composition containing very little material below the size of coarse gravel (Figure 8).

While there is some gravel appropriate for the spawning of Chum salmon, Coho salmon, and Steelhead trout, the area of spawning habitat for each of these species is also limited by the average large size of streambed material. Large areas were deemed poor quality habitat for these species because the average streambed composition exceeded the viable ranges for these species. More gravel within the size range of 1.1 cm to 3.3 cm should be provided for these species. Within this range of sizes, all three species can spawn viably, provided other conditions such as fine material content, water depth, and velocity are also suitable.

The second most limiting factor for spawning viability above the weirs was the presence of a high amount of fine material. Our study area had been eroded down to bedrock prior to its restoration in Fall 2012 (James 2013). To our knowledge, no fine material was added to the stream during the restoration project. There would be no reason to have done so, as fine material impedes the survival of salmon eggs (Jensen 2009). Hence, this fine material must have accumulated in the short amount of time that elapsed between the restoration project and our study. Future research should be conducted to determine if the main source of the fine materials in Stoney Creek is anthropogenic or not. This would inform possible future management strategies to reduce the amount of fine materials entering the creek. Alternatively, fine materials could be removed from the creek using settlement tanks or catch basins. It may be more cost-effective, however, to identify the source of the fine sediments entering the stream and work out a management strategy that would reduce their overall inputs.

Conclusion

While the weirs appear to be successful in improving spawning habitat for Coho, Chum, and Cutthroat trout, our analysis found that this goal was not met for Pink and Steelhead. We recommend that future management efforts alter the streambed conditions so that they are more suitable to these two species. However, our research concentrated on streambed composition as the only factor affecting spawning conditions. The inclusion of other important factors such as temperature, velocity, and depth could reduce the uncertainties of this assessment and therefore should be studied. Including these factors could alter our assessment of habitat upon the weirs, either for better or worse. The formation of the weirs has generally been beneficial to the spawning salmon population of Stoney Creek, especially as this area of the stream was mostly unsuitable for use as spawning grounds before the weirs were built. Given the fact that climate change is altering natural ecosystems and further endangering salmon populations – not only in British Columbia, but across the globe – the production of these weirs were an important step towards preserving salmon populations by restoring and enhancing their natural habitat.

References Cited

City of Coquitlam. (2013). Sewer and Drainage. http://www.coquitlam.ca/city-services/drainage-sewer/stormwater-management/integrated-watershed-management.aspx Accessed April 17th 2013.

Dietrich, W., Smith, D., and Dunne, T. (1979). Flow and sediment transport in a sand bedded meander. The Journal of Geology. 87(3): 305-315.

DFO (2001). Juvenile Salmonid studies in the Brunette River basin, Burnaby, BC, spring 2000. Fish, Wildlife, and Recreation Program, BC Institute of Technology.

English, K., Glova, G., and Blakley A. (2008). An upstream battle: declines in 10 Pacific salmon stalks and solutions for their survival. David Suzuki Foundation.

FWCP – Fish and Wildlife Compensation Program. (2011). Alouette Watershed, species of interest action plan, final draft. Fisheries and Oceans Canada.

Geist, D., and Dauble, D. (1998). Redd site selection and spawning habitat by fall chinook salmon: the importance of geomorphic features in large rivers. Environmental Management. 22(5): 655-669.

Lackey, Robert T. (2008). Salmon Decline in Western North America: Historical Context. In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, DC, Environmental Information Coalition, National Council for Science and the Environment).

James, A., and Ensing, C. 2013. Stoney Creek Weir Project – SFU. https://www.youtube.com/watch?v=nZUgKuxEuLk

Jensen, D., Ashley, S., Fullerton, A., and Pess, G. (2009). Impact of fine sediment on egg-to-fry survival of Pacific Salmon, a meta analysis of published studies. Fisheries Sciences. 17(3): 348-359.

Kondolf, M. (1993). Sizes of salmonid spawning gravel. Water Resources Research. 29: 2275-2285.

McPhail J., and Carveth R. (1993). Field key to the freshwater fishes of British Columbia. Resources Inventory Committee (Canada).

Ministry of Forests, Lands, and Natural Resource Operations for British Columbia – Canada. Sport fish of BC. 2013. http://www.env.gov.bc.ca/fw/fish/sport_fish/

Montgomery, D., Buffington, J., Peterson N., Schuett-Hames D., and Quinn T. (1996). Stream-bed scour, egg burial depths, and the influence of Salmonid spawning o n bed surface mobility and embryo survival. Canadian Journal of Fish and Aquatic Science.. 53: 1061-170

Moscrip, A., and Montgomery, D. (2007). Urbanization, flood frequency, and salmon abundance in puget lowland streams. Journal of American Water Resources Association. 33(6): 1289-1297.

Mull, K. (2005). Selection of spawning sites by coho salmon in freshwater creek, California. A thesis presented to the faculty of Humboldt state university.

Quinn, J., Philips, M. and Parkyn, S. Factors influencing retention- of coarse particulate organic matter in streams. Earth Surface Processes and Landforms. 32: 1186-1203.

Rubey, W. (1933). Settling velocity of gravel, sand, and silt particles. American Journal of Science. 148: 325-338.

SCEC – Spawner Report – Stoney Creek Environment Committee (2012). 3pp.

SCEC – Stoney Creek Environment Committee. (2012). Application of funding to pacific salmon foundation community salmon program. 11pp.

Slaney, P., and Zaldokas, D. (1997). Fish habitat rehabilitation procedures – watershed restoration technical circular No. 9. BC Ministry of Environment, Lands, and Parks, and Ministry of Forests.

Still Creek Rehabilitation and Enhancement Study. (2002). Prepared for the City of Vancouver, BC, Canada. Planning Department.

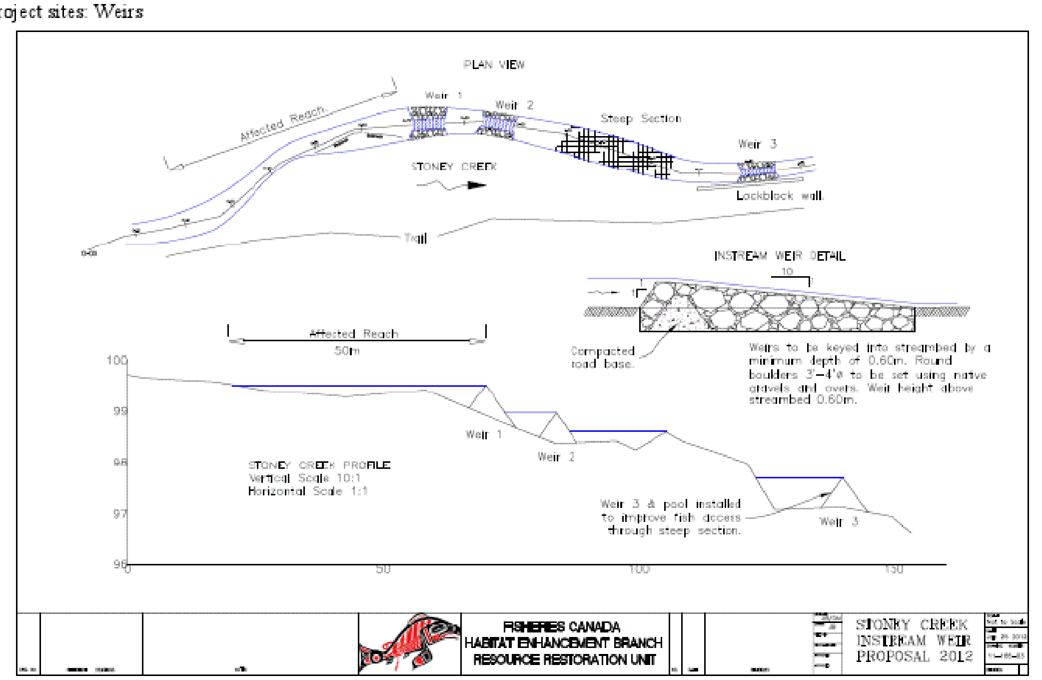
Velsen, F. (1987). Temp and incubation in pacific salmon and rainbow trout: compilation of data on medium hatch time, mortality, and embryonic staging. Fisheries and Aquatic Sciences. 626.

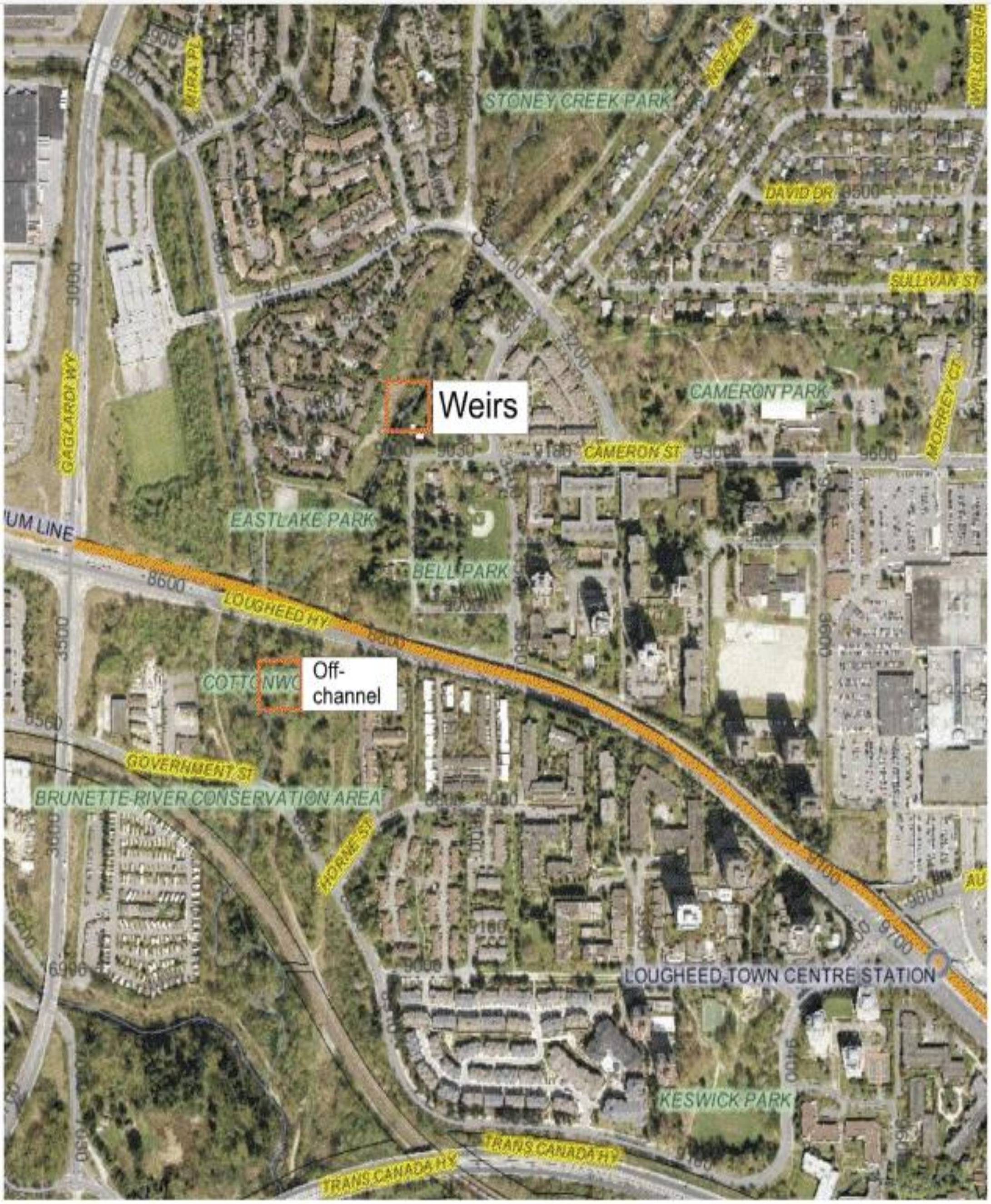
Wolman, M. (1954). A Method of Sampling Coarse River-Bed Material. Transactions of the American Geophysical Union 35(6):951-956.

Figures

Figure 1: Below is the schematic of the three weirs created in this restoration project, showing the outline of the work done. The second image is of the location of the weirs themselves – northeastern Burnaby, British Columbia, Canada (SCEC 2012).

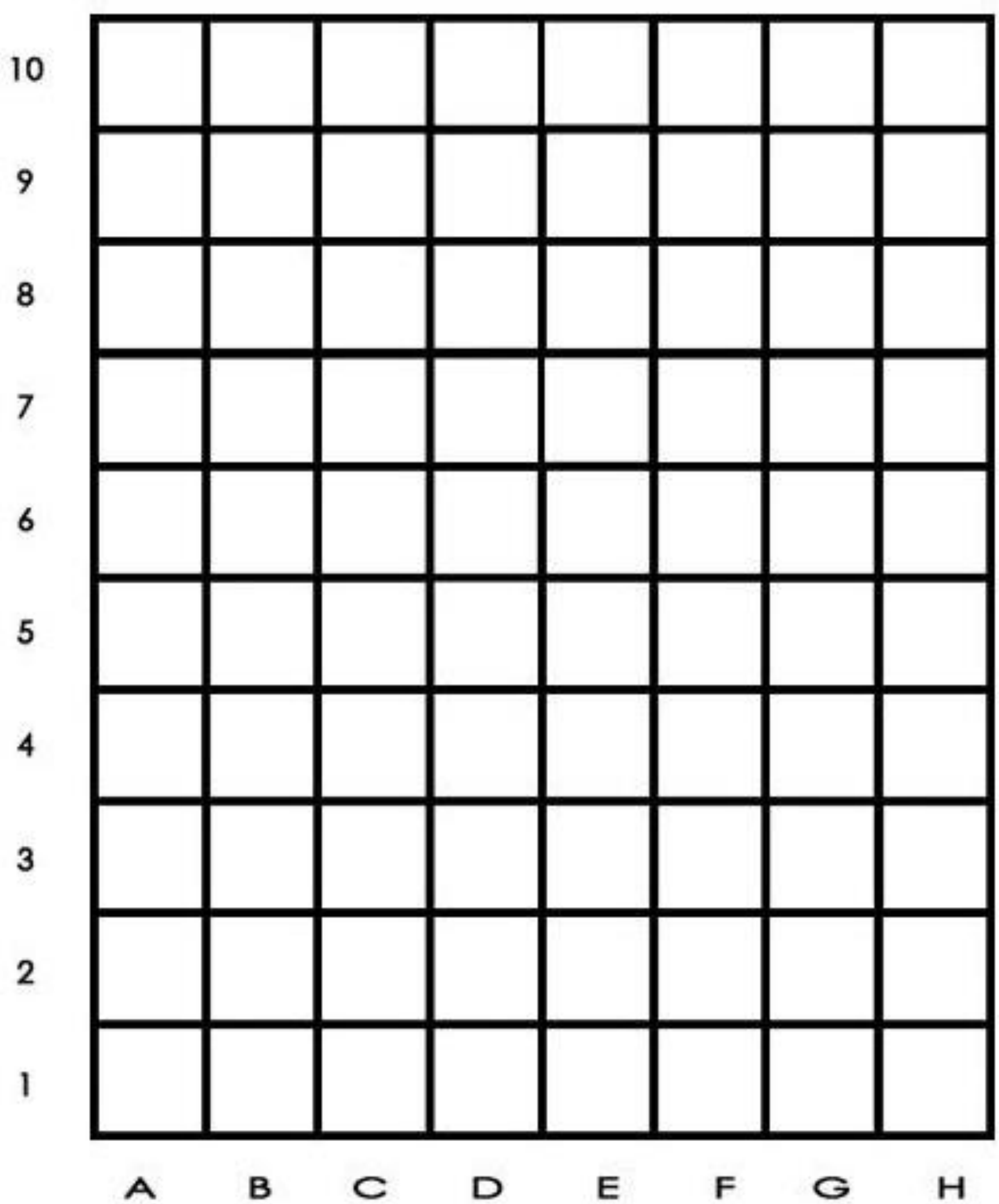
Project sites: Weirs





Stoney Creek Adjacent to Beaverbrook Crescent and Stoney Creek School
Upstream of Lougheed Highway in Burnaby BC

<u>Figure 2</u>: Below is a sample of the grid laid used out above each weir. Each square is a 1m x 1m quadrant. This grid was laid out for ten meters above each weir, from the high water mark to high water mark on either side of the stream. Ten random substrate samples were taken from each quadrant.



<u>Figure 3</u>: Below are photographs recording our sampling sites, process.

<u>Weir 1</u>:

Weir 2:

Weir 3:

Table 1: Below are the ranges of sizes used to classify the substrate material sampled from Stoney Creek. These measurements are based on Wolman's 1954 pebble count method.

	Size Range(cm)	
Sand	<	0.2
Very Fine Gravel	0.2	0.4
Fine Gravel	0.4	0.8
Medium Gravel	0.8	1.6
Coarse Gravel	1.6	3.2
Very Coarse Gravel	3.2	6.4
Small Cobble	6.4	9.0
Medium Cobble	9.0	12.8
Large Cobble	12.8	18.0
Very Large Cobble	18.0	25.6
Small Boulder	25.6	51.2
Medium Boulder	51.2	102.4
Large Boulder	102.4	204.8
Very Large Boulder	204.8	409.6

Figure 4: Visual of measurement parameters.

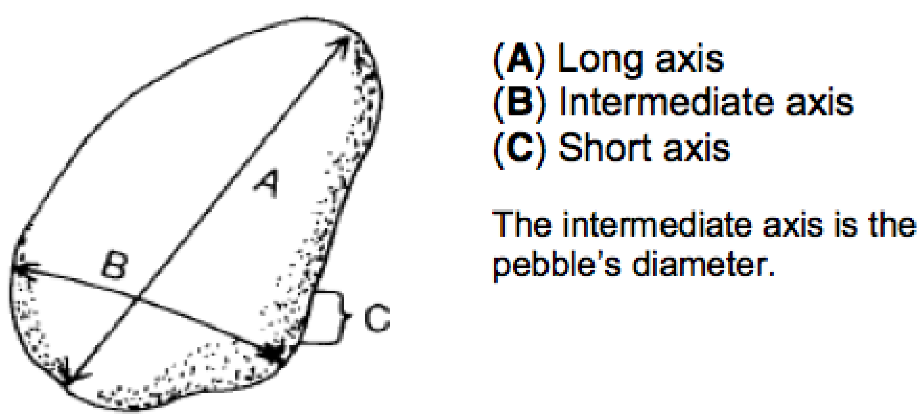
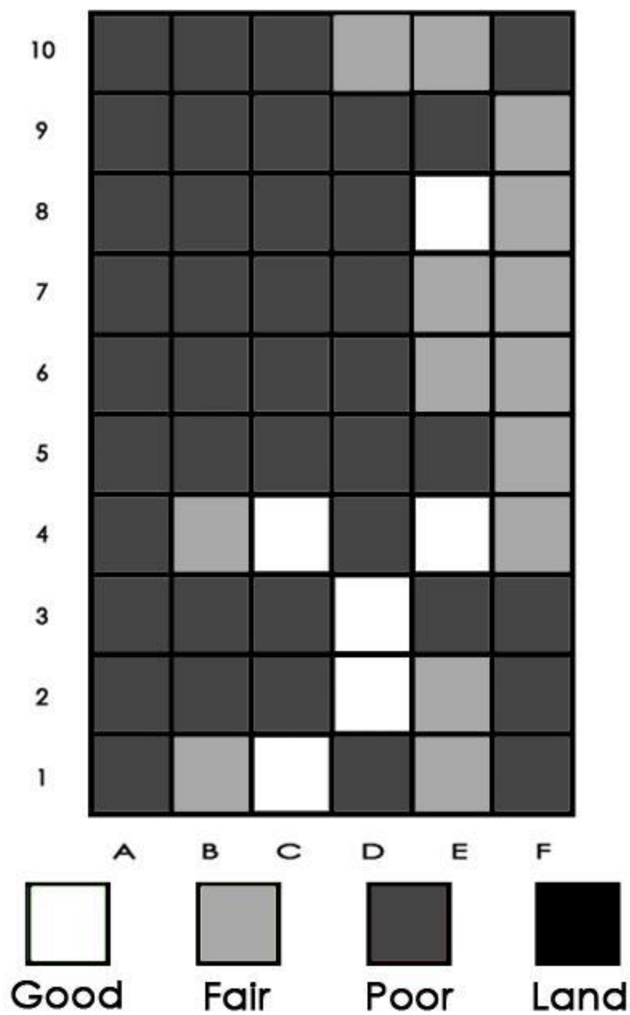
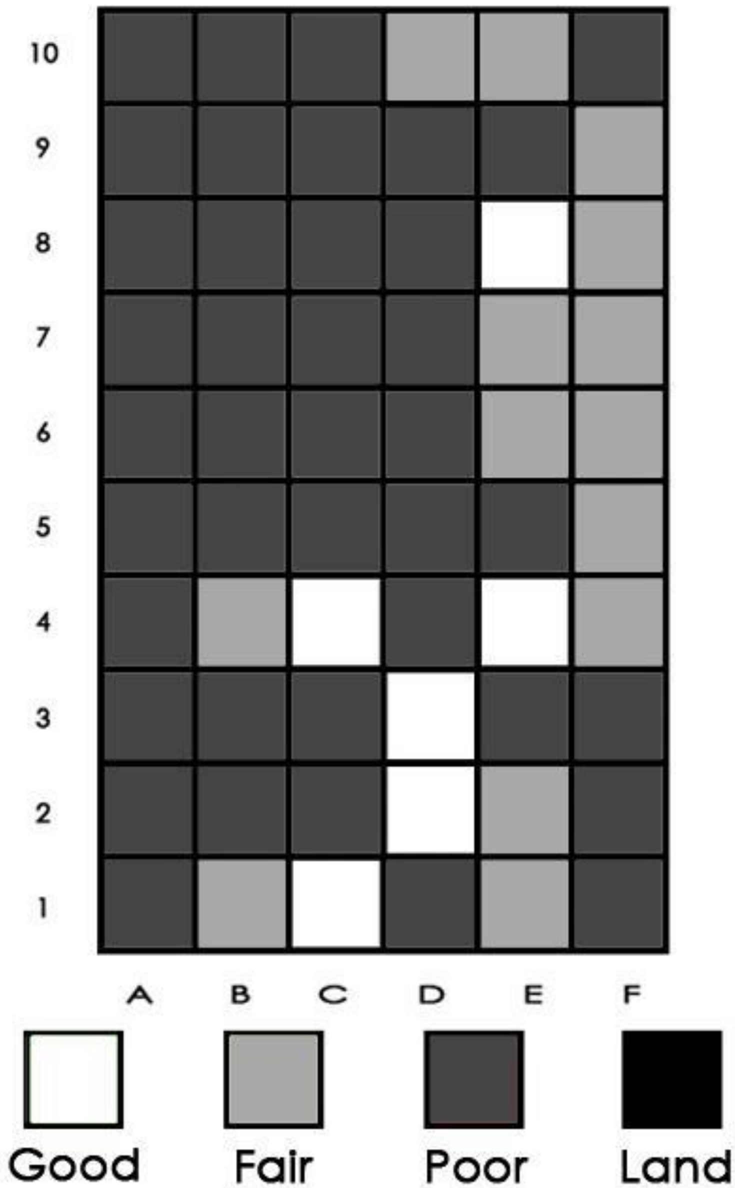


Figure 5: Below are the three spawning viability maps for weir 1, for Chum, Coho, and Steelhead. Pinks and Cutthroat trout maps were not created for the composition of the streambed material is not suitable for either of the two fish species in regards to spawning. The lines on each map represent a one by one meter square grid. Good = good spawning material, lacking fines. Fair = ok spawning material, some fines accumulation and some unfavorable sized material. Poor = not good for salmon spawning. Either too many fines are present or the material is too big or too small to be used by the spawning salmon.

Chum Spawning Map, Weir 1:



Coho Spawning Map, Weir 1:



Steelhead Spawning Map, Weir 1:

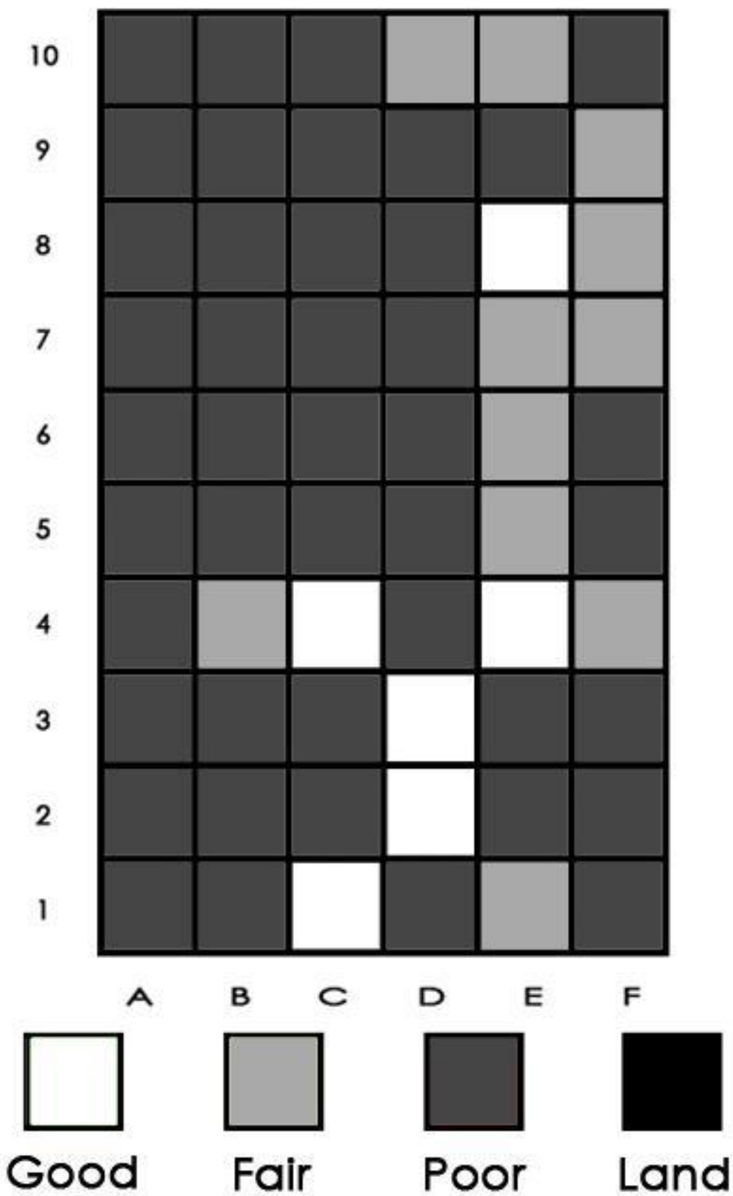
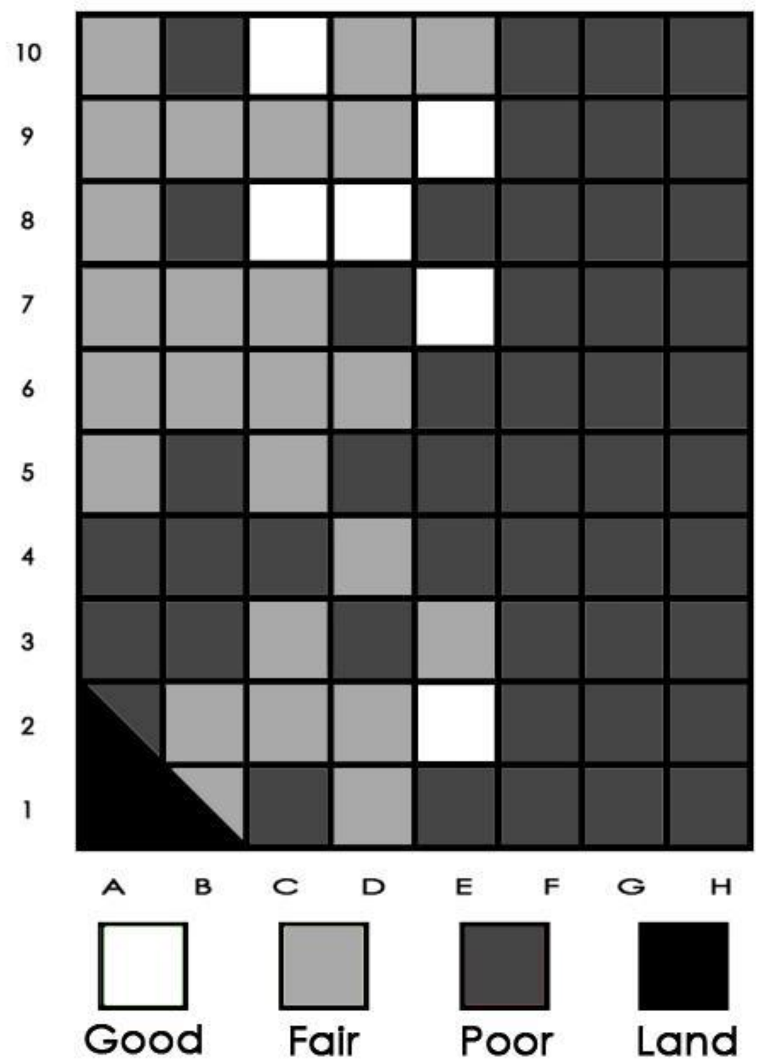
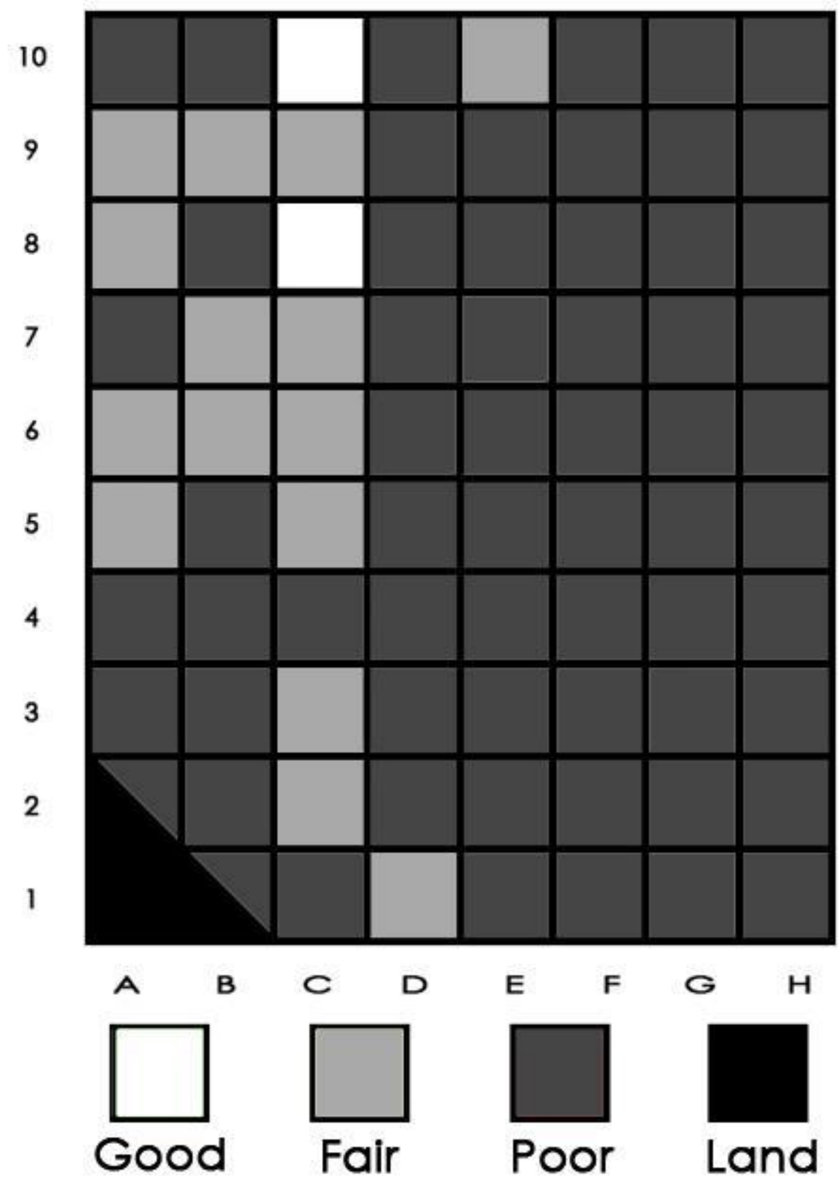


Figure 6: Below are the three spawning viability maps for weir 2, for Chum, Coho, and Steelhead. Pinks and Cutthroat trout maps were not created for the composition of the streambed material is not suitable for either of the two fish species in regards to spawning. The lines on each map represent a one by one meter square grid. Good = good spawning material, lacking fines. Fair = ok spawning material, some fines accumulation and some unfavorable sized material. Poor = not useful for salmon spawning. Either too many fines are present or the material is too big or too small to be used by the spawning salmon.

Chum Spawning Map, Weir 2:



Coho Spawning Map, Weir 2:



Steelhead Spawning Map, Weir 2:

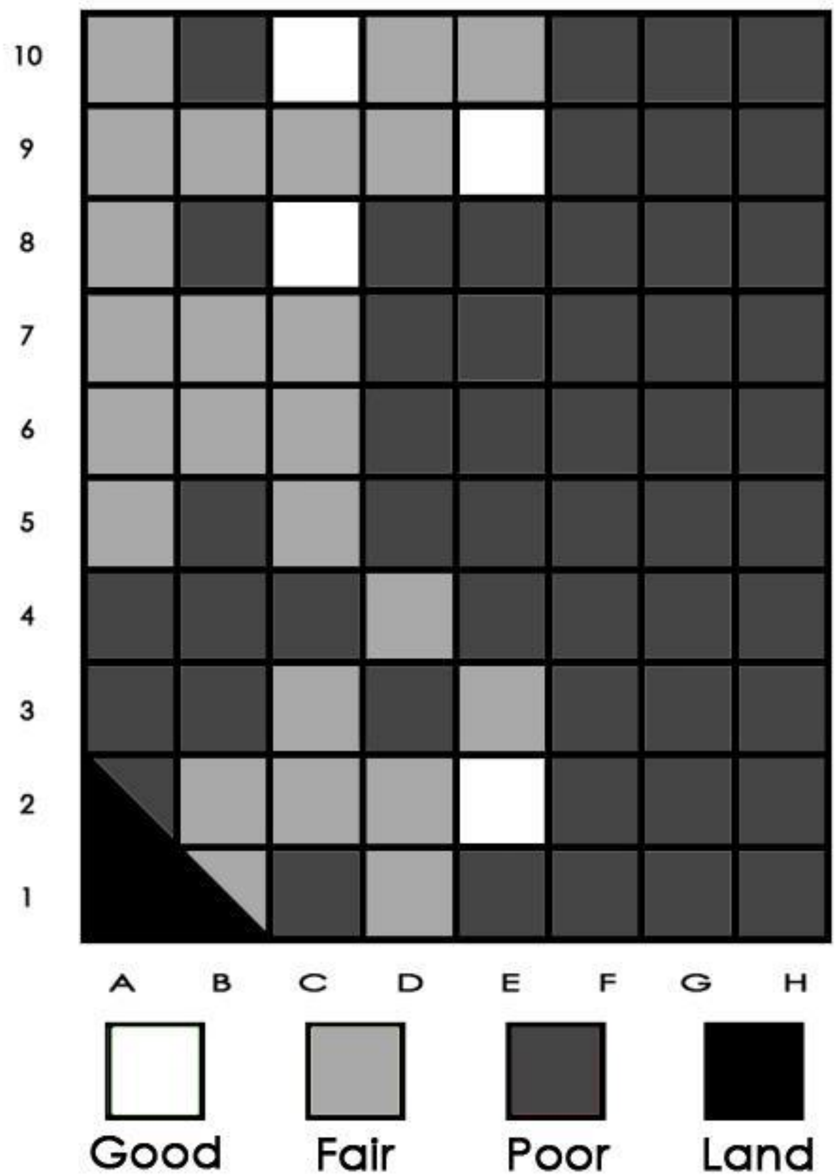
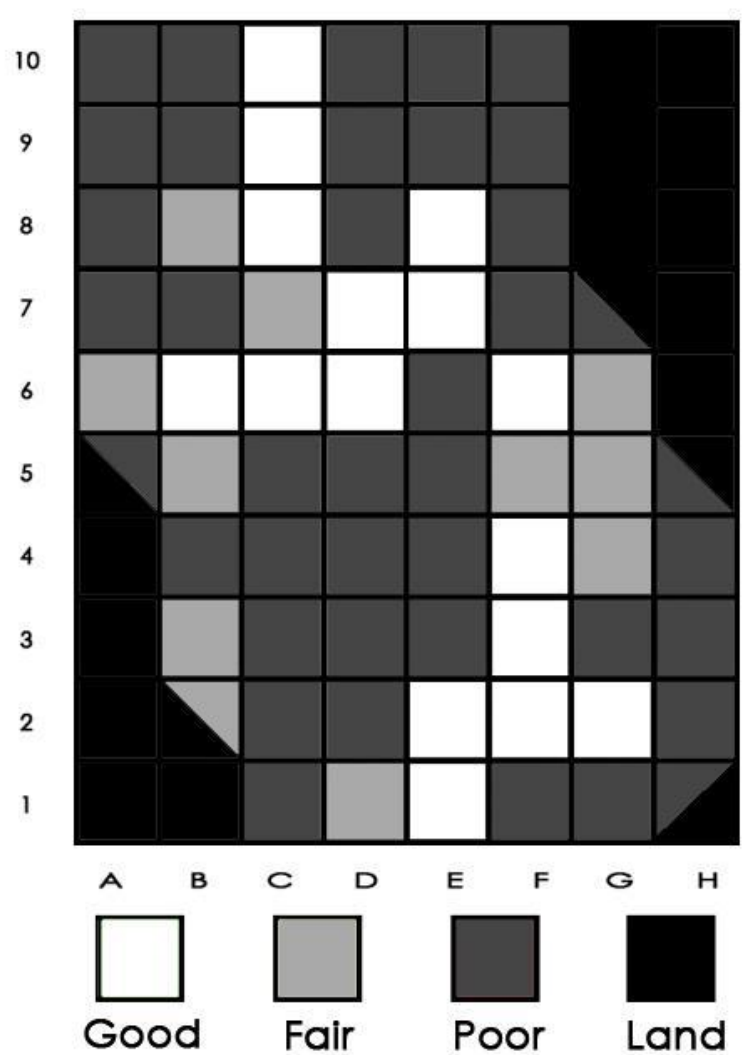
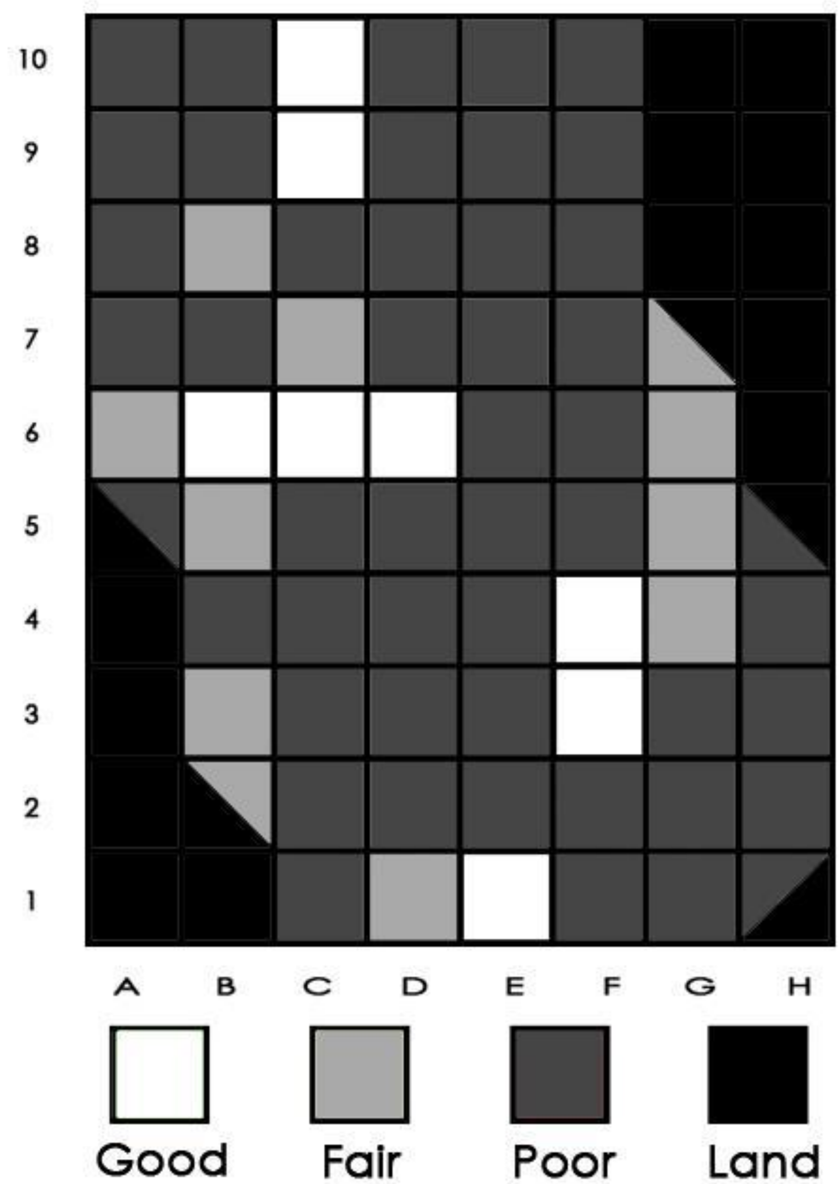


Figure 7: Below are the three spawning viability maps for weir 3, for Chum, Coho, and Steelhead. Pinks and Cutthroat trout maps were not created for the composition of the streambed material is not suitable for either of the two fish species in regards to spawning. The lines on each map represent a one by one meter square grid. Good = good spawning material, lacking fines. Fair = ok spawning material, some fines accumulation and some unfavorable sized material. Poor = not good for salmon spawning. Either too many fines are present or the material is too big or too small to be used by the spawning salmon.

Chum Spawning Map, Weir 3:



Coho Spawning Map, Weir 3:



Steelhead Spawning Map, Weir 3:

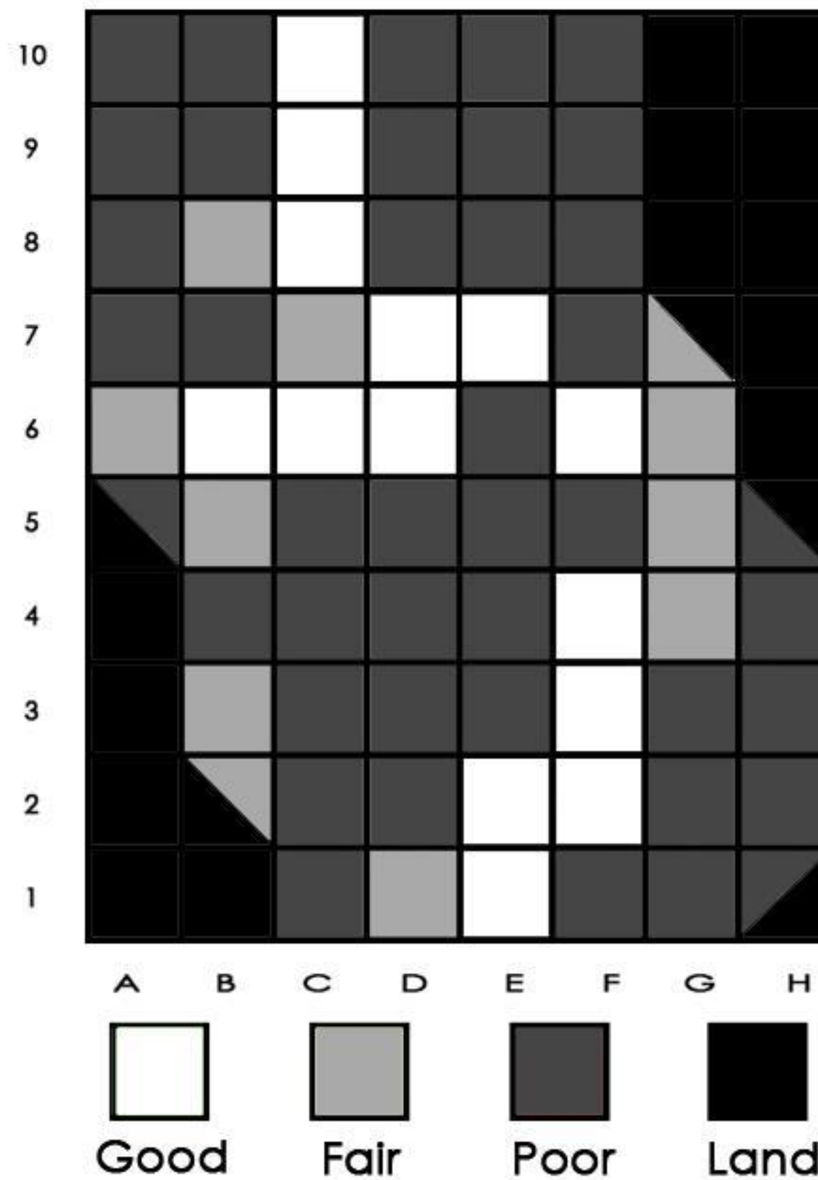
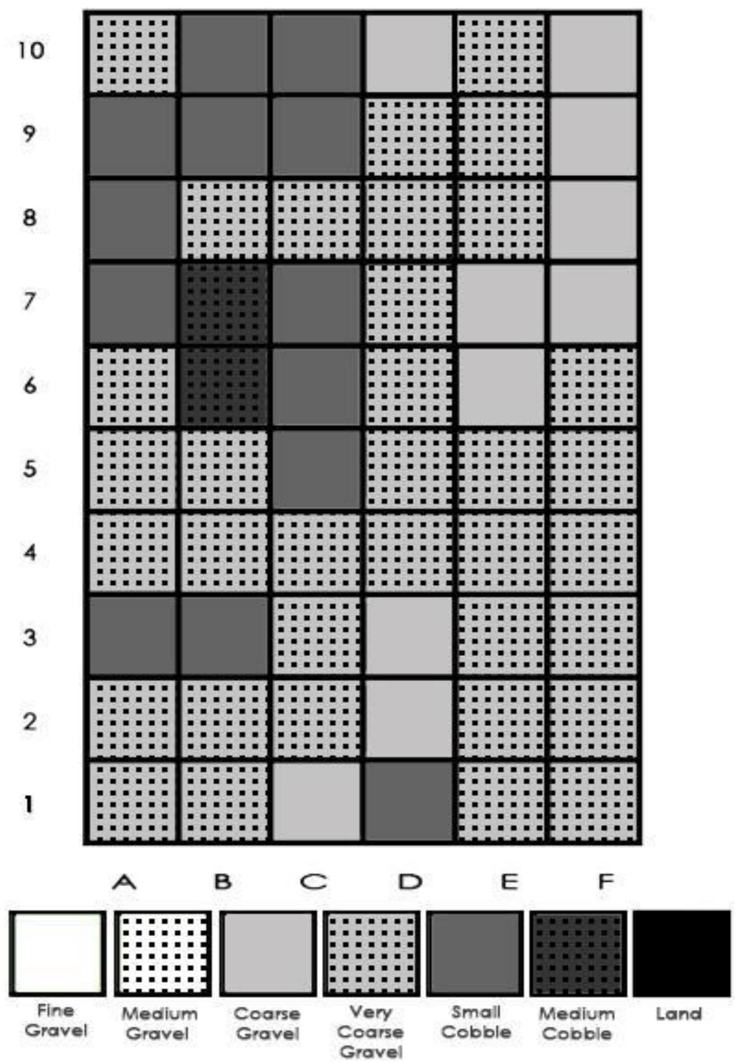
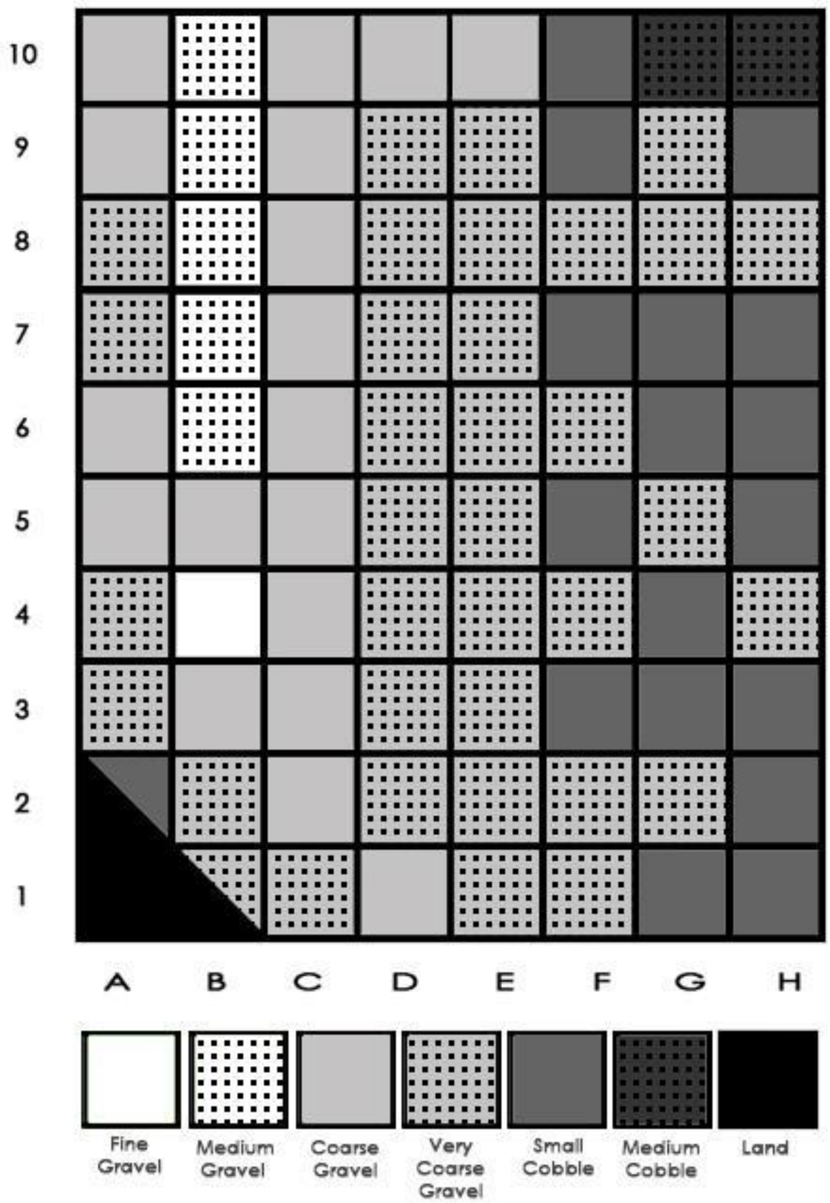


Figure 8: Below are the substrate material composition maps for each of the three weirs. They show the average size of the substrate found across the ten-meter stretch of stream above each weir.

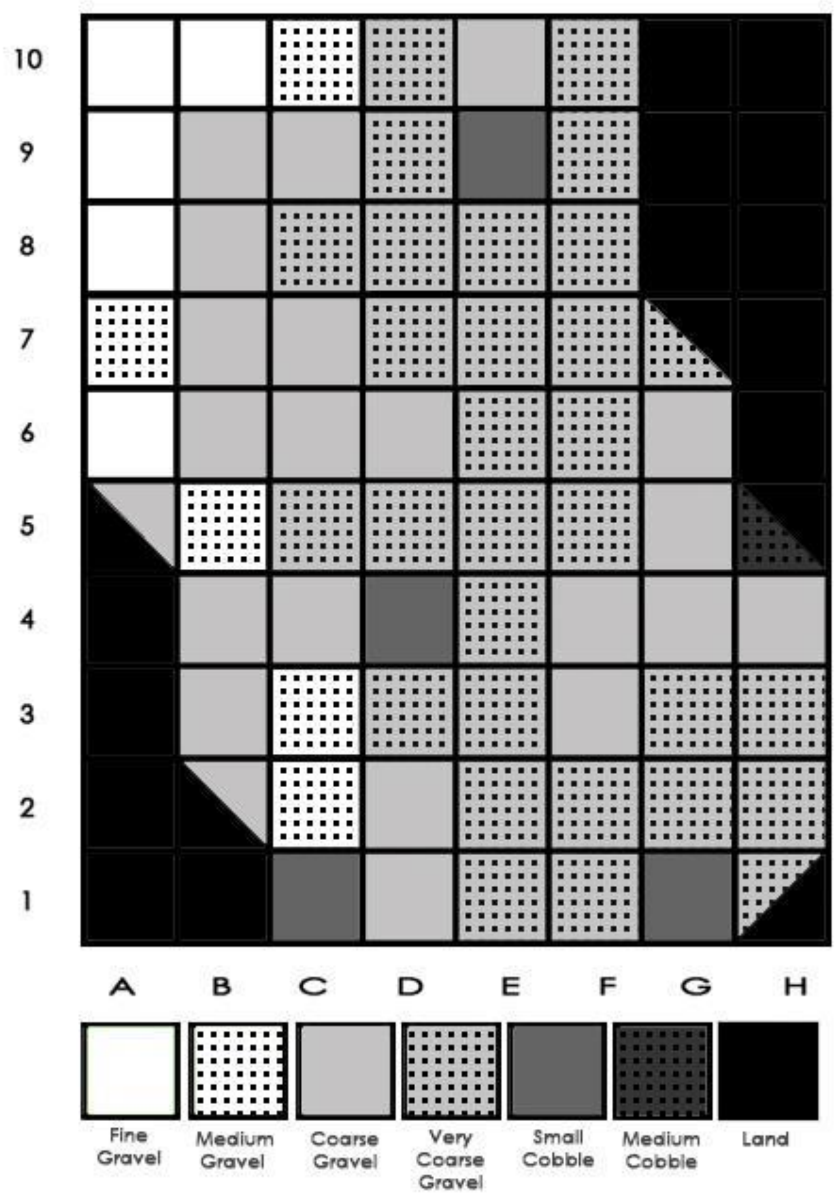
Weir 1:



Weir 2:


10
9
8
7
6
5
4
3
2
1
A
B
C
D
E
F
G
H
Fine Gravel
Medium Gravel
Coarse Gravel
Very Coarse Gravel
Small Cobble
Medium Cobble
Land

Weir 3:



10
9
8
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6
5
4
3
2
1
A
B
C
D
E
F
G
H
Fine Gravel
Medium Gravel
Coarse Gravel
Very Coarse Gravel
Small Cobble
Medium Cobble
Land

Table 2: Preferred Velocity and preferred depth for each species currently present in Stoney Creek. Data from Kondolf (1993), Mull (2005) and Geist (1998).

Salmonidea present:	Preferred Water Velocity (cm/s)		Preferred Water Depth (cm):	
	Min:	Max:	Min:	Max:
Coho:	1	101	4	30
Chum:	0	130	18	N/A
Cutthroat:	25	105	10	65
Pink:	40	85	20	N/A
Steelhead:	30	110	12	N/A

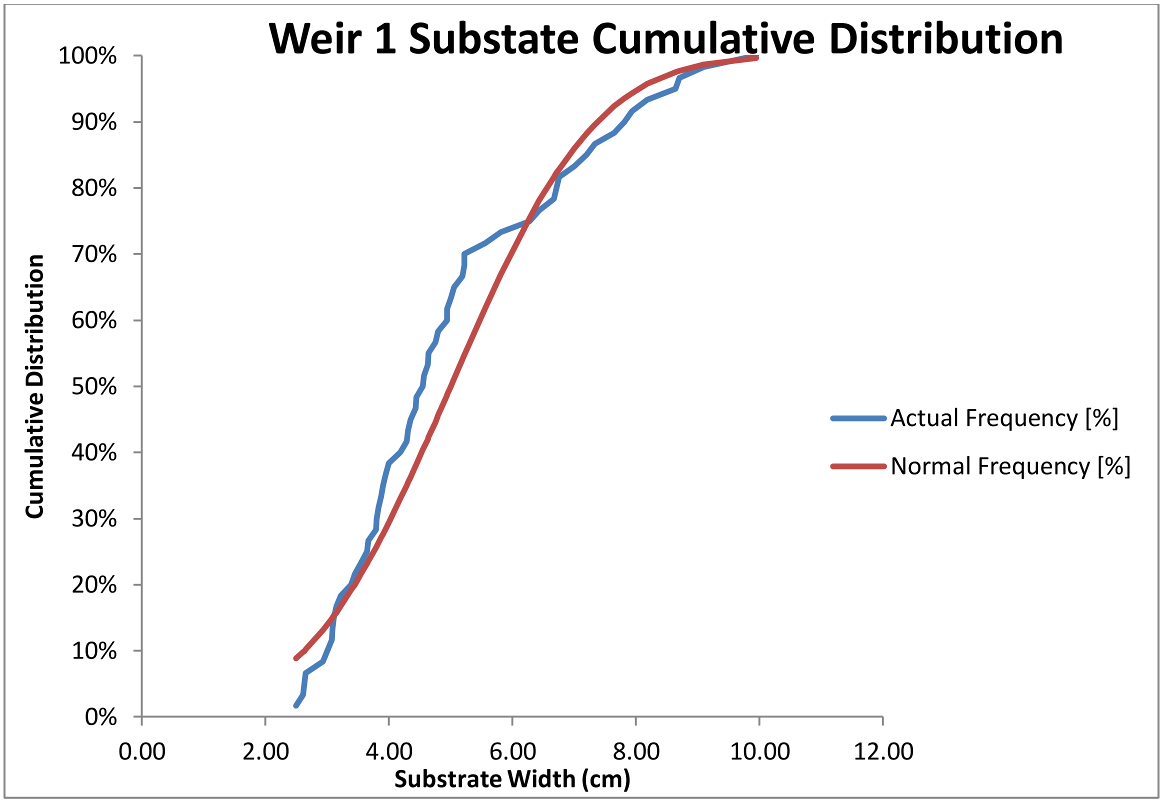
Table 3: Average velocities and depths over each weir.

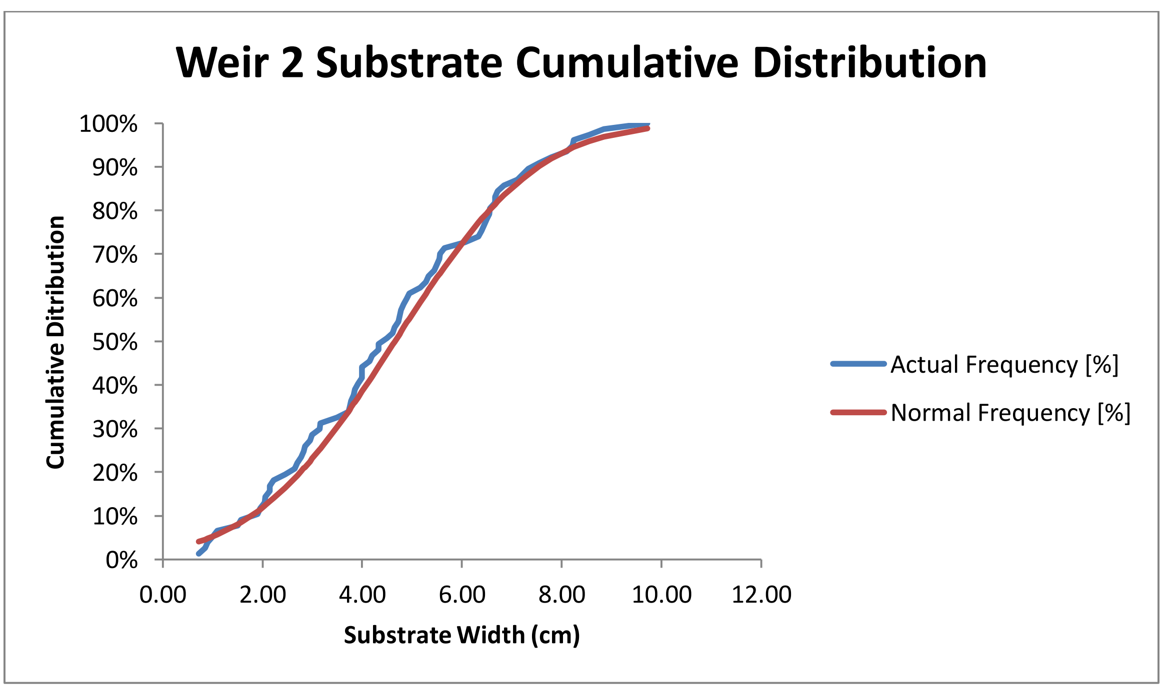
	Average Velocity	Average Depth
Weir One:	93.8 cm/s	12.64 cm
Weir Two:	79.6 cm/s	14.68 cm
Weir Three:	34.7 cm/s	20.22 cm

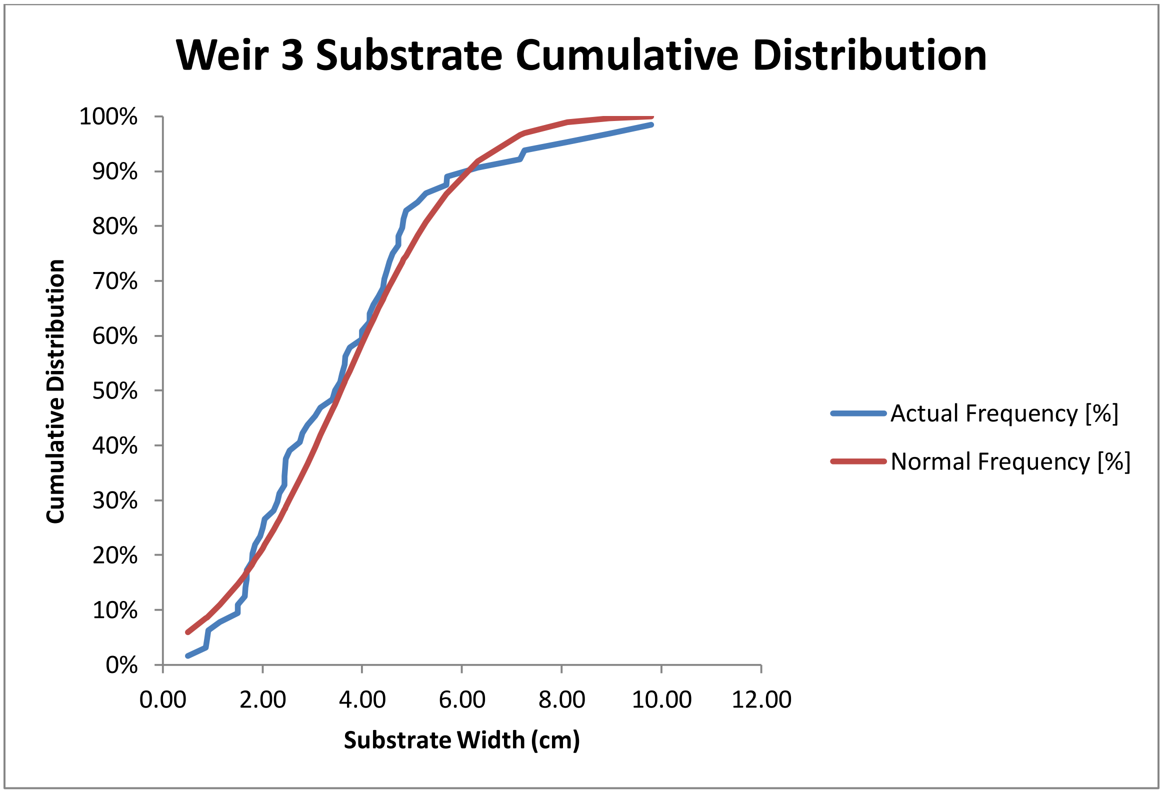
Table 4: Ideal substrate size range for the species of Salmonidea present in Stoney Creek. Data from Kondolf (1993).

	Range of Ideal Gravel Size	
	Min (cm):	Max (cm):
Chum	1.1	4.2
Coho	0.5	3.3
Cutthroat	0.2	0.8
Pink	0.8	1.1
Steelhead	1.0	4.0

Figure 9: The three graphs represent a Normal distribution of the gravel size for each weir separately.



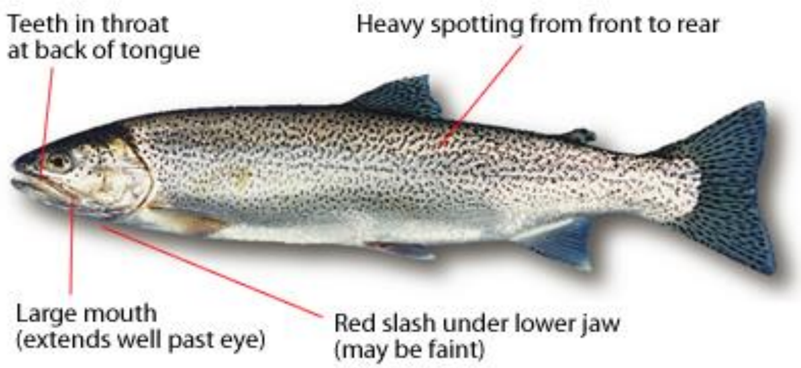



Weir 3 Substrate Cumulative Distribution
Cumulative Distribution
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.00
2.00
4.00
6.00
8.00
10.00
12.00
Substrate Width (cm)
Actual Frequency [%]
Normal Frequency [%]

Appendix 1:

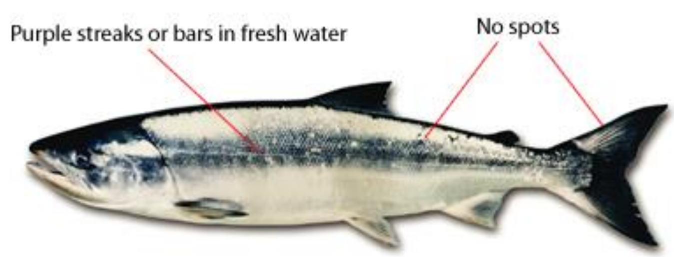
Fish of Stoney Creek:

→Cutthroat Trout (Coastal): Oncorhynchus clarki clarki. Cutthroat is a trout of the Salmonidea family, reaching up to 76cm in length and a maximum weight of 7.7kg. They are characterized by a dark red streak under their lower jaw, a dark green body and numerous spots over both sides of their body. Sometimes they are seen with a lemon colored stripe down the underside of their belly (McPhail 1993). They inhabit Stoney Creek year round.



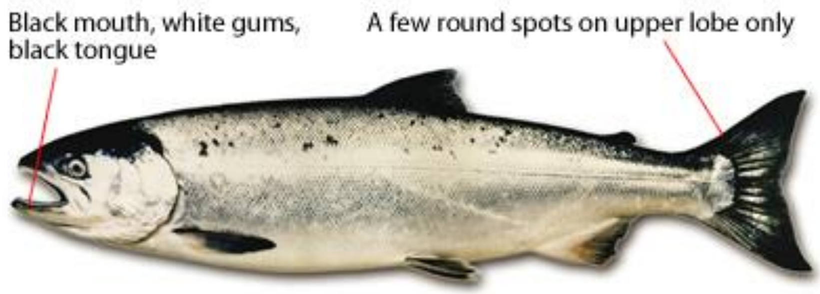
(Ministry of Forests, Lands and Natural Resource .2013).

→ Chum: Oncorhynchus keta. Chum are one of five species of salmon to inhabit the Pacific Northwest, reaching a length of 90 to 110cm, and generally weighing between 5 to 10kg. Once they migrate from salt water into the rivers, they change color and appearance. Chum can be recognized by their vertical blue-green and pink stripes on their sides, and their distinctively hooked jaws. They are usually one of the last salmon to migrate upstream and spawn (McPhail 1993), entering Stoney Creek in late October into early November.



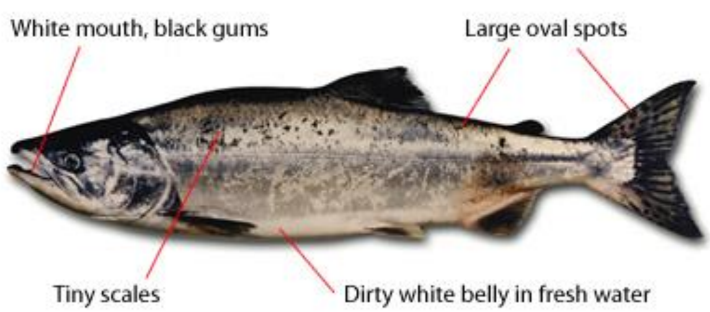
(Ministry of Forests, Lands and Natural Resource .2013).

→ Coho: Oncorhynchus kisutch. Coho are one of five species of salmon to inhabit the Pacific Northwest, reaching a length of 45 to 62cm, and usually weighing between 3 to 6 kilograms, but have been recorded up to weights of 14 kg. Once they begin their upstream migration, males develop dark red sides with a metallic blue back dotted with black spots. Female Cohos develop similar colors, albeit less striking, and with a hooked snout (McPhail 1993). They usually enter Stoney Creek in mid October.



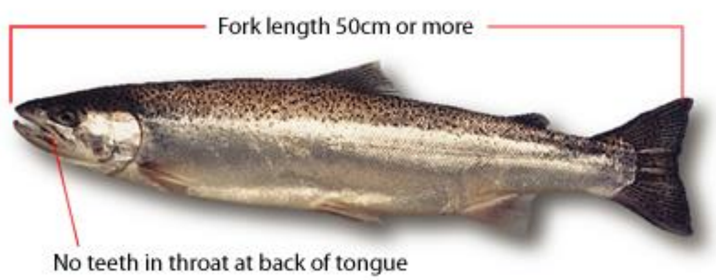
(Ministry of Forests, Lands and Natural Resource .2013).

→ Pink: Oncorhynchus gorbuscha. Pinks are one of five salmon species to inhabit the Pacific Northwest, reaching a length of 45 to 60cm, and usually weighing between 1.5 and 6 kg. Once they begin their upstream migration, their backs (especially the makes) develop a distinctive hump, with their lower bellies taking on a pinkish-white hue while their backs maintain a dark green, black speckled texture. Their mouths have distinctive black gums. They can enter small tributaries such as Stoney Creek anytime between mid August and October and are noted to migrate only on odd numbered years (McPhail 1993).



(Ministry of Forests, Lands and Natural Resource .2013).

→ Steelhead: Oncorhynchus mykiss. Steelhead is a subspecies of Rainbow trout that are born in freshwater systems and migrate out to sea, returning to small streams in order to spawn. Unlike other Salmonidea, they usually do no die after spawning but return back to the ocean. They are usually 60 to 120cm in size, weighting anywhere from 5 to 25 kg. When migrating, they are dark-olive green in color with dark speckles, a silvery-white underbelly, and a red stripe down the middle of their sides (McPhail 1993). The Steelhead that have been rumored to enter Stoney Creek would do so sometime between late November and February.



(Ministry of Forests, Lands and Natural Resource .2013).