KERR WOOD LEIDAL
consulting engineers

Greater Vancouver
200 - 4185A Still Creek Drive
Burnaby, BC V5C 6G9
T 604 294 2088
F 604 294 2090

Mackay-Mosquito Watersheds Integrated Stormwater Management Plan

Final Report
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KWL Project No. 099.125-300

Prepared for:

city of north vancouver

DISTRICT OF NORTH VANCOUVER

The following compendiums and their authors support the Mackay Mosquito Watersheds ISMP:

Compendium No.	Title	Author
1.	Watershed Overview	KWL
2.	Instream Species and Water Quality	Raincoast Applied Ecology
3.	Riparian Forest & Terrestrial Species	Raincoast Applied Ecology
4.	Drainage Asset Inventory	KWL
5.	Hydrologic and Hydraulic Modelling	KWL
6.	Drainage Assessment	KWL
7.	Land-Use Analysis	KWL
8.	Municipal Policy and Operations	KWL
9.	Watershed Values and Objectives	CNV and DNV
10.	Mitigation Measures & Alternatives	KWL, CNV and DNV
11.	Mackay/Mosquito Action Plan	KWL, CNV and DNV

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Compendium 1

WATERSHED OVERVIEWS

Mackay Mosquito Watersheds ISMP

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Purpose

Compendium 1. Watershed Overview

This compendium provides detailed information on the watershed overview of the Mackay and Mosquito Creek watersheds in North Vancouver, BC. It is a supporting document to the Mackay and Mosquito Watershed Integrated Stormwater Management Plan (ISMP) that was developed by the City and District of North Vancouver.

Information contained in this compendium includes:

1. List of background information
2. Overviews of the watersheds
3. Surficial geology of the watershed
4. Development and drainage history
5. Natural Risk - Debris flood and flow hazards, flood hazard and climate change

Refer to other compendiums for additional supporting information.

Mackay Mosquito Watersheds ISMP Compendiums

The following compendiums and their authors support the Mackay Mosquito Watersheds ISMP:

1. Watershed Overview - KWL
2. Instream Species and Water Quality – Raincoast Applied Ecology
3. Riparian Forest & Terrestrial Species – Raincoast Applied Ecology
4. Drainage Asset Inventory – KWL
5. Hydrologic and Hydraulic Modelling - KWL
6. Drainage Assessment - KWL
7. Land-Use Analysis -- KWL
8. Municipal Policy and Operations - KWL
9. Watershed Values and Objectives – CNV and DNV
10. Mitigation Measures & Alternatives – KWL, CNV and DNV
11. Mackay/Mosquito Action Plan – KWL, CNV and DNV

Figure and table identification numbering include the first digit related to compendium number and the second digit related to the figure number within the compendium, e.g. Figure C3-1 is the first figure within Compendium 3.

‘Blue boxes’ of explanative information are provided in each compendium where background information and context are helpful.

1. Introduction

The Mackay and Mosquito Watersheds are essential parts of the green infrastructure of the District and City of North Vancouver with important social, ecological, and infrastructure values. The streams that drain from these watersheds support fish and wildlife, drain neighbourhoods and commercial zones, provide parks and greenspace, and define the identity of both municipalities. Protecting and enhancing the Mackay and Mosquito Watersheds is a challenging but important goal for local governments, as well as residents, businesses, and institutions that call these watersheds home.

Both Mackay and Mosquito watersheds are important assets to both the District and City of North Vancouver. They support important social, environmental and economic values of the community and are recognized for a range of services including provisioning, regulating, cultural and supporting services. In particular, each watershed provides natural and man-made waterways that carry away rainwater, groundwater and snowmelt to the Burrard inlet, and allows us to carry about our business and protects property and infrastructure from intense rain events. These waterways also support a variety of fish species and land-based animals that rely on water year-round to drink and live in. Mackay and Mosquito watersheds also support local fishing activities that help sustain our economy and cultural heritage. Both watersheds are also visited by many locals and tourists who like to hike, bike and relax along the waters edge and under tall cedar forests.

The development and implementation of the Mackay and Mosquito Watersheds ISMP is intended to protect and enhance these values.

2. Overview of Watersheds

2.1 Overview of Shared Watershed Characteristics

The Mackay and Mosquito Watersheds encompass many of the most iconic and heavily used areas of North Vancouver. In their headwaters the two watersheds flank Grouse Mountain, with Mackay Creek beginning on the southwest slopes, and Mosquito Creek draining the eastern slopes, including the Grouse Mountain Ski Resort, and the western face of Mount Fromme. From these forested, high elevation headwaters, both watersheds travel through single-family neighbourhoods through their middle reaches. As they near Burrard Inlet, both watersheds include increasingly dense residential neighbourhoods, as well as heavily used commercial and industrial areas, before reaching their final destination on either side of the up-and-coming Harbourside neighbourhood. Refer to Figure C1-1.



Photo C1-1: Wagg Creek in Mahon Park (Sept 2014)

The watersheds have a distinct separation between the forest headwaters upslope of the powerline corridor (upper watershed, northeast above development), and the developed lower watershed. Approximately 64% of study area is defined as the lower watershed (55% of the Mosquito watershed; 73% of the Mackay watershed).

2.2 Mackay Creek Watershed

The Mackay Creek headwaters begin at an approximate elevation of 1,100m. The creek drains through forests in the upper third of the watershed, through single family residential neighbourhoods along its middle reach before flowing past commercial and industrial development south of Marine Drive. The creek flows through both the District and the City before discharging to Burrard Inlet.

The Mackay watershed is approximately 7 km long and approximately 1 km wide with a total drainage area of approximately 849 ha. Mackay Creek has a number of tributaries in the upper watershed including Upper Mackay, Mackay Creek West, and Mackay Creek East.

Mackay Creek's gradient is steep (>15%) in the upper reaches above the developed area levelling to approximately 7 to 10% mid-reach before flattening out to 1% below Marine Drive and becoming tidally influenced below 1st Street. The lower reaches are depositional areas where sand and gravel accumulate within the stream channel and floodplain.

2.3 Mosquito Creek Watershed

The headwaters of Mosquito Creek are located between Grouse Mountain and Mount Fromme. It drains from north to south with its headwaters at an approximate elevation of 1,200 m. The creek passes through the District, the City, and Squamish Nation's Indian Reserve No.1 before discharging to Burrard Inlet.

The Mosquito Creek watershed, shown in Figure C1-1, is approximately 9 km long and between 1 and 3 km wide with a total drainage area of approximately 1538 ha. Mosquito Creek has two significant tributaries: Thain Creek (319 ha) within the District, and Wagg Creek (387 ha) within the City. Thain Creek (formerly Mission Creek) was a tributary to Wagg Creek until it was diverted directly into Mosquito Creek at the City/District boundary in 1958.

The creek gradient is steep in the upper reaches above the developed area (on average approximately 17% and as high as 25% in some areas) and approximately 7% in the lower reach. The creek channel within the District is well confined within a steep-sided ravine. Within the City, Mosquito Creek is well confined within a ravine above 16th Street, but is not confined downstream of 16th Street to Burrard Inlet where development closely encroaches on both sides of the creek.

Approximately 860 m of stream channel is culverted between Evergreen Place and Queens Road. The culvert and its associated sediment basin prevent fish passage and disrupt sediment movement. Two tributaries of Wagg Creek are also enclosed at Highway 1.

An alluvial fan has formed in the lower reaches, although its extent is difficult to determine because the natural landscape has been extensively modified by land development.

2.4 Surficial Geology

Figure C1-2 depicts the surficial materials layer based on the Geological Survey of Canada maps in the upper watershed and DNV GIS in the mid to lower developed areas of the watershed.

Bedrock in Upper Mackay and Mosquito Watersheds

At higher elevations, the geology of both the Mackay and Mosquito watersheds are dominated by bedrock of granitic and associated rock types. Surficial glacial deposits and colluvium overlay this material over the entire extent.

Till in Upper-Mid Mackay Watershed and Thain and Wagg Subwatersheds

The surficial geology of the Wagg Creek and Thain Creek sub-catchments as well as Upper-Mid Mackay is dominated by Till (shown as "light blue" on Figure C1-2). Glacial drift within this formation consists of lodgement and minor flow till, with lenses and interbeds of glaciofluvial sand to gravel, and lenses and interbeds of glaciolacustrine laminated stony till up to 25 m thick. The region is overlain by glaciomarine and marine deposits consisting of silt loam to clay loam, normally 3 m thick but in places up to 10 m thick.[1]

The dense, well consolidated lodgement till will dominate the groundwater flow pattern within this region and is expected to be a barrier to high groundwater flows. The heterogeneous clay and silt rich surficial deposits will likely provide lower natural recharge in these regions as well as lower base flow contribution as clay rich glaciomarine sediments are not associated with well performing aquifers.

Glaciofluvial Deposits in Mid Mackay and Mosquito Watersheds

At lower elevations both watersheds are dominated by Capilano sediments consisting of raised deltaic and channel fill of medium sand to cobble gravel, up to 15 m thick commonly underlain by an aquitard of silty to silty clay loam. Shown as blue 'Glaciofluvial Deposits' on Figure C1-2, this region shows greater heterogeneity than the upper elevations. Within this formation exists small regions of bedrock; undivided Pre-Vashon, consisting of till, associated glacial deposits, marine and organic sediments; and Tertiary bedrock, including sandstone, siltstone, shale, and minor volcanic rock.

Fluvial Deposits in Lower Mackay and Mosquito Watersheds

The geology of the lower elevation postglacial sediments shown as green 'Fluvial Deposits' on Figure C1-2, are mountain stream marine deltaic sediments dominated by medium to coarse gravels and sands up to 8 m thick.

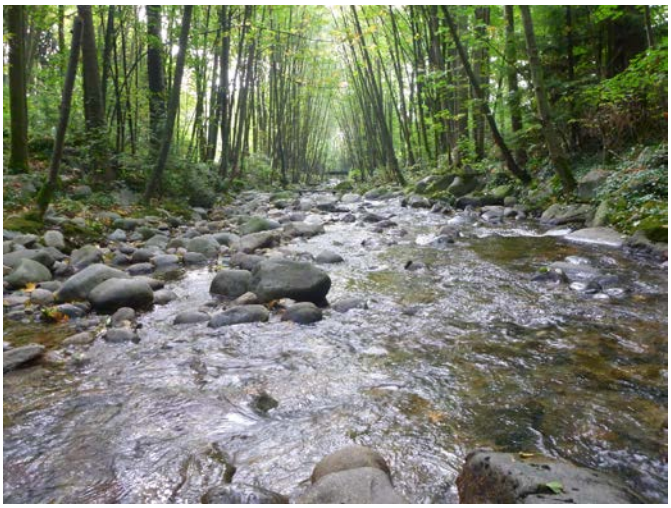


Photo C1-2: Mosquito Creek Boulder Substrate. (Sept 2014).

2.5 Background Information

Relevant background reports reviewed for this study are listed in Table C1-1 at the end of this report.

[1] Geological Survey of Canada maps

3. Watershed History

A detailed history of watersheds including an overview of the early days of development in the watersheds and a drainage work history is included in this section. Steep mountain creeks, such as those draining the North Shore Mountains, may be subject to a spectrum of flood events ranging from clear water floods to debris flows. The drainage history includes a long record of flooding, creek erosion, and debris flows in the Mackay and Mosquito watersheds.

3.1 Development History

North Vancouver has a long history, starting in the late 1800's.

- Moodyville and logging
- DNV was established in 1891
- Early ferry service in 1900 from Vancouver to the north shore, shipbuilding, cottage country
- CNV was established 1907 and underwent rapid change from logged/natural to urban hub
- After streetcar service up Lonsdale, into Capilano and Lynn Valleys – development follows, Victoria Park, Mahon Park, Ottawa Gardens, Grand Boulevard all established early
- During WWII – rapid expansion of developed area to house ship builders
- In 1947 the ferry was cancelled. Second Narrows Bridge was constructed around 1958 with emphasis on car travel and loss of compact community
- SeaBus started in 1977 and the Lonsdale Quay developed in 1986 with more concentrated development nearer water to 2000
- Grouse Mountain Road was constructed in 1924 with tow rope for skiing in the mid-1930s. in 1949, the world's first double chairlift was installed, with second lift from The Cut in 1951. The Grouse Mountain Chalet became a dining and dancing location. The Skyride with 1000 paved parking spots was developed in in 1966. Snowmaking began in 1973, and 1974 saw a second tramway. Modern attractions were added in the 1990s.

3.2 Drainage Works History in the Watersheds

In the early 1950s there was extensive flooding on the North Shore, notably on the larger creeks, including Lynn Creek and Mosquito Creek. The flooding on Mosquito Creek was further complicated by channel instability and sediment transport that led to the construction of the Evergreen debris/sediment basin and the kilometre-long culvert that discharges into William Griffin Park. Further downstream in the City, flooding in the 1950s led to construction and maintenance of dykes that are visible in historical aerial photographs. These dykes were maintained up until the 1980s.

In 1980 and 1981, there were large rain events that resulted in flooding, infrastructure damage, and numerous overtopping events at culverts throughout both watersheds. There was excessive damage on the Mosquito Creek system, most notably on the Mission Creek tributaries flowing from the west side of Upper Lonsdale. These events and restoration activities have been documented in a series of KWL "Technical Working Reports". Numerous in-stream projects were undertaken to stabilize the stream channels and repair damage.



Photo C1-3: Mountain Highway, paved toll road to Grouse Mountain. ***(NVMA 10686)***

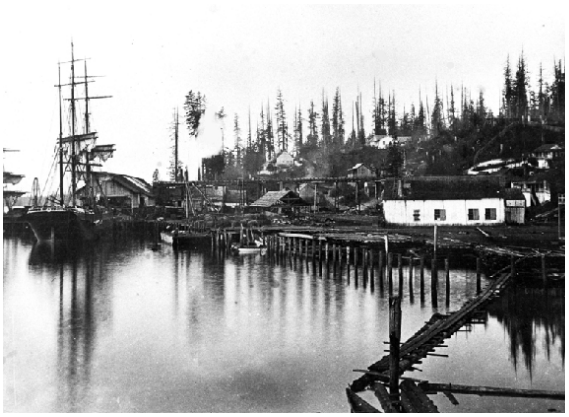


Photo C1-4: Moodyville Sawmill, closed in 1901. ***(BC Archives 846 – Copyright)***



Photo C1-5: 1924 – New blacktop on Edgemont Blvd near Queens Road. First log cabin field office for Service Realty's Capilano Highlands Development, Spring 1946. ***(NVMA 13073)***

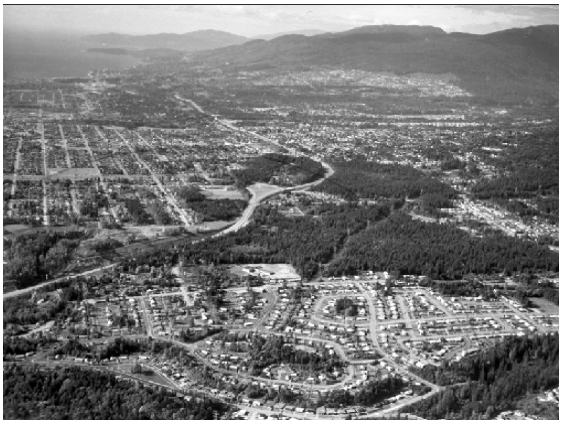


Photo C1-6: Upper Levels Hwy completed 1961. 6 major access points. 4 lanes for 9 km in North Van. ***(NVMA 106-4-8)***

As part of these events, the Mosquito Creek channel from upstream of Montroyal to Evergreen Basin was completely reconstructed, channel grade stabilization (concrete and riprap weirs) constructed on Mosquito Creek and Mackay Creek (near Montroyal), numerous culvert inlets were upgraded, and some crossings replaced.

Culvert Replacement Program

DNV has a culvert replacement program as part of their culvert asset management program. Culvert replacements are based on certain criteria including age, culvert material, condition, and fish passage. However, several old wood stave culverts have failed within the Mackay watershed resulting in emergency works. These emergency works, such as the Prospect Avenue crossing include provisions for fish passage.

2014 Flood Study

CNV and DNV commissioned a study on the creek hydrology and floodplain mapping for the Mackay, Mosquito, Lynn, and Seymour watersheds. This study, which included hydraulic modelling, was created specifically to understand the impact of climate change on streamflow changes and flooding extents along the lower reaches of each of the watersheds. The results of the study have been used to apply for federal funding for flood protection works along Lower Mackay Creek south of Marine Drive.

1995 Debris Flow on Mackay Creek

The 1995 debris flow on upper Mackay Creek resulted in several issues in the stream ranging from a response and recovery of the initial event to construction of the Mackay Creek debris barrier, and replacement and upgrading of culvert crossings. This included the innovative Sarita Road crossing that used an atypical culvert orientation to create deep baffles for fish passage up very steep grades.

The sediment introduced in Mackay Creek in the 1995 debris flow also resulted in the need for sediment management in the lower reaches of the creek, and the development of the *Lower Mackay Creek Management Plan, 1997.* The plan incorporated sediment management, instream works, and habitat enhancements to limit the frequent flood risk and protect habitat values in the lowest reaches of the creek. Sediment management activities were conducted by the District regularly at the Roosevelt Crescent sediment trap up to approximately 2008 but have not been required in the past few years. Zoann Morten (North Shore Streamkeepers) noted that there was limited fish usage in the sediment management reach of Mackay.

2007 Mackay Creek Inventory

In 2007, a detailed stream inventory for Mackay Creek and its tributaries was conducted by the District. The inventory involved the collection of a range of attributes including erosion severity and consequence, culvert crossing attributes, debris management concerns, and bank protection works. A summary figure of the inventory is shown in Compendium 4 – Drainage Asset Inventory.



Photo C1-7: Mackay Creek Flooding

2008 Upper Mackay Streamflow Analysis

In response to claims from a local homeowner around increased erosion associated with urbanization, DNV conducted a detailed analysis of changes in daily streamflow over the period of record and with respect to rainfall. The results of the analysis showed no more than minor changes in daily streamflow as a function of growing urbanization since the late 1970s upstream of Montroyal Boulevard[2].

[2] Mackay Creek at 974 Clements Ave Technical Memo, KWL, 2008.

Mosquito Creek

2013 Mosquito Creek Debris Net

Following numerous studies and risk assessments, DNV installed a debris net on the upper reaches of Mosquito Creek in the summer of 2013. The net was chosen over a traditional "dam type" barrier to minimize construction impacts on the fish-bearing creek.

2014 Mosquito Creek Spawning Channels

In partnership with DFO and the local stream keepers, both CNV and DNV have constructed and maintained spawning channels as well as off channel rearing habitats for Coho and Cutthroat.

Thain Creek

Historical Mission Creek Diverted to Thain in 1950's

The lower reach of Thain Creek is a highly modified tributary to Mosquito Creek. It is believed that in the 1950s, in response to flood events and development, Mission Creek upstream of 29th Street (in the District of North Vancouver) was diverted west and into the Thain Creek ravine that is located east of the William Griffin Recreation Centre Complex. In the ensuing period, development enveloped the remaining Thain Creek headwaters and lower Mission Creek was effectively cut off from the upper reaches with development and expansion of Highway 1. The result of diverting the larger headwaters of Mission Creek into Thain Creek was the overall destabilization of the Thain Creek ravine and a legacy of slope stability and landslide issues. On the City side, slope stability assessments were conducted in the 1990s and early 2000s, which included preliminary assessments, development of a management strategy and installation of a slope inclinometer. The City collected historical survey data as well.

Daylighting Thain Creek in 1999

In 1999, the Thain Creek diversion culvert was removed due to long term deterioration and replaced with a fish friendly "daylighted" channel. The daylighting project is still one of the largest culvert daylighting projects in the region. It is considered a very successful project resulting in new riparian, fish passage, and stable and low maintenance channel that provides for natural fluvial processes.

Mission Creek

A large portion of work on Mission Creek dates back to the early 1980s; however, in recent years, the following work was completed:

- 2000: replacement of the Cartelier culvert crossing.
- 2002: fish passage improvements under Queens Road and channel stabilization works downstream; and
- 2005: relining of large multi-plate culvert under Montroyal Boulevard;
- 2013: relining of culverts on the upper Mission tributaries (three sites);
- Windsor Road culvert upgrade with fish passage.

Wagg Creek

Work on Wagg Creek has been substantial. Many of the stormwater related efforts on Wagg Creek are summarized in the 1999 *Stormwater Management Strategy for Mission/Wagg Creek System*. An XP-SWMM model for the catchment was developed which was later used as a research tool for a Climate Change Assessment (UBC Master's Thesis - Denault, 2003).

Wagg Pond Upgrades

In 2005, major upgrades to the Wagg Creek pond were undertaken to increase its sediment trapping ability and provide for future fish passage. This work also included initial planning for additional stormwater regional facilities on the Wagg / Mission system.

15th Street Oil/Water Separator

CNV installed a large hydrodynamic separator unit on the storm pipe along 15th Street (refer to Figure C4-2 – copy included from *Compendium 4. Drainage Asset Inventory*) to remove pollutants prior to discharge into Wagg Creek. City Operations noted that they removed approximately 30 loads (vac truck) in 2014.

3.3 Surficial Geology

Figure C1-2 depicts the surficial materials layer based on the Geological Survey of Canada maps in the upper watershed and DNV GIS in the mid to lower developed areas of the watershed.

Bedrock in Upper Mackay and Mosquito Watersheds

At higher elevations, the geology of both the Mackay and Mosquito watersheds are dominated by bedrock of granitic and associated rock types. Surficial glacial deposits and colluvium overlay this material over the entire extent.

Till in Upper-Mid Mackay Watershed and Thain and Wagg Subwatersheds

The surficial geology of the Wagg Creek and Thain Creek sub-catchments as well as Upper-Mid Mackay is dominated by Till (shown as "light blue" on Figure C1-2). Glacial drift within this formation consists of lodgement and minor flow till, with lenses and interbeds of glaciofluvial sand to gravel, and lenses and interbeds of glaciolacustrine laminated stony till up to 25 m thick. The region is overlain by glaciomarine and marine deposits consisting of silt loam to clay loam, normally 3 m thick but in places up to 10 m thick.[3]

The dense, well consolidated lodgement till will dominate the groundwater flow pattern within this region and is expected to be a barrier to high groundwater flows. The heterogeneous clay and silt-rich surficial deposits will likely provide lower natural recharge in these regions as well as lower base flow contribution as clay rich glaciomarine sediments are not associated with well performing aquifers.

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At lower elevations both watersheds are dominated by Capilano sediments consisting of raised deltaic and channel fill of medium sand to cobble gravel up to 15 m thick, commonly underlain by an aquitard of

[3] Geological Survey of Canada maps

silty to silty clay loam. Shown as blue 'Glaciofluvial Deposits' on Figure C1-2, this region shows greater heterogeneity than the upper elevations. Within this formation exists small regions of bedrock; undivided Pre-Vashon, consisting of till, associated glacial deposits, marine and organic sediments; and Tertiary bedrock, including sandstone, siltstone, shale, and minor volcanic rock.

Fluvial Deposits in Lower Mackay and Mosquito Watersheds

The geology of the lower elevation postglacial sediments shown as green 'Fluvial Deposits' on Figure C1-2, are mountain stream marine deltaic sediments dominated by medium to coarse gravels and sands up to 8 m thick.

4. Natural Risks

4.1 Debris Flood and Flow Hazards

Mountain Creeks Spectrum of Floods

Steep mountain creeks may be subject to a spectrum of flood events ranging from clear water floods to debris flows. These events are often categorized by sediment concentration:

- floods (or 'clear water' floods) have the lowest sediment concentrations,
- debris floods have intermediate sediment concentrations, and
- debris flows have the highest sediment concentrations.

Potential for debris floods and debris flows is primarily dictated by basin characteristics, including gradient, watershed size, channel length, and the underlying geology/lithology of the area. Steeper watersheds with an abundance of lose material may be debris flow prone; whereas, watersheds with less relief and more stable surficial geology may only be vulnerable to flooding.

Within the Mackay and Mosquito watersheds, debris flood/flow activity occur in the steep, relatively undeveloped, upper watersheds, while floods occur in the lower-gradient, highly developed, lower watershed. DNV completed the *Debris Geohazard Risk and Risk Control Assessment, (BGC Engineering Inc., 2017)* study. Information and recommendations from this report and the ISMP should be integrated.

4.2 Flood Hazard & Floodplain Management

Creek Hydrology, Floodplain Mapping, and Bridge Hydraulic Assessment Study

CNV and DNV completed a *Creek Hydrology, Floodplain Mapping and Bridge Hydraulic Assessment Study (KWL, 2014)* to investigate the risk of flooding and the exacerbating effects of climate change on major creeks on the North Shore. Figures C1-5 and C1-6 show the DRAFT results of predicted extents of flooding from 200-year creek flooding and coastal flooding respectively from three time horizons 2012, 2100 and 2200. Overbank flooding is extensive in all these scenarios. Overland flooding is most extensive and initiates at lower return period events for Mackay Creek, followed by Mosquito Creek. There is a substantial flood hazard to large developed and redeveloping areas in Mackay and Mosquito watersheds.

Floodplain Management Philosophy

Current floodplain management philosophy recommends an integrated approach to flood management that includes a range of non-structural and structural flood protection measures, and integrated multi-institutional decision making and co-operation.

Non-structural measures are generally planning level instruments to either preserve existing areas for hazard management or reshape development to move development away from hazardous areas or provide for structural measures.

Structural measures include any constructed works to physically protect developed areas from floodwaters. Most typically these are flood protection dikes, but also include implementation of Flood Construction Levels for construction, and other measures.

Due to the level of development and foreseeable flood hazard in the study area, structural flood protection measures that span municipal and other private lands were recommended for implementation[4].

4.3 Climate Change

Climate change forces such as sea level rise, precipitation changes, air temperature changes also present natural risks to the North Shore watersheds. Climate change predictions are noted from various research as noted.

Sea Level Rise

BC Ministry of Environment Indicators of Climate Change for British Columbia, 2016 recommends planning for sea level rise with 1 m of global sea level rise by the Year 2100 and about 2 m by the Year 2200.

Precipitation Changes

Climate Projections for Metro Vancouver, 2016 predicts increased precipitation in winter and reduced precipitation in summer. Winters will experience increased frequency and intensity of extreme rainfall events. A single-day maximum rainfall over the whole region could increase by 17% by 2050 and 32% by 2080. This would result in significant impacts on existing stormwater collection infrastructure, natural watercourses, and crossing structures (e.g., culverts) highlighting the need for adaptation measures.

Summer is expected to become drier and last longer. Metro Vancouver projections show a decline in total summer precipitation of about 19% by the 2050s, and a decline of about 29% by the 2080s (Metro Vancouver, 2016). Projections also indicate an increase in the length of predicted dry spells (the number of consecutive days where daily precipitation is less than 1 mm). The past average longest period of consecutive days without rain (under 1 mm) in Metro Vancouver is 21 days. Metro Vancouver's projections indicate that dry spells are expected to increase to 26 days by the 2050s, and 29 days by the 2080s.

[4] CNV/DNV *Creek Hydrology, Floodplain Mapping and Bridge Hydraulic Assessment, KWL, 2014*

Air Temperature Increases

Climate Extremes in the Georgia Basin, Pacific Climate Impacts Consortium, 2012 indicates global air temperatures have increased due to increased concentrations of greenhouse gases in the atmosphere, especially CO_2. This is due to the effectiveness of greenhouse gases to trap heat within the atmosphere causing warming of the earth (IPCC, 2012).

Temperature projections suggest that warming will continue in all seasons, with the greatest increases to occur during summer. A median annual warming of about 1.7 ºC is projected by the 2050s and 2.7 ºC by the 2080s (PCIC, 2012).

With increased air temperatures, growing seasons will be longer but may be impacted by more frequent and severe droughts (Metro Vancouver, 2016). Additional impacts can include increased rates of soil erosion, loss of wetlands, reduced streamflows, increases in forest fire intensity, and potentially increased invasions of pests and invasive species (Metro Vancouver, 2016).

5. Summary of Findings

5.1 Findings

Findings from this compendium include:

Watershed Overview

C1-1. The Mackay watershed is approximately 849 ha with a number of tributaries; flows through both the District and the City before discharging to Burrard Inlet.

C1-2. The Mosquito Creek watershed has a total drainage area of 1538 ha, with two significant tributaries, Thain Creek (319 ha) in the District and Wagg Creek (387 ha) in the City. The mouth of the creek flows through Squamish Nation Indian Reserve No. 1 before discharging to Burrard Inlet.

C1-3. Both watersheds have steep, forested upper reaches, with mid-section residential neighbourhoods with commercial and industrial development south of Marine Drive. Soils consist of bedrock with overlaying soil veneers in the upper watershed, with predominantly glacial blanket (till) and glaciofluvial (sands/gravels) areas in the mid section, with alluvial sediments (sand/gravels) towards the mouth of the watersheds.

Watershed History

C1-4. There is much background information available within these watersheds, and a rich history starting in the late 1800's. DNV was established in 1891 and CNV established in 1907.

C1-5. Extensive flooding was noted in the early 1950's and 1980's, complicated by channel instability and sediment transport. This led to construction of debris/sediment basins, enclosed culverts, channel stabilization works, culvert inlets/upgrades, and dykes.

C1-6. A debris flow on upper Mackay Creek occurred in 1995, which resulted in the construction of a debris barrier, and replacement and upgrading of culvert crossings. A debris net was installed on upper Mosquito Creek in 2013.

C1-7. Upper Mission Creek was diverted to Thain Creek in 1950's. A section of Thain Creek was daylighted in 1999 resulting in new riparian, fish passage and a stable/low maintenance channel.

C1-8. Wagg Creek notably has a sedimentation pond and an oil/water separator on 15th Street.

Natural Risks

C1-9. Mountain creeks are susceptible to a spectrum of floods, debris floods and flows including Mackay and Mosquito Creeks. Refer to and integrate with the *Debris Geohazard Risk and Risk Control Assessment, BGC 2017* study.

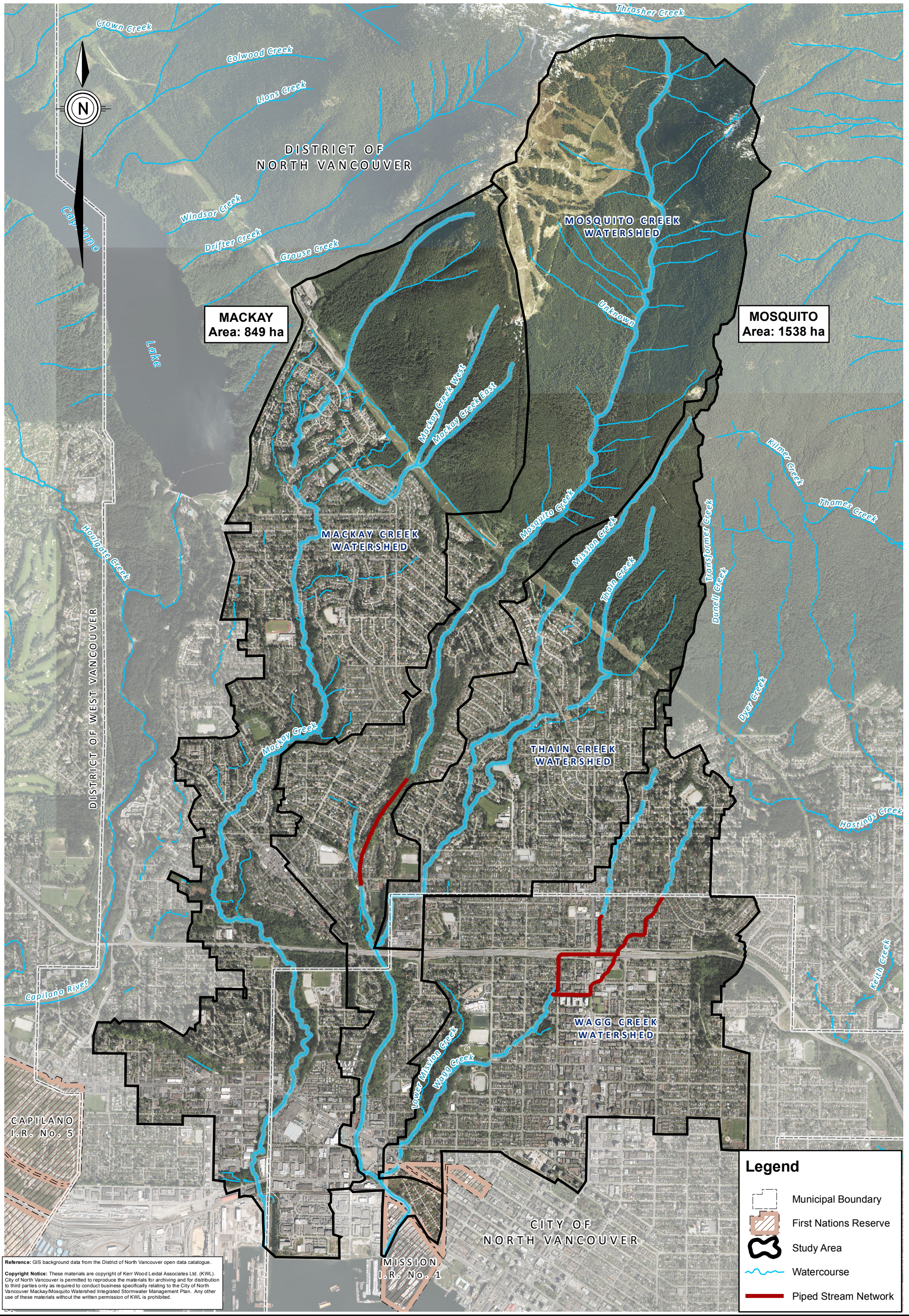
C1-10. CNV and DNV completed a *Creek Hydrology, Floodplain Mapping and Bridge Hydraulic Assessment Study (KWL, 2014)* to investigate the risk of flooding and the exacerbating effects of climate change on major creeks on the North Shore. Predicted extents of flooding from 200-year creek flooding and coastal flooding using three time horizons 2012, 2100 and 2200 was evaluated. The extent of overbank flooding is extensive in all these scenarios. There is a substantial flood hazard to large developed and redeveloping areas in Mackay and Mosquito watersheds. Non-structural and structural measures were previously recommended.

C1-11. Climate change predictions of sea level rise, increased precipitation and temperatures also pose a natural risk to the watersheds.

Table C1-1: List of Background Information

Year	Municipality	Report	Prepared By
Region-Wide Policies, Bylaws and Studies			
Drainage, Flood, Debris & Erosion Studies			
2014	CNV/DNV	Creek Hydrology, Floodplain Mapping and Bridge Hydraulic Assessment	KWL
2013	DNV	Culvert Infrastructure Assessment Review	KWL
2013	CNV/DNV	Flood Hazard Study North Vancouver	NHC for Natural Resources Canada
2010	CNV	Subdivision and Development Control Bylaw 2010 No 8014	
2007	DNV	Watercourse Inventory Program - Mackay and Mosquito Creek	KWL
2005	DNV	Development Servicing Bylaw - Bylaw 7388	
2003	DNV	Debris Flood Study and Risk Mitigation Alternatives	?
1995	CNV	Sewerage and Drainage Utility Bylaw 1995 No 6746	
1992	CNV	Report on North Shore Hydrology and Computer Modelling	KWL
Environmental			
2012	DNV	Tree Protection Bylaw - Bylaw 7671	
2009	DNV	Pesticide Use Control Bylaw 7686	?
2009	DNV	Environmental Protection and Preservation Bylaw 6515 – 1993	?
2008	DNV	Streamside Protection Bylaw 7658	?
2005	CNV	Environmental Monitoring Program [should be 2003?]	KWL
2004	DNV-EC	Comparison of B-IBI and CABIN benthic sampling approaches	Raincoast Applied Ecology
2007	UBC	Imperviousness and Trace Metalas in Stream Sediments (master's thesis)	UBC
1987	DFO	Historical Salmon Escapements for Burrard Inlet Streams	DFO
2006-2012	CNV	2006, 2008, 2010, 2012 Bi-annual stream health monitoring reports	Raincoast; Echo Blue
2000	CNV / DNV	NSSK Water Quality Monitoring Results (multiple streams)	NSSK
2003	DNV	Benthic Invertebrate Sampling – Watershed Health Indicator	Raincoast Applied Ecology
Land Use & Recreation			
2014	CNV	Official Community Plan	
2010	DNV	Official Community Plan	?
1990			?
1995	CNV	Zoning Bylaw 1995 No 6700	
1965	DNV	Zoning Bylaw	?
Mackay Creek			
Flood, Debris & Erosion Studies			
2007	GVRD	Mackay Creek Debris Flow Mitigation Measures	?
1996	DNV	Pre-Design Report on Debris Flow Mitigation Strategy for Upper Mackay Creek	?
1996	DNV	Mackay Creek Debris Flow Risk Assessment and Hazard Mitigation	?
1996	DNV	Mackay Creek Debris Flow - Risk Assessment and Hazard Mitigation	KWL
1982	DNV	Creek Systems and Stormwater Control Summary Report - Mackay Creek	KWL
Gravel Management			
2003	DNV	Lower Mackay Creek Management Plan - Gravel Management	?
Construction Projects/Facilities			
2014	DNV	Upper Mackay Creek Debris Basin Monitoring Report	KWL
2010	DNV	Upper Mackay Creek Debris Basin Monitoring Report	KWL
2005	DNV	Upper Mackay Creek Debris Basin Monitoring Report	KWL
2002	DNV	Operations and Maintenance Manual for Upper Mackay Creek Debris Basin	KWL
2001	DNV	Upper Mackay Creek Debris Basin Completion Report	KWL
Environmental			
2014?	CNV	MacKay Creek Estuary Restoration Presentation	Ken Ashley, Ph.D., NWC
2009	CNV / DNV	Mackay Creek Water Quality Assessment	NSSK
Ongoing	CNV / DNV	NSSK adult spawner surveys	NSSK
Pre-2000	DNV	Fish habitat work related to debris flow mitigation	KWL
2003	DNV	District of North Vancouver Benthic Monitoring Program	Raincoast Applied Ecology
2004	DNV / Env Can	B-IBI / CABIN benthic analysis comparison project	Raincoast Applied Ecology
Mosquito Creek			
Flood, Debris & Erosion Studies			
2013	DNV	Mosquito Creek Post-Mitigation Quantitative Risk Assessment	BGC Engineering
2003	DNV	Debris Flood Study and Risk Mitigation Alternatives for Mosquito Creek	KWL
2000	CNV	Mosquito Creek Flood and Erosion Study	KWL
1991	DNV	Overview Report on Mosquito Creek Flood and Debris Flow Protection	KWL
1982	DNV	Creek Systems & Stormwater Control Summary Report - Mosquito Creek	KWL
		Lower Mission Watershed Status Survey (geology)	NSSK
1982	DNV	Creek Systems & Stormwater Control Summary Report - Mission Creek	KWL
Gravel Management			
2001	DNV	Mosquito Creek Creek Management - Bedload Removal at Marine Drive	KWL
Construction Projects/Facilities			
2011	DNV	North Mosquito Creek Native Vegetation and Bank Restoration Plan	?
Land Use & Recreation			
2012	DNV	Overview of Mosquito Creek Trail System	Brittany McKinnon & Kristy Rasmus, Ecological Restoration, BCIT

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Author: JLau



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City and District of North Vancouver
Mackay/Mosquito Watershed Integrated Stormwater Management Plan

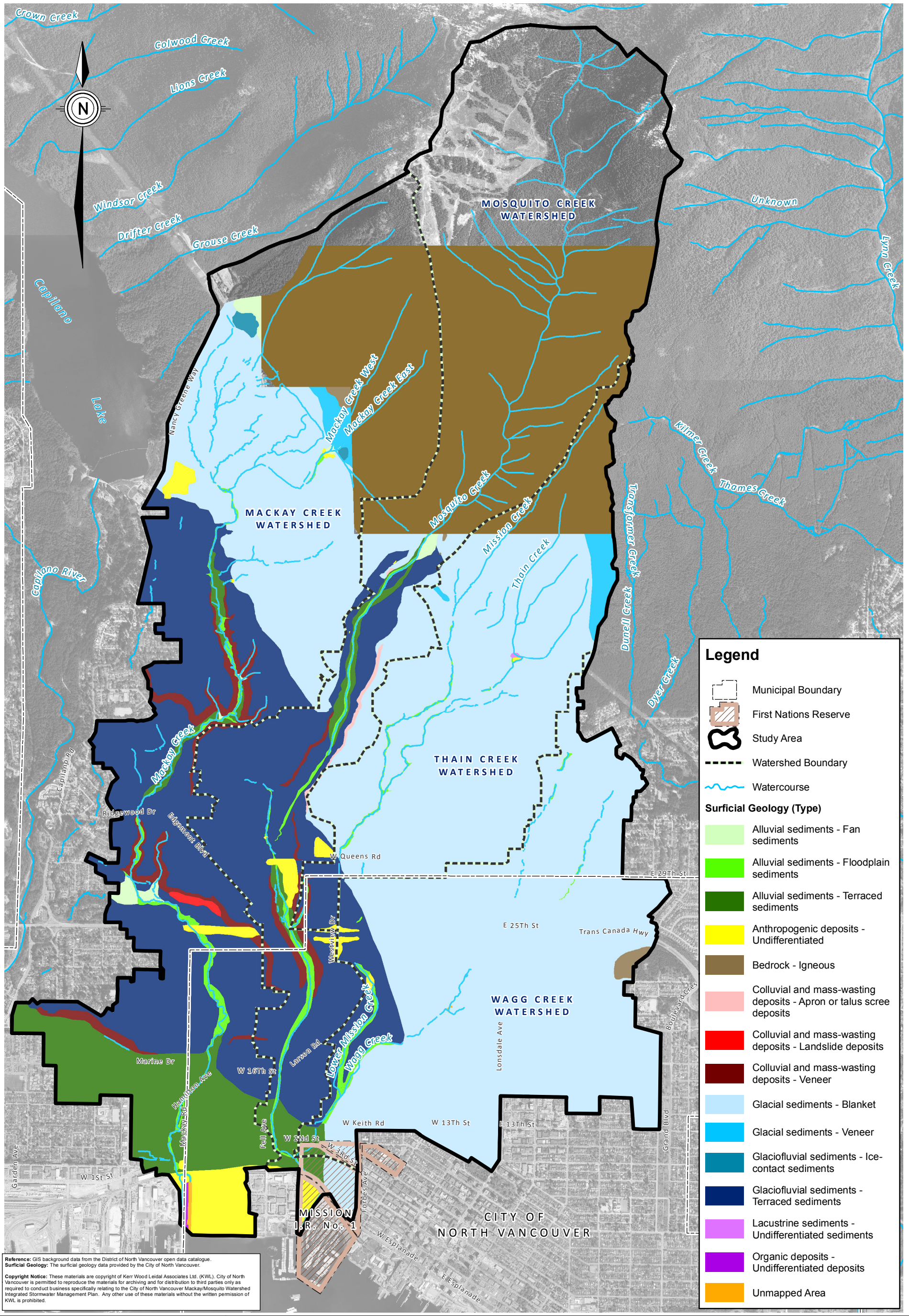
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2013 Air Photo of Watershed

Figure C1-1

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Legend

- Municipal Boundary
- First Nations Reserve
- Study Area
- Watershed Boundary
- Watercourse

Surficial Geology (Type)

- Alluvial sediments - Fan sediments
- Alluvial sediments - Floodplain sediments
- Alluvial sediments - Terraced sediments
- Anthropogenic deposits - Undifferentiated
- Bedrock - Igneous
- Colluvial and mass-wasting deposits - Apron or talus scree deposits
- Colluvial and mass-wasting deposits - Landslide deposits
- Colluvial and mass-wasting deposits - Veneer
- Glacial sediments - Blanket
- Glacial sediments - Veneer
- Glaciofluvial sediments - Ice-contact sediments
- Glaciofluvial sediments - Terraced sediments
- Lacustrine sediments - Undifferentiated sediments
- Organic deposits - Undifferentiated deposits
- Unmapped Area

Reference: GIS background data from the District of North Vancouver open data catalogue.
Surficial Geology: The surficial geology data provided by the City of North Vancouver.

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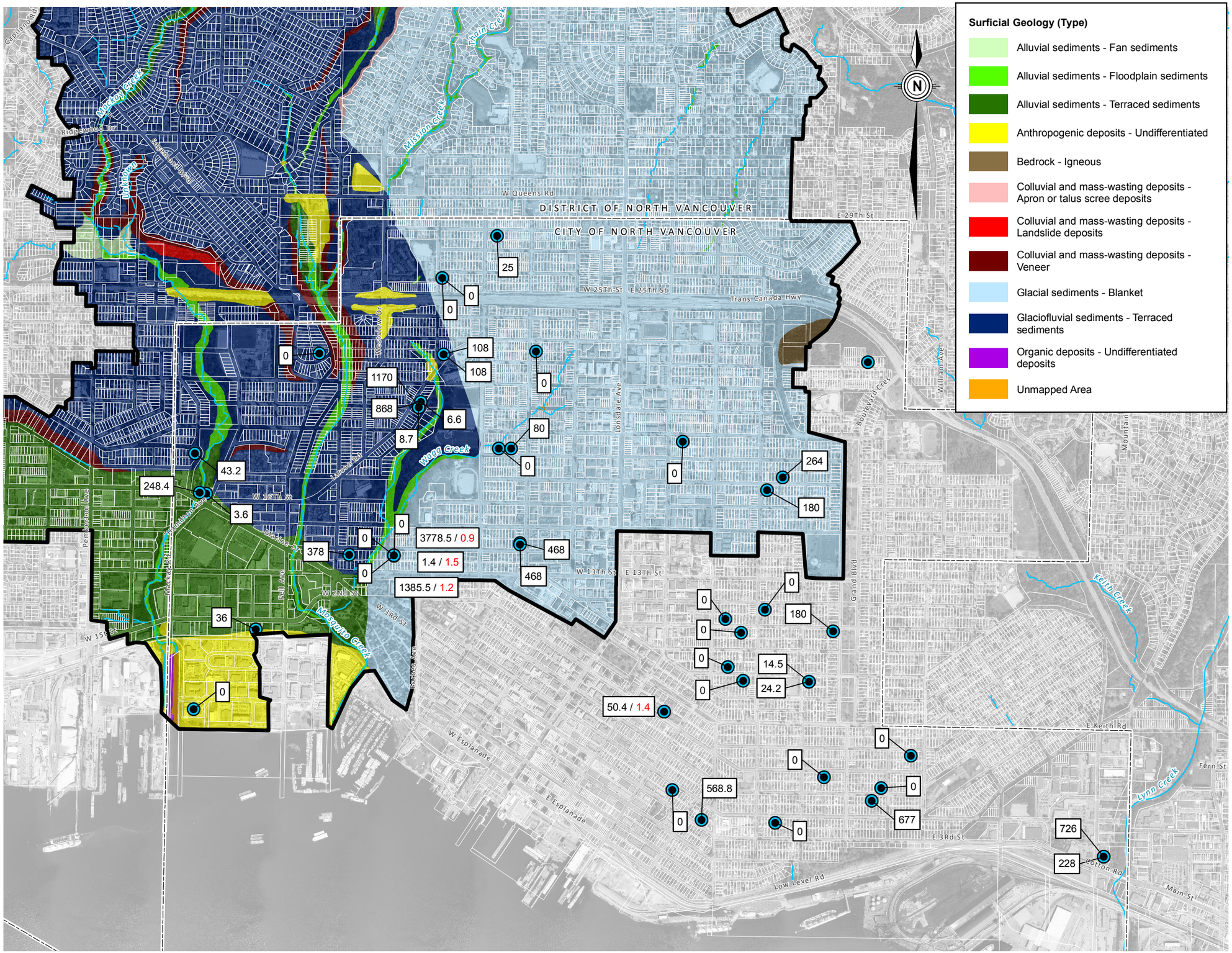
City and District of North Vancouver
Mackay/Mosquito Watershed Integrated Stormwater Management Plan

Project No. 99-125
Date December, 2016

500 0 500 (m)

Surficial Soils

Figure C1-2



Surficial Geology (Type)

- Alluvial sediments - Fan sediments
- Alluvial sediments - Floodplain sediments
- Alluvial sediments - Terraced sediments
- Anthropogenic deposits - Undifferentiated
- Bedrock - Igneous
- Colluvial and mass-wasting deposits - Apron or talus scree deposits
- Colluvial and mass-wasting deposits - Landslide deposits
- Colluvial and mass-wasting deposits - Veneer
- Glacial sediments - Blanket
- Glaciofluvial sediments - Terraced sediments
- Organic deposits - Undifferentiated deposits
- Unmapped Area

City and District of North Vancouver
Mackay/Mosquito Watershed
Integrated Stormwater Management Plan

Legend

- Study Area
- Municipal Boundary
- Watercourse

Data Taken from the City of North Vancouver Development Reports

- Hydrogeology Location
  - ## / ## — Infiltration Data Depth m (if available) / Infiltration Rate mm/hr

Reference: 2013 Orthophoto from the District of North Vancouver. GIS data from the City and District of North Vancouver.
Surficial Geology: The surficial geology data provided by the City of North Vancouver.

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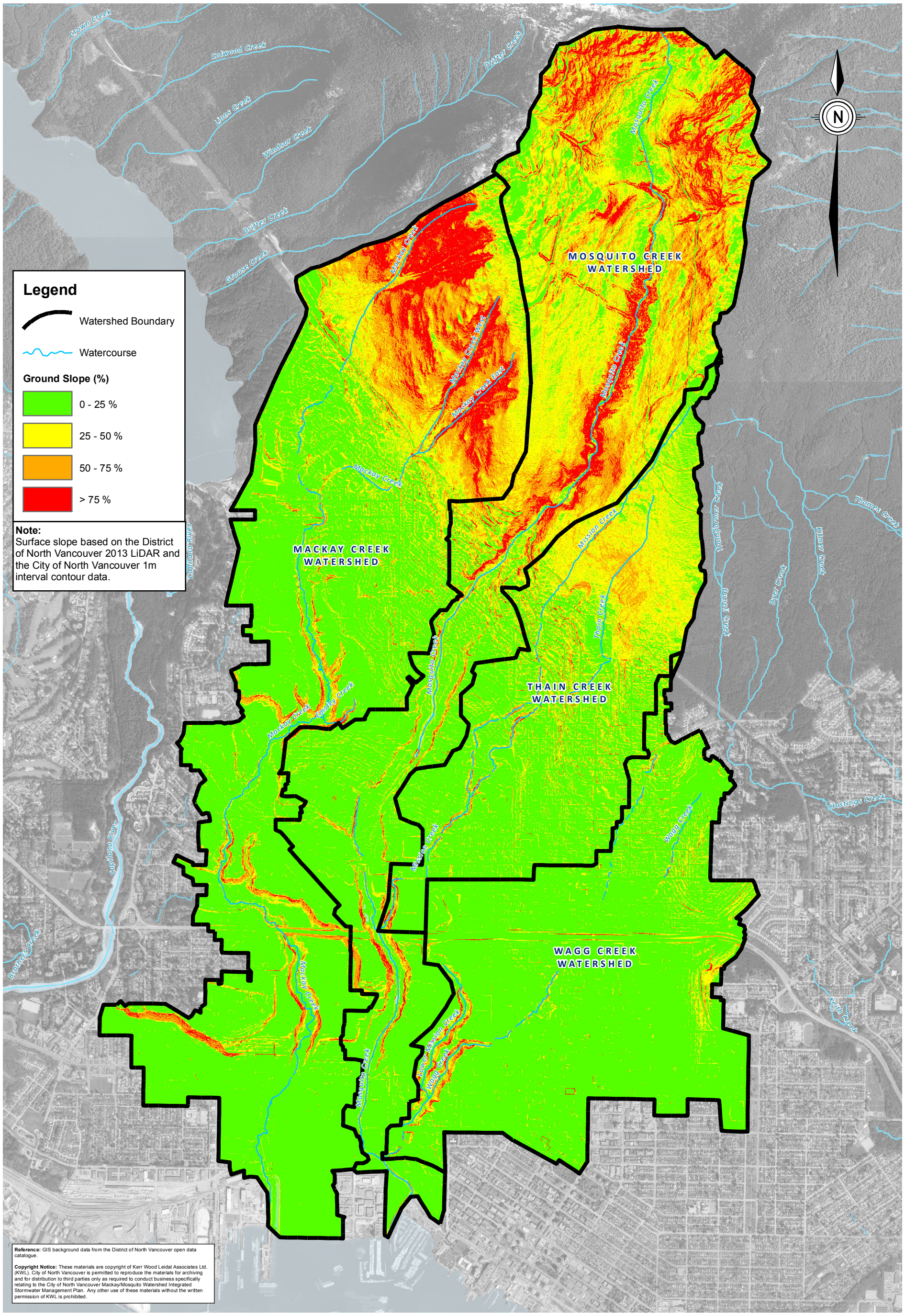
Project No.	Date
99-125	December 2016

CNV and DNV Hydrogeology Data Summary

Figure C1-3

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Author: JLau



Reference: GIS background data from the District of North Vancouver open data catalogue.

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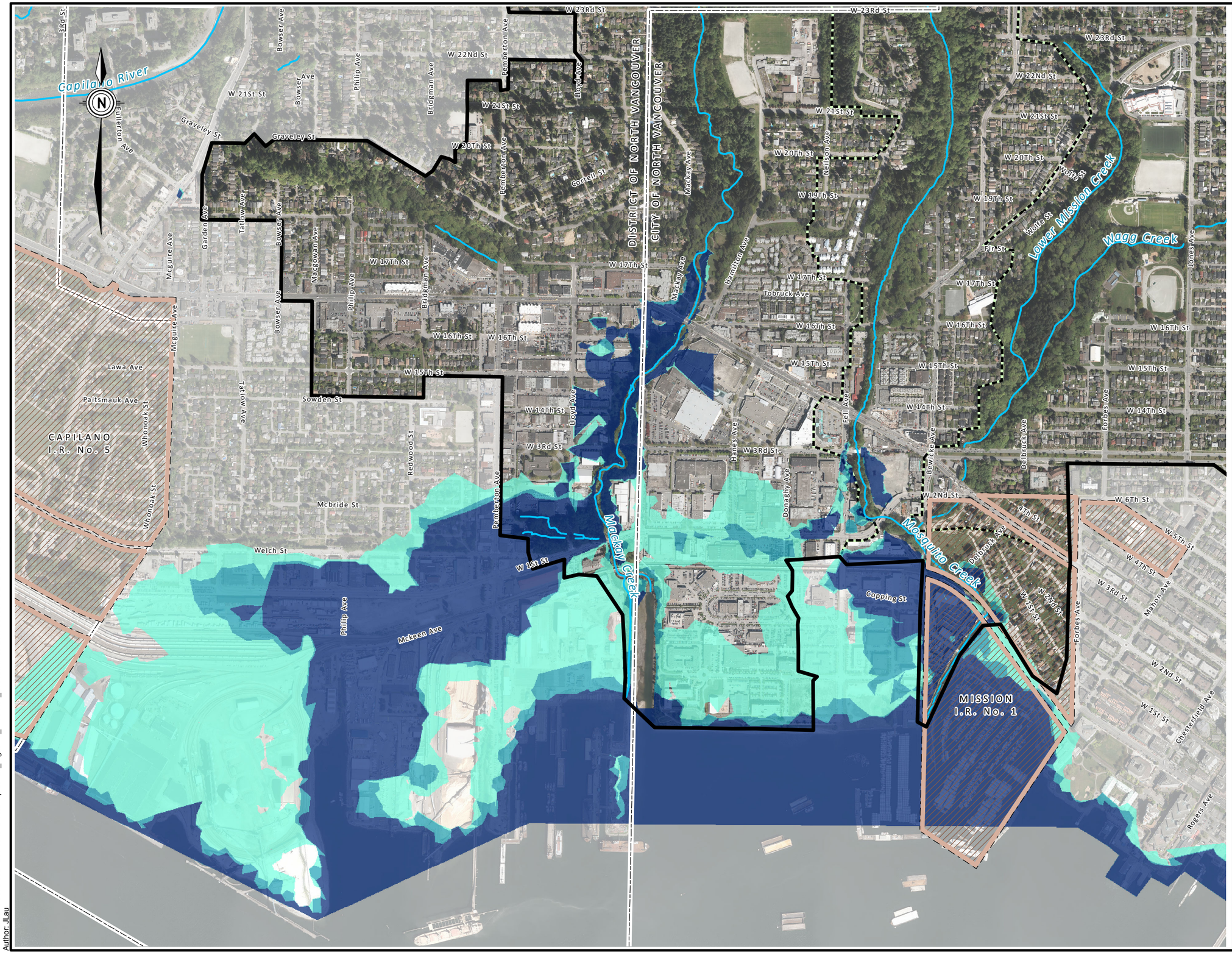
City and District of North Vancouver
Mackay/Mosquito Watershed Integrated Stormwater Management Plan

Project No. 99-125
Date December, 2016

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Watershed Slope Analysis

Figure C1-4



City and District of North Vancouver
Mackay/Mosquito Watershed
Integrated Stormwater Management Plan

Legend

- Municipal Boundary
- First Nations Reserve
- Study Area
- Watershed Boundary
- Watercourse

Maximum Water Depth (River Floods)

- Year 2012
- Year 2100
- Year 2200

Reference: GIS background data from the District of North Vancouver open data catalogue.

-Predicted River Floods from "Creek Hydrology Floodplain Mapping and Bridge Hydraulic Assessment", KWL Report October 24, 2014

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Project No.	Date
99-125	December 2016

Predicted 200-year Creek Floods –

Figure C1-5

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City and District of North Vancouver
Mackay/Mosquito Watershed
Integrated Stormwater Management Plan

Legend

- Municipal Boundary
- First Nations Reserve
- Study Area
- Watershed Boundary
- Watercourse

Maximum Water Depth (Coastal Floods)

- Year 2012
- Year 2100
- Year 2200

Reference: GIS background data from the District of North Vancouver open data catalogue.

-Predicted Coastal Floods from "Creek Hydrology Floodplain Mapping and Bridge Hydraulic Assessment", KWL Report October 24, 2014

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Project No.	Date
99-125	December 2016

Predicted Coastal Floods

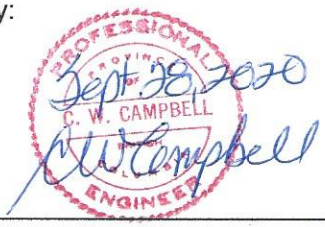
Figure C1-6

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Author: JLau

Report Submission

KERR WOOD LEIDAL ASSOCIATES LTD.

Prepared by:



Crystal Campbell, P.Eng.
Project Manager

Reviewed by:

David Zabil, P.Eng.
Technical Reviewer

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Revision History

Revision #	Date	Status	Revision	Author
0	September 21, 2020	Final	Issued as final for client copy.	CC

OQM CERTIFIED



Compendium 2

WATER QUALITY & INSTREAM SPECIES

Mackay Mosquito Watersheds ISMP

September 2020

Final Report

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Purpose

Compendium 2. Water Quality & Instream Species

This compendium provides technical information on water and sediment quality, benthic invertebrates, and the fish community of the Mackay and Mosquito Creek watersheds in North Vancouver, BC. It is a supporting document to the Mackay and Mosquito Creek Integrated Stormwater Management Plan (ISMP) that was developed by the City of North Vancouver and the District of North Vancouver.

Information is summarized in six sections:

1. Water quality
2. Sediment quality
3. Benthic invertebrate community
4. Fish populations
5. Fish passage
6. Instream habitat

Available data is summarized including the methods and results of new sampling undertaken as part of the ISMP. Historical data from other consultants, stewardship groups, and municipal projects is incorporated where available.

Supporting data is provided as hard-copy or digital appendices.

Mackay Mosquito Watersheds ISMP Compendiums

The following compendiums and their authors support the Mackay Mosquito Watersheds ISMP:

1. Watershed Overviews - KWL
2. Instream Species and Water Quality – Raincoast Applied Ecology
3. Riparian Forest & Terrestrial Species – Raincoast Applied Ecology
4. Drainage Asset Inventory - KWL
5. Hydrologic and Hydraulic Modelling - KWL
6. Drainage Assessment - KWL
7. Land-Use Analysis - KWL
8. Municipal Policy and Operations - KWL
9. Watershed Values and Objectives – CNV and DNV
10. Mitigation Measures & Alternatives – KWL, CNV and DNV
11. Mackay/Mosquito Action Plan – KWL, CNV and DNV

Figure and table identification numbering include the first digit related to compendium number and the second digit related to the figure number within the compendium. e.g. Figure C3-1 is the first figure within Compendium 3.

‘Blue boxes’ of explanative information are provided in each compendium where background information and context are helpful.

1. Introduction

The purpose of the ecological assessment was to determine stream health based on an assessment of water quality, benthic invertebrates, riparian areas, fish habitat, and other factors. The health of the stream is correlated to the level of development in the watershed and is used as a baseline to examine future change related to urban development, and improvements based on improved stormwater and riparian management.

1.1 Metro Vancouver's Monitoring and Adaptive Management

Condition 7 of the BC Minister of Environment's approval of Metro Vancouver's 2011 Integrated Liquid Waste Resource Management Plan (ILWRMP) requires that all municipalities, with coordination from Metro Vancouver, monitor stormwater to assess and report on the effectiveness of ISMP implementation. To fulfill this provincial requirement, Metro Vancouver and its member municipalities have developed a *Monitoring and Adaptive Management Framework for Stormwater (MAMF) (Metro Vancouver, 2014)*. The MAMF takes a weight of evidence approach, using several types of monitoring and indicators to develop an overall assessment of watershed conditions. Through repeated sampling, watershed health and the response to specific watershed protection measures and management actions can be tracked over time.

The MAMF provides direction on the general types of monitoring to be utilized for higher gradient, lower gradient, and piped systems, the methods and parameters to be used for monitoring, and the reporting required.

Table C2-1: Standard MAMF Monitoring Program Elements Based on Stream Type

Stream Type	Water Quality	Hydrometric	Benthic Invertebrate
Lower Gradient	Yes	Yes (natural channels only)	No
Higher Gradient	Yes	Yes	Yes
Piped Systems	Yes	No	No

Based on the MAMF, all the creeks within the Mackay Mosquito study area are classified as higher gradient streams (average channel slope >1%). Therefore, monitoring and performance indicators include water quality, flows and benthic invertebrates.

Monitoring Framework for Higher Gradient Streams

The MAMF recommends a monitoring framework and core parameters for higher gradient streams, grouped into three categories:

- Water quality monitoring indicators – selected general water quality parameters, nutrient, bacteriological parameters, and metals;
- Flow monitoring Indicators – seven flow-related metrics characterizing watershed hydrology; and
- Benthic invertebrates biomonitoring indicators – benthic index of biotic integrity (B-IBI) scores and mean taxa richness.

Table C2-2 summarizes the recommended parameters for monitoring implementation of the ISMP, as well supplemental performance indicators that may provide a more comprehensive assessment of watershed health and ISMP implementation over time depending on watershed values and issues.

The table also indicates the priority of each parameter for measurement (primary or secondary), whether baseline data has or is being collected, and sets short- and long-term targets for trends for different parameters.

Table C2-2: Summary of ISMP Performance Monitoring Indicators

Performance Indicator	Indicator Type	Short-term Trend/Target	Long-term Target
Water Quality Performance Indicators			
Dissolved Oxygen	Primary	Increasing	Good or Satisfactory as per MAMF classification levels
pH	Secondary	Stable	
Water Temperature	Primary	Decreasing in dry season	
Conductivity	Secondary	Decreasing	
Turbidity	Primary	Decreasing in wet season	
Nutrients (Nitrate as N)	Primary	Decreasing	
Bacteriological Parameters (*E. coli* and fecal coliform)	Primary	Decreasing, esp. in wet season	
Metals (Fe, Cd, Cu, Pb, Zn)	Primary	Decreasing, esp. in wet season	
Flow Monitoring Performance Indicators			
T_{Qmean}	Primary	Stable or increasing	Same as short-term
Low Pulse Count		Stable or decreasing	
Low Pulse Duration		Stable or increasing	
Summer Baseflow (L/s)		Stable	
Winter Baseflow (L/s)		Stable or increasing	
High Pulse Count		Stable or decreasing	
High Pulse Duration (days)		Stable of increasing	
Benthic Invertebrate Biomonitoring Performance Indicators			
B-IBI Scores	Primary	Stable or increasing	Category Fair or higher as per MAMF
Mean Taxa Richness	Primary	Stable or increasing	

2. Water Quality

The term "water quality" refers to the chemical, physical, and biological conditions of water and the degree to which it is impaired or degraded by human and non-human factors. Water quality in streams and rivers is vital to the protection of ecosystem function and aquatic life, such as salmon and other fish, as well as human uses for drinking water, recreation, health, and aesthetics, and cultural values.

Comparisons to guidelines such as the BC Water Quality Guidelines (BCWQGs) and the Canadian Water Quality Guidelines for the Protection of Aquatic Life (CWQGs) can help to assess whether current stormwater management practices are adequately protecting water quality. In addition, the MAMF recommends monitoring parameters for different stream and river types and identifies three classes to guide adaptive management: good (green), satisfactory (yellow), and needs attention (red). Mean values collected during two sampling periods are recommended for assessing streams and rivers: dry season (summer low flow) and wet season (winter high flow). Only low flow summer sampling was undertaken for Mackay and Mosquito creeks at this time. More details on MAMF, selection of parameters, sampling sites, and methods are available in Metro Vancouver's September 2014 report[1]. The District of North Vancouver is currently undertaking a District-wide sampling program following the MAMF protocol.

Three methods were used to assess water quality in the Mackay and Mosquito watersheds:

1. Review and analysis of existing water quality data collected by or for CNV, DNV, Northshore Streamkeepers (NSSK), and others (see datasets described below);
2. Survey of water temperature, pH, conductivity, dissolved oxygen, oxygen reduction potential, and turbidity throughout the watersheds in late August 2014 using a water quality probe; and
3. Sampling of nutrients, metals, and microbiological indicators using the MAMF protocol at four sites in September 2014.

More detailed methods are described in the following sections for new data collection. Methods for older datasets are described in background documents and sampling reports.

2.1 Existing Information

Existing information reviewed included:

- CNV's fall sampling of general parameters, nutrients, metals, and fecal coliforms in Mackay, Mosquito, Wagg, and Mission[2] creeks as part of its environmental monitoring program in 2006, 2008, 2010, and 2012;
- Limited sampling of water quality parameters in September 2003 as part of DNV's benthic invertebrate assessment project;
- Julia Brydon's master's thesis titled "The effectiveness of stormwater ponds in contaminant removal from urban stormwater runoff in the lower Fraser Valley", 2004, which examined metals and nutrients in water and sediment in multiple sites including the William Griffin and Westview biofiltration or detention ponds;
- Comparative sampling of Mackay and Mosquito creeks as part of DNV's 2012 ecology and geomorphology assessment of Hastings Creek;

[1] Metro Vancouver. Monitoring and Adaptive Management Framework for Stormwater. September 2014. 112 pp.

[2] Mission Creek is a confusing watershed because it used t

- DNV fecal coliform and bacteria source tracking study in 2007 for Deep Cove (Ng, 2008 draft report);
- Sampling by NSSK in 2000 (multiple North Shore streams) and more comprehensive
- Assessment of water quality in Mackay Creek from 2007–2008 (monthly sampling at four sites; reporting in 2009).



Photo C2-1: Stormwater generated from road runoff is an important contributor of contaminants (December 9, 2014 storm).

2.2 Summer 2014 Water Quality Survey

Water temperature, specific conductivity, DO, pH, oxygen reduction potential (ORP), and turbidity were measured in the field throughout the watersheds during low flow conditions on August 28 and 29, 2014 (23 sites on Mackay Creek; 27 sites on Mosquito Creek; 50 sites in total). A YSI 6820 multi-parameter probe was used for measurement. Sampling locations are shown in Figure C2-1. While one-time water quality sampling provides a limited snapshot of water quality, it is a useful way to quickly identify issues of potential concern on a watershed scale that should be managed as part of the ISMP.

2.3 Monitoring and Adaptive Management Framework (MAMF) Sampling

Under the MAMF, the recommended water quality monitoring parameters for higher gradient streams such as the Mosquito and Mackay creeks include temperature, conductivity, turbidity, and pH which are measured in the field, as well as lab-based measures including nitrate, microbiological indicators (E. coli and fecal coliforms), and five total metals (cadmium, copper, iron, lead, zinc).

Water samples for lab analysis were collected at eight sites (4 primary & 4 secondary) in the study streams on September 19, 2014 (see Figure C2-1). A core group of four sites (Mackay, Mosquito, Wagg, and Mission creeks) were sampled four additional times (September 29, October 3, 9, and 10, 2014) to meet the MAMF sampling requirements of five samples in 30 days (to capture variability and calculate a mean). These sites were selected to capture the broadest range of watershed influences on the study area streams as well as to be consistent with previous sampling programs.

2.4 Results

Summer 2014 Water Quality Survey

The August 2014 survey showed that water quality in Mackay and Mosquito creeks is typical of moderately urbanized streams in Metro Vancouver with good riparian forest cover: summer water temperature were generally below 20°C but higher in the lower reaches, specific conductivity was elevated above 100 µS/cm, pH values were slightly higher than neutral (overall mean of 7.48), turbidity was low (mean: <3 NTU), and dissolved oxygen around 10 mg/L. No hotspots or other areas of specific concern were identified during the survey. For example, drainage from the old landfill on the east side of Mackay Creek below Highway 1 was not identified in pH, conductivity, or dissolved oxygen measurements. The samples in upper Wagg Creek tributaries (north of Highway 1) had higher specific conductivity and turbidity values than other areas, which is not unexpected based on their level of urbanization.

Table C2-3 summarizes the minimum, maximum, and mean values of each parameter encountered, and the full dataset can be found in Appendix C2-A Table 1. Minimum and maximum values show the range of key water quality parameters in the watersheds, and mean values summarize the typical or average value.

Table C2-3: Values for General Water Quality Parameters (August 2014)

Parameter	Units	Parameter Values		
		Minimum	Maximum	Mean
Mackay Creek				
Water Temperature	^{0}C	13.0	19.9	16.5
Dissolved Oxygen	mg/L	6.2	10.2	9.5
Specific Conductivity	µS/cm	32	308	126
pH	pH units	7.22	7.80	7.49
Turbidity	NTU	0.0	8.7	0.6
Oxygen Reduction Potential	-	33.9	136.1	104.7
Mosquito Creek				
Water Temperature	^{0}C	14.3	18.3	16.8
Dissolved Oxygen	mg/L	4.6	10.1	9.5
Specific Conductivity	µS/cm	29	263	138
pH	pH units	6.61	8.12	7.47
Turbidity	NTU	0.0	86.1	5.3
Oxygen Reduction Potential	-	99.1	194.8	155.4

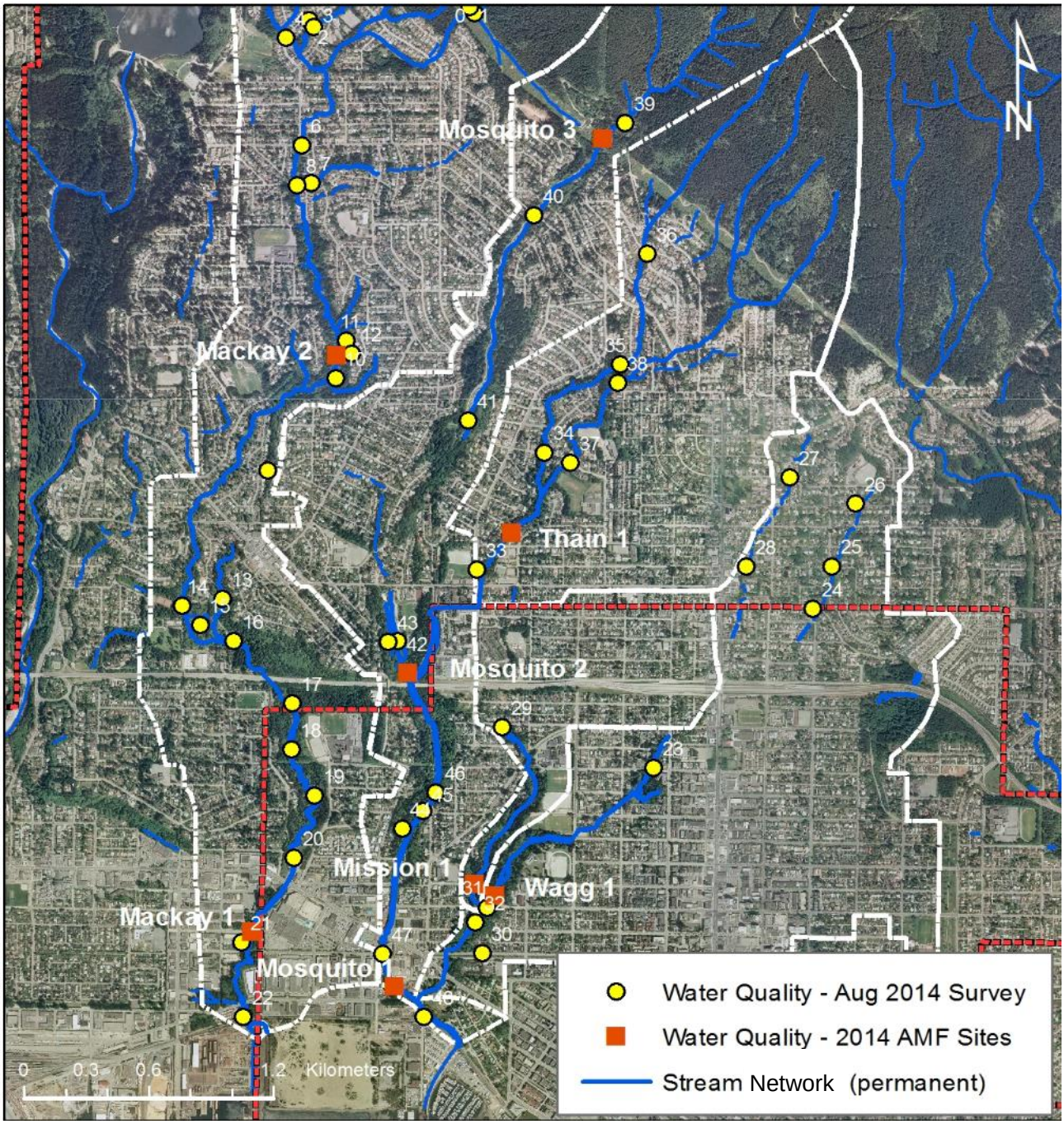


Figure C2-1: Location of Water Quality Sampling Sites in the Mackay and Mosquito Watersheds.

Monitoring and Adaptive Management Framework (MAMF) Sampling

Results from the MAMF sampling from summer 2014 are summarized in Table C2-4. The full results are presented in Appendix C2-A Table 1 including individual sample values.

The MAMF sampling showed that that majority of sites had mean values in the good or satisfactory range. Parameters that had one or more mean values in the yellow or red classes are discussed below.

Dissolved Oxygen: Dissolved oxygen (measured as mg/L) is temperature dependent and is typically a concern during summer low flow conditions when water temperature is highest: warm water is able to hold less oxygen than cool water. Mean dissolved oxygen was within the satisfactory category (6.5 to <11 mg/L) at all four primary sites during summer 2014. The Canadian Water Quality Guidelines for the Protection of Aquatic Life[3] state the lowest acceptable dissolved oxygen concentration is 9.5 mg/L for early life stages of fish, and 6.5 mg/L for other life stages. Dissolved oxygen values around 10 mg/L are considered normal for small streams in Metro Vancouver and are unlikely to impair fish populations.

Turbidity: Turbidity is the cloudiness of water caused by the suspension of fine particles. Fine sediment from construction sites, eroding banks, and other exposed soils increases turbidity. Elevated turbidity can reduce river productivity by interfering with photosynthesis, smother benthic organisms, and disrupt fish feeding. Mean turbidity was elevated above the MAMF "needs attention" category at the Mosquito Creek site in August 2014. This was caused by one measurement (129.6 NTU on Sept 29, 2014) that was likely associated with poor construction-phase sediment management. The mean of the remaining four measurements from Mosquito Creek was 2.3 NTU.

Table C2-4: Mean Water Quality Values from Summer 2014 Compared to MAMF Classes

Parameter	Mackay Creek	Mosquito Creek	Mission Creek	Wagg Creek
Dissolved Oxygen (mg/L)	10.5	10.3	10.3	10.2
pH (rel. Units)	7.2	7.1	7.1	7.3
Water Temp (summer) ^{o}C	12.1	12.3	12.4	13.5
Water Temp (winter) ^{o}C	3	28	4	4
Conductivity (uS/cm)	138	110	126	175
Turbidity (NTU)	3.3	27.7	4.4	4.1
Nitrate (as Nitrogen, mg/L)	194	101	270	2085
E. Coli (CFU/100ml	211	92	260	1344
Fecal coliforms (CFU/100ml)	0.019	0.026	0.021	0.021
Total Cadmium (ug/L)	1.2	6.6	2.2	3.1
Total Copper (ug/L)	348	159	244	175
Total Iron (ug/L)	0.5	0.5	0.9	0.5
Total Lead (ug/L)	5.1	5.7	8.1	8.7
(Green indicates "good", yellow "satisfactory", and red "needs attention")				

[3] Canadian Council of Ministers of the Environment. 1999. Canadian water quality guidelines for the protection of aquatic life: Dissolved oxygen (freshwater). In: Canadian environmental quality guidelines, 1999. Canadian Council of Ministers of the Environment, Winnipeg.

Conductivity: Conductivity[4] measures the presence of ions in water and elevated conductivity is often associated with the negative effects of urban runoff. For example, North Creek in the Lower Seymour Conservation Reserve has low flow conductivity of <20 uS/cm while heavily urbanized streams such as Still and Como creeks are >200 uS/cm. All four streams have mean conductivity >100 uS/cm, but <200 uS/cm which is considered satisfactory under MAMF. Wagg Creek had the highest mean value (175 uS/cm) which is typical of heavily urbanized streams in Metro Vancouver.

Fecal coliform and E. coli Bacteria: *E. coli* and fecal coliforms are bacteria which are used as indicators of pathogenic bacteria, viruses, and protozoa in water systems. Both microbiological indicators have been elevated above BCWQ guidelines in Wagg (2008, 2010, 2012) and Mackay (2008) creeks in the past (see summary in Echo Blue Environmental, 2012). The Northshore Streamkeepers (2009) found that E. coli levels were within the "satisfactory" (yellow) category at 3 of 4 sampling sites during the summer 2008, and 2 of 4 during the winter 2007 and 2008.

In summer 2014, mean values (geometric mean) of *E. coli* and fecal coliforms were in the "needs attention" (red) category in Wagg Creek and in the "satisfactory" (yellow) for *E. coli* in Mackay, Mosquito, Mission creeks. In addition, fecal coliforms were in the "satisfactory" (yellow) in Mackay and Mission creeks. There are likely several sources of contamination but the chronic elevated concentrations in Wagg Creek suggest it is from cross-connections between the sanitary and stormwater systems.

Total Metals: Mean concentrations of selected total metals (cadmium, iron, copper, lead, zinc) were compared to MAMF guidelines; all were in the green category except for total copper in Mosquito and Wagg creeks ("satisfactory" (yellow category)) and total zinc in Mission and Wagg creeks which were in the "satisfactory" (yellow category). None of the mean values were near the threshold for the MAMF "needs attention: (red) category. It is also noteworthy that mean lead concentrations in Mission Creek were in the MAMF "good" (green) category despite the elevated lead in streambed sediment (see Section 2).

2007–2008 Mackay Creek Water Quality Assessment

The Northshore Streamkeeprs led a collaborative project with North Shore Fish and Game Club, DNV, DFO, and others to monitor water quality in Mackay Creek from November 2007 to September 2008. Four sites were monitored on a monthly basis: (1) Mackay Creek Park; (2) Heywood Park; (3) Upper Mackay Creek Park; and (4) Sarita Park. Sampling included probe-based measurements of water temperature, pH, dissolved oxygen, conductivity, and turbidity, and lab-based measurement of total metals, dissolved metals, nutrients, and microbiological parameters. Fecal coliforms were not sampled (total coliforms were sampled instead). The summary report was published in 2009 (Northshore Streamkeepers, 2009).

The mean seasonal values from the 2007/08 sampling program were compared to MAMF criteria to identify specific water quality concerns similar to the summer 2014 MAMF assessment. While the NSSK 2007/08 sampling does not meet the MAMF protocol of 5 samples during 30 days in low flow and high flow, the samples were divided into two seasonal groups: winter (Nov to Apr; 6 samples), and summer (May to Sept; 5 samples) to calculate seasonal means. The monthly sampling measures the water quality variability which is consistent with the goals of MAMF sampling.

[4] Conductivity is different from specific conductivity; specific conductivity is temperature corrected for more consistent comparison.

Table C2-5 provides the seasonal means for the 13 MAMF parameters for the summer and winter sampling periods. MAMF classes (good, satisfactory, and needs attention) are shown by colour coding.

Table C2-5: Mean Summer and Winter Water Quality Values at Four Mackay Creek Sites (Nov 2007 to Sept 2008) (From NSSK, 2009)

	Summer 2008				Winter 2007/2008			
	Mackay Site 1	Mackay Site 2	Mackay Site 3	Mackay Site 4	Mackay Site 1	Mackay Site 2	Mackay Site 3	Mackay Site 4
Dissolved Oxygen (mg/L)	9.9	10.1	9.7	10.6	11.8	12.2	11.8	12.2
pH (rel. units)	6.8	7	7.1	7.1	7.2	7.1	7.2	6.7
Temperature (summer) ^{o}C	13.1	13.2	12.6	10.6	-	-	-	-
Temperature (winter) ^{o}C	-	-	-	-	6.9	6.8	6.5	5.5
Conductivity (uS/cm)	73	77	88	26	118	117	112	31
Turbidity (NTU)	28.7	28.4	10.1	0.7	2.5	1.5	1.1	0.4
Nitrate (mg/L)	0.36	0.33	0.17	0.08	0.49	0.48	0.24	0.06
E. Coli (CFU/100ml	160	86	236	6	67	101	245	2
Fecal coliforms (CFU/100ml)	-	-	-	-	-	-	-	-
Total Cadmium (ug/L)	0.08	0.06	0.03	0.02	0.03	0.02	0.02	0.02
Total Copper (ug/L)	16	8	4	1	2	1	1	1
Total Iron (ug/L)	3661	3353	816	34	341	172	112	30
Total Lead (ug/L)	3	3	1	1	1	1	1	1
Total Zinc (ug/L)	15	12	7	5	7	5	6	5

(Green indicates "good", yellow "satisfactory", and red "needs attention")

Northshore Streamkeepers Sampling Sites:
Mackay 1: Mackay Creek Park; downstream of Marine Drive; Mackay 2: Heywood Park; upstream of Marine Drive; Mackay 3: Upper Mackay Creek Park; Mackay 4: Headwater stream in Sarita Park

The 2007-08 results were noteworthy because of the effect of seasonality on the MAMF assessment. Only water temperature, conductivity, and E. coli levels were in the "satisfactory" (yellow) category in winter 2007/08, while several additional parameters were in the "satisfactory" or "needs attention" (red) categories during summer 2007 including dissolved oxygen, turbidity, and several metals. Winter dilution appears to reduce the concentration of several contaminants.

Similar to the summer 2014 results, dissolved oxygen was slightly above the "satisfactory" threshold in summer 2008 but the overall mean was 10.1 mg/L which is considered normal for small streams. Mean turbidity was in the "needs attention" category at two sites on Mackay Creek in summer 2008; total copper was also in the red category at one site. The elevated turbidity occurred on June 9, 2008 which, like 2014 Mosquito Creek results, was caused by a construction-related sediment source. The elevated sediment load also increased total suspended solids (data not shown), as well as concentrations of some total metals. Sediment is a source of total metals and it is not unusual that total copper was within the "needs attention" category and total cadmium in the "satisfactory" category. Total iron was also elevated but was below the upper limit of the "good category". Mean E. coli levels were within the "satisfactory" (yellow) category at 3 of 4 sampling sites during the summer, and 2 of 4 during the winter.

The 2009 NSSK report stated that nutrient levels were elevated during the summer of 2008 (0.012 mg/L ammonia; 0.62 mg/L nitrate, and 0.006 mg/l orthophosphate). However, we consider these values to typical for small streams in Metro Vancouver and are not normally associated with excessive algae growth in streams with good riparian forest cover.

CNV's Biannual Environmental Monitoring

CNV has sampled general water quality, nutrients, total metals, and fecal coliforms in Mackay, Mosquito, Wagg, and Mission creeks in 2006, 2008, 2010, and 2012 as part of its environmental monitoring program. Sampling was generally undertaken during low flows in September and October and consisted of single samples from each stream (2 sites on Wagg Creek). Five samples in 30 days were collected for fecal coliforms. Sampling locations were consistent with the benthic monitoring sites described in Section 3. More information on sites and methods is available in Echo Blue Environmental (2013) or Raincoast Applied Ecology (2009, 2011).

Key results included:

- General parameters including water temperature, specific conductivity, dissolved oxygen, and pH were considered normal for moderately urbanized streams in 2010 and 2012. In 2010 (the most recent year when general parameters were included), mean values for all sites combined were: water temperature 12.4ºC, specific conductivity 170 uS/cm, dissolved oxygen 10.4 mg/L, and pH 7.5. These values were similar to the NSSK 2007–2008 and the 2014 sampling programs.
- Nutrient concentrations in CNV streams were below provincial guidelines and similar to or lower than other urban streams in Metro Vancouver: mean nitrate was 0.51 mg/L and mean dissolved orthophosphate was 0.014 mg/L (all sites combined). Dissolved orthophosphate in September 2012 in Wagg Creek was 0.039 mg/L which was higher than other sites.
- In 2012, concentrations of total copper, zinc, and cadmium were slightly above BCWQG in both upper and lower Wagg Creek (also found in 2010 for copper and zinc); total aluminum was also above guidelines in upper Wagg Creek (not found in 2008 or 2010) and total iron was above guidelines in lower Wagg Creek (not found in 2010). Total cadmium was also above guidelines in Mission Creek and total iron was above guidelines in MacKay Creek (not found in 2008 or 2010).
- Mean fecal coliform concentrations (geometric mean of 5 samples in 30 days) were consistently above the BCWQ guideline (<200/ MPN/100 ml for primary contact recreation) in Wagg Creek and periodically above the guideline in Mackay Creek. During the most recent CNV sampling in fall 2012, fecal coliform concentrations were elevated in Wagg Creek at the both the upper (327 MPN/100 ml) and lower (262 MPN/100 ml) sampling sites but below the guideline in all other creeks. The lower Wagg Creek sampling site also exceeded the guidelines in 2008 (369 MPN/100 ml) and 2010 (524 MPN/100 ml) and the upper Wagg Creek site in 2008 (210 MPN/100 ml). Despite being higher than the BCWQ guideline, these concentrations are not considered unusual in urban streams in Metro Vancouver.

Other Water Quality Sampling

Hastings Creek Watershed Assessment (2012): Comparative sampling of Mackay and Mosquito creeks undertaken as part of DNV's Hastings Creek watershed assessment consisted of probe-based sampling on May 14, 2012 (see Page et al., 2013). It found the following mean values (2 sites per stream): water temperature in Mackay Creek 9.4°C and Mosquito Creek 6.3°C; specific conductivity in Mackay Creek 50 uS/cm and Mosquito Creek 12 uS/cm; dissolved oxygen in Mackay Creek 13.5 mg/L and Mosquito Creek 14.0 mg/L, pH in Mackay Creek 7.0 and Mosquito Creek 6.8, and turbidity in Mackay Creek 1.1 NTU and Mosquito Creek 2.4 NTU. All values are considered normal. See Appendix C2-A.

2003 DNV Benthic Invertebrate Assessment: Water quality was measured on September 29, 2003 at two sites in Mackay, Mosquito, and Wagg creeks as part of a benthic invertebrate sampling program (see Page, 2003 for more detail on sites). The results were (mean of two samples per stream):

- Water temperature was 12.9ºC in Wagg Creek, 13.2ºC in Mosquito Creek, and 13.0ºC in Mackay Creek.
- Dissolved oxygen was 10.3 mg/L in Wagg Creek, 10.1 mg/L in Mosquito Creek, and 10.1 mg/L in Mackay Creek.
- Specific conductivity was 168 uS/cm in Wagg Creek, 74 uS/cm in Mosquito Creek, and 117 uS/cm in Mackay Creek.
- pH was 7.1 in Wagg Creek, 7.3 in Mosquito Creek, and 7.3 in Mackay Creek.

DNV Fecal Coliform Assessment (2007): DNV sampled fecal coliforms at one site in Mackay Creek in Handsworth Avenue in summer 2007 as part of an assessment of fecal coliform contamination in Deep Cove and other North Vancouver sites (Ng, 2008). Eight samples were collected between July 1 and August 31, 2007. Mackay Creek had consistently high fecal coliform counts. The report described: "while the average fecal count obtained on July 24 was 1,227 MPN/100mLs, one water sample in that series showed a high count of 2,400 MPN/100mLs. Overall, the highest average fecal count, at 2,667 MPN/100mLs, occurred on August 21 in which one sample showed a count of 5,400 MPN/100mLs while the other two samples each showed a count of 1,300 MPN/100mLs."

Bacterial source tracking was undertaken as part of this study to determine likely sources based on genetic identifiers. They found: "all samples collected at station MACK-03 [Mackay 3] tested positive for human and ruminant animal sources. Fecal counts corresponding to these results were all high, with counts ranging from 940-1700 MPN/100mLs on August 6 and from 330-790 MPN/100mLs on August 13. In addition, there was a presence of fecal contamination from dogs in samples collected on August 13, and a questionable presence on August 13."

Julia Brydon Thesis Research: Julia Brydon investigated the quality of the stormwater quality entering five ponds in urban areas of Metro Vancouver and their effectiveness of trace metal and phosphorus removal in these ponds during the wet and dry seasons. Two sites were located in North Vancouver: Griffin Park Biofiltration Pond; and the Westview Interchange Detention Pond. The results are complex, and the reader should review her full thesis for method and results. The overall finding was the contaminant concentrations entering treatment ponds was often elevated above CCME and/or BCWQ guidelines, and that the range of total metal detention was between -15 to +72% for copper, lead, and zinc, while iron and manganese retention was generally poor.

Streamkeepers 2000 Water Quality Data. We compared a historical water quality dataset provided by Northshore Streamkeepers from 2000 from multiple sites in the study watersheds. The data is provided in Appendix C2-A with comparisons to MAMF classes. Fecal coliforms were above guidelines in Mackay, Mosquito, and Wagg creeks. Conductivity was also elevated into the "satisfactory" category in Thain and Mackay creeks.

2.5 Data & Sources

Water quality data collected in 2014 can be found in Appendices C2-1 through C2-5..

Brydon, J. 2004. The Effectiveness of stormwater ponds in contaminant removal from urban stormwater runoff in the Lower Fraser Valley, BC. M.Sc. thesis, Institute for Resources, Environment, and Sustainability, University of British Columbia, Vancouver, BC. 223 pp.

Echo Blue Environmental. 2013. 2012 Environmental Monitoring in City of North Vancouver Streams. Unpublished memo prepared for City of North Vancouver. 72 pp.

Metro Vancouver. Monitoring and Adaptive Management Framework for Stormwater. September 2014. 112 pp.

Ng, B. 2008. Deep Cove fecal coliform study. Unpublished report for DNV (two sections).

Northshore Streamkeepers. 2009. Water quality and watershed health of Mackay Creek 2007-2009 report. Unpublished report prepared by Northshore Streamkeepers. 63 pp. Available here.

Page, N. 2003 North Vancouver benthic sampling program. Unpublished report prepared for District of North Vancouver by Raincoast Applied Ecology. 7 pages + appendices.

Page, N., P. Lilley, D. Matsubara and N. Tokgoz. 2013. Hastings Creek Watershed: Ecology and Hydrotechnical Assessment. Unpublished report for District of North Vancouver prepared by Raincoast Applied Ecology and Kerr Wood Leidal Associates. 111 pp + appendices.

Raincoast Applied Ecology. 2009. 2008 Environmental Monitoring in City of North Vancouver Streams. Unpublished technical memorandum to the City of North Vancouver. 7 pp. + appendices.

Raincoast Applied Ecology. 2011. 2010 Environmental Monitoring in City of North Vancouver Streams. Unpublished technical memorandum to the City of North Vancouver. 10 pp. + appendices.

3. Sediment Quality

Stream sediments accumulate metals and other contaminants from a variety of sources in urban watersheds and provide a complimentary assessment of environmental chemistry when combined with water quality. They are also useful for long-term monitoring of stream condition because they are much less temporally variable than water quality measurements. Concentrations of total metals in stream sediments can be compared to the Canadian Environmental Quality Guidelines (CEQGs)) to determine potential effects on freshwater aquatic life. CEQGs are divided into a low value (*threshold effect level* (TEL)) which represents the concentration below which adverse biological effects are expected to occur rarely, and an upper value, referred to as the *probable effect level* (PEL), which is defined as the level above which adverse effects are expected to occur frequently.

3.1 Existing Information

Existing information reviewed included:

- Julia Brydon's 2004 master's thesis titled "The effectiveness of stormwater ponds in contaminant removal from urban stormwater runoff in the lower Fraser valley", 2004 which examined metals and nutrients in water and sediment in the William Griffin and Westview biofiltration ponds;
- Oh Iwata's 2003 master's thesis titled: Imperviousness and Trace Metals in Stream Sediments: Urbanisation in the Lower Fraser Valley between 1973-2006. It included several sites from the Mosquito watershed;
- CNV's sampling of Mackay, Mosquito, Wagg, and Mission creeks in 2006, 2008, 2010, and 2012 included an analysis of total metals in streambed sediments;
- Metro Vancouver's benthic invertebrate monitoring program included Wagg and Mosquito creeks and sediment samples were collected from benthic sampling sites; and
- Sediment sampling was undertaken as part of improvements to the Wagg Creek Pond in 2006.

3.2 2014 Sediment Sampling

A single composite sediment sample was collected at the eight benthic sampling locations on September 18, 2014 (see Figure C2-2). Each sample was a composite of surface and shallow sub-surface fine sediment collected from eight to ten sites from within the active stream channel within a ten-metre long stream section. Samples were analyzed for a suite of total metals to BC Contaminated Sites Regulation (CSR) standards.

The discussion below focuses on nine total metals that are often elevated in urban stream sediments and linked to degradation of stream health: aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, and zinc.

3.3 Results

Data on total metals was compiled from 129 sediment samples from streams in Metro Vancouver including 50 from streams in the District of North Vancouver and the City of North Vancouver. This includes the eight new samples collected in September 2014 from study area streams, as well as two samples collected by CNV from Wagg Creek Pond in August 2014. All samples have been collected in the past 10 years. Total metals have been analyzed in sediment samples from the study streams including Mosquito Creek (10 samples), Mackay Creek (8), Wagg Creek (15), Mission Creek (7), and Thain Creek (1).

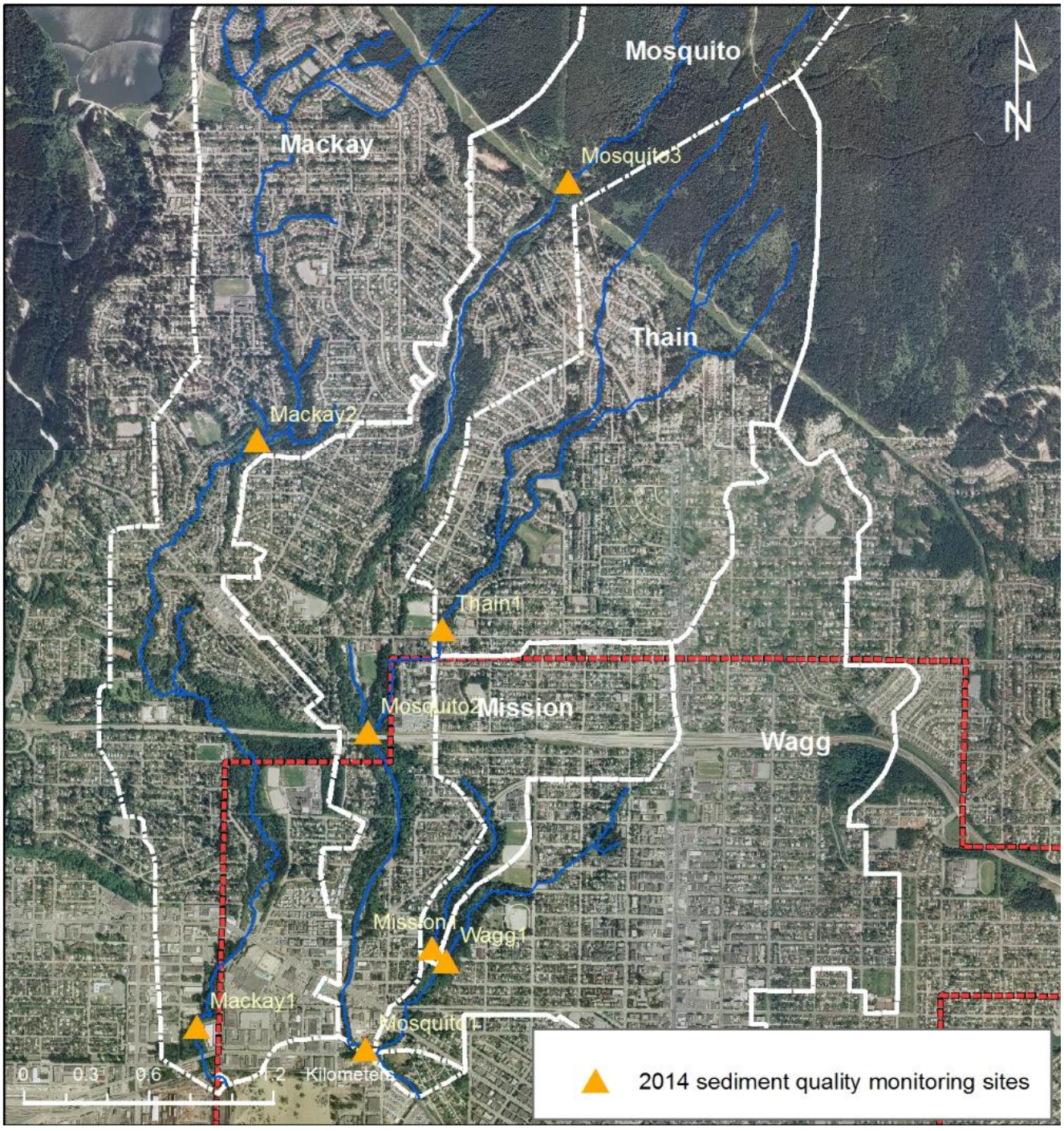


Figure C2-2: Location of Streambed Sediment Sampling Sites in Mackay and Mosquito Watersheds.



Photo C2-2: Wagg Creek Pond is effective at capturing fine sediment including sediment-bound contaminants. (CNV Clean-out, August 2014)

Total metal concentrations in streambed sediments from the Mackay and Mosquito creek watersheds were typical of urban streams from Metro Vancouver. All samples from Mackay, Mosquito, and Thain creeks had concentrations of total metals below CESQ guidelines, while Mission and Wagg creeks had elevated concentrations of some metals. The highest concentrations of total metals were found in the Wagg Creek sediment pond which traps sediment from the most urbanized part of the Mosquito Creek watershed (Appendix C2-B Table 1). Nineteen of the 41 samples from the study area streams had at least one metal elevated above the lower TEL CESQ threshold. One sample from the Wagg Creek Pond had total lead and zinc concentrations above the higher PEL CESQ threshold. Results are presented in Appendix C2-B and summarized by stream below:

- Mackay Creek: None of the eight samples from Mackay Creek had concentrations of total metals above CESQ guidelines.
- Mission Creek: Elevated concentrations of lead (seven of seven samples), copper (one of seven), and zinc (one of seven) were found in Mission Creek. Lead appears to be a novel issue in Mission Creek compared to other North Shore streams as the only other samples with lead concentrations above CESQ guidelines were found in the Wagg Creek Pond. More work is needed to look for potential natural or anthropogenic sources of lead in Mission Creek.
- Mosquito Creek: Sediment from Mosquito Creek very rarely had metal concentrations above CESQ guidelines: one of ten samples had elevated arsenic (7.4 mg/L compared to 5.9 mg/L TEL for CESQ guidelines).
- Thain Creek: All metals from the single sediment sample from Thain Creek collected in September 2014 were below CESQ guidelines.

- Wagg Creek: Not unexpectedly based on its level of watershed urbanization, most sediment samples collected from Wagg Creek in the past 10 years had a least one total metal concentrations above CESQ guidelines: four of 15 samples were high in total arsenic, two of 13 were high in total cadmium, three of 15 were high in total chromium, twelve of 15 were high in total chromium, five of 15 was high in total lead, and four of 15 were high in total zinc. One sample from the Wagg Creek Pond had total lead and zinc concentrations above the higher PEL CESQ threshold which indicates that adverse effects on biota are expected to occur frequently.

Both Brydon 2004) and Iwata (2003) provide more detailed information on sediment quality in two small catchments in the Mosquito watershed (Griffin Park and Westview Interchange) including links to land use and road networks. Brydon also examined contaminant removal effectiveness of biofiltration and detention pond. In general, both found elevated concentrations of total metals that could affect aquatic life.

3.4 Data & Sources

Sediment quality data and comparisons to CESQ guidelines can be found in Appendix C2-B.

Iwata, Oh. 2003. Imperviousness and Trace Metals in Stream Sediments: Urbanisation in the Lower Fraser Valley between 1973-2006. M.Sc. thesis, Institute for Resources, Environment, and Sustainability, University of British Columbia, Vancouver, BC. xii + 172 pp.

Brydon, J. 2004. The Effectiveness of stormwater ponds in contaminant removal from urban stormwater runoff in the Lower Fraser Valley, BC. M.Sc. thesis, Institute for Resources, Environment, and Sustainability, University of British Columbia, Vancouver, BC. 223 pp.

Canadian Council of Ministers of the Environment. 1999. Canadian sediment quality guidelines for the protection of aquatic life: In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg. Available here.

4. Benthic Invertebrate Community

Benthic invertebrates are insects and other organisms such as worms, flies, midges, snails, and amphipods that are found on and within streambed substrates. Many are larval stages of insects such as caddisflies and stoneflies. Benthic invertebrates are useful indicators of stream health as they are sensitive to changes to habitat and water quality. They can also be used to monitor changes or trends in condition over time. B-IBI (Benthic Index of Biotic Integrity) is a system of summarizing benthic invertebrate data by calculating several important metrics of community structure and composition. Metrics are scored 1, 3, or 5 and the 10-metric system provides an overall score of 10 (degraded) to 50 (pristine) condition. A useful summary of a benthic monitoring methods in Puget Sound using the same B-IBI data analysis methods is available here.

4.1 Existing Information

Benthic invertebrates have been collected from Mackay and Mosquito creeks since 1999. This includes:

- District of North Vancouver sampling in 2003 in 11 streams and rivers including Mackay, Wagg, and Mosquito creeks;
- Metro Vancouver (GVRD) sampling on Wagg and Mosquito (at Highway 1) creeks in 1999, 2005, and 2006;
- A follow-up study to the DNV work was undertaken in 2004 using Environment Canada's CABIN assessment method in 2004 (see Page and Sylvestre, 2006);
- City of North Vancouver sampling on lower Mackay, lower Mosquito, Mission, and Wagg creeks in 2006, 2008, 2010, and 2012;
- Sampling undertaken by Markus Eymann on Mackay and Mosquito creeks in 2002; and
- Sampling in September 2007 and February 2008 in Mackay Creek by NSSK using the Streamkeepers Module 4 (Stream Invertebrate Survey).

4.2 2014 Benthic Invertebrate Sampling

Benthic invertebrate samples were collected at eight sites in the study watersheds in September 2014 (see Figure C2-3). These included five previously established sampling sites in lower Mackay, lower Mosquito, middle Mosquito, Wagg, and Mission creeks, as well as three new sites on upper Mosquito, upper Mackay, and Thain creeks.

Sampling methods followed the field sampling protocol described in the GVRD Benthic Macroinvertebrate B-IBI Guide (2003). Composite samples were collected from four riffles within a 500 m long sampling reach, and each sample consisted of three subsamples collected with a 500-micron Surber sampler. Large, loose substrates were transferred to a bucket and the underlying sediment was then disturbed for 2 minutes to a depth of 10 cm using a trowel. All organic detritus and inorganic sediment were transferred to plastic jars and preserved in a 10% formalin solution.

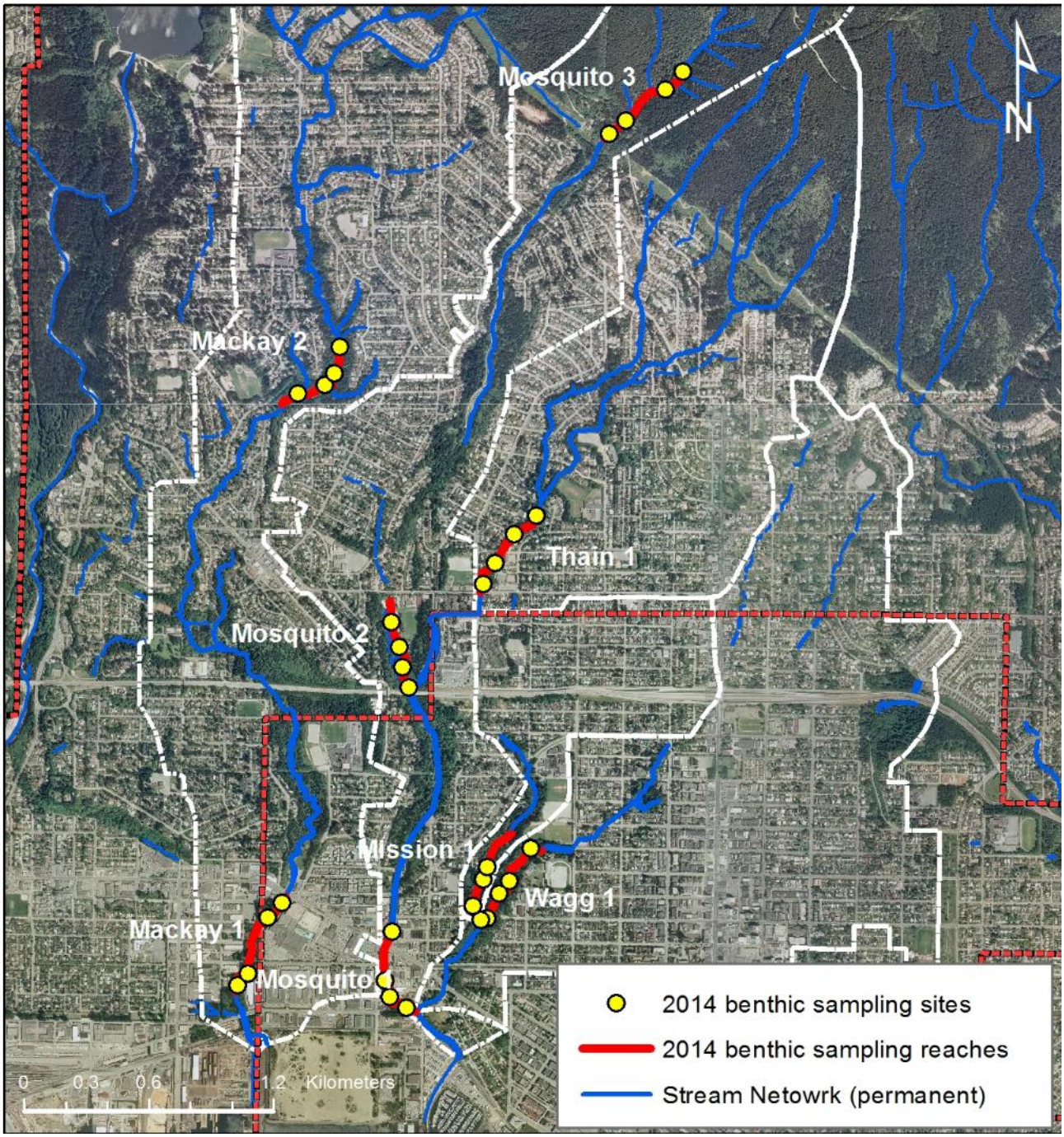


Figure C2-3: Location of Benthic Sampling Sites in Mackay and Mosquito Watersheds.

Environmental variables were also measured at the sampling site or reach including riparian cover, bank stability, etc.), and substrate (e.g., embeddedness and % substrate composition) or channel characteristics (e.g., bankfull width). See Appendix C2-C for more information.

Sorting, subsampling, identification, and B-IBI calculation was completed by Rhithron Associates Inc. All samples were subsampled using a Caton subsampling grid tray to standardize the sample size and reduce the number of organisms that required identification. This procedure randomly selected >400 organisms from the composite sample. The target number of organisms for B-IBI calculation is 400 organisms per sample. All invertebrates were identified to lowest practical taxonomic level (LPTL) using a 6.5 to 40X dissecting microscope. This level of taxonomic resolution was defined by the availability of keys for different groups and produced a mixed dataset with some taxa identified to family, while others were identified to genus or species. This followed the interpretation of lowest practical taxonomic level listed in Plotnikoff and White (1996). Chironimids, a particularly difficult family taxonomically, were only identified to family. A reference collection including all taxa found in the CNV/DNV samples is being assembled by Rhithron for taxonomic standardization and review. This includes organisms collected as part of the 2014 sampling.

4.3 Results

Mackay, Mosquito, and Wagg creeks are some of the best monitored streams in Metro Vancouver; data for several sites is available for multiple years since 1999 and lower Wagg Creek has been sampled nine times during this period using consistent or similar sampling and data analysis methods. See Figure C2-4 for all mean B-IBI scores.

2014 Benthic Sampling

The benthic invertebrate community in all sampling sites in 2014 reflected the effects of urbanization with higher taxa richness and more sensitive taxa in the less urbanized headwater sites (Mosquito 2 and 3, Mackay 2), and lower taxa richness and higher abundance of a few taxa tolerant of urban conditions at sites in the lower watershed (Wagg 1, Mackay 1). Oligochaete worms were the most abundant taxa (all sites combined = 12,084 individuals; 22%), followed by caddisfly Hydropsyche (8%), chironomids (8%), two mayfly taxa *Baetis Rhodani* Gp. (8%), and *Baetis tricaudatus* complex (8%), and amphipods (7%). Most taxa accounted for less than 5% of the total number of organisms.

Mean B-IBI values measured in September 2014 were:

- Mackay Creek Site 1: 22.0
- Mackay Creek Site 3: 26.5
- Mission Creek Site 1: 25.0
- Mosquito Creek Site 1: 27.5
- Mosquito Creek Site 2: 31.5
- Mosquito Creek Site 3: 33.5
- Thain Creek Site 1: 19.5
- Wagg Creek Site 1: 19.0

Individual samples value and metric scores for each B-IBI metric and a summary of B-IBI values are provided in Appendix C2-C.

Changes in mean B-IBI values were analyzed at five sites (Mackay 1, Mosquito 1, Mosquito 2, Wagg 1, Mission 1) for which at least 4 years of data was available. Figure C2-5 shows changes in mean B-IBI values including linear regression lines and significance lines. While all five sites show typical B-IBI variability, the only statistically significant change was the increase in mean B-IBI values at Wagg Creek Site 1.

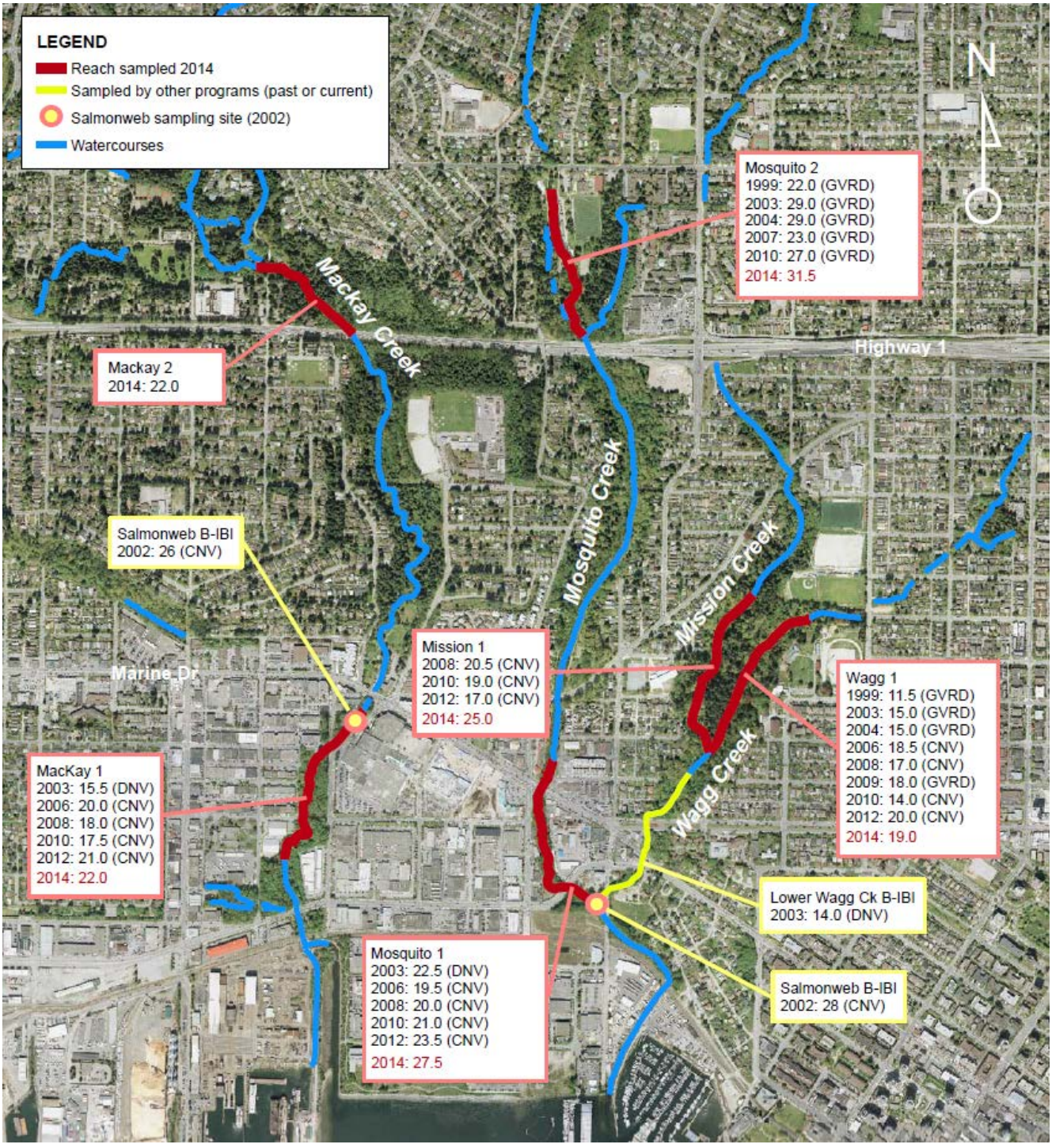


Figure C2-4: Results of 2014 Benthic Invertebrate Sampling in Comparison to Historical Data (all values as mean B-IBI)

B-IBI values at Wagg Creek Site 1 (confluence with Mission Creek to Jones Avenue) have increased significantly since 1999. This is caused by the decline or disappearance of taxa associated with urban streams (Chironomids (midges), Polycelis flatworms, and Gyraulus and Physa snails), and the colonization (or recolonization) of a range of taxa including mayflies (Paraleptophlebia, Rhithrogena, Cinygmula), as well as Heterolimus riffle beetles, Dicranota blackflies, Uenoidae caddiflies, and Zapada stoneflies. This change is noteworthy as it is only one of two significant increases in B-IBI documented in streams in Metro Vancouver since benthic invertebrate sampling began (the other is North Creek in Surrey). Significant declines have been documented in some streams undergoing rapid urbanization.

CABIN – B-IBI Comparison

As a follow-up study to District of North Vancouver's 2003 benthic sampling program, two approaches for collecting and analyzing benthic invertebrate community data were compared: 1) the benthic index of biological integrity (B-IBI) method used for most benthic invertebrate sampling programs in Metro Vancouver; and, 2) a reference condition approach (RCA) advocated by the Canadian Aquatic Biomonitoring Network (CABIN). Data from eight streams in North Vancouver from September–October 2003 and from 11 streams located more broadly in Greater Vancouver from September 2004 were used for the comparison. The results of the assessment are presented in Table C2-6. It is unusual that the CABIN assessment identified Mosquito Creek as "stressed" while Mackay and Wagg creeks were characterised as "possibly stressed". This may reflect the reference group that Mosquito Creek was compared to. See Page and Sylvestre (2006) for more information on methods and results.

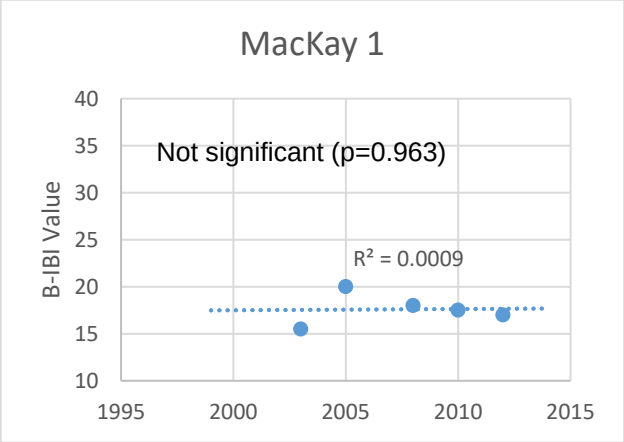
Table C2-6: Comparison of B-IBI and CABIN/RCA Sampling Methods and Analyses

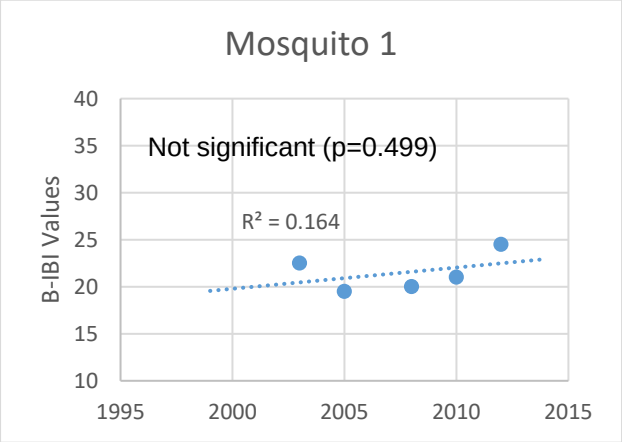
Stream	Kicknet B-IBI	Surber B-IBI	B-IBI Assessment	CABIN Assessment
MacKay Creek	24	15.5 (3.4)	Very poor	Possibly Stressed
Mosquito Creek	30	22.5 (5.3)	Poor	Stressed
Wagg Creek	18	14.0 (1.6)	Very poor	Possibly Stressed

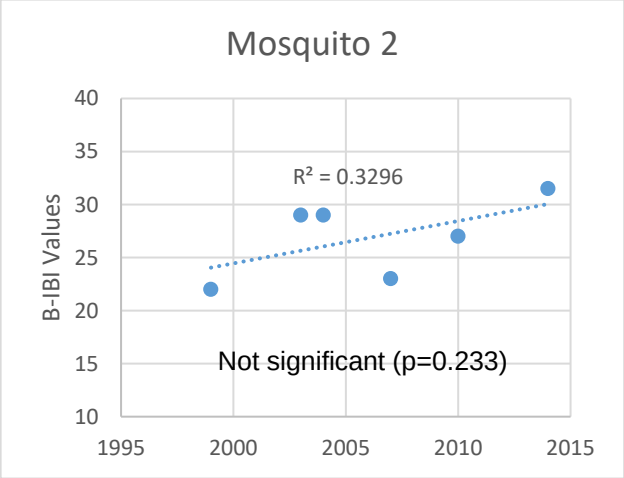
2007–2008 Mackay Creek Assessment

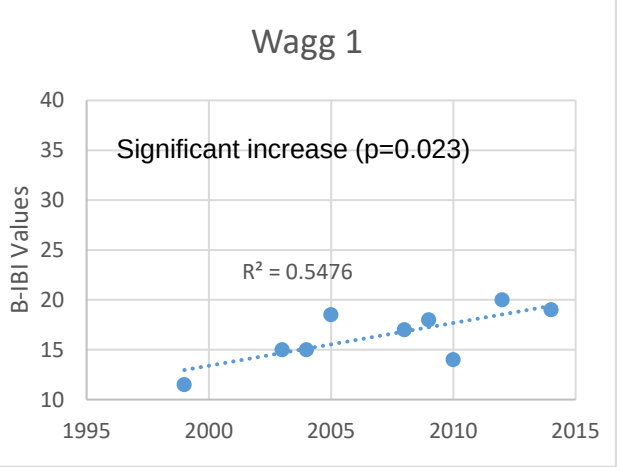
As part of their comprehensive assessment of water quality in Mackay Creek in 2007 and 2008, the Northshore Streamkeepers sampled benthic invertebrates at three sites (4 samples in total: Mackay 1 and 2 in September 2007, and Mackay 3 in February 2008 and Mackay 2 in September 2008). Sampling was undertaken with a Surber sampler, and each sample consisted of three Surber placements. The results were analyzed using the Streamkeeper's Module 3 (Stream Invertebrate Survey).

The 2009 report summarized the results: "the condition of the benthic invertebrate community was ranked "acceptable", based on scores of 2.75 to 3.5 out of 4 for the four samples. Results were influenced by a high proportion of Ephemeroptera (mayfly) larvae in the samples. While most of the mayflies were considered pollution sensitive organisms and provide food for salmonids, their predominance in the samples indicated reduced diversity". No data was provided in the 2009 report (Northshore Streamkeepers, 2009).









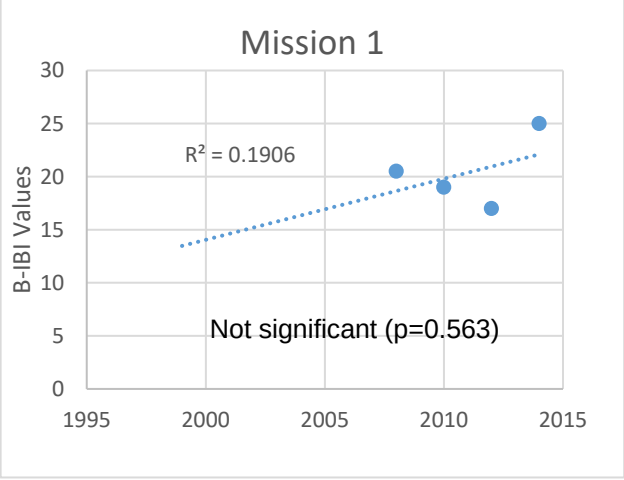


Figure C2-5: Changes in Mean B-IBI Values in Mackay and Mosquito Creek Watersheds (1999-2005)

Only the increase in B-IBI values in Wagg Creek is statistically significant.

4.4 Data and Sources

Appendices C2-7, 8, and 9 provide summary data on B-IBI metric values and scores from the 2014 sampling program, as well as overall B-IBI by sampling location. Raw benthic invertebrate data is available digital. Other sources of benthic invertebrate data include the following:

Page, N. A., L. S. Fore, M. Eymann, and C. Johnston. 2008. Assessment of the use of B-IBI in Greater Vancouver streams (2003–2006). Report prepared for Metro Vancouver. 58 pp. + appendices.

EVS (EVS Environmental Consultants). 2003. GVRD Benthic Macroinvertebrate B-IBI Guide. Prepared for the Greater Vancouver Regional District, Burnaby, BC by EVS Environment Consultants, North Vancouver, BC.

Northshore Streamkeepers. 2009. Water quality and watershed health of Mackay Creek 2007-2009 report. Unpublished report prepared by Northshore Streamkeepers. 63 pp. Available here.

Page, N, and S. Sylvestre. 2006. Comparison of two benthic invertebrate sampling and analysis methods for streams in Greater Vancouver. Unpublished report prepared for Greater Vancouver Regional District, District of North Vancouver, and Environment Canada. 28 pages + appendices.

5. Fish Populations

Fish, particularly salmon and trout, are an essential part of healthy streams in Metro Vancouver and have an iconic status as indicators of successful urban watershed management in the Pacific Northwest. Fish are part of stream foodwebs with a key role as the top aquatic predator in most small streams. Spawning coho and chum salmon also enhance stream productivity by providing a rich source of marine-derived nutrients to otherwise nutrient-poor coastal streams.

The fish community in streams and small rivers in Metro Vancouver is generally divided into three components:

- Permanently flowing headwater streams with higher-gradient channels which support resident cutthroat trout. Resident trout form relatively non-migratory populations with little upstream or downstream movement (often recaptured within 10 to 50 m). Adult fish vary from 10 to 45 cm in size dependent on pool volume (the largest fish are typically found in large pools below culverts).
- The mainstem and larger tributaries support a mix of anadromous salmon and trout including overwintering juvenile coho salmon, as well as resident cutthroat trout, sculpin species, threespine stickleback, and western brook lamprey. Steelhead (rainbow) trout may also be present. Juvenile coho salmon and juvenile and adult cutthroat trout are typically the most abundant fish both by numbers and biomass.
- The lower tidal reaches are often short (<250 m) sections which are transitional from freshwater to marine environments. While they may not have well-developed estuaries, they support some fish species such as starry flounder which are not found in freshwater habitats. Prickly and coastrange sculpins are very abundant in the lower reaches of Mackay Creek including the non-tidal section of Kiwanis Park. Threespine stickleback are common in these reaches.

5.1 Existing Information

Information on the fish community in Mackay and Mosquito creeks is available from fish salvages and fish surveys. These include:

- Large scale fish salvages in lower Mackay Creek as part of flood control (regular gravel removal) activities starting in 1999;
- Smaller scale fish salvages associated with culvert replacements, bank stabilization, or other instream construction activities;
- Post-construction monitoring associated with habitat compensation requirements;
- Student surveys including work by Capilano College on Mackay Creek and Vancouver Island University on lower Mackay Creek;
- Annual spawner surveys by volunteers with the Northshore Streamkeepers from 1995 to present (data appears to be unavailable; perhaps was with Karen Milne); and
- DFO historical escapement (spawning adults) records for salmon and steelhead.

5.2 2014 Fish Sampling

A minnow trapping survey was undertaken at 18 sites in Mackay and Mosquito creeks in between August 26 and September 10, 2014 (see Figure C2-6 for locations). The purpose of the trapping was to confirm the ongoing presence of fish in several streams and the limits of anadromous fish occupancy, particularly upstream of potential fish passage barriers or steep sections of stream. Trapping was undertaken using minnow traps. Traps were baited with tuna and placed in groups of three in deeper pools likely to contain rearing salmonids or, where pools were lacking, in deeper riffle sections. Traps were generally left in the stream overnight and for up to 24 hours prior to retrieval. A total of 54 trap nights (18 nights x 3 traps) of sampling was conducted.

5.3 Results

Mackay and Mosquito creeks support similar fish communities which include chum salmon, coho salmon, and cutthroat trout (resident and anadromous), as well as prickly and coastrange sculpins, threespine stickleback, and western brook lamprey. It is unknown if steelhead trout are still present in either system but occurred historically. Juvenile rainbow (steelhead) trout have been recorded in Mackay Creek. Pink salmon were observed through lower Mackay Creek in early September 2015 and were abundant in Heywood Park. They occurred historically in Mackay Creek but not in Mosquito Creek (at least after the effects of urbanization and flood control). Pink salmon are raised and released by the Northshore Fish and Game Club in Mackay Creek. Dolly Varden may also occur but are not abundant.

Fish Diversity Based on Historical Records

All historical fish sampling data from the Mackay and Mosquito watersheds was amalgamated to provide an overview of fish diversity (see Table C2-7). More records are available from fish salvages from lower Mackay Creek than other stream areas which reduces the usefulness of the data in estimating relative abundance. For example, sculpins and western brook lamprey are shown as the most abundant species which is likely only true for the section of Mackay Creek downstream for Marine Drive. As well, some fish species are difficult to identify (juvenile rainbow trout vs. juvenile cutthroat trout; coastrange vs. prickly sculpin) which confounds the estimate of fish diversity.

The most abundant species are sculpins (prickly and coast range), western brook lamprey, threespine stickleback, cutthroat trout, and coho salmon. Again, this reflects conditions in the lower watershed rather than the middle reaches where coho salmon and cutthroat trout are more abundant. However, the similarity of fish species captured measured using different methods in different sites and seasons appears to be a good reflection of fish diversity in the watershed. The only species not recorded is pink salmon which is unlikely to be captured during fish salvages or surveys. Pink salmon were observed in Mackay Creek in September 2015. Grant and Pestal (2009)[5] noted: “Burrard Inlet-Indian Arm tributaries that support pink salmon include Lynn Creek, MacKay Creek, Seymour River, Capilano River (Brothers Creek), and Indian River. Most of these populations are persistent at low abundance levels (<1000), except for the Indian River with a relatively large productive potential and a recent upward trend in escapement”. Mosquito Creek is not mentioned.

[5] Grant, S. and G. Pestal. 2009. Certification Unit Profile: Fraser River Pink Salmon. Can. Man. Rep. Fish. Aquat. Sci. 2875: vii + 36p.

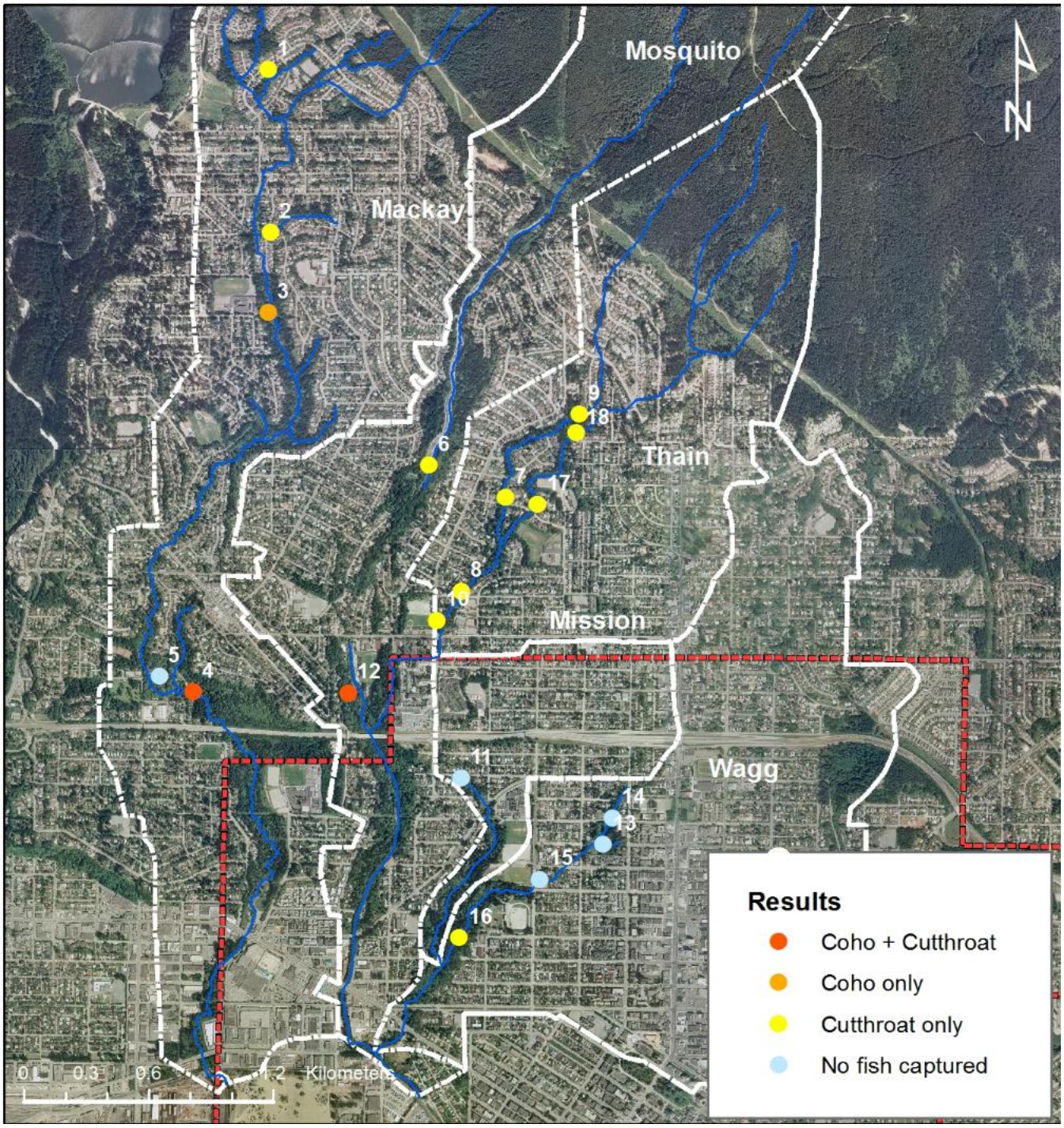


Figure C2-6: Results of August–September 2014 Minnow Trapping Survey.

Older DFO salmon escapement (adult spawners) records[6] indicate that Mackay Creek supported small numbers of coho (mean of 18 in the early 1980s), chum salmon (mean of 5), and steelhead trout (6). Pink salmon were not noted in Mackay Creek historically. Mosquito Creek was described as having only a mean escapement of 3 coho salmon during this period. It is also noted that in 1956 Mosquito Creek is "being continuously cleared as a flood control measures and very little area is left for spawning" and in 1958 "water conditions are seriously affected by extensive land clearing and residential development. During the past dry season, the stream beds were practically dry and a serious loss in resident coho fry is to be expected".

The locations of the spawning areas for coho, chum, and pink salmon have not been described or mapped. Additional information from Northshore Streamkeepers may address this information gap. A survey of spawning use in a portion of Mosquito and Thain creeks in 1997 found small numbers of spawning coho salmon and steelhead trout in Thain Creek below the daylighting reach, and in Mosquito Creek below Queens Avenue.

Table C2-7: Summary of Fish Captured in Historical Surveys or Fish Salvages

(#) Fish Captured in Mackay and Mosquito Creeks (All Records Combined)	
728 sculpins (no species listed)	28 prickly sculpin
510 western brook lamprey	22 chum salmon
496 threespine stickleback	12 rainbow trout
352 cutthroat trout	5 starry flounder
313 coho salmon	5 slimy sculpin (*likely misidentified;)
304 signal crayfish	3 steelhead trout
300 salmon (juvenile; no species provided)	2 chinook salmon

2014 Fish Trapping Survey

One hundred and two fish were captured during the fish trapping survey in August and September 2014: 5 juvenile coho salmon, 38 cutthroat trout, and 59 threespine stickleback. The survey confirmed the following observations about fish use in the study watersheds. Key results:

- The 2014 trapping survey and observations during field channel surveys confirmed that juvenile coho salmon and cutthroat trout are widely distributed in the Mackay and Mosquito watersheds. The release of hatchery-raised coho fry by DFO, NSSK, and school groups complicates that assessment of natural fish distribution in the watersheds. Field observations showed that juvenile coho salmon are abundant in Mackay Creek and lower Mosquito Creek.
- Wagg Creek does not support salmon or trout upstream of Jones Avenue, likely because of the combination of poor fish access (the Jones Avenue culvert in impassible) and historical fish kills. Resident cutthroat trout could occur in Wagg Creek if passage was restored. Coho salmon and cutthroat trout are found in Wagg Creek downstream of Jones Avenue (Mahon Park).
- Coho salmon are unconfirmed from Thain Creek upstream of Queens Avenue; it is suspected that the culvert and inclined outlet/fishway are not passable to adult coho or other fish.

[6] Hancock, M.J. and D.E.Marshall. 1986 Catalogue of Salmon Streams and Spawning Escapements of Statistical Area 28 Howe Sound - Burrard Inlet Can. Data Rep. Fish and Aquat. Sci. 557: xiv + 190 p.

- The distribution (upstream extent) of resident cutthroat trout presence in headwater areas of both Mackay and Mosquito Creek is unconfirmed. Cutthroat trout have been found on Mackay Creek (west tributary) near Blue Grouse Way (vicinity of Grousewoods Park), and on the east tributary to Sarita Avenue (but not found above Ranger Avenue) (Figure C2-6). On Mosquito Creek, there are reports of headwater populations of trout upstream of the transmission corridor but there are no sampling records to substantiate this distribution. Fish salvages and minnow trapping upstream of Montroyal Boulevard have failed to find fish.
- Figure C2-6 shows the distribution of anadromous (migratory) salmon in the Mackay and Mosquito watersheds.



Photo C2-3: Resident cutthroat trout, most common fish species captured in middle & upper reaches.

5.4 Data & Sources

Historical fish sampling summary results are available in Appendix C2-D.

Fish survey data collected in 2014 can be found in Appendix C2-D.

Howe Sound - Burrard Inlet Can. Data Rep. Fish and Aquat. Sci. 557: xiv + 190 pp.

EcoCat: The Ecological Reports Catalogue (online provincial listing of reports and data): see http://www.env.gov.bc.ca/ecocat/

Grant, S. and G. Pestal. 2009. Certification Unit Profile: Fraser River Pink Salmon. Can. Man. Rep. Fish. Aquat. Sci. 2875: vii + 36p.

Hancock, M.J. and D.E. Marshall. 1986 Catalogue of Salmon Streams and Spawning Escapements of Statistical Area 28.

6. Fish Passage

Fish passage barriers are natural or manmade obstructions that preclude or limit the movement of adult or juvenile fish, particularly migratory salmon and trout swimming upstream to spawn. Culverts are the most common manmade barriers to fish passage in North Shore streams, while cascades or bedrock controlled falls are common natural barriers.

Culverts, weirs, check-dams, and other stormwater infrastructure are important limiting factors for fish populations in many urban watersheds. Watersheds like Mackay and Mosquito with higher channel gradients are more susceptible because culvert gradients often limit upstream fish migration.

Fish passage can also be improved to enhance fish populations. For example, the natural falls at Ridgewood Drive were modified in 1982 by North Shore Fish and Game Club. The creation of steps and resting pools now allows coho salmon to access about 2,200 m of high quality habitat in the middle reaches of Mackay Creek.

6.1 Existing Information

Most existing reports and studies have not examined fish passage comprehensively. Exceptions include the planning and options review for the Thain Creek daylighting project that restored fish passage to Queens Avenue.

6.2 2014 Assessment

Fish passage was assessed qualitatively during field surveys as well as based on information on fish presence. The engineering assessment of stormwater infrastructure also contributed to understanding fish passage. Information from NSSK volunteers was also important for understanding barriers and obstructions to fish passage.

Fish passage was assessed as part of the engineering assessment of drainage infrastructure, during the instream habitat assessment, and as part of the review of fish distribution.

6.3 Results

Both natural and man-made barriers limit fish passage and distribution in the study watersheds (see Figure C2-7). Key fish passage issues in the study watersheds include:

- Mackay Creek: Anadromous salmon, particularly coho, are able to ascend to the channel control weir at the Belvedere Avenue footbridge on Mackay Creek. Additional weirs and culverts fragment habitat and limit fish movement between Belvedere Avenue and Ranger Avenue (on east Mackay) or the Grousewoods area of west Mackay Creek. Channel gradient increases substantially in this area and low summer flows (often subsurface) limit resident cutthroat trout populations. Recurring beaver dams on Mackay Creek at 1st Avenue are unlikely to be passage barrier to adult fish during storm flows when most migration occurs.

  A natural barrier (bedrock falls) historically occurred at Ridgewood Drive, however, it was modified to improve fish passage for coho salmon and steelhead trout in 1982 by North Shore Fish and Game Club. Historically, it was the upper limit of anadromous fish access in Mackay Creek.

  A tributary stream ("Edgemont Creek" in Murdo Frazer Park) is not accessible to fish because of a perched culvert where it joins Mackay Creek upstream of Lloyd Avenue. This small stream may be able to support overwinter salmon and trout but is likely prone to low summer flows.

- Mosquito Creek: The 850 m long culvert between Queens Avenue and the Evergreen Basin is impassable to all fish. Additional gradient barriers fragment fish habitat upstream of the basin. Resident cutthroat trout are found in Mosquito Creek above the limit of urban development. The weir downstream of 3rd Street may affect some upstream migration depending on stream discharge. The historical upper limit of anadromous fish access in Mosquito Creek is difficult to assess because of channel modifications for flood control. It was likely a boulder dominated, high gradient channel with lower values for fish than Mackay Creek.
- Wagg Creek: The Jones Avenue culvert (eastern edge of Mahon Park) is a barrier to all upstream fish migration. If this was removed, the culverts on the two tributary streams entering the Wagg Creek Pond would be the upper limit of fish use. The Keith Road culvert may reduce fish passage under some flows.
- Mission Creek: The Larson Road culvert on Mission Creek is impassable to all fish. A second culvert at 23rd Avenue is also a barrier.
- Thain Creek: Sampling records (lack of coho fry) indicate that the inclined fishway and culvert at Queens Avenue and Westview Drive prevent or restrict fish migration into the middle reaches of Thain Creek. Culverts at Windsor Road, Evergreen Place, and Silverdale Place also restrict or preclude fish passage.

6.4 Data & Sources

Kerr Wood Leidal Associates Ltd. 1997. Briefing Paper on Habitat Compensation Alternatives for Thain Creek Diversion Culvert Project Revised Draft for Final Review. 44 pp. (available through Ecocat).

Mosquito Creek Watershed Profile. http://www.mosquitocreek.org/. Website developed by K.R. Milne / Northshore Streamkeepers.

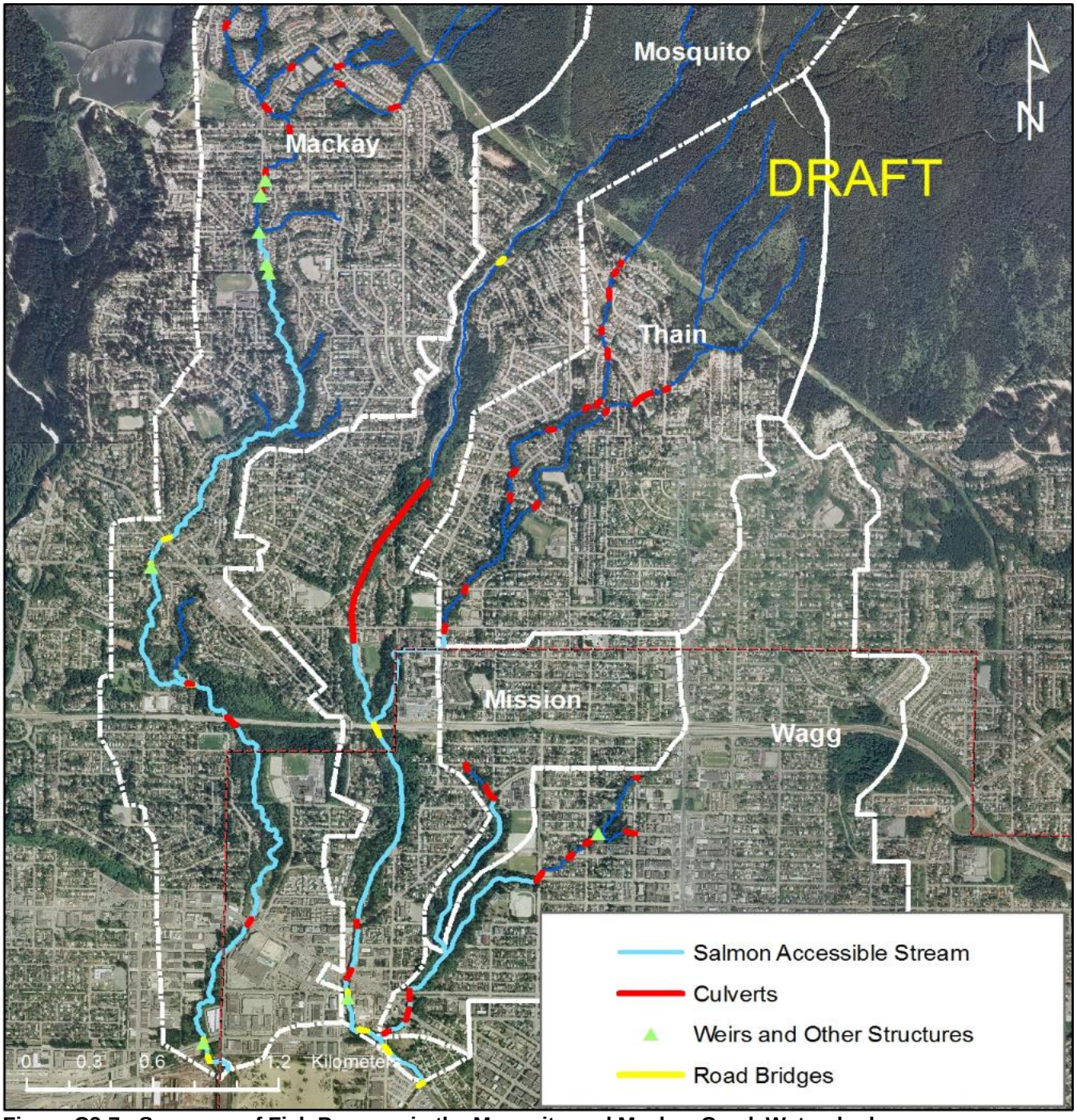
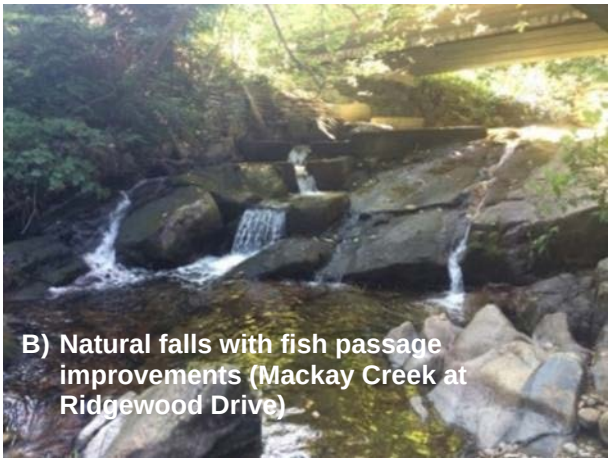


Figure C2-7: Summary of Fish Passage in the Mosquito and Mackay Creek Watersheds.



Photo C2-4: Channel control weir at Belvedere Place is the upper limit of salmon migration in Mackay Creek (November 2015 photo during a moderate flood).


A) Impassable culvert at mouth of Edgemont Creek


B) Natural falls with fish passage improvements (Mackay Creek at Ridgewood Drive)


C) Gasline weir at Mosquito Creek at 3rd Avenue


D) Wagg Creek at Jones Avenue


E) Beaver dam on lower Mackay Creek (1st Ave in 2014).


F) Chain Creek at Queens Avenue likely precludes access for coho.

Photo C2-5: Barriers and obstructions to fish passage in the Mackay and Mosquito watersheds.

7. Instream Habitat

Instream habitat includes channel dimensions, substrate composition, and channel structure/complexity as it influences fish habitat and other environmental values. In many urban streams, changes to hydrology associated with increased watershed imperviousness and higher storm flows, cause predictable changes in instream habitat including:

- Changes to channel equilibrium including erosion and downcutting or channel widening to accommodate increased storm flows;
- Loss of pool volume and hydraulic complexity associated with loss of large instream wood;
- Loss of bank stability and increased erosion; and
- Changes to sediment composition: loss of gravel and fine sediment in some sections; increase in sand and fine sediment in other sections).

7.1 Existing Information

While instream habitat has been assessed at individual sites (e.g., Thain Creek prior to daylighting; lower Mackay Creek) there is little comprehensive or consistently collected information on instream habitat in the study watersheds. Northshore Streamkeepers have undertaken assessments using the Streamkeepers Module 2 (Advanced Stream Habitat Survey) but that information was not easily available.

7.2 2014 Field Survey

Instream habitat was assessed in the field using two methods:

1. Channel dimensions (bankfull width; wetted width; riffle depth) and substrate (percent boulder, cobble, large gravel, small gravel, fine; % substrate embeddedness) were measured at 55 sites in the study watersheds; and
2. The location and size of large wood (pieces >10 cm in diameter and 2 m long within the bankfull channel) (Figure C2-8), and deep pools >40 cm deep (Figure C2-9) were recorded during field surveys of all stream reaches with anadromous fish use. Deep pools and large wood are closely tied to the amount and quality of habitat for juvenile coho salmon and cutthroat trout, as well as being indicators of the physical processes that sustain healthy streams (e.g., channel stability, hydraulic diversity, riparian-channel interactions).

7.3 Results

Key results of the channel assessment are:

Channel Dimensions: Mean bankfull width for all sites was 7.0 m and varied from 9.9 m in the Mosquito Creek mainstem to 5.4 m in Mission Creek. Thain Creek was 6.3 m, Wagg Creek was 6.0 m, and Mackay Creek was 5.7 m. Mean wetted width in September 2014 was 3.7 m and was generally about 52% of bankfull width.



Photo C2-6: Examples of typical instream habitat in Mackay and Mosquito creeks.

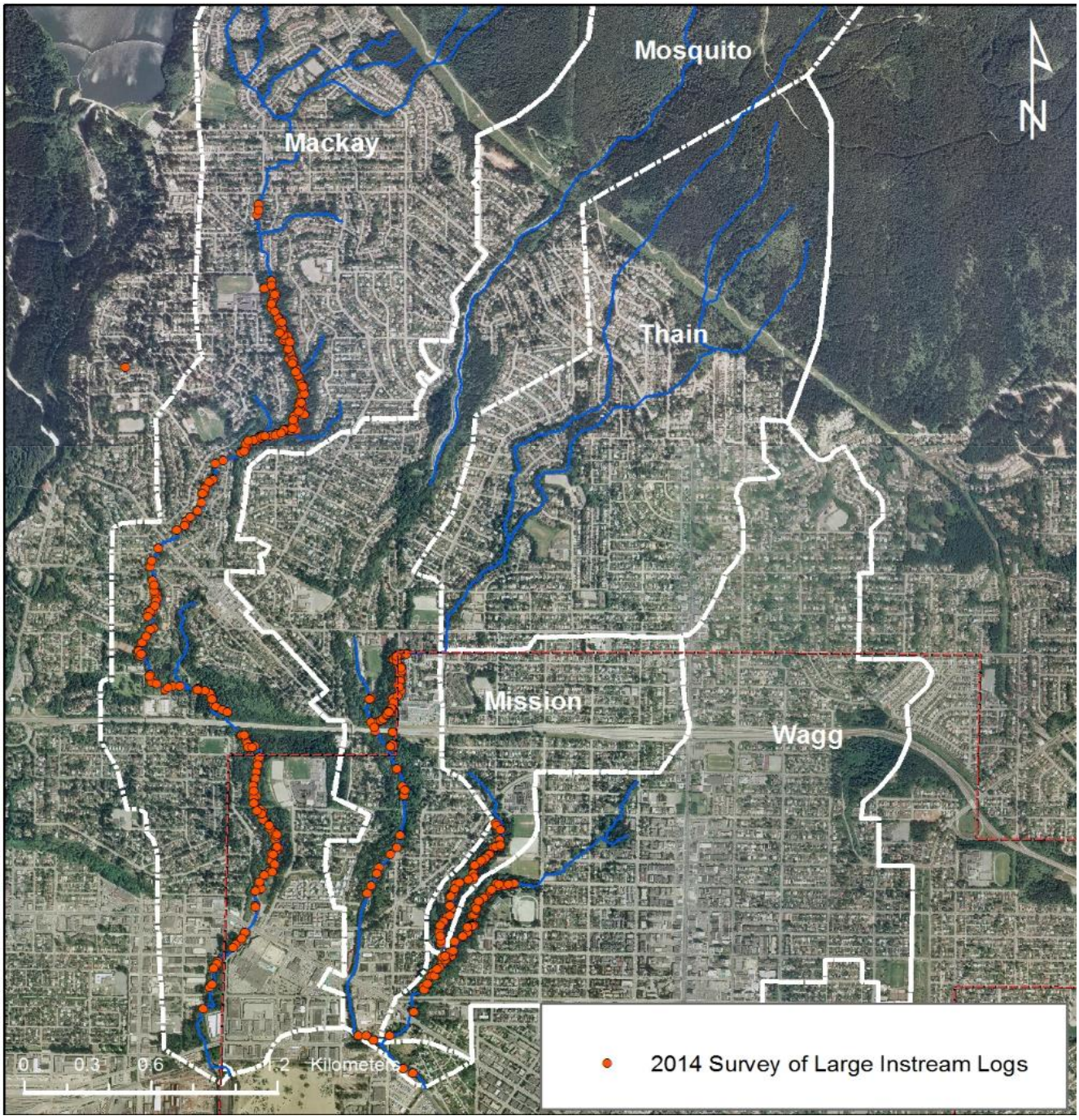


Figure C2-8: Distribution of Large Instream Logs With Anadromous Fish Use.

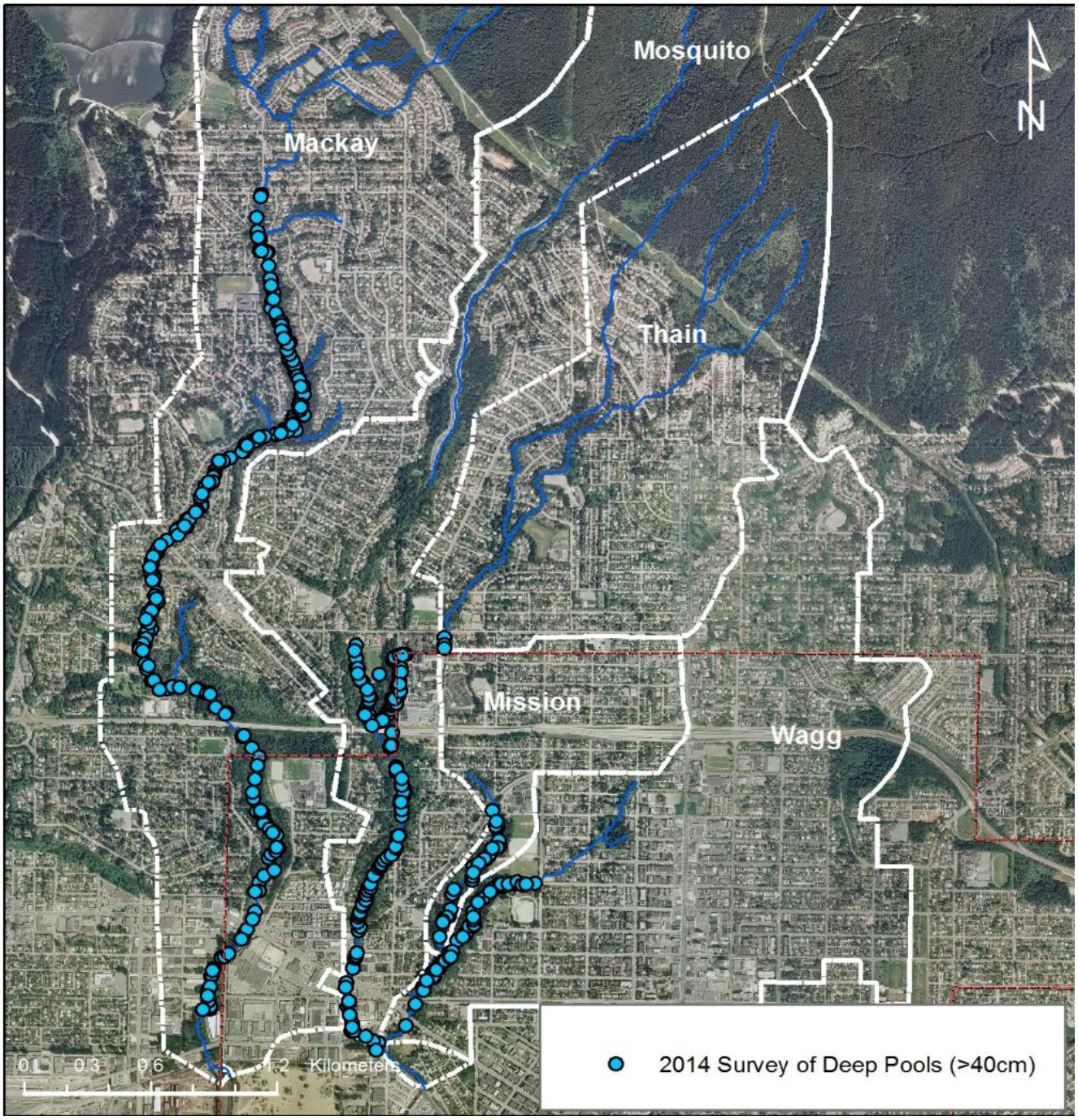


Figure C2-9: Locations of Deep Pools in Mackay and Mosquito Creeks With Anadromous Fish Use.



Photo C2-7: **Mackay Creek near Handsworth Secondary School in November 2015. Large wood is an essential part of healthy stream ecosystems.**

Large Wood: A total of 1346 pieces of large wood were surveyed with an average diameter of 37 cm, an average length of 4.8 m, and an average wood volume of 0.20 m^3. Wood pieces were not differentiated by species or age/condition. The mean density of large instream wood was 13.0 pieces per 100 m of stream channel but varied from 2.6 pieces per 100 m in Mosquito Creek to 23.4 pieces in Thain Creek. Natural streams typically have been 10 and 20 pieces per 100 m and wood volume is often much higher than was observed in the study watersheds.

Deep Pools: Five hundred and fifty pools deeper than 30 cm were measured in Mackay and Mosquito creeks in September 2014. Mean depth was 44 cm (range of 30 to 147 cm). Mean pool density was 5.3 pools per 100 m and varied from 3.2 in Mission Creek to 9.4 in Thain Creek. It is noteworthy that Mosquito Creek had a higher density of deep pools than Mackay Creek despite substantially fewer large logs. Deep pools were generated by a range of processes including lateral erosion against stable banks, scour around large wood, boulders, or other features, or the presence of culverts or other anthropogenic features.

Overall fish habitat quality was high in the study watersheds but did show some spatial patterns:

- The lowland reaches of Mosquito, Mackay, and Wagg creeks were less diverse and productive for fish based on pool and wood density;
- Mosquito Creek is generally barren of large stable wood which likely reflects historical channelization and disruption to wood movement from the headwaters; and
- Mackay Creek generally has more productive habitat than Mosquito Creek.

8. Summary of Findings and Recommendations

8.1 Findings

C2-1. Water Quality

Analysis of new and historical data showed that water quality in Mackay and Mosquito creeks is typical of moderately urbanized streams in Metro Vancouver. Assessment using Metro Vancouver's Adaptive Management Framework (MAMF) identified several parameters in the "satisfactory" (yellow) or "needs improvement" (red) categories including dissolved oxygen, turbidity, conductivity, E.coli, fecal coliforms, and total metals.

C2-2. Sediment Quality

Total metal concentrations in streambed sediments from the study area were typical of urban streams from Metro Vancouver. All samples from Mackay, Mosquito, and Thain creeks had concentrations of total metals below Canadian Environmental Sediment Quality (CESQ) guidelines, while Mission and Wagg creeks had elevated concentrations of some metals. Not unexpectedly based on its level of urbanization, most sediment samples collected from Wagg Creek in the past 10 years had a least one total metal concentrations above CESQ guidelines.

C2-3. Benthic Invertebrates

Benthic invertebrates were collected at eight sites in September 2014. Results reflected the effects of urbanization with higher taxa richness and more sensitive taxa in the less urbanized headwater sites, and lower taxa richness and higher abundance of a few taxa tolerant of urban conditions in the lower watershed.

Mean B-IBI values measured in September 2014 were:

- Mackay Creek Site 1: 22.0
- Mackay Creek Site 3: 26.5
- Mission Creek Site 1: 25.0
- Mosquito Creek Site 1: 27.5
- Mosquito Creek Site 2: 31.5
- Mosquito Creek Site 3: 33.5
- Thain Creek Site 1: 19.5
- Wagg Creek Site 1: 19.0

Changes in mean B-IBI values were analyzed at five sites (Mackay 1, Mosquito 1, Mosquito 2, Wagg 1, Mission 1) for which at least 4 years of data was available. While all sites show typical B-IBI variability, the only statistically significant change was the increase in mean B-IBI values at Wagg Creek Site 1.

C2-4. Fish Community

Mackay and Mosquito creeks support similar fish communities which include chum salmon, coho salmon, and cutthroat trout (resident and anadromous), as well as prickly and coastrange sculpins, threespine stickleback, and western brook lamprey. It is unknown if steelhead trout are still present in either system but occurred historically. Pink salmon were observed through lower Mackay Creek in early September 2015 and were abundant in Heywood Park. Dolly Varden may also occur but are not abundant.

C2-5. Fish Passage

Both natural and man-made barriers limit fish passage and distribution in the study watersheds. Key fish passage issues include:

- Mackay Creek: Anadromous salmon, particularly coho, are able to ascend to the channel control weir at Belvedere Avenue on Mackay Creek. Increasing channel gradient and manmade passage barriers compromise fish passage upstream.
- Mosquito Creek: The 850 m long culvert between Queens Avenue and the Evergreen Basin is impassable to all fish. Additional gradient barriers fragment fish habitat upstream of the basin.
- Wagg Creek: The Jones Avenue culvert is a barrier to upstream fish movement. If this was removed, the culverts on the two tributary streams entering the Wagg Creek Pond would be the upper limit of fish use.
- Mission Creek: The Larson Road culvert on Mission Creek is impassable to all fish. A second culvert at 23rd Avenue is also a barrier.
- Thain Creek: Sampling records (lack of coho fry) indicate that the inclined fishway and culvert at Queens Avenue and Westview Drive prevent or restrict fish passage into Thain Creek.

C2-6. Instream Habitat

Overall fish habitat quality was high in the study watersheds but did show some spatial patterns. The lowland reaches of Mosquito, Mackay, and Wagg creeks were less diverse and productive for fish based on pool and wood density. However, these channels are lower gradient and provide gravel substrates important for spawning.

A total of 1346 pieces of large wood were surveyed with an average diameter of 37 cm, an average length of 4.8 m, and an average wood volume of 0.20 m^3. The mean density of large instream wood was 13.0 pieces per 100 m of stream channel but varied from 2.6 pieces per 100 m in Mosquito Creek to 23.4 pieces in Thain Creek. Natural streams typically have been 10 and 20 pieces per 100 m.

Five hundred and fifty pools deeper than 30 cm were measured in Mackay and Mosquito creeks in September 2014. Mean depth was 44 cm (range of 30 to 147 cm). Mean pool density was 5.3 pools per 100 m and varied from 3.2 in Mission Creek to 9.4 in Thain Creek. It is noteworthy that Mosquito Creek had a higher density of deep pools than Mackay Creek despite substantially fewer large logs.

8.2 Recommendations

C2-1. Undertake ongoing monitoring of stream health to track changes in stream conditions and the success of watershed management activities. Monitoring should include water and sediment quality, benthic invertebrates, and fish population at a frequency of every 2 to 5 years.

C2-2. Investigate the source of elevated lead levels in streambed sediments in Mission Creek with further sampling.

C2-3. Assess fish passage barriers on Thain Creek and fish sampling.

C2-4. Undertake further sampling and analysis of the Wagg Creek benthic invertebrate community to better understand what may be leading to the statistically significant increase in B-IBI. It is unusual to see increasing B-IBI in a heavily urbanized stream.

C2-5. Undertake spawner surveys in representative stream segments by community stewards to estimate population size and highlight the importance of Mackay and Mosquito creeks for fish populations.

6.4 Data & Sources

Summary of instream channel measurements in Appendix C2-E and surveys of logs, deep pools, and other features in Appendix C2-E.

Kerr Wood Leidal Associates Ltd. 1997. Briefing Paper on Habitat Compensation Alternatives for Thain Creek Diversion Culvert Project Revised Draft for Final Review. 44 pp. (available through Ecocat).

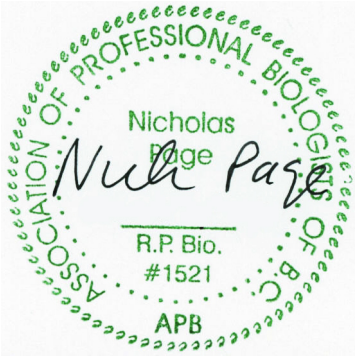
Mosquito Creek Watershed Profile. http://www.mosquitocreek.org/. Website developed by K.R. Milne / Northshore Streamkeepers.

Report Submission

Prepared by:

Raincoast Applied Ecology





Nick Page, BLA., M.Sc., R.P.Bio.
Project Biologist

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Revision History

Revision #	Date	Status	Revision	Author
0	September 2020	Final		NP

Appendix C2-A:

Water Quality Data

Appendix C2-A Table 1. Summary of 2014 water quality survey in Mackay, Mosquito, Mission, and Wagg creeks.

Location Description	Date	X	Y	Temp	Sp Cond	Cond	DO %	DO mg/L	pH	ORP	NTU
Primary Sites											
MacKay Creek #1	September-19-14	0492488	5463023	15.68	0.092	0.076	98.0	9.65	7.10	186.9	9.5
	September-29-14	0492488	5463023	13.45	0.148	0.115	96.2	10.30	6.98	128.4	0.0
	October-03-14	0492488	5463023	11.51	0.134	0.099	108.6	11.73	7.22	68.4	1.4
	October-09-14	0492488	5463023	9.90	0.157	0.127	102.9	10.38	7.42	160.1	3.7
	October-10-14	0492488	5463023	9.71	0.161	0.133	104.6	10.45	7.16	166.8	1.8
			Mean	**12.05**	**0.138**	**0.110**	**102.1**	**10.50**	**7.18**	**142.1**	**3.3**
Mission Creek #1	September-19-14	0493603	5463306	16.17	0.080	0.067	95.7	9.41	6.81	161.6	10.9
	September-29-14	0493603	5463306	14.27	0.119	0.094	96.6	9.89	7.17	182.8	6.1
	October-03-14	0493603	5463306	11.82	0.133	0.099	107.4	11.51	7.30	75.1	1.1
	October-09-14	0493603	5463306	9.80	0.141	0.113	102.7	10.44	7.04	171.1	2.2
	October-10-14	0493603	5463306	9.76	0.156	0.119	103.0	10.40	7.29	172.4	1.7
			Mean	**12.36**	**0.126**	**0.098**	**101.1**	**10.33**	**7.12**	**152.6**	**4.4**
Mosquito Creek #1	September-19-14	0493283	5462833	16.04	0.082	0.068	97.5	9.62	7.03	181.4	3.1
	September-29-14	0493283	5462833	13.58	0.105	0.082	98.9	10.25	7.07	175.3	129.6
	October-03-14	0493283	5462833	11.61	0.112	0.084	110.4	11.09	7.26	79.3	1.7
	October-09-14	0493283	5462833	10.20	0.129	0.102	102.3	10.49	6.91	175.3	2.5
	October-10-14	0493283	5462833	10.21	0.122	0.101	101.9	10.21	7.09	175.9	1.7
			Mean	**12.33**	**0.110**	**0.087**	**102.2**	**10.33**	**7.07**	**157.4**	**27.7**
Wagg Creek #1	September-19-14	0493622	5463242	17.06	0.077	0.060	98.5	9.44	7.18	199.4	8.4
	September-29-14	0493622	5463242	15.50	0.200	0.164	98.5	9.83	7.53	181.3	0.1
	October-03-14	0493622	5463242	13.25	0.191	0.148	106.5	11.06	7.46	95.2	6.3
	October-09-14	0493622	5463242	10.90	0.211	0.171	102.0	10.26	6.95	176.0	2.8
	October-10-14	0493622	5463242	10.63	0.198	0.165	104.5	10.56	7.23	169.9	2.7
			Mean	**13.47**	**0.175**	**0.142**	**102.0**	**10.23**	**7.27**	**164.4**	**4.1**
Secondary Sites											
MacKay Creek #3	September-19-14	0492692	5465827	15.27	0.088	0.071	103.2	10.24	7.24	176.1	0.7
Mosquito Creek #2	September-19-14	0493225	5464492	15.58	0.089	0.073	93.8	9.34	6.99	69.2	0.0
Mosquito Creek #3	September-19-14	0494249	5467154	12.69	0.030	0.023	101.8	10.71	7.60	186.7	0.0
Thain Creek #1	September-19-14	0493653	5464996	15.86	0.074	0.078	102.7	10.90	7.55	171.2	1.2

Appendix C2-A Table 2. Water quality in Mackay and Mosquito Creeks, lab-based parameters (Sept-Oct 2014).

Sample ID	MACKAY #1	MOSQUITO #1	WAGG #1	MISSION #1	MACKAY #1	MOSQUITO #1	WAGG #1	MISSION #1	MOSQUITO#1	MACKAY#1	MISSION#1	WAGG#1	MISSION#1	MOSQUITO#1	WAGG#1	MACKAY#1	MACKAY#1	MISSION#1	MOSQUITO 1	WAGG#1
Date Sampled	22-SEP-14	22-SEP-14	22-SEP-14	22-SEP-14	29-SEP-14	29-SEP-14	29-SEP-14	29-SEP-14	03-OCT-14	03-OCT-14	03-OCT-14	03-OCT-14	09-OCT-14	09-OCT-14	09-OCT-14	09-OCT-14	10-OCT-14	10-OCT-14	10-OCT-14	10-OCT-14
X	0492488	0493283	0493622	0493603	0492488	0493283	0493622	0493603	0492488	0493283	0493622	0493603	0492488	0493283	0493622	0493603	0492488	0493283	0493622	0493603
Y	5463023	5462833	5463242	5463306	5463023	5462833	5463242	5463306	5463023	5462833	5463242	5463306	5463023	5462833	5463242	5463306	5463023	5462833	5463242	5463306
Physical Tests (mg/L)																				
Hardness (as CaCO3)	40.7	38.3	51.5	35.7	35.7	29.3	58.9	43.0	31.7	37.2	45.2	56.2	41.6	57.7	31.8	36.8	37.0	43.1	31.8	58.2
Total Suspended Solids	<3.0	10.1	<3.0	<3.0	<3.0	<3.0	4.7	4.2	3.4	<3.0	14.1	3.7	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
Anions and Nutrients (mg/L)																				
Ammonia, Total (as N)	0.0102	0.0163	0.0101	<0.0050	0.0102	0.0101	0.0231	<0.0050	0.0077	0.0096	<0.0050	0.0180	<0.0050	0.0820	<0.0050	0.0112	0.0101	<0.0050	<0.0050	0.0288
Nitrate (as N)	0.484	0.316	0.635	0.235	0.588	0.605	1.15	0.626	0.611	0.583	0.708	1.06	0.427	0.821	0.398	0.473	0.463	0.406	0.397	0.773
Orthophosphate-Dissolved (as P)	0.0023	0.0221	0.0648	0.0047	0.0012	0.0048	0.0276	0.0055	0.0054	<0.0010	0.0051	0.0209	0.0073	0.0459	0.0015	0.0010	<0.0010	0.0072	0.0012	0.0259
Phosphorus (P)-Total	0.0086	0.0425	0.0683	0.0074	0.0021	0.0054	0.0361	0.0062	0.0120	0.0052	0.0233	0.0308	0.0096	0.0542	0.0033	0.0030	0.0034	0.0068	0.0024	0.0274
Bacteriological Tests (per 100 ml)																				
E. coli	236	49	2420	461	365	276	>2420	365	260	35	179	1150	139	38	>2420	613	148	345	77	2420
Coliform Bacteria - Fecal	350	23	>1600	350	350	240	>1600	240	350	49	240	400	350	70	3300	540	130	170	49	1300
Total Metals (mg/L)																				
Aluminum (Al)-Total	0.0139	0.0418	0.0376	0.0092	0.0275	0.112	0.133	0.0873	0.0863	0.0246	0.201	0.290	0.0120	0.0267	0.0399	0.0149	0.0239	0.0253	0.0428	0.0523
Antimony (Sb)-Total	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	0.00053	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Arsenic (As)-Total	<0.00050	0.00055	0.00083	<0.00050	<0.00050	<0.00050	0.00090	<0.00050	<0.00050	<0.00050	<0.00050	0.00062	<0.00050	0.00061	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	0.00064
Barium (Ba)-Total	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	0.022	<0.020	<0.020	<0.020	<0.020	0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Beryllium (Be)-Total	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Boron (B)-Total	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Cadmium (Cd)-Total	<0.000010	0.000015	0.000021	<0.000010	0.000053	0.000042	0.000023	0.000024	0.000045	0.000011	0.000042	0.000033	0.000013	0.000020	<0.000010	0.000011	0.000012	0.000016	0.000010	0.000020
Calcium (Ca)-Total	13.6	13.0	17.0	11.0	12.2	10.0	20.2	13.7	10.9	12.7	14.4	19.2	13.0	19.3	10.8	12.4	12.5	13.5	10.8	19.5
Chromium (Cr)-Total	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Cobalt (Co)-Total	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030
Copper (Cu)-Total	0.0014	0.0181	0.0038	<0.0010	0.0013	0.0048	0.0055	0.0027	0.0064	0.0010	0.0045	0.0027	0.0013	0.0024	0.0012	<0.0010	0.0011	0.0017	0.0013	0.0024
Iron (Fe)-Total	0.392	0.233	0.084	0.109	0.294	0.192	0.246	0.313	0.168	0.300	0.513	0.288	0.125	0.108	0.093	0.335	0.417	0.160	0.093	0.165
Lead (Pb)-Total	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	0.00066	0.00095	<0.00050	<0.00050	0.00207	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Lithium (Li)-Total	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Magnesium (Mg)-Total	1.60	1.40	2.16	1.97	1.30	1.04	2.04	2.12	1.06	1.33	2.23	2.00	2.21	2.29	1.18	1.42	1.42	2.30	1.18	2.33
Manganese (Mn)-Total	0.00807	0.0185	0.00230	0.00603	0.0119	0.0109	0.00731	0.0154	0.0111	0.0123	0.0310	0.00579	0.00785	0.00357	0.00261	0.0114	0.0129	0.00986	0.00303	0.00472
Mercury (Hg)-Total	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Molybdenum (Mo)-Total	<0.0010	0.0011	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Nickel (Ni)-Total	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Potassium (K)-Total	<2.0	<2.0	2.0	<2.0	<2.0	<2.0	2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Selenium (Se)-Total	<0.00010	0.00034	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Silver (Ag)-Total	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020
Sodium (Na)-Total	10.0	11.1	11.3	5.1	13.9	8.4	14.8	6.6	8.6	11.4	7.1	14.0	6.3	14.4	9.2	10.7	10.3	6.4	8.9	14.0
Thallium (Tl)-Total	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020
Tin (Sn)-Total	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Titanium (Ti)-Total	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.012	0.014	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Uranium (U)-Total	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020
Vanadium (V)-Total	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0010	<0.0010	<0.0010	<0.0010	0.0010	0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0010
Zinc (Zn)-Total	<0.0050	<0.0050	0.0091	<0.0050	<0.0050	<0.0050	0.0114	0.0095	<0.0050	<0.0050	0.0128	0.0090	0.0064	0.0087	<0.0050	0.0054	<0.0050	0.0068	<0.0050	0.0088

Appendix C2-A Table 3a. Water quality measurements (general parameters) collected from sites in Mackay Creek in 2007 and 2008 by Northshore Streamkeepers.

Site	MacKay 1	MacKay 1	MacKay 1	MacKay 1	MacKay 1	MacKay 2	MacKay 2	MacKay 2	MacKay 2	MacKay 2	MacKay 3	MacKay 3	MacKay 3	MacKay 3	MacKay 3	MacKay 4	MacKay 4	MacKay 4	MacKay 4	MacKay 4
X	492541	492541	492541	492541	492541	492728	492728	492728	492728	492728	492847	492847	492847	492847	492847	493188	493188	493188	493188	493188
Y	5463241	5463241	5463241	5463241	5463241	5463486	5463486	5463486	5463486	5463486	5465885	5465885	5465885	5465885	5465885	5467470	5467470	5467470	5467470	5467470
	Temp	Sp C	pH	DO%	Do mg/L	Temp	Sp C	pH	DO%	Do mg/L	Temp	Sp C	pH	DO%	Do mg/L	Temp	Sp C	pH	DO%	Do mg/L
WINTER																				
12-Nov-07	9	75	7.8	90	10.45	8.9	71	7.2	96	10.7	8.7	56	7.7	96	11.1	7.3	19	6.8	94	11.3
09-Dec-07	4.9	105	7.8	93	11.8	4.7	103	7.8	94	12.2	5.0	93	7.5	87	11.1	3.8	29	7.1	87.8	11.6
13-Jan-08	6.8	100	6.8			6.8	99	6.5			6.3	81	7			5.2	26	6.3		
18-Feb-08	4.6	99.3	6.3	107	13.8	4.4	103	6.2	112	14.6	5	114	6.6	111	14.2	4.3	25	6.14	112	14.6
16-Mar-08	6.3	86	7.0	91	11.3	6.1	85	7.6	91	11.2	5.4	82	7.2	86	10.9		22	7.2	87	11.3
13-Apr-08	9.9	122	7.5			9.7	119	7.1			8.3	112	7.4			7	27	6.7		
mean	6.9	97.9	7.2	95.3	11.8	6.8	96.7	7.1	98.3	12.2	6.5	89.7	7.2	95.0	11.8	5.5	24.7	6.7	95.2	12.2
SUMMER																				
11-May-08	9.8	96	6.9	100	11.3	11.3	99	7	96	10.7	8.4	82	7.3	90	10.5	6.8	24	6.8		
09-Jun-08	12.4	5	7.1	76	8.6	11		7.1	75	8.5	10.3		7.2	73	8.2	7.8		7	74	8.8
18-Jul-08	16.4	225	6.6	98		16.4	221	6.7	100		16.1	219	7	98		12.7	81	6.8	99	
18-Aug-08	17	260	6.6	98.7	9.5	17	248	7	114	11	17	256	7.2	106	10.2	14.3	92	7.5	122	12.6
15-Sep-08	13.8	256	6.65	85	8.8	14.2	255	7	90	9.2	14.8	279	7	89	9	13.1	75	7.2	93	9.9
26-Oct-08	8.9	119		98	11.5	9.1	121		96	11.2	9.2	113		92	10.5	8.6	37		86	11.2
mean	13.1	160.2	6.8	92.6	9.9	13.2	188.8	7.0	95.2	10.1	12.6	189.8	7.1	91.3	9.7	10.6	61.8	7.1	94.8	10.6

Mackay 1: Mackay Creek Park; downstream of Marine Drive
Mackay 2: Heywood Park; upstream of Marine Drive
Mackay 3: Upper Mackay Creek Park
Mackay 4: Headwater stream in Sarita Park

Appendix C2-A Table 3b. Mackay Creek 2007 and 2008 water quality collected by NS Streamkeepers.

SampleID	MACKAY1	MACKAY1	MACKAY1	MACKAY1	MACKAY1	MACKAY1	MACKAY1	MACKAY1	MACKAY1	MACKAY1	MACKAY1
X	492541	492541	492541	492541	492541	492541	492541	492541	492541	492541	492541
Y	5463241	5463241	5463241	5463241	5463241	5463241	5463241	5463241	5463241	5463241	5463241
Date	12-NOV-07	09-DEC-07	13-JAN-08	18-FEB-08	16-MAR-08	13-APR-08	11-MAY-08	09-JUN-08	14-JUL-08	18-AUG-08	15-SEP-08
Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Hardness	21	26.9	20.6	27.6	25.9	22.6	20.7	20.1	35.2	38.2	37.5
Conductivity	79.1	109	105	173	128	115	88.6	57.1	131	137	137
pH	7.37	7.38	7.33	7.52	7.56	7.05	6.72	7.09	7.80	7.77	7.87
TSS	3.8	36.2	3	3	3	3	3	111	3	3	3
Turbidity	3.3	6.31	1.09	1.14	1.85	1.59	1.61	55.7	1.63	2.26	1.53
Anions and Nutrients											
Ammonia as N	0.0050	0.0076	0.0094	0.0128	0.0071	0.0050	0.0074	0.0086	0.0059	0.0270	0.0076
Alkalinity, Total	15.3	19.6	15.3	17.9	18.7	17.3	16.2	13	29.2	33.6	30.3
Bromide (Br)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Chloride (Cl)	10.4	15.1	17.1	34.2	21.4	19.1	12.8	6.59	15.6	15.4	16.5
Fluoride (F)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.020	0.02
Sulfate (SO4)	4.04	4.74	3.81	4.89	4.56	3.88	3.94	2.19	5.29	5.75	5.33
Nitrate (as N)	0.442	0.595	0.462	0.580	0.451	0.401	0.464	0.259	0.555	0.623	0.577
Nitrite (as N)	0.001	0.001	0.001	0.0013	0.001	0.0016	0.0019	0.0041	0.0023	0.0059	0.0027
Ortho Phosphate as P	0.001	0.001	0.0012	0.0015	0.001	0.001	0.001	0.0012	0.0025	0.0025	0.0020
Total Dissolved Phosph	0.0027	0.0020	0.0025	0.0024	0.0020	0.0020	0.0024	0.0026	0.0042	0.0061	0.0035
Total Phosphate as P	0.0161	0.0310	0.0053	0.0045	0.0046	0.0071	0.0063	0.1720	0.0088	0.0136	0.0054
Bacteriological Tests											
Total Coliform	2420	201	365	276	866	1990	461	201	2420	24200	7700
E. coli	228	34	79	40	55	45	127	201	326	613	126
Total Metals											
Aluminum (Al)-Total	0.134	1.32	0.0485	0.0331	0.0411	0.0522	0.0445	2.28	0.0309	0.04	0.0184
Antimony (Sb)-Total	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.00117	0.0005	0.0005	0.0005
Arsenic (As)-Total	0.00061	0.00072	0.00050	0.00050	0.00050	0.00050	0.00069	0.00408	0.0005	0.0005	0.0005
Barium (Ba)-Total	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.032	0.02	0.02	0.02
Beryllium (Be)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Boron (B)-Total	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cadmium (Cd)-Total	0.000029	0.000051	0.000019	0.000020	0.000017	0.000017	0.000017	0.000213	0.000018	0.000022	0.000017
Calcium (Ca)-Total	7.1	9.09	7.06	9.46	8.73	7.67	7.04	6.44	11.8	12.7	12.5
Chromium (Cr)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0054	0.001	0.001	0.001
Cobalt (Co)-Total	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.00109	0.0003	0.0003	0.0003
Copper (Cu)-Total	0.0026	0.0040	0.001	0.001	0.001	0.0015	0.0022	0.0298	0.0013	0.0044	0.0011
Iron (Fe)-Total	0.266	1.02	0.141	0.176	0.209	0.234	0.242	7.08	0.295	0.369	0.295
Lead (Pb)-Total	0.00061	0.00316	0.0005	0.0005	0.0005	0.0005	0.0005	0.0149	0.0005	0.0005	0.0005
Lithium (Li)-Total	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Magnesium (Mg)-Total	0.81	1.02	0.71	0.98	0.99	0.84	0.77	0.97	1.41	1.58	1.51
Manganese (Mn)-Total	0.01150	0.03860	0.00727	0.00946	0.00934	0.00890	0.00992	0.12400	0.0113	0.0134	0.0115
Mercury (Hg)-Total	0.00002	0.00002		0.00002	0.00002	0.00002	0.00002	0.000037	0.00002	0.00002	0.00002
Molybdenum (Mo)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Nickel (Ni)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0022	0.001	0.001	0.001
Potassium (K)-Total	2	2	2	2	2	2	2	2	2	2	2
Selenium (Se)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Silver (Ag)-Total	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.000095	0.00002	0.00002	0.00002
Sodium (Na)-Total	6.4	9.9	10.6	19.6	12.5	13	8.3	4.9	10.5	10.6	10.7
Thallium (Tl)-Total	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Tin (Sn)-Total	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.00077	0.0005	0.0005	0.0005
Titanium (Ti)-Total	0.01	0.022	0.01	0.01	0.01	0.01	0.01	0.083	0.01	0.01	0.01
Uranium (U)-Total	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.00028	0.0002	0.0002	0.0002
Vanadium (V)-Total	0.001	0.0019	0.001	0.001	0.001	0.001	0.001	0.0073	0.001	0.001	0.001
Zinc (Zn)-Total	0.0080	0.0119	0.005	0.005	0.005	0.005	0.005	0.0559	0.005	0.005	0.005
Dissolved Metals											
Aluminum (Al)-Diss		0.0157						0.0197			
Antimony (Sb)-Diss		0.0005						0.0005			
Arsenic (As)-Diss		0.0005						0.00055			
Beryllium (Be)-Diss		0.001						0.001			
Cadmium (Cd)-Diss		0.000017						0.000017			
Chromium (Cr)-Diss		0.001						0.0014			
Cobalt (Co)-Diss		0.0003						0.0003			
Copper (Cu)-Diss	0.002	0.001	0.001		0.001	0.00125	0.002	0.0028	0.0010		
Lead (Pb)-Diss		0.0005						0.0005			
Lithium (Li)-Diss		0.005						0.005			
Manganese (Mn)-Diss		0.0077						0.00567			
Mercury (Hg)-Diss		0.00002						0.00002			
Molybdenum (Mo)-Diss		0.001						0.001			
Nickel (Ni)-Diss		0.001						0.001			
Selenium (Se)-Diss		0.001						0.001			
Silver (Ag)-Diss		0.00002						0.00002			
Thallium (Tl)-Diss		0.0002						0.0002			
Tin (Sn)-Diss		0.0005						0.0005			
Uranium (U)-Diss		0.0002						0.0002			
Vanadium (V)-Diss		0.001						0.001			
Zinc (Zn)-Diss	0.0064	0.005	0.005		0.005	0.0025	0.005	0.005	0.005		

Appendix C2-A Table 3b. Mackay Creek 2007 and 2008 water quality collected by NS Streamkeepers.

SampleID	MACKAY2	MACKAY2	MACKAY2	MACKAY2	MACKAY2	MACKAY2	MACKAY2	MACKAY2	MACKAY2	MACKAY2	MACKAY2
X	492728	492728	492728	492728	492728	492728	492728	492728	492728	492728	492728
Y	5463486	5463486	5463486	5463486	5463486	5463486	5463486	5463486	5463486	5463486	5463486
Date	12-NOV-07	09-DEC-07	13-JAN-08	18-FEB-08	16-MAR-08	13-APR-08	11-MAY-08	09-JUN-08	14-JUL-08	18-AUG-08	15-SEP-08
Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Hardness	21	24.4	19.8	27.4	24.2	21.9	19.5	20	32.7	35.9	33.8
Conductivity	75.4	108	104	173	127	113	93.3	60.5	124	133	137
pH	7.33	7.43	7.33	7.42	7.52	7.14	7.06	7.16	7.84	7.80	7.81
TSS	5.8	3.00	3.00	3.00	3.00	3.00	3.4	134	3	3	3
Turbidity	3.01	0.81	1.21	0.94	1.18	1.83	1.78	55.1	1.83	3.10	2.41
Anions and Nutrients											
Ammonia as N	0.0050	0.0085	0.0072	0.0112	0.0224	0.0050	0.0069	0.0107	0.0078	0.005	0.0052
Alkalinity, Total	16.4	19.3	14.4	17.3	18	14.3	16.8	12.2	27.5	30.5	29.3
Bromide (Br)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Chloride (Cl)	8.78	15.3	17.3	35.5	21.9	19.3	14.2	7.24	16.2	16.2	17.4
Fluoride (F)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Sulfate (SO4)	3.93	4.48	3.71	4.64	4.25	3.55	3.66	2.09	4.86	4.69	5.24
Nitrate (as N)	0.477	0.579	0.45	0.563	0.432	0.373	0.389	0.264	0.550	0.548	0.561
Nitrite (as N)	0.00	0.00	0.0010	0.0016	0.0010	0.0010	0.0010	0.0028	0.0015	0.0013	0.0012
Ortho Phosphate as P	0.00	0.00	0.0014	0.0013	0.0010	0.0010	0.0010	0.0016	0.0015	0.0011	0.001
Total Dissolved Phosph	0.0028	0.0020	0.0029	0.0024	0.0026	0.0020	0.0024	0.0028	0.0030	0.0047	0.0027
Total Phosphate as P	0.0098	0.0036	0.0058	0.0045	0.0040	0.0060	0.0065	0.1480	0.0086	0.0069	0.0048
Bacteriological Tests											
Total Coliform	2420	201	411	261	435	1200	921	201	2420	3080	2420
E. coli	179	200	82	45	79	33	37	201	79	105	54
Total Metals											
Aluminum (Al)-Total	0.0625	0.0304	0.0534	0.028	0.033	0.067	0.068	2.420	0.0524	0.04	0.0270
Antimony (Sb)-Total	0.00	0.00	0.00	0.001	0.001	0.001	0.001	0.0007	0.0005	0.0005	0.0005
Arsenic (As)-Total	0.00	0.00	0.00	0.00050	0.00050	0.00050	0.00050	0.00543	0.0005	0.0005	0.0005
Barium (Ba)-Total	0.02	0.02	0.02	0.02000	0.02000	0.02000	0.02000	0.032	0.02	0.02	0.02
Beryllium (Be)-Total	0.00	0.00	0.00	0.00100	0.00100	0.00100	0.00100	0.00100	0.001	0.001	0.001
Boron (B)-Total	0.10	0.10	0.10	0.100	0.100	0.100	0.100	0.100	0.1	0.1	0.1
Cadmium (Cd)-Total	0.00	0.00	0.00	0.000029	0.000017	0.000024	0.000017	0.000220	0.000017	0.000017	0.000017
Calcium (Ca)-Total	7.15	8.27	6.79	9.37	8.14	7.43	6.62	6.55	10.9	11.9	11.2
Chromium (Cr)-Total	0.00	0.00	0.00	0.00	0.00	0.00	0.001	0.0048	0.001	0.001	0.001
Cobalt (Co)-Total	0.00	0.00	0.00	0.00	0.00	0.00	0.0003	0.00115	0.0003	0.0003	0.0003
Copper (Cu)-Total	0.0021	0.00	0.00	0.00	0.00	0.0015	0.002	0.0208	0.0011	0.0017	0.001
Iron (Fe)-Total	0.130	0.165	0.138	0.156	0.180	0.260	0.305	6.4	0.421	0.374	0.329
Lead (Pb)-Total	0.00	0.00	0.00	0.00	0.00	0.00053	0.0005	0.0117	0.0005	0.0005	0.0005
Lithium (Li)-Total	0.01	0.01	0.01	0.01	0.01	0.01	0.005	0.005	0.005	0.005	0.005
Magnesium (Mg)-Total	0.77	0.90	0.69	0.96	0.93	0.82	0.73	0.89	1.33	1.51	1.42
Manganese (Mn)-Total	0.00617	0.00972	0.00701	0.00876	0.00886	0.00941	0.01090	0.1540	0.0159	0.0122	0.0133
Mercury (Hg)-Total	0.00	0.00		0.00	0.00	0.00	0.00002	0.000034	0.00002	0.00002	0.00002
Molybdenum (Mo)-Total	0.00	0.00	0.00	0.00	0.00	0.00	0.001	0.001	0.001	0.001	0.001
Nickel (Ni)-Total	0.00	0.00	0.00	0.00	0.00	0.00	0.001	0.0016	0.001	0.001	0.001
Potassium (K)-Total	2.00	2.00	2.00	2.00	2.00	2.00	2	2	2	2	2
Selenium (Se)-Total	0.00	0.00	0.00	0.00	0.00	0.00	0.001	0.001	0.001	0.001	0.001
Silver (Ag)-Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00002	0.000031	0.00002	0.00002	0.00002
Sodium (Na)-Total	5.8	10	11	20.5	12.6	13.3	8.7	5.2	10.8	10.9	12.3
Thallium (Tl)-Total	0.00	0.00	0.00	0.00	0.00	0.00	0.0002	0.0002	0.0002	0.0002	0.0002
Tin (Sn)-Total	0.00	0.00	0.00	0.00	0.00	0.00	0.0005	0.0005	0.0005	0.0005	0.0005
Titanium (Ti)-Total	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.076	0.01	0.01	0.01
Uranium (U)-Total	0.00	0.00	0.00	0.00	0.00	0.00	0.0002	0.00040	0.0002	0.0002	0.0002
Vanadium (V)-Total	0.00	0.00	0.00	0.00	0.00	0.00	0.001	0.0077	0.001	0.001	0.0025
Zinc (Zn)-Total	0.0051	0.01	0.01	0.01	0.01	0.01	0.005	0.0418	0.005	0.005	0.005
Dissolved Metals											
Aluminum (Al)-Diss		0.0154						0.016			
Antimony (Sb)-Diss		0.00						0.0005			
Arsenic (As)-Diss		0.00						0.00074			
Beryllium (Be)-Diss		0.00						0.001			
Cadmium (Cd)-Diss		0.00						0.000017			
Chromium (Cr)-Diss		0.00						0.001			
Cobalt (Co)-Diss		0.00						0.0003			
Copper (Cu)-Diss	0.0017	0.00	0.00		0.00	0.0008	0.002	0.002	0.001		
Lead (Pb)-Diss		0.00						0.0005			
Lithium (Li)-Diss		0.01						0.005			
Manganese (Mn)-Diss		0.00865						0.00409			
Mercury (Hg)-Diss		0.00						0.00002			
Molybdenum (Mo)-Diss		0.00						0.001			
Nickel (Ni)-Diss		0.00						0.001			
Selenium (Se)-Diss		0.00						0.001			
Silver (Ag)-Diss		0.00						0.00002			
Thallium (Tl)-Diss		0.00						0.0002			
Tin (Sn)-Diss		0.00						0.0005			
Uranium (U)-Diss		0.00						0.0002			
Vanadium (V)-Diss		0.00						0.001			
Zinc (Zn)-Diss	0.0056	0.0051	0.01		0.01	0.0020	0.005	0.005	0.005		

Appendix C2-A Table 3b. Mackay Creek 2007 and 2008 water quality collected by NS Streamkeepers.

SampleID	MACKAY4	MACKAY4	MACKAY4	MACKAY4	MACKAY4	MACKAY4	MACKAY4	MACKAY4	MACKAY4	MACKAY4
X	493188	493188	493188	493188	493188	493188	493188	493188	493188	493188
Y	5467470	5467470	5467470	5467470	5467470	5467470	5467470	5467470	5467470	5467470
Date	09-DEC-07	13-JAN-08	18-FEB-08	16-MAR-08	13-APR-08	11-MAY-08	09-JUN-08	14-JUL-08	18-AUG-08	15-SEP-08
Month	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Hardness	6.25	8.52	6.87	8.82	8.31	7.15	7	7.98	14.1	14.9
Conductivity	21	32.1	28.9	39.1	35.4	27.9	22.1	27.9	47.8	58.3
pH	7.09	7.22	6.92	7.02	7.14	6.83	6.95	7.08	7.51	7.60
TSS	3	3	3	3	3	3	3	3	3	3
Turbidity	0.67	0.17	0.23	0.4	0.33	0.47	0.41	1.3	0.20	0.19
Anions and Nutrients										
Ammonia as N	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.005	0.005
Alkalinity, Total	4.1	7.1	5.2	6.8	7.5	7.5	5.3	7.5	11.8	12.8
Bromide (Br)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Chloride (Cl)	2.07	2.95	3.28	5.95	4.06	2.49	1.76	1.51	4.25	4.37
Fluoride (F)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Sulfate (SO4)	2.15	2.62	2.17	2.74	2.47	1.94	1.91	1.59	3.14	3.00
Nitrate (as N)	0.0498	0.0677	0.0478	0.0657	0.0510	0.0716	0.0804	0.0837	0.151	0.238
Nitrite (as N)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ortho Phosphate as P	0.001	0.001	0.0012	0.0013	0.0011	0.0011	0.001	0.0015	0.0019	0.0012
Total Dissolved Phosph	0.0020	0.0020	0.0021	0.0025	0.0020	0.0020	0.0020	0.0020	0.0022	0.002
Total Phosphate as P	0.0035	0.002	0.0025	0.0026	0.002	0.0023	0.0024	0.0050	0.0024	0.0028
Bacteriological Tests										
Total Coliform	411	83	44	53	88	132	261	201	2420	2420
E. coli	5	1	4	1	1	1	1	201	19	3
Total Metals										
Aluminum (Al)-Total	0.0901	0.0305	0.0416	0.0319	0.0299	0.0582	0.0636	0.1150	0.0236	0.03
Antimony (Sb)-Total	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Arsenic (As)-Total	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Barium (Ba)-Total	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Beryllium (Be)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Boron (B)-Total	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cadmium (Cd)-Total	0.000017	0.000017	0.000017	0.000017	0.000017	0.000017	0.000017	0.000017	0.000017	0.000017
Calcium (Ca)-Total	2.01	2.76	2.2	2.84	2.66	2.29	2.26	2.6	4.61	4.85
Chromium (Cr)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Cobalt (Co)-Total	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Copper (Cu)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0013	0.001	0.001
Iron (Fe)-Total	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.052	0.03	0.03
Lead (Pb)-Total	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Lithium (Li)-Total	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Magnesium (Mg)-Total	0.3	0.4	0.33	0.42	0.41	0.34	0.33	0.36	0.64	0.68
Manganese (Mn)-Total	0.002	0.00039	0.00068	0.00052	0.00046	0.00094	0.00083	0.00364	0.00134	0.00174
Mercury (Hg)-Total	0.00002	0.00002		0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Molybdenum (Mo)-Total	0.001	0.0010	0.001	0.0010	0.0011	0.0011	0.001	0.001	0.0011	0.0013
Nickel (Ni)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Potassium (K)-Total	2	2	2	2	2	2	2	2	2	2
Selenium (Se)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Silver (Ag)-Total	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Sodium (Na)-Total	2	2.5	2.5	4.4	3	2.5	2	2	3.7	4.3
Thallium (Tl)-Total	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Tin (Sn)-Total	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Titanium (Ti)-Total	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Uranium (U)-Total	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Vanadium (V)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)-Total	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Dissolved Metals										
Aluminum (Al)-Diss		0.0254						0.0511		
Antimony (Sb)-Diss		0.0005						0.0005		
Arsenic (As)-Diss		0.0005						0.0005		
Beryllium (Be)-Diss		0.001						0.001		
Cadmium (Cd)-Diss		0.000017			-			0.000017		
Chromium (Cr)-Diss		0.001						0.001		
Cobalt (Co)-Diss		0.0003						0.0003		
Copper (Cu)-Diss	0.001	0.001	0.001		0.0011	0.00064	0.001	0.002	0.001	
Lead (Pb)-Diss		0.0005						0.0005		
Lithium (Li)-Diss		0.005						0.005		
Manganese (Mn)-Diss		0.0003						0.00057		
Mercury (Hg)-Diss		0.00002						0.00002		
Molybdenum (Mo)-Diss		0.001						0.001		
Nickel (Ni)-Diss		0.001						0.001		
Selenium (Se)-Diss		0.001						0.001		
Silver (Ag)-Diss		0.00002						0.00002		
Thallium (Tl)-Diss		0.0002						0.0002		
Tin (Sn)-Diss		0.0005						0.0005		
Uranium (U)-Diss		0.0002						0.0002		
Vanadium (V)-Diss		0.001						0.001		
Zinc (Zn)-Diss	0.005	0.005	0.005		0.005	0.001	0.005	0.005	0.005	

Appendix C2-A Table 3b. Mackay Creek 2007 and 2008 water quality collected by NS Streamkeepers.

SampleID	MACKAY3	MACKAY3	MACKAY3	MACKAY3	MACKAY3	MACKAY3	MACKAY3	MACKAY3	MACKAY3	MACKAY3	MACKAY3
X	492847	492847	492847	492847	492847	492847	492847	492847	492847	492847	492847
Y	5465885	5465885	5465885	5465885	5465885	5465885	5465885	5465885	5465885	5465885	5465885
Date	12-NOV-07	09-DEC-07	13-JAN-08	18-FEB-08	16-MAR-08	13-APR-08	11-MAY-08	09-JUN-08	14-JUL-08	18-AUG-08	15-SEP-08
Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
		1									
Hardness	16.3	18.2	15.6	22.8	18.5	15.8	13.3	12.3	25.2	29.3	29.6
Conductivity	58.3	96.9	96.1	188	124	106	78.3	50.1	126	136	149
pH	7.28	7.42	7.23	7.27	7.37	6.99	7.03	7.33	7.73	7.70	7.73
TSS	3	3	3	3	3.4	3	3	29.7	3	3	3
Turbidity	1.9	0.55	0.8	0.83	0.66	1.58	0.75	19.4	1.46	0.77	1.11
Anions and Nutrients											
Ammonia as N	0.0050	0.0079	0.0075	0.0111	0.0106	0.0050	0.0050	0.0170	0.0122	0.0087	0.0084
Alkalinity, Total	12.6	14.6	11.2	12.4	12.5	9.5	9.5	9.9	21.2	23.9	24.5
Bromide (Br)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Chloride (Cl)	6.37	2.95	18.2	44.1	25.5	22.2	14.3	6.36	20.3	21.1	25.1
Fluoride (F)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Sulfate (SO4)	3.16	2.63	2.84	3.33	3.06	2.46	2.66	1.37	3.66	3.47	3.94
Nitrate (as N)	0.353	0.0686	0.266	0.312	0.207	0.21	0.155	0.179	0.395	0.501	0.449
Nitrite (as N)	0.001	0.001	0.001	0.0013	0.001	0.001	0.001	0.0028	0.0040	0.0051	0.0033
Ortho Phosphate as P	0.001	0.0011	0.0011	0.0015	0.0016	0.001	0.001	0.0030	0.0058	0.0036	0.0037
Total Dissolved Phosph	0.0027	0.0026	0.0027	0.0026	0.0022	0.0020	0.0036	0.0033	0.0075	0.0085	0.0061
Total Phosphate as P	0.0079	0.0040	0.0048	0.0042	0.0065	0.0050	0.0068	0.0621	0.0121	0.0121	0.0090
Bacteriological Tests											
Total Coliform	1990	201	1200	2420	2420	1990	1550	201	2420	11200	5480
E. coli	128	201	91	649	579	115	276	201	1120	3260	1730
Total Metals											
Aluminum (Al)-Total	0.166	0.0275	0.0416	0.0275	0.0278	0.0635	0.0463	0.736	0.0450	0.04	0.0294
Antimony (Sb)-Total	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Arsenic (As)-Total	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.00373	0.0005	0.0005	0.0005
Barium (Ba)-Total	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Beryllium (Be)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Boron (B)-Total	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cadmium (Cd)-Total	0.000021	0.000017	0.000017	0.000018	0.000017	0.000021	0.000017	0.000059	0.000022	0.000017	0.000017
Calcium (Ca)-Total	5.64	6.31	5.44	7.96	6.38	5.43	4.58	4.2	8.80	10.2	10.3
Chromium (Cr)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0027	0.001	0.001	0.001
Cobalt (Co)-Total	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.00038	0.0003	0.0003	0.0003
Copper (Cu)-Total	0.0015	0.001	0.001	0.001	0.001	0.0017	0.002	0.0067	0.0014	0.0023	0.0015
Iron (Fe)-Total	0.129	0.094	0.081	0.111	0.102	0.154	0.132	1.500	0.245	0.238	0.199
Lead (Pb)-Total	0.0005	0.0005	0.0005	0.0005	0.0005	0.0007	0.0005	0.00274	0.0005	0.0005	0.0005
Lithium (Li)-Total	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Magnesium (Mg)-Total	0.53	0.59	0.49	0.72	0.64	0.53	0.45	0.45	0.79	0.94	0.96
Manganese (Mn)-Total	0.00777	0.00830	0.00583	0.00892	0.00773	0.00809	0.00692	0.04550	0.0145	0.0114	0.0120
Mercury (Hg)-Total	0.00002	0.00002		0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Molybdenum (Mo)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Nickel (Ni)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Potassium (K)-Total	2	2	2	2	2	2	2	2	2	2	2
Selenium (Se)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Silver (Ag)-Total	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Sodium (Na)-Total	4.8	10.3	11.2	24.4	14.1	13.9	8.8	4.8	13.0	14.1	15.8
Thallium (Tl)-Total	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Tin (Sn)-Total	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Titanium (Ti)-Total	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.027	0.01	0.01	0.01
Uranium (U)-Total	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002
Vanadium (V)-Total	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0020	0.001	0.001	0.001
Zinc (Zn)-Total	0.0103	0.005	0.005	0.005	0.005	0.005	0.005	0.0130	0.005	0.005	0.005
Dissolved Metals											
Aluminum (Al)-Diss		0.0186						0.0233			
Antimony (Sb)-Diss		0.0005						0.0005			
Arsenic (As)-Diss		0.0005						0.00127			
Beryllium (Be)-Diss		0.001						0.001			
Cadmium (Cd)-Diss		0.000017			-			0.000017			
Chromium (Cr)-Diss		0.001						0.0011			
Cobalt (Co)-Diss		0.0003						0.0003			
Copper (Cu)-Diss	0.0011	0.001	0.001		0.001	0.00054	0.001	0.002	0.001		
Lead (Pb)-Diss		0.0005						0.0005			
Lithium (Li)-Diss		0.005						0.005			
Manganese (Mn)-Diss		0.00808						0.0047			
Mercury (Hg)-Diss		0.00002						0.00002			
Molybdenum (Mo)-Diss		0.001						0.001			
Nickel (Ni)-Diss		0.001						0.001			
Selenium (Se)-Diss		0.001						0.001			
Silver (Ag)-Diss		0.00002						0.00002			
Thallium (Tl)-Diss		0.0002						0.0002			
Tin (Sn)-Diss		0.0005						0.0005			
Uranium (U)-Diss		0.0002						0.0002			
Vanadium (V)-Diss		0.001						0.001			
Zinc (Zn)-Diss	0.005	0.005	0.005		0.005	0.0019	0.005	0.005	0.005		

Appendix C2-A Table 4. Summary of fecal coliform and E. coli data

Samping Program	SampleID	X	Y	Date	E. coli	F Coliform
NSSK	MACKAY1	492541	5463241	12-NOV-07	228	
NSSK	MACKAY1	492541	5463241	09-DEC-07	34	
NSSK	MACKAY1	492541	5463241	13-JAN-08	79	
NSSK	MACKAY1	492541	5463241	18-FEB-08	40	
NSSK	MACKAY1	492541	5463241	16-MAR-08	55	
NSSK	MACKAY1	492541	5463241	13-APR-08	45	
NSSK	MACKAY1	492541	5463241	11-MAY-08	127	
NSSK	MACKAY1	492541	5463241	09-JUN-08	201	
NSSK	MACKAY1	492541	5463241	14-JUL-08	326	
NSSK	MACKAY1	492541	5463241	18-AUG-08	613	
NSSK	MACKAY1	492541	5463241	15-SEP-08	126	
NSSK	MACKAY2	492728	5463486	12-NOV-07	179	
NSSK	MACKAY2	492728	5463486	09-DEC-07	200	
NSSK	MACKAY2	492728	5463486	13-JAN-08	82	
NSSK	MACKAY2	492728	5463486	18-FEB-08	45	
NSSK	MACKAY2	492728	5463486	16-MAR-08	79	
NSSK	MACKAY2	492728	5463486	13-APR-08	33	
NSSK	MACKAY2	492728	5463486	11-MAY-08	37	
NSSK	MACKAY2	492728	5463486	09-JUN-08	201	
NSSK	MACKAY2	492728	5463486	14-JUL-08	79	
NSSK	MACKAY2	492728	5463486	18-AUG-08	105	
NSSK	MACKAY2	492728	5463486	15-SEP-08	54	
NSSK	MACKAY4	493188	5467470	09-DEC-07	5	
NSSK	MACKAY4	493188	5467470	13-JAN-08	1	
NSSK	MACKAY4	493188	5467470	18-FEB-08	4	
NSSK	MACKAY4	493188	5467470	16-MAR-08	1	
NSSK	MACKAY4	493188	5467470	13-APR-08	1	
NSSK	MACKAY4	493188	5467470	11-MAY-08	1	
NSSK	MACKAY4	493188	5467470	09-JUN-08	1	
NSSK	MACKAY4	493188	5467470	14-JUL-08	201	
NSSK	MACKAY4	493188	5467470	18-AUG-08	19	
NSSK	MACKAY4	493188	5467470	15-SEP-08	3	
NSSK	MACKAY3	492847	5465885	12-NOV-07	128	
NSSK	MACKAY3	492847	5465885	09-DEC-07	201	
NSSK	MACKAY3	492847	5465885	13-JAN-08	91	
NSSK	MACKAY3	492847	5465885	18-FEB-08	649	
NSSK	MACKAY3	492847	5465885	16-MAR-08	579	
NSSK	MACKAY3	492847	5465885	13-APR-08	115	
NSSK	MACKAY3	492847	5465885	11-MAY-08	276	
NSSK	MACKAY3	492847	5465885	09-JUN-08	201	
NSSK	MACKAY3	492847	5465885	14-JUL-08	1120	
NSSK	MACKAY3	492847	5465885	18-AUG-08	3260	
NSSK	MACKAY3	492847	5465885	15-SEP-08	1730	
MAMF	MACKAY #1	0492488	5463023	22-SEP-14	236	350
MAMF	MOSQUITO #1	0493283	5462833	22-SEP-14	49	23
MAMF	WAGG #1	0493622	5463242	22-SEP-14	2420	1600
MAMF	MISSION #1	0493603	5463306	22-SEP-14	461	350
MAMF	MACKAY #1	0492488	5463023	29-SEP-14	365	350
MAMF	MOSQUITO #1	0493283	5462833	29-SEP-14	276	240
MAMF	WAGG #1	0493622	5463242	29-SEP-14	2420	1600
MAMF	MISSION #1	0493603	5463306	29-SEP-14	365	240
MAMF	MOSQUITO#1	0492488	5463023	03-OCT-14	260	350
MAMF	MACKAY#1	0493283	5462833	03-OCT-14	35	49
MAMF	MISSION#1	0493622	5463242	03-OCT-14	179	240
MAMF	WAGG#1	0493603	5463306	03-OCT-14	1150	400
MAMF	MISSION#1	0492488	5463023	09-OCT-14	139	350
MAMF	MOSQUITO#1	0493283	5462833	09-OCT-14	38	70
MAMF	WAGG#1	0493622	5463242	09-OCT-14	2420	3300
MAMF	MACKAY#1	0493603	5463306	09-OCT-14	613	540
MAMF	MACKAY#1	0492488	5463023	10-OCT-14	148	130
MAMF	MISSION#1	0493283	5462833	10-OCT-14	345	170
MAMF	MOSQUITO 1	0493622	5463242	10-OCT-14	77	49
MAMF	WAGG#1	0493603	5463306	10-OCT-14	2420	1300

Appendix C2-A Table 5. Summary of E. coli and fecal coliform sampling in Mackay and Mosquito Creeks (2007 to 2014).

Samping Program	SampleID	X	Y	Date	E. coli	F Coliform
NSSK	MACKAY1	0492541	5463241	12-NOV-07	228	
NSSK	MACKAY1	0492541	5463241	09-DEC-07	34	
NSSK	MACKAY1	0492541	5463241	13-JAN-08	79	
NSSK	MACKAY1	0492541	5463241	18-FEB-08	40	
NSSK	MACKAY1	0492541	5463241	16-MAR-08	55	
NSSK	MACKAY1	0492541	5463241	13-APR-08	45	
NSSK	MACKAY1	0492541	5463241	11-MAY-08	127	
NSSK	MACKAY1	0492541	5463241	09-JUN-08	201	
NSSK	MACKAY1	0492541	5463241	14-JUL-08	326	
NSSK	MACKAY1	0492541	5463241	18-AUG-08	613	
NSSK	MACKAY1	0492541	5463241	15-SEP-08	126	
NSSK	MACKAY2	0492728	5463486	12-NOV-07	179	
NSSK	MACKAY2	0492728	5463486	09-DEC-07	200	
NSSK	MACKAY2	0492728	5463486	13-JAN-08	82	
NSSK	MACKAY2	0492728	5463486	18-FEB-08	45	
NSSK	MACKAY2	0492728	5463486	16-MAR-08	79	
NSSK	MACKAY2	0492728	5463486	13-APR-08	33	
NSSK	MACKAY2	0492728	5463486	11-MAY-08	37	
NSSK	MACKAY2	0492728	5463486	09-JUN-08	201	
NSSK	MACKAY2	0492728	5463486	14-JUL-08	79	
NSSK	MACKAY2	0492728	5463486	18-AUG-08	105	
NSSK	MACKAY2	0492728	5463486	15-SEP-08	54	
NSSK	MACKAY4	0493188	5467470	09-DEC-07	5	
NSSK	MACKAY4	0493188	5467470	13-JAN-08	1	
NSSK	MACKAY4	0493188	5467470	18-FEB-08	4	
NSSK	MACKAY4	0493188	5467470	16-MAR-08	1	
NSSK	MACKAY4	0493188	5467470	13-APR-08	1	
NSSK	MACKAY4	0493188	5467470	11-MAY-08	1	
NSSK	MACKAY4	0493188	5467470	09-JUN-08	1	
NSSK	MACKAY4	0493188	5467470	14-JUL-08	201	
NSSK	MACKAY4	0493188	5467470	18-AUG-08	19	
NSSK	MACKAY4	0493188	5467470	15-SEP-08	3	
NSSK	MACKAY3	0492847	5465885	12-NOV-07	128	
NSSK	MACKAY3	0492847	5465885	09-DEC-07	201	
NSSK	MACKAY3	0492847	5465885	13-JAN-08	91	
NSSK	MACKAY3	0492847	5465885	18-FEB-08	649	
NSSK	MACKAY3	0492847	5465885	16-MAR-08	579	
NSSK	MACKAY3	0492847	5465885	13-APR-08	115	
NSSK	MACKAY3	0492847	5465885	11-MAY-08	276	
NSSK	MACKAY3	0492847	5465885	09-JUN-08	201	
NSSK	MACKAY3	0492847	5465885	14-JUL-08	1120	
NSSK	MACKAY3	0492847	5465885	18-AUG-08	3260	
NSSK	MACKAY3	0492847	5465885	15-SEP-08	1730	
MAMF	MACKAY #1	0492488	5463023	22-SEP-14	236	350
MAMF	MOSQUITO #1	0493283	5462833	22-SEP-14	49	23
MAMF	WAGG #1	0493622	5463242	22-SEP-14	2420	1600
MAMF	MISSION #1	0493603	5463306	22-SEP-14	461	350
MAMF	MACKAY #1	0492488	5463023	29-SEP-14	365	350
MAMF	MOSQUITO #1	0493283	5462833	29-SEP-14	276	240
MAMF	WAGG #1	0493622	5463242	29-SEP-14	2420	1600
MAMF	MISSION #1	0493603	5463306	29-SEP-14	365	240
MAMF	MOSQUITO#1	0492488	5463023	03-OCT-14	260	350
MAMF	MACKAY#1	0493283	5462833	03-OCT-14	35	49
MAMF	MISSION#1	0493622	5463242	03-OCT-14	179	240
MAMF	WAGG#1	0493603	5463306	03-OCT-14	1150	400
MAMF	MISSION#1	0492488	5463023	09-OCT-14	139	350
MAMF	MOSQUITO#1	0493283	5462833	09-OCT-14	38	70
MAMF	WAGG#1	0493622	5463242	09-OCT-14	2420	3300
MAMF	MACKAY#1	0493603	5463306	09-OCT-14	613	540
MAMF	MACKAY#1	0492488	5463023	10-OCT-14	148	130
MAMF	MISSION#1	0493283	5462833	10-OCT-14	345	170
MAMF	MOSQUITO 1	0493622	5463242	10-OCT-14	77	49
MAMF	WAGG#1	0493603	5463306	10-OCT-14	2420	1300
CNV	MacKay Creek	0492448	5462952	18-Sep-08		49
CNV	Mosquito Creek	0493259	5462842	18-Sep-08		23
CNV	Wagg Creek (lower)	0493427	5462913	18-Sep-08		540
CNV	Wagg Creek (upper)	0493858	5463626	18-Sep-08		
CNV	Mission Creek	0493639	5463510	18-Sep-08		
CNV	Keith Creek	0497554	5462413	18-Sep-08		350
CNV	MacKay Creek	0492448	5462952	23-Sep-08		350
CNV	Mosquito Creek	0493259	5462842	23-Sep-08		70
CNV	Wagg Creek (lower)	0493427	5462913	23-Sep-08		920
CNV	Wagg Creek (upper)	0493858	5463626	23-Sep-08		350
CNV	Mission Creek	0493639	5463510	23-Sep-08		170
CNV	Keith Creek	0497554	5462413	23-Sep-08		
CNV	MacKay Creek	0492448	5462952	29-Sep-08		79
CNV	Mosquito Creek	0493259	5462842	29-Sep-08		49
CNV	Wagg Creek (lower)	0493427	5462913	29-Sep-08		240
CNV	Wagg Creek (upper)	0493858	5463626	29-Sep-08		70

Appendix C2-A Table 5. Summary of E. coli and fecal coliform sampling in Mackay and Mosquito Creeks (2007 to 2014).

Samping Program	SampleID	X	Y	Date	E. coli	F Coliform
CNV	Mission Creek	0493639	5463510	29-Sep-08		17
CNV	Keith Creek	0497554	5462413	29-Sep-08		
CNV	MacKay Creek	0492448	5462952	07-Oct-08		1600
CNV	Mosquito Creek	0493259	5462842	07-Oct-08		70
CNV	Wagg Creek (lower)	0493427	5462913	07-Oct-08		240
CNV	Wagg Creek (upper)	0493858	5463626	07-Oct-08		240
CNV	Mission Creek	0493639	5463510	07-Oct-08		110
CNV	Keith Creek	0497554	5462413	07-Oct-08		
CNV	MacKay Creek	0492448	5462952	14-Oct-08		280
CNV	Mosquito Creek	0493259	5462842	14-Oct-08		49
CNV	Wagg Creek (lower)	0493427	5462913	14-Oct-08		240
CNV	Wagg Creek (upper)	0493858	5463626	14-Oct-08		540
CNV	Mission Creek	0493639	5463510	14-Oct-08		49
CNV	Keith Creek	0497554	5462413	14-Oct-08		
CNV	MacKay Creek	0492448	5462952	15-Oct-08		
CNV	Mosquito Creek	0493259	5462842	15-Oct-08		
CNV	Wagg Creek (lower)	0493427	5462913	15-Oct-08		
CNV	Wagg Creek (upper)	0493858	5463626	15-Oct-08		130
CNV	Mission Creek	0493639	5463510	15-Oct-08		17
CNV	Keith Creek	0497554	5462413	15-Oct-08		
CNV	MacKay Creek	0492448	5462952	30-Sep-10		540
CNV	Mosquito Creek	0493259	5462842	30-Sep-10		540
CNV	Wagg Creek (lower)	0493427	5462913	30-Sep-10		220
CNV	Wagg Creek (upper)	0493858	5463626	30-Sep-10		350
CNV	Mission Creek	0493639	5463510	30-Sep-10		280
CNV	Keith Creek	0497554	5462413	30-Sep-10		
CNV	MacKay Creek	0492448	5462952	01-Oct-10		49
CNV	Mosquito Creek	0493259	5462842	01-Oct-10		33
CNV	Wagg Creek (lower)	0493427	5462913	01-Oct-10		540
CNV	Wagg Creek (upper)	0493858	5463626	01-Oct-10		110
CNV	Mission Creek	0493639	5463510	01-Oct-10		70
CNV	Keith Creek	0497554	5462413	01-Oct-10		
CNV	MacKay Creek	0492448	5462952	06-Oct-10		170
CNV	Mosquito Creek	0493259	5462842	06-Oct-10		79
CNV	Wagg Creek (lower)	0493427	5462913	06-Oct-10		1600
CNV	Wagg Creek (upper)	0493858	5463626	06-Oct-10		49
CNV	Mission Creek	0493639	5463510	06-Oct-10		79
CNV	Keith Creek	0497554	5462413	06-Oct-10		
CNV	MacKay Creek	0492448	5462952	13-Oct-10		130
CNV	Mosquito Creek	0493259	5462842	13-Oct-10		33
CNV	Wagg Creek (lower)	0493427	5462913	13-Oct-10		130
CNV	Wagg Creek (upper)	0493858	5463626	13-Oct-10		240
CNV	Mission Creek	0493639	5463510	13-Oct-10		170
CNV	Keith Creek	0497554	5462413	13-Oct-10		
CNV	MacKay Creek	0492448	5462952	12-Sep-12		130
CNV	Mosquito Creek	0493259	5462842	12-Sep-12		110
CNV	Wagg Creek (lower)	0493427	5462913	12-Sep-12		130
CNV	Wagg Creek (upper)	0493858	5463626	12-Sep-12		240
CNV	Mission Creek	0493639	5463510	12-Sep-12		170
CNV	Keith Creek	0497554	5462413	12-Sep-12		
CNV	MacKay Creek	0492448	5462952	19-Sep-12		170
CNV	Mosquito Creek	0493259	5462842	19-Sep-12		23
CNV	Wagg Creek (lower)	0493427	5462913	19-Sep-12		79
CNV	Wagg Creek (upper)	0493858	5463626	19-Sep-12		1600
CNV	Mission Creek	0493639	5463510	19-Sep-12		130
CNV	Keith Creek	0497554	5462413	19-Sep-12		
CNV	MacKay Creek	0492448	5462952	24-Sep-12		33
CNV	Mosquito Creek	0493259	5462842	24-Sep-12		540
CNV	Wagg Creek (lower)	0493427	5462913	24-Sep-12		540
CNV	Wagg Creek (upper)	0493858	5463626	24-Sep-12		350
CNV	Mission Creek	0493639	5463510	24-Sep-12		79
CNV	Keith Creek	0497554	5462413	24-Sep-12		
CNV	MacKay Creek	0492448	5462952	01-Oct-12		49
CNV	Mosquito Creek	0493259	5462842	01-Oct-12		350
CNV	Wagg Creek (lower)	0493427	5462913	01-Oct-12		920
CNV	Wagg Creek (upper)	0493858	5463626	01-Oct-12		350
CNV	Mission Creek	0493639	5463510	01-Oct-12		220
CNV	Keith Creek	0497554	5462413	01-Oct-12		
CNV	MacKay Creek	0492448	5462952	09-Oct-12		49
CNV	Mosquito Creek	0493259	5462842	09-Oct-12		49
CNV	Wagg Creek (lower)	0493427	5462913	09-Oct-12		240
CNV	Wagg Creek (upper)	0493858	5463626	09-Oct-12		79
CNV	Mission Creek	0493639	5463510	09-Oct-12		23
CNV	Keith Creek	0497554	5462413	09-Oct-12		

Appendix C2-B:
Sediment Quality Data

Appendix C2-B Table 1. Sediment quality data from Mackay and Mosquito watersheds.

Stream	Site ID	Aluminum	Arsenic	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Zinc
Mackay	MACKAY C-1	7960	2.5	0.25	9.4	13.6	11700	15	196	42.4
Mackay	MACKAY C-4	8140	2.5	0.25	10.5	12.8	11400	15	205	43.4
Mackay	MACKAY C-1	8700	2.5	0.25	6.8	12.5	12500	15	224	41.1
Mackay	MACKAY C-2	9370	2.5	0.25	6.9	14.9	11600	15	247	52.4
Mackay	MACKAY C-3	9760	2.5	0.25	12.0	24.4	13300	15	246	58.9
Mackay	MACKAY C-4	9730	2.5	0.25	6.8	17.5	12800	15	250	46.7
Mackay**	MACKAY #1	8350	2.2	0.11	8.6	19.5	12800	17	222	55.8
Mackay**	MACKAY #3	9330	2.8	0.10	7.4	13.2	13000	7	269	42.8
Mission	MISSION C-1	8200	2.5	0.25	9.2	27.0	13200	45	383	85.8
Mission	MISSION C-4	8910	5.3	0.25	15.8	26.6	15300	38	406	102.0
Mission	MISSION C-1	9630	2.5	0.25	12.1	23.1	16600	49	261	94.7
Mission	MISSION C-2	11100	5.4	0.25	13.2	46.0	19300	62	0.5.0	90.2
Mission	MISSION C-3	9400	2.5	0.25	15.3	29.5	16600	49	549	113
Mission	MISSION C-4	10100	2.5	0.25	11.0	27.1	18000	50	492	154
Mission**	MISSION #1	8630	4.2	0.21	10.0	25.4	14700	37	398	96.0
Mosquito	MOSQ1	10100	2.5	0.54	7.1	16.5	17200	15	377	58.8
Mosquito	L-MOSQ C-1	7720	2.5	0.25	6.3	12.0	11600	15	224	45.4
Mosquito	L-MOSQ C-4	8130	7.4	0.25	10.8	17.5	16200	15	270	62.1
Mosquito	MOSQUITO C-1	10700	2.5	0.25	10.8	16.7	19100	15	335	56.5
Mosquito	MOSQUITO C-2	9930	2.5	0.25	8.7	16.6	17100	15	307	62.6
Mosquito	MOSQUITO C-3	9170	2.5	0.25	9.3	13.7	16200	15	222	44.9
Mosquito	MOSQUITO C-4	10900	2.5	0.25	11.1	17.1	18100	15	306	54.8
Mosquito**	MOSQUITO #1	7760	2.0	0.12	9.9	24.1	13800	9	214	56.9
Mosquito**	MOSQUITO #2	10400	1.8	0.12	7.1	18.7	16600	7	349	65.5
Mosquito**	MOSQUITO #3	10600	1.1	0.20	7.5	15.1	19100	7	425	67.8
Thain**	THAIN #1	10600	3.4	0.19	8.3	26.9	16500	9	413	89.4
Wagg	WAGG1	10800	**5.9**	0.25	13.2	**39.5**	15800	15	300	125.0
Wagg	U-WAGG C-1	9400	2.5	0.52	13.6	27.0	18400	15	288	85.8
Wagg	U-WAGG C-4	9720	2.5	0.50	9.5	21.5	15400	15	319	100.0
Wagg	WAGG C-1	9630	2.5	0.25	17.6	**41.9**	18900	15	222	105
Wagg	WAGG C-2	11000	2.5	0.25	16.9	28.9	15700	15	339	114
Wagg	WAGG C-3	10100	5.7	0.25	27.9	**52.6**	17100	33	299	151
Wagg	WAGG C-4	10800	2.5	0.25	19.3	**44.8**	17200	33	376	131
Wagg	Pond - SE Trib 20 m		**11.3**	**1.37**	**52.5**	**193.0**		**111**		**469.0**
Wagg	Pond - N Trib 30 m		**9.7**	0.25	33.6	26.2		25		105.0
Wagg	Pond - N Trib 50 m		2.5	0.25	23.0	**49.2**		25		98.8
Wagg	Pond - N Trib 10 m		5.7	0.25	**37.8**	**43.3**		**96**		105.0
Wagg	Pond - SE Trib 30 m		2.5	**0.60**	29.9	**53.9**		**57**		**150.0**
Wagg	Pond (2014 cleanout)		**6.1**	0.45	26.8	**86.8**		**49**		**205.0**
Wagg	Pond (2014 cleanout)		5.4	0.50	**40.7**	**127.0**		**44**		**254.0**
Wagg**	WAGG #1	8330	4.9	0.30	23.8	**46.7**	17200	21	442	112.0
	No of Samples (regional)	102	123	118	123	118	97	118	103	118
	Mean (regional)	7905	4.3	0.43	15.4	35.0	13484	27	349	100.7
	Mean (Mackay/Mosquito)	4796	3.0	0.27	9.6	21.8	7938	19	127	60.5
	TEL CCME 2002 (Aquatic Life)		**5.9**	**0.60**	**37.3**	**35.7**		**35**		**123.0**
	PEL CCME 2002 (Aquatic Life)		**17.0**	**3.50**	**90.0**	**197.0**		**91**		**315.0**

** 2014 sample site

Appendix C2-C:

Benthic Invertebrate Sampling Data

Appendic C2-C Table 1. 2014 CNV / DNV Benthic Invertebrate Sampling Summary

SITE NAME	SITE ID	Sample date	Taxa richness	B-IBI
Mackay Creek 1	C-1	October-01-14	18.0	18
Mackay Creek 1	C-2	October-01-14	23.0	22
Mackay Creek 1	C-3	October-01-14	25.0	22
Mackay Creek 1	C-4	October-01-14	25.0	26
		Mean	22.8	22.0
Mackay Creek 3	C-1	October-01-14	25.0	24
Mackay Creek 3	C-2	October-01-14	25.0	28
Mackay Creek 3	C-3	October-01-14	30.0	30
Mackay Creek 3	C-4	October-01-14	22.0	24
		Mean	25.5	26.5
Mission Creek 1	C-1	September-28-14	25.0	26
Mission Creek 1	C-2	September-28-14	25.0	26
Mission Creek 1	C-3	September-28-14	23.0	22
Mission Creek 1	C-4	September-28-14	22.0	26
		Mean	23.8	25.0
Mosquito Creek 1	C-1	October-01-14	28.0	26
Mosquito Creek 1	C-2	October-01-14	32.0	30
Mosquito Creek 1	C-3	October-01-14	27.0	28
Mosquito Creek 1	C-4	October-01-14	28.0	26
		Mean	28.8	27.5
Mosquito Creek 2	C-1	September-22-14	31.0	34
Mosquito Creek 2	C-2	September-22-14	32.0	32
Mosquito Creek 2	C-3	September-22-14	28.0	30
Mosquito Creek 2	C-4	September-22-14	27.0	30
		Mean	29.5	31.5
Mosquito Creek 3	C-1	September-20-14	23.0	36
Mosquito Creek 3	C-2	September-20-14	24.0	36
Mosquito Creek 3	C-3	September-20-14	15.0	28
Mosquito Creek 3	C-4	September-20-14	17.0	34
		Mean	19.8	33.5
Thain Creek 1	C-1	September-23-14	15.0	20
Thain Creek 1	C-2	September-23-14	20.0	20
Thain Creek 1	C-3	September-23-14	21.0	20
Thain Creek 1	C-4	September-23-14	19.0	18
		Mean	18.8	19.5
Wagg Creek 1	C-1	September-28-14	15.0	20
Wagg Creek 1	C-2	September-28-14	15.0	22
Wagg Creek 1	C-3	September-28-14	11.0	16
Wagg Creek 1	C-4	September-28-14	12.0	18
		Mean	13.3	19.0

Appendix C2-C Table 2. B-IBI metrics values and scores for 2014 benthic sampling program.

SITE NAME	Mosquito Creek 1				Mosquito Creek 2				Mosquito Creek 3				Mackay Creek 1			
SITE ID	C-1	C-2	C-3	C-4	C-1	C-2	C-3	C-4	C-1	C-2	C-3	C-4	C-1	C-2	C-3	C-4
Sample date	01/10/2014	01/10/2014	01/10/2014	01/10/2014	22/09/2014	22/09/2014	22/09/2014	22/09/2014	20/09/2014	20/09/2014	20/09/2014	20/09/2014	01/10/2014	01/10/2014	01/10/2014	01/10/2014
Proportion of sample used	100.00%	70.00%	70.00%	100.00%	33.33%	33.33%	76.67%	83.33%	100.00%	100.00%	100.00%	100.00%	60.00%	53.33%	100.00%	86.67%
Total Organisms	267	428	417	323	421	434	424	403	234	215	271	267	424	415	296	435
Estimated Abundance	267	611	596	323	1263	1302	553	484	234	215	271	267	707	778	296	502
METRIC VALUES																
Taxa richness	28	32	27	28	31	32	28	27	23	24	15	17	18	23	25	25
E richness	4	4	4	4	5	4	4	1	5	6	2	4	3	2	3	4
P richness	4	4	4	3	4	6	5	4	5	6	5	4	1	3	3	4
T richness	5	5	6	6	9	7	7	8	6	6	4	5	1	0	4	5
INTOLERANT taxa richness	2	1	1	1	2	2	2	3	6	6	5	4	0	1	1	0
Clinger richness	14	13	14	13	17	17	17	14	12	13	8	10	5	6	10	11
LL richness	2	4	3	4	4	4	4	3	2	2	2	1	3	3	4	3
% tolerant	0.37	11.45	0.00	0.62	0.48	0.00	0.00	0.25	0.00	0.00	0.00	0.00	1.89	14.22	1.35	1.15
% predator	6.74	4.44	8.87	7.12	15.91	10.14	12.74	14.89	24.79	32.09	55.72	23.97	4.72	8.92	5.07	4.60
% dominance (3)	59.93	48.13	49.16	48.61	43.23	44.93	39.39	60.55	48.72	43.26	65.68	57.30	80.42	58.07	78.04	77.70
METRIC SCORES																
Taxa richness	3	5	3	3	5	5	3	3	3	3	3	3	3	3	3	3
E richness	1	1	1	1	3	1	1	1	3	3	1	1	1	1	1	1
P richness	3	3	3	1	3	3	3	3	3	3	3	3	1	1	1	3
T richness	3	3	3	3	3	3	3	3	3	3	1	3	1	1	1	3
INTOLERANT taxa richness	1	1	1	1	1	1	1	3	5	5	5	5	1	1	1	1
Clinger richness	3	3	3	3	3	3	3	3	3	3	1	3	1	1	3	3
LL richness	1	3	3	3	3	3	3	3	1	1	1	1	3	3	3	3
% tolerant	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
% predator	1	1	1	1	3	3	3	3	5	5	5	5	1	1	1	1
% dominance (3)	5	5	5	5	5	5	5	3	5	5	3	5	1	5	3	3
BIBI SCORE	**26**	**30**	**28**	**26**	**34**	**32**	**30**	**30**	**36**	**36**	**28**	**34**	**18**	**22**	**22**	**26**
Mean B-IBI Score				**27.5**				**31.5**				**33.5**				**22.0**

Appendix C2-C Table 2. B-IBI metrics values and scores for 2014 benthic sampling program.

SITE NAME	**Mackay Creek 3**				**Mission Creek 1**				**Wagg Creek 1**				**Thain Creek 1**			
SITE ID	C-1	C-2	C-3	C-4	C-1	C-2	C-3	C-4	C-1	C-2	C-3	C-4	C-1	C-2	C-3	C-4
Sample date	01/10/2014	01/10/2014	01/10/2014	01/10/2014	28/09/2014	28/09/2014	28/09/2014	28/09/2014	28/09/2014	28/09/2014	28/09/2014	28/09/2014	23/09/2014	23/09/2014	23/09/2014	23/09/2014
Proportion of sample used	100.00%	56.67%	50.00%	73.33%	70.00%	86.67%	25.00%	100.00%	100.00%	33.33%	53.33%	100.00%	36.67%	36.67%	50.83%	66.67%
Total Organisms	348	428	428	431	410	423	435	267	357	432	420	344	433	428	418	408
Estimated Abundance	348	755	856	588	586	488	1740	267	357	1296	788	344	1181	1167	822	612
METRIC VALUES																
Taxa richness	25	25	30	22	25	25	23	22	15	15	11	12	15	20	21	19
E richness	4	4	4	4	3	4	3	3	2	1	2	1	1	1	3	3
P richness	3	6	3	1	2	2	2	2	1	0	1	0	2	2	1	1
T richness	6	6	8	5	7	7	6	6	3	6	2	3	1	3	3	4
INTOLERANT taxa richness	1	2	2	0	1	1	1	0	0	1	0	0	0	0	0	1
Clinger richness	13	16	15	10	11	14	11	10	6	9	5	4	4	7	8	8
LL richness	4	5	6	3	2	2	2	2	3	2	1	2	3	2	2	2
% tolerant	0.00	0.00	0.23	0.00	1.95	0.00	0.46	0.37	0.28	0.00	0.00	0.00	0.00	0.23	0.00	0.00
% predator	6.61	4.21	6.78	3.94	13.17	11.11	6.90	17.23	2.80	4.17	2.86	11.34	7.39	7.48	4.07	6.13
% dominance (3)	65.80	70.09	57.24	67.98	49.51	57.21	65.06	58.43	66.95	72.45	77.86	66.28	75.06	56.78	48.33	62.99
METRIC SCORES																
Taxa richness	3	3	5	3	3	3	3	3	3	3	1	1	3	3	3	3
E richness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P richness	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T richness	3	3	3	3	3	3	3	3	1	3	1	1	1	1	1	1
INTOLERANT taxa richness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Clinger richness	3	3	3	3	3	3	3	3	1	3	1	1	1	1	1	1
LL richness	3	5	5	3	1	1	1	1	3	1	1	1	3	1	1	1
% tolerant	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
% predator	1	1	1	1	3	3	1	3	1	1	1	3	1	1	1	1
% dominance (3)	3	3	5	3	5	5	3	5	3	3	3	3	3	5	5	3
BIBI SCORE	**24**	**28**	**30**	**24**	**26**	**26**	**22**	**26**	**20**	**22**	**16**	**18**	**20**	**20**	**20**	**18**
Mean B-IBI Score				**26.5**				**25.0**				**19.0**				**19.5**

Appendix C2-C Table 3. Benthic invertebrate sampling results from Mackay and Mosquito Creeks (Sept 2014)

Raincoast Applied Ecology
City of North Vancouver Fall 2014
Determinations by
Rhithron Associates, Inc.

			Rhithron Sample ID	RAE14CNV001		RAE14CNV002		RAE14CNV003		RAE14CNV004		RAE14CNV005		RAE14CNV006		RAE14CNV007		RAE14CNV008	
			SITE NAME	Mosquito Creek 1		Mosquito Creek 1		Mosquito Creek 1		Mosquito Creek 1		Mosquito Creek 2		Mosquito Creek 2		Mosquito Creek 2		Mosquito Creek 2	
			SITE ID	C-1		C-2		C-3		C-4		C-1		C-2		C-3		C-4	
			Sample date	01/10/2014		01/10/2014		01/10/2014		01/10/2014		22/09/2014		22/09/2014		22/09/2014		22/09/2014	
			Proportion of sample used	100.00%		70.00%		70.00%		100.00%		33.33%		33.33%		76.67%		83.33%	
		Taxon		**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**
Non-insect taxa	Tetrastemmatidae	*Prostoma*																	
	Planariidae	*Polycelis*		4		14		8		5				32		12		3	
	Trepaxonemata	Trepaxonemata				1				1									
	Nemata	Nemata		2		4				1		3		1		1			
	Erpobdellidae	*Erpobdella*																	
	Sphaeriidae	Sphaeriidae		1		3		2											
	Ancylidae	*Ferrissia*				23													
	Lymnaeidae	Lymnaeidae - damaged																	
	Physidae	*Physella*								1									
		Physidae - damaged or immature				9													
	Planorbidae	Planorbidae - damaged or immature		1		12	no			1									
		Promenetus				5													
	Harpacticoida	Harpacticoida				1													
	Amphipoda	Amphipoda - damaged or immature		1	no			2	no	2	no					3	no	1	no
	Crangonyctidae	*Crangonyx*		9		18		24		16		11		88		37		53	
	Asellidae	*Caecidotea*																	
	Acari	Acari		3		4		17		6		22		5		5		3	
	Oligochaeta	Oligochaeta		105		152		105		60		34		26		34		109	
Odonata	Corduliidae	Corduliidae - damaged																	
Ephemeroptera	Ameletidae	*Ameletus*																	
	Baetidae	Baetidae - damaged								1	no								
		Baetis - early instar or damaged								2	no								
		Baetis bicaudatus complex										1							
		Baetis Rhodani Gr. - early instar or damaged		23								10	no	10	no	23	no		
		Baetis tricaudatus complex				23		42		18		2		12		52			
	Ephemerellidae	*Drunella doddsii*																	
		Ephemerella - early instar		2		3		7				11		1		1			
		Ephemerellidae - early instar																	
	Heptageniidae	*Epeorus*								1									
		Ironodes		4		22		15		20		1		18		9			
		Rhithrogena																	
	Leptophlebiidae	*Paraleptophlebia*		8		23		58		16		42		23		17		24	
Plecoptera		Plecoptera - damaged																	
	Capniidae	Capniidae - early instar																	
	Chloroperlidae	Chloroperlidae - early instar		5	no	4		8	no			6	no			11	no	17	no
		Sweltsa		4				1				4		5		4		11	
	Leuctridae	Leuctridae - damaged		1										2				2	
	Nemouridae	*Malenka*				1		1						1		1			
		Nemouridae - early instar or damaged		2	no	2	no	1	no	2	no	1	no					1	no
		Visoka cataractae		1		1				1		2		1		1		3	
		Zapada cinctipes		5		15		19		16		32		22		16		24	
		Zapada columbiana																	
		Zapada frigida																	
		Zapada Oregonensis Gr.																	
	Perlidae	*Calineuria californica*								2		3				3			
		Doroneuria																	
		Perlidae - early instar						1				4	no	7		2	no		
	Perlodidae	*Kogotus*																	
	Pteronarcyidae	Pteronarcyidae - early instar																	
		Pteronarcys princeps																	
Megaloptera	Corydalidae	Corydalidae - early instar																	
Trichoptera		Trichoptera - early instar or damaged								1	no	1	no						
	Apataniidae	*Apatania*																1	
	Brachycentridae	*Micrasema*								1		15				1			
	Glossosomatidae	*Anagapetus*														1			
		Glossosoma						4		13		3		6		4			
		Glossosomatidae - early instar, damaged, or pupa		1				1	no	1	no	2	no	2	no	5	no		
	Hydropsychidae	Arctopsychinae - early instar																	
		Hydropsyche		7		13		22		77		67		48		53		10	
		Hydropsychidae - early instar or pupa										1	no	1	no	7	no	1	no
		Parapsyche				3				6		1		8		13		2	
	Lepidostomatidae	*Lepidostoma*		5		7		15		3		22		9		11		15	
	Limnephilidae	*Ecclisomyia*																	
		Limnephilidae - early instar or damaged						1				1		1				1	
	Philopotamidae	*Dolophilodes*																	
		Philopotamidae - early instar																	
		Wormaldia																	
	Polycentropodidae	*Polycentropus*										6						1	
	Rhyacophilidae	*Rhyacophila* - early instar		1	no			3	no	2	no	2	no	3	no	2	no	2	no
		Rhyacophila atrata complex		1		1				2								1	
		Rhyacophila Betteni Gr.		2		1						2		1					
		Rhyacophila Brunnea/Vemna Gr.						1				3		4		7		4	
		Rhyacophila grandis						1											
		Rhyacophila narvae																	
Coleoptera	Elmidae	*Lara*		6		2		4		10		5		6		3		8	
		Narpus concolor		32		23		3		14		3		6		6		1	
Diptera	Ceratopogonidae	Ceratopogoninae		1		3		2		2		9		5				11	
	Dixidae	*Dixa*												4		1		1	
		Dixidae - pupa																	
	Empididae	*Chelifera*																	
		Empididae - pupa																	
		Hemerodromia		1															
		Neoplasta				1		1				3		3				4	
		Oreogeton																	
	Ephydridae	Ephydridae								1									
	Psychodidae	*Maruina*		1				5		4				5		1		1	
		Psychoda				1													
	Simuliidae	*Simulium*		4								1		5		8		1	
	Tabanidae	Tabanidae - damaged																	
	Tipulidae	*Antocha monticola*						1				8							
		Dicranota						2		2		2		3		7		4	
		Hexatoma																	
		Limnophila				1													
		Limonia										2						1	
		Tipula		1		1								1					
		Tipulidae - damaged																	
Chironomidae	Chironomidae			23		31		40		12		73		59		62		82	
			TOTAL	267		428		417		323		421		434		424		403	
		METRIC VALUES																	
		Taxa richness		28		32		27		28	28.75	31		32		28		27	29.5
		E richness		4		4		4		4	4	5		4		4		1	3.5
		P richness		4		4		4		3	3.75	4		6		5		4	4.75
		T richness		5		5		6		6	5.5	9		7		7		8	7.75
		INTOLERANT taxa richness		2		1		1		1	1.25	2		2		2		3	2.25
		Clinger richness		14		13		14		13	13.5	17		17		17		14	16.25
		LL richness		2		4		3		4	3.25	4		4		4		3	3.75
		% tolerant		0.37		11.45		0.00		0.62	3.11	0.48		0.00		0.00		0.25	0.18
		% predator		6.74		4.44		8.87		7.12	6.79	15.91		10.14		12.74		14.89	13.42
		% dominance (3)		59.93		48.13		49.16		48.61	51.46	43.23		44.93		39.39		60.55	47.02
		Taxa richness		3		5		3		3	5	5		5		3		3	5
		E richness		1		1		1		1	1	3		1		1		1	1
		P richness		3		3		3		1	3	3		3		3		3	3
		T richness		3		3		3		3	3	3		3		3		3	3
		INTOLERANT taxa richness		1		1		1		1	1	1		1		1		3	3
		Clinger richness		3		3		3		3	3	3		3		3		3	3
		LL richness		1		3		3		3	3	3		3		3		3	3
		% tolerant		5		5		5		5	5	5		5		5		5	5
		% predator		1		1		1		1	1	3		3		3		3	3
		% dominance (3)		5		5		5		5	5	5		5		5		3	5
		SAMPLE SCORE		**26**		**30**		**28**		**26**		**34**		**32**		**30**		**30**	
		SITE SCORE									**30**								**34**

Appendix C2-C Table 3. Benthic invertebrate sampling results from Mackay and Mosquito Creeks (Sept 2014)

Raincoast Applied Ecology
City of North Vancouver Fall 2014
Determinations by
Rhithron Associates, Inc.

			Rhithron Sample ID	RAE14CNV009		RAE14CNV010		RAE14CNV011		RAE14CNV012		RAE14CNV013		RAE14CNV014		RAE14CNV015		RAE14CNV016	
			SITE NAME	Mosquito Creek 3		Mosquito Creek 3		Mosquito Creek 3		Mosquito Creek 3		Mackay Creek 1		Mackay Creek 1		Mackay Creek 1		Mackay Creek 1	
			SITE ID	C-1		C-2		C-3		C-4		C-1		C-2		C-3		C-4	
			Sample date	20/09/2014		20/09/2014		20/09/2014		20/09/2014		01/10/2014		01/10/2014		01/10/2014		01/10/2014	
			Proportion of sample used	100.00%		100.00%		100.00%		100.00%		60.00%		53.33%		100.00%		86.67%	
		Taxon		**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**
Non-insect taxa	Tetrastemmatidae	*Prostoma*																5	
	Planariidae	*Polycelis*																2	
	Trepaxonemata	Trepaxonemata														1		1	
	Nemata	Nemata										3		1		2			
	Erpobdellidae	*Erpobdella*																	
	Sphaeriidae	Sphaeriidae										7		23					
	Ancylidae	*Ferrissia*																	
	Lymnaeidae	Lymnaeidae - damaged												1					
	Physidae	*Physella*												3					
		Physidae - damaged or immature										1							
	Planorbidae	Planorbidae - damaged or immature												35					
		Promenetus										3		15					
	Harpacticoida	Harpacticoida																	
	Amphipoda	Amphipoda - damaged or immature												21	no	9		11	
	Crangonyctidae	*Crangonyx*										13		1					
	Asellidae	*Caecidotea*										4		5		3		5	
	Acari	Acari		7		7		2		5		6		15		5		3	
	Oligochaeta	Oligochaeta		18		9		3		24		300		161		126		254	
Odonata	Corduliidae	Corduliidae - damaged																	
Ephemeroptera	Ameletidae	*Ameletus*		4		3				10									
	Baetidae	Baetidae - damaged																	
		Baetis - early instar or damaged		2		1	no	6											
		Baetis bicaudatus complex																	
		Baetis Rhodani Gr. - early instar or damaged																	
		Baetis tricaudatus complex				10						19		26		80		48	
	Ephemerellidae	*Drunella doddsii*				9		4											
		Ephemerella - early instar																2	
		Ephemerellidae - early instar		1												1			
	Heptageniidae	*Epeorus*																	
		Ironodes				1				3		1						1	
		Rhithrogena		2		34				5									
	Leptophlebiidae	*Paraleptophlebia*		5		1				3		5		3		7		17	
Plecoptera		Plecoptera - damaged																1	
	Capniidae	Capniidae - early instar												1					
	Chloroperlidae	Chloroperlidae - early instar		12	no	36		31	no										
		Sweltsa		9				104		25								3	
	Leuctridae	Leuctridae - damaged												1					
	Nemouridae	*Malenka*																	
		Nemouridae - early instar or damaged		1	no	4	no												
		Visoka cataractae		19		18		43		9									
		Zapada cinctipes		2		10		24		3		5		3		1		2	
		Zapada columbiana				2													
		Zapada frigida		2		1													
		Zapada Oregonensis Gr.																	
	Perlidae	*Calineuria californica*						2		5						1		1	
		Doroneuria		3		1		2											
		Perlidae - early instar		8	no	11	no												
	Perlodidae	*Kogotus*																	
	Pteronarcyidae	Pteronarcyidae - early instar																	
		Pteronarcys princeps														1			
Megaloptera	Corydalidae	Corydalidae - early instar																	
Trichoptera		Trichoptera - early instar or damaged																	
	Apataniidae	*Apatania*		1				3		4									
	Brachycentridae	*Micrasema*																	
	Glossosomatidae	*Anagapetus*																	
		Glossosoma																1	
		Glossosomatidae - early instar, damaged, or pupa														1			
	Hydropsychidae	Arctopsychinae - early instar																	
		Hydropsyche										1				4		12	
		Hydropsychidae - early instar or pupa		1															
		Parapsyche																	
	Lepidostomatidae	*Lepidostoma*		43		23		19		104						1		1	
	Limnephilidae	*Ecclisomyia*		50				4		11									
		Limnephilidae - early instar or damaged				5													
	Philopotamidae	*Dolophilodes*		1						6									
		Philopotamidae - early instar				3													
		Wormaldia																	
	Polycentropodidae	*Polycentropus*																1	
	Rhyacophilidae	*Rhyacophila* - early instar		2	no	3		8	no									1	
		Rhyacophila atrata complex														2			
		Rhyacophila Betteni Gr.				1		1											
		Rhyacophila Brunnea/Vemna Gr.		9		3				24									
		Rhyacophila grandis																	
		Rhyacophila narvae																	
Coleoptera	Elmidae	*Lara*		1		2						1		1		2		3	
		Narpus concolor										20		30		16		20	
Diptera	Ceratopogonidae	Ceratopogoninae		3												1			
	Dixidae	*Dixa*		1															
		Dixidae - pupa																	
	Empididae	*Chelifera*																	
		Empididae - pupa																	
		Hemerodromia										11		19		1			
		Neoplasta												1					
		Oreogeton				1													
	Ephydridae	Ephydridae																	
	Psychodidae	*Maruina*														1			
		Psychoda																	
	Simuliidae	*Simulium*												1					
	Tabanidae	Tabanidae - damaged														1			
	Tipulidae	*Antocha monticola*																	
		Dicranota		5		6		1		5		3		2		3		3	
		Hexatoma																1	
		Limnophila																	
		Limonia																	
		Tipula												1		1			
		Tipulidae - damaged		1	no														
	Chironomidae	Chironomidae		21		10		14		21		21		45		25		36	
			TOTAL	234		215		271		267		424		415		296		435	
		METRIC VALUES																	
		Taxa richness		23		24		15		17	19.75	18		23		25		25	22.75
		E richness		5		6		2		4	4.25	3		2		3		4	3
		P richness		5		6		5		4	5	1		3		3		4	2.75
		T richness		6		6		4		5	5.25	1		0		4		5	2.5
		INTOLERANT taxa richness		6		6		5		4	5.25	0		1		1		0	0.5
		Clinger richness		12		13		8		10	10.75	5		6		10		11	8
		LL richness		2		2		2		1	1.75	3		3		4		3	3.25
		% tolerant		0.00		0.00		0.00		0.00	0.00	1.89		14.22		1.35		1.15	4.65
		% predator		24.79		32.09		55.72		23.97	34.14	4.72		8.92		5.07		4.60	5.82
		% dominance (3)		48.72		43.26		65.68		57.30	53.74	80.42		58.07		78.04		77.70	73.56
		Taxa richness		3		3		3		3	3	3		3		3		3	3
		E richness		3		3		1		1	3	1		1		1		1	1
		P richness		3		3		3		3	3	1		1		1		3	1
		T richness		3		3		1		3	3	1		1		1		3	1
		INTOLERANT taxa richness		5		5		5		5	5	1		1		1		1	1
		Clinger richness		3		3		1		3	3	1		1		3		3	1
		LL richness		1		1		1		1	1	3		3		3		3	3
		% tolerant		5		5		5		5	5	5		5		5		5	5
		% predator		5		5		5		5	5	1		1		1		1	1
		% dominance (3)		5		5		3		5	5	1		5		3		3	3
		SAMPLE SCORE		**36**		**36**		**28**		**34**		**18**		**22**		**22**		**26**	
		SITE SCORE									**36**								**20**

Appendix C2-C Table 3. Benthic invertebrate sampling results from Mackay and Mosquito Creeks (Sept 2014)

Raincoast Applied Ecology
City of North Vancouver Fall 2014
Determinations by
Rhithron Associates, Inc.

		Rhithron Sample ID	RAE14CNV017		RAE14CNV018		RAE14CNV019		RAE14CNV020		RAE14CNV021		RAE14CNV022		RAE14CNV023		RAE14CNV024	
		SITE NAME	Mackay Creek 3		Mackay Creek 3		Mackay Creek 3		Mackay Creek 3		Mission Creek 1		Mission Creek 1		Mission Creek 1		Mission Creek 1	
		SITE ID	C-1		C-2		C-3		C-4		C-1		C-2		C-3		C-4	
		Sample date	01/10/2014		01/10/2014		01/10/2014		01/10/2014		28/09/2014		28/09/2014		28/09/2014		28/09/2014	
		Proportion of sample used	100.00%		56.67%		50.00%		73.33%		70.00%		86.67%		25.00%		100.00%	
		Taxon	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**
Non-insect taxa	Tetrastemmatidae	*Prostoma*																
	Planariidae	*Polycelis*	3				4		15									
	Trepaxonemata	Trepaxonemata					5		8		3		7		4		11	
	Nemata	Nemata	5		2		1		3		1		2					
	Erpobdellidae	*Erpobdella*																
	Sphaeriidae	Sphaeriidae	3				1		2		6						2	
	Ancylidae	*Ferrissia*																
	Lymnaeidae	Lymnaeidae - damaged																
	Physidae	*Physella*																
		Physidae - damaged or immature									4				2		1	
	Planorbidae	Planorbidae - damaged or immature									3							
		Promenetus					1											
	Harpacticoida	Harpacticoida																
	Amphipoda	Amphipoda - damaged or immature	2	no			5	no			64	no	46				86	
	Crangonyctidae	*Crangonyx*	1				3		4		2				147			
	Asellidae	*Caecidotea*									1							
	Acari	Acari	3		2		8		4		3		1		2		4	
	Oligochaeta	Oligochaeta	29		29		41		48		70		125		52		49	
Odonata	Corduliidae	Corduliidae - damaged							1									
Ephemeroptera	Ameletidae	*Ameletus*																
	Baetidae	Baetidae - damaged																
		Baetis - early instar or damaged									16							
		Baetis bicaudatus complex																
		Baetis Rhodani Gr. - early instar or damaged															11	
		Baetis tricaudatus complex	57		127		78		170				60		55			
	Ephemerellidae	*Drunella doddsii*																
		Ephemerella - early instar	29		59		57		75				1					
		Ephemerellidae - early instar																
	Heptageniidae	*Epeorus*																
		Ironodes	15		3		6		6		5		2		2		2	
		Rhithrogena																
	Leptophlebiidae	*Paraleptophlebia*	5		16		15		16		9		21		10		1	
Plecoptera		Plecoptera - damaged																
	Capniidae	Capniidae - early instar																
	Chloroperlidae	Chloroperlidae - early instar			2													
		Sweltsa	6															
	Leuctridae	Leuctridae - damaged			1													
	Nemouridae	*Malenka*									1				1		1	
		Nemouridae - early instar or damaged									3	no						
		Visoka cataractae																
		Zapada cinctipes	4		3		5		16		3		6		2		1	
		Zapada columbiana																
		Zapada frigida																
		Zapada Oregonensis Gr.					1											
	Perlidae	*Calineuria californica*	1		1													
		Doroneuria																
		Perlidae - early instar																
	Perlodidae	*Kogotus*			1								4					
	Pteronarcyidae	Pteronarcyidae - early instar					1	no										
		Pteronarcys princeps			1		1											
Megaloptera	Corydalidae	Corydalidae - early instar					1											
Trichoptera		Trichoptera - early instar or damaged																
	Apataniidae	*Apatania*																
	Brachycentridae	*Micrasema*					1						1					
	Glossosomatidae	*Anagapetus*																
		Glossosoma	12		30		17		1		67		18		81		20	
		Glossosomatidae - early instar, damaged, or pupa			2	no					4	no					1	no
	Hydropsychidae	Arctopsychinae - early instar					1	no										
		Hydropsyche	143		114		110		17		66		57		5		20	
		Hydropsychidae - early instar or pupa							2	no								
		Parapsyche	1		5		2		3		29		15		8		21	
	Lepidostomatidae	*Lepidostoma*	1		1		5		10		2				10		5	
	Limnephilidae	*Ecclisomyia*																
		Limnephilidae - early instar or damaged																
	Philopotamidae	*Dolophilodes*	1															
		Philopotamidae - early instar																
		Wormaldia					1											
	Polycentropodidae	*Polycentropus*																
	Rhyacophilidae	*Rhyacophila* - early instar	3	no			3	no	1		6	no	5	no	4	no		
		Rhyacophila atrata complex			1													
		Rhyacophila Betteni Gr.									1		2					
		Rhyacophila Brunnea/Vemna Gr.	7		3		4				10		6		7		6	
		Rhyacophila grandis					1				1		1		2			
		Rhyacophila narvae															3	
Coleoptera	Elmidae	*Lara*	1		7		6		9		4		5		3		3	
		Narpus concolor	7		3		13		3									
Diptera	Ceratopogonidae	Ceratopogoninae	1		2		1						5		2		1	
	Dixidae	*Dixa*																
		Dixidae - pupa																
	Empididae	*Chelifera*											1					
		Empididae - pupa																
		Hemerodromia																
		Neoplasta	1								1				1			
		Oreogeton																
	Ephydridae	Ephydridae																
	Psychodidae	*Maruina*	3										4		8		4	
		Psychoda																
	Simuliidae	*Simulium*					4		5		2		1		3			
	Tabanidae	Tabanidae - damaged																
	Tipulidae	*Antocha monticola*			1													
		Dicranota			1		3											
		Hexatoma																
		Limnophila																
		Limonia																
		Tipula											4		1		1	
		Tipulidae - damaged																
Chironomidae		Chironomidae	4		11		22		12		23		23		23		13	
		TOTAL	348		428		428		431		410		423		435		267	
		METRIC VALUES																
		Taxa richness	25		25		30		22	25.5	25		25		23		22	23.75
		E richness	4		4		4		4	4	3		4		3		3	3.25
		P richness	3		6		3		1	3.25	2		2		2		2	2
		T richness	6		6		8		5	6.25	7		7		6		6	6.5
		INTOLERANT taxa richness	1		2		2		0	1.25	1		1		1		0	0.75
		Clinger richness	13		16		15		10	13.5	11		14		11		10	11.5
		LL richness	4		5		6		3	4.5	2		2		2		2	2
		% tolerant	0.00		0.00		0.23		0.00	0.06	1.95		0.00		0.46		0.37	0.70
		% predator	6.61		4.21		6.78		3.94	5.38	13.17		11.11		6.90		17.23	12.10
		% dominance (3)	65.80		70.09		57.24		67.98	65.28	49.51		57.21		65.06		58.43	57.55
		Taxa richness	3		3		5		3	3	3		3		3		3	3
		E richness	1		1		1		1	1	1		1		1		1	1
		P richness	1		3		1		1	3	1		1		1		1	1
		T richness	3		3		3		3	3	3		3		3		3	3
		INTOLERANT taxa richness	1		1		1		1	1	1		1		1		1	1
		Clinger richness	3		3		3		3	3	3		3		3		3	3
		LL richness	3		5		5		3	5	1		1		1		1	1
		% tolerant	5		5		5		5	5	5		5		5		5	5
		% predator	1		1		1		1	1	3		3		1		3	3
		% dominance (3)	3		3		5		3	3	5		5		3		5	5
		SAMPLE SCORE	**24**		**28**		**30**		**24**		**26**		**26**		**22**		**26**	
		SITE SCORE								**28**								**26**

Appendix C2-C Table 3. Benthic invertebrate sampling results from Mackay and Mosquito Creeks (Sept 2014)

Raincoast Applied Ecology
City of North Vancouver Fall 2014
Determinations by
Rhithron Associates, Inc.

		Rhithron Sample ID	RAE14CNV025		RAE14CNV026		RAE14CNV027		RAE14CNV028		RAE14CNV029		RAE14CNV030		RAE14CNV031		RAE14CNV032	
		SITE NAME	Wagg Creek 1		Wagg Creek 1		Wagg Creek 1		Wagg Creek 1		Thain Creek 1		Thain Creek 1		Thain Creek 1		Thain Creek 1	
		SITE ID	C-1		C-2		C-3		C-4		C-1		C-2		C-3		C-4	
		Sample date	28/09/2014		28/09/2014		28/09/2014		28/09/2014		23/09/2014		23/09/2014		23/09/2014		23/09/2014	
		Proportion of sample used	100.00%		33.33%		53.33%		100.00%		36.67%		36.67%		50.83%		66.67%	
		Taxon	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**	**Count**	**Unique?**
Non-insect taxa	Tetrastemmatidae	*Prostoma*																
	Planariidae	*Polycelis*																
	Trepaxonemata	Trepaxonemata			2				4		18		18		8		9	
	Nemata	Nemata							1		11		4		5			
	Erpobdellidae	*Erpobdella*	2															
	Sphaeriidae	Sphaeriidae	1		1				4				2					
	Ancylidae	*Ferrissia*																
	Lymnaeidae	Lymnaeidae - damaged																
	Physidae	*Physella*																
		Physidae - damaged or immature																
	Planorbidae	Planorbidae - damaged or immature																
		Promenetus	1										1					
	Harpacticoida	Harpacticoida																
	Amphipoda	Amphipoda - damaged or immature	84		111		39	no	29	no	133	no	64	no	87	no	38	no
	Crangonyctidae	*Crangonyx*					4		5		4		35		24		25	
	Asellidae	*Caecidotea*																
	Acari	Acari					4		4		5		6				4	
	Oligochaeta	Oligochaeta	84		81		50		91		105		45		71		161	
Odonata	Corduliidae	Corduliidae - damaged																
Ephemeroptera	Ameletidae	*Ameletus*																
	Baetidae	Baetidae - damaged																
		Baetis - early instar or damaged																
		Baetis bicaudatus complex																
		Baetis Rhodani Gr. - early instar or damaged	71	no	121		231		99		87		134		44	no	58	no
		Baetis tricaudatus complex	3												19		7	
	Ephemerellidae	*Drunella doddsii*																
		Ephemerella - early instar																
		Ephemerellidae - early instar																
	Heptageniidae	*Epeorus*																
		Ironodes													3		2	
		Rhithrogena																
	Leptophlebiidae	*Paraleptophlebia*	6				6								14		4	
Plecoptera		Plecoptera - damaged																
	Capniidae	Capniidae - early instar																
	Chloroperlidae	Chloroperlidae - early instar																
		Sweltsa																
	Leuctridae	Leuctridae - damaged																
	Nemouridae	*Malenka*					1				3		2		3		3	
		Nemouridae - early instar or damaged																
		Visoka cataractae																
		Zapada cinctipes	3										6					
		Zapada columbiana																
		Zapada frigida																
		Zapada Oregonensis Gr.																
	Perlidae	*Calineuria californica*									2							
		Doroneuria																
		Perlidae - early instar																
	Perlodidae	*Kogotus*																
	Pteronarcyidae	Pteronarcyidae - early instar																
		Pteronarcys princeps																
Megaloptera	Corydalidae	Corydalidae - early instar																
Trichoptera		Trichoptera - early instar or damaged																
	Apataniidae	*Apatania*																
	Brachycentridae	*Micrasema*																
	Glossosomatidae	*Anagapetus*																
		Glossosoma			3								10		32		12	
		Glossosomatidae - early instar, damaged, or pupa																
	Hydropsychidae	Arctopsychinae - early instar																
		Hydropsyche	10		23		11		32				8		3		25	
		Hydropsychidae - early instar or pupa																
		Parapsyche	1		5				21									
	Lepidostomatidae	*Lepidostoma*									3		3		4		3	
	Limnephilidae	*Ecclisomyia*																
		Limnephilidae - early instar or damaged																
	Philopotamidae	*Dolophilodes*																
		Philopotamidae - early instar																
		Wormaldia																
	Polycentropodidae	*Polycentropus*																
	Rhyacophilidae	*Rhyacophila* - early instar																
		Rhyacophila atrata complex																
		Rhyacophila Betteni Gr.			1													
		Rhyacophila Brunnea/Vemna Gr.	7		9		8		10									
		Rhyacophila grandis			1												1	
		Rhyacophila narvae																
Coleoptera	Elmidae	*Lara*	11		3		10		6		4		12		7		12	
		Narpus concolor									4				2		4	
Diptera	Ceratopogonidae	Ceratopogoninae									3		5		4		8	
	Dixidae	*Dixa*									3		3		9			
		Dixidae - pupa											1	no	1	no		
	Empididae	*Chelifera*																
		Empididae - pupa									1	no			1	no		
		Hemerodromia																
		Neoplasta									3				3		2	
		Oreogeton																
	Ephydridae	Ephydridae																
	Psychodidae	*Maruina*	38		55		46						16		27		19	
		Psychoda																
	Simuliidae	*Simulium*			1								7		13			
	Tabanidae	Tabanidae - damaged																
	Tipulidae	*Antocha monticola*																
		Dicranota											3		1		1	
		Hexatoma																
		Limnophila																
		Limonia																
		Tipula	2												1			
		Tipulidae - damaged																
	Chironomidae	Chironomidae	33		15		10		38		44		43		32		10	
		TOTAL	357		432		420		344		433		428		418		408	
		METRIC VALUES																
		Taxa richness	15		15		11		12	13.25	15		20		21		19	18.75
		E richness	2		1		2		1	1.5	1		1		3		3	2
		P richness	1		0		1		0	0.5	2		2		1		1	1.5
		T richness	3		6		2		3	3.5	1		3		3		4	2.75
		INTOLERANT taxa richness	0		1		0		0	0.25	0		0		0		1	0.25
		Clinger richness	6		9		5		4	6	4		7		8		8	6.75
		LL richness	3		2		1		2	2	3		2		2		2	2.25
		% tolerant	0.28		0.00		0.00		0.00	0.07	0.00		0.23		0.00		0.00	0.06
		% predator	2.80		4.17		2.86		11.34	5.29	7.39		7.48		4.07		6.13	6.27
		% dominance (3)	66.95		72.45		77.86		66.28	70.88	75.06		56.78		48.33		62.99	60.79
		Taxa richness	3		3		1		1	1	3		3		3		3	3
		E richness	1		1		1		1	1	1		1		1		1	1
		P richness	1		1		1		1	1	1		1		1		1	1
		T richness	1		3		1		1	1	1		1		1		1	1
		INTOLERANT taxa richness	1		1		1		1	1	1		1		1		1	1
		Clinger richness	1		3		1		1	1	1		1		1		1	1
		LL richness	3		1		1		1	1	3		1		1		1	3
		% tolerant	5		5		5		5	5	5		5		5		5	5
		% predator	1		1		1		3	1	1		1		1		1	1
		% dominance (3)	3		3		3		3	3	3		5		5		3	3
		SAMPLE SCORE	**20**		**22**		**16**		**18**		**20**		**20**		**20**		**18**	
		SITE SCORE								**16**								**20**

Appendix C2-D:
Fish Survey Data

Appendix C2-D Table 1. Historical fish inventory information for Mackay and Mosquito watersheds.

Stream	Location	X	Y	Date	Sampling	Fish Captured	Reference	Description
Mackay Creek	Intertidal portion of lower creek	492544	5462608	Aug-06	Pole seine, dip nets	2006: 5 Starry Flounder, 5 Threespine Stickleback, 100 sculpins (unidentified)	Golder, 2006	Golder Associates undertook a fish salvage in MacKay Creek pursuant to the MacKay Creek Mouth Relocation Projec
Mackay Creek	Lower Mackay Creek Park	492516	5463122	Jan-07	Minnow traps	2007: 5 Rainbow Trout	Coast River, 2007	Coast River Environmental Services Ltd. undertook a series of fish salvages on MacKay Creek.
Mackay Creek	Multiple sites			2008 (multiple dates)	Minnow traps	2008: 1 Coastal Cutthroat Trout; 1 Coho Salmon; 13 Prickly Sculpin; 305 Threespine Stickleback	Golder, 2008	Golder Associates Ltd. undertook a fish inventory at MacKay Creek in 2008.
Mackay Creek	Lower Mackay Creek (mouth)	492530	5462622	Apr-09	Fyfe traps	2009: 22 Chum Salmon fry	Golder, 2009	Evaluation of the usage of the MacKay Creek sidechannel by out-migrating chum salmon fry.
Mackay Creek	Lower Mackay Creek	492516	5463122	Aug-09	Dip net	2009: 6 Rainbow Trout; 14 Coho Salmon	Dillon, 2009	Fish salvages for lower mainland municipalities including DNV
Mackay Creek	Lower Mackay Creek	492516	5463122	August + Sept 2013	Seining; electrofishing	2013: Salmon; Sculpins, Stickleback	Keystone, 2013	Fish salvage as part of fish habitat compensation work
Mackay Creek	Blue Grouse Way	492581	5467833	Aug-99	Dip net; electrofishing	1999: 32 Cutthroat Trout	Coast River, 2000	Fish salvage as part of channel stabilization and trail repair
Mackay Creek	Lower Mackay Creek Park	492516	5463122	Aug-09	Seining; dip net; electrofishing	2009: 144 Coho Salmon; 67 Cutthroat Trout; 160 Sculpins; 15 Threespine Stickleback; 141 Western Brook Lamprey; 86 Crayfish	Coast River, 1999	Fish salvage prior to gravel removal in Lower Mackay Creek Park
Mackay Creek	Lower Mackay Creek Park	492516	5463122	Jan-06	Minnow traps (15)	2006: 15 Prickly Sculpin; 5 Slimy Sculpin; 9 Coho Salmon; 2 Chinook Salmon; 2 Cutthroat Trout	Coast River, 2004	Fish sampling to document presence and abundance
Mackay Creek	Lower Mackay Creek Park	492516	5463122	Aug-05	Seine net; electrofisher	2005: 15 Coho Salmon; 21 Cutthroat Trout; 457 Sculpins; 369 Western Brook Lamprey; 300+ juvenile salmon; 44 Crayfish	Coast River, 2005	Fish salvage prior to construction activities (gravel removal)
Mackay Creek	Lower Mackay Creek Park	492516	5463122	Jul-05	Minnow traps (21)	2005: 10 Sculpin; 32 Threespine Stickleback; 1 Rainbow Trout; 3 Coho Salmon; 5 Crayfish	Coast River, 2005	Fish sampling to document presence and abundance
Mackay Creek	Heywood Park	492719	5463457	Jul-15	Minnow traps; seine nets; electrofishing	2015: 116 Coho Salmon; 4 Rainbow Trout; 9 Cutthroat Trout; 117 Prickly Sculpin; 53 Western Brook Lamprey; 24 Signal Crayfish	Envirowest, 2015	Fish salvage prior to restoration of Mackay Creek upstream of Marine Drive.
Wagg Creek	Wagg Creek Pond	494409	5463879	Sep-07	Seining; dipnetting	2007: 100+ threespinse stickleback; 25+ Crayfish	Raincoast, 2007	Fish salvage prior to construction of outwetland weir and pond excavation
Wagg Creek	Mahon Park	493759	5463490	Oct-06	Electrofishing	2006: 4 Coho Salmon; 26 Cutthroat Trout; 2 Threespine Stickleback; 1 Sculpin	Triton, 2007	Fish salvage prior to rehabilitation works (trails?)
Wagg Creek	Upstream of Jones Ave	494267	5463775	May-04	Minnow trapping (7 sites)	2004: 37 Threespine Stickleback	Capilano College, 2004	Fish sampling in Wagg Creek upstream of Jones Ave to document fish presence and absence
Wagg Creek	Downstream of Jones Ave	494039	5463613	Summer 2014	Unknown	2014: 1 Coho Salmon	Greenbank Environmental, 2014	Capture of 1 juvenile coho salmon downstream of Jones Avenue as part of bank protection work (D. Matsubara pers. comm.).
Thain Creek	Westview Drive	493507	5464767	Sep-04	Dipnetting; electrofishing; seining	2004: 161 Cutthroat Trout; 97 Coho Salmon; 144 Crayfish	Coast River, 2004	Fish salvage to remedial works downstream of Westview Drive
Thain Creek	Westview Drive	493563	5464772	Sep-99	Dipnetting; electrofishing	1999: 8 Coho Salmon; 42 Cutthroat Trout	Coast River, 2000	Fish salvage to stream daylighting downstream of Westview Drive
Mosquito & Thain Creeks	Lower Watershed (below Queens; below Westview)	493379	5464606	Nov to Jan 1996	Visual spawner surveys	1996: Mosquito: 3 Coho Salmon (adult); 2 Steelhead; 1 Coho Jack; Thain: 11 Coho Salmon (adult); 1 Steelhead; 3 Coho Jacks	Krzesinka and Egan, 1996	This report shows the results of spawner surveys done on Mosquito and Thain Creek.
Mosquito Creek	Mainstem upstream of Montroyal Blvd	493939	5466790	Aug-01	No method	2001: No fish observed or captured	Coast River, 2001	Fish salvage for improvements to channel bottom stabilizers in Mosquito Creek mainstem.

Appendix C2-D Table 2. Results of August-Sepember 2014 Fish Trapping Survey in Mackay and Mosquito Creeks.

Stream	Location	X	Y	CO	CT	TSB	Crayfish	Notes
Mackay Creek	Cliffridge/Esperanza	492792	5467679	0	5	0	0	~ 20 contained in culvert O/F apron, 50 cm deep, stream dry beyond/D/S
Mackay Creek	Belvedere/Mapleridge	492804	5466874	0	2	0	0	one fish > 150mm
Mackay Creek	Handsworth School	492791	5466478	2	4	0	0	CO ~60 mm, CT ~100-110 mm
Mackay Creek	D/S Murdo Fraser Park	492429	5464602	1	1	0	0	leaves clogged 2 openings
Mackay Creek	Murdo Fraser Pond	492268	5464680	0	0	28	0	6 turtles observed
Mosquito Creek	MS off Evergreen Rd	493565	5465724	0	7	0	0	U/S yellow pedestrian bridge
Mosquito Creek	Mission Creek at Evergreen Rd	493934	5465563	0	4	0	1	U/S culvert
Mosquito Creek	Mission Creek at Windsor Rd	493721	5465100	0	4	0	0	U/S culvert
Mosquito Creek	Mission Creek D/S Cartelier Rd	494290	5465974	0	1	0	0	D/S culvert
Mosquito Creek	Mission Creek U/S Queens Rd	493601	5464956	0	4	0	0	E of Delbrook Rd by old pedestrian bridge
Mosquito Creek	Mission Creek in Larson Park	493721	5464176	0	0	0	0	white stuff on benthos, brownish-beige stuck to traps - this site had elevated WQ (pH?) maybe this was reason?
Mosquito Creek	MS D/S William Griffin Rec Center	493174	5464597	2	3	0	0	CO to 90 mm, CT 50-100 mm
Mosquito Creek	Wagg Creek Wagg Creek Park Pond	494404	5463849	0	0	30	0	pond drained in August 26 visit - get salvage data from in-stream works?
Mosquito Creek	Wagg Creek	494448	5463979	0	0	0	0	behind daycare building U/S pedestrian bridge
Mosquito Creek	Wagg Creek	494100	5463675	0	0	1	0	access via dead-end alley between 18/19th
Mosquito Creek	Wagg Creek in Mahon Park	493711	5463388	0	1	0	0	access off 15th near armory
Mosquito Creek	Thain Creek at Evergreen Rd	494087	5465529	0	1	0	0	U/S culvert
Mosquito Creek	Thain Creek near Cartelier Road	494275	5465886	0	1	0	0	
			TOTAL	**5**	**38**	**59**	**1**	

Notes: Fish collected in 3 baited minnow traps in August and September 2014.
CO - coho salmon, CT = cutthroat trout, TSB = threespine stickleback, Crayfish = signal crayfish

Appendix C2-E:

Fish Passage Barriers and Instream Habitat Data

Appendix C2-E Table 1. Instream channel dimensions and substrate conditions in Mackay and Mosquito Creeks.

Stream	X	Y	BW	WW	RD	%B	%C	%LG	%SG	%F	Embed	Description of reach/stream
Mosquito MS	494311	5467169	11.0	1.2	10	75	10	10	4	1	10	upper Mosquito mainstem
Mosquito MS	493874	5466714	9.0	4.2	8	80	0	15	0	0	N/A	15% benthos concrete between boulders - manmade channel, D/S Mount Royal
Mosquito MS	493556	5465696	9.0	2.2	7	80	15	3	2	0	0	
Mosquito MS	493219	5464601	11.0	1.0	8	70	20	6	2	2	5	William Griffin Rec Center park
Mosquito MS	493174	5464597	3.5	2.0	5	5	0	0	10	85	40	William Griffin side channel - paralles MS to the west
Mosquito MS	493240	5463670	2.0	1.0	1	5	65	10	15	5	20	Lower Mosquito Creek Park, side channel west of MS
Mosquito MS	493339	5463758	11.0	3.9	10	50	30	10	5	5	5	Lower Mosquito Creek Park, MS
Mosquito MS	493400	5463851	2.5	0.3	1	0	5	5	10	80	70	Lower Mosquito Creek Park, outflow from side channel.pond east of MS (stagnant pond)
Mosquito MS	493345	5462749	16.5	10.2	12	2	60	3	5	30	40	
Wagg Creek	493649	5463281	8.0	4.0	11	40	30	5	20	5	15	accuracy
Wagg Creek	493712	5463387	7.9	2.7	10	30	25	35	10	0	15	off 15th Street near Armory
Wagg Creek	494448	5463979	3.8	1.5	3	15	30	30	25	0	10	U/S Wagg Creek Park
Wagg Creek	495214	5464763	2.6	0.6	3	15	40	35	10	0	15	D/S 29th
St Mary's Creek	495103	5465412	1.3	0.3	1	2	25	30	30	13	20	Wagg Creek trib
Mission Creek	493584	5463346	5.8	2.0	5	5	60	20	10	5	40	lower Mission Creek, old RAE site C-2
Mission Creek	493591	5463208	7.5	14.8	8	5	50	10	25	10	30	D/S confluence with Wagg Creek
Mission Creek	493721	5464176	3.4	1.9	4	1	40	19	25	15	20	
Mission Creek	493601	5464956	5.4	2.4	5	12	35	20	20	13	10	upper Mission Creek
Mission Creek	493721	5465100	5.4	2.1	10	60	15	15	10	0	5	U/S Windsor Rd culvert
Mission Creek	493434	5465563	5.6	1.8	5	25	30	35	10	0	5	
Mission Creek	494269	5465964	5.4	1.1	6	35	35	25	5	0	5	D/S Cartellier Rd
Thain Creek	494087	5465529	3.6	1.6	5	25	40	25	15	0	5	U/S culvert on Evergreen Rd
Thain Creek	494275	5465886	4.8	1.2	4	35	30	25	10	0	5	D/S Cartellier Rd
Mackay Creek	492764	5467109	6.2	5.1	7	2	60	30	7	1	5	U/S Mont Royal
Mackay Creek	493589	5467715	4.1	0.8	5	15	55	25	5	0	5	East Branch of Upper McKay (easterly most of the htree)
Mackay Creek	493565	5467744	4.3	0.2	1	80	15	5	0	0	0	West Branch of Upper McKay Creek (middle one)
Mackay Creek	493079	5468394	3.9	1.2	1	2	13	40	40	5	5	nearest Grouse base
Mackay Creek	492643	5468095	3.0	0.7	2	35	20	27	25	3	10	Grousewoods, fish observed
Mackay Creek	492868	5468057	3.2	0.3	2	40	2	15	40	3	0	
Mackay Creek	493113	5467701	2.1	0.0	0	5	40	20	30	5	0	Ranger @ Malspina, dry stream
Mackay Creek	492429	5464602	8.5	3.7	10	15	35	15	15	20	15	D/S of Murdo Fraser Park
Mackay Creek	492268	5464680	2.0	1.4	3	5	10	35	35	15	10	Murdo Fraser Park pond outflow, man-made channel
Mackay Creek	492183	5464775	15.5	5.5	10	15	15	30	20	20	15	Mainstem: U/S Murdo Fraser pond and wooden pedestrian bridge
Mackay Creek	492378	5464810	3.3	1.7	3	30	5	30	15	20	20	trib near Crestview, has big box culvert for storm water, lots of garbage
Mackay Creek	492594	5465449	6.9	4.8	10	10	30	30	25	5	15	Sunset Rd, D/S pedestrian bridge
Mackay Creek	492920	5465904	2.0	0.6	2	0	0	20	55	25	5	Upper McKay Creek Park (Elmsley Creek?) trib RL off Smith Trail
Mackay Creek	492972	5466090	0.9	0.5	2	0	30	20	20	30	20	Upper McKay Creek Park (unknown creek) trib RL off Smith Trail
Mackay Creek	492707	5466467	7.5	3.5	12	0	70	5	25	5	5	U/S Handsworth pedestrian bridge
Mackay Creek	492804	5466874	2.6	0.9	2	2	13	25	35	25	30	
Mackay Creek	492764	5467109	6.2	5.1	7	2	60	30	7	1	5	U/S Mont Royal
Mackay Creek	493589	5467715	4.1	0.8	5	15	55	25	5	0	5	East Branch of Upper McKay (easterly most of the htree)
Mackay Creek	493565	5467744	4.3	0.2	1	80	15	5	0	0	0	West Branch of Upper McKay Creek (middle one)
Mackay Creek	493079	5468394	3.9	1.2	1	2	13	40	40	5	5	nearest Grouse base
Mackay Creek	492643	5468095	3.0	0.7	2	35	20	27	25	3	10	Grousewoods, fish observed
Mackay Creek	492868	5468057	3.2	0.3	2	40	2	15	40	3	0	
Mackay Creek	493113	5467701	2.1	0.0	0	5	40	20	30	5	0	Ranger @ Malspina, dry stream
Mackay Creek	492429	5464602	8.5	3.7	10	15	35	15	15	20	15	D/S of Murdo Fraser Park
Mackay Creek	492268	5464680	2.0	1.4	3	5	10	35	35	15	10	Murdo Fraser Park pond outflow, man-made channel
Mackay Creek	492183	5464775	15.5	5.5	10	15	15	30	20	20	15	Mainstem: U/S Murdo Fraser pond and wooden pedestrian bridge
Mackay Creek	492378	5464810	3.3	1.7	3	30	5	30	15	20	20	trib near Crestview, has big box culvert for storm water, lots of garbage
Mackay Creek	492594	5465449	6.9	4.8	10	10	30	30	25	5	15	Sunset Rd, D/S pedestrian bridge
Mackay Creek	492920	5465904	2.0	0.6	2	0	0	20	55	25	5	Upper McKay Creek Park (Elmsley Creek?) trib RL off Smith Trail
Mackay Creek	492972	5466090	0.9	0.5	2	0	30	20	20	30	20	Upper McKay Creek Park (unknown creek) trib RL off Smith Trail
Mackay Creek	492707	5466467	7.5	3.5	12	0	70	5	25	5	5	U/S Handsworth pedestrian bridge
Mackay Creek	492804	5466874	2.6	0.9	2	2	13	25	35	25	30	

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mackay	492209	5465189							108	point of commencement, top of fish ladder
Mackay	492218	5465178				48			100	
Mackay	492215	5465173				48			99	CT sea
Mackay	492229	5465152				66			98	
Mackay	492225	5465135				38			97	
Mackay	492225	5465131		48.0	3.2				97	
Mackay	492225	5465130				88			96	
Mackay	492230	5465107		15.0	6.0				96	
Mackay	492227	5465097		30.0	8.0				95	
Mackay	492227	5465097		55.0	4.5					
Mackay	492231	5465095							95	storm out fall from road, Japanese knotweed, goutweed, ivy
Mackay	492232	5465078		65.0	10.5				94	
Mackay	492232	5465078		35.0	3.0				94	
Mackay	492232	5465078		15.0	11.0				94	
Mackay	492243	5465074				69			94	
Mackay	492236	5465066		45.0	1.5				93	
Mackay	492241	5465065		20.0	15.5				93	
Mackay	492241	5465065		65.0	8.5				93	
Mackay	492241	5465065		60.0	3.5				93	
Mackay	492241	5465065		90.0	5.0				93	
Mackay	492236	5465059				36			93	
Mackay	492237	5465050		29.0	28.0				92	
Mackay	492237	5465050		40.0	4.5				92	ivy both sides
Mackay	492248	5465042		45.0	2.7				90	
Mackay	492243	5465042				34			89	
Mackay	492243	5465033		44.0	85.0				89	
Mackay	492249	5465026				51			89	
Mackay	492239	5465025		62.0	5.1				89	
Mackay	492239	5465025		65.0	3.5				89	
Mackay	492239	5465025		30.0	1.5				89	
Mackay	492243	5465019				63			88	
Mackay	492230	5465005		25.0	15.5				89	big Japanese knotweed patch, blue shrub
Mackay	492230	5465005		22.0	6.0				89	
Mackay	492230	5465005		25.0	10.0				89	
Mackay	492233	5465004		24.0	2.2				88	
Mackay	492228	5464995				37			87	
Mackay	492225	5464980		45.0	8.5				87	
Mackay	492220	5464981				36			87	
Mackay	492224	5464979		77.0	2.5				86	
Mackay	492212	5464976		35.0	2.5				86	
Mackay	492212	5464976		30.0	2.2				86	
Mackay	492212	5464976		35.0	3.0				85	
Mackay	492205	5464974				69			85	massive boulder
Mackay	492204	5464974		47.0	2.7				85	
Mackay	492206	5464972		40.0	26.5				85	
Mackay	492200	5464951		10.0	1.5				84	
Mackay	492194	5464939				32			83	
Mackay	492206	5464920				33			83	junior Mt Everest (JR m Everest)
Mackay	492204	5464915				51			83	
Mackay	492226	5464895		47.0	9.5				84	
Mackay	492213	5464887		52.0	3.2				83	
Mackay	492219	5464888				61			82	CT 17 0
Mackay	492200	5464886				34			82	

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mackay	492201	5464888							81	27m long x 3.5 tall knotweed erosion site, glacial till exposed
Mackay	492188	5464860				47			81	large knotweed patch
Mackay	492193	5464853		32.0	6.5				80	
Mackay	492193	5464853		30.0	1.5				80	
Mackay	492194	5464843				32			79	
Mackay	492188	5464840		28.0	6.6				80	
Mackay	492191	5464841							80	same as above
Mackay	492191	5464833							80	wide open channel CO fry
Mackay	492178	5464823		65.0	2.6				79	jam!
Mackay	492175	5464822		28.0	3.2				79	channel island
Mackay	492175	5464822		40.0	1.5				79	lots of Japanese knotweed
Mackay	492175	5464822		30.0	14.0				79	
Mackay	492175	5464822		45.0	1.5				79	
Mackay	492176	5464817				31			78	
Mackay	492169	5464812		40.0	22.0				79	island
Mackay	492183	5464809				42			78	
Mackay	492164	5464811				37			77	
Mackay	492157	5464813							77	open access dog area
Mackay	492164	5464790				31			77	
Mackay	492159	5464781		38.0	3.1				76	
Mackay	492159	5464781		18.0	10.5				76	
Mackay	492159	5464781		35.0	3.2				76	
Mackay	492176	5464783				31			76	
Mackay	492170	5464762		15.0	2.6				75	
Mackay	492170	5464762		60.0	5.5				75	
Mackay	492168	5464753		55.0	2.5				75	bridge
Mackay	492177	5464715							78	intake
Mackay	492189	5464717				52			78	
Mackay	492202	5464708				30			77	
Mackay	492195	5464703							77	bank erosion west
Mackay	492198	5464692				31			77	Murdo Fraser bridge = fish passible boxes
Mackay	492206	5464667							76	powerline , pedestrian
Mackay	492210	5464659		30.0	3.0				75	
Mackay	492210	5464659		23.0	2.0				75	
Mackay	492207	5464654		12.0	2.3				75	
Mackay	492218	5464635				57			74	
Mackay	492218	5464638		55.0	7.8				74	
Mackay	492220	5464622		42.0	2.9				74	
Mackay	492219	5464617							74	top of [ ], = end
Mackay	492226	5464633							77	, top of plank wall
Mackay	492230	5464636				31			77	
Mackay	492230	5464636				36			78	
Mackay	492233	5464629				33			78	
Mackay	492239	5464615							78	small debris jam, bottom of plank wall
Mackay	492244	5464616		25.0	1.5				78	stacked wall on north bank
Mackay	492256	5464589				30			77	1 talls [knotweed?], ivy, laurel,
Mackay	492256	5464589				39			77	
Mackay	492269	5464588							77	outfall channel from south (dry)
Mackay	492283	5464586		85.0	15.0				77	across channel
Mackay	492293	5464593				56			75	
Mackay	492296	5464596		25.0	12.5				75	CO in pool
Mackay	492317	5464604		42.0	22.0				75	
Mackay	492304	5464598							74	intake pipe, concrete

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mackay	492320	5464606				38			74	
Mackay	492339	546411		45.0	1.5	48			74	bank protection site, Japanese knotweed, ivy, monkshood
Mackay	492351	5464605		40.0	1.2				73	bank protection site, Japanese knotweed, ivy, monkshood
Mackay	492355	5464599				31			71	
Mackay	492360	5464594							71	outlet channel from off-channel
Mackay	492366	5464600							71	riparian restoration site, ivy, knotweed
Mackay	492394	5464599							70	outfall, 1.9 m drop
Mackay	492392	5464598							69	bottomless [ ], U/S end
Mackay	492430	5464604							68	huge Japanese knotweed both sides * riparian [ ] √
Mackay	492436	5464593		37.0	13.5	56			68	
Mackay	492434	5464587		42.0	6.3	53			68	
Mackay	492438	5464583		12.0	6.0				67	small passable jam / plunge
Mackay	492444	5464582							67	
Mackay	492457	5464579				57			66	
Mackay	492469	5464581		35.0	1.2				67	
Mackay	492469	5464581		30.0	1.5				67	
Mackay	492484	5464571				42			66	lots of Japanese knotweed, lots of CO fry
Mackay	492494	5464575				51			66	
Mackay	492494	5464570		27.0	2.2				66	
Mackay	492496	5464566				40			66	
Mackay	492500	5464555		30.0	27.0				66	
Mackay	492500	5464555		25.0	6.5				65	Japanese knotweed patches
Mackay	492506	5464541		75.0	12.5				65	debris jam anchored by 2 large
Mackay	492506	5464541		95.0	8.0				65	
Mackay	492506	5464541		18.0	6.0				65	
Mackay	492506	5464541		30.0	1.5				65	
Mackay	492506	5464541		18.0	6.0				65	
Mackay	492506	5464541		30.0	1.5				65	
Mackay	492495	5464533					4.5 x 1.5		65	recent erosion site 4.5 tall, 1.5 long
Mackay	492505	5464517							64	less invasives, nice hemlock forest
Mackay	492512	5464514		70.0	18.0				63	
Mackay	492525	5464500		18.0	6.6	33.0			63	
Mackay	492525	5464500		85.0	11.0				63	
Mackay	492525	5464500		60.0	23.5				63	
Mackay	492556	5464484		20.0	4.5				61	
Mackay	492570	5464468				31.0			60	
Mackay	492576	5464475		15.0	5.5	32.0			61	trib from north
Mackay	492576	5464475		15.0	1.4				61	
Mackay	492576	5464475		20.0	7.5				61	
Mackay	492576	5464475		45.0	3.5				61	
Mackay	492575	5464449							60	top of double box highway culvert
Mackay	492580	5464446							60	
Mackay	492646	5464364							57	bottom of culvert
Mackay	492647	5464359		20.0	2.0				57	bottom of culvert apron
Mackay	492647	5464359		10.0	6.0				57	
Mackay	492647	5464359		30.0	12.5				57	
Mackay	492647	5464359		20.0	4.5				57	
Mackay	492659	5464361				38.0			55	CO fry
Mackay	492657	5464359		10.0	6.2				56	jam
Mackay	492657	5464359		40.0	7.5				56	
Mackay	492657	5464359		25.0	1.5				56	
Mackay	492657	5464359		10.0	1.5				56	
Mackay	492657	5464359		15.0	6.0				56	
Mackay	492652	5464355				60			55	
Mackay	492658	5464358		35.0	2.5				54	

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mackay	492658	5464358		12.0	6.5				54	
Mackay	492658	5464358		20.0	5.0				54	
Mackay	492657	5464350		25.0	2.5				54	
Mackay	492665	5464340		32.0	1.4				54	
Mackay	492670	5464331		20.0	11.0				53	jam
Mackay	492670	5464331		15.0	12.5				53	
Mackay	492670	5464331		28.0	6.0				53	
Mackay	492670	5464331		18.0	7.0				53	
Mackay	492670	5464331		10.0	6.0				53	
Mackay	492673	5464319		48.0	2.5				53	
Mackay	492673	5464319		20.0	1.5				53	
Mackay	492673	5464319		20.0	12.0				53	
Mackay	492673	5464319		25.0	1.5				53	
Mackay	492678	5464299		20.0	7.0				53	
Mackay	492678	5464299		15.0	4.5				53	
Mackay	492678	5464299		10.0	6.0				53	
Mackay	492678	5464299		25.0	1.5				53	
Mackay	492697	5464298		35.0	16.0	66			53	jam and pool
Mackay	492697	5464298		20.0	3.0				53	
Mackay	492697	5464298		5.0	4.5				53	
Mackay	492697	5464298		15.0	2.5				53	
Mackay	492706	5464305		35.0	7.2				53	trib from north
Mackay	492715	5464273							52	
Mackay	492729	5464252				52			51	
Mackay	492730	5464248		38.0	1.6				50	
Mackay	492722	5464231		40.0	7.0				50	
Mackay	492724	5464213		15.0	5.6	33			50	
Mackay	492724	5464213		15.0	5.6				50	
Mackay	492724	5464213		15.0	5.6				49	
Mackay	492723	5464197							48	pedestrian bridge, quite a lot of riparian disturbance
Mackay	492715	5464177		42.0	8.5				48	
Mackay	492715	5464177		20.0	10.5				48	
Mackay	492711	5464143		25.0	5.5	46			46	
Mackay	492700	5464107		28.0	4.0				44	
Mackay	492700	5464107		26.0	10.0				44	
Mackay	492703	5464083		10.5	2.5				44	lots of CO
Mackay	492698	5464079				32			44	
Mackay	492701	5464074		25.0	13.5				43	
Mackay	492701	5464074		25.0	8.0				43	
Mackay	492702	5464076		65.0	1.5				44	
Mackay	492705	5464102							44	landfill seepage
Mackay	492702	5464075		150.0	1.3				43	
Mackay	492715	5464056		20.0	10.5				43	2nd landfill seepage
Mackay	492704	5464047		30.0	1.5	52			41	
Mackay	492704	5464047		65.0	3.5				41	
Mackay	492704	5464019		10.0	4.0				41	
Mackay	492704	5464019		15.0	6.5				41	
Mackay	492704	5464019		20.0	3.5				41	
Mackay	492704	5464019		15.0	1.0				41	
Mackay	492704	5464019		40.0	12.5				41	
Mackay	492704	5464019		15.0	4.5				41	
Mackay	492710	5463999							40	large Japanese knotweed patch east side / both sides, powerline
Mackay	492720	5463983		30.0	5.0	55			39	jam, lots of CO & CT

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mackay	492720	5463983		25.0	8.0				39	
Mackay	492720	5463983		45.0	6.0				39	
Mackay	492720	5463983		10.0	8.0				39	
Mackay	492720	5463983		10.0	3.0				39	
Mackay	492720	5463983		45.0	2.5				39	
Mackay	492720	5463983		25.0	8.0				39	
Mackay	492720	5463983		20.0	8.0				39	
Mackay	492720	5463983		10.0	2.0				39	
Mackay	492720	5463983		30.0	1.5				39	
Mackay	492720	5463983		20.0	1.5				39	
Mackay	492732	5463992		25.0	8.0				38	
Mackay	492732	5463992		15.0	6.0				38	
Mackay	492737	5463988				32			38	
Mackay	492747	5463978		120.0	1.8	36			37	
Mackay	492741	5463966		70.0	4.5	52			37	jam
Mackay	492741	5463966		20.0	6.0				37	
Mackay	492741	5463966		20.0	6.0				37	
Mackay	492741	5463966		15.0	4.5				37	
Mackay	492741	5463966		8.0	10.0				37	
Mackay	492741	5463966		10.0	4.0				37	
Mackay	492741	5463966		15.0	4.0				37	
Mackay	492741	5463966		32.0	6.0				37	
Mackay	492741	5463966		20.0	4.0				37	
Mackay	492741	5463966		25.0	10.0				37	
Mackay	492741	5463966		10.0	6.0				37	
Mackay	492741	5463966		50.0	6.0				37	
Mackay	492741	5463966		10.0	6.0				37	
Mackay	492741	5463966		50.0	6.0				37	
Mackay	492741	5463966		30.0	6.0				37	
Mackay	492750	5463955				41			36	
Mackay	492750	5463938		60.0	11.5				36	
Mackay	492750	5463938		45.0	10.0				36	
Mackay	492753	5463923				40			35	
Mackay	492765	5463920				53			35	
Mackay	492774	5463912		20.0	2.0				35	
Mackay	492777	5463914		60.0	3.5				35	
Mackay	492777	5463914		10.0	10.0				35	
Mackay	492780	5463896		65.0	25.0	36			34	
Mackay	492780	5463896		60.0	1.5				34	
Mackay	492793	5463888		40.0	14.5	41			35	
Mackay	492793	5463888		30.0	10.5				35	
Mackay	492793	5463888		30.0	10.5				35	
Mackay	492794	5463877		40.0	3.5	32			34	
Mackay	492794	5463877		150.0	1.5				34	
Mackay	492809	5463872		35.0	22.0				34	
Mackay	492809	5463872		10.0	6.5				34	
Mackay	492809	5463872		10.0	6.0				34	
Mackay	492815	5463864		35.0	4.5	56			34	loose jam
Mackay	492815	5463864		35.0	6.0				34	
Mackay	492815	5463864		45.0	8.5				34	
Mackay	492815	5463864		10.0	6.0				34	
Mackay	492812	5463859		45.0	5.5				34	
Mackay	492812	5463859		12.0	8.0				34	
Mackay	492812	5463859		15.0	6.0				34	
Mackay	492812	5463859		20.0	6.0				34	

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mackay	492808	5463839		35.0	1.5				34	
Mackay	492814	5463805		15.0	4.0	46			33	
Mackay	492814	5463805		10.0	8.0				33	
Mackay	492814	5463805		10.0	1.5				33	
Mackay	492814	5463805		20.0	6.0				33	
Mackay	492814	5463805		40.0	7.0				33	
Mackay	492814	5463805		45.0	7.5				33	
Mackay	492814	5463805		20.0	3.0				33	
Mackay	492814	5463805		15.0	6.0				33	
Mackay	492814	5463805		45.0	1.5				33	
Mackay	492814	5463805		60.0	2.0				33	
Mackay	492820	5463799		30.0	7.5	62			32	
Mackay	492820	5463799		40.0	3.5				32	
Mackay	492820	5463799		40.0	1.5				32	
Mackay	492820	5463799		65.0	12.5				32	
Mackay	492811	5463786		35.0	1.5	50			31	
Mackay	492811	5463786		40.0	2.5				31	
Mackay	492811	5463786		151.0	2.5				31	
Mackay	492811	5463786		30.0	2.5				31	
Mackay	492811	5463786		45.0	3.5				31	
Mackay	492811	5463786		40.0	1.5				31	
Mackay	492811	5463786		30.0	3.5				31	
Mackay	492793	5463766		45.0	8.5				30	
Mackay	492793	5463766		20.0	4.0				30	
Mackay	492793	5463766		15.0	3.0				30	
Mackay	492793	5463766		15.0	2.0				30	
Mackay	492789	5463768		60.0	8.0	52			30	
Mackay	492774	5463752				73			30	
Mackay	492786	5463734		25.0	4.5				30	
Mackay	492786	5463734		45.0	2.5				30	
Mackay	492804	5463715		30.0	2.8				29	
Mackay	492804	5463715		15.0	8.0				29	
Mackay	492804	5463688				43			28	
Mackay	492796	5463681		120.0	1.5	68			28	
Mackay	492789	5463679		25.0	1.2				28	raft / LWD
Mackay	492789	5463679		25.0	1.2				28	
Mackay	492789	5463679		25.0	1.2				28	
Mackay	492789	5463679		25.0	1.2				28	
Mackay	492789	5463679		25.0	1.2				28	
Mackay	492789	5463679		25.0	1.2				28	
Mackay	492779	5463681		60.0	5.2				27	
Mackay	492779	5463681		40.0	1.5				27	
Mackay	492779	5463681		50.0	8.5				27	
Mackay	492779	5463681		45.0	10.0				27	
Mackay	492753	5463662		45.0	2.7	50			26	
Mackay	492753	5463662		25.0	8.5				26	
Mackay	492753	5463662		15.0	6.0				26	
Mackay	492753	5463662		10.0	4.0				26	
Mackay	492753	5463662		35.0	1.5				26	
Mackay	492753	5463662		10.0	4.5				26	
Mackay	492732	5463627		40.0	2.5	56			24	
Mackay	492732	5463627		55.0	2.0				24	
Mackay	492740	5463639							25	D/S edge of pedestrian bridge, 20 m D/S of park edge

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mackay	492737	5463595		55.0	3.5				24	
Mackay	492731	5463588		45.0	10.5	45			23	
Mackay	492710	5463582		10.0	3.5	36			23	steep rock bank protection
Mackay	492702	5463549							21	pedestrian bridge concrete
Mackay	492711	5463512		40.0	2.5				21	pedestrian
Mackay	492711	5463512		36.0	1.5				21	
Mackay	492710	5463501		15.0	2.5				20	
Mackay	492711	5463484				42			19	
Mackay	492709	5463454							22	middle of bridge / Heywood, abutment failing
Mackay	492701	5463444				32			18	old creosote bank protection
Mackay	492693	5463423							18	U/S end of Marine Dr. culvert, bottomless box, concrete
Mackay	492672	5463381							19	D/S end of culvert
Mackay	492671	5463395				55			19	storm outfall
Mackay	492660	5463378		65.0	7.5	105			18	tons of ivy
Mackay	492660	5463378		15.0	3.5				18	
Mackay	492648	5463347		10.0	1.5	50			17	tons of CO
Mackay	492640	5463333		35.0	6.5				17	
Mackay	492641	5463325							17	
Mackay	492617	5463315		15.0	6.0				17	
Mackay	492603	5463300		25.0	1.5				16	stacked concrete slab wall
Mackay	492597	5463284							16	storm outfall
Mackay	492587	5463275				35			16	
Mackay	492579	5463269							15	pedestrian bridge, start of concrete bank protection
Mackay	492566	5463259				46			14	end of concrete bank protection to east
Mackay	492549	5463255				65		47 cm drop	14	concrete drop 47 cm
Mackay	492538	5463249							14	diversion pipe, transition to sand
Mackay	492532	5463232		35.0	2.2				14	
Mackay	492530	5463230							13	main storm outfall
Mackay	492532	5463218		45.0	2.5				14	
Mackay	492529	5463222		35.0	1.5				13	tons of CO
Mackay	492511	5463197		35.0	3.5	46			12	
Mackay	492511	5463197		45.0	1.5				12	
Mackay	492511	5463197		10.0	5.5				12	
Mackay	492509	5463191				40			13	concrete drop 47 cm
Mackay	492506	5463168				60			13	
Mackay	492500	5463161				95			13	
Mackay	492505	5463119		25.0	2.5				12	end of diversion
Mackay	492505	5463119		25.0	11.5				12	
Mackay	492496	5463110		35.0	1.5	49			12	
Mackay	492493	5463102		35.0	1.5	95			12	
Mackay	492493	5463102		40.0	3.0				12	
Mackay	492485	5463066				38			12	weir, rip rap, gas and hydro crossing
Mackay	492487	5463068				85			11	large storm outfall, cray fish
Mackay	492490	5463037				42			11	
Mackay	492499	5463011				46			11	large CT seen
Mackay	492498	5462999				95			10	
Mackay	492462	5462995		10.0	3.1	36			10	jam, point of termination
Mackay	492462	5462995		10.0	4.0				10	
Mackay	492462	5462995		15.0	3.0				10	
Mackay	492462	5462995		45.0	3.4				10	

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mission	GPS 10U		(m)	(cm)	(m)	(cm)	(m)			Mission Creek walked from Larson Rd. to just U/S of 1st pedestrian bridge (near confluence of Wagg & Mission Creeks) October 03, 2014
Mission	0493868	5463839		50	3.0	33				GPS accuracy +/-8m
Mission	0493868	5463839		20	2.0	30				
Mission	0493868	5463839		10	4.0					
Mission	0493868	5463839		25	2.0					(damp) epheneral channel runs parallel to stream (runnoff from playing feilfd?)
Mission	0493872	5463813		10	2.0	65				
Mission	0493872	5463813		18	2.0					
Mission	0493865	5463813		80	8.0	40				epheneral channel joins stream
Mission	0493865	5463813		40	3.0					
Mission	0493865	5463813		10	3.0					
Mission	0493865	5463813		40	2.0					
Mission	0493865	5463813		40	8.0					more tires
Mission	0493865	5463813		40	3.0					
Mission	0493865	5463813		18	2.0					
Mission	0493865	5463800		20	5.0					
Mission	0493863	5463803		10	3.0	30				
Mission	0493852	5463802		25	6.0	32				
Mission	0493852	5463802		10	3.0					
Mission	0493839	5463798		40	2.0	30				wooden (stringer ACQ?/green coloured) pedestrain bridge
Mission	0493839	5463798			1.5					large cedar root wad
Mission	0493824	5463767		50	7.0	35				passable jam
Mission	0493824	5463767		20	6.0					
Mission	0493820	5463764		30	2.0					passable waterfall (boulder - 1 m drop) many large boulders randomly in reach
Mission	0493820	5463764		40	2.0					
Mission	0493809	5463748				55				
Mission	0493800	5463745		10	2.0	33				
Mission	0493800	5463745		18	2.5					
Mission	0493800	5463745		10	3.0					
Mission	0493793	5463735		50	5.0					
Mission	0493787	5463734		60	7.0					
Mission	0493781	5463735		70	2.5					more tires (like two dozen now since start - also several abandoned homelss camps)
Mission	0493781	5463735		70	2.5					
Mission	0493781	5463735		80	3.0					passable jam
Mission	0493781	5463735		30	2.0					
Mission	0493781	5463735		40	10.5					
Mission	0493781	5463735		12	2.0					
Mission	0493781	5463735		10	2.0					
Mission	0493781	5463735		18	2.0					
Mission	0493773	5463723		25	8.0					
Mission	0493773	5463723		18	8.0					
Mission	0493773	5463723		22	8.0					
Mission	0493773	5463723		22	7.0					
Mission	0493773	5463723		30	6.0					
Mission	0493774	5463722		40	8.0	30				
Mission	0493769	5463721				32				
Mission	0493776	5463724								
Mission	0493750	5463711		35	5.0					
Mission	0493750	5463711		15	3.0					
Mission	0493750	5463711		10	4.0					
Mission	0493750	5463711		20	2.5					
Mission	0493750	5463711		20	2.0					
Mission	0493748	5463709		60	5.0	37				

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mission	GPS 10U		(m)	(cm)	(m)	(cm)	(m)			Mission Creek walked from Larson Rd. to just U/S of 1st pedestrian bridge (near confluence of Wagg & Mission Creeks) October 03, 2014
Mission	0493748	5463709		22	7.0					
Mission	0493747	5463679		45	6.0	30				passable jam
Mission	0493747	5463679		50	15.0					
Mission	0493742	5463671		20	2.0					
Mission	0493742	5463671		35	5.0					
Mission	0493742	5463671		35	5.0					
Mission	0493745	5463659		30	2.0	35				
Mission	0493838	5463987	2.5			40				point of commencement, GPS accuracy +/- 10m, many fishes holding in culvert (Larson Rd.) outflow pool (2m x 5m)
Mission	0493838	5463987								car tires, someones garden debris (recent & many years worth), all kinds of trash
Mission	0493851	5463944								dry (ephemeral) storm water trib RL
Mission	0493857	5463932				31				
Mission	0493849	5463920		25	3.0					luarel, holly, oxalis, ivy abundant in reach both banks, GPS accuracy +/- 8m
Mission	0493849	5463920		25	2.5					
Mission	0493849	5463920		25	3.0					
Mission	0493853	5463910	2			38				
Mission	0493855	5463910		20	8.0					
Mission	0493855	5463910		23	3.0					
Mission	0493855	5463910		20	3.0					
Mission	0493861	5463903				70				lone or small groupigs of big bouolders occasionally found throughout reach
Mission	0493875	5463889		20	5.0					clumpings of few stems of Japanese knotweed
Mission	0493875	5463889		10	2.0					
Mission	0493747	5463651		22	10.0					
Mission	0493747	5463651		25	12.0					
Mission	0493747	5463651		22	10.0					
Mission	0493747	5463651		25	12.0					
Mission	0493747	5463651		18	2.0					
Mission	0493744	5463641		40	2.5	45				
Mission	0493742	5463638		50	10.0					
Mission	0493742	5463638		20	2.5					
Mission	0493742	5463638		25	2.5					
Mission	0493742	5463638		25	2.5					
Mission	0493742	5463638		25	2.0					
Mission	0493742	5463638		25	2.0					
Mission	0493742	5463638		22	2.0					
Mission	0493735	5463634	2							
Mission	0493719	5463638		40	7.0					large passable jam with impounded sand wedge behind it
Mission	0493719	5463638		35	5.0					
Mission	0493719	5463638		30	2.0					
Mission	0493719	5463638		12	2.5					
Mission	0493719	5463638		10	2.0					
Mission	0493702	5463640								U/S end of island with mature maple, salmonberry, water both sides
Mission	0493711	5463642								D/S end of vegetated island
Mission	0493702	5463640	5							clumpings of few stems of Japanese knotweed
Mission	0493678	5463624		20	7.0					
Mission	0493678	5463624		12	2.0					
Mission	0493671	5463625	5	33	2.0					field of Himalayan blackberry RR (est 20m x 15m) on floodplain bench
Mission	0493671	5463625		33	2.0					
Mission	0493671	5463625		18	2.0					
Mission	0493671	5463625			1.5					root wad
Mission	0493664	5463620		20	2.0					GPS accuracy +/- 5m
Mission	0493664	5463620		12	3.0					
Mission	0493664	5463620		25	2.0					

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mission	GPS 10U		(m)	(cm)	(m)	(cm)	(m)			Mission Creek walked from Larson Rd. to just U/S of 1st pedestrian bridge (near confluence of Wagg & Mission Creeks) October 03, 2014
Mission	0493658	5463597		55	12.0					
Mission	0493655	5463593		65	13.0	35				U/S end of treed island with seasonally flooded side channel
Mission	0493655	5463593		30	8.0					
Mission	0493655	5463593		10	3.0					
Mission	0493650	5463573								D/S end of treed island
Mission	0493649	5463570		55	12.0	45				
Mission	0493649	5463570		25	2.0					
Mission	0493649	5463570		27	3.0					
Mission	0493649	5463570		30	2.5					
Mission	0493649	5463570		32	3.0					
Mission	0493641	5463563		25	7.0					
Mission	0493641	5463563		20	5.0					
Mission	0493638	5463555		25	2.5					
Mission	0493638	5463555		18	3.0					
Mission	0493638	5463555		15	3.0					
Mission	0493638	5463555		18	2.5					
Mission	0493632	5463530								U/S end of island of shrubs created behind large boulder, RL riparian carpet (expansive colony) of lamium
Mission	0493628	5463516								D/S end of shrub island water both sides
Mission	0493635	5463509		20	2.0					dog use soil/bank disturbance
Mission	0493635	5463509		10	7.0					
Mission	0493640	5463494		22	3.0	32				
Mission	0493632	5463460		20	2.0	34				
Mission	0493620	5463457		20	4.0	30				
Mission	0493615	5463454				36				concrete pedestrian bridge
Mission	0493604	5463437		35	5.0	30				
Mission	0493602	5463431		35	3.0	30				
Mission	0493602	5463431		18	2.0					point of termination (POT)

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mosquito	0493458	5462674		10	10.0					point of commencement: rail bridge (tidal influence here)
Mosquito	0493458	5462674		40	30.0					
Mosquito	0493458	5462674			1.5					root wad
Mosquito	0493458	5462674		40	15.0					
Mosquito	0493414	5462700		15	15.0					
Mosquito	0493414	5462700		15	15.0					
Mosquito	0493414	5462700		10	10.0					no tidal influence here
Mosquito	0493383	5462723								island with shrubs ~25 m long, looks to be inundated in high flows, dry back channel ~ 50 m
Mosquito	0493285	5462792				36				wide shallow glide under Bewick bridge, good place for restoration boulder/root wad installation (?)
Mosquito	0493297	5462832	30			50				U/S Bewick bridge & Mission creek confluence, 12 m long glide 30-50 cm deep, undercut RB
Mosquito	0493285	5462835								D/S end of 12m wide island with mature alder, thimbleberry, ivy
Mosquito	0493238	5462863								U/S end of island just D/D 1s Ave Bridge
Mosquito	0493271	5462840		10	3.0					jam passable of mostly smalls on RB
Mosquito	0493271	5462840		10	3.0					
Mosquito	0493271	5462840		10	3.0					
Mosquito	0493271	5462840		12	2.0					
Mosquito	0493271	5462840		12	2.0					
Mosquito	0493271	5462840		10	12.0	40				jam passable, spanning logs and double root wads LB
Mosquito	0493271	5462840		10	12.0					
Mosquito	0493271	5462840		20	22.0					
Mosquito	0493271	5462840			1.5					root wad
Mosquito	0493271	5462840			1.5					root wad
Mosquito	0493238	5462863		30	12.0	40				logs jammed against U/S point of island, glide 30-40 cm deep x 8m long RB
Mosquito	0493238	5462863		12	6.0					
Mosquito	0493238	5462863		12	6.5					
Mosquito	0493238	5462863		10	6.0					
Mosquito	0493238	5462863		10	6.0					
Mosquito	0493238	5462863		10	5.5					
Mosquito	0493238	5462863		10	4.5					
Mosquito	0493238	5462863		10	3.5					
Mosquito	0493200	5462863		12	6.0					
Mosquito	0493170	5462890				75				U/S 1st Ave bridge, glide 50-75 cm deep by 8 m long
Mosquito	0493180	5462890				35				erosion undermining mature cottonwood tree, RB
Mosquito	0493172	5462908				33				
Mosquito	0493173	5462928	5			55				glide 40-55 cm deep by 8 m with overhanging bank LB
Mosquito	0493161	5462970	3			40				glide 30-40 cm deep by 6 m with overhanging bank RB
Mosquito	0493150	5463010				70				glide 50-70 cm deep, ~ width of stream, outfall pools from weir
Mosquito	0493157	5463025				50				
Mosquito	0493157	5463025				50				
Mosquito	0493156	5463032				100				outfall pool immediately D/S weir, 3 m long
Mosquito	0493155	5463037				40				glide 30-40 cm deep by 8 m long and 5 m wide under bridge
Mosquito	0493142	5463108				40				glide 40 cm by 5 m long D/S Marine Dr. bridge, new riparian restoration LB (wood install) inadequate to influence flow
Mosquito	0493147	5463128				50				glide 30-50 cm deep by 7 m long D/S Marine Dr. bridge
Mosquito	0493172	5463173								D/S end of sparsely vegetated island (frequently inundated) with young ladders & salmonberry, main flow RR ww:5m, wb: 7.5m
Mosquito	0493176	5463188								U/S end of sparsely vegetated island, 7m widest point, barely wetted back channel: ww 1.0, wb: 2.5
Mosquito	0493177	5463200				45				
Mosquito	0493177	5463200				50				
Mosquito	0493188	5463252				35				and a large boulder
Mosquito	0493192	5463263				35				
Mosquito	0493196	5463279				30				
Mosquito	0493202	5463387				70				50-70 cm pools at outfall from concreted apron under Larson Rd. bridge, old creosote retaining wall
Mosquito	0493212	5463408				40				30-40 cm pool under U/S end of Larson Rd. bridge
Mosquito	0493197	5463431				30				two small pools within channel width

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mosquito	0493197	5463431				30				
Mosquito	0493200	5463434				35				many very small (0.5-1.5 m diameter) boulder step-pools in this reach, really no flow refugia from Marine Dr. to ~17th street (493379,5463806)
Mosquito	0493200	5463440				40				
Mosquito	0493200	5463446				35				
Mosquito	0493202	5463456				30				
Mosquito	0493211	5463467				30				
Mosquito	0493211	5463478				30				
Mosquito	0493210	5463485				31				
Mosquito	0493213	5463495				33				
Mosquito	0493218	5463502				33				
Mosquito	0493222	5463509				30				
Mosquito	0493223	5463516				35				
Mosquito	0493223	5463518				30				
Mosquito	0493223	5463525				31				
Mosquito	0493232	5463533				35				
Mosquito	0493236	5463541				30				
Mosquito	0493238	5463562				40				
Mosquito	0493238	5463568				30				
Mosquito	0493240	5463569				30				
Mosquito	0493240	5463570		50	5.0					
Mosquito	0493247	5463588				30				
Mosquito	0493249	5463601				34				
Mosquito	0493259	5463601				30				
Mosquito	0493260	5463603				30				
Mosquito	0493260	5463609				38				
Mosquito	0493260	5463609		12	7.5					spans across creek but affects flow at wb only
Mosquito	0493260	5463620				45				
Mosquito	0493260	5463622				30				
Mosquito	0493275	5463661				30				
Mosquito	0493285	5463672				35				GPS accuracy now +/- 12m where D/S was 5m
Mosquito	0493285	5463672		12	8.0					spans across creek
Mosquito	0493285	5463672		15	2.0					GPS accuracy now +/- 8m
Mosquito	0493296	5463699				32				
Mosquito	0493297	5463701		40	2.0	30				
Mosquito	0493297	5463701			1.5					root wad center of stream
Mosquito	0493311	5463709				30				
Mosquito	0493312	5463718				30				
Mosquito	0493316	5463734				34				
Mosquito	0493317	5463735				31				
Mosquito	0493332	5463737				35				
Mosquito	0493323	5463739				33				
Mosquito	0493323	5463739				35				
Mosquito	0493325	5463740				30				
Mosquito	0493325	5463740				32				
Mosquito	0493341	5463755				30				
Mosquito	0493353	5463766		15	3.5	50				
Mosquito	0493357	5463767				30				
Mosquito	0493357	5463769				40				
Mosquito	0493366	5463774				45				
Mosquito	0493370	5463781				31				
Mosquito	0493371	5463782				36				
Mosquito	0493375	5463789				43				
Mosquito	0493381	5463799		18	6.5	30				tree with root ball attached

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mosquito	0493381	5463799								D/S end of island, sapling alders one cedar and shrubs, seasonally flooded side channel (dry) RR
Mosquito	0493381	5463831								U/S end of island
Mosquito	0493379	5463806				30				outlet from rearing pond on east side of MS
Mosquito	0493387	5463849	3			37				undercut bank RR
Mosquito	0493394	5463859				30				
Mosquito	0493396	5463860		25	8.5	35				
Mosquito	0493409	5463960				30				
Mosquito	0493408	5463991				33				
Mosquito	0493407	5463992				30				
Mosquito	0493407	5463993				34				
Mosquito	0493407	5463999				45				
Mosquito	0493408	5464002				42				
Mosquito	0493401	5464019				34				
Mosquito	0493401	5464021				35				
Mosquito	0493401	5464021				33				
Mosquito	0493404	5464029				30				
Mosquito	0493404	5464042				40				
Mosquito	0493404	5464042				72				
Mosquito	0493416	5464058		30	13.0	46				
Mosquito	0493416	5464058		12	5.5					
Mosquito	0493415	5464059				45				
Mosquito	0493420	5464084		10	2.5	57				GPS accuracy +/-15m
Mosquito	0493420	5464084		10	3.0					
Mosquito	0493420	5464084		10	3.5					
Mosquito	0493417	5464077				44				
Mosquito	0493417	5464077				32				
Mosquito	0493417	5464077				32				
Mosquito	0493415	5464097				35				GPS accuracy +/-12m
Mosquito	0493415	5464100				42				
Mosquito	0493409	5464105		10	3.5	49				
Mosquito	0493409	5464105				37				
Mosquito	0493408	5464114				30				
Mosquito	0493408	5464114				32				
Mosquito	0493408	5464122				43				
Mosquito	0493410	5464146				30				GPS accuracy +/-8m
Mosquito	0493410	5464146				52				
Mosquito	0493382	5464193		15	8.5	33				GPS accuracy +/-22m (highway bridge overhead interfering?)
Mosquito	0493382	5464193				41				
Mosquito	0493381	5464179				40				
Mosquito	0493381	5464185		35	6.0					U/S end of lower Mosquito Creek side channel intake & lock block weir
Mosquito	0493381	5464196				60				lost GPS signal, UTM estimated
Mosquito	0493382	5464204				39				lost GPS signal, UTM estimated
Mosquito	0493382	5464204				36				lost GPS signal, UTM estimated
Mosquito	0493353	5464304		15	6.5	35				GPS accuracy +/-22m (highway bridge overhead interfering?)
Mosquito	0493353	5464304		12	5.0					three logs clustered RR
Mosquito	0493353	5464304		10	5.0					
Mosquito	0493355	5464309				30				lost GPS signal, UTM estimated, @ old wood stave (wood gone, wire remains) RR
Mosquito	0493356	5464310				44				lost GPS signal, UTM estimated
Mosquito	0493356	5464310				42				lost GPS signal, UTM estimated
Mosquito	0493356	5464310				30				lost GPS signal, UTM estimated
Mosquito	0493357	5464311				30				lost GPS signal, UTM estimated
Mosquito	0493358	5464315		35	10.0	33				lost GPS signal, UTM estimated
Mosquito	0493359	5464312		40	12.0					lost GPS signal, UTM estimated
Mosquito	0493362	5464370		70	6.0					GPS accuracy +/-15m, two wetted channels under highway bridge on vegetation on island (active)
Mosquito	0493361	5464374								split channels start directly under northern span of highway bridge

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Mosquito	0493361	5464375		15	6.0	34				debris jam on U/S end of island affects flow @ WB
Mosquito	0493361	5464375		18	6.5					
Mosquito	0493361	5464375		30	10.0					
Mosquito	0493361	5464375		12	6.0					
Mosquito	0493361	5464375		12	5.5					
Mosquito	0493361	5464375		10	5.0					
Mosquito	0493361	5464375			1.5					root wad
Mosquito	0493361	5464375			1.5					root wad
Mosquito	0493361	5464375		40	2.5					
Mosquito	0493361	5464375		38	2.0					
Mosquito	0493277	5464378		60	2.0					
Mosquito	0493278	5464396			1.5					root wad
Mosquito	0493276	5464398		40	2.0					
Mosquito	0493276	5464398		15	2.0					
Mosquito	0493276	5464398		12	2.5					
Mosquito	0493276	5464398		12	5.0					
Mosquito	0493268	5464409	3			30				Thain Creek confluence, undercut bank RR
Mosquito	0493260	5464424		35	5.0					U/S Thain Creek, GPS accuracy +/- 5m
Mosquito	0493260	5464424		30	2.5					
Mosquito	0493260	5464424		30	2.0					
Mosquito	0493256	5464434	10							RL
Mosquito	0493251	5464439				31				GPS accuracy +/-8m
Mosquito	0493256	5464459				32				
Mosquito	0493232	5464463				34				
Mosquito	0493232	5464463				30				
Mosquito	0493230	5464465				51				
Mosquito	0493232	5464467				69				
Mosquito	0493229	5464470				32				
Mosquito	0493241	5464499	2			35				
Mosquito	0493252	5464537	3			30				RR
Mosquito	0493252	5464537				30				
Mosquito	0493255	5464540		35	4.0	42				
Mosquito	0493255	5464540				32				
Mosquito	0493254	5464538		60	14.0					60 cm log spans creek affecting flow @ wb
Mosquito	0493254	5464538		15	6.0					
Mosquito	0493254	5464538		90	2.0					
Mosquito	0493259	5464545	4	50	8.0	33				glide 8m and pool associated with undercut bank RL, GPS accuracy +/-11m
Mosquito	0493254	5464557				31				
Mosquito	0493252	5464557				30				
Mosquito	0493244	5464588				30				
Mosquito	0493221	5464625				35				manmade step pools here, D/S William Griffin Rec Center, GPS accuracy +/-6m
Mosquito	0493217	5464632				32				
Mosquito	0493212	5464640				32				
Mosquito	0493302	5464665				42				
Mosquito	0493199	5464670				45				
Mosquito	0493199	5464684				39				GPS accuracy +/-22m
Mosquito	0493199	5464670				30				
Mosquito	0493198	5464694				33				
Mosquito	0493190	5464701				45				
Mosquito	0493190	5464745				35				GPS accuracy +/-6m
Mosquito	0493185	5464782				30				
Mosquito	0493192	5464811				60				large pool across stream (10m) 40-60 cm deep by 3m long, directly D/S Queens sediment trap/culvert outflow, POT

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	GPS	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Wagg		0493668	5463314								concrete pedestrian bridge, GPS accuracy +/-22m
Wagg		0493656	5463332			1.5					root wad
Wagg		0493670	5463337				48				
Wagg		0493694	5463359	4	30	2.0					passable jam, undercut bank RR, GPS accuracy +/-12m
Wagg		0493694	5463359	4	35	7.0					undercut bank RL
Wagg		0493694	5463359		12	2.5					
Wagg		0493694	5463359		10	2.0					
Wagg		0493694	5463359			1.5					root wad
Wagg		0493697	5463354		35	7.0					three logs from old, failing retaining wall RL, GPS accuracy +/-3m
Wagg		0493697	5463354		35	7.0					
Wagg		0493697	5463354		35	7.0					
Wagg		0493699	5463356				31				
Wagg		0493699	5463359				42				old log retaining wall intact 10m long RL
Wagg		0493713	5463372				34				dog use soil/bank disturbance
Wagg		0493718	5463376		44	3.0					
Wagg		0493718	5463376			1.5					root wad
Wagg		0493713	5463376	2							RR, glacial till exposed (unconsolidated on top of consolidated)
Wagg		0493712	5463379				35				dog use soil/bank disturbance
Wagg		0493711	5463391	10							RR
Wagg		0493712	5463323								D/S end of island with trees and shrubs, both channels wetted
Wagg		0493723	5463409								U/S end of island with trees and shrubs
Wagg		0493718	5463405		10	2.5					
Wagg		0493718	5463405		12	5.5					
Wagg		0493718	5463405		12	5.0					
Wagg		0493718	5463405		12	3.0					
Wagg		0493723	5463409		50	3.5					
Wagg		0493723	5463409		45	6.0					
Wagg		0493727	5463411				34				
Wagg		0493727	5463412		60	7.0					GPS accuracy +/-8m
Wagg		0493738	5463409		28	5.0	38				
Wagg		0493738	5463409		45	2.0					
Wagg		0493746	5463412		35	6.0					two logs from old, failing retaining wall RL, GPS accuracy +/-11m
Wagg		0493746	5463412		35	6.0					
Wagg		0493746	5463412		55	10.0					
Wagg		0493749	5463413				42				
Wagg		0493752	5463418	2			33				undercut bank RL, GPS accuracy +/-22m
Wagg		0493747	5463443	12			30				RL: recorded as undercut bank but is really bank retention structure made of 4"x4" cribbing which creates cover/ habitat (photographed) as flow can go through, CT darted out ~ 120mm
Wagg		0493748	5463455	5	35	6.0	30				undercut bank RR, dog use soil/bank disturbance RL
Wagg		0493749	5463445								
Wagg		0493738	5463460		30	6.0					
Wagg		0493747	5463463	2	48	2.0	37				pool in glide 3 m long associated with undercut bank
Wagg		0493759	5463483					2			erosion RR, dog use soil/bank disturbance RL
Wagg		0493749	5463485				33				GPS accuracy +/-12m
Wagg		0493759	5463486		55	12.0					
Wagg		0493759	5463486		15	7.0					
Wagg		0493759	5463486		12	5.0					
Wagg		0493759	5463486		12	5.0					
Wagg		0493759	5463486		10	6.0					
Wagg		0493759	5463495		35	2.0					dog use soil/bank disturbance, GPS accuracy +/-11m
Wagg		0493759	5463495		15	2.5					
Wagg		0493759	5463495		15	2.0					
Wagg		0493759	5463495			1.5					root wad
Wagg		0493755	5463507		28	2.0					D/S end of island with dead-standing tree and shrubs, seasonally wetted secondary channel
Wagg		0493755	5463507		27	3.0					
Wagg		0493755	5463507		25	2.5					
Wagg		0493755	5463507		25	2.0					
Wagg		0493755	5463507		25	2.0					

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	GPS	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Wagg		0493755	5463507		20	2.0					
Wagg		0493755	5463507		30	8.0					
Wagg		0493755	5463507		34	3.5					
Wagg		0493755	5463507		32	3.0					
Wagg		0493773	5463529	3	40	3.0					U/S end of island with dead-standing tree and shrubs, jam at point
Wagg		0493773	5463529		37	3.0					
Wagg		0493773	5463529		35	2.0					
Wagg		0493773	5463529		30	5.0					
Wagg		0493773	5463529		40	5.0					
Wagg		0493773	5463529		10	5.0					
Wagg		0493771	5463531		35	9.0	30				jam outflow pool
Wagg		0493771	5463532	3.5	60	18.0	50				
Wagg		0493771	5463532		45	2.0					large (passable) jam across stream ~7m wide, 2-2.5m high
Wagg		0493771	5463532		40	3.0					
Wagg		0493771	5463532		40	2.5					
Wagg		0493771	5463532		35	2.5					
Wagg		0493771	5463532		30	3.0					
Wagg		0493771	5463532		30	2.0					
Wagg		0493771	5463532		10	2.0					
Wagg		0493771	5463532		10	2.0					
Wagg		0493771	5463532		12	3.0					
Wagg		0493771	5463532		12	3.0					
Wagg		0493781	5463548	10							D/S end of island, water both sides, shrubs/forbs: salmonberry, Japanese knotweed, policemen's helmet, goutweed, Himalayan blackberry
Wagg		0493793	5463548		12	10.0					U/S end of small island, wood debris at point
Wagg		0493793	5463548		21	3.0					
Wagg		0493793	5463548		15	3.0					
Wagg		0493793	5463548		18	2.5					
Wagg		0493793	5463548		18	2.0					
Wagg		0493794	5463548		55	10.0	32				GPS accuracy +/-12m
Wagg		0493794	5463548			1.5					root wad
Wagg		0493794	5463550		40	3.5					
Wagg		0493794	5463550		30	3.0					
Wagg		0493794	5463550		60	9.0					
Wagg		0493794	5463550		30	2.5					
Wagg		0493812	5463565		35	2.5					
Wagg		0493812	5463565		35	2.0					
Wagg		0493817	5463571								concrete pedestrian bridge
Wagg		0493821	5463573		28	8.0					
Wagg		0493822	5463576		12	5.0	35				
Wagg		0493822	5463576		10	8.0					
Wagg		0493825	5463578		20	2.0	42	3			eroding bank of compacted glacial till, GPS accuracy +/- 11m
Wagg		0493825	5463578		15	4.0					
Wagg		0493825	5463578								D/S end of small island with salmonberry and ferns, water both sides
Wagg		0493828	5463582								U/S end of small island with salmonberry and ferns, water both sides
Wagg		0493827	5463582		12	2.5					
Wagg		0493827	5463582		15	3.0		1.5			eroding bank of compacted glacial till
Wagg		0493828	5463583		12	7.0	32				
Wagg		0493828	5463583		18	2.0					
Wagg		0493829	5463584				30				
Wagg		0493829	5463584				48				
Wagg		0493829	5463584		12	7.5	32				
Wagg		0493829	5463584		10	3.0					
Wagg		0493833	5463589		10	2.0	55				
Wagg		0493833	5463589		18	2.0					
Wagg		0493834	5463590				43				
Wagg		0493845	5463602				42				
Wagg		0493853	5463620		48	8.0			debris jam		unpassable currently

Appendix C2-E Table 2. Survey of instream habitat including deep pools and large logs in Mosquito, Mackay, Wagg, and Mission Creeks (Aug-Sept 2014).

Stream	GPS	Location		Undercut	LWD diameter	LWD length	Pool depth	Erosion	Barrier	Elevation	Notes
Wagg		0493853	5463620		45	12.0					photos taken
Wagg		0493853	5463620		40	8.0					
Wagg		0493853	5463620		30	2.0					
Wagg		0493853	5463620		30	2.0					
Wagg		0493853	5463620		55	3.5					
Wagg		0493862	5463605		25	2.0					passable jam
Wagg		0493862	5463605		25	2.0					
Wagg		0493862	5463605		30	3.0					
Wagg		0493862	5463605		30	7.0					
Wagg		0493862	5463605		29	3.0					
Wagg		0493864	5463616		15	2.0					GPS accuracy +/-8m
Wagg		0493875	5463617		18	2.5	38				
Wagg		0493880	5463621		20	2.5	31				
Wagg		0493887	5463613		30	2.5	40				
Wagg		0493894	5463609		20	2.0	42				concrete pedestrian bridge, erosion U/S side, dog use
Wagg		0493910	5463616				35				
Wagg		0493912	5463616		20	2.0	37				
Wagg		0493912	5463616		25	4.0					
Wagg		0493912	5463616		40	2.0					
Wagg		0493912	5463616		10	2.0					
Wagg		0493914	5463616				47		waterfall		1.5 m drop, boulders, passable in high flow only, fish holding in pool half way up
Wagg		0493915	5463621				30				
Wagg		0493926	5463620				41				
Wagg		0493934	5463618		34	2.5					
Wagg		0493934	5463618		40	20.0					
Wagg		0493937	5463622		20	2.0		3			very recent bank failure (erosion)
Wagg		0493941	5463622				37				
Wagg		0493942	5463624				32				
Wagg		0493959	5463631				30				
Wagg		0493965	5463623				50				erosion
Wagg		0493974	5463616								concrete pedestrian bridge, D/S erosion from dogs accessing creek
Wagg		0493980	5463618				30				
Wagg		0493980	5463621				41				glacial clay benthos
Wagg		0493998	5463619				30				concrete pedestrian bridge, very recent riparian/instream works U/S from here (accounting for opaqueness/clay fines water/benthos?)
Wagg		0494042	5463623				90				(Jones Ave.) box culvert outflow pool with a dozen fish up to 120mm holding
Wagg		0494043	5463624						culvert ht		(Jones Ave.) box culvert empties onto angular rip rap 3m above pool, POT



Compendium 3

FOREST COVER & TERRESTRIAL SPECIES

Mackay Mosquito Watersheds ISMP

September 2020

Final Report

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Purpose

Compendium 3. Forest Cover & Terrestrial Species

This compendium provides technical information on riparian forest cover, watershed forest cover, terrestrial wildlife, and species at risk in the Mackay Mosquito Creek Watersheds in North Vancouver, BC. It is a supporting document to the Mackay and Mosquito Creek Integrated Stormwater Management Plan (ISMP) that was developed by the City and District of North Vancouver.

Information is summarized in two sections:

1. Riparian and watershed forest cover
2. Terrestrial wildlife and species at risk

Available data is summarized including the methods and results of new sampling undertaken as part of the ISMP. Historical data from other consultants, stewardship groups, and municipal projects is incorporated where available.

Mackay Mosquito Watersheds ISMP Compendiums

The following compendiums and their authors support the Mackay Mosquito Watersheds ISMP:

1. Watershed Overview - KWL
2. Instream Species and Water Quality – Raincoast Applied Ecology
3. Riparian Forest & Terrestrial Species – Raincoast Applied Ecology
4. Drainage Asset Inventory - KWL
5. Hydrologic and Hydraulic Analysis - KWL
6. Drainage Assessment - KWL
7. Land-Use Analysis - KWL
8. Municipal Policy and Operations - KWL
9. Watershed Values and Objectives – CNV and DNV
10. Mitigation Measures & Alternatives – KWL, CNV, DNV
11. Mackay/Mosquito Action Plan – KWL, CNV and DNV

Figure and table identification numbering includes the first digit related to compendium number and the second digit related to the figure number within the compendium. e.g. Figure C3-1 is the first figure within Compendium 3.

1. Watershed and Riparian Forest Cover

Forest cover regulates many important watershed processes, such as the movement and provision of water, sediment, nutrients, organic matter, and wood. Forests influence the hydrologic response of stream through rainfall interception, capture, and evapotranspiration. Forests within the riparian area, the interface zone between the water and land, also protect stream health by providing shade and stabilizing banks, as well as supplying food, nutrients, organic matter, and instream wood debris that are important components of aquatic ecosystems and fish habitat. Riparian forest cover, in particular, is strongly linked to measures of stream health: declining riparian forest cover in urban watersheds is associated with reduced instream complexity, warmer water temperature, and loss of bank stability.

Maintaining stream health including abundant fish populations depends on maintaining adequate riparian areas. Buffer width, vegetation quality, vegetation age, adjacent land use, recreation use, and other variables influence the function of the riparian zone. May et al. (1997[1]) found that ecosystem health was highest in small streams with mature riparian forests at least 30 m in width from the stream channel. They also summarized the importance of quality in understanding riparian function: “The riparian quality of the stream corridor is as important as the width or extent in determining how well a particular riparian area performs all of the functions required of it. Areas dominated by mature, naturally complex forest have a much higher conservation potential than disturbed areas, young stands of native forest, or exotic vegetation”.

Streamside Protection Regulations

The federal Fisheries Act and the provincial Riparian Areas Regulation (RAR) under the Fish Protection Act require local governments to protect streamside areas during development activities. The District of North Vancouver’s Streamside Development Permit Area (DPA) establishes a Streamside Protected Area where development should not occur either 10 m or 15 m from the top of bank depending on the width of the stream ravine. For large sites greater than 0.5 ha along major rivers including the portion of Mackay Creek south of Marine Drive, the DPA guideline is for a 30 m SPEA.

The City of North Vancouver also has a Development Permit Areas for Streamside Protection and Enhancement which identifies residential, commercial and industrial properties which fall within the Streamside Protection and Enhancement area, defined as the area within 15 m (50 feet) of the top of bank of a watercourse or within 10 m (33 feet) of the top of a ravine bank. Properties located within the DPA are required to apply for a Development Permit before starting any new 'development' within the Streamside Protection and Enhancement area. These activities include any construction, paving, use of pavers, and the removal of soil, vegetation or trees.

1.1 Existing Information

Riparian and watershed forest cover was measured in a portion of the Mosquito Creek watershed (upstream of Highway 1) and in the Wagg Creek watershed as part of a 2013 assessment of benthic invertebrate and land use change (see Raincoast Applied Ecology, 2013[2]). This was undertaken as part of Metro Vancouver’s ongoing environmental monitoring of small streams in the region and compared benthic invertebrate community characteristics to land use change between 1999 and 2011.

[1] May, C.W., E.B. Welch, R.R. Horner, J.R. Karr, and B.W. Mar. 1997. Quality Indices for Urbanization Effects in Puget Sound Lowland Streams. Washington Department of Ecology, Olympia, WA.

[2] Raincoast Applied Ecology. 2013. Stream Health Monitoring in Metro Vancouver: Changes in Land Use and the Benthic Invertebrate Community in Eleven Reference Streams (1999 to 2011)/. Report prepared for Metro Vancouver. 38 pp.

The Metro Vancouver study found there was a minor (+2.1%) increase in watershed forest cover in Mosquito Creek between 1995 and 2011 because of forest establishment in the upper watershed and along the engineered creek corridor (regrowth of red alder). Riparian forest cover increased more modestly (+0.2%). Watershed and riparian forest cover in the Wagg Creek watershed was stable (very minor decline in riparian forest).

Blackwell and Associates mapped forest in the District of North Vancouver including portions of the Mackay and Mosquito creek riparian corridors. Polygon attributes focused on tree species (primary, secondary, etc) as well as their percentage cover by decile. Mapping methods (date of survey, plots or field review) were not reviewed. The lack of watershed-scale mapping reduced the usefulness of this dataset.

The BC Vegetation Resources Inventory provides forest cover mapping for most areas of the province. This dataset provides a comprehensive but somewhat dated (1996) dataset of forest polygons with attribute data.

1.2 2014 Forest Cover Assessment

Forest cover in the Mackay and Mosquito creek watersheds was measured using orthophoto imagery from 1995 and 2013. The Triathalon 1995 imagery was the first orthophoto imagery that was available for the lower Fraser Valley and is considered a baseline for comparing recent land use change. District of North Vancouver's 2013 imagery is the most recent available for the study area.

Forest was measured as closed canopy patches of tree cover greater than 5 m in height and larger than 0.1 ha patch size. Individual trees or small groups of trees were not mapped. Riparian forest cover was measured as forest cover within 30 m of the centerline of permanent streams. Permanent streams were chosen because they provide a consistent standard for defining the stream channel network. Long culverted sections such as the 850 m section of Mosquito Creek (Evergreen) were excluded from the analysis because of the lack of riparian zone interactions.

Riparian forest cover in 1995 and 2013 was assessed by watershed. For 2013 mapping, riparian forest cover was also assessed for the undeveloped portion of the study area (generally 350 m asl; and upslope of the BC Hydro transmission corridor) and the forested headwaters. Table C3-1 shows the portion of each subwatershed which is in the upper and lower watershed areas.

Table C3-1: Riparian Areas by Watershed and Subwatershed (2013 Mapping)

Watershed	RFI Area (ha)	Lower Watershed	Upper Watershed
Mosquito Creek	140.6	77.9 ha (55%)	62.7 ha (45%)
Wagg Creek	12.8	12.8 ha (100%)	0.0 ha (0%)
Thain Creek	50.5	29.0 ha (57%)	21.5 ha (43%)
Mission Creek	6.7	6.7 ha (100%)	0.0 ha (0%)
Mackay Creek	106.5	78.1 ha (73%)	28.4 ha (27%)
All Creeks	**317.1 ha**	**204.5 ha (64%)**	**112.6 ha (36%)**

Note: Lower watershed includes all areas downslope of the BC Hydro transmission corridor which defines the upper limit of urban land use.

1.3 Watershed Forest Cover

Watershed forest cover in the Mackay and Mosquito watersheds is considered high compared to many Metro Vancouver watersheds, partially because of the forested headwaters. Approximately 42% (648 ha) of the Mosquito watershed and 42% (305 ha) of the Mackay watershed is forested. Approximately 58% (177 ha) of forest cover in the Mackay watershed is located in the upper watershed (upslope of the BC Hydro transmission corridor), while 72% (466 ha) of the forest cover in Mosquito watershed is in the undeveloped upper watershed.

Watershed forest cover in both watersheds has remained stable since 1995 (see Figure C3-1 and Table C3-2). Wagg Creek has only 9% forest cover which is typical of heavily urbanized watersheds in Metro Vancouver and Puget Sound.

Table C3-2: Watershed Forest Cover Change (1995 To 2013).

Watershed	Watershed (ha)	1995 WFC (ha)	1995 WFC%	2013 WFC (ha)	2013 WFC%
Mosquito Creek	1,553.0	651.9	42%	647.9	42%
Wagg Creek	387.1	36.6	9%	35.4	9%
Thain Creek	318.7	127.1	40%	124.0	39%
Mission Creek	92.1	11.6	13%	10.8	12%
Mackay Creek	731.2	307.7	42%	304.8	42%
All	**3,082.0**	**1,134.9**	**37%**	**1,122.9**	**36%**
Note That Wagg, Thain, And Mission Creeks Are Subwatersheds Of Mosquito Creek.					

1.4 Riparian Forest Cover

Riparian forest cover within 30 m of permanent streams varies from 67% in the Wagg watershed to 90% in the Mission watershed with a mean across the study area of 78% in 2013 (Table C3-3). This is considered high for streams in Metro Vancouver, and partially reflects the forested headwaters. Riparian forest cover has remained remarkably stable since 1995 (see Figure C3-2 and Table C3-3); in fact there has been a slight increase (1.5 ha) as the Mosquito Creek corridor has naturally reforested with red alder after channelization for flood control in the 1980s.

Table C3-3: Riparian Forest Cover in 1995.

Watershed	1995 RFI (ha)	1995 RFI% (all)	2013 RFI (ha)	2013 RFI% (all)
Mosquito Creek	111.0	79%	112.9	80%
Wagg Creek	8.7	68%	8.6	67%
Thain Creek	41.4	82%	41.0	81%
Mission Creek	6.0	90%	6.0	90%
Mackay Creek	79.8	75%	79.9	75%
All Creeks	**246.9**	**78%**	**248.4**	**78%**

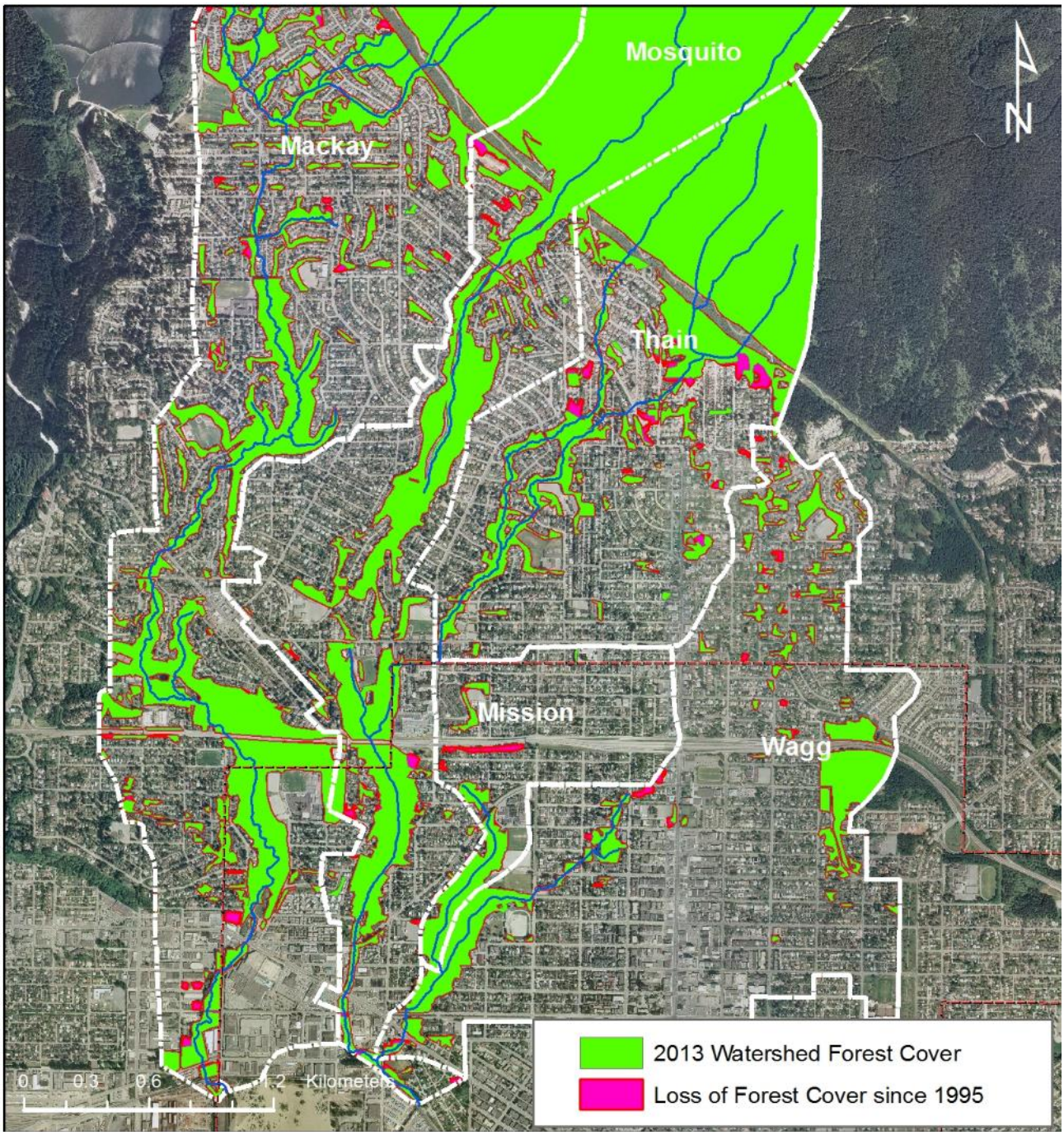


Figure C3-1: Current Watershed Forest Cover and Forest Cover Loss (1995-2013)

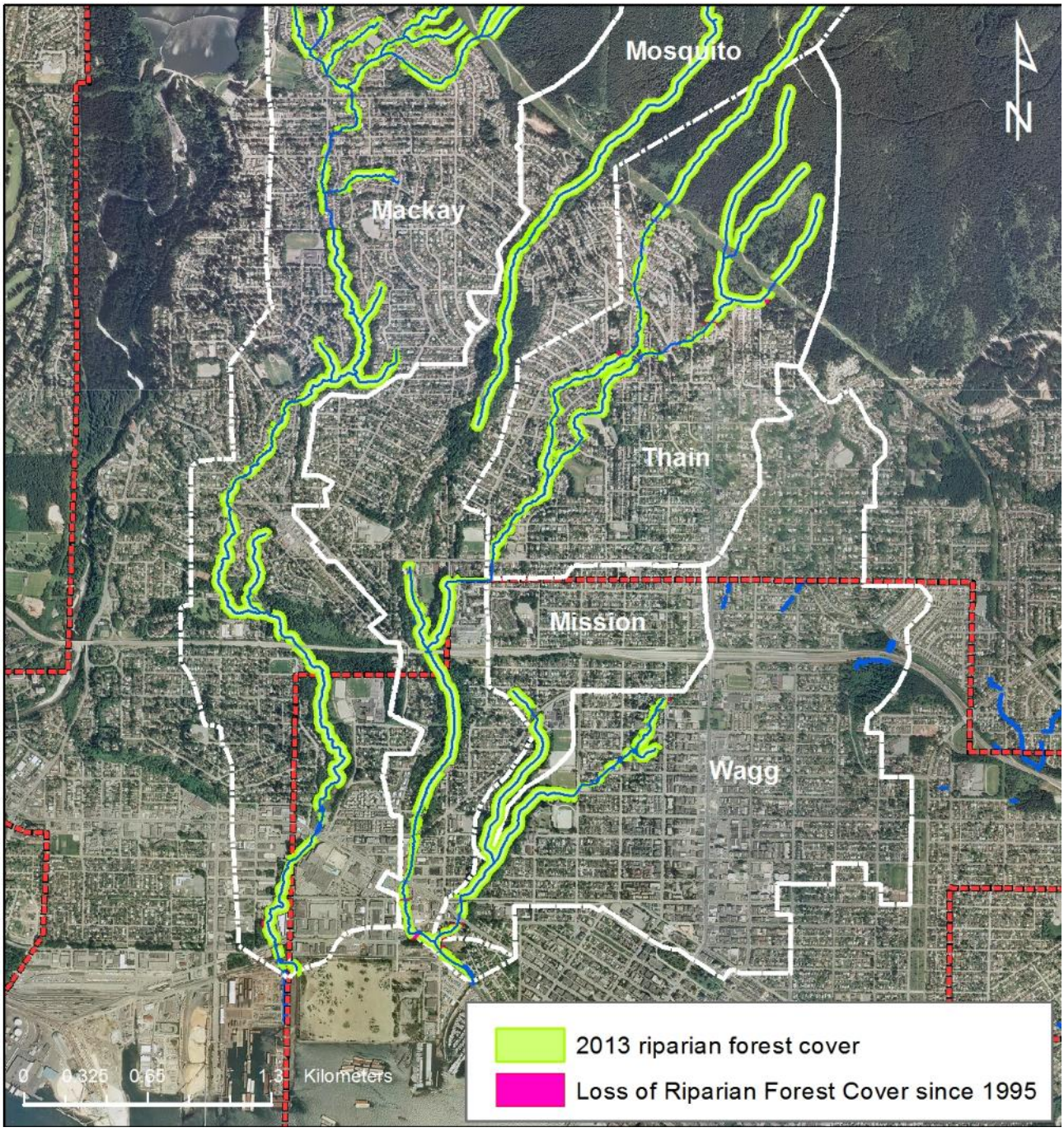


Figure C3-2: Current Riparian Forest Cover and Riparian Forest Cover Loss (1995-2013)

The stability of riparian forest cover indicates three main processes:

1. The rate of urbanization has slowed substantially and most of the riparian forest losses occurred prior to 1995. See Figure C3-2 for mapping of riparian forest cover loss since 1995.
2. Riparian protection measures by CNV and DNV are generally effective at maintaining riparian forest cover. The main losses of watershed forest cover have been incremental changes during development infill away from stream channels (see Figure C3-2).
3. The undeveloped headwaters protect riparian forests and provide some resilience to forest cover loss in the lower watershed.

It is also noteworthy that Wagg Creek has an RFI value of 67%, despite the low watershed forest cover. This reflects the amount of riparian forest protected in Mahon and Wagg Creek parks, as well as riparian forest cover within older residential areas. As well, culverted sections of Wagg Creek northeast of Wagg Creek Park were not included in RFI calculations (no interaction between stream and riparian zones), which accentuates the importance of riparian forest in the lower watershed (Table C3-4).

Table C3-4: Riparian Forest Cover in 2013 in Upper and Lower Watershed

Watershed	RFI Area (ha)	Riparian Forest (ha)	2013 RFI%
In Lower Watershed (Urban Portion of Watersheds)			
Mosquito Creek	77.9	53.9	69%
Wagg Creek	12.8	8.6	67%
Thain Creek	29.0	19.5	67%
Mission Creek	6.7	6.0	90%
Mackay Creek	78.1	52.3	67%
All Creeks	**204.5**	**140.3**	**69%**
In Upper Watershed (Forested Headwaters)			
Mosquito Creek	62.7	59.0	94%
Wagg Creek	0	-	-
Thain Creek	21.5	21.5	100%
Mission Creek	0	-	-
Mackay Creek	28.4	27.6	97%
All Creeks	**112.6**	**108.1**	**96%**

The riparian forest calculations were separated into lower and upper watershed units to better measure the effects of urban development on riparian forests. As described previously, the study watersheds have a distinct separation between the forest headwaters upslope of the BC Hydro transmission corridor (upper watershed), and portion of the stream channels in the developed lower watershed. The transition is about 325 m asl. About 64% (205 ha of 317 ha) of riparian areas (all combined) are in the lower watershed (55% of the Mosquito watershed; 73% of the Mackay watershed) (see Table C3-1). All of the riparian areas surrounding Wagg and Mission creeks are in the lower watershed (no headwater tributaries exist upstream of the transmission corridor).

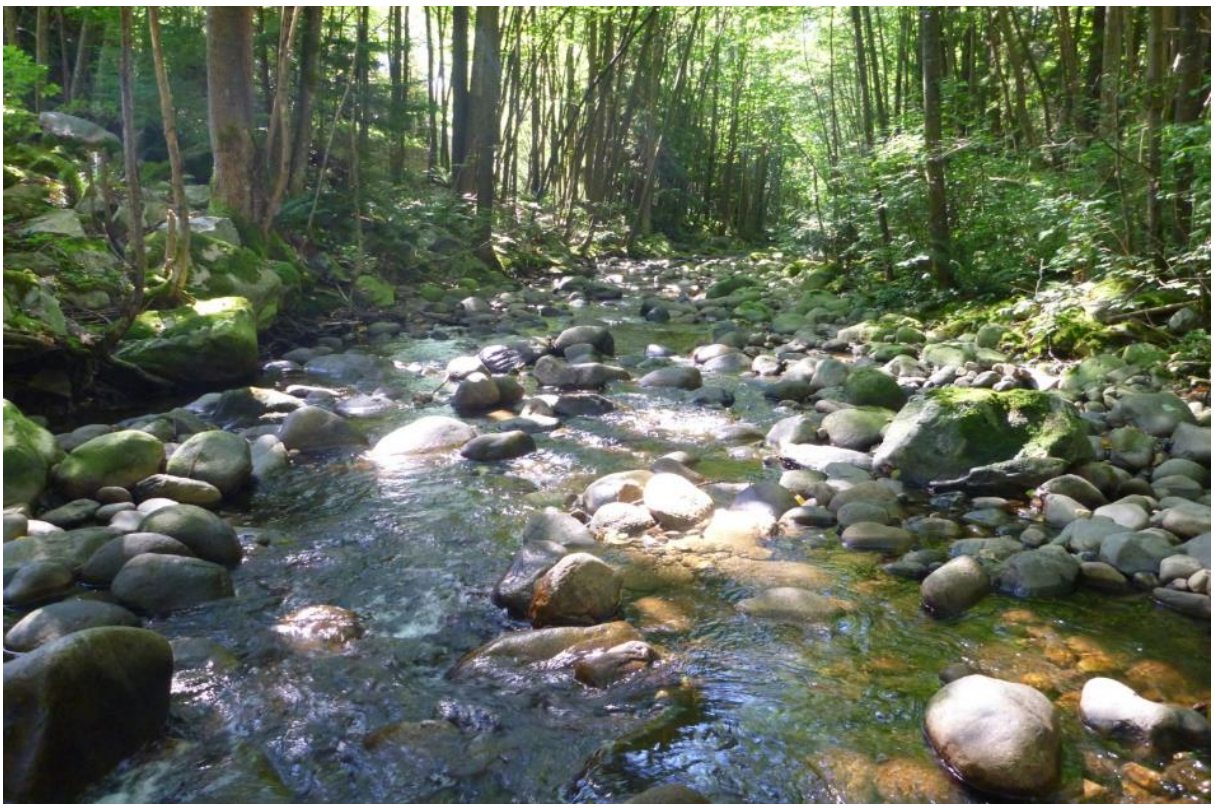


Photo C3-1: Deciduous forest (bigleaf maple, red alder, and black cottonwood) This is common along sections of Mosquito Creek which were modified for flood control in the 1980s. Channel disturbance promotes establishment of young deciduous forest.

When all riparian areas are included, the RFI value for the entire study area is 78% (80% for Mosquito Creek; 75% for Mackay Creek). But when they are divided into watershed units, RFI is 69% for the lower watershed (69% for Mosquito Creek; 67% for Mackay Creek), and 96% for the upper watershed (94% for Mosquito Creek; 97% for Mackay Creek). This highlights both the importance of the forested headwaters in maintaining stream health through riparian forest, and the more typical RFI values of the portion of the streams within the developed portion of the watershed. Table C3-4 summarizes the results.

1.5 Forest Composition and Age

The character, age, and composition of forests in the study area reflects the disturbance history (early logging, more recent urban development), as well as site factors such as aspect, soil, and drainage. The lower portions of the watersheds (below 600 m asl) are found in the driest subzone of the Coastal Western Hemlock (CWH) biogeoclimatic zone (dry maritime). In this subzone, western hemlock forms the climax forest on mesic sites. On drier sites, Douglas-fir is more prevalent, and on sites with impeded drainage, western red cedar in association with skunk cabbage is common. Black cottonwood is often abundant on floodplain sites with high water tables and regular flood disturbance. The headwater areas are found in the very wet maritime subzone (montane variant) of the CWH zone.

The province-wide Vegetation Resources Inventory (VRI)[3] was used to better characterize forest vegetation in the study area. Analysis of general vegetation patterns showed that the upper watershed area (upslope of the transmission corridor) is dominated by mature conifer forests: 50% of forest cover is dominated by hemlock (undifferentiated), 31% by western hemlock, 12% by Douglas-fir, 6% by western redcedar, and 2% by mountain hemlock. Note that most VRI polygons contain a range of tree species and these percentages refer only to dominant species. There are no deciduous dominated forest polygons in the upper watershed. Forest age is variable: 2% of forest in the upper watershed area are <50 years old, 51% between 50 and 100 years old, 33% between 100 and 200 years old, and 13% >200 years old. In the lower watershed, forest cover was also generally conifer dominated: 89% is dominated by western redcedar, 6% by western hemlock, 4% by Douglas-fir, <1% by bigleaf maple, and <0.5% by red alder. Forests in the lower watershed were substantially younger than the upper watershed: 0% <50 years old, 95% between 50 and 100 years old, and 5% between 100 and 150 years old. There were no forests >150 years in the lower watershed.

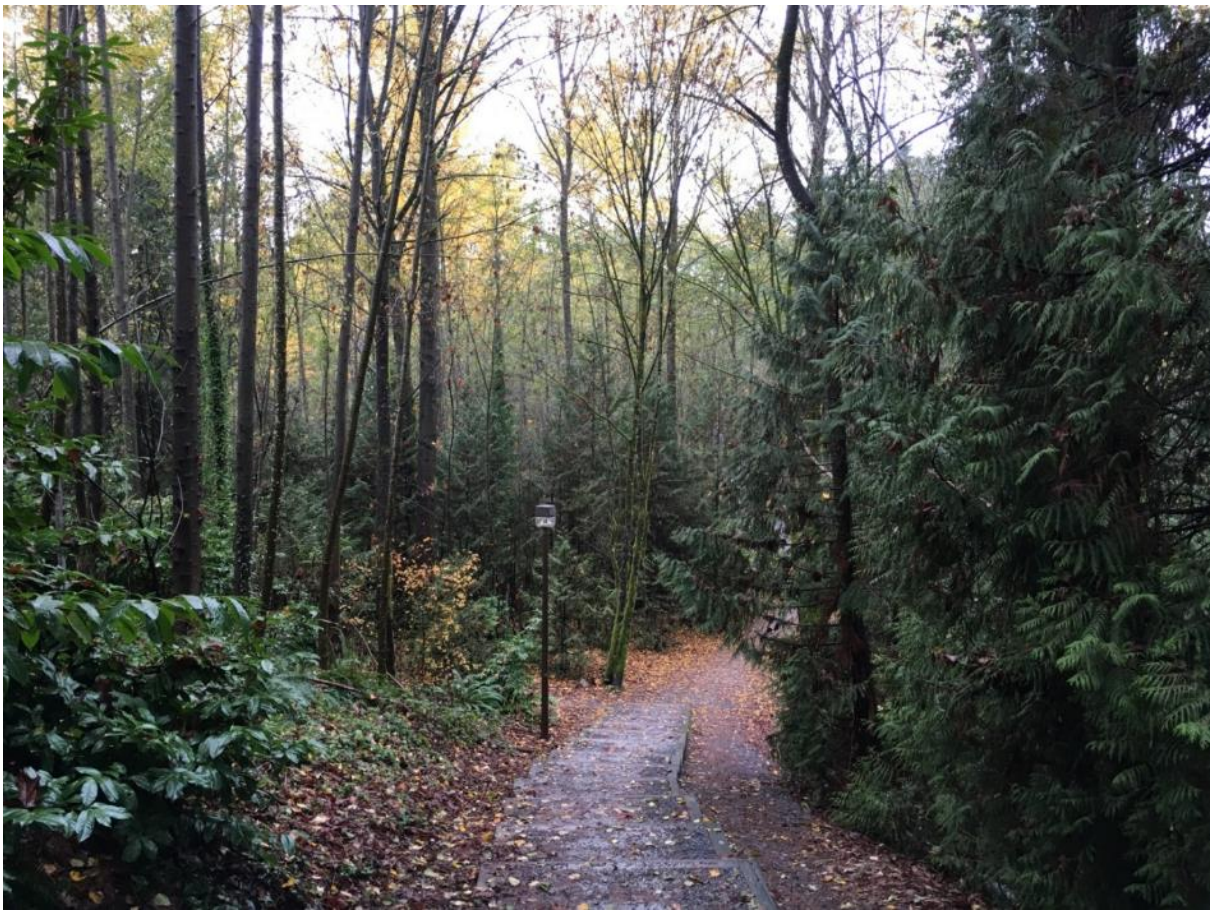


Photo C3-2: Mixed forest with black cottonwood, bigleaf maple, western redcedar, red alder is common in the Mosquito Creek ravine near the Evergreen Basin

[3] Sandvoss, M. et al. 2005. Users Guide to the Vegetation Resources Inventory. 98 pp. Available here.

Riparian areas in the Mosquito and Mackay watersheds have forests that reflect higher moisture, richer soils, and more frequent disturbance from floods and channel erosion. Most are mixed forests with evergreen (Douglas-fir, western hemlock, Sitka spruce, and western redcedar) and deciduous (red alder, bigleaf maple, black cottonwood). Conifer trees are typically found on less disturbed areas, while the lower reaches are predominantly red alder and black cottonwood. In fact, coniferous trees are almost completely absent on Mackay Creek downstream of Marine Drive and on Mosquito Creek downstream of Larson Road (see Figure C3-1 and Image C3-1). Coniferous trees are more prevalent on the upper slopes of the larger stream ravines which are drier than the valley bottoms.



Image C3-1: Riparian forest vegetation in lower reaches of Mackay and Mosquito creeks The downstream reaches are typically narrow and support deciduous forest.

1.6 Invasive Plants

Invasive plant species are common throughout riparian and forest areas in both watersheds, particularly in road ends, adjacent to residential gardens, old residential areas, or in sites that were cleared and then abandoned. Primary species are Himalayan blackberry, English ivy, and Japanese knotweed while secondary species include Policeman's helmet, giant hogweed, Himalayan knotweed, American holly, lamium, and common vinca.

Both CNV[4] and DNV[5] have Invasive Plant Management Strategies that identify priority species, sites or areas, and actions for addressing invasive plants within the study area. Riparian areas were identified as priority areas for actions. The more recent DNV strategy identified two priority areas in the Mackay and Mosquito watersheds for invasive plant management: (1) the forested headwaters which have few invasive plants now but have high ecological values; and (2) riparian areas in the lower watershed which ecosystem values have already been significantly degraded by invasive plants. This includes the portion of Mackay Creek downstream of Marine Drive, areas of Murdo Frazer Park, and the narrow band of riparian vegetation in Mosquito Creek Park.

The challenge for invasive plant management in riparian areas in the Mackay and Mosquito watersheds is the extent of the problem. CNV identified almost 3.0 ha of Heywood Park that had invasive plants including 1.6 ha of English ivy. Similarly, 4.5 ha of Mosquito Creek Park, 3.6 ha of Mahon Park, and 0.9 ha of Wagg Creek Park need treatment for invasive plants. Few riparian areas assessed as part of this ISMP did not have some invasive species present; American holly is common although seldom abundant in most forested areas and even hydrangea (a garden escapee) was observed in riparian areas of central Mackay Creek. Deciduous forest in the lower watersheds generally have more invasive plant cover than mixed or conifer forest of the middle watershed because of higher light levels and history of disturbance.

1.4 Data & Sources

Page, N., P. Lilley, D. Matsubara and N. Tokgoz. 2013. Hastings Creek Watershed: Ecology and Hydrotechnical Assessment. Unpublished report for District of North Vancouver prepared by Raincoast Applied Ecology and Kerr Wood Leidal Associates. 111 pp + appendices.

Raincoast Applied Ecology. 2013. Stream Health Monitoring in Metro Vancouver: Changes in Land Use and the Benthic Invertebrate Community in Eleven Reference Streams (1999 to 2011)/. Report prepared for Metro Vancouver. 38 pp.

[4] CNV. 2013. Invasive Plant Management Strategy. 82 pp. Available here.

[5] Steele, F., M. Coulthard, and N. Page. 2015. Draft Invasive Plant Management Strategy. 82 pp. Available here.



Photo C3-3: Examples of Riparian Conditions in the Mackay and Mosquito Watersheds

2. Terrestrial Wildlife and Species at Risk

Terrestrial wildlife is often a secondary focus of ISMPs, but streams and their associated riparian corridors and natural areas are essential habitat for many birds, amphibians, and mammals. Riparian corridors along Mackay and Mosquito creeks are often directly connected to the forested headwaters which act as reservoirs for many wildlife species. Stream corridors are the only remaining linear habitats providing habitat connections for wildlife, although those connections are typically north-south with few east-west connections in the lower watersheds.

Species at risk encompass a smaller component of wildlife which are ranked and tracked by the federal and provincial government because of rarity, threats, or declining populations. The BC Conservation Data Centre manages data on species at risk in BC. The federal Species at Risk Act applies to federal land and the occurrence of listed species in the study area watersheds does not imply or require specific management activities or restrictions. However, species at risk conservation is considered a component of environmental management by local governments and measures to protect species at risk should be incorporated into the ISMP.

2.1 Existing Information

Terrestrial wildlife was not inventoried as part of the ISMP field assessment and wildlife presence was assessed based on observations, inferences about habitat, and limited background reports or surveys.

- Mosquito Creek Watershed Profile. http://www.mosquitocreek.org/. Website developed by K.R. Milne / Northshore Streamkeepers.
- Metro Vancouver Sensitive Ecosystem Inventory (spatial data) (see Figure C3-3).
- Wild Bird Trust of British Columbia. 2012. Compiled Bird Checklist: The Conservation Area at Maplewood Flats, North Vancouver.

2.2 2014 Assessment

No wildlife surveys, other than anecdotal information collected during field surveys, were undertaken during the 2014 field assessment.

2.3 Results

The following species are recorded or their presence inferred in the study watersheds:

Mammals: black-tailed deer, black bear, cougar, bobcat, striped skunk, spotted skunk (possible), raccoon, river otter, American mink, Douglas' squirrel, eastern gray squirrel, black rat, Norway rat, bat species, vole species, shrew species, mice species.

Amphibians and Reptiles: northwestern salamander, rough skinned newt, ensatina, garter snakes, red-backed salamander, tailed frog, Pacific tree frog, northern red-legged frog.

Birds: high bird diversity in riparian areas and remnant woodlands; no specific lists or records from study watersheds; review bird list from Maplewood Flats for context.



Figure C3-3: Sensitive Ecosystem Inventory (SEI) Polygons in the Study Area
The lower watershed is either young forest, riparian forest, or old forest.

Species at Risk: The BC Conservation Data Centre records 137 plant and animal species at risk in non-marine areas of Metro Vancouver. Most of these species are unlikely to occur in the study area based on lack of habitat. Species at risk that are likely to be found in the study area include: green heron (observed in Lower Mackay Creek Park), coastal tailed frog (observed in Mosquito Creek), northern red-legged frog (observed in Mackay Creek corridor), Pacific water shrew (no recent records), and western screech ssp kennicottii subspecies (no recent records).

Mackay and Mosquito watersheds support a wildlife community typical of the North Shore. Characteristics species found in riparian corridors and small forest patches are listed in Table C3-5 and Table C3-6.

Table C3-5: Characteristic Wildlife in the Mackay and Mosquito Watersheds

Common Name	Species Name	Notes
Black bear	*Ursus americanus*	Seasonal visitor; more common in upper watersheds
Black-tailed deer	*Odocoileus hemionus*	Infrequent to frequent in riparian areas
Raccoon	*Procyon lotor*	Common throughout
River otter	*Lontra canadensis*	Lower reaches adjacent to marine areas; Wagg Creek to Jones Avenue
American beaver	*Castor canadensis*	Present in lower Mackay Creek
American mink	*Neovison vison*	Status unknown; inquire with hatchery
Striped skunk	*Mephitis mephitis*	Infrequent
Douglas squirrel	*Tamiasciurus douglasii*	Common throughout
Eastern gray squirrel	*Sciurus carolinensis*	Common throughout

Table C3-6: Potential Species at Risk in the Mackay and Mosquito Watersheds

Common Name	Species Name	Notes
Green Heron	*Butorides virescens*	Blue; S3S4B; G5: observed in Kiwanis Park in late 1990s; not known to breed in watershed
Coastal Tailed frog	*Ascaphus truei*	Blue; SC; S3S4; G4; Occurs in Mosquito Creek; not known from Mackay Creek
Northern Red-legged Frog	*Rana aurora*	Blue; SC; S3S4; G4: Infrequent in moist riparian areas with seasonal wetlands
Pacific Water Shrew	*Sorex bendirii*	Red; E; S1S2; G4: unknown but possible from study watersheds; prefers mixed or coniferous riparian zones
Western Screech Owl *kennicottii* subspecies	*Megascops kennicottii kennicottii*	No recent data



Photo C3-4: Coastal tailed frog (juvenile) captured in benthic sampling in Mosquito Creek near the Highway 1 corridor

2.4 Data & Sources

Mosquito Creek Watershed Profile. http://www.mosquitocreek.org/. Website developed by K.R. Milne / Northshore Streamkeepers.

Metro Vancouver Sensitive Ecosystem Inventory (spatial data).

Wild Bird Trust of British Columbia. 2012. Compiled Bird Checklist: The Conservation Area at Maplewood Flats, North Vancouver.

3. Summary of Findings and Recommendations

3.1 Findings

C3-1. Watershed and Riparian Forest Cover

Watershed forest cover in the Mackay and Mosquito watersheds is considered high compared to many Metro Vancouver watersheds, partially because of the forested headwaters above the urban development boundary. Approximately 42% of the Mosquito watershed and 42% of the Mackay watershed is forested in 2013. Forest cover in both watersheds has remained stable since 1995.

Riparian forest cover varies from 67% in Wagg Creek to 90% in Mission Creek with a mean across the study area of 78%. This is considered high for streams in Metro Vancouver, and partially reflects the forested headwaters in Mosquito and Mackay creeks. Riparian forest cover has remained remarkably stable since 1995; in fact there has been a slight increase (1.5 ha) as the Mosquito Creek corridor has naturally reforested with red alder after channelization for flood control in the 1980s.

C3-2. Terrestrial Wildlife and Species at Risk

Terrestrial wildlife is often a secondary focus of ISMPs, but streams and their associated riparian corridors and natural areas are essential habitat for many birds, amphibians, and mammals. Riparian corridors along Mackay and Mosquito creeks, are often directly connected to the forested headwaters which act as reservoirs for many wildlife species. Stream corridors are the only remaining linear habitats providing habitat connections for wildlife.

The BC Conservation Data Centre records 137 plant and animal species at risk in non-marine areas of Metro Vancouver. Most of these species are unlikely to occur in the study area based on lack of habitat. Species at risk that are likely to be found in the study area include: green heron (observed in Lower Mackay Creek Park), coastal tailed frog (observed in Mosquito Creek), northern red-legged frog (observed in Mackay Creek corridor), Pacific water shrew (no recent records), and western screech owl kennicottii subspecies (no recent records).

3.2 Recommendations

C3-1. Monitor watershed and riparian forest cover every 5 years using methods that are consistent with those presented in this report. The next monitoring period should occur in spring 2018.

C3-2. Undertake more detailed analysis of riparian forest cover in residential areas to identify opportunities for reforestation or other improvements to riparian vegetation.

C3-3. Identify young deciduous stands in riparian areas that are suitable for conifer underplanting and invasive species management using Lidar based forest cover mapping.

C3-4. Undertake mapping of forested wetlands (swamps) using Lidar-based analysis of topography and impeded drainage.

C3-5. Compile general wildlife and species at risk information collected by consultants, municipal staff, stewards, and the public to better understand biodiversity in the study watersheds.

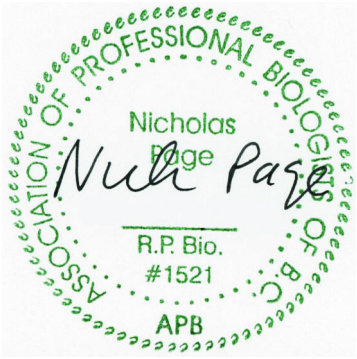
C3-6. Undertake volunteer-based bird surveys in representative riparian areas such as Heywood Park and Murdo Frazer Park as a key component of biodiversity.

C3-7. Undertake species at risk information and surveys by qualified biologists to address data gaps. Riparian and wetland species should be emphasized. Information is generally lacking.

Report Submission

Prepared by:

Raincoast Applied Ecology



Nick Page, BLA., M.Sc., R.P.Bio.
Project Biologist

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Revision History

Revision #	Date	Status	Revision	Author
0	Sept 21, 2020	Final	Issued as final for client copy.	NP



Compendium 4

DRAINAGE ASSET INVENTORY

Mackay/Mosquito Watersheds ISMP

September 2020

Final Report

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Figure C4-3: Mackay and Mosquito Creeks Erosion (2007 and 2014)
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Purpose

Compendium 4. Drainage Asset Inventory

This compendium provides detailed information on the drainage asset inventory of the Mackay and Mosquito Creek watersheds in North Vancouver, BC. It is a supporting document to the Mackay and Mosquito Watershed Integrated Stormwater Management Plan (ISMP) that was developed by the City and District of North Vancouver.

Information includes GIS layers, field reconnaissance findings including identification of erosion, channel obstructions and stream bank protection works.

Mackay Mosquito Watersheds ISMP Compendiums

The following compendiums and their authors support the Mackay Mosquito Watersheds ISMP:

1. Watershed Overview - KWL
2. Instream Species and Water Quality – Raincoast Applied Ecology
3. Riparian Forest & Terrestrial Species – Raincoast Applied Ecology
4. Drainage Asset Inventory - KWL
5. Hydrologic and Hydraulic Modelling - KWL
6. Drainage Assessment - KWL
7. Land-Use Analysis - KWL
8. Municipal Policy and Operations - KWL
9. Watershed Values & Objectives – CNV and DNV
10. Mitigative Measures & Alternatives – KWL, CNV, DNV
11. Mackay/Mosquito Action Plan – KWL, CNV, DNV

Figure and table identification numbering includes the first digit related to compendium number and the second digit related to the figure number within the compendium. e.g. Figure C3-1 is the first figure within Compendium 3.

'Blue boxes' of explanative information is provided in each compendium where background information and context are helpful.

1. Introduction

One of the main objectives of an ISMP is to address potential flooding and erosion issues in a watershed. Management of flooding and erosion is important for safety of residents, protection of property and structures, and preservation of aquatic habitat.

The drainage asset system consists of:

- Natural assets or capital
- Green infrastructure
- Grey infrastructure

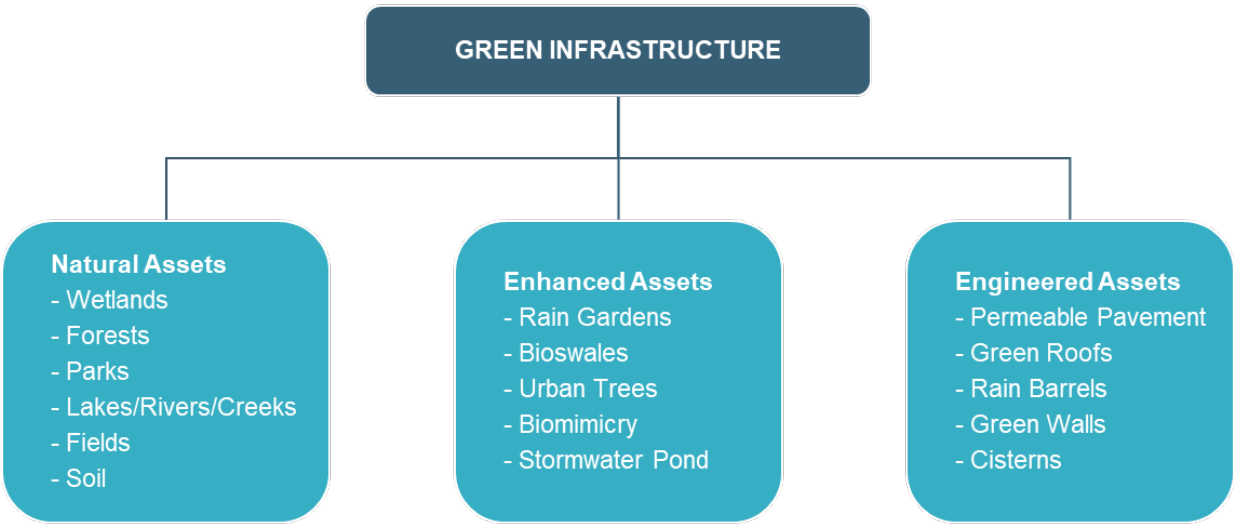


Figure 1: Relationship between various terms used to describe green infrastructure and natural assets. (Source: Defining and Scoping Municipal Natural Assets, Sept 2017)

A drainage inventory is the first step in the assessment of drainage system capacity and flooding hazard in a watershed.

The drainage inventory for Mackay and Mosquito ISMP consisted of:

- Desktop review of GIS data on the drainage system;
- Field reconnaissance consisting of observations of sections of both creeks / tributaries in 2014; and
- Review of information collected during a 2007 drainage inventory of Mackay Creek[1].

The purpose of the field reconnaissance was to document information on culverts, stormwater outfalls, structures, typical creek cross sections, significant erosion sites, and obstructions in the creeks. The information collected during the field work is used for hydraulic modelling and asset management.

Figures C4-1 and C4-2 provide a detailed overview of the drainage system.

[1] DNV 2007 Watercourse Inventory Program, KWL

2. GIS Layers of Existing Drainage System

A desktop analysis of the GIS drainage infrastructure was undertaken to understand the drainage system and identify gaps and errors in the data prior to undertaking the field inventory. CNV and DNV provided GIS data for the Mackay and Mosquito drainage systems including streams (channels), ditches, culverts, storm sewer pipes, storm manholes, energy dissipators, oil/grit separators, and outfalls. Refer to Figure C4-1 and Figure C4-2.

The storm sewer GIS layer contains the length, size, material, invert elevations, upstream manhole name, and downstream manhole name. The DNV storm sewer layer was missing some data including pipe sizes, pipe materials, and upstream and downstream invert elevations. KWL addressed missing data points through interpolation within the hydrologic/hydraulic model.

3. Mackay / Mosquito Creek Field Reconnaissance

The Mackay and Mosquito Creek field reconnaissance and inventory entailed hiking both creeks and their major tributaries in July, August and September 2014. On Mackay Creek, creek walk was limited to downstream of Handsworth Secondary. Upstream of the school, culverts and bridges were inspected but a full length creek walk was not conducted due to access issues. Creek areas reviewed in 2014 are shown on Figure C4-3 and Figure C4-4. KWL had previously conducted a similar inventory on Mackay Creek in 2007 (see Figure C4-3), but Mosquito Creek was not included in the 2007 work.

A standard field observation form was used to record observations using a mobile GIS collection application. Table C4-1 provides a summary of the inventory data collected. Each recorded feature is associated with a GPS position and photographs and stored in a GIS database.

Table C4-1: Summary of Field Inventory Data Collected

Culvert	**Measured**			**Observed**				
	Size or Diameter			Material	Shape	Headwall Type	Debris Rack	Maintenance	Condition
Outfall	**Measured**			**Observed**				
	Dia	Height	Drop	Material (Concrete, PVC, etc.)	Shape (Circular, Box)	Headwall Type	Energy Dissipation	Condition
Bridge	**Measured**			**Observed**				
	Low Chord	Chord to Creek		Material (Concrete, Wood, Steel)		Type		Face (Upstream, Downstream)
	Measured Approx.			**Observed**				
	Length	Height		Type (Retaining, Gabion, Riprap, etc.)		Bank		Condition
Other Structure	**Observed**							
	Comments							
Erosion	**Measured Approx.**			**Observed**				
	Length	Height		Location (Left, Right)		Hazard (Low, Med, High)		Consequence (Low, Med, High)
Deposition	**Measured Approx.**			**Observed**				
	Length	Width		Location (Left, Right)			Vegetated	

Obstruction	**Measured**	**Observed**		
	Height (Downstream)	Type (Anthropogenic, LWD)	Sedimentation	Stability (High, Med, Low)
Confluence	**Observed**			
	Location			
Data was added or updated based on field measurements and observations.				

Prior to conducting the inventory, GIS data from CNV and DNV were imported to the mobile GIS collection application, as was the 2007 Mackay Creek inventory data. As the 2014 field reconnaissance progressed, if a recorded feature already existed in the GIS database and the relevant data fields were populated, a review of the data was performed to confirm its accuracy. Missing or inaccurate data were updated from field measurements and observations. New locations of any missing items were added to the relevant GIS data set and populated. This updated information was used throughout the project including in the PCSWMM model build (summarized in Compendium 5). Erosion features that were updated based on 2014 observations were noted as such.

4. Erosion

4.1 Erosion Qualitative Risk Rating

Bank erosion is of concern as it has the potential to damage infrastructure, private property and/or pose a risk to public safety.

The intent of the risk framework is to provide a simple and straightforward method to assess relative risk associated with erosion. Erosion sites were identified and assigned a hazard and consequence level based on a visual assessment of the following parameters:

Hazard: based on the measured height of visible scour or slippage.

- low: height of erosion < 0.3 m;
- moderate: height of erosion from 0.3 m to 1.2 m; and
- high: height of erosion > 1.2 m.

Consequence: based on the proximity of manmade features (sheds, fences, buildings, retaining structures, etc.) to the eroding bank

- low: setback > 10 m;
- moderate: setback between 5 m and 10 m; and
- high: setback < 5 m.

Risk is the product of hazard (i.e., probability of occurrence) and consequence. Table C4-2 below presents the qualitative risk reference matrix used in this report. Risk is rated on a qualitative scale from Very Low (green) to Very High (burgundy).

Table C4-2: Qualitative Risk Matrix

Likelihood of Occurrence (Hazard)	Consequence		
	Low	Moderate	High
High	Moderate	High	Very High
Moderate	Low	Moderate	High
Low	Very Low	Low	Moderate

Risk designations in above table may be understood to have the following general characteristics:

- **Very High / High Risk:** likely or immediate risk to public safety, or damage to structures or infrastructure.
- **Moderate Risk:** no anticipated risk to structures and no significant risk to public safety, but increasing risk may develop over time.
- **Low / Very Low Risk:** minimal risk of impact to private property or public safety in the near or foreseeable future.

As indicated in Table C4-2, low hazard (height of erosion < 0.3 m) does not generate a high risk regardless of consequence. Similarly, low consequence (i.e. undeveloped areas with no apparent consequence to property or infrastructure) does not generate high risk regardless of hazard.

Figure C4-3 and Figure C4-4 present erosion sites based on the field reconnaissance conducted in 2007 and 2014. Previously recorded erosion sites on Mackay Creek were summarized in the DNV *2007 Watercourse Inventory Program* completed by KWL. To allow comparison between the 2007 and 2014 observations, the same relative risk rating system was used for this project, based on a high-level categorization of hazard and consequence.

Table C4-3 presents a summary of the erosion sites for each major creek or tributary, as well as a breakdown of the qualitative risk ratings.

Table C4-3: Summary of Erosion Sites

Watercourse	Total # Erosion Sites Observed	Qualitative Risk Rating, # Sites				
		Very High	High	Moderate	Low	Very Low
Mackay Creek	104 (1)	14	19	25	43	3
Mosquito Creek (Thain Creek)	3 (2)	2	1	0	0	0
Mosquito Creek (Wagg Creek)	15 (2)	3	2	6	4	0

Notes:
1. Combined 2007 and 2014 field reconnaissance results.
2. 2014 field reconnaissance only (creek not included in 2007 work).

The results are discussed for each creek, below. The Mosquito Creek watershed includes the major tributaries of Thain Creek (formerly Mission Creek) and Wagg Creek, which are discussed separately.

4.2 Very High and High Risk Erosion Sites

Mackay Creek

Mackay Creek is the only study watercourse to be visited in both 2007 and 2014, although the study area was somewhat different as indicated on Figure C4-3. The 2014 field observations indicated that conditions were generally similar to that observed in 2007: one additional erosion site was added in Murdo Fraser Park.

Five sites (circled on Figure C4-3) were noted to have worsened in condition from 2007 to 2014. Four of the five sites have a Very High risk rating, while the other has a Low risk rating. Although the risk rating for these sites has not changed (as indicated in Table C4-2 there is a range for a given hazard and consequence level), the field observations indicated that the condition of the site had worsened compared to 2007. These sites are located upstream of Ridgewood Drive (see Figure C4-3).

The sites assigned a Very High risk rating are generally concentrated in the reach of channel around Ridgewood Drive (11 sites). Additionally, three sites are located in upper reaches of development, and one site is located in Murdo Fraser Park. The distribution of sites assigned a High risk rating occupies a similar reach of the creek, but there are more sites in the upper developed area (12 sites) compared with downstream areas (7 sites). As sites with high erosion (> 1.2 m vertical erosion height) are distributed between the upstream limit of development and Highway 1, one of the main drivers for risk is the proximity of adjacent development and infrastructure. There does appear to be a concentration of high erosion sites around Ridgewood Drive (roughly 30% of the high erosion sites). Just south of the Ridgewood Bridge, there is a house located very close to the creek with a vertical compact sediment wall along the creek bank. Due to the property's proximity to the creek and this study's erosion rating criteria, the whole stretch of creek adjacent to the property is considered high risk.

Mosquito Creek – Mainstem

The 2014 field reconnaissance included the mainstem Mosquito Creek channel as well as both Thain and Wagg Creeks. No erosion sites were recorded on the mainstem channel of Mosquito Creek (Figure C4-3). In part, this finding may be related to the bank protection works constructed after the 1981 floods in the upper-mid reach of Mosquito Creek (from Evergreen Basin to just upstream of Montroyal Boulevard).

Mosquito Creek – Thain Creek

Thain Creek in the DNV has three erosion sites: two are Very High risk and one is High risk (Figure C4-4). One site is located just south of Madeley Road and two are just north of W Rockland Road. These sites are in close proximity to development and could cause parts of private property close to the bank to fall into the creek in the future.

Mosquito Creek – Wagg Creek

Fifteen erosion sites were recorded within the Wagg Creek catchment (Figure C4-4). Within Mahon Park in CNV there is particularly severe erosion downstream of Jones Avenue (3 Very High risk sites and 1 High risk site). The erosion is compromising a number of trails along Wagg Creek and pedestrian bridges crossing the Creek. Further upstream in the catchment at the West 21st Street crossing, some recent moderate erosion was noted: this is associated with one High risk site.

4.3 Erosion Next Steps

The 'Very High' and 'High' risk erosion sites should be further evaluated in detail to assess the liability risk to CNV/DNV and plan for rehabilitation/stabilization works as needed. As a minimum these sites should be monitored regularly to ensure they do not threaten infrastructure.

5. Channel Obstructions

Channel obstructions are shown in Figure C4-5. Obstructions were classified in the field as either: large woody debris (LWD), boulder, anthropogenic or other (e.g. bed rock, etc.).

The 2007 field reconnaissance noted a number of obstructions in Mackay Creek: these are primarily LWD and boulders (62% of total). It should not be assumed that the obstructions are necessarily problematic as LWD and boulders are part of the natural creek system. Several anthropogenic obstructions in Mackay Creek were noted in 2007 as well. Examples of anthropogenic obstructions observed include:

- Concrete lock blocks,
- Drop structures or weirs composed of various materials (e.g. concrete, rocks, wood, etc.), and
- Debris barriers (trash racks).

In many cases, the observed obstructions appeared to have accelerated erosive processes along the banks and channel bottom. In addition, most obstructions are associated with observed channel sedimentation (deposition).

6. Stream Bank Protection

Stream bank protection also was documented in 2007 and 2014 as part of the field reconnaissance. The observed bank protection works were recorded by its location, as well as its height, length, material and current condition. These data will be provided as part of the inventory database to CNV and DNV. It should be noted that, in some instances, existing bank protection may have been overlooked if hidden by well-established vegetation.

Most open channels within the urbanized sections of Mackay and Mosquito watersheds had some form of bank protection. Most of the bank protection was adjacent to developed areas (e.g., where streams flowed through private property), and some bank protection was noted in parks especially in the vicinity of pathways and footbridges where it appeared that erosion risk could compromise public safety. Noted forms of bank protection included riprap and retaining walls. The upper-mid reach of Mosquito Creek from the Evergreen Basin to just upstream of Montroyal Boulevard was engineered and armoured after the 1981 floods to prevent future floods from overtopping the banks and causing extensive damage to the surrounding areas.

In many cases the observed bank protection works are discontinuous (bank protection on one property but not the next). It is assumed that current or past property owners undertook most of these works. Discontinuous bank protection is not ideal since it may simply shift an erosion issue to a location upstream or downstream of the protected section. The condition of existing bank protection was noted as good, fair, or poor. Poor condition bank protection may be at risk of failing into the creek: should this occur, it might result in an obstruction to the flow and a potential increase in erosion.

7. Summary of Findings and Recommendations

7.1 Findings

Findings from this compendium include:

C4-1. CNV/DNV GIS drainage layers were used for figure generation and asset inventory. GIS gaps were picked up in the field reconnaissance or interpolated from existing data.

C4-2. A field reconnaissance and inventory was conducted in the summer of 2014 collecting data on culverts, stormwater outfalls, structures, typical creek cross sections, significant erosion sites, and obstructions in the creeks.

C4-3. Erosion sites were documented and qualitatively rated for risk; the following 'very high' and 'high' risk sites were noted:

Watercourse	Very High Risk	High Risk	Jurisdiction
Mackay Creek	14	19	DNV
Thain Creek	2	1	DNV
Wagg Creek	3	2	CNV

C4-4. Stream bank protection and channel obstructions such as anthropogenic (blocks, drop structures, weirs, debris barriers), large woody debris, and boulders were recorded.

7.2 Recommendations

Based on the foregoing, it is recommended that CNV/DNV:

C4-1. Further evaluate the Very High and High Risk Erosion Sites to assess the liability risk to CNV/DNV and plan for rehabilitation/stabilization works as needed. As a minimum these sites should be monitored regularly to ensure they do not threaten existing buildings and infrastructure.

City and District of North Vancouver
Mackay/Mosquito Watershed
Integrated Stormwater Management Plan

MACKAY CREEK WATERSHED

MOSQUITO CREEK WATERSHED

THAIN CREEK WATERSHED

WAGG CREEK WATERSHED

Capilano Lake

Capilano River

Mackay Creek West

Mackay Creek East

Mackay Creek Debris Basin

Mosquito Creek Debris Net

Mosquito Creek

Unknown

Kilmer Creek

Thames Creek

Dyer Creek

Transformer Creek

Duvuell Creek

Mountain Hwy

Thain Creek

Hastings Creek

Mackay Creek

Emsley Creek

Evergreen Sediment Basin

Existing Box Culvert
Approximately 825 m
Long x 2.3 m x 3 m

DISTRICT OF NORTH VANCOUVER

CITY OF NORTH VANCOUVER

Legend

- Municipal Boundary
- Study Area
- Watershed Boundary
- Contours (20m Interval)
- Watercourse
- Bridge Location
- Storm Manhole
- City of North Vancouver Outfall
- Energy Dissapator
- Oil/Grit Separator
- Culvert
- Assumed Drainage

Storm Mains (mm Diameter)

- Storm Mains (<600 mm)
- 600 - 900
- 1050 - 1200
- 1200 - 1900
- 1900 - 3050

Reference: GIS background data from the District of North Vancouver open data catalogue.

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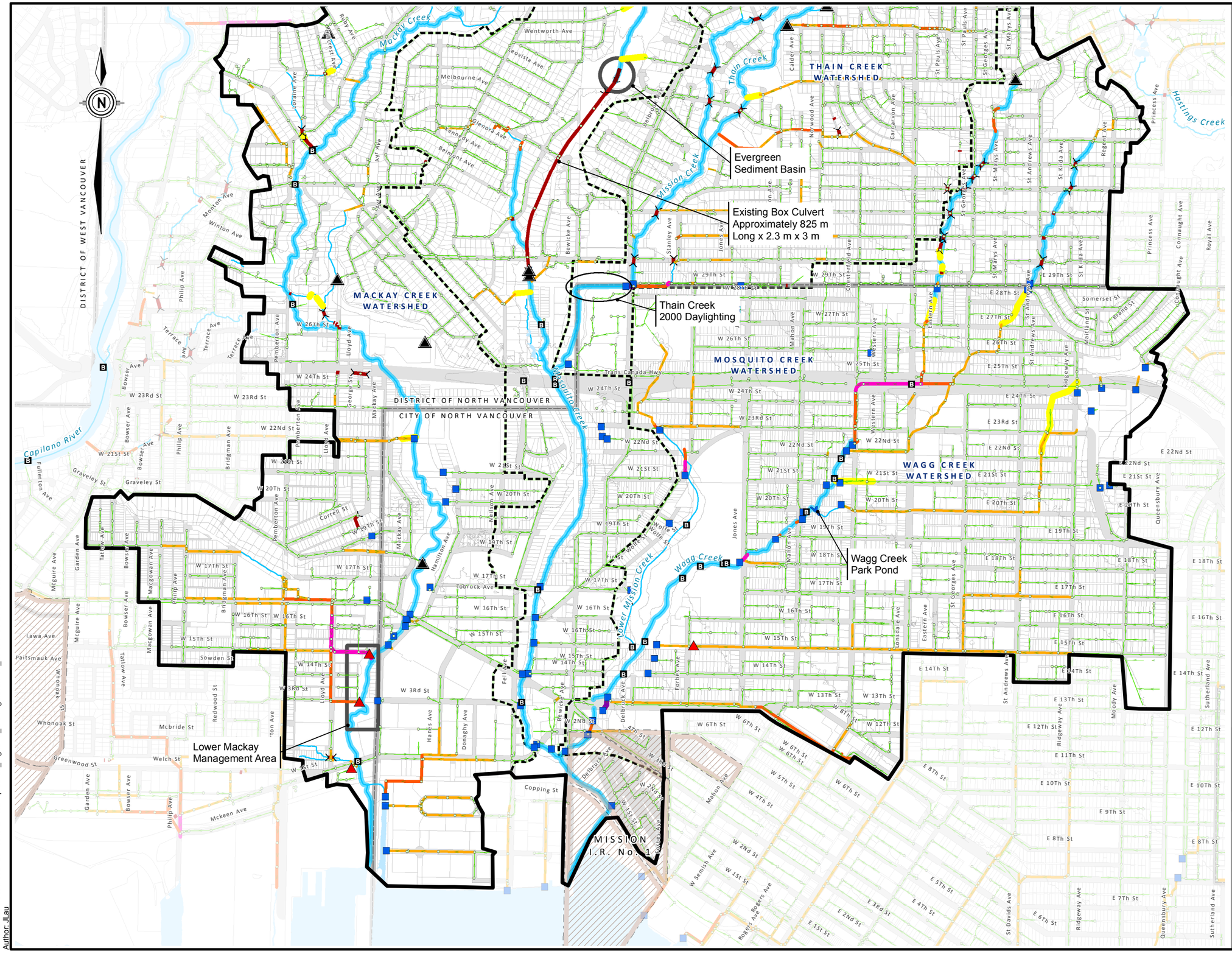
Project No.	Date
99-125	December 2016

Drainage System Overview - Upper Developed Area

Figure C4-1

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City and District of North Vancouver
Mackay/Mosquito Watershed
Integrated Stormwater Management Plan



Legend

- Municipal Boundary
- First Nations Reserve
- Study Area
- Watershed Boundary
- Contours (20m Interval)
- Watercourse
- Storm Manhole
- City of North Vancouver Outfall
- Energy Dissapator
- Oil/Grit Separator
- Culvert
- Bridge Location
- Assumed Drainage

Storm Mains (mm Diameter)

- Storm Mains (<600 mm)
- 600 - 900
- 1050 - 1200
- 1200 - 1900
- 1900 - 3050

Reference: GIS background data from the District of North Vancouver open data catalogue.

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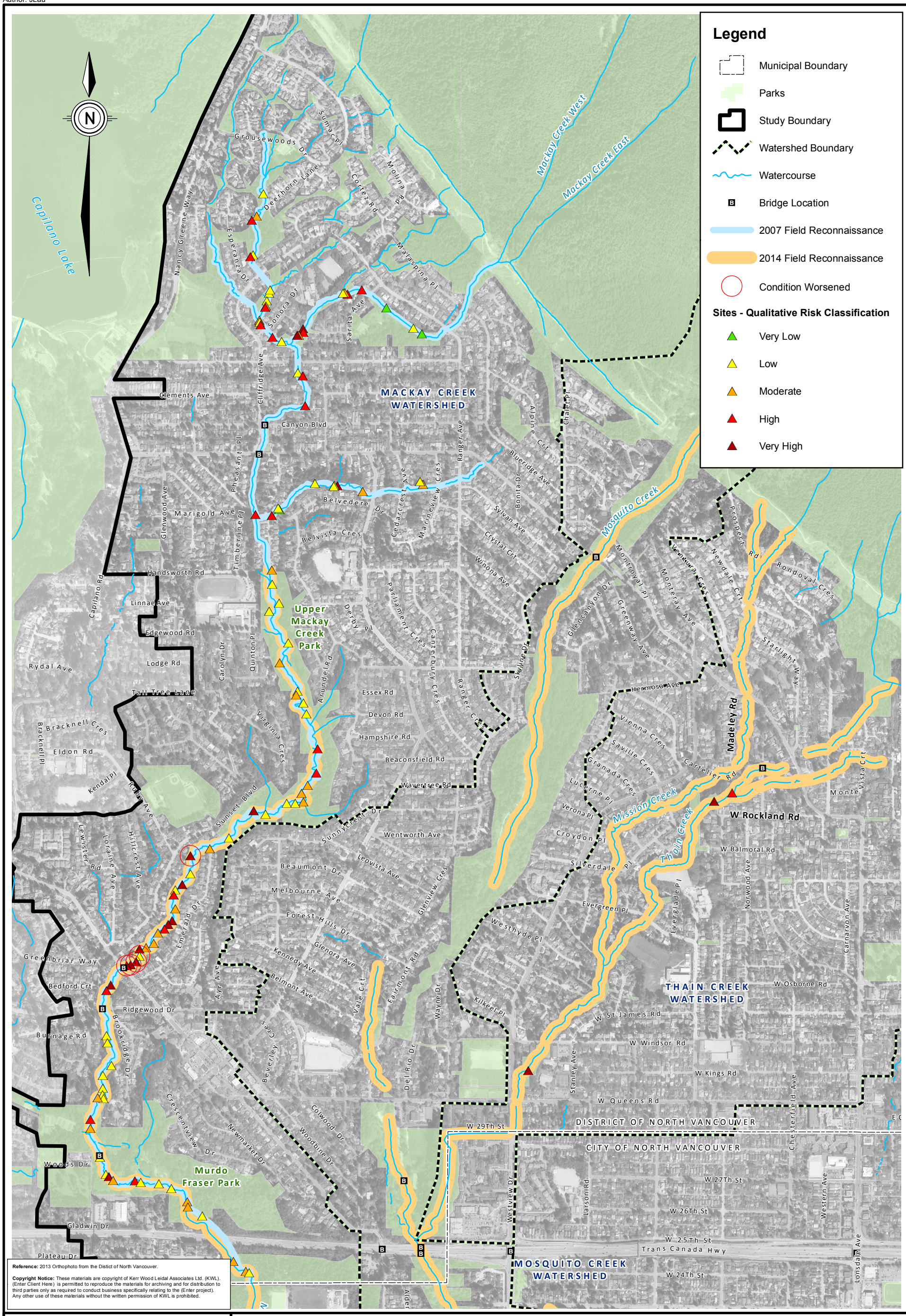
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Drainage System Overview - Lower Developed Area

Figure C4-2

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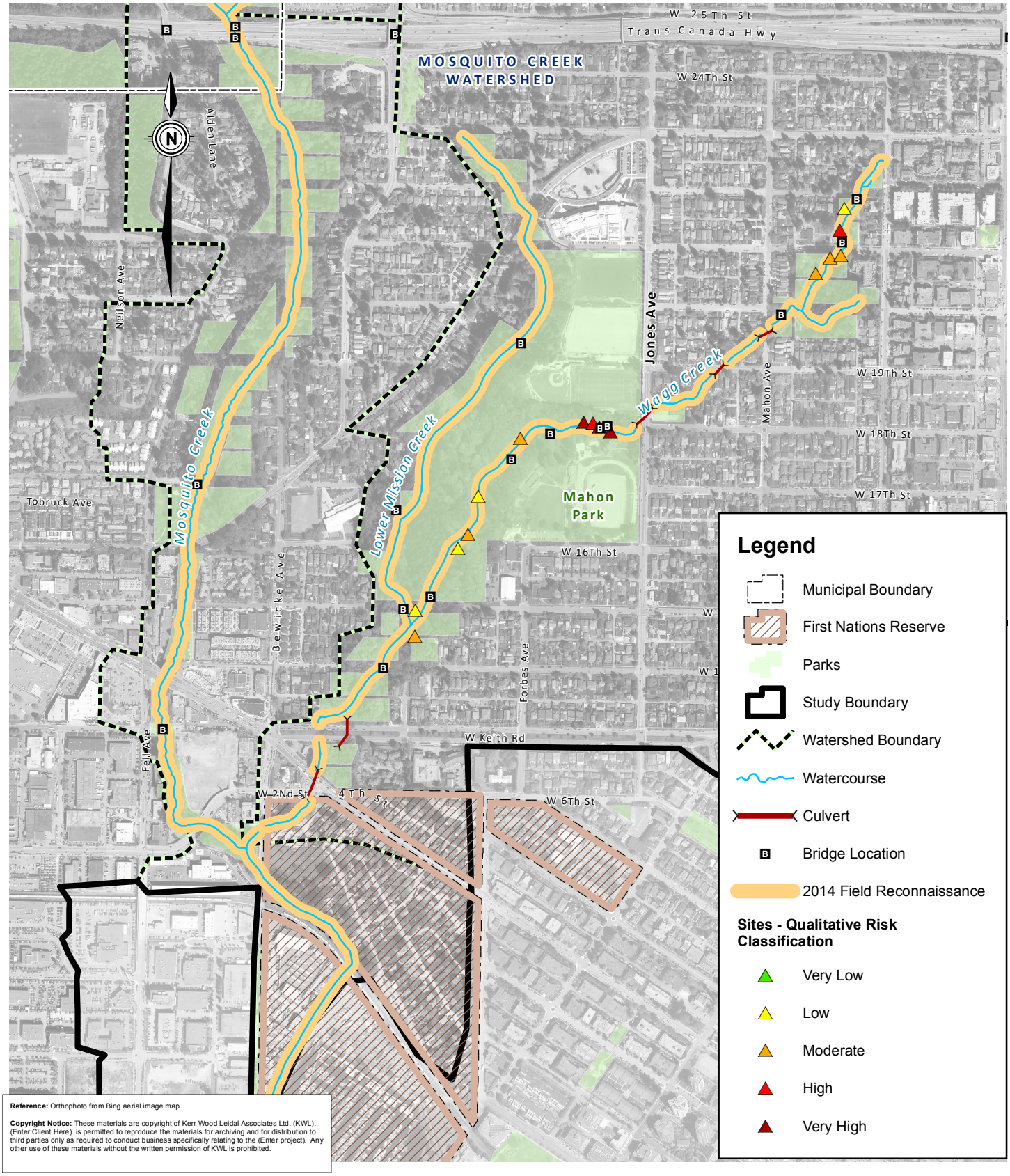
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Mackay and Mosquito Creeks Field Reconnaissance (2007 and 2014)

Figure C4-3



Reference: Orthophoto from Bing aerial image map.

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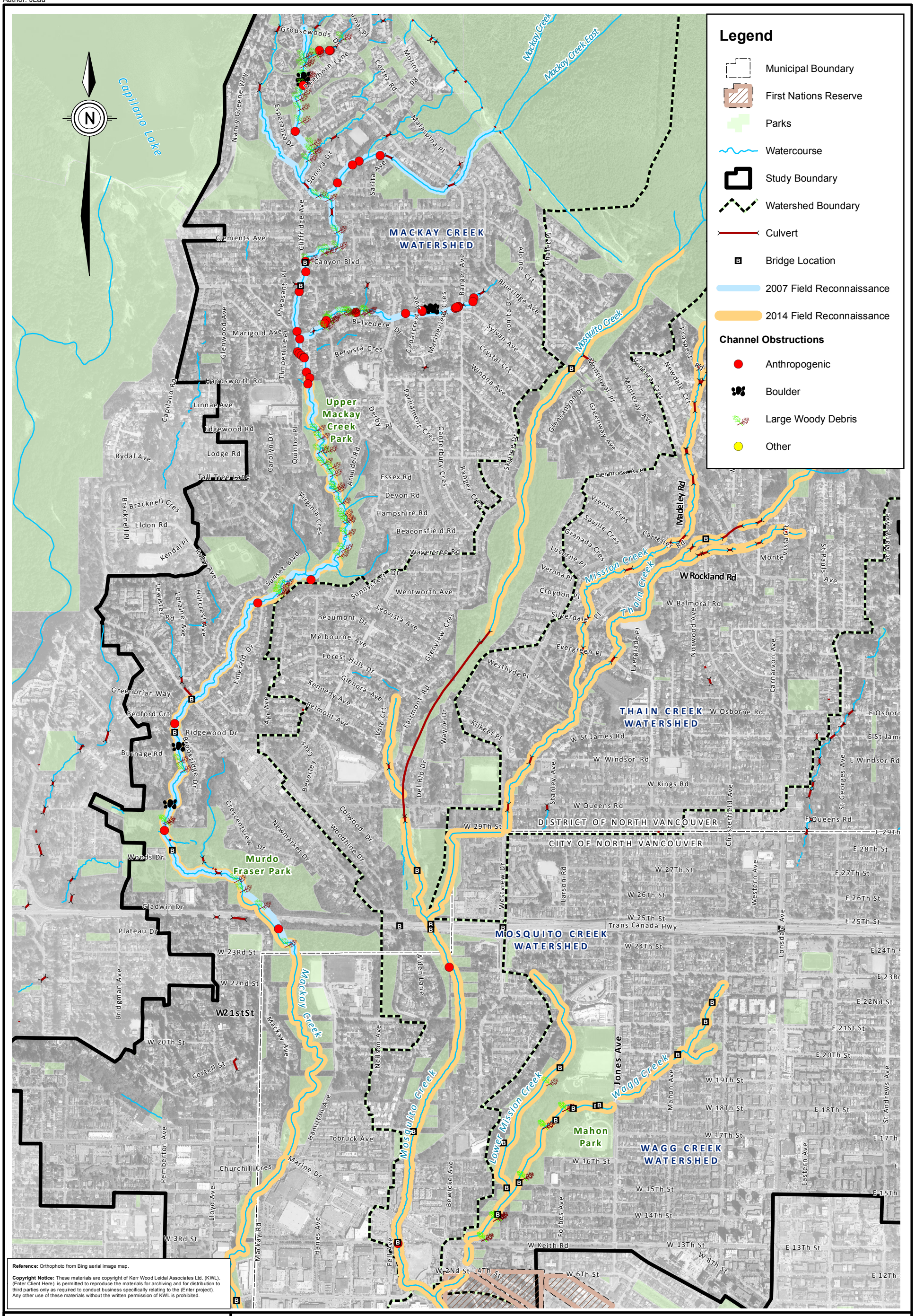
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Lower Mosquito (Wagg Creek) Erosion (2014)

Figure C4-4

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Project No.	Date
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Mackay and Mosquito Creeks Obstructions (2007 and 2014)

Figure C4-5

Report Submission

KERR WOOD LEIDAL ASSOCIATES LTD.

Prepared by:



Bryce Whitehouse, A.Ag.
Project Hydrologist

Reviewed by:



28 Sept 2020

David Zabil, M.A.Sc., P.Eng.
Technical Reviewer

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Revision History

Revision #	Date	Status	Revision	Author
0	Sept 21, 2020	Final	Issued as final for client copy.	CC



Compendium 5

HYDROLOGIC AND HYDRAULIC MODELLING

Mackay Mosquito Watersheds ISMP

September 2020

Final Report

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Purpose

Compendium 5. Hydrologic and Hydraulic Modelling

This compendium provides detailed information on the PCSWMM computer modelling undertaken, including the purpose, setup, inputs, calibration, and validation. It also summarizes the model results not associated with hydraulic conveyance capacity assessment which are contained in *Compendium 6. Drainage Assessment*. This is a supporting document to the *Mackay and Mosquito Watersheds Integrated Stormwater Management Plan* (ISMP) developed by the City of North Vancouver (CNV) and District of North Vancouver (DNV).

Information contained in this compendium includes:

1. Introduction and Purpose of Model
2. Model input information
3. Model Development
4. Model Calibration and Validation
5. Summary of Peak Flow Estimates
6. Summary of Continuous Simulation

Refer to other compendiums for additional supporting information.

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The following compendiums and their authors support the Mackay Mosquito Watersheds ISMP:

1. Watershed Overview - KWL
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Figure and table identification numbering include the first digit related to compendium number and the second digit related to the figure number within the compendium. E.g. Figure C3-1 is the first figure within Compendium 3.

'Blue boxes' of explanative information are provided in each compendium where background information and context are helpful.

1. Introduction and Purpose of Model

Hydrologic and hydraulic models of Mackay and Mosquito watersheds were created from the CNV and DNV GIS information, record drawings and field reconnaissance information. The model is a representation of the existing drainage system composed of the minor drainage system (storm sewers) and the major drainage system (storm trunks and creeks). This network collects stormwater runoff from impervious surfaces such as roads, roofs and both runoff and shallow groundwater from pervious areas.

CNV preferred the PCSWMM software, while DNV preferred InfoSWMM. The modelling and assessments were completed in PCSWMM, and then converted to InfoSWMM for DNV.

The primary purpose of modelling was to:

1. Assess the conveyance capacity of the storm sewers and creek culverts. Bridges were assessed in previous study: *Creek Hydrology, Floodplain Mapping and Bridge Hydraulic Assessment Study (KWL, 2014)* and bridge findings summarized in *Compendium 6. Drainage Assessment*. The analysis includes clear-water flow estimates only. Debris floods and flows are addressed in DNV's current study *Debris Geohazard Risk and Risk Control Assessment (BGC, 2017)*.
2. Estimate the Effective Impervious Area (EIA) under both existing and unmitigated future land use conditions to inform minimum mitigation targets for future development to achieve no-net-loss in ecological health.

2. Rainfall and Flow Monitoring Data

North Vancouver climate and flow monitoring stations are summarized in Table C5-1 and shown on Figure C5-1. Shaded data sources were used in the model calibration/validation process and design events. Applicable rainfall design depths are summarized in Table C5-2 and design storm applications are summarized in Table C5-3. The Modified Chicago Design storm distribution is shown in Graph C5-1.

Table C5-1: Hydrometric and Climate Stations

Hydrometric Stations	Elev (m)	Period of Record	Type of Data	Owner
Flow Monitoring Stations				
1. Mackay Debris Basin	~285	09/21/2003 to Present	5-Minute Continuous	DNV
2. Mackay Creek at Montroyal Blvd (08GA061)	182	01/12/1970 to Present		WSC
3. Mosquito Creek at William Griffin at Queens Rd W	~90	01/11/1998 to Present		DNV
4. Wagg Creek at Keith Road	~30	10/16/2002 to Present		CNV

Hydrometric Stations	Elev (m)	Period of Record	Type of Data	Owner
Rainfall Monitoring Stations				
1. North Vanc Grouse Mtn Resort (1105658)	1103	01/10/1971 to Present	Daily	Env Canada
2. Mackay Debris Basin	~285	09/21/2003 to Present	5 min	DNV
3. North Vanc Sonora Dr (110N6FF)	193	01/1976 to 02/2011	Hourly	Env Canada
4. Cleveland Dam (DN15)	156	02/02/2004 to Present	Daily	Metro Van
5. DNV Municipal Hall (DN25)	~99	01/01/1980 to Present	Hourly	Metro Van
6. CNV City Hall	80	01/19/1994 to Present	5 min	CNV
7. Mahon Park (DN72)	~65	05/28/2001 to Present	5 min	Metro Van
Refer to Figure C5-1 for locations.	Used for Calibration		Used for modelling assessment	

2.1 Climate Change

Increased rainfall due to climate change was based on CNV's future climate change IDF curves; rainfall totals are summarized in Table C5-2. The future IDF estimates were developed using historical data and the IDF CC Tool (FIDS-Western University, 2014). Relative Concentration Pathways 8.5 (RCP 8.5) (Moss R.H., et al., 2008) climate change scenario was used to design for the "worst" case scenario.

Climate change associated with sea level rise was not included in this modelling assignment because boundary conditions were not needed.

Table C5-2: Total Precipitation Amounts for CNV City Hall and Sonora Drive Climate Stations

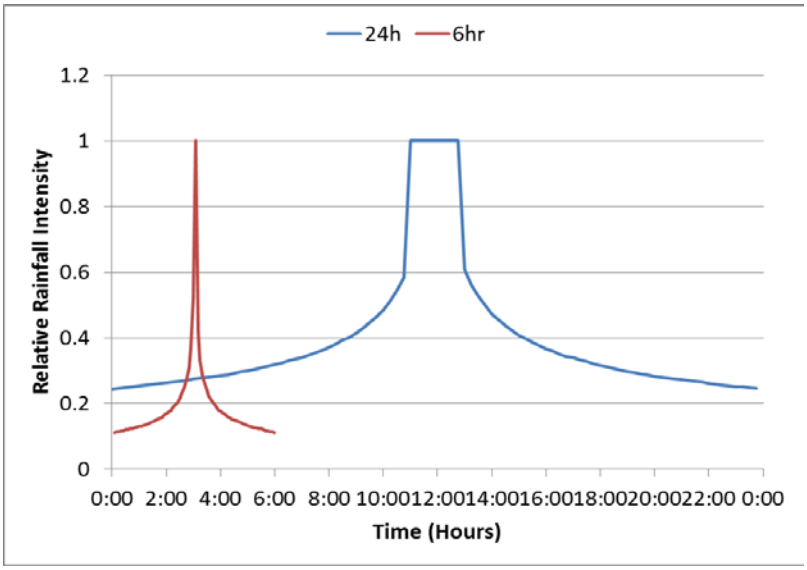
Duration	Total Rainfall (mm)					
	Existing IDF Curve			Climate Change (RCP 8.5)		
	2-yr	10-yr	100-yr	2-yr	10-yr	100-yr
CNV City Hall (1994 – 2014)						
1 Hour	10.97	14.59	19.1	14.5	19.54	25.75
2 Hour	8.22	10.35	13	10.29	13.25	16.9
6 Hour	5.74	8.08	11.01	8.03	11.29	15.32
12 Hour	4.16	6.08	8.49	6.04	8.72	12.03
24 Hour	2.82	4.05	5.59	4.02	5.74	7.87

Duration	Total Rainfall (mm)					
	Existing IDF Curve			Climate Change (RCP 8.5)		
	2-yr	10-yr	100-yr	2-yr	10-yr	100-yr
North Vancouver Sonora Drive (1990 – 2010)						
1 Hour	15.89	19.94	31	22.42	31.73	43.33
2 Hour	11.45	13.72	19.94	15.12	20.35	26.87
6 Hour	7.81	9.39	13.72	10.36	14	18.54
12 Hour	5.92	7.26	10.94	8.09	11.18	15.04
24 Hour	4.11	4.97	7.32	5.5	7.48	9.95
Rainfall totals provided by CNV.						

Table C5-3: Application of Design Storms

Design Storms	
Duration/Shape	**Description**
6-Hour DNV Modified Chicago[2] **24-Hour DNV Modified Chicago[2]**	10-year & 100-year return period storms used to assess drainage capacity and pipe sizing. Larger of two resulting flows (6-Hour or 24-Hour) governs. 200-year return period used for creek culvert assessment.[1] 2-year (6- & 24-hour), 6-month (24-hour only) storms used to for volume reduction & rate control unit sizing.

1. *CNV extrapolated 200-year from 100-year IDF curve, approx 7 – 10% increase in precipitation. KWL tested these numbers in model to determine impact on peak flows - on average peak 200-year flows were approx 8 – 12% larger than peak 100-year flows. Therefore, 100-year flows were factored up by 12% (conservative) to estimate 200-year flows at key creek hydraulic structures.*
2. *6-Hour and 24-hour DNV Modified Chicago design storm distribution are shown in Figure C5-1, below.*



Graph C5-1: Modified Chicago Design Storm Distribution

3. PCSWMM Model Development

3.1 Model Build

Hydrologic and hydraulic models were developed using PCSWMM software. A summary of the model statistics and model build information is presented below.

Table C5-4: Model Statistics Summary and Model Build Information

About the Model				
Watersheds & Areas	Mackay Watershed	862 ha	**Hydrologic Model:**	PCSWMM
	Mosquito Watershed	1,539 ha	**Hydraulic Model:**	PCSWMM
	Mainstem Sub-watershed	821 ha	**Creek Channel (km):**	66
	Thain Sub-watershed	347 ha	**Storm Sewer (km):**	194
	Wagg Sub-watershed	371 ha		
	Number of:			
	Non-Residential Catchments:	514	**Storm Sewer:**	5,075
	Residential Catchments:	10,346	**Detention Facilities:**	1
	Park / Forested Catchments:	820	**Culverts:**	213
	Road Catchments:	5,903	**Manholes:**	5,097

Model Build	
Digital GIS Databases	CNV/DNV storm pipes, culverts, watercourses, 2013 LiDAR, 1 m contours, cadastral, ground cover pixel analysis Existing Land Use imperviousness, OCP Future Land Use.
Missing Data Gaps	Missing pipe sizes were filled in by either assuming missing diameter was equal to the size of the upstream pipe or with information gathered during field inventory. Missing inverts were estimated by interpolating the slope between known inverts upstream and downstream. Manhole rim elevations were estimated using CNV/DNV 2013 LiDAR. Assumed data is flagged in the databases.
Creek Cross Sections	Developed from CNV/DNV 2013 LiDAR. Invert elevations of open channel links were assigned based on culvert and/or outfall invert elevations.
Watershed Boundary	Reviewed & updated based on DNV & CNV 1 m contours & drainage system extents. Figure C5-2
Slopes	Based on CNV/DNV LiDAR elevations
Model Schematic	Figure C5-1
Soils	Figure C1-2: Surficial Soils from *Compendium 1. Watersheds Overview*
Land Use	Figure C7-2: Existing Land Use. Figure C7-3: OCP – 2030 Future Land Use 2010 Spectral Image land cover pixel analysis for existing land use, and CNV and DNV 2030 OCP Zoning data for unmitigated future land use. Refer to *Compendium 7. Land Use Analysis* Sections 2.1 and 3.1 respectively

3.2 Model Catchments and Land Uses

The study drainage area was delineated into catchments and sub-catchments. In urban areas, the cadastral data is used to generate lot by lot sub-catchments. All storm sewer pipes and select watercourses were included in the model and therefore small catchments were needed to provide flow to each model node. An automated process assigned each lot sub-catchment to a node based on its proximity. The road rights-of-way (ROW) catchments were created in GIS, and then split up to assign the correct portions to the model nodes in a similar fashion as the lot catchment assignment.

In total the model includes 17,583 sub-catchments. Catchments were assigned the following attributes:

- slopes, using digital elevation mapping (DEM) information,
- impervious areas (see above table under Land Use subheading), and
- groundwater parameters based on soils mapping, Figure C1-2.

Catchment information is summarized in Table C5-4 and shown on Figure C5-2.

3.3 Groundwater and Soil Parameters

The groundwater portion of PCSWMM was used to better estimate the groundwater and interflow portions of the total flow hydrograph. Figure C1-2 shows the surficial geology that was used to determine soil and groundwater parameters. Infiltration rates, soil depths, and soil hydraulic conductivity were input based on previously used and typical values.

4. Model Calibration and Validation

The model build and calibration was an iterative process. Three calibration locations were used:

- Wagg Creek at Keith Road which is a primarily urbanized catchment,
- Mackay Creek at Debris Basin which is a primarily forested catchment, and
- Mosquito Creek at Queens Road W which includes a combination of both urbanized catchments and forested headwaters.

4.1 Urban Catchment Parameters

The initial Wagg catchment model parameters were based on the *City of North Vancouver Stormwater Management Strategy for Mission Wagg Creek System (1999)* calibrated Wagg model parameters. This model was further calibrated with more recent flow events listed in Table C5-5. Infiltration and groundwater parameters were adjusted. The calibrated Wagg parameters formed the basis for all urban catchments in both Mackay and Mosquito Watersheds.

Table C5-5: Summary of Calibration/Validation Events

Type	Date	Refer to	Comments
Wagg Creek at Keith Road			
Dry	Jul 13 - 16, 2011	Graph C5-2	Modelled peaks are within 5%, shown in the recorded data.
Wet	Dec 30, 2009 – Jan 4, 2010		Modelled peaks are consistently higher than recorded.
Validation	Jul 16 –17, 2011		Modeled peaks are <30% overestimated and volumes are 5% underestimated. Acceptable validation.
Upper Mackay Creek at Debris Basin			
Dry	Oct 22 – Nov 3, 2010	Graph C5-3	Modelled peak flow was underestimated by 20%.
Wet	Jan 11 – 18, 2010		Modelled peak flows underestimated by <12%; Volumes were within 7% and groundwater tails are a good fit.
Validation	Dec 6 – 18, 2010		Modelled volumes are 10% higher; First modelled peak is 15% lower and second is 13% higher lower than recorded. Acceptable validation given calibration underestimation of peaks.
Mosquito Creek at Queens Road W			
Dry	Oct 30 – Nov 2, 2010	Graph C5-4	Peaks are about 20% lower than recorded in bigger event conditions, receding limbs are acceptable.
Wet	Jan 14 – 16, 2010		Modelled peaks are 10% lower than recorded, receding limb stays higher; minor adjustments made to groundwater parameters.
Validation	Feb 26 – Mar 1, 2010		Model volume nearly equals recorded. Large modelled peak is within 5% of recorded flow and groundwater tails are close. Acceptable Validation

4.2 Forested Catchment Parameters

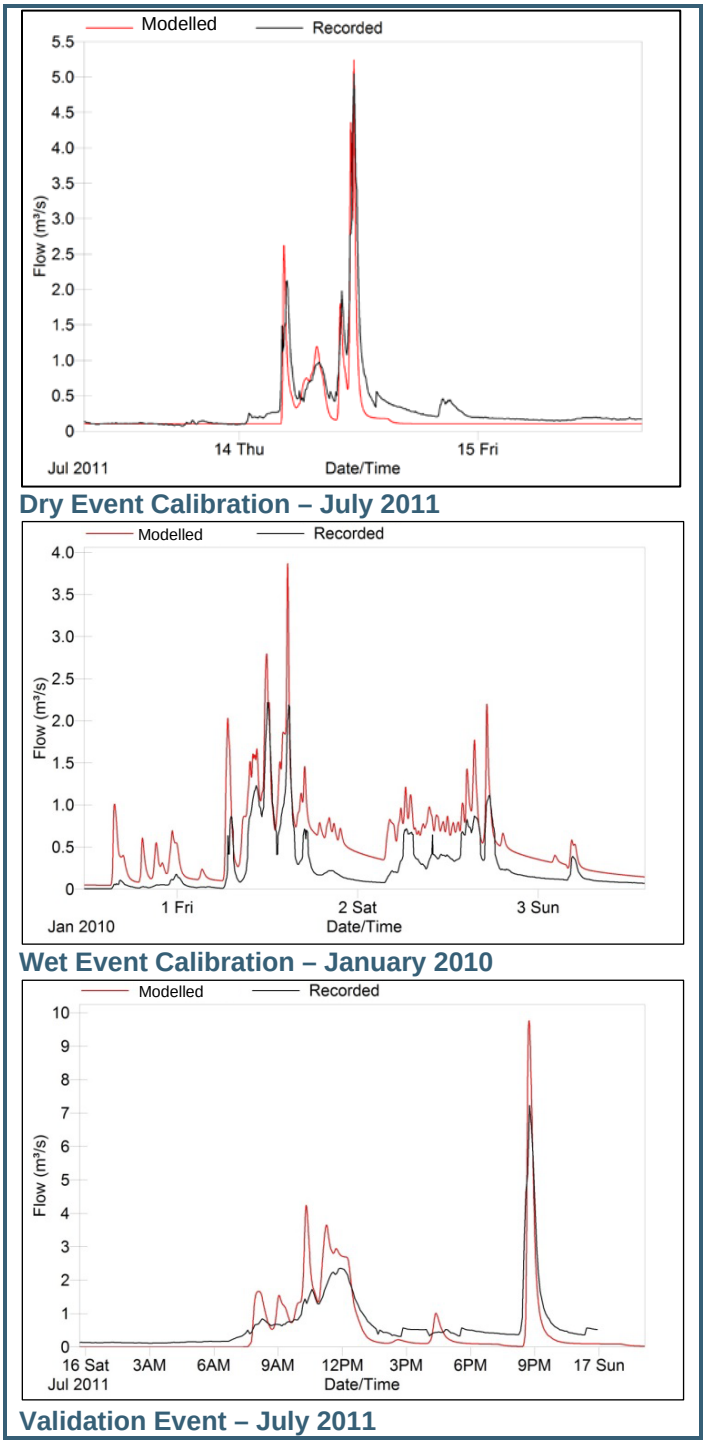
The catchment upstream of the Upper Mackay Creek basin was used for calibration to establish the forested condition parameters for the Mackay Watershed model. During the calibration process, groundwater parameters were adjusted to provide a better match in modelled and recorded flows.

The Mosquito Creek model calibration used the calibrated Wagg catchment urban parameters (unaltered) for the urban portions. However, the calibrated Upper Mackay Creek undeveloped parameters needed to be adjusted to increase the modelled flows to better match the flow monitoring.

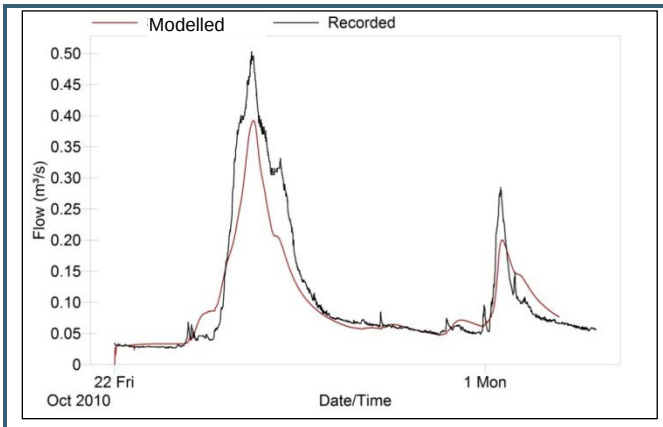
During the calibration/validation process forested catchment parameters adjusted until predicted peaks and volumes matched flow monitoring as close as possible. The calibration was a difficult process of balancing competing objectives (matching flow peaks and volumes and differences from storm to storm).

The model sensitivity was tested and the resulting calibration was the best achievable result with estimated model flow volumes within 12% and model peak flows both overestimating and underestimating the recorded values. Table C5-5 and Graphs C5-2

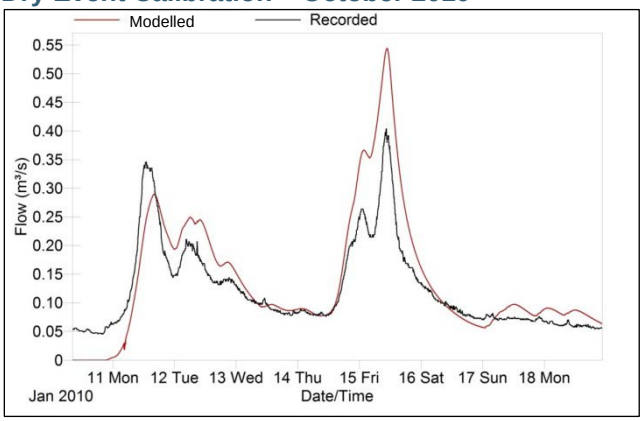
Validation also included comparison of modelled design event peak flows with previous flow estimates as described in the next section.



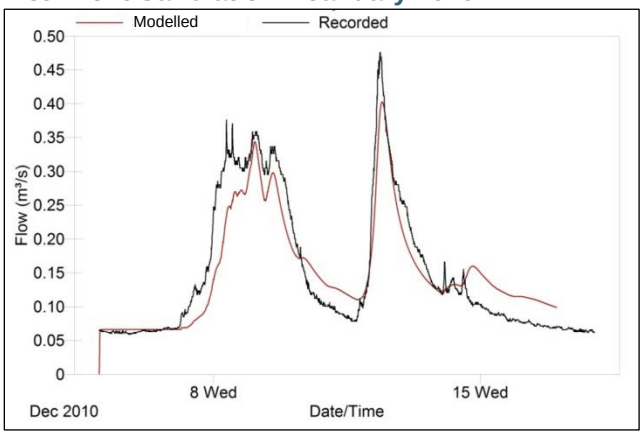
Graph C5-2: Wagg Calibration and Validation



Dry Event Calibration – October 2010

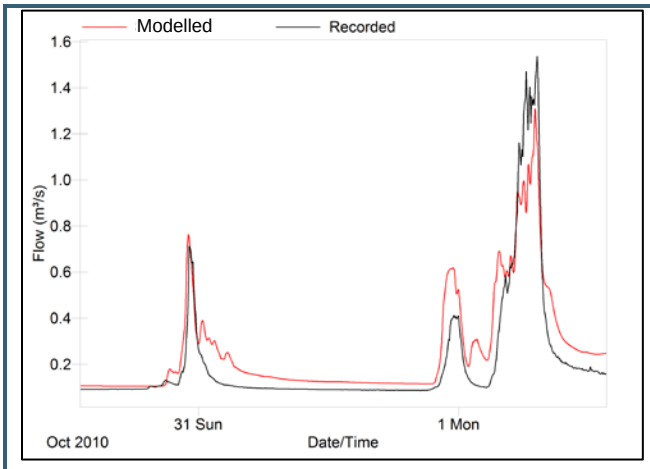


Wet Event Calibration – January 2010

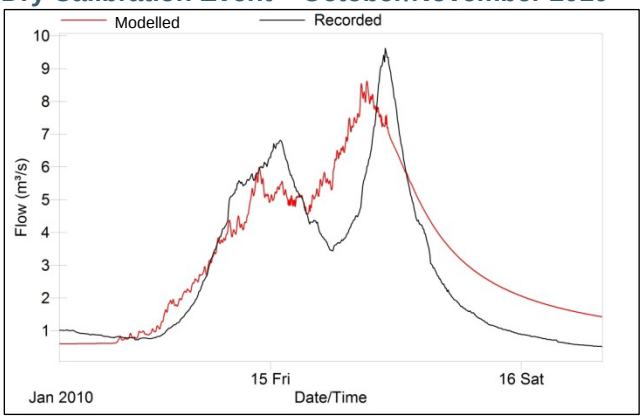


Validation Event – December 2010

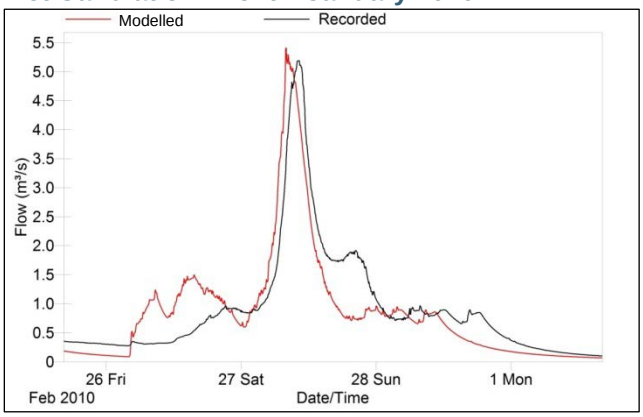
Graph C5-3: Upper Mackay Calibration and Validation



Dry Calibration Event – October/November 2010



Wet Calibration Event – January 2010



Validation Event – February 2010

Graph C5-4: Mosquito Calibration and Validation

5. Model Scenarios and Peak Flow Estimates

5.1 Modelling Scenarios

Table C5-6 summarizes the 22 modelling scenarios agreed upon with CNV and DNV, including:

1. Existing Land Use (2010),
2. Unmitigated Future Land Use (OCP 2030); and
3. Unmitigated Future Land Use (OCP 2030) with Climate Change (RCP 8.5).

This includes design storm events and continuous simulations runs.

The existing land use model scenario percent impervious values are based on the 2010 spectral analysis and the unmitigated future land use scenario (without stormwater controls) was based on OCP land uses. Refer to *Compendium 7. Land Use Analysis* Sections 2.1 and 3.1.

5.2 Peak Flow Estimates

200-Year Peak Flow Estimates

The 200-year peak flow estimates were factored up from 100-year estimates by 1.12. This factor is based on:

a) the historical rainfall frequency analysis which showed a range of 200-year-to-100-year rain factors of 1.08 to 1.12, and

b) a test model of the 100-year and 200-year rainfall to determine the ratio of flow peaks in the modelled pipes which showed a range of 200-year-to-100-year flow factors of 1.08 to 1.12.

The upper end of the flow factor range was used to scale the 100-year flows to estimate the 200-year flows, as discussed with and agreed to by CNV and DNV staff.

Comparison with Previous Peak Flow Estimates

Table C5-7 summarizes the comparison of peak flow estimates with previous hydrology estimates at key locations. Figure C5-1 shows the key strategic flow reporting locations.

Flow estimates were governed primarily by the 6 hour duration events, especially for the larger 100-year return period. Generally, the majority of 100-year ISMP modelled flows are higher than 1992 historical flow estimates. The difference ranges from 2% to 25% higher and appears to be closer at points further downstream.

The difference in the 200-year estimates between ISMP and 2014 flow estimates is a much smaller range, from 1% to 12%. This may be attributed to the closer input data such as rainfall and impervious area. This project used the most up to date IDF curves which are based on recent climatic trends (1990 to 2010 and 1994 to 2014) and more detailed modelling, including groundwater components, than in previous studies.

Peak Flow Estimates

Table C5-8 summarizes the peak flow estimates at strategic locations.

Table C5-6: Summary of Modelling Scenarios

Type of Assessment	Rainfall		Pre-dev Land Use	Existing Land Use	Future Land Use						No. of Model Runs	Rationale
					Unmitigated	w BMPs	Unmitigated		Unmitigated			
			Historical Climate (Existing IDFs)				RCP[1] 4.5		RCP[1] 8.5			
			2 Storm Durations (6 hr, 24 hr)				2 hr	24 hr	2 hr	24 hr		
Watershed-wide SWMM Modelling	Design Storms	6-month	--	--	--	--	--	--	--	--		Use continuous simulation runs instead
		2-year	--	--	--	--	--	--	--	--		Use continuous simulation runs instead
		10-year		X X	X X	--	X	X	X	X	8	Assess minor storm sewer system
		100-year		X X	X X	--	X	X	X	X	8	Assess major drainage system
		200-year	Factor Up 100-year Flows & Analyse Creek Crossings in spreadsheet									Assess creek crossings
	Continuous Simulation	Low rainfall year	X	X	X						3	Assess impact of development, estimate volume reduction target
		High rainfall year	X	X	X						3	
									Total SWMM Model Runs		**22**	

1. RCP = **Representative Concentration Pathways** for greenhouse gas concentration scenarios
   - RCP 4.5 - 2-year events are 5-9% larger, 2h to 12h events are 3% to 9% larger, 24hr events are all larger, but the difference decreases from 7% to 0% from 2-year to 100-year, and all short duration and long return period events are with 2%
   - RCP 8.5 - all storms are larger, ranging from 7% to 31%. The largest increases are for the shorter return periods, decreasing toward longer return periods.

Table C5-7: Comparison with Previous Peak Flows Estimates

Creek	Location	Peak Flow Estimates (m^3s)									% Difference Between Historical & 2015 Flow Estimates	
		From Previous Reports[1]		2014 Report[3]	2015 Chicago Distribution[4]							
					10-year		100-year		200-year[5]			
		100-year	200-year	200-year	6 hour	24 hour	6 hour	24 hour	6 Hour	24 Hour	100-year	200-year
Mackay	Debris basin	N/A	N/A	N/A	1.0	1.5	6.0	2.8	6.7	3.1	N/A	N/A
	Montroyal Blvd	16.1	18.5	25.3	11.6	7.3	20.5	11.6	23.0	13.0	21%	-10%
	City Boundary	27.6	31.7	N/A	23.9	17.8	30.9	23.7	34.6	26.5	11%	N/A
	Mouth	37.9	43.6	44.1	29.8	20.5	38.8	30.1	43.5	33.7	2%	-1%
Mosquito	Montroyal Blvd	N/A	N/A	34.0	11.0	13.1	34.8	20.6	38.9	23.0	N/A	12%
	West Queens	38.7	44.5	N/A	16.3	17.4	52.1	37.2	58.4	41.7	25%	N/A
	Wagg mouth	19.0	25.7	N/A	20.5	13.0	23.4	16.5	26.2	18.5	18%	N/A
	Mouth	62.4	78.0[2]	77.7	50.8	44.4	77.0	62.0	86.2	69.4	19%	9%

All flow estimates are 'peak instantaneous flows'. N/A – No data Grey shading – Governing duration that yields the maximum flow for each return period.

1. From *Report on North Shore Regional Hydrology and Computer Modelling* (KWL, 1992). One exception noted.
2. From *Mosquito Creek Flood and Erosion Study* (KWL, 2000)
3. From *Creek Hydrology, Floodplain Mapping and Bridge hydraulic Assessment* (KWL, 2014)
4. DNV Modified Chicago distributions scaled to meet updated NV Sonora and CNV City Hall IDF curve intensities.
5. 100 year Chicago storms results factored up by 1.12

Refer to Figure C5-1 for strategic flow reporting locations.

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Table C5-8: Summary of Design Peak Flow Estimates

Creek	Location	Area[1] (ha)	TIA[1]		Peak Flow Estimates (m^3s)											
					10-year				100-year				200-year			
			Existing Land Use	Future Land Use	Existing Land Use[2]	Future Land Use			Existing Land Use[2]	Future Land Use			Existing Land Use[2]	Future Land Use		
						IDF[2]	RCP 4.5	RCP 8.5		IDF[2]	RCP 4.5	RCP 8.5		IDF[2]	RCP 4.5	RCP 8.5
Mackay	Debris basin	70	1%	1%	1.5[3]	1.5[3]	2.8	5.2	6.0	6.0	10.2	14.3	6.7	6.7	11.4	16.0
	Montroyal Blvd	307	16%	31%	11.6	12.5	16.4	19.9	20.5	21.2	27.4	33.8	23.0	23.7	30.7	37.9
	City Boundary	615	24%	48%	23.9	25.7	28.6	31.2	30.9	32.1	36	40.1	34.6	36.0	40.3	44.9
	Mouth	858	32%	57%	29.8	32.3	36.1	39.4	38.8	40.3	45.9	50.5	43.5	45.1	51.4	56.6
Mosquito	Montroyal Blvd	456	3%	7%	13.1[3]	13.[3]	20.6	31.5	34.8	34.9	53.7	73.7	39.0	39.1	60.1	82.5
	West Queens	593	10%	21%	17.4[3]	17.6[3]	31.3	48.3	52.1	52.5	70.8	104.4	58.4	58.8	79.3	116.9
	Wagg Creek	447	50%	79%	20.5	21	22.4	23.3	23.4	23.6	24.4	26.0	26.2	26.4	27.3	29.1
	Thain Creek	369	26%	51%	14.1	14.8	16.4	18.0	18.0	18.5	22.5	24.7	20.2	20.7	25.2	27.7
	Mouth	1541	45%	76%	50.8	53.7	64.4	76.2	77	79.3	95.3	110.5	86.2	88.8	106.7	123.8

Grey shading = Existing Land Use results.

1. Area and Total Impervious Areas (TIA) refer to catchment area tributary to strategic flow reporting location. Refer to Figure C5-1.
2. Historical IDF Curves: City Hall 1994 - 2014 and Sonora 1990 – 2010
   RCP = **Representative Concentration Pathways** for greenhouse gas concentration scenarios
   - RCP 4.5 - 2-year events are 5-9% larger, 2h to 12h events are 3% to 9% larger, 24hr events are all larger, but the difference decreases from 7% to 0% from 2-year to 100-year, and all short duration and long return period events are with 2%
   - RCP 8.5 - all storms are larger, ranging from 7% to 31%. The largest increases are for the shorter return periods, decreasing toward longer return periods.
3. Peak flow estimate governed by 24-hour rainfall event, all other estimates governed by 6-hour event.

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6. Continuous Simulation Modelling

PCSWMM continuous simulation hydrologic modelling (CSM) was conducted to quantify the impact of future land development on total annual runoff at strategic locations in the watersheds. CSM was also used to estimates the Effective Impervious Area (EIA) in each watershed for existing and future land use scenarios. Climate change was not considered in the CSM analysis. Continuous simulation modelling provides the data necessary to better evaluate how development has and could affect the total annual runoff in a watershed.

Total impervious area (TIA) refers to total area of impervious land within a parcel / catchment / watershed.

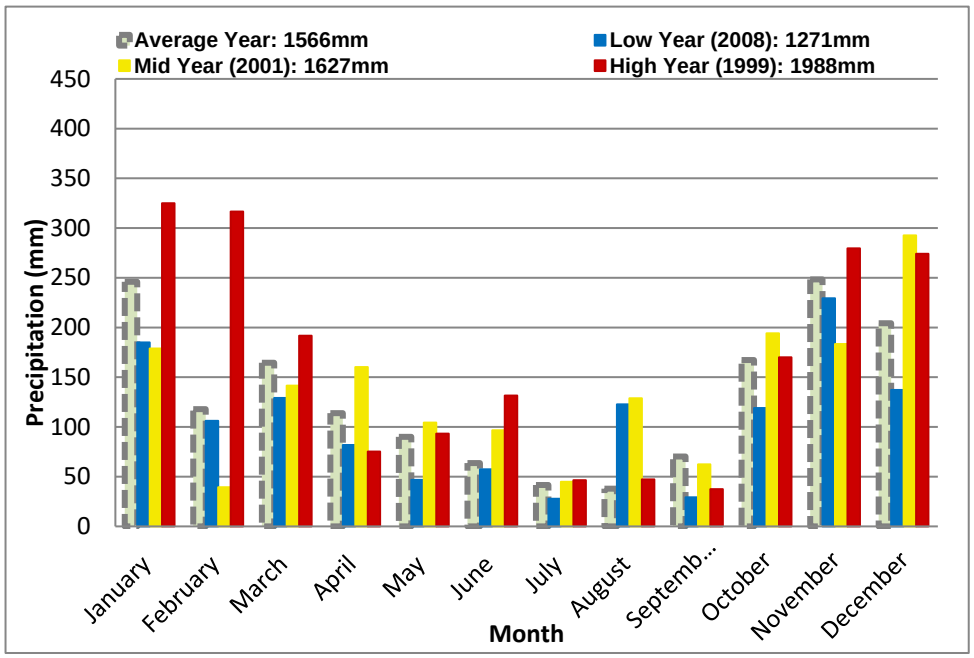
Effective impervious area (EIA) refers to area of impervious land that is directly connected to a storm sewer or a stream.

6.1 Selection of Low, Mid, and High Rainfall Years

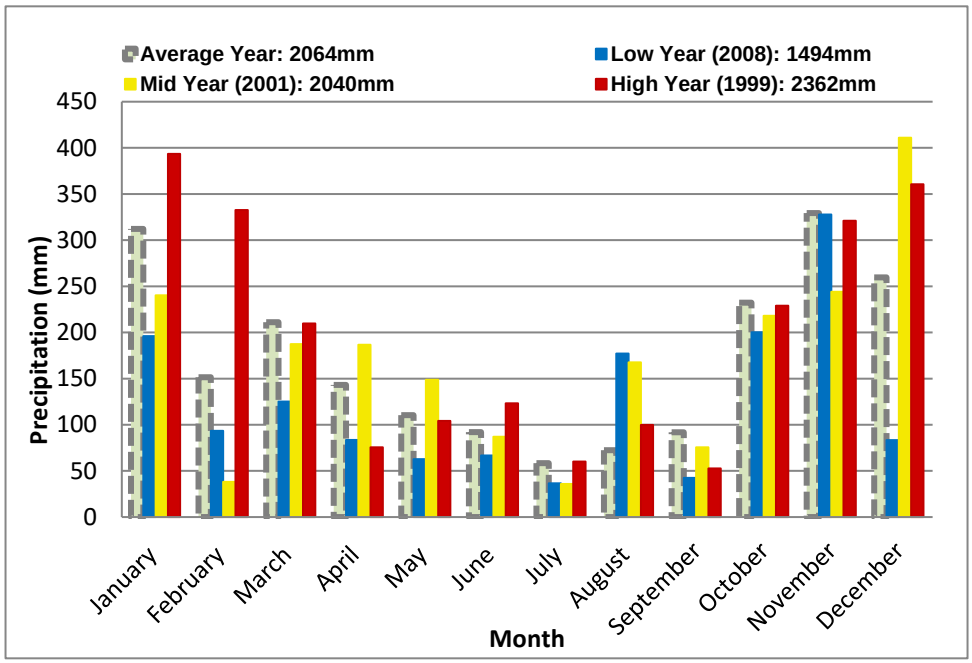
Because EIA changes from year to year based on the amount and intensity of rainfall, a range of annual rainfall years was investigated. Graph C5-5 summarizes the annual high, mid, and low rainfall years and their averages with precipitation totals compared on a monthly basis for the CNV City Hall and Sonora Drive climate stations. Graph C5-6 shows the annual rain hyetographs and cumulative rainfall of the high, low and average rainfall years for CNV City Hall and Sonora Drive climate stations. The high and low hyetographs were used as rainfall inputs in the continuous models to identify the range of highest and lowest EIA values.

6.2 Continuous Simulation Resulting Cumulative Runoff Graphs

Each continuous simulation graph (Graphs C5-7 to C5-8) shows the modelling results of the total annual cumulative runoff of the area upstream of 4 locations along Mackay and Mosquito creeks. Graph C5-7 shows the low rainfall year (2008) and Graph C5-8 shows the high rainfall year (1999). These graphs provide the effective impervious area (EIA) of the contributing catchment and their respective total annual runoff volumes. The EIA percentages are shown on the right hand side of the graphs and represent the fraction of each scenarios annual cumulative total in relation to the total rainfall (100% EIA) and forested predevelopment conditions (0% EIA).

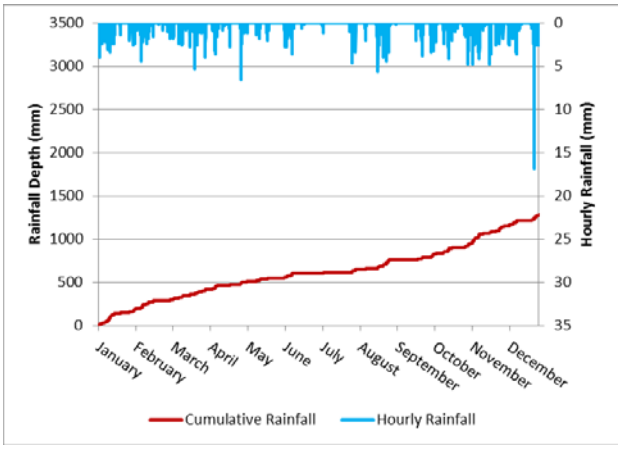


CNV City Hall Station

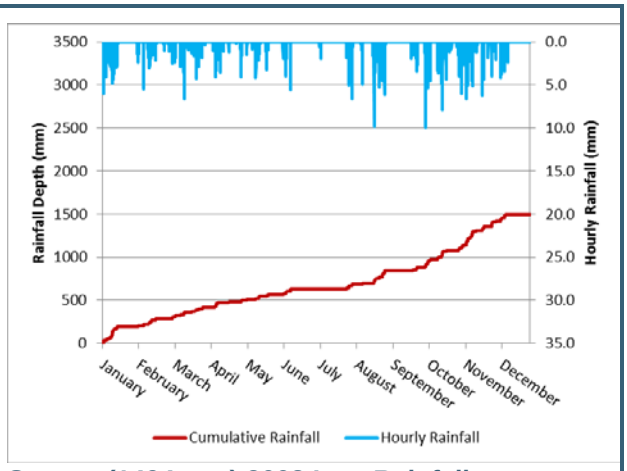


Sonora Station

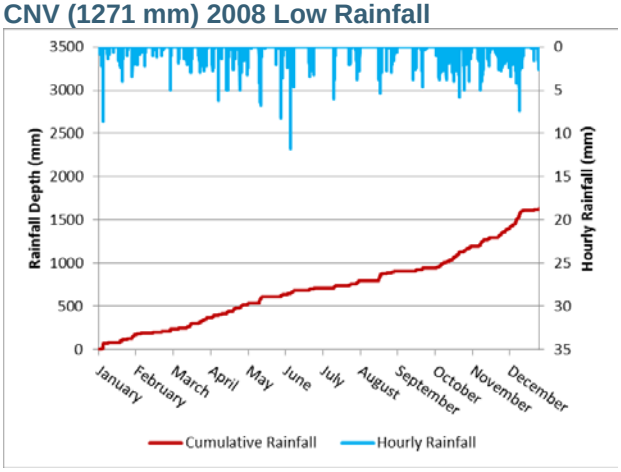
Graph C5-5: Annual Precipitation Comparison for CNV City Hall and Sonora Climate Stations



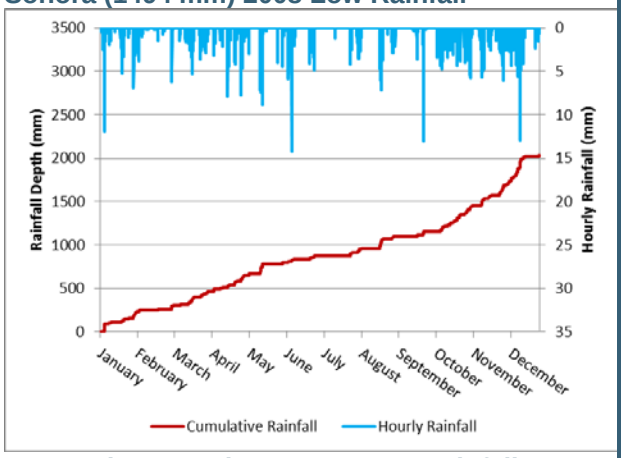
CNV (1271 mm) 2008 Low Rainfall



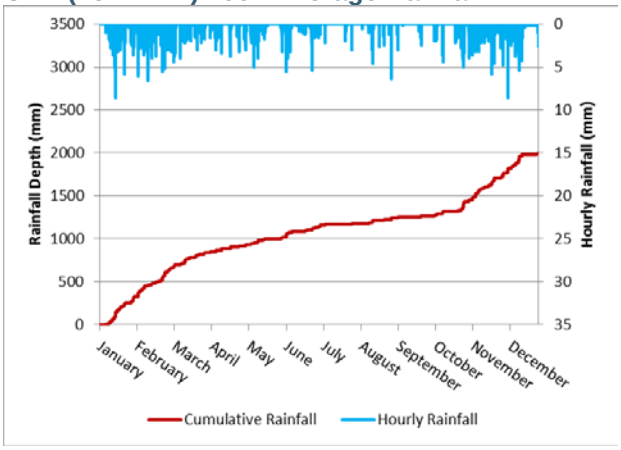
Sonora (1494 mm) 2008 Low Rainfall



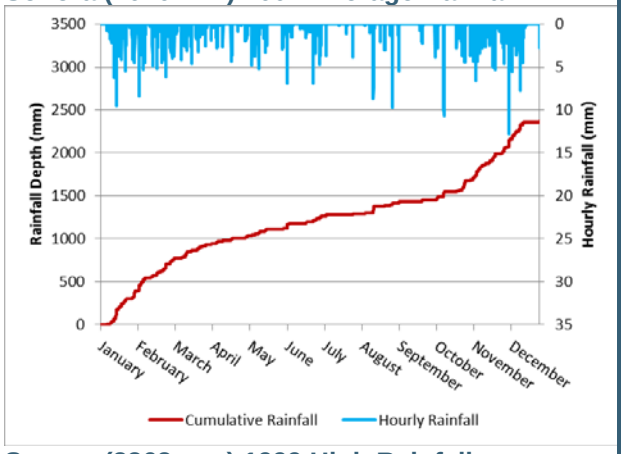
CNV (1627 mm) 2001 Average Rainfall



Sonora (2040 mm) 2001 Average Rainfall

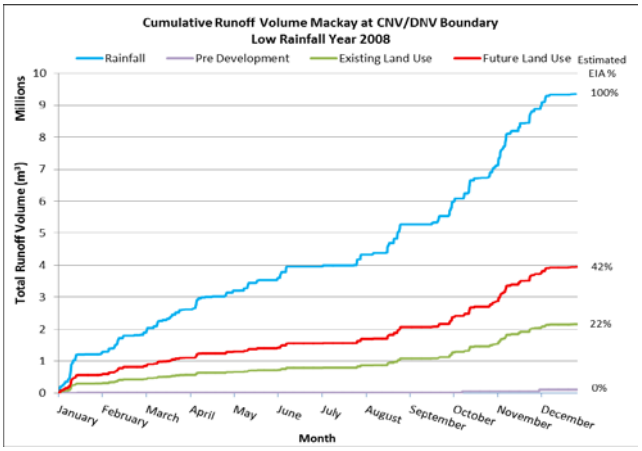


CNV (1988 mm) 1999 High Rainfall

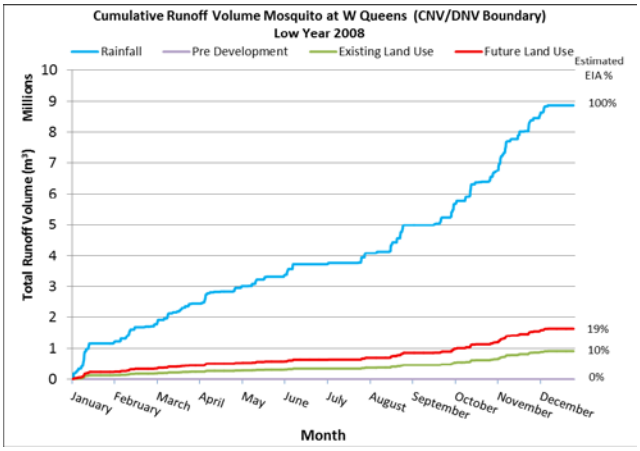


Sonora (2362 mm) 1999 High Rainfall

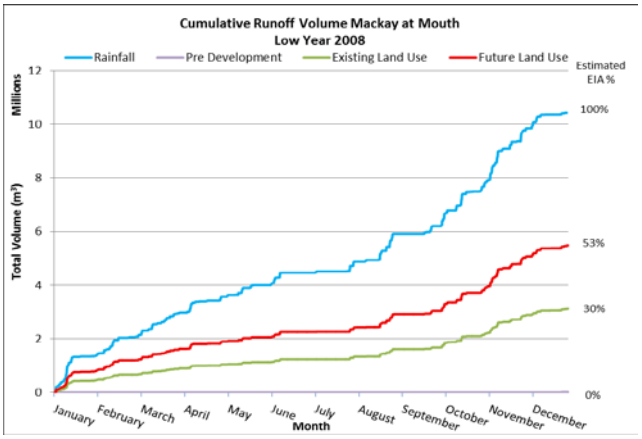
Graph C5-6: Low, Average, High Rainfall Years At CNV and Sonora Climate Stations



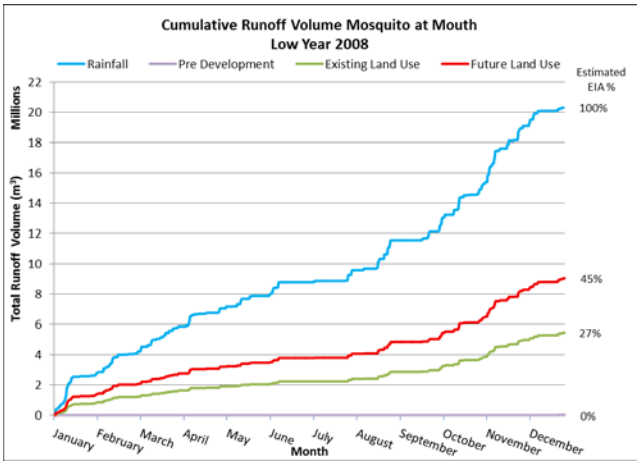
Mackay at CNV/DNV Boundary



Mosquito at CNV/DNV Boundary

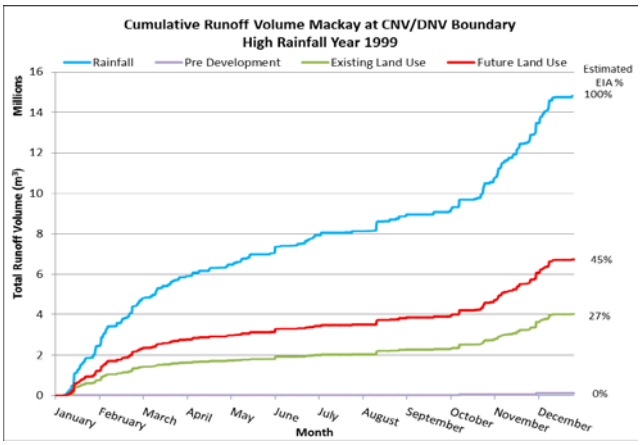


Mackay at Mouth

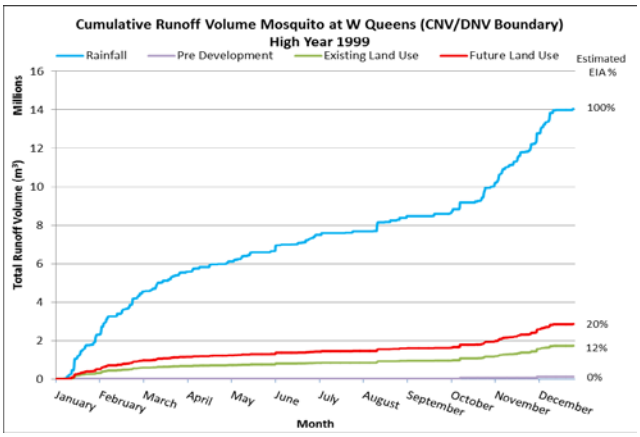


Mosquito at Mouth

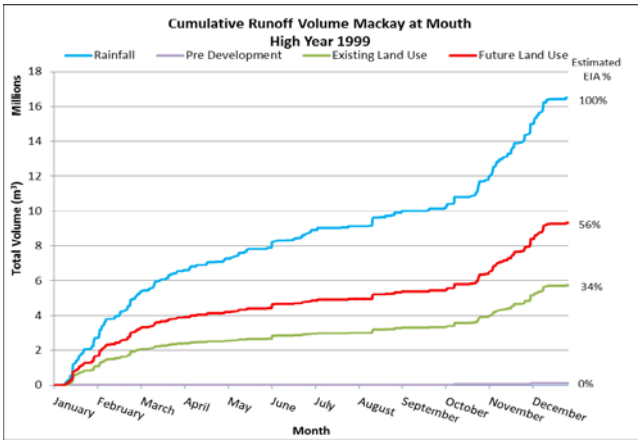
Graph C5-7: Annual Cumulative Runoff Volumes (Low Year) At Various Locations



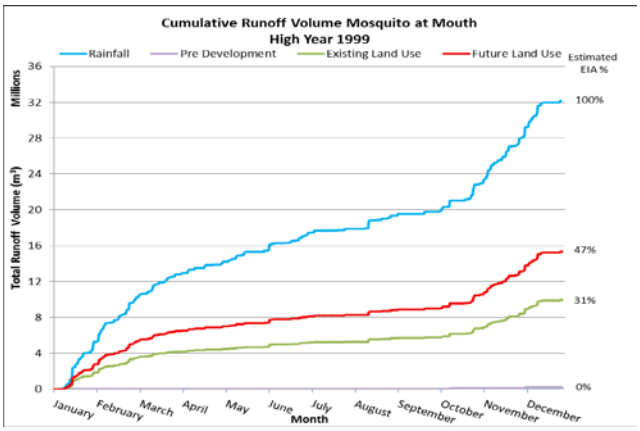
Mackay at CNV/DNV Boundary



Mosquito at CNV/DNV Boundary



Mackay at Mouth



Mosquito at Mouth

Graph C5-8: Annual Cumulative Runoff Volumes (High Year) at Various Locations

6.3 Interpretation of Cumulative Runoff Graphs

In the pre-development scenario model, impervious percentages were all set to 0% TIA, e.g. forested conditions. Even though it is possible to have pervious runoff during heavy storm events, the forested pre-development condition is labelled with EIA of 0%, suggesting no improvement is needed on natural conditions. At the other end of the range, total rainfall volume has an EIA of 100% because that is the total volume of rainfall that could possibly runoff if there was a scenario where the whole catchment was 100% TIA, with no abstractions (depression storage, evaporation).

To calculate existing land use (ELU) EIA and future land use (FLU) EIA, the total ELU or FLU runoff volume is divided by the difference between the rainfall and pre-development volumes and added to the pre-development EIA value.

$$EIA = \frac{Q_x - Q_P}{R - Q_p} \times 100\%$$

Where:

EIA = is the Effective Impervious Area percentage of the land use in question
Q_X = is the annual volume of runoff of the land use in question
Q_P = is the annual volume of runoff of the forested predevelopment case
R = is the annual volume of rainfall (rain multiplied by the catchment area)

The EIA values give a good indication of the runoff response of the catchment, and the difference between ELU and FLU EIA values is a representation of the estimated future hydrologic change if future development is not mitigated. The difference in volume between the ELU and FLU scenarios would be the approximate volume of runoff that would have to be controlled in order to satisfy a plan that proposes no further increases in runoff. Alternatively, if the plan was to also reduce impacts of existing development, source controls would have to accommodate the difference in ELU and FLU runoff volume plus an additional amount to reduce the EIA to lower than ELU conditions.

6.4 Mackay Mosquito EIA Results

Table C5-9 summarizes the estimated TIA & EIA values for the existing and future land use scenarios under the high and low rainfall years, with their averaged values.

Table C5-9: Summary of Estimated EIA values

Location	Existing		Future		Increase in EIA
	TIA	EIA[1]	TIA	EIA[1]	
Mackay at CNV/DNV Border	24%	24% (22% to 27%)	48%	43% (42% to 45%)	+19%
Mosquito at CNV/DNV Border	10%	11% (10% to 12%)	21%	19% (19% to 20%)	+8%
Mackay Outlet	30%	32% (30% to 34%)	55%	54% (53% to 56%)	+22%
Mosquito Outlet	27%	29% (27% to 31%)	47%	46% (45% to 47%)	+17%

1. Average of low and high rainfall year EIA values with the range given in parentheses (low year EIA to high year EIA).

The EIA and TIA values appear to be similar.

6.5 Continuous Simulation EIA and Potential Capture Targets

In order to minimize the impacts of future development / redevelopment (refer to *Compendium 7. Land Use Analysis*, Sections 4, 5, and 6) the increase in volume of runoff from existing to unmitigated future development should be captured and infiltrated and evapo-transpirated. This is can be achieved through **Low Impact Development (LID)** design and implementation of **Source Controls**. EIA should not increase as the watersheds redevelop. Runoff volume and EIA can assist in developing watershed-specific stormwater volume reduction targets.

EIA values converted to minimum stormwater volume reduction targets are summarized in Table C7-10. These targets are watershed averages and targets for individual developments can vary.

Table C7-10: Potential EIA and Volume Capture Targets

	Existing EIA	Future EIA	Target Max. EIA	Target Min. Capture (mm of rain)
Mackay Watershed	32%	55%	32%	28% of 2yr 24hr (19mm below & 28mm above 150m elev.)
Mosquito Watershed	29%	46%	29%	32% of 2yr 24hr (22mm below & 32mm above 150m elev.)

These are minimum targets to maintain watershed health at existing levels. The Mackay Mosquito Watershed ISMP goal is to **enhance** ecological health better than existing conditions. Recommended watershed targets are discussed in *Compendium 7. Land Use Analysis*, Section 7.

7. Summary of Findings and Recommendations

7.1 Findings

Findings from this compendium include:

Model Calibration and Validation

C5-1. Models of the entire study area, including all storm sewers, culverts and major watercourses, were developed using the PCSWMM software.

C5-2. Model calibration/validation was undertaken using seven separate storm events at three flow monitoring locations. An acceptable calibration was achieved with peak flows underestimated in some events and overestimated in others. Groundwater hydrograph shape and total hydrograph volume were also calibrated.

C5-3. The design event peak flow estimates were compared to those in previous studies and were found to be in general agreement with differences that could be explained by the more detailed model used in this study than previously.

Model Scenarios

C5-4. Design event and continuous simulation models were created to simulate predevelopment (forested), existing, and unmitigated future land uses, with and without climate change. Minor (10-year) and major (100-year) design storms were simulated. RCP 4.5 and RCP 8.5 climate change scenarios were simulated. In total, 22 models were created.

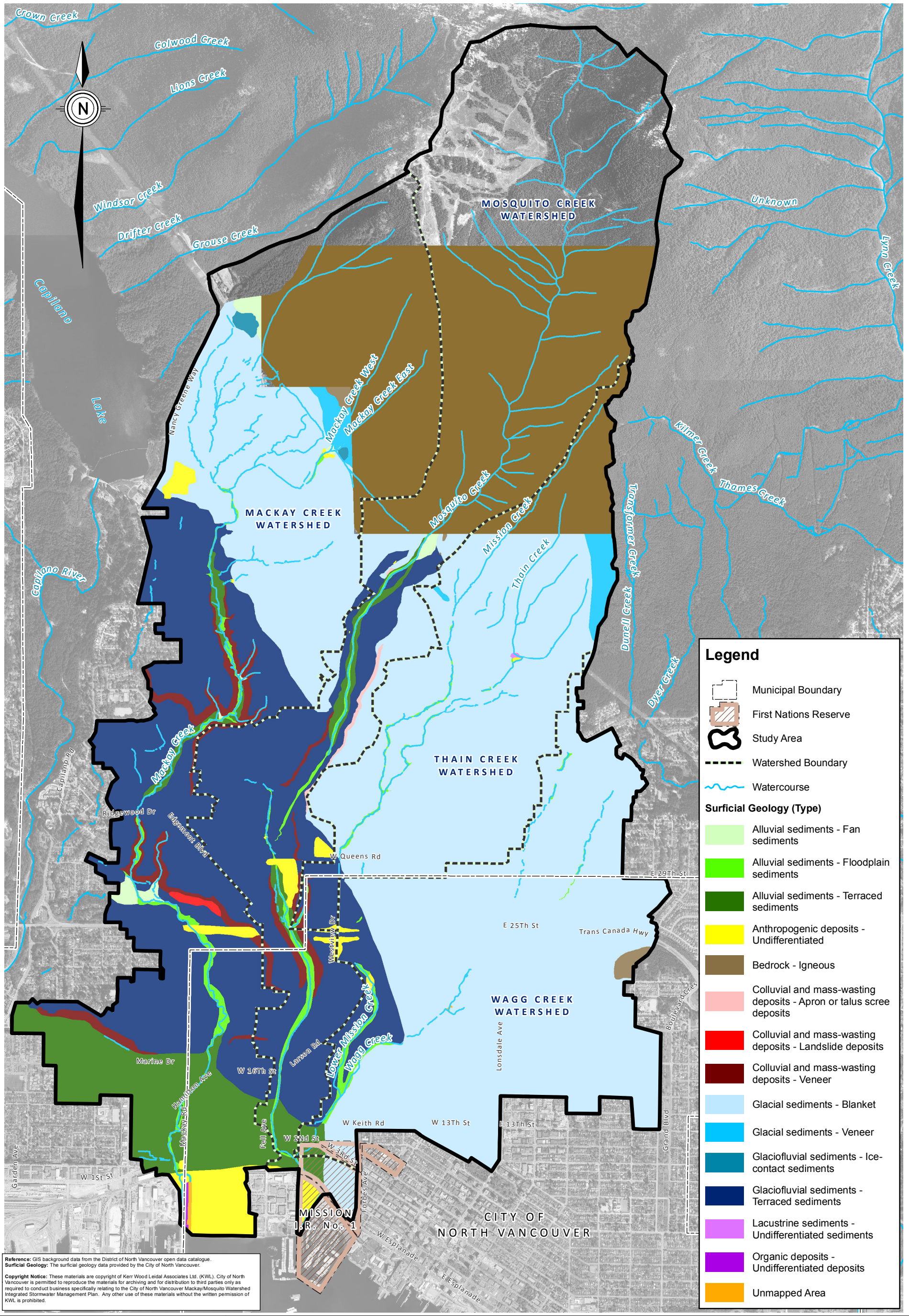
Continuous Simulation Modelling

C5-5. Identified high and low rainfall years continuous simulation models were used to estimate the runoff volume (excluding groundwater and interflow) at key locations. The EIA was then estimated using the runoff volume and the rain volume with the assumption that the predevelopment forested model runoff volume represents a 0% EIA and the total rain represents 100% EIA.

C5-6. Unmitigated future land use is expected to increase EIA by 22% in the Mackay Watershed and by 17% in the Mosquito Watershed compared with TIA estimates of 23% and 19% for Mackay and Mosquito respectively

C5-7. EIA was converted to watershed-specific stormwater volume reduction targets for development/redevelopment aimed to maintain the existing EIA as a minimum to achieve no-net-loss. The overall watershed capture targets are approximately 30% of the 2-year 24-hour rain depth (21mm below and 30mm above 150m elevation).

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Legend

- Municipal Boundary
- First Nations Reserve
- Study Area
- Watershed Boundary
- Watercourse

Surficial Geology (Type)

- Alluvial sediments - Fan sediments
- Alluvial sediments - Floodplain sediments
- Alluvial sediments - Terraced sediments
- Anthropogenic deposits - Undifferentiated
- Bedrock - Igneous
- Colluvial and mass-wasting deposits - Apron or talus scree deposits
- Colluvial and mass-wasting deposits - Landslide deposits
- Colluvial and mass-wasting deposits - Veneer
- Glacial sediments - Blanket
- Glacial sediments - Veneer
- Glaciofluvial sediments - Ice-contact sediments
- Glaciofluvial sediments - Terraced sediments
- Lacustrine sediments - Undifferentiated sediments
- Organic deposits - Undifferentiated deposits
- Unmapped Area

Reference: GIS background data from the District of North Vancouver open data catalogue.
Surficial Geology: The surficial geology data provided by the City of North Vancouver.

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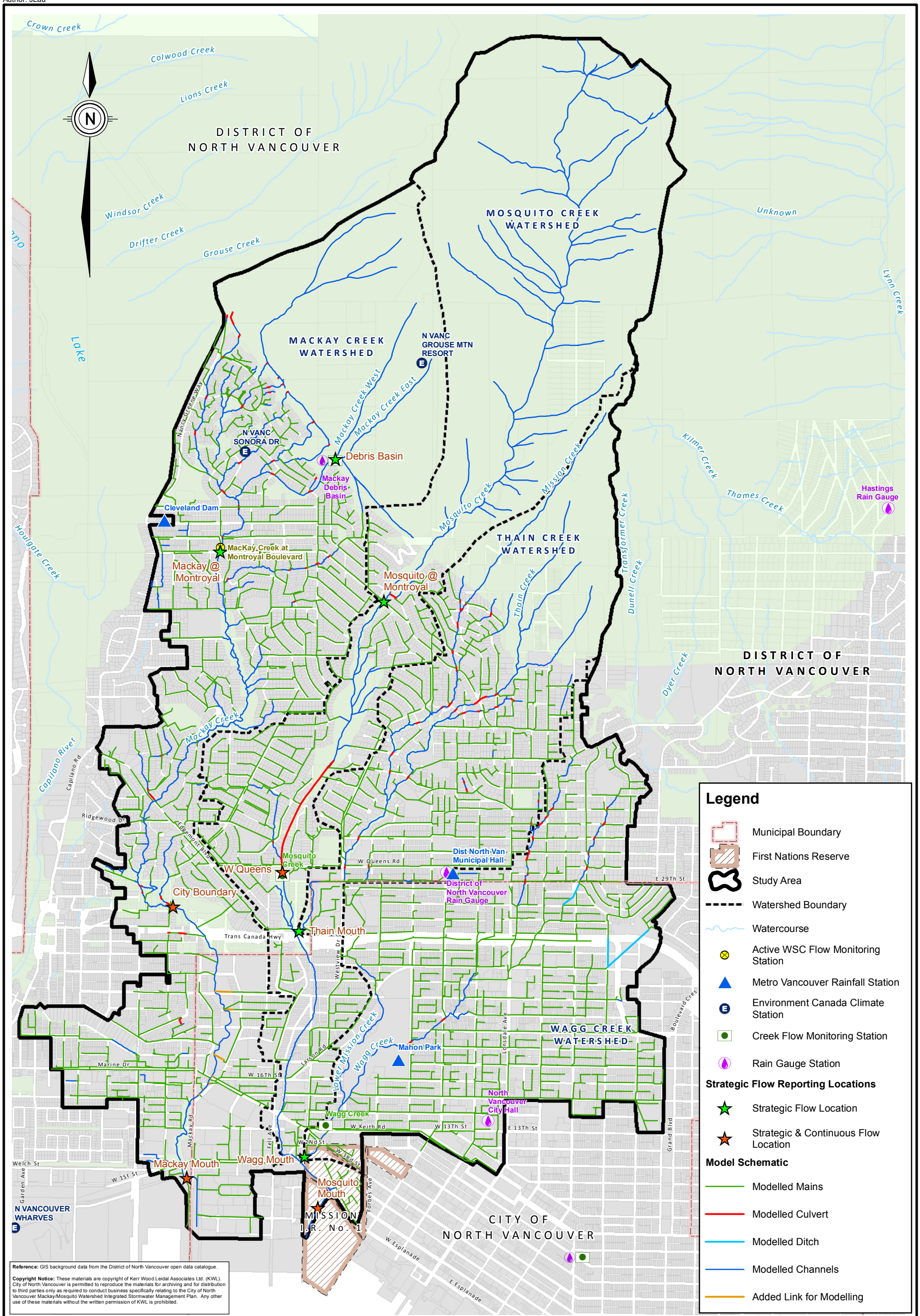
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Surficial Soils

Figure C1-2

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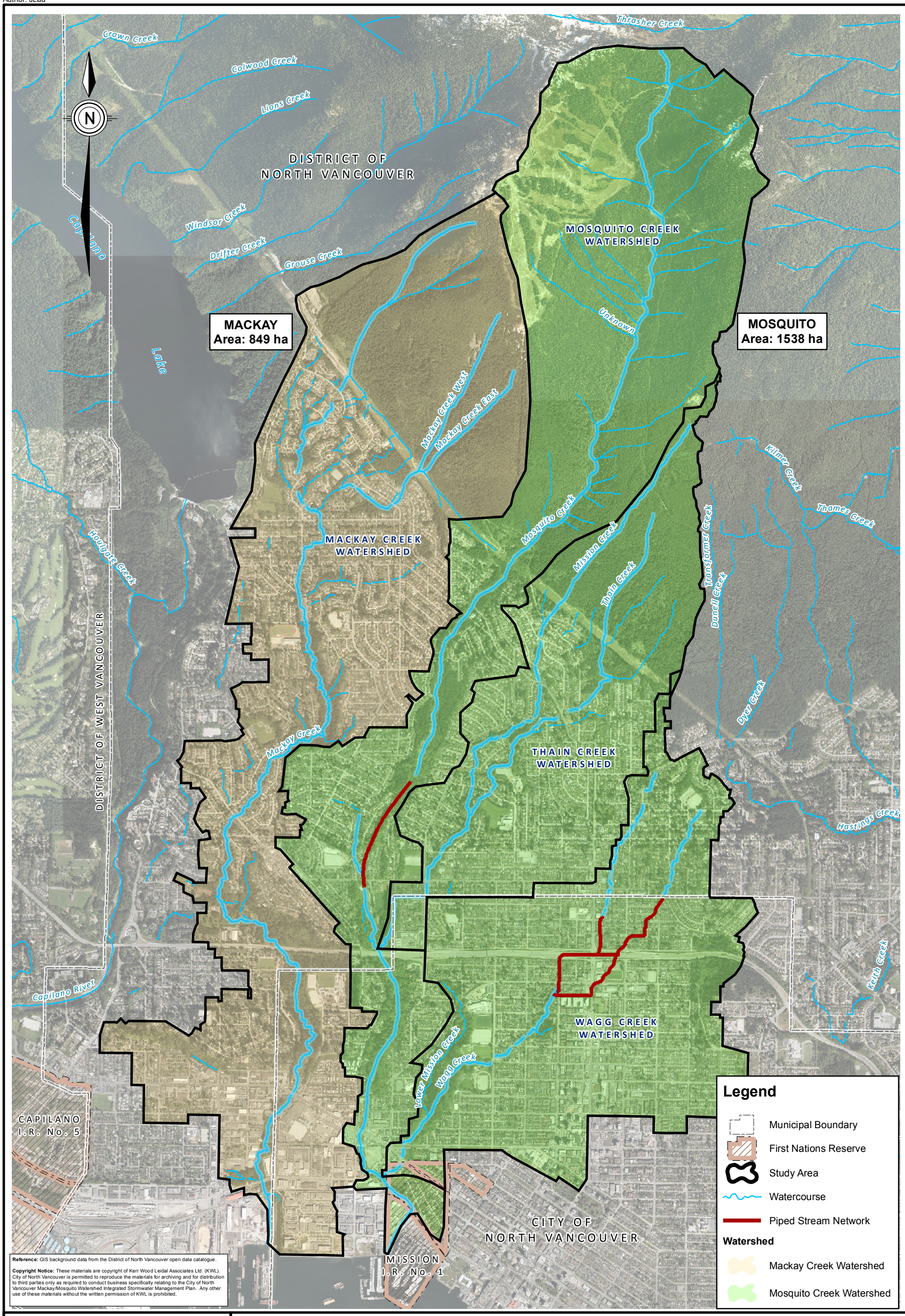
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99-125	December, 2016

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Model Schematic and Strategic Flow Reporting Locations

Figure C5-1

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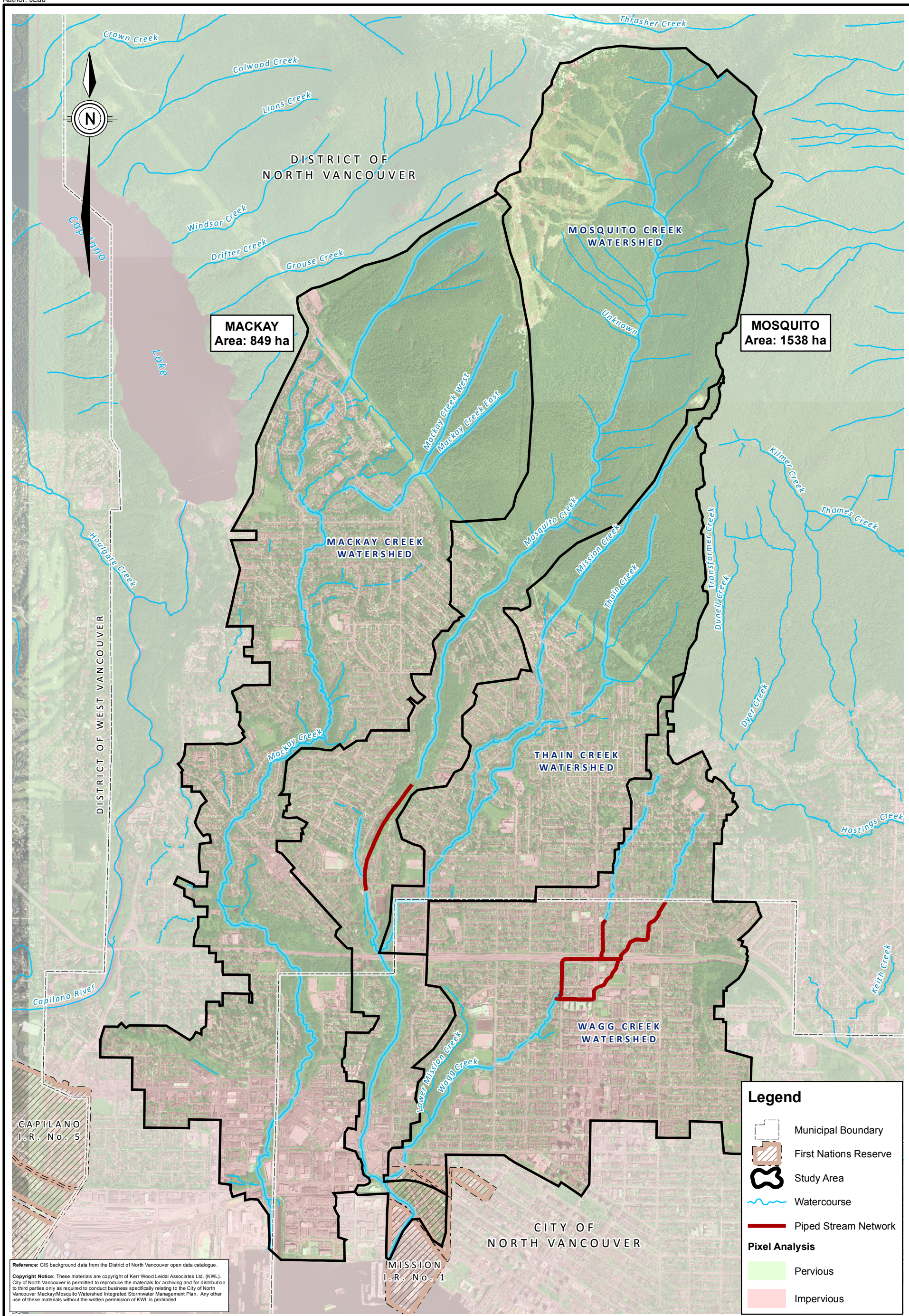
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Mackay & Mosquito Watershed Catchments

Figure C5-2

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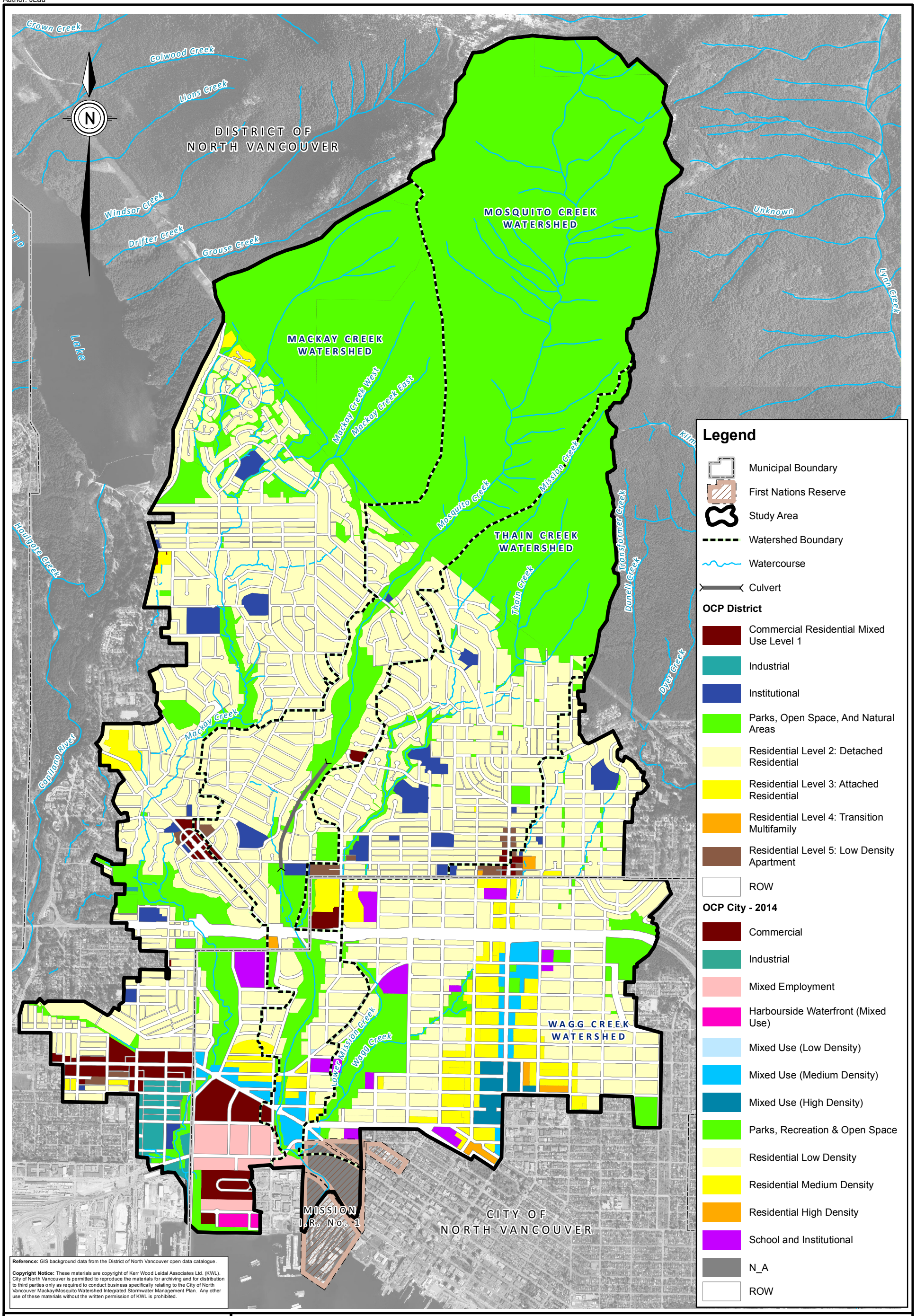
Project No. 99-125
Date December, 2016

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Existing Land Use Imperviousness

Figure C7-2

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City and District of North Vancouver
Mackay/Mosquito Watershed Integrated Stormwater Management Plan

Project No. 99-125
Date December, 2016

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OCP - 2030 Future Land Use

Figure C7-3

Report Submission

KERR WOOD LEIDAL ASSOCIATES LTD.

Prepared by:

Bryce Whitehouse, B.Sc.
Project Hydrologist

Reviewed by:



David Zabil, M.A.Sc., P.Eng.
Technical Reviewer

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Revision History

Revision #	Date	Status	Revision	Author
0	Sept 21, 2020	Final	Issued as final for client copy.	BW/DZ

OQM CERTIFIED



Compendium 6

DRAINAGE ASSESSMENT

Mackay Mosquito Watersheds ISMP

September 2020

Final Report

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Appendices

Capacity Assessment Result Database (GIS database)

Purpose

Compendium 6. Drainage Assessment

This compendium provides detailed information on the PCSWMM model scenarios and capacity assessment results. It also summarizes a recommended upgrade prioritization to address the capacity issues predicted by modelling. It is a supporting document to the *Mackay Mosquito Watershed Integrated Stormwater Management Plan* (ISMP) that was developed by the City of North Vancouver (CNV) and District of North Vancouver (DNV).

Information contained in this compendium includes:

1. Introduction and Purpose of Assessment
2. Model Scenarios and Assessment Criteria
3. Storm Sewer Capacity Assessment
4. Culvert Capacity Assessment
5. Summary of Previous Bridge Assessment
6. Upgrade Prioritization

Refer to other compendiums for additional supporting information.

Mackay Mosquito Watersheds ISMP Compendiums

The following compendiums and their authors support the Mackay Mosquito Watersheds ISMP:

1. Watershed Overview - KWL
2. Instream Species and Water Quality – RAE
3. Riparian Forest & Terrestrial Species – RAE
4. Drainage Asset Inventory - KWL
5. Hydrologic and Hydraulic Modelling - KWL
6. Drainage Assessment - KWL
7. Land-Use Analysis - KWL
8. Municipal Policy and Operations - KWL
9. Watershed Values & Objectives – CNV and DNV
10. Mitigation Measures & Alternatives – KWL, CNV and DNV
11. Mackay/Mosquito Action Plan – KWL, CNV and DNV

Figure and table identification numbering include the first digit related to compendium number and the second digit related to the figure number within the compendium. e.g. Figure C3-1 is the first figure within Compendium 3.

1. Introduction

The primary objective of the hydraulic assessment was to assess the capacity of the existing drainage system to convey the minor and major clear water flows (debris flows were not evaluated in this study) and provide recommendations to address deficiencies and minimize flood risks. Two future land use scenarios are also used to forecast the potential deficiencies to the existing drainage system by taking into account land use changes, densification, and climate change (rainfall volume increase).

PCSWMM hydrologic and hydraulic models were created for the Mackay and Mosquito watersheds for existing and future development land use conditions as described in *Compendium 5.* The methodology and findings of the capacity assessment are summarized in this compendium.

A Capacity Assessment Result Database (GIS database) accompanies the report.

The drainage system components, assessment criteria and results are described below.

1.1 Three Land Use/Climate Change Scenarios

The drainage system capacity is assessed for three scenarios:

1. Existing land use conditions (2010),
2. Unmitigated Future Land Use (OCP 2030); and
3. Unmitigated Future Land Use (OCP 2030) with Climate Change (RCP 8.5).

The system capacity assessment only considers the effect of climate change on rainfall. Sea level rise is not included in this analysis. Impacts of climate change on coastal flooding and the floodplains were examined in a separate CNV-DNV study entitled *Creek Hydrology, Floodplain Mapping and Bridge Hydraulic Assessment Study (KWL, 2014).*

1.2 Major and Minor System Definitions

Components of the drainage network are categorized as follows.

Overland Drainage Paths – Major System

In the event of a major storm (100-year return period), it is expected that water in the storm sewers surcharges and likely flows out of the catch basins at ground level (or runoff may not even be able to enter the pipes due to capacity limitations of inlets). The stormwater that reaches the surface (or stays on the surface) is then carried overland via the overland paths (e.g. street curb & gutter) following the topography of the area until it enters a receiving watercourse or major system pipe. This is not considered “flooding” as long as the gutter flow is contained in safe overland flow paths designed to convey the major flows. Flooding occurs if flows leave the safe overland flow path and enter public and private property or buildings.

Major Storm Sewers – Major System

In this assessment, the major drainage system is defined as:

- storm sewer trunks 750 mm diameter or larger,
- storm sewers smaller than 750 mm diameter without a safe overland flow route (low sags in road or pipes through private property).

These storm sewers convey the major flows, including the flows from the upstream minor system and the overland flows that enter the major storm sewers at major flow inlets. The size and importance of storm sewer trunks, potentially carrying much higher flows than the minor system, justify the requirement for assessment as part of the major drainage system for 100-year flows.

Creeks – Major System

In this assessment, the major drainage system also includes creek channels and the culverts and bridges located in creeks. Culverts in creeks were assessed for 200-year clear water flows.

Minor System

The minor drainage system is defined as storm sewers less than 750 mm diameter that are not part of the major drainage system as defined above. The minor system is expected to convey flows up to and including the 10-year return period design storm without surcharging.

1.3 Drainage Capacity Assessment Criteria

The drainage system was assessed with the following criteria:

- minor storm sewers - 10-year return period storms.
- major storm sewers - 100-year return period storms.

Both short term (6-hour) and long term (24-hour) duration storms were assessed, and the highest peak flow governed.

- Creek culverts - 200-year clear water flows. .

A systematic method for assessing the drainage system was developed for both the major and minor drainage systems to identify deficiencies and upgrade needs. Storm sewers were assessed on conveyance capacity and height and time of surcharging. A tolerance for brief surcharging was added to the criteria (longer than 15 minutes) to avoid flagging storm sewers as undersized due to flow spikes and/or minor model instabilities. This surcharge allowance was not permitted for culverts due to the risk of debris blockage if water levels exceed the crown of culverts.

The modelling results are assessed with the criteria listed below and presented in Figures C6-1 to C6-4.

Each storm sewer segment and culvert is categorized and colour coded based on the following criteria:

- Green = No Capacity Issues (design flow <80% of full pipe capacity and no surcharging)
- Yellow = Design flow between 80% - 100% of full pipe capacity and no surcharging
- Orange = Design flow greater than 100% of full pipe capacity but no significant surcharging
- Red = > 100% capacity (and higher than 30 cm surcharging for longer than 15 minutes for storm sewers only).
- Purple = Steep pipes with design flows less than 100% of full pipe capacity (Manning's formula) but surcharging higher than 30 cm and longer than 15 minutes. It is unclear whether the surcharging is caused by backwater or by inlet capacity which is likely smaller than Manning's formula capacity for steep pipes. It is recommended that these pipes be manually checked by CNV/DNV prior to any further action or upgrading.

2. Capacity Assessment Results

The findings of the capacity assessment are summarized in this section. Undersized storm sewer and culverts refers to pipes that **surcharge** higher than 30 cm above the crown of the pipe and for longer than 15 minutes and culverts with a q/Q > 1.0 and no surcharge allowance (i.e. the pipes/culverts coded red in Figures C6-1A to C6-4F). Results are depicted as follows:

- Figures C6-1A to D - existing land use model results showing undersized minor and major storm sewers/culverts and duration of surface flooding at manholes/nodes
- Figures C6-2A to F - 10-year storm sewer assessment for all three scenarios
- Figures C6-3A to F - 100-year storm sewer assessment for all three scenarios
- Figures C6-4A to F - 200-year culvert assessment for all three scenarios

2.1 Storm Sewer Assessment Results

Table C6-1 summarizes the assessment findings in terms of length of undersized pipes in each scenario broken down by municipality.

Table C6-1: Storm Sewer Capacity Assessment - Summary of Undersized Pipes by Municipality

Municipality	100 year Major		10 year Minor	
	Length Undersized (m)	% of Total System Undersized	Length Undersized (m)	% of Total System Undersized
Existing Land Use				
DNV	2,773	1.9%	20,095	14.4%
CNV	5,424	9.8%	12,046	21.9%
Future Land Use				
DNV	3,128	2.2%	22,994	16.4%
CNV	5,469	9.9%	13,385	24.3%
Future Land Use and RCP 8.5 Climate Change				
DNV	6,748	4.8%	28,496	20.3%
CNV	7,461	13.5%	28,427	51.7%

Note: % of Total System Undersized was calculated as (Total Length Undersized ÷ Total Length)
Total Length is 140km in DNV and 55km in CNV.

Table C6-2 summarizes more detail, such as length and percentage of each size of storm sewer pipe that is currently undersized in Mackay and Mosquito watersheds separately, and pipes that would be undersized in the future land use scenario and future RCP 8.5 climate change scenario.

Table C6-2: Percentage of Undersized Storm Sewers by Size, Municipality, and Watershed

Municipality	Pipe Size (mm)	Total Length (m)	% of Total System	Existing Land Use Scenario				Future Land Use Scenario				Future Land Use Scenario with RCP 8.5			
				100yr Major		10yr Minor		100yr Major		10yr Minor		100yr Major		10yr Minor	
				Length Under Capacity (m)	% of Total System Under Capacity	Length Under Capacity (m)	% of Total System Under Capacity	Length Under Capacity (m)	% of Total System Under Capacity	Length Under Capacity (m)	% of Total System Under Capacity	Length Under Capacity (m)	% of Total System Under Capacity	Length Under Capacity (m)	% of Total System Under Capacity
Mackay Watershed															
DNV	< 200	1,078	1.7%	0	0.0%	108	0.2%	0	0.0%	138	0.2%	0	0.0%	318	0.5%
	200	8,260	13.0%	0	0.0%	1,263	2.0%	0	0.0%	1,350	2.1%	0	0.0%	2,406	3.8%
	250	15,244	23.9%	75	0.1%	2,014	3.2%	75	0.1%	2,283	3.6%	158	0.2%	4,263	6.7%
	300	13,153	20.6%	39	0.1%	2,034	3.2%	46	0.1%	2,288	3.6%	141	0.2%	3,614	5.7%
	375	8,016	12.6%	246	0.4%	1,289	2.0%	246	0.4%	1,570	2.5%	380	0.6%	2,312	3.6%
	450	5,659	8.9%	129	0.2%	670	1.1%	129	0.2%	762	1.2%	312	0.5%	1,522	2.4%
	525	2,912	4.6%	220	0.3%	370	0.6%	333	0.5%	370	0.6%	437	0.7%	370	0.6%
	600	4,030	6.3%	153	0.2%	544	0.9%	153	0.2%	544	0.9%	153	0.2%	805	1.3%
	675	293	0.5%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	750	2,626	4.1%	607	1.0%	0	0.0%	607	1.0%	0	0.0%	1,272	2.0%	0	0.0%
	900	1,530	2.4%	318	0.5%	0	0.0%	318	0.5%	0	0.0%	750	1.2%	0	0.0%
	1050	206	0.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	140	0.2%	0	0.0%
	1200	550	0.9%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	156	0.2%	0	0.0%
	>1200	161	0.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	Total	**63,717**	**100.0%**	**1,787**	**2.8%**	**8,292**	**13.0%**	**1,906**	**3.0%**	**9,305**	**14.6%**	**3,899**	**6.1%**	**15,611**	**24.5%**
CNV	200	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	250	1,635	23.0%	0	0.0%	584	0.9%	0	0.0%	666	1.0%	0	0.0%	908	1.4%
	300	1,695	23.9%	0	0.0%	465	0.7%	0	0.0%	669	1.1%	0	0.0%	1,035	1.6%
	375	588	8.3%	0	0.0%	4	0.0%	0	0.0%	21	0.0%	0	0.0%	347	0.5%
	450	818	11.5%	0	0.0%	207	0.3%	0	0.0%	218	0.3%	0	0.0%	387	0.6%
	525	234	3.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	600	558	7.9%	0	0.0%	77	0.1%	0	0.0%	77	0.1%	0	0.0%	77	0.1%
	675	525	7.4%	0	0.0%	125	0.2%	0	0.0%	125	0.2%	0	0.0%	240	0.4%
	750	467	6.6%	100	0.2%	0	0.0%	100	0.2%	0	0.0%	137	0.2%	0	0.0%
	900	227	3.2%	2	0.0%	0	0.0%	2	0.0%	0	0.0%	227	0.4%	0	0.0%
	1050	91	1.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	91	0.1%	0	0.0%
	1200	164	2.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	147	0.2%	0	0.0%
	>1200	97	1.4%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	97	0.2%	0	0.0%
	Total	**7,098**	**100.0%**	**102**	**1.4%**	**1,461**	**20.6%**	**102**	**1.4%**	**1,776**	**25.0%**	**699**	**9.8%**	**2,993**	**42.2%**
Mackay Watershed Total		**70,816**	**36.1%**	**1,889**	**2.7%**	**9,754**	**13.8%**	**2,008**	**2.8%**	**11,081**	**15.6%**	**4,599**	**6.5%**	**18,605**	**26.3%**

bold highlighting = increased # of storm sewers from previous scenario

Table C6-2: Percentage of Undersized Storm Sewers by Size, Municipality, and Watershed

Municipality	Pipe Size (mm)	Total Length (m)	% of Total System	Existing Land Use Scenario				Future Land Use Scenario				Future Land Use Scenario with RCP 8.5			
				100yr Major		10yr Minor		100yr Major		10yr Minor		100yr Major		10yr Minor	
				Length Under Capacity (m)	% of Total System Under Capacity	Length Under Capacity (m)	% of Total System Under Capacity	Length Under Capacity (m)	% of Total System Under Capacity	Length Under Capacity (m)	% of Total System Under Capacity	Length Under Capacity (m)	% of Total System Under Capacity	Length Under Capacity (m)	% of Total System Under Capacity
Mosquito Watershed															
DNV	< 200	2,502	3.3%	0	0.0%	940	1.5%	0	0.0%	1,226	1.9%	0	0.0%	864	1.4%
	200	17,948	23.3%	0	0.0%	3,967	6.2%	0	0.0%	4,535	7.1%	12	0.0%	2,844	4.5%
	250	17,564	22.8%	77	0.1%	2,555	4.0%	77	0.1%	2,789	4.4%	77	0.1%	3,678	5.8%
	300	12,116	15.8%	12	0.0%	1,622	2.5%	17	0.0%	2,053	3.2%	116	0.2%	2,385	3.7%
	375	8,462	11.0%	204	0.3%	1,010	1.6%	436	0.7%	1,320	2.1%	571	0.9%	1,320	2.1%
	400	44	0.1%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	450	6,053	7.9%	260	0.4%	870	1.4%	260	0.4%	927	1.5%	360	0.6%	927	1.5%
	525	3,204	4.2%	0	0.0%	525	0.8%	0	0.0%	525	0.8%	179	0.3%	525	0.8%
	600	4,426	5.8%	344	0.5%	307	0.5%	344	0.5%	307	0.5%	1,035	1.6%	307	0.5%
	675	167	0.2%	0	0.0%	8	0.0%	0	0.0%	8	0.0%	0	0.0%	36	0.1%
	750	1,037	1.3%	23	0.0%	0	0.0%	23	0.0%	0	0.0%	412	0.6%	0	0.0%
	900	2,135	2.8%	36	0.1%	0	0.0%	36	0.1%	0	0.0%	58	0.1%	0	0.0%
	915	274	0.4%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	1050	380	0.5%	29	0.0%	0	0.0%	29	0.0%	0	0.0%	29	0.0%	0	0.0%
	1200	235	0.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	>1200	328	0.4%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	Total	**76,876**	**100.0%**	**986**	**1.3%**	**11,803**	**15.4%**	**1,222**	**1.6%**	**13,689**	**17.8%**	**2,849**	**3.7%**	**12,885**	**16.8%**
CNV	< 200	2,568	5.3%	0	0%	826	1.3%	0	0.0%	0	0.0%	0	0.0%	1,726	2.7%
	200	13,385	27.7%	141	0.2%	3,402	5.3%	141	0.2%	4,153	6.5%	195	0.3%	9,943	15.6%
	250	9,641	20.0%	235	0.4%	3,036	4.8%	235	0.4%	3,271	5.1%	343	0.5%	6,173	9.7%
	300	5,024	10.4%	156	0.2%	1,167	1.8%	156	0.2%	1,350	2.1%	274	0.4%	2,309	3.6%
	375	4,664	9.7%	179	0.3%	1,113	1.7%	179	0.3%	1,488	2.3%	179	0.3%	2,142	3.4%
	400	141	0.3%	0	0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	13	0.0%
	450	3,987	8.3%	368	0.6%	560	0.9%	368	0.6%	675	1.1%	819	1.3%	1,761	2.8%
	525	1,758	3.6%	416	0.7%	235	0.4%	425	0.7%	240	0.4%	435	0.7%	630	1.0%
	600	1,339	2.8%	196	0.3%	246	0.4%	196	0.3%	432	0.7%	208	0.3%	737	1.2%
	675	140	0.3%	0	0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	750	880	1.8%	746	1.2%	0	0.0%	783	1.2%	0	0.0%	896	1.4%	0	0.0%
	900	2,987	6.2%	2,372	3.7%	0	0.0%	2,372	3.7%	0	0.0%	2,741	4.3%	0	0.0%
	915	17	0.0%	240	0%	0	0.0%	240	0.4%	0	0.0%	247	0.4%	0	0.0%
	1050	1,084	2.2%	106	0.2%	0	0.0%	106	0.2%	0	0.0%	241	0.4%	0	0.0%
	1200	345	0.7%	0	0%	0	0.0%	0	0.0%	0	0.0%	17	0.0%	0	0.0%
	>1200	315	0.7%	168	0.3%	0	0.0%	168	0.3%	0	0.0%	168	0.3%	0	0.0%
	Total	**48,274**	**100.0%**	**5,322**	**11.0%**	**10,585**	**21.9%**	**5,367**	**11.1%**	**11,609**	**24.0%**	**6,762**	**14.0%**	**25,434**	**52.7%**
Mosquito Watershed Total		**125,150**	**63.9%**	**6,307**	**5.0%**	**22,388**	**17.9%**	**6,590**	**5.3%**	**25,297**	**20.2%**	**9,611**	**7.7%**	**38,320**	**30.6%**
Mackay + Mosquito Totals		**195,966**	**100.0%**	**8,197**	**4.2%**	**32,141**	**16.4%**	**8,598**	**4.4%**	**36,378**	**18.6%**	**14,210**	**7.3%**	**56,924**	**29.0%**

Note: Only pipes that are classified as RED (q/Q > 1 AND h/D > 1 AND Surcharging > 15 mins AND > 0.3 m) in the Pipe vs Diameter assement are summarized in this table and Figures F-1 to F-12
Criteria for under capacity: surcharging exceeds 15 mins and 0.3 m

bold highlighting = increased # of storm sewers from previous scenario

2.2 Culvert Capacity Assessment

Culverts on the modelled main creeks and tributaries were assessed for 200-year clear water peak flow conveyance. Tables C6-3 and C6-4 provide a summary of the capacity assessment results for each scenario broken down by municipality and number and percentage of culverts that are undersized in the existing land use scenario, in the future land use scenario, and in the future land use with RCP 8.5 climate change scenario.

Table C6-3: Culvert Assessment Summary by Municipality

Municipality	Existing Land Use		Future Land Use		Future Land Use with RCP 8.5	
	# Undersized	% of Total System Undersized	# Undersized	% of Total System Undersized	# Undersized	% of Total System Undersized
DNV	73	65.8%	76	68.5%	85	76.6%
CNV	52	64.2%	53	65.4%	57	70.4%

Note: % of Total System Undersized was calculated as (Total number Undersized ÷ Total Number of Culverts)
Total Number of Culverts is 111 in DNV and 79 in CNV

Refer to Figures C6-4A to F - 200-year Culvert Assessment for all three scenarios.

This assessment is based on clear water peak flow conveyance. The creek culvert sizing should be revisited with the results of the *Debris Geohazard Risk and Risk Control Assessment* BGC, 2017) study. Debris flows and floods may govern culvert sizing. Costs for culvert upgrades have not been included because sizing may change.

2.3 Summary of Previous Bridge Capacity Assessment

Bridges along Mackay and Mosquito creeks were assessed in a previous *Creek Hydrology, Floodplain Mapping and Bridge Hydraulic Assessment (KWL, 2014)* study. It found that all Mackay Creek crossings are substantially undersized; and Mosquito Creek had several issues:

- Mosquito Park footbridge crossing was marginally undersized,
- marginal head-watering at Marine Drive,
- head-watering for the Bewicke Avenue, and
- all downstream crossings under a high tide scenario.

The 2014 report did not make any recommendation for bridge upgrades. Given the flood control works being planned for Mackay Creek, any bridge upgrades need to take those works into consideration. A preliminary design should be undertaken for the above bridges that will include the findings from the *Debris Geohazard Risk and Risk Control Assessment* (BGC, 2017) study and the effects of flood control/containment to estimate the design flows to be conveyed under each bridge.

Table C6-4: Culvert Assessment Summary by Culvert Size, Watershed, and Municipality

Muncipality	Size (mm)	Total Number	% of Total System	Existing Land Use Scenario		Future Land Use Scenario		Future Land Use Scenario with RCP 8.5	
				Number Under Capacity	% of Total System Under Capacity	Number Under Capacity	% of Total System Under Capacity	Number Under Capacity	% of Total System Under Capacity
Mackay Watershed									
DNV	300	1	2%	1	2%	1	2%	1	2%
	375	3	6%	2	4%	2	4%	2	4%
	450	3	6%	3	6%	3	6%	3	6%
	525	2	4%	2	4%	2	4%	2	4%
	600	7	14%	5	10%	5	10%	5	10%
	675	1	2%	0	0%	0	0%	1	2%
	750	1	2%	0	0%	0	0%	0	0%
	900	15	31%	11	22%	11	22%	11	22%
	1050	2	4%	1	2%	1	2%	1	2%
	1200	4	8%	3	6%	3	6%	3	6%
	1350	1	2%	0	0%	0	0%	0	0%
	1800	1	2%	1	2%	1	2%	1	2%
	>2000	2	4%	0	0%	0	0%	0	0%
	Boxed	6	12%	2	4%	3	6%	3	6%
	Total	**49**	**100%**	**31**	**63%**	**32**	**65%**	**33**	**67%**
CNV	Boxed	1	100%	0	0%	0	0%	0	0%
	Total	**1**	**100%**	**0**	**0%**	**0**	**0%**	**0**	**0%**
Mackay Watershed Total		**50**	**100%**	**31**	**62%**	**32**	**64%**	**33**	**66%**

Notes: All culverts assessed with 200-year return period flow estimates.

Criteria for under capacity: surcharging exceeds 15 mins and 0.3 m

bold highlighting = increased # of culverts from previous scenario

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Table C6-4: Culvert Assessment Summary by Culvert Size, Watershed, and Municipality

Muncipality	Size (mm)	Total Number	% of Total System	Existing Land Use Scenario		Future Land Use Scenario		Future Land Use Scenario with RCP 8.5	
				Number Under Capacity	% of Total System Under Capacity	Number Under Capacity	% of Total System Under Capacity	Number Under Capacity	% of Total System Under Capacity
Mosquito Watershed									
DNV	250	2	3%	2	4%	2	4%	2	4%
	300	1	2%	1	2%	1	2%	1	2%
	375	0	0%	0	0%	0	0%	0	0%
	450	1	2%	0	0%	0	0%	1	2%
	600	2	3%	1	2%	1	2%	**1**	**2%**
	750	3	5%	3	6%	3	6%	3	6%
	900	17	27%	8	16%	8	16%	**12**	**24%**
	1050	9	15%	7	14%	7	14%	**8**	**16%**
	1200	13	21%	11	22%	11	22%	11	22%
	1350	2	3%	2	4%	2	4%	2	4%
	1500	2	3%	2	4%	2	4%	2	4%
	1800	3	5%	1	2%	1	2%	**3**	**6%**
	2000	1	2%	0	0%	**1**	**2%**	1	2%
	>2000	1	2%	1	2%	1	2%	1	2%
	Boxed	5	8%	3	6%	**4**	**8%**	4	8%
	Total	**62**	**100%**	**42**	**68%**	**44**	**71%**	**52**	**84%**
CNV	250	2	3%	2	4%	2	4%	2	4%
	750	19	24%	18	37%	**19**	**39%**	19	39%
	900	26	33%	19	39%	19	39%	**22**	**45%**
	1050	6	8%	4	8%	4	8%	4	8%
	1200	15	19%	5	10%	5	10%	**6**	**12%**
	1350	0	0%	0	0%	0	0%	0	0%
	1500	4	5%	3	6%	3	6%	3	6%
	>2000	1	1%	0	0%	0	0%	0	0%
	Boxed	5	6%	1	2%	1	2%	1	2%
	Total	**78**	**100%**	**52**	**67%**	**53**	**68%**	**57**	**73%**
Mosquito Watershed Total		**140**	**100%**	**94**	**67%**	**97**	**69%**	**109**	**78%**
Mackay + Mosquito Totals		**190**	**100%**	**125**	**66%**	**129**	**68%**	**142**	**75%**

Notes: All culverts assessed with 200-year return period flow estimates.

Criteria for under capacity: surcharging exceeds 15 mins and 0.3 m

bold highlighting = increased # of culverts from previous scenario

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2.4 Upgrade Prioritization

With the assessment of the overall drainage system, the following storm sewers and culverts were identified as undersized:

Table C6-5: Summary of Undersized Storm Sewers and Culverts

Scenario	Undersized		
	Minor System	Major System	
	Storm Sewers	Storm Sewers	Culverts
Existing land use	32 km (16% of whole system)	8 km (4% of whole system)	125 culverts (66% of all culverts)
Future land use	36 km (19% of whole system)	9 km (4% of whole system)	129 culverts (68% of all culverts)
Future land use with climate change	57 km (29% of whole system)	14 km (7% of whole system)	142 culverts (75% of all culverts)
Refer to: Figures C6-2A to F - 10-year storm sewer assessment for all three scenarios Figures C6-3A to F - 100-year storm sewer assessment for all three scenarios Figures C6-4A to F - 200-year Culvert Assessment for all three scenarios.			

Identified undersized pipes and culverts were prioritized into the following five categories:

- **Priority 1 Upgrades**: Major system (Culverts and Storm Sewers) with design flows >100% of pipe full flow capacity under existing land use. The upgrade sizes are based on future land use with RCP 8.5 climate change 100-year peak flow. CNV and DNV indicated that new **culverts** or replacement culverts should be sized for 80% full at the design flow.
- **Priority 2 Upgrades**: Minor system with design flows >100% of pipe full flow capacity under existing land use AND require 2 or more pipe diameter upgrades to convey future land use with RCP 8.5 climate change peak flow.
- **Priority 3 upgrades**: Minor system with design flows >100% of pipe full flow capacity under existing land use AND only require one pipe diameter upgrade to convey future land use with RCP 8.5 climate change peak flow.
- **Priority 4 upgrades**: (DCC's). Culverts and storm sewers that are undersized in the future land use without climate change scenario but adequate for existing land use flows. The upgrade sizes are based on future land use with RCP 8.5 climate change peak flow.
- **Priority 5 upgrades**: (Climate Change Upgrades). Pipes that are undersized only in the future land use with RCP 8.5 climate change scenario.

Storm sewers that did not fail under the existing land use conditions modelling but failed under future land use conditions modelling are categorized as Development Cost Charge (DCC) upgrades and would not need to be upgraded at this time. These storm sewers should only be upgraded at the time of development or when redevelopment occurs in the same vicinity or in tributary areas. Storm sewers that did not fail under the existing conditions modelling or the future conditions modelling but failed under future land use with climate change conditions modelling are categorized as climate change upgrades. These storm sewer upgrades are considered long-term, beyond the 20-year capital upgrades plan as the predicted climate change effects will not occur immediately.

Pipes that fall under the first four categories are identified for upgrades.

A recommended upgrade implementation plan was not produced to allow flexibility for municipal staff to choose projects to be undertaken from year to year given annual budgets. When choosing projects, the preference would be to complete the Priority 1 upgrades first and then Priority 2 projects. Priority 3 projects can likely be put off until the end of asset life. Figures C6-5A and C6-5B show the prioritized upgrades in plan view for the upper and lower watershed areas. The individual pipes along with their recommended sizes are listed in the GIS database described in the next section.

2.5 Capacity Assessment Result Database

The model results for all three scenarios (existing land use, future land use, future land use with RCP 8.5 climate change) are summarized in a GIS database. For each modelled pipe/culvert, the following information is included in the database:

- Existing pipe capacity.
- Peak flow/pipe capacity (q/Q) for each scenario.
- Recommended pipe size for future land use with RCP 8.5 climate change conveyance.
- Class D cost estimates for storm sewer upgrades.
- Upgrade priority (see previous section)

The Capacity Assessment Result Database is appended to this report.

2.6 Class 'D' Cost Estimate and Assumptions

The cost estimates provided are Class 'D' accuracy. This means that the general requirements for upgrading including size and approximate depth of excavation, as well as some general site conditions are known. The projects identified have not considered the following factors affecting construction:

- relocation of adjacent services (gas, hydro, telephone, etc.);
- special permitting requirements (fisheries windows, contaminated site, etc.);
- geotechnical issues requiring special construction such as pile-supported piping, buoyancy problems or rock blasting; and
- critical market shortages of materials.

As the above factors have not been allowed for in estimating construction unit rates or project design, the following factors are applied to all projects:

- Contractor Markup/Overhead – 6% (included in unit price);
- Mobilization/Demobilization – 6%;
- Bonding/Insurance – 2%;
- Engineering – 20%; and
- Contingency – 40%.

GST has not been included in the estimated project costs. The unit prices reflect KWL's recent experience with similar work, and therefore represent the best prediction of actual (2016) costs as of the date prepared. Actual tendered costs would depend on such things as market conditions generally, remoteness factor, the time of year, contractors' workloads, any perceived risk exposure associated with the work, and unknown conditions.

Costs were estimated for the storm sewers that are undersized for existing land use flows (Priority 1, 2, and 3). Table C6-5 below summarizes the cost totals.

Table C6-6: Storm Sewer Upgrade Cost Summary

Municipality	Length Undersized (m)	Cost Estimate
Priority 1 – Major Storm Sewers		
DNV	2,773	$7,755,400
CNV	5,424	$19,768,400
	Priority 1 Total	**$27,523,800**
Priority 2 – Minor Storm Sewers (requiring 2 or more diameter upsize)		
DNV	18,222	$24,355,000
CNV	11,237	$19,521,500
	Priority 2 Total	**$43,876,500**
Priority 3 – Minor Storm Sewers (requiring 1 diameter upsize)		
DNV	1,622	$1,604,500
CNV	1,036	$1,469,200
	Priority 3 Total	**$3,073,700**
Costs include mob/demob, bonding/insurance, engineering, and contingency.		

3. Summary of Findings and Recommendations

3.1 Findings

Findings from this compendium include:

Major Systems

C6-1. The Major System defined is as all 750mm and larger diameter storm sewers, smaller storm sewers without a safe overland flow path, all culverts, and overland flow paths.

C6-2. Trunk storm sewers and sewers without overland flow routes were assessed with the 100-year 6-hour and 24-hour Modified Chicago distribution design storms.

C6-3. Culverts were assessed using 200-year flow estimates.

Minor Systems

C6-4. The Minor System is comprised of all other storm sewers assessed using the 10-year 6-hour and 24-hour Modified Chicago storms.

Capacity Assessment Criteria

C6-5. Storm sewers were classified by their design flow to full flow capacity ratio and degree of surcharge. Storm sewers were flagged as undersized if design flows exceeded full flow capacity and surcharge exceeded 15 minutes in duration and 0.3m height above crown of pipe (not road).

C6-6. Culverts were classified by their design flow to full flow capacity ratio. No surcharge time allowance was permitted for culverts due to debris risk.

Capacity Assessment Results

C6-7. With the assessment of the overall drainage system, the following storm sewers and culverts were identified as undersized:

Table C6-7: Summary of Undersized Storm Sewers and Culverts

Scenario	Undersized		
	Minor System	Major System	
	Storm Sewers	Storm Sewers	Culverts
Existing land use	32 km (16% of whole system)	8 km (4% of whole system)	125 culverts (66% of all culverts)
Future land use	36 km (19% of whole system)	9 km (4% of whole system)	129 culverts (68% of all culverts)
Future land use with climate change	57 km (29% of whole system)	14 km (7% of whole system)	142 culverts (75% of all culverts)
Refer to: Figures C6-2A to F - 10-year storm sewer assessment for all three scenarios Figures C6-3A to F - 100-year storm sewer assessment for all three scenarios Figures C6-4A to F - 200-year Culvert Assessment for all three scenarios.			

Prioritization and Cost Estimates

C6-8. Undersized pipes were classified into five categories (Priority 1 through 5) based on the consequence of overflows/surcharging.

C6-9. Priority 1 to 3 upgrades identify pipes that are undersized for existing land use flows.

C6-10. Priority 4 upgrades are pipes that will be undersized under the future land use condition.

C6-11. Priority 5 pipes are undersized only in the future RCP 8.5 climate change scenario.

C6-12. Upgrades for Priority 1 to 4 pipes are sized for the future land use with RCP 8.5 climate change design flows and Class D cost are estimated for the storm sewers.

C6-13. Culvert sizes will need to be reviewed once the findings of the *Debris Geohazard Risk and Risk Control Assessment* (BGC, 2017) study are available. For this reason, culvert upgrades have not been costed at this time.

3.2 Recommendations

Based on the foregoing, it is recommended that CNV/DNV:

C6-1. Confirm creek culvert (and bridge) upgrade sizes with the *Debris Geohazard Risk and Risk Control Assessment (BGC. 2017)* study recommendations because the ISMP assessed clear water peak flow capacities only.

C6-2. Upgrade Priority 1 storm sewer and culvert projects first and then Priority 2 projects. Priority 3 projects can likely be put off until the end of asset life. Priority 4 projects should be undertaken as development proceeds either by developers of properties adjacent to the pipes or as DCC funded projects by the municipality.

C6-3. Size new or replacement culverts for 80% full for the design flow (CNV/DNV request).

C6-4. Manually check purple colour coded pipes prior to further action/upgrading. They represent steep pipes with design flows <100% full but surcharging higher than 30 cm and longer than 15 minutes. It is unclear whether this is caused by backwater or inlet capacity limitations.

C6-5. Undertake study to design bridges upgrades identified in the *Creek Hydrology, Floodplain Mapping and Bridge* Hydraulic *Assessment Study (KWL, 2014)* report. The preliminary design should include an assessment of flood containment and incorporate the findings of the *Debris Geohazard Risk and Risk Control Assessment, (BGC, 2017)* study to estimate the design flows (clear water or debris, as appropriate) to be conveyed under each bridge.

References

BGC, (2017). *Debris Geohazard Risk and Risk Control Assessment*.

Kerr Wood Leidal, (2014). *Creek Hydrology, Floodplain Mapping and Bridge Hydraulic Assessment.*

Moss, R.H., (2008). *Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies*. Geneva: Intergovernmental Panel on Climate Change. p. 132.

City and District of North Vancouver Integrated Stormwater Managment Plan Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

- No Surcharging
- Pipes* & Culverts > 100 % Capacity

** And surcharging that exceeds 30 cm and for longer than15 minutes*

Flooded Manholes in Minutes

- No Flooding
- < 5
- 5 - 10
- 10 - 15
- > 15

Note: Culverts and Bridges assessed with 200-year event

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Project No.	Date
099-125	December 2016

Existing Major Storm Sewer Assessment - Upper Watershed

Figure C6-1A

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City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

- No Surcharging
- Pipes* & Culverts > 100 % Capacity

** And surcharging that exceeds 30 cm and for longer than15 minutes*

Flooded Manholes in Minutes

- No Flooding
- < 5
- 5 - 10
- 10 - 15
- > 15

Note: Culverts and bridges assessed with 200-year event

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Project No.	Date
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Existing Major Storm Sewer Assessment - Lower Watershed

Figure C6-1B

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Author: JLau

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

- No Surcharging
- Pipes > 100 % Capacity

Surcharging that exceeds 30 cm and for longer than15 minutes

Flooded Manholes in Minutes

- No Flooding
- < 5
- 5 - 10
- 10 - 15
- > 15

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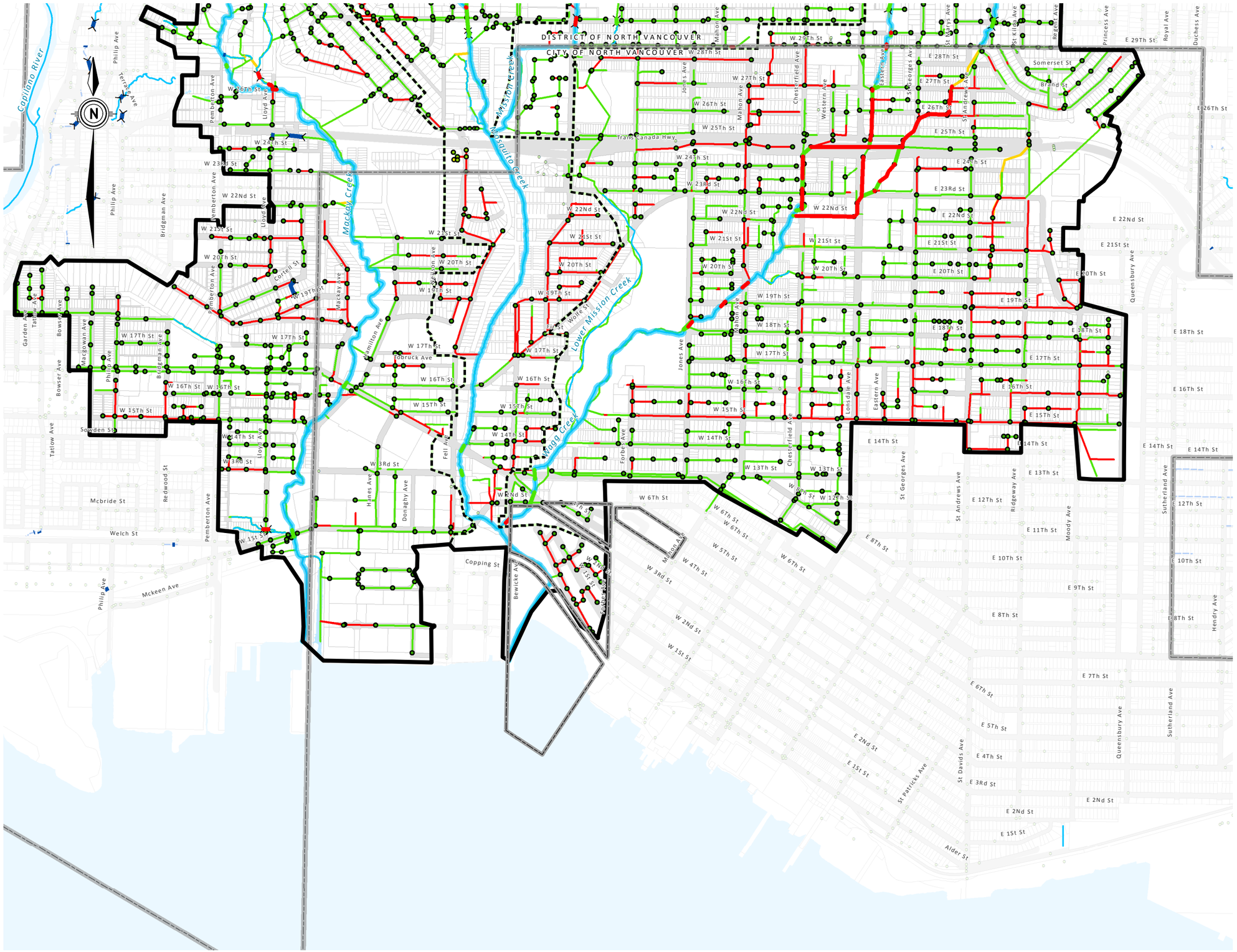
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Project No.	Date
099-125	December 2016

Existing Minor Storm Sewer Assessment - Upper Watershed

Figure C6-1C

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Author: JLau

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

- No Surcharging
- Pipes > 100 % Capacity

Surcharging that exceeds 30 cm and for longer than15 minutes

Flooded Manholes in Minutes

- No Flooding
- < 5
- 5 - 10
- 10 - 15
- > 15

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Project No.	Date
099-125	December 2016

Existing Minor Storm Sewer Assessment - Lower Watershed

Figure C6-1D

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

10-Year Storm Sewer Assessment - Existing Land Use - Upper Watershed

Figure C6-2A

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City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

10-Year Storm Sewer Assessment - Existing Land Use - Lower Watershed

Figure C6-2B

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City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

10-Year Storm Sewer Assessment - Future Land Use - Upper Watershed

Figure C6-2C

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City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Culvert
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

10-Year Storm Sewer Assessment - Future Land Use - Lower Watershed

Figure C6-2D

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Author: JLau

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Culvert
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

10-Year Storm Sewer Assessment - Future RCP 8.5 - Upper Watershed

Figure C6-2E

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Author: JJ.au

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Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

10-Year Storm Sewer Assessment - Future RCP 8.5 - Lower Watershed

Figure C6-2F

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Author: JLau

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

100-Year Storm Sewer Assessment - Existing Land Use Upper Watershed

Figure C6-3A

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Author: JLau

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

100-Year Storm Sewer Assessment - Existing Land Use Lower Watershed

Figure C6-3B

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Author: JLau

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

100-Year Storm Sewer Assessment - Future Land Use Upper Watershed

Figure C6-3C

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Author: JLau

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

100-Year Storm Sewer Assessment - Future Land Use Lower Watershed

Figure C6-3D

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Author: JLau

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

100-Year Storm Sewer Assessment - Future RCP 8.5 Upper Watershed

Figure C6-3E

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Author: JJLau

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Flow Depth vs Pipe Diameter

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	December 2016

100-Year Storm Sewer Assessment - Future RCP 8.5 Lower Watershed

Figure C6-3F

Path: O:\10000-0099\099-125\430-GIS\MXD-Rp\99125_Fig-C6-3F_Fu8_5_100yr_CapacityAssessment_Lower.mxd Date Saved: 12/21/2016 5:29:14 PM
Author: JLau

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Assumed Drainage
- Culvert

Culvert Capacity

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	March 2017

200-year Culvert Assessment - Existing Land Use - Upper Watershed

Figure C6-4A

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Author: BWhitehouse

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Major Watercourse (Within Study Area)
- Minor Watercourse
- Assumed Drainage
- Culvert

Culvert Capacity

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	March 2017

200-year Culvert Assessment - Existing Land Use - Lower Watershed

Figure C6-4B

Path: O:\0000-0099\099-125\430-GIS\MXD-Rp\99125_Fig-C6-4B_Ex_200yr_Culvert_CapacityAssessment_Lower.mxd Date Saved: 13/03/2017 2:03:05 PM
Author: BWhitehouse

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Assumed Drainage
- Culvert

Culvert Capacity

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	March 2017

200-year Culvert Assessment - Future Land Use - 200-year - Upper Watershed

Figure C6-4C

Path: O:\0000-0099\099-125\430-GIS\MXD-Rp\099125_Fig-C6-4C_Fu_200yr_Culvert_CapacityAssessment_Upper.mxd Date Saved: 13/03/2017 2:03:26 PM
Author: BWhitehouse

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Major Watercourse (Within Study Area)
- Minor Watercourse
- Assumed Drainage
- Culvert

Culvert Capacity

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	March 2017

200-year Culvert Assessment - Future Land Use - 200-year - Lower Watershed

Figure C6-4D

Path: O:\0000-0099\099-125\430-GIS\MXD-Rp\99125_Fig-C6-4D_Fu_200yr_Culvert_CapacityAssessment_Lower.mxd Date Saved: 13/03/2017 2:03:41 PM
Author: BWhitehouse

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Assumed Drainage
- Culvert

Culvert Capacity

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	March 2017

200-year Culvert Assessment - Future RCP 8.5 - 200-year - Upper Watershed

Figure C6-4E

Path: O:\0000-0099\099-125430-GIS\MXD-Rpt\99125_Fig-C6-4E_Fu8_5_200yr_Culvert_CapacityAssessment_Upper.mxd Date Saved: 14/03/2017 11:39:02 AM
Author: BWhitehouse

City and District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Assumed Drainage
- Culvert

Culvert Capacity

No Capacity Issues	
80% - 100% Capacity	*No Surcharging*
> 100% Capacity	*No Significant Surcharging*
> 100% Capacity	*Surcharging Exceeds 15 Minutes and 0.3 Meters*
Manual Check	*Surcharging May Be Due to Backwater*

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Project No.	Date
099-125	March 2017

200-year Culvert Assessment - Future RCP 8.5 - 200-year - Lower Watershed

Figure C6-4F

Path: O:\0000-0099\099-125\430-GIS\MXD-Rpt\99125_Fig-C6-4E_Fu8_5_200yr_Culvert_CapacityAssessment_Lower.mxd Date Saved: 14/03/2017 11:47:39 AM
Author: BWhitehouse

City & District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Storm Sewers

- No Upgrade Required

Priority Upgrades

- 1
- 2
- 3

Note: See Section 2.4 pg,12 for prioritization criteria

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Project No.	Date
099-125	January 2017

Prioritized Upgrades - Lower Watershed

Figure C6-5B

Path: O:\0000-0099\099-125\430-GIS\MXD-Rp\Phase_2Fig_C6-5A_PrioritizedUgrades_Lower.mxd Date Saved: 06/01/2017 1:26:18 PM
Author: BWhitehouse

City & District of North Vancouver
Integrated Stormwater Managment Plan
Mackay & Mosquito

Legend

- Municipal Boundary
- Minor Watercourse
- Major Watercourse (Within Study Area)
- Culvert
- Assumed Drainage

Storm Sewers

- No Upgrade Required

Priority Upgrades

- 1
- 2
- 3

Note: See Section 2.4 pg,12 for prioritization criteria

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Project No.	Date
099-125	January 2017

Prioritized Upgrades - Upper Watershed

Figure C6-5A

Path: O:\0000-0099\099-125430-GIS\MXD-Rpt\Phase_2\Fig_C6-5A_PrioritizedUgrades_Upper.mxd Date Saved: 06/01/2017 1:19:48 PM
Author: BWhitehouse

Report Submission

KERR WOOD LEIDAL ASSOCIATES LTD.

Prepared by:



Bryce Whitehouse, A.Ag.
Stormwater Modeller

Reviewed by:



David Zabil, M.A.Sc., P.Eng.
Technical Reviewer

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Revision History

Revision #	Date	Status	Revision	Author
0	Sept 21, 2020	Final	Issued as final for client copy.	BW/DZ



Compendium 7

Land Use Analysis

Mackay Mosquito Watersheds ISMP

September 2020

Final Report

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3. Future Land Use 4
3.1 Total Impervious Area Analysis 4

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4.1 Understanding the Effects of Land Development and Redevelopment on Stormwater 6
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Purpose

Compendium 7. Land Use Analysis

This compendium provides detailed information on the existing and proposed land uses for the Mackay and Mosquito Creek watersheds in North Vancouver, BC. It is a supporting document to the *Mackay Mosquito Watershed Integrated Stormwater Management Plan* (ISMP) that was developed by the City and District of North Vancouver.

Information contained in this compendium includes:

- an overview of the current and future land uses in each watershed,
- analysis of land use changes specifically related in total impervious area,
- a summary of the potential impacts of unmitigated development,
- assessment of watershed health,

Refer to other compendiums for additional supporting information.

Mackay Mosquito Watersheds ISMP Compendiums

The following compendiums and their authors support the Mackay Mosquito Watersheds ISMP:

1. Watershed Overview - KWL
2. Instream Species and Water Quality – RAE
3. Riparian Forest & Terrestrial Species – RAE
4. Drainage Asset Inventory - KWL
5. Hydrologic and Hydraulic Analysis - KWL
6. Drainage Assessment - KWL
7. Land-Use Analysis - KWL
8. Municipal Policy and Operations - KWL
9. Watershed Values & Objectives – CNV and DNV
10. Mitigation Measures – KWL, CNV, DNV
11. Mackay/Mosquito Action Plan – KWL, CNV and DNV

Figure and table identification numbering includes the first digit related to compendium number and the second digit related to the figure number within the compendium. e.g. Figure C3-1 is the first figure within Compendium 3.

‘Blue boxes’ of explanative information are provided in each compendium where background information and context are helpful.

1. Introduction

Land use changes are the primary drivers of change in watershed hydrology, ecology, and overall watershed health. Land use changes also drive the demand for infrastructure servicing. The *Mackay Mosquito Watersheds ISMP* provides the City and the District with strategies to preserve watershed health and to provide adequate level of drainage infrastructure servicing and flood protection for the `planned level of development in each watershed.

The impact of future land use and increasing impervious area on the drainage network capacity is assessed in *Compendium 6 - Drainage Assessment*.

2. Existing Land Use

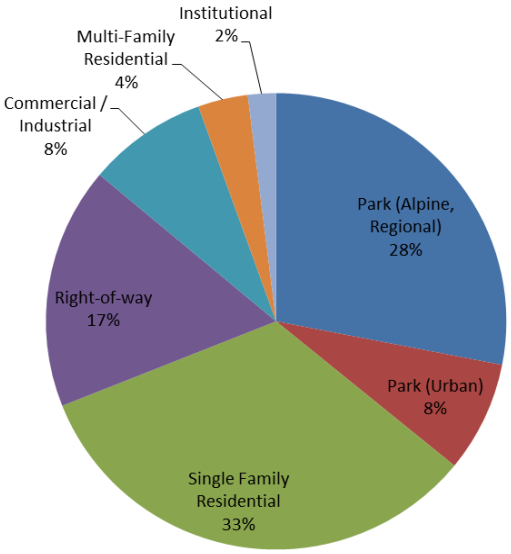
The existing land use within the Mackay and Mosquito watersheds is depicted on *Figure C1-1: 2013 Air Photo of Watersheds* and *Figure C7-1: Existing Zoning – 2010 Land Use*. The upper third of the watersheds are forested except for some clearing for the Grouse Mountain ski area and mountain access roads. The lower two thirds of the watersheds are developed with denser urban areas found near Burrard Inlet.

The District portions of the watersheds consist of mostly residential development with a few commercial areas.

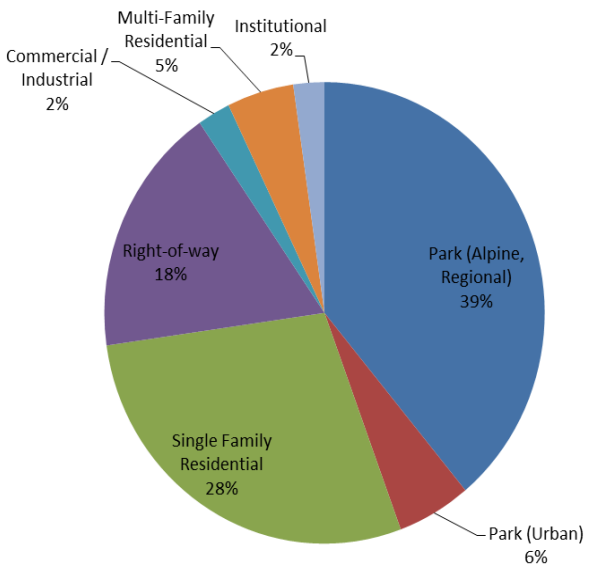
In the Mackay watershed, development within the City is a mix of residential uses immediately below the Upper Levels Highway and transitions to commercial and industrial uses, below Marine Drive.

In the Mosquito watershed, development within the City is primarily residential, with commercial strips along Lonsdale Avenue and Marine Drive. A small industrial area is also located on Marine Drive. The Squamish Nation lands are developed with residential areas and the Mosquito Marina at the foreshore of the Burrard Inlet. Existing land use categories in each watershed is summarized as follows.

Existing Mackay Watershed Land Use



Existing Mosquito Watershed Land Use



2.1 Total Impervious Area Analysis

Total impervious area (TIA) refers to the total area of impervious land within a defined area. The TIA calculation was completed for the entire watershed irrespective of land use category. A snapshot of the spectral imagery received and the classification of the land into pervious and impervious areas is shown below.



Spectral Imagery and Percent TIA Estimation
Classification of impervious (in red) and pervious land (in green).

Figure C7-2 shows the results of the pixel analysis of pervious and impervious areas watershed-wide.

Using ArcGIS software and existing GIS zoning data from the City and District, the study area was divided into the following land use categories:

- park (alpine, regional),
- park (urban),
- single family residential,
- right-of-way,
- commercial/industrial,
- multi-family residential, and
- Institutional.

Each land use category was assigned a percentage total impervious area (percent TIA) value based on analysis of spectral imagery of the area. The spectral imagery was broken down into cells and each cell was classified as either pervious or impervious. For a given parcel of land, impervious percentage was found by calculating how much land is occupied by impervious cells within the parcel.

Table C7-1 summarizes existing land use percent imperviousness estimates. The pixel analysis results were compared with the traditional methodology of using typical impervious values for the various land use categories. The pixel analysis methodology resulted in lower TIA estimates, ranging from 5% - 8% lower. This may be attributed to 'leaves on vegetation' covering parts of impervious area on the July 2010 spectral image. DNV requested that the pixel analysis results be used.

The analysis of land use and total impervious area was based on the following data sources:

- CNV Zoning & OCP GIS data: 'Adm_Zoning_CNV' & 'Adm_OCP_2014_ LandUseFinal_CNV' (2014);
- DNV Zoning & OCP GIS data 'AdmZoning_DNV' & 'AdmOCP_DNV' (2014);
- CNV & DNV legal parcel GIS data: 'Adm_Legal_Parcel_CNV' & 'AdmParcels_ DNV' (2014);
- Orthophotos (2013) & DNV Spectral Imagery 'DNVLandcover' (2015).

Table C7-1: 2010 Existing Land Use Assessment - % Impervious Estimates

Study Area / Land Use	2010 Existing Land Use						
	Area (ha)	% Land Use in Total Watershed	Pixel Analysis[1]		Estimated Impervious[2]		% Change in Pixel & Estimated TIA
			Imperv Area (ha)	Estimated TIA[3] (%)	DNV Bylaw % Imperv	Imperv Area & Est TIA (ha)	
Mackay Watershed							
Park (Alpine, Regional)	242	28%	7	3%	5%	12	2%
Park (Urban)	68	8%	5	7%	20%	14	13%
Single Family Residential	285	33%	99	35%	40%	114	5%
Right-of-way	148	17%	80	54%	70%	103	16%
Commercial / Industrial	73	8%	62	85%	90%	65	5%
Multi-Family Residential	30	4%	16	54%	78%	24	24%
Institutional	17	2%	8	45%	80%	14	35%
Total	**862**	**100%**	**277**	**32%**		**346**	
						39%	**7%**
Mosquito Mainstem Subwatershed							
Park (Alpine, Regional)	479	58%	15	3%	5%	24	2%
Park (Urban)	38	5%	6	15%	20%	8	5%
Single Family Residential	161	20%	60	37%	40%	65	3%
Right-of-way	90	11%	50	55%	70%	63	15%
Commercial / Industrial	22	3%	16	71%	90%	20	19%
Multi-Family Residential	21	3%	12	57%	78%	16	21%
Institutional	11	1%	6	52%	80%	9	28%
Total	**824**	**100%**	**164**	**20%**		**205**	
						25%	**5%**
Thain Subwatershed							
Park (Alpine, Regional)	121	35%	1	1%	5%	6	4%
Park (Urban)	5	1%	0	2%	20%	1	18%
Single Family Residential	146	42%	53	36%	40%	59	4%
Right-of-way	62	18%	31	51%	70%	43	19%
Commercial / Industrial	1	0%	0	74%	90%	1	16%
Multi-Family Residential	2	0%	1	68%	78%	1	10%
Institutional	11	3%	4	39%	80%	9	41%
Total	**347**	**100%**	**91**	**26%**	**35%**	**119**	
						35%	**8%**
Wagg Subwatershed							
Park (Alpine, Regional)	0	0%	0	0%	5%	0	5%
Park (Urban)	41	11%	7	18%	20%	8	2%
Single Family Residential	129	35%	52	40%	40%	52	0%
Right-of-way	120	32%	70	59%	70%	84	11%
Commercial / Industrial	15	4%	13	88%	90%	13	2%
Multi-Family Residential	53	14%	35	66%	78%	41	12%
Institutional	12	3%	8	64%	80%	10	16%
Total	**371**	**100%**	**185**	**50%**	**57%**	**209**	
						57%	**7%**
Mosquito Watershed including Wagg + Thain Subwatersheds							
Park (Alpine, Regional)	600	39%	16	3%	5%	30	2%
Park (Urban)	83	5%	13	16%	20%	17	4%
Single Family Residential	437	28%	165	38%	40%	175	2%
Right-of-way	272	18%	152	56%	70%	190	14%
Commercial / Industrial	37	2%	29	78%	90%	34	12%
Multi-Family Residential	76	5%	48	63%	78%	59	15%
Institutional	35	2%	18	52%	80%	28	28%
Total	1541	**100%**	**440**	**29%**	**35%**	**533**	
						35%	**6%**

1. Based on DNV July 30, 2010 Spectral Image
2. Based on BC Assessment Existing Zoning x DNV Impervious Values
3. Total Impervious Area

Gray shading is a typical value, not in DNV bylaw

> 40% diff
> 30% diff
> 20% diff
> 10% diff

3. Future Land Use

The future land use zones are shown on Figure C7-3 based on the proposed CNV Official Community Plan (2031) and the Ratified DNV Official Community Plan (2030). In general, the current and future zoning is similar (in terms of total area) with small percentage changes in single family residential and commercial/industrial from the existing to future zoning. However, the total impervious area in the watersheds is projected to change significantly as the District and the City expect significant increase in impervious area with redevelopment.

3.1 Total Impervious Area Analysis

To estimate 2030 TIA, like the existing land use analysis, land use was separated into the same seven categories. KWL estimated future impervious coverage for each land use based on a combination of:

- DNV Bylaw (2005)
- Typical values for Metro Vancouver (LWMP – SWM, GVSDD 1999),
- *Innovative Stormwater Management: Hoskins Creek District of North Vancouver* (Hoskins 2014) paper, and
- Refinement of values based on the conversations with City and District staff reflecting acceptable values based on informal development trends and formal zoning bylaws that stipulate the amount of allowable impervious surface on a lot.

Table C7-2 summarizes estimated TIA ranges based on the above-mentioned sources, and the agreed upon values to use (shaded grey) based on discussions with CNV and DNV.

Table C7-2: Change in Total Impervious Area by Land Use

Land Use	DNV Bylaw % Impervious[1]	Pixel Analysis % Impervious[2]	Metro Van Typical Impervious Values[3]	Projected Future % Imperv[4]
Park (Alpine, Regional)	5%	1 - 3 %	1 - 10%	5%
Park (Urban)	20%	2 - 20%	1 - 10%	20%
Single Family Residential	40%	35 - 40%	35 - 60%	70%
Right-of-way	70%	55 - 60%		90%
Commercial / Industrial	90%	70 - 85%	75 - 90%	98%
Multi-Family Residential	78%	55 - 70%	60 - 80%	95%
Institutional	80%	40 - 65%	90%	80%

[1] DNV Zoning Bylaw, 1965, Bylaw 3120.
[2] Based on Pixel Analysis and Discussions with CNV-DNV.
[3] Table 3.2 of Liquid Waste Management Plan – Stormwater Management (GVSDD 1999).
[4] Agreed upon values to use based on discussions with CNV-DNV.

Table C7-3 shows estimated future TIAs for the Mackay and Mosquito watersheds as a whole and for the Thain and Wagg sub-watersheds. About 19% to 26% increase in total impervious area is expected in these watersheds attributed to increase in impervious area through redevelopment.

Table C7-3: 2030 Future Land Use - % Impervious Estimates

Study Area / Land Use	Area[1] (ha)	Existing Land Use Pixel Analysis Estimated TIA[2] (%)	DNV Bylaw % Imperv	Metro Van Typical % Imperv[3]	Future Land Use 2030[4]		% Change in Existing & Future TIA
					Mackay Mosquito Imp Values	Imperv Area & Estimated TIA (ha)	
Mackay Watershed							
Park (Alpine, Regional)	242	3%	5%	1 - 10%	5%	12	2%
Park (Urban)	68	7%	20%	1 - 10%	20%	14	13%
Single Family Residential	285	35%	40%	35 - 60%	70%	200	35%
Right-of-way	148	54%	70%		90%	133	36%
Commercial / Industrial	73	85%	90%	75 - 90%	98%	71	13%
Multi-Family Residential	30	54%	78%	60 - 80%	95%	29	41%
Institutional	17	45%	80%	90%	80%	14	35%
Total	**862**	**32%**				**472**	
						55%	**23%**
Mosquito Mainstem Subwatershed							
Park (Alpine, Regional)	479	3%	5%	1 - 10%	5%	24	2%
Park (Urban)	38	15%	20%	1 - 10%	20%	8	5%
Single Family Residential	161	37%	40%	35 - 60%	70%	113	33%
Right-of-way	90	55%	70%		90%	81	35%
Commercial / Industrial	22	71%	90%	75 - 90%	98%	22	27%
Multi-Family Residential	21	57%	78%	60 - 80%	95%	20	38%
Institutional	11	52%	80%	90%	80%	9	28%
Total	**824**	**20%**				**276**	
						34%	**14%**
Thain Subwatershed							
Park (Alpine, Regional)	121	1%	5%	1 - 10%	5%	6	4%
Park (Urban)	5	2%	20%	1 - 10%	20%	1	18%
Single Family Residential	146	36%	40%	35 - 60%	70%	102	34%
Right-of-way	62	51%	70%		90%	55	39%
Commercial / Industrial	1	74%	90%	75 - 90%	98%	1	24%
Multi-Family Residential	2	68%	78%	60 - 80%	95%	2	27%
Institutional	11	39%	80%	90%	80%	9	41%
Total	**347**	**26%**				**176**	
						51%	**24%**
Wagg Subwatershed							
Park (Alpine, Regional)	0	0%	5%	1 - 10%	5%	0	5%
Park (Urban)	41	18%	20%	1 - 10%	20%	8	2%
Single Family Residential	129	40%	40%	35 - 60%	70%	91	30%
Right-of-way	120	59%	70%		90%	108	31%
Commercial / Industrial	15	88%	90%	75 - 90%	98%	14	10%
Multi-Family Residential	53	66%	78%	60 - 80%	95%	51	29%
Institutional	12	64%	80%	90%	80%	10	16%
Total	**371**	**50%**				**282**	
						76%	**26%**
Mosquito Watershed including Wagg + Thain Subwatersheds							
Park (Alpine, Regional)	600	3%	5%	1 - 10%	5%	30	2%
Park (Urban)	83	16%	5%	1 - 10%	20%	17	4%
Single Family Residential	437	38%	40%	35 - 60%	70%	306	32%
Right-of-way	272	56%	90%		90%	245	34%
Commercial / Industrial	37	78%	90%	75 - 90%	98%	37	20%
Multi-Family Residential	76	63%	78%	60 - 80%	95%	72	32%
Institutional	35	52%	80%	90%	80%	28	28%
Total	**1541**	**29%**				**734**	
						48%	**19%**

1. From Table 2a
2. Based on DNV July 30, 2010 Spectral Image
3. Based on GVRD Watershed Classification System, May 1999
4. Based on 2014 CNV OCP and Received OCP layer from DNV

Gray shading is a typical value, not in DNV bylaw

Current Trend is Higher than MV Upper Range	> 40% diff
Based on CNV assessment of recent developments	> 30% diff
DNV Bylaw	> 20% diff
	> 10% diff

Both existing and future TIA are summarized below, together with the increase in TIA for each watershed and sub-watershed.

Table C7-4: Estimated Change in TIA by Watershed

Watershed / Sub-watershed	Existing TIA	Future TIA	Increase in TIA
Mackay Watershed	32%	55%	23%
Thain Sub-Watershed	26%	51%	25%
Wagg Sub-Catchment	50%	76%	26%
Mosquito Watershed (including Thain and Wagg)	29%	48%	19%

Colour Legend
> 20% diff
> 10% diff

4. Impacts of Unmitigated Development/Redevelopment

4.1 Understanding the Effects of Land Development and Redevelopment on Stormwater

Land development typically involves replacing pervious forested areas with impervious pavement, concrete and building structures. Redevelopment typically involves increasing the density of developed areas and/or increasing the coverage of buildings and paved areas further increasing the total impervious area. Increase in impervious area alters the natural hydrology of the watershed, changing the quantity, quality, and timing of runoff.

Stormwater Quantity Impacts:

- **During Extreme Rainfall Events:** increased and faster responding peak flow rates can cause or exacerbate flooding and erosion;
- **During Typical Rainfall Events:** increased and faster responding peak flow rates can trigger instability and deteriorate aquatic habitat along the watercourse.
- **During Dry Weather Periods:** decreased baseflow rates reduce the capacity of a watercourse to support fish.

Stormwater Quality Impacts:

- Land development and building construction activities result in sedimentation of watercourses. It has been found that urbanization of a watershed (over 30% total impervious area) also results in **Non-Point Source (NPS)** pollution in receiving waters and poor stream water quality. Together, sediment and contaminants can significantly degrade a creek system.

Hydrology is one the most important factors governing stream ecology. The cumulative hydrologic effects of increasing impervious area in a watershed in combination with loss of riparian corridor integrity will have an increasingly detrimental effect on stream ecology.

4.2 Impacts to Urban Stream Ecological Health

Recent research on urban streams indicates that four primary factors affect its ecological health. They are listed, in order of importance, as follows:

- Changes in hydrology;
- Disturbance to the riparian corridor;
- Disturbances to fish habitat; and
- Deterioration in water quality.

'Changes in hydrology' can be viewed as the paramount factor because it can impact the other factors. Hydrological changes (increase in flow, volumes and the frequency of floods) accelerate natural rates of erosion and sedimentation, degrades and/or washes out aquatic and riparian habitat, and deteriorates water quality.

By the time pollutant loading is a significant water quality problem affecting fish survivability, the higher frequency of occurrence of increased flows resulting from land use densification have already degraded or disturbed the physical features associated with productive fish habitat.

Understanding the four contributing factors is key to developing guiding principles for an integrated approach to the environmental protection component of the ISMP. Address 'changes in hydrology' on a watershed basis, and there will be spin-off benefits in mitigating the other three factors.

5. Watershed Health Tracking System

To quantify watershed health and to predict changes between existing and future watershed health conditions, several watershed health indicators are commonly used in ISMPs:

- Impervious area;
- Riparian forest cover; and
- Integrity of benthic invertebrate populations. [1]

The Watershed Health Tracking System (WHTS) is one simple tool that could be used for ISMPs that relates watershed health indicators to overall watershed health. Currently, watershed health is required to be assessed using the approach developed in the regional Monitoring and Adaptive Management Framework.

5.1 Watershed Health Indicators

The watershed health tracking system uses the three watershed health indicators noted below. **Maintaining riparian forest and minimizing imperviousness are the two most effective methods of preserving watershed health.** Riparian forest integrity and effective impervious area are used to predict a B-IBI score for the watershed which is compared against measured B-IBI values when available.

[1] Proposed Watershed Classification System for Stormwater Management in the GVS&DD Area (GVS&DD, 1999)
Assessment of Current And Future GVS&DD Area Watershed and Catchment Conditions (GVS&DD, 1999)

1. Impervious Area

Research shows a strong relationship between the impervious area in the watershed and a stream's health (based on its fish and benthic insect community):

Stream Health Relative to Impervious Area

Health	Watershed Impervious Cover
Stressed (minor changes to watershed health)	1 – 10%
Impacted (moderate changes to watershed health)	11 – 25%
Degraded (severe changes to watershed health)	26 – 100%
The Importance of Imperviousness, 1994, by T.R. Schueler	

2. Riparian Forest Integrity (RFI)

Riparian areas are those adjacent to watercourses that may be subject to temporary, frequent, or seasonal inundation, and which support plant life typical of wetter soil conditions. These riparian areas provide natural features, functions, and conditions that support productive fish community.

3. Benthic Index of Biological Integrity (B-IBI)

The biological integrity in a watershed is measured in by rating the benthic macro-invertebrates community or streambed insects. Benthic macro-invertebrates occupy all watercourses, and their presence is independent of barriers and blockages, commercial and sport fishing quotas, and ocean survival of salmonids. The index ranges from a score of 10, which indicates the watershed health is in a "poor" condition, to a score of 50 indicating that the watershed health is "excellent". Wild salmon are expected to be found in watersheds with high scores, while fewer fish species and lower salmonid densities are expected in watershed with scores below 25. Land use changes can be linked to the B-IBI scores (or number and diversity of macroinvertebrates) in a creek system. The index can also be used as a predictive planning tool.

5.2 Total and Effective Impervious Areas

Total Impervious Area and Effective Impervious Area are two terms that are often used in discussions of land use in the context of stormwater management.

Total impervious area (TIA) refers to total area of impervious surfaces within a parcel / catchment / watershed.

Effective impervious area (EIA) refers to area of impervious surfaces that is directly connected to a storm sewer or a stream.

If runoff from impervious surfaces is directed to adequately sized pervious areas that capture, store, infiltrate, and evaporate runoff, then the area is disconnected from the drainage system and is not part of the EIA. For example, if runoff from an impervious area is directed to a rock trench and infiltrated into in-situ soils, then the parcel is not directly connected to the drainage system and is not part of the EIA.

TIA and EIA are both key watershed health indicators.

Significance of EIA on Watershed Health

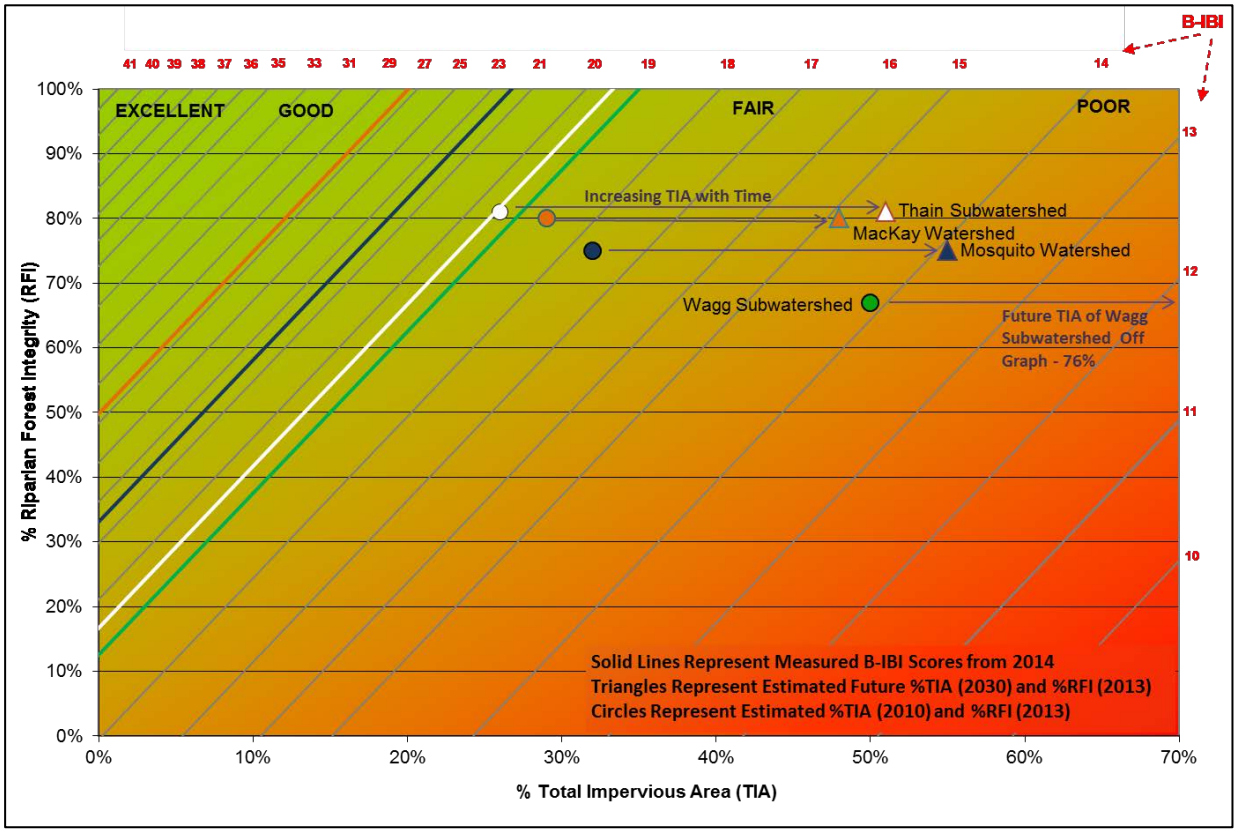
EIA% is a measure of the effectiveness of stormwater mitigation processes in a catchment. The smaller the EIA%, the more the catchment's hydrological cycle resembles the hydrological cycle for the area before it was developed and the catchment's hydrological cycle mimics nature.

5.3 Mackay Mosquito Watershed Health

Using the impervious values determined in Sections 2 and 3, together with riparian forest integrity values, Graph C7-1 shows the potential watershed health of the Mackay, Mosquito watersheds and Thain and Wagg sub-watersheds for both existing (circle) and future (triangle) conditions.

Watershed / Sub-watershed	Existing TIA	Future TIA
Mackay Watershed	32%	55%
Thain Sub-Watershed	26%	51%
Wagg Sub-Catchment	50%	76%
Mosquito Watershed (including Thain & Wagg)	29%	48%

This simple tool can be verified by plotting measured B-IBI scores (coloured diagonal lines) as well. The B-IBI scores show better watershed health than the predicted indicators. This can potentially be attributed to large undeveloped headwaters providing benefits to benthic invertebrates, and that impervious area may be disconnected from the drainage system, lessoning the impact of imperviousness.



Graph C7-1: WHTS – Mackay, Mosquito, Thain, & Wagg Watersheds

The existing TIA would classify the watersheds as “impacted” to "degraded" with moderate to severe changes to watershed health, however the strong riparian forest integrity provides for a healthier system. The B-IBI values for the three streams however indicate better health than would be predicted using the WHTS plot approach. Only the Thain Creek subwatershed plots with equivalent TIA and riparian forest integrity metrics. The WHTS may not be the best tool to track health in Mosquito Creek or Mackay Creek, or that more data is needed to establish appropriate relationships for each subcatchment.

Mitigate the Impacts of Future Development/Redevelopment

The WHTS graph predicts that unmitigated redevelopment would result in watershed health worsening, moving watershed indicators (increasing imperviousness) to the fair to poor classification.

6. Summary of Findings and Recommendations

6.1 Summary of Findings

Findings from this compendium include:

C7-1. The upper third of the watersheds are forested except for some clearing for the Grouse Mountain ski area and mountain access roads. The lower two thirds of the watersheds are urbanized with denser development found near Burrard Inlet.

C7-2. The District portions of the watersheds consist of mostly residential development with a few commercial areas.

C7-3. In the Mackay watershed, development within the City is a mix of residential types immediately below the Upper Levels Highway and transitions to commercial and industrial uses, below Marine Drive. In the Mosquito watershed, development within the City is primarily residential, with commercial strips along Lonsdale Avenue and Marine Drive. A small industrial area is also located on Marine Drive.

C7-4. The Squamish Nation lands are developed with residential areas and the Mosquito Marina at the foreshore of the Burrard Inlet.

C7-5. The assessment of existing and future predicted TIA yielded the following:

Study Area	Increase in TIA between Existing and Future Development
Mackay Watershed	23%
Mosquito Watershed (including Thain and Wagg)	19%

C7-6. Unmitigated land development/redevelopment increases peak flows and volumes increasing flooding and erosion and adversely impacting aquatic habitat and baseflows. It also degrades water quality.

C7-7. Stream health is affected by hydrology/flows, riparian corridor, water quality, and instream disturbances.

C7-8. The Watershed Health Tracking System (WHTS) uses indicators of riparian forest integrity and impervious areas to estimate the benthic index of biotic integrity (B-IBI) value. The B-IBI value is an indicator of stream health. The WHTS was used to understand the effects of unmitigated development on the stream health. With unmitigated development, the Mackay and Mosquito watersheds are predicted to decrease in heath from the current fair condition to a poor condition. The WHTS doesn't appear to replicate measured levels of benthic invertebrates instream and may not be appropriate for use without further data collection and calibration.

Report Submission

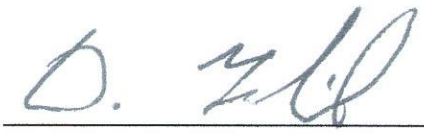
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Prepared by:



Crystal Campbell, P.Eng.
Project Manager

Reviewed by:



David Zabil, P.Eng.
Technical Reviewer

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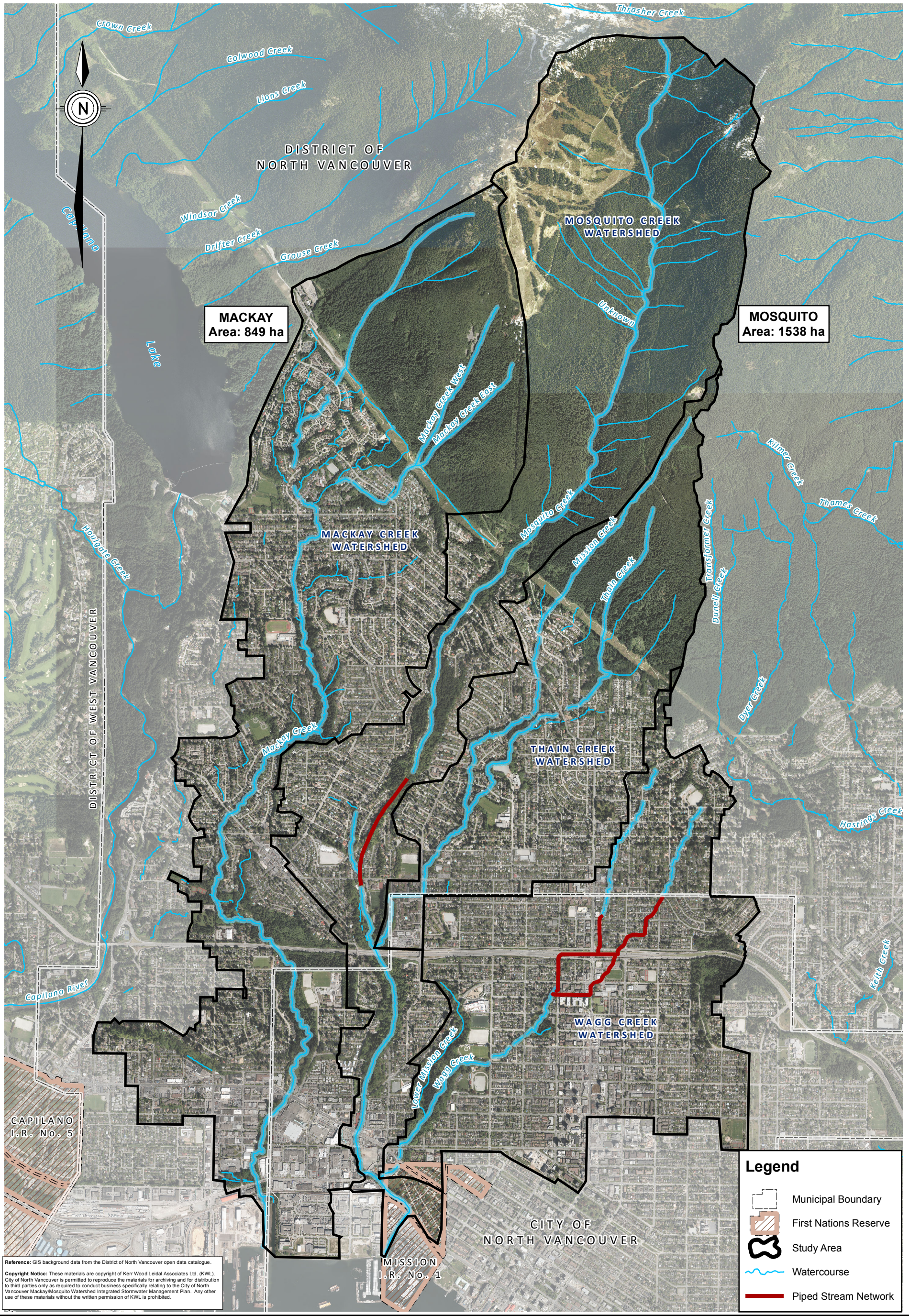
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Revision History

Revision #	Date	Status	Revision	Author
0	Sept 21, 2020	Final	Issued as final for client copy.	CC

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Author: JLau



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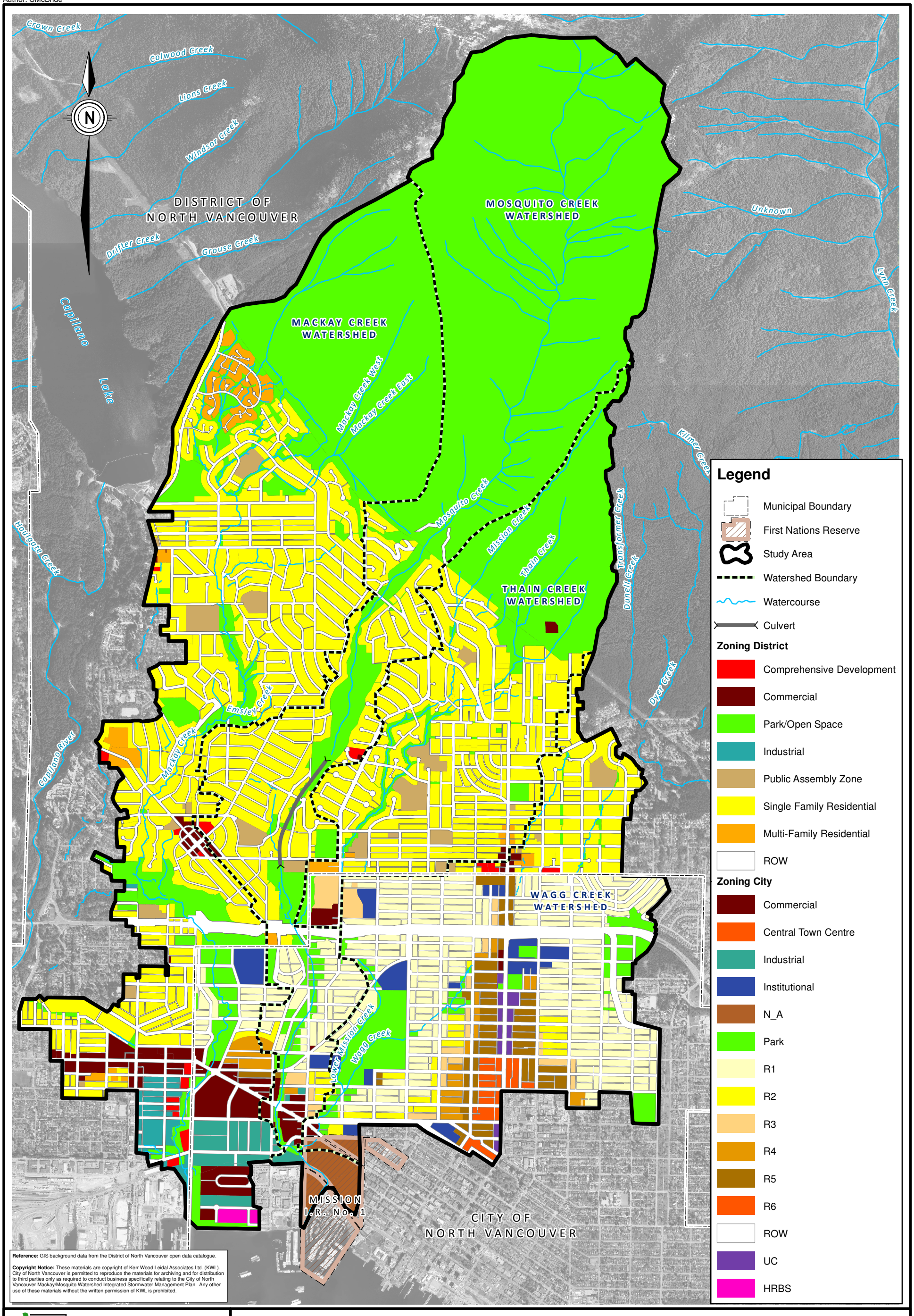
Project No. 99-125
Date December, 2016

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2013 Air Photo of Watershed

Figure C1-1

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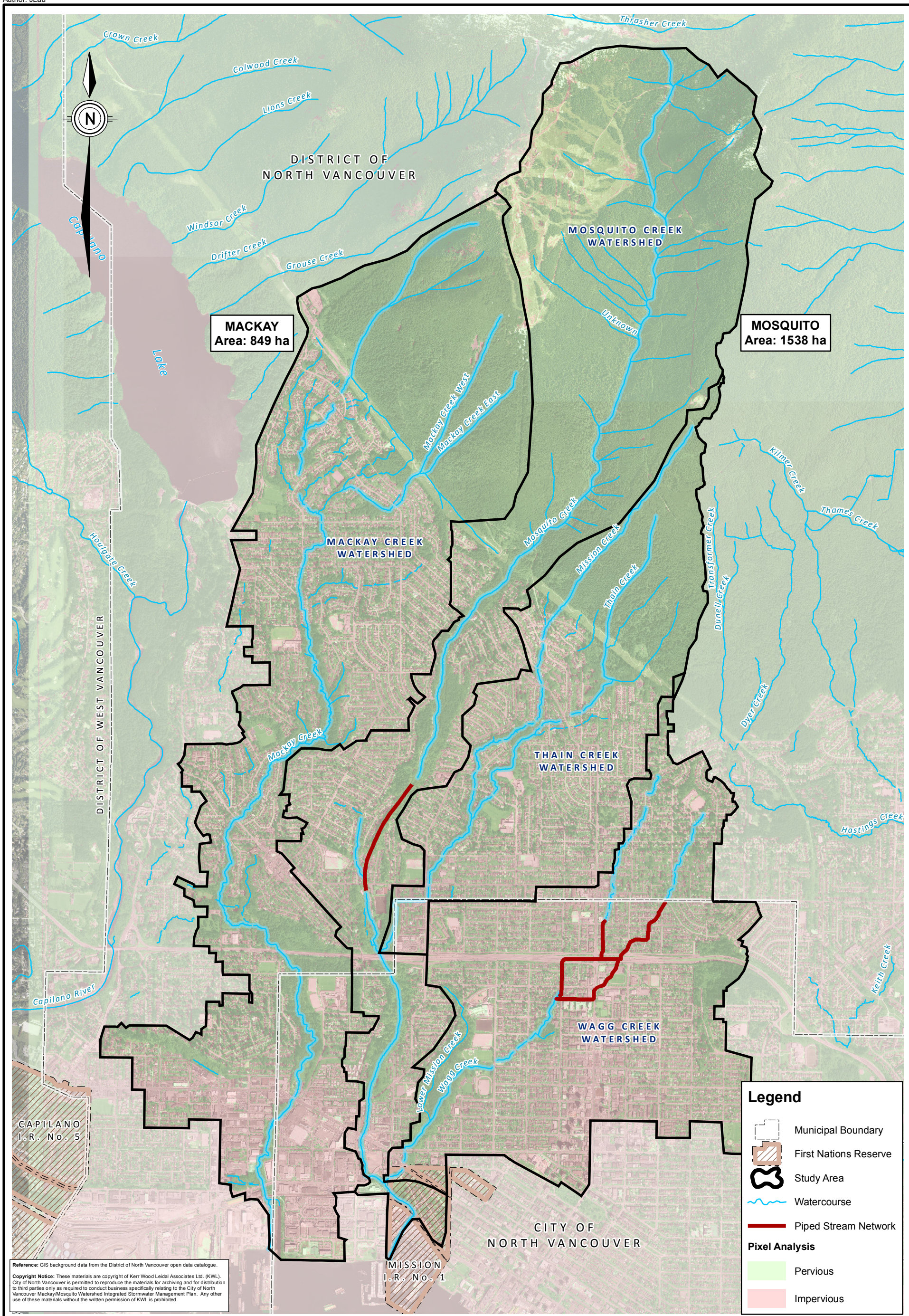
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99-125	April, 2016

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Existing Zoning

Figure C7- 1

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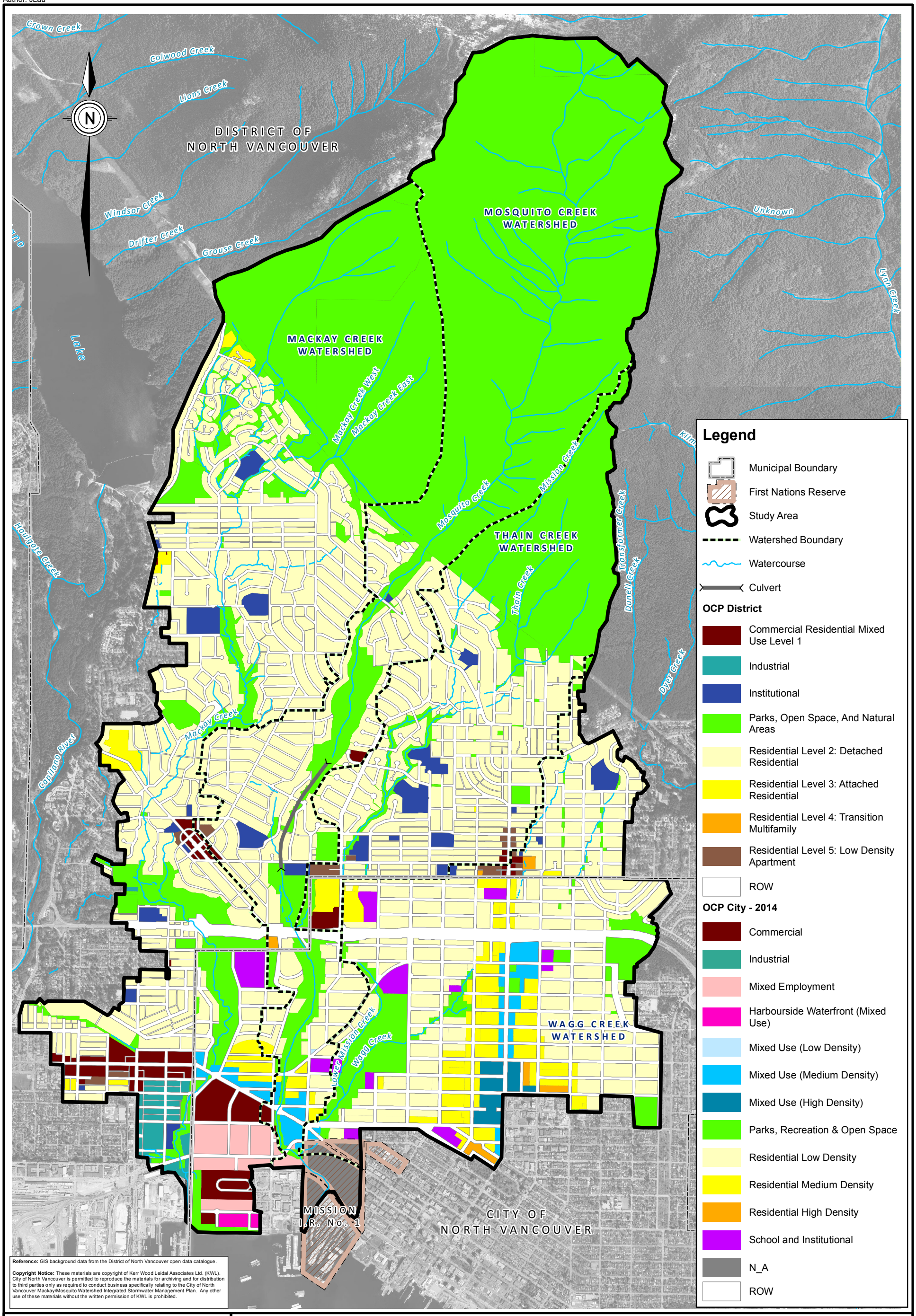
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Date December, 2016

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Existing Land Use Imperviousness

Figure C7-2

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Mackay/Mosquito Watershed Integrated Stormwater Management Plan

Project No. 99-125
Date December, 2016

500 0 500 (m)

OCP - 2030 Future Land Use

Figure C7-3



Compendium 8

MUNICIPAL POLICY & OPERATIONS

Mackay Mosquito Watersheds ISMP

September 2020

Final Report

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Purpose

Compendium 8. Municipal Stormwater Program

This compendium provides a summary of CNV and DNV stormwater related bylaws and policies and drainage system maintenance practices. It is a supporting document to the Mackay and Mosquito Watershed Integrated Stormwater Management Plan (ISMP) that was developed by the City and District of North Vancouver.

Refer to other compendiums for additional supporting information.

Mackay Mosquito Watersheds ISMP Compendiums

The following compendiums and their authors support the Mackay Mosquito Watersheds ISMP:

1. Watershed Overview - KWL
2. Instream Species and Water Quality – Raincoast Applied Ecology
3. Riparian Forest & Terrestrial Species – Raincoast Applied Ecology
4. Drainage Asset Inventory – KWL
5. Hydrologic and Hydraulic Modelling - KWL
6. Drainage Assessment - KWL
7. Land-Use Analysis - KWL
8. Municipal Policy and Operations - KWL
9. Watershed Values & Objectives – CNV and DNV
10. Mitigation Measures – KWL, CNV and DNV
11. Mackay/Mosquito Action Plan – KWL, CNV and DNV

Figure and table identification numbering include the first digit related to compendium number and the second digit related to the figure number within the compendium. e.g. Figure C3-1 is the first figure within Compendium 3.

'Blue boxes' of explanative information are provided in each compendium where background information and context are helpful.

1. Introduction

This compendium provides an overview of ISMP requirements, supporting programs, studies, and existing institutions within each municipality.

2. Regional Stormwater Guidance

2.1 Metro Vancouver LWMP Stormwater Commitments

The 2001 Metro Vancouver *Liquid Waste Management Plan* (LWMP) included commitments for stormwater management that incorporated:

- Sharing of information and knowledge through the Stormwater Interagency Liaison Group (SILG);
- Stakeholder participation;
- Updating and adopting policies and bylaws; and
- Undertaking watershed-scale Integrated Stormwater Management Plans (ISMPs).

In 2002, Metro Vancouver, SILG members and KWL developed the Terms of Reference Template for ISMPs to provide guidance and a flexible framework to the ISMP planning process. The Template document was updated in 2005 based on feedback from member municipalities on its application.

Metro Vancouver updated the LWMP in 2010 to create the *Integrated Liquid Waste and Resource Management Plan (ILWRMP), May 2010*. The key stormwater points are summarized as follows:

- Continue requirement for ISMP planning and implementation;
- Place emphasis on managing rainwater runoff at the site level which reduces negative quality and quantity effects;
- Integrate land use planning and stormwater management;
- Improve stormwater bylaws and development of design standards and guidelines;
- Promote the collection and use of rainwater for non-potable water uses; and
- Develop watershed health indicators.

Condition 7 of the BC Minister of Environment's approval of Metro Vancouver's 2010 Integrated Liquid Waste Resource Management Plan (ILWRMP) required that all municipalities, with coordination from Metro Vancouver, monitor stormwater to assess and report on the effectiveness of ISMP implementation. To fulfill this provincial requirement, Metro Vancouver and its member municipalities have developed a Monitoring and Adaptive Management Framework for Stormwater (MAMF) (Metro Vancouver, 2014). The MAMF takes a weight of evidence approach, using several types of monitoring and indicators to develop an overall assessment of watershed conditions. Through repeated sampling, watershed health and the response to specific watershed protection measures and management actions can be tracked over time.

Metro Vancouver and its members provide progress reports to the province every two years and will review and update the ILWRMP on an eight-year cycle.

2.2 Other Regional Stormwater Guidance

Other regional initiatives and guidance are summarized as follows.

Metro Vancouver

- 2017 Region-wide Baseline for On-site RWM
- 2014 Metro Vancouver Monitoring and Adaptive Management Framework for Stormwater
- 2012 Metro Vancouver Stormwater Source Control Guidelines Update
- 2012 Metro Vancouver ISMP Lessons Learned
- 2010 Metro Vancouver Integrated Liquid Waste and Resource Management Plan (ILWRMP),
- 2005 GVRD Integrated Stormwater Management Planning Template
- 2001 GVRD Liquid Waste Management Plan.

Provincial Guidebook

- 2010 Beyond the Guidebook 2010,
- 2007 Beyond the Guidebook – Context for RWM & Green Infrastructure in BC, and
- 2002 Stormwater Planning: A Guidebook for BC,

Provincial Government

- Riparian Areas Protection Act, 2016,
- Sea Level Rise Adaptation Primer (2013),
- Develop with Care 2012: Environmental Guidelines for Urban and Rural Land Development in British Columbia (2012),
- Riparian Areas Regulation 2004
- Dike Maintenance Act,
- Drainage, Ditch and Dike Act,
- Drinking Water Protection Act,
- Environment and Land Use Act,
- Environmental Assessment Act,
- Environmental Management Act (and Waste Discharge Regulation),
- Fish Protection Act (and Riparian Areas Regulation),
- Integrated Pest Management Act,
- Water Act (and Water Regulation, Groundwater Protection Regulation),
- Water Protection Act, and
- Agricultural Land Commission Act

Federal Government

- 2001 Urban Stormwater Guidelines & BMPs for Protection of Fish and Fish Habitat (draft, DFO).
- Fisheries Act,
- Canada Water Act,
- Canadian Environmental Protection Act,
- Species at Risk Act,
- Canada Wildlife Act, and
- 1992 Land Development Guidelines.

3. Existing Municipal Stormwater & Watershed Related Bylaws and Policies

Municipal policies, bylaws and regulations form part of the context for the ISMP study. Existing bylaws related to stormwater management are included below.

3.1 City of North Vancouver

Existing City bylaws related to stormwater management include:

Subdivision & Development Control Bylaw, 2010, No. 8014

- Required levels of service for subdivision development – on-site landscaping (for rainwater management) is required for **all developments (1,2,3-Unit & Larger, Subdivision) on private land.**
- The City has developed two guidance documents: *STORMWATER MANAGEMENT One to Two Residential Units* and *STORMWATER MANAGEMENT Three or More Units* (see Table C8-1).

Table C8-1: CNV Existing Stormwater Management Criteria (2014)

Category	Target Amount	Objective
For New Development and Redevelopment:		
One to Two Residential Units	Capture 50% of MAR[1]	**Reduce total runoff and provide WQ improvements**. Capture 50% 24-hour Mean Annual Rainfall, or 40 mm over 24 hours from all roof, deck, & concrete areas (impervious surfaces) from entire site. Direct (slope) all paving and concrete areas to garden or grassed area, and/or collect in a sump style drain basin (catch basin).
Three or More Units[2]	Capture 56 mm	SW source controls shall consume (i.e. not release to receiving water) 56 mm of rain over a 24-hour period from all impervious building surfaces. All impervious areas surrounding the building shall be directed to pervious vegetated areas or a source control for treatment and attenuation. All roadways reporting to catch basins at property edge shall be treated or consumed with source controls potentially located in road ROW. All source controls should provide the means to monitor performance. All residential development at FSR 1.0 or greater and any other Land Use Designations (e.g. Commercial, Industrial, Institutional, etc.) shall include source control performance monitoring for two years by the proponent.[3]

Notes:
[1] MAR is Mean Annual Rain Event (approximately a two-year storm event)
[2] This category includes commercial, institutional, and industrial land uses.
[3] This table summarizes guidelines documents *STORMWATER MANAGEMENT One to Two Residential Units* and *STORMWATER MANAGEMENT Three or More Units*.

Stream and Drainage System Protection Bylaw, 2003, No. 7541 and Amendment Bylaw, 2013, No. 8290

- Open Streams Policy – maintain open streams and require fish-bearing or potentially fish-bearing streams to be fish-passable.
- Protection of Drainage System During Construction Work – prohibits the release of prohibited substances into drainage system from any activity requiring a permit or approval from the City.
- Erosion and Sediment Control – requirement for "Sediment Control Plans", use of Best Management Practices, and monitoring during construction for development projects.

Zoning Bylaw, 1995, No. 6700, Amendment Bylaw, 2006, No. 7759 (Development Permit Areas for Streamside Protection and Enhancement)

- A Streamside Protection and Enhancement Development Permit is required for any work to be done within 15 m (50 feet) of the top of bank of a watercourse or within 10 m (33 feet) of the top of a ravine bank, including: constructing any structure or building; constructing an impervious / semi-impervious surface (paving); or undertaking landscaping changes including removal of soil, vegetation or trees.[1]
- Streamside Protection and Enhancement Development Permit Guidelines – provide owners of affected property and the development community with an outline of the legal requirements to protect riparian areas on privately owned lands; and process for development approval.

Development Procedures Bylaw, 2001, No. 7343, Specifically Amendment Bylaw 2006, 7760 and Amendment Bylaw 2010, 8136 and Sewerage and Drainage Utility Bylaw, 1995, No. 6746

- Procedure and fees for establishing and severing sanitary and storm drainage services by owners.
- Regulation for discharging to storm sewers and watercourses.
- Flood Plain Designation and Flood Construction Levels within the City.

3.2 District of North Vancouver

District bylaws regulating drainage, watercourses, and environmental protection form part of the context for the ISMP study, including:

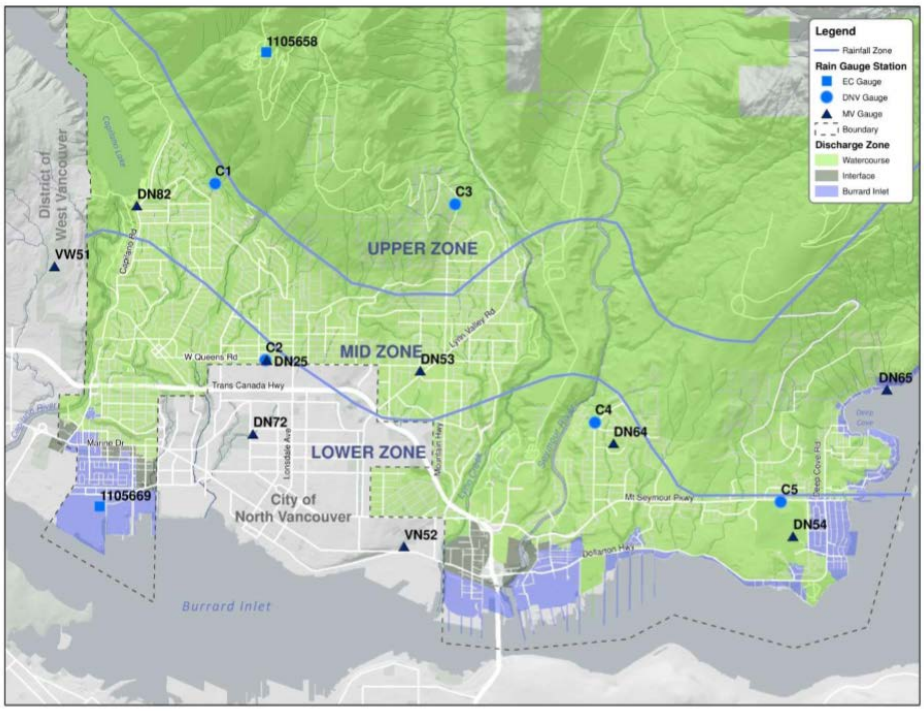
Development Servicing Bylaw No. 8145, 2017

- regulates subdivisions and the development of land. This includes the design criteria manual and supplementary master municipal construction document. The design criteria manual for municipal infrastructure is intended to provide a balanced approach based on the principles of sustainability and asset management. Section 4.0, which applies to both new developments and redevelopment, provides design guidelines for drainage networks and facilities.

Drainage management criteria is summarized as follows.

[1] http://www.cnv.org/Property-and-Development/Building-and-Development/Development-Applications/Development-Permits/Streamside-Development-Permit-Areas

Table C8-2: 2017 DNV Bylaw Stormwater Criteria

<table>
<tr><th>Category</th><th>Criteria</th></tr>
<tr><td>Volume Reduction & Water Quality Treatment</td><td>
Mean Annual Rainfall (MAR) Event Performance Target[1]
Figure 4a – Rainfall and Drainage Management Zones


<table>
<tr><th colspan="4">Table 4b: Performance Targets (Mean Annual Rain Event)</th></tr>
<tr><th></th><th>Lower Zone</th><th>Mid Zone</th><th>Upper Zone</th></tr>
<tr><td>MAR (mm)</td><td>116</td><td>166</td><td>215</td></tr>
<tr><td>50% MAR</td><td>58</td><td>83</td><td>108</td></tr>
<tr><td colspan="4">Targets include climate change</td></tr>
</table>
Above targets apply to larger developments/redevelopments.
No volume reduction target for single family residential.
</td></tr>
<tr><td>Rate Control Detention/Diversion</td><td>

Control 2-year 24 hour post-development flows to the pre-existing conditions or the 50% impervious condition in Table C8-3 below.
For new development, 10-year flows must be controlled to meet natural forest conditions to not exceed the existing downstream infrastructure. For redevelopment, 10-year flows must be controlled to be accommodated by the downstream minor drainage system.

</td></tr>
</table>

For new development and redevelopment areas tributary to creeks and rivers, the following stormwater management criteria are required. For areas that do not drain to creek or river system but discharge directly to Burrard Inlet, source controls may not be required for hydrological control, but may be required for water quality treatment.

The following table repeated from Table 4c and 4d in the DNV Development Servicing Bylaw, 2017

Table C8-3: 2017 DNV Bylaw Drainage Guidance

Category	Target Amount	Objective
For New Development:		
Rainfall Capture for Small Storms	Up to 50% MAR[1]	**Runoff volume reduction and water quality control.** Capture 90% of the rainfall in a typical year at source (building parcels and roads) and infiltrate, evaporate, transpire or reuse it[2].
Runoff Control for Large Storms	50% to 100% MAR	**Runoff rate reduction.** Store runoff from infrequent large storms and release at a rate that approximates the natural forested condition[3] to decrease the erosive impact of the large storm events.
Flood Risk Management for Extreme Storms	>MAR up to 100-yr	**Peak flow conveyance.** Ensure that the drainage system is able to convey extreme storm events with only minimal damage to public and private property.
Notes: 1. MAR is Mean Annual Rain Event (e.g., a two-year storm event) – based on BC Stormwater Guidebook (2002) 2. Capture volume = 50% MAR x impervious area 3. Maximum release rate based on 2-year 24-hour pre-development flows		
For Redevelopment:		
• No net increase in the rate & volume of stormwater runoff from existing to developed conditions up to the MAR (2-year return period). OR • If existing imperviousness is > 50%, no net increase in the rate and volume of stormwater runoff beyond a maximum 50% effective imperviousness up to the MAR (2-year return period).		
Notes: Effective imperviousness – directly connected impervious area (without rainfall capture)		

The *Development Servicing Bylaw* also outlines Erosion and Sediment Control requirements as set out in the MMCD.

Tree Protection Bylaw No. 7671, 2017 – to protect, preserve and conserve trees and their physical, societal, economic and environmental characteristics as associated with the forested character of the District.

Environmental Protection and Preservation Bylaw No. 6515, 2017 – to protect and preserve aquatic areas, sloping terrain, and soil.

Official Community Plan Bylaw 7900, 2011 – Specific development guidelines apply to all new development within delineated Development Permit Areas (DPA). Several development permit areas are defined in Schedule B of the OCP; ones most relevant to the ISMP are:

- **Streamside Protection DPA** - sets out requirements to meet Provincial Regulation, and to safeguard other important ecological functions such as wildlife habitat and corridors.

  Any development activity within the Streamside Protection Area requires a Development Permit. This includes but is not limited to all properties or portions of properties that are:

  - Within 15 m of the top of bank of a stream; or
  - Within 10 m of the top of bank of a ravine more than 60 metres wide; or
  - Within 30 m of the top of bank of a stream for properties greater than 0.5 ha located on or adjacent to Capilano River, Lynn Creek, Seymour River, or MacKay Creek south of Marine Dr.[2]

- **Creek Flood Hazard DPA** - established to minimize the risk to people and property from creek hazards. Includes properties adjacent to watercourses.
- **Slope Hazard DPA** - established to minimize the risk to people and property from slope hazards such as landslides and rock fall. It includes properties near the crest (top) or base of steep slopes.
- **Natural Environment DPA** –adopted to protect the District's natural setting, ecological systems, biodiversity, and wildlife corridors.

Table C8-4: DNV's 2011 OCP Stormwater Objectives

Objective	Strategy
1. Reduce risk of health hazards, loss of life & property damage	• Provide both major & minor drainage. • Protect life, livelihood & property. • Control nuisance/damage related to flooding within an acceptable frequency. • Protect municipal infrastructure.
2. Preserve & improve the environment for present & future generations	• Minimize potential stormwater impacts of development, such as changes in groundwater regime, alteration of fish & wildlife habitat, increased pollution, increased erosion & sediment transport, & altered stream flows. • Maintain shape & composition (geomorphology) of natural stream channel or ravine geometry, natural biological indicator conditions & the flow conditions. • Employ stream protection measures to prevent adverse hydrological & water quality impacts, for all recognized watercourses. • Promote sound development that respects the natural environment; • Restore watercourses currently enclosed, to open channels, where feasible.

[2] https://www.dnv.org/sites/default/files/edocs/streamside-protection-faq.pdf

Objective	Strategy
3. Conserve social & financial resources	• Treat stormwater as a resource rather than waste, ensure stormwater facilities are functional & aesthetically pleasing, & integrate multi-use objectives. • Provide infrastructure & services that enhance general public convenience & safety, aesthetics, & allows development to proceed according to community plan. • Sustain future development, supporting orderly & managed development of resources & integration of land uses. • Use best available technologies & management practices. • Encourage economic design of drainage systems. • Provide consistency & fairness for balanced & planned development.

Sewer Bylaw No. 6656, 2018 – includes information on the storm and sanitary sewer utilities, requirements for work on and use of sewer systems, monitoring, oil and grit interceptors, inspection chambers, sewer connections, service, costs, right of entry, offences, penalties, charges and fees.

Construction Bylaw 8271 – requires erosion and sediment control plans, implementation, and security deposits.

Street & Traffic Bylaw 7125 – prohibits dropping or deposit of materials on highways.

4. Stormwater Environmental Protection Criteria

Stormwater environmental protection criteria has been evolving over the past few decades, but currently recommended criteria include volume reduction, rate control and water quality treatment components. This section discusses existing criteria within the CNV and DNV bylaws, other applicable regional criteria, as well as recommendations for criteria for Mackay Mosquito watersheds, and for application municipality wide.

4.1 Current Municipal Bylaw Criteria

Criteria from existing CNV (2014) and DNV (2017) bylaws are summarized in Table C10-3.

Table C10-5: Current CNV and DNV Bylaw Stormwater Criteria

<table>
<tr><th colspan="2">Stormwater Criteria for Environmental Protection & Minimizing Watercourse Erosion</th></tr>
<tr><th colspan="2">DNV, Development Servicing Bylaw, 2017</th></tr>
<tr><td>Volume Reduction &
Water Quality Treatment</td><td>Mean Annual Rainfall (MAR) Event Performance Target[1]
Figure 4a – Rainfall and Drainage Management Zones
 

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Above targets apply to larger developments/redevelopments.
No volume reduction target for single family residential.</td></tr>
<tr><td>Rate Control
Detention/Diversion</td><td>Control post-development flows to pre-development levels for 50% to 100% MAR.</td></tr>
<tr><th colspan="2">CNV, STORMWATER MANAGEMENT One to Two Residential Units and Three or More Units, 2014</th></tr>
<tr><td>Volume Reduction
Source Controls</td><td>Capture 50% 24-hour MAR (40mm) from impervious surfaces for 1 – 2 residential units.
Capture 72% 24-hour MAR (56 mm) from building surfaces for 3 or more units. Retention release rate limited to 0.25 l/s/ha (equivalent to forested lands)</td></tr>
<tr><td colspan="2">1. DNV Development Servicing Bylaw, 2017 p 43</td></tr>
</table>

4.2 Comparison with Regional Volume Reduction Criterion

Criteria for the Protection of Fish and Fish Habitat

DFO developed draft stormwater criteria for the protection of fish and fish habitat for fish-bearing streams in the lower mainland of BC. It requires stormwater management on three fronts:

Table C10-6: DFO Stormwater Guidelines

Environmental Protection & Minimize Erosion	
Volume Reduction Source Controls	On-site rainfall capture (runoff volume reduction) for 72% of the 2-year 24-hour storm.
Water Quality Treatment	Remove 80% of Total Suspended Solid based on 50 µm particle size from 72% of the 2-year 24-hour storm.
Rate Control Detention/Diversion	Control post-development flows to pre-development levels for 6-month, 2-year and 5-year 24-hour events.
Based on *Urban Stormwater Guidelines and BMPs for the Protection of Fish and Fish Habitat (DFO, 2001).*	

Comparison with Regional Volume Reduction Criterion

Table C10-5 summarizes a comparison with regional volume reduction criteria as follows.

Table C10-7: Comparison of Regional Volume Reduction Criteria

Source	Volume Reduction Criterion	Volume Reduction Targets For 3 DNV Rainfall Zones[1] (mm)		
		Lower	Mid	Upper
DNV *Development Servicing Bylaw (DSB)*, 2017	MAR (mm)[1]	116[1,2]	166[1,2]	215[1,2]
	50% MAR[1]	58[1,2]	83[1,2]	108[1,2]
Stormwater Guidebook, 2002 DNV *DSB, 2005*[4]	MAR (mm)[4]	80[4]	120[4]	
	50% MAR[4]	40[4]	60[4]	
CNV, Stormwater Management 2014	MAR (mm)[3]	80[3]		
	50% MAR for 1-2 residential 72% MAR for >3 residential units	40[3] 58[3]		
DFO *Urban SWM Guidelines for the Protection of Fish & Fish Habitat, 2001.*	72% of 2-year, 24 hour event (90% average annual runoff)	83[1,2]	120[1,2]	155[1,2]
		58[4]	86[4]	
Metro Vancouver *Region-wide Baseline for On-site RWM, 2015*.	40% of 2-year, 24 hour event (75% average annual runoff)	46[1,2]	66[1,2]	86[1,2]
		32[4]	48[4]	

Source	Volume Reduction Criterion	Volume Reduction Targets For 3 DNV Rainfall Zones[1] (mm)		
		Lower	Mid	Upper

1. Update DNV 2017 bylaw. The lower zone values were derived from DNV Municipal Hall (DN25) data. The upper zone values were derived from the Hastings weather station (C3). The mid zone values were an interpolation of the lower zone and upper zone values.
2. Green shading denotes DNV criteria with climate change included in target
3. Based on DNV Municipal Hall (DN25)
4. Based on DNV Municipal Hall (DN25) & AES N Vanc Lynn Creek IDF curve data.

Because of Mackay Creek's susceptibility to erosion and for the protection of aquatic species and their habitats, the DFO 2001 *Draft Urban Stormwater Management Guidelines for the Protection of Fish and Fish Habitat* standard would be applicable. This is also consistent with CNV/DNV's goal to enhance watershed health beyond existing conditions.

The CNV has established 72% MAR volume reduction targets for development/redevelopments >3 residential units and 50% MAR for 1 – 2 residential units. This meets the DFO guidelines for larger developments and re-developments and is greater than the Metro Vancouver region-wide baseline targets.

The DNV criteria targets include 50% MAR with climate change. The resulting targets are similar to the 72% MAR with climate change targets.

Both CNV and DNV have progressive targets in place and seem adequate. Long term monitoring and adaptive management should be reviewed to inform whether increases should be considered.

4.3 Potential Improvements to Stormwater Environmental Protection Criteria

Because of the strong environmental values within the Mackay and Mosquito watersheds and across the North Shore and the desire to improve watershed health, the following potential improvements would provide increased protection and enhancement:

- DNV to establish and apply a progressive volume reduction target for single family residential development / redevelopment. A higher than region-wide baseline is recommended. The 72% of the 2-year DFO criteria or 50% MAR criteria with climate change would be desirable.
- CNV to consider rate control criteria for:
    - Catchment areas draining to watercourses:
        - If source controls volume reduction targets cannot be achieved, release at baseflow rate (0.5 L/s/ha), the 6-month 24-hour storm (56 mm)
        - Detain and release at pre-development rate, the 2-year and 5-year return period storms to better mimic natural hydrology and reduce erosive flows
    - Catchment areas draining directly to the ocean:
        - No environmental capture or detention required, provide water quality treatment for the 6-month 24-hour storm (56 mm) – see bullet 3.

  - Protection of downstream drainage infrastructure for all catchment areas – detain post-development flows proportionally to downstream drainage infrastructure limited capacity up to the 10-year event.

- CNV/DNV to consider clarifying and strengthening requirements for water quality treatment for pollutant generating surfaces such as roads, parking lots, etc. An example would include 'remove 80% of total suspended solid based on 50 µm particle size from 72% of the 2-year 24-hour storm for runoff from pollutant generating surfaces'. Require spill control measures for high-risk land uses. Continue to monitor most biologically relevant metals cadmium, copper, zinc, lead and iron through the Monitoring and Adaptive Management Framework for Stormwater. Monitoring may also include PAHs as the most biologically relevant hydrocarbons.
- CNV/DNV to implement and improve erosion and sediment control requirements during construction for water quality benefits.

5. Municipal Maintenance Practices

The descriptions of the municipal practices included in this section are based on conversations with CNV and DNV staff. Each municipality was asked to provide information on the following practices:

- Street sweeping,
- Culvert inspection and maintenance,
- Debris and sediment removal,
- Storm sewer flushing,
- Gravel removal from streambed,
- Invasive species removal, and
- Native species planting.

Summary of municipal maintenance practices are included below.

5.1 City of North Vancouver Maintenance Practices

CNV's current drainage system maintenance practices include:

Street Sweeping

The City has one street sweeper with a maintenance schedule based on levels of use. The sweeper is in use and on the road at least 40 hours per week. The City prioritizes sweeping in the following order: arterial roads, collector roads, and local roads. The frequency of sweeping is based on conditions, presence of bike routes, need for storm sewer clean up, and requests for sweeping. Main routes are serviced up to three times per week. 100/200 blocks get service approximately once per week. The City has designated 'hot spots' that receive more service. Local roads receive service based on staff knowledge or service calls. There are parking regulations to facilitate cleaning along the gutter on major roads. On roads that are swept less frequently (i.e. residential streets), there are no parking regulations for street sweeping and the area swept is restricted by parked cars.

Culvert Inspection/Maintenance

The City does not have a formal culvert inspection and maintenance program. Informally, the City's crews visit areas of known issues during heavy rain events. Typically, the City responds quickly to debris-related maintenance issues but does not have a preventative maintenance program in place.

Debris and Sediment Removals

Sediment removals are conducted at the following locations:

- Mosquito Creek at Marine Drive: Bridge hydraulics combined with a lower gradient stream channel result in depositions. Sediment removals occur at the 10 to 15 year frequency.
- Wagg Creek Pond: Fine sediment is trapped in the Wagg Creek Park Pond. Sediment was removed in 2006 as part of a capital upgrade project and again in summer 2014. Sediment removed from Wagg Creek pond is roughly estimated at 25 supervactor loads (relatively dry material) or approximately 300 m^3.
- Instream Woody Debris: is not removed unless it poses a risk to a crossing. If wood debris needs to be managed, it is typically cut in smaller pieces and left instream or moved to the floodplain / overbank.
- Catch Basins (CBs): The City cleans CBs that are problematic or identified as not working. The City waits until a number of CBs require maintenance and then send out one vactor. In the past, while funding was available for West Nile Virus management, the City cleaned every CB each year. At a rate of approximately 50 CBs a day, cleaning every CB in the City amounts to approximately one month of work.
- Oil Grit Separator (OGS): The City has twelve end of pipe OGS units for about 104 documented public outfalls to all receiving waters. There is one large Vortechnics OGS on the 15th Street outlet to Wagg Creek. The oldest OGS units are the Harbourside neighbourhood, on all outfalls, two of which discharge to the Mackay Creek estuary. More recent swirl separation units have been installed on Mackay Creek near Marine Drive, and Mosquito Creek near 3rd Street.

Storm Sewer Flushing

The City currently addresses storm sewer flushing through the annual CCTV program which is completing about 7% of the system annually. The City also has dedicated catchbasin cleaning funding to pre-emptively reduce sediment load on the storm sewer and receiving waters.

Invasive Species Removal and Native Species Planting

The City has an Invasive Plant Management Strategy and conducts regular inventory updates and uses best management practices to manage these species. Priority species include:

- Giant hogweed (Heracleum mantegazzianum)
- Knotweed, Bohemian (Fallopia × bohemica)
- Knotweed, Giant (Fallopia sachalinensis)
- Knotweed, Himalayan (Polygonum polystachyum)
- Knotweed, Japanese (Fallopia japonica)

Management of invasive species near streams is challenging since the provincial regulation limits the use of chemical treatment near streams. More information on the City's Invasive Plant Management Strategy can be found at the following link: http://www.cnv.org/Your-Government/Living-City/Environmental-Protection/Invasive-Species/Invasive-Plants

Proposed Program Improvements

CNV's future goals for the municipal maintenance program include:

- Develop an asset management framework for culverts;
- Determine what level of street sweeping and catch basin management is required to achieve water quality goals; and
- Improve documentation of maintenance work completed in the City.

5.2 District of North Vancouver Maintenance Practices

Street Sweeping

The District has one street sweeper operated by the Streets Department. Each road in the District is swept at least twice per year and is tracked through a list. The main sweeping seasons are from March to June and September to October when the sweeper is in use approximately 45 hours per week. During this time, the sweeper works on a special schedule. The operator starts at 5:00am and works ten hours per day. He starts at 5:00am so that he can sweep industrial areas without the interference of parked cars. During the dry months of July and August, streets are swept as needed and on a request / complaint basis. During this time, the sweeper is out approximately 16 to 24 hours per week. The sweeper is not in service during the winter months due to snow and ice concerns.

Bike routes, town centres, and arterial roads are swept more often. Hot spots include bike lanes and Edgemont Village. Parking regulations are not such to facilitate sweeping. At times, if an area is getting very dirty, no parking signs will be used and swept the next day. This is not regular operations because the sweeper is often called out to respond to emergency spills and it is not desired to have people move their cars to wonder why their road was not swept.

Culvert Inspection / Maintenance

Culvert inlets and outlets are inspected in the fall and before and during expected heavy rainfall events, as needed. Culverts maintenance is completed by Streets Department crews. Each culvert is on a list and maintenance is tracked through a field application that inputs data in real-time.

There is not a formal culvert CCTV inspection program. Inspection service contracts are put out based on funding and staff availability. It is the District's goal to inspect culverts by CCTV a minimum of once every twenty years. Inspected culverts with poor condition and graded as operational are placed in our culvert asset renewal program. Culvert repair methods are based on required capacity, fish passage, and construction considerations. If possible, trenchless rehabilitation methods are preferred.

Debris and Sediment Removals

The District has several debris and sediment capture structures within the watersheds. Each is inspected in the fall and after large rainfall events and cleaned out as needed:

- Blue Grouse Way Debris Barrier: On MacKay Creek near Deerhorn Lane. Debris removal on an event basis or if deemed necessary during fall inspection. Removed approximately 40 cubic meters in fall 2017.
- Fish ladders: On MacKay Creek. Remove an average of 55 cubic meters per year.

- Evergreen Debris Basin: On Mosquito Creek at Evergreen Place. Average fall debris removal of 150 cubic meters of wet material per year. Potential for significantly more material to be removed after large debris flow events.
- Mission Debris Basin: On Mission Creek above Rondoval Crescent. Installed in 2018 so no debris removal yet.
- Grousewoods Inlet: This is an inlet structure that repeatedly fills up with sediment. The District hopes to construct a formal basin at this location in summer 2019.

DNV Streets crews regularly check catch basins during road inspections. Catch basins are cleaned on an as needed or complaint basis. The DNV has a number of oil grit separators that are checked and cleaned either annually or semi-annually, as required, by vactor truck.

Storm Sewer Inspection / Maintenance

A designated list of storm sewer mains is cleaned by power rodding and flushing by our Utilities Department crews. There are three lists based on frequency of inspection / maintenance: 3 months, 6 months, and 12 months. The lists were developed and are updated based on severity of known operational issues.

The District has a formal storm sewer CCTV inspection program that runs on a three to four-year cycle. Storm sewer inspections take place on a twenty-year cycle or by priority due to known maintenance / operational issues.

Invasive Plants and Insects

Removal of invasive plant species and control of invasive insects is overseen by the District's Parks Department and is conducted as part of the Invasive Plant Management Strategy: https://www.dnv.org/programs-and-services/invasive-plants-and-insects

Priority plant species for removal include:

- English holly
- Spurge laurel
- Knotweed
- Policeman's helmet
- Butterfly bush
- Giant hogweed
- Periwinkle
- English ivy
- Himalayan blackberry
- Lamium
- Scotch broom
- Cherry laurel

Management of invasive species near creeks is challenging since the provincial regulation limits the use of chemical treatment near watercourses.

Priority insect species for control include:

- Chafer beetles
- European fire ants

Proposed Program Improvements

The DNV's future goals for the municipal maintenance program include:

- Develop a Green Infrastructure Asset Management Plan to realize and track the value of natural capital.
- Improve accuracy of drainage system data in our GIS system specifically culverts, fish passage infrastructure, debris hazard mitigation structures, low impact development features, and natural assets.
- Develop a list or application for catch basin maintenance to address conveyance and water quality issues.
- Implement real-time water quality monitoring on commercial, industrial, institutional, and multi-family development construction sites.

Erosion and Sediment Control Improvements

Since 2016, the District implemented improvements to the single family construction ESC process including an updated Construction Bylaw, and automation of proactive, mandatory acceptable ESC inspections prior to allowing building permit inspections. Automation was made possible because of the District's newly upgraded Energov building permit processing computer system. This proactive requirement significantly reduced reactive complaint based ESC enforcement.

5.3 Regular Drainage System Maintenance

Regular drainage system and stormwater facility maintenance is required to effectively convey design flows, minimize flooding and erosion, and mitigate the impacts of development. The following general inspection and maintenance procedures are typically recommended.

Inspection: Drainage systems should be inspected every 5 years during low flow conditions, ideally in the winter so that remediation of identified problems can be undertaken during the following summer dry months. The inspection should assess the condition of the conveyance facilities including all open channels, culverts, bridges, ponds, hydraulic structures, and diversions and identify the need for maintenance. An overall drainage system inspection should also be completed after large storm events.

Vegetation Maintenance: Access to ditches and the conveyance ditches themselves should be maintained to prevent the growth of weeds, small trees and bushes. The hydraulic conveyance capacities of the ditches must be maintained. Ditch maintenance should occur annually.

Sediment Removal: Sand/silt accumulation in sumps, oil/grit separators, and catch basins is expected and should be removed every two years, ideally at the end of summer before the autumn rainy season.

Debris Control: Debris blockages at hydraulic structures can cause flooding problems. Annual inspection and regular debris removal (as required) from creek and drainage systems is necessary.

Wet Ponds: Inspect periodically during wet weather to observe function, clean sediment forebay every 5 to 7 years or when 50% capacity has been lost, remove accumulated sediment form pond bottom when 10 to 15% of pool volume is lost, inspect hydraulic and structural facilities annually and mow side-slopes, embankments and spillways as required to prevent excessive over growth that may reduce the flow capacity.

Detention Tanks: Inspect annually and remove floating debris and oil.

Wetlands: Inspect annually and after each major storm event. At beginning of wet season remove trash and floatables and unclog outlet structures.

Grassed Swales: Inspect routinely especially after large storm events. Correct erosion problems as necessary, mow to keep grass in the active growth phase, remove clippings to prevent clogging of outlets, and remove trash and debris.

Bioretention with Underdrain: Remove leaves each autumn, inspect overflow, hydraulic and structural facilities annually. Clean out sediment forebays / pre-treatment areas.

6. Summary of Findings and Recommendations

6.1 Findings

Findings from this compendium include:

C8-1. Metro Vancouver Liquid Waste Management Plan includes stormwater commitments such as undertaking ISMPs, including stakeholder participation, and updating/adopting bylaws and policies. MOE requires monitoring to assess and report on the implementation of ISMPs.

C8-2. CNV has the following stormwater related bylaws:

a. Subdivision & Development Control Bylaw, 2010
b. Stream and Drainage System Protection Bylaw, 2003
c. Zoning Bylaw, 1995, Amendment Bylaw 2006
d. Development Procedures Bylaw, 2001, Amendment Bylaw 2006
e. Sewerage and Drainage Utility Bylaw, 1995

C8-3. DNV has the following stormwater related bylaws:

a. Development Servicing Bylaw, 2017
b. Tree Protection Bylaw, 2017
c. Environmental Protection and Preservation Bylaw, 2017
d. Official Community Plan Bylaw, 2011
e. Sewer Bylaw, 2018
f. Construction Bylaw 8271
g. Street & Traffic Bylaw 7125

C8-4. CNV/ DNV undertakes drainage system maintenance: street sweeping, culvert inspection/maintenance, debris/sediment removals, storm sewers flushing, and invasive species removal and native species planting.

6.2 Recommendations

Based on the foregoing, it is recommended that:

C8-1. DNV to establish and apply a progressive volume reduction target for single family residential development / redevelopment. A higher than region-wide baseline is recommended. The 72% of the 2-year DFO criteria or 50% MAR criteria with climate change would be desirable.

C8-2. CNV to consider rate control criteria for:

a. Catchment areas draining to watercourses:

    i. If source controls volume reduction targets cannot be achieved, release at baseflow rate (0.5 L/s/ha), the 6-month 24-hour storm (56 mm)

    ii. Detain and release at pre-development rate, the 2-year and 5-year return period storms to better mimic natural hydrology and reduce erosive flows

b. Catchment areas draining directly to the ocean:

    i. No environmental capture or detention required, provide water quality treatment for the 6-month 24-hour storm (56 mm) – see bullet 3.

c. Protection of downstream drainage infrastructure for all catchment areas – detain post-development flows proportionally to downstream drainage infrastructure limited capacity up to the 10-year event.

C8-3. CNV/DNV to consider clarifying and strengthening requirements for water quality treatment for pollutant generating surfaces such as roads, parking lots, etc. An example would include 'remove 80% of total suspended solid based on 50 µm particle size from 72% of the 2-year 24-hour storm for runoff from pollutant generating surfaces'. Require spill control measures for high-risk land uses. Continue to monitor most biologically relevant metals cadmium, copper, zinc, lead and iron through the Monitoring and Adaptive Management Framework for Stormwater. Monitoring may also include PAHs as the most biologically relevant hydrocarbons.

C8-4. CNV/DNV to implement and improve erosion and sediment control requirements during construction for water quality benefits.

C8-5. CNV/DNV continue to inspect and maintain oil/grit separators, catch basins, and debris traps.

Report Submission

KERR WOOD LEIDAL ASSOCIATES LTD.

Prepared by:



Crystal Campbell, P.Eng.
Project Manager

Reviewed by:

David Zabil, M.A.Sc., P.Eng.
Technical Reviewer

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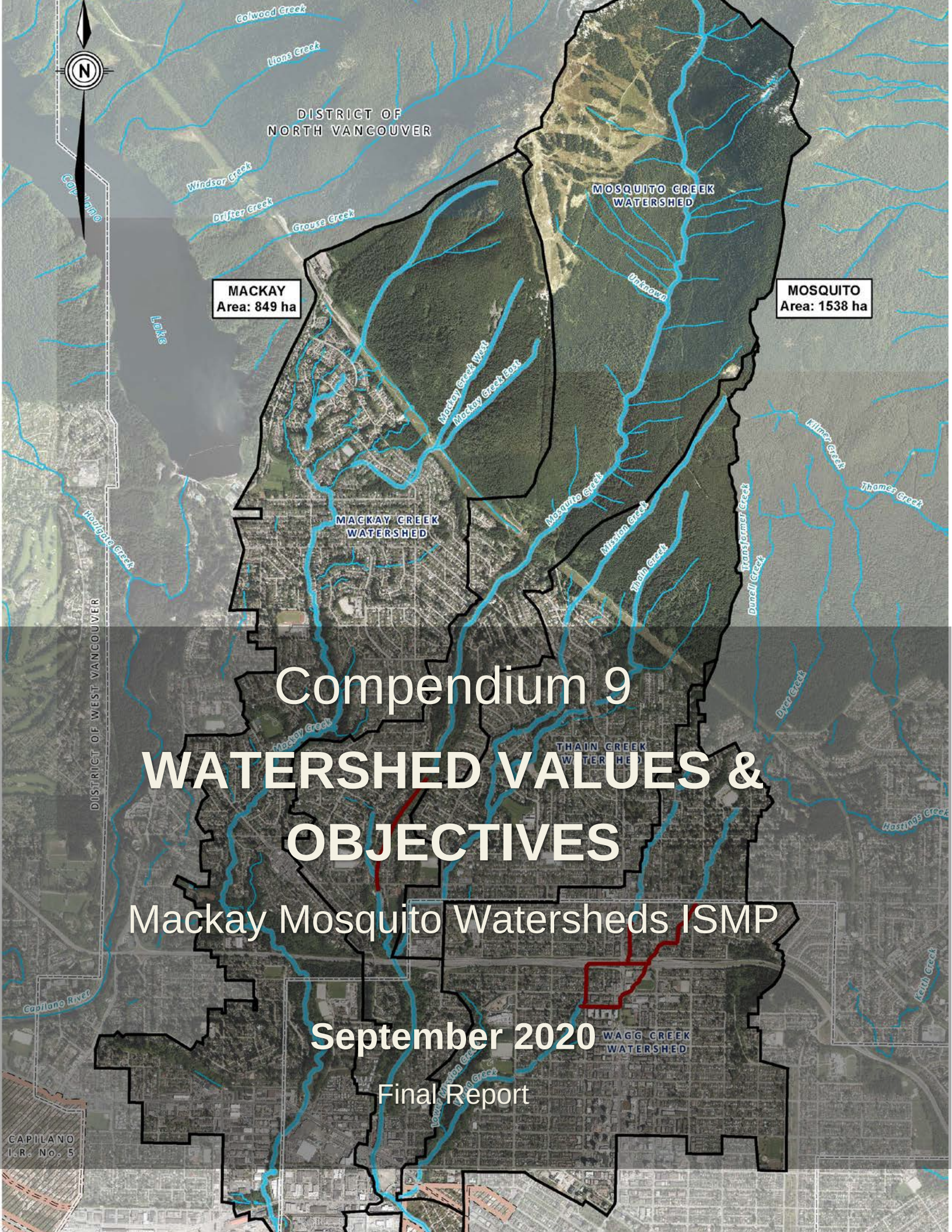
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Revision History

Revision #	Date	Status	Revision	Author
0	Sept 21, 2020	Final	Issued as final for client copy.	CC



Compendium 9

WATERSHED VALUES & OBJECTIVES

Mackay Mosquito Watersheds ISMP

September 2020

Final Report

Contents

District of North Vancouver Integrated Stormwater Management Plan Framework and Objectives

City of North Vancouver Integrated Stormwater Management Plan

NORTH VANCOUVER
DISTRICT

District of North Vancouver Integrated Stormwater Management Plan Framework and Objectives

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INTRODUCTION

The District of North Vancouver (District) is uniquely situated at the base of the North Shore Mountains where the land intersects with the water of the Burrard Inlet. Both the mountains and inlet support one another through the supply of rainwater and delivery of freshwater down the mountain slopes where they pick up nutrients and provide aquatic habitat on route to the Burrard inlet. These diverse and abundant watersheds have supported the first inhabitants of this land, the Coast Salish people (Tsleil Waututh Nation, Squamish Nation and Musqueam Nation), since time immemorial.

Today, these watersheds continue to service the Tsleil Waututh Nation, Squamish Nation and Musqueam Nation along with the citizens of the District and City of North Vancouver. Our use and non-use values of the local watersheds range from rainwater conveyance, recreational use, cultural use, drinking water supply, natural habitat and a beautiful place to live. Values that support the vision of the District:

"Inspired by nature, enriched by people."

This ISMP along with future implementation plans will help protect, support and move the community towards this vision.

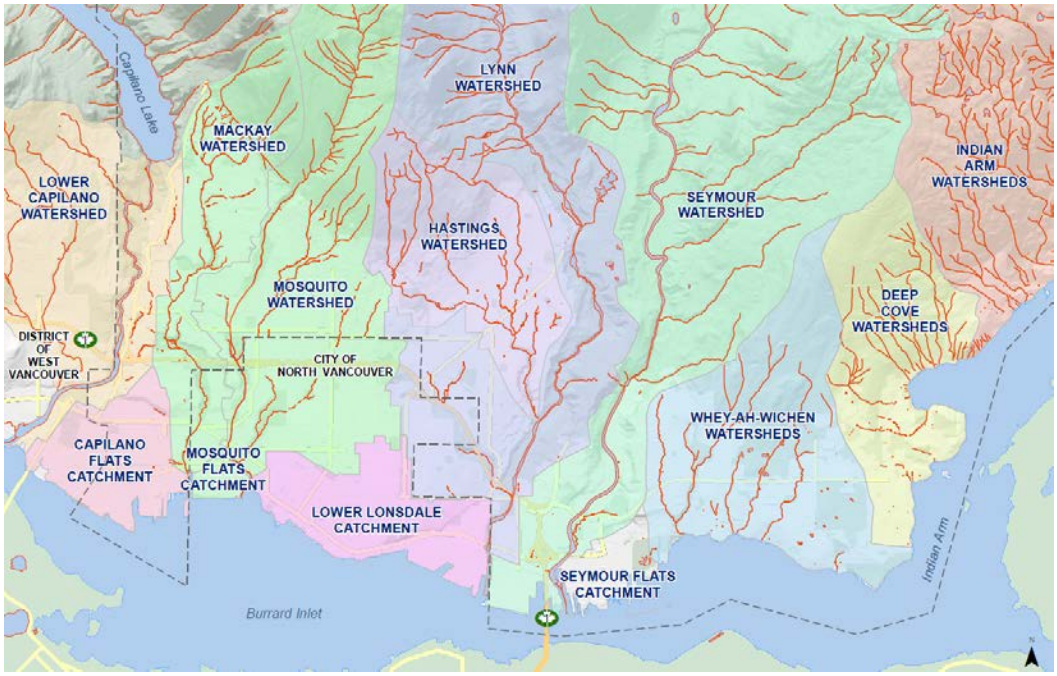


Figure 1: Watersheds in the District and City of North Vancouver

PURPOSE

In developed areas, impervious surfaces such as pavement and roofs prevent rain from naturally soaking into the ground. When rain is prevented from soaking into the ground, it flows overland and is collected into drainage infrastructure where it is directed to local watercourses. This overland flow is called stormwater runoff and as we continue to increase the amount of impervious surface in our communities from land use change, we increase the amount of stormwater runoff, decrease the recharge of groundwater, how fast it flows and the pollutants it picks up along the way. Historically, natural forest was harvested and replaced with housing and roads that extended up the mountainside as streams and wetlands were covered over. The traditional approach to dealing with stormwater, piping it as quickly as possible to natural streams or the sea, as the community expanded, has led to negative impacts from disturbing the natural Water Balance. These impacts include:

- Stream bank erosion and flooding;
- Toxic pollution in watercourses;
- Ecological damage and habitat loss;
- Expensive drainage sewer upgrades and maintenance; and
- Insufficient groundwater supply to support stream base flow requirements.

The 2011 Official Community Plan (OCP) is based on compact, complete and connected networks of densified centres. It identifies a slowing trend of community expansion that results in the displacement of natural land and a commitment to mitigate damage to watershed health. However, disturbance to the natural Water Balance (evapotranspiration, runoff, and infiltration) can be expected to increase in the District of North Vancouver as development continues to increase in order to serve a rising population unless effective mitigation measures are applied. The OCP is projecting a population increase of 20,000 people by 2030 and 10,000 net new housing units through mainly higher density developments. Higher density developments should protect the displacement of natural land, however, there are still impacts on the natural water balance through reduced green space, increased impervious surfaces and underground construction. In some cases, single family homes are having a greater impact on the natural water balance than in the past as their lots become smaller through infill and homes and driveways get larger. Basements and underground parking structures are also impacting underground water movement and limiting the amount of infiltrating soil that would otherwise naturally recharge our local watercourses. Other forms of land use change will accompany development through road construction, park transformation and increased access to natural areas and trail networks will also impact the natural water balance.

In addition to our direct impacts on the land, climate change is projected to cause wetter winters and dryer summers. A recent climate change study completed by the District has identified an increase in rainfall by approximately 30% in the lower lands and 35% in the upper lands by 2100.

Therefore, as our communities continue to grow and rainfall events become more intense in the winter and less frequent in the summer, more holistic and integrated planning is needed to better understand the impact of decisions on all social, economic and environmental values.

Integrated Stormwater Management Planning (ISMP) was first envisioned in British Columbia in the 1990s to address observed degradation of watershed values and health as a function of new land development in undeveloped watersheds. This was commonly expressed as a loss of fish and fish habitat in streams due to removal of forested conditions and development of highly impervious landscapes. The concept of ISMPs were formalized in the early 2000s with both the Province and the Greater Vancouver Regional District (Metro Vancouver) creating guideline documents to assist in the creation of plans. At the same time, the Province mandated that all member municipalities prepare ISMPs for watersheds where there was substantial, planned or existing development.

APPROACH

To mitigate the cumulative impacts of stormwater runoff resulting from changes to land use, the proposed ISMP aims to connect the natural and built environments to protect and enhance social, economic and environmental values of our community in essence to move towards the OCP vision. An "aid to thinking" framework is used to identify, understand and balance trade-offs building on the core planning elements identified by the Province: What do we have; what do we want; and how do we get there?



Figure 2: Core elements of the planning process

The framework incorporates an iterative process to support adaptation requirements as environments, needs, values and knowledge change over time. As such, the adopted framework includes a five step process that is transparent, communicates decision making and is continually improved and built upon over time. A description of the process is provided below and illustrated in Figure 3.

Step 1: Identify values and problems
The first step of the framework includes the systematic identification of problems and values through a participatory approach that merges community knowledge and values with scientific findings. This approach helps develop a systematic understanding of what we have, how we have gotten here and what we want.

Step 2: Define objectives and performance measures
The second step includes the identification of planning goals and objectives along with performance measures to identify how to meet the intended objectives. These performance measures are then applied in the third stage to evaluate alternative activities that have been identified. They can also be applied outside the ISMP context to help integrate ISMP objectives in other plans and designs.

Step 3: Develop and evaluate alternatives
The third step involves the identification of various actions or activities relevant to the problems and objectives in our watersheds. By ensuring several alternatives are developed, decision makers can compare a range of solutions based on the trade-offs of estimated consequences and values attributed to each objective.

Step 4: Implement plans
Once solutions have been evaluated, the implementation of these solutions is to be carried out through the ISMP Implementation Plans and supporting programs. The implementation of solutions will also include the development of specific monitoring criteria and indicators which are not part of the region wide *Monitoring and Adaptation Management Plan* but considered relevant for that watershed.

Step 5: Monitor and evaluate
Following the implementation of each ISMP Implementation Plan, ongoing monitoring and evaluation is to carried out and inform values and problems observed post implementation.

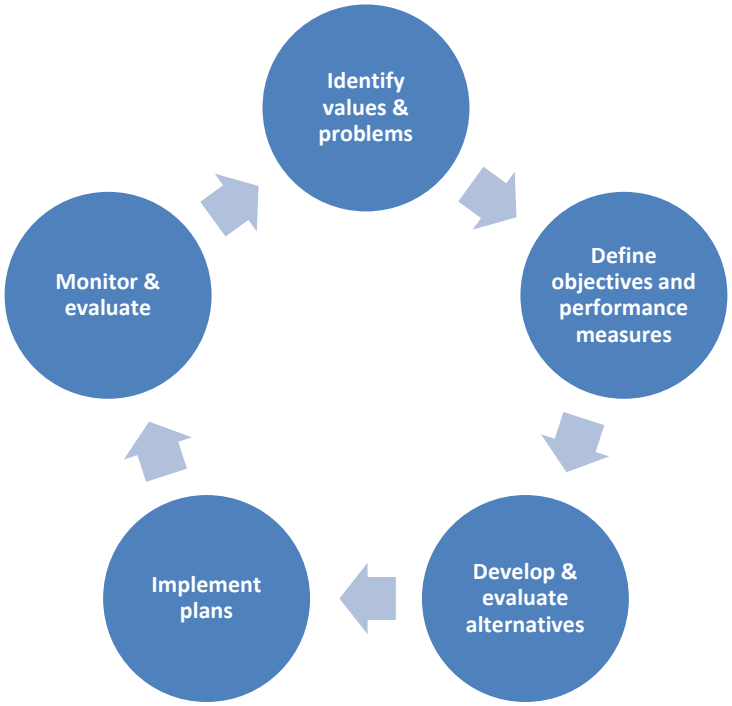


Figure 3: Framework

Given that there are many watersheds within the District's municipal boundaries with unique land use priorities and social-ecological environments, the proposed ISMP aims to inform the policy component of the integrated planning process. Following the adoption of the ISMP, Watershed Implementation Plans for each watershed will be developed to the needs and constraints of individual watersheds through the development of local performance measures, evaluation of alternative activities and monitoring efforts. As such, the ISMP focuses on the identification of values, problems, objectives and supporting programs to carry out the remaining steps at the watershed level.

VALUE AND PROBLEM IDENTIFICATION

Values and problems were identified throughout the District using a participatory approach that integrated the OCP, external public consultation and scientific studies and reports.

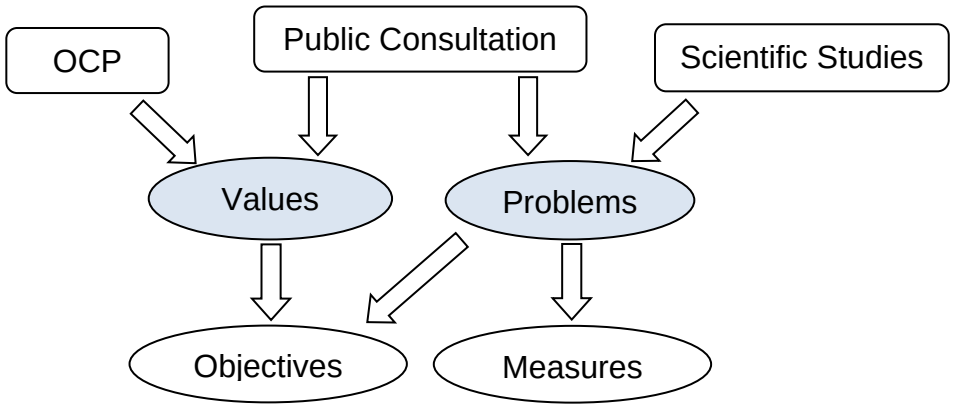


Figure 4: Value and problem inputs and outputs

District OCP

The District's OCP identifies a long term vision for the District that is: "inspired by nature and enriched by people". The plan is intended to help guide District Councils, stakeholders and citizens effect positive change over a twenty-year time horizon. It also includes polices that impact a broad range of municipal affairs and provides ongoing guidance to municipal decision making and operations. The vision, principles and goals identified in the OCP were developed over a 2 year community engagement initiative. Policies directly related to watersheds are identified in section 9.3 and include:

1. Prepare and implement integrated watershed/stormwater management plans for all District watersheds prioritizing watersheds containing key growth areas;
2. Facilitate the protection and enhancement of streams, riparian areas and wetlands;
3. Facilitate the maintenance of fish passage in all streams and restore habitat and connectivity in riparian areas for the District;
4. Encourage measures to infiltrate rainwater onsite, where appropriate, and manage impervious areas to reduce runoff volumes, improve water quality, and recharge groundwater; and
5. Facilitate the protection and maintenance of groundwater levels where appropriate, and manage the amount of groundwater pumped into drainage infrastructure.

Public Consultation

Public input was obtained from a series of open houses, advisory group meetings and workshops with the local streamkeeprs group. These public sessions were held with the City of North Vancouver to coordinate efforts in shared watersheds.

A total of two open houses were held at the beginning of the ISMP process to encourage public interest and identify values and connections citizens had with their local watersheds. Concerns were also identified and citizens shared stories about how the watercourses have changed over time due to land alterations and every day human activities. These initial open houses also provided an opportunity for citizens to sign up to receive ongoing communication around ISMP development.

Feedback from the open houses also identified that citizens were interested in contributing in the development of the ISMPs so combined meetings with the ISMP Advisory group and the Parks and Natural Environment Advisory Committee (PNEAC) were carried out. This approach was also seen as being more holistic and followed the integrated goals of the planning process. These meetings focused on communicating identified concerns and opportunities for collaboration on park, natural environment and watershed objectives. It also provided an opportunity to understand constraints and value conflicts between objectives.

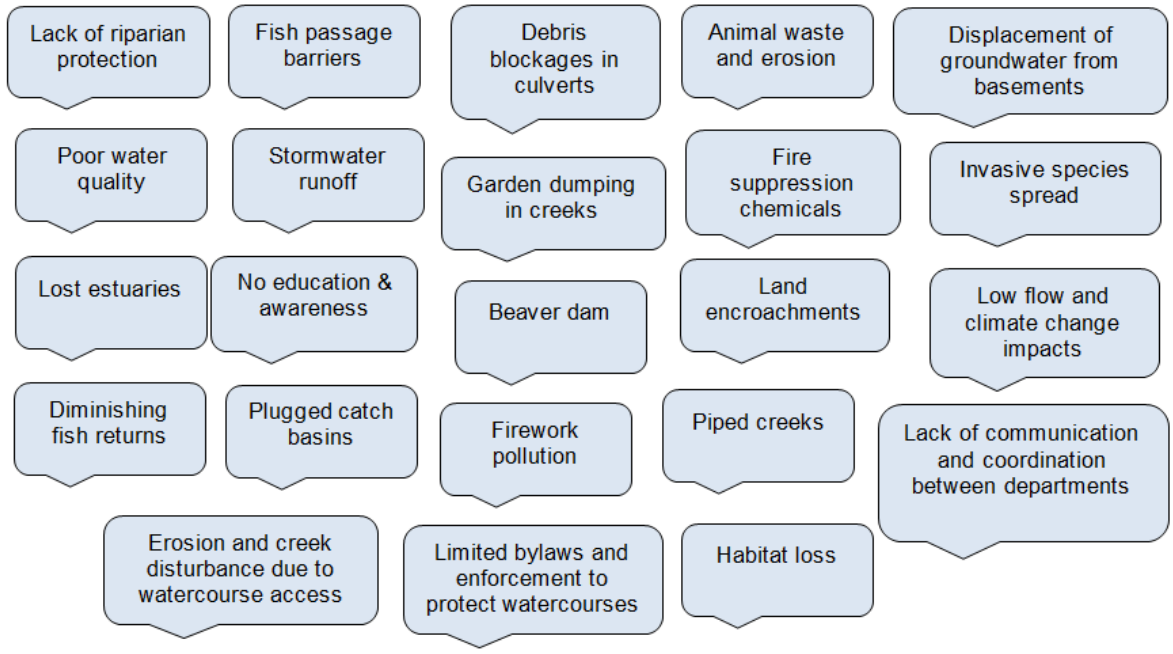
District and City staff also hosted workshops with North Shore Streamkeeper's (NSSK). As active community members, the NSSK have been monitoring, improving and protecting local watercourses for over 20 years. To ensure the planning process compliments their efforts and knowledge, workshops focused on the identification of watershed issues, collaboration and opportunities throughout our communities.

Table 1: Summary of public consultation

Date	**Location**	**Number of Attendees**
Open Houses		
February 27, 2014	City of North Vancouver	9
November 25, 2014	District of North Vancouver	22
Advisory Meetings and Workshops		
September 23, 2014	District of North Vancouver	12
February 25, 2015	District of North Vancouver	17
October 29, 2015	District of North Vancouver	10
June 21, 2016	District of North Vancouver	7

In addition to the open houses and advisory meetings, District and City web sites provided ongoing information on the ISMP progress, meeting notifications and contact information for further inquiries. The City also provided an online survey that allowed citizens to provide input at their convenience.

Overall, the public identified a wide array of values associated with local watercourses and watersheds including fish, wildlife, habitat, clean water, open channels, riparian protection, and recreation. These values stem through generations and tell the story of a strong cultural connection to nature here on the north shore. Concerns were also identified and are used to help identify cause and effect relationships specific to our watersheds and human behaviour. Concerns are summarized below.



Scientific Studies

The District has completed several studies to better understand the current state of our watersheds and identify existing and future risks that may impact local values and municipal services.

The first study was to identify the impact of a changing climate on rainfall events on the North Shore. Intensity, duration and frequency curves (IDF curves) are used to estimate rainfall amounts to size infrastructure and identify return periods for storm events (i.e. 100 year rain fall event) and IDF data had not been updated since 1980. To update this information, data was used from rainfall gauges throughout North Vancouver owned by both the District and Metro Vancouver. Climate change impacts were then added to the analysis using an RCP of 8.5 in line with the District's Climate Adaptation Strategy.

Using the newly updated IDF curves, a drainage analysis of municipal infrastructure was carried out using the hydraulic modeling software InfoSWMM. The analysis included modeling scenarios for current and future land use to identify runoff rates and volumes and the corresponding loads for drainage infrastructure such as storm sewers, ditches and culverts. The results of the analysis are currently being assessed and do not identify any immediate concerns regarding existing infrastructure sizing. In the future, the analysis can be broadened to assess the effects of implementing low impact

development techniques and can also include the modeling of watercourses to identify low and peak flow needs.

In accordance with the Regional Monitoring and Adaptation Management Framework required by the Ministry of Environment, the District began its water and aquatic health monitoring in 2015. This includes the monitoring of watercourse flows, water quality and biotic integrity at 27 sites throughout the District. Results from the 2015 monitoring program identified concerns with the following water quality indicators that were more than 5 times above the acceptable limit ("needs attention"):

- E. coli
- Fecal Coliforms
- Dissolved Oxygen
- Copper
- Zinc
- Iron
- Aluminium
- Beryllium
- Conductivity
- Turbidity

Biotic integrity also ranged from very poor to fair which support the water quality results obtained which require us to improve the quality of our drainage effluent and watercourse health to meet regional standards.

Values

To ensure a holistic value-based foundation, the ISMP process has integrated the vision and values of all stakeholders to identify the following values:

Environmental Values

- Protect and restore environmentally sensitive and vulnerable areas
- Preserve the environment and ecosystem functions
- Integrate climate change adaptation into decision-making
- Promote environmental stewardship within our communities and organizations

Cultural, Spiritual and Social Values

- Promote human connections to land and water
- Promote health and wellness
- Respect and protection for indigenous Cultural Heritage
- Reduce the risk of property damage

Economic Values

- Maintain a strong economy and employment opportunities
- Support economic development opportunities
- Integrate efficiency, feasibility and acceptability into decision-making

Problems

To help communicate what the problems are and why the problems are occurring, the development of a problem tree, or problem analysis, was completed using public and scientific information and knowledge. Figure five on the following page shows the cause and effect relationships of watersheds in the District. The main focal problem has been identified as being our inability to implement new methods and approaches in a coordinated manner which has led to continual social-ecological inefficiencies and losses.

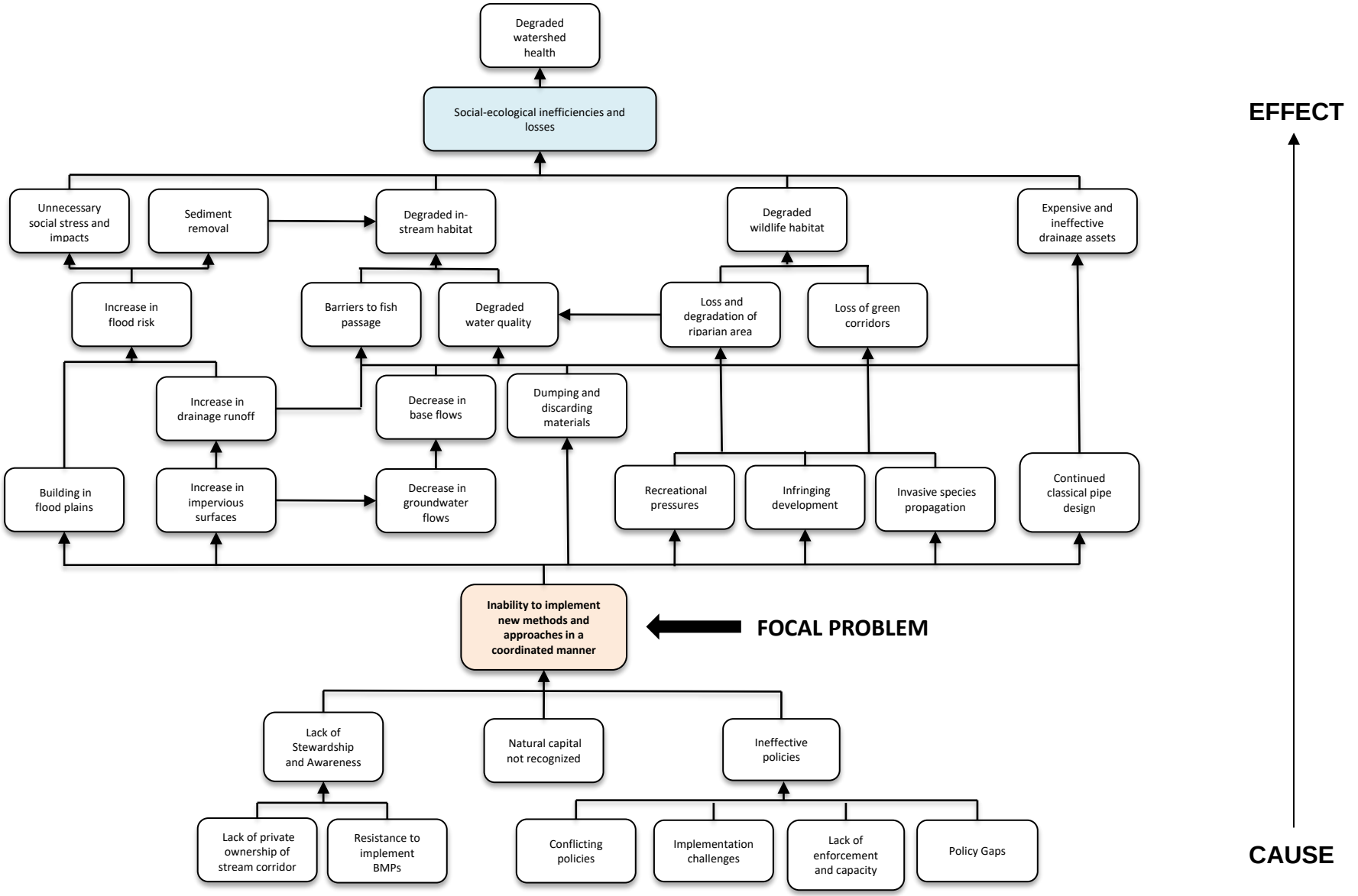


Figure 5: Problem Tree

OBJECTIVES AND PERFORMANCE MEASURES

Objectives are concise statements of the fundamental interests that could be affected by a decision. They are the things that matter and become the basis for creating and evaluating management alternatives.

Objectives

Using the problem tree we were able to identify preliminary objectives for the watersheds to achieve the overall goal of improved watershed health. Figure six illustrates the goal and primary objectives grouped into the broad areas of environmental, social and economic wellbeing.

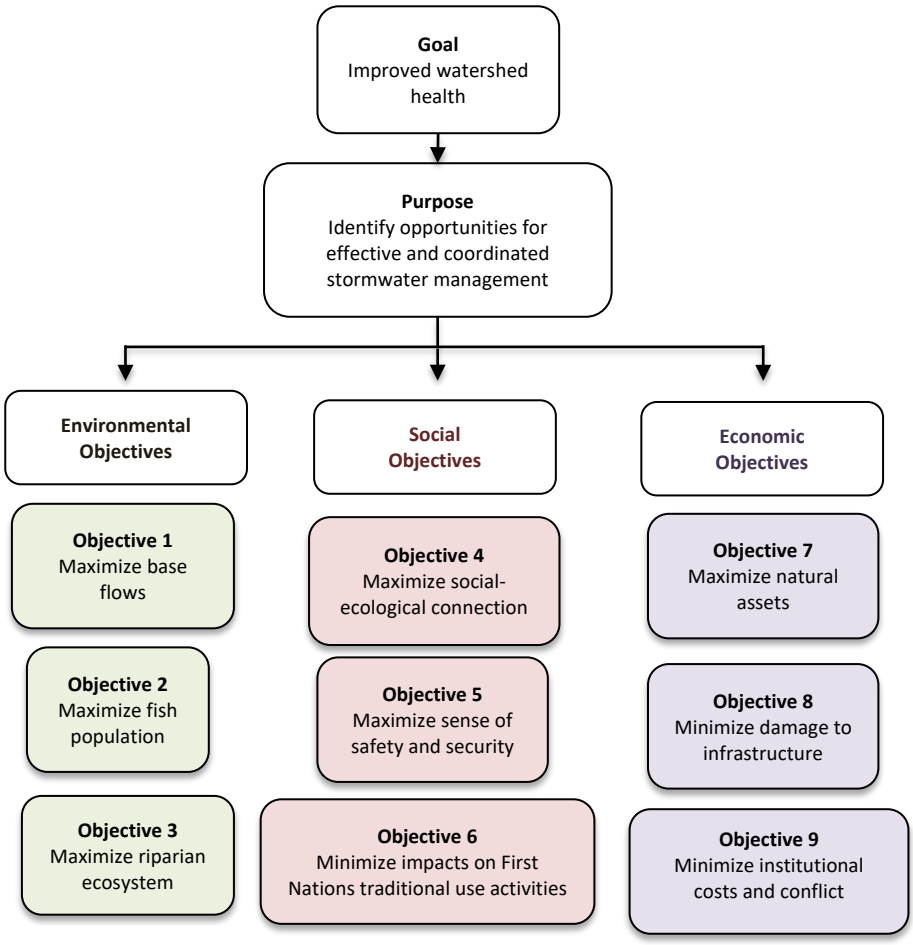
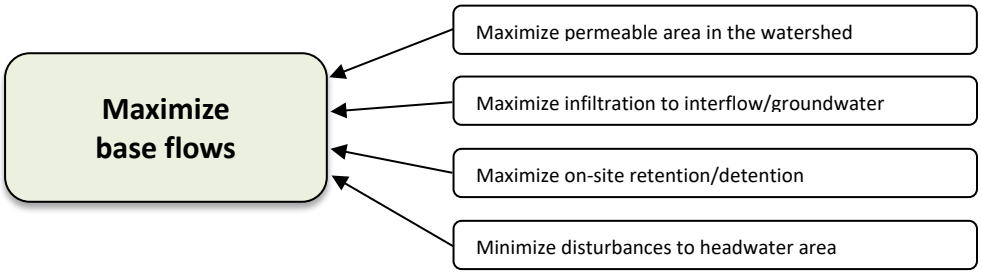


Figure 6: Objective tree

Environmental Objectives and Sub-objectives:

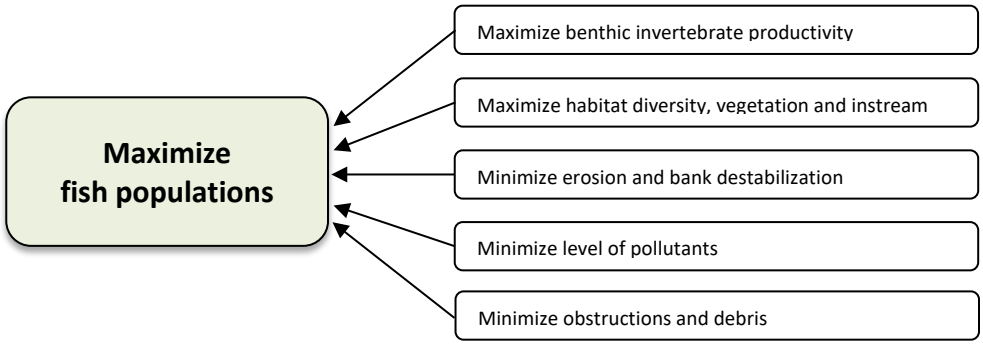
Maximize base flows

Understanding base flow conditions in surface water resources is an important aspect of water management and environmental protection. Base flows come from delayed sources, such as groundwater, and ensure our watercourses have sufficient water to support habitat, food production, water quality, livelihoods, and wellbeing. Here in the District, base flows are under threat from an increase in impervious surfaces and the displacement of groundwater caused by land use change. To mitigate this threat, we can protect the natural environment and mitigate the impacts of land use change by infiltrating rainwater and hold back rainwater to mimic the natural water balance.

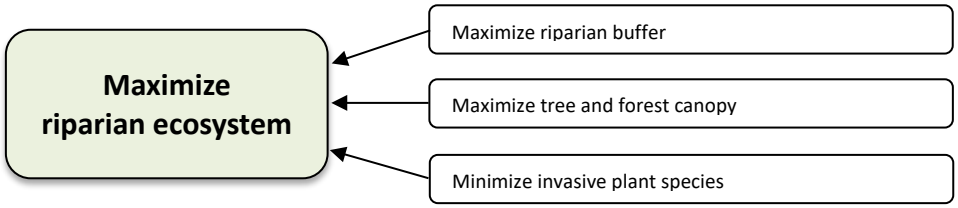


Maximize fish populations

Fish are an important value to North Vancouver through the provision of food, culture, recreation and supporting tourism services. Local watercourses provide fish spawning and habitat for both local and anadromous fish that travel out into the pacific beyond Vancouver Island before returning to our local watercourses. Decreasing ability of our watersheds to maintain healthy fish populations have resulted in the establishment of the Capilano and Seymour fish hatcheries to ensure natural salmon (coho, stealhead and chinook) can continue to thrive in British Columbia. To minimize the risk to remaining fish populations, or tragedy of the commons, it is important that we ensure our watercourses provide food, habitat, clean water, and enough flow. It is also important that we do not increase flows too much causing erosion or block the ability of fish to pass through culverts and other structures.

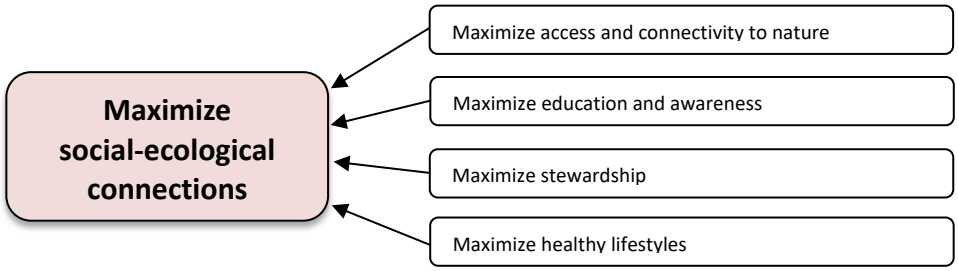


Maximize riparian ecosystem
Riparian refers to the unique ecosystems that surround the banks of watercourses that produce lush vegetation due to better soil and water availability. Healthy riparian areas have many important functions in our watersheds including the storage of floodwater, reduction of erosion, provision of habitat, and improved water quality. To protect our riparian ecosystem we can reduce the amount of development within 45 metres of the high water level, plant native vegetation including trees and remove invasive species.

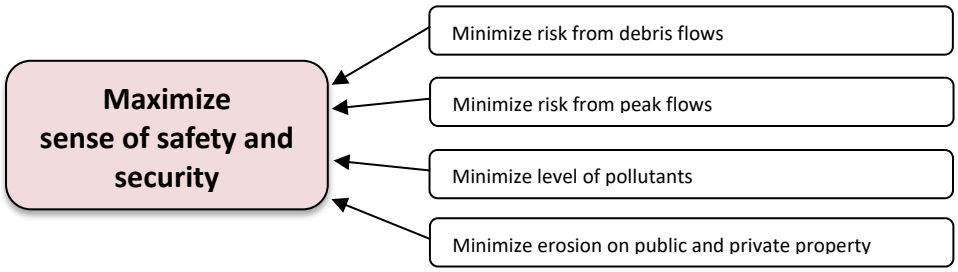


Social Objectives and Sub-objectives:

Maximize social-ecological connection
Recreation in our watersheds supports a variety of interests and values and can provide an opportunity to increase education and awareness on the services provided by our watersheds. It is also known that being in and near water increases our personal well-being. Ensuring public access to local watercourses will have long lasting positive impacts on our community and the individuals that visit our watersheds daily.

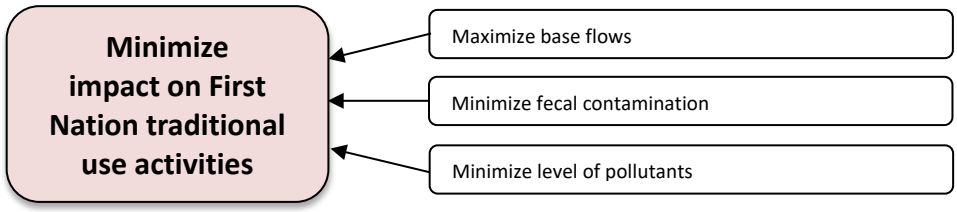


Maximize sense of safety and security
As rainfall events become more intense and we continue to change the land that once absorbed and slowed down that rainwater, we increase our risk to hazards. These hazards are common for communities located in similar environments, however, it is how we develop that can change our level of risk. To improve our safety and security, it is important that we understand how and where hazards such as peak flows and water contamination can impact our community and consider designs and standards that minimize risks in a cost effective manner. This will include the identification of an acceptable level of disruption under certain circumstances or areas.



Minimize impacts on First Nation traditional use activities

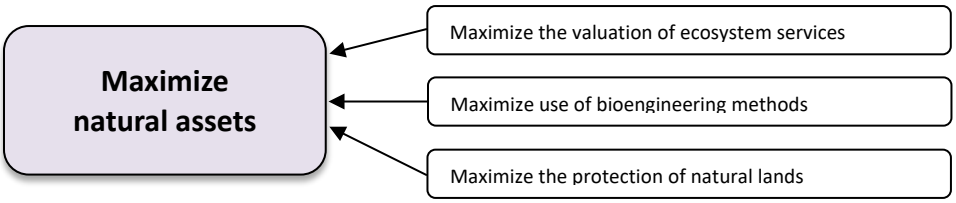
The Tsleil-Waututh Nation and Squamish Nation have lived on the North Shore and occupied land surrounding North Vancouver along with the Musqueam Nation and Stó:Lo Nation since beyond recorded history. Their intimate knowledge of the lands and waters within their territories has shaped their people and continue to provide traditional use activities. To ensure that our communities can sustain and enhance our cultures, it is important that we care for the waters together. This includes ensuring there are base flows available in creeks and the removal of fecal and other contaminants in watercourses that are used for traditional activities.



Economic Objectives and Sub-objectives:

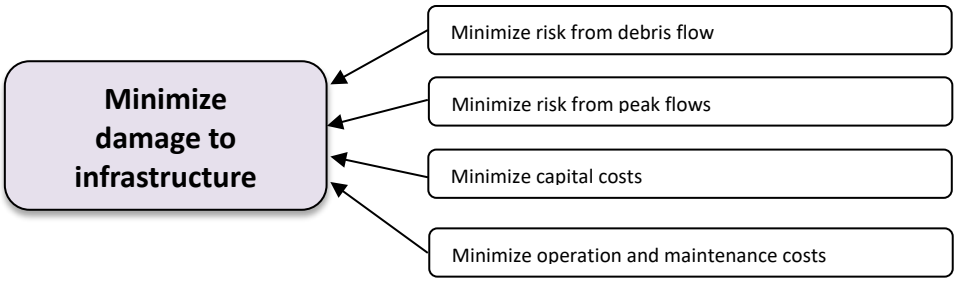
Maximize natural assets

Natural assets are naturally occurring environments that provide municipal services through their naturally occurring ecosystem services (provisioning, regulating, supporting and cultural services). District relies on natural assets for the provision of stormwater conveyance to the Burrard Inlet, the regulation of flows and water quality through natural lands and estuaries, and cultural benefits through outdoor recreation and tourism. Recognizing our natural assets and encouraging designs that provide both ecosystem and municipal services is important for strong sustainability and to minimize negative externalities from development.



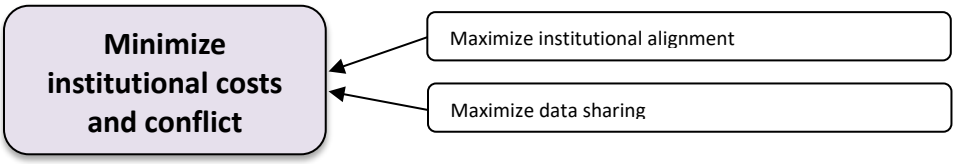
Minimize damage to infrastructure

As rainfall events become more intense and we continue to change the land that once absorbed and slowed down that rainwater, we increase our risk to hazards. These hazards are common for communities located in similar environments, however, designs and development standards can change our level of risk and ability to restore services. To minimize damage to infrastructure, it is important that we understand how and where hazards such as peak flows and erosion can impact our infrastructure and consider tiered design standards that serve multiple risk levels in a cost effective manner. This will include the identification of on site and off site solutions that work together and compliment other services.



Minimize institutional costs and conflict

Institutional transaction costs include costs associated with information, coordination and enforcement. It is considered that when these costs are minimized, institutions are efficient and able to achieve their intended outcomes. To minimize institutional costs and conflict, it is important that local, regional, provincial and federal expectations are aligned and do not describe conflicting standards. It is also important to ensure we share information with other organizations to improve knowledge and trust.



Performance Measures

When making a choice among possible actions, performance measures can be used to consistently estimate and report on how well each alternative will performance in respect to a particular objective. Whereas objectives may be quite broad, performance measures need to be specific because they define how an objective is to be interpreted and evaluated for the purposes of decision making.

Performance measures will be identified in the implementation plan of each watershed as although objectives and their sub-objectives identified in the previous section will be consistent across the District, watersheds may have slightly difference performance measures (or targets) for each sub-objective depending on current conditions and local constraints. For example, Capilano watershed has high groundwater flows making infiltration in some areas unreasonable due to potential risks of daylighting groundwater further downhill. In addition, flows in Capilano River are also controlled by the Capilano dam managed by Metro Vancouver to ensure water supply to Metro member municipalities. Flows can vary in the river from dam operations resulting in less of an impact from peak stormwater runoff rates from land use change caused by development. As such, performance measures related to maximizing base flows will reflect these constraints with modified targets in the Capilano Watershed Implementation Plan.

Integrated Stormwater Management Plan

NOVEMBER 2016 | ENGINEERING PARKS AND ENVIRONMENT









Document Number: 1465270

Images from Cover – Left to Right: Mosquito Creek at Burrard Inlet (year unknown), Mouth of Lynn Creek prior to port development (1953), Mouth of Lynn Creek (2015)

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Section 1 – Commitment and Purpose

The City of North Vancouver (City) has made a commitment in the Official Community Plan to prepare and implement an Integrated Stormwater Management Plan in support of the regional Integrated Liquid Waste and Resource Management Plan (Metro Vancouver, 2011) as mandated by the Ministry of the Environment under the Environmental Management Act.

Integrated Stormwater Management Plans (ISMPs) are watershed based plans that are created to protect watershed values as development and redevelopment changes the landscape. Watershed values are often measured in terms of ecological health, such as abundance and diversity of aquatic and terrestrial animals, or density and health of forest areas. Watershed values also include social elements, which include public safety and health and traditional uses and values of First Nations citizens, and could be measured in terms of protection from floods, quality of water in streams, and access and recreation opportunities in stream corridor parks.

The Plan establishes a framework to recognize and integrate these different values, and focuses on evolving the established practice of managing rain as stormwater in storm sewers to support an overall goal of net change.

The City shares, to varying degrees, three streams with the District of North Vancouver, Squamish Nation and Port Metro Vancouver. These include: Mosquito Creek (and tributaries Wagg Creek, Thain Creek, and Mission Creek), Mackay Creek, and Lynn Creek (and tributary Keith Creek).

Section 2 - Problem Statement

Prior to settlement and development, the watersheds of North Vancouver were densely forested, with a rich layer of organic (humic) soil over a mantle of dense sand, silt, and gravel that was deposited following the last glaciation. On an average rainy day in the forest, most of the rain would be intercepted in the tree canopy, and the remainder captured in the forest soils where it would slowly move to the streams as shallow groundwater in a process that may have taken weeks. This natural hydrological process would temper the flow in streams, providing a steady source of streamflow during dry periods and limiting the streamflow peaks during rainy periods which provided an environment for an abundance of local and sea-faring (anadromous) fish and the natural food web that they are part of.

Development has introduced an artificial efficiency where the roads and roofs are directly connected to storm sewers to deliver rainfall to streams in minutes as stormwater instead of days or weeks. The introduction of hard (or impervious) surfaces (roads and roofs) and loss of tree cover and absorbent soil is the largest change to the hydrological response of watersheds, and is the prime reason for the environmental degradation in streams and coastal areas. The rapid delivery of rainfall to streams has resulted in channel instability and erosion, loss of habitat, and loss of species. In addition, the connection of roads and other areas to storm sewers is a direct route for pollutants (e.g. heavy metals and hydrocarbons) to reach streams, as well as biological pathogens such as fecal coliform bacteria (e.g. *Escherichia coli*).

While the development of our community and watersheds necessitated an efficient storm sewer network to safely drain areas, proper consideration of environmental consequences were not included between the 1940s and 1980s when much of this growth occurred. Research

conducted in the 1990s in Puget Sound found that once a watershed became more than 10% impervious (total impervious area), that permanent cumulative impacts to aquatic habitat would begin to occur.

The recent *Living Planet Report* prepared by the World Wildlife Foundation (October, 2016) indicated that, on average, world populations of vertebrate species declined by 58% between 1970 and 2012. More significant is that freshwater habitats (rivers, streams, wetlands, and lakes) represent only 0.8% of the Earth's surface and only 0.01% of the world's water. Total populations of freshwater species (fish, birds, amphibians) are estimated to have declined by 81% in the same period from 1970 to 2012, while both freshwater and anadromous fish populations only declined by about 41%.[1]





The key identified threats to wildlife populations are: habitat loss and degradation, species over-exploitation, pollution, invasive species and disease, and climate change. Habitat loss is by far the most dominant driver to declining freshwater and terrestrial species, where the most common causes of loss are attributed unsustainable agriculture, logging, transportation, residential and commercial development, and other resource development.

These global estimates of species population decline are alarming, and they illustrate the magnitude of environmental loss that has already occurred and scarcity and importance of freshwater and freshwater habitats. They further underscore that all freshwater resources should be protected and enhanced to support what remaining wildlife still exists, even in urban streams.

The City's development began at the onset of the 20th century and saw periods of rapid growth in the early part of that period, and again in the 1950s and 1960s. By the 1980s, the last major new residential development in the City occurred as the Tempe Heights neighbourhood was developed, and since that time the overall extent of development in the City has not substantially changed. Since the 1990s the City has been in a period of redevelopment, where the first generation of development is being surpassed by a second generation that is being built to meet the present and future needs of the City. The second generation of development is generally increasing the impervious areas on an incremental level as smaller houses make way for larger ones, and more intensive use of hard surfaces is used to support all modes of transportation.

A multi-spectral image that assesses landscape cover, captured in 2010, was used to estimate the percentage of hard or impervious surfaces in the City. The analysis of this image allows for identification of different vegetation types, as well as identification of hard surfaces like paving and roofing, and could be used for future comparative analysis of land cover.

[1] 2016, *Living Planet Report 2016*, World Wildlife Federation (including images)

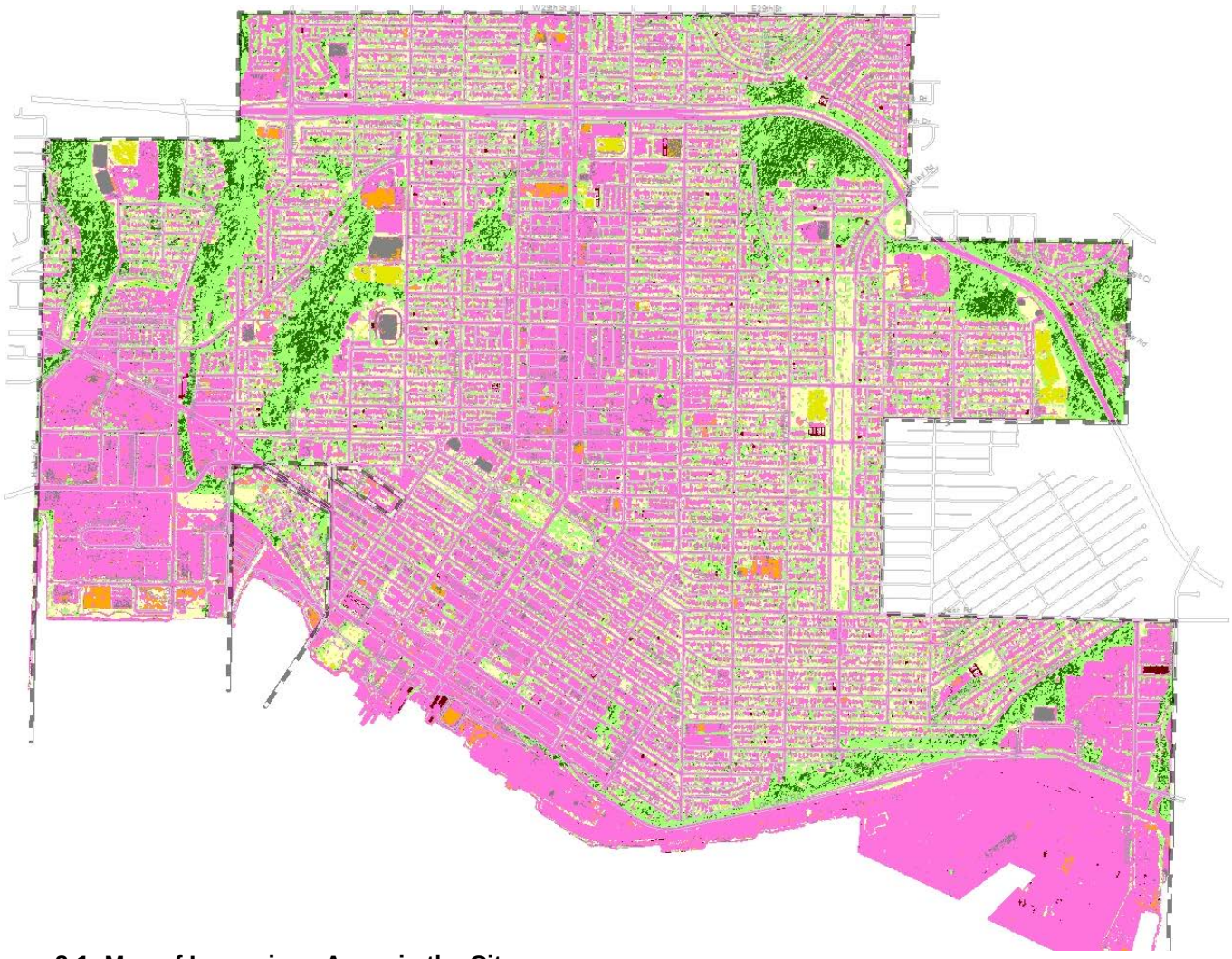


Figure 2-1: Map of Impervious Areas in the City

In Figure 2-1, the mass of pink area represents impervious surface, while the range of yellows to greens indicate a range of vegetation from grass to deciduous and coniferous trees. Based on this tool, the total impervious areas (TIA) in the City can be estimated as follows:

Table 2-1: Summary of Total Impervious Areas by Region

Area	Description	Percent Impervious
City-wide	Including all land-uses	55%
Wagg Creek watershed	Including District areas	50%
Mosquito Creek watershed	Including District and undeveloped areas	29%
City Street Right-of-Ways	About 17% of City area	83%
Typical Low Density City Lot	Range of older home to new build	35% - 65%

CURRENT STREAM HEALTH

The increase of total impervious area in the City has had an effect on health of streams. A common method to assess the biological productivity of streams and the effect of poor water quality and rapid runoff of rain is through stream insects or benthic invertebrates. Metro

Vancouver began the first round of benthic invertebrate measurements in 1999, which included Wagg Creek, and the City has continued a program of monitoring as part of the City's Environmental Protection Program (2000). The Biological - Index of Benthic Invertebrates (B-IBI) is the recommended system to evaluate the quantity and diversity of stream insects, where a very low value would be below 10.0 and a very high value would be above 35.0.

At the onset of the measurements in 1999, Wagg Creek measured a B-IBI of **11.5** and has steadily improved over the years with a peak measurement of **20.0** in 2012. Table 2-2 summarizes the B-IBI values of the three main benthic invertebrate measurement locations.

Table 2-2: Summary of Benthic Monitoring Data (B-IBI)

Year	Mackay Creek	Mosquito Creek	Wagg Creek
1999	-	-	11.5
2003	15.5	22.5	15.0
2004	-	-	15.0
2006	20.0	19.5	18.5
2008	18.0	20.0	17.0
2009	-	-	18.0
2010	17.5	21.0	14.0
2012	21.0	23.5	20.0
2014	22.0	27.5	19.0

Wagg Creek is the most urbanized stream in the City, has a total impervious area (TIA) of greater than 50%, and receives a large portion of runoff from roadways, including Highway 1, near Lonsdale. The B-IBI in 1999 is very similar to other very urbanized streams, most notably Still Creek in the City of Vancouver. A B-IBI score of **11.5** suggests that the stream is subjected to poor water quality (e.g. metals, hydrocarbons, etc.) and stream flows may be too high to allow the lowest level of the food web to establish.

A secondary issue associated with increase in TIA is a diminishing capacity of storm sewer infrastructure. The City storm sewers were first recorded to have been constructed in 1910, with only 10% of the present day storm system constructed by 1960, about 50% constructed by 1970, and more than 85% constructed by 1985. The majority of the City's current storm system was constructed during a short period in the 1960s at a time when the design of this infrastructure was based on the practice of the day, and likely did not foresee the level of impervious surfaces that are being presently introduced.

As green space on each property parcel lessens, the demand on the storm sewer infrastructure increases. The performance criterion for the storm sewer system is the ability to carry a rain storm that would on average only occur once every 10 years (10-year return period rain event). As impervious surfaces increase, the runoff associated with a 10-year return period rain storm will increase proportionally with TIA, and a 20% increase in hard surfaces would roughly result in 20% more flow into the storm sewers.

CLIMATE CHANGE

Climate change due to atmospheric forcing of greenhouse gases is anticipated to occur more rapidly in the coming decades and is foreseen to result in warmer temperatures, more rainfall, seasonally heavier rainfall, and increase in mean sea level. While the rate and magnitude of

climate change is uncertain, global climate scientists have developed possible climate change estimates associated with possible carbon emissions scenarios.

For the Pacific Northwest, it is foreseen that total rainfall will increase during the three wetter seasons, with rainfall decreasing in the summer period. Based on a moderate carbon forcing scenario (RCP 4.5), a change in total seasonal rainfall is foreseen for this region, and is summarized in Table 2-3

Table 2-3: Summary of Total Rainfall by Season Change Under Moderate CO2 Emissions Scenario

Period	Fall	Winter	Spring	Summer
Current	0%	0%	0%	0%
2050	11%	5%	8%	-18%
2080	19%	14%	12%	-29%

In this region, there are two seasonal families of rain storms: long, moderately-heavy rain events that occur between October and January, and short, intense rain events that typically occur in the summer. The most notable storm in the City in recent history is the August 29, 2013 rain event that was centred over central Lonsdale resulted in over 60 mm/hour over a 10 minute period.

Using a higher carbon emissions scenario (RCP 8.5), an analysis using data from existing global climate models was used to estimate the frequency of future rain storm magnitudes. This preliminary analysis assumes that relationship between short rain events and daily rain events would be similar to the current climate. Under this possible future scenario:

- August 2013 storm would move from a 50-year event to that less than a 10-year return period event;
- 100-year events would roughly occur on a 10-year return period frequency; and
- 10 year events would occur approximately every two years.

Figure 2-2 below illustrates how the rainfall intensity curves would shift up relative to the indicator points for the 5 minute, 1 hour, and 24 hour storms. The hollow blue and red points indicate the August 29, 2013 storm, and how the 50-year return period storm in 2013 would be between a 2-year and 5-year event near the end of the century.

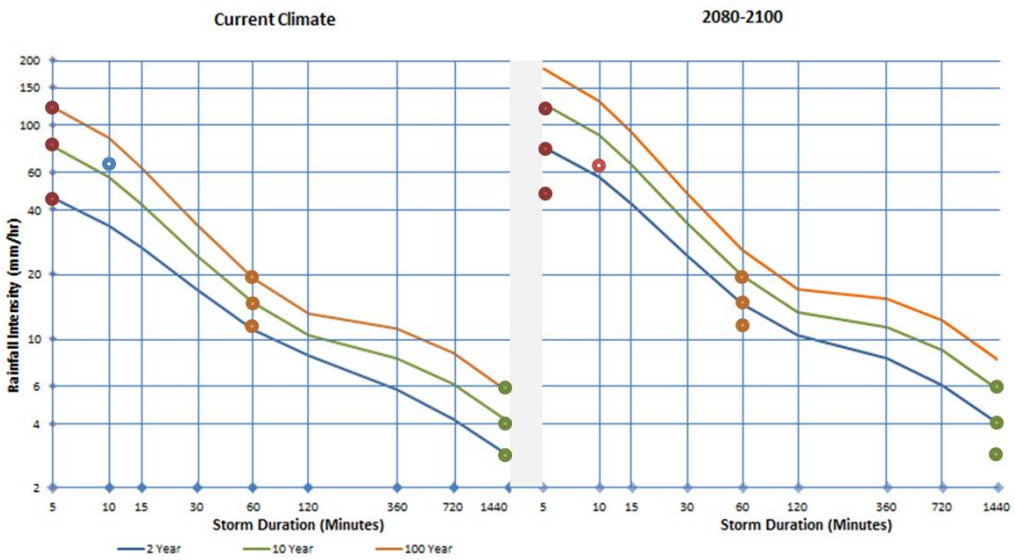


Figure 2-2: Estimate of Short Duration Storms For RCP 8.5 Scenario

Increased rain associated with climate change and an increase in impervious areas from ongoing redevelopment will further diminish the capacity of the storm sewer infrastructure and increase the risk associated with more frequent overland conveyance of storm water.

STORM SEWER AND INFRASTRUCTURE

The storm sewer system was first constructed in the 1910s with the construction of back-of-sidewalk drains that were typically constructed from 4" (100 mm) diameter clay tiles that collected local drainage and helped keep the sidewalks dry.







Since that time, the back-of-walk system has grown into a 148 km storm sewer system, where in some places the 4" back-of-walk system or laneway ditches are still the primary drainage infrastructure. Areas primarily relying on back-of-walk drains are considered "unserviced" and are a priority for new storm sewer construction. In addition to the 4" back-of-walk drains, we have a portion of the current storm sewer system that does not meet the current 10-year return period criteria. While these pipes are not normally problematic, capacity issues will increase with increased TIA and climate change. The following table summarizes the percentage of storm sewers that currently do not the design criteria, and the increase as TIA would be expected to increase under our current Official Community Plan and climate change.

Table 2-4: Pipe Capacity Summary

Condition	Length Undersized	Percent Undersized	Upgrade Cost
Current	32.1 km	21.7%	$16M
Future Total Impervious Area	72.6 km	49.2%	$36.3M
Future TIA and Climate Change	103 km	69.6%	$51.5M

The costs to upgrade storm sewer to meet the existing and changing drainage demand are substantial considering that most of the drainage infrastructure has not exceeded the current service life. In addition, upgrading pipes do not resolve the fundamental issue of water quality, and stream health. Upgrading pipes for capacity only is not an approach that would make efficient use of funding and is not the direction the City is proposing.

Addressing Urbanization and Climate Change:

The solution to address ongoing increase in total impervious area and adapt to increased rain associated with climate change is to increase the efficiency of the landscape to capture and slowly release rainwater to the streams. While existing green public space can and should be preserved and property setbacks maintained on private property for the same purpose, new impervious areas must be connected back to the ground to establish an effective impervious area (EIA) that would re-establish the natural process of rainwater moving to the soil. This

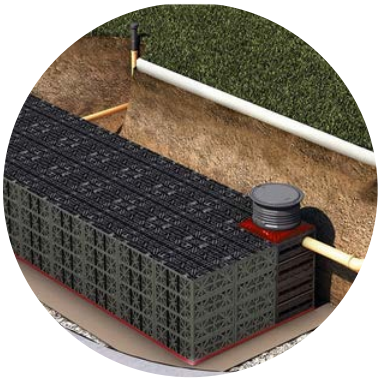
approach of managing stormwater at the source (source controls) is widely in effective for limiting the negative hydrological effects of urbanization and addressing a potential infrastructure gap associated with climate change.

Whereas Total Impervious Area (TIA) is a measure of all the hard surfaces in the landscape, Effective Impervious Area (EIA) is the measure of hard surfaces that are not directly connected to the ground. In our City, the TIA is about **55%** (including all private properties, public street area, and parks), while the EIA has been estimated to be between about **39% and 50%** based on data from the Wagg Creek streamflow gauging station for a period of seven years. Given that stream habitat and species begin to be adversely effected at about 10% TIA, the general goal for protection of aquatic species is to manage about 90% of the annual rainfall in source controls to achieve an EIA of 10%.

Source controls that can be employed to achieve this objective and include a wide variety of infiltration facilities like:

- underground infiltration chambers on private property;
- raingardens on private or public property;
- underground soil cells in our City boulevards that support healthy street trees and rainwater volume control.

All of these approached are currently used in the City for private sites and in public rights-of-way and are illustrated below in the three images.







The City's current guidelines for development are based on the 90% annual capture for high density sites (i.e. town homes and larger), and presently about 75% annual capture for single family sites and duplex. Based on a uniform capture and infiltration of 75% of average annual rainfall, the outlook for infrastructure is drastically improved.

Table 2-5: Pipe Capacity Summary with Source Controls Utilized

Condition	Length Undersized	Percent Undersized	Upgrade Cost
Current	32.1 km	21.7%	$16M
Future Total Impervious Area with source controls	2 km	1.4%	$1M
Future TIA and Climate Change with source controls	25 km	17%	12.5M

The effect of implementing source controls will address current infrastructure size deficits as the TIA of the City increases with redevelopment. Under a future increase in precipitation and TIA, the effect of source controls is still a net improvement over current conditions. This underscores the importance of implementing source controls for all levels of development and for street drainage infrastructure.

In order to achieve the objectives associated with source controls, it will be important to set goals for all new and existing impervious surfaces. There is presently a policy in place to implement source controls on all new private property developments. While challenging, City staff has been successful in having source controls applied to almost all new developments.

In addition, the City has been very active in the construction of raingardens, in addition to receiving contributed raingardens and soil cell facilities associated with development. Presently the City has more than 100 street drains that are managed by either raingardens or soil cells. This represents about **3%** of the 3,100 catchbasins we have in the City.

Section 3 - Our Environment

The City of North Vancouver sits on the lower flank of the North Shore Mountains, where steep, linear mountain streams with narrow watersheds occur regularly. The creeks are such a defining feature for the City, such that the western and eastern City boundaries coincide with Mackay Creek and Lynn Creek respectively. At the time of incorporation, these natural boundaries likely served as practical boundaries for the City. The majority of the City is within the Mosquito Creek watershed, with major tributary creeks including: Wagg Creek, Thain Creek, and Mission Creek.

MOSQUITO CREEK

The majority of the City is within the Mosquito Creek watershed, with major tributary creeks including: Wagg Creek, Thain Creek, and Mission Creek. Mosquito Creek and the associated watershed is the largest environmental feature in the City of North Vancouver. In the City, Mosquito Creek extends from 29th Street to 2nd Street, where the upper watershed is within the District of North Vancouver and the mouth of the creek is on Squamish Nation lands.

Historically Mosquito Creek would have been an important resource for First Nations people and would have supported a wide range of resident and anadromous fish species. The onset of development in the 1900s underscored the inherently hazardous nature of Mosquito Creek. Large floods in the 1950s led to damaging floods and channel instability. This led to the construction of the Evergreen debris flood basin by the Greater Vancouver Sewerage and Drainage District (Metro Vancouver) and the 1.2 km Evergreen Culvert upstream of Queens Road in the District, and resulted in decades of sediment management in the City portion of the creek downstream of Highway 1. The City still manages sediment in Mosquito Creek at Marine Drive with the most recent project occurring in 2016.

In addition to the Evergreen culvert, Mosquito Creek has seen fundamental modification when the Mission Creek tributary was diverted into the neighbouring Thain Creek tributary in the 1950s, and a large section of Mission Creek from 29th Street to 23rd Street was converted into a storm sewer network. The historical location of these streams has been interpreted from existing aerial photography and topography, which is shown in Figure 3-1. This figure is a first

attempt to characterize these lost streams, and the lost streams have been named for the purpose of this study based present day features that indicate the alignment.

The Wagg Creek tributary watershed is the most dominant drainage area in the City, where about 3.7 km^2 (or roughly 25%) of the City contributes runoff to Wagg Creek. Wagg Creek captures water from areas like Tempe Heights and Greenwood Park, and is the central feature in Mahon Park. Given the area of Wagg Creek that is directly influenced by City decisions, the City has the greatest potential to improve and enhance the quality and habitat of Wagg Creek of all the City streams.

In the City, Mission Creek is a small tributary to Wagg Creek and generally resides in the Mahon Park ravine. Since the headwaters have been diverted to Thain Creek, Mission Creek has not been degraded as much by urbanization, and has many valuable habitat features that persist from when the stream was much larger. Presently, Mission Creek provides valuable habitat potential to the Wagg Creek system; however, this section of stream is limited by an ability to provide stable baseflows.

Thain Creek was historically a relatively small creek that was substantially altered with the addition of the Mission Creek watershed. Thain Creek joins Mosquito Creek just upstream of Highway 1, and flows along the deep ravine west of Westview Shopping Centre and the Cypress Gardens residential development before turning east to meet Mission Creek at Westview Drive and 29th Street. The consequence of the contribution of Mission Creek to Thain Creek was more rapid erosion of the creek and ravine and associated landslide hazards between 29th and about 23rd. Much of the initial erosion was controlled by protective works that were constructed by the original owners of the Cypress Gardens development. Since then the City has been actively monitoring hazards completing preventative maintenance work, and conducting small projects to stabilize erosion areas. The largest single change to the Thain Creek and (upper) Mission Creek system was the daylighting of the 250 m long Thain Creek culvert which provided access for anadromous fish to areas above 29th Street and valuable local spawning habitat.

MACKAY CREEK

Mackay Creek is the western-most stream and is the represents the second largest section of stream in the City. Extending from about 23rd Street (Highway 1) to about Mackay Avenue and Roosevelt Street (in the District), then entering the City again downstream of 1st Street, the City portion of Mackay Creek is about 1.2 km long. Mackay Creek is still a very important environmental resource in North Vancouver, with large areas of intact riparian area and natural channel area, and fish passage being possible up to Handsworth School.

The Mackay Creek estuary was used for a wide range of industrial port-related since the 1940s and the valuable mud flat habitats have largely been lost in the past 100 years. However, since the Harbourside lands have ceased to be Port based industrial lands, a substantial amount of work has been completed to maximize the environmental values in the Mackay Creek estuary with creation of valuable off-channel habitats by Seaspan (in the District), the restoration of intertidal habitats in the City, and restoration of the riparian areas along Kings Mill Walk park.

The majority of Mackay Creek in the City is protected in Heywood Park, and the smaller Hyak Park, west of Capilano Mall. In Heywood Park, the City has been very active in protecting Mackay Creek by relocating the park trail systems away from the stream channel, facilitating the restoration of the channel upstream of Marine Drive, and supporting the North Shore Streamkeepers fish hatchery.

Development and historical land-use in the City, such as the former landfill site, between Mackay Creek and the Lucas Centre site, has marginalized habitat and confined Mackay Creek. A fundamental issue in Mackay Creek is the management of flood hazards. Flooding on Mackay Creek occurs regularly from the lower sections of Heywood Park to 1st Street. In this section, the size of the channel, low-lying topography and undersized bridge crossings (in the City and District) all contribute to flooding that would occur on average every 10 years.

To address this, the City is currently working on a joint project to construct a flood protection dike in this section of Mackay Creek. This project, which is also funded by the Federal and Provincial government, will provide flood protection for all areas from Heywood Park to 1st Street, and considers the need for replacement of the Mackay Creek – Marine Drive Bridge, new setbacks for redeveloping areas south and west of Marine Drive, and incorporation of greenway networks with the new dyke.

LYNN CREEK

A small portion of Lynn Creek and the tributary stream Keith Creek, fall in the City. While small in area, the watershed includes lands on the east side of Tempe Heights, Greenwood Park, eastern Grand Boulevard, Loutet Park, Cedar Village, and Brooksbank areas. Lynn Creek was once the City's source of drinking water, and is an important environmental resource in North Vancouver. As the only large stream system without a dam west of Indian Arm, Lynn Creek has the potential to support much more significant fish populations. Only a small section of Lynn Creek, from 5th Street to about Cotton Road lies in the City and in Lynnmouth Park, and is an important part of the Lynn Creek riparian protection area. This area is also an important recreational amenity as part of a greater park and future greenway system, as the eastern section of the Spirit Trail will connect to the District in this area.

Keith Creek is an entirely urbanized stream, with the headwaters originating on the east side of the Tempe Heights neighbourhood. Keith Creek is heavily segmented as the Highway 1 "cut" slices through the watershed, and proposed new Highway works to further impact Keith Creek. There is also a decommissioned landfill under Loutet Fields in the Keith Creek watershed, and the City collects and conveys contaminated drainage from this area for treatment.

The largest intact sections of Keith Creek in the City are in the Cedar Village neighbourhood, where Eastview Park, other park lands, and steep lands around the highway represent the small remaining sections of watershed forest.

BURRARD INLET (HISTORIC STREAMS)

In between the Mosquito Creek watershed and the Lynn Creek watershed is portion of the City, south of about Keith Road (west of Lonsdale) and south of 19th Street (around Grand Boulevard), that would have once been home to a number of small streams that may have occurred as regularly as every other block. Old subdivision maps, decommissioned culverts, and early storm sewers indicate that a larger stream originating from Greenwood Park would have crossed Lonsdale at 13th, as it travelled south to Burrard Inlet somewhere near Chesterfield. Another major stream would have flowed south east of St Andrews through present day Lower Lonsdale Parks to meet Burrard Inlet west of St Patricks. A third major stream would have flowed from the Grand Boulevard area to the Moodyville neighbourhood before reaching Burrard Inlet near the foot of Moody Avenue. The easternmost large stream would have flowed from the Calverhall – Cloverly neighbourhoods and portions of the creek

channel can still be seen in Sunrise Park before disappearing under the Port lands. Figure 3-1 provides a first look at these lost streams.

As smaller streams with very steep sections around Low Level Road and lower Lonsdale, these streams likely did not have the same environmental resources and support as abundant fish populations as larger streams. They did however form part of the natural drainage system which effectively and safely managed rain prior to the development of the City. These streams were largely moved into the storm sewer network by the 1960s, and now provide a more direct connection from City streets and properties to Burrard Inlet. While the loss of stream habitat is almost entirely complete, there are still some small reminders of these lost historic streams.

STREAM HEALTH

Stream health has been strongly linked the percentage of impervious area (TIA or EIA), where at a level of 10% EIA irreversible stream quality impairment can be observed, and severe impairment (i.e. loss of fish species) occurs at about 30% TIA. In addition to impervious area, local studies have shown that there are direct relationships between the level of contaminants that enter the stream and the volume of traffic.

As discussed earlier, the basic health in streams have been assessed using the diversity and abundance of stream insects. Another method to understand cumulative water quality impacts in streams is through sampling of stream sediments. While contaminants (e.g. metals or hydrocarbons) may intermittently enter a stream, these contaminants tend to bind to fine sediments which can begin to tell the story of pervasive contaminant inputs. Finally, where possible, the presence and absence of fish species has been assessed as part of regular City operations, where all fish have been relocated to support an instream infrastructure project.

These parameters have been mapped symbolically in the Figure 3-2 where data is available, which begins to tell the story of the current status of stream.

Higher concentrations of metals were found in the Wagg Creek Pond, Wagg Creek downstream of Jones, and in Mackay Creek downstream of Roosevelt Crescent. Generally, the higher concentrations of metals were Lead, Zinc and Chromium, all metals that are known to come from automobiles (e.g. brake pads). The concentrations of metals in these areas at times exceed the limits for protection of aquatic life, and indicate that there is a need to address water quality from storm outfalls.

In the City, Mackay Creek, is almost entirely set in Heywood Park and Hyak Park, and there are no major fish passage issues in the lower reaches. For Mackay Creek, lower B-IBI values indicate that the stream is stressed, and could be due to a combination of water quality issues and potentially relatively regular high peak flows and/or low baseflows.

The Mosquito Creek mainstem from the City-District boundary to Larson Road is largely protected in Mosquito Park. Given the extensive decades of sediment removals in Mosquito Creek, the available habitat is degraded, but extensive stewardship has created and diversified habitat in the reach between Larson Road and Queens Road. Mosquito Creek is limited by fish passage issues. The Metro Vancouver weir due to the trunk sewer at 3rd Street limits fish passage, as passage is only provided via a small fish ladder. Initial discussions with Metro Vancouver indicated that they would be open to a joint project to reconstruct a series of channel steps at this location to improve fish passage. The next major fish passage barrier is at the Evergreen culvert at Queens Road in the District of North Vancouver.

Given the limited fish passage due to the Evergreen Culvert, the Wagg Creek, Mission Creek, and Thain Creek tributaries are even more important to the system. Some fish passage improvements can be made to the existing culverts on Wagg Creek at 3rd Street and Keith Road now that the Bewicke Avenue culvert has now been replaced. Mission Creek (in the City) has great habitat potential, but is limited by baseflows during drier periods and could be improved by connecting some drainage from Mission Creek at 29th to the Mission Creek storm sewer catchment.

Thain Creek, given the very deep ravine, has potential for good and protected fish habitat, and ongoing monitoring and minor management of local erosion is needed until Cypress Gardens is redeveloped and access to the stream and a top of bank setback can be restablished. Once fish passage is provided in the District at Queens Road, the potential for fish use in the Thain-Mission Creek system will increase substantially.

Wagg Creek currently supports fish passage up until Jones Avenue. Wagg Creek has the largest percentage of impervious area contributing to it and it is degraded due to the regular peak flows and water quality issues. The Wagg Creek watershed will benefit the most from implementation of source controls. Based on the monitoring data collected to date, current City policies and programs appear to be improving the health of Wagg Creek, which supports the continued course of action.

WATERSHED HEALTH

Watershed health is more than instream habitat and aquatic species. It includes a broad range of ecosystem functions and services that occur over large scales and also integrates all of the day-to-day actions by the people the live, work, and recreate in the City watersheds. Some basic environmental watershed health indicators include percent forest cover and riparian (near-stream) forest integrity. Baseline values for these parameters have been developed for parts of the lower developed parts of the watershed (City area) and are summarized in the Table 3-1 below.

Table 3-1: Watershed Health Parameters

Watershed	Riparian Forest (ha)	RFI
Mosquito Creek	53.9	69%
- Wagg Creek	8.6	67%
- Thain Creek	19.5	67%
- Mission Creek	6.0	90%
Mackay Creek	52.3	67%
All Creeks	140.3	69%

Overall, given the density of the City, the integrity of the riparian forest is quite good at an average of 69%. Since the establishment of the Streamside Protection Development Permit Area, there have been better tools to protect and retain riparian, over the past ten years there should have been little loss of riparian areas and gains at the site level. As land is redeveloped, it is important to look for opportunities to regain those setbacks, especially in the lower reaches of Mosquito Creek and Mackay Creek near Marine Drive where development often backs onto the stream channel.

Section 4 - Goals and Objectives

Given our shared watersheds, the City and the District of North Vancouver, with participation from the public and discussions with First Nations, have defined the **ISMP Goal** as **Improved Watershed Health**, where ongoing and incremental improvements throughout the City would result in cumulative positive change. Supporting this goal, nine main objectives were identified in the categories of Environment, Social, and Economic objectives.

The flow chart (shown as Figure 4-1) illustrates the ISMP goal and primary objective framework, where the objectives all support furthering the goal.

These nine objectives are intended to be broad in nature, where numerous sub-objectives can be developed to address more specific actions and reflect the integration of values throughout the plan. A policy, program, or project that addresses multiple objectives would be seen to be more effective than an action that would only achieve a single objective. Development of a unified goal and objectives is key to implementing a plan that can be implemented in shared watersheds across both municipalities and First Nation territories.

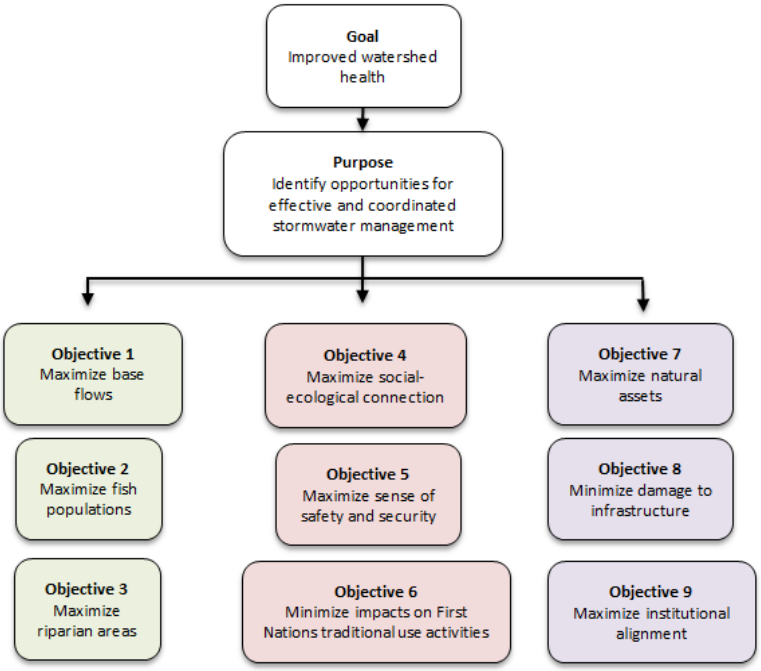


Figure 4-1: ISMP Goals and Objectives

Policy changes, creation of new programs, or implementation of a particular project would likely and ideally support more than one objective.

Environmental Objectives

The environmental objectives include initiatives around rainfall and runoff (hydrology), support of existing and potential aquatic species, and support of the lands surrounding the stream.

Objective 1 - Maximize Base Flows: this objective addresses the linkage between rainfall and runoff in streams. High total impervious area restricts infiltration and groundwater entering streams, providing the base flow that is very important to aquatic life, especially in summer periods. Transforming total impervious are to effective impervious area by implementing "green stormwater infrastructure" source controls will achieve this goal and also contribute to the decrease of regular peak flows which will extend the service life of the City storm sewer system and reduce physical damage to stream habitat.

Objective 2 – Maximize Fish Populations: a major indicator of good watershed health is the ability for natural indigenous fish species to thrive in streams. Many factors support maximizing

fish populations, such as: improved water quality, stability of stream channels, and provision of abundant and diverse habitats.

Objective 3 - Maximize Riparian Areas: this objective is intended to support both instream and terrestrial habitats by providing the broadest and most continuous riparian area possible. Riparian vegetation provides food and shade directly to the stream and acts to buffer human disturbance to the stream.

Social Objectives

Objective 4 - Maximize Social-Ecological Connection: maximizing community connectivity and relationship with the ecological values of the watershed will foster a greater sense of the importance of these resources and should reflect in the behaviour around rainwater, pollutants, and other stewardship activities.

Objective 5 - Maximize Sense of Safety and Security: streams and watercourses are inherently hazardous, and minimizing risks associated with flooding, slope stability, and water quality has a positive social benefit to the community.

Objective 6 - Minimize Impacts on Traditional First Nations Uses: historically the streams included in this plan were fundamental to traditional First Nations life. Preservation and enhancement of environmental resources will allow local First Nations people to retain local contact with the environment.

Economic Objectives

Objective 7 - Maximize Natural Assets: streams, watersheds, and groundwater are all natural assets that have fundamental value to the City that is not accounted for. If streams were no longer part of the drainage system, the cost to replace them with hard infrastructure would be substantial. It is important that these natural assets are protected and maintained appropriately to ensure their continued ecosystem and drainage function.

Objective 8 - Minimize Damage to Infrastructure: the City drainage infrastructure was constructed over about 4 decades and has a replacement value in excess of $70M. The plan shall include actions to minimize damage to infrastructure and maximize useful life.

Objective 9 - Maximize Institutional Alignment: maximum benefit and efficiency of both funding and staff time is achieved by aligning policies, programs, and coordinating complementary projects. Initiatives that act to align institutions will be more beneficial to the City than individual efforts.

PROPOSED PLAN ACTIONS

Mackay Creek and Mosquito Creek ISMP is being developed to be specific to the watersheds, but also to include governance to be applied uniformly across all North Vancouver watersheds.

The key elements of the plan will include:

- Policy Recommendations
- Program Development Recommendations
- Project Recommendations

In order to meet the objectives and make progress on the overall goal, a number of proposed approaches to refine existing policy, develop new programs, and implement a series of projects have been developed. The following section outlines the key actions identified for the ISMP.

Proposed Policies

To support the City's goal of Improved Watershed Health and to specifically address the objectives of increasing baseflow to streams and improving fish habitat and the safety and security of receiving waters an overarching policy decision from this plan should be:

All newly constructed impervious surfaces shall be mitigated to meet the objectives with by source controls insofar as is practicable.

In doing so all new impervious surfaces (i.e. Roofs, concrete paving and sidewalks, and asphalt paths and roads) shall be effective impervious surfaces that allow all runoff to enter the ground or to be released slowly to streams. Presently, the Subdivision and Development Control Bylaw requires that all new impervious surfaces from private developments shall be managed in a source control. This policy decision will also ensure that all City projects (e.g. Multi-use paths, road expansion, new facilities), include source controls or shed water to pervious green space. For example, a multi-use path or sidewalk that sheds runoff to a grassy boulevard would be an effective impervious area and would not require any additional source control measures.

By implementing this policy, the City will ensure that:

- Source Controls are implemented on all new private development projects.
- Source controls are included in the public drainage features, where a new public frontage is constructed by a development.
- All new public capital projects that increase impervious space include source controls where either the runoff will reach a stream or downstream drainage infrastructure will be foreseeably undersized due to development under the current Official Community Plan.

A second guiding principal shall be that:

All instream infrastructure projects shall improve fish habitat and passage

The actions for implementation for this policy decision will include:

1. Update of the Subdivision and Development Control Bylaw to better describe the requirements.
2. Review and alignment of the Construction Regulation Bylaw to support the policy initiative.
3. Recognition of the policy for City projects and incorporation into future projects.

City Operational Programs

The City has been implementing a variety of green stormwater source controls for more than 10 years. The variety of green infrastructure has been achieved through careful coordination of road improvement projects, capital projects, and developer delivered improvements. Through this plan, a series of core green stormwater programs are proposed to support a variety of ISMP objectives. These include:

1. **Stormwater Quality Treatment Captial Program:** improvements to stormwater quality originating from City streets and right-of-ways, that could include controls at the source (e.g. Raingardens), treatment at the outfall (e.g. stormwater oil and grit separators, or treatment wetlands), or treatment in the stream (e.g. treatment ponds).

   The goal of the stormwater treatment program is that 30% of all road drains (catchbasins) have a source control and that 50% of all outfalls have a treatment structure by the end of the Official Community Plan planning horizon (about 25 new source controls per year). To meet this interim goal for stormwater treatment, the City will need to begin to fund and plan for the capital costs based on the utility rates, and incorporate developer delivered infrastructure in an efficient manner.

   As part of the stormwater quality treatment capital program, a Local Area Service fund would be established for neighbourhood raingardens. This program would fund the majority of the cost of a raingarden and would allow residents of a block to elect to "sponsor" a raingarden, constructed by Operations, but block residents would be involved in planting and maintenance. This would provide local stewardship opportunities and could help prioritize projects to areas desired.

2. **Riparian setbacks, enhancement and diversification:** the integrity and width of the riparian area around streams has a direct relationship to the stream health as measured through stream insects. The existing riparian area should be maintained, increased and enhanced to provide the largest benefit to streams.

   The ***Streamside Protection Development Permit Area*** is the City's primary tool to protect and enhance riparian areas. This guideline was developed in 2006 in response to changes to the Provincial Fish Protection Act and the creation of the Riparian Areas Regulation. The development permit area is based on participation from senior levels of government (Fisheries and Oceans Canada) which is no longer available due to policy changes in the Federal Fisheries Act. An update of the Development Permit Area guidelines is required to provide clarity to development applicants and provide clear opportunities for off-site enhancement of riparian areas.

3. **Operational Programs:** there is a strong correlation between volumes of traffic and pollutant concentrations in streams. Upgrading and regular maintenance of street catchbasins shall be a core goal for the City. This shall include bringing catchbasins to the current standard, introducing source controls, and conducting regular maintenance of catchbasins.

   The current standard for catchbasins includes a sump and hood to collect sediment and trap floating debris and oils. Catchbasins should be regularly cleaned (by vacuum truck) to ensure that the trapped sediment and oils are not remobilized into the storm sewer. This program shall include creating an inventory of older catchbasins for upgrading to the current standard, with a source control, and annual cleaning of priority catchbasins at key times (e.g. Late Spring to address the winter sediment).

   There would also be a benefit to for increased and improved communication and education around the protection of fish habitat for all of our operations staff. Many of our operational practices have a direct effect on fish and fish habitat. With our operations staff growing and evolving with staff taking on new roles and new staff joining the City, annual updates and reminders on best practices for work on the drainage system and creeks would be beneficial.

4. **Outreach and Education:** transfer of information to City residents is key to changing behaviour around watershed health, recognition of streams, ownership of source controls and street frontages.

   Based on all baseline data collection, new data can be added to CityMap around watershed features, and health parameters. This could include a map of stormwater ponds, raingardens, and other treatment facilities. It could also include health indicators such as B-IBI, fish presence, and sediment quality data. This initiative could be realized as part of the property search web tool that would include key watershed information, initiatives, and values (e.g. mywatershed.cnv.org).

   Dedicated outreach activities can be developed around key watersheds, such as Wagg Creek, where household contaminants are often spilled into drains leading to Wagg Creek. This would entail development of communications material that could sent to the entire watershed.

   The City could work to a larger degree with School District No. 44 to develop a school rain garden program, whereby local government could sponsor a project that would involve constructing raingardens at local schools. Under this program, there could be both some volunteer effort from students that would include ongoing stewardship. A similar program was developed in the Corporation of Delta and was found to be successful in terms of engaging students. This could be done in participation with the District of North Vancouver and the North Shore First Nations.

   Another approach to engage the community would be through a program of “Citizen Science”. This would be similar to programs that the North Shore Streamkeepers have established where interested members of the community could use relatively simple and established methods to develop more information about the health of the North Vancouver streams. This would be coupled with a program to publish, or map the observations for general observation.

Capital Projects

Projects that support the ISMP would be unique capital works that are implemented to address a local problem or take advantage of a local opportunity. Projects could entail:

- Instream habitat projects (e.g. off-channel habitat, fish passage projects, etc.).
- Riparian vegetation projects (e.g. adding/diversifying near to stream vegetation that benefits the aquatic life the most).
- Watershed forest cover projects (e.g. looking at wildlife connections between forest patches with higher density or specific street tree plans).
- Green streets (e.g. selecting street for 100% stormwater capture and treatment, inclusion of street trees for canopy connection).
- Water quality treatment (e.g. biofiltration wetland, oil and grit separators, ponds, etc.).

Greater than 40 different unique projects watershed projects have been developed, in addition to the proposed objectives for new catchbasin source controls and general end of pipe

treatment work. Implementation of these projects will improve local conditions in each stream, but projects alone do not solve the watershed level issue of imperviousness and source derived water quality problems. This initial list of projects was evaluated based on the total number of objectives that are achieved, and based on indicative costs and potential spatial impact of the project, a cost to benefit ratio was developed to rank these projects.

The following table, Table 4-1, summarizes the top ten ranked projects to illustrate the potential projects.

Table 4-1: Summary of Top Ten Ranked Capital Projects

Project Name	Stream	Description	Preliminary Cost	Cost to Area Benefited ($/m^2)
Larson Park Pond and reconnection to of storm sewer to Mission Creek at 29th Street	Mission	Fish Habitat and Stream Baseflow Objectives	$220,000	$0.3
Heywood Park - Biowetland - Hamilton Outfall	Mackay	Water Quality	$75,000	$4.8
Green Street - 23rd (St Georges to Grand Boulevard)	Wagg	Forest Integrity	$50,000	$7.9
Green Street - 21st (Eastern to Chesterfield)	Wagg	Forest Integrity	$50,000	$10.3
Metro Sanitary Weir Fish Channel	Mosquito	Fish Passage	$250,000	$25.0
West Keith Culvert Fish Passage and Upgrade	Wagg	Fish Passage	$150,000	$53.5
Keith Boulevard - Mahon Park Linear Raingarden / Stream	Wagg	Water Quality	$915,000	$80.9
Hyak Park – move creek right, obtain greater setbacks, deal with outfalls.	Mackay	Fish Habitat	$300,000	$91.0
Green Streets - 19th (Hamilton to Fell)	Mackay	Water Quality	$270,000	$92.3
Harry Jerome - Creek Daylighting	Wagg	Fish Habitat	$342,000	$131.5

Given the large number of projects and capital cost, it is neither foreseeable nor practical to commit or plan to achieve each project on a fixed timeline. Therefore, the list of potential capital projects is intended to serve as a “visionary blueprint” for long-term watershed improvement, where other initiatives in the City may create an opportunity for a complex project to be implemented.

For example, the proposed Mackay Creek flood protection project currently planned for construction in 2017 may provide an opportunity to enhance a portion of the Mackay Creek stream channel and improve a number of storm system outfalls in the area at much higher efficiency than implementing the project alone.

Funding

Implementation of capital projects under the ISMP will be subject to available funding and will compete with other storm drain system build out goals. Sources of existing funding for projects could include:

- Drainage Levy funding from utility rates.
- Capital funding from general revenue as part of other capital projects.
- Contributions from development.

The Drainage Levy currently funds all capital and operational drainage system costs, including storm system expansion and upgrading. Over time, the goal would be to allocate 20% of the capital drainage budget for green stormwater infrastructure projects.

Funding from general revenue (i.e. property taxes), is not typically used for drainage system projects. This source of funding may indirectly achieve the goals of the ISMP as other capital projects strive to meet the "no new total impervious areas" objective, but could also serve to support the community Raingarden Local Area Service (LAS) fund. Currently the annual project plan funds our Sidewalk LAS program, and a similar fund could be established for raingardens.

Currently new development contributes effective impervious roof areas for all scales of development, and larger developments add source controls to the local street area as it is reconstructed. In some cases local site conditions limit or do not allow for mitigation of the entire impervious area. For these sites, the preferred approach would be for the development to provide source controls for an equivalent area of street (ideally close to the site). Alternatively, the developer could provide cash in lieu of meeting the bylaw requirements. Any cash received in lieu of works would be held in a Green Stormwater Infrastructure fund.

The actions for implementation for this policy decision will include:

- create Green Stormwater Infrastructure fund to create efficiencies between bylaw requirements and capital funding of projects to use funding in the most efficient manner.
- allow possible developments to contribute to the Green Stormwater Infrastructure Fund where meeting the criteria is not feasible

Natural Asset Valuation

Natural capital assets, and the ecosystem services they provide, are a fundamental and integral part of drainage infrastructure. In general, natural capital assets provide clear advantages over engineered infrastructure, whereby they:

- are less costly to operate and maintain for the capacity provided;
- may provide "free" ecosystem services;
- do not depreciate if properly managed and are not permitted to degrade; and
- are carbon neutral or even carbon positive.

The Town of Gibsons is one of the first Canadian municipalities to explore managing the natural capital, such as green space, aquifers, foreshore area and streams by using infrastructure and financial management concepts for asset management. The rationale is that natural services provided by these systems, in the form of stormwater management have tangible value to the community, and have more benefit than engineered infrastructure. Bringing these natural assets into the same asset management system as engineered infrastructure recognizes the quantifiable value they provide to the community and integrates them into the municipal framework for operating budgets, maintenance and regular support. The concept of Natural Capital Assets has also been introduced into a number of American cities.

Considering streams and other features as Natural Assets will change the focus and the level of importance regarding care and maintenance. Currently there is not a process in the Canadian Public Sector Accounting Standards for natural assets and appreciation of natural assets; however, the conversation has started and under the ISMP the City could consider the benefits associated with Natural Assets accounting.

The ISMP proposes that existing streams be brought into the City's asset management framework (i.e. Infor Public Sector), so that the assets can be quantified and costs and improvements can be tracked.

Future Funding Model

Currently all new developments are implementing source controls to limit the volume of runoff resulting from rain on impervious surfaces, and these sites all benefit the storm drain system and stream health. Creation of a Storm Water Utility is an approach that is being adopted by local governments in North America, including the City of Victoria. Instead of a drainage levy, based on property assessment, a utility rate could be established that was more equitable for sites that have invested in source controls.

For example, a typical single family home would have the standard utility rate, and a discounted rate would be available for sites that constructed source controls. This approach, in additional to being equitable, could incent some older homes that would not foreseeably be torn down to upgrade and include a source control.

Larger developments may have a more involved process, given that there is greater diversity in the size and scale of development, and these sites may involve a combination of assessment of total impervious area and drainage connection size.

As part of the ISMP, it is proposed that a Storm Water Utility approach be investigated further to assess the benefits to the City and rate payers.

Objective – Actions Framework

A summary of the objectives have been expressed in the following Table 4-1, with respect to the proposed actions outlined above.

Table 4-1: Summary of Plan Objectives and Associated Action

No.	Objective	Action
1.	Maximize Baseflow	Policy: All new impervious areas shall be mitigated by source controls

No.	Objective	Action
2.	Maximize Fish Populations	Policy: All instream infrastructure projects shall improve fish habitat and passage
3.	Maximize Riparian Areas	Program: Riparian setbacks, enhancement and diversification; Capital Projects
4.	Maximize Social-Ecological Connection	Program: Outreach and Education
5.	Maximize Sense of Safety and Security	Policy: All new impervious areas shall be mitigated by source controls, Program: Stormwater Quality Treatment; Program: Education and Outreach
6.	Minimize Impacts on Traditional First Nations Uses	Policy: All new impervious areas shall be mitigated by source controls; Policy: All instream infrastructure projects shall improve fish habitat and passage; Capital Projects
7.	Maximize Natural Assets	Policy: All instream infrastructure projects shall improve fish habitat and passage
8.	Minimize Damage to Infrastructure	Policy: All new impervious areas shall be mitigated by source controls
9.	Maximize Institutional Alignment	Policy: All new impervious areas shall be mitigated by source controls – aligns development with environmental goals. Policy: All instream infrastructure projects shall improve fish habitat and passage

MONITORING

To determine the effectiveness of the ISMP, Metro Vancouver has developed a "Monitoring Adaptive Management Framework" (MAMF), or a standard for monitoring biological and hydrological indicators as part of the Plan.

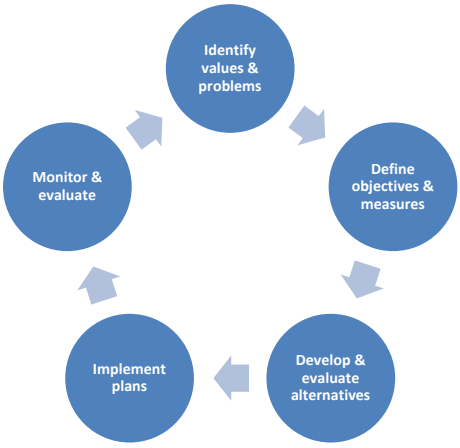
The City already conducts some monitoring, including measurement of rainfall at City Hall, measurement of streamflow in Wagg Creek, and periodic measurement biological indicators as part of the City's Environmental Protection Plan. To meet the MAMF, the general monitoring requirements would include:

- hydrometric (streamflow) monitoring of major streams
- continuous water quality measurement at hydrometric stations (e.g. temperature, conductivity, turbidity)

- Water quality monitoring every 2 years, with samples taken during two periods of the year – once in the wet season (Nov-Dec) and once in the dry season (July-Aug), including: dissolved oxygen, temperature, turbidity, pH, conductivity, nitrate, E. Coli, fecal coliforms, total iron, total copper, total lead, total zinc, and total cadmium
- Marine effluent monitoring station at the Foot of Lonsdale (in participation with the Vancouver Aquarium).

Section 5 – Plan Implementation

Integrated stormwater management planning is an ongoing and proactive process to provide the necessary tools to accommodate development growth and increase imperviousness while protecting property and aquatic habitat from stormwater. In the previous sections, the need for integrated stormwater management planning was explored, along with a framework to target objectives that support a goal of Increased Watershed Health.



The proposed actions under the plan include: two fundamental policies were proposed, in addition to a number of ongoing programs and an initial number of unique projects. Based on these actions, the following priority for implementation has been established:

The Plan

1. The City shall adopt the Integrated Stormwater Management Plan and all actions in principle

2. Engineering, Parks and Environment and Community Development will identify a departmental staff leader to coordinate interdepartmental efforts.

3. Staff will update and align the Subdivision and Development Control Bylaw and Construction Regulation Bylaw such that the bylaws support the objectives and goals of the Plan.

4. Staff will formalize a process for off-site contributions or cash in-lieu for Stormwater Management Source Controls that cannot be achieved due to development massing and site constraints.

5. Staff will provide input into the review of the Streamside Protection Development Permit Area Guidelines to support the ISMP.

6. Staff will initiate the ongoing capital program to provide street level source controls and end of pipe treatment.

7. Engineering Planning and Operations will plan to initiate priority street and catchbasin cleaning for the Wagg and Mission Creek watersheds for 2018.

8. Engineering Planning and Environment will work with communications to develop an initial strategy for outreach in the Wagg Creek watershed as a priority.

9. Engineering Planning will develop conceptual designs and costs to support the 10-Year Capital Plan. Projects will be implemented subject to funding, and based on efficiency to deliver the project.

10. Engineering Planning will initiate a process for tracking costs associated with Natural Assets, and explore alternate funding models for future plan implementation.

11. Engineering Planning will initiate a monitoring program to meet the ISMP requirements.



Compendium 10

Mitigation Measures

Mackay Mosquito Watersheds ISMP

September 2020

Final Report

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Appendix C10-C: Hydrogeological Questions and Piteau Answers

Purpose

Compendium 10. Mitigative Measures

This compendium summarizes findings from previous compendiums about the current status of the watershed and the key issues that need to be addressed. Key issues are examined and options for mitigating the current and future pressures on the watershed to meet the ISMP goal are discussed. A discussion of stormwater environmental protection criteria and what would benefit the Mackay Mosquito watersheds is also included.

Mackay Mosquito Watersheds ISMP Compendiums

The following compendiums and their authors support the Mackay Mosquito Watersheds ISMP:

1. Watershed Overviews - KWL
2. Instream Species and Water Quality – Raincoast Applied Ecology
3. Riparian Forest & Terrestrial Species – Raincoast Applied Ecology
4. Drainage Asset Inventory – KWL
5. Hydrologic and Hydraulic Modelling - KWL
6. Drainage Assessment - KWL
7. Land-Use Analysis - KWL
8. Municipal Policy and Operations - KWL
9. Watershed Values & Objectives – CNV and DNV
10. Mitigation Measures & Alternatives – KWL, CNV and DNV
11. Mackay/Mosquito Action Plan – KWL, CNV and DNV

Figure and table identification numbering include the first digit related to compendium number and the second digit related to the figure number within the compendium. e.g. Figure C3-1 is the first figure within Compendium 3.

1. Introduction

One of the main objectives of an ISMP is to develop solutions that address the key issues identified for maintaining and improving the health of the watershed. The key issues include those that represent impacts that have already occurred in the watershed, as well as pressures that are currently affecting the watershed and are expected to impact watershed health in the future.

This compendium summarizes findings from previous compendiums about the current status of the watershed and the key issues that need to be addressed. Key issues are examined and options for mitigating the current and future pressures on the watershed to meet the ISMP goal are discussed.

2. Summary of Watershed Findings and Key Issues

The 'findings and recommendations' from the previous compendiums (1 – 9) are compiled in Appendix C10-A. The key watershed findings are summarized below.

Table C10-1: Summary of Watershed Findings

Environmental	Fish & Fish Habitat	▪ **Fish communities** included chum salmon, coho salmon, pink salmon, and cutthroat trout (resident and anadromous), as well as prickly and coastrange sculpins, threespine stickleback, and western brook lamprey. It is unknown if steelhead trout and Dolly Varden may still occur. ▪ **Fish passage** - Both natural and man-made barriers limit fish passage and distribution. Five impassable pipes were noted. ▪ **Fish habitat quality** was high but did show spatial patterns. The lowland reaches of Mosquito, Mackay, and Wagg creeks were less diverse and productive based on pool and wood density but are lower gradient and provide gravel substrates important for spawning.
	Biodiversity	▪ **Watershed forest cover** is high compared to many Metro Vancouver watersheds, partially because of the forested headwaters. Based on the whole watersheds, approximately 42% of Mosquito and 42% of Mackay were forested in 2013. ▪ **Riparian forest cover** is high for streams in Metro Vancouver. It varies from 67% in Wagg Creek to 90% in Mission Creek for the watersheds as a whole with a mean across the study area of 78%.
	Wildlife	▪ **Terrestrial wildlife habitat** for many birds, amphibians, and mammals is provided by streams and their associated riparian corridors and natural headwaters. Stream corridors are the only remaining linear habitats providing habitat connections to the forested headwaters for wildlife. ▪ **Species at risk** likely found in the study area include green heron, coastal tailed frog, northern red-legged frog, Pacific water shrew, and western screech owl kennicottii subspecies.

Table C10-1: Summary of Watershed Findings

<table>
<tr><td>Environmental
Indicators</td><td>

Water quality is typical of moderately urbanized streams in Metro Vancouver. MAMF identified several parameters in the “satisfactory” (yellow) or “needs improvement” (red) categories including dissolved oxygen, turbidity, conductivity, E.coli, fecal coliforms, and total metals.
Sediment quality showed total metal concentrations in streambed sediments were typical of Metro Vancouver urban streams. Elevated concentrations of some metals were found in Mission and Wagg creeks. Elevated metal concentrations were also found during gravel removals in Mackay Creek sediments.
Mean B-IBI values ranged from 19 at Wagg Creek to 33.5 in Upper Mosquito Creek. Results reflected the effects of urbanization with higher taxa richness and more sensitive taxa in the less urbanized headwater sites. There was a statistically significant increase at Wagg Creek Site 1.

</td></tr>
<tr><td>Land Use & Development</td><td>

Existing land use includes a forested upper third of the watersheds except for Grouse Mountain ski area. The lower two thirds are urbanized with a mix of residential, commercial and industrial areas. The Squamish Nation lands are residential with the Mosquito Marina.
Future land use is similar to current conditions with densification of single family residential and changes to commercial/industrial zoning. The total impervious area in the watersheds is projected to change significantly as the District and the City expect significant increase in impervious area with redevelopment.

<table>
<tr><th rowspan="2">Watercourse</th><th colspan="3">Total Impervious Area</th></tr>
<tr><th>Existing</th><th>Future</th><th>% Increase</th></tr>
<tr><td>Mackay Creek</td><td>32%</td><td>55%</td><td>23%</td></tr>
<tr><td>Mosquito Creek</td><td>29%</td><td>48%</td><td>19%</td></tr>
<tr><td>Wagg Creek</td><td>50%</td><td>76%</td><td>26%</td></tr>
<tr><td>Thain Creek</td><td>26%</td><td>51%</td><td>25%</td></tr>
<tr><td colspan="4">1. Mission Creek is included in Mosquito Creek.
2. TIA for Mackay Creek does not include the additional Single Lot Infill Areas as per Zoning Bylaw 3210 Amendments (Bylaws 8265, 8266, 8267)</td></tr>
</table>

Hydrologic impacts of development and redevelopment result in increased flows and frequency of flows which exacerbate flooding, watercourse instability and degradation of fish and fish habitat. These increases need to be mitigated to protect the ecological health.

</td></tr>
</table>

Table C10-1: Summary of Watershed Findings

Flooding & Erosion

- **Drainage System Assessment**

Land Use Conditions	% Undersized[1]	
	Storm Sewers	Culverts
Existing	21%	66%
Future	23%	68%
Future with RCP 8.5 climate change	36%	75%

1. Undersized storm sewer & culverts refer to pipes that **surcharge** higher than 30 cm above the pipe crown for longer than 15 minutes and culverts with a q/Q > 1.0 and no surcharge allowance.

- **Erosion Sites**

Watercourse	Very High Risk	High Risk
Mackay Creek	14	19
Thain Creek	2	1
Wagg Creek	3	2
Mosquito Creek Mainstem	0	0

- **Floodplain and Coastal Flooding Hazards** - Overbank flood hazards in lower Mackay and Mosquito watersheds were found in *CNV DNV Creek Hydrology, Floodplain Mapping & Bridge Hydraulic Assessment Study (KWL, 2014)*.

  Creek Hazards - Mackay and Mosquito creeks are susceptible to floods and debris floods and flows. Integrate findings and recommendations from the *Debris Geohazard Risk & Risk Control Assessment (BGC, 2017)* study.

Hydro-geology

- High level infiltration rate estimates range from severely limited (0 – 20mm/hr) to moderately limited (>50mm/hr).
- Infiltration allowed on slopes flatter than 10H:1V, but site-specific assessment recommended for multi-home developments, close to retaining walls or within 200m of slopes steeper than 3H:1V.

3. ISMP Values and Objectives

The *DNV ISMP Framework and Objectives* and *CNV Integrated Stormwater Management Plan, 2016* (Compendium 9) outlines the values and objectives for the Mackay Mosquito Watersheds ISMP summarized on Figure C 10-1. Mapping for the key objectives are shown on Figures C10-2 to C10-8.

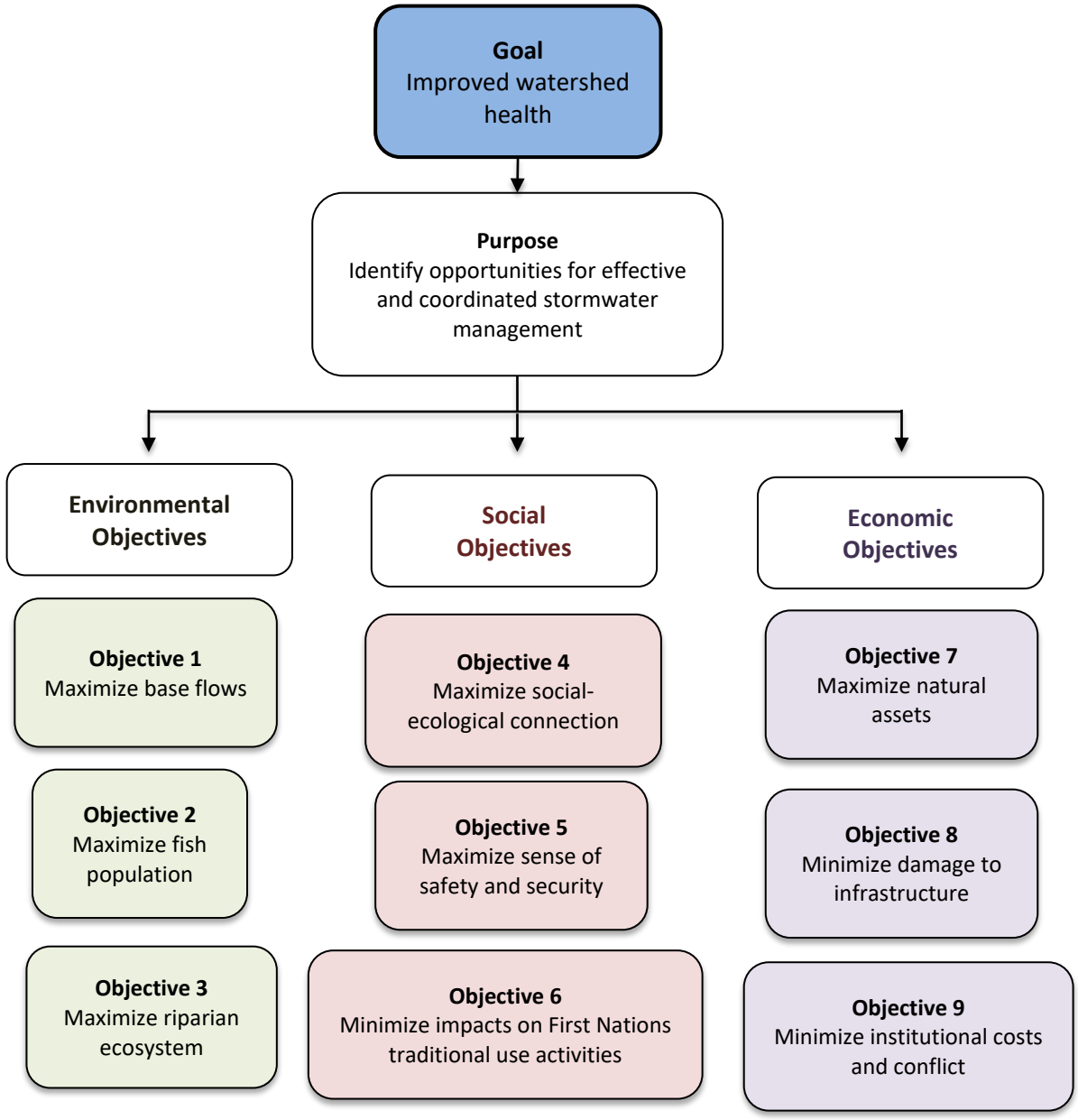


Figure C10-1: ISMP Goals and Objectives

4. Mitigation Measures for Development

The primary goal of the Mackay Mosquito Watershed ISMP is to **improve watershed health**. Table C10-2 summarizes potential policy, program and project options related to that goal and the objectives and sub-objectives for review and discussion.

4.1 Future Development and Redevelopment Mitigation

Future development / redevelopment mitigation focusses on:

1. **Mitigate Hydrologic Impacts** – management measures for rainfall – runoff events including volume reduction and water quality treatment for most of the annual average rainfall and rate control for mid-sized events.
2. **Protect and Enhance Riparian Areas** – protect streamside forested areas by continuing to enforce riparian setbacks for new development and redevelopment based on the Streamside DPA and enhance disturbed areas with restoration projects.
3. **Compensation Measures and Enhancement Projects** – offset unavoidable impacts with compensation measures elsewhere on the same stream reach or tributary or watershed by utilizing:
    a. hydrologic enhancement,
    b. reforestation of impacted riparian areas reforestation, and/or
    c. construction of in-stream complexing.

    The City and District identified environmental enhancement opportunities, discussed them with stakeholders and prioritized them. These projects summarized in the Compendium 11 Mackay/Mosquito Action Plan.

Many of these approaches to managing urban stormwater runoff also provide potential co-benefits to communities such as: flood mitigation, terrestrial biodiversity, urban cooling, supplementing water supply, and resilience to climate change.[1]

4.2 Mitigating Hydrologic Impacts

Various measures for volume reduction include

Low Impact Development Practices – Minimize Imperviousness

- Reducing Road Widths, Parking Stalls
- Limiting Surface Parking
- Pervious Parking Surfaces
- Reducing Building Footprints
- Building Compact Communities
- Preserving Naturally Significant Features

Stormwater Source Control Technologies

- Absorbent Landscaping
- Surface & Sub-Surface Infiltration Facilities
- Bio-Retention Facilities
- Green Roofs
- Biofilters
- Urban Forests and Leave Strips
- Constructed Wetlands
- Wet Detention Ponds

[1] Principles for urban stormwater management to protect stream ecosystems, Freshwater Science, Christopher J. Walsh, Derek B. Booth, 2016.

- Rainwater Re-Use
- Water Quality BMPs & Practical Technologies
- Oil and Grit Separators
- Construction Best Practices

Regional Facilities

- Stormwater Detention / Diversion Systems
- Infiltration Systems

Appendix C10-B provides additional details about the various mitigation measures.

4.3 Source Controls within Mackay Mosquito Watersheds

Future Land Use Change in Watersheds

Figure C10-9 shows areas of expected future land use change within the watersheds. This was determined by comparing existing zoning with future OCP zoning. Land use change is scattered throughout the watersheds, with concentrated pockets around Lonsdale Ave, Marine Drive and W 1st St.

The infiltration potential layer is also included on the figure and shows severely and moderately limited infiltration locations relative to land use change areas. Implementation of source controls is easier in areas with higher infiltration capabilities because they require less surface area footprint. Source controls in poor infiltration areas tend to require larger footprint area and may be designed to utilize slow release (attenuated release at baseflow levels) of stored water to the storm system through an orifice in addition to infiltration into the ground. Areas where future development is expected and that have better infiltration potential are preferred areas for planned implementation of source controls in association with development and infrastructure improvements.

4.4 Hydrogeology and Geotechnical Limitations and Recommendations

CNV and DNV posed broad hydrogeology and geotechnical questions to Piteau Associates, whose responses are summarized in Appendix C10-C. A thorough area-specific hydrogeological assessment was not included, but high-level guidance was provided.

Increasing infiltration around steep slopes can exacerbate slope instabilities and is not recommended. Piteau recommended broad guidance related to implementation of infiltration facilities.

1. No infiltration on slopes steeper than 10H:1V (without a lot-specific geotechnical assessment)
2. Consider proximity to retaining walls
3. Multi-home developments should require site specific hydrogeotechnical assessment
4. Preliminary infiltration setbacks for areas without site-specific geotechnical assessment:
    - Setback 100 m from crest of any 3H:1V slope (Greatest risk is seepage breakout on slope)
    - Setback of 200 m behind crest of slopes steeper than3H:1V

Figure C10-9 shows CNV and DNV identified steep slope hazards within the watershed, slopes greater than and less than 10%, and a conservative 200 m setback from slopes steeper than 3H:1V.

Mitigation measures tie to all three categories of objectives for the ISMP, environmental, social, and economic. The mitigation measures that provide the most benefits under these categories are the most obvious candidates for uptake.

Table C10-2: Watershed Management Objectives and Potential Mitigative Measures

Watershed Management Objectives[1]	Sub-objectives[1]	Possible Actions		
		Policy	**Programs**	**Projects**
Environmental Objectives				
1. Maximize Base Flows[1] / Restore Natural Hydrology[2]	• Maximize permeable areas, infiltration to interflow / groundwater, on-site retention/detention • Minimize disturbances to headwater area	A-1. All new impervious areas to be mitigated by source controls. Update bylaws. A-2. Maximize infiltration in well-draining soils. A-3. Minimize impervious area in redevelopment.	B-1. Develop Green Infrastructure Program - Develop Standards / Examples / Education; GI Inventory and Maintenance; Increase understanding for on-site & public realm works.	C-1. Construct GI projects for development and redevelopment, including public spaces C-2. Construct regional infiltration facilities.
2. Maximize Fish Population	• Maximize benthic invertebrate productivity, habitat diversity, vegetation and instream complexing • Minimize erosion & bank destabilization, level of pollutants, obstructions & debris • Reduce hydrology Impacts[2]	• Items A-1 and A-2 above. A-4. Update bylaws or policies: All instream infrastructure projects to improve fish passage and habitat A-5. Update bylaws: Add water quality treatment requirements for pollutant generating surfaces	• Item B-1 above. B-2. Develop Stormwater Quality Treatment Program B-3. Continue Outreach and Education Program	• Items A-1 and A-2 above. C-3. Implement water quality treatment projects. C-4. Upgrade fish passage barriers C-5. Improve instream complexity & riparian restoration
3. Maximize Riparian Ecosystem[1] / Biodiversity[2]	• Maximize riparian buffers, tree & forest canopy • Minimize invasive plant species • Increase biodiversity & wildlife populations[2] • Enhance terrestrial habitat quality[2]	A-6. Enforce Riparian & Tree bylaws with minimal variances.	B-4. Develop Biodiversity study to inventory & protect B-5. Develop Riparian Setbacks, Enhancement & Diversification Program	C-6. Create riparian & forest cover enhancement / restoration projects. C-7. Create wildlife connective corridors.
Social Objectives				
4. Maximize Social Ecological Connections	• Maximize access & connectivity to nature, education & awareness, stewardship, healthy lifestyles • Improve quality of experience	A-7. Update Parks Master Plan (CNV, 2010) to include actions for MacKay Mosquito Creek.	• All items above. B-6. Work closely with volunteer stewardship groups to encourage action along MacKay Mosquito Creek B-7. Work with Squamish Nation to install signage honouring Hul'qumi'num' place names B-8. Hold annual tour/event to build awareness of recreational facilities and opportunities B-9. Work with Vancouver School District 44 to develop educational programming B-10. Develop a program to improve surveillance to improve safety along the creek?	C-8. Acquire connective lands & restore biodiversity C-9. Install public or Indigenous art along trail. C-10. Implement Trail Enhancement Program to improve signage, waste facilities, and extend accessibility for a range of physical abilities

Table C10-2: Watershed Management Objectives and Potential Mitigative Measures

Watershed Management Objectives[1]	Sub-objectives[1]	Possible Actions		
		Policy	Programs	Projects
5. Maximize Sense of Safety & Security	• Minimize risk from debris flows, stormwater flooding, erosion • Consider climate change[2]	• Item A-1 above. A-8. Continue to enforce flood protection requirements and provide adequate flood conveyance.	• Items B-1 and B-2 above. B-11. Continue with flood protection requirements and providing adequate flood conveyance B-12. Integrate with *Creek Hydrology, Floodplain* Mapping *and Bridge* Hydraulic *Assessment Study (KWL, 2014)* and *Debris Geohazard Risk and Risk Control Assessment, (BGC, 2017)* recommendations	• Items C-1 and C-2 above. C-11. Upgrade drainage improvement projects. C-12. Updated plan for flood and debris hazard mitigation projects.
	• Minimize level of pollutants	• Item A-5 above.	• Item B-2 above.	• Item C-3 above.
6. Minimize Impacts on First Nations Traditional Use Activities	• Maximize base flows • Minimize fecal contamination & level of pollutants • Protect culturally significant sites[2]	• Items A-1 - A-5 above.	• All items above. B-13. Invite Squamish Nation to sit on a Mosquito Creek Stewardship Working Group to discuss ongoing measures to protect cultural sites and reduce impacts from recreation.	• All items above. C-13. Install fencing and landscaping and signage to protect culturally significant sites.
Economic Objectives				
7. Maximize Natural Assets	• Establish the valuation of ecosystem services, use of bioengineering methods & protection of natural lands	• Items A-1 - A-3 above. A-9. Develop an Asset Management Policy that includes Natural Assets	B-14. Complete a Natural Assets Inventory and Plan	• Items C-1 to C-8 above.
8. Minimize Damage to Infrastructure	• Minimize risks from debris flows, stormwater flooding, erosion • Minimize capital and O& M costs	• Item A-1 above A-10. Keep Asset Management Plan up to date.	B-15. Continue with O & M Programs to maintain existing infrastructure.	• Items C-11 and C-12 above.
9. Minimize Institutional Costs & Conflict	• Maximize institutional alignment & data sharing	A-11. Align development with environmental goals. A-12. Synchronize processes across municipal departments.	B-16. Consult and coordinate with internal departments including development planning, building (permitting), development inspection staff, municipal parks and road operations.	C-14. Develop processes to inform, consult, and coordinate among staff in different departments.

Notes:

1. Objectives and sub-objectives from *DNV ISMP Framework and Objectives* document.
2. Sub-objectives added by KWL.
3. A-# refers to Policies, B-# refers to Programs, C-# refers to Projects.

Report Submission

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.



Crystal Campbell, P.Eng.
Project Manager

Reviewed by:

Laurel Morgan, P.Eng.
Technical Review

Statement of Limitations

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Revision History

Revision #	Date	Status	Revision	Author
0	Sept 29, 2020	Final	Addressed client comments	CC

OQM CERTIFIED

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City of North Vancouver
Mackay/Mosquito Watershed Integrated Stormwater Management Plan

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- DNV / CNV Boundary
- Watershed Boundary
- Watercourse
- Contour (20m Interval)
- Creek Connectivity Conveyance Pipe
- Greenspace /Natural Parks
- Estuaries
- Notable Erosion Sites
- Slope Hazard

Slope Hazard from the District of North Vancouver Open Data and the City of North Vancouver

Infiltration Potential
From Piteau's Hydrogeological Questions and Answers Appendix C10-C

- Severely Limited 0 - 20 mm/hr
- Severely Limited 3 - 30 mm/hr
- Moderately Limited ~ 50 mm/hr

Note:
Geology data provided by the City of North Vancouver.

Potential Opportunities

* Require stormwater source controls, WQ treatment, and detention to mitigate rainfall runoff impacts

Stream Health Impervious Area Threshold

Watercourse Health	Total Impervious Areas (% TIA)
Stressed (minor changes to watershed health)	1 - 10 %
Impacted (moderate changes to watershed health)	11 - 25 %
Degraded (severe changes to watershed health)	26 - 100 %





N

MOSQUITO CREEK WATERSHED
MACKAY CREEK WATERSHED
THAIN CREEK WATERSHED
WAGG CREEK WATERSHED
DISTRICT OF NORTH VANCOUVER
CITY OF NORTH VANCOUVER
CAPILANO I.R. No. 5
MISSION I.R. No. 1

Drifter Creek
Mosquito Creek
Mackay Creek
Mackay Creek East
Mackay Creek West
Mosquito Creek East
Mosquito Creek West
Thain Creek
Mission Creek
Lower Mission Creek
Wagg Creek
Capilano River
Transformer Creek
Dunell Creek
Dyer Creek

Lynn Headwaters Park
Gvwd Capilano Watershed
Grousewoods Park
Malaspina Park
Cleveland Park
Sarita Park
Alpine Park
Montroyal Blvd
Glenwood Park
Upper Mackay Creek Park
Eldon Park
Mosquito Creek Park
St Albans Park
Rockland Park
Carisbrooke Park
Fairmont Park
Delbrook Park
William Griffin Park
North Lonsdale / Delbrook Trails
Murdo Frazer Park
Murdo Frazer Pitch & Putt
Sowden Park
Larson Park
Norsman Park
McDougall Park
Greenwood Park
Rey Sargent Park
Rodgers Burnes Green
Wagg Creek Park
Mahon Park
Tempe Heights Park
McLeod Park
Heywood Park
Bowser Trail
Iwanis Park
Lower Mackay Creek Park
Lower Mackay Creek Marsh Park
Ray Perrault Park

Nancy Greene Way
Capilano Rd
Highland Blvd
Edgemont Blvd
Ridgewood Dr
Delbrook Ave
W Queens Rd
W 23rd St
Larson Cres
W 19th St
W 16th St
W Keith Rd
W 13th St
E 13th St
Jones Ave
Grand Blvd E
Boulevard Cres
29th St
Taylor Way
Lions Gate Bridge

Divert baseflow from Upper Mission back to Lower Mission through storm sewer.

Murdo Frazer Pond

Murdo Frazer Off Channel Pond

Well Draining

Lower Mackay Creek Wetland

Tempe Heights Pond

Wagg Pond

Baseflows in Lower Mission are low due to historic diversions

Filled with Sand, Well Draining, High Water Table

Thain Creek Subwatershed Total Impervious Area

2014	2030 Unmitigated
26 %	51 % *

Mackay Creek Watershed Total Impervious Area

2014	2030 Unmitigated
32 %	55 % *

* Need stormwater source controls, WQ treatment, and detention to mitigate rainfall runoff impacts

Mosquito Creek Watershed Total Impervious Area

2014	2030 Unmitigated
29 %	48 % *

Wagg Creek Subwatershed Total Impervious Area

2014	2030 Unmitigated
50 %	76 % *

Reference: 2013 Orthophoto and GIS background data from the City and District of North Vancouver.

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Project No.: 99-125 | Date: September 2020

0 250 500 1,000 Meters

Objective 1: Maximize Base Flows

Figure C10-2

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Mackay/Mosquito Watershed Integrated Stormwater Management Plan

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DNV / CNV Boundary
First Nations Reserve
Watershed Boundary
Watercourse
Storm Main
Estuaries
2013 Riparian Forest Cover
Greenspace /Natural Parks
Parking Area
Oil/Grit Separator

Fish Distribution - 2014 Survey Results

Historical Fish Community Locations (Various Sources)
Both
Coho
Cutthroat
None

Other Species

Crayfish
Z Spine
Historical Pink Salmon

Sampling Sites

Primary Water Quality Sampling Sites (AMF) + Sediment
Secondary Water Quality Sampling Sites
Benthic Sampling Reaches

2016 Fish Habitat

Anadromous Fish
Resident Fish
Tidal Fish
Unknown
Unknown-Unlikely
No Fish

Fish Passage Issue (Priority)

Low
Moderate
High
(Impassable Pipe)

Potential Opportunities

Water Quality Projects

Upper Mackay Creek Fish Passage
Murdo Frazer Off Channel Pond
Murdo Frazer Pond
Monitor Mackay Creek Crossing Under Highway 1 for Fish Passage Debris Jams and Opportunities for Improvement
Develop Off-Channel Habitat along Mackay Creek in Upper Heywood Park
Cooperate with DFO on maintenance and operation of Mosquito Creek Fell Side Channel
Lower Mackay Creek Wetland
Fish Passage Improvements on Mosquito at GVS&DD Weir
Fish Passage Improvement on Mackay at Lloyd Ave
Fish Passage - Mission at Queens Ave
Wagg Pond
Fish Passage Improvements at 3rd and West Keith
Wagg Creek Pond - Engineered Outlet for Fish Passage and Sediment Trapping
Tempe Heights Pond

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Project No.: 99-125 | Date: September 2020

0 250 500 1,000 Meters

Objective 2: Maximize Fish Population

Figure C10-3

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Mackay/Mosquito Watershed Integrated Stormwater Management Plan

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- DNV / CNV Boundary
- First Nations Reserve
- Watershed Boundary
- Watercourse
- Creek Connectivity Conveyance Pipe
- Estuaries
- 2013 Riparian Forest Cover Within 30m Corridor
- 2013 Watershed Forest Cover
- Riparian Forest Cover at Risk

Potential Opportunities

- Riparian Projects

Upper Mackay Creek generally has good riparian forest integrity. This reach is most segmented and would benefit from enhancement opportunities

Riparian forest is narrow near Edgemont Boulevard and between Hillcrest Avenue and Emerald Drive and opportunities for enhancement should be considered with redevelopment of lots or added density near Edgemont Boulevard, Ridgewood Drive and Sunset Boulevard

Explore riparian enhancement opportunities on the south edge of Murdo Fraser Park

Murdo Frazer Pond

Murdo Frazer Off Channel Pond

Riparian forest at risk - conduct reforestation in Heywood Park

Riparian enhancement opportunities exist in Lower Mackay Creek Park (DNV) and Heywood Park (CNV)

Lower Mackay Creek Wetland

Enhancement of Riparian on both sides of the Mackay Creek estuary is needed to develop a sustainable riparian forest

Upper Mission Creek has highly segmented riparian forest and increased protection and enhancement through redevelopment would be a benefit

As redevelopment is considered in this area, greater riparian setbacks and enhancement would be a benefit

Tempe Heights Pond

Future Zoning under a new OCP in this neighbourhood could facilitate daylighting of Wagg Creek

Wagg Pond

Continued protection and enhancement of riparian through regular redevelopment. Future OCP should consider how density could benefit stream corridor protection.

Continued protection and enhancement of existing riparian in Lower Mosquito Creek and Wagg Creek

Future development by the Squamish Nation could provide riparian setbacks for Mosquito Creek

MACKAY CREEK WATERSHED
MOSQUITO CREEK WATERSHED
THAIN CREEK WATERSHED
WAGG CREEK WATERSHED
DISTRICT OF NORTH VANCOUVER
CITY OF NORTH VANCOUVER
DISTRICT OF WEST VANCOUVER
CAPILANO I.R. No. 5
MISSION I.R. No. 6

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Project No.: 99-125 | Date: September 2020

0 250 500 1,000 Meters

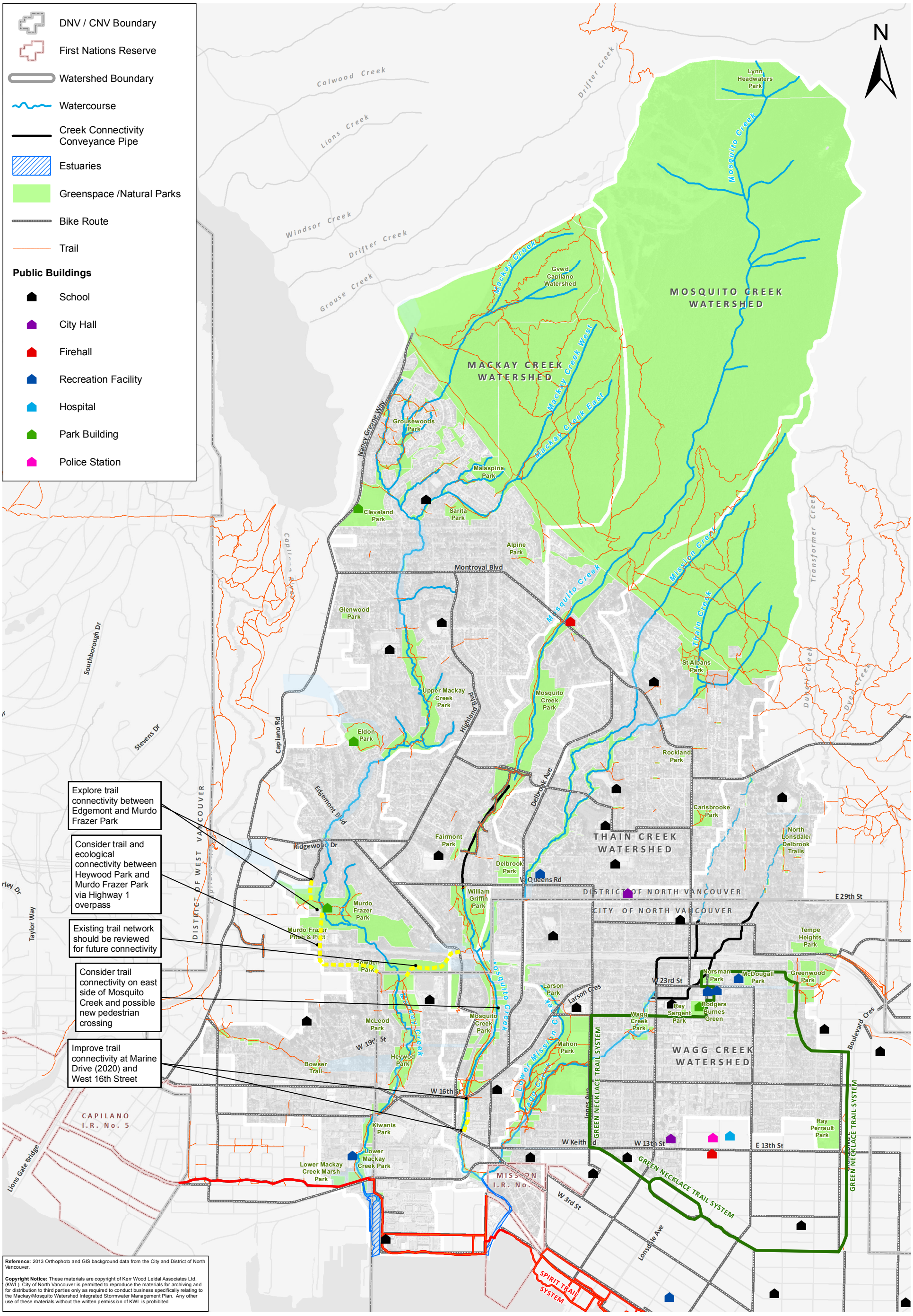
Objective 3: Maximize Riparian Ecosystem

Figure C10-4

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Project No.: 99-125 | Date: September 2020

0 250 500 1,000 Meters

Objective 4: Maximize Social - Ecological Connection

Figure C10-5

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- DNV / CNV Boundary
- Watershed Boundary
- Watercourse
- Major Roads
- Disaster Response Route
- Parking Area
- Industrial Building
- Estuaries
- Slope Hazards
- Creek Hazards
- Wildfire Hazard

Hazards from the District of North Vancouver Open Data and the City of North Vancouver

- Creek Fan (from District of North the Vancouver Overview Report on Debris Flow Hazards 1999)
- Creek Connectivity Conveyance Pipe
- Undersized Culvert (200 Yr)
- Undersized Minor System Pipe (10 Yr)
- Notable Erosion Sites
- Future Dike

Public Buildings

- School
- City Hall
- Firehall
- Recreation Facility
- Hospital
- Park Building
- Police Station

Maximum Water Depth (River Floods)

- Year 2012
- Year 2100
- Year 2200

-Predicted River Floods from "Creek Hydrology Floodplain Mapping and Bridge Hydraulic Assessment", KWL Report October 24, 2014

- Flood Construction Level Contours

Proposed Debris Net
Mackay Creek Debris Basin
Mosquito Creek Debris Net
Mosquito Creek Debris Basin
Evergreen Sediment Basin
Review overland flood routes in Wagg Creek (CNV)
Address Mackay Creek (east bank) flood capacity with future redevelopment of Capilano Mall
2019 Dike Construction
Future Dike
Coastal Dike Future
Implement coastal flood construction levels

MOSQUITO CREEK WATERSHED
MACKAY CREEK WATERSHED
THAIN CREEK WATERSHED
WAGG CREEK WATERSHED
DISTRICT OF NORTH VANCOUVER
CITY OF NORTH VANCOUVER
CAPILANO I.R. No. 5
MISSION I.R. No. 1

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Project No.: 99-125 | Date: September 2020

0 250 500 1,000 Meters

Objective 5: Maximize Sense of Safety and Security

Figure C10-6

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Author: Pbuskas

City of North Vancouver
Mackay/Mosquito Watershed Integrated Stormwater Management Plan

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DNV / CNV Boundary
First Nations Reserve
Watershed Boundary
Watercourse
Creek Connectivity Conveyance Pipe
Estuaries
2013 Riparian Forest Cover

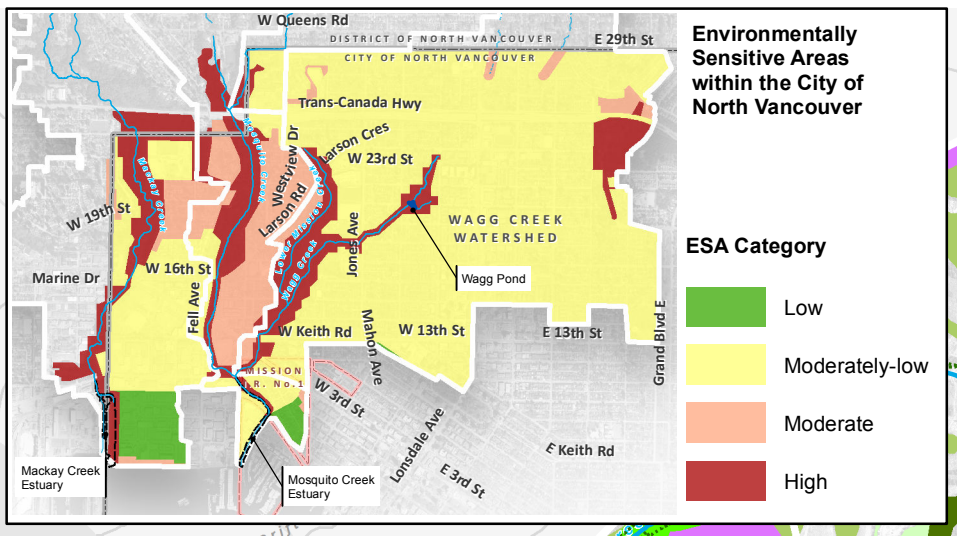
Ecosystem Type

Alpine
Young Forest
Mature Forest
Old Forest
Riparian
Sparsely Vegetated
Woodland

Ecosystem Type from Metro Vancouver
Technical Report Prepared by:
Del Meidinger, Meidinger Ecological Consultants Ltd.,
Josephine Clark, Metro Vancouver, and
David Adamoski, Metro Vancouver
January, 2014 for Metro Vancouver & Abbotsford
2010-2012

Potential Opportunities

Forest Integrity
Habitat
Riparian
Ecological Network Projects (Rain Coast)



Environmentally Sensitive Areas within the City of North Vancouver

ESA Category

Low
Moderately-low
Moderate
High

N

Opportunity for setbacks and riparian enhancement along Mapleridge Drive and up to Clements Avenue

Future OCP reviews should consider how land-use change could provide opportunities for improvement

Opportuntiy for Ecological Corridor to Eldon Park and Bracknell Crescent

Opportuntiy for Ecological Corridor and stream connectivity north of Elizabeth Way

Murdo Frazer Pond

Murdo Frazer Off Channel Pond

Opportuntiy for Ecological Corridor to green space Pemberton Heights

Lower Mackay Creek Wetland

Opportuntiy for Ecological Corridor to Lloyd Avenue

Mackay Creek Estuary

Mosquito Creek Estuary

Opportunity for stream setback improvement with redevelopment between 29th and Queens

Stream setback needed at 254 East 27th Street

Opportunity for Stream Daylighting - 237 E 27th and 234 E 26th

Provide additional setbacks with redevelopment at Cypress Gardens

Tempe Heights Pond

Wagg Pond

MOSQUITO CREEK WATERSHED
MACKAY CREEK WATERSHED
THAIN CREEK WATERSHED
WAGG CREEK WATERSHED
CAPILANO I.R. No. 5
MISSION I.R. No. 1
DISTRICT OF WEST VANCOUVER
DISTRICT OF NORTH VANCOUVER
CITY OF NORTH VANCOUVER
Montroyal Blvd
Highland Blvd
Edgemont Blvd
Delbrook Ave
Jones Ave
Grouse Creek
Transformer Creek
Dunell Creek
Dyer Creek
Mackay Creek
Mackay Creek West
Mackay Creek East
Mosquito Creek
Thain Creek
Lower Wagg Creek
Nancy Greene Way
W 19th St
W 16th St
W Keith Rd
W 13th St
W 23rd St
Larson Cres
Jones Ave
W Queens Rd

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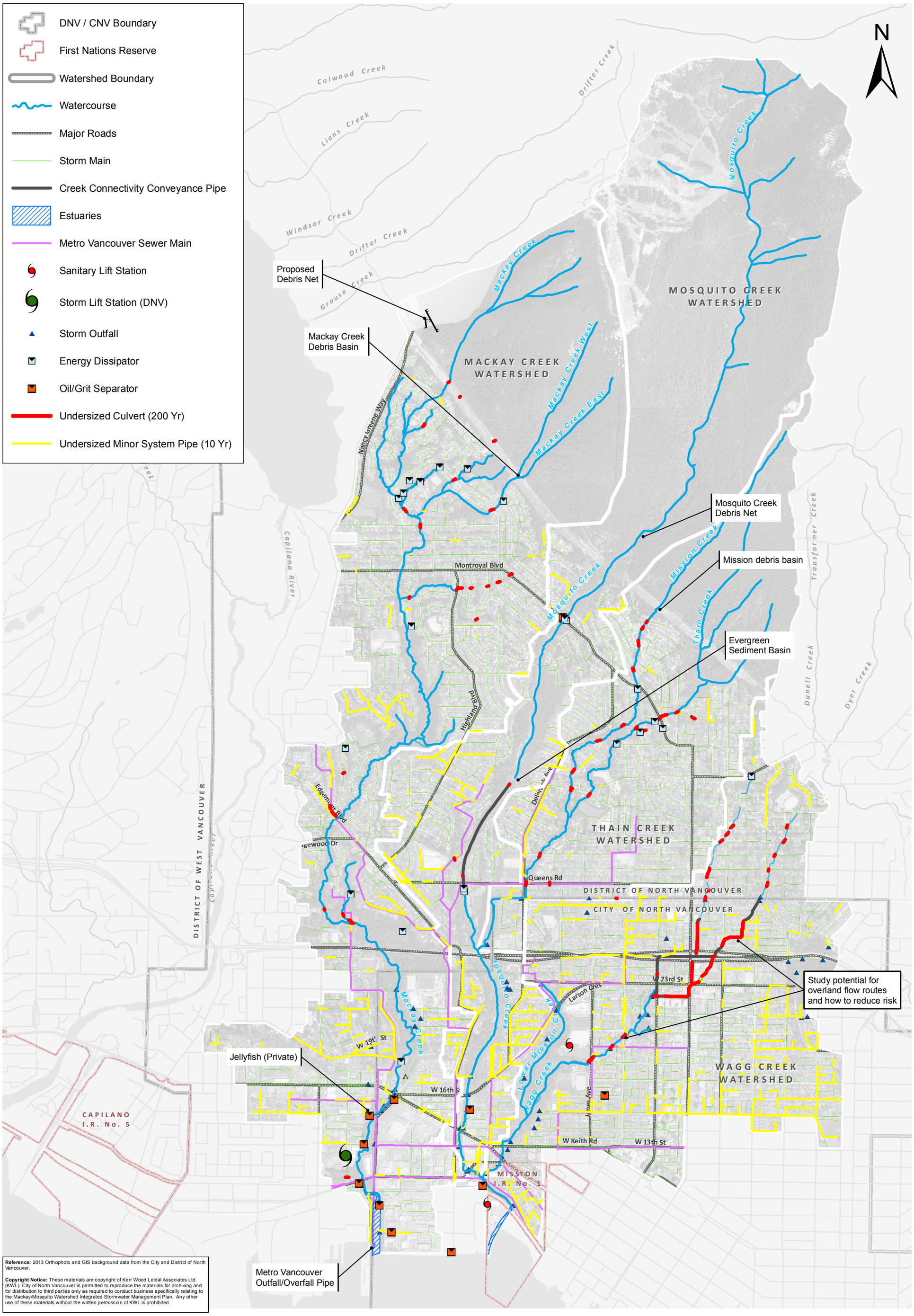
Objective 6/7: Minimize Impacts on First Nation Traditional Use Activities & Maximize Natural Assets

Figure C10-7

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Objective 8 Minimize Damage to Infrastructure

Figure C10-8

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DNV / CNV Boundary
First Nations Reserve
Watershed Boundary
Watercourse
Creek Connectivity Conveyance Pipe
Estuaries
Areas of Land Use Change
Single Lot Infill

Note:
Land Use Change based on comparing CNV OCP (2031) and Ratified DNV OCP (2030) land uses with existing zoning (2010).

Infiltration Potential
From Piteau's Hydrogeological Questions and Answers Appendix C10-C

Severely Limited 0 - 20 mm/hr
Severely Limited 3 - 30 mm/hr
Moderately Limited ~ 50 mm/hr

Note:
Geology data provided by the City of North Vancouver.

N

Colwood Creek
Lions Creek
Windsor Creek
Drifter Creek
Grouse Creek
Capilano River
Mackay Creek
Mackay Creek West
Mackay Creek East
Mosquito Creek
Thain Creek
Mission Creek
Transformer Creek
Dunell Creek
Dyer Creek
Lower Mission Creek
Wagg Creek
Nancy Greene Way
Edgemont Blvd
Highland Blvd
Delbrook Ave
Jones Ave
Larson Cres
W 23rd St
W 19th St
W 16th St
W Keith Rd
W 13th St
Queens Rd
MACKAY CREEK WATERSHED
MOSQUITO CREEK WATERSHED
THAIN CREEK WATERSHED
WAGG CREEK WATERSHED
DISTRICT OF NORTH VANCOUVER
CITY OF NORTH VANCOUVER
DISTRICT OF WEST VANCOUVER
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0 250 500 1,000 Meters

Land Use Change

Figure C10-9

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Author: rtaylor

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Mackay/Mosquito Watershed Integrated Stormwater Management Plan

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- DNV / CNV Boundary
- First Nations Reserve
- Watershed Boundary
- Watercourse
- DNV Rainfall Zones
- Creek Connectivity Conveyance Pipe
- Estuaries
- Slope Hazards
- Areas < 10 % Slope
- Areas > 10 % Slope

Site-specific Geotechnical Assessment Required for the Following Conditions:

- Within setback of 100m from crest of any 3H:1V slope (Greatest risk would be seepage breakout on slope) - Not shown on this figure
- Within setback of 200m behind crest of slope >3H:1V - schematically depicted on this figure

- *on slopes greater than 10H:1V*
- *proximity to retaining walls*
- *Multi-home developments*

Lower Watershed Source Control Target
CNV 50 % MAR = 40 mm
for 1-2 Residential Units
72 % MAR = 58 mm for > 3 m
Residential Units

DNV 50 % MAR with
Climate Change = 58 mm

Mid Watershed Source Control Target
DNV 50 % MAR with
Climate Change = 83 mm

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Project No.: 99-125 | Date: September, 2020

0 250 500 1,000 Meters

Stormwater Source Controls Limitations in Mackay Mosquito Watersheds

Figure C10-10

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Appendix C10-A

Summary of Compendium Findings and Recommendations

Contents

1. Introduction 1

2. Summary of Findings and Recommendations 1

2.1 Watershed Overviews 1
2.2 Instream Species and Water Quality 2
2.3 Riparian Forest and Terrestrial Species 3
2.4 Drainage Asset Inventory 4
2.5 Hydrologic and Hydraulic Modelling 4
2.6 Drainage Assessment 5
2.7 Land-Use Analysis 7
2.8 Municipal Policy and Operations 8
2.9 Watershed Values and Objectives 9

Tables

Table C6-5: Summary of Undersized Storm Sewers and Culverts 6

1. Introduction

This document summarizes the Findings and Recommendations from all the compendiums.

2. Summary of Findings and Recommendations

2.1 Watershed Overviews

Findings

Findings from this compendium include:

Watershed Overview

C1-1. The Mackay watershed is approximately 849 ha with several tributaries; flows through both the District and the City before discharging to Burrard Inlet.

C1-2. The Mosquito Creek watershed has a total drainage area of 1538 ha, with two significant tributaries, Thain Creek (319 ha) in the District and Wagg Creek (387 ha) in the City. The mouth of the creek flows through Squamish Nation Indian Reserve No. 1 before discharging to Burrard Inlet.

C1-3. Both watersheds have steep, forested upper reaches, with mid-section residential neighbourhoods with commercial and industrial development south of Marine Drive. Soils consist of bedrock with overlaying soil veneers in the upper watershed, with predominantly glacial blanket (till) and glaciofluvial (sands/gravels) areas in the mid section, with alluvial sediments (sand/gravels) towards the mouth of the watersheds.

Watershed History

C1-4. There is much background information available within these watersheds, and a rich history starting in the late 1800's. DNV was established in 1891 and CNV established in 1907.

C1-5. Extensive flooding was noted in the early 1950's and 1980's, complicated by channel instability and sediment transport. This led to construction of debris/sediment basins, enclosed culverts, channel stabilization works, culvert inlets/upgrades, and dykes.

C1-6. A debris flow on upper Mackay Creek occurred in 1995, which resulted in the construction of a debris barrier, and replacement and upgrading of culvert crossings. A debris net was installed on upper Mosquito Creek in 2013.

C1-7. Upper Mission Creek was diverted to Thain Creek in 1950's. A section of Thain Creek was daylighted in 1999 resulting in new riparian, fish passage and a stable/low maintenance channel.

C1-8. Wagg Creek notably has a sedimentation pond and an oil/water separator on 15th Street.

Natural Risks

C1-9. Mountain creeks are susceptible to a spectrum of floods, debris floods and flows including Mackay and Mosquito Creeks. DNV is currently undertaking a *Debris Geohazard Risk and Risk Control Assessment (*BGC, 2017) study.

C1-10. CNV and DNV completed a *Creek Hydrology, Floodplain Mapping and Bridge Hydraulic Assessment Study (KWL, 2014)* to investigate the risk of flooding and the exacerbating effects of climate change on major creeks on the North Shore. Predicted extents of flooding from 200-year creek flooding and coastal flooding using three time horizons 2012, 2100 and 2200 was evaluated. The extent of overbank flooding is extensive in all these scenarios. There is a substantial flood hazard to large developed and redeveloping areas in Mackay and Mosquito watersheds. Non-structural and structural measures were recommended.

2.2 Instream Species and Water Quality

Findings

The purpose of the ecological assessment is to determine stream health based on an assessment of water quality, benthic invertebrates, riparian areas, fish habitat, and other factors. The health of the stream is correlated to the level of development in the watershed and is used as a baseline to examine future change related to urban development, and improvements based on improved stormwater and riparian management.

C2-1. Water Quality

Analysis of new and historical data showed that water quality in Mackay and Mosquito creeks is typical of moderately urbanized streams in Metro Vancouver. Assessment using Metro Vancouver's Adaptive Management Framework (AMF) identified several parameters in the "satisfactory" (yellow) or "needs improvement" (red) categories including dissolved oxygen, turbidity, conductivity, E.coli, fecal coliforms, and total metals.

C2-2. Sediment Quality

Total metal concentrations in streambed sediments from the study area were typical of urban streams from Metro Vancouver. All samples from Mackay, Mosquito, and Thain creeks had concentrations of total metals below Canadian Environmental Sediment Quality (CESQ) guidelines, while Mission and Wagg creeks had elevated concentrations of some metals. Not unexpectedly based on its level of urbanization, most sediment samples collected from Wagg Creek in the past 10 years had a least one total metal concentrations above CESQ guidelines.

C2-3. Benthic Invertebrates

Benthic invertebrates were collected at eight sites in September 2014. Results reflected the effects of urbanization with higher taxa richness and more sensitive taxa in the less urbanized headwater sites, and lower taxa richness and higher abundance of a few taxa tolerant of urban conditions in the lower watershed.

Mean B-IBI values measured in September 2014 were:

- Mackay Creek Site 1: 22.0
- Mackay Creek Site 3: 26.5
- Mission Creek Site 1: 25.0
- Mosquito Creek Site 1: 27.5
- Mosquito Creek Site 2: 31.5
- Mosquito Creek Site 3: 33.5
- Thain Creek Site 1: 19.5
- Wagg Creek Site 1: 19.0

Changes in mean B-IBI values were analyzed at five sites (Mackay 1, Mosquito 1, Mosquito 2, Wagg 1, Mission 1) for which at least 4 years of data was available. While all five show typical B-IBI variability, the only statistically significant change was the increase in mean B-IBI values at Wagg Creek Site 1.

C2-4. Fish Community

Mackay and Mosquito creeks support similar fish communities which include chum salmon, coho salmon, and cutthroat trout (resident and anadromous), as well as prickly and coastrange sculpins, threespine stickleback, and western brook lamprey. It is unknown if steelhead trout are still present in either system but occurred historically. Pink salmon were observed through lower Mackay Creek in early September 2015 and were abundant in Heywood Park. Dolly Varden may also occur but are not abundant.

C2-5. Fish Passage

Both natural and man-made barriers limit fish passage and distribution in the study watersheds. Key fish passage issues include:

- Mackay Creek: Anadromous salmon, particularly coho, are able to ascend to the channel control weir at Belvedere Avenue on Mackay Creek. Increasing channel gradient and manmade passage barriers compromise fish passage upstream.
- Mosquito Creek: The 850 m long culvert between Queens Avenue and the Evergreen Basin is impassable to all fish. Additional gradient barriers fragment fish habitat upstream of the basin.
- Wagg Creek: The Jones Avenue culvert is a barrier to upstream fish movement. If this was removed, the culverts on the two tributary stream
- Mission Creek: The Larson Road culvert on Mission Creek is impassable to all fish. A second culvert at 23rd Avenue is also a barrier.
- Thain Creek: Sampling records (lack of coho fry) indicate that the inclined fishway and culvert at Queens Avenue and Westview Drive prevent or restrict fish passage into Thain Creek.

C2-6. Instream Habitat

Overall fish habitat quality was high in the study watersheds but did show some spatial patterns. The lowland reaches of Mosquito, Mackay, and Wagg creeks were less diverse and productive for fish based on pool and wood density. However, these channels are lower gradient and provide gravel substrates important for spawning.

A total of 1346 pieces of large wood were surveyed with an average diameter of 37 cm, an average length of 4.8 m, and an average wood volume of 0.20 m^3. The mean density of large instream wood was 13.0 pieces per 100 m of stream channel but varied from 2.6 pieces per 100 m in Mosquito Creek to 23.4 pieces in Thain Creek. Natural streams typically have been 10 and 20 pieces per 100 m.

Five hundred and fifty pools deeper than 30 cm were measured in Mackay and Mosquito creeks in September 2014. Mean depth was 44 cm (range of 30 to 147 cm). Mean pool density was 5.3 pools per 100 m and varied from 3.2 in Mission Creek to 9.4 in Thain Creek. It is noteworthy that Mosquito Creek had a higher density of deep pools than Mackay Creek despite substantially fewer large logs.

Recommendations

C2-1. Undertake ongoing monitoring of stream health to track changes in stream conditions and the success of watershed management activities. Monitoring should include water and sediment quality, benthic invertebrates, and fish population at a frequency of every 2 to 5 years.

C2-2. Investigate the source of elevated lead levels in streambed sediments in Mission Creek with further sampling.

C2-3. Assess fish passage barriers on Thain Creek and fish sampling.

C2-4. Undertake further sampling and analysis of the Wagg Creek benthic invertebrate community to better understand what may be leading to the statistically significant increase in B-IBI. It is unusual to see increasing B-IBI in a heavily urbanized stream.

C2-5. Undertake spawner surveys in representative stream segments by community stewards to estimate population size and highlight the importance of Mackay and Mosquito creeks for fish populations.

2.3 Riparian Forest and Terrestrial Species

Findings

C3-1. Watershed and Riparian Forest Cover

Watershed forest cover in the Mackay and Mosquito watersheds is considered high compared to many Metro Vancouver watersheds, partially because of the forested headwaters above the urban development boundary. Approximately 42% of the Mosquito watershed and 42% of the Mackay watershed is forested in 2013. Forest cover in both watersheds has remained stable since 1995.

Riparian forest cover varies from 67% in Wagg Creek to 90% in Mission Creek with a mean across the study area of 78%. This is considered high for streams in Metro Vancouver, and partially reflects the forested headwaters in Mosquito and Mackay creeks. Riparian forest cover has remained remarkably stable since 1995; in fact, there has been a slight increase (1.5 ha) as the Mosquito Creek corridor has naturally reforested with red alder after channelization for flood control in the 1980s.

C3-2. Terrestrial Wildlife and Species at Risk

Terrestrial wildlife is often a secondary focus of ISMPs, but streams and their associated riparian corridors and natural areas are essential habitat for many birds, amphibians, and mammals. Riparian corridors along Mackay and Mosquito creeks, are often directly connected to the forested headwaters which act as reservoirs for many wildlife species. Stream corridors are the only remaining linear habitats providing habitat connections for wildlife.

The BC Conservation Data Centre records 137 plant and animal species at risk in non-marine areas of Metro Vancouver. Most of these species are unlikely to occur in the study area based on lack of habitat. Species at risk that are likely to be found in the study area include: green heron (observed in Lower Mackay Creek Park), coastal tailed frog (observed in Mosquito Creek), northern red-legged frog (observed in Mackay Creek corridor), Pacific water shrew (no recent records), and western screech owl kennicottii subspecies (no recent records).

Recommendations

C3-1. Monitor watershed and riparian forest cover every 5 years using methods that are consistent with those presented in this report. The next monitoring period should occur in spring 2018.

C3-2. Undertake more detailed analysis of riparian forest cover in residential areas to identify opportunities for reforestation or other improvements to riparian vegetation.

C3-3. Identify young deciduous stands in riparian areas that are suitable for conifer underplanting and invasive species management using Lidar based forest cover mapping.

C3-4. Undertake mapping of forested wetlands (swamps) using Lidar-based analysis of topography and impeded drainage.

C3-5. Compile general wildlife and species at risk information collected by consultants, municipal staff, stewards, and the public to better understand biodiversity in the study watersheds.

C3-6. Undertake volunteer-based bird surveys in representative riparian areas such as Heywood Park and Murdo Frazer Park as a key component of biodiversity.

C3-7. Undertake species at risk information and surveys by qualified biologists to address data gaps. Riparian and wetland species should be emphasized. Information is generally lacking.

2.4 Drainage Asset Inventory

Findings

Findings from this compendium include:

C8-1. CNV/DNV GIS drainage layers were used for figure generation and asset inventory. GIS gaps were picked up in the field reconnaissance or interpolated from existing data.

C8-2. A field reconnaissance and inventory were conducted in the summer of 2014 collecting data on culverts, stormwater outfalls, structures, typical creek cross sections, significant erosion sites, and obstructions in the creeks.

C8-3. Erosion sites were documented and qualitatively rated for risk; the following 'very high' and 'high' risk sites were noted:

Watercourse	Very High Risk	High Risk	Jurisdiction
Mackay Creek	14	19	DNV
Thain Creek	2	1	DNV
Wagg Creek	3	2	CNV

C8-4. Stream bank protection and channel obstructions such as anthropogenic (blocks, drop structures, weirs, debris barriers), large woody debris, and boulders were recorded.

Recommendations

Based on the foregoing, it is recommended that CNV/DNV:

C8-1. Further evaluate the Very High- and High-Risk Erosion Sites to assess the liability risk to CNV/DNV and plan for rehabilitation/stabilization works as needed. As a minimum these sites should be monitored regularly to ensure they do not threaten existing buildings and infrastructure.

2.5 Hydrologic and Hydraulic Modelling

Findings

Findings from this compendium include:

Model Calibration and Validation

C5-1. Models of the entire study area, including all storm sewers, culverts and major watercourses, were developed using the PCSWMM software.

C5-2. Model calibration/validation was undertaken using seven separate storm events and three flow monitoring locations. An acceptable calibration was achieved with peak flows underestimated in some events and overestimated in others. Groundwater hydrograph shape and total hydrograph volume were also calibrated.

C5-3. The design event peak flow estimates were compared to those in previous studies and were found to be in general agreement with differences that could be explained by the more detailed model used in this study than previously.

Model Scenarios

C5-4. Design event and continuous simulation models were created to simulate predevelopment (forested), existing, and unmitigated future land uses, with and without climate change. Minor (10-year) and major (100-year) design storms were simulated. RCP 4.5 and RCP 8.5 climate change scenarios were simulated. In total, 22 models were created.

Continuous Simulation Modelling

C5-5. Identified high and low rainfall years continuous simulation models were used to estimate the runoff volume (excluding groundwater and interflow) at key locations. The EIA was then estimated using the runoff volume and the rain volume with the assumption that the predevelopment forested model runoff volume represents a 0% EIA and the total rain represents 100% EIA.

C5-6. Unmitigated future land use is expected to increase EIA by 22% in the Mackay Watershed and by 17% in the Mosquito Watershed compared with TIA estimates of 23% and 19% for Mackay and Mosquito respectively.

C5-7. EIA was converted to watershed-specific stormwater volume reduction targets for development/redevelopment aimed to maintain the existing EIA as a minimum to achieve no-net-loss. The overall watershed capture targets are approximately 30% of the 2-year 24-hour rain depth (21mm below and 30mm above 150m elevation).

2.6 Drainage Assessment

Findings

Major Systems

C6-1. The Major System defined is as all 750mm and larger diameter storm sewers, smaller storm sewers without a safe overland flow path, all culverts, and overland flow paths.

C6-2. Trunk storm sewers and sewers without overland flow routes were assessed with the 100-year 6-hour and 24-hour Modified Chicago distribution design storms.

C6-3. Culverts were assessed using 200-year flow estimates.

Minor Systems

C6-4. The Minor System is comprised of all other storm sewers assessed using the 10-year 6-hour and 24-hour Modified Chicago storms.

Capacity Assessment Criteria

C6-5. Storm sewers were classified by their design flow to full flow capacity ratio and degree of surcharge. Storm sewers were flagged as undersized if design flows exceeded full flow capacity and surcharge exceeded 15 minutes in duration and 0.3m height above crown of pipe (not road).

C6-6. Culverts were classified by their design flow to full flow capacity ratio. No surcharge time allowance was permitted for culverts due to debris risk.

Capacity Assessment Results

C6-7. With the assessment of the overall drainage system, the following storm sewers and culverts were identified as undersized:

Table C6-1: Summary of Undersized Storm Sewers and Culverts

Scenario	Undersized		
	Minor System	Major System	
	Storm Sewers	Storm Sewers	Culverts
Existing land use	32 km (16% of whole system)	8 km (4% of whole system)	125 culverts (66% of all culverts)
Future land use	36 km (19% of whole system)	9 km (4% of whole system)	129 culverts (68% of all culverts)
Future land use with climate change	57 km (29% of whole system)	14 km (7% of whole system)	142 culverts (75% of all culverts)
Refer to: Figures C6-2A to F - 10-year storm sewer assessment for all three scenarios Figures C6-3A to F - 100-year storm sewer assessment for all three scenarios Figures C6-4A to F - 200-year Culvert Assessment for all three scenarios.			

Prioritization and Cost Estimates

C6-8. Undersized pipes were classified into five categories (Priority 1 through 5) based on the consequence of overflows/surcharging.

C6-9. Priority 1 to 3 upgrades identify pipes that are undersized for existing land use flows.

C6-10. Priority 4 upgrades are pipes that will be undersized under the future land use condition.

C6-11. Priority 5 pipes are undersized only in the future RCP 8.5 climate change scenario.

C6-12. Upgrades for Priority 1 to 4 pipes are sized for the future land use with RCP 8.5 climate change design flows and Class D cost are estimated for the storm sewers.

C6-13. Culvert sizes will need to be reviewed once the findings of the Debris Geohazard Risk and Risk Control Assessment *(BGC, 2017)* study are available. For this reason, culvert upgrades have not been costed at this time.

Recommendations

Based on the foregoing, it is recommended that CNV/DNV:

C6-1. Confirm creek culvert (and bridge) upgrade sizes with the *Debris Geohazard Risk and Risk Control Assessment (BGC. 2017)* study recommendations because the ISMP only assessed clear water flow capacities.

C6-2. Upgrade Priority 1 storm sewer and culvert projects first and then Priority 2 projects. Priority 3 projects can likely be put off until the end of asset life. Priority 4 projects should be undertaken as development proceeds either by developers of properties adjacent to the pipes or as DCC funded projects by the municipality.

C6-3. Size new or replacement culverts for 80% full for the design flow (CNV/DNV request).

C6-4. Manually check purple colour coded pipes prior to further action/upgrading. They represent steep pipes with design flows <100% full but surcharging higher than 30 cm and longer than 15 minutes. It is unclear whether this is caused by backwater or inlet capacity limitations.

C6-5. Undertake study to design bridges upgrades identified in the *Creek Hydrology, Floodplain Mapping and Bridge* Hydraulic *Assessment Study (KWL, 2014)* report. The preliminary design should include an assessment of flood containment and incorporate the findings of the *Debris Geohazard Risk and Risk Control Assessment, (BGC, 2017)* study to estimate the design flows (clear water or debris, as appropriate) to be conveyed under each bridge.

2.7 Land-Use Analysis

Summary of Findings

Findings from this compendium include:

C7-1. The upper third of the watersheds are forested except for some clearing for the Grouse Mountain ski area and mountain access roads. The lower two thirds of the watersheds are urbanized with denser development found near Burrard Inlet.

C7-2. The District portions of the watersheds consist of mostly residential development with a few commercial areas.

C7-3. In the Mackay watershed, development within the City is a mix of residential immediately below the Upper Levels Highway and transitions to commercial and industrial, below Marine Drive. In the Mosquito watershed, development within the City is primarily residential, with commercial strips along Lonsdale Avenue and Marine Drive. A small industrial area is also located on Marine Drive.

C7-4. The Squamish Nation lands are developed with residential areas and the Mosquito Marina at the foreshore of the Burrard Inlet.

C7-5. The TIA assessment yielded the following:

Study Area	Increase in TIA between Existing and Future Development
Mackay Watershed	23%
Mosquito Watershed (including Thain and Wagg)	19%

2.8 Municipal Policy and Operations

Findings

Findings from this compendium include:

C8-1. Metro Vancouver Liquid Waste Management Plan includes stormwater commitments such as undertaking ISMPs, including stakeholder participation, and updating/adopting bylaws and policies. MOE requires monitoring to assess and report on the implementation of ISMPs.

C8-2. CNV has the following stormwater related bylaws:

a. Subdivision & Development Control Bylaw, 2010
b. Stream and Drainage System Protection Bylaw, 2003
c. Zoning Bylaw, 1995, Amendment Bylaw 2006
d. Development Procedures Bylaw, 2001, Amendment Bylaw 2006
e. Sewerage and Drainage Utility Bylaw, 1995

C8-3. DNV has the following stormwater related bylaws:

a. Development Servicing Bylaw, 2005
b. Tree Protection Bylaw, 2012
c. Environmental Protection and Preservation Bylaw, 2009
d. Official Community Plan Bylaw, 2011
e. Sewer Bylaw, 1995

C8-4. CNV undertakes drainage system maintenance: street sweeping, culvert inspection/maintenance, debris/sediment removals, and invasive species removal and native species planting.

C8-5. DNV undertakes drainage system maintenance: storm sewers mains flushing, culvert inspection/maintenance, outlet inspections, and invasive species removal and native species planting.

Recommendations

Based on the foregoing, it is recommended that:

C8-1. DNV to establish and apply a progressive volume reduction target for single family residential development / redevelopment. A higher than region-wide baseline is recommended. The 72% of the 2-year DFO criteria or 50% MAR criteria with climate change would be desirable.

C8-2. CNV to consider rate control criteria for:

a. Catchment areas draining to watercourses:

i. If source controls volume reduction targets cannot be achieved, release at baseflow rate (0.5 L/s/ha), the 6-month 24-hour storm (56 mm)

ii. Detain and release at pre-development rate, the 2-year and 5-year return period storms to better mimic natural hydrology and reduce erosive flows

b. Catchment areas draining directly to the ocean:

i. No environmental capture or detention required, provide water quality treatment for the 6-month 24-hour storm (56 mm) – see bullet 3.

c. Protection of downstream drainage infrastructure for all catchment areas – detain post-development flows proportionally to downstream drainage infrastructure limited capacity up to the 10-year event.

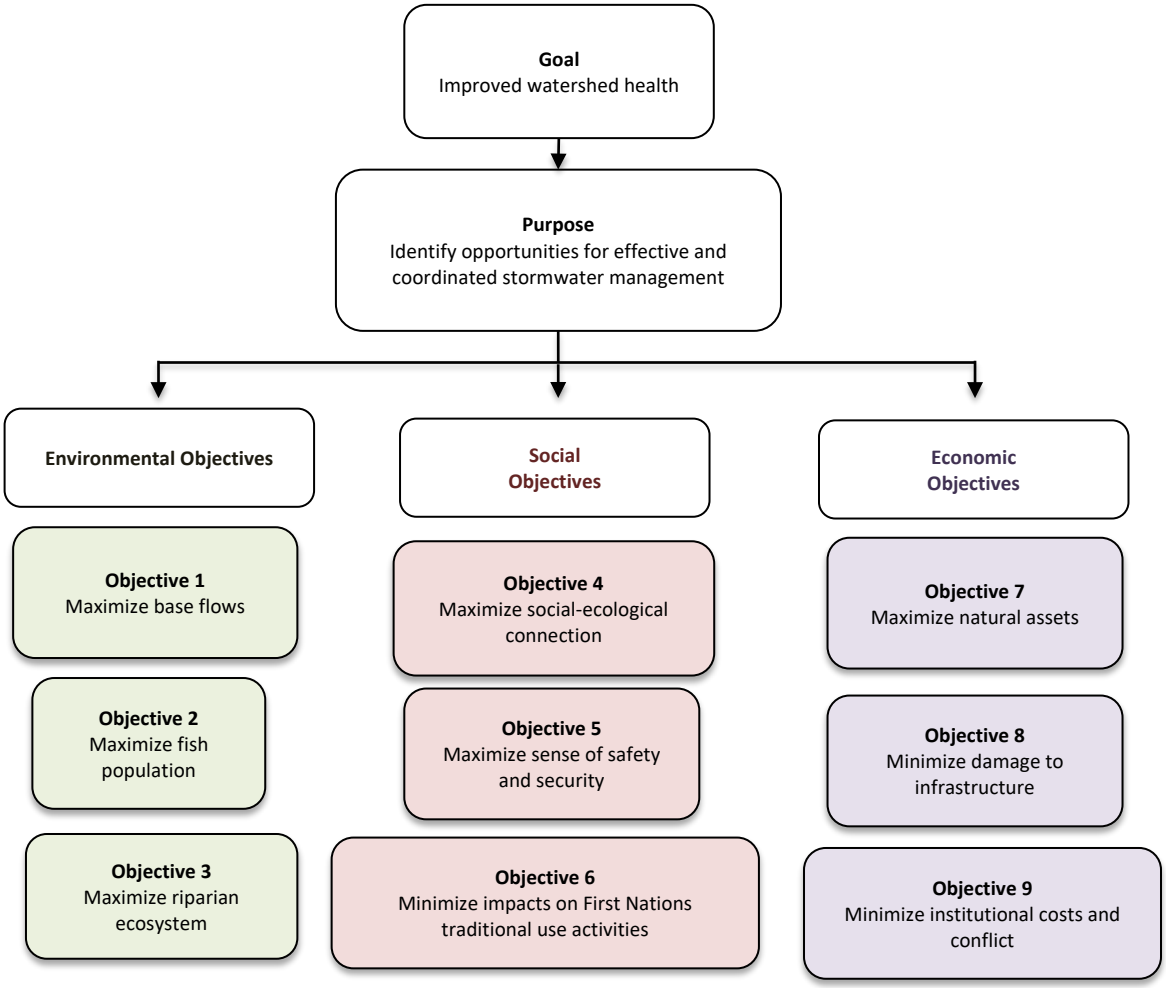
C8-3. CNV/DNV to consider clarifying and strengthening requirements for water quality treatment for pollutant generating surfaces such as roads, parking lots, etc. An example would include 'remove 80% of total suspended solid based on 50 µm particle size from 72% of the 2-year 24-hour storm for runoff from pollutant generating surfaces'.

C8-4. CNV/DNV to implement and improve erosion and sediment control requirements during construction for water quality benefits.

C8-5. CNV/DNV continue to inspect and maintain oil/grit separators, catch basins, and debris traps.

2.9 Watershed Values and Objectives

DNV and CNV developed the following Objective Tree to guide ISMPs.



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Appendix C10-B

Mitigation and Compensation Measures

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1. Mitigation Measures for Hydrologic Impacts

1.1 Low Impact Development Practices – Minimize Imperviousness

Introduction

Low Impact Development (LID) is a design with nature approach that reduces a development's ecological footprint. LID concepts embodied at the planning stage, often affords more opportunities to reduce the overall negative effects of development and reduce costs. Requirements for expensive traditional stormwater infrastructure may also be reduced as less runoff will be generated.

There are many best management practices (BMPs) commonly used in LID, however it is not always possible to incorporate all of them into a development, and even with adoption of all available LID options, there will still be changes to the hydrologic regime relative to the pre-development conditions and some additional measures or facilities will often be required. LID practices are most effective in mitigating adverse stormwater effects when used in combination with other BMPs, such as constructed source controls and detention. The *Puget Sound Action Team's LID Technical Guidance Manual*[1] is an excellent resource for LID planning and design.

Reduced Road Widths

Traditional road pavement widths may be larger than they need to be, particularly for streets that are residential access only, and not thoroughfares. Road widths can be narrowed to a minimum that allows necessary traffic flow, but that discourages excess traffic and excess speed, both of which are beneficial in a family- and pedestrian-oriented neighbourhood. Road widths do, however, need to meet the community's needs for utility and emergency vehicle access and these requirements will often determine acceptable minimum road widths.

Reduced Building Footprints

Building footprints, and impervious roof area, may be reduced without compromising floor area by increasing building height. This also allows greater flexibility to develop layouts that preserve naturally vegetated areas and provide space for infiltration facilities. Some relaxation of building height restrictions may be necessary to allow this type of design.

Reduced Parking Standards

Reducing the required number of parking spaces for a development reduces the impervious area and encourages pedestrian and public transit-friendly communities. Reducing the required parking spaces also reduces development costs.

Limiting Surface Parking

Limiting surface parking and restricting parking to below building roof areas also directly reduces the impervious area in a development.

[1] Low-Impact Development Technical Guidance Manual Puget Sound, 2005. http://www.psparchives.com/our_work/stormwater/lid.htm

Pervious Parking Surfaces

Use of pervious paving materials rather than impervious concrete or asphalt can reduce the runoff generated from parking areas. Pervious materials may include pavers, reinforced clean crushed gravel, reinforced turf, or engineered permeable pavements.



Reinforced Clean Crushed Gravel



Geogrid

Building Compact Communities

A complete and compact development plan preserves more natural watershed features and significantly reduces imperviousness. In some cases, compact communities have up to 75% less roadway pavement per dwelling unit, and parking needs are reduced because local services are more accessible by pedestrians and via public transit.

Preserving Naturally Significant Features

Preservation of natural areas in a watershed is always an important consideration, which can provide recreational as well as environmental benefits but some natural areas perform special aquatic ecosystem functions and as such are vital to maintaining watershed health. These areas, which include riparian forests, wetlands, floodplains and natural infiltration depressions with highly permeable soils, are particularly important to inventory and protect from alteration.

1.2 Stormwater Source Control Technologies

Stormwater source controls reduce the runoff that is discharged to the stream network by managing the water balance at the site level. Source controls play a key role in achieving Rainwater Management Criteria for volume reduction, water quality treatment, and runoff control and can be very effective at reducing runoff volumes and peak runoff rates from events smaller than the 50% of 2-year storm. Though they do provide some flow-detention benefits for the 2-year storms, source controls have limited ability to reduce peak runoff rates from large storms and must be designed with adequate overflow capacity. Additional stormwater infrastructure must be provided to safely convey stormwater offsite for the larger events.

Several standard source control technologies are described below. The *Metro Vancouver Stormwater Source Control Design Guidelines*[2] is an excellent reference for source control BMP design advice.

Absorbent Landscaping

Natural topsoil is generally permeable. The vegetation on topsoil provides a layer of organic matter which is mixed into the soil by worms and micro-organisms, creating voids, which allow rain water to percolate through, and making the soil more structurally capable of providing storage in the void spaces when saturated.

Standard construction practice is often to strip the existing topsoil, compact or excavate a site surface to the desired grade, and then cover it with a thin layer of imported topsoil. Although lawns and other ornamental landscaping will establish a vegetated surface, both the original surface and subsurface flows and storage capacities have been altered and surface runoff will be increased. Instead of stripping and removing, original topsoil it should be replaced on the site and augmented with organic matter and sand to improve soil structure and increase macropore development.

To increase absorbency, surface soils should have a minimum organic content to facilitate plant growth and a soil depth sufficient to meet the 50% of 2-year rainfall capture target. Increased soil depths also provide retention for runoff from adjacent hard surfaces. Surface vegetation should include herbaceous groundcovers with a thickly matted rooting zone, deciduous trees, or evergreens.

Some maintenance over the long term is required for the absorbent landscape to continue to provide stormwater benefits. Maintenance activities may include replacing soils that have eroded and replanting dead or dying vegetation.



Absorbent Landscaping



Absorbent Landscaping

Surface Infiltration Facilities

Rainfall runoff is stored at or near the surface in a layer of absorbent soil, sand, gravel, or rock, and/or on the ground surface in a ponding area. The stored runoff that infiltrates into the soil becomes interflow and augments groundwater in the sub-surface.

2 Metro Vancouver, Stormwater Source Control Design Guidelines, 2005 http://www.gvrd.bc.ca/sewerage/stormwater_reports.htm

Surface infiltration facilities can look like normal vegetated swales or ponds, and can be aesthetically landscaped and integrated into the design of open spaces. They include bioretention facilities and rain gardens. Both surface and sub-surface infiltration facilities can be effective at the lot level, as well as at the neighbourhood level, where individual lot sizes or layouts don't support on-lot facilities or where more permeable soils or groundwater recharge areas are located off-site. Surface infiltration facilities can, depending on their design, provide some level of water quality treatment as well.

Surface infiltration can be combined with detention, where the detention release rate allows sufficient time for infiltration through the pond. Infiltration facilities are highly dependent on the hydrologic properties of the sub-surface soils.

Surface infiltration can also be promoted by the used of permeable pavers or other pervious surfacing materials.

Bio-Retention Facilities

If infiltration rates are low, such as is likely in clay and till soils, bio-retention facilities can be designed to store the volume reduction target in soil and rock trench voids and infiltrate it slowly over time.

Where applicable, a retention facility may also be designed as a baseflow augmentation facility that retains the design capture volume in a tank or pond and releases it at baseflow rates. These rates are very low, and are based on measured summer baseflows in a watercourse divided by the contributing watershed area, and then applied to the area of the site contributing runoff. Baseflow augmentation facilities discharge the capture volume to the downstream stormwater system or watercourse at a maximum of the determined baseflow rates. Any volumes above the capture volume must be allowed to bypass the baseflow augmentation facility.



Bio-Retention Swale



Bio-Retention Swale

Sub-surface Infiltration Facilities

A similar design process is used for sub-surface infiltration as for surface infiltration facilities. The main advantage of sub-surface facilities is that they often have vertical walls and do not require as much dedicated ground area, allowing them to be located beneath paved impervious areas.

Sub-surface facilities must be located at least 0.5 m above the level of the water table so that they can discharge through the sides and bottom of the structure and will not merely store infiltrated groundwater. Generally, the deeper an infiltration facility is located, the less effective it will be. Subsurface infiltration facilities can be as simple as a trench filled with clean, free-draining rock that is protected from soil by a permeable membrane. There are numerous products available commercially for subsurface infiltration as well.



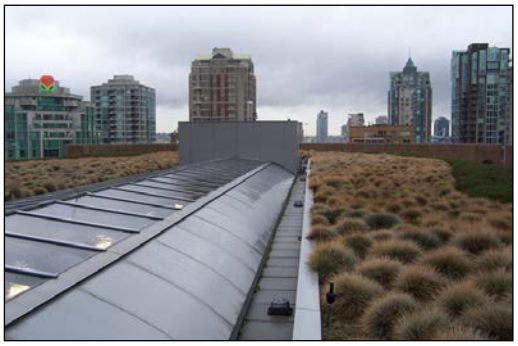
Sub-Surface Infiltration

Green Roofs

Installing a green roof rather than a conventional impervious roof can significantly reduce the volume and rate of runoff from a building lot particularly for the smaller, more frequent storm events.

A green roof is essentially a roof with a layer of absorbent soil and vegetation on top of a drainage collection layer or system. Rainfall is absorbed or stored by the soil and vegetation for later evapotranspiration. The green roof has a limited storage capacity, so any excess rainfall percolates through and is collected by a drainage system. The excess rainfall is then routed to the ground for detention and conveyance.

Green roofs are more expensive to build as they have structural costs as well as landscaping costs and do require maintenance to ensure their ongoing functionality. However, when compared with land costs for alternate facilities in high density urban areas, the costs for a green roof may be favourable. Green roofs also have other benefits, in addition to stormwater benefits, that can include heating or cooling cost savings by insulating the building, aesthetic benefits, air quality benefits, and reduced solar gain that decreases the urban heat island effect. Green roofs should only be designed and constructed by qualified professionals as structural engineering, building envelope and landscape design as well as stormwater engineering are all critical components. Green roofs are the preferable source control in areas where ground surface controls are not possible. For more information on green roofs readers are referred to the *Green Roofs for Healthy Cities* website.



Green Roof



Green Roof

Rainwater Re-use

Rainwater re-use is commonly afforded by residential rain barrels which are effectively retention facilities for roof runoff. Limitations of rain barrels are that rainfall is seldom a reliable source for water during the dryer seasons and rain barrels are often not large enough to store the 50% of 2-year capture target. The most significant reductions in runoff volume from re-use are achieved by capturing and re-using rainwater for indoor grey-water uses, or for commercial and industrial applications with high water consumption rates or where water supplies are limited. Recycling rainwater reduces demands from surface waters and reservoirs and can reduce supply infrastructure costs. Rainwater re-use can also be combined with infiltration facilities.



Re-Use Tank



Re-Use Rain Barrel

Water Quality Best Management Practices

Changes in land use, loss of natural biofiltration capacity, increases in impervious area, and pollutant laden runoff associated with urban development can contribute to reduced water quality which impacts fish and fish habitat. BMPs designed to capture and treat runoff need to be incorporated into RWMPs.

Water Quality BMPs are physical, structural or management practices that reduce or prevent water quality degradation. Many of these are the same as, or similar to those used for runoff volume reduction and rate control and but have ancillary benefits for water quality. Source control remains the key means of reducing introduction of toxic and hazardous materials or organic and inorganic contaminants, originating from land and water use or as a result of commercial or industrial spills. Without source control, runoff water quality is limited by the effectiveness of treatment technology.

Treatment controls are point-source water quality management measures. They are generally constructed facilities and are often individual installations incorporated into the stormwater management infrastructure. They should be designed on a site-specific basis, after examining all alternative treatment technologies, and selecting the best available options based on cost and effectiveness. These controls should be designed and constructed by appropriately qualified environmental professionals.

Water Quality Best Practical Technologies

Several technologies have the ability to provide both water quality benefits and runoff control. Water quality benefits are derived from contaminant removal mechanisms that use biological and physical processes. Runoff control is accomplished by improving stormwater detention and retention which reduces peak runoff discharge rates and volumes.

Biofilters

Biofilters are vegetated filter strips, swales and rain gardens that remove deleterious substances, notably particulate contaminants, though some combination of physical (e.g.: adsorption) and biological (biodegradation) removal mechanisms. Biofilter technology is suitable for sheet flow runoff, typical of large linear impervious developments like roadways and parking lots.

Urban Forests and Leave Strips

Depending on the extent of tree canopy and ground cover retained, runoff reduction and pollutant removal can be achieved by maintaining natural well functioning urban forested areas. The contaminant removal processes forests and natural vegetation provides include: filtration, adsorption, absorption, and biological uptake and conversion by plant life. Urban forests also provide habitat refuges for many species whose habitats have been fragmented while riparian leave strips along watercourses, provide critical fish and wildlife habitat.

Infiltration Systems

Infiltration systems generally require pre-treatment for water quality to prevent clogging and binding-off of the permeable materials and contamination of underlying aquifers. Physical removal of deleterious substances by filtration and adsorption, as well as conversion of soluble pollutants by bacteria, also occurs within the infiltrating soils.

Constructed Wetlands

Physical, biological and chemical processes combine in wetlands to remove contaminants and either surface or subsurface flow wetlands can be constructed specifically to treat stormwater runoff. Constructed wetlands also offer retention benefits and can create preferred habitats for aquatic and terrestrial wildlife species. **The use of existing natural wetlands to treat stormwater however is not an acceptable practice**.



Small Wetland



Wetland

Wet Detention Ponds

Permanent wet ponds remove pollutants and other deleterious substances through physical processes such as sedimentation, filtration, absorption and adsorption and through biological mechanisms such as: uptake and conversion by plants, and microbial degradation. Wet ponds can also detain flows thereby contributing to rate control and volume reduction objectives. General design parameters need to include vegetation types (floating, emergent and submergent vegetation), water depth and ponding area, and will often require consideration of detailed pond specific operational parameters.

Oil and Grit Separators

Oil and grit separators are suitable for spill control and removal of floatable petroleum-based contaminants as well as coarse grit and sediment from small areas, such as gas stations, automotive service areas and parking lots. Oil and grit separators have limited application in large-scale stormwater runoff applications and should be limited to small area generation sites.



Oil Grit Separator



Oil Grit Separator

Construction Best Practices

Construction Best Practices for instream stormwater management works include timing of the works to minimize impacts. Timing windows should be adhered to in order to minimize impacts to fish and wildlife and specifically to avoid sensitive periods for certain life history stages of fish (e.g.; adult spawning, egg and alevin intergravel incubation). Where information is available on critical life history stages and timing for any identified Species at Risk, these times should also be avoided. Clearing should only be undertaken immediately in advance of work, and only during vegetation clearing timing windows, where these have been identified for protection of nesting birds. To the extent possible, work should be restricted to cells and undertaken in a systematic manner to limit the area disturbed at any given time. Works should only be undertaken during favourable weather conditions and low water conditions.

Measures must be taken to prevent the release, from any work site, of silt, sediment, sediment-laden water, raw concrete, concrete leachate, or any other *deleterious substance* into any ditch, watercourse, stream, or storm sewer system. The work area should be isolated from flowing water as much as possible and diversions around the site should be provided for overland flow paths. Ensuring that all equipment used on-site is in good working order and having a ready spill containment kit and staff trained in its use, are also critical measures.

For further information on managing erosion and sediment discharges during construction, see the Erosion and Sediment Control section of the *Land Development Guidelines and the* Standards and Best Practices for Instream Works.[3]

1.3 Stormwater Detention / Diversion Systems

The rainwater detention or diversion objective is to limit the post-development runoff to the pre-development rate, volume, and approximate shape of the hydrograph and to maintain, as closely as possible, the natural pre-development flow pattern in the receiving watercourse.

These flow control levels have been adopted to address increases in impervious areas in developments and the environmental impacts (e.g. stream erosion, sedimentation; loss of riparian habitat, changes in stream morphology, etc.) that are occurring due to the more frequent, smaller storm events being rapidly conveyed off hard surfaces into fish bearing waters.

1.4 Infiltration Systems

Stormwater infiltration systems can provide many benefits to urban streams. Infiltration systems can retain runoff, recharge groundwater and control peak flows. The soil, through which the stormwater runoff passes, also acts as a filter removing a large percentage of the common pollutants normally discharged to the stream or creek. Infiltration can recharge local groundwater which in turn feeds smaller streams and creeks through seepage. Groundwater which is slowly discharged back into streams and can constitute all or part of a stream's baseflow. This baseflow can be critical for fish and fish habitat during extended periods of little or no precipitation and runoff. It maintains preferred spawning conditions for several salmon species which key on groundwater seepage areas for spawning and egg incubation.

In areas with well-draining soils, stormwater runoff from a site can be collected and discharged into an infiltration system where there are no conventional stormwater removal systems, or infrastructure, which reduces the costs of providing offsite conveyance.

2. Mitigation Measures for Riparian Areas

Protect riparian areas.

[3] BC Ministry of Water, Land and Air Protection's *Standards and Best Practices for Instream Works* (draft March 2004) http://wlapwww.gov.bc.ca/sry/iswstdsbpsmarch2004.pdf.

2. Compensation Measures

2.1 Hydrologic Enhancement

Retrofit existing conditions – All of mitigation measures discussed previously but applied to existing development.

2.2 Reforest Impacted Riparian Areas

Reforest Impacted Riparian Areas within designated setbacks. Remove invasive species and reforest with native tree and shrub species.

2.3 Construct In-stream Complexing

Construct in-stream complexing such as wood structures, boulder groups/spurs, stable debris jams & gravel spawning platforms, & off-channel habitats.

Improve/Remove Fish Passage Barriers.

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Appendix C10-C

Hydrogeological Questions and Piteau Answers

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1. Hydrogeological Questions and Answers from Piteau

The City and District compiled five broad hydrogeological questions for Piteau Associates to answer. They are summarized here with brief answers (in blue text) provided by Andy Holmes, P.Eng. and Jen Mancer in April 2016.

1.1 Capacity of Current Interflow

What is the capacity for adding to current interflow (shallow groundwater, how quickly should it move through the shallow ground, aside from wet ground, could we determine a threshold where we could be damaging road structure, etc?

- Doubt road structure damage would be limiting criteria (except possibly for steeply graded roads), unless associated with seepage along mains.
- Damage to bedding along mains more likely risk. Would need to establish a setback.
- Would need some piezometric data to estimate velocities and travel times but could estimate some bounds with some reasonable permeability data. With current knowledge, could probably estimate a range of travel times in aquifer south of Marine Drive. Sediments beneath other areas too heterogeneous and probably have limited recharge potential.
- Useful data for each area: Test pits; Perc Tests; Double ring; Depth to groundwater.

1.2 Deep Groundwater

Is there deep groundwater here in North Van (can we map areas)?

- Limited data available but well logs indicate sediments to a depth of:
  - >45m close to MacKay creek; and
  - up to 24m of sediments in upper Mosquito Creek (at Montroyal)
- Only mapped aquifer is below Marine Drive/3rd Street (shallow groundwater)
- Other aquifers may exist, but sediments are likely heterogeneous and probably layered with perched water tables

1.3 Deeper Basements

What is the effect of deeper (10') basements over negligibly deep (or shallow) foundations?

- Deeper foundations could have a slight effect on water table, but effect would be mitigated where perimeter drains flow by gravity into storm drains. Effects on water table (and baseflows) could become more significant where sump pumps are implemented. In till areas, probably not a big concern, but in more permeable sediments, could influence baseflows. Would need to know natural end of summer water table to quantify effect.
- Known depths to water shown on Image C1-1. Most are <3m but data are very limited.

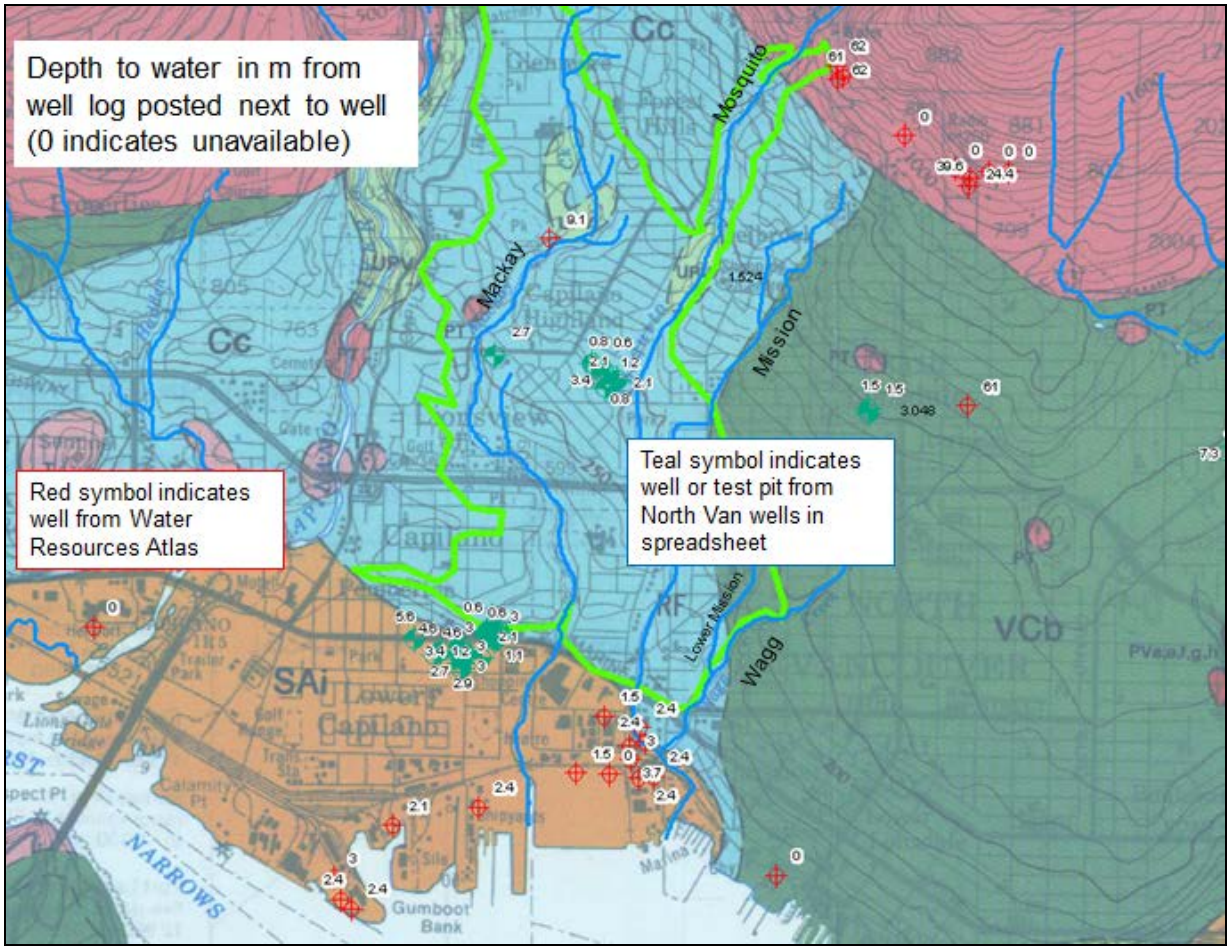


Image C1-1: Depth to Groundwater

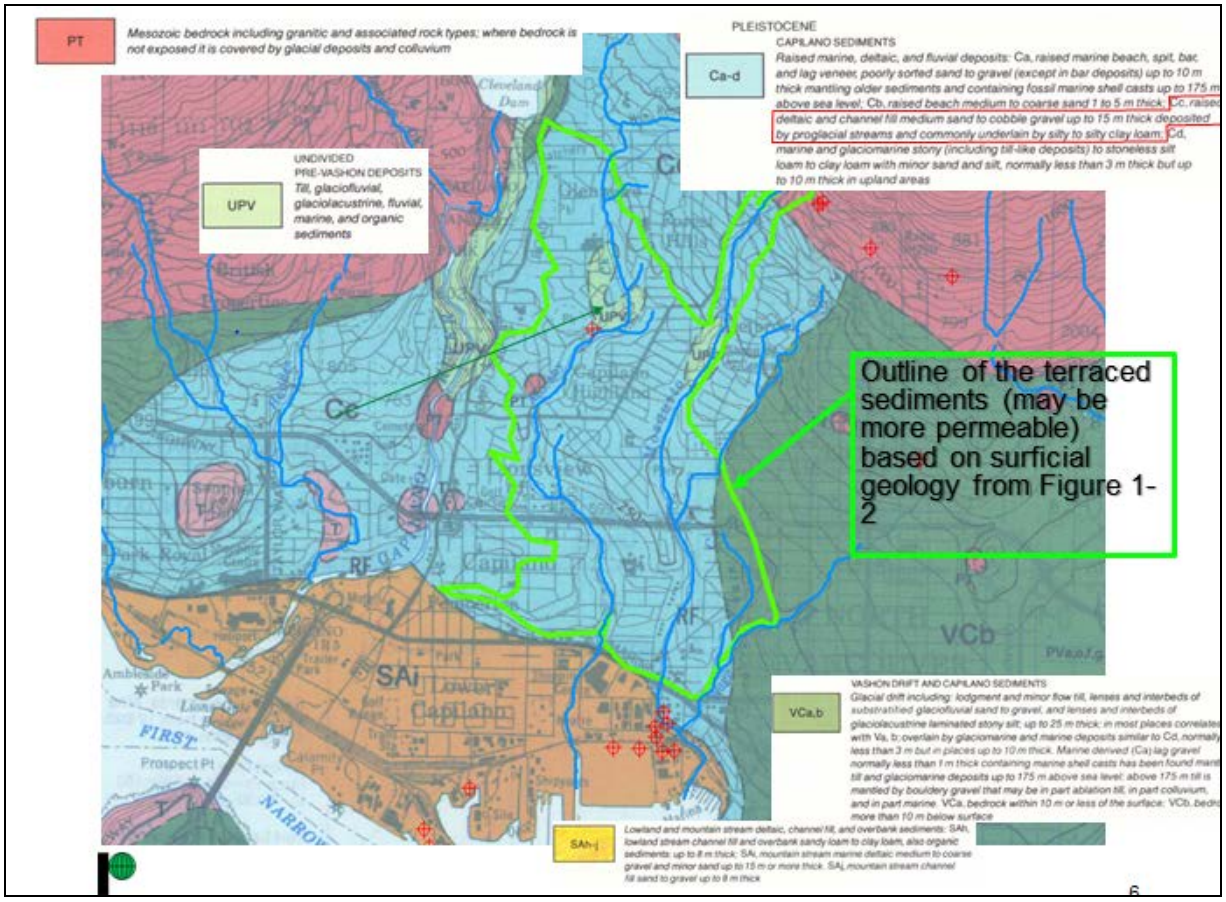


Image C1-2: Outline of the Terraced Sediments

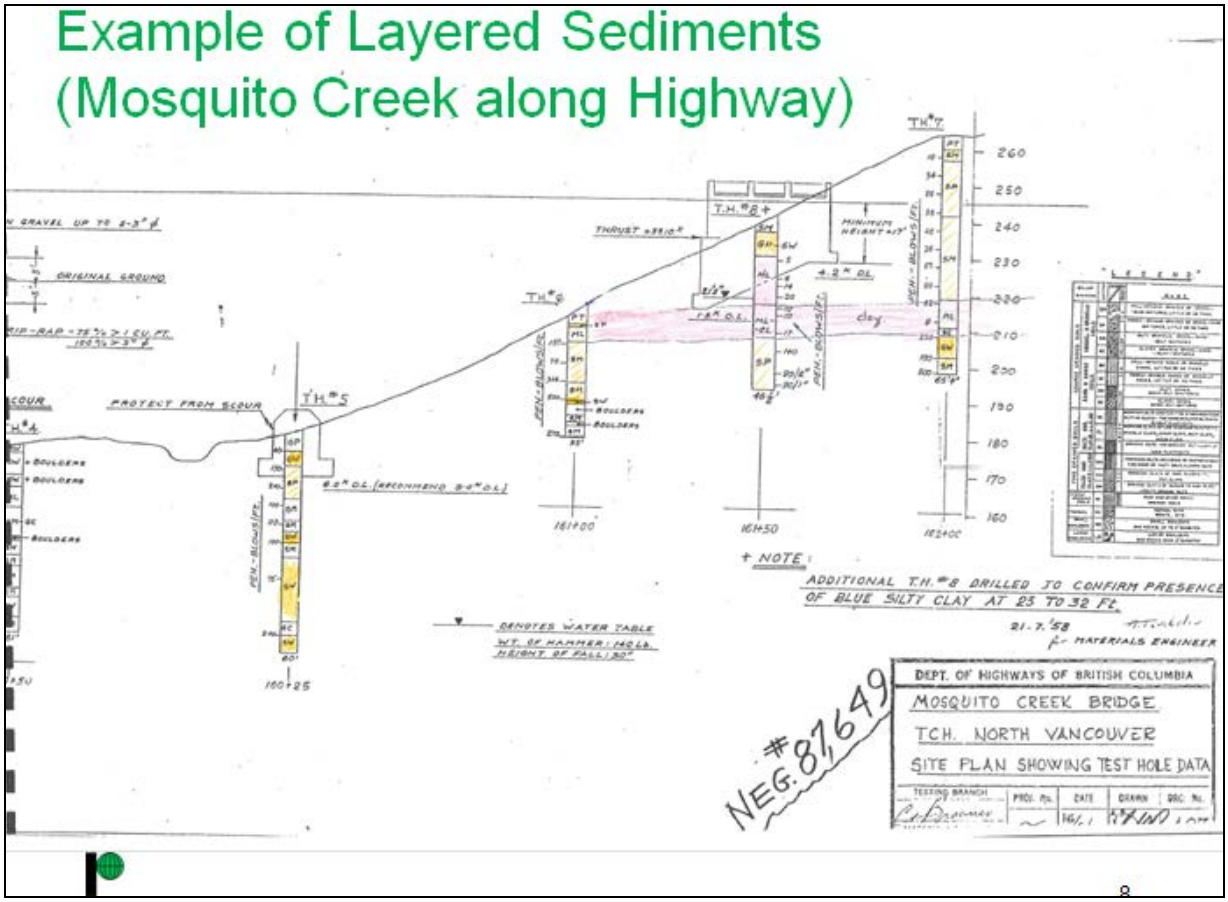


Image C1-3: Example of Layered Sediment

1.4 Infiltration Near Slopes

How close should we be getting to slopes with stormwater infiltration? Refer to Figure C1-4: Slope Analysis.

- No infiltration on slopes greater than 10H:1V (without a lot specific geotechnical assessment)
- Also need to consider proximity to retaining walls
- Multi-home developments should require site specific hydrogeotechnical assessment
- Preliminary guidelines without site specific geotechnical assessment:
  - Setback of 100m from crest of any 3H:1V slope (Greatest risk would be seepage breakout on slope)
  - Setback of 200m behind crest of slope >3H:1V

1.5 Groundwater Catchment Areas

Can we map the groundwater catchment areas? What reports are there?

- Assume surface water catchments roughly define groundwater catchments.
- Stream baseflow data collected for Wagg, Thain and Mission creeks in 2002 and 2003, as reported by GL (2004) indicates significant groundwater discharge enters these watercourses. The upper limit of significant groundwater discharge not well delineated. Additional baseflow measurements with more stations, and possibly some spring mapping, would provide useful data for mapping extent of aquifers along creek traces.

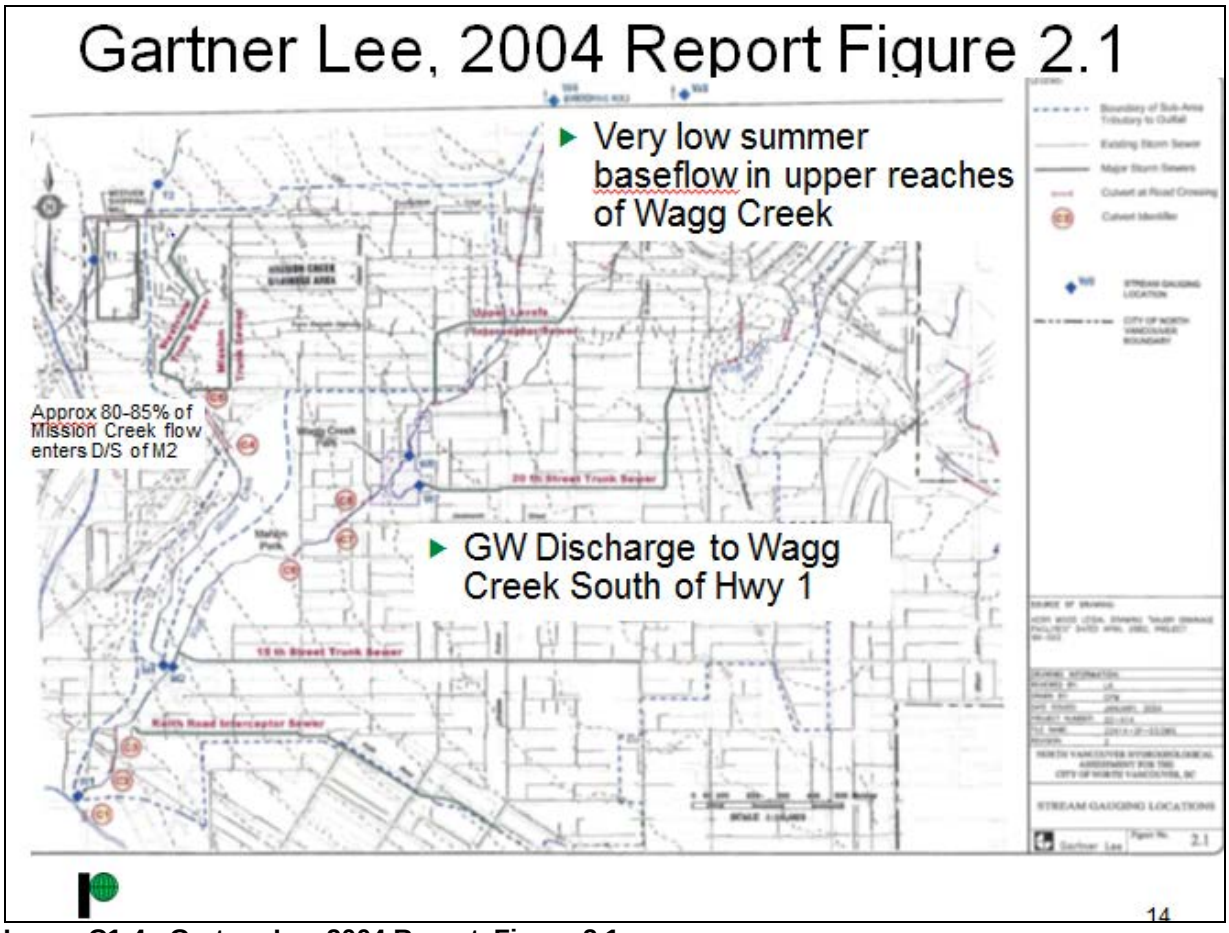


Image C1-4: Gartner Lee 2004 Report, Figure 2.1

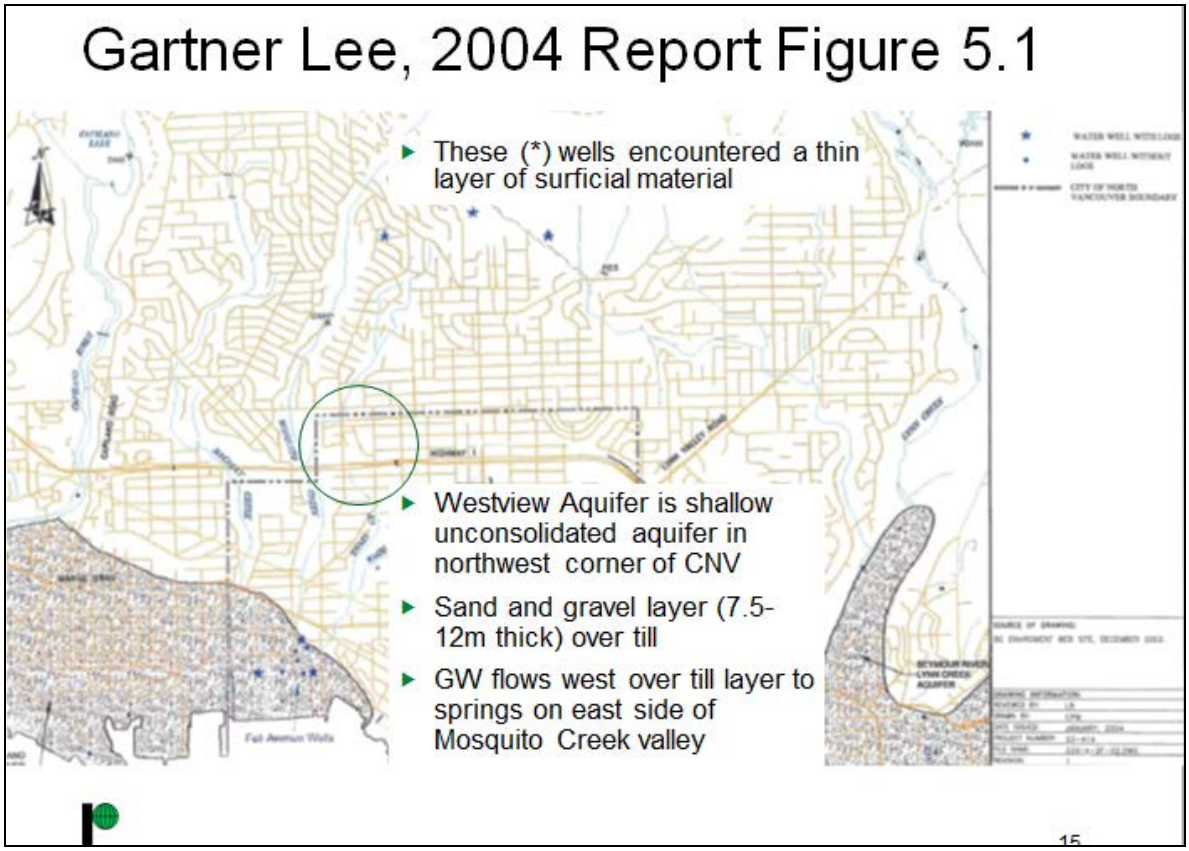


Image C1-5: Gartner Lee 2004 Report, Figure 5.1

1.6 Estimated Infiltration Rates

It is very difficult to provide infiltration rates at this broad planning level, as they are a function of the shallow surface soil, the presence of an underlying low permeability layer at a relatively shallow depth (which is typical of the layered glacio-fluvial sediments that cover much of the area), and the shallow water table that would develop in many areas during a wet month. An elevated water table would preclude any infiltration at a depth of more than a few decimeters below ground.

Piteau provided the following range of infiltration rates as a planning tool only. They would be weather dependent. During very wet periods, the rates would be on the low end of the range. During periods of moderate or limited precipitation, they could be in the high range. Site specific assessments would be required to determine design rates.

- alluvial sediments – terraced sediments: 3 to 30 mm/hr;
- Anthropogenic deposits – Undifferentiated: difficult to say, so conservative assumption – 0 to 20 mm/hr;
- Glacial sediments – blanket: 2 to 20 mm/hr;
- Glaciofluvial sediments – terraced sediments: 50mm/hr, subject to water table relative to infiltration surface.



Compendium 11

Action Plan

Mackay Mosquito Watersheds ISMP

September 2020

Final Report

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Purpose

Compendium 11. Municipal Stormwater Program

This compendium provides a summary of CNV and DNV stormwater related bylaws and policies and drainage system maintenance practices. It is a supporting document to the Mackay and Mosquito Watershed Integrated Stormwater Management Plan (ISMP) that was developed by the City and District of North Vancouver.

Refer to other compendiums for additional supporting information.

Mackay Mosquito Watersheds ISMP Compendiums

The following compendiums and their authors support the Mackay Mosquito Watersheds ISMP:

1. Watershed Overview - KWL
2. Instream Species and Water Quality – Raincoast Applied Ecology
3. Riparian Forest & Terrestrial Species – Raincoast Applied Ecology
4. Drainage Asset Inventory – KWL
5. Hydrologic and Hydraulic Modelling - KWL
6. Drainage Assessment - KWL
7. Land-Use Analysis - KWL
8. Municipal Policy and Operations - KWL
9. Watershed Values & Objectives – CNV and DNV
10. Mitigation Measures – KWL, CNV and DNV
11. Mackay/Mosquito Action Plan – KWL, CNV and DNV

Figure and table identification numbering include the first digit related to compendium number and the second digit related to the figure number within the compendium. e.g. Figure C3-1 is the first figure within Compendium 3.

‘Blue boxes’ of explanative information are provided in each compendium where background information and context are helpful.

Preface

The Mackay and Mosquito Watersheds are a vital part of the land that forms the unceded and traditional territory of the Sḵwx̱wú7mesh (Squamish), Sel̓íl̓witulh (Tsleil-Waututh), and xʷməθkʷəy̓əm (Musqueam) peoples, and lie within the municipalities of the City of North Vancouver, District of North Vancouver, and the Port of Vancouver. Long before development of these watersheds, this land was cared for by and supported these communities.

The work conducted as part of this integrated watershed management plan has shown that urbanization, development of residiential, industrial, and commercial properties along with all of the supporting drainage and transportation infrastructure has degraded the health of Mackay Creek and Mosquito Creek. Development began in the early part of the 1900s, with much of the modern development being established by the 1980s. These two watersheds are largely in a phase of redevelopment where very little or no undisturbed land is being developed and all redevelopment provides an opportunity to improve the health of both watersheds.

This compendium outlines the key actions that should be considered or implemented to achieve the objectives of this plan and further the goal of improved watershed health.

1. ISMP Action Plan

The proposed action plan for the Mackay Mosquito Watershed is shown in Table C11-1, and presents a suite of actions that together fulfill the goals and objectives for the ISMP.

Table C11-1: Mackay Mosquito Watersheds ISMP Plan

ISMP Projects and Actions
Policies – Apply Municipality Wide
1. DNV - Establish and apply a progressive volume reduction target for single family residential development / redevelopment. A higher target than the region-wide baseline is recommended. 72% of the 2-year rainfall (DFO criteria) or 50% MAR criteria would be desirable. Climate change should be incorporated in the target for infrastructure design. 2. CNV - add rate control criteria to reduce post-development flows to pre-development levels up to the 2-year or 5-year return period to better mimic natural hydrology and reduce erosive flows. Add 10-year detention requirement to protect downstream infrastructure. 3. CNV/DNV - Add water quality treatment criterion for pollutant generating surfaces such as roads, parking lots, etc. such as 'remove 80% of total suspended solids based on 50 µm particle size from 72% of the 2-year 24-hour storm'. Require spill control measures for high-risk land uses. 4. CNV/DNV – Continue to implement and improve erosion and sediment control requirements & apply to all development and redevelopment construction. 5. CNV/DNV - DNV to continue to protect riparian setbacks with development as outlined and enforced in Streamside Protection Development Permit Area. Review DPA effectiveness and progress ISMP monitoring and review of indicators. 6. CNV/DNV - Require all instream infrastructure projects to improve fish passage and habitat. 7. DNV – Create a policy that restricts piping or enclosing watercourses to protect the remaining open channels and ditches.
Programs
A. Flood Management Program • CNV to investigate an overland flood risk study for Wagg Creek watershed. • Continue with information developed in ISMP to further quanitify flood risks associated with major drainage infrastructure (culverts and trunk mains) • Consider ISMP goals when developing coastal and creek-based flood risk reduction measures • Consider long-term minor drainage needs as distributed volume reduction is implemented and with future climate change in the DNV and CNV.

Table C11-1: Mackay Mosquito Watersheds ISMP Plan

ISMP Projects and Actions
B. Erosion Management Program • Further Assess Existing Very High and High Risk Erosion Sites – Evaluate the liability risk to CNV/DNV and plan for rehabilitation/stabilization works as needed for the 19 Very High and 22 High Risk Erosion Sites. • Monitor sites regularly to ensure they do not threaten existing buildings and infrastructure.
C. Source Control Program • DNV - Develop pilot study neighbourhood for source controls. Document impacts of LID/source controls on watershed health and identify challenges. • CNV/DNV – Create or improve examples and standards to apply to all development/redevelopment to aid with implementation. • DNV - Allow disconnected roof leaders on single-family lots where applicable.
D. Water Quality Treatment Program • CNV/DNV - Develop a program to encourage real time water quality monitoring on large construction sites. • CNV/DNV - Develop a pollution prevention program for businesses in specific areas, such as Lloyd & Pemberton Ave. Create a water quality improvement educational campaign targeted to small industrial businesses. • DNV – Review water quality data and consider if ski operations on Grouse Mountain Operations have a measurable effect on stream health. • CNV/DNV – Update bylaws/policies to include water quality treatment requirements for pollutant generating surfaces.
E. Storm Outfall Condition Analysis • Look for opportunities to create treatment areas and improve erosion issues at storm outfalls.
F. Watershed Monitoring • Continue regular watershed monitoring in accordance with the Monitoring and Adaptive Management Framework. Share data inter-municipally for coordinated activities. • Develop policy changes that require large developments to continuously monitor groundwater and real-time water quality during construction.
G. Biodiversity Program • Invasive species management plan. Assess levels of infestation, prioritize and develop management plans.
H. Trail Improvements in Upper Mackay Creek • Move trails out of riparian areas and install fencing.

Table C11-1: Mackay Mosquito Watersheds ISMP Plan

ISMP Projects and Actions
I. Outreach and Education Program • Online and trail program to increase watershed stewardship.
J. Outreach and Education Program • Online and trail program with signage to increase watershed stewardship.
Projects
Construct Environmental Enhancement Projects – Figure C11-1 and Table C11-2 **1.** Construct in-stream complexing such as wood structures, boulder groups/spurs, stable debris jams & gravel spawning platforms, & off-channel habitats. Construct creek daylighting. **2.** Bank rehabilitation. **3.** Improve fish passage. **4.** Reforest impacted riparian areas within designated setbacks. Remove invasive species and reforest with native species. Plant native trees/shrubs. **5.** Construct water quality improvement facilities. **6.** Create trails and wildlife corridors to enhance connectivity.
Upgrade Drainage System for Safe Flood Conveyance **Upgrade Undersized Culverts** **7.** 66%, 68%, and 75% of creek culverts were identified as undersized for safe 200-year flood conveyance for the existing, future, and future w climate change land uses respectively. **8.** Confirm creek culvert & bridge upgrade sizes with the Debris Geohazard Risk and Risk Control Assessment, (BGC, 2017) recommendations because the ISMP assessed clear water peak flow capacities only. Debris flows/floods may govern sizing. **9.** Size new or replacement culverts for 80% full for the design flow (CNV request).
Upgrade Undersized Bridges **10.** Undertake study to design bridge upgrades identified in the *Creek Hydrology, Floodplain Mapping and Bridge* Hydraulic *Assessment Study (KWL, 2014)* report. The preliminary design should include an assessment of flood containment and incorporate the findings of the *Debris Geohazard Risk and Risk Control Assessment, (BGC, 2017)* study to estimate the design flows (clear water or debris, as appropriate) to be conveyed under each bridge.

Table C11-1: Mackay Mosquito Watersheds ISMP Plan

ISMP Projects and Actions
Upgrade Storm Sewers
11. Upgrade Priority 1 storm sewer projects first and then Priority 2 projects.
12. Priority 3 projects can likely be put off until the end of asset life.
13. Priority 4 projects should be undertaken as development proceeds either by developers of properties adjacent to the pipes or as DCC funded projects by the municipality.
14. Further investigate purple colour coded pipes (see Compendium 7 figures) prior to further action/upgrading. They represent steep pipes with design flows <100% full but surcharging higher than 30 cm and longer than 15 minutes. It is unclear whether this is caused by backwater or inlet capacity limitations.

Table C11-2: CNV/DNV Identified Environmental Enhancement Projects List

No.	Name	Creek	Municipality	Priority Ranking	Location	Description
Fish Passage Improvements						
1	Mackay Creek at Hwy 1	Mackay	DNV	Short Term	At Highway 1	Inspect annually to assess fish passage and debris jams.
2	Mackay Creek at Lloyd Ave.	Mackay	DNV		Lloyd Ave north of Highway 1	Improve fish passage.
3	Mosquito Creek at 3rd Street	Mosquito	CNV		3rd St W., south of Marine Drive	Improve fish passage with GVS & DD Weir
4	Canyon and Montroyal Channel	Mackay	DNV	Medium Term	West of Cliffridge Avenue between Canyon and Montroyal	Improve fish passage in channel with bridge improvements, possible ladders and/or weir removal or redesign.
5	W Queens Culvert at Mission	Mission			Mission Creek south of W Queens Road	Improve fish passability as existing fish ladder silts up. Undersized culvert.
6	Marigold Pedestrian Bridge	Mackay		Long Term	Trail between Marigold and Mapleridge	Remove creosote wood wall and weir fish barrier at bridge. Investigate feasibility of passage via ladder.
7	Ridgewood Fish Ladder	Mackay			Ridgewood and Mackay Creek crossing west of Sunset	Assess & make improvements to existing concrete fish ladder under bridge.
Aquatic Habitat Improvements						
8	Coordinate with DFO and NSSK on habitat initiatives	Mackay Mosquito	DNV	Short Term	All watersheds	Engage with Planning to understand how changes in development planning could provide setbacks for Mackay Creek in next OCP revision.
9	Murdo Frazer Off Channel Pond	Mackay	DNV		Murdo Frazer Park Brookridge Brook	Provide off channel and rearing pond east of Duncan Gold pond.
11	Restore Lower Mission Creek Baseflow	Mission	CNV/DNV		W. Queens Road to Larson Park	Restore baseflow from Upper Mission Creek to Lower Mission Creek at 29th Street
12	Murdo Frazer Off Channel Pond	Mackay	DNV	Medium Term	Murdo Frazer Park base of Crescentview Drive escarpment	Provide off channel pond near natural spring.
13	West Bank of Mackay Creek Downstream of 19th Street	Mackay	DNV		Downstream of 19th Street	
14	Mapleridge Channel Improvements	Mackay	DNV	Long Term	West side of Mapleridge Drive	Long term channel stability and complexity improvements.
15	Evergreen Culvert Diversion Replacement	Mosquito	DNV		W Queens Road to Evergreen Place	Begin long term planning to daylight Mosquito Creek at the end of culvert diversion life. Include possible land-use considerations for future OCP.
Bank Stability						
16	Thain Creek channel at Westview	Mission	CNV/DNV	Short Term	William Griffin Park at CNV border	Improve bank stability issues on both sides of channel as redevelopment occurs at Westview. Channel stabilization needed.
17	William Griffin Main Channel	Mosquito	DNV	Long Term	William Griffin Park from Queens to Hwy 1	Channel improvements to reduce slope & increase complexity while stabilizing grade to prevent further downcutting.
Water Quality Treatment						
18	Sediment Pond - Lower Mission Creek at 22nd Street	Mission	CNV	Short Term	at 22nd Street	Trap sediment and contaminants prior to entering Lower Mission Creek.
19	William Griffin Wetland Maintenance	Mosquito	DNV		Existing off channel in Willian Griffin Park near Colwood	Reconfigure and enhance existing treatment wetland.

Table C11-2: CNV/DNV Identified Environmental Enhancement Projects List

No.	Name	Creek	Municipality	Priority Ranking	Location	Description
20	South Murdo Frazer Park Treatment Area	Mackay	DNV		Pemberton Avenue at W 26th Street	Consider treatment area or separator at storm outfall.
21	Carisbrooke Elementary Wetland	Wagg	DNV	Medium Term	East of Carisbrooke Elementary gravel field	Convert existing swamp to wetland and define channel and create riparian corridor.
22	William Griffin Off Channel Opportunity	Mosquito	DNV		William Griffin Park near LaCrosse box	Wetland / off channel rearing habitat opportunity.
Trail Connections						
23	Mosquito Creek at 16th Street	Mosquito	CNV	Medium Term	Marine Drive (2020) to W 16th St	Extend trail connections.
24	Mosquito Creek East Bank 19th to 23rd	Mosquito	CNV	Short Term	East Bank 19th to 23rd	Provide trail connectivity on east side of Mosquito Creek and possible new pedestrian crossing.
25	Mackay Creek East Bank North of 19th	Mackay Mosquito	DNV/CNV	Medium Term	East Bank North of 19th	Connect Mackay east trail at Heywood Park to Mosquito west side trail.
26	Upper Mackay Creek trails to Lower Mackay Creek Trails	Mackay	DNV		Heywood Park and Murdo Frazer Park	Consider trail and ecological connectivity between Heywood Park and Murdo Frazer Park via Highway 1 overpass.
27	Edgemont to Murdo Frazer Park				Paisley Road	Consider trail connectivity from Edgemont bike route to Murdo Fraser Park.
Creek Daylighting						
28	Stream Daylighting 237 and 234 E 26th E 27th Street	Wagg	DNV	Long Term	237 and 234 E 26th E 27th Street	Daylight existing pipe enclosure
Ecological Corridors,						
29	Eldon Park and Bracknell Crescent	Wagg	DNV	Long Term	Eldon Park and Bracknell Crescent	Opportunity for ecological corridor to Eldon Park and Bracknell Crescent.
30	Elizabeth Way		DNV		North of Elizabeth Way	Opportunity for ecological corridor and stream connectivity.
31	Pemberton Heights Escarpment Toe.		DNV		Pemberton Heights	Opportunity for ecological corridor to green space.
Riparian Restoration						
32	Setbacks Cypress Gardens	Mission	CNV	Medium Term	W. Queens Road	Provide additional riparian setbacks and enhancements with redevelopment.
33	Stream Setback Needed 254 East 27th	Wagg	CNV		254 East 27th	Stream setback needed.
34	Riparian Restoration Program	Mackay Mosquito Mission Wagg	CNV DNV	Short Term	All watercourses	1. Identify and map all parcels on Mackay and Mosquito Creek where rezoning is proposed (Fig C10-9) in the riparian area for communication to Planning for riparian forest enhancement. 2. Develop CNV/DNV joint project (or separate) to assess riparian needs for Mackay Creek Estuary and enhancement project 3. Each municipality shall review and identify possible riparian gains in parks along each creek and implement incrementally.

Project #s are shown on Figure C11-2. **Priority Ranking:** Short Term = 0 - 5 years, Medium Term = 5 - 10 years, Long Term = 10+ years

2. Monitoring and Adaptive Management

2.1 Introduction

Implementation of an ISMP relies not just on the action plan, but also on reviewing the progress of watershed health over time and adjusting the action plan to ensure the progress of the watershed's health is in line with the goal of the ISMP. A strategy for monitoring stream and watershed condition and for adaptive management in the Mackay and Mosquito watersheds in response to changing land use and stormwater management activities is presented that fulfills this responsibility of the ISMP.

In the context of urban watersheds, monitoring is the repeated measurement of biological and/or physical attributes to determine status and trends in stream or watershed condition. It typically includes a suite of attributes encompassing a variety of scales and processes ranging from watershed-scale land cover to benthic invertebrates and sediment quality.

This involves tracking ISMP implementation including the impact of development and re-development, the effectiveness of mitigation measures, and the influence of stormwater management activities on creek health.

2.2 Metro Vancouver's Monitoring and Adaptive Management

Condition 7 of the BC Minister of Environment's approval of Metro Vancouver's 2011 Integrated Liquid Waste Resource Management Plan (ILWRMP) requires that all municipalities, with coordination from Metro Vancouver, monitor stormwater to assess and report on the effectiveness of ISMP implementation. To fulfill this provincial requirement, Metro Vancouver and its member municipalities have developed a *Monitoring and Adaptive Management Framework for Stormwater (MAMF) (Metro Vancouver, 2014)*. The MAMF takes a weight of evidence approach, using several types of monitoring and indicators to develop an overall assessment of watershed conditions. Through repeated sampling, watershed health and the response to specific watershed protection measures and management actions can be tracked over time.

The MAMF provides direction on the general types of monitoring to be utilized for higher gradient, lower gradient, and piped systems, the methods and parameters to be used for monitoring, and the reporting required.

Table C11-3: Standard MAMF Monitoring Program Elements Based on Stream Type

Stream Type	Water Quality	Hydrometric	Benthic Invertebrate
Lower Gradient	Yes	Yes (natural channels only)	No
Higher Gradient	Yes	Yes	Yes
Piped Systems	Yes	No	No

Based on the MAMF, all the creeks within the Mackay Mosquito study area are classified as higher gradient streams (average channel slope >1%). Therefore, monitoring and performance indicators include water quality, flows and benthic invertebrates.

Monitoring Framework for Higher Gradient Streams

The MAMF recommends a monitoring framework and core parameters for higher gradient streams, grouped into three categories:

- Water quality monitoring indicators – selected general water quality parameters, nutrient, bacteriological parameters, and metals;
- Flow monitoring Indicators – seven flow-related metrics characterizing watershed hydrology; and
- Benthic invertebrates biomonitoring indicators – benthic index of biotic integrity (B-IBI) scores and mean taxa richness.

Table C11-4 summarizes the recommended parameters for monitoring implementation of the ISMP, as well supplemental performance indicators that may provide a more comprehensive assessment of watershed health and ISMP implementation over time depending on watershed values and issues.

The table also indicates the priority of each parameter for measurement (primary or secondary), whether baseline data has or is being collected, and sets short- and long-term targets for trends for different parameters.

Table C11-4: Summary of ISMP Performance Monitoring Indicators

Performance Indicator	Indicator Type	Short-term Trend/Target	Long-term Target
Water Quality Performance Indicators			
Dissolved Oxygen	Primary	Increasing	Good or Satisfactory as per MAMF classification levels
pH	Secondary	Stable	
Water Temperature	Primary	Decreasing in dry season	
Conductivity	Secondary	Decreasing	
Turbidity	Primary	Decreasing in wet season	
Nutrients (Nitrate as N)	Primary	Decreasing	
Bacteriological Parameters (*E. coli* and fecal coliform)	Primary	Decreasing, esp. in wet season	
Metals (Fe, Cd, Cu, Pb, Zn)	Primary	Decreasing, esp. in wet season	
Flow Monitoring Performance Indicators			
T_{Qmean}	Primary	Stable or increasing	Same as short-term
Low Pulse Count		Stable or decreasing	
Low Pulse Duration		Stable or increasing	
Summer Baseflow (L/s)		Stable	
Winter Baseflow (L/s)		Stable or increasing	
High Pulse Count		Stable or decreasing	
High Pulse Duration (days)		Stable of increasing	

Performance Indicator	Indicator Type	Short-term Trend/Target	Long-term Target
Benthic Invertebrate Biomonitoring Performance Indicators			
B-IBI Scores	Primary	Stable or increasing	Category Fair or higher as per MAMF
Mean Taxa Richness	Primary	Stable or increasing	
Additional Recommended Performance Indicators			
No. of Erosion Sites	Supplemental	Decreasing	No high consequence sites
Effective Impervious Area (EIA)	Supplemental	n/a (for tracking only)	n/a (for tracking only)
Riparian Forest Integrity (RFI)	Supplemental	Stable or increasing	Increasing
No. of Species / Locations of Spawners	Supplemental	Stable or increasing	Increase in spawners from current levels
No. of Fish Passage Barriers	Supplemental	Decreasing	No human-made passage barriers

2.3 Existing Monitoring Information

Five monitoring programs have collected data on Mackay and Mosquito creeks:

- **CNV's biannual stream health** monitoring (water quality, sediment quality, and benthic invertebrates) in 2006, 2008, 2010, and 2012; 2014, 2016, 2018.
- **DNV's stream health monitoring** included benthic invertebrate sampling in 2003 in 11 streams and rivers, including Mackay and Mosquito creeks, but no additional sampling has been undertaken to monitor change. DNV has also started the MAMF water quality sampling in 2018 and plans to sample every three years.
- **Metro Vancouver's benthic invertebrates monitoring** of stream health throughout the region included repeated sampling on Wagg and Mosquito creeks in 1999, 2005, and 2006. This has also included additional work to identify associated land cover (watershed and riparian forest cover, imperviousness) and sediment quality values.
- **Stream Flow and Precipitation -** Four hydrometric (Mackay Debris Basin, Mackay Creek at Montroyal Blvd, Mosquito Creek William Griffin Queens Rd W, Wagg Creek at Keith Road) and six rainfall monitoring stations (North Vanc Grouse Mtn Resort, Mackay Debris Basin, Cleveland Dam (DN15), DNV Municipal Hall (DN25), CNV City Hall) continue to be in operation: Refer to Table C5-1.
- **NSSK** has used Streamkeepers protocols to monitor stream health in both streams periodically and undertook at comprehensive assessment of water quality in Mackay Creek from 2007 to 2009 (monthly sampling at four sites).

Data from these programs establish baseline data which future monitoring results can be compared with to identify trends.

2.4 Proposed Monitoring Plan

The proposed monitoring program focuses on monitoring to answer two essential questions:

1. Is development/redevelopment negatively impacting the ecological health of creeks?

2. Are stormwater management activities resulting in no-net-loss of the overall health of the creeks?

Table C11-5 summarizes the proposed monitoring program for the Mackay Mosquito ISMP, including monitoring components, methods, sites, monitoring frequency, and recommended implementation approach. Both existing and future proposed components have been included. Monitoring locations are shown on Figure C11-2.

Table C11-5: Proposed Monitoring Program

Monitoring Program Component	Method	Monitoring Locations	Monitoring Frequency	Recommended Implementation Approach
MAMF Core Parameters				
Water Quality Monitoring	5 samples in 30 days in dry & wet seasons as per MAMF	Minimum 4 sites in CNV 4 sites in DNV	Every 2 (CNV) 3 (DNV) years minimum	Establish within municipality-wide monitoring program
	Continuous monitoring of physical water quality parameters (temperature, conductivity, dissolved oxygen, turbidity, pH)[1]	3 DNV sites	1 to 3 years	Continue program and expand as resources allow.
Flow Monitoring	Flow & precipitation gauges	4 continuous flow and 6 climate monitoring sites	Ongoing Analyze data every 3 years	Continue hydrometric program
Benthic Invertebrate Monitoring	Fall sampling (three replicates in 30 m reach) as per MAMF	4 sites in CNV 4 sites in DNV	Every 3 years recommended	Establish within municipality-wide monitoring program
Additional Recommended Performance Indicators				
Sediment Quality	Comparison to BC Sediment Quality Guidelines & regional urban streams dataset	4 sites in CNV 4 sites in DNV	Every 3 years minimum	Establish within municipality-wide monitoring program
Erosion Monitoring	Monitor very high and high risk priority sites	Figure C11-2	Every 2 - 5 years	Establish within municipality-wide monitoring program

[1] cross-ref with corresp with DNV/Raincoast).

Monitoring Program Component	Method	Monitoring Locations	Monitoring Frequency	Recommended Implementation Approach
Effective Impervious Area (EIA) Assessments	Estimated using GIS-based hydrologic modelling or other analysis approach	Full watersheds & major subwatersheds	Every 2 - 5 years	Track TIA and Volume Reduction in GIS and populate with as-built submissions
Watershed & Riparian Forest Cover Assessments	GIS-based analysis of orthophotos	Full watersheds & major subwatersheds	Every 2 - 5 years	Undertake with municipality-wide analyses for all ISMPs
Refer to Figure C11-3.				

Water Quality Monitoring

Continuous Monitoring

Objective: Measure long term trends in water quality, as well as seasonal and shorter-term water quality characteristics related to weather, precipitation, spills, and other events.

Parameters: Water temperature, conductivity, dissolved oxygen, turbidity, and pH

Methods, Standards, and Analysis: Continuous (5-, 15-, or 30-minute interval) monitoring; Regression analysis to detect trends

Seasonal MAMF Monitoring

Objective: Measure water quality in relation to regionally established guidelines (MV Adaptive Management Framework).

Parameters: General parameters: water temperature, conductivity, dissolved oxygen, turbidity, and pH; lab parameters, including nutrients (nitrate), metals, and microbiological parameters (E. coli)

Methods, Standards, and Analysis: Sampling according MV AMF protocol (mean of five samples in 30 days); comparison to AMF green, yellow, red categories, as well as trend analysis once sufficient data is available; only summer/early fall monitoring is recommended as winter flow levels are more variable, and there is no evidence of impaired during the winter in North Vancouver streams

Benthic Invertebrates

Objective: Measure long-term changes to stream health influenced by watershed management activities using metrics derived the diversity and abundance of streambed invertebrates.

Parameters: Benthic index of biological integrity (10-metric B-IBI: 10–50) and component metrics

Methods and Standards: Sampling according to Metro Vancouver AMF method benthic sampling method, but 500 micron Surber in late summer/early fall from same sampling reaches as used since 1999; identification of invertebrates to Washington State LPTL 1996 standard; ten metric B-IBI calculation (Puget Sound standard); regression analysis to detect trends

Sediment Quality (Total Metals)

Objective: Measure accumulation of potentially toxic metals in streambed sediment as an indicator of environmental quality.

Parameters: Total metals (ICP-MS), including aluminum, copper, cadmium, iron, lead, manganese, and zinc

Methods, Standards, and Analysis: Comparison to BC Sediment Quality Guidelines and regional urban streams dataset; trend analysis using regression after sufficient data is available

Watershed and Riparian Forest Cover

Objective: Track long-term changes to riparian and watershed forest cover as an indicator of ecological processes (rainfall interception, shading, etc.); also suitable for tracking implementation of riparian restoration activities.

Parameters: Total watershed forest cover (not total tree cover); total riparian forest cover within 30 m of permanent stream channels

Methods, Standards, and Analysis: GIS mapping using recent orthophotos as per methods described in this report

2.5 Adaptive Management Plan

Maintaining and enhancing the ecological health of a watershed is best achieved through adaptive management. Using an adaptive management approach for ISMP implementation allows for regular feedback on the effectiveness of measures recommended in the ISMP such that informed decisions can be made about future measures based on whether watershed goals are being achieved. In cases where existing measures are not achieving results, changes can be made to improve their effectiveness, or new measures can be pursued. Monitoring also allows assessment of progress towards the plan's goal and reporting to decision-makers, stakeholders, and the public. Adaptive management is also recommended to ensure improvements in watershed health are achieved in the most cost-effective manner.

Within the MAMF, measures taken to mitigate the impacts of land development on watershed health are defined as Adaptive Management Practices (AMPs). These include measures under a variety of functional categories such as source controls, runoff detention and infiltration facilities, runoff pollution control, runoff treatment, outreach and education, and mitigation of construction impacts. The iterative process of carefully collecting, analyzing, and interpreting data will allow for the effectiveness of these AMPs to be assessed, and if not achieving the desired results, to change measures or to target different priority areas. The process requires proper planning but also flexibility as stormwater management practices and knowledge evolve over time and new technologies become accessible.

The basis for adaptive management is long-term monitoring of indicators. If the monitoring results indicate issues or worsening in aquatic health, previously implemented AMPs should be re-evaluated or new, more appropriate AMPs should be implemented to mitigate the problem. Analysis of monitoring data should occur on a regular basis. The indicators selected in the monitoring program do not all have to move in the same direction to show improvement or degradation in watershed health. The full suite of indicators should be reviewed in regular cycles to:

- Note changes or trends indicators;
- Evaluate possible causes of those changes;
- Determine if changes in the indicators represent an impact;
- Evaluate if observed changes are expected or unforeseen; and
- Review the goals, elements, and implementation plan of the ISMP to assess if changes should be made to the plan to remain on track and achieve the overall stormwater goals over the implementation timeline for the ISMP.

The collection and review of data for the watershed health indicators should be conducted once every five years. After the implementation period is complete, monitoring should continue once every five years.

Municipality-Wide Adaptive Management Plan

Rather than preparing an adaptive management plan for each watershed, the MAMF recommends a municipal wide adaptive management plan.

Adaptive Management Implementation

The primary focus for adaptive management for the first few years after completion of the ISMP will be to:

- Set up tracking systems in accordance with Table 11-5 for metrics that are not currently tracked;
- Track implementation of mitigation measures and habitat enhancement projects in a GIS database;
- Further investigate concerns and issues identified in 2014 monitoring and baseline analysis, such as source of elevated lead levels in streambed sediments in Mission Creek;
- Conduct desktop monitoring of changes in effective impervious area (EIA) and riparian forest integrity (RFI) from aerial photos and GIS-based analysis (this could be implemented on a city-wide basis for all of the City's ISMPs);
- Evaluate trends of metrics at the end of five years (compare to ISMP and other program data results) and assess whether results indicate that:
  - Trends are in the desired directions,
  - Issues and concerns have been mitigated or improved, and
  - Revised mitigation or management approaches are needed.

The review and evaluation of trends and issues at the end of the first five years will set the priorities for the next five years of monitoring, review of data, and adaptation of programs and policies.

3. Recommendations

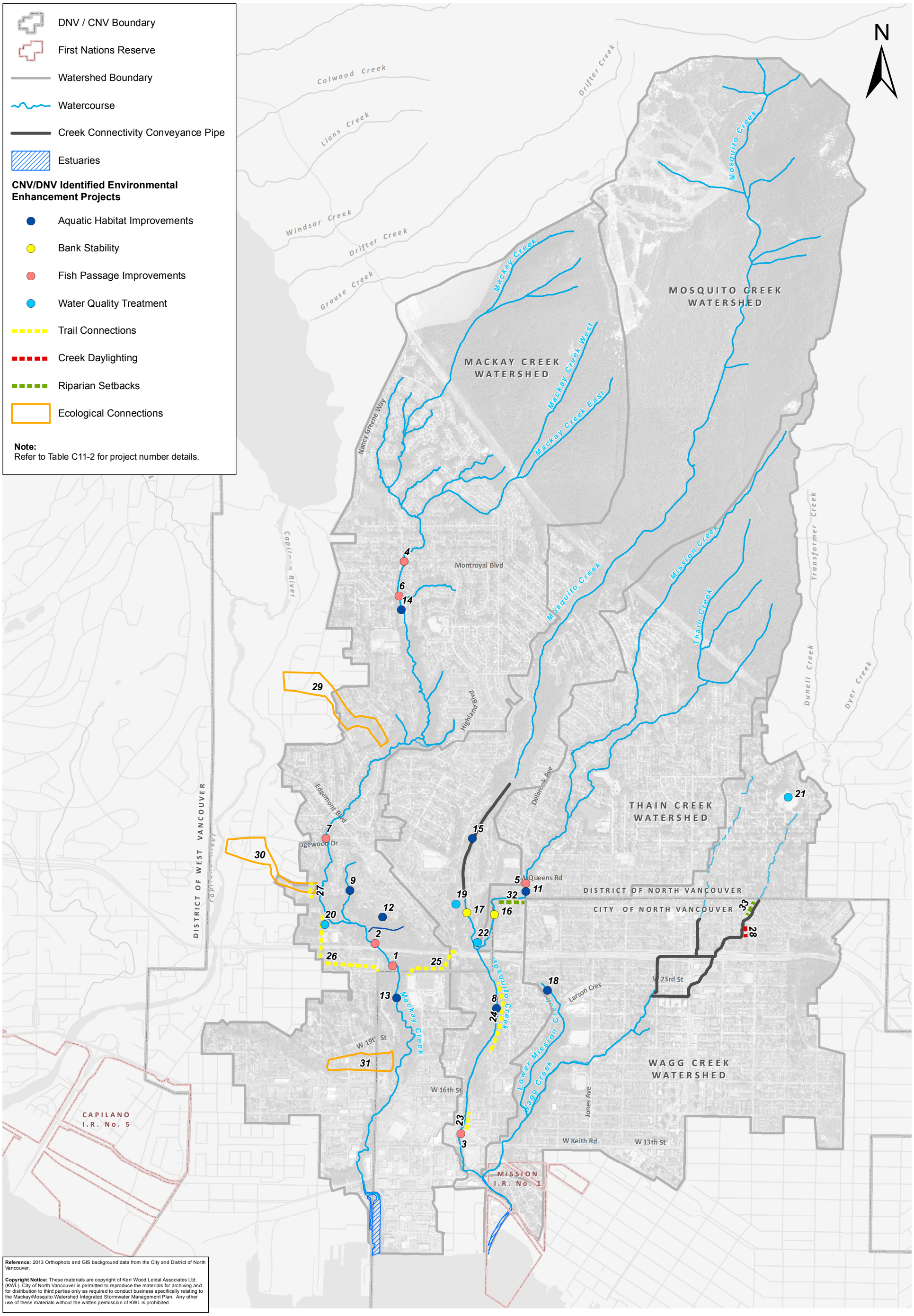
In summary of the above and based on the foregoing compendiums, it is recommended that CNV/DNV:

1. Monitor Watershed Health Parameters (MAMF) and any additional parameters. CNV and DNV review together to identify emerging priorities and upcoming schedule for monitoring.
2. Pursue bylaw and policy changes and enhancements to enable and support protection and enhancement of watershed health, sustainable re-development, community involvement, and public safety.
3. Identify possible areas and parcels for special consideration for future planning initiatives and OCP updates.
4. Pursue studies and other program development work that can and should be implemented in the short term.
5. Review current storm asset capital plans for re-prioritization based on capacity and fish habitat or passage needs.
6. Develop prioritized list of other projects for scoping, funding and implementation.

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Author: Pbuskas

City of North Vancouver
Mackay/Mosquito Watershed Integrated Stormwater Management Plan

KERR WOOD LEIDAL
consulting engineers
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Reference: 2013 Orthophoto and GIS background data from the City and District of North Vancouver.

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Project No.: 99-125 | Date: October 2020

0 250 500 1,000 Meters

City of North Vancouver/District of North Vancouver Identified Environmental Enhancement Project Locations

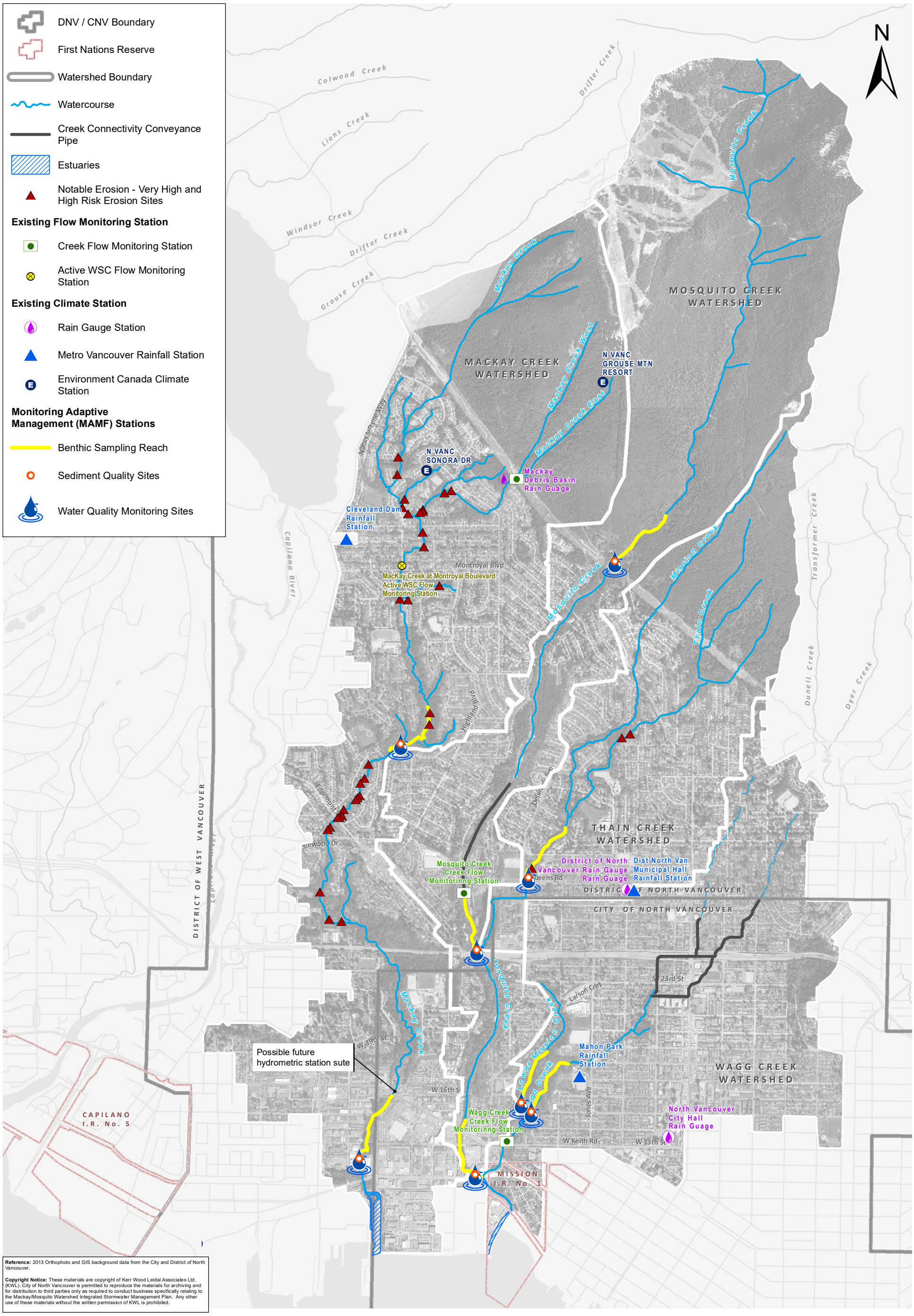
Figure C11-1

Path: Z:\0000-0999\0000-0099\099-125\430-GIS\MXD-Rp\Objective Figures\99125_FigC11-2_Proposed_MonitoringPlan.mxd Date Saved: 2020-09-24 2:28:11 PM
Author: rtaylor

City of North Vancouver

Mackay/Mosquito Watershed Integrated Stormwater Management Plan

KERR WOOD LEIDAL
consulting engineers
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Reference: 2013 Orthophoto and GIS background data from the City and District of North Vancouver.

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Project No.: 99-125 | Date: September, 2020

Proposed Monitoring Plan

Figure C11-2

Report Submission

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

Sept 29, 2020

C. W. CAMPBELL

ENGINEER

Crystal Campbell, P.Eng.
Project Manager

Reviewed by:

Laurel Morgan, P.Eng.
Technical Review

Statement of Limitations

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Revision History

Revision #	Date	Status	Revision	Author
0	Sept 29, 2020	Final	Issued as final for client copy.	CC

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