Restoring a Salmon Spawning Stream to the Jericho Watershed

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Executive Summary

The Jericho Lands is a 21-hectare plot of land located in the West Point Grey neighbourhood of Vancouver. It is directly upslope of Jericho Park, which itself has significant ecological and recreational value to the community. Jericho Lands is currently planned to undergo redevelopment in the coming years by the Musqueam, Squamish, and Tsleil-Waututh First Nations and is currently in the research, planning, and consulting stage. This redevelopment could make it possible to restore salmon-spawning streams that once existed in the area.

The aim of this project is to explore the possibility of re-introducing salmon to Jericho Park. The main objectives of our project are to explore the characteristics of Jericho Park using GIS software, explore water sources, propose potential locations for possible holding ponds, and propose possible stream routes for these holding ponds.

Chum were determined to be the best species for reintroduction at the park based on a meeting that we had with Scott Hinch, an aquatic ecologist at UBC. The criteria for streamflow was based on the biological needs of salmon. The amount of water needed to sustain a healthy salmon stream was determined to be 40 L/s or 0.04 m^3/s (1.5 m wide, 0.13 m deep, flowing at 0.20 m/s). This streamflow would be needed from November to the end of April. In other months (May through October), we set a target streamflow (0.00039 m^3/s to 0.0027 m^3/s) to mitigate potential evapotranspiration in order to keep the channel wet, but not necessarily flowing.

There are currently two watersheds contributing to Jericho Park, which provide two possibilities for stream channel locations. The western watershed is 230 ha and eastern is 264 ha. Both have 62% impervious cover (including roads, roofs, etc.). Because of the urban nature of the system, streamflow is likely to rely on storm sewers and streamflow might be very flashy (i.e., short floods followed by periods of very low flow).

An analysis of surface water was carried out to estimate potential streamflow. This was done using water balance equations with weather parameters from 2016, parameters obtained from literature, municipal databases, and GIS software. Weather data from 2016 was used for water balance equations.

Stormwater would be the main water source for the stream. However, not all watersheds could reach the target flow rate (0.04 m^3/s). The average streamflow from November to April would be 0.05 m^3/s in the eastern watershed, which is greater than the target flow rate. Meanwhile, the western watershed only has average streamflow of 0.024 m^3/s during this period. Holding ponds could be used to help prevent the flashiness of a stream and store water for use in April, but a holding pond would have to be enormous (103680 m^3, the size of a football field 19 m deep) to give 0.04 m^3/s of water for one month.

HVAC (Heating, Ventilation, and Air Conditioning) systems could produce 14 to 46 L/day/1000 ft^2 during the summer. This would be enough, given a reasonable number of newly developed buildings in Jericho Lands, to mitigate evapotranspiration in the stream channel, and help mitigate water losses from evaporation and plant uptake in the channel and the existing ponds

in Jericho Park. However, it would not be of use for the spawning season as there would be no Chum in the stream throughout the summer.

We have proposed two possible locations of holding ponds as well as the resulting stream that would be constructed at each possible location shown in Figures 9 and 10, section 3.5. The holding pond proposed in Figure 9 could be possible with sufficient groundwater pumping, although dry seasons could be a problem. However, the holding pond proposed in Figure 10 would provide enough water during a dry season due to its water input mainly sourced from the eastern stormwater catchment.

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1 Introduction

Jericho Park is located in northern Point Grey, a neighbourhood of Vancouver, BC. Jericho Park provides habitat for many native plants and animals; habitats include forests, forested wetlands, ponds, sandy beaches, and lawns. Oral history tells that the streams in Jericho Park and its adjacent neighborhoods once supported salmon (Lesack and Proctor 2011). However, increased urbanization and land use changes in the Park (including development as a military base and a golf course) affected the hydrology of the streams and have caused salmon to disappear from the area.

The Jericho Stewardship Group, a non-profit organization that manages the natural habitat of Jericho Park, envisions the restoration of this historical stream and the reintroduction of salmon as a long-term goal for their organization. In the coming years the east block of Jericho Lands, an area directly upslope of Jericho Park, will be redeveloped by the Musqueam, Squamish, and Tsleil-Waututh First Nations in joint with the Canada Lands development group. This will bring opportunities for changes in storm sewer connections and the creation of stream channels which may be essential to the Jericho Stewardship Group's visions.

Our major objective is to explore the hydrological possibility of creating a salmon-spawning stream in Jericho Park and its uplands. This is broken down into three minor objectives:

1. To explore the climatic, physical, and hydrological characteristics of the Jericho watersheds
2. To evaluate sources of water for potential streams, including stormwater, holding ponds, and HVAC (Heating, Ventilation, and Air Conditioning)
3. To propose several feasible routes for the stream, taking into consideration the biological needs of salmon

There is precedent for the reintroduction of salmon in Vancouver. In 2000, there was a salmon restoration project at Spanish Banks Creek, which is adjacent to Jericho Park. This project introduced salmon to the creek for the first time in over fifty years. However, the Spanish Banks watershed is much less urbanized than the Jericho watershed. At Spanish Banks, a suitable salmon habitat already existed, and to restore the stream, the only change made was to remove a culvert and create an outlet to the ocean that salmon were able to pass. The creek runs down a steep wooded ravine in Pacific Spirit Park, and is mostly groundwater fed. At Jericho Park, the existing habitat is less suitable for salmon and the challenges of a restoration will be quite different. The environment at Jericho park is much drier than the environment at Spanish Banks, so the methods used to re-introduce salmon to Spanish Banks cannot be used to re-introduce salmon to Jericho Park.

The urban nature of the system may pose the greatest challenge to a stream restoration at Jericho Park. Residence time is a measure for how long a substance remains in a reservoir and can be calculated by dividing the total amount of water in a reservoir by the amount of input or output. The residence time for water in urban systems can be very small (Fletcher et al. 2013), causing urban streams to be very flashy (Finkenbine et al. 2000). Flashy urban streams flood very quickly after rainfall occurs but run dry soon after rain stops falling. Members of the Jericho Stewardship Group and the authors have observed that the stream is completely dry throughout the summer and remains very low even into late fall. Furthermore, the ponds were also almost completely dry in the summer of 2017, and residents were claiming that the animals in the park were dying from the water shortage (CBC News 2017).

This report focuses on stream restoration in the context of salmon reintroduction. However, a restored stream would have inherent value regardless of its ability to support salmon. Streams in Jericho Park and Lands could add recreational and aesthetic value to the neighbourhood, support other aquatic organisms, provide food and water for urban wildlife, and supply water to the ponds to help prevent them from drying out in future summers.

2 Methods

2.1 Salmon

A literature review was conducted to review the life histories and freshwater needs of salmon. This was mostly done using information from Groot and Margolis (1991). The target species of Chum was determined based on their lower biological requirements compared to other species of salmon according to Scott Hinch, an aquatic ecologist at UBC. The low end of the range of its spawning needs (water velocity and water depth) were used to give us criteria for the streamflow needed in Jericho Park. Other elements of its needs (gravel, percent grade, etc.) were used as criteria for the design of potential stream channels. Furthermore, a consultation with a salmon expert (Dr. Scott Hinch, UBC Forestry) confirmed our findings.

2.2 Climate and climate change

To investigate the climate of Vancouver and inform the water balance (section 2.4), we used daily temperature and precipitation data from YVR (Government of Canada 2018a) and latent heat data from the Vancouver-Sunset eddy-covariance tower (Christen et al. 2016). Evapotranspiration (ET) was then converted from the latent heat by using the equation 1,

$$ET = \text{Latent heat} / Lv \tag{1}$$

where Lv (MJ kg^{-1}) was latent heat of vaporization and it was a temperature dependent coefficient. The values of Lv were included in the latent heat data package as well.

Average monthly precipitation, evapotranspiration, and temperature was plotted for 2012 to 2016 (the most recent five years with data on all three variables). 2016 was chosen as a model year for the water balance, as it was an unusually dry spring and therefore would better represent future years in Vancouver, and as it was the most recent year with evapotranspiration measurements.

A literature review was conducted to investigate climate change in Vancouver. Changes in temperature, rainfall, and sea level rise were considered. A fine resolution DEM was used in GIS to plot potential sea level rise in the park.

2.3 Watershed characteristics

Watershed characteristics were investigated using ArcMap 10.4, a Geographic Information System (GIS). Most GIS data was obtained from the Vancouver Open Data Catalogue (City of Vancouver 2018a). This includes contour lines, a 0.5 x 0.5 m resolution digital elevation model (DEM), the storm sewer network, and orthophoto imagery taken in the spring of 2015. A coarse resolution DEM (23 x 23 m resolution) was obtained from Geogratis (Government of Canada (2018b).

Watersheds (total areas that drain into a certain point) and flow accumulation maps (which show where stream channels would have been located), were generated in ArcMap based on the coarse resolution DEM. The Fill, Flow Direction, Flow Accumulation, and Watershed tools were used. The coarse resolution DEM was chosen to minimize processing time in ArcMap. These results represent the movement of water under non-urbanized conditions.

To investigate urban watersheds, the coarse DEM was depressed by 5 m at the locations of storm sewers in order to “trap” simulated flow into the storm sewer system. This was done using the Extract by Mask and Raster Calculator tools. The same tools as before were then used on the altered DEM to delineate watersheds under the urban system. The urban watersheds differed in some locations from those in a report on stormwater management by the City of Vancouver (2016). Therefore, these watersheds were manually altered in places to match both the report and the locations of existing storm sewers.

To determine the extent of impervious surfaces in these watersheds, the normalized difference vegetation index (NDVI) analysis was used on the 2015 orthoimage of Vancouver. The result, a raster with continuous NDVI values, was reclassified into two categories by a visual comparison to the original orthoimage. Categories were impervious, representing colors associated with streets and roofs, and pervious, representing colors associated with lawns, gardens, and forests.

Based on the locations of storm sewers around Jericho Lands, two possible locations for storm sewer output into streams or holding ponds were determined. The watersheds for these two points were determined manually based on the connections of storm sewers.

2.4 Water balances and sources of water

Based on the finding from literature (section 2.1) and field, our salmon-spawning stream would have 1.5 m width, 0.2 m depth and flow rate at 0.13 m/s. That means, the target flow rate of this stream was would be 0.04 m^3/s and it represented the mean water velocity of all cross sections along the stream channel. However, 0.04 m^3/s was required only for the total juvenile season

(November to April) not for the whole year. From May to September, the minimum flow rate (Q_m) to mitigate ET from the stream was calculated through equation 2:

$$Q_m = L * 1\ m * PET \qquad (2)$$

where L was the length of the stream channel, and PET was the potential evapotranspiration. PET was estimated from EcoHydRology package in R, using albedo = 0.07 (Coakley 2003). Here we assumed the width of the stream was 1 m was because it would easier to keep the stream wet if it has smaller size. In case where stream was connected to the existing pond in the Jericho Park, one more variable will added in this equation and it would be:

$$Q_m = (L * 1m + A_p) * PET \qquad (3)$$

where A_p was the area of the pond.

2.4.1 Stormwater

Combining climate data (section 2.2) and watershed characteristics (section 2.3), the predicted streamflow was calculated from the equation 4:

$$Q_P = P * E * r_{impervious} * A_C \qquad (4)$$

Where Q_P was predicted streamflow (m^3/s) and it was a function of precipitation (P), evaporation ratio (E), impervious surface percentage ($r_{impervious}$) and contributing area (A_C). In this equation, we assumed there was a linear relationship between daily evaporation and precipitation in order to determine E. Infiltration rate was equal 1 on the pervious surface and was 0 for the impervious surface. ET was not correlated with $r_{impervious}$. Notes that no changing in storage and groundwater flow were involved in this equation.

2.4.2 Holding ponds

Other than input only from stormwater, other alternative water sources such as holding pond and HVAC system were explored as well. We estimated the amount of each alternative water source necessary to reach the 0.04 m^3/s target flow rate. Each alternative water source was quantified using literature and estimations.

Due to seasonal changes in precipitation and evapotranspiration, the size of holding pond was estimated by equation 5:

$$\Delta N = 0.04 m^3/s * 86400 * \text{water-shortage days.} \qquad (5)$$

Where ΔN is needed amount of water for the water-shortage days in total juvenile season. While the possible locations of the holding pond were determined in consideration of the topography feature in the Jericho Lands, and the two possible storm sewer output locations.

2.4.3 HVAC

Glawe (2013) wrote a report about collecting condensate from commercial building heating, ventilation, and air-conditioning systems. In this report, she showed the amount of water that could be generated from the HVAC system within a wide range of temperatures in San Antonio, Texas. Estimations from the Alliance for Water Efficiency (2016) were valid for a building in San Antonio in the spring and fall, which are climatic conditions similar to that of a Vancouver summer.

Then, we developed two scenarios, shopping mall scenario and apartment scenario, and tested them to see if they could generate enough amount of water for the salmon stream. If not, how many of them would be enough. The shopping mall scenario assumed the size of the mall would be very similar to the size of Oakridge Mall. Unlike Pacific Centre and Metrotown, Oakridge Mall was chosen not only because it had feasible size, but also because we wanted to keep green space as much as we could. Apartment scenario assumed each building had 8 floors and each floor was 429 m^2. It was designed based on the apartments beside the intersection of W 10th Ave and Blanca St, which is near the location of the redevelopment project and is representative of the area.

2.5 Routes and channel morphology

The salmon stream channel direction was determined based on elevation of the watershed in GIS. A field trip has been done in September to inspect the biological conditions, the topography, and the main characteristics in Jericho Park and Jericho Land. A further literature review supports the further determination. The holding pond was located based on the location of stormwater inflow from the whole watershed and the possible starting point of salmon stream. The stormwater inflow was generated from watersheds and flow accumulation maps from GIS. Possible starting point of salmon stream is controlled by the elevation of the whole watershed.

Channel morphology is related with the geological conditions within Jericho Park, which was investigated through the field trip and topographic map. A literature review was conducted to the types of salmon stream. When the topographic condition is practicable to construct more than one types of salmon stream. It is decided based on the preference of the Jericho Stewardship Group.

3 Results and Discussion

3.1 Salmon

Salmon spend their adult lives at sea, and return to their natal stream to spawn. Usually, spawning salmon return to the stream in the fall. When they arrive, they dig nests, called redds, into the stream substrate. They choose their redds to be located in areas of the stream where they can sense upwelling of groundwater (Scott Hinch, personal communication, January 2018) to best provide their eggs with oxygen-rich water. They lay their eggs, bury them, and die. The eggs will hatch roughly two months later, and the juvenile salmon (fry) soon rise to surface. The fry eventually migrate downstream to the ocean, and generally live as adults for a number of years at sea before returning to spawn. Details of the life histories of Chum and Coho salmon are summarized in Table 1.

Many salmon species, such as Coho and Sockeye, inhabit freshwater streams or ponds year round, with fry residing in streams throughout the summer. Because streams in Jericho Park are likely to be completely dry during the summer (section 3.4), they would be less suitable for these species. However, unlike most salmon, Chum do not spend the summer in fresh water; the fry begin the their downstream migration immediately after emerging from the gravel, and in small streams will have reached the ocean within a month (Groot and Margolis 1991; see Table 1). For this reason, Chum are the best species for reintroduction to Jericho Park.

Table 1. Freshwater life histories of Chum and Coho, the two species reintroduced at Spanish Banks Creek. The table is based on studies from small streams in southern British Columbia and Washington, in Groot and Margolis (1991).

Parameter	**Full range**	**Mean or preferred range**
Chum		
Timing of run and spawning	November to January	
Age at spawning	3-5 years	
Spawning substrate	Silt to gravel >15 cm	Gravel <15 cm diameter
Spawning water velocity	0-168 cm/s	21-84 cm/s
Spawning water depth		13-50 cm
Egg dissolved oxygen	No less than 2 mg/L	
Time to egg hatching	52-61 days	
Juvenile residence time in stream		30 days
Timing of fry run	February to June	Mid-March to end of April
Coho		
Timing of spawning run	All months of the year	September to October
Timing of spawning	October to March	November to January
Age at spawning	1-3 years	2 years
Spawning substrate		1-15 cm diameter gravel
Spawning water velocity	Up to 240 cm/s	
Spawning water depth		20-30cm
Egg dissolved oxygen	No less than 5 mg/L	8 mg/L
Time to egg hatching	42-56 days	
Juvenile residence time in stream	One to four years	One year
Timing of fry run	April to May	

3.2 Climate and climate change

Understanding the climate is the first step to understanding the hydrologic system. Figure 1 shows the mean monthly precipitation, evapotranspiration, and temperature for five years. While there has usually been rainfall throughout the summer, it is exceeded by evapotranspiration from May through August. Climate projections for Vancouver under the "business as usual" greenhouse gas scenario show increased rainfall during the fall and winter, decreased rainfall in the summer, and warmer temperatures throughout the year (Metro Vancouver 2016). By 2050, precipitation is expected to have increased by 5% overall, with an increase of 25% in the winter and a decrease of 20% in the summer. This will exacerbate the current problem of low streamflow in the summer. In addition, the number of days per summer with daily highs above 25°C is expected to have increased from 22 to 55. This will not only increase potential evapotranspiration, but also increase demands for air conditioning and the amount of water that could be harvested from this source.

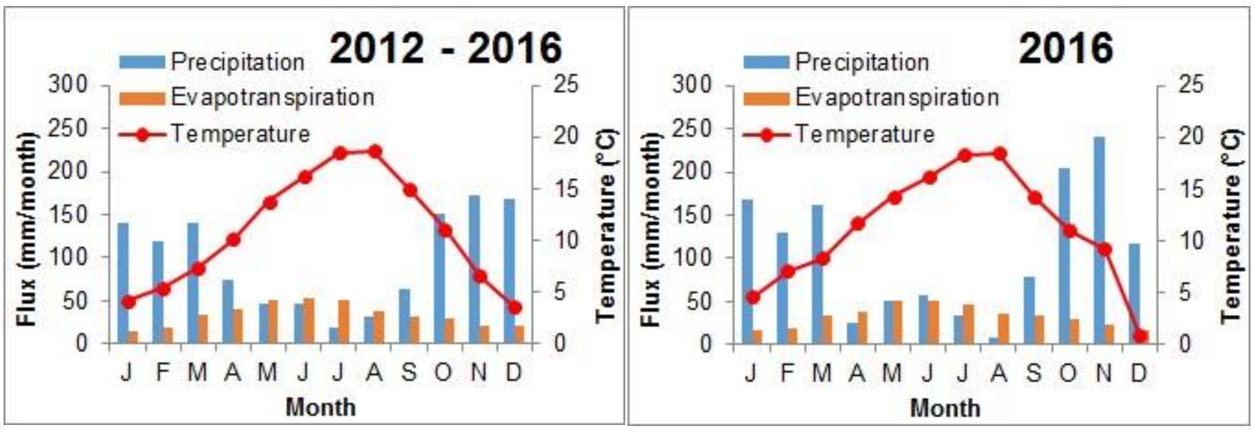


Figure 1. Left, monthly climate averages for 2012 to 2016. Right, monthly climate for 2016. 2016 was a year with an unusually dry April and wet fall, which likely better represents future climate. Precipitation is from YVR (Government of Canada 2018a), and evapotranspiration is from the Vancouver-Sunset eddy-covariance tower (Christen et al. 2016).

Weather data from 2016 was used for water balances (section 3.4). This was a year with a particularly dry April and wet fall, which should be more representative of future climate than other years.

Furthermore, rising sea levels are expected as temperatures increase. By 2100 there is expected to be 0.6 to 1.0 m of sea level rise (NHC 2014), which would not have a large impact on the park (figure 2). Extreme storm events could cause temporary flooding by wave action into some of the east portions of the park (NHC 2014).

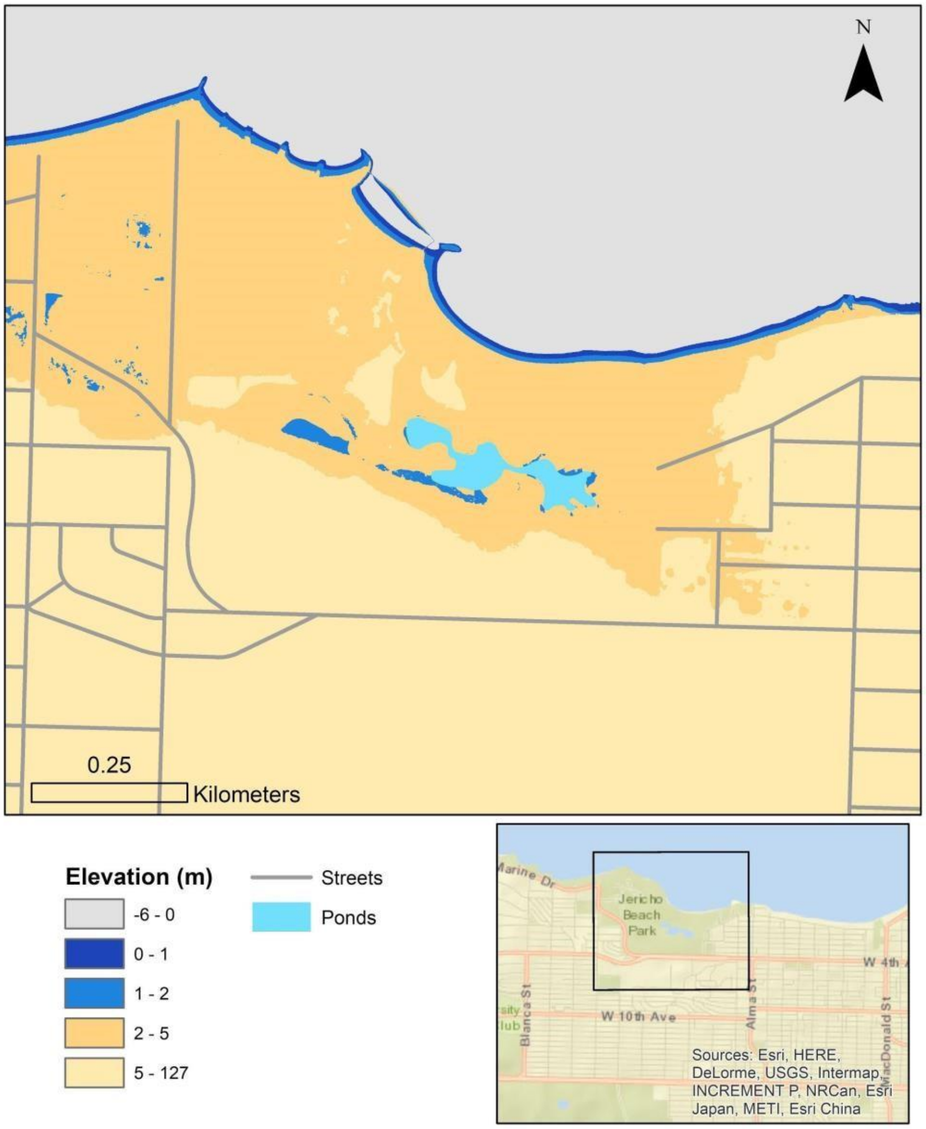


Figure 2. Areas affected by permanent sea level rise by 2100 in Jericho Park. Sea level is expected to rise 0.6 to 1 m by 2100, and normal high tides might regularly flood up to 2 m. Areas under 2 m are shown in dark blue and areas of higher elevation are shown in orange.

3.3 Watershed Characteristics

In its natural state, there would be three basins contributing to Jericho Park (figure 3).These correspond fairly well to the believed locations of lost streams of Vancouver (Lesack and Proctor 2011). However, a large portion of the eastern watershed (in red) should probably drain into Tatlow Creek, and the actual watershed would be smaller even under natural conditions. Regardless, both watersheds are almost entirely residential or commercial areas, with high cover of impervious areas that drain into storm sewers and decreased cover of natural vegetation.

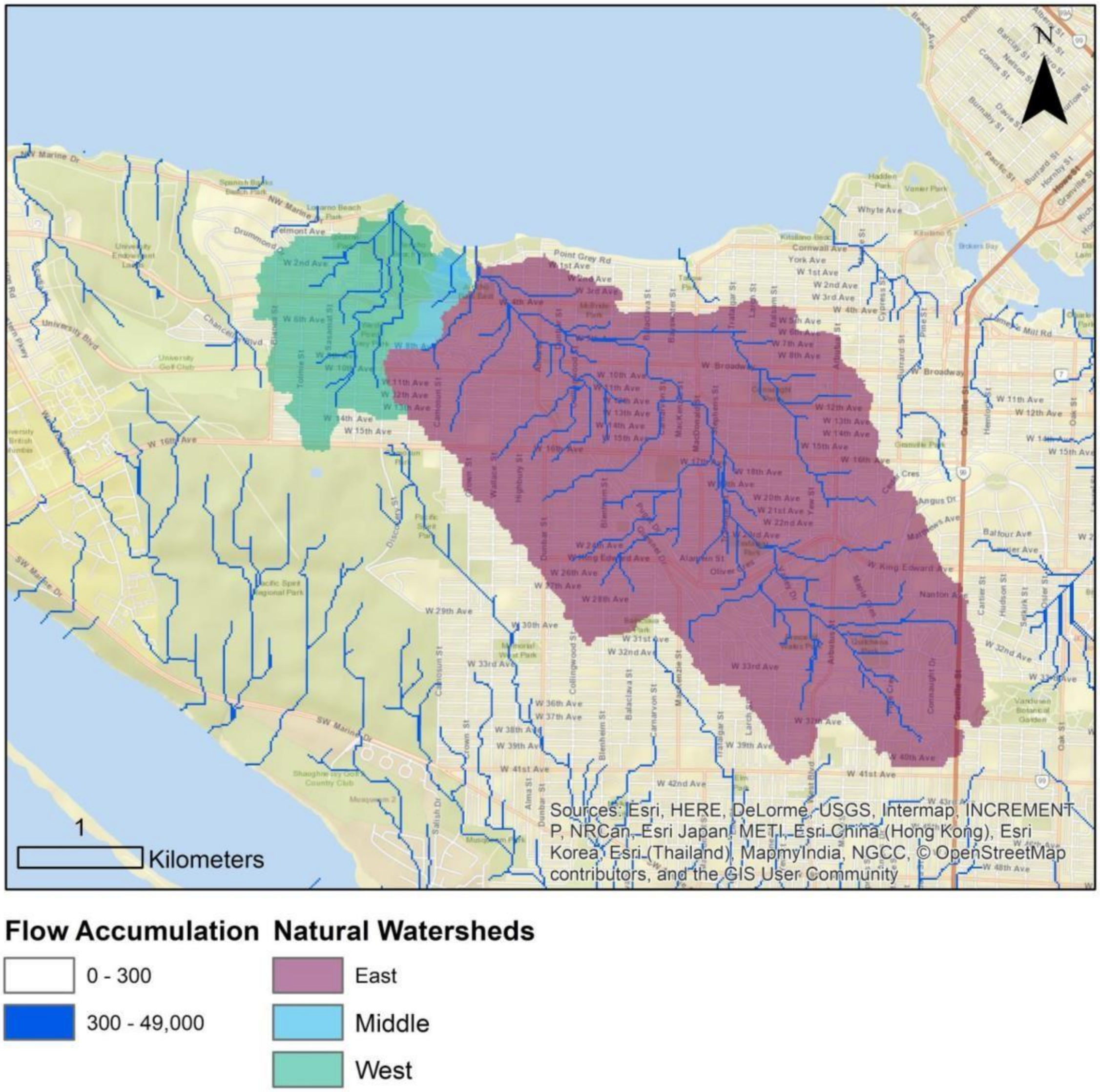


Figure 3. Watersheds contributing to Jericho Park under natural (historical) conditions. In blue are areas with high flow accumulation, showing likely locations of stream channels. Flow accumulation values are given in number of cells (ie. number of pixels in the DEM) draining into that particular cell.

Because of the urbanization of Vancouver, a large portion of water will be diverted into the sewer system rather than flow over land. Taking this altered flow path into account, the watersheds will be slightly different (Figure 4).

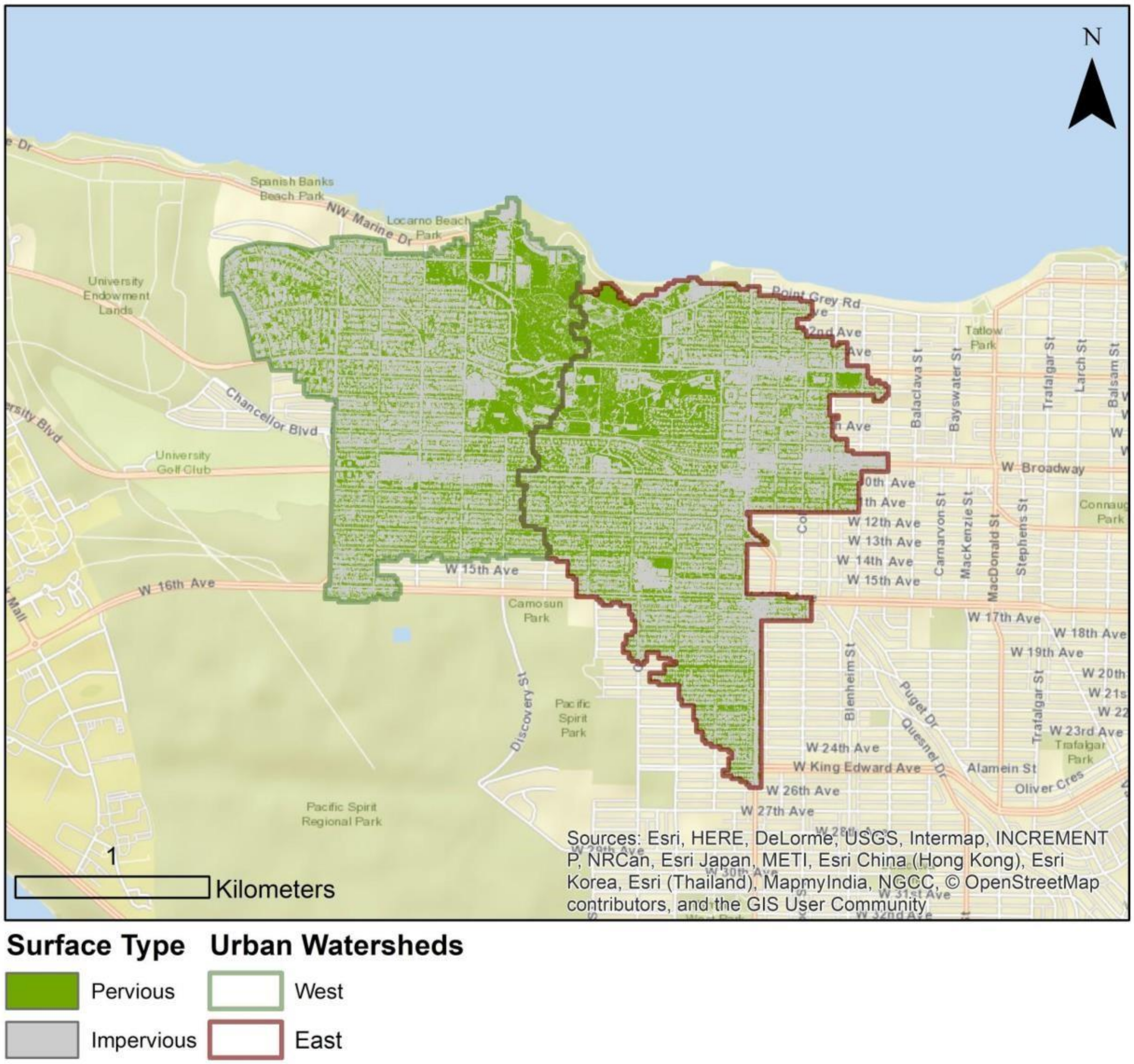


Figure 4. Current watersheds of Jericho Park. The western watershed is 230 ha and 62% impervious; the eastern watershed is 264 ha and is also 62% impervious. Storm sewers currently drain into English Bay at several outlet points, with the exception of the one that feeds the stream and ponds at Jericho Park.

Currently, there is only one small storm-sewer fed stream in the park (Figure 5). It is not known where the water comes from that supplies this stream since storm sewer data in Jericho Lands is restricted. The stream originates at a storm-sewer splitter, which only allows water into the stream when the flow in the pipe is above a certain level. The stream feeds into a forested wetland and eventually empties into the ponds, and an underground outflow pipe connects the ponds to the ocean.

Figure 5. Water flow in Jericho Park, including the location of the storm-sewer fed stream, storm sewer splitter, and the underground outflow pipe.

Barring groundwater, stormwater will be the primary source of water for any streams in this watershed. Based on the locations of storm sewers and how flow will accumulate within them, there are two good locations for starting points of the channel in Jericho Lands. These, along with their contributing areas, are shown in Figure 6.

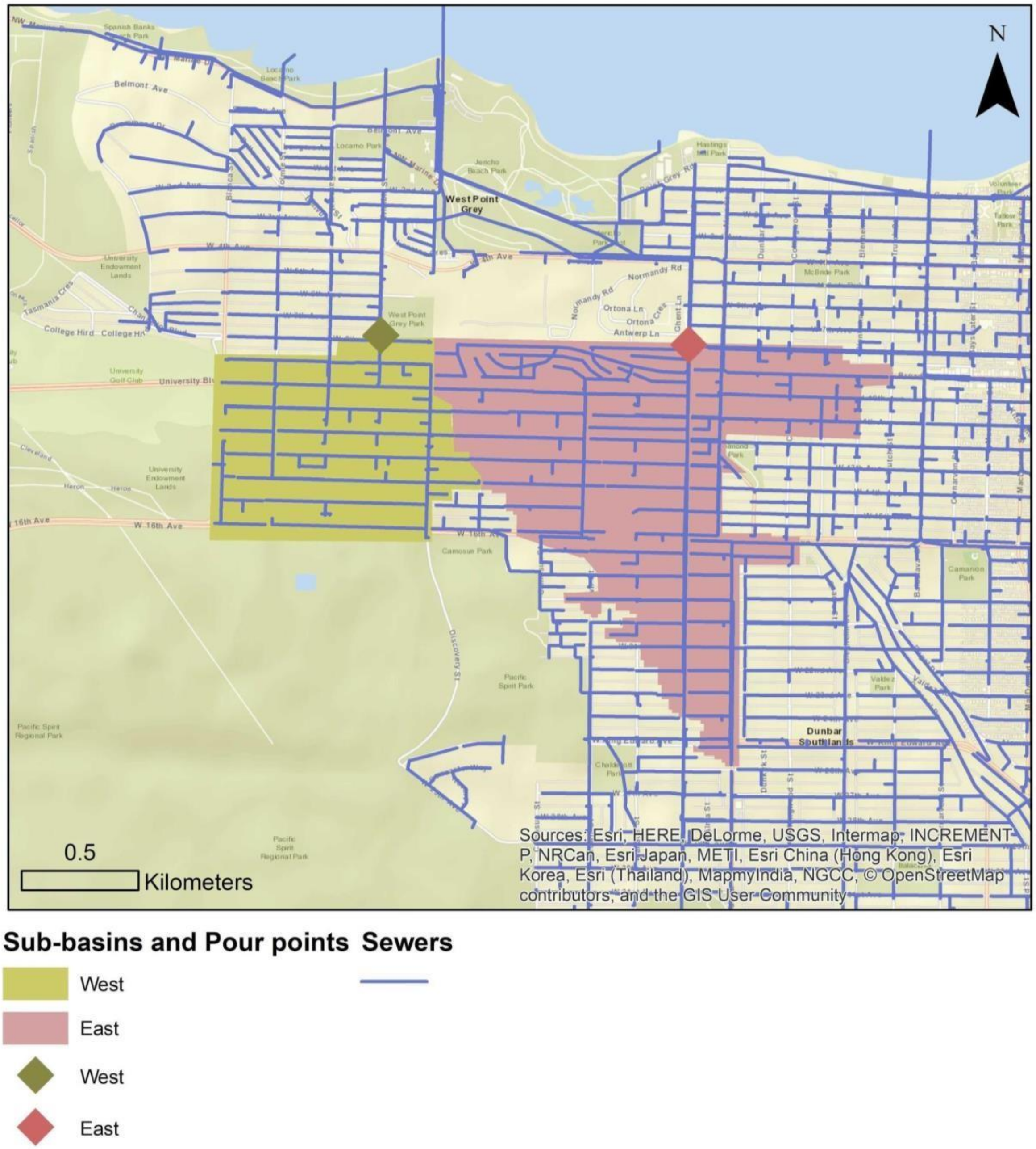


Figure 6. Two potential stream channel starting locations are at the southwest and southeast corners of Jericho Lands. The contributing areas (basins) of each are shown. Moving the western starting point northward or eastward would cause minor increases in contributing areas. Moving the eastern point westward at all would decrease the contributing area dramatically but moving it northward would cause increase it slightly.

3.4 Water balances and sources of water

Our criteria for this section are based on the life history of Chum (Table 1) and are as follows:

- a spawning season of 92 days (November through January)
- a total juvenile (eggs, alevins, and fry) season of 182 days (November through April)
- a streamflow of 0.04 m^3/s required to support both juveniles and spawning
- a variable average monthly water supply (0.00039 - 0.0027 m^3/s) needed to mitigate evapotranspiration based on potential evapotranspiration

The streamflow requirements (0.04 m^3/s) are based on a stream 1.5 m wide, 0.13 m deep, flowing with a velocity of 0.20 m/s. Depth and velocity measurements are from Table 1 and the width of a stream was estimated. Velocity measurements were assumed to represent an average across the cross-section of the channel. Chum have been observed spawning in stagnant water, and other species have been observed spawning in water only 5 cm deep; however, these extreme conditions can cause extremely high egg and juvenile mortality and we have chosen parameters we believe to be at the lower end of streamflow needed for healthy spawning conditions.

3.4.1 Stormwater

The 2016 water balance result for the western channel show that stormwater would only support spawning conditions for 30 out of 92 of days of the spawning season (November to January) and 44 of 182 days of the juvenile season (November to April) (Figure 7). The average daily streamflow would be 0.03 m^3/s for the spawning season, and 0.024 m^3/s for the juvenile season. The channel would support juvenile life stages for 44 out of 182 days. With unaltered stormflow, streamflow would be negligible from April through August.

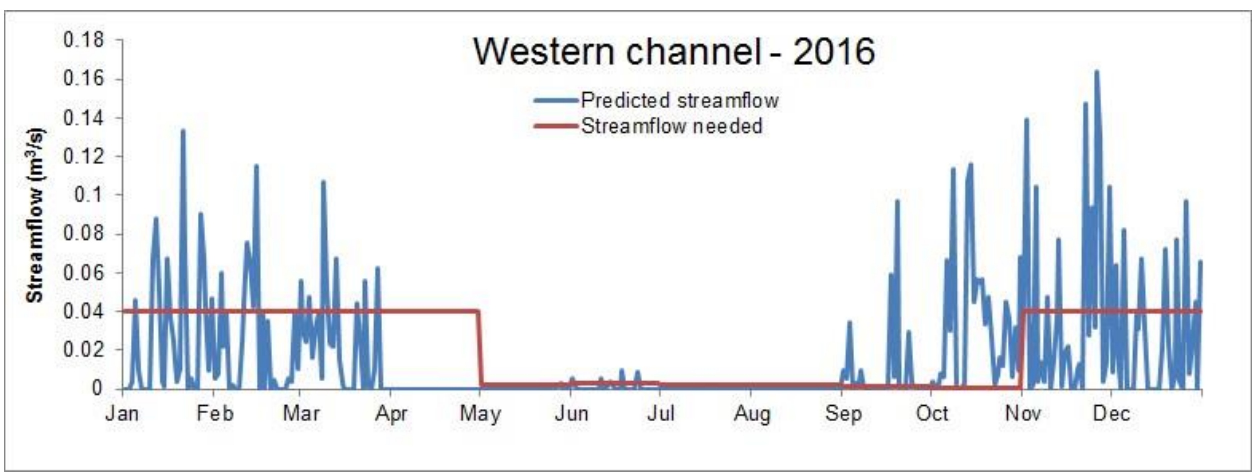


Figure 7. Predicted daily streamflow (blue) for the western watershed in 2016. Target flow rate (red) is 0.04 m^3/s for months that Chum inhabit the stream, and at a rate to mitigate evaporation for the remainder of months. Predicted streamflow is based on overland flow over impervious surfaces above storm sewer access points (equation 4); streamflow needed during the salmon season is based on equation 5; and streamflow needed to mitigate evaporation is based on equation 2&3.

The eastern channel shows more promise (Figure 8). The channel would support spawning for 42 out of 92 days and juvenile life stages for 69 out of 182 days. There would be an average streamflow in the spawning season of 0.067m^3/s, and in the juvenile season of 0.050 m^3/s. Again, streamflow would be negligible from April through August. On average there would be adequate water throughout the spawning season, but more would be needed in the spring for the last of the fry and in the summer to keep the channel wet.

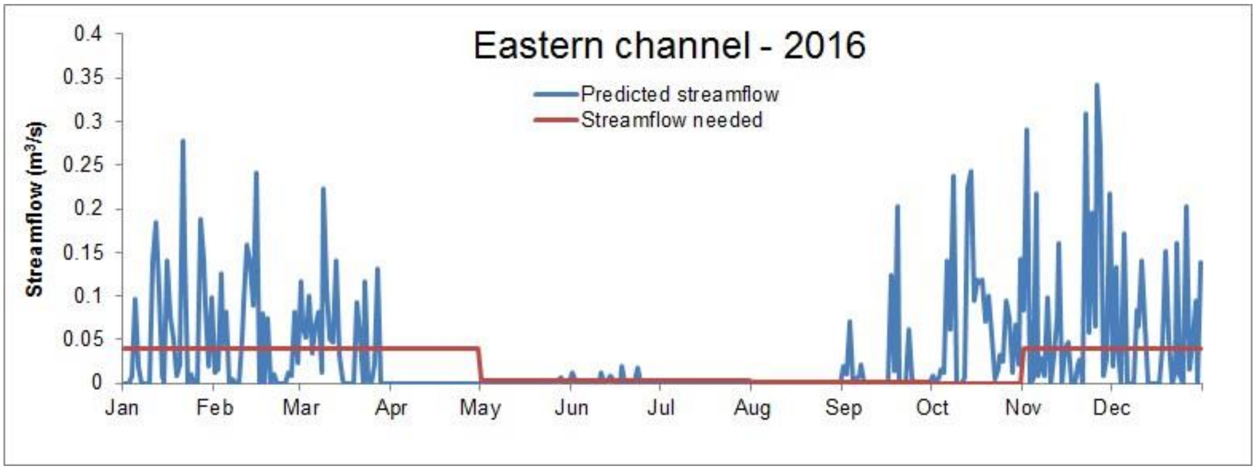


Figure 8. Predicted daily streamflow (blue) for the western watershed in 2016. Target flow rate (red) is shown at 0.04m^3/s for months that Chum inhabit the stream, and at a rate to mitigate evaporation for the remainder of months. Predicted streamflow is based on overland flow over impervious surfaces above storm sewer access points (equation 4); streamflow needed during the salmon season is based on equation 5; and streamflow needed to mitigate evaporation is based on equation 2&3.

3.4.2 Holding ponds

However, if the assumption is correct that all stormwater reaches the stream channel in the same day that it falls, then the extreme low- and high-flows throughout the winter would make a channel directly connected to the storm sewers inhospitable to salmon. With that in mind, holding ponds would be essential to manage stormwater flow.

Holding ponds at the top of the channels could be used to control outflows to prevent both high- and low-flow events. They could also be used to store water to be used for streamflow during dry months (April especially). However, stormwater would need to be in excess in order to fill up a holding pond to extend streamflow for a whole month; therefore a pond at the top of the western stream would be ineffective at storing water for this purpose (although it would still be needed to decrease the flashiness of the stream).

To support salmon in the eastern stream and keep the stream channel wet throughout the year (one month of 0.04 m^3/s and four months of mitigating evaporation), a pond would have to contain 103680 m^3 of water. This is approximately the size of a football field 19 m deep. While there is enough excess stormwater to fill this up, developers (and residents) would likely object to such an enormous water feature.

3.4.3 HVAC

The estimate of condensate produced by HVAC systems is 14 - 46 L per day per 1000 ft^2 of building (Alliance for Water Efficiency 2016), which has been tested in climatic conditions similar to a current Vancouver summer (Glawe 2013). Table 2 shows the number of buildings needed to supply various streamflow targets. HVAC output would only be provided in the warmest summer months when there is demand for air conditioning. However, as climate change proceeds in Vancouver, the summers will become warmer and the amount of water produced will increase. Many homes in Vancouver do not have air conditioning at all, but with warmer summers in the future new developments may choose to include them.

Table 2. Number of buildings needed to support different types of streamflow with reclaimed HVAC condensate. During the warmest summer months (July and August) there will only be a need to mitigate evaporation, not supply spawning conditions; the numbers in that column are given for reference only.

Source of HVAC	**Number needed...**		
	to supply spawning conditions (0.04 m^3/s)	to mitigate evaporation from stream and ponds	to mitigate evaporation from stream only
Apartments	2600 - 8600	130 - 340	6.5 - 21
Malls	160 - 530	8 - 26	0.4 - 1.3

3.4.4 Limitations

Thus far the analysis of hydrology in this area has been focused on surface water. However, there are numerous possible fates for rainwater falling over these watersheds. Water falling onto pervious surfaces may infiltrate into the soil -- water falling onto forested areas will almost certainly enter the ground, but a portion rainfall might run off of saturated lawns in the winter. In theory, water falling on impervious surfaces, such as roads or roofs, will either pond or run off. In reality, 6% to 9% of water falling onto asphalt might actually permeate through the road (Fletcher et al. 2013). Overland flow over roads will almost invariably drain into the sewer system. In many parts of the city, roads drain into combined sewers, which combines household wastewater with storm water and sends it all to a water treatment plant. The city of Vancouver is in the process of separating combined sewers into storm and sanitary sewers in this neighbourhood, and the transition is planned to be complete in 2020 (City of Vancouver 2018b).

Water flowing over roofs will have a fate dependent on the construction of individual houses; some houses might divert downspouts into their gardens, though many might divert downspouts into underground weeping tiles. Weeping tiles are porous plastic pipes which allow water to escape when under pressure but allow groundwater to seep in when the water table is high. These may lead directly or indirectly to the sewer system and may enter storm or sanitary sewers depending on the age and construction of the house.

In our analysis, we assume all impervious surfaces are connected directly to a storm sewer system. While this is not true, as discussed above, it does provide an approximation of stream flow potentially coming from storm sewers. We also assume that there is no exchange of water (gains or losses) between the stream and groundwater. It is likely that stream channels would be gaining inputs from groundwater, especially in the winter, and based on the cover of pervious surfaces 40% of rainfall might infiltrate into the ground. Therefore, the results of our water balances should be interpreted with caution.

In addition, our analysis does not take travel time into account, and all water is assumed to reach the channel on the day that it falls. Figures 7 and 8 may be showing a system that is much flashier than it would be in reality, as water may travel more slowly.

3.5 Routes and channel morphology

3.5.1 Routes

Based on the current geological and biological conditions of Jericho Park, we provide two potential plans for reconstructing a salmon stream.

The first plan is to construct a holding pond in the southwest corner of Jericho Lands (Figure 9). Stormwater will flow directly from storm sewers into this pond. The stream will flow north through Jericho Lands, underneath west 4th Avenue, into the existing stream and ponds in the park, and finally out to sea through the beach at the eastern end of the ponds. The total length of this stream would be 1850 m. However, the estimated amount of stormwater is not enough to support spawning conditions at this location. The stream would need, on average, an extra water input of 860 m^3/day from November to April to support the stream in 2016, which is a relatively dry year.

The second plan is to have a holding pond in the middle of Jericho Lands, which would be fed by stormwater from the southwestern corner of the Lands (Figure 10). Plan 2 and plan 1 are similar. The only difference is the designed stream won't connect with the existing stream in the park.

The existing ponds are proposed to be connected to the stream. In the summer, the ponds could serve as refuge for aquatic organisms if the stream channels dry out.

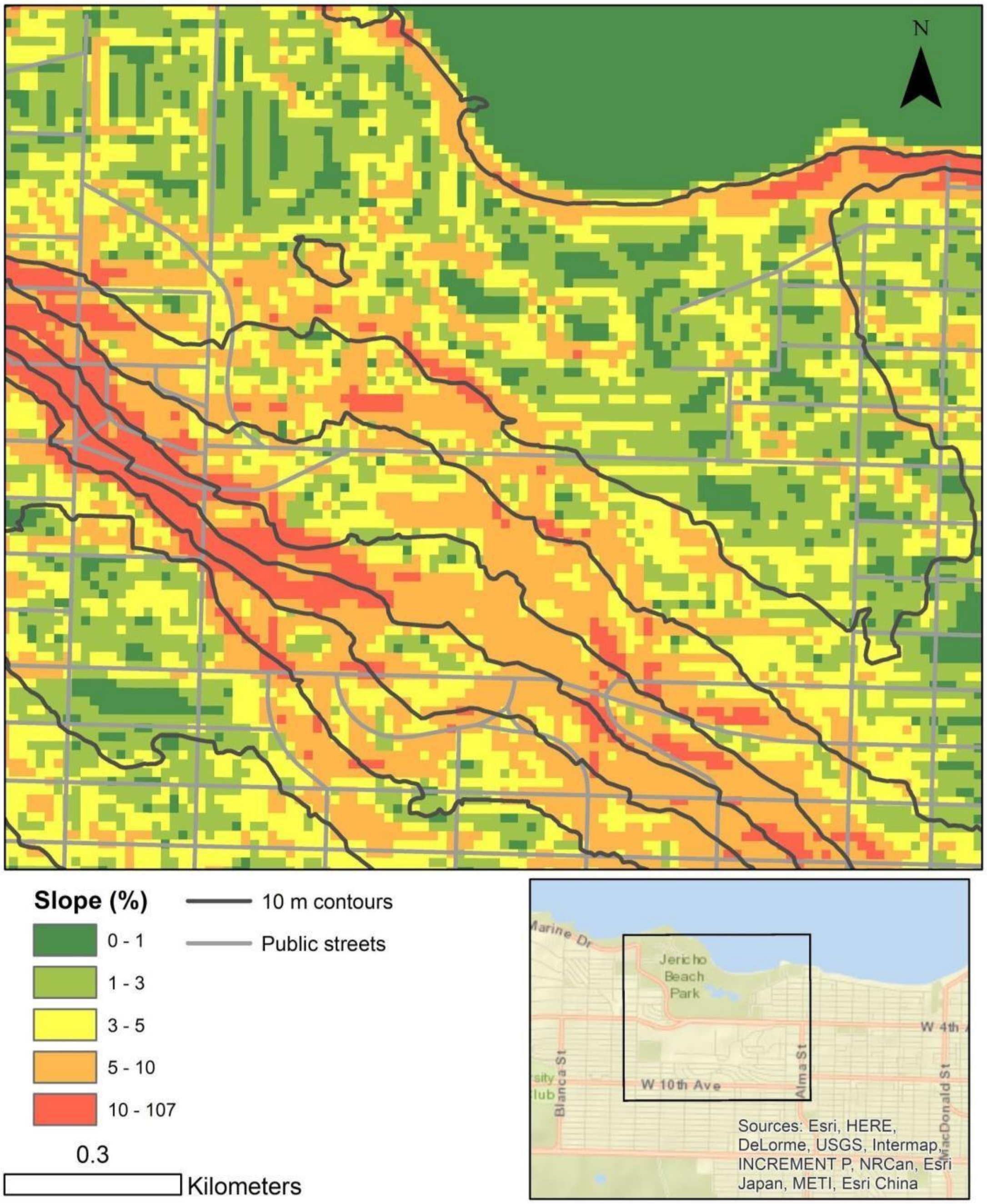
Figure 9. Plan 1: To construct a holding pond in the west corner of Jericho Land. Stormwater flows into the pond from the western basin.

Figure 10. Plan 2: To construct a holding pond in the middle of Jericho Lands. New storm sewer pipes are created to connect stormwater from the eastern basin to the holding pond.

3.5.2 Slope

Most of the slope over Jericho Lands exceeds 3%, which is preferred for Chum (Figure 11). Where the slope exceeds 3%, the stream can be made to meander and thereby decrease stream channel slope.

Figure 11. Slope over Jericho Lands and Park. Slope in the park is generally good for Chum spawning (green to yellow), but some areas of Jericho Lands are too steep (red). Where the slope is slightly too steep, the channel can be made to meander, but where



the slope is extremely steep, portions of the stream in these locations might simply not be able to support spawning.

3.5.3 Channel morphology

In different locations, there are four types of streams are proposed: a natural stream channel, bridge, culverts, and artificial stream. Natural stream channels could look like Musqueam Creek (figure 12), with vegetated streambanks and large woody debris in the stream channel. Woody debris in the stream create a more natural habitat, help retain water, and reduce mobilization of gravel. Small bridges would be needed in areas of high foot traffic (such as along trails in the park). Bridges should be at least 1 m above the water level in the stream to prevent adult salmon from jumping onto them. Culverts would be needed to allow the stream to pass underneath the street. They would be 10 m long with a diameter of 1 m or more. An artificial stream would be needed at Jericho beach. Sand has high permeability, which means water could flow through it quickly. While salmon stream flows through the beach, water can sink to the bottom of sand instead of flowing overland to the ocean. Also, water on the surface of sand can evaporate very fast in sunlight since sand has low specific heat capacity and will get hot fast. So, an artificial stream is designed to isolate our stream water from the sand. It would be wood on both sides and the bottom like Figure 13 shows. The artificial stream would be 10 meters long in total.

Figure 12. Musqueam Creek in February. It is the last natural salmon stream in Vancouver. (Photo: Lucy Li)

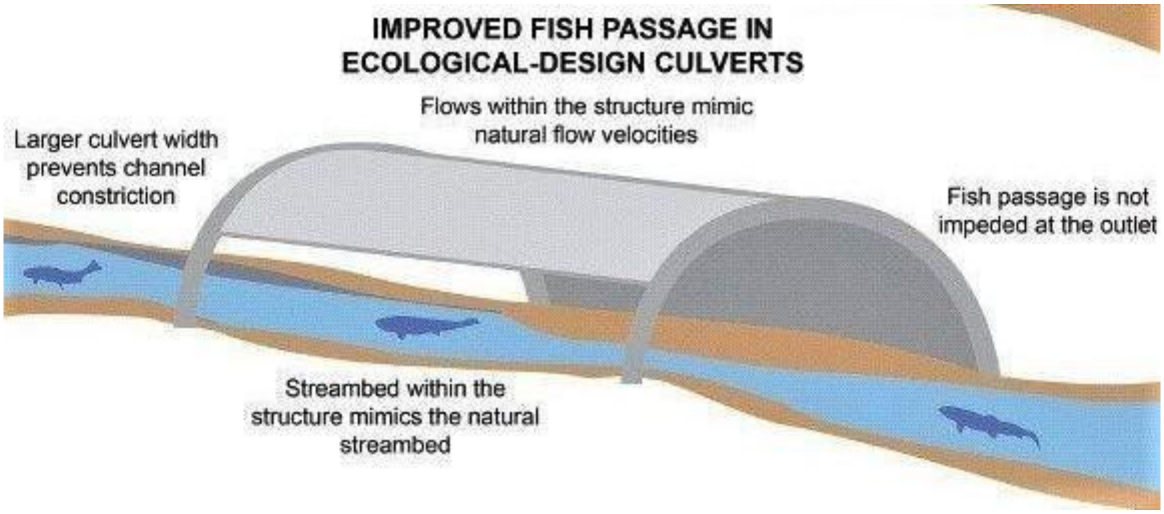


Figure 13. A culvert designed to reduce the ecological impacts of traditional culverts. (Photo from Salmon and Trout Restoration Association of Conception Bay Central Inc.)

3.5.4 Gravel

Research shows that the size of spawning sediment is very important to Chum survival and productivity. Cobbles and boulders are the best sediments for salmon habitats, which range 15 - 40 mm (Kondolf 1993). Gravel would likely need to imported initially after the stream construction, and gravel should be at least 25 cm deep. Gravel could be flushed downward by stream water, so the state of the channel sediments would need to be monitored regularly.

4 Conclusions

Increased impervious cover and the replacement of stream channels with storm sewers have changed the hydrology of Jericho Park including the shape of the watersheds. Because of the high percent cover of impervious surface in the watersheds, water flow through storm sewers is a dominant pathway and restored streams would likely have to rely on stormwater. There are two watersheds currently contributing water to Jericho Park, and two general locations to tap into storm sewers. Water coming from storm sewers will likely be very flashy and holding ponds would be needed to mediate this flashiness.

Chum are the best species to reintroduce to a stream channel in Jericho Park because, unlike other species, they do not live in the stream throughout the summer. They require an estimated 40 L/s of flowing water from November to April. In the western watershed, the average estimated stormwater inputs would be 24 L/s, which does not meet the target; in the eastern watershed, the average stormwater inputs would be 50 L/s. Water shortage is likely to occur in both watersheds in April, which would affect the last of the migrating fry.

In that case, we proposed two possible holding pond plans corresponding to the two different routes for the stream. Plan 1 is currently unlikely to work due to an insufficient contributing area, but would likely be possible if a sufficient amount of groundwater is available to supply the stream route. Plan 2 for the eastern watershed would be optimal since it has larger contributing area and as a result, would provide enough water for a majority of the juvenile season. After the construction of the holding pond, the salmon stream would also need periodic maintenance, such as the addition of gravel to ensure a healthy salmon habitat. Holding ponds would help prevent flashiness in the stream channel but would likely never be large enough to supply water through a dry April.

In the summer, (May to August), the best-case scenario of HAVC systems would only mitigate evapotranspiration from the stream but not the ponds of Jericho Park. Furthermore, climate change projection shows that higher temperature and less rainfall would occur in summer which will make it more challenging to restore the stream. However, sea level rise should not affect the park or the efforts to restore streams to it.

In hindsight, surface water sources were not a good idea to research as they are heavily reliant on precipitation and are also highly vulnerable to evapotranspiration. Groundwater and water quality may have been more worthwhile to research as groundwater is less vulnerable to evapotranspiration and less reliant on precipitation. Given the dry conditions at Jericho Park, it is likely that a lot more water could be harvested from groundwater sources.

5 Recommendations

Further research into water quality and the groundwater situation in the Jericho watersheds is needed to make further conclusions on the possibility of re-introducing salmon to Jericho Park. Water quality testing to ensure stormwater does not contain unsafe pollution levels would be needed to before stream channels are created. Furthermore, an estimated 40% of precipitation goes into groundwater, which could provide the proposed stream channels with a sufficient (and possibly cleaner) water source. Further research into surface flow would be needed to improve the accuracy of our calculations, as our analysis is based on the assumption that 100% of impervious flow goes into the storm sewer system, which is not accurate.

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