HASTINGS CREEK WATERSHED:
Ecology and Hydrotechnical Assessment

June 2013

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District of North Vancouver

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SUMMARY

Purpose

The purpose of this project was to assess hydrology, stormwater infrastructure, and ecological conditions in the Hastings Creek watershed, and to identify strategies and actions for improving the ecological health of the stream and managing the drainage system. This project forms one component of an Integrated Stormwater Management Plan (ISMP) for Hastings Creek.

Study Area

Hastings Creek flows through an 862 ha watershed located in the Lynn Valley area of the District of North Vancouver. About 61% of the watershed is urbanized including 34% zoned for single-family residential use. The headwaters are mountainous and forested. Hastings Creek flows through the northern edge of the redeveloping Lynn Valley Town Centre (LVTC).

Ecology Assessment

Approximately 49% of the total watershed area is forested; however, only 20% of the urbanized lower watershed has forest cover. Watershed forest cover has declined since the 1960s (62% in 1963 and 51% in 1995). Riparian forest cover was 73% in 2009, and has remained relatively constant over the last 50 years (74% in 1963; 73% in 1995).

Hastings Creek supports Coho Salmon, Cutthroat Trout, and Dolly Varden based on new or recent sampling. Threespine Stickleback, sculpin species, and Western Brook Lamprey are also likely present. Steelhead Trout was present historically but was not captured during the survey.

Productive habitat for Coho Salmon is found in the middle reaches of Hastings Creek and the lower reaches of Coleman and Thames creeks where channel gradient is <2%. Six fish passage barriers were identified. Anadromous fish access to the upper reaches of Hastings Creek is limited by a steep channel section above Donovan Pond (natural barrier). Culverts or wood weirs limit fish use in Coleman and Thames creeks.

Channel conditions were assessed in 26 stream segments using the Streamkeepers Module 2 methods. Habitat scores ranged from 40 (Marginal) to 112 (Good). Scores were generally higher (>70) in Hastings Creek adjacent to Ross Road School and lower (≤70) above the Lynn Valley Town Centre (LVTC) outfall and in Coleman and Thames creeks.

Water and sediment quality sampling showed that Hastings Creek is similar to other moderately urbanized streams in Metro Vancouver. Concentrations of total metals in water samples from the LVTC catchment were generally higher than other sites in the watershed (total copper, manganese, and zinc exceeded BC Water Quality Guidelines). Fecal coliforms were also elevated. Arsenic in sediment was above BC Sediment Quality Guidelines (BCSQGs) in Kilmer Creek and Hastings Creek. Cadmium, copper, lead, manganese, nickel, and zinc were elevated in sediment at the LVTC outfall site but not above BCSQGs.

Hydrotechnical and Stormwater Infrastructure Assessment

Stream discharge and precipitation have been monitored in the Hastings Creek watershed since 2003. Compared to eight streams from the region, Hastings Creek had the lowest unit mean annual discharge which suggests that a larger proportion of rainfall was intercepted or retained in Hastings Creek, but also has low baseflows and is moderately susceptible to peak flows. The maximum flow recorded since 2004 has not surpassed the 10-yr return period flow estimate.

There is approximately 54 km of storm pipes within the urbanized portion of the Hastings Creek watershed. The largest stormsewer network in the watershed captures the majority of the storm runoff from the LVTC and neighbouring areas to the south.

Fifty-seven culverts were identified in the Hastings Creek watershed. Culvert capacity screening based on culvert diameter and material identified 27 culverts which could not convey the 200-yr return period discharge without headwater controls. Based on the assessment, seven culverts have been identified for priority upgrading.

A detailed reconnaissance of Hastings Creek and its tributaries was conducted in 2007 and reviewed as part of this project. A total of 12 erosion sites of high consequence were identified as District assets (three footbridge sites and nine trail sites). Many of the trail sites were identified in Hunter Park. Standard bank protection practices are recommended to protect infrastructure (e.g., bridges); however, in areas where there is sufficient space, integrating aquatic habitat structures and soil bioengineering is a preferred solution to traditional practice.

Strategies and Priority Projects

Four broad strategies and eight priority projects or groups of projects for restoring instream, floodplain, and riparian habitat or addressing deficient stormwater infrastructure were identified. They combine infrastructure replacement, stormwater management, riparian restoration, instream habitat improvement, and stream daylighting. Additional projects were identified that address flooding, erosion, fish passage, and other issues.

Monitoring

Five monitoring approaches are recommended to measure the success of the ISMP in mitigating the impacts of future development:

1. Continuous stream discharge and precipitation monitoring;
2. Benthic invertebrate monitoring every 3 years;
3. Sediment quality monitoring every 3–5 years;
4. Watershed and riparian forest cover monitoring every 5 years; and
5. Annual fish population monitoring in Hunter Park and other reference sites.

Acknowledgements

This plan was developed under the management and direction of Ariel Estrada (Engineering) and Richard Boase (Environment) of the District of North Vancouver.

Members of the North Shore Streamkeepers (NSSK) provided essential data and advice for the project. Specifically, we thank Doug Hayman, Jan Lander, Karen Munro, Greg Howie, Bob Gelling, and Janet Dysart for their time and assistance. Graham Knell (District of North Vancouver Parks), Julie Pavey (District of North Vancouver Environment) and Karen Rendek (District of North Vancouver Planning) also contributed to the project.

Other contributors to the plan were Karenn Bailey (Raincoast Applied Ecology), and Erica Ellis, Jack Lau, and Jason Miller of Kerr Wood Leidal Associates.

Recommended citation:

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.

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PART 1. INTRODUCTION

The purpose of this project was to assess hydrology, stormwater infrastructure, and ecological conditions in the Hastings Creek watershed, and to identify priority actions for improving the ecological health of the stream and managing stormwater infrastructure, erosion, and flooding. It identifies strategies for restoring instream, floodplain, and riparian habitat, and recommends priority projects to be undertaken over the next 2–10 years. It is important to note that this project focuses on the stream channel and riparian corridor (within approximately 30 m), and does not address watershed- or catchment-scale stormwater management planning including rainwater management. The District of North Vancouver is in the process of developing an overall Integrated Stormwater Management Plan (ISMP) for the Hastings Creek watershed, of which this project forms one component.

Hastings Creek is an 862 ha watershed located in the Lynn Valley area of the District of North Vancouver (Figure 1-1). It drains from Mount Fromme at an elevation of 998 m to discharge into the lower reach of Lynn Creek with a total of 27.5 km of stream channels. About 61% of the watershed is urbanized including 34% zoned for single family residential use. Like many small streams in North Vancouver, the headwaters are forested and not zoned for urban development. An important feature of Hastings Creek is its location in the heart of the redeveloping Lynn Valley Town Centre (see Figure 1-1). A summary of watershed characteristics is presented in Table 1-1.

Proposed Vision and Goals

A vision statement and goals were developed to guide the selection of management strategies and priority projects. However, they will be reviewed and revised as part of the ISMP process and should be considered preliminary at this time.

Vision
Over the next 50 years, collaborative planning, rainwater management, and habitat restoration by the District of North Vancouver, local residents, and developers will result in abundant fish populations, thriving riparian forests dominated by native species, safe and cost-effective drainage systems, and enhanced recreational opportunities for Lynn Valley residents in the Hastings Creek watershed.

Goals

1. Reduce the hydrologic and water quality impacts of stormwater runoff from the Lynn Valley Town Centre and other intensively urbanized areas on stream health.
2. Incorporate rainwater management (infiltration and storage) into redeveloping residential and commercial areas.
3. Upgrade failing or undersized stormwater infrastructure.
4. Restore and enhance fish and wildlife habitat with emphasis on stream channels, floodplains, and surrounding riparian areas.
5. Reduce riparian zone encroachment in residential areas, and increase riparian

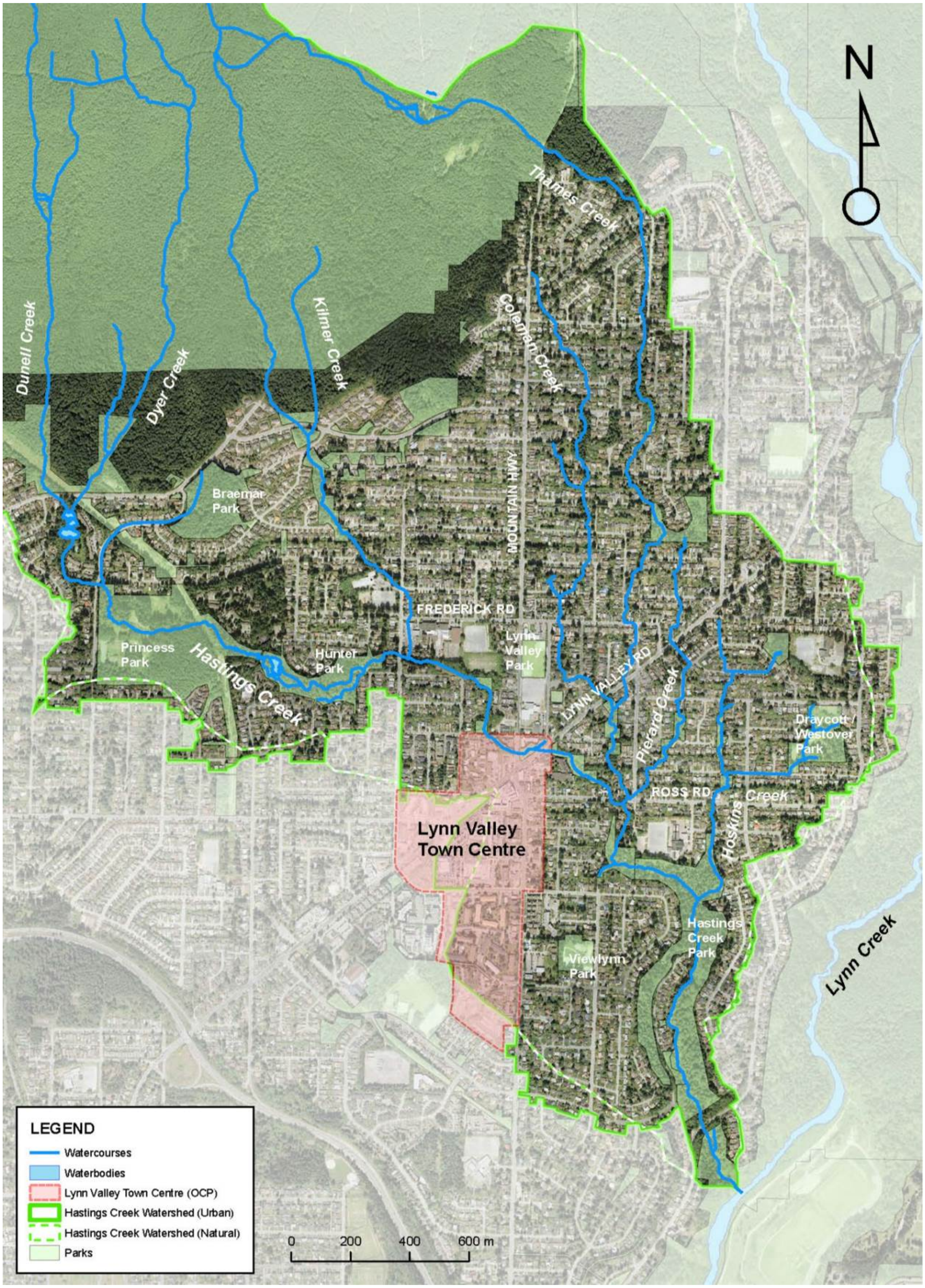

Figure 1-1. Lower portion of Hastings Creek watershed showing location of stream channels.

Table 1-1. Summary of Hastings Creek watershed characteristics.

1. General Characteristics	
Watershed Area / Urban Watershed Area	862 ha / 523 ha (70%)
Stream Channel Length / Length with Fish	27.5 km / 10.3 km (37%)
Stream Channel Density	3.2 km/km^2
Max / Min Elevation	998 m / 23 m
Watershed Slope	12.7%
Annual Precipitation	2941 mm/yr (at urban boundary)
2. Land Cover	
Total Imperviousness (%)	21% (GVRD, 1999 estimate)
Riparian Forest Cover (%)	73% (110 ha)
Watershed Forest Cover (%)	50% (424 ha)
Road crossings	49 crossings (including bridges and culverts)
3. Zoning (of 688 ha zoned)	
Park and Open Space	357 ha (52%)
Single-family Residential	297 ha (43%)
Multi-family and Low-rise Residential	23 ha (3%)
Commercial and Comprehensive	8 ha (2%)
4. Fish Populations	
Present: Coho Salmon, Cutthroat Trout (resident), Dolly Varden	
Likely present: Sculpin species, Threespine Stickleback, Western Brook Lamprey	
Possibly/historically present: Steelhead Trout, Chum Salmon, Chinook Salmon	
6. Benthic Invertebrate Community	
B-IBI (2003)	23.5 (Poor)
Benthic Taxa Richness (2003)	23.3
EPT Taxa Richness (2003)	10
CABIN Score (2003)	Group 1 (0.63); Possibly Stressed
7. Hydrology	
Average Discharge (Q_m)	0.165 m^3/s
Min Summer Discharge (7-day low flow)	0.051 m^3/s
Max Storm Discharge (Q_{max})	3.334 m^3/s
8. Available Monitoring Data	
Discharge (Stage)	1 gauge site since 2004
Precipitation	1 site at 350 m asl since 2003 (mean: 2,941 mm/yr)
Benthic Invertebrates	5 samples in 2003
Water Quality	Surveys in 2000 and 2012
Land Cover & Land Use	spectral imagery; MV land use in 1996, 2001, 2006

protection requirements including landscaping during redevelopment.

6. Manage recreation impacts and invasive plant species that affect the health of riparian forests.
7. Assess the long-term benefit of management activities using a comprehensive monitoring program.
8. Involve streamkeepers and local residents in project planning, implementation, and monitoring.

Report Structure

This report is divided into five parts. Part 1 provides an introduction to the project and the characteristics of the Hastings Creek watershed. Part 2 presents the methods and results of the ecological assessment including instream habitat, riparian habitat, characteristics of the fish community, and water and sediment quality. Part 3 examines hydrology, stormwater infrastructure, bank stability, and flood risk. Part 4 presents project descriptions for a range of high priority projects for improving ecological conditions and stormwater infrastructure. Part 5 provides a monitoring plan for assessing long-term change in the watershed. Two appendices are included. Appendix 1 provides a map folio of spatial information relevant to watershed management, and Appendix 2 presents a range of data from the assessment components of the project.

Integrated Stormwater Management Planning (ISMP)

This report will form a component of DNV's ISMP for Hastings Creek. Metro Vancouver's Integrated Liquid Waste and Resource Management Plan (ILWRMP) presents the region's vision for wastewater management (both sanitary and storm) and how it will meet its requirements under the provincial Environmental Management Act. Approved by the B.C. Ministry of Environment in June 2011, the *ILWRMP* replaces the previous Liquid Waste Management Plan that has been in place since 2002. The ILWRMP protects public health and the environment by requiring municipalities to use bylaws to reduce pollutant discharges into streams, develop integrated stormwater management plans (ISMPs) for urban or urbanizing watersheds, and incorporate on-site rainwater management into new developments. The District of North Vancouver is taking a novel approach to meeting its commitment to developing ISMPs that focuses on site-level rainwater management and the implementation of instream and riparian restoration projects.

Previous Assessment Work

A range of reports and studies were used in the preparation of this project. They include:

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Climate and Hydrology

Hastings Creek originates on the east slope of Mount Fromme, and flows through Princess Park, Hunter Park, the Lynn Valley commercial area, and residential areas until it joins Lynn Creek in the Arborlynn area. The main tributary of Hastings Creek is Thames Creek while smaller tributaries include Dunell Creek, Dyer Creek, Coleman Creek, Pierard Creek, Hoskins Creek and several unnamed tributaries. The Hastings Creek watershed rises from 30 m elevation at the outlet into Lynn Creek to almost 1,000 m elevation on the east slope of Mount Fromme. The mean basin elevation is approximately 262 m.

The climate within the Hastings Creek watershed is typical of the Coast Mountains of mainland British Columbia, being dominated by a wet maritime climate with a small range of annual temperatures. Because of a strong orographic effect, annual precipitation is extremely variable. Typical precipitation ranges from about 1,850 mm/yr near sea level to over 4,000 mm/yr at higher elevations. The precipitation is unevenly distributed through the year with a majority occurring between October and March. Flowworks Inc. has operated a rain gauge on the east side of the Hastings creek catchment (123°02’09”W, 49°21’32”N) on a continuous basis since 2003. The elevation of the monitor is approximately 350 m above sea level. For the period 2003 to 2011, the average annual precipitation was 2,941 mm.

Logging and Development History

Prior to the mid-1800’s, North Vancouver District was inhabited by the Coast Salish. Small-scale logging began in Lynn Valley and surrounding area likely as early as the 1860s and commercial logging began later in the mid-1880s. Due to the wet conditions and rich soils, the large old-growth western redcedar and Douglas-fir trees were some of the largest trees in the region. The logs were a sought-after resource for shipbuilding as well as for houses and factories being built across Burrard Inlet in Vancouver. The large cedar trees, some up to 4 m in diameter, that grew in the area and in the headwaters of Lynn Creek were ideal for shingles and shakes. Trees were felled by hand and pulled out by teams of horses along a network of skid roads. Later, water-filled flumes were also used to transport shingle bolts down to the Moodyville waterfront area near the foot of Lonsdale. Historical photos show a large flume crossing Pipe Line Road (now Lynn Valley Rd) just east of a large wooden trestle bridge spanning Hastings Creek (see Figure 1-2).

The earliest non-First Nations settlements were logging camps, the largest of which was located adjacent to Hastings Creek. By the 1890s, several mills were located in the watershed. One of the largest mills, owned by the Hastings Shingle and Manufacturing Company, was located on the current site of Lynn Valley United Church. Another was located in the headwaters of Coleman Creek (also called Mountain Creek) on what is now Mill St. The first houses were constructed in the 1890s and, as the number of residents grew, a larger area of land was cleared for a permanent settlement, centred around the current intersection of Lynn Valley Rd and Mountain Hwy. By the early 1900s, the community of Lynn Valley consisted of the mills, houses, several stores, a school, at least one church, and a public building known as the Lynn Valley Institute.

Figure 1-2. Hastings Creek bridge on Pipe Line Road (now Lynn Valley Road) in 1909. This wooden trestle bridge was constructed in 1907 and was demolished and replaced by a concrete culvert in 1952. One of the flumes used to move shingle bolts can be seen crossing over Pipe Line Road at the east end of the bridge. Photo courtesy of North Vancouver Museum & Archives.

After World War I and II, Lynn Valley expanded as a residential area. Newer developments consisted of infill housing in already developed areas and new subdivisions of single-family homes, increasing both the impervious area and the footprint of development within the watershed. The most rapid expansion of development occurred from the 1940s (central Lynn Valley) to the 1970s (Westlynn area), although several newer subdivisions have also occurred in recent years. Houses along Carmaria Court in the Hastings Creek ravine were developed in the early 1980s and Braemar Connector area in upper Kilmer Creek watershed was developed in the 1990s. Lynn Valley has now entered a redevelopment phase rather than focusing on primary development.

Although it is difficult to determine specific impacts from the early logging and settlement history of the Lynn Valley area, some general impacts to aquatic habitat and riparian conditions in the Hastings Creek watershed have been known to have occurred. In some cases, these impacts have been long-lasting and are still reflected in the ecological conditions observed today.

Much of the wood harvested was floated downstream as shingle bolts using flumes. Water diverted for use in the flumes may have impacted flow conditions for fish at certain times of the year.

Figure 1-3. Swimming in the lower mill pond on Hastings Creek. Photo courtesy of North Vancouver Museum & Archives.

In addition to flumes, stream channels were used to transport and store shingle bolts. By 1900, Hastings Creek and its tributaries were already heavily modified by logging activities. Dams were installed to create several inline ponds for wood storage, and channels were used to transport shingle bolts downstream using splash-dams. Channelization likely occurred in some sections to improve log transport. Hastings Creek was dammed in what is now Princess Park to create a holding pond (known as Prince's Pond) for shingle bolts, which were then floated downstream to a large collection pond upstream of another dam upstream of Mountain Highway (near Lynn Valley Road) where they awaited milling. (Historical photos shows this pond was used for a swimming pool (Figure 1-3) and froze over and was used as a skating rink by Lynn Valley residents during some winters.) There is also a record of a "Mill Pond" located on

Thames Creek. In addition to being a barrier to fish passage, the dams and channelization likely led to reduced habitat complexity by removing instream wood debris, and impacted the amount and size of pools.

Road construction in the 1950’s and subsequent culverting of creeks created additional barriers to fish passage which severely impacted coho runs. For example, in 1952, the wooden trestle bridge over Hastings Creek on Lynn Valley Road was replaced with a concrete culvert which impeded fish passage. In 1962, a large flood protection wall was built downstream of Arbourlynn Drive, stopping anadromous fish passage further upstream.

All remaining forested areas, including the headwaters above the current-day development boundary, are second-growth forest. Only occasional older trees remain. The removal of large trees from riparian areas along Hastings Creek and its tributaries has reduced the recruitment of large wood debris. The lack of large trees has been further exacerbated by the expansion of development in the 1940’s and 1950’s without riparian setbacks, reducing the forested buffer along the creek channels. Several large-scale forest fires, occurring in the early 1900s, also affected forest ages and composition in the watershed.

Historical Fisheries Values

Historically, the Hastings Creek watershed was known to support healthy Coho Salmon and Steelhead Trout populations. One of the earliest references to the fish in Hastings Creek came from pioneer Lynn Valley resident Walter McKay Draycott, who in 1912 claimed that every year “at least fifty salmon and ‘salmon-trout’ (Steelhead) swam up Draycott Brook [now called Coleman Creek] and kept him awake at night with their ‘flipping and flapping’ in the stream". It is likely that adult fish returns were in the hundreds or thousands prior to development.

As mentioned previously, several barriers to fish passage were created during development in the 1950’s and 1960’s, restricting Coho and Steelhead access to a short lower section of the creek. After fish access was restored further upstream by the construction of the fishway at Arbourlynn Drive in 1980, several releases of juvenile Coho and Steelhead occurred into Hastings Creek from 1980 to the mid-1990’s. There were also sightings of returning Chum Salmon in the lower reaches of Hastings Creek in 2012.

Other species recorded from Hastings Creek include Cutthroat Trout, Chinook Salmon, Dolly Varden, and sculpin. The records of Chinook Salmon spawning in Hastings Creek between Ross Road and Lynn Valley Road during the 1980s may be erroneous.

Coho Salmon Escapement and Fish Population Monitoring

North Shore Streamkeepers (NSSK) has been monitoring Coho Salmon populations in the Hunter Park portion of Hastings Creek since 1993. Monitoring has consisted of adult spawner surveys in late fall (November and December), smolt trapping in May, and fry trapping in July (Table 1-2).

Historical escapement data indicates that Coho Salmon and Steelhead Trout were more abundant historically. The average Coho escapement in Hastings Creek was 63 between 1971–1980, 77 from 1981–1985, and 41 from 1984–1995 (FISS, 2012; Farwell, 1987). The maximum recorded was 175 in 1980. Methven (1987) estimated a Steelhead population of 3,140 and a Coho population of 357 (likely estimates of juveniles). The current status of Steelhead populations, likely confined to lower sections of the watershed below where monitoring efforts have occurred, is not well-known. No juvenile Steelhead Trout were captured during the minnow trapping survey in 2011–2012.

Table 1-2. North Shore Streamkeepers monitoring results for Coho Salmon and Cutthroat Trout surveys in Hunter Park, 2003–2012.

	Coho Salmon			**Cutthroat Trout**	
Year	Smolts (April/May)	Fry (July)	Adults (Fall)	Adults + Fry (April/May)	Adults + Fry (July)
2003			6		
2004			32		
2005			3		
2006	51	10	0		
2007	19	0	6		
2008	0	19	3	48	
2009	11	10	0		
2010	5	7	3	11	59
2011	4	5	4	9	47
2012	0	16	0	9	53

District of North Vancouver's Official Community Plan (OCP)

Adopted in June 2011, the District's new Official Community Plan[1] (OCP) is the primary long range planning document that sets the direction for future development and servicing requirements for the community. It captures community values and translates them into policies that affect many aspects of community life including social well-being, housing, economic development, environmental management, climate action and infrastructure. Through the OCP, the District is hoping to create a "Network of Centres" of more complete, compact and connected communities. Establishment of an urban containment boundary also protects natural areas and the District's ecological assets from urbanization.

In the area of environmental management (Section 9), the OCP has set a target of completing Integrated Stormwater Management Plans and implementation on all urbanized watersheds by 2030. DNV's environmental management objective is to protect and improve the ecological health of the natural ecosystems within its boundaries, by protecting and enhancing biodiversity (9.1), urban forests and soil systems (9.2), and aquatic ecosystems (9.3), reducing and mitigating the risk associated with natural hazards (9.4), and creating a stewardship ethic where citizens and businesses engage in environmental efforts (9.6).

[1] For more information on the District's OCP, visit identity.dnv.org.

Lynn Valley Town Centre (LVTC) Implementation Plan

The Lynn Valley Town Centre (LVTC), one of two designated town centres in the OCP, is prominently located within the central part of the Hastings Creek watershed. Identified as the District's Municipal Town Centre, the LVTC will be re-developed to incorporate medium and high-density land uses including residential, commercial, employment, recreational, and civic. DNV land use policies will provide for an additional 2,500 residential units within the LVTC by 2030. Approximately 75% of the LVTC planning area is located in the Hastings Creek watershed (see Figure 1-1). The remainder is located in the Keith Creek watershed to the west.

As part of planning for re-development of the LVTC, the District hopes to achieve several environmental goals:

- Protect natural parkland and local ecosystems including forest and riparian habitat, and seek to rehabilitate Hastings Creek at Lynn Valley Road;
- Integrate the natural environment into the LVTC by planting landscaping, protecting pocket parks and heritage stumps, and encourage innovative rain gardens / rainfall capture features, green walls and roofs to utilize ecological services and reflect and natural context;
- Complete an integrated stormwater management plan for the Hastings Creek watershed and implement measures to maintain and enhance the health of the watershed; and
- Require integrated stormwater management strategies for new development in the LVTC and seek to manage and re-use stormwater on site to the greatest extent possible.

A Lynn Valley Town Centre Implementation Plan is currently being developed that will seek to achieve these goals. The Plan, once completed, will include detailed design guidelines, community amenities and development contributions, transit integration, servicing, infrastructure, rainwater management and phasing strategies for development over the next 20 years. Figure 1-4 presents the land use concept plan for the town centre (version spring 2012). Hastings Creek is shown with the curving green arrow in the north part of the plan.

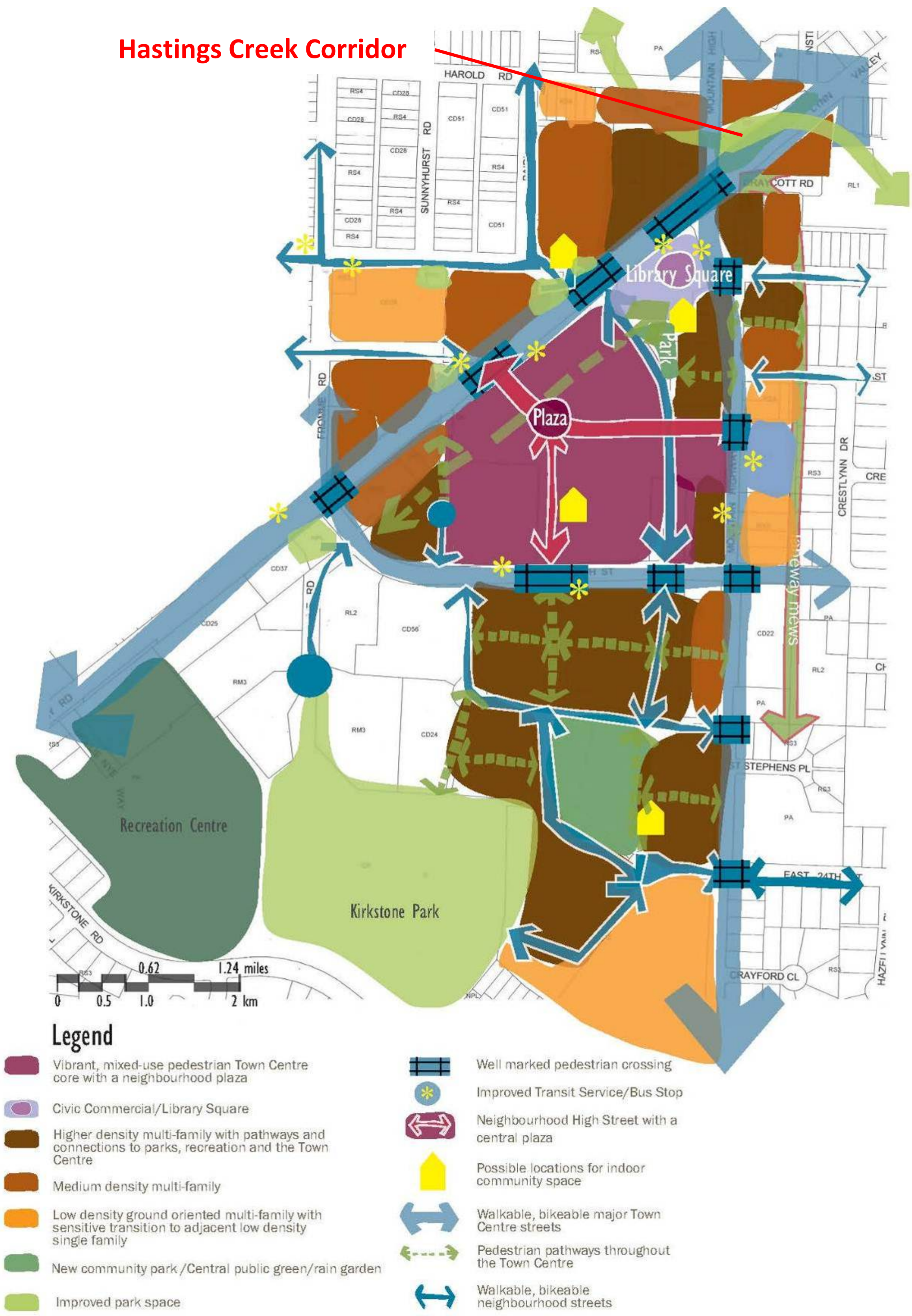


Figure 1-4. Land use concept plan for Lynn Valley Town Centre (Spring 2012).

Stewardship Activities

Community members have played an important role in the stewardship of Hastings Creek. Historically, several Lynn Valley residents were individually involved in efforts to protect and enhance fish habitat in the watershed.

In 1980, the Squaretailers Anglers Club installed a fishway at Hoskins Road near the intersection with Arborlynn Drive. North Shore Streamkeepers (NSSK) was formed in 1993 as an umbrella organization of individuals and watershed groups interested in protecting and preserving the streams on the North Shore. Since its inception, members of NSSK have been active monitoring and restoring important fish habitat in the watershed. The Lynn Valley Road fishway on Hastings Creek was installed by the District in 1994 with support from NSSK. In 1999, NSSK championed a major project to improve and enhance Donovan's Pond, including enhancement of upstream inlet to provide access to the pond for fry from the creek, installation of outgoing fish weir to allow outmigration of fry, plantings to improve riparian cover, and fencing to protect the pond shoreline. Friends of Hunter Park have organized regular invasive plant pulls and planting of native vegetation within the park.

Ongoing NSSK projects have also included habitat assessments, monitoring of spawner returns and fry and smolt numbers in Hunter Park, removal of invasive plant species, plantings of native riparian trees and shrubs, and various forms of watershed education. NSSK work also includes working with local residents, schools, and organizations in the area to encourage community interest in Hastings Creek. The skills and experience of the NSSK members will be incorporated into the monitoring component of this plan.

PART 2. ECOLOGY ASSESSMENT

Summary

Watershed Forest Cover: A total of 49% (424 ha) of the Hastings Creek watershed is forested (based on 2009 orthophotos); however, only 20% of the urbanized portion of watershed is forested. Watershed forest cover was 62% (535 ha) in 1963 and 51% (439 ha) in 1995.

Riparian Forest Cover: Riparian Forest Integrity (RFI) across the whole watershed was 73% in 2009. Riparian forest cover has remained relatively constant over the last 50 years. RFI was 74% in 1963; 73% in 1995.

Fish Community: Hastings Creek supports Coho Salmon, Cutthroat Trout, and Dolly Varden based on new or recent sampling. Threespine Stickleback, sculpin species, and Western Brook Lamprey are also likely present. Steelhead Trout was present historically but was not captured during the survey.

Instream Fish Habitat: Instream fish habitat in the main stream channel varies with gradient and ravine confinement. Productive habitat for Coho Salmon is found in the middle reaches of Hastings Creek and the lower reaches of Coleman and Thames creeks.

Fish Passage: Six fish passage barriers were identified. Anadromous fish access to the upper reaches of Hastings Creek is limited by a steep channel section above Donovan Pond (natural barrier). Culvert or wood weirs limit anadromous fish use in Coleman and Thames creeks.

Detailed Channel Assessment: Channel conditions were assessed in 26 stream segments using the Streamkeepers Module 2 methods. Habitat scores ranged from 40 (Marginal) to 112 (Good). Scores were generally higher (>70) in Hastings Creek adjacent Ross Road School and lower (≤70) above the Lynn Valley Town Centre (LVTC) outfall and in Coleman and Thames creeks.

Water Quality: Survey measurements indicated that water quality is typical of moderately urbanized streams in Metro Vancouver. Dry- and wet-weather samples showed that concentrations of some metals (total copper, manganese, and zinc) in stormwater from LVTC catchment were higher than BC Water Quality Guidelines. Fecal coliforms were also elevated in the LVTC stormwater.

Sediment Quality: Arsenic in sediment was above BC Sediment Quality Guidelines (BCSQGs) in Kilmer Creek and Hastings Creek (just above LVTC outfall). It is not known whether the high arsenic levels are related to human impacts or are naturally-occurring. Other metals that are typical of highly urbanized catchments (cadmium, copper, lead, manganese, nickel, and zinc) were found to be elevated at the LVTC outfall site but not above BCSQGs.

Introduction

A biophysical inventory of Hastings Creek and its tributaries was undertaken to assess the condition of stream channels and surrounding riparian areas. The ecological assessment was divided into four components:

1. Assessment of watershed and riparian forest cover in the Hastings Creek watershed;
2. Assessment of the fish community based on existing information and new sampling;
3. Inventory of stream channel condition including a detailed channel assessment of priority sections of the Hastings Creek mainstem and fish passage; and
4. Assessment of sediment and water quality with emphasis on the LVTC catchment.

It is important to note that the ecological assessment focused on the stream channels and their adjacent riparian areas with only limited analysis of watershed-scale land cover and land use (e.g., watershed forest cover). Imperviousness was not assessed.

Watershed and Riparian Forest Cover

Forest cover contributes to or regulates many important watershed processes, such as the movement and provision of water, sediment, nutrients, organic matter, and wood. Within watersheds, forests are important regulators of streamflow through rainfall interception, capture, and evapotranspiration. Forests within the riparian area, the interface zone between the water and land, also protect streams 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.

Methods. Watershed and riparian forest cover was assessed to measure the amount and distribution of tree canopy cover within different regions of the Hastings Creek watershed and identify areas for potential riparian forest restoration. Current watershed and riparian forest cover was mapped using 2009 orthophotos in GIS based on visual interpretation of forest canopy. It included large forest patches as well as smaller patches distributed within urban areas and parks. Historical forest cover was assessed using 1995 orthophotos provided by DNV, and scanned and rectified air photos from 1963. Older air photos were available but their scale and coverage made them difficult to rectify. Riparian forest cover mapping followed methods followed those used by Page and Johnston (2006)[2]. A standard 30 m buffer on either side of the stream centreline (60 m total width) around all permanent streams was used to assess riparian forest integrity (RFI) across the watershed. RFI has been used as an indicator of riparian function in urbanizing watersheds in Metro Vancouver as part of ISMP planning[3].

Results. Figures 2-1 and 2-2 (Appendix 1: Maps 4–5) provide a graphical summary of forest cover. Table 2-1 summarizes RFI values by catchment (see also Appendix 1: Map 6). Key findings

[2] Page, N. and C. Johnston. 2006. Review of Environmental Monitoring Approaches for Urban Streams in the GVRD. Draft report prepared by Raincoast Applied Ecology and Kerr Wood Leidal Associates for Greater Vancouver Regional District, December 2006.
[3] Greater Vancouver Regional District. 2005. Template for Integrated Stormwater Management Planning 2005. Draft report produced by Kerr Wood Leidal Associates for Greater Vancouver Regional District, December 2005.

of the analysis were:

- A total of 49% (424 ha) of the Hastings Creek watershed was forested in 2009. However, below the current urban development boundary, only 20% of the watershed is forested. Below the current urban development boundary, most of the existing forest cover is protected in parks and greenbelts.

- Watershed forest cover was 62% (535 ha) in 1963 and 51% (439 ha) in 1995 suggesting that most of the forest loss accompanying urbanization occurred before 1995.

- Riparian Forest Integrity (RFI) across the whole watershed was 73% in 2009. When considering only riparian areas below the current urban development boundary, RFI was 55%. The low watershed forest cover and higher RFI values indicated that much of the intact forest cover in the watershed occurs along the watercourses.

- Across Hastings Creek and its tributaries, RFI ranged from 34% (Pierard Creek) to 88% (Kilmer Creek).

- Riparian forest cover has remained relatively constant over the last 50 years. RFI was 74% in 1963; 73% in 1995; and 73% in 2009.

Table 2-1. Total Riparian Forest Cover and Riparian Forest Integrity (RFI) by Tributary for 2009.

Tributary	**Whole Watershed**		**Below Urban Development Boundary Only**	
	Riparian forest cover (ha)	Riparian forest integrity (RFI)	Riparian forest cover (ha)	Riparian forest integrity (RFI)
Hastings Creek (all sections)	58.3 ha	85%	24.6 ha	7%
Kilmer Creek	22.8 ha	88%	3.9 ha	55%
Coleman Creek	5.9 ha	40%	No change	
Thames Creek	16.5 ha	69%	6.8 ha	48%
Pierard Creek	2.2 ha	34%	No change	
Hoskins Creek	5.2 ha	44%	No change	
Overall Watershed	109.8 ha	73%	48.6 ha	54%

Summary of General Riparian Conditions. The following points summarize the results of the overview riparian assessment. Figure 2-3 provides representative photos of riparian conditions.

Along the lower section of Hastings Creek from the confluence with Lynn Creek up to Hoskins Road, there are wide riparian buffers (ranging from 35–65 m wide) of mixed forest within a wide undeveloped ravine. The tree canopy is dominated by red alder and western hemlock with an intact understory of sword fern and salmonberry. Several spot infestations of ivy and yellow lamium were found in the understory, extending along Arborlynn Drive and Greenock Place.

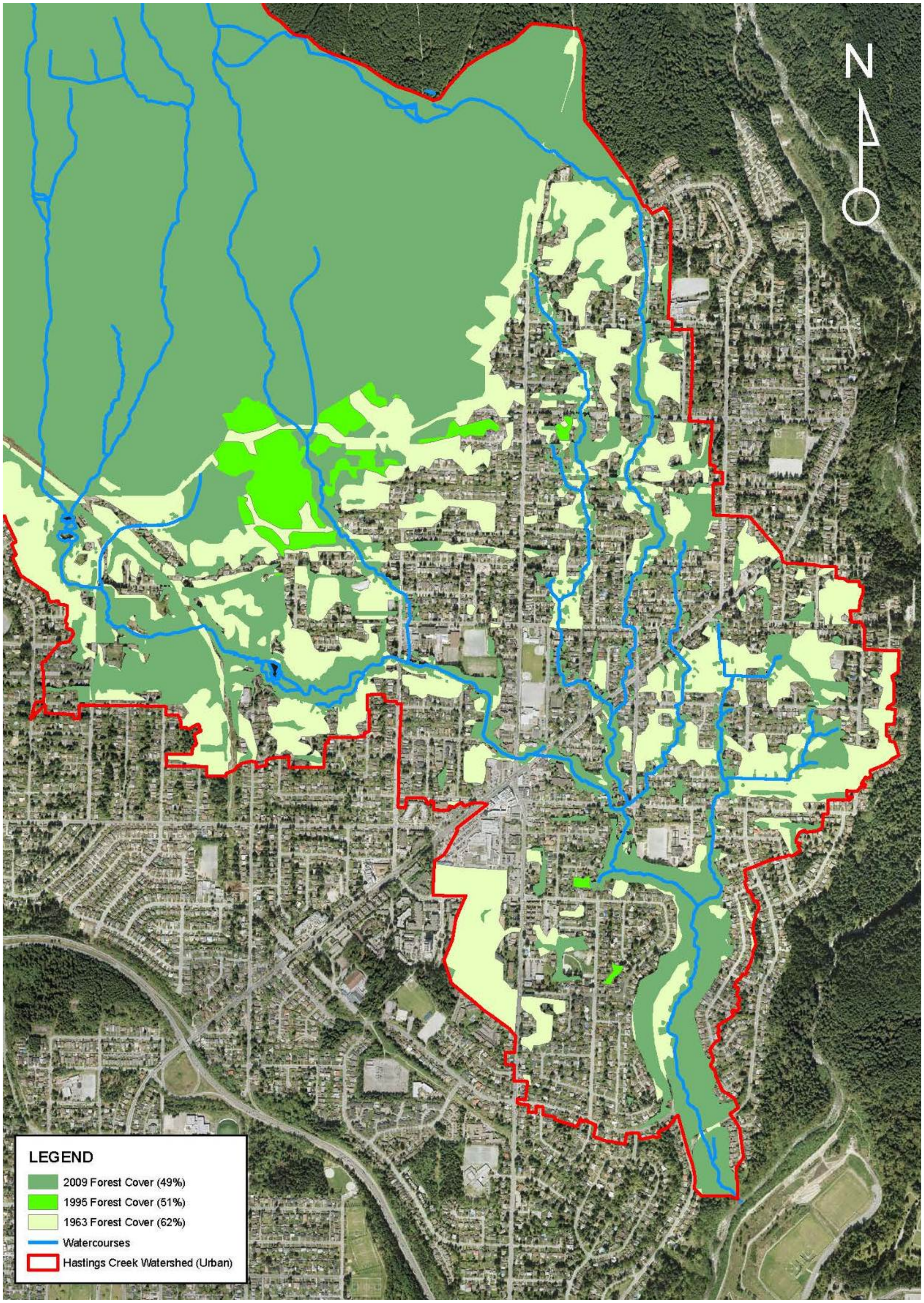


Figure 2-1. Watershed forest cover in the Hastings Creek watershed (2009, 1995, and 1963).

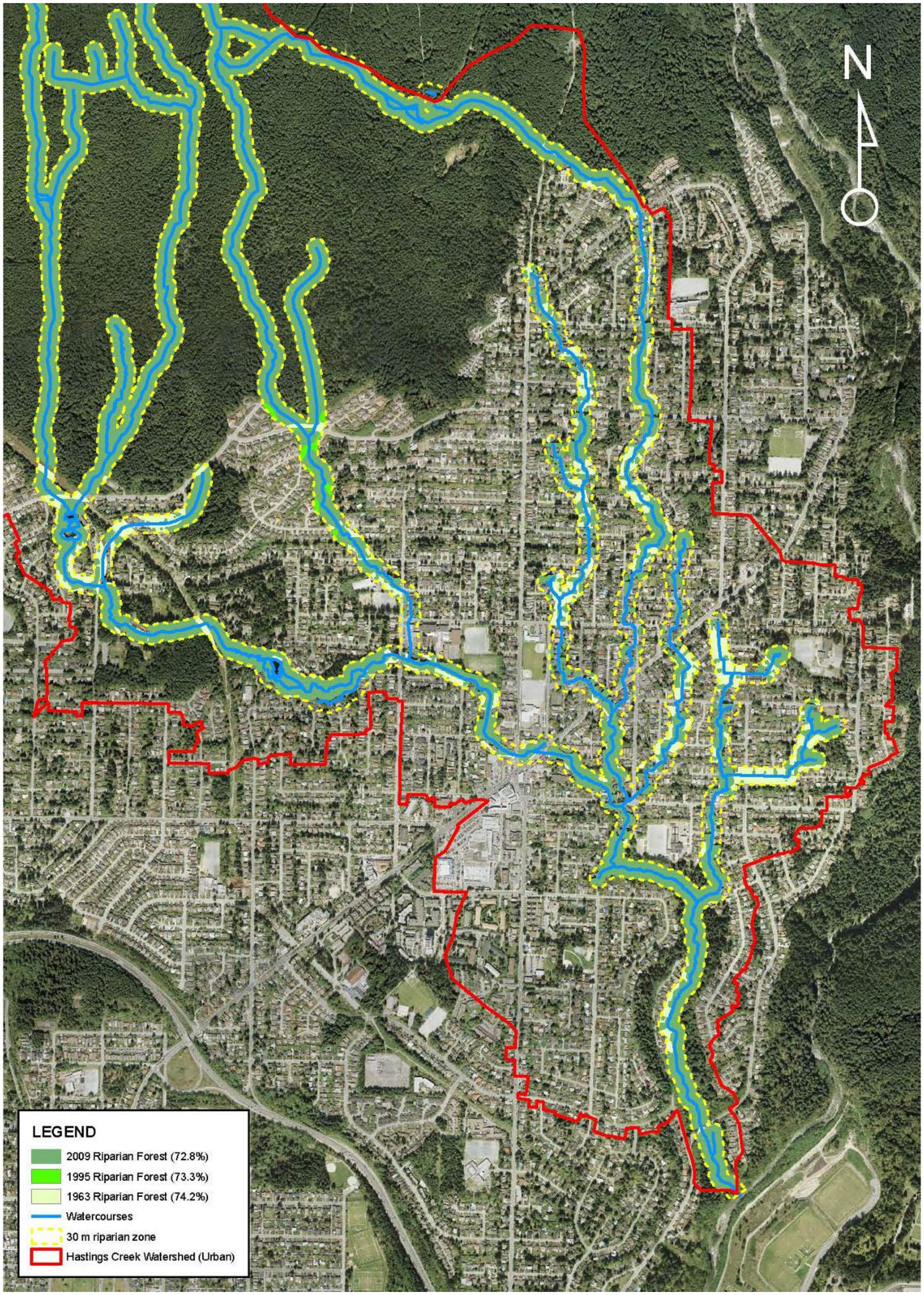


Figure 2-2. Riparian forest cover in the Hastings Creek watershed (2009, 1995, and 1963).

Figure 2-3. Riparian habitat in Hastings Creek: (a) natural understory vegetation in ravine section of Hastings Creek; (b) Japanese knotweed infestation along Hastings Creek near Carmaria Court; (c) English ivy and yellow lamium extending from yard edge into Hastings Creek ravine; (d and e) examples of yard encroachment through central Lynn Valley; and (f) sparse understorey vegetation and compacted soils in Hunter Park due to heavy recreational use.

Above Hoskins Road up to the foot bridge adjacent to Ross Road School, wide riparian buffers (30–75 m wide) have also been largely preserved in this steep ravine section. The exception is along Carmaria Court, where yards and landscape features (i.e., decks, gardens, lawns, rock walls) extend right to the west bank of the creek. Ravine areas are dominated by coniferous forest, mostly western hemlock and western redcedar. Salmonberry is common along the banks of the creek. Above the confluence with Hoskins Creek where the stream gradient is lower, there are several large alder and cottonwood trees along the creek banks (large wood debris frequency is also higher through this area). There is a very large infestation of knotweed downstream of Carmaria Court near a District sewer lift station within the channel and on the adjacent banks as well as spot infestations of knotweed and giant hogweed further upstream. There are also large areas of ivy and yellow lamium extending down the ravine slopes from the houses along 27th St, likely from yard waste dumping or garden escapees. The Hastings Creek Trail along the east side of the creek encroaches on the stream in some areas and has created some minor erosion areas along the creek bank.

Upstream of the 27th St-Ross Rd School footbridge through central Lynn Valley to the downstream edge of Hunter Park, historical development along this lower gradient section of Hastings Creek has occurred near to right up to the creek banks. As a result, riparian areas are narrow (often 2–5 m) or non-existent, except in parks. Invasive sycamore maple trees have become a dominant riparian species in several reaches of this section. Recreational impacts are also more severe owing to more frequent recreational use. Along some riparian areas that have been protected as parks and greenbelts, some understory areas have been denuded by recreational use, particularly in and around Argyle School. Infestations of invasive understory species, such as ivy, holly, and yellow lamium, are most common in this part of the watershed.

Within Hunter Park and up to Princess Park, intact coniferous riparian forest along Hastings Creek has largely been preserved in these major park areas in the watershed. Invasive plant removals have been undertaken to try to manage or remove populations and prevent further spread. Recreational impacts from dog walking and other off-trail users are a major riparian management issue in the parks. Riparian vegetation has been lost and soils are severely compacted and eroding in well-used areas of Hunter Park and Princess Park.

Riparian areas along the major tributaries of Hastings Creek have generally been more impacted by urban development. Of all of the tributaries, upper Kilmer Creek has the most intact riparian areas because the upper section of the creek is contained within a ravine and upstream sections of the watershed were developed after stream setback requirements were enacted. However, the lower sections of the creek (below Fromme Rd) have been channelized through yards and lack any riparian vegetation, and the creek has been culverted under Argyle School. Similarly, Coleman, Thames, and Hoskins creeks are all heavily encroached upon and have little to no riparian buffers, except where parks or greenbelts exist along the stream corridors. Remaining riparian vegetation is a mix of veteran conifer trees and pioneering species such as red alder and black cottonwood. On some of these tributaries, the creek has often been channelized by retaining walls, has been culverted for longer sections (e.g., Thames Creek between Frederick Road and Lynn Valley Road), or runs under houses, garages, and decks.

Above the urban development boundary in the watershed, riparian areas are second-growth western hemlock forest within intact understory vegetation and few invasive species.

As a result of the overview assessment, four major riparian management issues have been identified:

Yard and Landscaping Encroachment. Yards and landscaping encroach on several creek reaches in the watershed, owing to a lack of stream setbacks during historic urban development in the watershed. The lack of natural riparian vegetation reduces large wood debris recruitment and nutrient influxes into the stream while facilitating bank erosion, introductions of invasive species, and increasing the potential for instream habitat disturbance. Areas where this issue is most prominent include: (1) Hastings Creek along Carmaria Court, (2) Hastings Creek from 27th St-Ross Road School footbridge upstream to Hunter Park, and (3) sections of Coleman and Thames Creek above Lynn Valley Road.

Building Encroachment. At several locations throughout the watershed, buildings and infrastructure have been built adjacent to or directly over creek channels. Most of these buildings were constructed prior to any stream setback requirements. The close proximity of the buildings to the creek both reduces the ecological integrity of the creek and results in the increased potential of flooding and property damage from high flows. Although this encroachment is difficult to reverse, the District may be able to slowly make progress on this issue as these properties change ownership or re-develop.

Invasive Plants. Invasive plants are present throughout most riparian areas below the urban development boundary. They are generally more dominant where riparian encroachment is greater and sources of invasive species are more common. Development patterns also influence invasive plant abundance; larger infestations are generally associated with older neighbourhoods. Along forested ravine sections, invasive groundcovers (e.g., ivy, yellow lamium, periwinkle) have been introduced through yard waste dumping or as garden escapees and are growing down into the creek. Major areas with ivy and yellow lamium include: (1) on Hastings Creek along Arborlynn Drive and Greenock Place and (2) on Hastings Creek along 27th St across the creek from Ross Road School. In other areas where riparian areas have been disturbed or cleared by development, invasive species, such as sycamore maple, Japanese knotweed, and Himalayan blackberry have rapidly colonized without management or intervention.

Trail and Recreational Impacts. The heavy recreational use of parts of the Hastings Creek corridor has led to severe impacts to riparian areas, resulting in riparian vegetation loss, compacted soils, and bank erosion. Areas with denuded understory areas as a result of recreational use include: (1) Hastings Creek in park area west of creek and north of Harold Rd cul-de-sac, (2) Hastings Creek adjacent to Argyle School, and (3) the north bank of Hastings Creek through Hunter Park. Successful use of fencing and native plantings was observed in some areas to protected sensitive banks and riparian areas.

Fish Community

The occurrence and distribution of fish species in the Hastings Creek watershed was determined through review of existing information and local knowledge, new sampling, and some inferences of presence based on habitat conditions and connectivity. Sources of existing information and local knowledge included past fish sampling summaries, historical reports, interviews and meetings with local Streamkeepers, documented fish releases, and fish salvage reports from recent construction works such as culvert replacements. New field work included an adult spawner survey in December 2011 and trapping from January to May 2012.

Spawner Surveys. A visual survey of the Hastings Creek mainstem as well as the lower sections of Coleman Creek and Thames Creek was conducted on December 12, 13, and 14, 2011 to look for adult spawning salmon or carcasses. In total, four adult Coho carcasses were found in the Hastings Creek mainstem at the following locations (see photos in Figure 2-5 and locations in Appendix 1: Map 7):

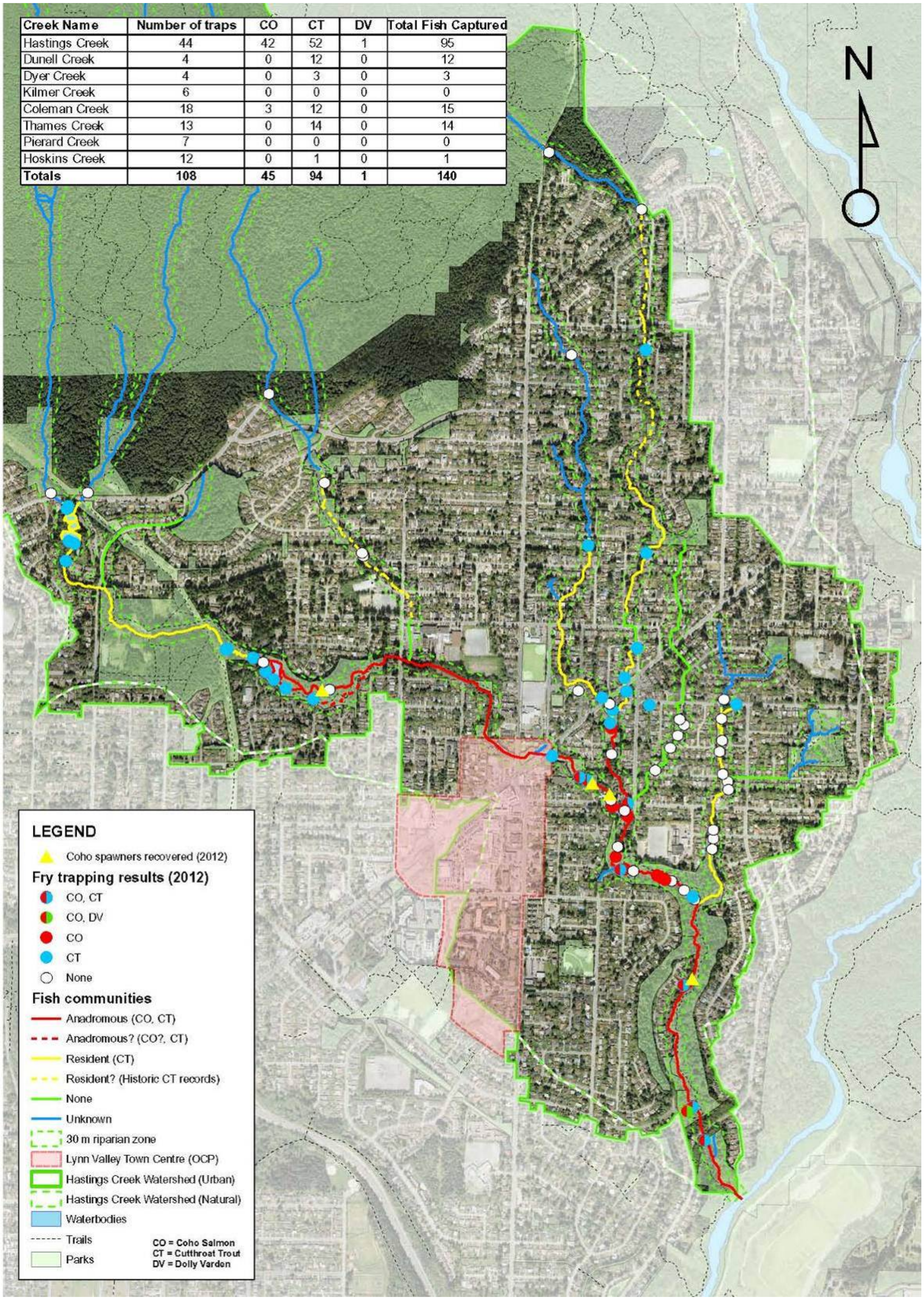
- Opposite houses on Carmaria Court in the Hastings Creek ravine (1 carcass);
- 10-30 m upstream of Ross Road (2 carcasses); and
- Within Hunter Park (1 carcass; approximately 50 m downstream of the boundary between stream sections 4a and 4b).

Because the survey was undertaken very late in the spawning season, all of the carcasses were too decomposed to accurately determine sex or whether they had successfully spawned.

Fish Trapping. Extensive trapping using minnow traps was undertaken in Hastings Creek and its tributaries from late January through early June 2012. 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 Gee minnow traps. Traps were baited with tuna and placed in pairs or 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. Locations of where trapping was undertaken are shown in Figure 2-4 (Appendix 1: Map 7).

A total of 108 trap nights were conducted resulting in the capture of 45 Coho Salmon, 94 Cutthroat Trout, and 1 Dolly Varden (140 fish in total) (see Table 2-2 for summary and Appendix 2-1 and 2-2 for complete datasets). Representative photos of captured fish are shown in Figure 2-6. Coho were located in the Hastings Creek mainstem up to Lynn Valley Rd, although Coho fry are regularly captured in Hunter Park by the North Shore Streamkeepers. The Dolly Varden was found in the plunge pool just below the Arborlynn Dr culvert at the base of the Denil fishway. Dolly Varden is a blue-listed species in BC, and rarely encountered in small streams in the Lower Fraser Valley. Sculpin species and Threespine Stickleback were not captured during the survey which is unusual for small streams on the North Shore.



Creek Name	Number of traps	CO	CT	DV	Total Fish Captured
Hastings Creek	44	42	52	1	95
Dunell Creek	4	0	12	0	12
Dyer Creek	4	0	3	0	3
Kilmer Creek	6	0	0	0	0
Coleman Creek	18	3	12	0	15
Thames Creek	13	0	14	0	14
Pierard Creek	7	0	0	0	0
Hoskins Creek	12	0	1	0	1
Totals	**108**	**45**	**94**	**1**	**140**

Figure 2-4. Fish presence and fish sampling results for the Hastings Creek watershed.


a


b

Figure 2-5. Coho Salmon carcasses surveyed in Hastings Creek in December 2011: (a) carcass located in Hastings Creek opposite Carmaria Court; and (b) one of two carcasses located in Hastings Creek just upstream of Ross Rd.

Trapping results suggest relative abundance of Coho Salmon was higher in the lower ravine section of Hastings Creek, although abundance may have been affected by the long season across which sampling was conducted. Cutthroat Trout abundance was highest within and upstream of Twin Lakes, in Hastings Creek in Hunter Park, and in the lower sections of Thames Creek. Steelhead Trout is known historically from the Hastings Creek watershed but was not captured during the sampling. Steelhead Trout, if still present, would likely utilize the lower ravine section of the watershed for spawning and rearing where habitat is more suitable. The distributions of Coho Salmon and Cutthroat Trout are summarized in Table 2-3 and Figure 2-4.

It is noteworthy that Cutthroat Trout were not captured in Pierard Creek despite repeated sampling of suitable habitat where they were present as recently as the early 2000s (R. Boase, pers. comm.).

Table 2-2. Trapping results summary by watercourse in Hastings Creek watershed.

Watercourse	No. of traps	CO	CT	DV	Total Fish Captured
Hastings Creek	44	42	52	1	95
Dunell Creek	4	0	12	0	12
Dyer Creek	4	0	3	0	3
Kilmer Creek	6	0	0	0	0
Coleman Creek	18	3	12	0	15
Thames Creek	13	0	14	0	14
Pierard Creek	7	0	0	0	0
Hoskins Creek	12	0	1	0	1
Totals	108	45	94	1	140

CO = Coho Salmon, CT = Cutthroat Trout, DV = Dolly Varden

Figure 2-6. Examples of fish captured during minnow trapping survey in spring 2012: (a) Cutthroat Trout in Thames Creek from plunge pool below Lynn Valley Rd culvert; and (b) Dolly Varden captured in culvert plunge pool on Hastings Creek below Arborlynn Dr; (c) Cutthroat Trout from Doran Park; and (d) juvenile Coho Salmon from Hastings Creek.

Watercourse Inventory and Condition Assessment

Overview Stream Survey. An overview inventory of all watercourses in the developed portion of the Hastings Creek watershed was undertaken from January to March 2012. Most major watercourses were walked and significant features, issues, and structures were mapped. The objective of the inventory was to update DNV’s existing watercourse mapping, map key features (see list below), and identify opportunities for restoration and. Condition and function of existing fish passage enhancements was also assessed. Types of features identified and mapped included:

- Barriers or impediments to fish passage;
- Existing fish passage enhancements;
- Unmapped tributaries, side channels, off-channel areas, and wetlands;
- Major ditch or pipe outfalls;

- Culverted, channelized, or bank stabilized sections;
- Specific habitat impairments (e.g., pollution, garbage, debris);
- Unstable banks or bank areas lacking riparian vegetation; and
- Failing infrastructure.

Table 2-3. Distribution of Coho Salmon and Cutthroat Trout by watercourse in the Hastings Creek watershed.

Watercourse	Salmonid Presence/Distribution
Hastings Creek	Coho: From mouth up to steeper section above Donovan Pond below powerline right-of-way and Princess Park. Cutthroat: From mouth up to Braemar Rd (may be above in Dunell and Dyer Creeks but 2012 trapping inconclusive).
Kilmer Creek	Coho: No anadromous access due to culverted section to Hastings Creek under Argyle school. Cutthroat: Known historically but none detected during 2012 fry trapping.
Coleman Creek	Coho: Up to wood weir dam below Lynn Valley Rd. Cutthroat: Up to at least Doran Rd (no 2012 trapping conducted above this point).
Thames Creek	Coho: None due to wood weir dam on Coleman Creek below. Cutthroat: Known historically up to McNair Dr; confirmed up to Mill St during 2012 fry trapping.
Pierard Creek	No fish present in 2012.
Hoskins Creek	Coho: None due to steep section above confluence with Hastings Creek. Cutthroat: Known historically, single capture in vicinity of Westover Rd in 2012.

Summary of General Channel Conditions. The following points summarize the results of the overview assessment:

- The lower section (1,130 m) of Hastings Creek from the mouth at Lynn Creek up to the confluence with Hoskins Creek is contained in a moderate-to-steep gradient ravine. In this section, the channel is largely pool-cascade habitat and is dominated by cobble and boulder substrates. Habitat is most suitable to Steelhead Trout and Cutthroat Trout. Riparian areas are wide and intact within the ravine although top-of-bank areas above the ravine crest are developed. A more recent housing development (along Carmaria Court) exists on a bench within the historic ravine on the west side of the creek. Yards of these properties extend right to the bank of the creek. Hastings Creek Trail runs parallel to the creek channel on the east side of the creek and is adjacent to the creek at several points.

- The middle section (2,160 m) of Hastings Creek from Hoskins Creek up to and including Hunter Park (upstream to Donovan Pond) is lower gradient as it travels west to east across the main central Lynn Valley area and has more cobble and gravel substrates. While Hunter Park and the ravine section adjacent to Ross Road Elementary School are more natural with complex channels with large wood debris, some deeper pools, and wide riparian areas, the section from Hunter Park to downstream of Ross Rd has been heavily impacted by development. This includes some straightened or channelized sections with stabilized banks and largely lacking in wood debris or deep pools, although undercut banks are still quite abundant. Except through parkland or DNV-owned greenbelts, riparian areas are mostly narrow or non-existent. Most of the road crossings of the creek are also concentrated in this part of the watershed. Prior to development in Lynn Valley, these were likely productive spawning and rearing habitats but were modified early on in the history of the development when the creek was used for transporting and holding shingle bolts, and were maintained as urban development progressed.

- The upper surveyed section (530 m) of Hastings Creek is a mix of lower and higher gradient channel flowing through parkland and developed areas. The section from Donovan Pond up to the footbridge and an old timber dam in Princess Park is steep with boulder-cobble substrates, while the section from the footbridge and dam to Princess Ave is lower gradient with more cobble-gravel substrates. From Princess Ave up to Braemar Rd, the channel has been highly modified due to the damming of the creek to create Twin Lakes and housing developments in this area. Riparian areas are generally present in park areas and absent in developed areas. Above Braemar Rd, headwater tributaries of Hastings Creek are in relatively pristine condition.

- Below the boundary of urban development, most of the major tributaries of Hastings Creek have been heavily impacted by surrounding development. Except in park areas or DNV-owned greenbelts, development has occurred up to and, in some cases, over the creek (including decks, garages, and houses). Most road crossings are culverts.

Fish Passage Barriers. Fish passage barriers are natural or manmade obstruction that preclude or limit the movement of adult or juvenile fish, particularly migratory salmonids 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.

Six complete fish passage barriers were identified in the watershed: three on Hastings Creek, one on Kilmer Creek, one on Coleman Creek, and one on Thames Creek (see Figures 2-7 and 2-9 and Appendix 1: Map 8). Anadromous fish (Coho Salmon, sea-run Cutthroat Trout, Steelhead Trout) access to the upper reaches of Hastings Creek is limited by a steep channel section above Donovan Pond (natural barrier). A wood weir dam on Coleman Creek (downstream of Lynn Valley Rd and confluence with Thames Creek) and an elevated culvert and concrete apron on Thames Creek (downstream of Lynn Valley Road) limits anadromous fish passage into those tributaries.

Additional barriers include: (1) an old timber dam on Hastings Creek at footbridge in Princess Park; (2) two dams below each of the Twin Lakes on Hastings Creek (above Princess Ave); (3) a wood weir dam on Coleman Creek (downstream of Lynn Valley Rd and confluence with Thames Creek).

Figure 2-7. Fish passage barriers in the Hastings Creek watershed: (a) one of two Twin Lakes dams showing outfall into Hastings Creek below; (b) outfall of culvert under Argyle School and houses on Kilmer Creek; (c) wood weir dam on Coleman Creek downstream of Lynn Valley Rd; and (d) elevated culvert and concrete apron on Thames Creek at Lynn Valley Rd.

Several debris jams and steep sections were mapped as being possible barriers to fish passage under certain flow conditions and were identified as concerns by the North Shore Streamkeepers (see Figure 2-9 and Appendix 1: Map 8). Debris jams may limit fish passage under some flow but they also provide an important function by creating complex habitat.Steep sections identified were naturally occurring features, such as a cascades and a small falls. All sites were deemed as sites to monitor but are not considered impediments to fish passage at this time.

Existing Fish Passage Improvements. Four fish passage enhancements have been installed in the watershed: (1) a Denil fishway at Arborlynn Dr (installed in 1980); (2) a Denil fishway at Lynn Valley Rd (installed in 1994); (3) concrete no-post barriers to create resting pools on the concrete apron under the Mountain Highway bridge; and (4) a timber box-type fish ladder on the outlet channel to Donovan Pond (installed in 1990s to allow for juvenile coho escapement from pond) (see Figure 2-8). The no-post barriers under Mountain Highway are breaking apart and need replacement or another fish passage solution installed at this location. The fish ladder on Donovan Pond is reported to be sinking and requires maintenance (North Shore Streamkeepers, pers. comm.). The Denil fishways are both in good condition and appear to be functioning well.

Figure 2-8. Existing fish passage enhancements in the Hastings Creek watershed: (a) Denil fishway on Hastings Creek at downstream end of culvert under Arborlynn Dr; (b) Denil fishway on Hastings Creek at upstream end of culvert under Lynn Valley Rd; (c) concrete no-post barriers used to improve fish passage on Hastings Creek under Mountain Highway bridge; and (d) wood box fish ladder on outlet channel to Hastings Creek from Donovan Pond.

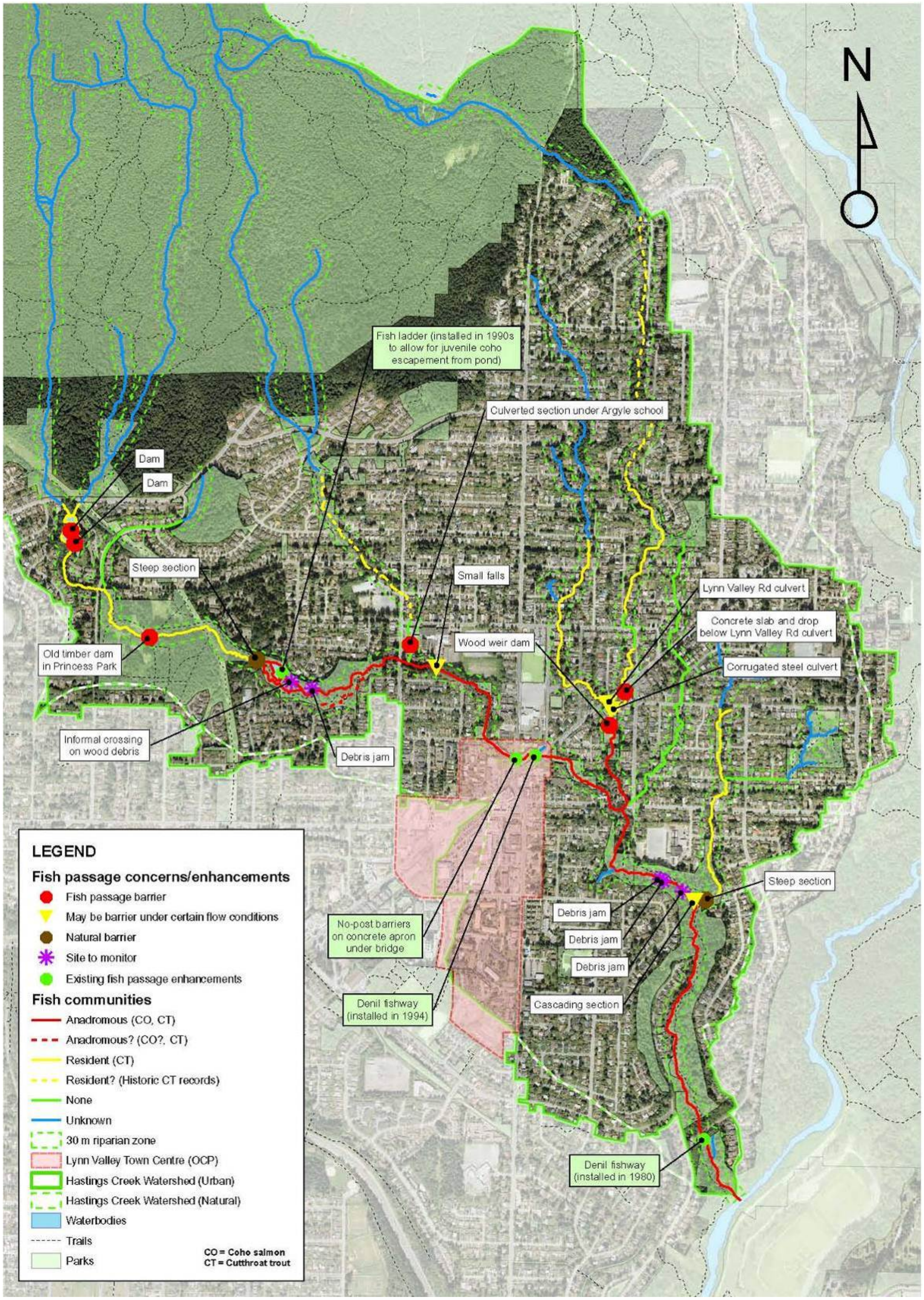
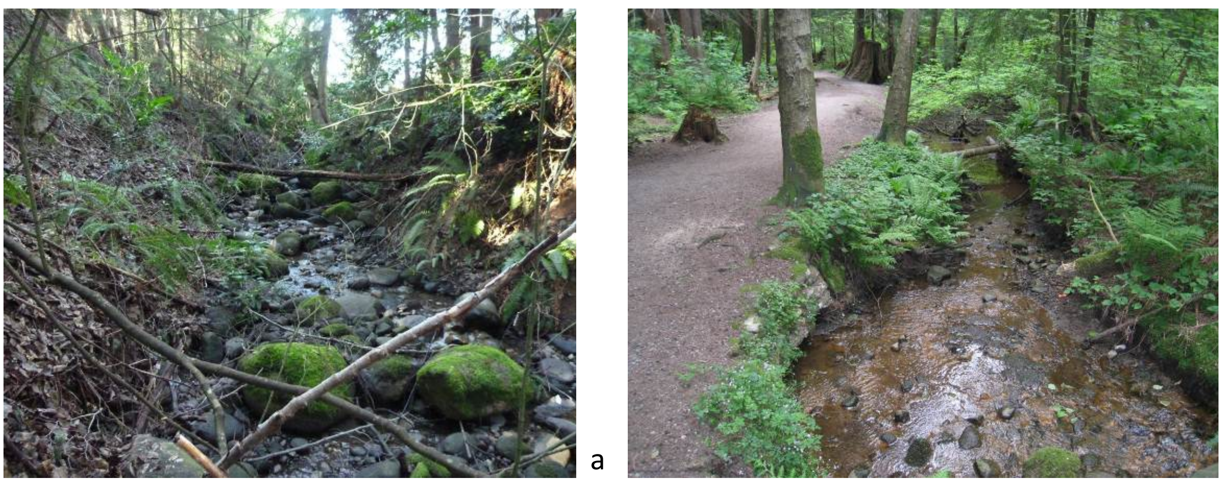


Figure 2-9. Fish passage barriers in the Hastings Creek watershed.

Fish Habitat Use. General fish habitat conditions and fish use was identified based on stream gradient and habitat structure. Major rearing areas in the watershed with abundant cover and deep pools are in Hunter Park and the lower ravine sections of Hastings Creek. Existing off-channel habitat is generally lacking in the watershed, although some small off-channel or side channel areas exist adjacent to Ross Road School and in the ravine section. Habitat complexity, particularly coarse wood debris and large pools, are generally lacking in the middle section of Hastings Creek, between Ross Road Elementary School and Hunter Park.

The most suitable spawning areas for Coho Salmon in the watershed are: (1) the section of Hastings Creek adjacent to and south of Ross Road Elementary School, (2) Hunter Park, and (3) the lower section of Coleman Creek up to Lynn Valley Rd. These sections have complex instream habitat and suitable spawning gravel for Coho Salmon (see Figure 2-11 for examples).

New Watercourses. In general, many channels connecting major outfalls to watercourses have not been previously mapped. For example, the stream channel connecting the major outfall north of East 27th Ave at Viewlynn Dr as well as several outfalls into Hunter Park were not mapped in existing DNV data (Figure 2-10). Several major outfall channels were mapped but a full review of outfall connections to major watercourses should be undertaken to ensure completeness.



a b

Figure 2-10. Examples of unmapped outfall channels identified during the stream survey: (a) unmapped channel connecting Lynn Valley Town Centre outfall to Hastings Creek; and (b) unmapped watercourse connecting outfall near Tennyson Crescent to Hastings Creek within Hunter Park (potential anadromous fish habitat).

Detailed Channel Assessment

A detailed channel assessment was also undertaken to characterize habitat conditions in several priority sections of stream. Based on the overview inventory, more detailed assessment was focused on the section of Hastings Creek upstream of the ravine section (above the confluence of Hoskins Creek) and downstream of Hunter Park, as well as the lower sections of

Figure 2-11. Examples of instream habitat in Hastings Creek and tributaries: (a) higher gradient boulder and cobble dominated channel in lower Hastings Creek; (b) heavily modified section of Coleman Creek with loss of riparian forest; (c) high quality spawning habitat on Hastings Creek adjacent to Ross Road School; (d) complex rearing habitat (large wood and pools) found within Hastings Creek (e) spawning habitat in Coleman Creek; and (f) off-channel habitat on Hastings Creek opposite Ross Road School.

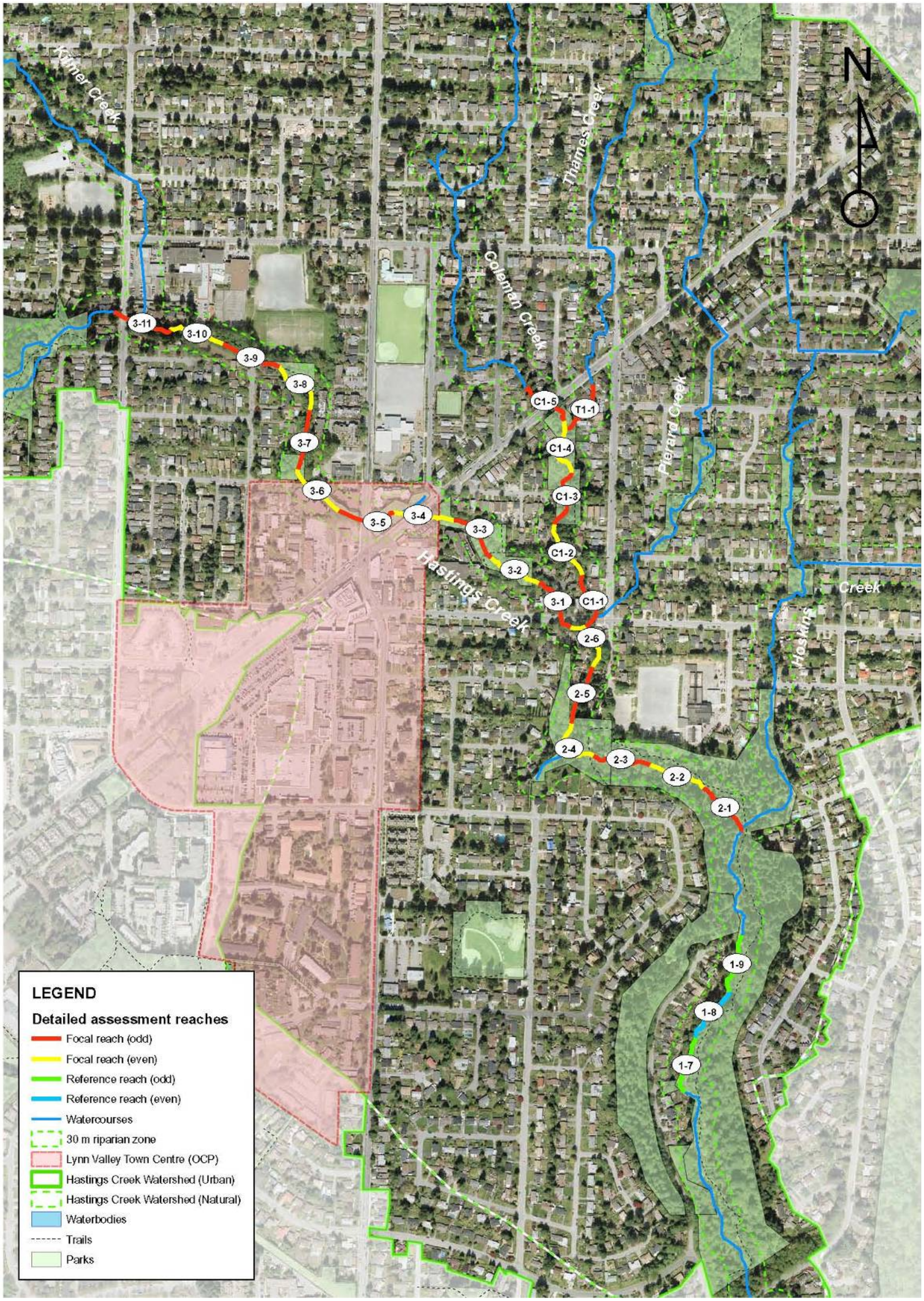


Figure 2-12. Location of stream segments assessed using detailed channel assessment methods.

The detailed assessment was conducted using Module 2 of the Streamkeepers Handbook developed by DFO[4]. Module 2 (Advanced Stream Habitat Survey) was chosen as an appropriate method because it quantitatively characterizes stream condition based on channel geometry, riparian condition, bank erosion and stability, substrate composition, and instream physical habitat. These attributes related directly to factors that limit watershed productivity in urban streams and can be used to identify opportunities for action and improvement. Module 2 also scores overall habitat quality (possible scores range from 0 to 135) for each reach based on a nine-metric scoring system, which is useful for comparing different reaches. Streamkeeper methods are well-established and repeatable, and could be used for long-term monitoring by volunteers in the future.

Due to time and budget constraints, it was not possible to assess all streams using the detailed assessment methods. Priority stream segments for more detailed assessment were chosen based on a range of factors, including fish accessibility, historical fish habitat values, known historical impacts, riparian forest integrity and condition, and proximity to future re-development in the watershed.

For the detailed assessment, each priority stream section was divided into 100 m segments with Module 2 undertaken on each segment. The cross-sectional survey was undertaken at the mid-point of each reach and the longitudinal survey was undertaken along the full 100 m of each segment. In addition to sampling in the priority areas, three additional 100 m reach sections were assessed in the ravine section of the watershed for reference purposes. In total, 26 segments were assessed in detail: 17 on Hastings Creek mainstem between the confluence with Hoskins Creek and Hunter Park, three in the lower ravine section (as reference sections), five on Coleman Creek between Ross Rd and Lynn Valley Rd, and one on Thames Creek between the confluence with Coleman Creek and Lynn Valley Rd (Figure 2-12; Appendix 1: Map 9).

Results. The results of the detailed channel assessment can be summarized as follows:

- On Hastings Creek, bankfull width (not including the ravine sections) varied from 3.7 m to 10.8 m (mean = 6.5 m). On Coleman and Thames Creek, bankfull width varied from 2.7 m to 7.8 m (mean = 4.6 m). Channel widths were more constrained through the sections of creek adjacent to the Lynn Valley Town Centre where bank stabilization is more frequent (see below).

- Percent cobble and boulder substrate, an indicator of spawning habitat quality, ranged from 10% to 95% (mean = 41%) in the priority stream sections sampled (Figure 2-13). Lower percentages (<40%) were present in Hastings Creek between Mountain Hwy and Fromme Rd, as well as in Coleman Creek and Thames Creek, from Draycott Rd to Lynn

[4] Fisheries and Oceans Canada. 1995. Module 2 – Advanced Stream Habitat Survey. In: Taccogna G. and K. Munro. 1995 (ed.). The Streamkeepers Handbook: A Practicial Guide to Stream and Wetland Care. Fisheries and Oceans Canada.

Valley Rd. These segments also had higher levels of substrate embeddedness (15–40%), also indicating lower quality areas for spawning.

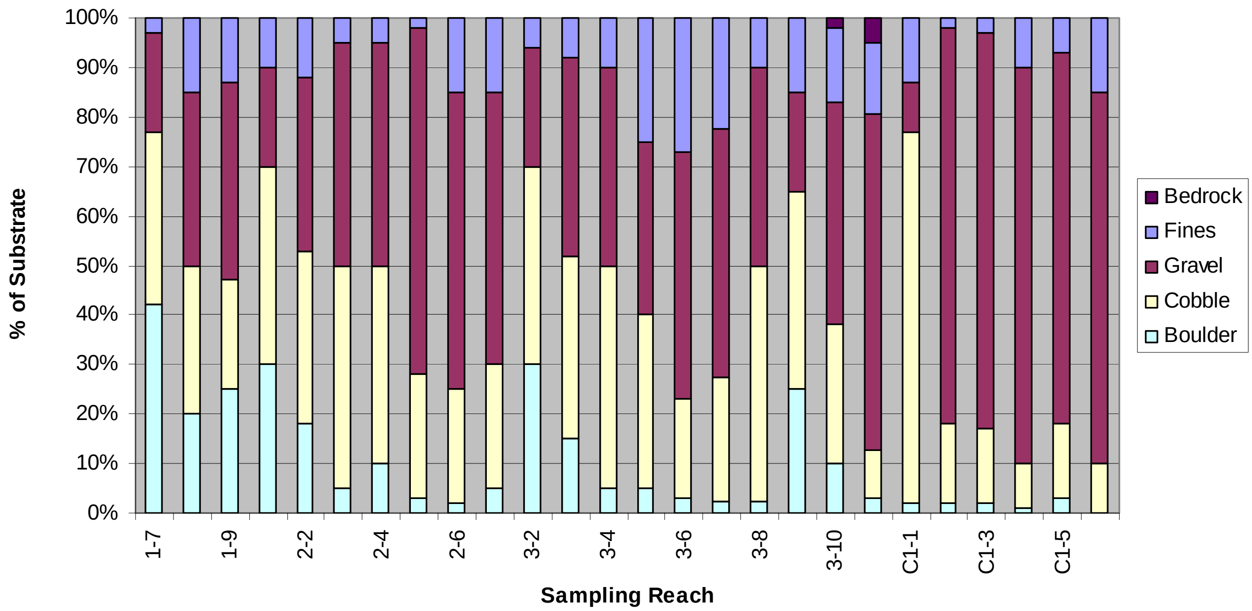


Figure 2-13. Substrate composition (%) by sampling reach in Hastings Creek and major tributaries.

- Instream cover was generally low throughout all of the segments sampled, although it was lowest downstream of Ross Rd and extending up to Hunter Park. It was higher in the more natural ravine reference segments sampled.

- 238 pieces of large wood were measured in the sampling segments (9.2 pieces per 100 m) (Figure 2-14 for distribution of LWD). This is lower than many natural streams but higher than urban streams in Metro Vancouver (e.g., Quibble Creek in Surrey had 3.2 pieces per 100 m).

- Pool habitat is also generally lacking throughout the sections sampled, including the reference section, except for a very small number of segments (Figure 2-14). Mean % pool habitat ranged from 0% to 68% (mean = 28%). Existing pools were often a result of unique conditions rather than the presence of natural pool-forming features such as large wood debris and boulders.

- Bank stabilization ranges from 0 m to 180 m (mean = 52.9 m) out of a total 200 m bank length (including right and left banks). The most highly stabilized channels were upstream of Mountain Hwy on Hastings Creek and downstream of Lynn Valley Rd on all three creeks. Across all segments, over 25% of the areas sampled had some form of bank stabilization. Bank erosion was generally low except in the lower three sections of Coleman Creek, where over 50% of the linear bank length showed some form of erosion.

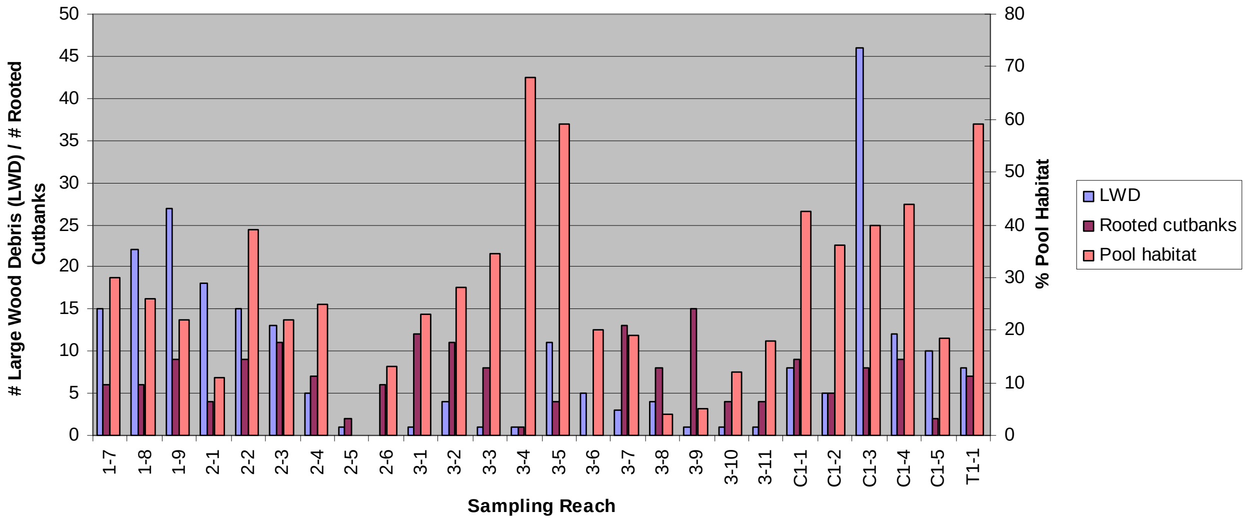


Figure 2-14. Distribution of large instream wood (LWD), rooted cutbanks, and pools in selected stream segments of Hastings Creek and major tributaries.

The amount of bank with no vegetation ranged from 0–180 m (mean = 51.1 m) out of a total 200 m bank length (including right and left banks). The highest levels of bank vegetation loss were on Hastings Creek from the section in the vicinity of Lynn Valley Rd to the Harold Rd footbridge.

Canopy cover (range: 2–90%; mean = 55%) as well as riparian zone width (# of bankfull widths; range: 0–3, mean = 1.2) were variable and dependent largely on whether the sampled segment was found in a park or a DNV-owned greenbelt.

Overall habitat scores ranged from 40 (Marginal) to 112 (Good). The next highest score was 91 (Acceptable). The mean habitat score was 59.6 (Marginal). In contrast, the mean habitat score for the three ravine reference reaches sampled was 89.3 (Acceptable). Scores were generally higher (>70) in the section of Hastings Creek adjacent Ross Road Elementary School and lower (≤70) above the LVTC outfall channel and in the sampled sections of Coleman and Thames creeks.

Detailed assessment data and metric scores can be found in Appendix 2.

Water and Sediment Quality Sampling and Assessment

Four methods were used to assess water and sediment quality in the Hastings Creek watershed: (1) a survey of general water quality parameters throughout the watershed (e.g., temperature, pH); (2) dry-weather sampling at nine sites in the lower watershed; (3) wet-weather sampling (2 events) at the outfall from the Lynn Valley Town Centre (LVTC) catchment and the adjacent area of Hastings Creek; and (4) instream water temperature probes. The results of benthic invertebrate sampling in lower Hastings Creek in 2003 and 2004 are also summarized.

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 natural or anthropogenic factors. Water quality in streams is vital to the protection of ecosystem functioning and aquatic life, such as fish, as well as human uses for drinking water and recreation, and aesthetics. Comparisons to 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 is adequately protecting these values.

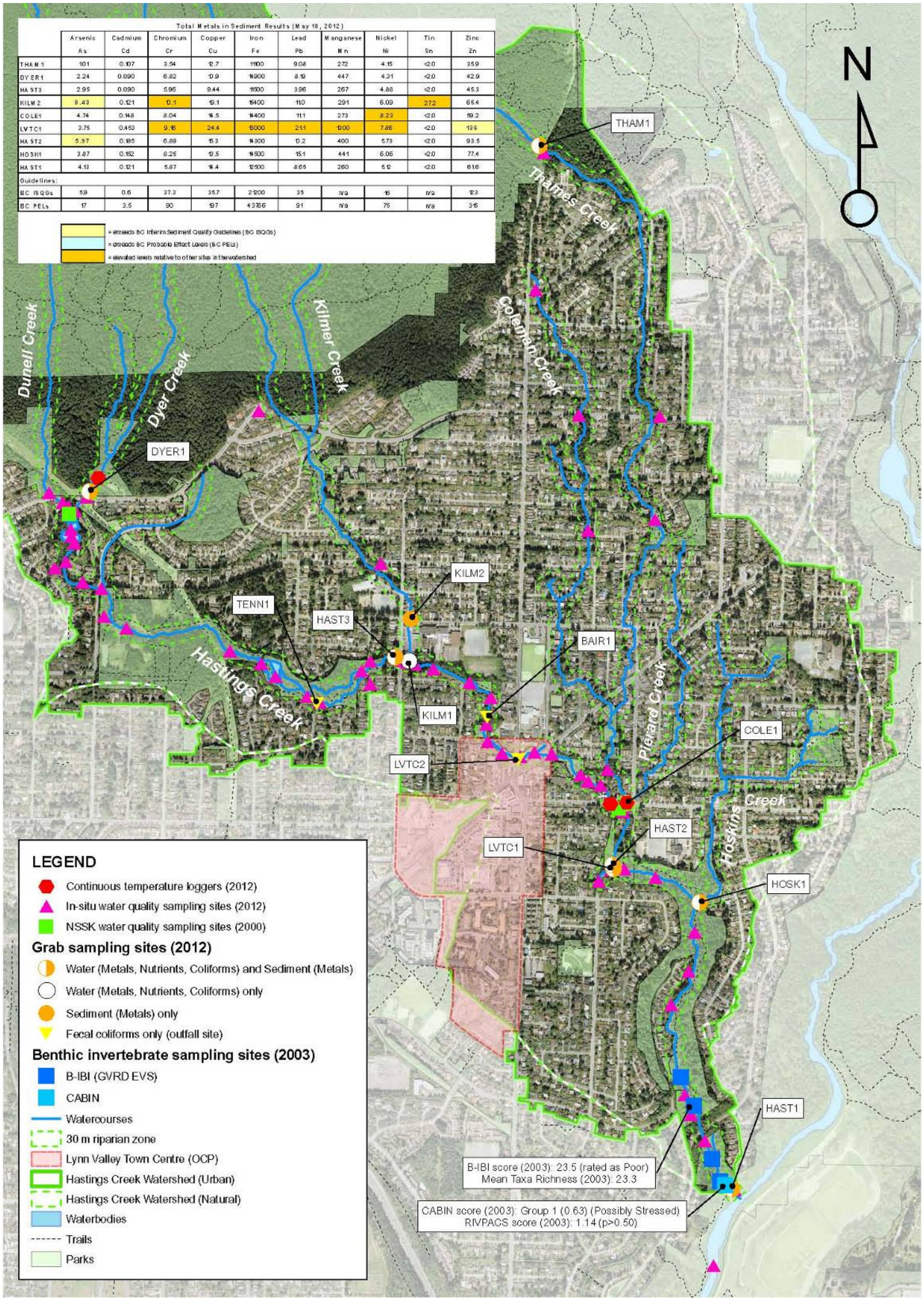
General Water Quality Survey. In-situ measurements of general water quality parameters (temperature, specific conductivity, DO, pH, oxygen reduction potential (ORP), and turbidity) were undertaken throughout the watershed during low flow conditions on May 14 and 15, 2012 (86 sites in total). A YSI 6820 multi-parameter probe was used to conduct the measurements. Sites sampled are illustrated on Figure 2-15 (Appendix 1: Map 10). While one-time water quality sampling provides a limited snap-shot of parameter concentrations, it is a useful way to screen for issues of potential concern that should be managed as part of watershed planning and a future ISMP[5].

Table 2-4 summarizes the minimum, maximum, and mean values of each parameter encountered and the full dataset can be found in Appendix 2-6.

Table 2-4. Minimum, maximum, and mean values for general water quality parameters in the Hastings Creek watershed.

Parameter	**Units**	**Parameter Values**		
		Minimum	Maximum	Mean
Water Temperature	^{o}C	7.94	13.46	10.89
Dissolved Oxygen	mg/L	9.10	12.50	11.07
Specific Conductivity	µS/cm	10	269	83
pH	pH units	5.89	7.67	7.24
Turbidity	NTU	0.0	37.7	2.4
Oxygen Reduction potential (ORP)	-	30.6	192.8	102.5

[5] Because of a limited budget for sampling, water and sediment sampling did not include the replication (e.g., 5 samples in 30 days) or broader spatial sampling needed to more rigorously characterize environmental contaminants and for proper comparisons to appropriate federal or provincial guidelines. However, it is still useful to undertake such comparisons as a screening-level analysis to flag issues of concern, and as part of a weight-of-evidence approach used in ISMPs.



	Arsenic As	Cadmium Cd	Chromium Cr	Copper Cu	Iron Fe	Lead Pb	Manganese Mn	Nickel Ni	Tin Sn	Zinc Zn
THAM1	1.01	0.107	3.54	12.7	11100	9.08	272	4.15	<2.0	35.9
DYER1	2.24	0.090	6.82	10.9	14900	8.19	447	4.31	<2.0	42.9
HAST3	2.95	0.090	5.96	9.44	11500	3.96	267	4.88	<2.0	45.3
KILM2	8.43	0.121	10.1	19.1	16400	11.0	291	6.09	27.2	65.4
COLE1	4.74	0.148	8.04	14.5	14400	11.1	273	8.23	<2.0	59.2
LVTC1	3.75	0.453	9.16	24.4	16000	21.1	1300	7.86	<2.0	136
HAST2	5.97	0.185	6.89	15.3	14300	10.2	400	5.73	<2.0	93.5
HOSK1	3.87	0.152	8.25	13.5	14500	15.1	441	6.06	<2.0	77.4
HAST1	4.13	0.121	5.87	14.4	12500	8.65	260	5.12	<2.0	61.6
Guidelines:										
BC ISQGs	5.9	0.6	37.3	35.7	21200	35	n/a	16	n/a	123
BC PELs	17	3.5	90	197	43766	91	n/a	75	n/a	315

Figure 2-15. Water, sediment, and benthic invertebrate sampling sites.

General water quality results were within expected ranges for each parameter. Specific conductivity, an indicator of the presence of ions in water and often correlated with impacts from urban runoff, generally increased from upstream to downstream in each tributary. Specific conductivity was higher in the lower sections of Coleman Creek and in Pierard Creek, than in Hastings Creek or Thames Creek. Readings were higher in flows from outfalls than from within the stream channels themselves.

Turbidity, sometimes an indicator of impacts from the construction phase of development, was above 20 NTU at three locations: in Donovan Pond, in flows from the outfall at Roblin Place into Hastings Creek downstream of Twin Lakes, and in flows from the outfall from Hendecourt Rd into Hastings Creek in Hunter Park.

As expected based on the time of year of sampling and the intact headwaters in Hastings Creek and many of its major tributaries, water temperatures were below levels known to have detrimental to salmonid growth and survival. Water temperatures were highest in Hastings Creek downstream of Fromme Road and in Coleman Creek.

Dry-weather Water Quality Sampling. Dry-weather water quality sampling was undertaken on May 18, 2012. Sampling consisted of discrete (grab) sampling for the following parameters:

- Fecal and total coliforms;
- Nutrients (nitrate, ammonia nitrogen, and orthophosphate);
- Alkalinity and hardness;
- Total suspended solids (TSS); and
- Total and dissolved metals.

All parameters were measured at nine sites: two sites above development (one on Hastings Creek and one on Thames Creek), three sites on the Hastings Creek mainstem, one site on Kilmer Creek, one site on Coleman Creek, and one site on Hoskins Creek, as well as the major outfall from the Lynn Valley Town Centre (LVTC) area. Three additional outfalls were also sampled for fecal coliforms only. Sampling sites were chosen to isolate the contributions of each major tributary or outfall to overall water quality conditions in Hastings Creek. Sampling sites are illustrated in Figure 2-15 (Appendix 1: Map 10).

Results. Key results of the dry-weather water quality sampling were:

- Total copper and total lead were above BCWQGs in flows from the LVTC outfall (Figure 2-16). Total copper was also above BCWQGs in Hoskins Creek. High levels of copper in urban streams most commonly originates as dust from the brake linings of vehicles washing off of road and parking lots. The LVTC outfall catchment has the highest total impervious area of any catchment in the watershed and includes a high density of roads and several large parking lots. Lead pollution in urban streams historically was a result of leaded gasoline exhaust but more recently are usually the result of diffuse sources of contamination.

- Dissolved copper, iron, and lead levels were also elevated in flows from the LVTC outfall relative to other sites. No guidelines for dissolved levels of these metals exist in BC.

- Total aluminum in water above CWQGs at the two reference sites above development (Thames Creek and Dyer Creek) and in Hoskins Creek (Figure 2-16). Dissolved aluminum was also above BCWQGs in Thames Creek at Mountain Highway, upstream of the urban development boundary. This suggests the underlying geology of the watershed may lead to naturally high aluminum levels in creeks in the watershed.

- Nitrate and orthophosphate levels were elevated at the LVTC outfall compared to other sites. However, levels were not above guidelines and are unllikely to have major biological effect at the levels observed.

- Fecal coliform counts at all sites sampled, including the additional outfalls sampled, were below the BCWQG of 200 MPN/100 mL. The only site with an elevated level was Coleman Creek (upstream of the confluence at Hastings Creek at 170 MPN/100 mL. All other sites sampled were below 50 MPN/100 mL.

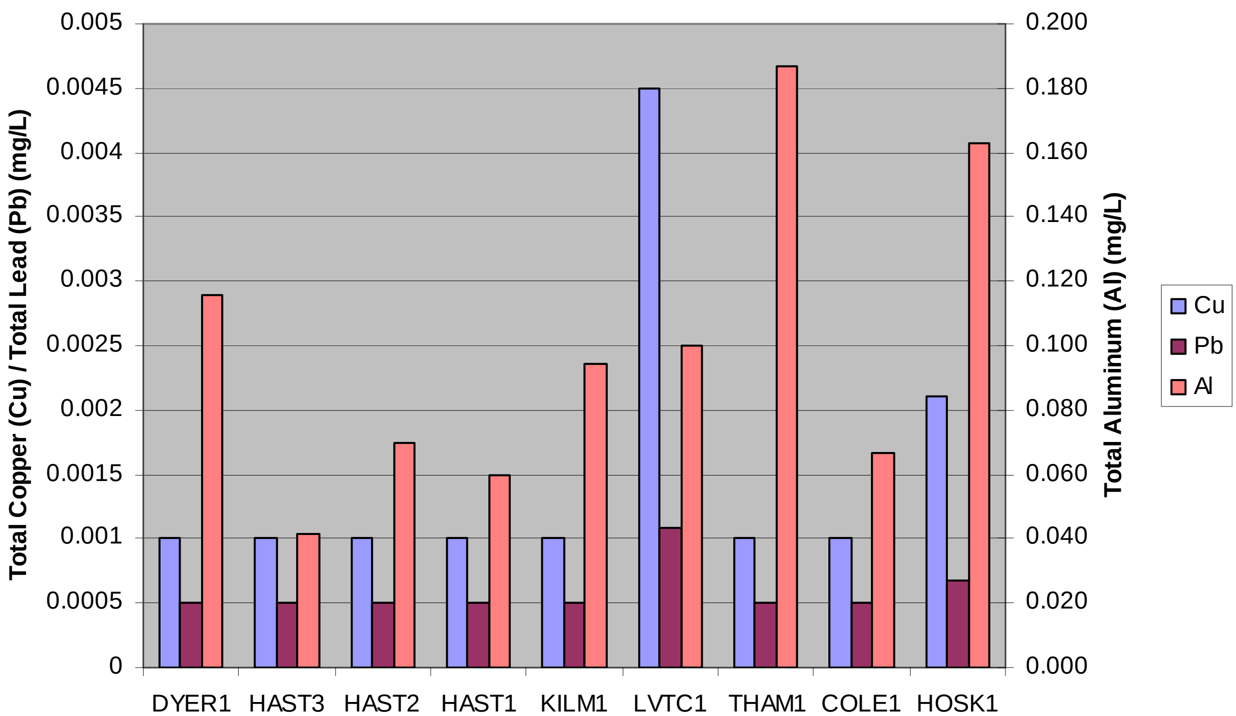


Figure 2-16. Concentrations of copper, lead, and aluminum at sites sampled in dry weather on May 18, 2012.

Full dry-weather water quality sampling data can be found in Appendix 2-7, 2-8, and 2-9.

Wet-weather (Rainfall Event) Water Quality Sampling. Based on the results of the dry-weather sampling, wet-weather sampling was undertaken to further examine the contributions of the LVTC outfall to water quality in Hastings Creek. Total metals and total and fecal coliforms were sampled during the initial part of two separate small rainfall events (June 5, 2012: <2 mm and June 7, 2012: 5 mm) both in the channel from the LVTC outfall and at a comparison site just upstream of the confluence of the outfall channel with Hastings Creek.

Results. Key results of the wet-weather water quality sampling were:

- Levels of aluminum, copper, iron exceeded BCWQGs at both the LVTC outfall and the upstream site in Hastings Creek for both events. However, while aluminum levels were similar between the LVTC outfall and creek sampling sites, copper levels were roughly two times higher at the LVTC outfall versus the upstream creek site and iron levels were 2–6 times higher at the LVTC outfall versus the upstream creek site. This suggests the LVTC outfall contributes to higher levels of copper and iron in Hastings Creek downstream of the outfall.

- Zinc levels were above BCWQGs at the LVTC outfall site during the second rainfall event sampled.

- Levels of manganese were also elevated at the LVTC outfall compared to the upstream creek sampling site during both rainfall events but levels were not above BCWQGs.

- Fecal coliforms concentrations exceeded the BCWQGs at both the LVTC outfall and adjacent Hastings Creek sampling site during both rainfall events.

Full results of storm event sampling can be found in Appendix 2-10.

Sediment Quality Sampling. Stream sediments accumulate metals and other contaminants from a variety of sources in developed 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 variable than water quality measurements. Concentrations of total metals in stream sediments can be compared to the Canadian Interim Sediment Quality Guidelines (CSQGs), BC Working Sediment Quality Guidelines (BCSQGs), and regional studies.

Sediment quality sampling was undertaken on May 18, 2012 at five sites (same as grab water quality samples minus one lowland site which could not be sampled) and tested for total metals. Where possible, each sample was a composite of surface and shallow sub-surface fine sediment collected from 10–15 sites from within the active stream channel. Sampling sites are illustrated in Figure 2-15 (Appendix 1: Map 10).

Results. Key results of the sediment sampling were:

- Arsenic in sediment was above BCSQGs in Kilmer Creek and Hastings Creek (just above LVTC outfall). It is not known whether the high arsenic levels are related to human impacts or are naturally-occurring.

- Zinc levels in sediment were above the BCSQGs at LVTC outfall.

- Other metals that are typical of highly urbanized catchments (cadmium, copper, lead, manganese, nickel, and zinc) were found to be elevated at the LVTC outfall site and higher than the majority of other sites sampled but not above BCSQGs.

Full sediment quality sampling data can be found in Appendix 2-11.

Instream Temperature Monitoring. Temperature probes (Onset Hobo) were installed at three locations in the Hastings Creek watershed: (1) Hastings Creek mainstem at Ross Road (2) Coleman Creek at Ross Road; and Dyer Creek at Braemar Road. Each probe measures temperature every 15 minutes. They were installed in February 2012 and were retrieved in September 2012. Figure 2-17 provides data from April 15 to September 10, 2012.

Monitoring showed two noteworthy results. First, Hastings and Coleman creeks have very similar temperature patterns with a relatively strong diurnal signal of up to 2.5^{o}C during warm weather. Dyer Creek (blue line in Figure 2-17) is generally cooler and more stable. Second, the maximum temperature in the summer of 2012 was around 19^{o}C. This is higher than the recommended range for salmon and trout habitat but below levels which cause mortality.

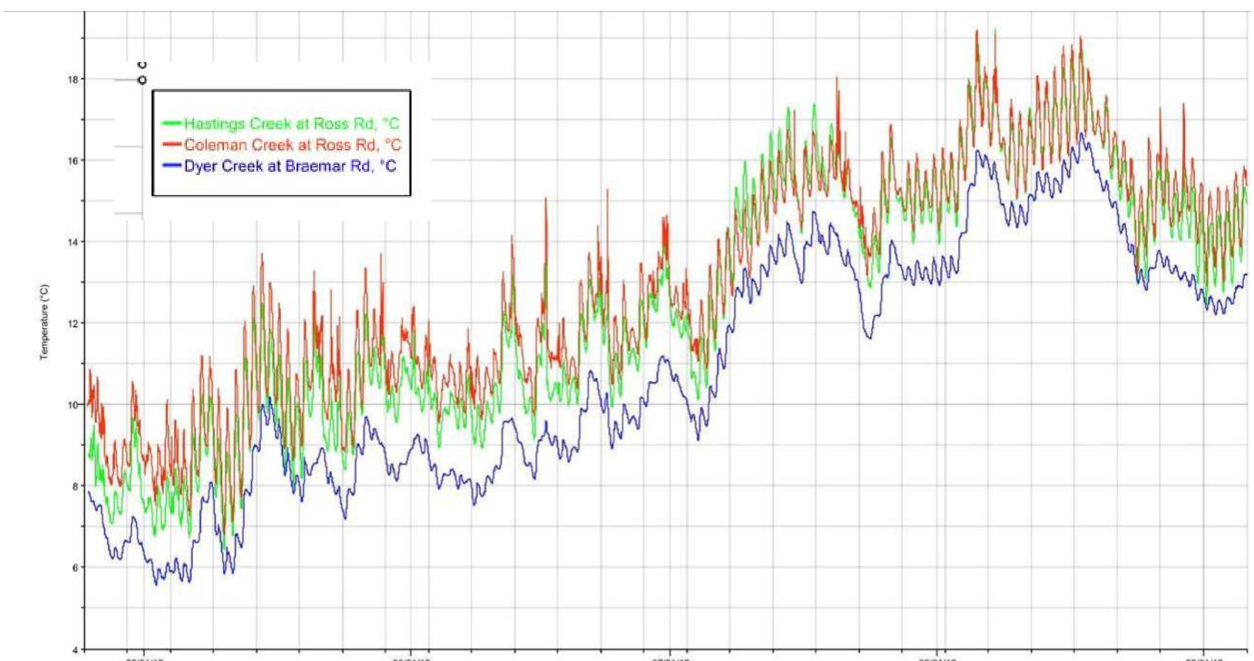


Figure 2-17. Seasonal water temperature in Hastings, Dyer, and Coleman creeks (April 15 to September 10, 2012).

Benthic Invertebrate Assessment (2003, 2004). Benthic invertebrates were collected from the lower reach of Hastings Creek in September 2003 and 2004 to assess overall watershed condition. Two methods were used. In September 2003, four samples were collected using a Surber sampler in the lower 500 m of Hastings Creek as part of larger watershed assessment study undertaken by the District of North Vancouver (see report[6]). A follow-up study was undertaken in 2004 using Environment Canada's CABIN assessment method in 2004 (see report[7]).

The 2003 study found that the mean B-IBI score for Hastings Creek was 23.5 (SD 1.9) indicating the benthic community was substantially different from undeveloped streams (B-IBI >30) but was healthier than most small streams in Metro Vancouver. The CABIN assessment classified Hastings Creek as "possibly stressed" based on a comparison to similar small streams.

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

[7]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.

PART 3. HYDROTECHNICAL AND STORMWATER INFRASTRUCTURE ASSESSMENT

Summary

Hydrology: Stream discharge and precipitation have been monitored in the Hastings Creek watershed since 2003 which allowed for hydrologic metrics to be calculated and compared to eight watersheds in the region including four streams in North Vancouver. Hastings Creek has the lowest unit mean annual discharge which suggests that a larger proportion of rainfall was intercepted or retained in Hastings Creek.

Peakflows: The urbanized portion of the Hastings Creek watershed was divided into ten subcatchments to estimate peak storm flows. The maximum flow recorded since 2004 has not surpassed the 10-yr return period flow estimate and the average flow is consistent with the regional 2-yr return peak flow estimate.

Storm Sewers: There is approximately 54 km of storm pipes within the urbanized portion of the Hastings Creek watershed. The largest storm sewer network belongs to Sub-catchment 1 and captures the majority of the storm runoff from the Lynn Valley Center, south of Lynn Valley Road and west of Mountain Highway.

Culverts: Fifty-seven culverts were identified in the Hastings Creek watershed. Culvert capacity screening has been conducted for each culvert based on culvert diameter and material. A total of 27 culverts were identified that could not convey the 200-year return period discharge without headwater above the pipe crown at the inlet. A total of seven culverts with low capacity (less than 70% conveyance capacity) were recommended for replacement or retrofitting.

Flood Potential: During a period of unusually severe storms between 1980 and 1984, flooding was experienced throughout the Hastings Creek watershed, primarily due to blockages at culvert inlets. To better understanding flood routing, recent Lidar mapping was used to identify flood routes during overbank floods.

Erosion Control: In 2007, a detailed reconnaissance of Hastings Creek and the tributaries was conducted by KWL. The inventory resulted in the identification of 248 independent erosion sites, or a total or approximately 3,900 m or 4,100 m^2 of varying hazard and consequence. A total of 12 sites of high consequence were identified for District assets (three footbridge sites and nine trail sites). Many of the trail sites were identified in Hunter Park, where the lack of defined trail system has led to encroachment on the creek.

Introduction

This section utilizes available data to characterize the current hydrological response of the Hastings Creek catchment and place it in a regional context with other urban streams. The dataset is also used to assess the potential hazards in the watershed, including potential for flooding along the mainstem, existing erosion sites along the creek channels, assessment of drainage infrastructure, and possible opportunities for larger scale infrastructure related projects associated with the health of the stream.

Evolution of streams is predominately defined by three main factors:

- Hydrology: the quantity and temporal distribution of water volume in the stream;
- Topography: the overall change in elevation, presence of controlling landscape features; and
- Geology: the quality or resilience of the subsurface soils along the stream channel and availability and transport of sediment in the stream.

The morphology (or geomorphology) of the stream is the long-term evolution of the channel, based on the governing conditions listed above. Topography and geology are not generally affected by urbanization, however, increase of impervious areas (e.g. pavements, roof areas) and conveyance improvements (e.g. storm sewer networks) drastically affect the response of frequently occurring rainfall events. Depending on topography and geology, a system will typically adjust to the new governing conditions by adjusting channel slope, length, and cross-section to manage the increase in stream energy. These changes are usually exhibited as erosion at some locations in the channel and likely deposition in others.

Overview on Morphology

The headwaters of Hastings Creek originate on Fromme Mountain, on the south and southeast flanks of the mountain. The upper reaches are weakly incised with gradients of about 30% and higher, where the channels are generally step-pool structures, controlled by bedrock and boulder structural elements. It should be noted that all the upper tributaries to Hastings Creek are crossed by the Fromme Mountain access road to Grouse Mountain, which is used extensively to access downhill mountain biking trails. The upper channels of the Hastings Creek tributaries were not included in this assessment.

Within the developed areas, Hastings Creek and Kilmer Creek have substantial ravine features upstream of Lynn Valley, while Thames Creek exhibits broader and shallower gully features and there are very limited and localized incised areas on Coleman Creek within the reach from the upper extent of development to Lynn Valley Road. The upper reaches of Coleman Creek and Thames Creek are about 13%, while the upper reaches of Hastings Creek (downstream of Twin Lakes) are shallower at about 4%. The steepest section of Hastings Creek is through Princess Park and Hunter Park where grades exceed 15%.

Across the base of Lynn Valley (from Baird Road to Crestlynn Road), the grades in Hastings Creek are less than 2%, providing some of the lowest gradient reaches of the creek. In the lower ravine reach, the gradients are uniformly between about 5% and 6% up to the confluence with Lynn Creek. The Hastings Creek tributaries in Lynn Valley are also very low gradient, dropping below 1% in the case of Thames Creek upstream of the confluence with Hastings Creek.

Generally, the upper reaches of the creeks within the urbanized reach are alluvial in nature, with a well-developed bed of gravel, cobble and boulder. In the lower gradient reaches the bed material becomes finer, with exception to isolated steeper areas. In some of the tributaries, namely lower Thames Creek, and Hoskins Creek, there is a large degree of fine sediment in the channel (sand and silt) that suggests that the available discharge for sediment transport (perhaps seasonally) is quite low. It is also noted that there are some bedrock controlled sections of Hastings Creek just downstream of Fromme Road. There is also a large debris levee in just upstream of the Hoskins Road culvert, and under the current footbridge. While Hastings Creek is not a debris flow creek, the slope instabilities in the ravine upstream could have resulted in small isolated geomorphic events.

Generally we expect more vertical erosion in steeper reaches and deposition in shallower reaches (sometimes leading to floodplain type areas and lateral erosion). For Hastings Creek and associated tributaries the channel appears to be generally vertically stable, with well graded bed sediments. Erosion is however present throughout the watershed and in patches, but can be generalized as lateral erosion in most cases. In either case the presence of erosion indicates that there is excess energy in the stream flow of Hastings Creek for the available resistance of the bank materials. Available stream energy is a balance of available stream flow (runoff), channel gradient, and sediment availability and transport.

Urbanization of the watershed has increased the response of runoff in the past century, and more so in the past fifty years. Hastings Creek does not have a substantial volume of sediment being contributed to the channel from the upstream natural processes, so any excess energy is being directed towards lateral erosion, and the opportunity to increase the total stream length (and decrease the slope). This is most prevalent, in areas like upper Princess Park, and Hunter Park where the channel bank and bed materials have changed, but there is still excess energy.

Data Sources

Stream and watershed characteristics are best assessed and understood through direct monitoring, and often through a series of nested data collection stations to understand interactions in the watershed. As operation and maintenance of data collection systems are relatively costly, it is a rare occasion to have direct measurements of either rainfall or runoff or both at any site. It is extremely fortunate that the District has established several rainfall and streamflow monitoring stations that can be used to develop a dataset to begin to understand the interactions in urban watersheds.

A number of hydrometric stations and rain gauges have been established in the Hastings Creek watershed and for the Lower Mainland area. The purpose of the following dataset is to provide a regional context for the hydrological response of Hastings Creek and to provide information to develop peak flows for infrastructure assessment. Data used for analysis pertaining to Hastings Creek was gathered from stations and gauges operated by the District, the Water Survey of Canada (WSC), Greater Vancouver Sewerage and Drainage District (GVSDD), and the City of Surrey. The data sources are summarized in Table 3-1.

Table 3-1. Hydrometric and rainfall data sources summary.

Station Owner	Station Name	Station Type	Period of Record
DNV	Hastings Creek	Hydrometric	2003 - 2011
DNV	Mosquito Creek	Hydrometric	2006 - 2011
DNV	Keith Creek	Hydrometric	2003 - 2011
DNV	Gallant Creek	Hydrometric	2003 - 2011
WSC	Mackay Creek	Hydrometric	2003 - 2011
Surrey	Little Campbell River	Hydrometric	2001 - 2011
Surrey	Morgan Creek	Hydrometric	1997 - 2010
Surrey	Mahood / Bear Creek	Hydrometric	1997 - 2010
Surrey	Quibble Creek	Hydrometric	1997 - 2010
GVS&DD	DN 82 rain Gauge (Cleveland Dam)	Rain Gauge	2002 - 2010

Streamflow Analysis

A streamflow analysis was performed on data for Hastings Creek as well as eight other creeks: four of which exist within the District of North Vancouver and four within the City of Surrey. Surrey was selected given a wider range of monitored streams and a longer length of data. This was done to provide regional context to the Hastings Creek streamflow analysis results based on daily averaged discharges. The analysis was based on metrics presented in the report entitled 'Analysis of Streamflow, Water Quality, and Benthic Community Changes in North Creek (1999-2009)' authored by Raincoast Applied Ecology. The metrics used are described as follows:

Annual Mean Discharge (Q_{mean}): Annual mean discharge is the central measure discharge in a stream and indicator of annual runoff volume. Changes in annual Q_{mean} without corresponding changes in precipitation indicate that changes are occurring at a watershed level to result in more or less connectivity from watershed to the creek and potential effects to aquatic habitat in terms of depth and wetted area of a stream.

Annual Discharge Volume to Precipitation Ratio ($Q_{precip\text{-}ratio}$): Both rainfall and discharge are currently measured in the Hastings Creek catchment. A ratio of runoff volume to rainfall volume (precipitation excluding snowfall) provides a general comparable metric of the watershed ability to retain runoff. $Q_{precip\text{-}ratio}$ was developed from the District's Hastings Creek hydrometric station (at Lynn Valley Road) and the rain gauge located at the top of Mountain Highway (at the water reservoir).

Annual 7-day Low Flow (Q_{min}): The minimum daily discharge for seven consecutive days annually. Q_{min} provides a measure of the lowest streamflow during summer baseflow conditions and the severity of annual droughts in a stream affecting habitat availability for fish and other aquatic life. Empirical data from other regions of North America have found that Q_{min} may increase, decrease, or remain unchanged as a result of urban development (Konrad and Booth, 2002).

Annual (instantaneous) Maximum Discharge (Q_{max}): The magnitude of the largest flood in a stream during a given year. Longer-term datasets may provide some insights into watershed changes and Q_{max}; however, the magnitude of peak events is very dependent on the dominant storms in any season. Q_{max} is an important metric in determining peak flows for less frequent flood events (e.g. 200-year return period). Two to ten-fold increases in Q_{max} have been measured in streams following urban development in Puget Sound (Konrad and Booth, 2002).

Annual Mean Discharge Exceedance (T_{Qmean}): The fraction of time that streamflow exceeds the annual mean discharge (Q_{mean}). Q_{mean} is a common discharge value and is typically equaled or exceeded about 1/3 of the time in urban streams (Booth et al., 2004). T_{Qmean} is higher in streams with gradual post-storm recession rates and relatively high baseflow and lower in streams where stormflows have high peaks and recede rapidly (i.e., "flashy" hydrographs). T_{Qmean} is likely to vary inversely with traditional urban development as a result of increased impervious area resulting in declining subsurface storage and runoff and increased overland flow (Konrad et al., 2005). T_{Qmean} was calculated based on daily discharge values.

All Hastings creek streamflow data were taken from the Hastings Creek hydrometric station located on the creek at Lynn Valley Rd and Mountain Hwy. Flow monitoring equipment was installed in September 2003 and consists of a permanent weir, pressure transducer (water level sensor), and data logger. Water levels over the weir are logged automatically at 5 minute intervals. Measurements have been taken near continuously since 2003. Average Raw Daily Discharge data were used for analysis. The data were validated and abnormalities were corrected or removed. Data from December 20, 2008 through March 18, 2009 were removed as the five minute recording jumped from 0.01185 m^3/s to 161.5 m^3/s and stayed above 84 m^3/s during the identified period. The spike was likely due to power failure, sensor malfunction, or other technical issues.

Flow data were used for all years except for 2003 and 2009, as previously explained. Precipitation data were not available for the years 2003 and 2008. Data from 2009 was not complete enough to use in the analysis. Precipitation data were taken from the Hastings Rain Gauge. Results from the Hastings Creek streamflow analysis are presented in Table 3-2.

Table 3-2. Streamflow analysis summary for Hastings Creek.

	Daily Discharge		Daily Rain							
Year	Points	Proportion of year	# Points	Proportion of year	Q_{mean} [m^3/s]	Total Rain [mm]	$Q_{precip\text{-}ratio}$ [%]	Q_{min} [m^3/s]	Q_{max} [m^3/s]	T_{Qmean} %
2003*	102	100.0%	-	-	-	-	-	-	-	-
2004	366	100.0%	8784	100.0%	0.12	3,022	37.3	0.029	2.957	22.7%
2005	365	100.0%	8760	100.0%	0.18	2,910	57.0	0.049	4.666	19.7%
2006	365	100.0%	8760	100.0%	0.19	2,848	62.4	0.066	4.715	25.2%
2007	365	100.0%	8439	96.3%	0.21	3,353	58.7	0.050	5.755	23.3%
2008*	354	96.7%	2219	79.8%	0.09	-	46.9***	0.034	1.314	26.6%
2009*	288	78.9%	-	-	-	-		-	-	-
2010	365	100.0%	365	100.0%	0.16	2,680	57.0	0.057	2.107	27.1%
2011	365	100.0%	365	100.0%	0.20	2,835	64.3	0.074	1.824	30.1%
		mean**			0.165	2,941.2	54.8	0.0514	3.334	25.0%
		trend **			not signif.	not signif.	not signif.	not signif.	decrease	increase

* incomplete years of data, not included in trend analysis
** includes only years for which appropriate data were available
*** rainfall was estimated from other raingauges in North Vancouver

The results indicate that there are no significant trends for the majority of the of the meterics including: Q_{mean}, Total Rain , $Q_{min,}$ and $Q_{precip\text{-}ratio}$; however, and a significant trend using the Mann-Kendall non-parametric test indicated that T_{Qmean} is increasing while is Q_{max} decreasing over the seven years of data. This observation is positive in terms of the hydrological health of Hastings Creek, indicating that there have been lower annual peak flows, and more uniform (less peaky) general response. The two results are intuitively linked indicating that a higher T_{Qmean} would be possible with lower peak flows.

Q_{mean} is a valuable parameter to check as it provides an overall value for daily discharge in Hastings Creek. It may not be a very good parameter to track for hydrological response given that it may not be sensitive to change provided that peak flows are decreasing and baseflows increasing.

$Q_{precip\text{-}ratio}$ is an interesting metric as it provides an annual value for total water abstracted from precipitation to runoff. This value lumps together watershed processes such as evaporation, transpiration, and losses to groundwater that would not be seen in the stream channel. This value was selected to provide a comparative value to the numerical hydrological modelling that the District commissioned for Hastings Creek under a separate contract. For the available data, the majority of the values are between 55% and 65%, which a low outlier for 2004, and a lower value for 2008 where there was incomplete precipitation data. These generally consistent results indicate that the upper portion of Hastings Creek retains or abstracts a large percentage rainfall from the runoff.

Q_{min} is a valuable metric to track, and while insignificant for a trend, this value is a direct measure of baseflow in the creek.

Q_{max} is a valuable metric for understanding peak flow hydrology, but may not provide a good metric for trend analysis until a longer data set is collected. The peak flow data is variable by nature and is strongly linked to storm magnitude. In large storms much of the normal hydrologic function of the watershed is overwhelmed and therefore Q_{max} would not be a good indicator of general health, but could be used to indicate the effectiveness of large regional facilities or development controls in the future.

T_{Qmean} indicates overall stream hydrologic response, and is a good metric for hydrologic tracking. The data indicates a significant increase in T_{Qmean} over the seven year period indicating a less peaky response. The reason for this trend is not entirely clear based on what is known about the watershed, but could be attributable to current development bylaw practices implemented in the early to mid 2000s.

In order to provide regional context to the Hastings Creek, eight other urban creeks were included in the analysis. Four of the creeks are other North Vancouver watersheds (Mackay Creek, Mosquito Creek, Keith Creek, and Gallant Creek), and four additional creeks from the City of Surrey were also included (Little Campbell River, Mahood Creek, Morgan Creek, and Quibble Creek). Data from these three creeks were released by the City of Surrey for this purpose and to provide a greater overall understanding of urban creek hydrology. The Surrey creeks were selected from a number of available datasets managed by KWL given the longer duration of monitoring. Given differing watershed size, each metric value is evaluated on a unit per km^2 basis. The catchment area for Hastings Creek was calculated based on flow originating upstream of the gauge. The results of all streamflow analysis compared on a per km^2 basis are presented in Table 3-3.

Table 3-3. Summary of regional streamflow analysis results.

		Average Rainfall	Catchment Area	Q_{mean}	$Q_{response}$	Q_{min}	Q_{max}	T_{Qmean}
Site Location and Name		[mm/yr]	[ha]	[$m^3/s/km^2$]	[$m^3s^{-1}/mm/km^2$]	[$m^3/s/km^2$]	[$m^3/s/km^2$]	%
North Vancouver	Hastings	2,941	339	0.049	0.0000052	0.015	0.98	25%
	Mosquito	2,668	603	0.102	0.0000054	0.035	2.41	23%
	Keith	2,668	272	0.060	0.0000084	0.038	1.34	17%
	Gallant	1,986	185	0.037	0.0000120	0.024	0.24	9%
	Mackay	1,794	363	0.063	0.0000353	0.028	0.84	29%
Surrey	Little Campbell	1,087	7,580	0.010	0.0000001	0.006	0.11	32%
	Morgan	1,090	186	0.024	0.0000121	0.013	0.37	27%
	Mahood / Bear	1,423	2,557	0.032	0.0000009	0.011	0.50	25%
	Quibble	1,634	6,500	0.03	0.0000033	0.02	0.53	28%

Hastings Creek has the highest average annual rainfall among all the creeks analyzed, though Mosquito and Keith Creeks are relatively similar (<200 mm/yr difference). The amount of rainfall is a function of elevation, as upper watershed areas have increased rainfall due to orographic effects. Hastings and Mackay creeks have very similar catchment areas in addition to mean, min and max flows; however Mackay Creek's annual discharge response is approximately double that of Hastings Creek. This indicates that a lower proportion of rainfall leaves the Hastings Creek catchment by streamflow versus by other methods (groundwater recharge, evapotranspiration, evaporation) than Mackay (overall basin relief is likely a factor in addition to other watershed factors). In addition, contributions from snowmelt (not included in rainfall) may increase the average discharge relative to Hastings Creek. Visual representations of the results are presented in Figure 3-1 through 3-5.

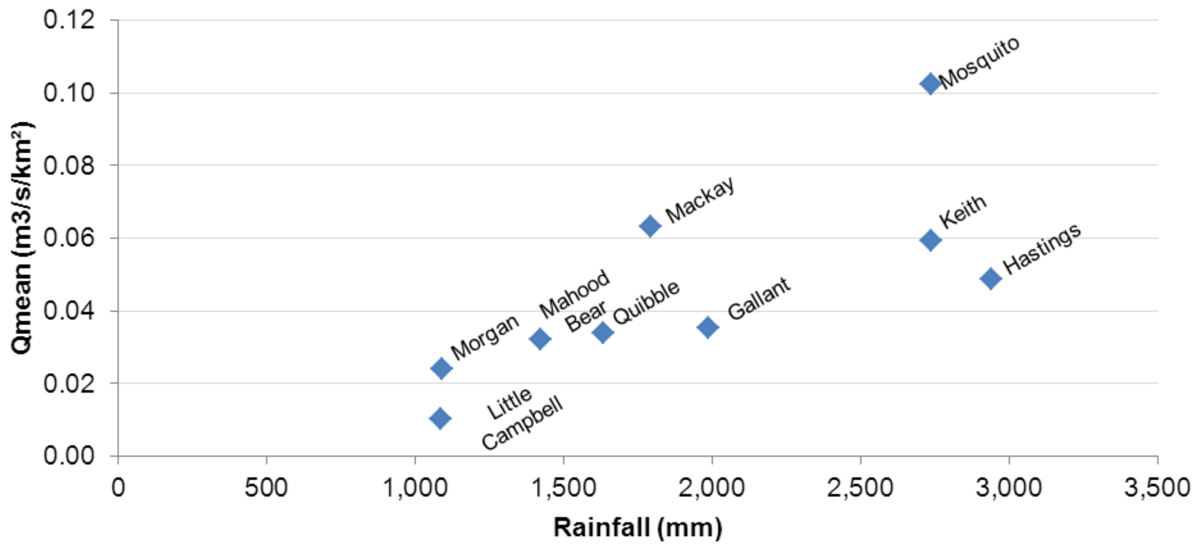


Figure 3-1. Q_{mean} vs. Rainfall.

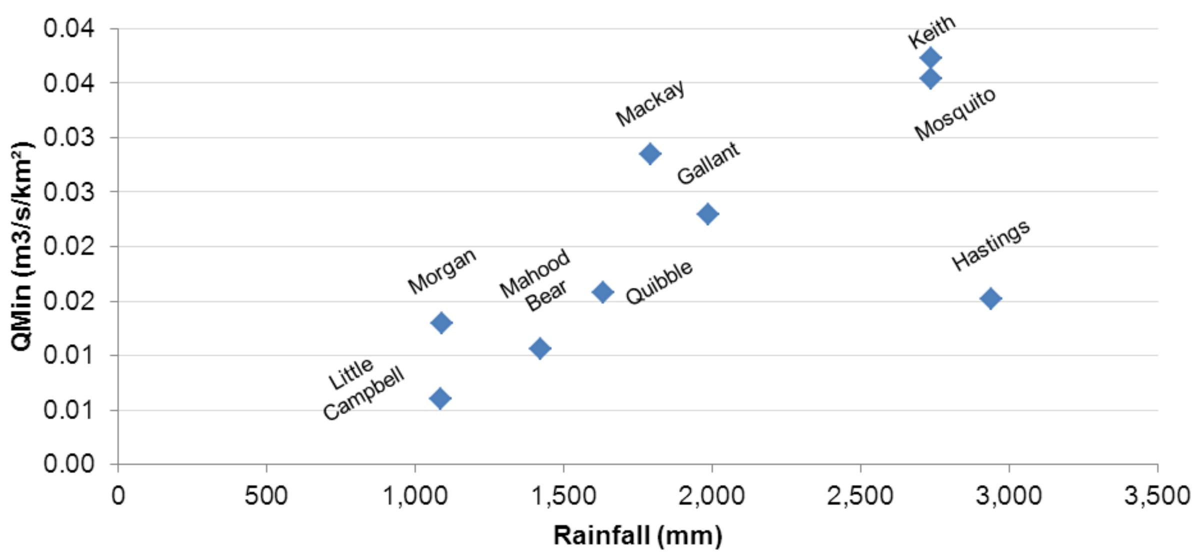


Figure 3-2. Q_{min} vs. Rainfall.

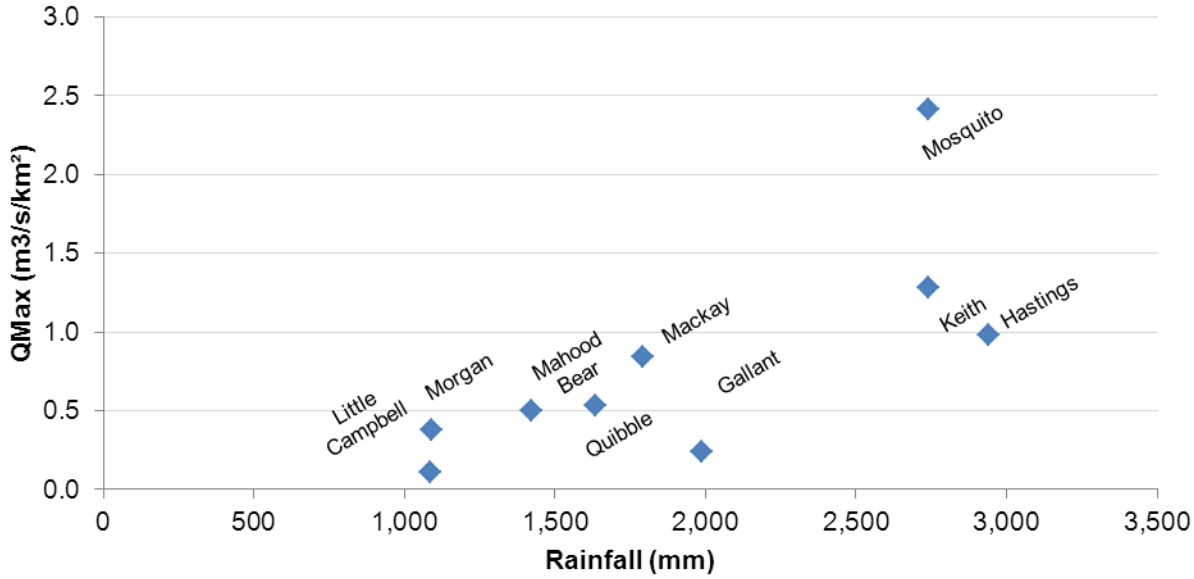


Figure 3-3. Q_{max} vs. Rainfall.

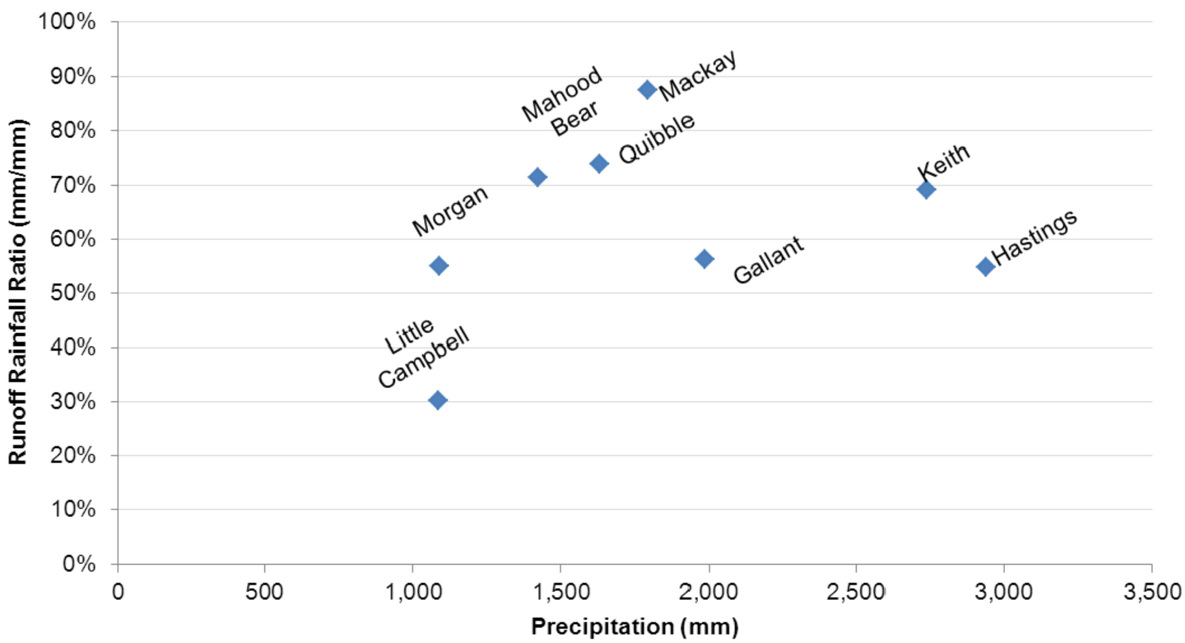


Figure 3-4. $Q_{precip\text{-}ratio}$ vs. Precipitation.

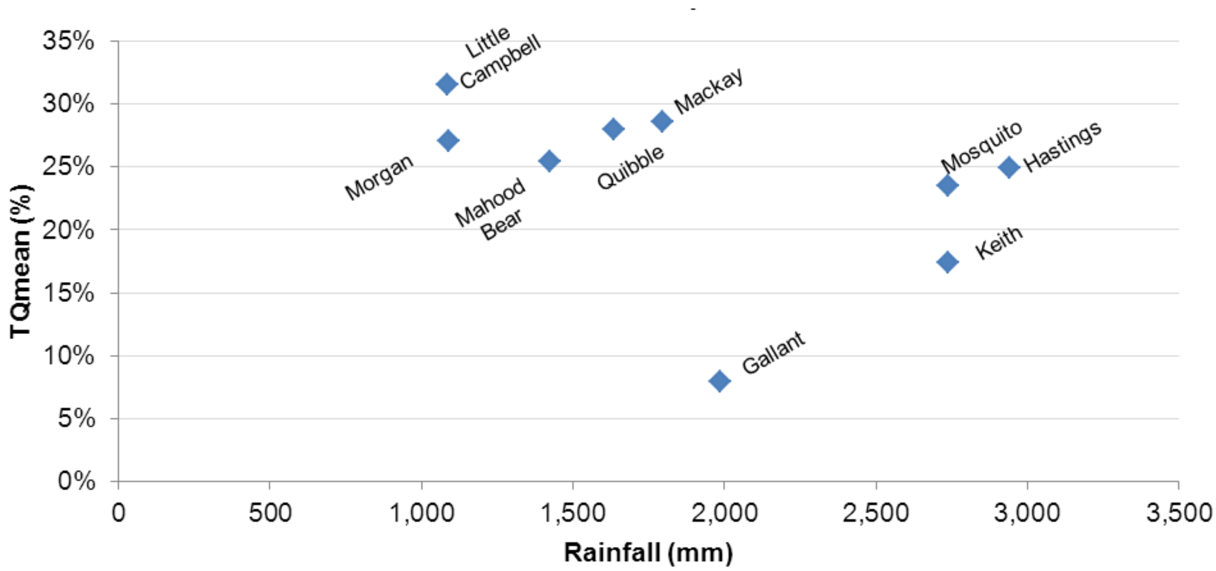


Figure 3-5. T_{Qmean} vs. Rainfall.

Based on the regional assessment, the following can be summarized:

- Q_{mean}: Hastings Creek can be compared to Mosquito Creek and Keith Creek in terms of total precipitation; however, Hastings Creek has the lowest unit mean annual discharge suggesting that rainfall is intercepted or retained to a higher degree in Hastings Creek. Furthermore, comparison of total annual runoff only represents about 55% of the rainfall for the period monitored.

- $Q_{min:}$ Similarly Hastings Creek has the lowest minimum 7-day discharge for the North Vancouver creeks, and is similar to the two smaller Surrey creeks. This indicates low summer baseflows and possible limitations for instream habitat during some parts of the year, and could stress the importance of creating deeper water refuge areas for some aquatic species.

- Q_{max}: Similarly to the previous two metrics, Hastings Creek exhibits lower peak flows than the two other North Vancouver creeks, indicating that the upper watershed has some capacity to attenuate peak flows, but is still relatively peaky.

- $Q_{precip-ratio}$: Hastings Creek exhibits a generally low runoff to rainfall ratio for the eight creeks assessed, and commensurately as low as Gallant Creek, a relatively well forested but steep North Vancouver creek. Interestingly, the ratio is similar to Morgan Creek, a relatively well-developed, but shallow creek with lower rainfall, but higher than Little Campbell River a larger and largely less densely developed watershed.

- T_{Qmean}: Hastings Creek has flows above mean about 25% of the time. This is similar to most of the regional set of creeks, but not as flashy as Gallant Creek or Keith Creek which are much smaller streams and very steep with shallow soil depths for Gallant, and entirely urbanized for Keith.

This regional review finds that the direct flow measures of mean, max, and minimum daily discharge are strongly linked to the climate and total rainfall, with values increasing with precipitation. Deviations from this trend, such as Hastings Creek for Q_{min}, indicate a counterintuitive value that may be specific to watershed physiography, or a function of infrastructure development.

The measures of watershed response: $Q_{precip\text{-}ratio}$, and T_{Qmean} both show relative independence from rainfall volume and watershed size. These are both interesting from a managed urban watershed sense as the values could compare the effect of low impact development or other best management practices in a watershed.

Generally, Hastings Creek tracks well in relation to the other North Vancouver creeks, but can be compared to the relatively high stream health in the Little Campbell River system in Surrey. Based on this review, two clear areas for improvement in Hastings Creek include:

- baseflow augmentation, likely through development of infiltration best management practices or Low Impact Development techniques (LID); and
- peak flow attenuation and lengthening of storm recession, also achievable through infiltration, but also potentially in detention facilities.

Peak Flow Estimates

Peak flow estimates were developed for Hastings Creek using regional analysis of discharge data from gauged hydrologically similar watersheds with substantially long records in the vicinity of the study site. This data is used to determine a streamflow pattern and frequency distribution of floods which are representative in the region. There are three nearby watersheds that are gauged by Water Survey of Canada (WSC). These are shown in Table 3-4.

Table 3-4. Regional hydrometric stations.

Station	WSC gauge	Area (km^2)	Period of Record	Flow Data Available
Kanaka Creek near Webster's Corner	08GA077	47.7	1960 - 2010	49 years of max daily 40 years of max instantaneous
Mackay Creek at Montroyal Blvd	08GA061	3.63	1970 - 2010	37 years of max daily 35 years of max instantaneous
Roberts Creek at Roberts Creek	08GA047	32.6	1959 - 2010	48 years of max daily 15 years of max instantaneous

Notes:
Maximum instantaneous is the maximum flow at any instant in the year of record.
Maximum daily flow is the maximum average flow for one day in the year of record.

All three gauges have both maximum daily and peak instantaneous discharge data. When using regional analysis, it is assumed that that the watersheds have similar physical and hydrological characteristics to each other and Hastings Creek; however, there are possibly significant differences including:

- the amount of rainfall that falls in each of the watersheds (rainfall is spatially variable in the North Shore Mountains);
- the variability in area (varies from 0.1 to 10 times Hastings Creek Watershed, although Hastings Creek and Mackay Creek have similar watershed areas above the measurement points); and
- the varying degree of urbanization in each watershed.

Despite these differences, the gauged watersheds represent the best available data set.

The stations were analyzed using the available maximum instantaneous and annual maximum daily flow data. The resulting peak flow estimates are summarized below in Table 3-5 (the values shown represent the average of the three methods).

Table 3-5. Peak flow estimates for regional hydrometric stations.

Return Period (years)	Kanaka		Mackay		Roberts	
	Peak flow max daily (m^3/s)	Peak flow max inst. (m^3/s)	Peak flow max daily (m^3/s)	Peak flow max inst. (m^3/s)	Peak flow max daily (m^3/s)	Peak flow max inst. (m^3/s)
2	34.4	35.0	2.1	3.8	8.8	16.5
5	51.3	51.8	3.0	5.5	12.6	28.8
10	64.9	65.0	4.4	8.2	18.4	44.5
20	80.0	79.2	5.4	10.1	22.5	54.0
50	103.3	100	6.5	12.1	26.7	62.5
100	123.0	118	8.0	15.0	32.6	72.9
200	145.7	138	9.2	17.3	37.3	80.2

Index Flood Method

To estimate peak instantaneous flows, a type of regional analysis called the index flood method was applied to the North Shore Mountains. The index flood method involves development of a regression equation expressing the “index flood” – usually the mean annual flood – to physiographic and/or climatic variables. In most cases, most of the variability can be correlated with drainage area.

The mean annual flood (the average of the annual maximum daily flows) for the three gauged watersheds. These are:

- Kanaka Creek – 40.2 m^3/s
- Mackay Creek – 3.36 m^3/s
- Roberts Creek – 14.1 m^3/s

Figure 3-6 plots mean annual flood (MAF) versus drainage area for the watersheds. While the relation shown is relative strong ($r^2 = 0.914$), it should be noted that the best-fit equation is only based on three points. Ideally, several more watersheds would be available. However, using the relation shown on Figure 3-6, the MAF for Hastings Creek is estimated at 5.8 m^3/s (based on a 7.4 km^2 drainage area for the Hastings Creek urban catchment as measured from the mouth). These values also compare well with the gauged MAF at Lynn Valley road for the period of record, 3.33 m^3/s based on a 3.39 km^2 catchment.

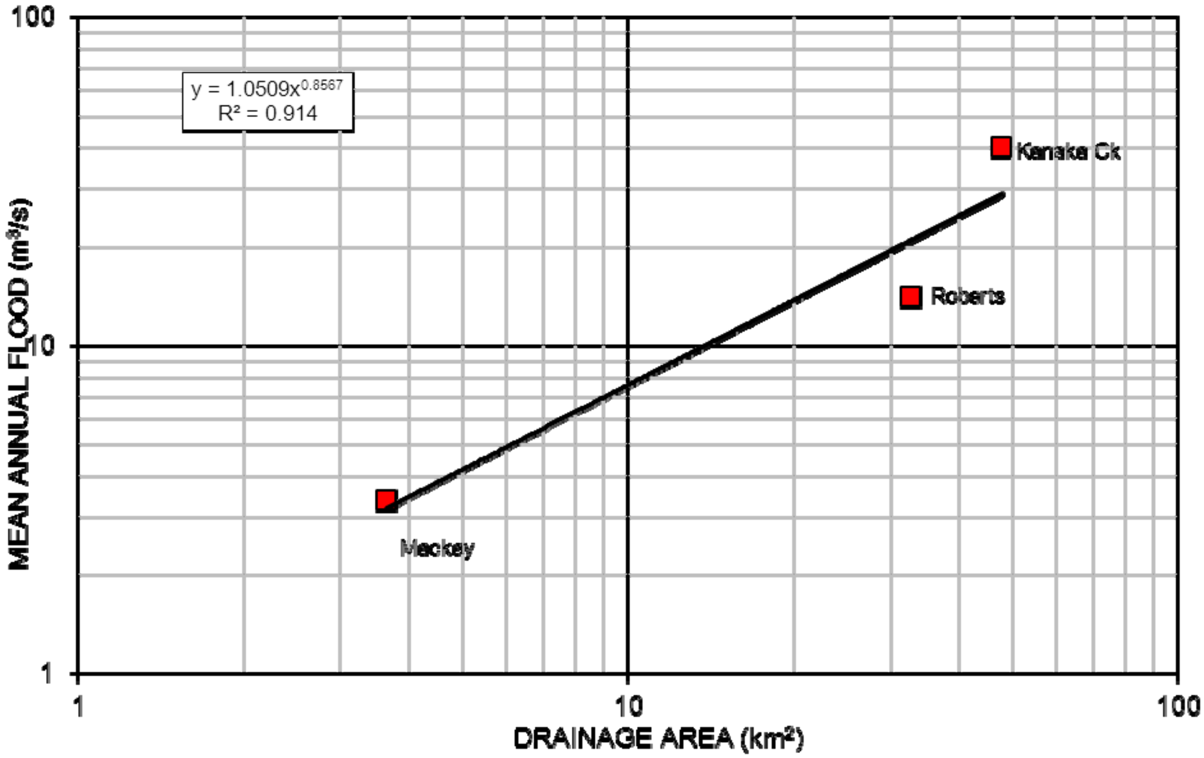


Figure 3-6. Mean annual flood (MAF) vs. drainage area.

A dimensionless regional curve based on the longer hydrometric records and flood frequencies is developed, where the ratio Cr, Q_T/MAF (where Q_T is the discharge of a specified return period) is plotted versus return period (Figure 3-7). Based on Figure 3-7, regional Cr ratios are applied to Hastings Creek for various return periods.

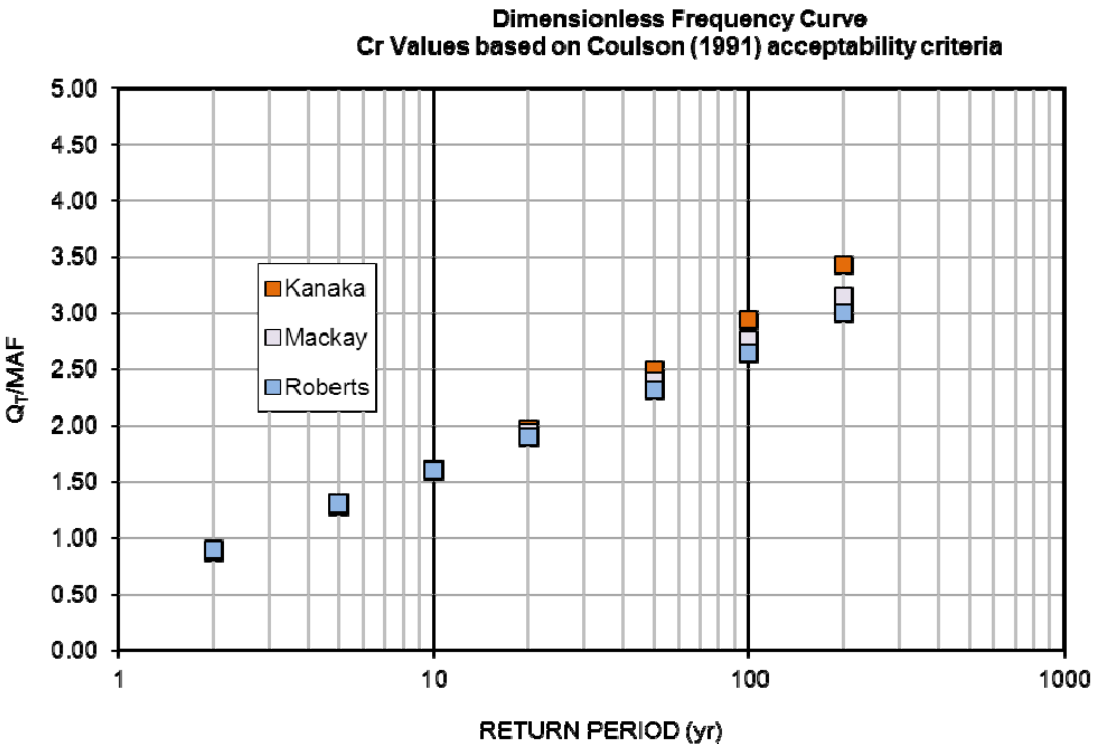


Figure 3-7. Hastings Creek regional hydrology dimensionless frequency curve.

The ratio of peak annual instantaneous flow to maximum daily flow (I/D ration) for Kanaka, Mackay and Roberts creeks are 1.95, 2.05 and 2.15 respectively. The average value of 2.05 was used to develop peak instantaneous discharges for Hastings Creek. Results of the regional analysis are listed in Table 3-6.

In summary, the 200-year return period peak instantaneous flow for Hastings Creek at the mouth using regional analysis that is estimated to be 39 m^3/s.

Table 3-6. Peak flow estimates for Hastings Creek at the mouth based on regional analysis.

Return Period (years)	MAF (m^3/s)	Cr	I/D	Maximum Daily Peak Flow (m^3/s)	Instantaneous Peak Flow (m^3/s)	Instantaneous Peak Flow ($m^3/s/km^2$)
2	6.47	0.89	2.05	5	11	1.4
5	6.47	1.30	2.05	8	16	2.1
10	6.47	1.61	2.05	10	19	2.6
20	6.47	1.94	2.05	11	23	3.2
50	6.47	2.40	2.05	14	29	3.9
100	6.47	2.78	2.05	16	34	4.5
200	6.47	3.20	2.05	19	39	5.2

Subcatchments & Kilmer Diversion

The Hastings Creek Watershed was broken down into ten urban sub catchments totaling 7.4 km^2. Seven sub catchments drain into tributaries of Hastings Creek. The remaining three sub catchments drain into both Hastings Creek and the Kilmer Diversion. The Kilmer Diversion is a manmade channel approximately 2.2 km long which runs from Kilmer Creek along Kilmer Rd and drains directly into Lynn Creek. The diversion drains into Lynn Creek approximately 2.8 km upstream of the mouth of Hastings Creek. Three tributaries to Hastings Creek, Kilmer Creek, Coleman Creek, and Thames Creek, are intersected by the diversion. Flow from these three creeks is only partially diverted into the Kilmer Diversion and the remaining flow carries on to Hastings Creek. Flow originating north of the diversion that does not drain into the three tributary creeks is directed entirely into the Kilmer diversion. As such, only three subcatchments representing the three creeks intersected by the diversion are included as part of the Hastings Creek catchment.

Based on monitoring data for the Kilmer Diversion, a relationship between flow in Hastings Creek and level in the Kilmer Diversion can be developed (Figure 3-8).

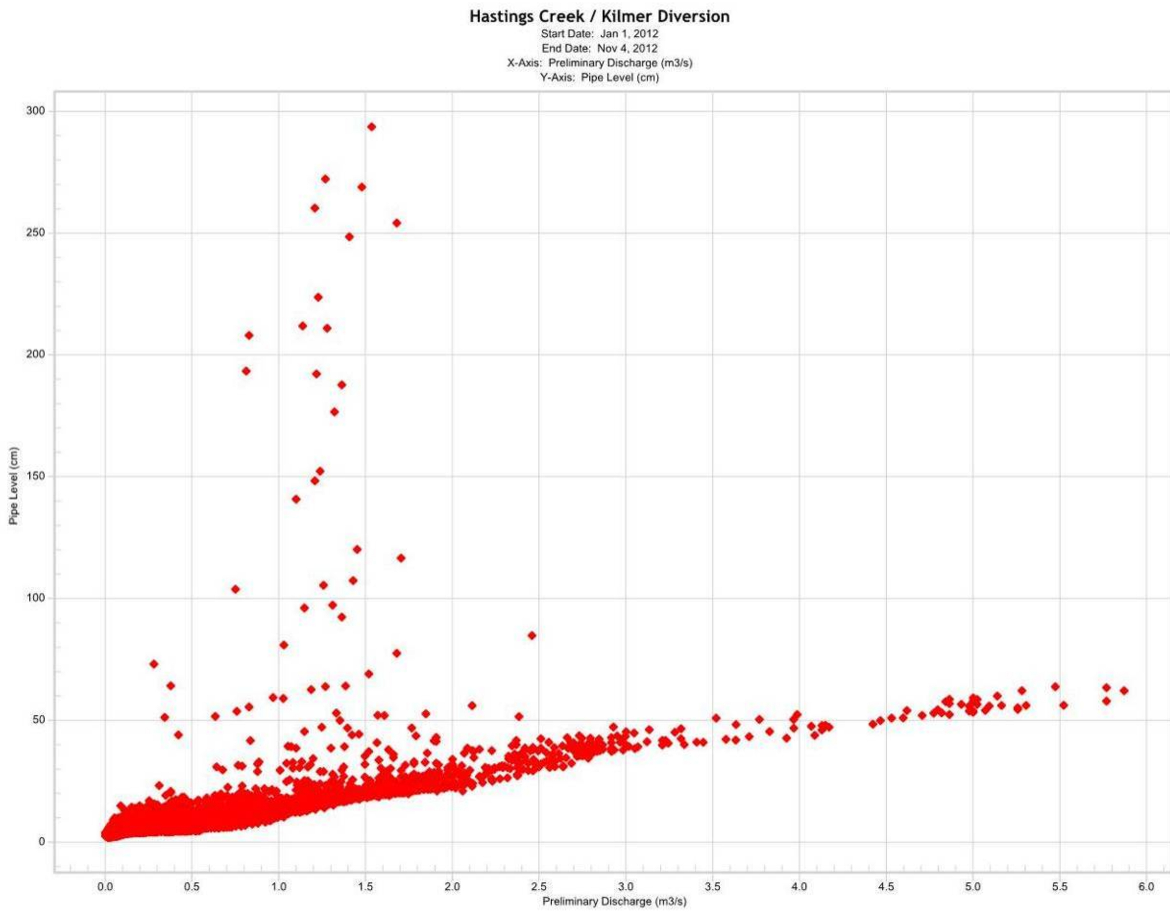


Figure 3-8. Relationship of flow in Hastings Creek to Kilmer Diversion level.

The data in Figure 3-8 is the flow data for 2012 up until November 4. Based on this data, the very strong correlation between the two parameters is evident. The lower bound of the dataset indicates that there are three distinct slopes 1) between 0 and 0.75 m^3/s level where the diversion is not contributing very much, 2) between 0.75 and 3.0 m^3/s where there is a strong linear correlation between flow and level, and 3) above 3.0 m^3/s where the slope is moderately less. Generally, the Kilmer Diversion appears to be taking a very proportional volume of discharge from the Hastings Creek catchment relative to the mainstem. The small scatter of points above the dense grouping is attributed to splash and spray from a tributary storm pipe near the sensor location.

Peak Flows

The peak flows for each subcatchment within Hastings creek were calculated based on the results of the regional analysis. The unit instantaneous peak flows were applied to aggregate sub catchment areas. As only baseflow (less than a mean annual flood) is not diverted into the Kilmer diversion from subcatchments 8, 9 and 10, the subcatchments were treated as independent areas and were not included in aggregated areas contributing to flows into Hastings Creek. The calculated peak flows are presented in Table 3-7. The shading is relative to the value of the results. The darker the shading, the higher the peak flow value is compared to all other values.

Table 3-7. Hastings Creek subcatchment peak flows.

Subcatchment	Area (km^2)	Subcatchment Areas included	Total Area	Q_2	Q_{10}	Q_{100}	Q_{200}
1	0.92	1, 6, 2, 7, 3, 5	5.31	7.4	13.8	23.9	27.6
2	0.83	2, 7, 3, 5	3.81	5.3	9.9	17.2	19.8
3	1.23	3, 5	2.66	3.7	6.9	12.0	13.8
4	0.71	4	0.71	1.0	1.9	3.2	3.7
5	1.43	5	1.43	2.0	3.7	6.4	7.4
6	0.58	6	0.58	0.8	1.5	2.6	3.0
7	0.33	7, 3, 5	2.98	4.2	7.8	13.4	15.5
8	0.03	8	0.03	0.0	0.1	0.1	0.1
9	0.58	9	0.58	0.8	1.5	2.6	3.0
10	0.80	10	0.80	1.1	2.1	3.6	4.2

Figure 3-9 (Appendix 1: Map 11) outlines the subcatchments and the Kilmer Diversion.

To provide context, the results of the streamflow analysis indicated that the maximum flow recorded over seven years of data for Hastings Creek was 5.8 m^3/s. The average was 3.3 m^3/s.

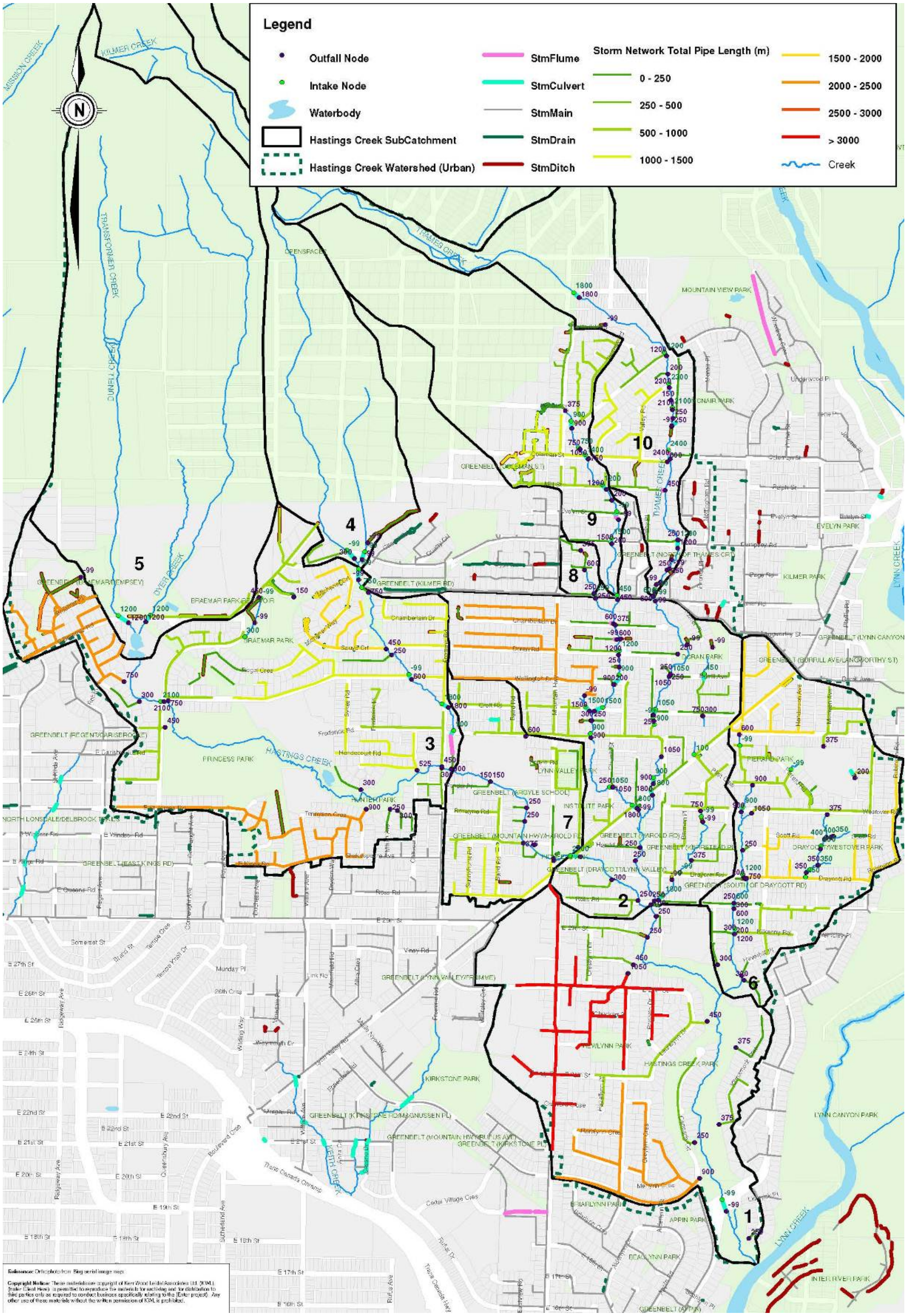


Figure 3-9. Overview of stormsewers in the Hastings Creek watershed.

This represents the flow based on passing through catchments 7, 3 and 5. The results indicate that the maximum flow recorded since 2004 has not surpassed the 10 year return period flow estimate and the average flow is in line with the regional 2-year return peak flow estimate.

Drainage Infrastructure

Like most urbanized catchments, distal parts of the watershed collect rainfall from roads and rooftops which is conveyed in a storm sewer network towards the creek. Once in the creek, the creek flow is conveyed through culverts and under bridges until reaching the receiving water. The storm sewer network (away from the mainstem) includes flumes, culverts, stormmains, drains and ditches which all meet the creek. This stormwater collection and conveyance network has been reviewed as part of the project to understand the importance of the various subcatchments, but has not been assessed technically. An overview of the collection network is shown in Figure 3-9 (Appendix 1: Map 11) within the Hastings Creek catchment.

Along the creek corridor, culvert crossings at roads present the largest potential for conveyance limitations, and for fish passage issues. A technical assessment of the culvert crossings has been included in the following section.

Storm Sewers

The storm sewer network for Hastings Creek is substantial. There is approximately 54 km of storm pipes within the Hastings Creek urban catchment. Each storm pipe is part of a network of pipes that drains into a Hastings Creek tributary creek. Figure 3-9 (Appendix 1: Map 11) shows the locations and symbolized total length of the storm pipe networks in addition to outfall nodes. Table 3-8 details the pipe networks information.

Table 3-8. Storm pipe networks by subcatchment.

Subcatchment ID	Total Number of Network Pipes	Total Number of Networks	Total Length of Pipes for all Networks (m)
1	155	12	7,994
2	273	47	10,901
3	358	35	14,235
4	37	4	1,371
5	19	3	718
6	185	30	7,236
7	112	16	4,251
8	12	3	334
9	152	14	4,177
10	86	23	2,782

The largest network belongs to Subcatchment 1 and captures the majority of the storm runoff from the Lynn Valley Center located at the corner of Lynn Valley Rd and Mountain Hwy. The network is comprised of approximately 3,400 m of pipe and has a 1050 mm diameter outfall, the largest for the Hastings storm sewer system.

While the capacity of the storm sewers is not being assessed by this study, the District has contracted another engineering consultant to conduct an assessment of pipe capacity. The review of the network does however identify both key outfalls that could significantly improve watershed health, and outfalls of key opportunity where an end of pipe facility could be integrated for the benefit of Hastings Creek. The key sites include:

- Outfall Lynn Valley Town Centre at 27th Street;
- Outfall from Princess Park (south) at Hunter Park;
- Outfall from Wendell Place at Argyle School;
- Outfall at Harold Road;
- Outfall at Institute Road and Mountain Highway; and
- Institute Road at South-East corner of playfields.

These sites are described in more detail in Section 4; however, all possible or conceivable sites have been included for the purposes of the draft report to generate ideas. Further refinement of the sites is foreseen.

Culverts

Fifty-seven culverts were identified in the Hastings Creek watershed, based on the District GIS system. Based on the data available, the distribution of culverts are presented in Figures 3-10, 3-11 and 3-12 (Appendix 1: Maps 12-14) by size (diameter), age and material respectively.

Culvert capacity screening has been conducted for each culvert based on culvert diameter and material. The flow conveyance capacity of the culverts was evaluated based on inlet conditions of the pipe for inlet controlled culverts. While a calculation was not conducted for each culvert location, general capacities where developed for each culvert shape, size, and material. The capacity assessment considered:

- Maximum allowable headwater (set to culvert crown);
- Tailwater elevation (set to zero);
- Shape;
- Material;
- Size;
- Manning's roughness coefficient;
- Entrance type (K_e set to 0.5); and
- Slope (to a nominal inlet control condition).

Culvert capacities were compared to an estimated 200-year peak flow for the subcatchment or in some cases to the culvert location. Where capacity was not an issue a detailed catchment review was not conducted, however, where capacity was not met a coarse estimate of watershed area was made to refine the flow estimate.

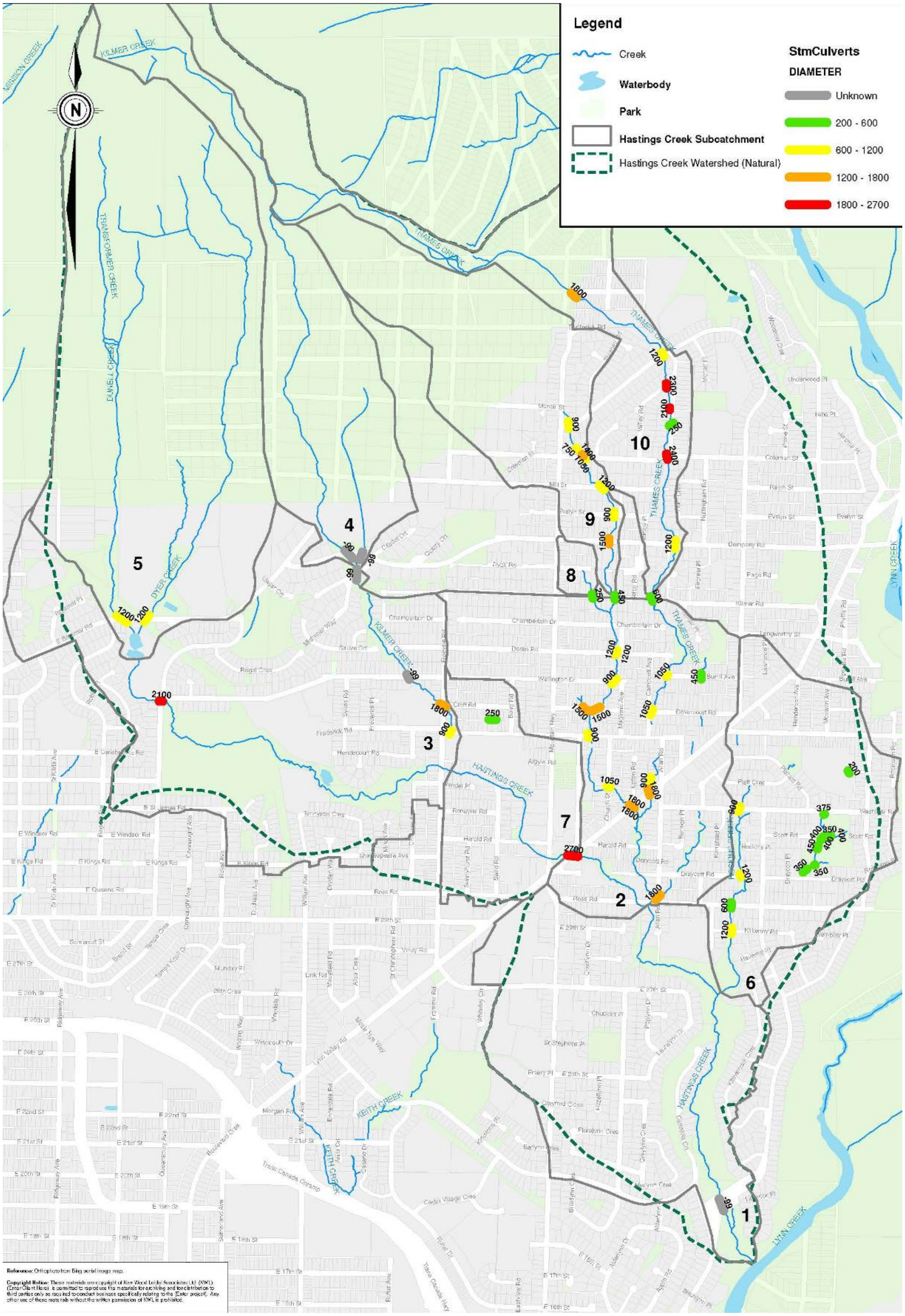


Figure 3-10. Culverts by size (diameter).

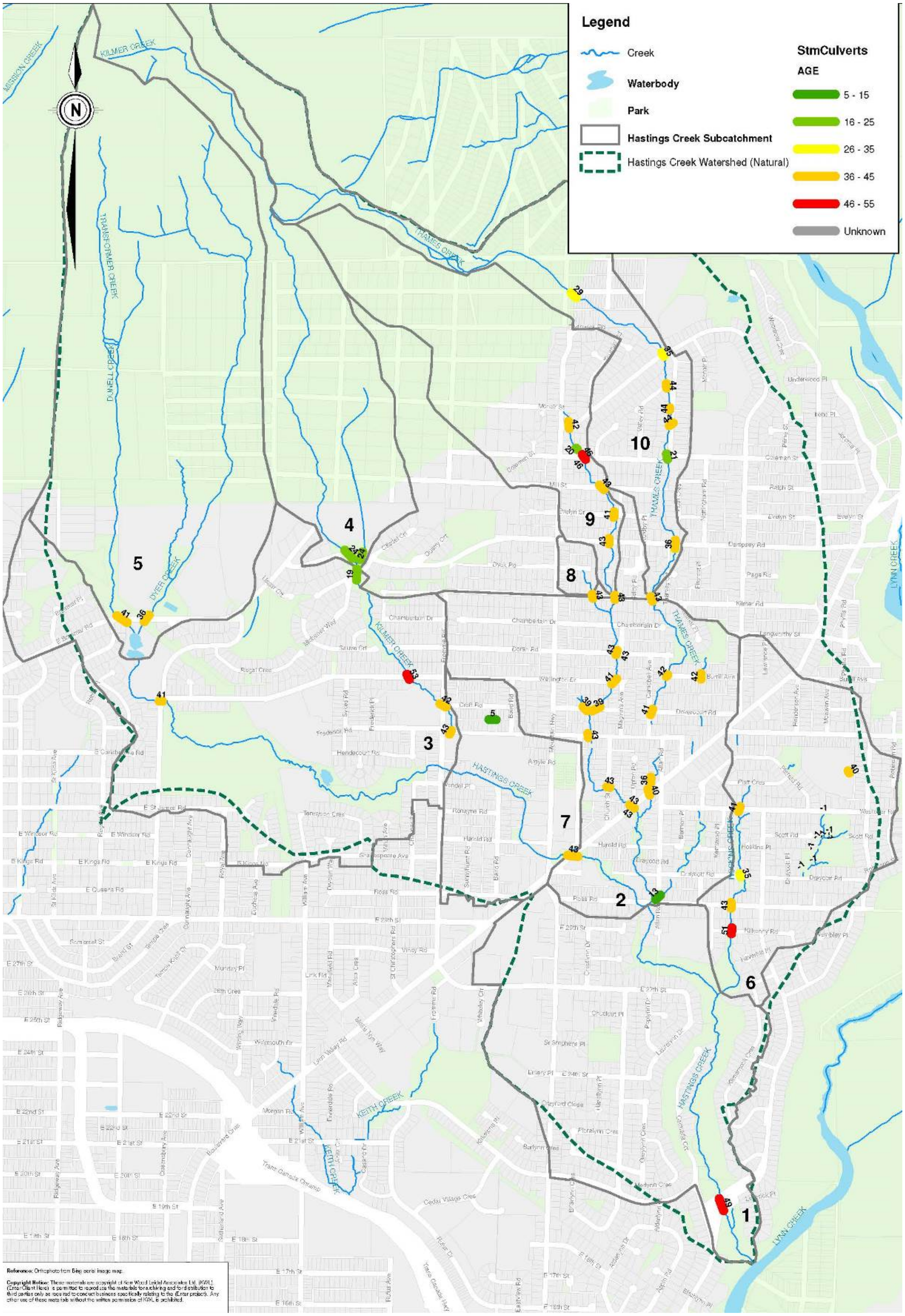


Figure 3-11. Culverts by age.

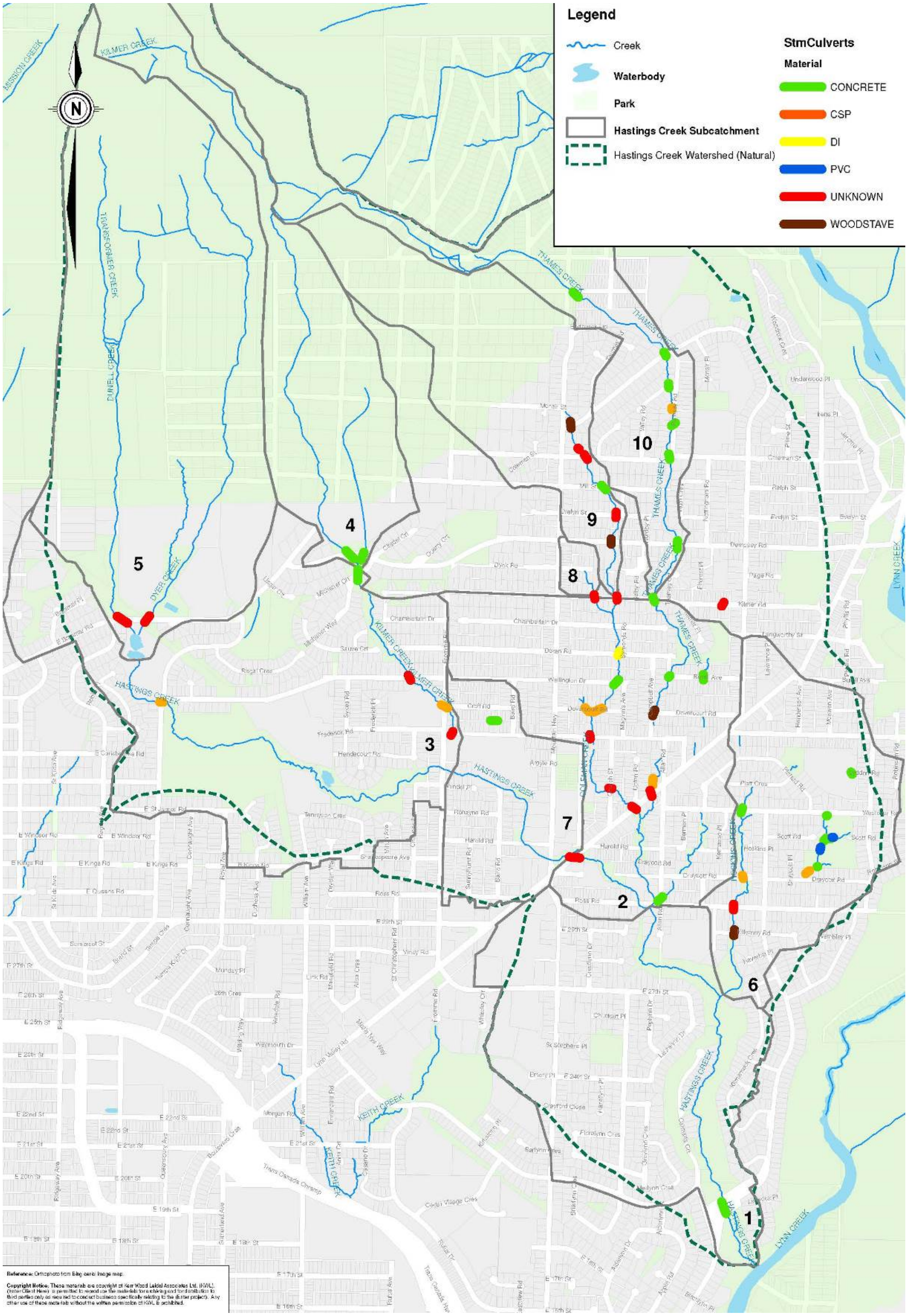


Figure 3-12. Culverts by material.

Capacities were calculated for the 57 culverts, a total of 27 culverts had culverts that could not convey the 200-year return period discharge without headwater (Figure 3-14). Based on the assessment there are:

- 11 culverts that can only convey less than 35% of the peak flow;
- 8 culverts that can convey from 36% to 70% of the peak flow; and
- 8 culverts that can convey between 71% and 100% of the peak flow.

While the total number of culverts that do not convey the peak flow appear to be high, the assessment includes all culverts (including small diameter culverts on small tributaries) as well as large culverts on the mainstem.

Based on capacity and condition, seven culverts have been identified as priorities for upgrading or replacement (Figure 3-13 and 3-14), where one small local drainage culvert north of Argyle School not included. An additional two culverts, Hastings Creek at Hoskins Road and Kilmer Creek at Wellington Road should be considered for regular inspection, based on age. All the culverts identified are mapped and noted on Figure 3-14. High priority culverts for upgrading are also identified and discussed in Section 4.

The review of the culvert crossings found very few high priority crossings for replacement. It did underscore the need for regular inspections (e.g., annually or biannually) to ensure no new maintenance is required. This is true of the last two photos in Figure 3-13, where these are not high priority crossings for replacement or upgrading, but maintenance issues.

Flood Potential

Flooding along the Hastings Creek mainstem would occur during infrequent large floods. During a period of unusually severe storms between 1980 and 1984, flooding was experienced throughout the Hastings Creek watershed, primarily due to:

- blockages at culvert inlets; and
- debris deposition and debris jams as a function of erosion.

The majority of the issues were restricted to the upper Lynn Valley area (upstream of the town centre), where development has encroached on the smaller tributaries of Hastings Creek, such that the tributaries often flow through landscaped yards and adjacent to and potentially under houses.

The culvert assessment described above identified 27 culverts that would not convey the 200-year flood event (Figure 3-14). These culverts could all be upgraded; however, debris management and potential blockages could occur at any culvert location in an unpredictable manner. In order to assess flood potential, the location of the culvert crossings have been coupled with a spatial assessment of topography. The District has acquired high resolution Lidar mapping. Lidar is generally found to provide high quality mapping with general accuracy or resolution of less than 0.1 m horizontally and between 0.1 m and 0.3 m vertically.

Figure 3-13. Examples of culvert crossings requiring upgrade or replacement: (a) inlet at Hoskins Creek at Kilkenny – note some inlet improvements; (b) outlet at Hoskins at Kilkenny – note backwater; (c) Coleman Creek at McNair – undersized and woodstave; (d) Hoskins at Ross Road – undersized (e) Thames Creek at Mill Street structural issues; and (f) Thames tributary at Dempsey Road – requires maintenance.

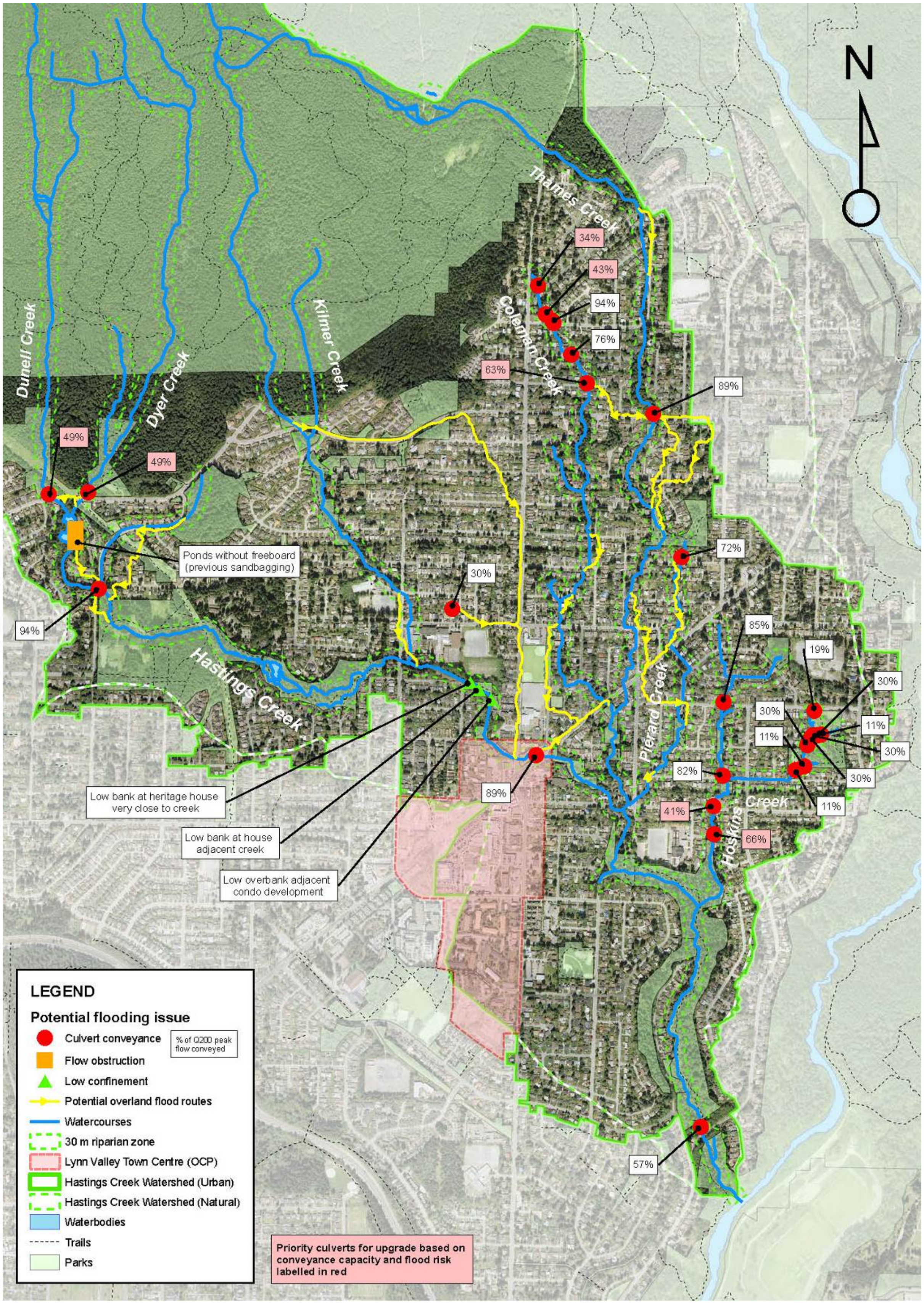


Figure 3-14. Potential flooding based on flood flow exceedance at road crossings.

To understand how urbanization has affected the natural watershed of Hastings Creek, the Lidar mapping was used to create a digital elevation model (DEM) based on 1 m grid sizes. A flow accumulation analysis was then used to collect flow from the bare urbanized landscape, without regard for stormsewers or culverts. The result is a network of channels that would form during a severe rain event that would collect water from every metre of the watershed, and would find flood routes in the event of a culvert blockage. Figure 3-14 (Appendix 1: Map 20), identifies all the culverts, the culvert deficiencies, and the flood routes that could be activated if a culvert where blocked. Examples of flood prone areas are shown in Figure 3-15.

Figure 3-14 indicates that flood routes could occupy streets until the topography would suggest that the water would find a route across private properties until finding the creek channel again.

a b c d

Figure 3-15. Examples of flood prone areas: (a) at Twin Lakes upstream of Princess – note sandbagging in recent season; (b) inlet on Kilmer Creek at Fredrick Road, prone to blockage and across from Argyle School; (c) house a short distance from Hastings Creek, with limited containment (near Argyle School); (d) Older home downstream of Argyle School, with below grade basement adjacent to Hastings Creek.

Erosion Control

In 2007, a very detailed reconnaissance of Hastings Creek and the tributaries was conducted by KWL. All erosion sites identified are mapped on Figure 3-16 (Appendix 1: Map 19), and these are linked to a photo reference in the GIS spatial database. The inventory resulted in the identification of 248 erosion sites of varying hazard and consequence. Erosion hazard was identified in terms of erosion height where:

- Low Hazard: Less than 0.3 m high;
- Moderate Hazard: between 0.3 m and 1.2 m high; and
- High Hazard: Higher than 1.2 m.

Consequence was rated in terms of proximity to an asset, which could include: houses, garages, driveways, fences, footbridges, or trails. Of the assets considered, only footbridges and trails are District assets, while the others items are private property assets. To assess consequence, the following rating system was used:

- Low Consequence: Greater than 15 m away;
- Moderate Consequence: Between 5 m and 15 m away; and
- High Consquence: Less than 5 m away.

Erosion is a natural and necessary process in a stream to adjust to changing governing conditions. For example, if the dominant discharge were to increase, in order to manage the excess energy, the stream would need to transport more sediment, and based on the availability of sediment, erosion would likely occur to produce sediment or adjust stream length and slope. While is an indication of a change in the stream, it is a process whereby the stream is attempting to cope with the change.

Where possible, erosion should be left to proceed; however, where the consequence is high, bank protection works may be necessary to protect an asset or piece of infrastructure. From the District's perspective, the identified areas of concerns are:

- District footbridges; and
- District trails.

A total of 12 sites of high consequence were identified for District assets, three footbridge sites and nine trail sites (see examples in Figure 3-18). Many of the trail sites were identified in Hunter Park, where the lack of defined trail system has led to encroachment on the creek.

For the bridge sites, relatively conventional protection should be undertaken, unless restricted by access (likely for one site). Many of the trail erosion sites could utilize a habitat structure style bank protection, incorporating large wood elements, boulder elements and live planting. The 12 erosion sites are mapped on Figure 3-17 (Appendix 1: Map 21) along with the high consequence private sites.

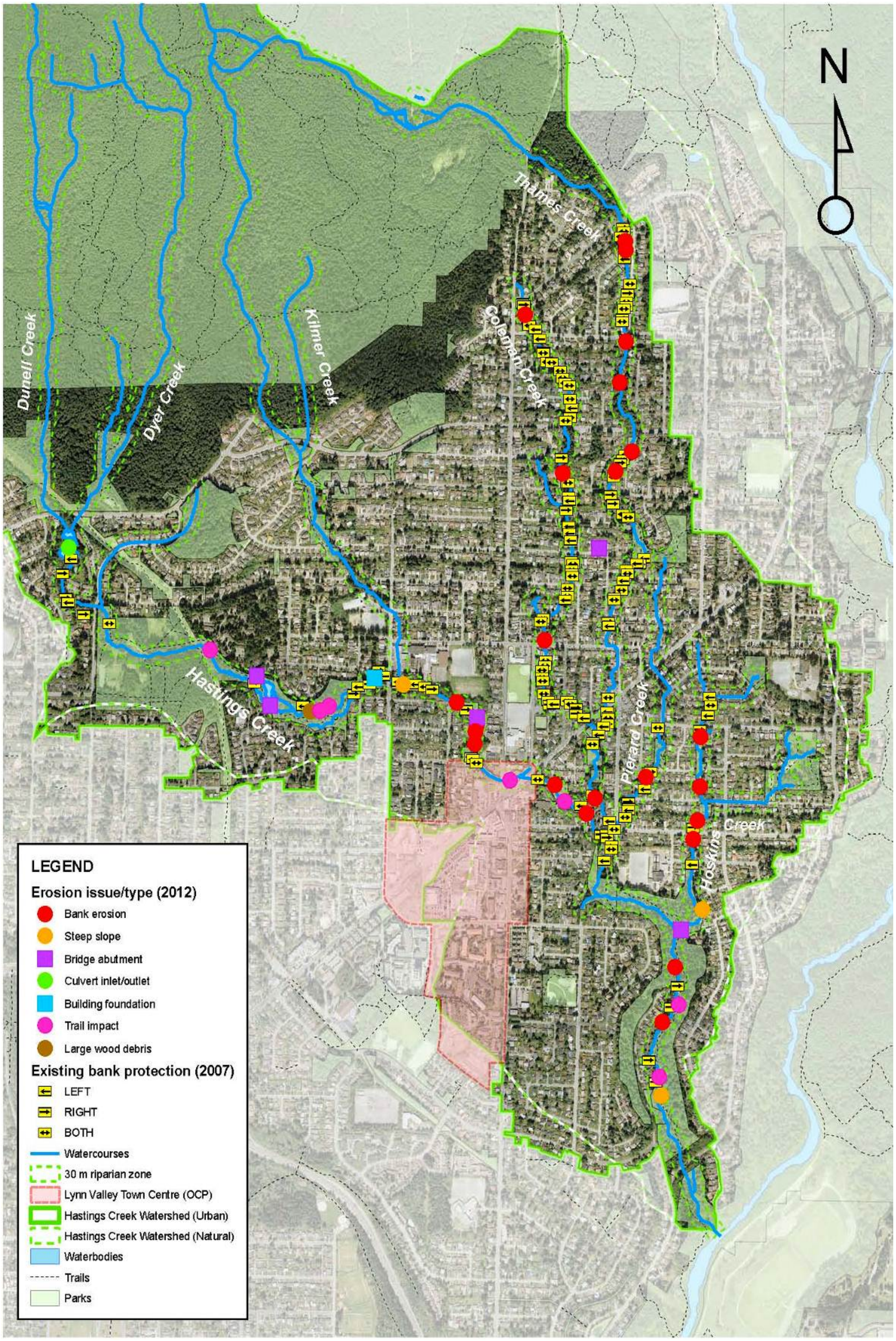


Figure 3-16. Erosion sites and existing bank protection works.

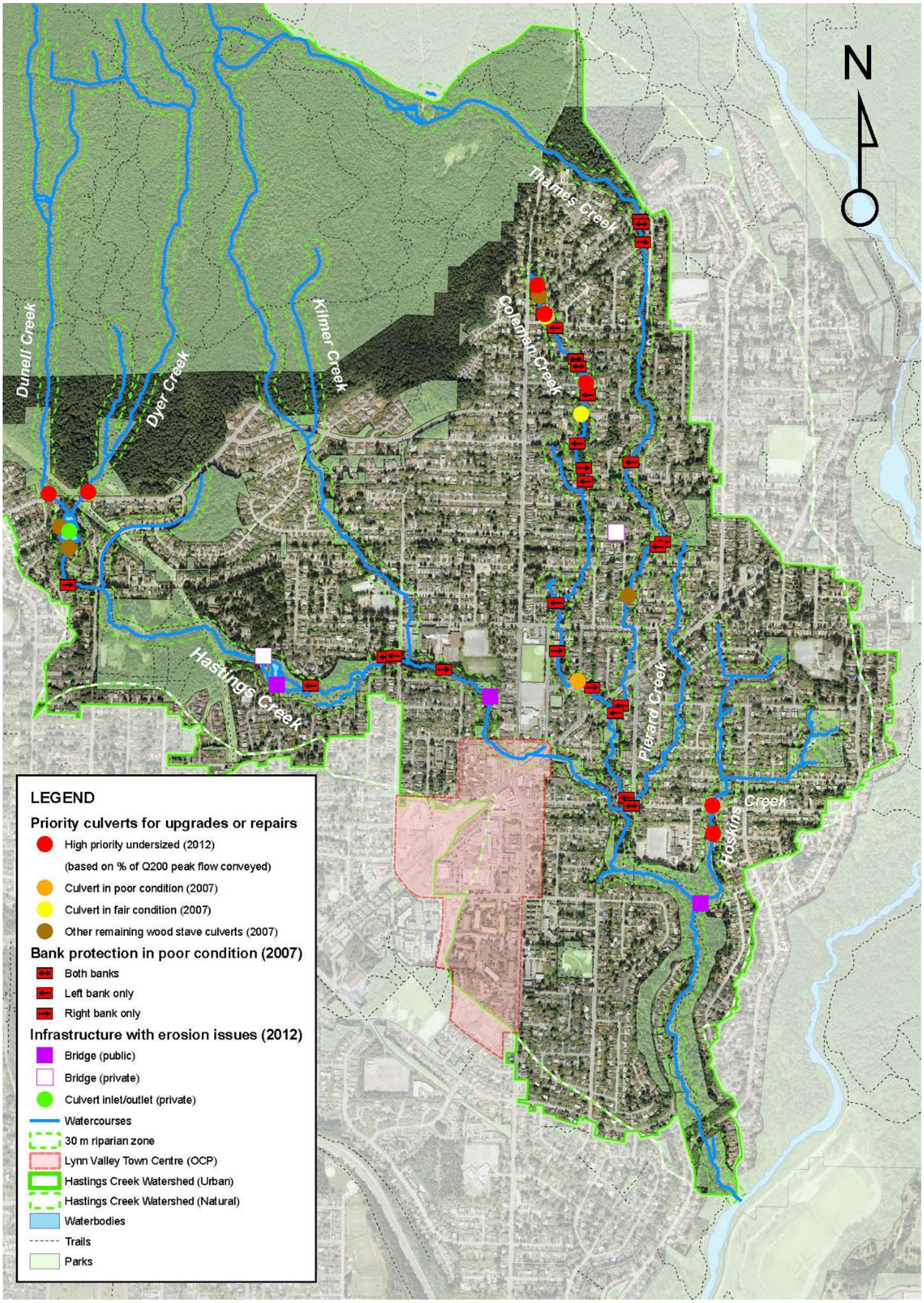


Figure 3-17. Priority infrastructure for upgrades and repairs.

Figure 3-18. Examples of erosion and bank protection: (a) exposed till slope on Thames Creek downstream of Dempsey; (b) Hastings Creek upstream of Princess typical erosion; (c) erosion in Thames Creek upstream of Ross Road - erosion threatening retaining wall and carport; (d) Typical undercut erosion in Hunter Park – likely more beneficial as fish habitat and is not a priority site for bank protection; (e) Deltalok slope in Hunter Park, a balance between traditional protection and large habitat structure enhancement; (f) Deltalok slope on Coleman Creek at Mill Street – note high flows shown above resulted in damage.

Review of Morrison Hershfield's LVTC Stormwater Report

Morrison Hershfield conducted an independent study for the District that examined both elements of the Hastings Creek watershed and development in the LVTC. The report comprised several key components, as follows:

- Storm sewer capacity screening for the entire watershed;
- Hydrologic modelling of the entire watershed to determine pre-development flows; and
- Outlining of goals for LID practice for the LVTC (i.e. determine retention rates).

This project was conducted in partnership with the District GIS staff that preprocessed the spatial data for analyses.

The storm sewer capacity screening work uses the District GIS data to determine incremental catchment areas for each pipe segment in the watershed. By attributing lot areas, based on storm leads, and road areas (likely based on CB locations or leads), a small watershed per pipe is developed that both includes paved and other (e.g. single family, multi-family, or commercial) land-use. A separate spreadsheet based assessment then uses traditional but simple hydrological formulae (e.g. rational method) and pipe conveyance equations to assess the local contribution and upstream contribution. The assessment also includes a 10% factor for climate change, and projects land-use change for future scenarios.

The assessment found 20 pipe segments between 150 mm and 1200 mm diameter that failed to convey the flow in the current or future scenarios. Several 300 mm diameter pipe segments reported to only convey 22% of the design flow. It is assumed that this is a 100-year return period capacity; however, this is not explicit in the draft report. The findings were mapped in a series of plate maps, which identify deficient pipes, and pipes missing invert data or having incomplete data. Based on quick review, there appears to be a substantial number of pipes having incomplete data at the draft report stage. The total number of pipes not assessed is not summarized in the draft report.

The hydrological modelling for Hastings Creek used a continuous simulation model (Qualhymo) to run 19 years of data from the Environment Canada – North Vancouver Lynn Creek station (1964-1983), which is the longest dataset available for the catchment. Model parameters were selected based on basin physiography, and the 19 year data set was used to produce hourly discharge values. For model verification, flood frequency analysis was conducted on the daily flow series and compared to flood frequency analysis from the WSC Mackay Creek at Montroyal Station for an overlapping period (1971-1983, not including 1972 and 1973). Flood frequency results agreed well, indicating that the model reproduces peak flows well. It is unclear whether a comparison of daily flows was conducted to assess average and low flows.

The model land-use parameters were then adjusted to both assess predevelopment flows and future development flows without any LID practices in place. The results for a 2-year return period event found:

- Year 1890: 1.60 $m^3/s/km^2$;
- Year 2012: 1.69 $m^3/s/km^2$;
- Year 2040: 1.81 $m^3/s/km^2$; and
- LVTC (Post Development: 4.14 $m^3/s/km^2$.

The modelling is based on the assumption that the soil in Hastings Creek is quite shallow and incapable of holding rainwater. An important clarification should be that the 2012 results are based on data prior to 1983.

Comparison to the Hydrological Assessment

The District requested that the modelling results and this hydrological assessment be compared to determine the major differences and a general rationale for the differnces.

This assessment examined seven years of contemporary data on Hastings Creek from 2004 to 2011 (excluding 2009) from the hydrometric station located at Lynn Valley Road based on 3.34 km^2 watershed area. The hydrological modelling work is an uncalibrated model, based on the entire watershed (8.62 km^2), and utilized runoff data from 1964 to 1983. The following provides data available from the modelling report for direct comparison:

Table 3-9. Summary of comparable hydrologic parameters

Parameter	Hastings Creek Hydrometric Data	Hastings Creek Hydrologic Model
Minimum Runoff to Precipitation Ratio	37.3%	71%
Maximum Runoff to Precipitation Ratio	64.3%	86%
Average Runoff to Precipitation Ratio	54.8%	79%
Mean Annual Flood (Daily)	0.983 $m^3/s/km^2$	n/a
Mean Annual Flood (Instantaneous)	2.14 $m^3/s/km^2$	1.69 $m^3/s/km^2$
Average Annual Rainfall	2,941 mm	2,575 mm

The two largest attributable differences in the two approaches is:

1. Watershed area (and land cover percentage differences);
2. Climate data (differing periods);
3. No inclusion of the Kilmer Diversion in the hydraulic model.

Based on the results there are two general comparative values: runoff to rainfall ratio (discharge coefficient), and mean annual flood.

The observed data for the runoff to rainfall ratio is much lower than the modelling results. This could be due to the higher contribution of urban drainage at the mouth of Hastings Creek as compared to the hydrometric gauge, and no allowance for the Kilmer Diversion in the modelling work. Higher urban contribution could result in a real increase dishcharge to rainfall, and exclusion of the Kilmer Diversion would artificially increase the runoff ratio. The hydraulic model has only been compared to Mackay Creek data.

The observed instantaneous mean annual flood is more than 20% higher than the modeled results. This could be due to the storms during the observed period, where more precipitation fell on average between 2004 and 2011 than 1973 to 1983.

The final comparison that can be made is that the Hastings Creek model was validated against the Mackay Creek hydrometric record during the same period. A comparison of Mackay Creek and Hastings Creek data finds that annual peak flows are very similar for the overlapping period, but mean flows and low flows are less comparable. This suggests that the hydrologic model may be a good indicator of peak flows, but may not represent normal and low flows as well. This is a typical challenge in hydrologic modelling, where hydrograph peaks are more easily matched, while hydrograph shape and timing is more challenging.

The model results are then used to determine retention rates for the LVTC required LID facilities. As this work is not directly related to this assessment, a review of the values has not been conducted. The retention rates are stated for 2-year return periods and higher, and given that the model represents peaks well, this may not be an issue. However, the model suggests that a larger percentage of runoff is occurring annually than is measured at Lynn Valley Road, so the retention rates could potentially be lowered. If additional detail results were provided, this could be assessed further.

Should more modelling work be undertaken, it is recommended that:

- calibration of the model against the Hastings Creek rain and hydrometric data is conducted;
- refine the model and check results prior to using them for the LVTC.

Both the infrastructure screening and the hydrologic model are very good tools for the District moving forward with ISMPs and infrastructure asset management. It is foreseeable that the infrastructure screening tool could be coded into the District GIS system for entire in-house analysis. The approach is relatively straightforward and most critical tasks are related to the spatial data analysis. Some cleaning and maintenance of the District GIS storm datasets may be required to complete incomplete information.

The hydrological model is also a very good tool that could be applied across the District. Since there are several hydrometric stations (Mosquito Creek, Keith Creek, Gallant Creek), the model could be adapted to assess response in these areas without substantial new effort. These results would then be used to develop goals for ISMP activities District wide.

GIS Data Maintenance

This project and the review of the LVTC report finds that the District GIS is a powerful tool, and could be used for much more, with some more effort in updating the datasets based on analyses such as these and building additional tools. The District has both a public (GeoWeb)

GIS data set, and likely has internal sets that may not be ready for public use. Our assessment is based solely on the data made available through the GeoWeb site. Recommendations include:

- Addressing incomplete data (e.g. storm and culvert data sets often have missing data)
- Providing additional data columns for culvert upgrading (i.e. date, material and method for culvert rehabilitiation)
- Providing spatial references for culvert crossings (stream crossing and road crossing / address where applicable)
- Connectivity in the storm sewer network (connecting pipes makes network analysis possible and efficient)
- Identifying storm outfalls as independent nodes (important for analysis and monitoring)
- Identifying storm inlets (presently incomplete for capacity concerns)
- Consideration for development of in-house tools for infrastructure assessment.

Additional Hydrometric Station

Based on the review of hydrometric data at Mountain Highway, the importance of the LVTC's contribution to the watershed, the rapid proposed land-use change, and aggressive need for LID techniques, a second monitoring site is recommended to understand how land-use change and BMPs will address densification in the District. There are two likely sites:

- an in-pipe / in manhole sensor upstream of the outfall at 27th Street; and/or
- a hydrometric station at or in the Hoskins Road culvert.

The 27th Street outfall site will be a direct measurement of a large urban, redeveloping catchment, but will need to rely on the existing hydrometric station for areas north of Lynn Valley Road, and will not capture areas east of Mountain Highway. The benefit of an in pipe manhole is the use of alternate technology for monitoring. KWL has used both "Flodar" instruments that are mounted in a manhole barrel and measure depth and velocity with a radar instrument, and acoustic doppler instruments that are mounted on the invert of the pipe. Both instruments do not need the extensive field maintenance to develop stage-discharge curves, but have a higher initial hardware cost (about $25,000 for either unit). This site would best assess land-use change and BMPs in the LVTC. KWL has recently added 5 Flodar sites to Flowworks in the City of North Vancouver, and two in the District of West Vancouver. KWL installed and maintained an acoustic Doppler sensor in a trunk sewer in the City of Abbotsford for about five years without issue.

The Hoskins Road site would provide a total picture of the watershed, with the LVTC as a smaller component. This station could be used as the data has been used early to detect trends in key hydrological metrics that could suggest that the health of the stream is improving or degrading. It would however lump the response of the LVTC in the entire 7 km^2 watershed. The costs of a station at this location would be initially lower due to equipment costs, but would require field verification and development of a stage discharge curve. This station could eventually replace the Lynn Valley Road station, but should be run simultaneously for two to three years to correlate the data sets. This station could also utilize equipment from other existing stations should some be decommissioned.

Hastings Creek will be the first ISMP in the District of North Vancouver, and will be used to develop tools for other areas. It may be beneficial to use Hastings Creek as a reference basin to monitor long term land-use change and stream health. Therefore centralizing two or more hydrometric monitoring sites in the Hastings Creek watershed may provide more benefit than additional streams.

PART 4. STRATEGIES AND PRIORITY PROJECTS

This section recommends four broad strategies for improving the ecological health or condition of Hastings Creek, describes eight priority projects, and identifies additional engineering and ecology-related projects and actions. Most priority projects combine activities in a defined area where implementation is cost-effective and results in a broader range of benefits (see Figure 4-1 for locations). They include activities to: (1) address fish passage impediments and barriers; (2) improve fish habitat through instream complexing; (3) create off-channel habitat; (4) improve water quality using wetlands and other measures; and (5) control invasive species. Projects not found in priority areas are also presented (see Figures 4-2 to 4-5 and Priority Projects 7 and 8).

Strategies

1. Address Riparian Zone Encroachment. Many riparian areas surrounding Hastings Creek and its tributaries are affected by residential development including forest loss, bank armouring, construction of buildings or landscape structures, and creation of residential gardens. While individually these issues have a minor effect on Hastings Creek, the cumulative effects of neighbourhood-scale habitat loss or change is substantial. The District should develop a long-term program of education, incentives for tree planting or naturalization, assistance with invasive species removal, and enforcement of existing bylaws to improve riparian habitat. This should include leadership from DNV in parks and public lands. In addition, acquisition priorities should be identified for purchasing important riparian properties to create a network of protected areas throughout the watershed. The increase in population from the implementation of the LVTC provides impetus for expanding park areas along Hastings Creek.

2. Integrate the Hastings Creek Corridor into LVTC. While only a small portion of the Hasting Creek corridor bisects the northern edge of the LVTC, there is a range of opportunities to better incorporate the stream into the redeveloping community. Expanded trails, unique signage, fences in high use areas, and education information could make Hastings Creek an essential part of the LVTC. Information on raingardens and other stormwater management activities in the redeveloping town centre should be linked with signs, maps, and other information so residents understand their importance for protecting stream health.

3. Fund an Annual Program of Fish Habitat Enhancement in Collaboration with North Shore Streamkeepers. A range of fish habitat restoration opportunities are described in the following project descriptions, of which many are in public parks or other accessible areas. Modest seed or partnership funding from the District combined with the expertise of District Operations crews could result in annual implementation of restoration projects that would contribute to the stream's ecological health, as well as improved community stewardship. Direct funding could be relatively modest ($10,000 to $30,000 annually) but the District could also provide materials (e.g., logs from other cleared sites or gravel from Lynn Creek flood control activities), staff time, or equipment. Enhancement activities could include instream complexing using logs and boulders, creation of small off-channel features, and improvements to fish passage.

4. Combine Habitat Restoration with Infrastructure Replacement. Habitat restoration should combined with projects addressing failing or undersized infrastructure such as road culverts, trail bridges or abutments, and bank protection. The incremental cost of adding useful habitat improvement features is usually small relatively to overall project costs. As well, the availability of construction equipment and site access make habitat enhancement more efficient when combined with other project activities.

Priority Projects

Priority projects presented in the following sections were selected based on three criteria:

1. Projects which emphasize fish and riparian habitat in the lower gradient section of Hastings Creek and downstream sections of Thames and Coleman creeks.

2. Projects which are linked directly or indirectly to stormwater management activities and can be implemented as part of the District of North Vancouver's efforts to improve the ecological health of Hastings Creek.

3. Projects which are practical to implement based on site access and land ownership, and use methods that have been used successfully in similar habitats in other watersheds.

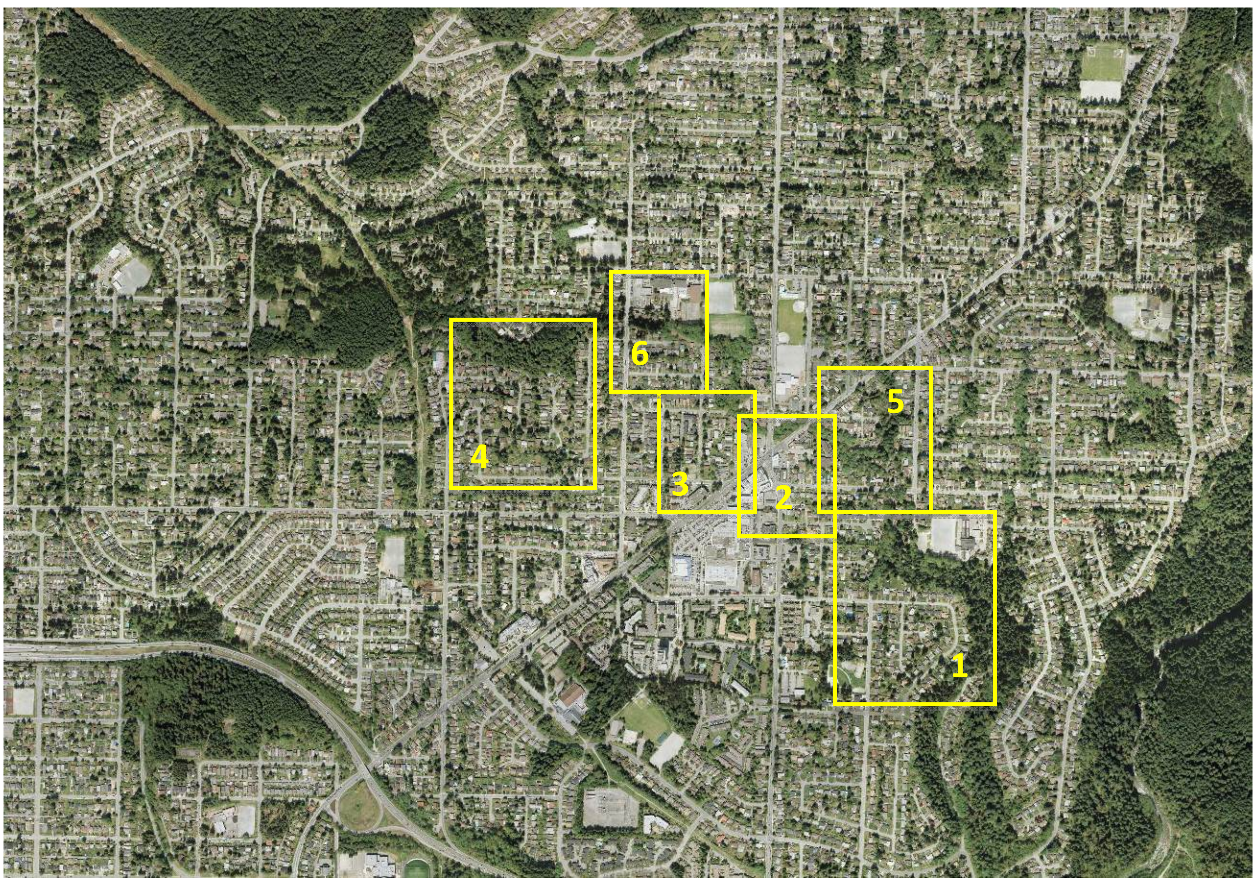


Figure 4-1. Location of key priority projects in the Hastings Creek watershed.

Priority Project 1: Ross Road School Off-Channel Habitat Creation

Project Overview

The habitat assessment identified off-channel habitat is generally lacking in the watershed and that rearing habitat is lacking in the middle reaches of the watershed. This area is one of the few areas in the watershed with low bank ravine bottom areas that are DNV-owned. Low bank areas exist both upstream and downstream of the 27th St-Allan Rd footbridge exist where existing off-channel habitat could be enhanced or new off-channel areas created in a phased approach. Instream complexing above the footbridge would further improve habitat in the main channel. Taken together, these projects have the potential to substantially increase the availability of rearing and high-flow refuge habitat for salmonids in an important part of the watershed.

Identified Issues and Opportunities

- Large low-bank areas with sites suitable for off-channel habitat but existing off-channel areas limited in extent currently.
- Lack of instream complexity in vicinity of and upstream of footbridge.
- Large number of invasives, including knotweed, ivy, cherry-laurel, yellow lamium, Japanese coltsfoot, and Policeman’s helmet.
- Problems with yard waste dumping along south ravine top-of-bank upstream and downstream of footbridge.
- Water quality impacts from LVTC outfall.

Potential Restoration Projects and Techniques

Short-term (0-5 years):

- Remove or treat priority invasive plants on both banks within ravine, particularly knotweed patches, ivy, cherry-laurel, and large yellow lamium area south of house on southwest corner of Allan Rd cul-de-sac north of creek.
- Work with landowners to address yard waste dumping and manage invasive plants (ivy, yellow lamium) extending down ravine slope into DNV parkland and riparian area.
- Enhance 60 m of existing side channel downstream of footbridge on right bank by deepening the channel inlet and outlet, and adding a large pool (Pond A; total area = 40 m^2). Most of work to completed by hand because of difficulties of machine access. Consider additional work to enhance existing high water off-channel habitat upstream and downstream of side channel to be accessible year-round.
- Establish a long-term water quality monitoring station on LVTC outfall channel.

Medium-term (5-15 years):

- Create a new 60 m^2 off-channel pond (Pond B) on large floodplain bench area on right bank, 15-25 m upstream of the LVTC outfall channel and connect to creek via new inlet and outlet channels.
- Add 6 instream complexing structures (large wood or boulder clusters) in channel in vicinity of and upstream of footbridge and adjacent to new off-channel pond.

(a) Existing side channel on right bank of Hastings Creek downstream of footbridge. Note channel still had standing water in July 2012.

(b) Existing inlet to side channel from Hastings Creek.

(c) Existing off-channel pond on right bank downstream of side channel. Additional side channels could increase the total year-round wetted off-channel area.

(d) Low-bank area on right bank upstream of LVTC outfall suitable for off-channel pond. Knotweed (seen here in foreground) stands are present throughout this area and require management.

(e) Example of yard waste dumping by landowners at top of ravine slope.

(f) Channel conditions upstream of LVTC outfall showing lack of instream complexity.

Identified issues and opportunities in Priority Area 1.

Long-term (15-50 years):

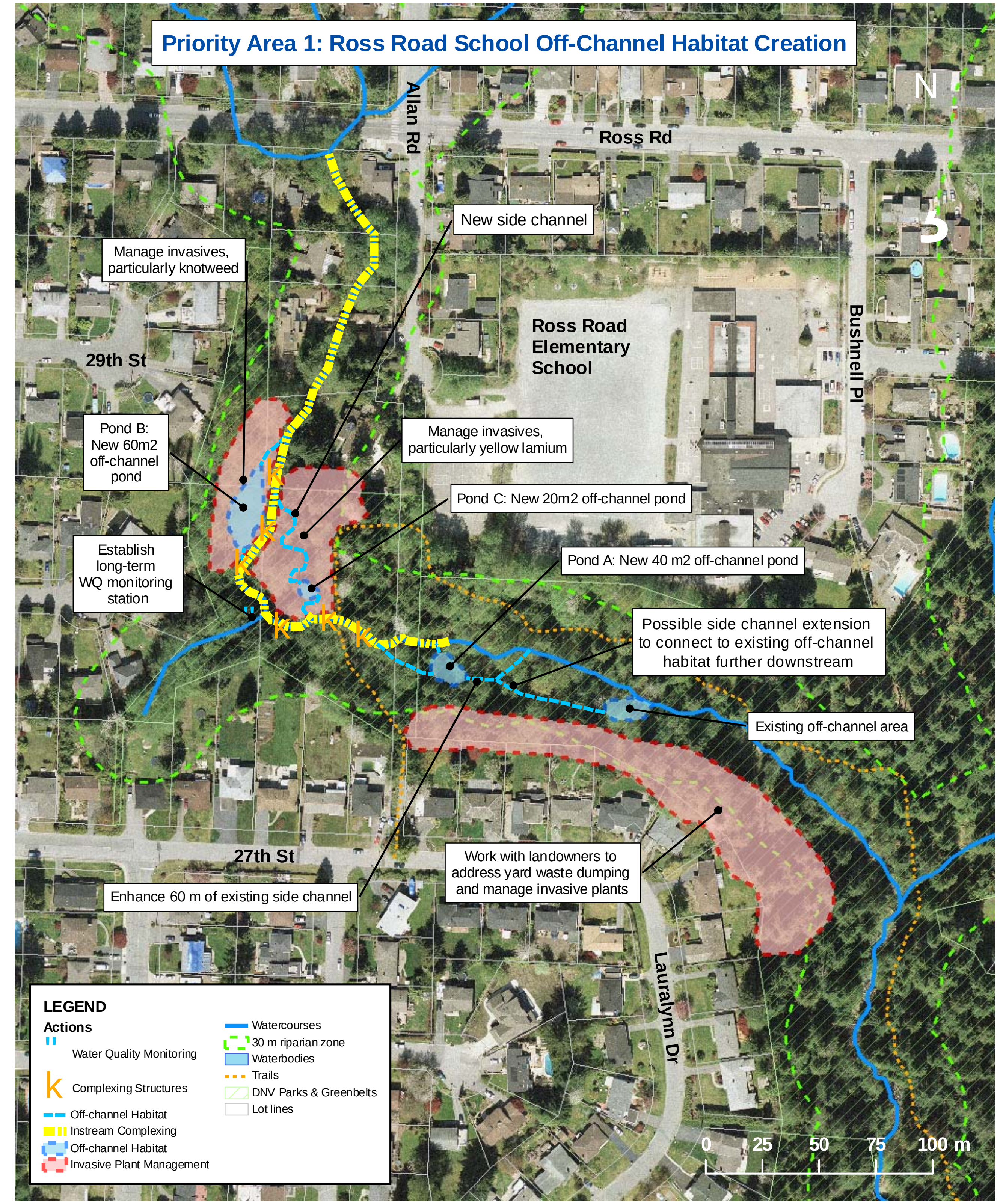
- Create 50 m of new side channel and a 20 m^2 pond (Pond C) for rearing juvenile salmonids in DNV parkland on left bank. This area is slightly higher bank and would require more excavation to undertake. However, the location is more accessible and could incorporate a short trail or viewing platform for interpretation.

Ongoing (As Re-development Occurs):

- Address impacts to water quality from LVTC outfall through implementation of on-site rainwater management and/or treatment.

Approximate Costs

Invasive Plant Management (spot removals and treatments for knotweed, ivy, cherry-laurel, and yellow lamium)	$15,000
Existing Side Channel Enhancement and Pond 60 m x $200/m (channel) + $25,000 (pond)	$37,000
New Off-channel Pond on Right Bank 30 m x $200/m (channel) + $25,000 (pond) + $8,000 (planting)	$38,000
Instream Complexing 6 structures x $5000 ea.	$30,000
New Side Channel and Pond on Left Bank 50 m x $200/m (channel) + $8,000 (pond) + $2500 (planting)	$22,500
TOTAL	**$142,500**



Priority Project 2: Pioneer Park Improvements

Project Overview

The middle reaches of Hastings Creek are the sections where the stream channel and riparian zones has been most altered by road crossings, channelization, and where riparian areas along the creek are narrow or non-existent. The small riparian area in Pioneer Park lacks native vegetation and is currently dominated by several invasive plants, including ivy, English holly, Sycamore maple, ivy, and periwinkle. Although small in size, Pioneer Park is an opportunity to address one fish passage issue, create a small new area of off-channel habitat (few opportunities exist to do so in this part of the watershed), and improve the quality of the riparian zone. The boulevard in front of the Community History Centre and adjacent to Lynn Valley Elementary School also offers an ideal location for a pilot rain garden project. As the only part of the creek running through the Lynn Valley Town Centre, this part of the creek also has the potential to act as a gateway to the creek and a showcase site for restoration and enhancement activities.

Identified Issues and Opportunities

- No-post barriers under Mountain Highway bridge are breaking apart and need to be replaced and reconfigured to maintain and improve fish passage.
- Large infestations of invasives, including ivy, holly, Sycamore maple, and periwinkle, and lack of native tree and shrub cover in riparian areas.
- Lack of off-channel habitat in this part of the watershed.
- Water quality impacts from LVTC north area outfall downstream of Mountain Highway and outfall from Institute Rd.

Potential Restoration Projects and Techniques

Short-term (0-5 years):

- Replace and re-configure concrete no-post barriers under Mountain Highway to maintain and improve fish passage.
- Remove invasive understory plants (ivy, holly, periwinkle) on both banks.
- Thin dense canopy of invasive sycamore maple trees to allow for increased light penetration and plant area with native conifers and riparian shrubs.

Medium-term (5-15 years):

- Create new 25 m^2 off-channel habitat pond in existing low area on north side of creek, just downstream of Mountain Highway.
- Install rain garden on boulevard in front of Community History Centre to infiltrate and treat water entering creek from Institute Rd area and adjacent parking lots. This would be an ideal location for a rain garden pilot project within the District.
- Construct a top-of-slope viewing platform with interpretive signage at edge of Pioneer Square to provide an "interpretive gateway" from Lynn Valley Town Centre to Hastings Creek.

(a) Existing no-post barriers to aid in fish passage under Mountain Highway bridge.

(b) Invasive ivy and sycamore maple found throughout forest understory in Pioneer Park.

(c) Low-bank area suitable for off-channel habitat creek on left bank just downstream of Mountain Highway.

(d) Existing channel from Institute Rd showing sediment deposition and possible location of water quality treatment pond.

(e) Existing LVTC north area outfall on right bank downstream of Mountain Highway.

(f) Boulevard in front of Community History Centre with opportunity for a rain garden pilot project.

Identified issues and opportunities in Priority Area 2.

Long-term (15-50 years):

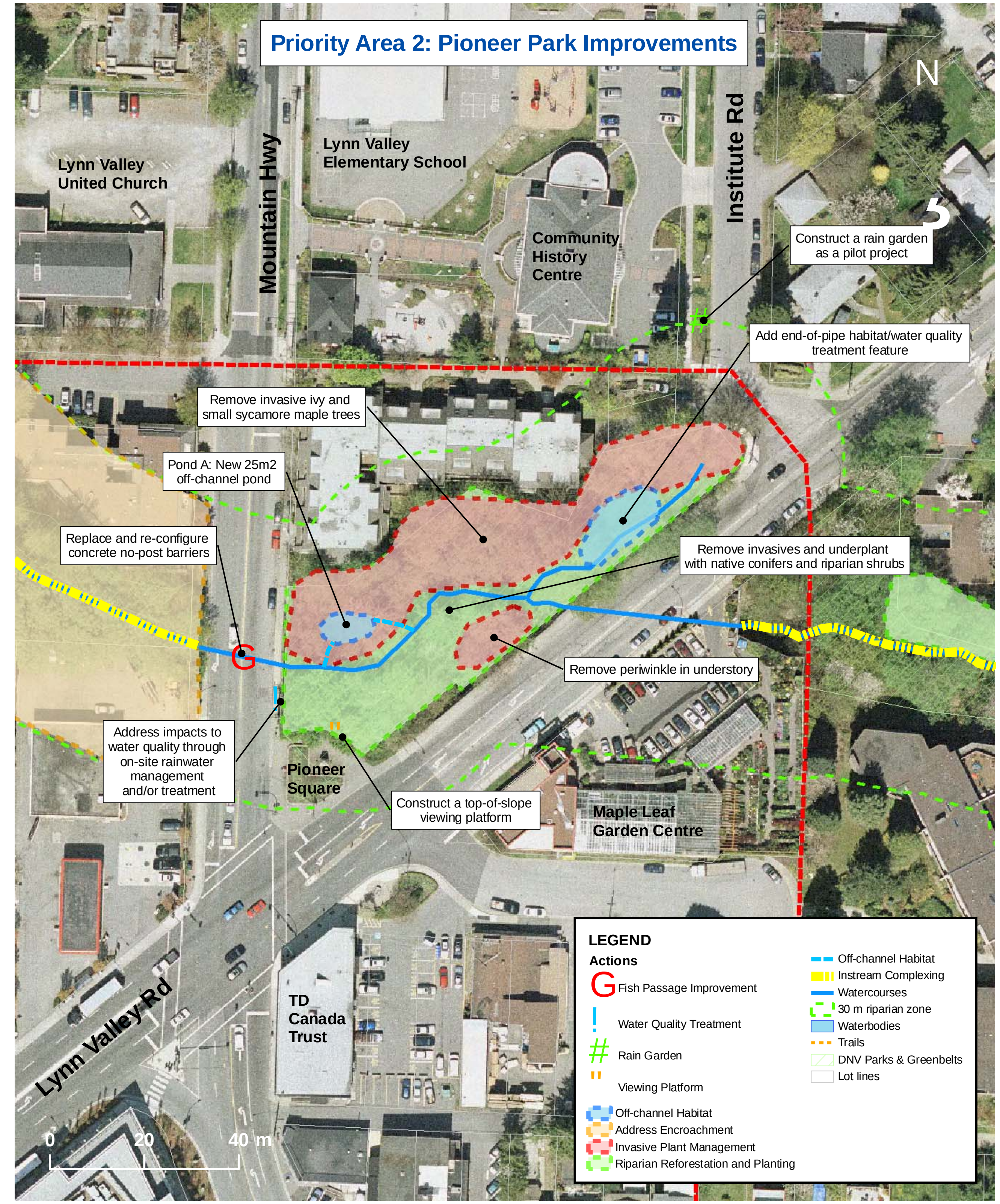
- Modify or replace Mountain Highway bridge to remove concrete-lined channel and replace with natural creek channel.
- Add end-of-pipe habitat / water quality treatment feature on existing outfall channel from Institute Rd, upstream of Lynn Valley Rd.

Ongoing (As Re-development Occurs):

- Increase width of riparian setbacks on both banks during re-development of area.
- Address impacts to water quality from Lynn Valley Mall area outfall on right bank downstream of Mountain Highway through implementation of on-site rainwater management and/or treatment.

Approximate Costs

No-post Barrier Replacement and Reconfiguration	$10,000
Invasive Plant Management and Tree Thinning (1600 m^2 x $7/$m^2$)	$11,200
Riparian Planting (1250 m^2 x $12/$m^2$)	$15,000
Off-channel Habitat Creation 15 m x $200/m (channel) + $10,000 (pond)	$13,000
Boulevard Rain Garden for Water Quality Treatment	$15,000
Viewing Platform and Interpretive Signage off of Pioneer Square area	$35,000
End-of-pipe Habitat / Water Quality Treatment Feature on Institute Rd outlet channel	$35,000
TOTAL	**$134,200**



Priority Project 3: Argyle School to Mountain Highway Instream and Riparian Improvements

Project Overview

This section of Hastings Creek, likely channelized historically as a result of logging activities and now having significant sections where banks have been stabilized, lacks habitat complexity, such as pools and instream cover. There is one site with severe bank erosion at a large bend in the creek and other sites where banks are eroding due to recreational use. There are low bank areas with houses very close to the creek in this area. Although some riparian areas are in good condition, other areas have been heavily impacted by recreation and have invasive plants such as knotweed, yellow lamium, holly, and cherry-laurel. This section is an opportunity to address bank erosion and flood protection, provide increased rearing habitat capacity that is generally lacking in the middle watershed by adding instream habitat complexity, as well as concurrently improving riparian areas and recreational opportunities and managing impacts of recreational use on the creek. There is also an opportunity to improve trail connectivity between the Lynn Valley Town Centre and upstream park areas along Hastings Creek (Hunter Park, Princess Park) during re-development.

Identified Issues and Opportunities

- Major bank erosion on left bank below footbridge at lower Argyle School playing field.
- Lack of instream complexity due to historic channelization and bank hardening.
- Recreational impacts from off-trail use and dog use.
- High number of invasives (yellow lamium, English holly, small-flowered impatiens, cherry-laurel) and denuded understory vegetation in park area west of creek and north of Harold Rd cul-de-sac.
- Small number of knotweed stands noted along creek upstream of Harold Rd footbridge.

Potential Restoration Projects and Techniques

Short-term (0-5 years):

- Stabilize 25 m of major bank erosion on left bank downstream of footbridge.
- Remove spot areas with knotweed scattered along creek upstream of Harold Rd footbridge.
- Remove spot invasives in park area west of creek and north of Harold Rd cul-de-sac, place new soil in compacted areas, and replant with native shrubs.

Medium-term (5-15 years):

- Add 8-10 instream complexing structures (large wood or boulder clusters) between Mountain Highway and footbridge at lower Argyle School playing field.
- Add end-of-pipe habitat / water quality treatment feature in park area west of creek and north of Harold Rd cul-de-sac and divert base flows from existing outfall at Harold Rd into it.
- Define and, where possible, relocate trail away from unstable right bank between Harold St and footbridge at lower Argyle School playing field.


(a) Bank erosion below footbridge at lower Argyle School playing field.


(b) Lamium infestation in parkland west of Hastings Creek and north of Harold Rd cul-de-sac.


(c) Denuded understory area in parkland west of Hastings Creek and north of Harold Rd cul-de-sac.


(d) Lack of instream complexity upstream of Mountain Highway bridge.


(e) Lack of channel complexity upstream of Harold Rd footbridge.


(f) Trail beside creek showing width, close proximity to unstable bank, and impacts to streamside vegetation.

Identified issues and opportunities in Priority Area 3.

- Fence entire length of trail along right bank to reduce bank erosion from recreational and dog use. Replant bank areas between fence and creek with native riparian shrubs to reduce erosion and restore overhanging vegetation.
- Define trail (using surfacing or fencing) south of Argyle School playing fields and replant denuded areas with native conifers and riparian shrubs.
- Add end-of-pipe habitat / water quality treatment feature on old Argyle School parking lot area to and divert baseflows from Kendel Pl into it.

Long-term (15-50 years):

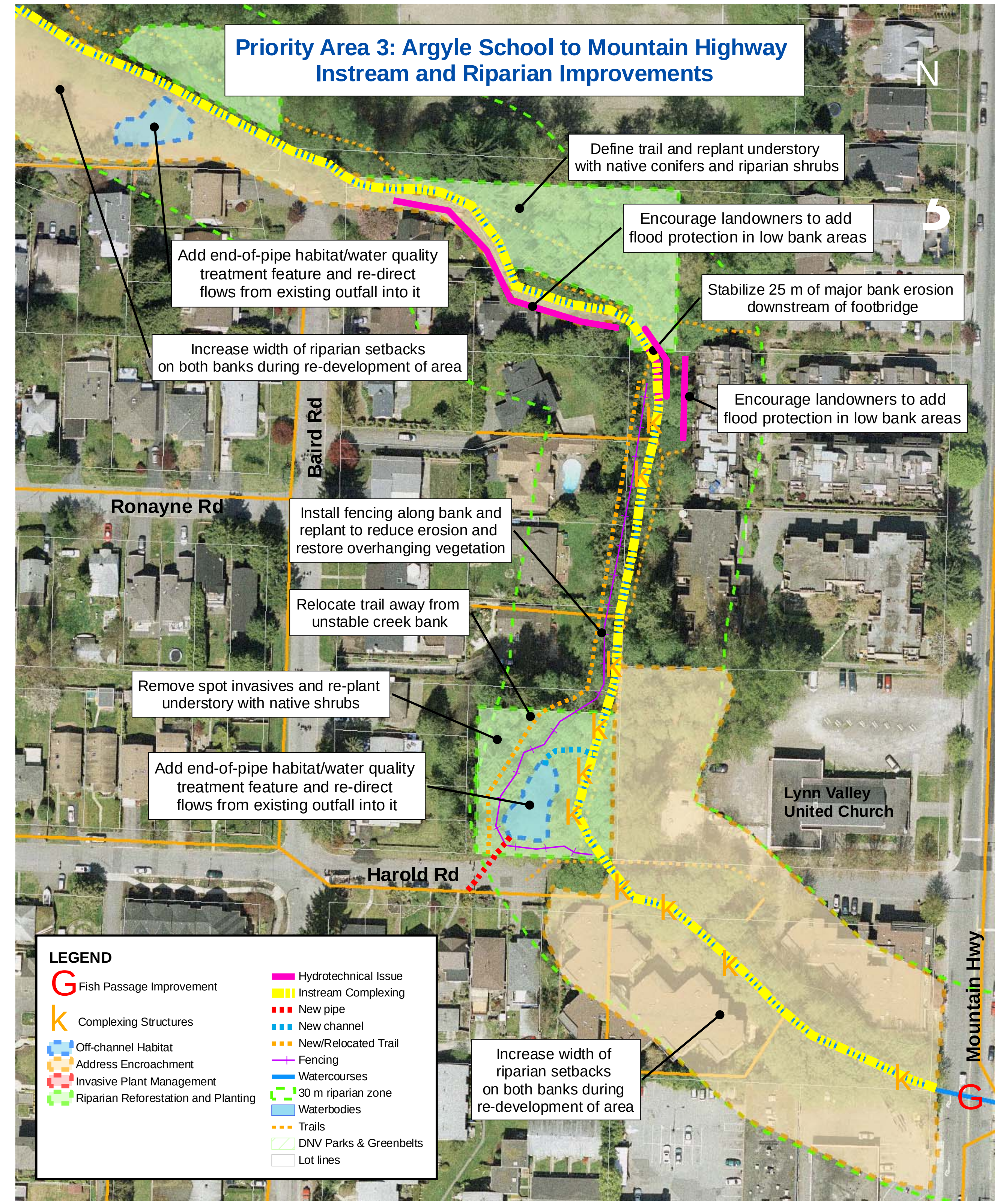
- None.

Ongoing (As Re-development Occurs):

- Encourage landowners to add flood protection measures in low bank area where houses and condo development are close to creek.
- Increase width of riparian setbacks on both banks during re-development of area.
- Create connection between Lynn Valley Town Centre to creekside trail as part of creation of recreational corridor to park areas further upstream.

Approximate Costs

Bank Stabilization (25 m long x 1.5 m high)	$75,000
Invasive Plant Management, Soil Placement, and Native Plantings 200 m^2 x $7/$m^2$ (invasives) + 400 m^2 x 17/m^2 (soil and plantings)	$8,200
Instream Complexing 8 structures x $5000 ea.	$40,000
End-of-pipe Habitat / Water Quality Treatment Feature on Harold Rd outfall	$75,000
Trail Surfacing and Re-alignment -North of Harold creekside section (200 m^2 x $20/$m^2$) -Argyle field section (75 m^2 x $20/$m^2$)	 $4,000 $1,500
Trailside Fencing (200 m x $75/m)	$15,000
End-of-pipe Habitat / Water Quality Treatment Feature on Kendel Pl outfall	Costs to be borne by developer
TOTAL	**$218,700**



Priority Project 4: Hunter Park Geotechnical, Habitat, and Recreation Improvements

Project Overview

Hunter Park is one of the most important habitat areas in the watershed and District but also supports high levels of recreational and dog use. As a result, some habitat areas are being degraded and measures are needed to allow continued human use while protecting and restoring the habitat values of the park. A suite of recreational improvements and habitat protection measures are recommended combined with education of adjacent residents and park users using signage, mailouts, and other public awareness campaigns. Because of the public sensitivity regarding uses of this park, it is recommended a stakeholder process be undertaken to review and comment on the changes proposed.

Identified Issues and Opportunities

- Hunter Park contains some of the best instream fish habitat in the Hastings Creek watershed and as well as sensitive terrestrial habitats, such as skunk-cabbage swamps.
- One area of bank erosion below tree on right bank at “bubble pool” opposite Donovan Pond.
- West side of Deltalok wall that was used to create Donovan Pond is leaking and needs repair.
- Donovan Pond fish ladder is sinking and needs stabilization and ongoing maintenance.
- Riparian understory vegetation being degraded or lost in some areas due to recreational use.
- Invasive plants (yellow lamium, ivy) present although being managed in many areas by North Shore Streamkeepers.
- Poor water quality at Tennyson Cres outfall on south side of park.

Potential Restoration Projects and Techniques

Short-term (0-5 years):

- Assess and determine need for bank stabilization of right bank at “bubble pool” opposite Donovan Pond.
- Restore leaking Deltalok pond wall on west side of pond to help maintain adequate summer water levels.
- Repair Donovan Pond fish ladder and develop a maintenance schedule.
- Fence sensitive wetland areas (skunk cabbage swamps) to protect habitat values.
- Support existing invasive plant management efforts by North Shore Streamkeepers and revegetate priority understory areas with native trees and shrubs.
- Undertake stakeholder process regarding options for further trail development, meant to increase recreational capacity of the park while constraining use to low-impact areas and protecting areas with high habitat values.

Medium-term (5-15 years):

- Upgrade inlet channel on Donovan Pond to improve fish passage and remove excess sediment.
- Replace Donovan Pond fish ladder with upgraded outlet channel to improve fish passage and provide improved level control for shallow water mark.
- Add end-of-pipe habitat/water quality treatment feature on outfall from Tennyson Cres and divert base flows from storm system into it.

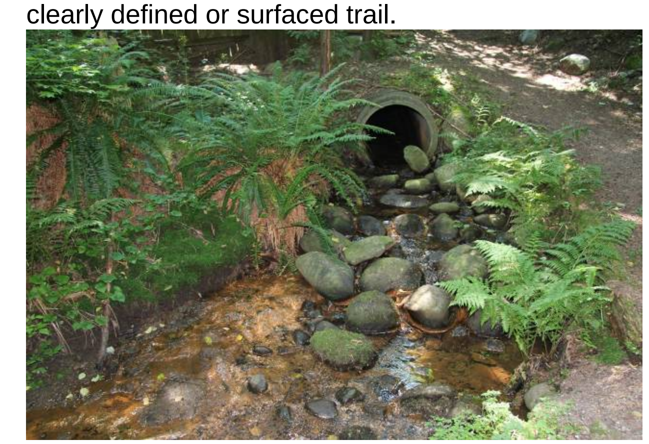

(a) Sensitive skunk-cabbage swamp areas within Hunter Park.


(b) Area of bank erosion on right bank at “bubble pool” opposite Donovan Pond.


(c) Sinking fish ladder on Donovan Pond outlet channel.


(d) Wide denuded understory area on north side of creek due to heavy use of this area as a trail but no clearly defined or surfaced trail.


(e) Beach area along trail used to access creek for human crossings and dog use.


(f) Poor water quality from Tennyson Cres outfall.

Identified issues and opportunities in Priority Area 4.

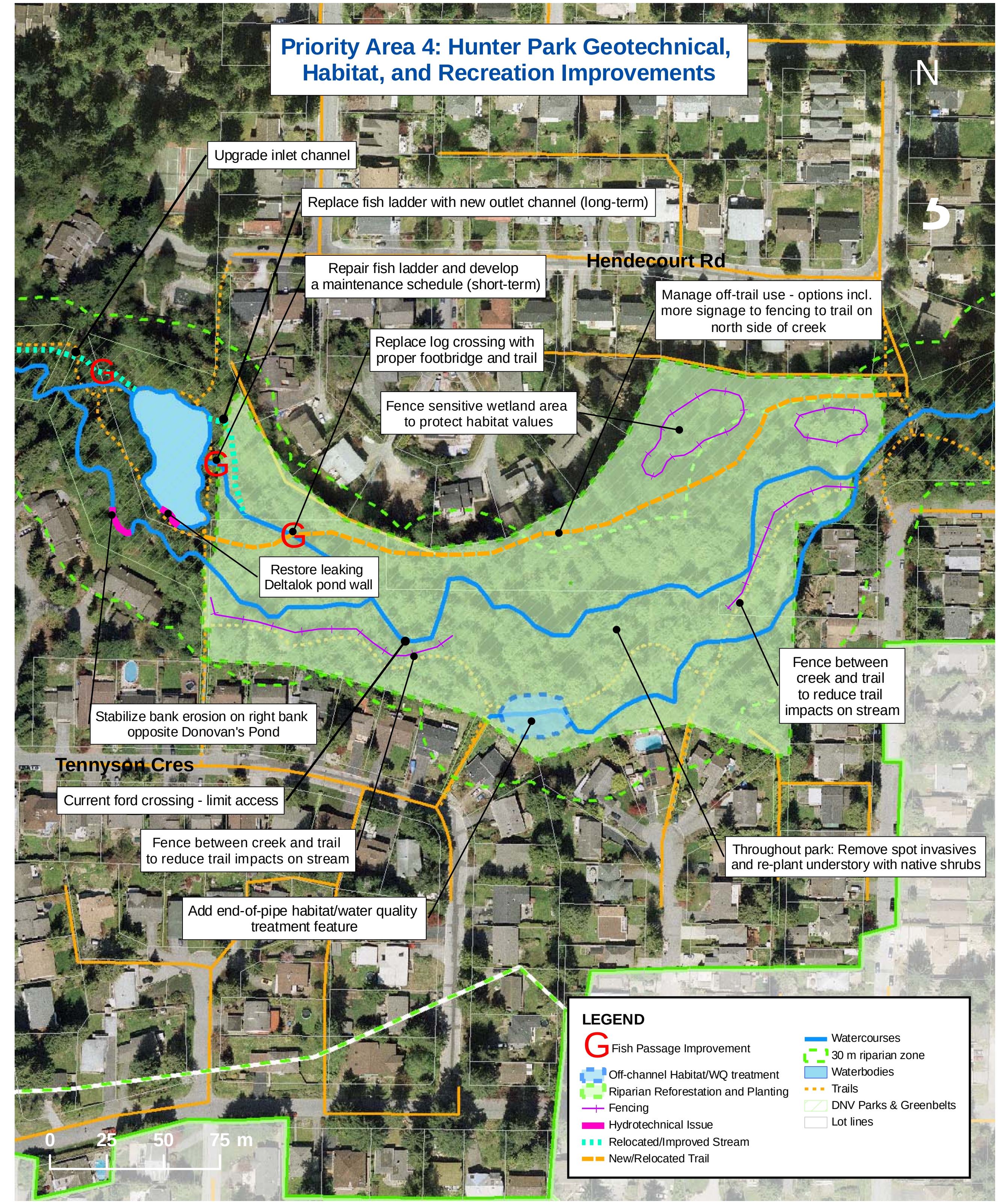
- Implement identified options from planning process to manage off-trail use, particularly on the north side of the creek. Options include user education, signage, fencing, trail resurfacing, or creation of a new trail on the north side of the creek to create a “loop trail” through the entire park.

Long-term (15-50 years):

- Purchase lot upstream of Fromme Rd on north side of creek and demolish house to widen creek corridor and reduce flood risk.

Approximate Costs

Assess and Address Bank Stabilization Requirements	$25,000
Pond Wall Leak Repair	$35,000
Fish Ladder Stabilization and Maintenance	$7,500
Fencing of Wetland Areas (200 m x $75/m)	$15,000
Invasive Plant Management, Soil Placement, and Native Plantings -Invasive plant management: $7/m^2 (depends on species) -Soil placement: $5m^2 -Plantings: $12/m^2	$15,000
Upgrade Donovan Pond Inlet Channel	$10,000
Upgrade Donovan Pond Outlet Channel	$15,000
End-of-pipe Habitat / Water Quality Treatment Feature on Tennyson Cres outfall	$25,000
Additional Recreation Impact Reduction Measures -User Education -Signage ($500/sign) -Trail Resurfacing ($20/m^2) -Fencing ($75/m) -Trail Creation	$75,000
Purchase lot on north side of creek upstream of Fromme Rd	$750,000
TOTAL	$972,500



Priority Project 5: Coleman Creek Fish Passage and Instream Habitat Improvements

Project Overview

Coleman Creek, as the only tributary of Hastings Creek accessible to anadromous fish species, contains important additional habitat for coho spawning and rearing. However, several degrading channel structures limit upstream fish passage and could be addressed. Habitat complexity is also lacking in some sections and could be improved. There are also two areas of significant bank erosion along this tributary that need addressing. Opportunities also exist to improve the quality of the riparian zone through removing invasive plants (knotweed, cherry-laurel, Japanese coltsfoot) and planting native species.

Identified Issues and Opportunities

- Wood weir dam 80 m downstream of Lynn Valley Rd limits fish passage to upstream areas. Dam and upstream ponds are no longer maintained. Pond retaining walls are failing and old ponds are filling in with gravel. Dam appears to be affecting gravel composition downstream (mostly fines).
- Old corrugated steel culvert 30 m downstream of Lynn Valley Rd is no longer needed and could be removed.
- Lack of instream habitat complexity in portions of lower Coleman Creek.
- Large number of invasives, including knotweed, cherry-laurel, yellow lamium, Japanese coltsfoot, and small-flowered impatiens.
- Isolated problems with yard waste dumping.

Potential Restoration Projects and Techniques

Short-term (0-5 years):

- Remove or treat priority invasive plants, particularly knotweed and yellow lamium patches.
- Work with individual landowners to address yard waste dumping and manage invasive plants (ivy, yellow lamium) extending into riparian area.
- Remove wood weir dam to allow upstream fish passage.
- Remove corrugated steel culvert and restore section of stream.
- Address two major bank erosion areas on left bank upstream and downstream of Harold Rd footbridge.

Medium-term (5-15 years):

- Restore pond area with retaining walls upstream of wood weir dam (Option A) to natural stream channel or relocate stream channel into DNV greenbelt (Option B).
- Add 4 instream complexing structures (large wood or boulder clusters) in channel at key locations upstream and downstream of Harold Rd footbridge.
- Define trail (using surfacing or fencing) along east side of Coleman Creek as well as in vicinity of Harold Rd footbridge and replant denuded areas with native conifers and riparian shrubs.

(a) Wood weir dam limiting fish passage to Coleman Creek upstream.

(b) Failing retaining walls on ponds upstream of wood weir dam.

(c) Corrugated steel culvert downstream of Lynn Valley Rd which is no longer needed and could be removed.

(d) Lack of instream complexity and sediment deposition in lower Coleman Creek in vicinity of Harold Rd footbridge.

(e) Bank erosion and instability on left bank of Coleman Creek downstream of Harold Rd footbridge.

(f) Bank erosion and instability on left bank of Coleman Creek upstream of Harold Rd footbridge.

Identified issues and opportunities in Priority Area 5.

Long-term (15-50 years):

- Improve fish passage through Lynn Valley Rd culvert through addition of baffles or culvert replacement.

Ongoing (As Re-development Occurs):

- Increase width of riparian setbacks on both banks during any future re-development in the area.

Approximate Costs

Invasive Plant Management	$5,000
Wood Weir Dam Removal	$7,500
Steel Culvert Removal and Channel Restoration 5 m x $1200/m	$6,000
Bank Stabilization -Downstream of Harold Rd footbridge -Upstream of Harold Rd footbridge	 $30,000 $35,000
Pond Rehabilitation or Channel Relocation	$35,000
Instream Complexing 4-6 structures x $3500 ea.	$20,000
Trail Definition and Habitat Restoration: -Trail Definition (120 m x $20/m) -Soil placement and native plantings (150 m^2 x $17/m^2$)	$5,000
TOTAL	$143,500

Priority Project 6: Argyle School – Kilmer Creek Daylighting

Project Overview

The habitat assessment identified off-channel habitat is generally lacking in the watershed and that rearing habitat is lacking in the middle reaches of the watershed. The longest culvert in the Hastings Creek watershed is located on Kilmer Creek between Fredrick Road and Hastings Creek. This culvert runs under the western portion of Argyle School and under a small infill subdivision directly south.

This project could represent the largest potential instream habitat gain in Hastings Creek, and could be designed to create the most desirable habitat required. While this project is ambitious, it addresses a long term debris maintenance issue at the upstream end of the culvert(s) at Fredrick Road, and would be a great benefit for the system. This project has substantial challenges, but immediate opportunities. The North Vancouver School District is planning to renovate/rebuild portions of Argyle School. Based on this current proposed development, the School District may be able to incorporate a vision of a sustainable school site, where development has considered the natural environment.

As part of the project scoping, Ian Abercrombie, Director of Facilities and Planning for the School District was contacted. The School District has proposed to completely replace Argyle School; however, Argyle has only currently been approved for a detailed seismic review and upgrade. Depending on the outcome of the detailed review, large portions of the school may require substantial renovation or reconstruction. They foresee that a major project will occur at Argyle School in about a 5 year period.

If the school were reconstructed, the new school would be constructed on the eastern playing fields and the western-side of the school grounds used for future athletic fields. Any incorporation of creek daylighting would need to consider the functionality of the school, and one opportunity could be the alignment of the creek between the school and playfields. While the School District could incorporate the vision into their plans, project funding would likely have to come from the District.

This work could be planned together with trail and footbridge realignments associated with pending development of School District land at the east end of the Wendel Place cul-de-sac.

Identified Issues and Opportunities

- Lack of instream habitat and fish passage due to 150 m culvert.
- Problematic debris rack at inlet to culvert on Kilmer Creek.

Potential Restoration Projects and Techniques

Medium-term (5-15 years):

- Replace culvert under Fredrick Road with a new concrete box or open-bottom concrete culvert.
- Construct 250 m long creek channel to provide fish habitat and passage;
- Construct off channel rearing areas near the new confluence.
- Develop a functional riparian area across the school grounds to enhance the new channel and the school grounds simultaneously.

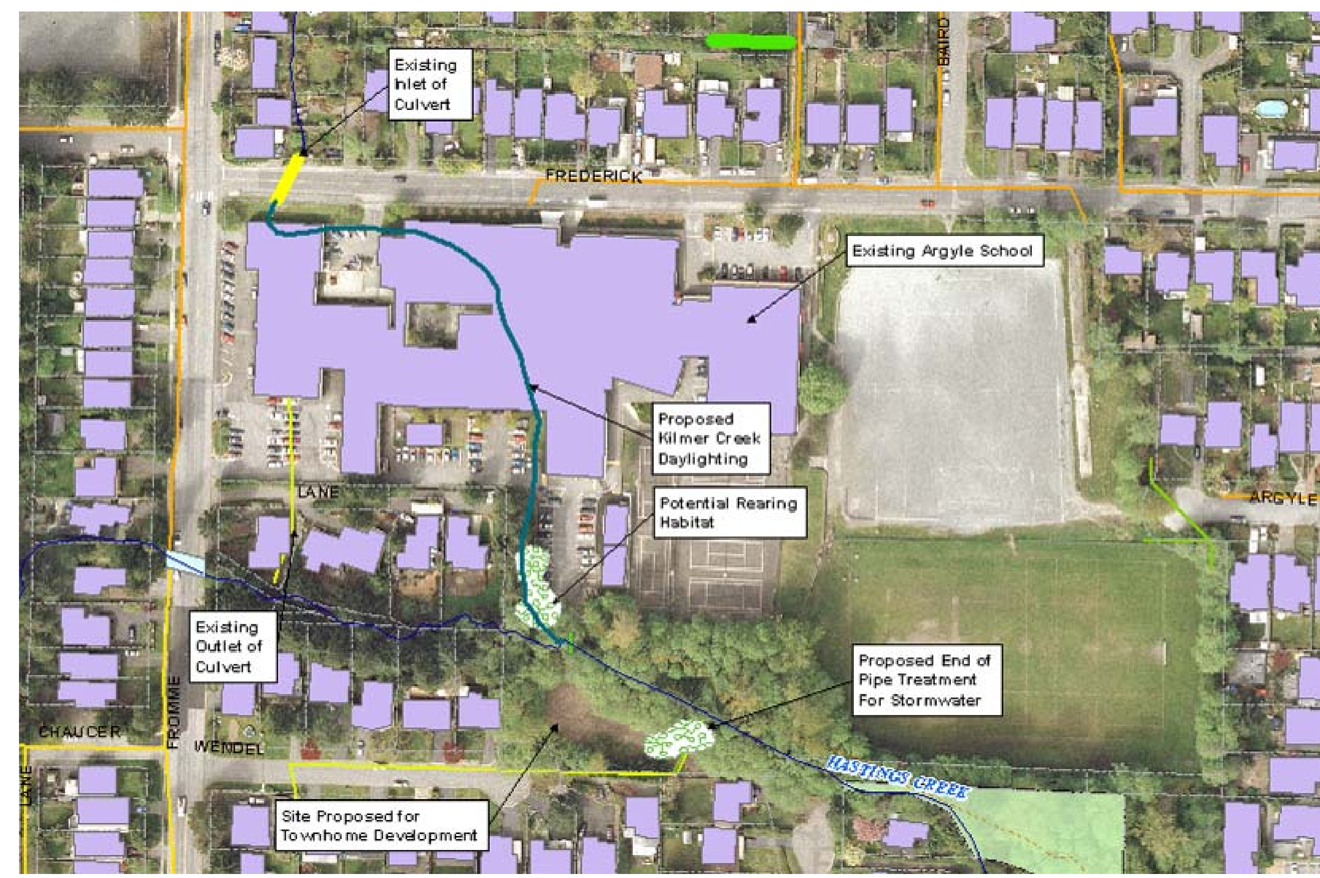
(a) Oultet of Kilmer Creek culvert at Argyle School.

(b) Existing inlet to culvert at Fredrick Road.

Identified issues and opportunities in Priority Area 6.

Approximate Costs

Box Culvert	$350,000
Creek Daylighting	$500,000
Off-channel Pond on Right Bank	$75,000



Priority Project 7: Flood and Erosion Projects

Project Overview

The hydrotechnical assessment resulted in three types of projects:

1. Culvert upgrading or replacement projects;
2. Bank erosion and protection at bridge site projects
3. Flood protection related projects

Culvert Upgrading or Replacement

Seven priority culverts were identified for upgrading or replacement the following table summarizes the culvert and proposed scope presented earlier

Hoskins Creek at Kilkenny Road: Open cut replacement with 1.2 m by 1.2 m box culvert complete with baffles	$400,000
Hoskins Creek at Ross Road: Open cut replacement with 1.2 m by 1.2 m box culvert complete with baffles	$475,000
Coleman Creek at McNair: 900 mm diameter wood stave culvert sliplining, and inlet headwall upgrades.	$85,000
Coleman Creek at 1344 Coleman Street: 2 - 750 mm diameter culvert is located on private property and only conveys 43% of the 200-year peak flow. A 1200 by 900 mm culvert replacement would address capacity	$175,000
Coleman Creek at Evelyn Street: This 2 - 900 mm diameter culvert is confined on both upstream and downstream sides by private property amenities. Inlet improvements and sliplining could be feasible.	$85,000
Dyer Creek at Braemar Road is undersized, while this crossing is substantially undersized, the culvert is contained in a broad valley and flooding woud have lower consequences. Upgrades to the inlet headworks to improve efficiency could be effective in improving capacity without replacing the crossing.	$65,000
Dunnell Creek at Braemar Road is undersized like the Dyer Creek culvert and should be considered for headworks improvements.	$65,000
TOTAL (including Engineering Costs)	**$1,350,000**

Note: this list does not include Thames Creek at Mill Street, which presently requires maintenance to forestall replacement. This was assessed previously and roughly $60,000 was estimated for channel improvements to stabilize the channel and provide fish passage, $150,000 was estimated for culvert replacement, and $125,000 for replacement with a footbridge.

Bank Erosion and Protection at Bridge Sites

Three bank erosion sites at footbridges were identified, these are relatively minor and are summarized in the following table:

Footbridge upstream of Donovan Pond	$10,000
Footbridge downstream of Argyle School	$25,000
Footbridge near Harold Road	$18,000
TOTAL (including Engineering Costs)	**$53,000**

Other bank protection project may be undertaken and could include bioengineering works or habitat enhancement features. Costs for these types are projects are dependent on access and scale, but two standard bioengineering approaches include vegetated geogrids, and brush layers

(a) Typical vegetated geogrid at New Brighton Park

(b) Brush layer treatment on Seymour River.

For these projects, vegetated geogrids could be about $500/lin.m (about 1 m high) whereas brush layering could be about $75/lin.m per layer.

Flood Protection Projects

While no specific capital works are proposed for flood protection, two recommendations were made for Hastings Creek between Fromme Road and Mountain Highway.

Prepare Hec-Ras model for reach based on District survey data	$10,000
Work with District planning and risk management to establish DPA area is indicated by model results	$5,000
TOTAL	**$15,000**

Priority Project 8: Low Impact Development (LID) and Stream Corridor Projects

Project Overview

A total of ten projects were developed to improve stream health through either construction of LID facilities and/or creating habitat opportunities. This section provides a quick concept view of the area and a summary of costs and two of the projects are shown on Priority Area 6. The descriptions are provided in the text.

(a) Current off-set fish baffles under Mountain Highway

(b) Concept for LID facility at Viewlynn Park – proposed surface and subsurface facility with new stormmain along Viewlynn Road

(c) Outfall from Princess Park (south) at Hunter Park – Proposed treatment wetland and possible off channel habitat

(d) Outfall at Harold Road proposed treatment wetland and possible off channel habitat.

(e) Concept for LID facility at Lynn Valley Park – proposed surface and subsurface facility

(f) Outfall at Institute Road proposed treatment wetland

(g) Concept for attenuation facility in Draycott Park – some storm sewer work on Westover Road could move more discharge here.

Approximate Costs

Lynn Valley Road Fish Passage Reconstruction	$95,000
Outfall from Lynn Valley Town Centre area at 27th Street: Off Line Treatment	$700,000
Outfall from Princess Park (south) at Hunter Park end of pipe treatment	$180,000
Outfall at Harold Road	$75,000
Outfall at Institute Road and Mountain Highway	$90,000
Institute Road at South-East corner of playfields	$400,000
Draycott Park stormwater attenuation areas.	$250,000
TOTAL (Including Engineering)	**$1,790,000**

Engineering Based Projects

Flood: Based on the review of all culverts, there are 25 culverts of varying size and condition that do not meet the 200-year return period criteria. Based on this screening, eight priority culverts were identified for consideration in implementation plan. While some older culverts constructed could be upgraded through sliplining or other trenchless methods, the following culverts will likely require traditional cut and cover replacement:

1. Hoskins Creek at Kilkenny Road: This 1200 mm diameter wood stave is undersized (66% of 200-year capacity) and is further impaired by a downstream backwater condition. It is probably that this culvert could fail catastrophically at an unpredictable time.
2. Hoskins Creek at Ross Road: These 3 - 600 mm concrete culverts only meet 44% of the 200-year capacity and are prone to blockage.
3. Coleman Creek at McNair: 900 mm diameter wood stave culvert only conveys 34% of the 200-year peak flow, and could be prone to failure. This crossing could be considered for an interim sliplining, provided the inlet is improved to increase capacity.
4. Coleman Creek at 1344 Coleman Street: This 2 - 750 mm diameter culvert is located on private property and only conveys 43% of the 200-year peak flow. A detailed inspection of this culvert should be undertaken with appropriate permissions.
5. Coleman Creek at Evenlyn Street: This 2 - 900 mm diameter culvert is confined on both upstream and downstream sides by private property amenities. Inlet improvements and sliplining could be feasible.
6. "Draycott Creek": There are two 300 mm diameter culverts in Draycott Park that could be problematic in larger events. These structures have created backwater areas that could be resolved through upgrades. These sites should consider potentially retaining more stormwater as an attenuation project.

Erosion: Erosion is occurring throughout the Hastings Creek watershed, and adjacent to both District and private infrastructure. The highest priority erosion sites should be focused at:

1. Footbridge downstream of Argyle School (and downstream condo areas)
2. Footbridge near Harold Road
3. Footbridge upstream of Donovan Pond

Erosion at bridges can be limited to standard riprap bank protection, but other bank protection works could be implemented through the watershed at the numerous trail locations. Other bank protection works should incorporate instream and riparian habitat features that include:

- boulder scale roughness and refugia;
- embedded large wood and cover structures;
- riparian planting through bioengineering techniques.

Bank protection is made more complex through access. Easy to access sites will be overall lower cost, and access and restoration could comprise 50% of the overall cost in complex areas.

Action No.	Action	Priority	Timeline	Identified By
A1-1	Work with landowners to address yard waste dumping and manage invasive plants (ivy, yellow lamium) extending down ravine slope into riparian area.	Medium	5-15 years	RAE
A1-2	Monitor Denil fishway at Hoskins Rd culvert for blockages	High	Ongoing	RAE / NSSK
A1-3	Major knotweed infestation in channel and adjacent riparian area. Explore management options including herbicide treatment (if an acceptable option within stream channel).	High	0-5 years	RAE
A1-4	Reduce encroachment of backyard structures and landscape features into creek from houses along Carmaria Court.	Medium	5-15 years	RAE
A1-5	Install fencing where Hastings Creek Trail is adjacent to creek and/or relocate trail to reduce trail impacts on stream.	Low	5-15 years	RAE

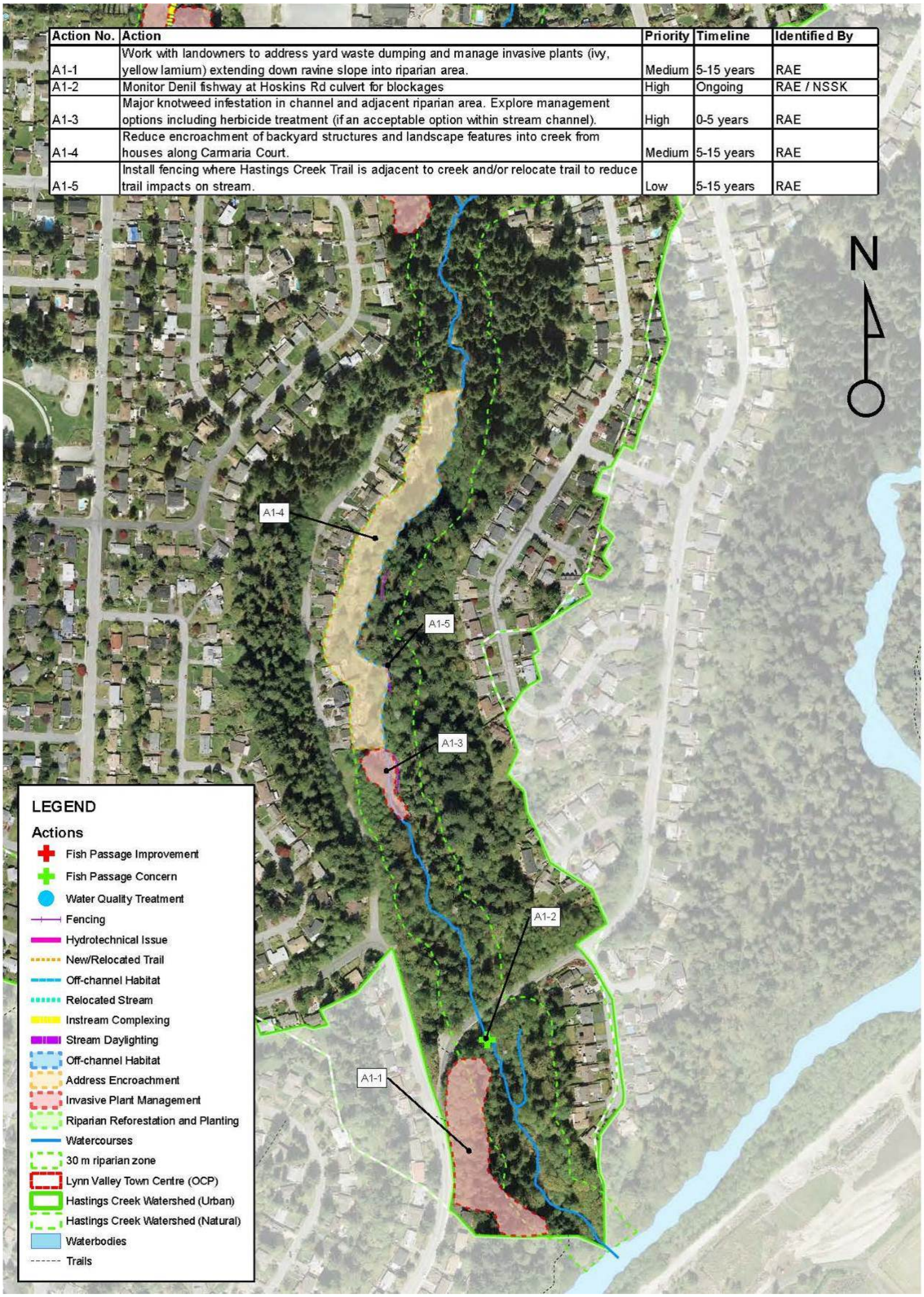
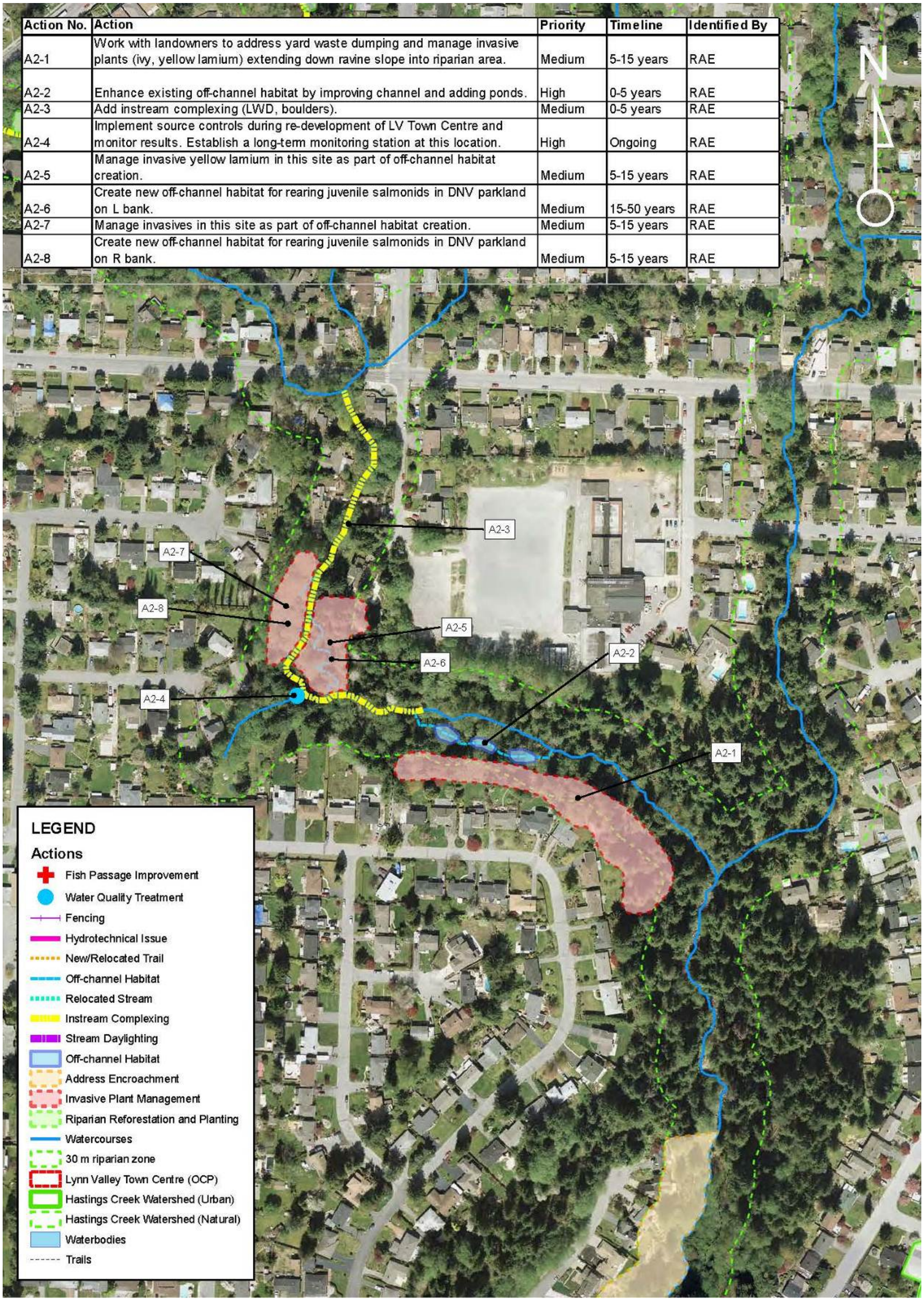
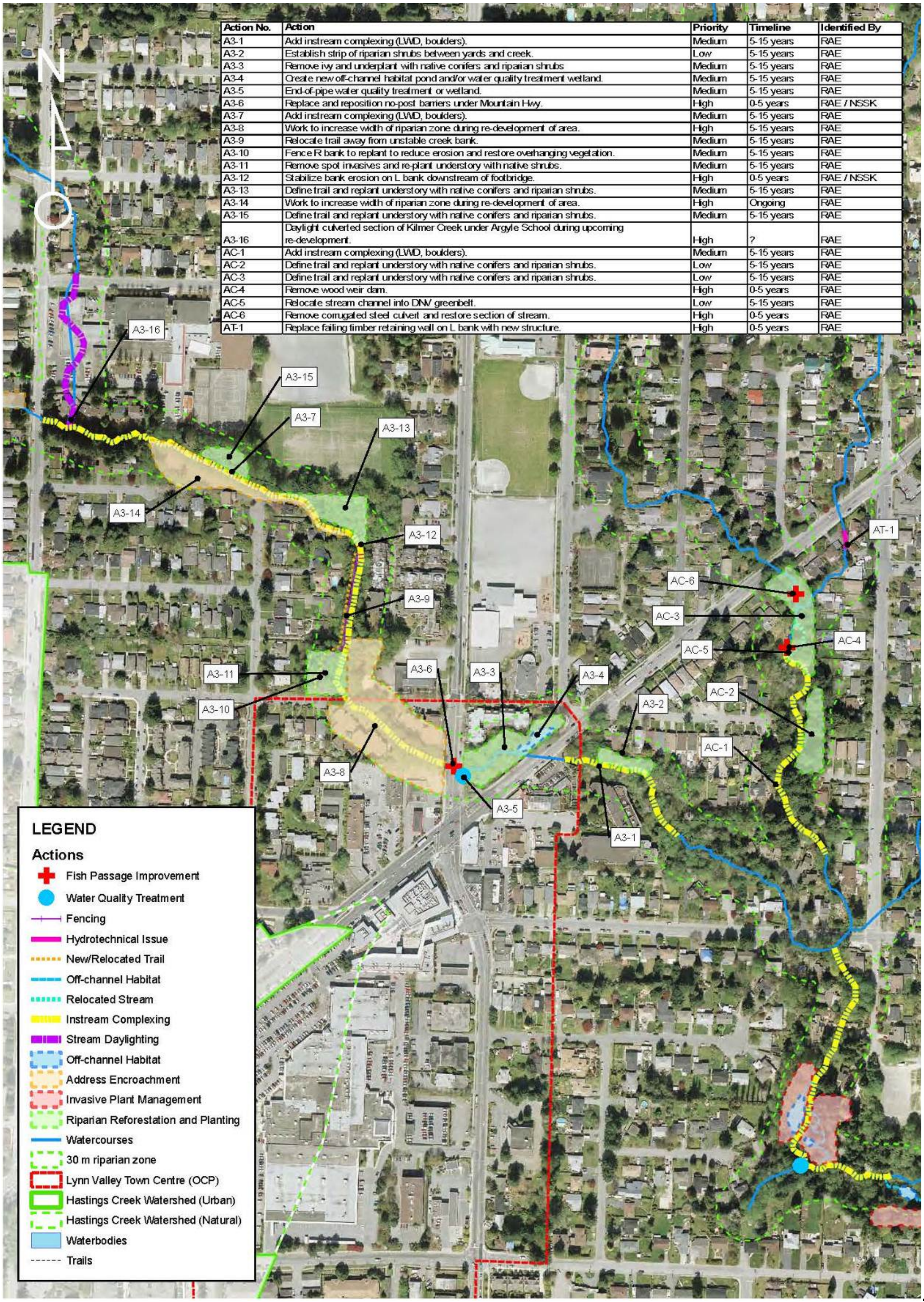


Figure 4-2. Habitat restoration and enhancement opportunities: Hastings Creek - Section 1.



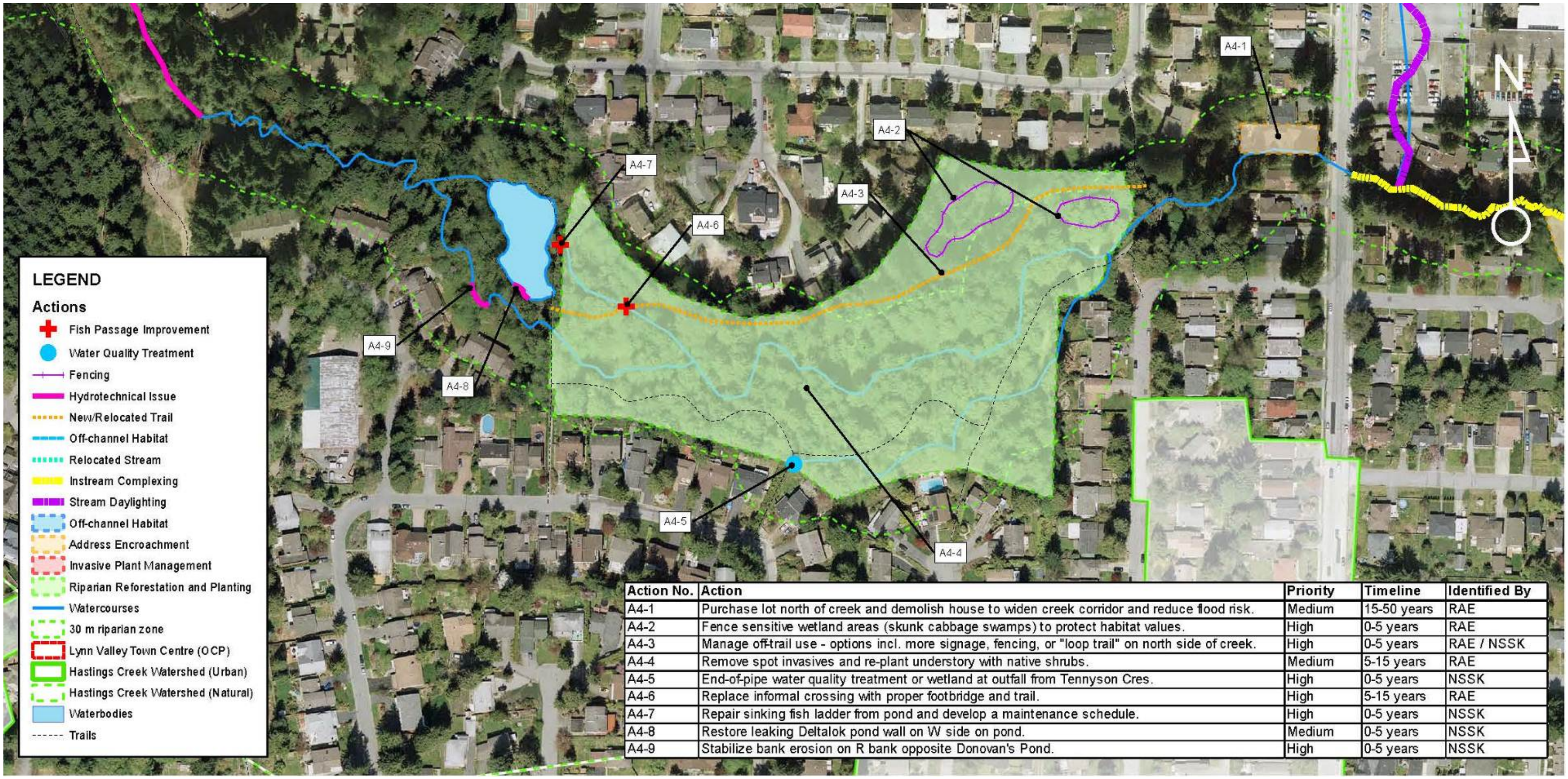
Action No.	Action	Priority	Timeline	Identified By
A2-1	Work with landowners to address yard waste dumping and manage invasive plants (ivy, yellow lamium) extending down ravine slope into riparian area.	Medium	5-15 years	RAE
A2-2	Enhance existing off-channel habitat by improving channel and adding ponds.	High	0-5 years	RAE
A2-3	Add instream complexing (LWD, boulders).	Medium	0-5 years	RAE
A2-4	Implement source controls during re-development of LV Town Centre and monitor results. Establish a long-term monitoring station at this location.	High	Ongoing	RAE
A2-5	Manage invasive yellow lamium in this site as part of off-channel habitat creation.	Medium	5-15 years	RAE
A2-6	Create new off-channel habitat for rearing juvenile salmonids in DNV parkland on L bank.	Medium	15-50 years	RAE
A2-7	Manage invasives in this site as part of off-channel habitat creation.	Medium	5-15 years	RAE
A2-8	Create new off-channel habitat for rearing juvenile salmonids in DNV parkland on R bank.	Medium	5-15 years	RAE

Figure 4-3. Habitat restoration and enhancement opportunities: Hastings Creek - Section 2.



Action No.	Action	Priority	Timeline	Identified By
A3-1	Add instream complexing (LWD, boulders).	Medium	5-15 years	RAE
A3-2	Establish strip of riparian shrubs between yards and creek.	Low	5-15 years	RAE
A3-3	Remove ivy and underplant with native conifers and riparian shrubs	Medium	5-15 years	RAE
A3-4	Create new off-channel habitat pond and/or water quality treatment wetland.	Medium	5-15 years	RAE
A3-5	End-of-pipe water quality treatment or wetland.	Medium	5-15 years	RAE
A3-6	Replace and reposition no-post barriers under Mountain Hwy.	High	0-5 years	RAE / NSSK
A3-7	Add instream complexing (LWD, boulders).	Medium	5-15 years	RAE
A3-8	Work to increase width of riparian zone during re-development of area.	High	5-15 years	RAE
A3-9	Relocate trail away from unstable creek bank.	Medium	5-15 years	RAE
A3-10	Fence R bank to replant to reduce erosion and restore overhanging vegetation.	Medium	5-15 years	RAE
A3-11	Remove spot invasives and re-plant understory with native shrubs.	Medium	5-15 years	RAE
A3-12	Stabilize bank erosion on L bank downstream of footbridge.	High	0-5 years	RAE / NSSK
A3-13	Define trail and replant understory with native conifers and riparian shrubs.	Medium	5-15 years	RAE
A3-14	Work to increase width of riparian zone during re-development of area.	High	Ongoing	RAE
A3-15	Define trail and replant understory with native conifers and riparian shrubs.	Medium	5-15 years	RAE
A3-16	Daylight culverted section of Kilmer Creek under Argyle School during upcoming re-development.	High	?	RAE
AC-1	Add instream complexing (LWD, boulders).	Medium	5-15 years	RAE
AC-2	Define trail and replant understory with native conifers and riparian shrubs.	Low	5-15 years	RAE
AC-3	Define trail and replant understory with native conifers and riparian shrubs.	Low	5-15 years	RAE
AC-4	Remove wood weir dam.	High	0-5 years	RAE
AC-5	Relocate stream channel into DNV greenbelt.	Low	5-15 years	RAE
AC-6	Remove corrugated steel culvert and restore section of stream.	High	0-5 years	RAE
AT-1	Replace failing timber retaining wall on L bank with new structure.	High	0-5 years	RAE

Figure 4-4. Habitat restoration and enhancement opportunities: Hastings Creek - Section 3.



Action No.	Action	Priority	Timeline	Identified By
A4-1	Purchase lot north of creek and demolish house to widen creek corridor and reduce flood risk.	Medium	15-50 years	RAE
A4-2	Fence sensitive wetland areas (skunk cabbage swamps) to protect habitat values.	High	0-5 years	RAE
A4-3	Manage off-trail use - options incl. more signage, fencing, or "loop trail" on north side of creek.	High	0-5 years	RAE / NSSK
A4-4	Remove spot invasives and re-plant understory with native shrubs.	Medium	5-15 years	RAE
A4-5	End-of-pipe water quality treatment or wetland at outfall from Tennyson Cres.	High	0-5 years	NSSK
A4-6	Replace informal crossing with proper footbridge and trail.	High	5-15 years	RAE
A4-7	Repair sinking fish ladder from pond and develop a maintenance schedule.	High	0-5 years	NSSK
A4-8	Restore leaking Deltalok pond wall on W side on pond.	Medium	0-5 years	NSSK
A4-9	Stabilize bank erosion on R bank opposite Donovan's Pond.	High	0-5 years	NSSK

Figure 4-5. Habitat restoration and enhancement opportunities: Hastings Creek - Section 4.

PART 5. MONITORING

This section describes a strategy for monitoring stream and watershed condition in the Hastings Creek watershed in response to changing land use or stormwater management activities. 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. Monitoring and adaptive management are considered essential components of watershed management because of the lack of proven methods and technologies for maintaining or restoring ecological processes.

The recommended strategy is divided into primary monitoring approaches, as well as secondary monitoring approached that could be undertaken with more resources or to address a specific need.

Monitoring results should be provided to the public every 2 to 4 years through development of a web-based report card.

Primary Monitoring Approaches

Five monitoring approaches are recommended to measure the success of the ISMP in mitigating the impacts of future development:

1. Continuous stream discharge and precipitation monitoring;
2. Benthic invertebrate monitoring every 3 years;
3. Sediment quality monitoring every 3–5 years;
4. Watershed and riparian forest cover monitoring every 5 years; and
5. Annual fish population monitoring in Hunter Park and other reference sites.

Precipitation and Flow

Objective: Track changes to the rate and timing of stream discharge in relation to rainfall, land cover; measure seasonal or long-term climate differences.
Parameters: Precipitation (rain and snow) (mm/hr) and stream discharge (m^3/s)
Sites: Rainfall monitoring at Hastings rain gauge located north of Mountain Highway (since 2003); flow monitoring at Mountain Highway (since 2003); propose a second monitoring station in the LVTC outfall or at the Hoskins Road culvert to capture the changes in the LVTC (see discussion on Page 81)
Timing and Frequency: Continuous (5 minute interval) monitoring of rainfall and stream discharge.
Methods, Standards, and Analysis: Standard hydrometric data protocols (see Flowworks website for more information); calculation of flow metrics (see Hydrology section); regression analysis to detect trends.
Cost:

- $12,000 annually (for existing system); or
- $30,000 for new in-pipe (e.g. Flodar or ADCP type device) at the 27th Street outfall, with annual operating costs of $2,000 to address battery changes, and data cleaning; or
- $15,000 for a standard hydrometric station at Hoskins Road, and $7,500 per year for several years to develop a rating curve

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 (B-IBI: 10–50) and component metrics.
Sites: Single sample site (1 composite sample) within lower 500 m reach of Hastings Creek (starting at stream mouth).
Timing and Frequency: Summer baseflow sampling every 2 years starting in 2013.
Methods and Standards: Sampling according to Metro Vancouver benthic sampling method but refined to collect only one sample; identification of invertebrates to Washington State LPTL 1996 standard; 10 metric B-IBI calculation (Puget Sound standard); regression analysis to detect trends.
Cost: $1,250 per year ($750 for sampling and lab costs; $500 for reporting)

Sediment Quality (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.
Sites: seven sites including lower Hastings Creek; below LVTC outfall, above LVTC outfall, Hunter Park, upper watershed, lower Thames Creek, lower Coleman Creek
Timing and Frequency: every 2 years; no seasonal variation.
Methods, Standards, and Analysis: Comparison to BC Sediment Quality Guidelines; comparison to regional dataset for urban stream; trend analysis using regression after sufficient data is available.
Cost: $1,150 per year ($350 in field sampling; $300 in lab costs; $500 in reporting)

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.
Sites: Entire Hastings Creek watershed; subdivide into catchments if required.
Timing and Frequency: Every 6 years (less frequent if land use change is slow).
Methods, Standards, and Analysis: GIS mapping using recent orthophotos as per methods described in this report.
Cost: $1,500 per year (mapping and reporting)

Fish Population Monitoring
Objective: Measure changes to salmon and trout abundance in representative habitat areas.
Parameters: Species occurrence; Coho Salmon and Cutthroat Trout (fry, smolts, adults) abundance; biomass (g/m^2 or g/m^3)
Sites: Hunter Park; other sites if resources available
Timing and Frequency: adult spawner surveys in late fall (November and December), smolt trapping in May, and fry trapping in July.

Methods, Standards, and Analysis: Methods consistent with NSSK sampling sites and methods.
Cost: $500 for supplies and equipment (potential contribution from DNV to offset some material costs)

Secondary Monitoring Approaches

Depending on management activities and funding, additional monitoring could be undertaken to better measure changes in stream condition or water quality. Secondary monitoring approaches include:

Measurement of Stream Channel Change: The collection of detailed information on channel dimensions, substrate, and structure for this project using the Streamkeepers assessment methods can be repeated every 5 or 10 years to track channel change. This would be particularly valuable if channel conditions worsen or restoration activities are used to improve instream habitat.

Continuous Water Quality Monitoring: A water quality monitoring station at the outlet of the LVTC catchment would effectively track general water quality in the most urbanized stormwater catchment in the Hastings Creek watershed. Parameters could include temperature, conductivity, pH, dissolved oxygen, and turbidity. Continuous monitoring will be useful for tracking construction-related impacts during redevelopment activities, as well as the benefits of rainwater management incorporated into the new centre.

Fecal Coliform Monitoring: Bacteriological contamination is an ongoing health concern in most urban watersheds. Annual attainment monitoring (geometric mean of 5 samples in 30 days) is useful for measuring the potential effect of sanitary waste.