DRAFT

"State of the Watershed"

Report on the hydrology and biological productivity of the Musqueam Creek watershed

Prepared for

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Abstract

Table of Content

Page

Table of Figures

Page

List of Tables

List of Appendices

Page

1.0 Introduction

Musqueam Creek watershed is located in the southwest corner of the City of Vancouver. It drains the University of British Columbia (UBC) Endowments Lands the Pacific Spirit Park (PSP) flowing across southwest marine drive and the Musqueam Nation lands eventually emptying into the north arm of the Fraser River.

Musqueam Creek and its main tributary, Cutthroat Creek currently support the last "wild" run of Pacific salmonids within the City of Vancouver limits supporting small runs of Coho (*Oncorhynchus kisutch*) and Chum (*O. keta*) salmon, anadromous and non-anadromous Coastal Cutthroat trout (*O. clarki clarki*). The watershed has undergone various changes in the last 100years. Its headwaters originate with the UBC Endowment Lands and have been protected by Pacific Spirit Park. The lower reaches from Southwest Marine Drive flow through a variety of urban development including housing and associated infrastructure and golf courses. The mouth enters the Fraser River through flood control structures emptying onto on tidal mudflats.

Although partially protected from development, unique landscapes and resources that historically contribute to the health of the watershed have been manipulated through development. The results of this development has resulted in the interception of ground and surface waters that may have contributed to the overall Musqueam Creek water balance, re-alignment and moving of tributary streams including ephemeral streams and the enclosing of channels in both culverts and storm drains.

In the last 15 years the Musqueam Ecosystem Conservation Society in partnership with the Musqueam First nation has been working to preserve, protect and rehabilitate this watershed and its aquatic resources. This document is a summary of work conducted in the Musqueam watershed in 2009/2010. The information presented is a summary of results and opinions on the relative health of the watershed and future activities that may help protect this unique watershed.

2.0 Project Description/Background

In 2008/2009 a review of the hydrology and related aquatic habitats found in the Musqueam and Cutthroat Creeks was completed. In this project it was determined that the watershed was in relatively "good" condition but hydrologic data and knowledge was limited. This project also reviewed studies on the rearing salmonid population in the Musqueam Creek watershed focusing on work conducted within the lower anadromous section of the watershed. Like the hydrology, information was limited and dated (*Bates and Termuende*, 2009).

In 2009/2010, the work and review completed in 2009 was continued. A more detailed hydrological analysis was completed and "new" information on the rearing salmonid population in the upper section of the anadromous section of both Musqueam and Cutthroat Creeks was completed. In 2009/2010 the project provided:

A final hydrological assessment with comparison to other area hydrologic records that may provide and indication of expected baseflows in the watershed.

- An assessment of the salmonid production capability on the upper anadromous sections of the watershed;
- A review of the effective use of the Imperial Trail well and its contribution to the Musqueam Creek baseflows;
- Provide options and ideas for the augmentation of water volume in lower Musqueam and Cutthroat Creeks;
- Carrying capacity estimates for both Musqueam and Cutthroat Creeks based on 2009 sampling results;
- A review of the riparian health and areas to increase protection;
- Development of a GIS based outreach map with data storage within a GIS framework using Arcview 9.3;
- Specific recommendations for the continued protection and rehabilitation of the Musqueam and Cutthroat Creek aquatic habitats.

3.0 Hydrological Assessment

3.1 Background

In *Bates and Termuende* (2009), regional hydrological analyses were undertaken to assess the hydrology of Musqueam and Cutthroat Creeks. A regional approach was used because there was little or no actual hydrological data for theses creeks. The regional analyses consisted of comparing precipitation and runoff records from nearby stations (**Table I**), with long-term records, to predict the most likely hydrological regime for Musqueam and Cutthroat Creeks. The long-term station that was thought to exhibit the most similar hydrological response to Musqueam and Cutthroat

Creeks, was the Water Survey Canada Station (WSC) 08MH090 – Salmon River. In 2009, actual stream gauge data was collected for Musqueam and Cutthroat Creeks from the five stream gauges installed on the creeks in March 2009 (**Appendix I**- Map 1). Software problems encountered and a gauging record was established at all 5 sites form July to date. In addition to the initial 5 stations, an additional stream gauge was installed in September 2009 on the "West" Creek just before it enters the Shaughnessy Golf and Country Club. In this assessment, previous assumptions' regarding the hydrological responses of the creeks is tested with data collected from these stream gauges. Concurrent data from theses gauges and WSC Salmon River gauge is compared to validate assumptions.

Table I: Regional stream gauges near the Musqueam Creek watershed.

Station Number	Station Name	Years		No. Water Years	Drainage Area (km^2)	Median Elev. ASL (m)	Mean Annual Q (m^3/s)	Unit Area Q (m^3/s)
08MH155	Nicomekl River at 203 Street Langley	1985	2009	25	69.2	53	1.9	0.027
08MH090	Salmon River at 72 Ave Langley	1960	2009	47	49	59	1.42	0.029
08MH129	Murray Creek at 216 Street Langley	1969	1983	15	26.2	63	0.581	0.022
08GA047	Roberts Creek at Roberts Creek	1959	2009	52	32.6	536	1.04	0.032

3.2 Watersheds

New map information regarding the relief of Pacific Spirit Park has revised the drainage areas and drainage patterns for the Musqueam and Cutthroat Creek watersheds (**Appendix I**). The Musqueam Creek watershed area above Southwest Marine Drive has been revised from 2.3 km^2 to 2.23 km^2, while the Cutthroat Creek watershed has been revised from 1.77 km^2 to 1.85 km^2. The "West" Creek is approximately 0.36 km^2. The drainage patterns are now more accurately positioned on the map. Field reconnaissance was performed in February 2010 to assess the influence of the Imperial Trail upon the drainage of Musqueam and Cutthroat Creeks. Drainage crossings and flows were recorded. It can be observed (**Appendix I**, Inset 2) that both Imperial Drive and Imperial Trail intercept drainage for Musqueam Creek. The present contour information does not reveal the historic path of the channel. However as the relief is fairly low, the effect of the interception has most like resulted in directing more runoff to the present channel of Musqueam Creek. The present drainage of Cutthroat Creek appears to only slightly re-directed by the trail, so has most likely experienced negligible effects. It is suspected that the small tributary (**Appendix**, Inset 2, Point 12, photo#) that has been intercepted by the trail was once connected to "West" Creek. So the net result has been increased runoff into Cutthroat Creek.

3.3 Stream Flow Data

The location of the stream gauges as shown on **Appendix I – Map 1**. The gauges measure and record water level and water temperature on an hourly basis. As these are measurements of open channel flow, it is necessary to collect discrete samples of stream depth and discharge in order to develop rating curves for each gauge. The rating curves for each gauge are shown in **Figures 3.1 through 3.6**. Ideally, a rating curve would have enough samples to describe all the seasonal flows of the stream. Because the stream channel changes geometry as it gets scoured during high flows, and in-filled during low flows, it is necessary to continue to collect discrete samples. As the present curves have little high flow information, the relationship between the water level (stage) and the corresponding high discharge has been estimated from the lower flow data. The stage data is subsequently transformed into discharge data using the rating curves. The time series of stream flow data for Cutthroat Creek can be seen in the **Figures 3.7**. The time series of stream flow data for Musqueam Creek stations can be seen in the **Figure 3.8**. The time series for concurrent data for "west creek" and Cutthroat Creek at the Golf course can be seen in the **Figure 3.9**. It should be noted that the rating curves are preliminary and the high flow data is incomplete, therefore the high flow data should be used accordingly.

3.4 Correlation to Concurrent Long Term WSC Station

To verify previous assumptions made regarding the hydrology of Musqueam and Cutthroat Creeks and "West" Creek it was necessary to compare data from these stations with concurrent daily stream flow data from the long term Salmon River WSC 08MH090 station located in Langley. The daily average flow data was plotted to observe similarities as seen in the **Figures 3.10 and 3.11.** Regression analysis was then performed to verify [1]correlation between the flows recorded at the stations as seen in **Figures**

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[1] The correlation coefficient, r, ranges from -1 to 1: 0>r>1 indicates that the two variables tend to increase or decrease together; r = 1 indicates perfect correlation. A small "p" value indicates that the correlation is not a coincidence.

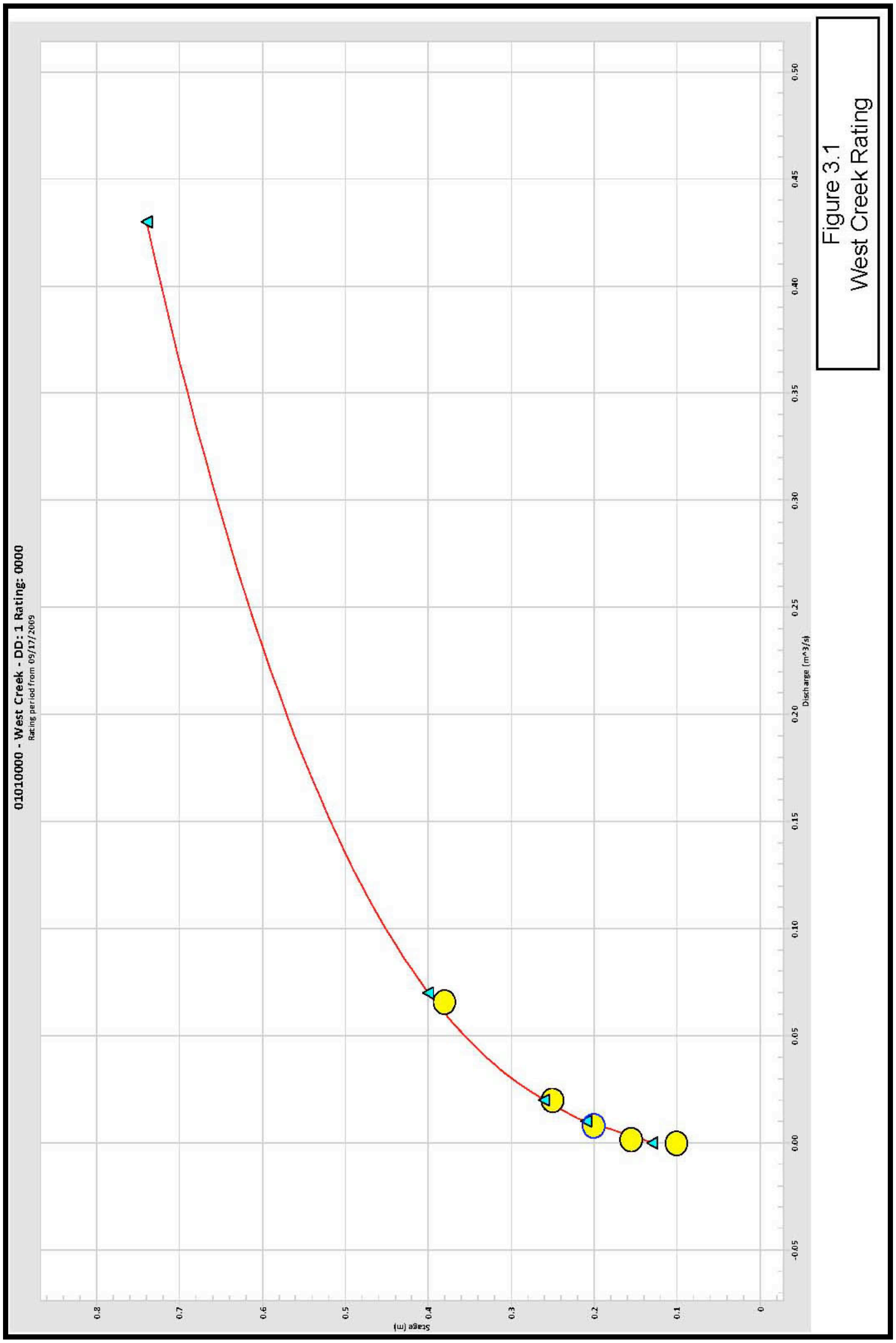


Figure 3.1: Rating curve for “West” Creek a tributary located west of Cutthroat Creek.

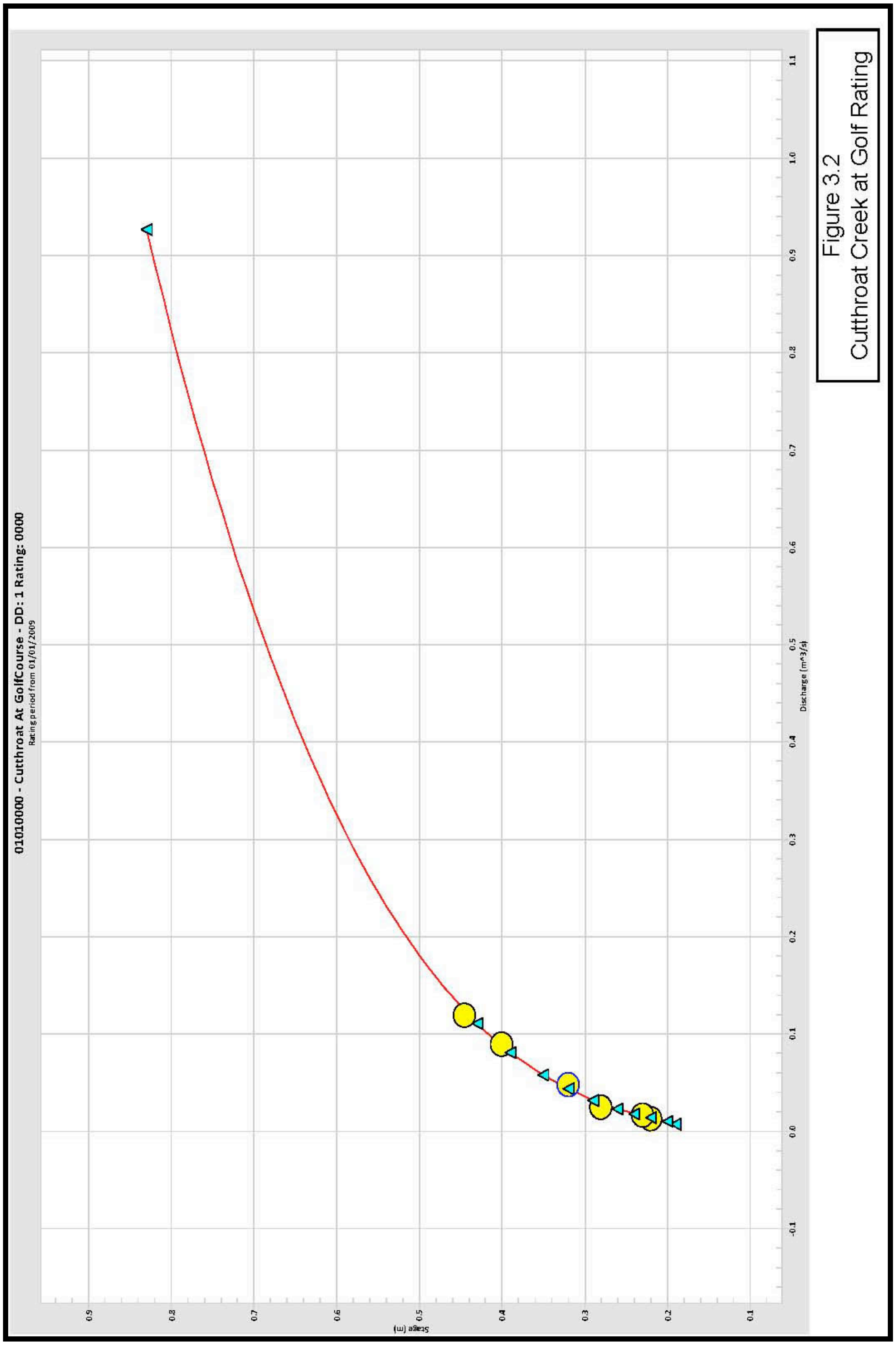


Figure 3.2: Rating curve for Cutthroat Creek at the Shaughnessy Golf and Country Club.

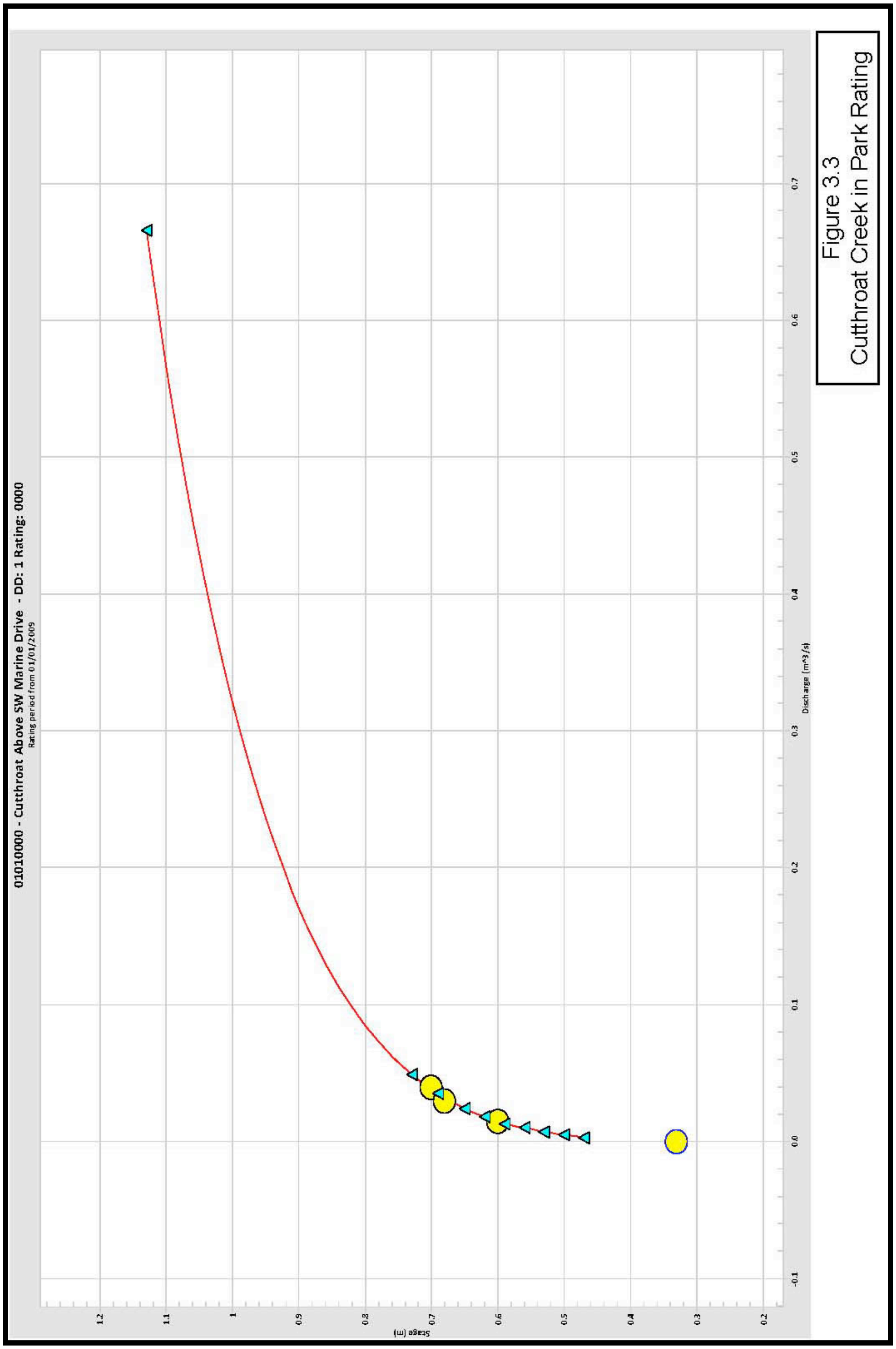


Figure 3.3: Rating curve for gauging station at Cutthroat Creek in Pacific Spirit Park.

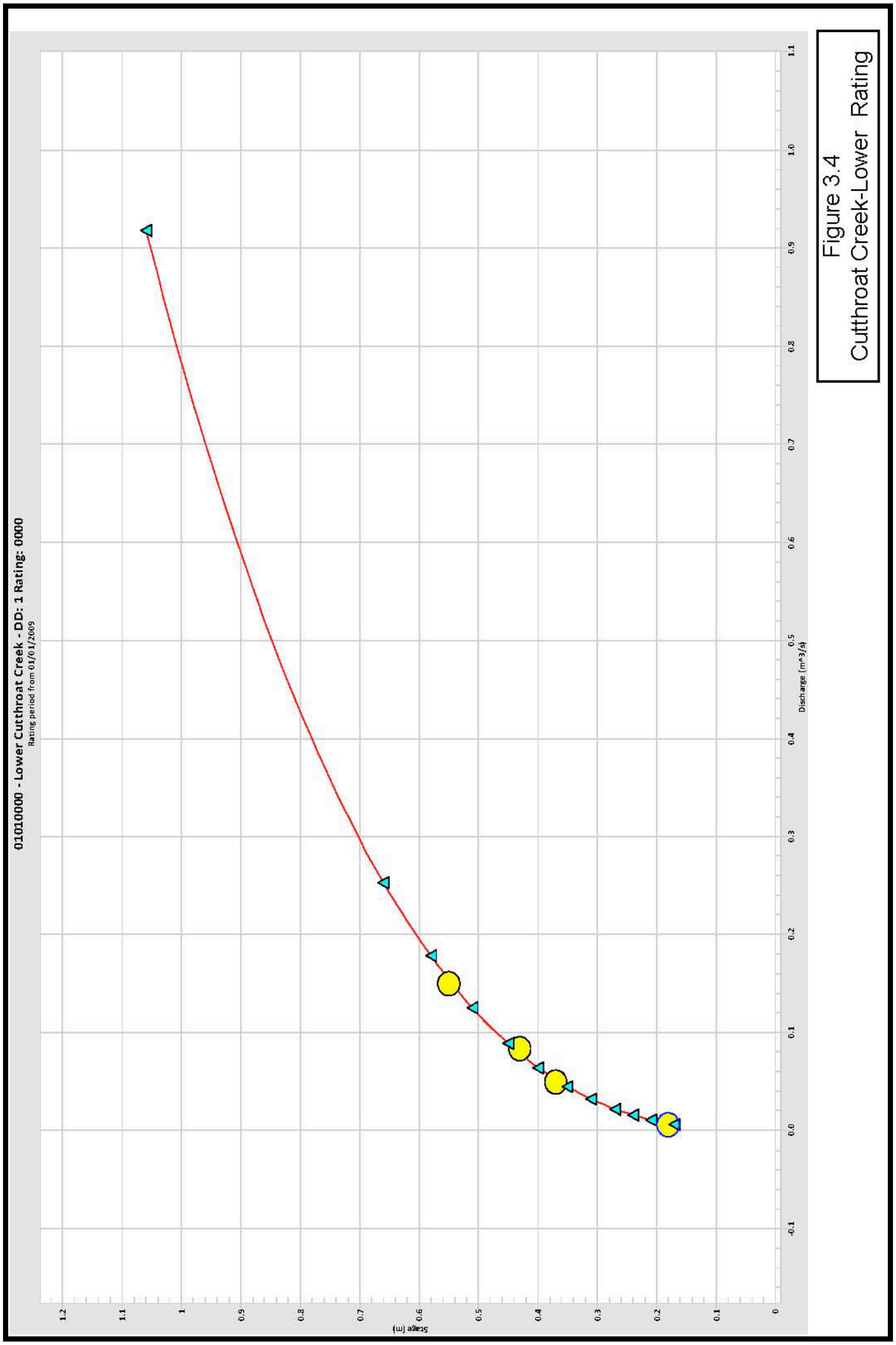


Figure 3.4: Rating curve for gauging station at Cutthroat Creek below Crown Street near the Musqueam Creek confluence.

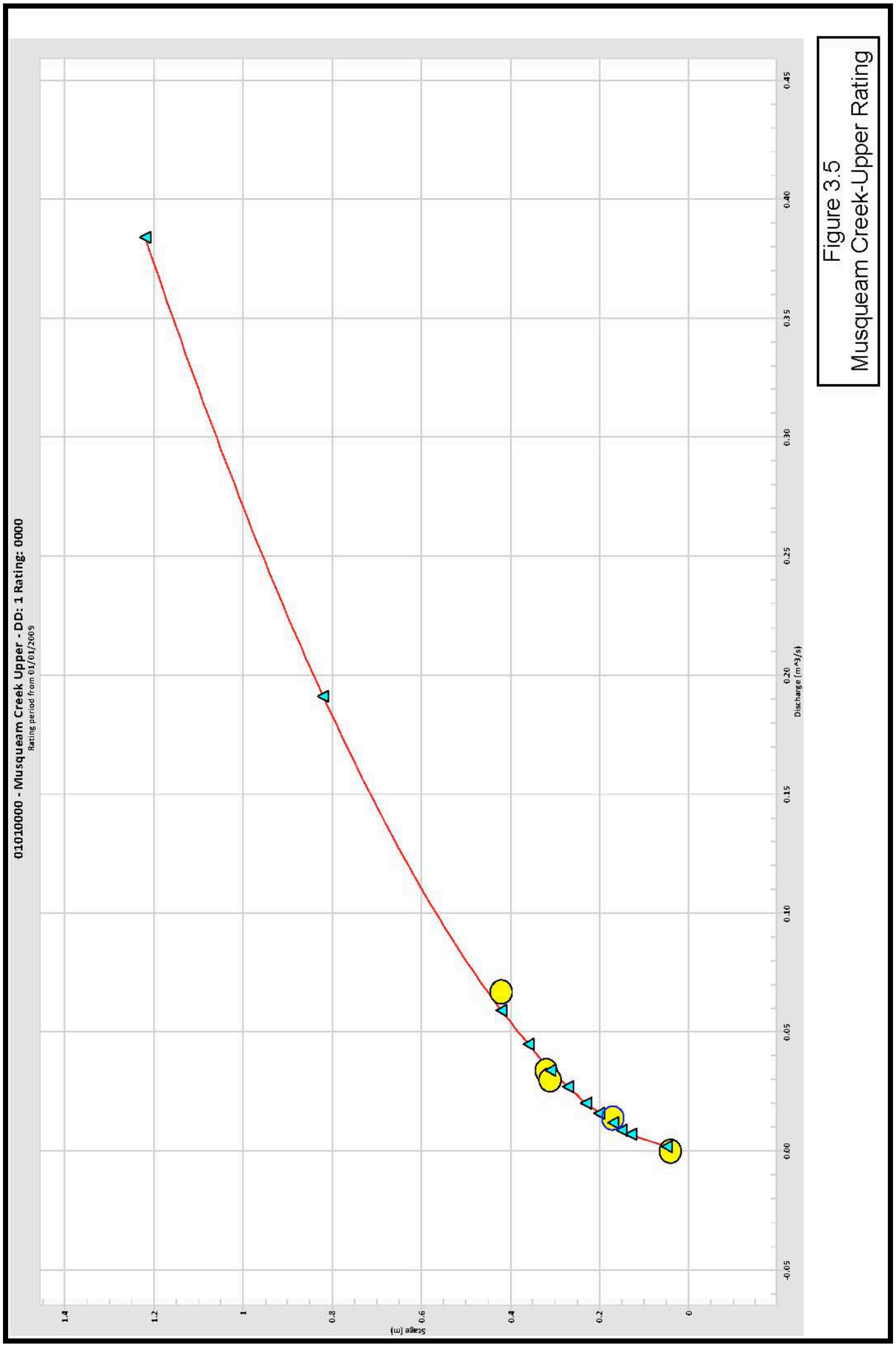


Figure 3.5: Rating curve for gauging station at Musqueam Creek in Pacific Spirit Park.

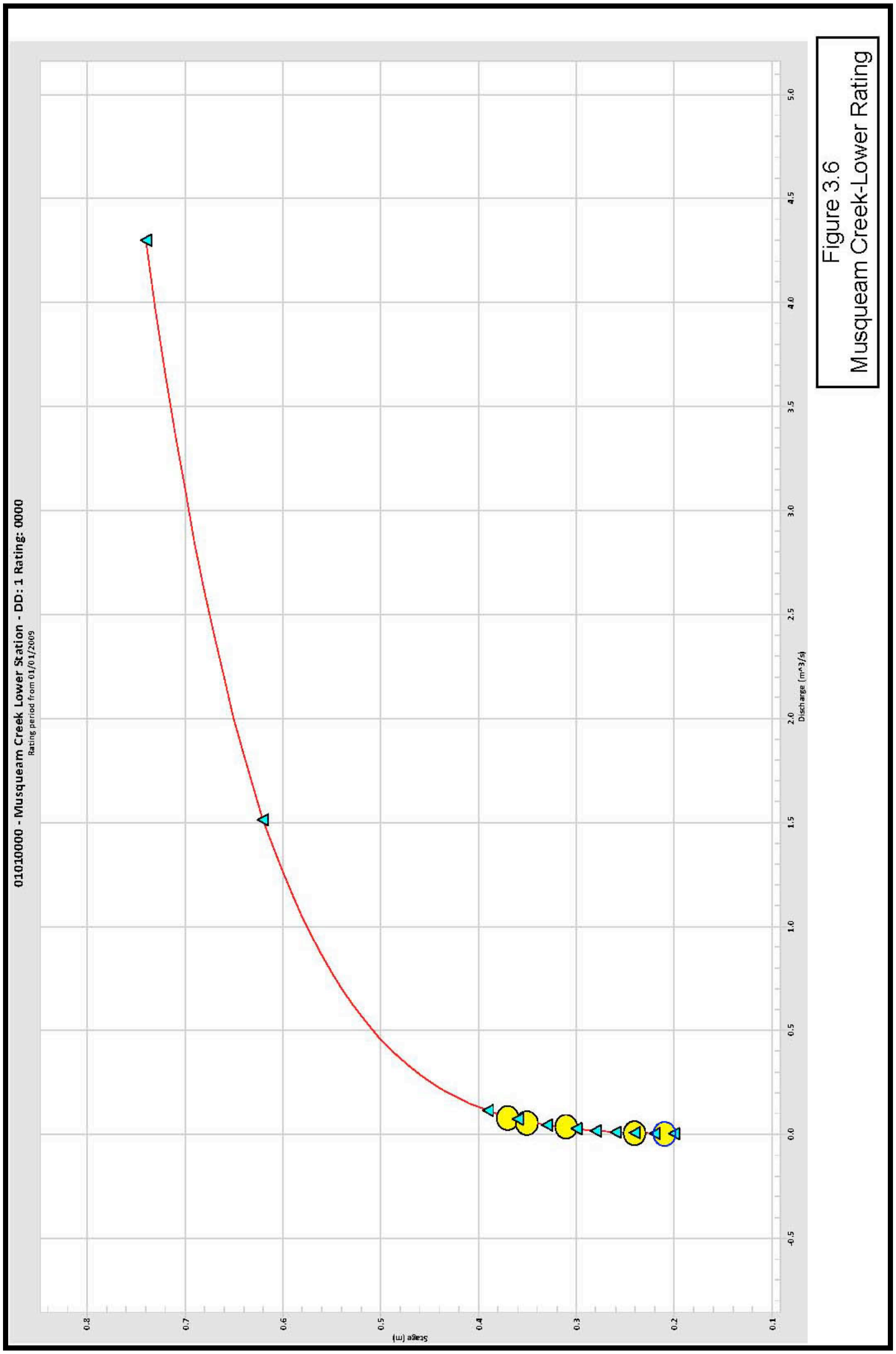


Figure 3.6: Rating curve for gauging station at Musqueam Creek near Crown Street.

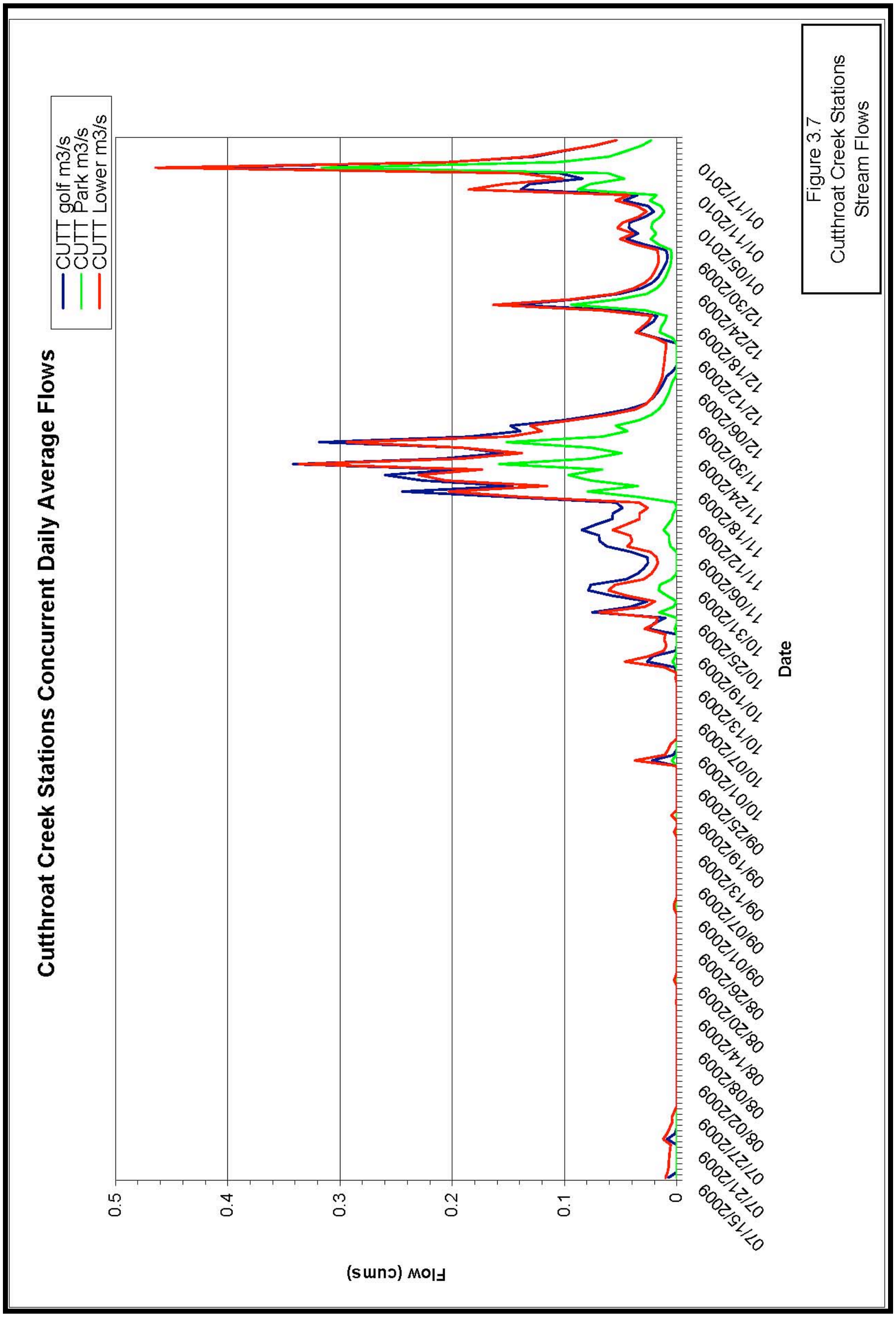


Figure 3.7: Stream discharge recorded for Cutthroat Creek gauging stations between July 2009 and January 2010.

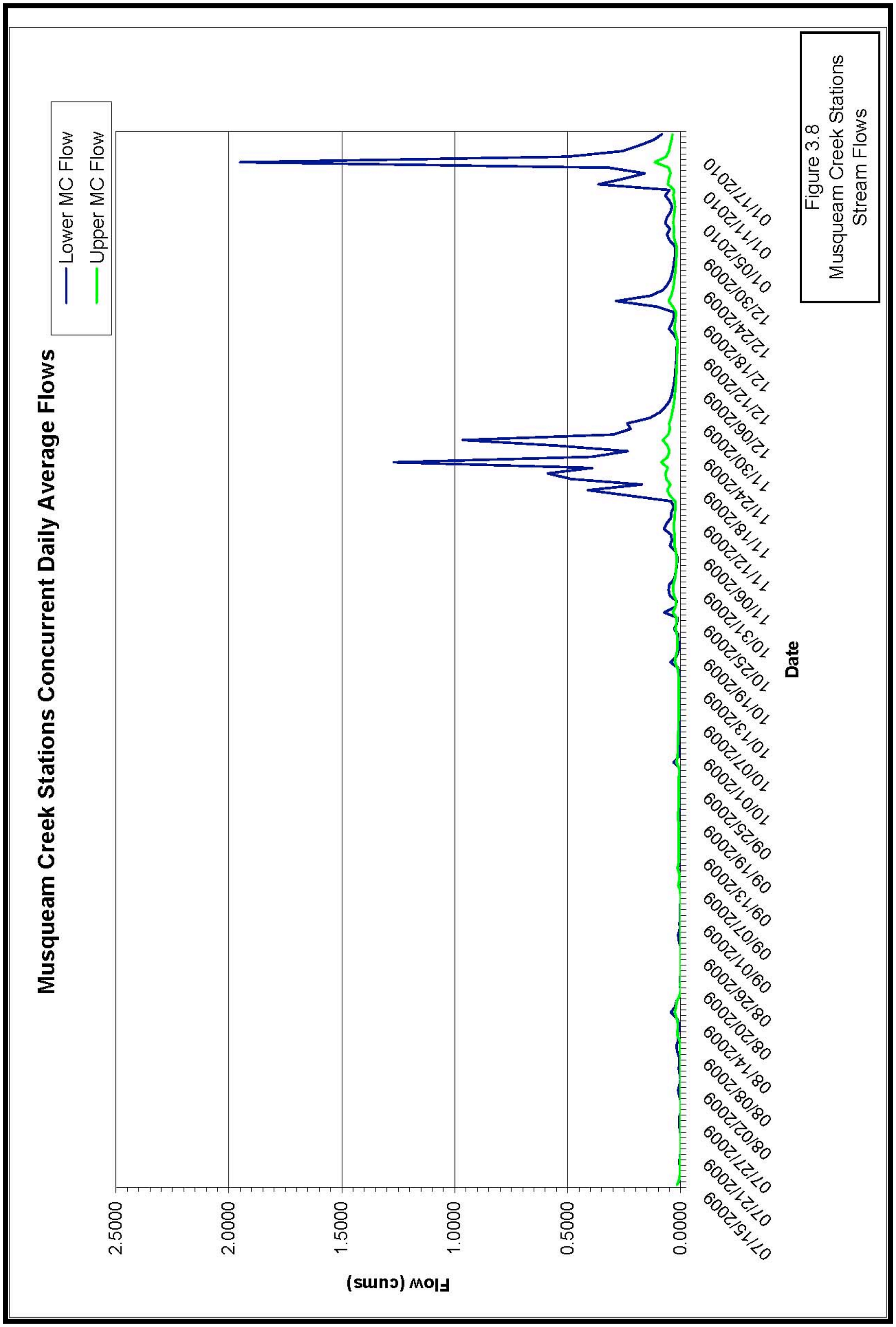


Figure 3.8: Stream discharge recorded for Musqueam Creek gauging stations between July 2009 and January 2010.

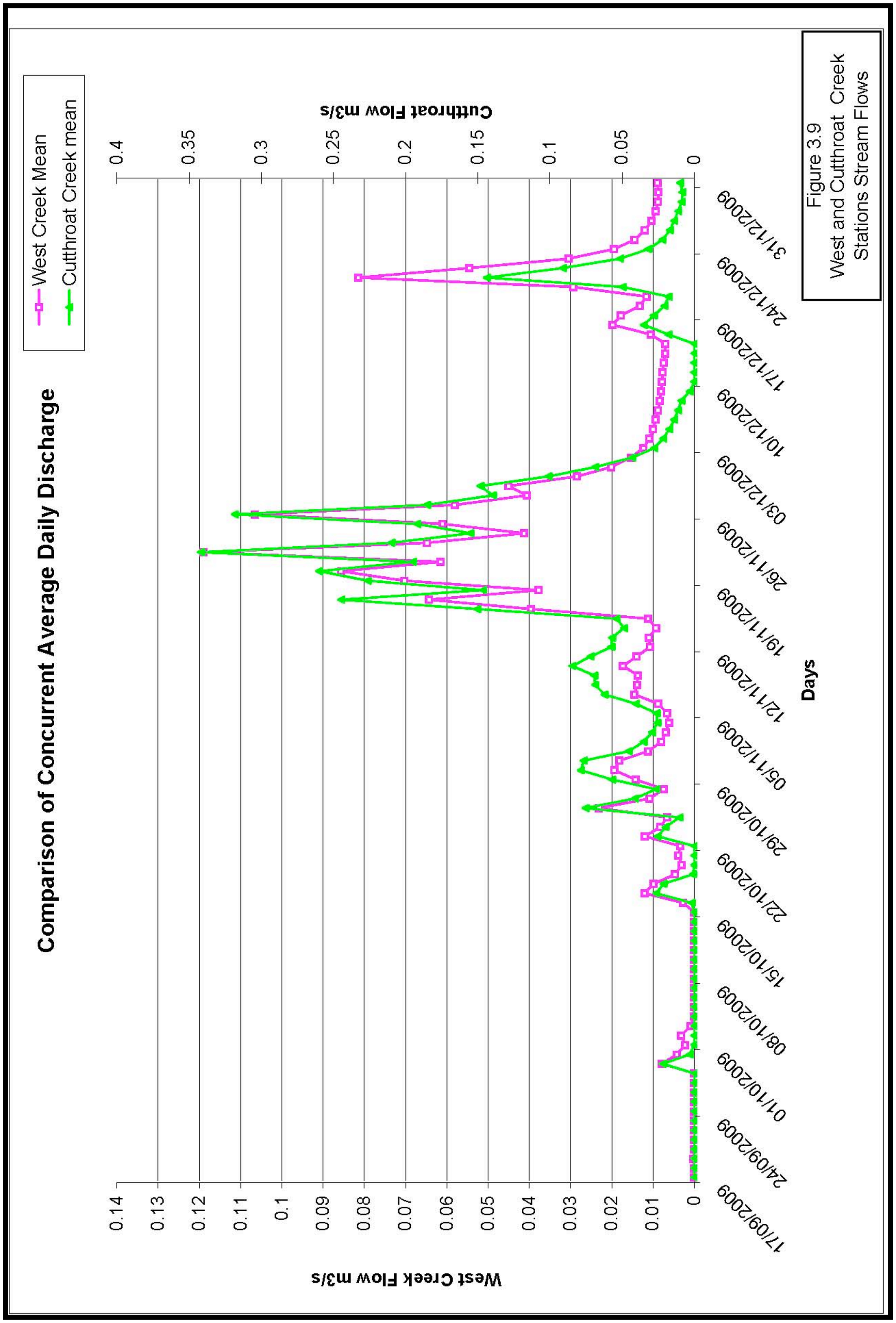


Figure 3.9: Stream discharge recorded for West and Cutthroat Creek gauging stations between July 2009 and January 2010.

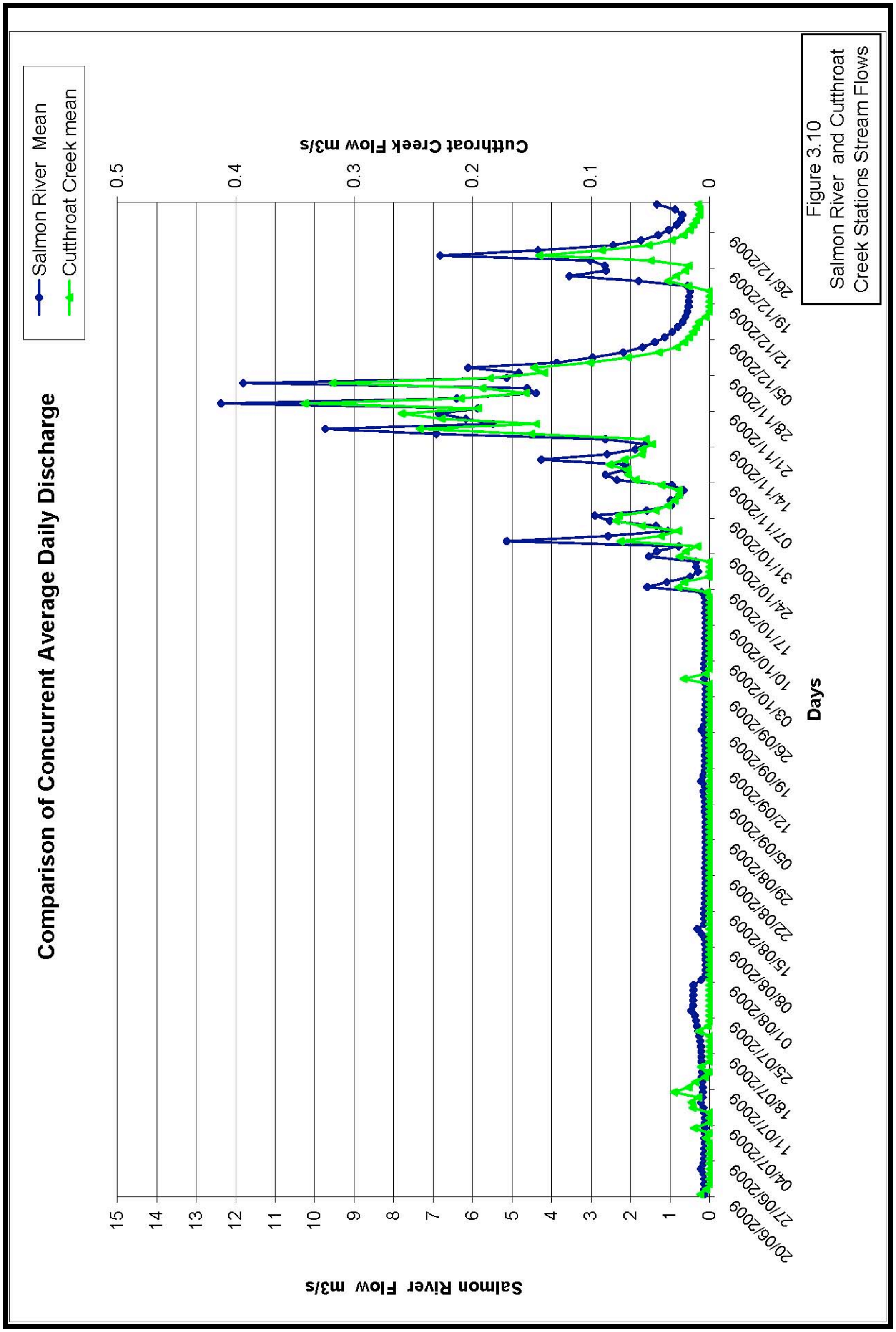


Figure 3.10: Stream discharge comparison between Salmon River and Cutthroat Creek gauging stations between June 2009 and January 2010.

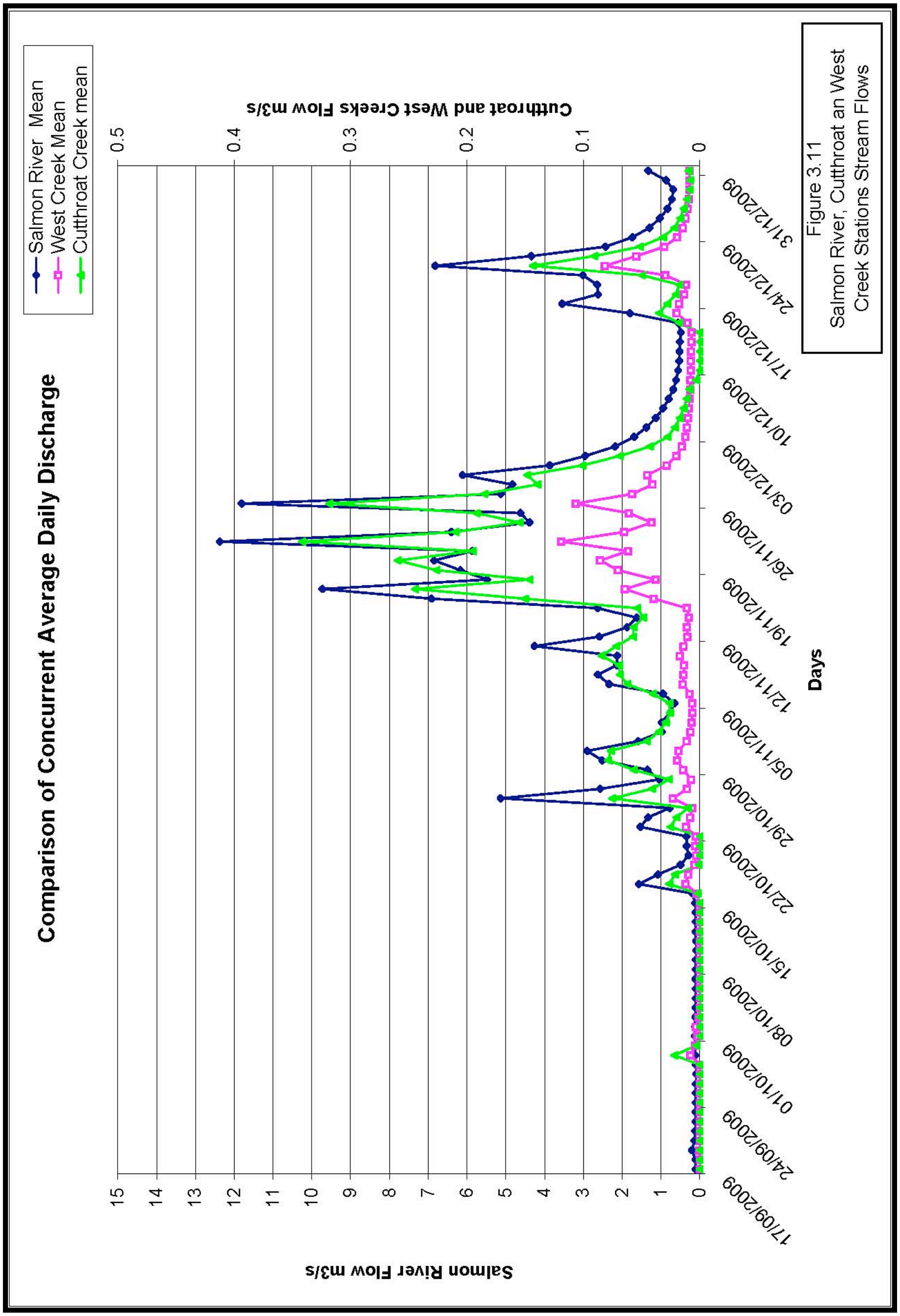
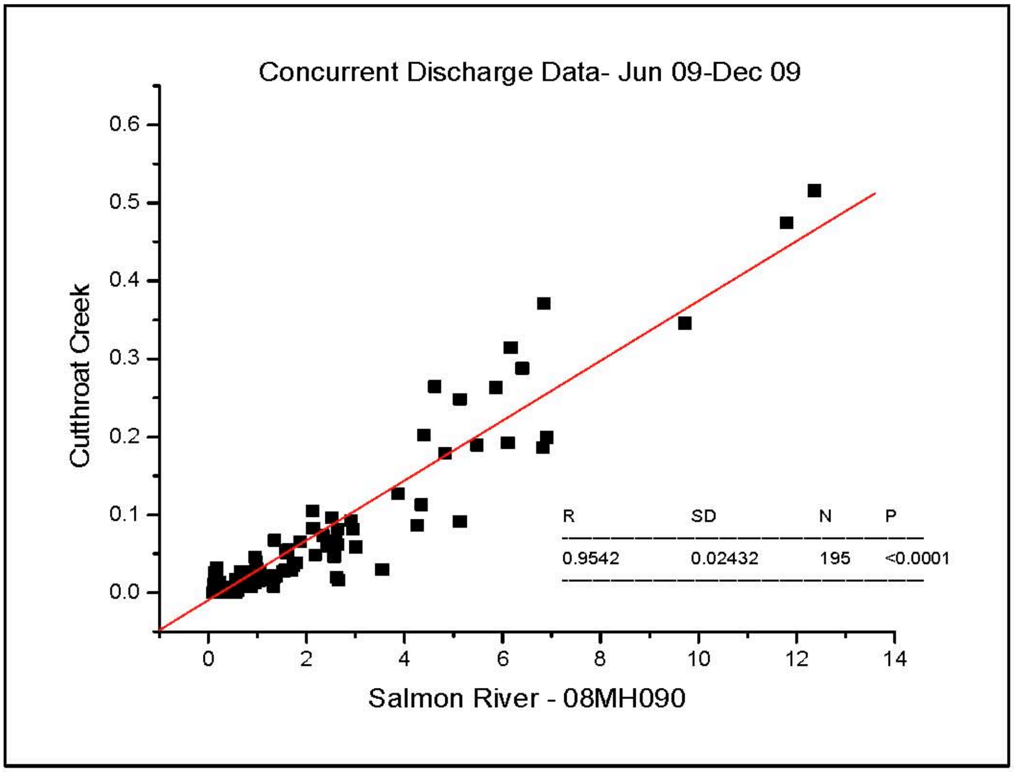


Figure 3.11: Stream discharge comparison between Salmon River, West and Cutthroat Creek gauging stations between June and January 2010.



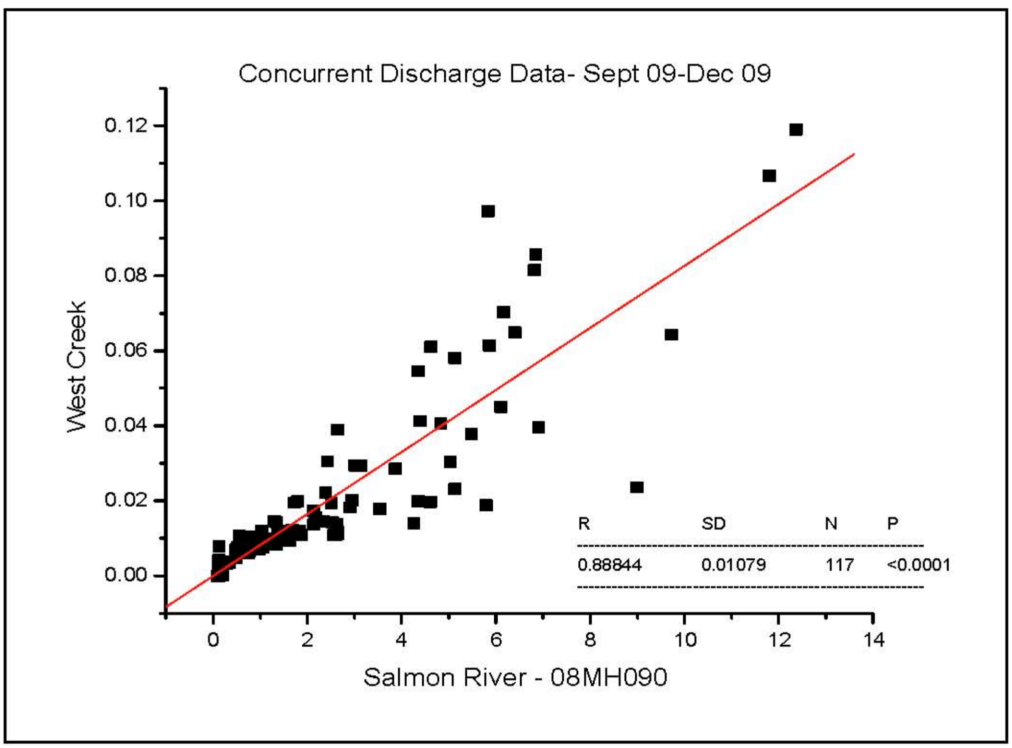


Figure 3.12: Correlation of stream flow data between Cutthroat and West Creeks and Salmon River.

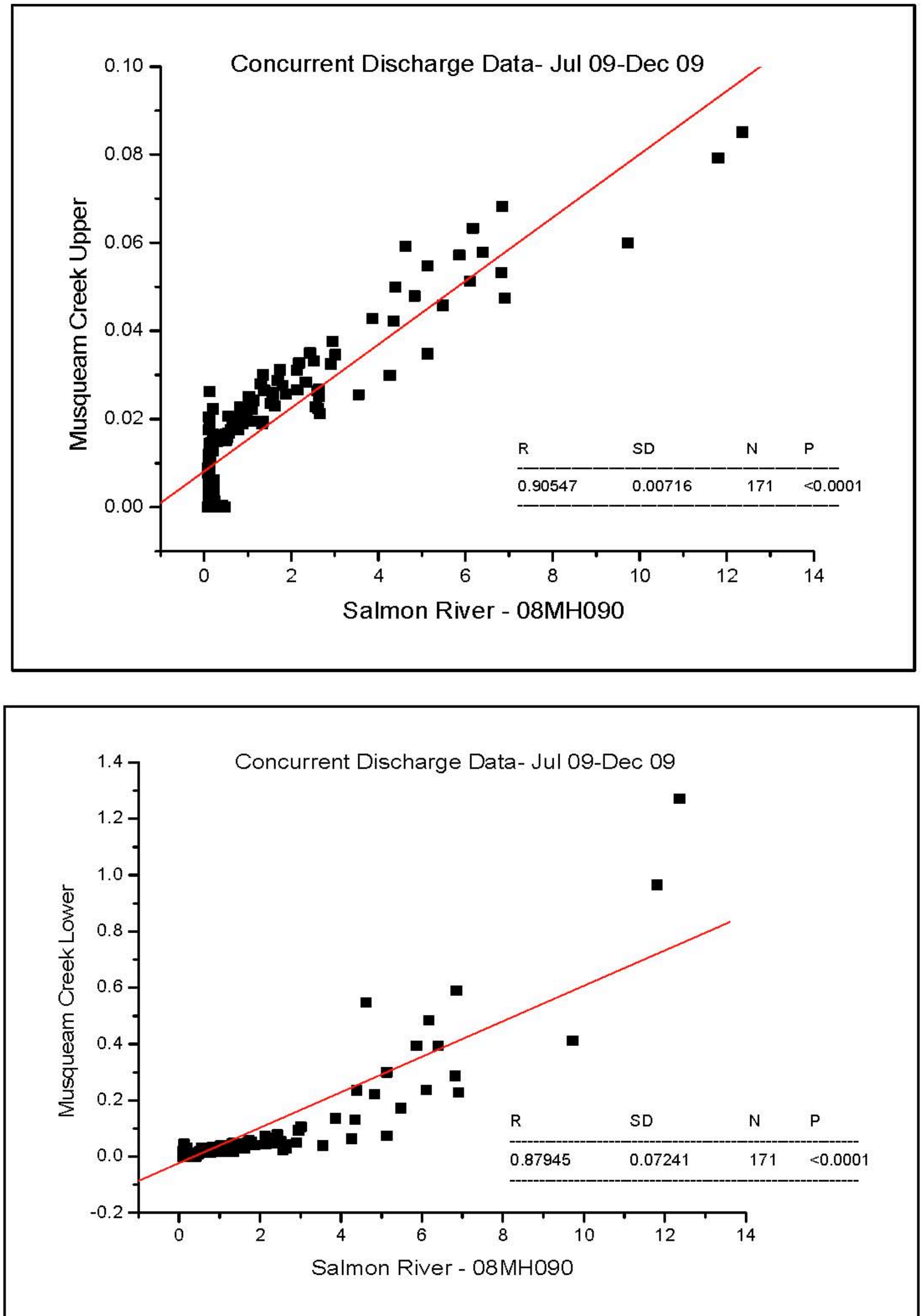


Figure 3.13: Correlation of stream flow data between Musqueam Creek and Salmon River.

3.12 to 3.13. The correlations range from 0.87 to 0.95 indicating good correlation. This means that it should be possible to use the long-term data from Salmon River with an area proration to predict hydrological responses for Musqueam, Cutthroat and "West " Creeks. However comparisons representing a full year of concurrent data would provide more confidence. Comparisons with other long term WSC gauging stations do not exhibit good correlation are not included.

4.0 Imperial Trail Well

4.1 Background

The Imperial Trail well, (**Appendix I** Point #1, Inset 2) was drilled in 1998. A pump was installed into the well in June 2000. The intent of the well was to provide flow to Musqueam Creek to augment summer season low flows. The pump as tested on July 6th 2000 had a flow of 50 US gallons per minute (3.15 l/s). The well water is discharged through a grate into Musqueam Creek (**Figure 4.1**). The initial test indicated a [2]drawdown of approximately 10 feet after approximately 60 minutes of continual pumping. Specification for the well can be seen in the **Appendix II**. The well continues to be maintained by Fisheries and Oceans Canada. In 2009, the well was activated on June 2nd. The recent records from the start up indicate a drawdown of approximately 22 feet after 20 minutes of pumping. The well tester identified the rapid drawdown as an indication of reduced well efficiencies.

Figure 4.1: The discharge grate from the Imperial Trail well. Water from the well is discharged into Musqueam Creek through the grate.

[2] The drawdown is a measurement of the difference between the static water level in the well, and the water level after an increment of time of continuous pumping.

4.2 Aquifer Test

An aquifer, or pumping test, can be performed to ascertain hydraulic properties of an aquifer. The principal of a single-well aquifer test is that a well is pumped and the effect of this pumping on the aquifer hydraulic head is measured in the well itself, and/or in a number of nearby observation wells. The change in the water level induced by the pumping is known as the drawdown. The hydraulic properties can also be found from a recovery test. In a recovery test, a well that has been pumping for some time is shut down, and thereafter the recovery of the aquifers hydraulic head is measured in the well. The diagram **Figure 4.2** illustrates the time-drawdown relationship for a pumped well. An aquifer test is typically carried out to estimate the transmissivity and storativity of the aquifer. Transmissivity describes the ability of the aquifer to transmit water, and storativity describes the ability of the aquifer to release water. The single well test cannot be use to estimate storativity. A single well test can however be used determine the specific capacity of the aquifer; that is the ratio of sustained pumping rate divided by the incurred drawdown. The plotted data from a recovery test can also be used to give information regarding aquifer conditions. **Figure 4.3** illustrates the various sources of water that is derived from the different aquifer conditions. **Figure 4.4** illustrates the typical plotted data from a recovery test.

There are four possible types of aquifers that may be present in the pacific Spirit park area surrounding the Imperial Trail well. These aquifers are:

- The confined aquifer, where the source of water is only from the confined aquifer;

- The semi-confined aquifer where the source of water is from the semi-confined aquifer and an aquifer situated above or below the semi-confined aquifer;

- The semi-confined aquifer with a compressible overlying or under lying layer where the source of water is from the semi-confined aquifer, the semi-confining layer, and an aquifer above or below the semi-confined layer;

- The unconfined aquifer is when the source of water is from the unconfined layer.

4.2 Imperial Trail Well Recovery Test

An aquifer test was performed on the Imperial Trail well on October 20th, 2009. The method employed was to lower a sealed pressure transducer type water level logger down the well casing and then to allow the level logger to record a time series of hydraulic head. The well had been continuously pumping since June 2nd, 2009. The water level logger was lowered into the well while the well was pumping. After approximately 20 minutes the pump was then shut down and the well was allowed to recover for approximately 60 minutes, whereupon the pump was reactivated, and the hydraulic head was recorded for approximately 60 more minutes. **Figure 4.5** shows a plot of the data from the water level logger. The recovery test data was analyzed to determine the permeability and transmissibility of the aquifer that is the source of the water for the well. The rate of movement of the groundwater is determined by the geological properties of the aquifer and the hydraulic gradient of the aquifer. The capacity of a water bearing material for transmitting water under hydraulic head is its permeability. The coefficient of permeability is typically expressed as the rate of flow of water, in gallons per day, through a cross sectional area of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60^{o} F. The coefficient of transmissibility is a similar measurement and is defined as the number of gallons of water per day transmitted through each section 1 mile wide extending the height of the aquifer (*Theis*, 1935). The coefficient of transmissibility is equivalent to the coefficient permeability multiplies by the thickness of the aquifer. The graphical analysis of the aquifer test can be seen in **Figures 4.6 and 4.7**.

The transmissibility was determined to be approximately 1869 gallons $day^{-1}ft^{-1}$ (16.1-litres min^{-1} $metres^{-1}$), and the coefficient of permeability was determined to be approximately 196 gallons ft^{-1} . The specific capacity is determined by dividing the pump discharge rate of sustained pumping by the incurred drawdown. The specific capacity of the aquifer from the initial pump test performed in July 2000 was 4.85 gallons min^{-1} ft^{-1}. In June 2009 the specific capacity had declined to 2.25 gallons min^{-1} ft^{-1} . Measurements of discharge from the well into Musqueam Creek taken on October 20th 2009 averaged 50.45 gallons per minute, or approximately 3.15-litres per second.

4.4 Aquifer test summary

The recover test performed on the Imperial Trail Well indicates that the source of the water for the well is from a confined aquifer. This is consistent with the observations contained in the drill log, where it shows that the water bearing strata is confined below a layer of clay. Field measurements of the water discharge into Musqueam Creek from the well are consistent with the pump specifications. The reduction of specific capacity over the period of

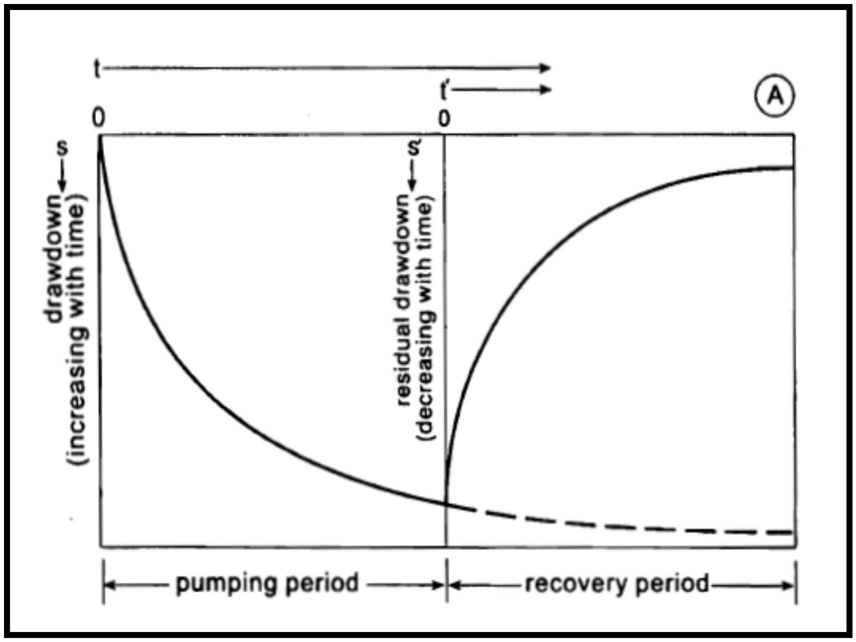


Figure 4.2: Example of a time drawdown relationship during a pumping test, followed by a recovery test.

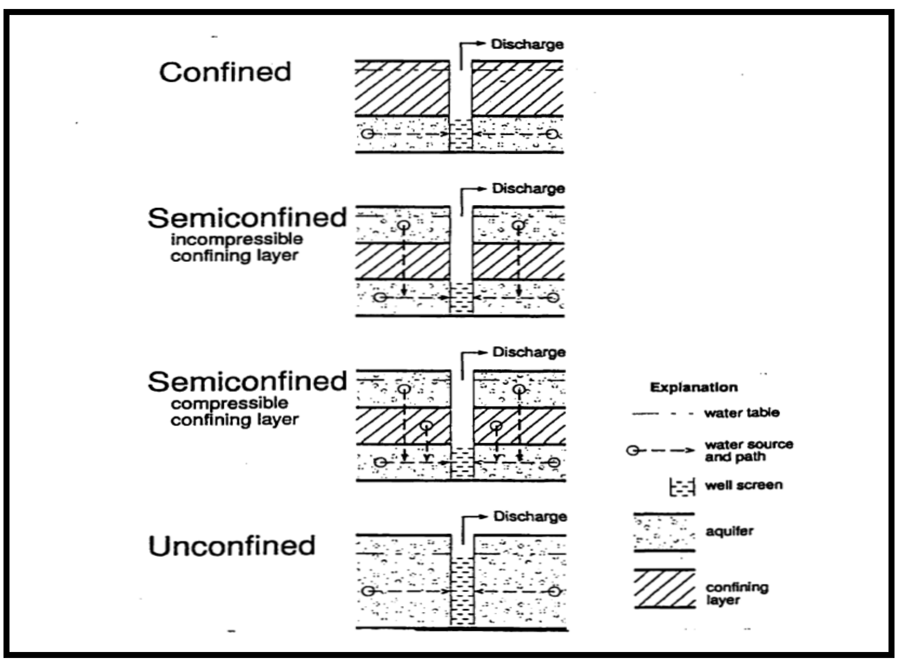


Figure 4.3: Example of typical aquifer conditions.

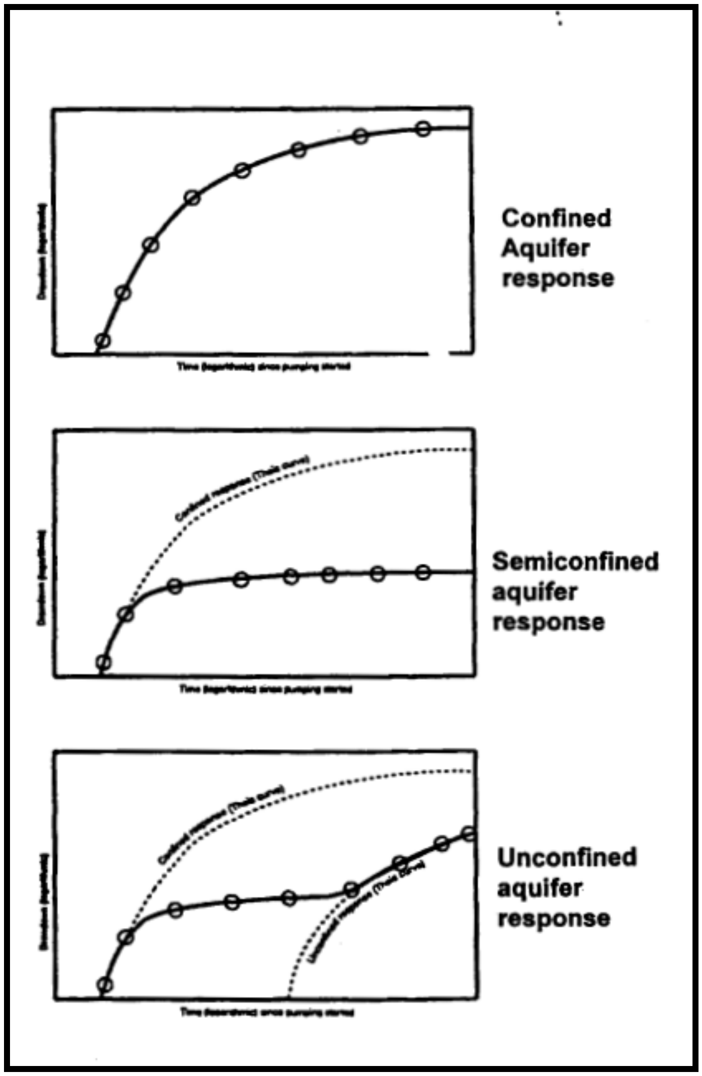


Figure 4.4: Examples of plotted recover test data from a groundwater well. The typical recovery test is shown for the three types of aquifers.

10 years since the well was developed, as evidenced by the rapid drawdown, indicates a problem with the well. The recovery test should result in a plot of data similar to **Figure 4.2**, which it clearly does not do. The data form the aquifer recovery shows typical logarithmic plot, while the drawdown upon pump start up is a straight line. This indicates that the well screen is most likely not allowing water to enter the well from the aquifer. Further testing is recommended to confirm the results.

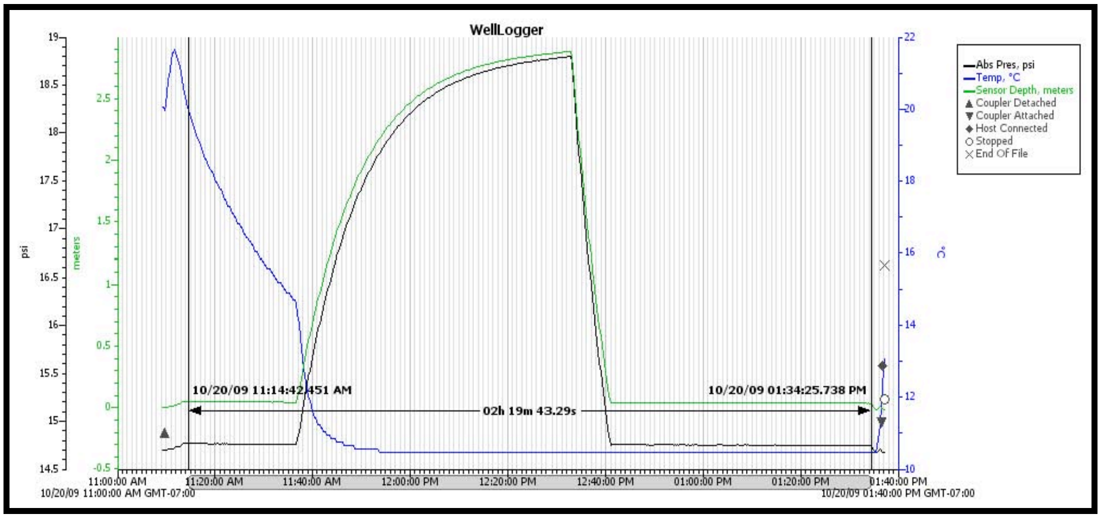


Figure 4.5: The water level logger data from the Imperial Trail well test. The well was tested on October 20th 2009.

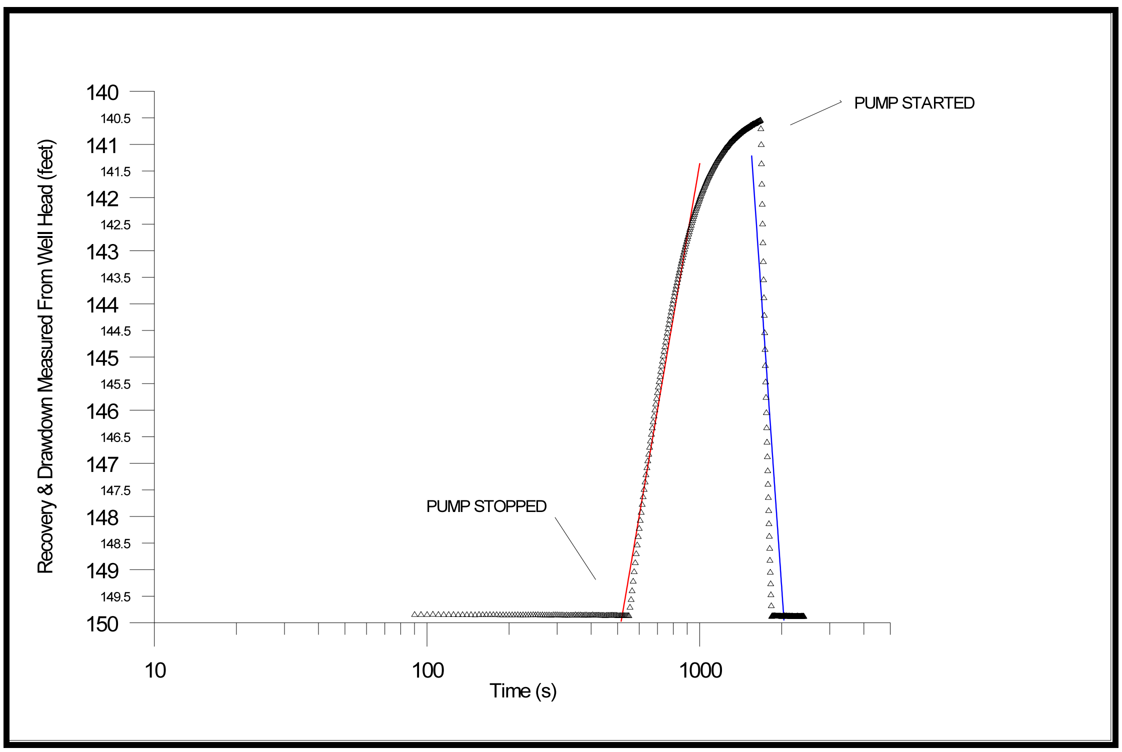


Figure 4.6: The plot of the Imperial Trail well pump test data conducted on October 20th 2009.

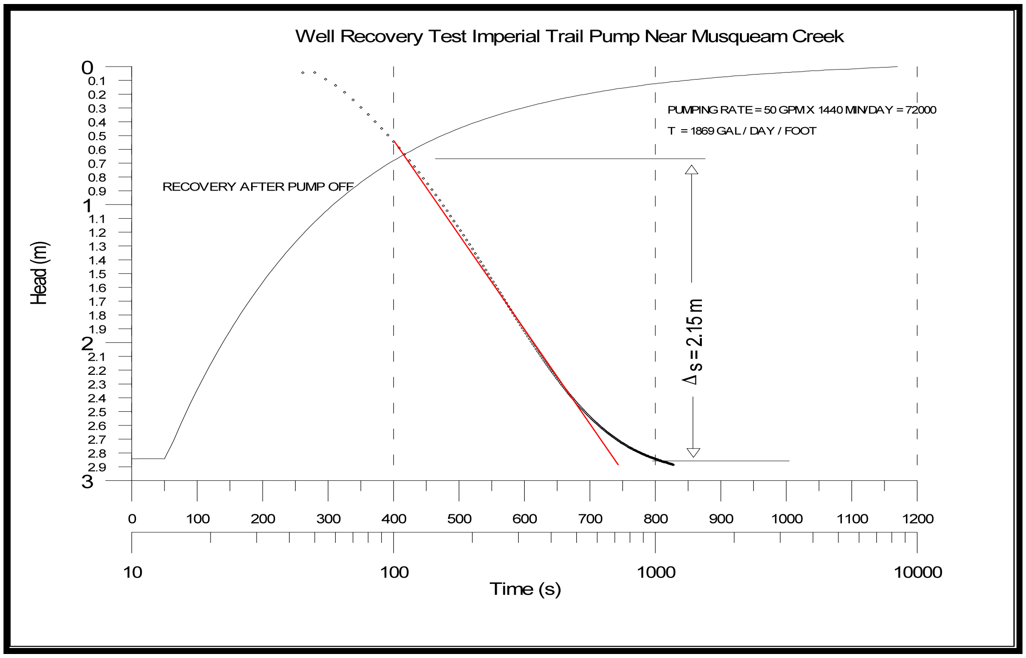


Figure 4.7: Derivation of transmissibility T = 2.3 Q/4 p D s for the Imperial Trail well.

4.5 Imperial Trail Well Discharge

The discharge form Imperial Trail Well flows directly into the Musqueam Creek channel on the south side of the trail. The flow was confirmed to be approximately 3.15-litres per second. Investigation during field reconnaissance revealed that the flow in the channel becomes zero at approximately 50-metres downstream from where the water is discharged into the channel from the well. The discharge from the well is not sufficient to overcome the infiltration loss of the channel, therefore surface flow ceases. It would appear that the discharge form the well serves only to supply recharge of depleted soil water system.

Summer season soil water losses due to evapotranspiration from west coast Douglas fir forests have been estimated to average approximately 1.57 mm day^{-1}, and can be a maximum of 3.56 mm day^{-1} (*Humphreys*, 1999). Water use in Pacific Northwest conifers (*Hinkley*, 2008) is estimated to be in the range of 4 to 5 mm day^{-1}. Using these numbers and converting to equivalent forested area losses per day, one can see on map inset 2 that the daily discharge form the Imperial Trail well is enough to recharge the daily soil moisture losses from only a small portion of forested area south of the trail.

5.0 Salmonid Production Capacity

5.1 Background

In conjunction with a review of the “state” of the Musqueam watershed a rearing juvenile salmonid standing stock survey was completed in the summer of 2009. This study was intended to meet two objectives. The first, to determine the numbers of juveniles rearing in these creeks expressed as a biomass and number by area and species; the second to assess the use of rehabilitated habitats by rearing salmonids. Details of the sampling methodology can be found in *Bates* (2009).

The focus of the juvenile sampling was on what is referred to as the upper anadromous reaches of the Musqueam Creek watershed. This includes the accessible reach of Cutthroat Creek from the confluence with Musqueam Creek to the Shaughnessy Golf and Country Club boundary.

5.3 Available Habitat

In 2009 the accessible and suitable habitats for rearing were significantly reduced. The stream was walked in mid July and early August 2009 when periods of low waters were observed. Juvenile sampling was completed in early August. The review of the available habitat in mid July and August found that summer baseflows were a significant limitation to carrying capacity. This watershed characteristic was reported in *Fausch* (1990) where summer baseflows were considered the single greatest limitation to salmonid production. *Bates* (2009) reported that Musqueam Creek had an estimated available rearing habitat of 2250-m^2 with Cutthroat creek providing 1386-m^2. These were estimates based on values measured by the Musqueam Nation in 2007. The results from the 2009 sampling found these values too high and were adjusted down 84% in Cutthroat Creek and 36% in Musqueam Creek and were a direct result of extreme summer baseflow conditions. Habitats in the upper stream channel were found to either; dry over riffles (**Figure 5.1**), pool in small pockets (**Figure 5.2**) or become increasing shallow and complex free in glide areas (**Figure 5.3**). In the case of habitat and stream channel above Salish Drive on Cutthroat Creek, extreme conditions in August 2009 resulted in observed isolation and death of rearing juvenile cutthroat trout (**Figure 5.4**).

Table I summaries the available habitat in each creek expected to be utilized for rearing juvenile coho salmon and cutthroat trout. The habitat observed was primarily standing pools for long shallow glides with little complexity. The portion of the stream flowing through the Eagleview Golf Course was pooled in places but also lacks complexity.

Table II: Estimated available habitat within the anadromous sections of Musqueam and Cutthroat Creeks in the summer of 2009.

Creek	Length	Wetted Width (m)	Area	% wet	Available Area
Musqueam	1200	2.00	2400	50	1200
Cutthroat	300	1.85	555	40	222
Total	1500				**1422**

5.2 Standing Stock Estimates

Juvenile sampling was completed from August 5th to 7th 2009. Representative stream segments were isolated and a total removal method used for estimate density in the sampled stream segments. Details of the sampling methodology are described in *Bates* (2009).

Figure 5.1: Riffle habitat observed in Musqueam Creek during extreme low summer base flows. Water in most riffle areas was pooled behind the riffle and goes sub-surface.

Figure 5.2: Pool habitat formed in areas of the channel where the scour has resulted in a deeper channel depression and the control (riffle) elevation at the tail maintains water upstream.

Figure 5.3: Glide habitat was observed throughout the streams but dominated the lower reaches of Musqueam Creek. These areas were uniform in depth and very shallow. Complexity and suitable parr habitat was minimal resulting in poor rearing conditions.

Sampling revealed two principle species of salmonids, coho salmon (Figure 5.4) and cutthroat trout (**Figure 5.5**). Only one age class (age 0) of coho salmon was found while 3 age classes (0, 1 and 2) for cutthroat trout were found. In addition to the salmonids a large number of Threespine stickleback (*Gasterosteus aculeatus*) (**Figure 5.6**) and Western brook lamprey (*Lampetra richardsoni*) were captured.

Results from the summer samples are reported in **Table III**. These values show variable SD resulting from the absence of certain species or age classes within each sample. A total of 8 sample sites were completed in Musqueam and only 3 in Cutthroat Creek. The challenge in Cutthroat was the selection of suitable sample sites. Extreme low summer base flows resulted in much of the accessible stream dry and/or areas of stagnated oxygen depleted water. This was evident by the observation of dead juveniles in the section of Cutthroat Creek above Salish Drive.

The density estimates for the sample sites on both Musqueam and Cutthroat Creeks were then used to determine the estimated total number of juveniles and biomass in the area of each stream that was considered suitable rearing habitat for each species and age class. **Table IV** summarizes the total estimated juvenile population for Musqueam and Cutthroat Creek during an extreme summer low flow condition.

Figure 5.4: Example of juvenile coho salmon found rearing in both Musqueam and Cutthroat Creeks.

Figure 5.5: Example of an age 1 juvenile cutthroat trout found rearing in Musqueam and Cutthroat Creeks.

Figure 5.6: Threespine sticklebacks were found throughout the lower sample sites on Musqueam Creek and the sample sites on Cutthroat Creek. Various age classes were observed.

Table III: Estimated biomass and individual densities determined at sample locations in Musqueam and Cutthroat Creeks, August 5 to 7th, 2009.

Stream	Species	Age	Biomass Density (gms/m^2) Mean(SD)	Density (No/m^2) Mean(SD)
Musqueam	Coho	0	3.90(3.15)	2.14(1.74)
Musqueam	Cutthroat	0	1.94(1.75)	2.19(1.96)
Musqueam	Cutthroat	1	3.81(5.00)	0.51(0.62)
Cutthroat	Coho	0	8.83(8.46)	0.15(0.13)
Cutthroat	Cutthroat	0	13.6(4.55)	0.54(0.30)
Cutthroat	Cutthroat	1	29.4(22.3)	0.09(0.04)

These estimates are based on data summarized in **Table II and III**. Standing stock will vary each year depending on the baseflow available to each creek. The 2009 summer season was considered one of the driest for this watershed and the data should be considered at the "worst" end of the scale. Regardless the low summer standing stock will be reflected in expected future adult returns.

Table IV: A summary of the estimated total biomass (gms) and number of juvenile salmonids rearing in Musqueam and Cutthroat Creeks in the summer of 2009.

Stream	Species	Age	Total Biomass (gms)[1]	Total Number[2]
Musqueam	Coho	0	4680	2568
Musqueam	Cutthroat	0	2328	2628
Musqueam	Cutthroat	1	4572	612
Cutthroat	Coho	0	1960	33
Cutthroat	Cutthroat	0	3019	120
Cutthroat	Cutthroat	1	6527	20

1-Total biomass is estimated by the available habitat reported in Table II and the average biomass density reported in Table III.
2 -Total number is estimated by the available habitat reported in Table II and the individual density reported in Table III.

In reviewing the standing stock estimates and the available habitat it was noted that although all age classes of trout were found, habitat suitable for parr (yearling) rearing was very limited. Higher biomass density noted in Cutthroat Creek appeared to be a result of the dewatering of the stream and pooling of remaining baseflow in deeper sections of stream increasing the density of individuals. These areas were small and offered limited protection.

In order to compare the existing standing stock a predictive model for biomass density was used. The model uses measured alkalinity and in this case values of 14-mg/L for Cutthroat Creek and 10-mg/L for Musqueam Creek were used. These values were taken from Lab analysis data collected in October 2007 during a period of low flows.

The model for cutthroat trout was developed by R. Ptolemy of the BC Ministry of Environment and is expressed as:

$$\text{Predicted Biomass (gms/100}^2\text{)} = 35 * \text{Alk}^{0.663}$$

The values estimated for juvenile coho salmon is approximately double the above value.

Using this model and average summer salmonid sizes the estimated biomass density was calculated to be 201-gms/100m^2 and 161-gms/100^2 for cutthroat juveniles in Cutthroat and Musqueam Creeks. These values doubled would result in 402 and 335-gms/100m^2 for coho in Cutthroat and Musqueam Creeks. Using these estimates the estimated total biomass and number using the values for available habitat in **Table II** is presented in **Table V**.

Table V: Summary of the estimated number of coho and cutthroat rearing in Musqueam and Cutthroat Creeks based on the Ptolemy Model and average juvenile size.

Creek	Spp	Age	Mean Weight (gms)	Est. Total Biomass (using Model and available habitat)	Est. Number (using Model)
Musqueam	Co	0	2.0	4020	2010
	Ctt	0	0.9	1932	2147
	Ctt	1	6.4	1932	302
	Ctt	2	17.0	1932	114
Cutthroat	Co	0	2.6	892	343
	Ctt	0	1.21	446	369
	Ctt	1	9.9	446	45
	Ctt	2	19.8	446	23

In comparing the results presented in **Tables IV and V** values calculated in the summer of 2009 meet of exceed the model values. This suggests that the model may underestimate the number of juveniles expected in the watershed or that the streams are fully seeded. We have assumed that given the results both streams are seeded to capacity. Although this appears to be the case it needs to be emphasized that the streams are seeded to capacity given the extreme low summer base flows. If the goal is to increase productive capacity of these streams additional stable wetted habitat is required. This again refocuses efforts on flow augmentation. Until the issue of reduced summer flows and loss of important habitats is addressed both Cutthroat and Musqueam Creeks are likely producing at their maximum.

It was also noted that efforts to increase stream complexity in the past using rehabilitation techniques was used on both streams. These rehabilitation designs were implemented to help scour the channels and pool water. On Musqueam Creek these structures were provided some limited benefit. Unfortunately in Cutthroat Creek the rehabilitated section of stream was completely de-watered. This suggests instream design for rehabilitation should be re-thought and the focus of any future designs tailored to water storage. Such constructed features may include development of deep watered alcoves in the lower reaches of both creeks.

5.3 Smolt Production

Ultimately the measure of success in the Musqueam Creek watershed is the number of out-migrating smolts the stream is producing. Protection and rehabilitation efforts to date have been designed to maximize the health and available spatial habitat for anadromous salmonids with the end goal to maximize smolt production. Given the results of the August 2009 and previous studies (*Bates*, 2009; *Fausch*, 1990) it is certain the "bottleneck" to salmonid smolt production the limited summer base flows and reduced over summer habitat with the critical deficiencies in parr habitat and riffle function.

It has been proposed that these streams be trapped during spring smolt migration. This activity will help to determine any over summer survival , smolt size and number. Although no trapping has been preformed to date the value and future data is again emphasized.

6.0 Flow Augmentation

6.1 Imperial Trail Well

Section 4.0 described the results of the pumping test for the well. The well most likely requires enhancements to continue with its operation, and its usefulness as a source of flow augmentation is now in question. It is suggested that it not be considered as a source of flow augmentation for either Musqueam or Cutthroat Creeks.

6.2 West Creek

Refer to **Appendix III** - Inset 1. Following up on recommendations described in the earlier report, a stream gauge was installed on "west" creek, in September 2009 to investigate the possibility of using the flow from this creek to augment low flows in Cutthroat Creek. Section 3.0 describes the correlation of "West" and Cutthroat Creeks with the long term WSC gauge, 08MH090. **Figures 6.1 to 6.6** show the relevant hydrological characteristics for "West" creek prorated from the WSC long-term record.

6.3 Storage Scenario for the Triangle Lands

The triangle lands comprise an area of approximately 0.14 km^2, outlined in red dotted line (**Appendix III**, Inset 1.). Within this area, a conceptual storage pond of approximately 73,000 m^2 has been displayed as shown on the map. Results of a possible storage scenario are shown in **Table VI**. The table shows an example of a storage/release model whereupon for the wet months of November to May, 85% of the flow from "West" Creek is diverted into the conceptual storage pond that has a surface area of 73000 m^2 and a depth of 3.5 m.

By the end of May the storage pond is 114% full (overflowing), and there is enough water stored in the pond to release 18 litres per second into Cutthroat Creek to augment summer season low flows. The chart, **Figure 6.7**, illustrates the example, modeled scenario. **Figure 6.8** and **Figure 6.9** shows the modeled storage scenario as flow augmentation to the seasonal low flows of Cutthroat Creek.

6.4 Wells In Pacific Sprit Park

Wells producing small amounts of discharge, such as the Imperil Trail Well, would be better sited closer to the stream reaches with productive aquatic habitat. This would tend to overcome the excessive summer season water losses due to vegetative evapotranspiration, and would perhaps leave enough water in the stream for effective flow augmentation.

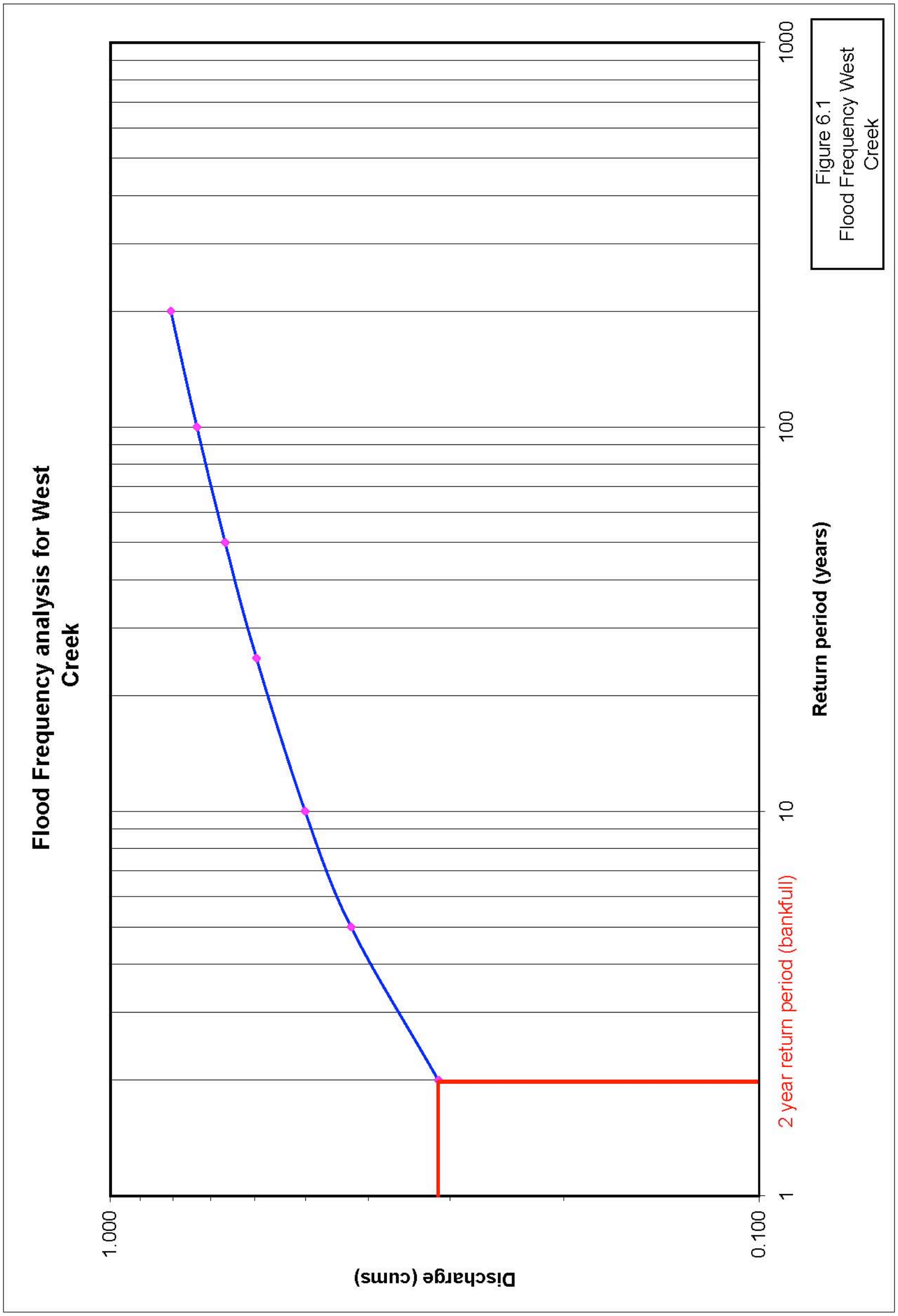


Figure 6.1: Flood frequency curve for "West Creek.

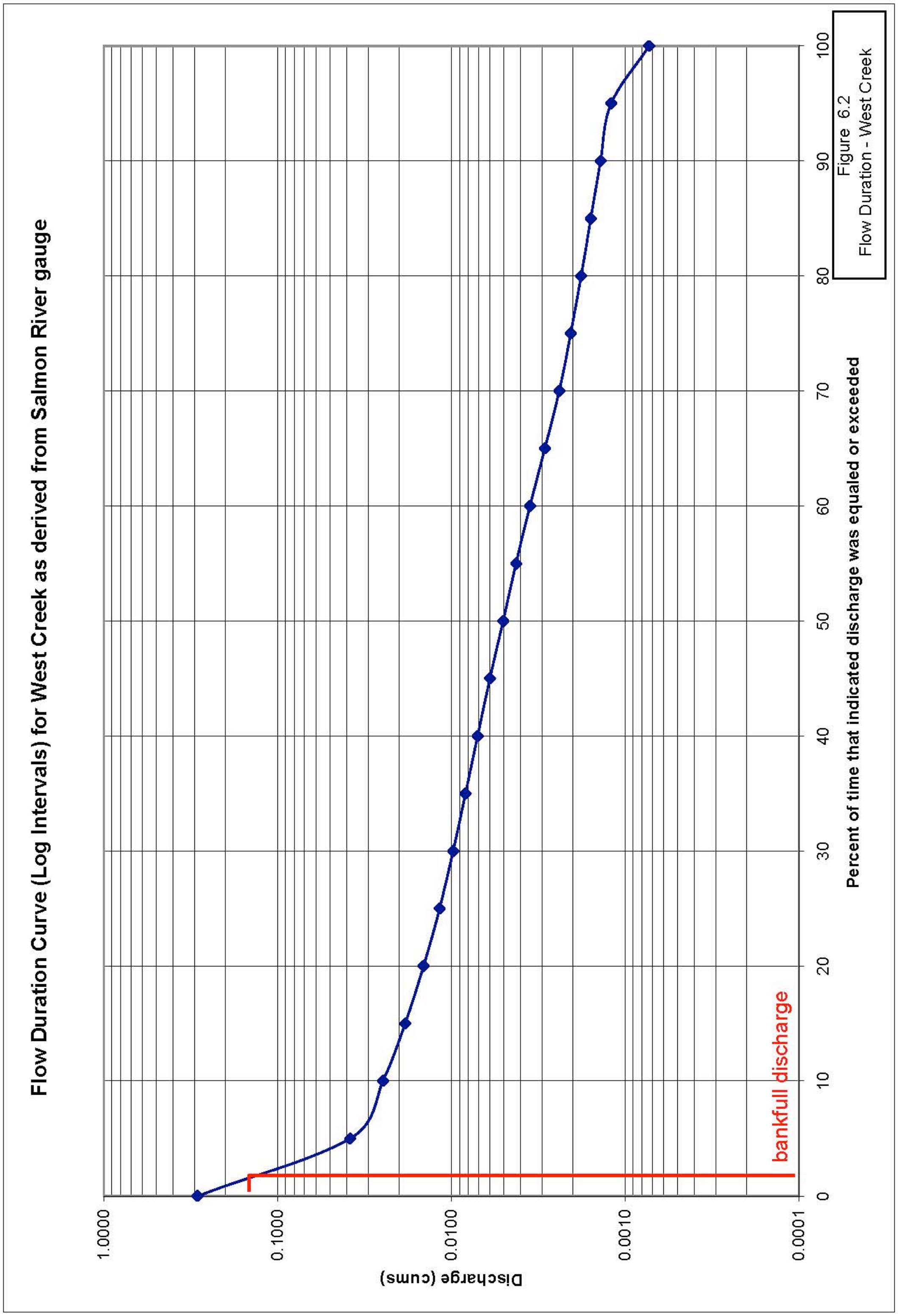


Figure 6.2: Flow duration curve for "West" Creek located to the west of Cutthroat Creek.

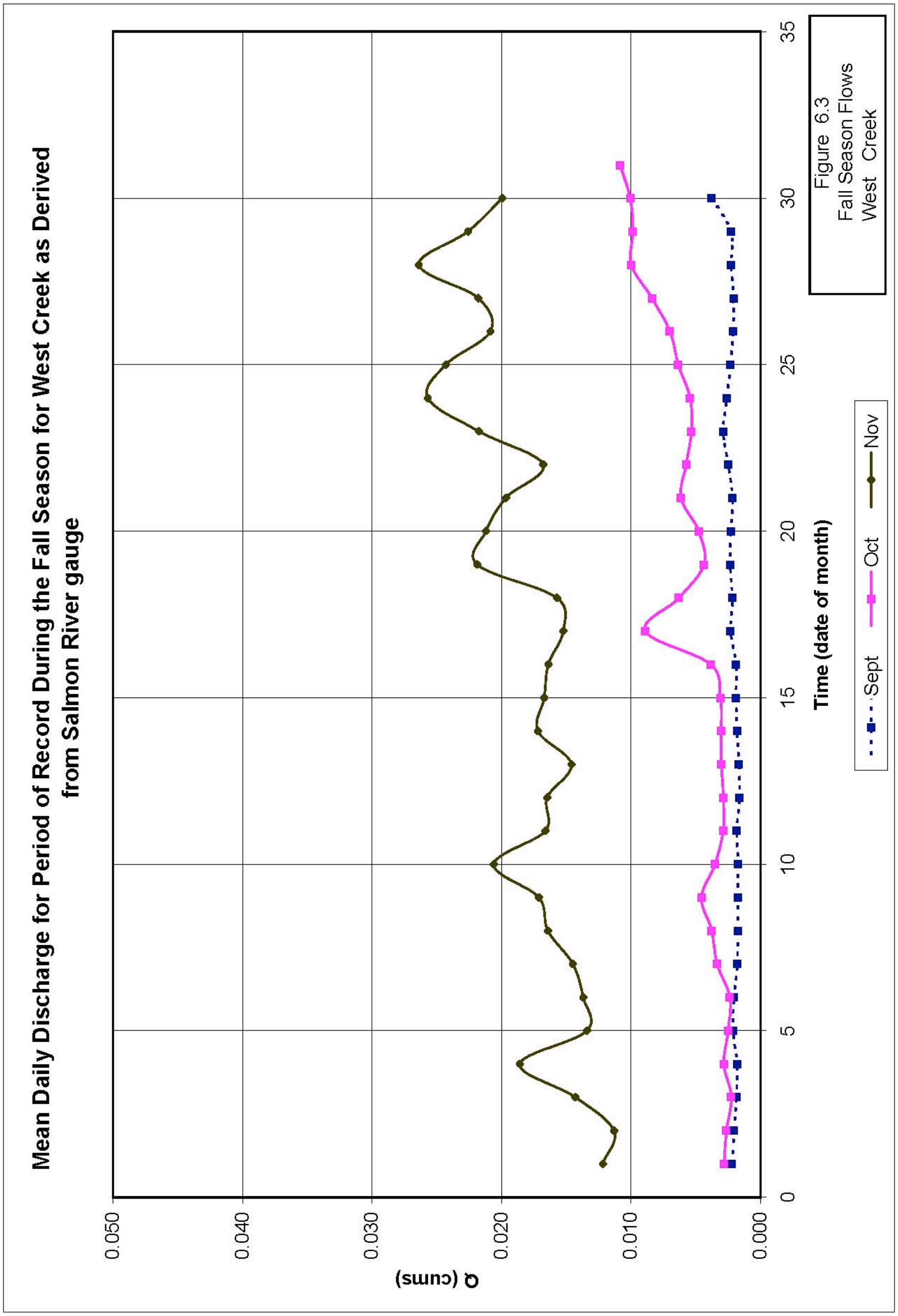


Figure 6.3: Estimated fall flows for “West” Creek to be used in the planning design for retention pond to augment Cutthroat Creek flows.

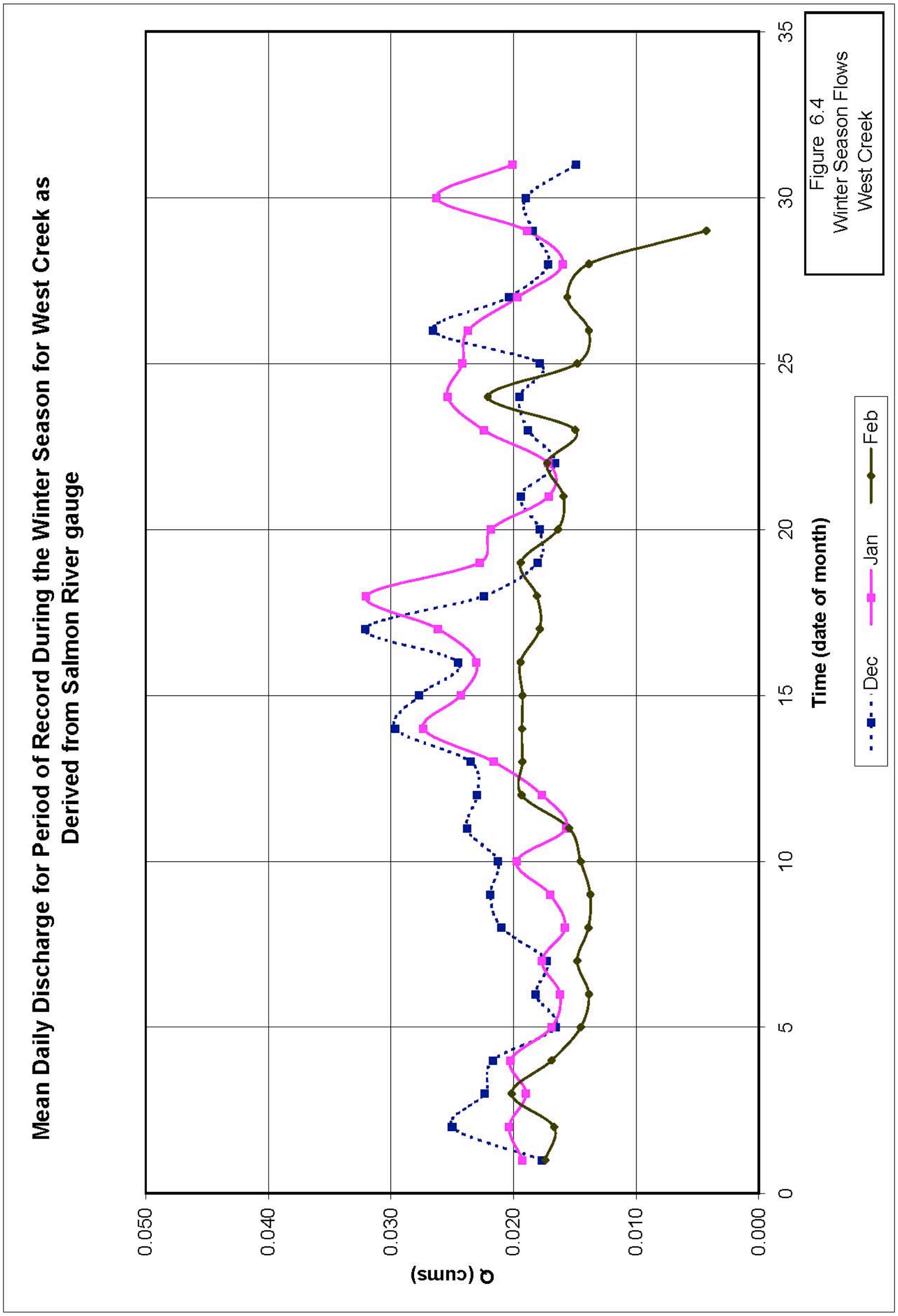


Figure 6.4: Estimated winter flows for "West" Creek to be used in the planning design for retention pond to augment Cutthroat Creek flows.

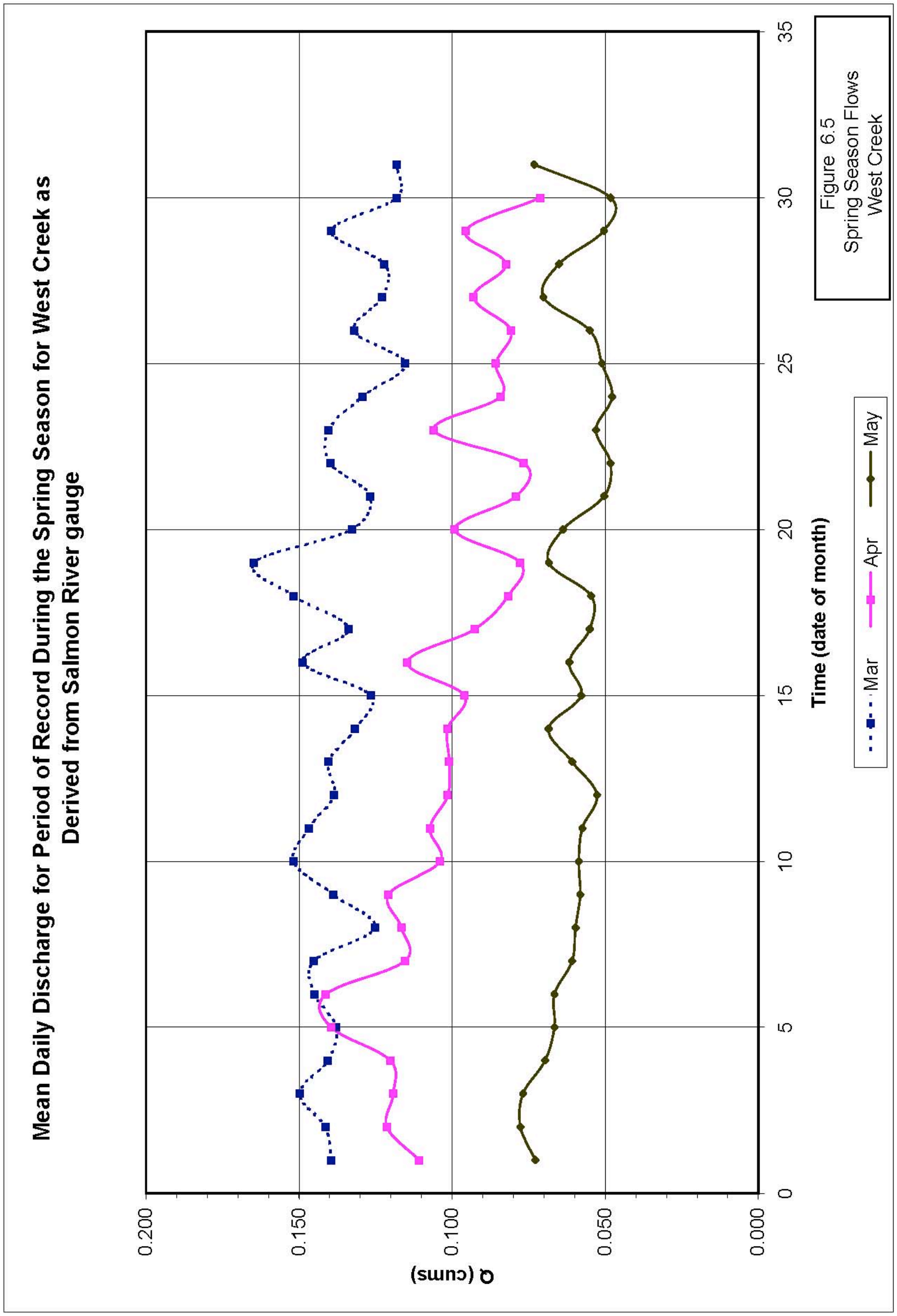


Figure 6.5: Estimated spring flows for "West" Creek to be used in the planning design for retention pond to augment Cutthroat Creek flows.

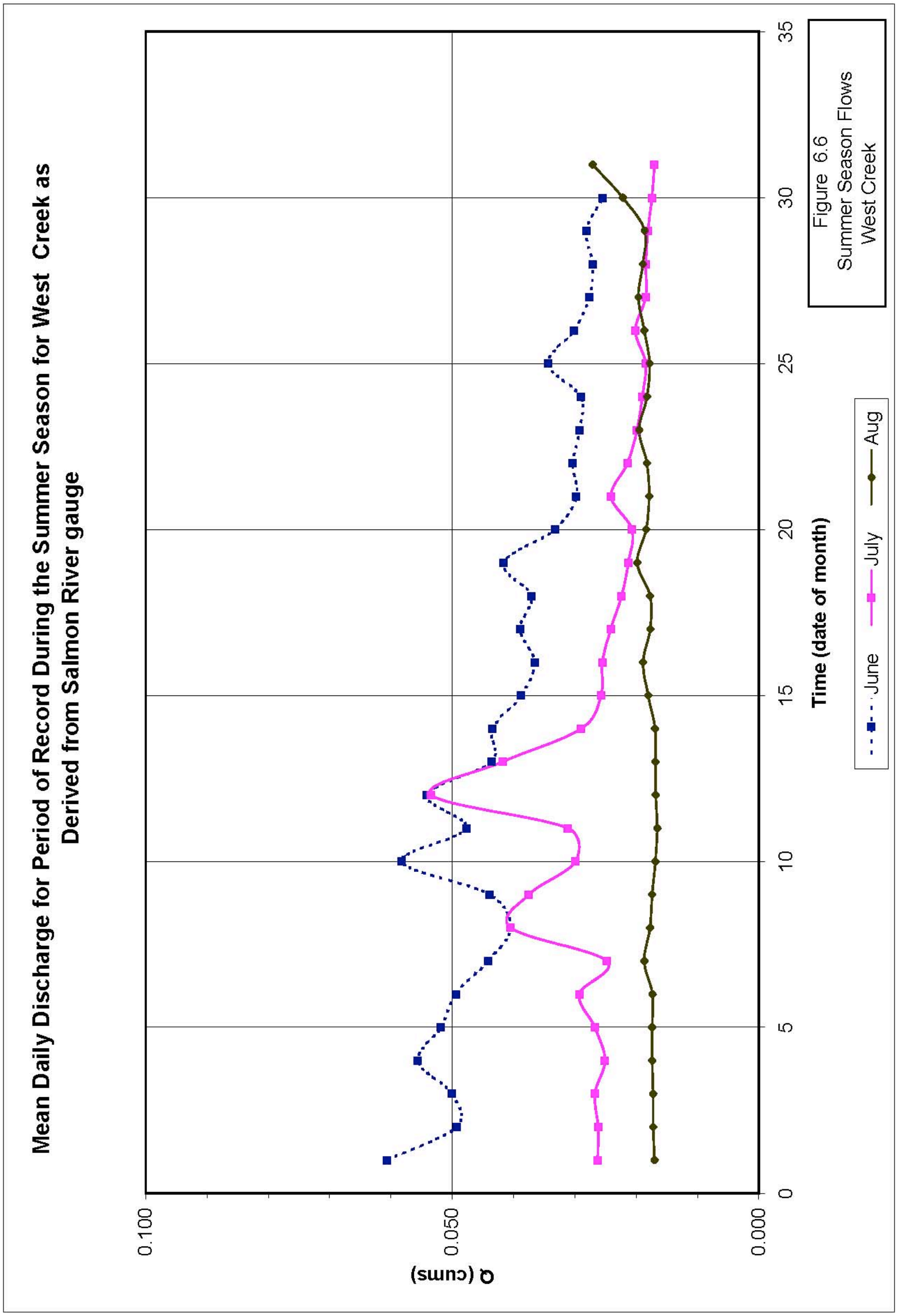


Figure 6.6: Estimated summer flows for "West" Creek to be used in the planning design for retention pond to augment Cutthroat Creek flows.

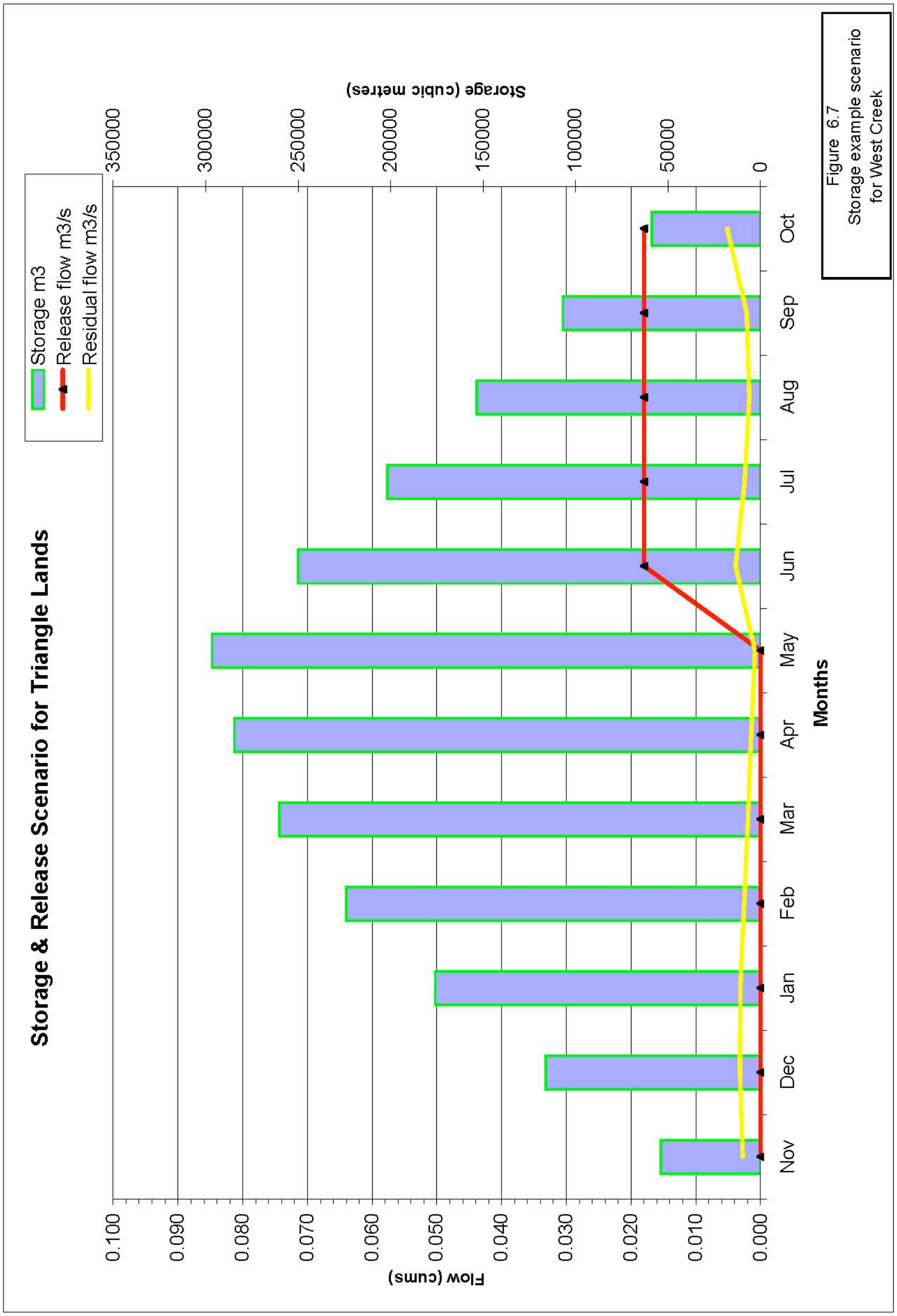


Figure 6.7: Storage example scenarios for “West” Creek.

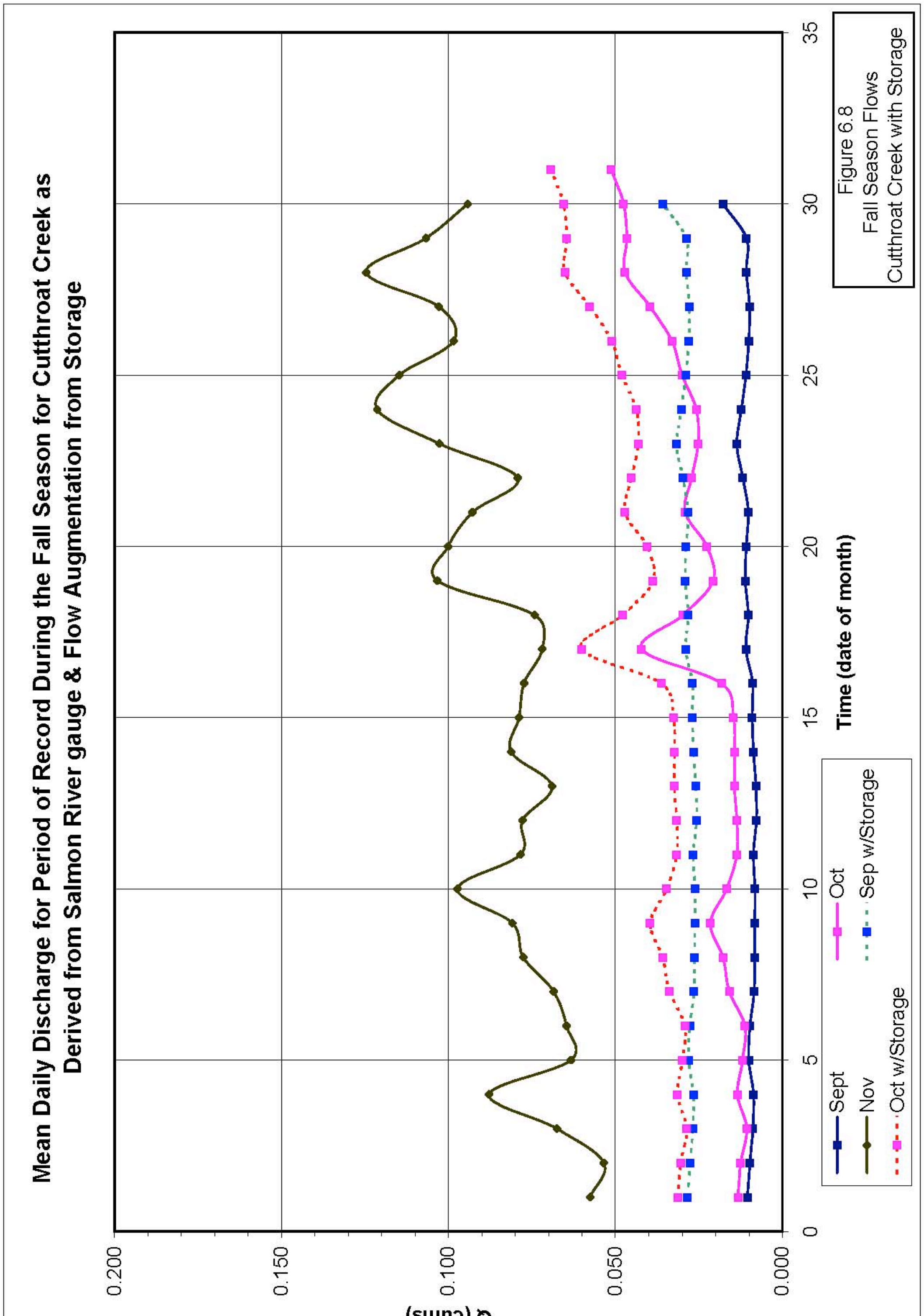


Figure 6.8: Estimated fall season flows in Cutthroat Creek at the SGCC with augmented flows (storage).

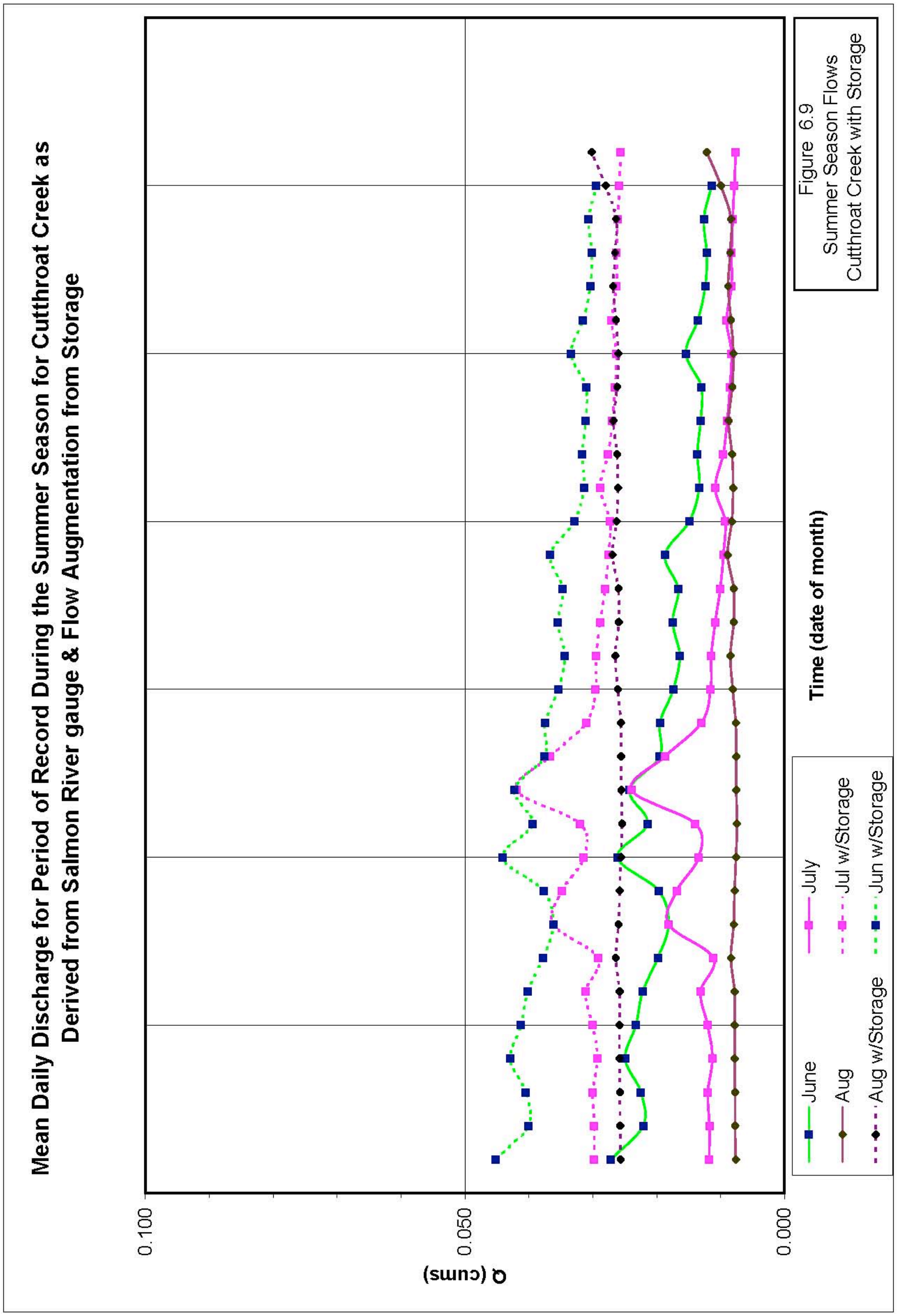


Figure 6.9: Estimated summer season flows in Cutthroat Creek at the SGCC with augmented flows (storage).

Table VI: Results of possible storage/release models where wet months would recharge the pond and water could be released during the low summer periods.

Store ?	Month	[3]Avg PPT mm	[4]Avg Evap mm	[5]Avg Q m^3/s	[6]m^3/ month	[7]Storage m^3	% [8]Pond Storage	[9]Available Flow m^3/s	[10]Residual flow (m^3/s)	[11]Release flow m^3/s
y	Nov	203	12.5	0.018	46995	53853	21.1%	0.0000	0.003	0.000
y	Dec	204	7.6	0.021	56524	116235	45.5%	0.0000	0.003	0.000
y	Jan	176	8.3	0.021	55774	175885	68.8%	0.0000	0.003	0.000
y	Feb	152	16.1	0.017	44845	223923	87.6%	0.0000	0.003	0.000
y	Mar	131	36.8	0.013	34723	260314	101.9%	0.0000	0.002	0.000
y	Apr	97	63.8	0.010	25726	284605	111.4%	0.0000	0.001	0.000
y	May	82	96	0.006	15424	296693	116.1%	0.0000	0.001	0.000
n	Jun	62	108.7	0.004	10251	250037	97.9%	0.0754	0.004	0.018
n	Jul	47	125.1	0.002	6562	201826	79.0%	0.0574	0.002	0.018
n	Aug	48	107.3	0.002	4663	153615	60.1%	0.0394	0.002	0.018
n	Sep	65	66.9	0.002	5718	106959	41.9%	0.0219	0.002	0.018
n	Oct	138	31.2	0.005	13740	58747	23.0%	0.0039	0.005	0.018
							% Flow	Area of basin m^2	Depth of basin m	Release Flow l/s
							85%	73000	3.5	18

6.5 Benefits to Aquatic Resources

The results of the hydrological assessment and review of the Imperial Well confirmed earlier observations regarding extreme low summer base flows. The salmonid populations community groups and government are working hard to protect in the Musqueam Creek watershed all have a requirement for year round freshwater rearing. As a result of the low summer base flows much of the potential habitat in these streams is either completely isolated and degraded or dry. This presents a significant bottleneck to overall juvenile

[3] Climate normal data generated by Climate BC v3.2
[4] Climate normal data, Environment Canada, Lake evaporation, UBC station 1971- 2000
[5] Monthly average flow generated for area proration of WSC 08MH090 daily average flows
[6] Monthly average flow converted to cubic metres
[7] This is the % of flow diverted times the monthly average flow in cubic metres
[8] This is the % of the storage pond that accumulates from the diverted flow for the month
[9] This is the available flow for release from storage once the storage has stopped accumulating
[10] This is the residual flow left in "west" creek as habitat IFR
[11] This is the augmentation flow release from storage into Cutthroat Creek

survival and reduced productive capacity of both Musqueam and Cutthroat creek.

Assuming no significant change in hydrologic function few improvements will be possible to salmonid production. Flow augmentation and/or replacement and new placement of augmentation wells may help to resolve base flow issues. Two ideas are presented above and intended for further discussion.

It is obvious that the Imperial Train well is no longer helping augment Musqueam Creek flows. It is also unclear whether any real advantage was realized from this well. Data on flow augmentation downstream of the well following its inception is unavailable. What is certain is that at this point in time the well is not likely contributing downstream as it appears much of the water is helping to recharge the aquifer it is being pulled from.

The concept of pumping water from a well is an interesting concept and may be better suited closer to the most productive anadromous rearing habitats.

The idea of water storage is a viable option for Cutthroat Creek. This would involve the dedication of land for the creation of a storage lagoon and could be designed as unique ecological landform and feature. The parcel of land identified on the earlier figures is currently un-developed. This concept would require further discussion and design considerations.

7.0 Riparian Corridor and Proper Functioning Condition

The importance of riparian canopies cannot be underestimated. In both Musqueam and Cutthroat Creeks the riparian canopy varies. The upper basin is generally protected through Pacific Spirit Park. In the lower basin the canopy is fragmented through developed areas.

Although difficult to regain efforts should be made to recapture riparian corridors and reestablish riparian proper functioning condition wherever possible. The development of a riparian protection strategy is encouraged using current provincial Fish Protection legislation and the Riparian Area Regulations. This would result in a riparian setback between 15 and 30-m on each side of the creek that requires the establishment of native vegetation including re-establishment of suitable conifer and deciduous tree canopies.

8.0 Conclusions

In the 2009/2010 study a number of conclusions were drawn from the data collection and analysis. These are:

- The prior hydrological assessment that relied on regional hydrological data from the long term WSC 08MH090 gauge has been validated by analysis of actual data collected from Musqueam, Cutthroat and "West" Creeks. While the regression analyses show good correlation, the period of concurrent data used for the validation is not of sufficient duration to provide high enough confidence in the results. Prorated data from the WSC gauge can be used to produce synthetic long-term data for Musqueam, Cutthroat and "West" Creeks. The synthetic data should be regarded as qualitative, and therefore used as such. The rating curves used to derive the flow data form the stage data are preliminary and require more discrete samples to verify high flow relationships.

- The pumping test for the Imperial Trail well indicates that the source of the water is from confined aquifer. The transmissivity and permeability of the aquifer is sufficient to supply the current daily pumped discharge of water from the well into Musqueam Creek channel. There appears to be a problem with the well screen, which manifests itself as excessive drawdown at the initiation of pumping.

- The water that is discharged from the well into Musqueam Creek is not sufficient to overcome losses from infiltration. It appears that the daily soil water depletion due to the evapotranspiration from the forested land of Pacific Sprit Park exceeds the daily discharge from the Imperial Trail well. The well is therefore not useful so far as providing summer season water augmentation for supporting downstream aquatic habitat.

- The amount of accessible rearing habitat for anadromous salmonids requiring year round habitat is less than that reported in 2009 and the amount of available habitat is a direct function of summer base flows. Extreme low summer flow in 2009 resulted in observed fish kills in the section of Cutthroat Creek above Salish Drive. Summer habitat limitations are a bottleneck to anadromous salmonid production.

- The population estimates determined from juvenile sampling in 2009 meets or exceed a modeled population estimate provided by the BC Ministry of Environment. The model, suitable for the south Fraser is based on water chemistry. Results form sampling found density and total numbers were at or near saturation. This is based on the estimated available habitat. Presumably increased base flows would result in additional habitat and increased productivity over wetted riffles. This increase-wetted area should provide an concomitant increase in production.

- Smolt migration numbers and smolt size and timing are unknown. Data provided through smolt trapping would help to identify and additional bottlenecks to salmonid production from this watershed.

- Riparian canopy and protection has been implemented in much of the existing watershed. The most important stream reaches for anadromous salmonid protection is still vulnerable. These lower reaches are the heaviest developed and a plan should than ensures protection of the riparian and rehabilitation and development of riparian corridors should be developed on the lower reaches of Musqueam Creek. In addition to fisheries values and protection such corridors would also function in protecting and developing other wildlife use.

9.0 Future Recommendations

The last 2 years has allowed for the investigation of a variety of important ecological components of the Musqueam watershed. As a result of the data presented in 2008/2009 and 2009/2010 the following recommendations are provided.

1. Continue the collection of stage discharge and development of the rating curves in "West", Cutthroat and Musqueam Creeks. The streams currently house data loggers and assuming issues with the loggers have been solved they will continue to collect stage data. Additional points for the rating curves is critical to "fine" tuning the hydrology portion of this and any future projects. These curves should be continuously developed.

   The maintenance of the stations and data collection may be possible using local staff form Musqueam First Nation with guidance and additional training from professional staff.

2. The use of Imperial Trail Well should be reviewed. Given the results of the well test and the volume and end result of the pumped water it is unlikely little benefits are being achieved form this well. It is recommended that its use be critically reviewed and if found ineffective as these results suggest the operational expense be re-

directed to other means of developing and/or protecting aquatic values in the watershed.

3. Current results of salmonid populations suggest we are at ort near saturation given the current base flows. In 2009 the base flows seemed unusually low. It is recommended that in 2010 the streams are again sampled and standing stock determined. This data is useful for long term monitoring and if relatively in expensive given its value for analysis.

4. Argumentation options are limited. The idea of developing an impoundment to hold re-directed water from :west: Creek should not be dismissed without further discussion. This area is currently unused wetland like habitat. Development of the parcel identified and the determination of a release strategy would likely help a greater length of Cutthroat Creek and increase the wetted habitat available for rearing salmonids downstream. Further surveys and design would be required.

5. Development of wells with discharge into the creeks immediately upstream of the anadromous sections of both streams would help solve the issue of reduced wetted area. This idea would presumably be costly but may provide for future discussion if it could be rolled into new development.

10.0 Overall Conclusion

At a large scale efforts to preserve and protect Musqueam Creek appear to be working. The area of protected and "natural" habitats account for an estimated 60-70% of the stream length. The greatest challenge to this watershed and its aquatic resources is base flows and maintenance of flows that will reduce the bottleneck to rearing salmonid survival. A solution to this issue should continue to be the focus of efforts in the watershed as its implications impact both aquatic and terrestrial species relying on flowing water for success.

11.0 References

Bates, D.J. 2009. Post construction review of juvenile salmonid populations in a rehabilitated reach of Musqueam Creek, BC. Report for Musqueam Ecosystem Conservation Society and City of Vancouver. ***FSCI*** Biological Consultants, Halfmoon Bay, BC.

Bates, D.J. and Termuende, J. 2009. Review of the hydrology and salmonid production limitations in Musqueam and Cutthroat Creeks, Vancouver, BC. Report for Musqueam Ecosystem Conservation Society. ***FSCI*** Biological Consultants, Halfmoon Bay, BC.

Fausch, K. 1990. Management of habitat in Musqueam Creek for resident and anadromous salmonids., BC Ministry of Environment, Victoria, BC and Greater Vancouver Regional District, Vancouver, BC.

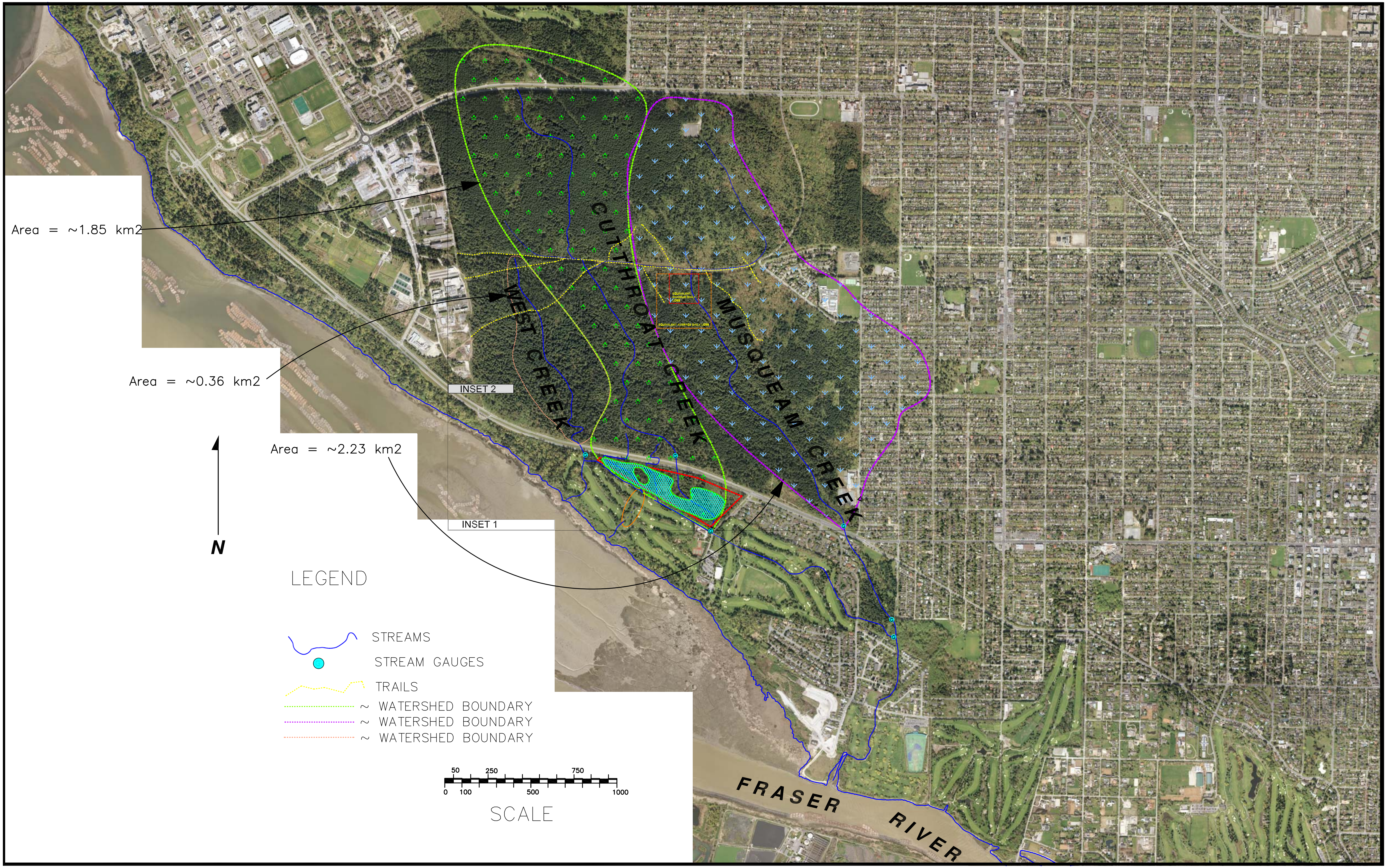
Hinkley, T. 2008. Water use in Pacific Northwest conifers. Presented at Northwest Forest Soils Council Technical meeting, University of Washington, Seattle, Washington.

Humphreys , E.R. 1999. Evaporation from a Canadian westcoast Douglas-fir forest: Seasonal patterns and controls. Master of Science, Department of Soils Science, University of BC, Vancouver, BC.

Theis, C.V. 1935. The lowering of the pieziometric surface and the rate of discharge of a well using groundwater storage. Transactions of the American Geophysical Union. Vol. 16, pp519-524.

12.0 Appendices

Appendix I: Map of the Musqueam, Cutthroat and West Creek watersheds and locations of hydrometric stations and data collection/analysis points.


Area = ~1.85 km2
Area = ~0.36 km2
Area = ~2.23 km2
CUTTHROAT CREEK
WEST CREEK
MUSQUEAM CREEK
INSET 2
INSET 1
N
LEGEND
STREAMS
STREAM GAUGES
TRAILS
~ WATERSHED BOUNDARY
~ WATERSHED BOUNDARY
~ WATERSHED BOUNDARY
50 250 750
0 100 500 1000
SCALE
FRASER RIVER

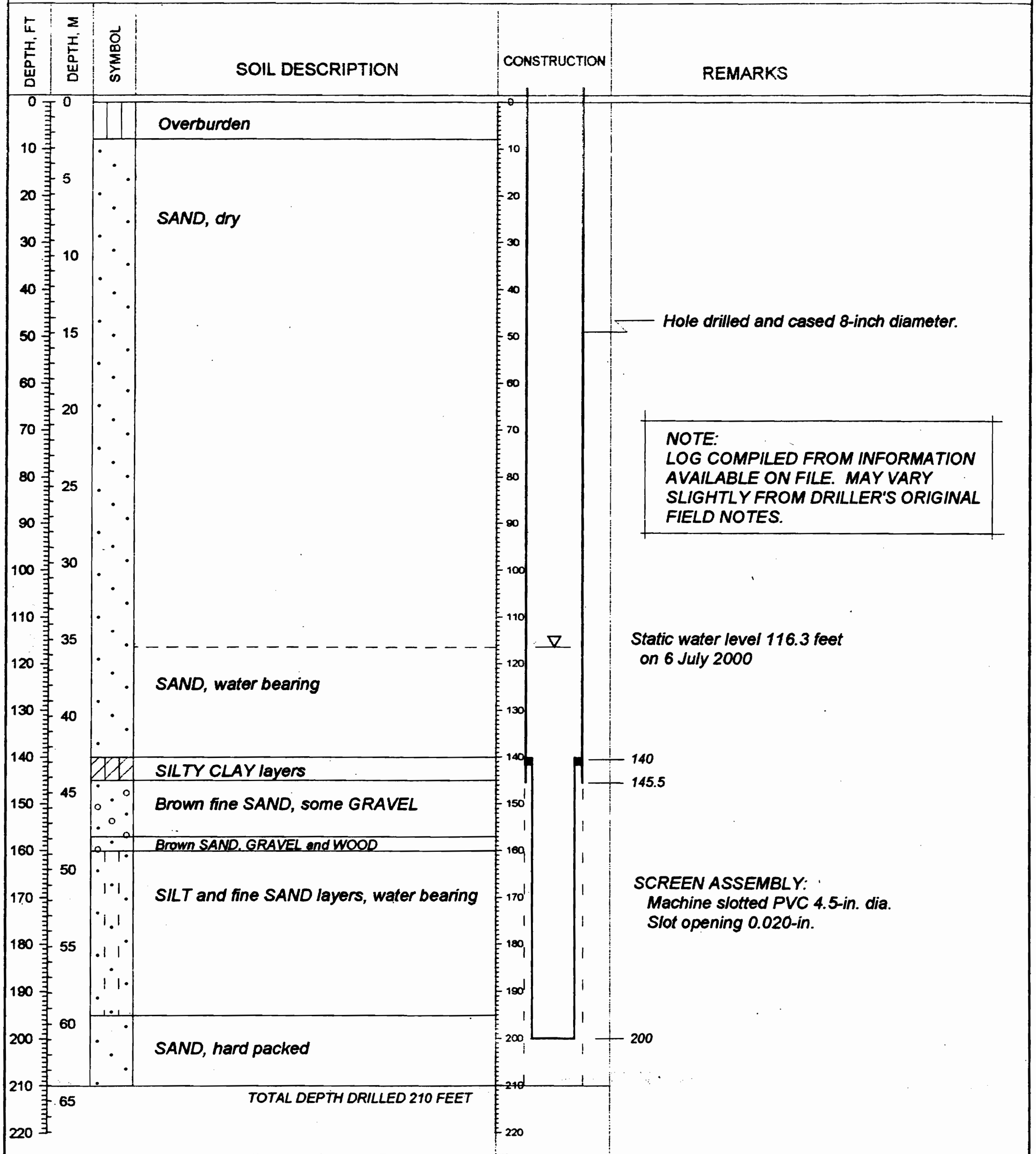
Appendix II: Well specifications for the Imperial Trail well located in Pacific Spirit Park.

BOREHOLE NO. WELL NO. 1

LOCATION IMPERIAL TRAIL AT MUSQUEAM CREEK, VANCOUVER B.C.

DRILLER FIELD DRILLING CONTRACTORS LTD.

EQUIPMENT CABLE TOOL DRILL RIG



FISHERIES & OCEANS CANADA

PRECISION SERVICE & PUMPS INC.
2265 WINDSOR STREET ABBOTSFORD B.C.

INDUSTRIAL - RESIDENTIAL PUMP SUPPLY & REPAIRS

PROJECT	LOG OF WELL	W.O. NO.	DATE COMPLETED
MUSQUEAM CREEK STREAM AUGMENTATION	MUSQUEAM CREEK WELL	2418	22 DEC 94
		BY: HWR	DRAWING NO.: 2418-02

PRECISION SERVICE & PUMPS INC.
2265 WINDSOR STREET ABBOTSFORD B.C.

WELL COMMISSION TEST

SHEET 1

NAME :	FISHERIES & OCEANS	WELL I.D. :	MUSQUEAM CREEK	W. O. NO. :	2418
LOCATION :	IMPERIAL TRAIL AT MUSQUEAM CREEK, VANCOUVER B.C.	DIAMETER :	8-INCH	PUMP USED :	GOULDS 40GS30 - 3HP
		DEPTH :	200 FEET	DEPTH :	147.6 FEET
DRILLER :	FIELD DRILLING	PACKER :	4.5-IN. RISER TO SFC.	ORIFICE :	FLOWMETER
ENGINEER :		SCREEN L :	60 FT. OF 4.5-IN. PVC	DISCH. L :	TO LINE
DATE :	6 JULY 2000	DATUM :	TOP OF CASING	TEST TYPE :	OPERATION CHECK

TIME	ELAPSED TIME MINUTES	DEPTH TO WATER FEET	PUMPING RATE USGPM			REMARKS
10:30	0	117.60				
	1	120.75	50	(= 0.19 m^3/min)		WATER RUSTY
	5	122.55				
	10	126.92				WATER CLEAR
	20	127.19	50			
	40	127.61				
	52	127.83				
	61	127.91	50			
	84	127.91				PUMP OFF

ELECTRICAL TESTS

AMPERAGE: Y = 17.00 B = 14.00 R = 4.20
VOLTAGE: Y = 222 B = 222
INSULATION
RESISTANCE: Y = ∞ B = ∞ R = ∞

B/W LOW LEVEL SHUTOFF - O.K.

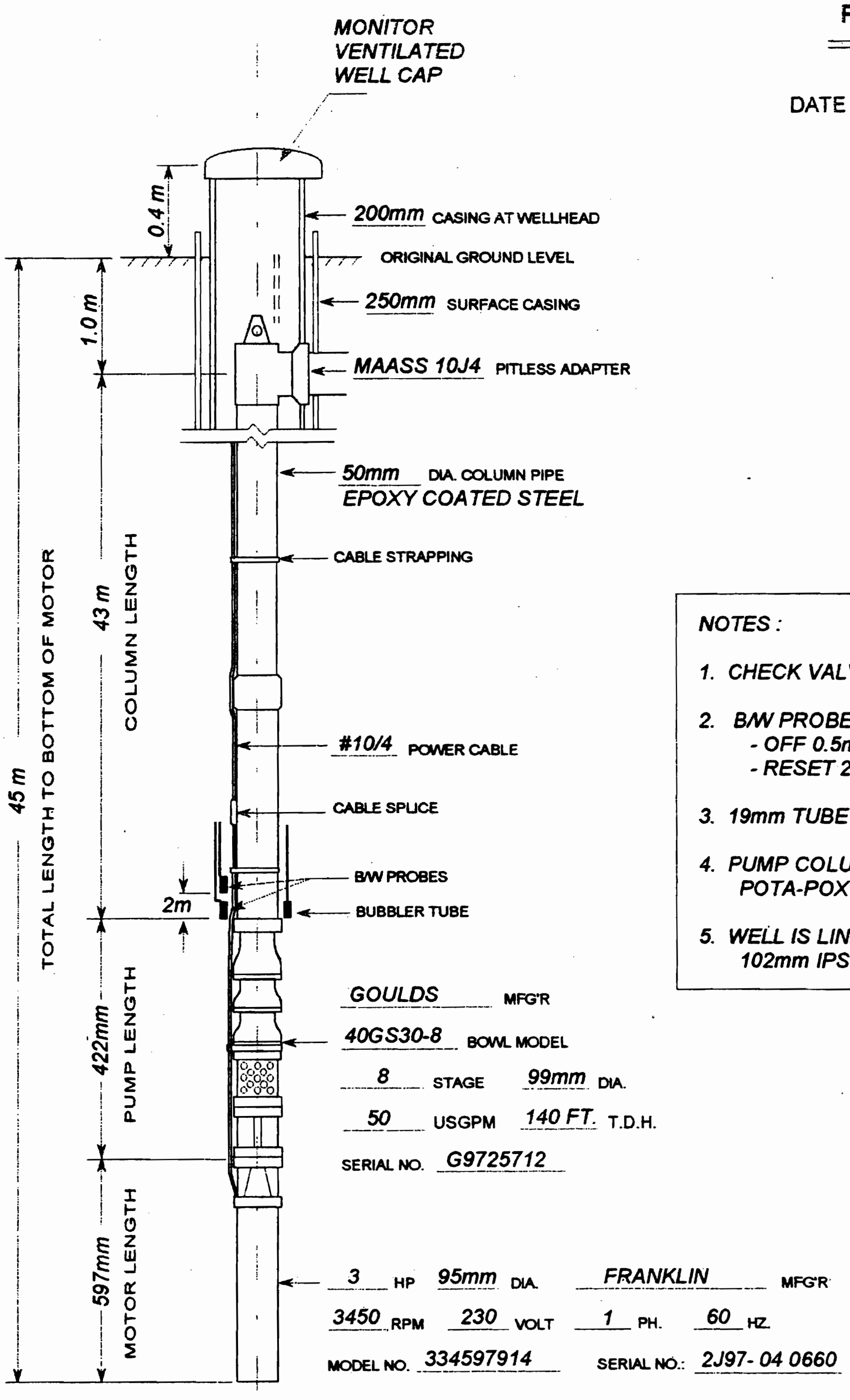
OVERLOAD PROTECTION - FACTORY SET

PSP
PRECISION SERVICE & PUMPS INC.
2265 WINDSOR STREET ABBOTSFORD B.C.

INDUSTRIAL AND RESIDENTIAL
PUMP SUPPLY AND REPAIRS
PH. 604-850-7010 FX. 604-850-9666

PUMP SET RECORD

DATE *17 JUNE 1998*



NOTES :

1. *CHECK VALVE IN TOP OF PUMP*
2. *B/W PROBES:*
   - *OFF 0.5m ABOVE PUMP INTAKE*
   - *RESET 2.5m ABOVE PUMP INTAKE*
3. *19mm TUBE 3m ABOVE PUMP INTAKE*
4. *PUMP COLUMN IS COATED WITH POTA-POX (EPOXY)*
5. *WELL IS LINED WITH 18m OF 102mm IPS PVC SCREEN PLUS RISER*

CUSTOMER	*FISHERIES & OCEANS CANADA*	WELL I.D.	*MUSQUEAM CREEK WELL*
LOCATION	*IMPERIAL TRAIL AT MUSQUEAM CREEK, VANCOUVER B.C.*	W.O. NO. *2418*	DWG. NO. *2418-03*

SUBMERSIBLE MOTOR INSTALLATION RECORD

Well Owner :	FISHERIES & OCEANS CANADA	Address :	Imperial Trail at Musqueam Creek, Vanc.
Well I.D. :	Musqueam Creek Well	Install Date :	17 June 1998
Installer :	Precision Service & Pumps Inc.	Commissioned	6 July 2000
	2265 Windsor St., Abbotsford, B.C.	Technicians :	Earl Binning & G. Tribe (Electrician)

MOTOR DATA

Model No.	334597914	Date Code	2J97	Serial No.	04 0660

PUMP DATA

Model No.	40GS30-8	Manufacturer	GOULDS	Serial No.	G9725712
Curve No.	40GS	Rated	50 USgpm @ 140 ft. TDH	Date Code	

MOTOR CONTROL PANEL

Manufacturer	Franklin	Model No.	282 302 8110	Size	3 HP
Contactor Model		Size			
Overloads Make		No. Used		Overload Setting	
Lightning Protection		Model No.		Grounding Details	Motor to control panel main
Subtrol Protection		Kit No.			
Warranty Registration No.					
Auxiliary Control Devices	B/W 5200 HF2 Critical Low Level				

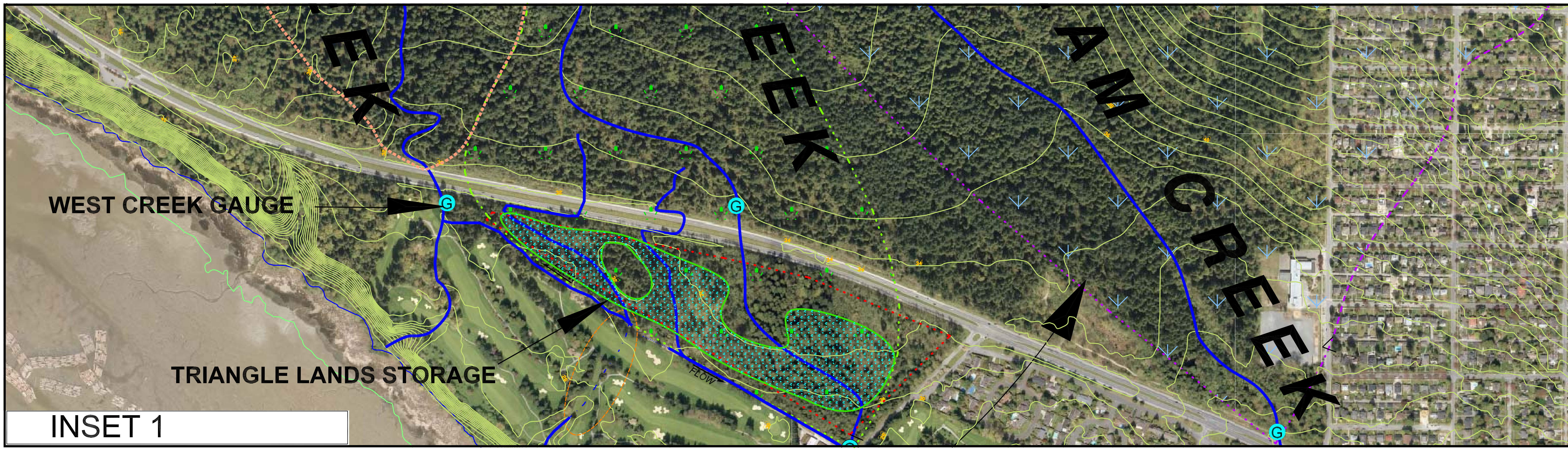
WELL DATA

Well Diameter	8-inch	Well Depth	200	Casing Material	8-inch mild steel
Casing Depth	146 feet	Screen depth	140-200 feet	Motor Setting	147.6 feet
Static Water Level	118 feet	Discharge Size	2-inch	Column Pipe	4-in. T&C, epoxy
Check Valves	Top of pump			Supply Cable - Service to Panel	#6-3c + Ground
Splice Kit	Crimp-on connectors, vulcanizing tape			Drop Cable - Panel to Motor	#10-4c Sub Cable

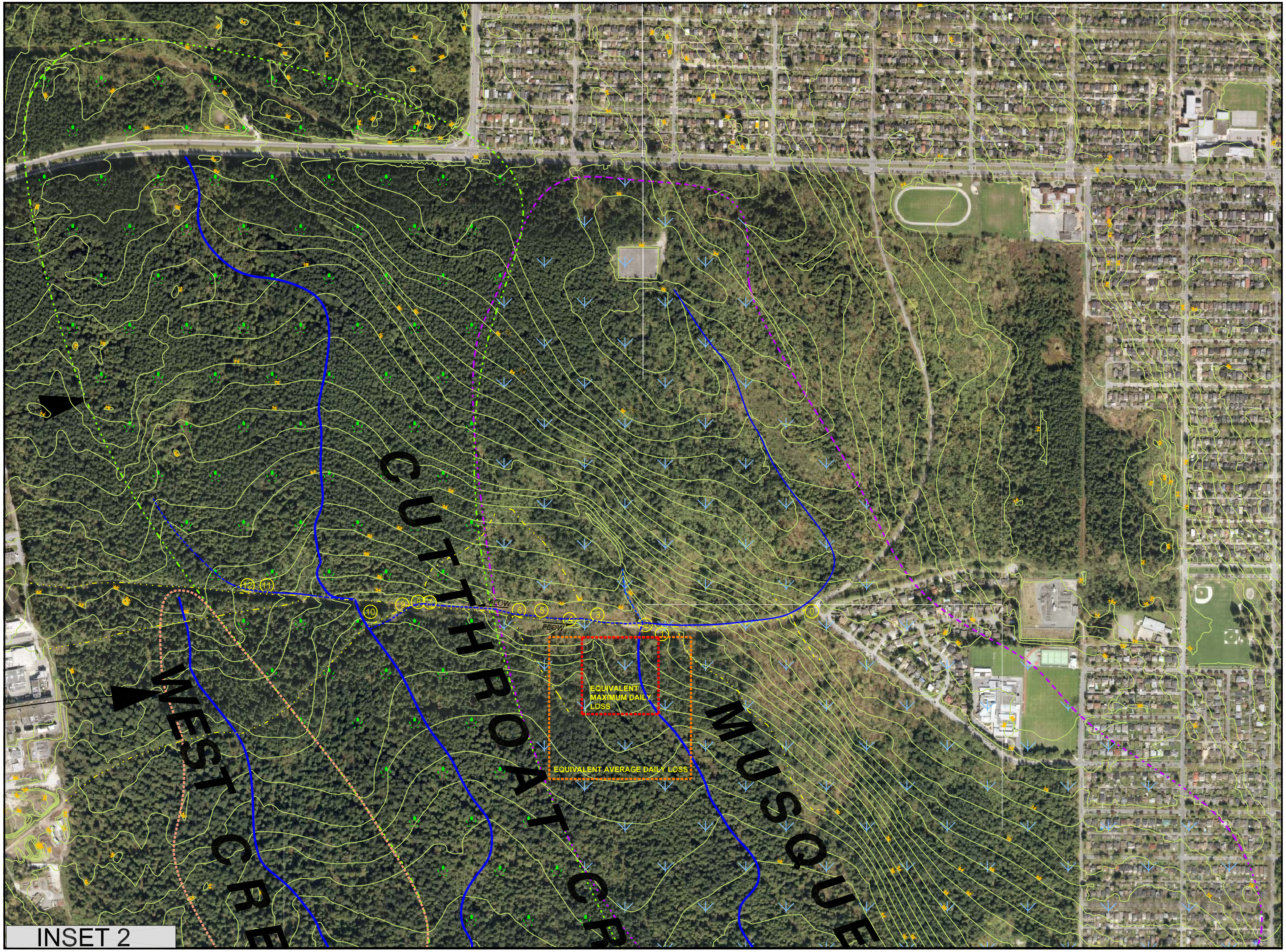
START UP DATA

Insulation Check	INITIAL MEGS - MOTOR TO PIGTAIL ONLY				BLUE		RED		YELLOW	
	FINAL MEGS -INSTALLED MOTOR & CABLE				BLUE	∞	RED	∞	YELLOW	∞
Voltage at Panel	50.2	USGPM		PSI	BLUE	222	RED		YELLOW	222
		USGPM		PSI	BLUE		RED		YELLOW	
		USGPM		PSI	BLUE		RED		YELLOW	
Line Amps	50.2	USGPM	n/a	PSI	BLUE	14.00	RED	4.20	YELLOW	17.00
		USGPM		PSI	BLUE		RED		YELLOW	
		USGPM		PSI	BLUE		RED		YELLOW	
Pump Cycle Time	Manual operation in summer									

Appendix III: Proposed areas for potential water storage using "West" Creek adjacent to Cutthroat Creek.



WEST CREEK GAUGE
TRIANGLE LANDS STORAGE
INSET 1


CUTTHROAT CR
WEST CRE
MUSQUE
EQUIVALENT MAXIMUM DAILY LOSS
EQUIVALENT AVERAGE DAILY LOSS
FLOW
INSET 2