Overview & Level 1 Fish Habitat Assessment and Enhancement Opportunities

Brooklyn Creek Watershed, Comox, BC

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Executive Summary

This document contains a combined Overview and Level 1 Assessment Report for Brooklyn Creek (WC: 920-558600), which flows through the City of Courtenay, Comox Valley Regional District, and the Town of Comox. The mainstem of Brooklyn Creek originates from headwaters located in the Crown Isle Golf Course and associated development in the City of Courtenay, and the Park at Crown Isle (formerly called Longlands Golf Course) in the Comox Valley Regional District. The 6 km mainstem of Brooklyn Creek can be divided into three sections based on the predominant land use; the upper reach largely developed into golf courses, middle reach subjected to urban and agricultural development, and lower zone which is mostly in a natural state due to being predominately in a system of parks. This assessment focused on the bottom two zones beginning at the Anderton Road crossing (Reach 6, km 4+535) and ending where Brooklyn Creek enters the estuary in Baybrook Nature Park (tidal reach, km 0+000; Figure 1). The results of the Level 1 Assessment include a visual presence/absence fisheries assessment, and detailed reach descriptions that include the results of the habitat assessment and recommended enhancements for each of six reaches of the Brooklyn Creek mainstem (Figure 1).

Study objectives include:

a. assessing the status of historical enhancement project components and making recommendations for their repair or maintenance;
b. identifying limitations to fish productivity on a reach-by-reach basis; and
c. providing recommendations for new enhancement/restoration projects based on ground-level assessment results.

The overview assessment provides background information on geological and hydrological characteristics, land-use regime changes, and fish habitat enhancement efforts within the watershed. The Level 1 Assessment compares the quantitative values of critical habitat conditions for salmonids within each reach and characterizes the quality of the feature as *Poor*, *Fair*, or *Good*. The Level 1 Fish Habitat Assessment is based on methods adapted from Fish Habitat Assessment Procedures (FHAP) (Johnston & Slaney 1996) and Urban Salmon Habitat Program (USHP) Assessment Procedures (Michalski, Reid, & Stewart 1997). Enhancement/restoration recommendations (Section 6) are detailed by reach and chainage that include the proposed removal of potential barriers to fish migration, and restoration of reaches affected by residential development and agricultural practices.

The results of the Level 1 Assessment and visual fish presence assessment, undertaken in summer/fall 2021, showed that one of the assessed reaches received a *Good* rating (Reach 1), four of the assessed reaches received a *Fair* rating (Reaches 2 – 5), and one of the reaches received a *Poor* rating (Reach 6). Coho fry/parr, juvenile cutthroat trout, and threespine stickleback were observed in all of the reaches downstream of km 1+615, predominantly in deeper pools with cover. Limited observations of salmonids in the upper portion of Reach 3 (km 1+615 – 1+908) and in Reach 4 may be due to poor water quality associated with a sewage spill that has since been mitigated. We expect that fish production in Reaches 3 and 4 will recover following recent remediation efforts. Salmonids were visually observed in Reach 5 and 6 in low densities during the site surveys in late summer. Follow-up minnow trapping in Reach 6 in early September confirmed under-utilization in this reach with no salmonids captured in baited minnow traps soaked overnight.

Limiting factors to salmonid productivity across most assessed reaches include low LWD frequency and low % wetted area (low summer flows). Bank erosion and the loss of gravels is a significant concern in

Brooklyn Creek due to the confined and flashy system. The combination of high winter flows resulting from runoff from adjacent impervious surfaces and the lack of wetlands and off-channel habitats to hold and dissipate water has resulted in scouring and erosion, mobilization of limited spawning gravels, bedload accumulations, and decreasing bank stability. Additionally, invasive species are very pervasive throughout the watershed due to the residential and agricultural impacts throughout.

Proposed enhancement projects requiring instream modification should be directed by a Qualified Environmental Professional (QEP) and be preceded by a Level 2 Assessment (or equivalent) to help provide site specific prescriptions on proposed enhancement project components. The prioritization of enhancement projects should be based on the BCWS' current needs and capacities and should be discussed with their QEP in the period leading up to any Level 2 Assessment efforts. Proposed enhancement activities are detailed by reach but include the following general recommendations:

a. Removal of invasive plant species and planting appropriate native riparian plants.
b. Increasing hydraulic complexity by installation of instream Large Woody Debris (LWD)/Boulder complexes in pools that are currently lacking cover and habitat complexity.
c. Increasing pool frequency by construction of instream control weirs and riffles including gravel spawning platforms. Maintenance and repair of existing constructed riffles.
d. Increasing available overwintering habitat by creation of two off-channel habitats in Reach 2 and one off-channel habitat in Reach 3.
e. Gravel nourishment at select locations to address the overall lack of gravel recruitment in the watershed

The priority restoration/enhancement actions for Brooklyn Creek are as follows:

1. Adding spawning gravels, constructing riffles, improving channel conveyance and enhancing riparian areas in Reach 6 to improve salmonid rearing, spawning, and overwintering habitat in the section of Brooklyn Creek that runs through Birkdale Farm. This has been discussed with the landowner who is supportive of these works.
2. Repairing the existing fish ladder at Balmoral Road (upstream end of Reach 2) since there is surface flow disconnection, causing a potential fish barrier at low flows.
3. Creating pool/riffle complexes in the upper 293 m section of Reach 3, which currently has no habitat or bed complexity and is providing limited salmonid rearing opportunities.
4. Repairing and maintaining the constructed riffles in Reaches 2 and 3, since many of these are acting as potential low flow barriers to juvenile salmonid migration. Scouring of the toe rocks and a lack of gravels/pit run materials in the previously constructed riffles was a common observation throughout Reaches 2 and 3.
5. Removing invasive species throughout the watershed – specifically, removing Japanese knotweed, English ivy, and Himalayan blackberry in Reach 1, and removing English ivy in Reaches 2 and 3.
6. Creating off-channel habitats in Reach 2, by re-connecting the historical channels that are visible along the left bank of the reach.

Contents

1 Introduction

The Brooklyn Creek Watershed Society (BCWS) contracted Current Environmental Ltd. (CEL) to carry out a Level 1 Fish Habitat Assessment (the Assessment) including recommendations towards salmon habitat enhancement in the Brooklyn Creek Watershed (WC: 920-558600). The mainstem of Brooklyn Creek originates from headwaters located in and around the Crown Isle Golf Course and associated development in the City of Courtenay, and the Park at Crown Isle (formerly called Longlands Golf Course) in the Comox Valley Regional District (CVRD). The study area for this OL1 Assessment extends from Anderton Road to the Comox estuary, with the upstream end of the study area beginning east of Anderton Road (Figure 1). This document contains a combined Overview and Level 1 Assessment Report for the Brooklyn Creek watershed.

The objectives of this project were to complete an assessment of existing enhancement features, determine limiting factors to salmon productivity, and identify candidate locations for future restoration efforts. The overview assessment provides background information on geological and hydrological characteristics, land-use regime changes, and fish habitat enhancement efforts. These sections of the overview assessment are organized under the *Description of Study Area* heading (Section 2), whereas historical *Fisheries Information* such as distribution, life history, and abundance information based on escapement, hatchery production, and smolt outmigration data are compiled in Section 3.

The Level 1 Fish Habitat Assessment is based on methods described in Fish Habitat Assessment Procedures (FHAP) (Johnston & Slaney 1996) and Urban Salmon Habitat Program (USHP) Assessment Procedures (Michalski, Reid, & Stewart 1997) and was executed according to *Methods* detailed in Section 4. Changes were made to the FHAP and USHP methods, as discussed in Section 4.

The *Results* of the Level 1 Assessment are shown in Section 5 and include a limited presence/absence *Fisheries Assessment* (Section 5.1), *Water Quality Assessment* (Section 5.2), and detailed *Reach Descriptions* that include the results of the *Habitat Assessment* and *Recommended Enhancements* for each of the six reaches in the mainstem (Section 5.3). For ease of reading and reference, *Recommended Enhancements* for each reach are included under their individual descriptions (Section 5.3) while a *Discussion & Summary of Recommended Enhancements* table is separated into Section 6. Appendix A contains the raw quantitative data for each reach presented in USHP spreadsheet format. Previously constructed riffles were assessed in Reaches 1-4 and were scored to determine their condition and priority maintenance levels (Appendix B).

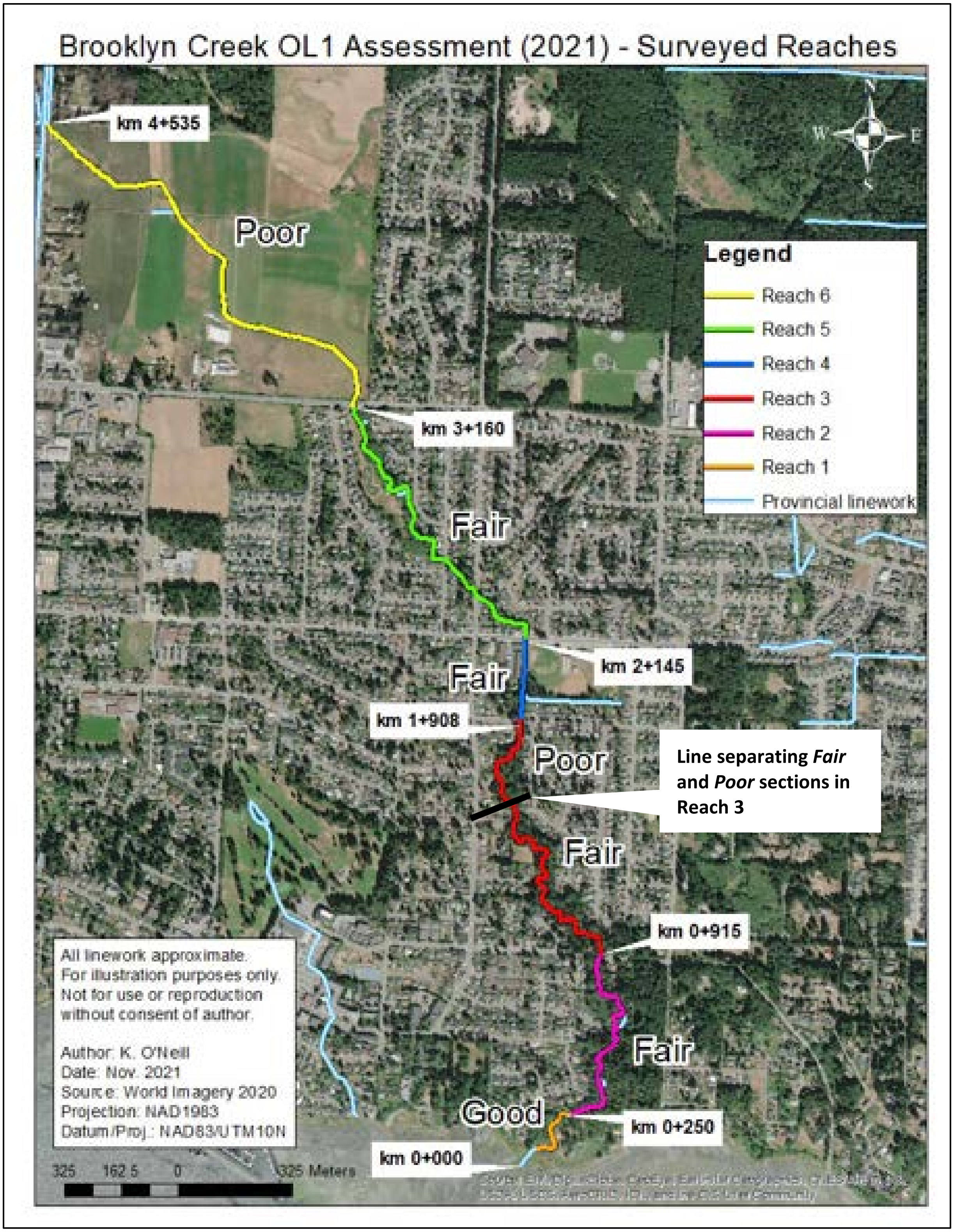

Figure 1. Assessment area overview showing assessed reaches during the 2021 Brooklyn Creek study, including overall ratings for each reach. Reach 3 has an overall *Fair* rating, however for the purposes of this map and enhancement opportunities it has two distinct segments – the lower portion of Reach 3 is *Fair*, while the upper 293 m of the reach is *Poor*, as described in Section 5 below.

1.1 Scope and limitations

1. The assessment focussed on the Brooklyn Creek watershed, covering the mainstem Brooklyn Creek from Anderton Road to the outlet at the estuary. Six reaches were surveyed in the mainstem channel, having been identified based on their morphological differences and/or human-made reach breaks (e.g. culvert road crossings). Many of these reaches were separated into multiple habitat units. The assessment area covers approximately 4.5 linear km of the mainstem. The majority of the linear channel was walked and assessed, with approximately 2-37% of each reach surveyed using the modified FHAP/USHP methods.

2. The primary objectives of this assessment include:

    a. assessing the status of historical enhancement project components and making recommendations for their repair or maintenance;
    b. identifying limitations to fish productivity on a reach-by-reach basis; and
    c. providing recommendations for new enhancement/restoration projects based on ground-level assessment results.

3. The methods used in the collection and treatment of habitat assessment data were adapted from the FHAP (Johnston & Slaney 1996) and *USHP Assessment Procedures* (Michalski, Reid, & Stewart 1997). A summarized account of the assessment procedures is in *Methods* (Section 4).

4. The assessment of instream features was timed to coincide with periods of low flow to help highlight habitat function (August – September 2021). The system is known to both contain reaches that are exposed to periods of late-summer low flow and periods of high peak flows during storm events; neither of which are ideally suited to understating how fish productivity is limited within the reaches.

5. The Fisheries Assessment was limited to a visual survey throughout the majority of the reaches, with a more detailed presence/absence survey conducted in Reach 6 using seven baited minnow traps (Section 5.1; Figure 4). The Fisheries Assessment was conducted in August and September 2021, prior to smolt out-migration. Fisheries Assessment information is not appropriate for use in abundance estimates but does help to show the distribution of some species in the watershed and the potential presence of downstream obstructions to fish passage.

2 Overview - Description of Study Area

The Brooklyn Creek watershed drains a catchment area of approximately 650 ha, making it the largest watershed in the Town of Comox (Wong 2012). The mainstem of Brooklyn Creek originates from headwaters located in and around the Crown Isle Golf Course and associated development in the City of Courtenay, and the Park at Crown Isle (formerly called Longlands Golf Course) in the Comox Valley Regional District (CVRD). Brooklyn Creek flows from a large detention pond within the Crown Isle development in a southeasterly direction through a 360 m culvert and into an open channel east of Parry Place, through major culvert crossings at Idiens Way and Anderton Road in the CVRD, and Guthrie Road, Salish Street, Pritchard Road, Noel Avenue, Dogwood Avenue, and Balmoral Avenue in the Town of Comox (van der Eerden and Lee 1999). Brooklyn Creek then enters a deep ravine and finally outflows into the Comox Estuary, approximately 900 m east of the Comox Marina (Bainbridge and Kuta 2000). The 6 km mainstem of Brooklyn Creek can be divided into three sections based on the predominant land use; the upper reach largely developed into golf courses, middle reach subjected to urban and agricultural development, and lower zone which is mostly in a natural state due to being predominately in a system of parks. This assessment focused on the lower two zones beginning at the Anderton Road crossing (Reach 6, km 4+535) and ending where Brooklyn Creek enters the estuary in Baybrook Nature Park (tidal reach, km 0+000).

2.1 Geology

The Brooklyn Creek watershed is within the Nanaimo Lowland physiographic region, which is characterized by Upper Cretaceous sedimentary rocks of the Nanaimo Group (Jungen et al. 1989).

According to the Ministry of Environment's iMap BC online database (2021), the Brooklyn Creek Watershed is in Aquifer 411, called the “Nanaimo Group, Campbell River to Courtenay” aquifer. Aquifer 411 is divided into several smaller aquifers, with the entirety of the Brooklyn Creek watershed located in Aquifer 408, called the “Comox-Merville” aquifer. Details on these aquifers, including their sizes and material types are shown in Table 1 below.

Table 1. Brooklyn Creek Watershed Aquifers and their material types (iMap BC 2021).

Name and Number	Size (km^2)	Material Type	Material Sub-type
Nanaimo Group, Campbell River to Courtenay; Aquifer 11	731.9	Bedrock	Fractured sedimentary rock
Comox-Merville; Aquifer 408	148.8	Sand and gravel	Unconfined sand and gravel – late glacial outwash

Surface soils in the majority of the watershed are primarily poorly drained and highly erodible silts and silty sands, most likely originating from glacial recession, and possibly of post-glacial marine origin (Cousens and Lee 1999). The silt limits the ability of surface water to penetrate into the ground, promoting surface pooling and sheet flow runoff without well-defined channels. In the upper sections of the Brooklyn Creek watershed, clay or clay/glacial till (hardpan) are found 20-30 cm beneath the soil surface layers (Cousens and Lee 1999). This material is essentially impermeable to water, which limits penetration of rainfall to the shallow surface soil layers. In the lower sections of the watershed, a thin gravel layer is present between the surface soil layer and the clay/hardpan, which allows limited lateral movement of sub-surface water into the channel.

Beneath the clay/hardpan later, there is the interglacial sand/gravel deposit, geologically known as the Quadra sands/sediments, which contains an aquifer accessible through shallow wells in agricultural areas (Kellerhals 1996). The impermeable nature of the soil within the watershed means that the increase in anthropogenic impermeable surfaces over time disrupts the hydrological patterns of the watershed, causing a flashy system with decreased water infiltration and retention, as described in Section 2.2 below.

2.2 Hydrology

The Brooklyn Creek watershed is characterized by low summer flows and high peak flows during storm events. The topography of the watershed is relatively flat with low hills. The geographical region of Brooklyn Creek watershed has no snowpack; therefore, the drainage regime is not directly influenced by snow melt, and thus stream flow is primarily influenced by precipitation patterns (Bassett, Lyver, & Silvester 2010).

Flow monitoring has historically been conducted within the Brooklyn Creek watershed, using flow meters, gauges, and visual assessments. Mean annual discharge (MAD) for Brooklyn Creek is estimated at 0.29 m^3/s, based on a unit discharge of 44.5 $L/s/km^2$ and the watershed area of 650 ha (Chilibeck 2005). Flows during flooding events are described in the table below.

Table 2. Brooklyn Creek estimated flows during flood events (m^3/s).

Return Period	1:2	1:5	1:10	1:100
Maximum Instantaneous Flow	2.55	3.20	3.62	5.33

Return Period is "the average number of years between floods of a certain size (Water Science School 2018)" E.g. the probability of a 1:100-year flood occurring in any given year is 1% and the probability of a 1:2-year flood occurring in any given year is 50%).
Maximum Instantaneous flow is the peak flow (in m^3/s) during each of the return periods shown in Table 2. E.g. During a 1:2 year flood, the maximum flow in Brooklyn creek is 2.55 m^3/s, whereas during a 1:100 year flood, the maximum flow in the creek is 5.33 m^3/s (thus, a much larger, and less frequent flood event).

Winter storms result in high flow events which can lead to flooding, sediment loading, and debris accumulation (Cousens and Lee 1999). According to the Brooklyn Creek Master Drainage Plan (van der Eerden and Lee 1999), flooding and increased runoff has been a concern for more than 60 years. The rapid flow can be explained by the impermeable silt hardpan which is common in this area, and the rapid increase in development within the Brooklyn Creek watershed. Development within the watershed leads to a reduction in pervious surfaces, reduced depression storage, and a greater addition to the Town of Comox's stormwater system.

Contributing factors to low summer flows in the Brooklyn Creek watershed include the high percentage of impervious surfaces from residential development, the infilling of wetlands, and increasing drainage density (e.g. drainage ditches and underground pipes) due to urbanization (Cousens and Lee 1999). The headwaters of the Brooklyn Creek watershed within the Crown Isle Golf Course and Resort and the Park at Crown Isle golf course have been significantly altered due to the increase of impervious surfaces in development, infilling of ponds, and other residential and commercial water uses. This results in a flashy system with less water retention during the summer months, limiting fish passage throughout Brooklyn Creek and suitable juvenile rearing habitat.

There are currently three detention ponds within the Brooklyn Creek watershed that contribute to water retention. They are as follows:

1) Crown Isle detention pond systems - 3 interconnected ponds leading to a large retention pond that reduces outflow to a maximum of 0.75 m^3/s
2) Highwood detention pond - A 3,620 m^2 pond with a 0.25 m high berm
3) Salish Park Off-line Engineered wetland - A 1,860 m^2 detention facility

A more detailed hydrotechnical study being completed by Northwest Hydraulic Consultants (NHC) in 2021 will accompany this Level OL1 Assessment to provide a better understanding of the creek flows and inform habitat restoration project design criteria, including flood discharges and summer base flows.

2.3 Land use

For the purposes of this study, land use changes are defined as anthropogenic modifications to the Brooklyn Creek watershed affecting its natural hydrologic and nutrient cycles. These modifications include *Agricultural Land Use* (Section 2.3.1) and *Rural Development/Urbanization* (Section 2.3.2). As of 2010, the land-use composition of Brooklyn Creek was approximately 42% rural lots and 55% suburban lots (Bassett, Lyver, and Silvester 2010). Water withdrawal is a component of both of these land uses. According to the Ministry of Environment's iMap BC online database (2021), there are 93 unlicensed groundwater wells within the Brooklyn Creek watershed, broken up into the following water uses: 51 private domestic, three irrigation, one commercial, one observation well, 30 unknown, and seven not applicable. There are also six water licenses within the Brooklyn Creek watershed: five are surface water licenses for domestic use from Huntley spring to the east of Brooklyn Creek, and one is a surface water license on Brooklyn Creek at Pritchard Road for conservation (construct works) purposes.

2.3.1 Agricultural Land Use

There are several agricultural properties within the Brooklyn Creek watershed between Parry Place and Guthrie Road. The largest agricultural property within the Brooklyn Creek watershed is the 77 ha dairy farm called Birkdale Farm on Guthrie Road. According to the property owner, there were approximately 6 acres of wetlands extending between the Birkdale Farm and the properties to the east, that were historically drained for both agriculture and residential development in the Highwood area immediately east of the farm. In-stream woody debris cover is absent, and there are minimal riffle-pool structures due to ditching, scouring at high flows, and sediment deposition (Cousens and Lee 1999). Riparian vegetation is characterized by a narrow strip dominated by shrubs and trees with limited crown cover. Juvenile rearing is poor to moderate with little or no suitable salmonid spawning habitat (see Reach 6 results from 2021 OL1 assessment). According to the property owner, flooding and ponding occurs on the agricultural lands during the winter due to nearby residential developments and upstream runoff caused by drainage alterations. Rilling and evidence of flooding and ground saturation was observed by a Current Environmental Ltd. biologist during a February 2022 site visit. Bedload accumulations and in-stream growth of bullrushes and reed canary grass were observed in the lower sections of the channel on the farm, due to a change in gradient, with topography flattening out toward the southeastern portion of the property. Additionally, the property owner has observed an increase in sedimentation/turbidity into the creek in recent years due to waterfowl disturbing the fields, creating bare soils prone to erosion and runoff.

2.3.2 Rural Development/Urbanization

Expected negative effects from urbanization include increased areas of impervious surfaces and drainage density leading to elevated peak flows due to a decrease in rainfall interception and evapotranspiration. Additionally, reduced vegetative cover results in an increase in erosion, leading to reduced rearing/spawning habitat quality. Urbanization also results in a loss of wetlands and terrestrial/aquatic habitat, causing species to be displaced. Finally, urbanization can lead to poor water quality, with contaminants entering the watershed from roadways, storm drains, and other urban land uses. Since the late 1980s, the headwaters and section of Brooklyn Creek downstream of Guthrie Road has been significantly altered due to resort, residential, and commercial development.

2.3.2.1 Impervious Surfaces

Rural development and urbanization within the watershed include residential development as well as commercial businesses such as retail shops. The mainstem of Brooklyn Creek also crosses several major roads in the watershed that add to impervious surface cover including Ryan Road, Anderton Road, and Guthrie Road. According to a 2010 report, approximately 40% of the Brooklyn Creek watershed is made up of impervious surfaces (Bassett, Lyver, and Silvester). This qualifies the Brooklyn Creek watershed as a “non-supporting stream” (25-60% impervious cover) and categorized as being poorly supportive of aquatic life (Bassett, Lyver, and Silvester 2010). Diminished water quality, habitat quality, and aquatic diversity is likely to correspond with being classified as a “non-supporting stream”. Numerous studies have shown that fish habitat quality, channel stability, fish spawning, and benthic macroinvertebrate and fish diversity decline when the percent impervious cover is greater than 10% in a watershed (Scheuler 2000). Table 3 shows the watershed broken down by land use and vegetation cover, as of 2010.

Table 3. Brooklyn Creek watershed land use and vegetation cover (Bassett, Lyver, and Silvester 2010).

Table 2: Brooklyn Creek watershed land use and vegetation coverage.

Land Use		Vegetation Coverage	
Rural Lots	276.3ha (42%)	Forested	147.3ha (22%)
Suburban Lots	361.3ha (55%)	Cleared	151.9 (23%)
Park	17.5ha (3%)	Developed	355.8 (55%)
+/- 40% Impervious area			

Source: Adapted from Paul de Greef Copyright Document

Impervious surfaces within the Brooklyn Creek watershed have increased since 2010, with further urbanization resulting in a loss of forested area. For example, since 2010, several new developments have been constructed within the Brooklyn Creek watershed in Crown Isle, located in the headwaters of the watershed. Additionally, several retail stores have opened since 2010, including Costco and Thrifty’s, resulting in a large increase in impervious areas from paved parking lots. These residential/commercial developments constructed between 2010 and 2021 resulted in a conversion of approximately 23.1 ha of forest into urban areas. This is not a detailed land use study and is not comprehensive, therefore these numbers are estimates only. The new developments including their approximate size are as follows:

- 5.6 ha - housing development consisting of single-family detached homes to the east of the golf course on Crown Isle Drive. Clearing of the forested area occurred between 2016 and 2018, with road and house construction beginning in 2019.
- 2.3 ha – housing development consisting of single-family detached homes to the south of the golf course on Crown Isle Drive. Clearing of the forested area occurred between 2012 – 2018, with house construction beginning between 2012 and 2015.

- 4.6 ha – Costco/retail area and parking lots constructed in 2010/2011, to the northwest of Ryan Road (was previously forested).
- 5.7 ha - Thrifty's store/parking lot constructed in 2011/2012 and residential development to the northeast of it constructed between 2012 and 2015.
- 4.9 ha – housing development consisting of single-family detached homes to the north of the Malahat Drive. Clearing of the forested area occurred in 2012, with house and road construction beginning in 2015.

This results in a vegetation cover change from Table 3 to be as follows:
- Forested = 124.2 ha (19%)
- Cleared = 151.9 ha (23%)
- Developed = 378.9 ha (58%)

For the purposes of this assessment, it has been assumed that 50% of the developed area since 2010 is impervious, based on a conservative estimate of the impervious area of medium density single family homes (Scheuler 2000). This results in an additional 11.5 ha of impervious surfaces in the watershed, compared to the land use assessment from 2010.

2.3.3 Benthic Invertebrate Diversity and Water Quality

Stream condition was assessed for Brooklyn Creek as part of the Technical Diploma Study for Camosun College (Bassett, Lyver, and Silvester 2010) to determine if there were significant correlations between out-migration and water quality. Water quality measurements were conducted between April 17 to June 6, 2010, within Brooklyn Creek approximately 200 m upstream from the Comox estuary. There were no BC Standard exceedances for dissolved oxygen, conductivity, temperature, pH, or total dissolved solids in Brooklyn Creek in the spring of 2010 and each parameter measured was within the desirable range for salmon health. Current standards for measuring stream health have been established from the Monitoring and Adaptive Management Framework (MAMF) for Stormwater (Metro Vancouver 2014). MAMF protocols suggest that sampling of benthic macro-invertebrates and certain water quality parameters every 5 years at a minimum to monitor stream health.

Benthic invertebrate diversity was assessed in 1999 during the fisheries resource and habitat assessment (Cousens and Lee, 1999). Throughout the entire system Cousens and Lee observed limited abundance of insect larvae and other macro-invertebrates, likely due to the limited supply of suitable coarse gravel in the upper reaches of the watershed, and the clogging of suitable gravels by fine sediments. There were signs of algal film on surfaces, but the expected benthic communities which feeds on this material was almost entirely absent. Due to the lack of a healthy benthic invertebrate community, the major energy source and nutrient supply of autumn leaf and litter fall is likely flushed from the system at high flows or buried in sediments providing very little benefit to the salmonid population (Cousens and Lee 1999). BCWS may want to consider implementing a stream health monitoring program that adapts MAMF methodology.

2.4 Past Watershed Assessments and Enhancement Projects

Watershed assessment have been conducted in Brooklyn Creek since the late 1990s, with multiple enhancement projects conducted as an outcome of these studies. Past reports were provided by the BCWS for background review as part of this OL1 assessment. The enhancement recommendations made as part of the 2021 OL1 assessment considered past restoration work and recommendations from these previous watershed assessments.

2.4.1 Past Watershed Assessments

Past enhancement projects in the Brooklyn Creek watershed began with a series of field and reporting efforts describing limiting factors to fish habitat in the Brooklyn Creek watershed in the late 1990s. Reports relating to the condition of Brooklyn Creek watershed that have informed restoration/enhancement projects and/or that have provided information about the watershed condition include:

a. *Preliminary Fisheries Resource, Habitat and Development Impact Assessment of Brooklyn Creek in Comox-Courtenay, BC* (Cousens and Lee 1999).
b. *Brooklyn Creek Master Drainage Plan* (van der Eerden and Lee 1999).
c. *Brooklyn Creek Mapping and Inventory Project- Sensitive Habitat Inventory and Mapping (SHIM) Survey* (Bainbridge and Kuta 2000).
d. *Brooklyn Creek Juvenile Salmon Out-Migration Study* (Bassett, Lyver, and Silvester 2010).
e. *Accessing the Worth of Ecological Services Using the Ecological Accounting Process for Watershed Assessment- Brooklyn Creek Demonstration Application in the Comox Valley (*Pringle, Dumont, Huer & Stephens 2018*).*

Preliminary Fisheries Resource, Habitat and Development Impact Assessment of Brooklyn Creek in Comox-Courtenay, BC (Cousens and Lee 1999)

Based on the field study and available historical information, this assessment concluded that there were numerous salmonid habitat restoration and enhancement opportunities in Brooklyn Creek but the success of these projects relies on the reduction of peak flow volumes, control of soil erosion and resulting sediment transport, removal of sediments from the stream channel, installation of large woody debris and boulders to improve habitat complexity, and the establishment of adequate summer flows to maintain fish habitat in Brooklyn Creek. Recommendations to improve salmonid habitat included the removal of the accumulation of sediment downstream of Guthrie Road and expanding the Highwood detention pond to limit downstream peak flows and limit sediment transport.

Brooklyn Creek Master Drainage Plan (van der Eerden and Lee 1999)

This management plan provided improvements to limit the extent of drainage problems along Brooklyn Creek to levels consistent with pre-development conditions. Drainage recommendations within the Brooklyn Creek watershed to reduce flood elevations, flood durations, and water depths to pre-development levels included constructing a berm around the detention pond in the Highwood development; upgrading road culverts at Parry Place, Idiens Way, Anderton Road, Guthrie Road, Salish Street, Pritchard Road, and Noel Avenue; installing three detention ponds at the corner of Parry Place and Idiens Way, at the corner of Anderton Road and Dryden Road, and along Anderton Road between McQuinn Road and Hector Road; and improving channel conveyance downstream of Guthrie Road. To limit channel erosion and bank instability from the increased stream velocity, the report recommended bank protection along the creek downstream of Salish Park and Dogwood Avenue where signs of slope failure was present, and at all outlets of outfalls and culverts.

Brooklyn Creek Mapping and Inventory Project- Sensitive Habitat Inventory and Mapping (SHIM) Survey (Bainbridge and Christine Kuta 2000)

Results of the SHIM survey in Brooklyn Creek and its tributaries in 1999/2000 showed that the greatest limiting factor to salmonid productivity is dependable summer flow. Recommendations to address this concern included managing retention water collected in the spring and regulating the output throughout the low flow summer, and closing the gate valve between the Parry Place tributary and the Park at Crown Isle / Anderton Rd. tributary to maximize available summer flow. The 2000 SHIM results also provided recommended channel restoration actions including adding complexity to the channel with large woody debris (LWD), stabilizing the riparian bank to limit erosion and downstream siltation, and developing additional juvenile salmonid rearing and summer refuge habitat (Bainbridge and Kuta 2000).

Brooklyn Creek Juvenile Salmon Out-Migration Study (Bassett, Lyver, and Silvester 2010)

The study of the abundance of salmonids migrating from Brooklyn Creek to marine waters in the summer of 2010 found that coho salmon (*Oncorhynchus kisutch*) is the primary species in Brooklyn Creek and 3,680 smolts migrated out of the creek between April 17 to June 6, 2010. It was predicted that there were approximately 245,000 eggs and between 43-91 spawning salmon in Brooklyn Creek in 2008 and that 129 adult coho salmon would return in 2011, with half of these being female spawners. The study also determined that there is a positive correlation between water temperature and the total number of migrating coho salmon. The creation of this baseline dataset and determination of the significant correlation between water temperature and migration is useful for comparisons to other creeks in Comox Valley and can be used to help direct future restoration projects to improve the health and productivity of salmonids in Brooklyn Creek.

Assessing the Worth of Ecological Services Using the *Ecological Accounting Process* for Watershed Assessment- Brooklyn Creek Demonstration Application in the Comox Valley (Pringle, Dumont, Huer & Stephens 2018)

This assessment evaluated Brooklyn Creek through an Ecological Accounting Process (EAP) to help understand the function condition of the dependent ecosystems and to determine certain activities that stakeholders could undertake to improve the ecological services of the Brooklyn Creek watershed through management, enhancement, and maintenance. The EAP analysis determined a unit value of ~$2,700 per metre of stream corridor of the 2.5 km section of Brooklyn Creek in the Town of Comox jurisdiction. This value for the land underlying the stream and riparian zone provides an idea of the worth of the ecological services provided by Brooklyn Creek and can be used in future management plans. This assessment also mentioned that without improvements in the upper and middle sections of the Brooklyn Creek watershed, the hydrologic condition will remain threatened and degraded. Efforts in the developed areas of the Brooklyn Creek watershed should be focused on meeting the water balance targets based on volume of retention, infiltration system area, and base flow release rate. Suggested targets are retention volumes of 164 m^3/ha of development within the creek, and neighbouring detention facilities have a retention of 420 m^3/ha of contributing area; the release rate of base flows should be 1.0 L/s/ha for sites within the creek and a maximum release rate of 11.2 L/s/ha for developed areas neighbouring the creek; and the infiltration area for within-creek facilities should be 100 m^2/ha.

2.4.2 Past Enhancement Projects

The assessments outlined above were used to inform restoration/enhancement opportunities that have been implemented as part of the Brooklyn Creek Channel Enhancement Project by the Town of Comox, BCWS, and other stakeholders throughout the years. The main goal of this project was to improve channel stability and increase productivity and survival of anadromous salmonids within Brooklyn Creek. Table 4 below describes several large restoration/enhancement projects that have been completed as part of the Brooklyn Creek Channel Enhancement Project since 2005. Additionally, riparian planting efforts have been conducted throughout the watershed. These have not been described in detail here. Figure 2 provides a map of the location of enhancement projects completed between 2005 and 2015.

Table 4. Past enhancement projects conducted within the Brooklyn Creek watershed since 2005.

Enhancement/Restoration Activity	Location	Date	Rationale for Project	Assessed in 2021 OL1?
Construction of a high flow storm runoff diversion, an 1,860 m^2 off-line engineered wetland, and mainstem channel enhancement features including 10 rock riffles, 2 LWD placement features, and 2 bank revetment features (Wong, Komori, and Chilbeck 2005)	In Salish Park (km 2+575 – 3+160) and at Pritchard Rd (km 2+385).	2005	Mitigated intermittent peak flows and reducesd stormwater pollutants and sediment; improved bank stability in over 540 m of the mainstem channel; provided rearing and spawning habitat for salmonids; estimated increase in 315 cutthroat trout and 660 coho smolts.	No – several constructed rock riffles in Salish Park (Reach 5) were assessed visually, however detailed assessments were not conducted in these areas.
Installation of 5 rock riffles, 6 LWD placements, and 3 bank revetments (Wong 2009).	Km 0+667 to 0+869	2008	Restored 1,800 m^2 of fish habitat and protected 202 m of eroding banks. Estimated increase of 225 cutthroat trout and 473 coho smolts produced annually.	Yes – constructed riffles and bank revetments/LWD structures were assessed in detail in Reach 2.
Installation of 4 bank revetment features, 4 rock riffle features, spawning habitat, and 1 LWD placement (Wong 2009).	Km 0+366 to 0+580	2009	Restored 215 m of fish habitat in the mainstem of the channel. Increased habitat for spawning and refuge during high flows for adult and juvenile salmonids; and helped moderate erosive energy. Estimate increase of 120 cutthroat trout and 390 coho smolts produced annually.	Yes – constructed riffles and bank revetments/LWD structures were assessed in detail in Reach 2.
Channel enhancement and habitat complexing in Brooklyn Creek mainstem-	Km 1+100 to 1+460	2010	Restored 2,500 m^2 of wetted channel in 335 m of the main	Yes – constructed riffles and bank revetments/LWD

Enhancement/Restoration Activity	Location	Date	Rationale for Project	Assessed in 2021 OL1?
constructed 10 pool features with rock riffles, 7 LWD structures, and 1 bank stabilization feature (Wong, Silvester, and Palmer 2010).			channel. Estimated increase of 185 cutthroat trout and 510 coho smolts annually.	structures were assessed in detail in Reach 3.
Installation of 6 pool complexes, 5 LWD placements, and 3 bank revetment features (Wong 2011).	Km 1+200 and 0+930	2011	Restored 1,900 m^2 of mainstem habitat in 225 m of the mainstem channel. Decreased risk of channel destabilization, increased productivity and survival of salmonids. Estimated annual increase of 250 cutthroat and 525 coho smolts.	Yes – constructed riffles and bank revetments/LWD structures were assessed in detail in Reach 3.
Installation of 4 pool complexes, 3 LWD placements, and 3 bank revetment features. Developed a 200 m side channel (Current Environmental Ltd 2012).	Km 0+050 to 0+250	2012	Restored 1,200 m^2 wetted channel in the 200 m mainstem and 200 m side channel; created spawning and rearing habitat; and moderated erosive energy. Estimated annual increase of 248 cutthroat and 520 coho smolt.	Yes – constructed riffles and bank revetments/LWD structures were assessed in detail in Reaches 2 and 3.
Installation of 5 pool complexes (constructed rock riffles, LWD features, and spawning habitat) and installation of 1 bank revetement feature (Wong 2013).	Km 0+247 to 0+360	2013	Improved rearing and spawning habitat in 115 m of the main channel, restored fish passage, and reduced erosion. Estimated annual increase of 64 cutthroat and 209 coho smolts.	Yes – constructed riffles and bank revetments/LWD structures were assessed in detail in Reach 2.

Enhancement/Restoration Activity	Location	Date	Rationale for Project	Assessed in 2021 OL1?
Installation of 7 pool complexes with constructed rock riffles (Current Environmental Ltd 2014).	Km 2+550 to 2+920 and at Km 0+835	2014	Enhanced 1,850 m^2 of wetted channel and restored 370 m of the mainstem channel. Helped moderate erosive energy and increased habitat for salmonid reproduction and rearing. Estimated increase of 145 cutthroat and 480 coho smolts annually.	No – several constructed rock riffles in Salish Park (Reach 5) were assessed visually, however detailed assessments were not conducted in these areas.
Habitat complexing in mainstem- restored natural meandering pattern, built 3 riffle/pool sequence features and installed 4 LWD features (Wong 2015).	1475 Noel Ave.	2015	Restored channel complexity, increased channel capacity to mitigate flooding and erosion, and enhanced 150 m of salmonid rearing and spawning habitat. Estimated annual increase of 107 cutthroat and 351 coho smolts annually.	Yes – constructed riffles and LWD structures were assessed in detail in Reach 4.
Re-established off-channel pond/wetland habitat, installed 1 riffle/pool feature, and 4 LWD placements (Wong 2016).	1475 Noel Ave.	2016	Created 600 m^2 of off-channel juvenile salmonid rearing habitat, and habitat for amphibians, reptiles, aquatic insects, birds, and mammals. Enhanced an estimated 1,200 m^2 riparian corridor between 2 new greenways. Estimated annual increase of 85 cutthroat and 400 coho smolts.	The constructed riffle was assessed, however the off-channel pond/wetland was not assessed as part of this study.
Extension of Off-Channel Pond and installation of	1475 Noel Ave.	2017	Provided an additional 600 m^2	No – the off-channel pond/wetland was

Enhancement/Restoration Activity	Location	Date	Rationale for Project	Assessed in 2021 OL1?
east side augmentation structure (O'Neill and Wong 2017).			salmonid rearing and spawning habitat; improved streamflow and reduced impact of peak flow events	not assessed as part of this study.

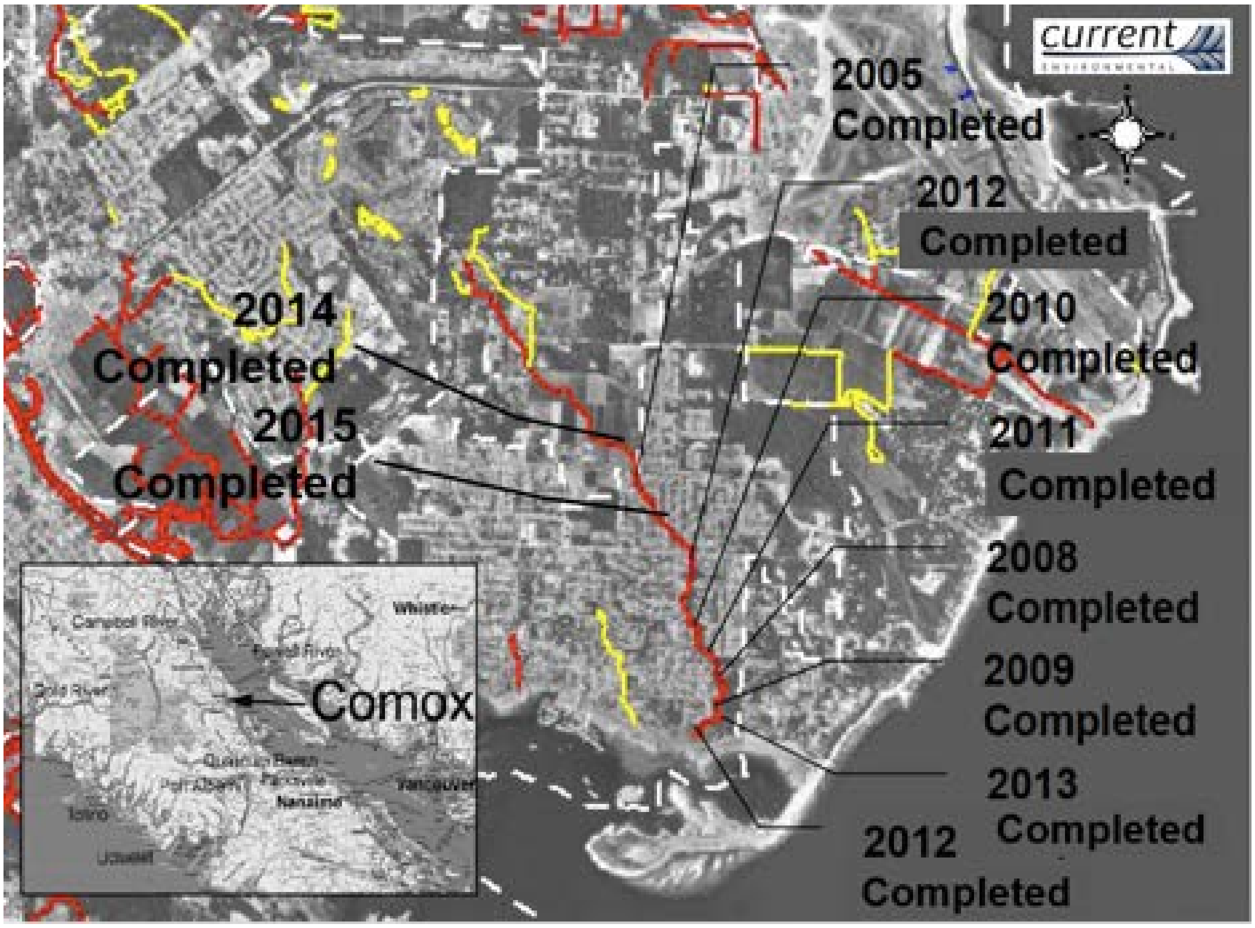

Figure 2. Past enhancement projects completed in Brooklyn Creek between 2005 and 2015, as part of the Brooklyn Creek Channel Enhancement Project (Current Environmental Ltd. 2015).

Several of the above-mentioned historical enhancement sites were located within the reaches surveyed in 2021 (Table 4) and were assessed for their current physical status and habitat function (Section 5.3). The remaining enhancement projects were located outside of surveyed reaches and were not assessed as part of this study.

3 Overview - Fisheries Information

Fisheries information has been gathered from several sources including past Brooklyn Creek assessments and online government databases and records. The intent is to supply a comprehensive overview of historical and contemporary salmonid utilization in the Brooklyn Creek watershed which can be used to compare pre-enhanced salmonid abundances and ecology to post-restoration conditions. The known *Distribution* of salmonid species in the watershed is described in Section 3.1, while a summary of the *Life History Timing* of salmonids during their freshwater residence and migration is in Section 3.2.

3.1 Distribution

A predominantly visual assessment of fish presence was conducted in Brooklyn Creek during the habitat assessments in summer 2021. Presence of fish was noted in each reach, identifying where fish were congregating and where they appeared to be absent or present in low numbers during the assessment. Four traps were set in the creek at various locations on Birkdale Farm, to determine whether salmonids were using this section of the watershed. This OL1 assessment did not include a detailed juvenile fish trapping program or spawner survey. The distribution of salmonid fry in the watershed observed during the 2021 OL1 assessment is discussed in Section 5.1.1.

A search of the BC Fish Inventory Data Query (FIDQ)[1] system indicated historical records for the presence of coho salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*O. clarkii clarkii*) in Brooklyn Creek. There is also mention of pink salmon (*O. gorbuscha*) and chum salmon (*O. keta*) as 'Escapements" in the FIDQ system, and reports that a few chum and pink use the lower reaches (Cousens and Lee 1999). The Brooklyn Creek Juvenile Salmon Out-Migration Study (Bassett, Lyver, and Silvester 2010) also list three-spined stickleback, prickly sculpin, and coastrange sculpin.

The Brooklyn Creek Juvenile Salmon Out-Migration Study installed and maintained a smolt fence approximately 200 m upstream of the Comox Harbour between April 17 and June 6, 2010. The number and type of species, along with water measurements were recorded daily. A total of 3,680 coho smolts, 620 coho fry, 17 cutthroat trout, 59 sculpins, and 13 three-spined sticklebacks were recorded over the 51 days.

Past watershed assessments and restoration projects have assessed fish presence throughout the Creek. Cousens and Lee (1999) performed a fisheries resource and habitat assessment of Brooklyn Creek and determined that the entire system up to Parry Place is accessible at high flows to adult coho spawners, fry, and juveniles, as well as anadromous and fresh water-resident cutthroat trout. The SHIM Survey (Bainbridge and Kuta 2000) examined 10.2 km of the mainstem and side channels of Brooklyn Creek and found fish distribution was limited to Parry Place due to a 337 m long culvert and manhole structure at the downstream end of the Crown Isle retention pond. The SHIM Survey also noted that seasonal fish passage barriers can occur downstream due to log jams and partially blocked culverts at low flows. This Level 1 Assessment conducted for the Brooklyn Creek watershed in 2021 provides additional information on fish presence/absence and identified potential barriers to fish migration, with the aim of refining the understanding of fish distribution within the watershed.

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[1] http://a100.gov.bc.ca/pub/fidq/viewSingleWaterbody.do

3.2 Life History Timing

Available Brooklyn Creek fisheries data regarding spawning is limited, but results from the Brooklyn Creek Juvenile Salmon Out-Migration Study included expected life history timings of salmon accessing the Brooklyn Creek system. The life history timing of salmonids varies by species, but the focus for Brooklyn Creek is coho and cutthroat trout. Coho begin to return to their origin river system in September or October, following approximately a year and a half at sea (Sandercock 1991; Table 5). Water levels are required to reach a sufficient depth before the upstream migration of the adult coho to spawn; therefore, if fall precipitation freshets are infrequent, upward migration may be delayed.

Table 5. A generalized timetable of expected salmonid movement in and out of Brooklyn Creek based on information in reports from nearby watersheds.

Species	Spawning	Out-Migration
Coho	Late September – December	Late April – Mid June
Cutthroat Trout (anadromous)	January- March	End of March- June

3.2.1 Escapement/Adult Spawning Migration

Migrating salmon must have suitable streamflow velocities and depths to provide successful upstream passage - particularly relevant in systems like Brooklyn Creek that contain multiple potential barriers from perched culverts/fish ladders and log/debris jams.

The leaping capabilities of adult salmon have been linked to their swimming speeds (Bell 1973; Powers & Orsborn 1985; Bjorn & Reiser 1991; Corvallis 2017) where coho salmon have a maximum burst speed of 3.23 - 6.55 m/s. Based on a study of salmonid leaping abilities by Stuart (1962) it was determined that a minimum plunge pool depth of 1.25x any plunge height (i.e. over constructed weirs) is required for successful passage.

Using the maximum burst speeds proposed by Bell (1973) and assuming optimal jumping conditions from Stuart (1962), adult coho are expected to have a maximum jump height of 2.19 m (Figure 3). As a result, it is anticipated that healthy coho migrating under suitable flow conditions can pass over the majority of culverts/fish ladders in the watershed with the exception of any culvert barriers that either do not have a sufficient plunge pool depth, excessive plunge height, or combination of both.

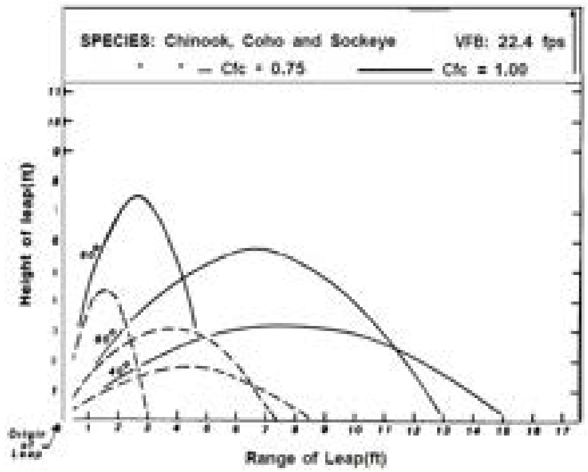


Figure 3. Chart of coho leap height/range (ft.) curves based on maximum burst speeds and leaping angles (Powers & Orsborn 1985).

Juvenile coho jumping abilities have also been described in Pearson et al. (2005) where it was experimentally shown that flow and outfall drop are the primary factors affecting leaping success, while downstream pool depth and morphological characteristics also play a part. It was shown that an outfall drop of 25 cm is impassable to 97 % of coho salmon juveniles (~100 mm length).

It is apparent that spawning adult coho gather at the mouths of shallow coastal streams, such as Brooklyn Creek, and begin to move upstream when the water levels reach a sufficient depth to allow passage. If autumn precipitation freshets do not occur for a sustained duration and are instead infrequent, the upstream migration will be pulsed. Coho spawners are most likely to begin their migration upstream when the stream experiences a large flow in conjunction with a high tide (Fraser et al. 1983), water temperatures between 7.2 - 15.6°C, depth at a minimum of 18 cm, and the water velocity at a maximum of 2.44 m/s (Reiser & Bjorn 1979). It is believed that the conditions at the mouth of streams are conducive to allowing coho passage to “small headwater tributaries where good spawning and rearing conditions may be found” further upstream (Sandercock 1991).

3.2.2 Fry/Parr

Coho emerging from their winter gravel incubation are called fry and measure approximately 30 mm in length. According to Neave (1949), coho fry may migrate upstream or downstream where they are capable of inhabiting areas inaccessible to adults, such as wetlands. The fry will distribute themselves throughout the stream where they will establish territories for extended periods. This behaviour has the beneficial result of creating a relatively low density of fry in any one area and reduces competition for food resources. However, territorial tendencies can have some negative results, for example the size disparity between late emerging fry and their larger, early emergent relatives, may be compounded by smaller fry being chased out of prime feeding grounds to less favourable sites, consequently, the later emergent fry grow more slowly (Chapman 1962).

Regarding out-migration, Hartman et al. (1982) found “most coho fry move out of river systems with freshets. However, even during periods of stable flow, fry continue to migrate. The numbers of fry moving do not correlate well with the water discharge rate because the first freshet may move most fish, whereas the second freshet, a few days later, may move only the few that are still left in the stream."

3.2.3 Smolt

In general, it has been found that the timing of coho smolt out-migration depends on a number of factors including the size of fish, flow conditions, water temperature, dissolved oxygen levels, amount of daylight, and food availability (Shapovalov & Taft 1954). Flow conditions and temperatures leading to migration have been outlined by Lawson et al. (2004) where "correlates for the Oregon Coast stocks were the dates of first fall freshets and flow during smolt outmigration. Air temperature is correlated with sea surface temperature and timing of the spring transition so that good freshwater conditions are typically associated with good marine conditions", and where "annual air temperatures and second winter flows correlated strongly with smolt production."

The study conducted in Brooklyn Creek by Bassett and Silvester (2010) caught a total number of 3,680 coho smolts within 51 days. The mean daily number of coho smolts out-migrating through the smolt fence was 72, with two migration spikes on April 27 and 19 where 442 and 1781 smolts were captured respectively. Based on calculations using known survival rates, it is estimated there were between 43-91 spawning female coho salmon in 2008, as described below in Table 6.

Table 6. Prediction of number of female Coho spawners in Brooklyn Creek in 2008 based on number of smolts caught between April and June 2010 (Bassett, Lyver, and Silvester 2010).

Parameter	Method of Calculation	Result
Number of eggs	smolts (3680)/ egg-smolt survival (0.015)	245334 eggs
Number of female spawners based on number of eggs	eggs (245334)/avg eggs per female (2699)	91 female spawners
Number of female spawners based on 85 smolts per female	smolts (3680)/smolts per female spawner (85)	43 female spawners

4 Level 1 Assessment Methods

Habitat Assessment sampling was completed in mainstem Brooklyn Creek, between the estuary and Anderton Road. These assessments were conducted during the driest period of the year in August and September 2021 to help reveal habitat deficiencies under low flow conditions. Field methodology for the Level 1 Assessment was adapted from the WRP Technical Circular No. 8 – FHAP by Johnston and Slaney (1996), the Resource Inventory Standards Committee (RISC) Standards and Procedures (RIC 2001), and the USHP Assessment Procedures for Vancouver Island Manual (Michalski, Reid, & Stewart 1997). Several changes were made to the FHAP/USHP methodology in order to assess the entirety of Brooklyn Creek between the estuary and Anderton Road, to ensure the survey was logistically possible and efficient. A portion of each reach was assessed using the modified FHAP/USHP survey, with habitat units (e.g. riffle, pool, or glide) selected randomly within the reach to survey. The remainder of the reaches (with the exception of Reaches 5 and 6 where small representative sections were observed and assessed) were walked and assessed visually, recording environmentally significant features such as the condition and functionality of past enhancement work, limiting factors to fish productivity, and opportunities for future enhancement work. Detailed measurements following the modified FHAP/USHP methodology were not conducted on the majority of the reaches.

As such, there are several metrics that are typically part of the USHP spreadsheet that were not used in this assessment, since they are not representative or accurate due to the methodology used. These are as follows:

- % pool area – this was not calculated for each reach since individual habitat units were surveyed instead of the entire reach. This means that a reach where more pool habitat units were surveyed would score higher than a reach where less pool habitat units were surveyed, which is not an accurate representation of the percent pool area in each reach. Instead, the frequency and quality of pool habitats were assessed qualitatively during the visual reach surveys.
- # of erosion sites, altered stream sites, and obstructions – these were not tallied since varying lengths of each reach were assessed according to the FHAP/USHP methodology and the number of sites would be different according to the number and length of habitat units surveyed in each reach. For example, nine habitat units were assessed in Reach 3, while only two habitat units were assessed in Reach 4; as such, Reach 3 would likely show a higher number of erosion sites than Reach 4, thereby skewing the final score for that reach. Instead, erosion sites, altered stream sites, and obstructions were recorded and discussed qualitatively as part of the visual reach surveys.

Representative photos of sample sites and significant habitat features were recorded. Raw data sheets including reach characteristics and chainages are available in Appendix A. Specific methods for *Data Collection* are described below in Section 4.1, and *Data Processing* in 4.2.

The Assessment was completed in stages prescribed by Michalski, Reid, & Stewart (1997) and is described as follows:

1. <u>Overview Assessment</u>: An overview assessment was done to determine the extent of past documented assessment and enhancement efforts to help inform the assessment process moving forward. A literature and information search was completed before field work began, including a search of Department of Fisheries and Oceans (DFO) and BC Ministry of Environment online databases. Existing literature on the study area was accessed from BCWS and Current Environmental.
    a. Preliminary reaches and reach breaks identified for field assessment were also delineated during the Overview process.
2. <u>Field Assessment</u>: Field collection of stream habitat data. Field data collection was done using a hybridization of FHAP methods described in Johnston and Slaney (1996) and USHP methods described by Michalski, Reid, & Stewart (1997).
    a. Field work to collect stream habitat data was completed in August and September 2021.
    b. Water quality assessments (temperature and dissolved oxygen) were conducted in the reaches during the OL1 habitat surveys.
3. <u>Juvenile Fish Presence:</u> Visual assessments of fish presence and species were conducted during the field assessment. Passive minnow trapping was conducted in Reach 6 (Birkdale Farm) in September 2021 to determine whether fish are rearing in this section of the creek.
4. <u>Habitat Data Entry</u>: A standardized Excel spreadsheet supplied by Tracy Michalski, Ministry of Forests Lands and Natural Resource Operations (MFLNRO), and USHP methods described in Michalski 1997 were used to input collected field data. As described above, % pool area, erosion sites, altered stream sites, and obstructions were not included in the Excel spreadsheet

for each reach since they are not representative of the actual ratings for the reaches. The final rating scale was adjusted because of these changes (see Section 4.2 below).

5. Mapping: Maps were generated according to USHP Mapping Procedures using methods described in Section 4.1.

4.1 Data Collection

Field data was collected and transcribed according to methods described in Johnston and Slaney (1996). Reach breaks were determined wherever a significant man-made break such as a bridge crossing, culvert, or natural feature such as tributary confluence was encountered. Representative photographs were taken of each reach during the low flow summer period. Locations for photographs, chainages, reach breaks, habitat unit breaks, obstructions, off-channel habitat, and other points of interest were recorded using Avenza. Relevant points and linework are shown graphically in maps produced using a desktop GIS platform.

4.2 Data Processing

Raw field data (Appendix A) was input into a Microsoft Excel spreadsheet produced by the USHP and retrieved from the online Ministry of Environment Ecological Reports Catalogue[2]. The USHP spreadsheet automatically generates ratings for the habitat parameters to help identify habitat limitations in the watershed. The rating scale is as follows: 1 = Good; 3 = Fair; 5 = Poor. The ratings for each parameter are totaled to produce an overall rating for the reach with a separate rating scale: <15 = Good; 15-25 = Fair; >25 = Poor. Table 7 shows the criteria used in rating habitat parameters:

Table 7. Habitat Parameter Ratings for the Comparison of Assessment Data to Habitat Diagnostics.

Habitat Parameter	Ratings (1 - 5) for the Comparison of Assessment Data to Habitat Diagnostics
Pools (% area)	< 40% (Poor)= 5; 40 - 55% (Fair) = 3; >55 % (Good) = 1
Large Woody Debris freq (pcs/bfw)	< 1(Poor) = 5; 1 -2 (Fair) = 3; > 2 (Good) = 1
Pool Frequency (# channel widths/pool)	>4 (Poor) = 5; 2-4 (Fair) = 3; <2 (Good) = 1
Percent Cover in Pools	0-5% (Poor) = 5; 6-20% (Fair) = 3; > 20 (Good) = 1
Boulder Cover	<10% (Poor) = 5; 10 - 30% (Fair) = 3; >30% (Good) = 1
Overhead cover	< 10/% (Poor) = 5; 10-20% (Fair) = 3; >20 %(Good) = 1
Substrate (% Fines)	>20 (Poor) = 5; 10-20 (Fair) = 3; < 10 (Good) = 1
Erosion Sites	1 point assigned for each identified site
Number of Obstructions (eg. Dams, perched culverts, bedload);	1 point assigned for each obstruction
Number of Stream Alteration Sites (eg. Riparian removal, channelization, infilling);	1 point assigned for each altered site
% Wetted Area (Wetted Area/Total Area);	<70%(Poor) = 5; 70%-90% (Fair) = 3; >90% (Good) = 1
Substrate % gravel	<20 (Poor) = 5, 20-40 (Fair) = 3; >40 (good) = 1

Note: % pool area, erosion sites, stream alteration sites, and number of obstructions were not assessed or included in the Excel spreadsheet.
Log jams were counted as 5 pieces of LWD.

The resulting parameter ratings and overall reach ratings help exemplify where and how each reach may be deficient in habitat features that are known to improve salmonid productivity and highlight areas that may prove to be good candidates for enhancement works. *Level 1 Assessment Results* are shown in Section 5 and a *Discussion & Recommended Enhancement Summary* is in Section 6.

[2] https://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=8766

5 Level 1 Assessment Results

Level 1 Assessment Results include the outcomes of a limited *Fisheries Assessment* (Section 5.1), *Water Quality Assessments* (Section 5.2), and a summary of *Reach Descriptions, Habitat Assessments, Previous Enhancement Works Conducted & Recommended Enhancements* are separated by reach in Section 5.3.

5.1 Fisheries Assessment

A predominantly visual assessment of fish presence was conducted in Brooklyn Creek during the habitat assessments in summer 2021. Presence of fish was noted in each reach, identifying where fish were congregating and where they appeared to be absent or present in low numbers during the assessment. Seven traps were set in the creek at various locations on Birkdale Farm, to determine whether salmonids were using this section of the watershed. This OL1 assessment did not include a comprehensive juvenile fish trapping program or spawner survey.

5.1.1 Juvenile Fish Presence

Visual assessments of juvenile fish presence were conducted during the OL1 assessment. Fish observations (including species when identification was possible) were recorded throughout the assessment. Coho fry/parr, juvenile cutthroat trout, and threespine stickleback were observed in all of the reaches downstream of km 1+615, predominantly in deeper pools with cover. No salmonids were observed between km 1+615 and Dogwood Avenue (upstream end of Reach 3). Several salmonids were observed in Reach 4 (both on August 26th and September 2nd, 2021), however these were all dead. Limited observations of salmonids in the upper portion of Reach 3 (km 1+615 – 1+908) and in Reach 4 may be due to poor water quality associated with a sewage spill that has since been mitigated. We expect that fish production in Reaches 3 and 4 will recover following recent remediation efforts. Salmonids were visually observed in Reach 5 and 6 in low densities during the site surveys in late summer. Follow-up minnow trapping in Reach 6 in early September confirmed under-utilization in this reach with no salmonids captured in baited minnow traps soaked overnight, as described below.

Seven minnow traps were set in various locations in Brooklyn Creek on Birkdale Farm on September 2nd, 2021, to determine whether fish are migrating up to this portion of the watershed during the summer months. Three traps were set in a pool at km 4+335, three traps were set in a pool at km 3+700, and 1 trap was set in a pool at km 4+050 (Figure 4). Traps were baited with salted roe and left to soak a minimum of 22 hrs. Traps were checked on September 3rd, with all fish released back into the creek where they were caught. No salmonids were caught in these traps – 3 threespine stickleback were caught in the traps at km 4+335 and no fish were caught in the traps at km 4+050 or 3+700 (Figure 4).

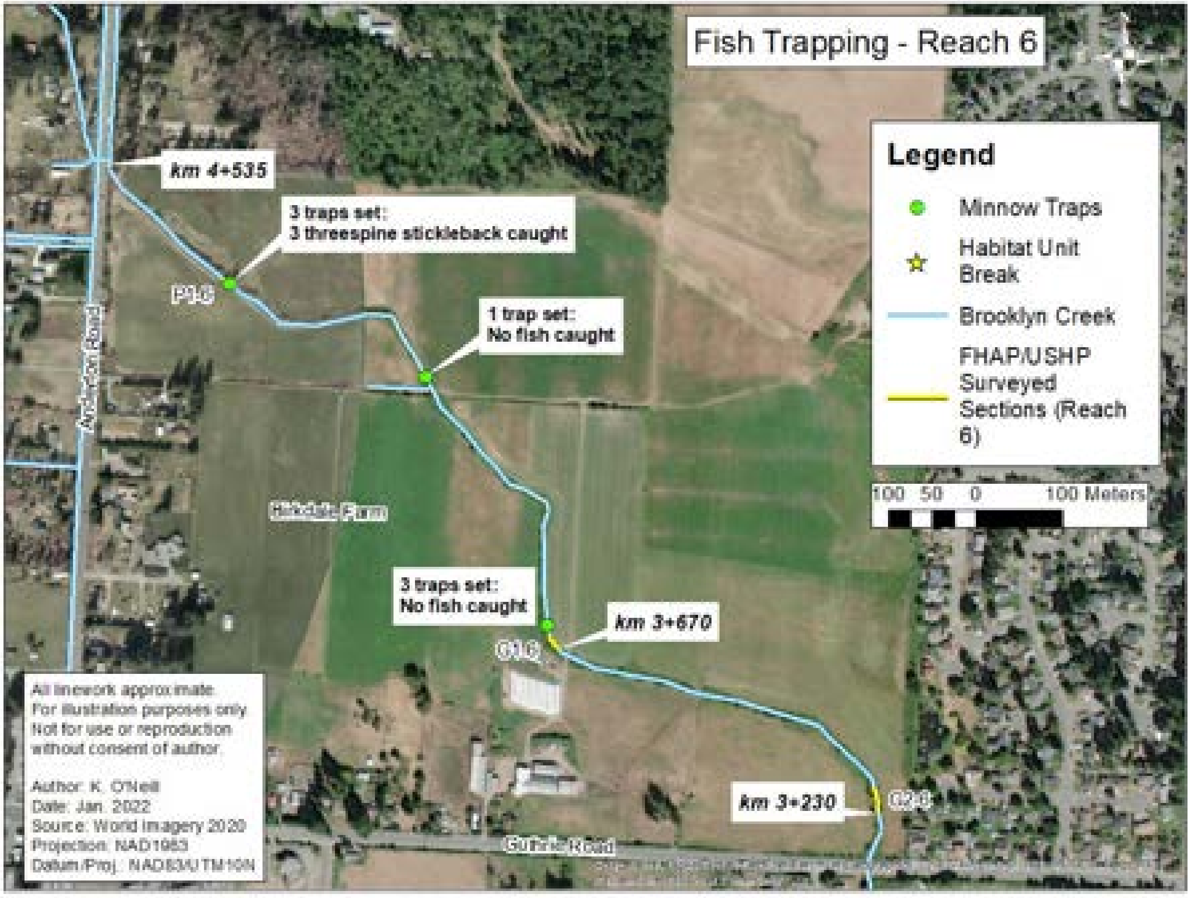


Figure 4. Locations of minnow traps set in September 2021 as part of fish habitat assessment; including results from trapping.

5.2 Water Quality Assessment

Temperature and dissolved oxygen measurements were collected in pools throughout the reaches, with the aim of determining the suitability of these reaches for juvenile fish rearing. The water quality measurements are presented in Table 8 below.

Table 8. Water Quality Measurements in Brooklyn Creek during Field Surveys (Aug. - Sept. 2021).

Date	Time	Location	Temperature (°C)	DO (mg/L)
Aug. 12, 2021	10:30 am	Side channel in Reach 1	20.1	1.32
Aug. 12, 2021	10:48 am	At inflow of side channel in Reach 1	18.3	6.35
Aug. 19, 2021	12:29 pm	km 0+220; pool in Reach 1	21.5	6.28
Aug. 20, 2021	9:42 am	km 0+485; glide in Reach 2	17.2	7.38

Aug. 20, 2021	1:10 pm	km 0+905; plunge pool at bottom of fish ladder in Reach 2	17.6	7.37
Aug. 25, 2021	10:35 am	km 0+990; Reach 3	16.5	8.40
Aug. 25, 2021	3:00 pm	km 1+335; Reach 3	18.3	8.10
Aug. 26, 2021	4:26 pm	km 1+805; Reach 3	17.9	7.79
Aug. 26, 2021	10:10 am	km 1+995; Reach 4	17.2	1.35
Aug. 26, 2021	2:38 pm	km 3+670; Reach 6	17.4	6.64
Aug. 26, 2021	2:48 pm	km 4+345; Reach 6	16.7	6.5
Sept. 2, 2021	12:37 pm	Km 2+165; Reach 5	---	7.3

According to the BC Water Quality Guidelines for Aquatic Life (Freshwater), the instantaneous minimum dissolved oxygen for all life stations with the exception of buried eggs and alevins is 5 mg/L (Ministry of Environment 1997). Dissolved oxygen levels were higher than this minimum guideline at all locations with the exception of the standing water in the constructed side channel in Reach 1 on August 12th, 2021 and in the sewage contaminated reach immediately downstream of Noel Avenue on August 26th, 2021, before the leak was identified and remediated (Table 8). Dissolved oxygen levels at all other locations was between 6.28 mg/L and 8.40 mg/L (Table 8). The majority of the water quality sampling locations were pool habitats where salmonids (coho fry and juvenile cutthroat trout) were observed, therefore dissolved oxygen is adequate in these pool habitats for summer rearing.

Water temperature measured at these water quality sampling locations was between 16.5°C and 21.5°C (Table 8). Provincial water quality guidelines for temperature in streams with known fish distribution is "+ or - 1 degree Celsius change beyond optimum temperature range as shown in Table 2 for each life history phase of the most sensitive salmonid species present" (BC Ministry of Environment 2001). According to the Fish Inventories Data Queries (Single Waterbody Query) for Brooklyn Creek, the only two fish species present in Brooklyn Creek are coastal cutthroat trout and coho salmon (BC Ministry of Environment 2021). Table 2 in the BC Water Quality Guidelines for the Protection of Freshwater Aquatic Life shows that the optimum temperature range of rearing coho salmon is 9.0°C – 16.0°C and the optimum temperature range of rearing cutthroat trout is 7.0°C – 16.0°C (BC Ministry of Environment 2001). Coho salmon are the most sensitive fish species present in the creek, therefore the BC Water Quality Guideline for temperature in Brooklyn Creek is between 8.0 °C and 17.0°C. Temperatures measured in Brooklyn Creek in August 2021 exceeded 17.0°C in the majority of locations measured (Table 8). The lethal temperature thresholds for both coho salmon and coastal cutthroat trout during their juvenile rearing life stage is 23°C (Bjornn and Reiser 1991 in Leach et al. 2011; Beechie et al. 2013), therefore there were no exceedances of the lethal threshold during the August 2021 temperature measurements, however temperatures did exceed the optimal temperatures for both coastal cutthroat trout and coho salmon at many of the water quality sampling locations.

5.3 Reach Description & Habitat Assessment

The study area between Anderton Road and the estuary was broken up into six reaches (not including the tidal reach, which was assessed visually but not surveyed according to the modified FHAP/USHP methodology), with portions of these reaches (2% - 37%) assessed according to the modified FHAP/USHP methodology, resulting in a rating score for each reach. With the exception of Reaches 5 and 6, the remainder of the reach portions that were not assessed according to the modified FHAP/USHP methodology were walked and assessed visually, with the aim of identifying limitations to fish productivity, identifying areas in need of restoration/enhancement, and evaluating the condition/effectiveness of previous enhancement work. Reach 5 has been studied extensively in the past and a large portion of it is along private property, therefore the entire reach was not walked and several sections were assessed visually instead. Reach 6 is difficult to access due to the narrow channel and dense riparian vegetation, therefore several sections were assessed visually and the entire reach was not walked.

According to the results of this *Fish Habitat Assessment* (both the FHAP/USHP results and visual assessments), one of the assessed reaches received a *Good* rating (Reach 1), four of the assessed reaches received a *Fair* rating (Reaches 2 – 5) and one of the assessed reaches received a *Poor* rating (Reach 6; Table 9).

Table 9. Rating for each of the six reaches assessed as part of the OL1 assessment, including a summary of the habitat quality in each reach.

Reach	Rating	Description/Summary
Reach 1	Good	Reach 1 is located in Baybrook Nature Park and does not have a trail or residences adjacent to it, therefore it is the least impacted reach. Riparian cover and depth is good and there are an adequate number of deep pools with overhanging cover that provide rearing opportunities to salmonids. Several patches of spawning gravels were observed and the riffles were in good condition.
Reach 2	Fair	Reach 2 is located in Mack Laing Park with a pedestrian trail adjacent to the creek in many areas. The trail has been re-aligned in several areas to reduce impacts on the mainstem, and bioengineering techniques have been used to reduce bank erosion. Scouring and erosion of the banks and substrates from high winter flows is evident in this reach, resulting in a lack of LWD and spawning gravels, and deterioration of previously constructed riffles. There are several potential barriers to salmonid migration during the low flow summer months, such as previously constructed riffles and the fish ladder at Balmoral Avenue. Crown cover and in-stream cover in Reach 3 are good, although there are dense patches of invasive species along both banks. Much of this reach has been enhanced/restored, which has significantly improved fish habitat within the reach. However, pressure from flooding and high flows originating in the upper watershed are having an adverse effect on past restoration projects within the reach.
Reach 3	Fair	Reach 3 is located in the Brooklyn Creek Greenway with a pedestrian trail adjacent to the majority of the creek. The majority of this reach has been restored, however pressure from flooding and high flows originating in the upper watershed are having an adverse effect on past restoration projects

Reach	Rating	Description/Summary
		within the reach. The LWD structures and constructed riffles in Reach 3 are in better condition than those in Reach 2. Many of the pools in Reach 3 have in-filled with gravel and gravel has washed downstream in high flows, resulting in a lack of spawning areas. Crown cover and in-stream cover in Reach 3 are good, although there are dense patches of invasive species along both banks. Although the overall Reach 3 rating is *Fair*, there are two distinct segments of Reach 3 – the lower segment up to km 1+615 and the upper 293 m segment to Dogwood Road. **The upper 293 m segment is considered *Poor* as it is one long glide that has eroded down to hard pan, has a complete lack of habitat and hydraulic complexity (no pool or riffle habitats) and may impede upstream migration by juvenile salmonids (Photos 37 and 38).**
Reach 4	Fair	Reach 4 is in the upper portion of the Brooklyn Creek Greenway. This reach has historically been straightened and lacks hydraulic and habitat complexity. The upper portion of the Reach between the walking bridge and Noel Avenue has been restored, as it used to look like the upper portion of Reach 3 (eroded with no riffle or pool habitats) and now has several constructed riffle/pool complexes, LWD structures, and spawning gravels. The riparian area adjacent to this portion of Reach 4 is lacking as there are apartment buildings immediately beside the right bank and a walking trail between the channel and the Phil & Jennie Gaglardi Academy along the left bank, with a narrow strip of planted trees and shrubs. The portion of Reach 4 between Dogwood Avenue and the walking bridge is one long glide with no pool or riffle habitats or LWD structures. The riparian area is slightly better than upstream with larger trees and shrubs, although the riparian depth is very narrow with residences on either side of the channel. The concrete fish ladder immediately upstream of Dogwood Avenue is potentially limiting fish passage under certain flow conditions (both low and high flows).
Reach 5	Fair	Reach 5 has two distinct segments, with the lower segment flowing through residential properties and the upper segment flowing through Salish Park. The riparian depths are narrow and manipulated with bank armouring and retaining walls in the residential portion, and there is a lack of riffle/pool complexes. The portion that flows through Salish Park is higher quality, with multiple constructed riffles and LWD structures, good riparian cover and depth, and adequate in-stream cover.
Reach 6	Poor	Reach 6 is entirely located on agricultural land that is owned and operated by Birkdale Farm Ltd., with a narrow and shrubby strip of riparian vegetation on both banks. There are no mature trees and invasive species are pervasive throughout the riparian areas. There is a lack of pool and riffle habitat, and no previous restoration has been done in this reach. This reach has a high percentage of fine substrates and limited features to support spawning and rearing habitat.

Based on both the modified FHAP/USHP assessments and visual assessments, limiting factors to salmonid productivity across most assessed reaches include low % pool area (many pools have in-filled with gravels washed downstream during high flows), low LWD frequency, low % wetted area (and therefore potential barriers to upstream salmonid migration due to water flowing between boulders in constructed riffles, low flows over fish ladders, etc.), and impacts to riparian vegetation related to clearing on private property and narrow riparian depths.

The following sub-headings (Sections 5.3.1 - 5.3.7) are categorized by reach number and with associated chainages. They include reach *Descriptions* discussing general characterizations of riparian habitat and instream features; *Habitat Assessment Results* expounding the findings of the Fish Habitat Assessment survey and a description of habitat deficiencies. *Previous Enhancement Conducted in* Reach includes a description of restoration work that has been done as well as an assessment of its state/condition. *Recommended Enhancement* projects and candidate sites have been identified and discussed in Section 6. Prior to initiating any instream enhancement work a Qualified Environmental Professional (QEP) should be consulted to provide detailed prescriptions for project design and implementation, including acquisition of relevant permits.

5.3.1 **Tidal Reach (km 0+000 – km 0+070)**

Description

Brooklyn Creek flows into the estuary, approximately 900 m east of the Comox Marina. The shoreline where Brooklyn Creek outlets is composed of valuable low salt marsh, as indicated by the WN:ms (Wetland, marsh) SEI polygon (S1170) along the entire shoreline where Brooklyn Creek flows into the estuary (Figure 5; Community Mapping Network 2018). A field assessment conducted by Rupert Wong in 2006 confirmed that that the estuary contains the provincially red-listed (S1S2) *Distichlis spicata* – *Sarcocornia pacifica* (seashore saltgrass – Pacific swampfire) ecological community. Additional species present in the salt marsh, as inventoried by Rupert Wong in 2006 include American glasswort (part of provincially red-listed community), Puget sound gumweed, Gmelin's orache, common orache, coastal pearlwort, Lingbye's sedge, seaside arrow-grass, sea plantain, seashore saltgrass, foxtail barley, dune grass, salt meadowgrass, and coast silverweed, among others (Wong 2006). The low salt marsh is also a nationally significant Important Bird Area (BC057; Wong 2006).

Figure 5. SEI polygons within Brooklyn Creek watershed. Brown polygon denotes "Old Forest, coniferous" and the green polygon denotes "wetland, marsh" (showing the low salt marsh along the estuary shoreline; Community Mapping Network 2018).

Salt marshes are extremely valuable and important ecosystems, as they perform various functions in the marine environment such as filtering pollutants and sediments eroding from the backshore environment, stabilizing shorelines, and dampening the effects of storm surges on the backshore and intertidal environments (Fisheries and Oceans Canada 2019). Salt marsh habitat is considered critical to salmonid rearing and production as juveniles transition to the marine environment (Simenstad et al. 1982; Hering et al. 2010). Fry residence in and around estuary habitats on east coast Vancouver Island streams can last up to 60 days after the outmigration of smolts during the spring and early summer. Salt marsh provides cover for juvenile salmonids from seals, marine mammals, and birds. Detritus from the salt marsh also provides juvenile salmonids with an important food source as they grow and prepare to move into their ocean life phase.

There are several depressions in the low salt marsh (Photo 2), where water is retained during low tide, shown with red outlines in Figure 6. These areas provide habitat for fishes and other aquatic organisms during the low tide cycle. Based on aerial imagery from 2021 (Google Earth 2021), the approximate total area of these depressions is 360 m^2.

Figure 6. Depressions (outlined in red) in the low salt marsh habitat at the outlet of Brooklyn Creek – these retain water during low tide (Google Earth 2021).

The mainstem channel is approximately 3.5 m wide at the downstream confluence of the mainstem and the constructed side channel (at the downstream end of Reach 1; Photo 3). The channel widens as it enters the estuary, reaching a width of approximately 21 m at the seaward edge of the low salt marsh (Photo 4). The hardpan banks of the channel within the estuary portion of the watershed are steep and eroding, held together with dense grass and sedge roots (Photo 5) until the channel reaches the walking bridge over the creek, at approximately km 0+040. The banks become less steep and eroded downstream of the walking bridge, with low salt marsh sedges and grasses lining the channel edges (Photo 4). Substrates within the channel in the estuary portion of the watershed upstream of the walking bridge are primarily composed of hardpan overlain with gravel, cobble, and boulders (Photo 5), while the portion downstream of the walking bridge is primarily composed of gravels and sand, with several larger cobbles scattered throughout (Photo 6). This channel is accessible to spawning fish migrating upstream from the ocean since sandy drift cells do not tend to block the channel mouth during tidal fluctuations.

Habitat Assessment Results

A modified FHAP/USHP survey was not conducted within the tidal reach, therefore there are no habitat assessment results.


Photos 1 & 2. Low salt marsh through which Brooklyn Creek flows through at downstream end of watershed (above left; Aug. 12, 2021). Low salt marsh to the east of the channel, with depression retaining water shown in centre of photo (above right; Aug. 12, 2021).


Photos 3 & 4. Looking upstream at confluence between side channel and mainstem from low salt marsh, showing constructed side channel in left side of photo and mainstem in right side of photo (above left; Aug. 12, 2021). Wider channel at seaward edge of low salt marsh, looking toward estuary (above right; Aug. 12, 2021).

Photo 5. Eroding hardpan banks upstream of walking bridge, looking downstream toward estuary (above left; Aug. 12, 2021).

Previous Enhancement Conducted in Reach

There has not been any previous enhancement/restoration work done in the estuary portion of the Brooklyn Creek watershed, with the exception of the constructed side channel, since the lower section is tidal.

Recommended Enhancement

The salt marsh is intact and functioning well and there are no access issues for fish into Brooklyn Creek. As such, no enhancement or restoration measures are recommended at this time.

5.3.2 Reach 1 (km 0+070 – 0+260)

Description

Reach 1 begins at the confluence of the mainstem and the constructed side channel at the landward edge of the estuary (Photo 3), and extends upstream for 190 m through Baybrook Nature Park, until reaching the park bridge, just downstream of the fish counting fence. There is a constructed side channel to the north of the mainstem, as described in the previous enhancement section below. This reach has good overhead canopy cover as well as in-stream cover, dominated by overhanging vegetation within one meter of the stream surface (Photo 6). The modified FHAP/USHP methodology was conducted on eight habitat units (HUs) within this reach, for a total of 85 m (33% of the entire reach; Figure 7). The gradient of this reach is low, with an average channel gradient for the eight assessed HUs of 1.44%

Channel substrates are dominated by gravel (68%) with sub-dominant fines (16.25%). The remaining substrate composition includes cobble (10%) and boulders (6%). This reach had the highest LWD/bankfull width metric compared to the other five reaches that were assessed according to the modified FHAP/USHP methodology. There is one large log jam at approximately km 0+180 (Photo 7). The banks in this reach are soft and steep, with erosion creating undercut banks and exposing roots (Photo 8). This reach had an adequate number of riffles, pools, and glides, with pools creating rearing habitat for salmonids (Photo 9), riffles oxygenating the water, and glides/riffles providing spawning opportunities for salmonids. Several small patches of cutthroat trout spawning gravel were observed throughout this reach. Coho fry and stickleback were observed in the pools during the site visit.

Vegetation along the banks of this reach is dominated by deciduous species such as red alder, Pacific ninebark, salmonberry, red-osier dogwood, horsetail, small-flowered bullrush, lady fern, hedge nettle, snowberry, and skunk cabbage. There are several sitka spruce trees in the downstream portion of the reach, however the riparian forest transitions from mixed coniferous/deciduous to deciduous closer to the upstream limits of the reach. There is one large overhanging western red cedar providing cover in HU P3-1 (Photo 9). The banks of this reach are covered with invasive species; primarily Himalayan blackberry and English ivy, with morning glory, fireweed, English holly, and bamboo interspersed. Canopy closure is estimated at 75% on average in this reach. The riparian depth is between 15-40 m since this reach flows through a park, with no residential development within the riparian area. There is a pedestrian trail adjacent to the left bank through the park.

Habitat Assessment Results

Reach 1 shows a *Good* rating for % crown and % in-stream cover, resulting in good summer rearing habitat due to shade, protection from predators, and food sources from litter fall. The riparian depth along its southern (left) bank has been modified by a pedestrian trail within 15 m of the creek. Substrates are *Good* for % gravel and *Fair* for % fines. This reach had *Poor* percent wetted area, with large, exposed gravel bars throughout the glide habitat units (Photo 8). Overall, Reach 1 receives a *Good* rating (Table 10) and provides the best in-stream habitat compared to the five other reaches that were assessed. The reach could benefit from some recommended instream enhancements (see below), however it is of lower priority.

Table 10. Habitat Ratings for Reach 1

Habitat Parameter	Reach 1	Ratings	
% Pool Area	n/a	n/a	-
LWD/BFW	1.38	3	Fair
% Stream Cover	29.31	1	Good
Average % Fines	16.25	3	Fair
Average % Gravel	68.13	1	Good
% Wetted Area	53.99	5	Poor
% Crown Cover	75.00	1	Good
Erosion Sites	n/a	n/a	-
Obstructions	n/a	n/a	-
Alteration Sites	n/a	n/a	-
Totals		**14**	Good

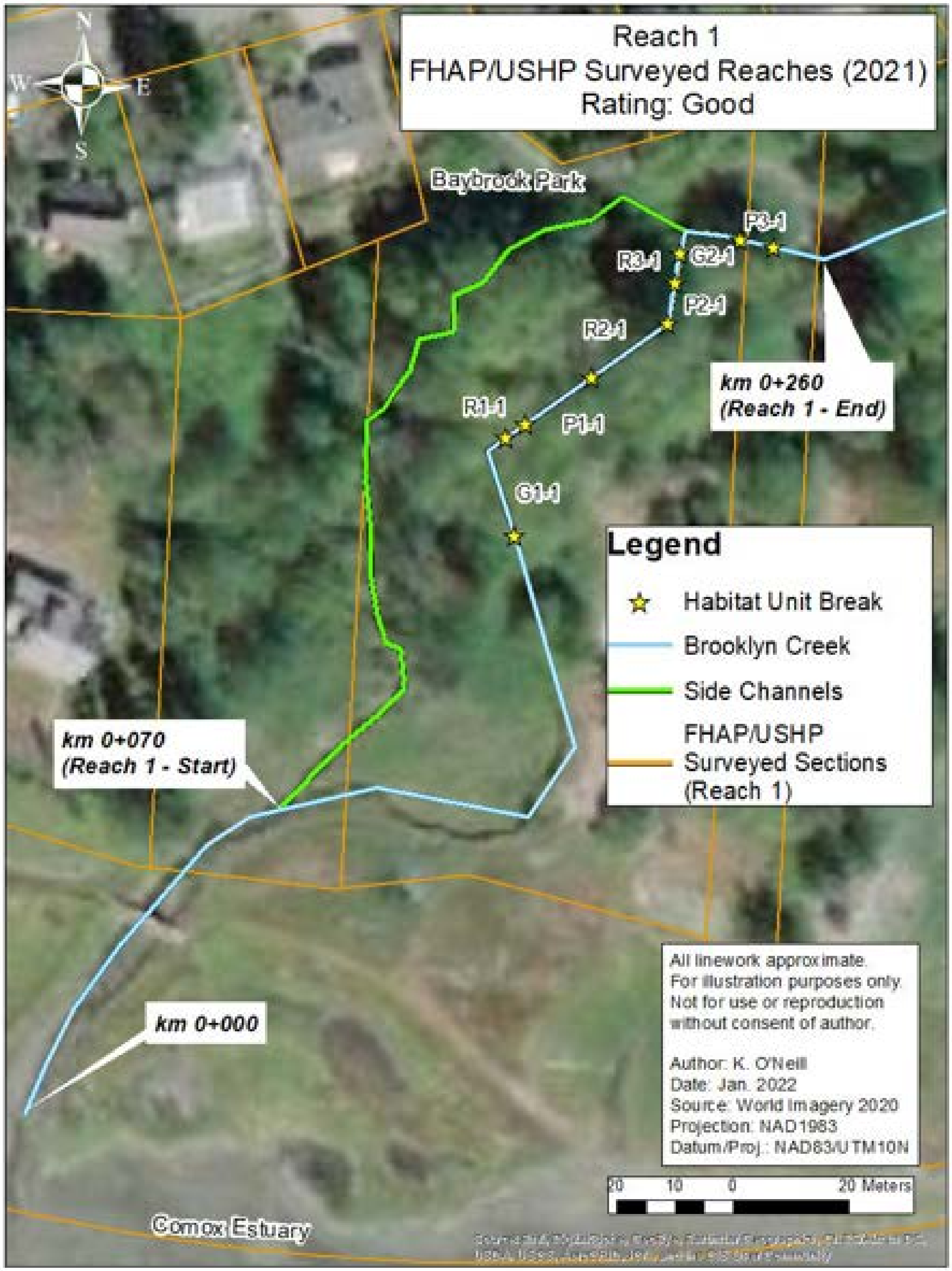
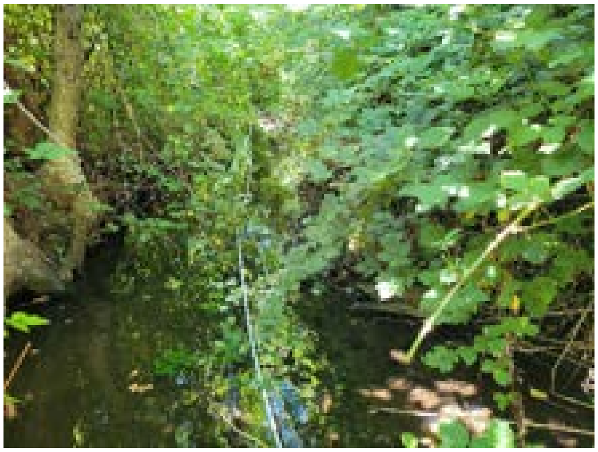


Figure 7. Modified FHAP/USHP Surveyed Habitat Units in Reach 1.



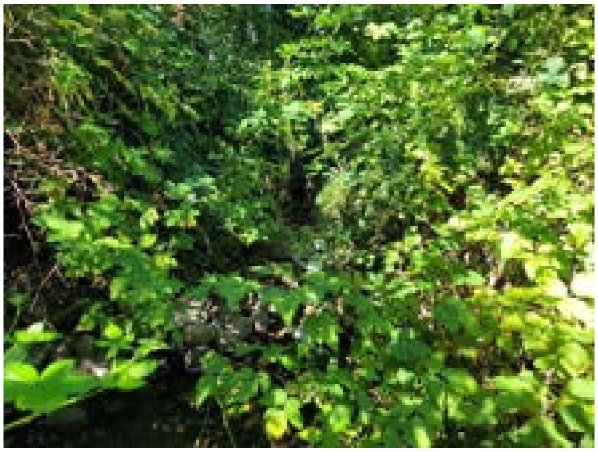
Photos 6 & 7. Pool at approximately km 0+195 (HU P1-1) showing good overhanging vegetation and canopy cover (above left; Aug. 12, 2021). Log jam at approximately km 0+180 (HU G1-1), looking upstream toward riffle (HU R1-1). This log jam does not appear to be a barrier to fish passage (above right; Aug. 12, 2021).

Photos 8 & 9. Undercut banks with exposed roots along right bank in HU G1-1 (km 0+165 to 0+180). Exposed gravel bar along left bank and overhanging invasive English holly (above left; Aug. 12, 2021). Pool at approximately km 0+245 (HU P3-1) providing shaded rearing habitat for salmonids. Himalayan blackberry canes visible in background of photo (above right; Aug. 19, 2021).

Previous Enhancement Conducted in Reach
Multiple enhancement projects were conducted in Reach 1, as part of the multi-year Brooklyn Creek Channel Enhancement Project, which began in 2005. The Reach 1 projects included the construction of a riffle/pool complex in 2012 (called CR1.1; Appendix B), the installation of LWD structures (including two LWD complexes in HU P2-1 (Photo 10), and the construction of a 200 m long side channel (as described below). The LWD complexes appear to be functioning well, providing cover and structural complexity for salmonids in the pool. The constructed riffle (CR1.1; Appendix B) is functioning well, is not scouring, and does not appear to be causing a low flow barrier to salmonids. The four assessed HUs between km 0+165 to 0+218 are natural and have not been restored.

Photo 10. Installed LWD structure along left bank of pool (HU P2-1; looking downstream), beneath overhanging Himalayan blackberry (above; Aug. 19, 2021).

A 200 m long side channel was constructed off the right bank of Reach 1 in 2012 with the upstream end at approximately km 0+235, re-entering the mainstem at approximately km 0+065. There appears to be an overflow channel between the mainstem and the side channel in HU R1-1 (approximately km 0+185), although it was dry at the time of the site visit. The side channel was wetted during the site visit, however the inlet at approximately km 0+235 was dry, with exposed cobble and no surface connection between the mainstem and the side channel at the time of the site visit (Photo 11). The channel likely does not completely dry during the summer months due to groundwater upwelling. There are several constructed riffles within the side channel, which appear to be functioning as intended with no scouring at the toe (Photo 12). The pools upstream of the riffles where LWD complexes were installed are also in good condition (Photo 13), and spawning gravels that were placed throughout the channel remain in place. The riparian plantings are well established; however, there is a high prevalence of Himalayan blackberry along the banks of the side channel (Photo 14), and a large patch of knotweed was observed along the right bank near the upstream end of the channel (Photos 11 and 15). Stickleback were observed in the side channel at the time of the site visit. The DO in the side channel was very low (1.32 mg/L) and the temperature was high (20.1°C; Table 8), therefore this channel is not providing appropriate summer rearing habitat for salmonids due to the lack of surface connectivity to the mainstem. This side channel likely provides good overwintering habitat at higher flows.



Photos 11 & 12. Upstream end of constructed side channel from mainstem (with invasive species), looking downstream toward side channel. Exposed cobbles at inlet of channel, no surface connectivity at time of site visit (above left; Aug. 12, 2021). Constructed riffle at downstream end of side channel, no scouring at toe of riffle (above right; Aug. 12, 2021).

Photos 13 & 14. Installed LWD/boulder complex in pool upstream of constructed riffle in side channel; providing cover and habitat complexity for fish (above left; Aug. 12, 2021). Himalayan blackberry covering banks of side channel, looking upstream (above right; Aug. 12, 2021).

Photo 15. Large patch of Japanese knotweed along right bank of constructed side channel, near upstream end where it connects to the mainstem (above; Aug. 12, 2021).

Recommended Enhancement
Reach 1 provides the best in-stream habitat compared to the five other assessed reaches. Riparian cover is good and there is an adequate number of pools and riffles to provide oxygenation, spawning opportunities, and summer rearing habitat. There are several patches of invasive species that should be removed, including Himalayan blackberry, English ivy, and a patch of Japanese knotweed along the right bank near the upstream end of the constructed side channel (Figure 7).

The constructed riffle assessed in Reach 1 (CR1.1) is in good condition and is low priority for maintenance/repair works (Figure 7), however it could be improved by increasing the height of the crest to deepen the pool upstream.

The side channel is not connected to the mainstem during low flow in summer months, precluding the channel from being used for summer rearing. The constructed mainstem riffle located immediately downstream of the side channel intake was originally installed at a conservative invert to observe the hydraulic response at various water levels. The control riffle can be adjusted incrementally to gradually increase the amount of surface flow connectivity to the side channel without impacting supply to the mainstem.

5.3.3 **Reach 2 (km 0+260 – 0+910)**

Description
Reach 2 begins immediately upstream of the bridge in Baybrook Nature Park where the old counting fence was located, extending for 565 m upstream to Balmoral Road. The counting fence may be a barrier to juvenile fish migration during low flows (Photo 16), with a 7-8 cm drop from the top of the wood board to the water surface below, at the time of the August 19th site visit. There have been many restoration/enhancement projects conducted in this reach over the years, as described in the previous enhancement section below. This reach has good canopy cover (Photo 17) at 32% on average, with the majority of the reach located in Mack Laing Park. The majority of this reach is in a ravine, with a residential development located at the top of the ravine to the west of the creek and MacDonald Wood Park to the east. There is a pedestrian trail along the right bank of the creek in Reach 2 (Photo 18). The modified FHAP/USHP methodology was conducted on seven HUs within this reach, for a total of 155 m (27% of the entire reach; Figure 8). The gradient of this reach is low, with an average channel gradient for the seven assessed HUs of 1.93%.

Channel substrates are dominated by gravel (60%) with sub-dominant boulders (17%). The remaining substrate composition includes cobble (13%), and fines (10%). This reach is lacking LWD, with an average of only 0.77 LWD pieces/bankfull width. In general, this reach showed many signs of erosion and a flashy confined system, with cutbanks (Photo 19), exposed roots (Photo 19), armoured banks near the walking path (Photos 18 and 20) and eroded hardpan along banks (Photo 21). There are several LWD/boulder complexes installed parallel to the right bank at km 0+745 which appear to be functioning well to prevent further erosion of the bank where the pedestrian trail is located. The left bank directly upstream of the walking bridge at approximately km 0+360 in Mack Laing Park was very steep and unstable (Photo 22), however this was stabilized during construction of the walking bridge in August 2021 and is no longer of concern. The trail has been re-aligned in several areas to reduce impacts on the mainstem, and bioengineering techniques have been used to reduce bank erosion (Photo 23).

There were many large, exposed gravel bars in this reach (Photo 21), with both cutthroat trout and coho spawning gravel patches observed (Photo 24). The pool habitats appear to be functioning well in this reach, due to cutbanks and overhanging tree roots providing cover and shade; these cutbanks and exposed tree roots are caused by erosion during the high flow winter months. Many LWD/boulder complexes have been installed in the pools throughout this reach during past restoration/enhancement efforts. Coho fry, juvenile cutthroat trout, and threespine stickleback were observed in the pools throughout this reach.

This reach is situated within a mixed deciduous/coniferous second-growth forest, with vegetation dominated by red alder, bigleaf maple, grand fir, hemlock, Sitka spruce, skunk cabbage, small-flowered bullrush, slough sedge, salmonberry, stink currant, red elderberry, swordfern, and lady fern. The Georgia Basin Habitat Atlas (Community Mapping Network 2018) shows a 5.6 ha OF:co (Old Forest, coniferous) SEI polygon (S1165) overlaying the majority of Reach 2 in Mack Laing Park (Figure 5). Wetland vegetation species were observed in the riparian area to the west of the creek; the floodplain between the creek and the residential development to the west presents as pockets of wetlands, with the walking path intersecting them. There is a culvert beneath the path and the residences to the west, connecting the wetland pockets to the stream at approximately km 0+450 (Photo 25). This overflow channel was dry at the time of the site assessment, however it likely connects during the winter months. Vegetation species present within the dry wetland included slough sedge, skunk cabbage, salmonberry, lady fern, and bamboo (Photo 26).

Invasive species are pervasive in this reach, with Himalayan blackberry and English ivy covering many of the banks (Photo 27). Invasive yellow archangel was observed between km 0+555 and km 0+615. Spurge laurel, lemon balm, and yellow archangel covered the banks around km 0+745. Canopy closure is lower in this reach compared to Reach 1 (32% on average), due to the walking path and residences to the west of the creek. The riparian depth is good (between 20-90 m on the right bank and greater than 80 m for the majority of the left bank) along this reach since the creek is within a park and there are no residences directly adjacent to the channel.

There are two historical side channels along the left bank of Reach 2. There is potential to restore these channels and provide access during the winter months (as discussed in the recommended enhancement opportunities section below). These are described as follows:

1. There is a historical side channel along the right bank of Reach 2, between approximately km 0+418 and km 0+435. The upstream end of the channel is indistinct and was dry at the time of the assessment, therefore the mapping for this channel is approximate. The upstream end of the channel has infilled with vegetation (predominantly salmonberry), with bigleaf maple, hemlock, and red alder providing cover and shade. Several pieces of LWD have been deposited across the old channel. The banks are somewhat visible but are not clearly defined at the upstream end, however, the downstream end of the channel has clearly eroded and defined banks, alluvium, and standing water (Photos 28 and 29). The eroded banks suggest that the side channel has received flows from the mainstem during winter months, however, due to the deep and muddy fines in the downstream end and the presence of terrestrial vegetation in the upstream end, it appears that the channel is no longer connected to the mainstem and likely never provides summer rearing habitat for fish. This historical side channel may provide habitat during extreme high flows.
2. There is a second historical side channel along the left bank of Reach 2, between approximately km 0+615 to 0+690. This channel was dry at the time of the site assessment and does not appear to have had flow recently, however the banks are distinct in several locations (mainly near the upstream end) and there is evidence of alluvium and rafted debris within the old channel (Photo 30); it is likely that this channel was once connected to the mainstem during the

high flow winter season. The side channel near the upstream end is filled with slough sedge (Photo 31). The inlet of the side channel along the upstream end in the main channel does not appear to connect, since the left bank along the mainstem is very steep. There was one pocket of standing water with deep mucky fines during the August 2021 site visit between the mainstem and this historical channel at approximately km 0+635 (Photo 31). Stickleback were observed within this isolated pool during the site visit; this pool likely connects to the mainstem during high flow events but was isolated during the summer low flow assessment period.

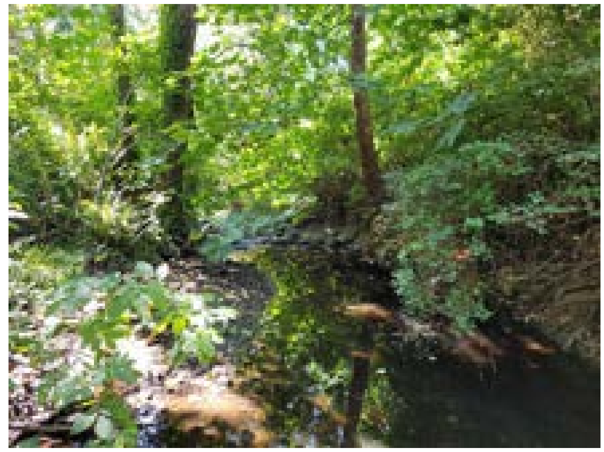
The Balmoral Avenue fish ladder is located at the upstream end of the reach, and has the potential to be a low flow barrier for juvenile salmonids during the summer months (Photo 32). The native base of the ladder has eroded over recent years and water can be typically observed seeping under the structure when base flows are insufficient for surcharging one or more of the ladder cells. Surface flow disconnection at the ladder may be impairing juvenile fish passage and nutrient supply. Corrective measures have been implemented by the Town of Comox in the past by re-nourishing the bed of the ladder with a mix of aggregates, however erosive energy from heavy flows continue to pose maintenance challenges. The Town of Comox will be exploring options to restore the ladder, which may involve sealing the base of each cell with concrete. Obstructions, such as dams and in-stream structures can cause fish passage issues, resulting in fewer rearing habitats for salmonids during the low flow summer months (Government of Canada 2010). Water was flowing around the left bank of the structure (Photo 33) instead of outletting at the bottom step of the ladder during the assessment on August 19th, 2021. The outlet drop was 17.6 cm, the outlet pool depth was 54.0 cm and the maximum pool depth beneath the fish ladder was 89.6 cm. This means that the outlet drop is 33% of the pool depth immediately downstream of the fish ladder outlet.

Habitat Assessment Results
Reach 2 shows a *Good* rating for % crown and % in-stream cover, resulting in good summer rearing habitat due to shade, protection from predators, and food sources from litter fall. The riparian depth along its western (left) bank has been modified by a pedestrian trail adjacent to the creek, with the trail creating erosion problems and requiring bank armouring in several locations. Substrates are *Good* for % gravel and *Fair* for % fines. This reach had *Poor* percent wetted area, with large, exposed gravel bars throughout the glide and riffle habitat units (Photo 20). Many of the pools upstream of constructed riffles have filled in with gravel over time, resulting in less rearing opportunities for salmonids during the summer months. Overall, Reach 2 receives a *Fair* rating (Table 11). It should be noted that enhancement work has been done in this reach, including the construction of riffles, installation of LWD/boulder complexes, and addition of spawning gravel. Since only 27% of the entire reach was assessed according to the modified FHAP/USHP methodology (Figure 8), the overall reach score does not account for all restoration work completed in the reach and should be considered in conjunction with the reach descriptions and visual observations made while assessing the remainder of the reach.

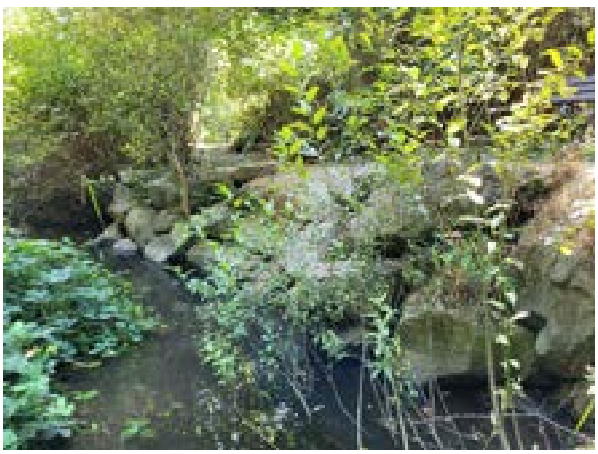
Table 11. Habitat Ratings for Reach 2

Habitat Parameter	Reach 2	Ratings	
% Pool Area	n/a	n/a	-
LWD/BFW	0.77	5	Poor
% Stream Cover	26.86	1	Good
Average % Fines	10.00	3	Fair
Average % Gravel	60.00	1	Good
% Wetted Area	37.81	5	Poor
% Crow n Cover	32.14	1	Good
Erosion Sites	n/a	n/a	-
Obstructions	n/a	n/a	-
Alteration Sites	n/a	n/a	-
Totals		**16**	Fair

Figure 8. Modified FHAP/USHP Surveyed Habitat Units in Reach 2.



Photos 16 & 17. Fish counting fence at km 0+265; potential barrier to juvenile salmonids during the low flow period (above left; Aug. 19, 2021). Looking downstream toward constructed riffle at approx. km 0+310. Good canopy cover providing shade and litter fall (above right; Aug. 19, 2021).



Photos 18 & 19. Pedestrian trail along right bank of Reach 2 at km 0+410; looking downstream at armoured bank (above left; Aug. 19, 2021). Cutbank with exposed roots in HU G1-2 (above right; Aug. 19, 2021).

Photos 20 & 21. Armoured bank with riprap to prevent further erosion in HU G2-2 (km 0+660; above left; Aug. 20, 2021). Eroded hardpan along right bank in HU G3-2 resulting in cutbanks at higher flows (above right; Aug. 20, 2021).

Photos 22 & 23. Steep and eroding left bank immediately upstream of walking bridge at km 0+345; looking upstream – this has since been stabilized and is no longer an issue (above left; Aug. 19, 2021). Bank revetments and LWD complex at km 0+507 (above right; Aug. 20, 2021).

Photos 24 & 25. Spawning gravels along bank in HU P1-2 at km 0+385 (above left; Aug. 19, 2021). Culvert beneath walking path connecting wetted area to the west and Brooklyn Creek during high flow events (above right; Aug. 20, 2021).

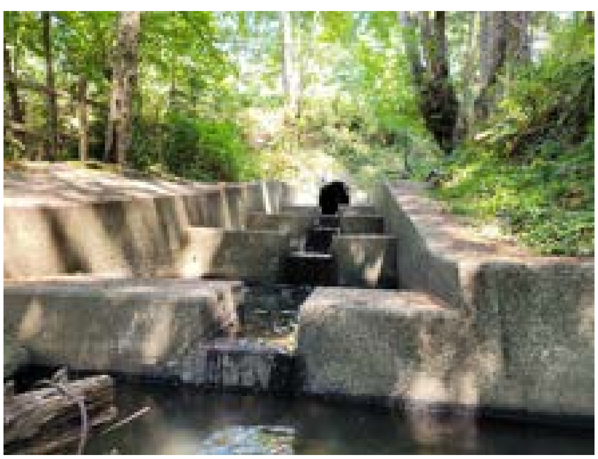
Photos 26 & 27. Wetted area to west of creek at km 0+450, showing salmonberry, skunk cabbage, lady fern, and bamboo (above left; Aug. 20, 2021). Invasive English ivy covering banks in Reach 2 (above right; Aug. 20, 2021).

Photos 28 & 29. Dry side channel between km 0+418 and km 0+435 with defined banks and deep and muddy substrates (above left; Aug. 20, 2021). Standing water in a section of the dry side channel (above right; Aug. 20, 2021).

Photos 30 & 31. Dry side channel between km 0+615 to 0+690 with defined banks and rafted debris (above left; Aug. 20, 2021). Isolated pool adjacent to left bank of mainstem at km 0+635 (above right; Aug. 20, 2021).

Photos 32 & 33. Fish ladder downstream of Balmoral Avenue potentially acting as fish barrier during low flows (above left; Aug. 20, 2021). Water flowing around left bank of fish ladder instead of all through centre of fish ladder downstream of Balmoral Avenue (above right; Aug. 20, 2021).

Previous Enhancement Conducted in Reach
There are several constructed riffles between the Baybrook Nature Park bridge (start of Reach 2) and km 0+385 (see ratings, photos, and locations in Appendix B). These riffles were constructed in 2013 (Figure 2). Detailed FHAP/USHP measurements were not conducted on these riffles, however they were assessed to determine their condition and effectiveness. All four of these riffles may be creating partial barriers to juvenile salmonids in the low flow summer months since water is flowing between the boulders and creating scouring at the toe of the riffles due to high flows in the winter months.

Additional enhancement projects were conducted in Reach 2 as part of the multi-year Brooklyn Creek Channel Enhancement Project, which began in 2005. The Reach 2 projects included the construction of riffle/pool complexes, the installation of LWD structures, and bank stabilization/revetment works. Constructed riffle/pool complexes in the mid- to upper portion of Reach 2 were constructed in 2008 and 2009 (Figure 2). Ten of these previously constructed rock riffles were observed and assessed during the 2021 study (called CR2.1 – CR2.10; Appendix B).

Many of the riffles in Reach 2 are in need of maintenance, as discussed in Appendix B. Many of the constructed riffles in this reach have scoured toe rocks, riffle crest flanks and there is a lack of gravel due to poor recruitment. The lack of gravels topping the riffles creates potential low flow barriers to juvenile salmonids.

Recommended Enhancement
Potential restoration opportunities within Reach 2 include the removal of fish barriers, addition of spawning gravels, repair of constructed riffles, repair of LWD complexes, riparian enhancement (native species planting and removal of invasive species), and off-channel creation. Specific enhancement recommendations including locations are described below.

Removal of Fish Barriers
The fish counting fence immediately upstream of the Baybrook Nature Park bridge may be causing a fish barrier during low flows (Photo 16). A wooden board spans the channel width, creating a 7-8 cm drop at the time of the site visit on August 19th, 2021. This should be further assessed during future low flows to determine whether

Additionally, the fish ladder at Balmoral Avenue is in need of repair since it is a potential barrier to upstream migration by salmonids during the low flow months. Water was observed flowing along the side of the concrete structure, entering the mainstem on the left bank. This results in lower flows over the center of the ladder, with a larger drop (17.6 cm at the time of the August 20th site visit) between the outlet and the pool below. The Town of Comox will be exploring options to restore the ladder, which may involve sealing the base of each cell with concrete.

Addition of Spawning Gravels
Spawning gravels should be placed throughout, since gravel recruitment is limited in this reach and spawning gravel previously installed has remobilised downstream during high flow events. Specifically, gravel should be re-seeded on most of the existing constructed riffles, as well as in the pools upstream of these constructed riffles. Access routes for the placement of spawning gravels can follow the same routes used during the initial installation of these constructed riffles.

Repair of Constructed Riffles
The majority of the constructed riffles in this reach need to be repaired/maintained since there is scouring along the banks of some of these riffles, there is a lack of spawning gravels upstream and on top of the riffles, and the riffles are creating potential low flow barriers to juvenile salmonids. Out of the ten constructed riffles assessed in Reach 3, eight of them are high priority for maintenance and two of them are moderate priority (Appendix B). The potential low flow barriers being created by the constructed riffles are of concern. The height of the riffle immediately downstream of each of the constructed riffles should be raised to backwater and permanently protect the toe of the subsequent upstream riffle and improve the pools upstream of the riffles. Additionally, gravel has eroded away from the majority of the constructed riffles due to high flows, therefore all of the constructed riffles should be re-seeded with spawning gravels, as indicated above.

The pools between km 0+775 and the Balmoral Avenue fish ladder appear to have been infilled by gravels that have washed downstream from high flows (and potentially gravels that were placed during riffle construction) – the pool depths are no longer sufficient for summer rearing. The crests of the riffles downstream of these pools should be raised to backwater the pools, increasing their depths. The scoring of each of the constructed riffles in Reach 2 is shown in Appendix B.

Repair/Installation of LWD Complexes
There are multiple constructed LWD/boulder structures within the pools upstream of the constructed riffles in this section that are beginning to rot. The majority of these do not need replacement at this time, however they should be inspected frequently and replaced as required.

Riparian Enhancement
Riparian cover is good in Reach 2, with trees and shrubs along the banks in the majority of the reach. The right bank is narrow in many locations since the pedestrian trail extends to the edge of the creek, however the ravine slope to the west of the path has good vegetative cover, providing shading, litter fall, and woody debris to the stream. There is one large, denuded area along the right bank at km 0+690, lacking in understory species (Photo 34). This area should be de-compacted, amended with native topsoil, and planted with native species such as sword fern, salmonberry, lady fern, salmonberry, Douglas fir, Bigleaf maple, and red alder.

Invasive species such as Himalayan blackberry, English ivy, yellow archangel, lemon balm, and spurge laurel should be removed form the banks to improve riparian functionality. Invasive species are pervasive in this reach, therefore we recommend that removal efforts coincide with areas where riffles are repaired/maintained.

Photos 34. Denuded area along right bank at km 1+690 where native planting should be conducted (above; Aug. 20, 2021).

Off-channel Creation
There is an opportunity to improve connectivity and functionality to the two natural side channels in Reach 2. If connected to the mainstem flows, these channels would provide summer rearing and overwintering habitat to salmonids, as well as dissipate flows during high discharge events, minimizing further scouring and erosion concerns in the mainstem. The lower side channel between km 0+418 and km 0+435 is within Mack Laing Park. The upper side channel between km 0+615 to 0+690 is split between Mack Laing Park (on the downstream end) and private property to the east, zoned residential low density (R1.1) in the Town of Comox.

5.3.4 Reach 3 (km 0+910 – 1+910)

Description
Reach 3 extends between Balmoral Road and Dogwood Road, for a distance of 1 km. This reach is almost entirely within the Brooklyn Creek Greenway, with the exception of the 65 m stretch at the upstream end of the reach, immediately downstream of Dogwood Road. Restoration has also been conducted in a large portion of this reach, as described in the previous enhancement section below. This reach has good canopy cover at 52% on average. The pedestrian trail continues north through this reach, along the right bank until the walking bridge across the creek at km 1+080, where the path follows the left bank of the creek until the end of the park at approximately km 1+755. The creek is in a ravine for the majority of this reach, with steep and eroding banks on both sides of the creek. Residential developments are at the top of the ravine on both sides of the creek, outside of the park. There are several locations where the banks are armoured with riprap or retaining walls due to the steep eroding banks (Photos 35 and 36). The modified FHAP/USHP methodology was conducted on nine HUs within this reach, for a total of 372 m (37% of the entire reach; Figure 9). The gradient of this reach is similar to that of Reach 2, with an average channel gradient for the nine assessed HUs of 1.83%.

Channel substrates are dominated by gravel (57%) with sub-dominant cobble (18%). The remaining substrate composition includes boulder (14%), fines (7%), and hardpan (4%). This reach is lacking LWD, with an average of only 0.31 LWD pieces/bankfull width. In general, this reach showed many signs of erosion and a flashy confined system, with substrates that have been eroded down to hardpan in the upper portion of the reach (Photo 37), cutbanks and exposed roots (Photo 38), armoured banks near the walking path (Photo 36), steep and eroded banks (Photo 39) and scouring at the toe/along the banks of some of the constructed riffles (Appendix B). A seasonal off-channel pond was observed along the left

bank of Reach 3 at km 1+555. This pond is shallow and was dry at the time of the assessment, however it has defined banks and is filled with slough sedge and skunk cabbage indicating that it is wetted during high flow conditions (Photo 40).
Several patches of cutthroat trout and coho spawning gravel were observed throughout the reach (Photo 41), however gravel has washed downstream in a large portion of this reach due to high flows in the winter months. There were many good pool habitats between Balmoral Avenue and km 1+550 (e.g. Photo 42), with cutthroat trout and juvenile coho observed throughout. Cutbanks, overhanging vegetation, and LWD complexes are providing cover for salmonids in these pools. Pools become very shallow upstream of km 1+550, with the exception of one deeper pool at km 1+615 (Photo 43), however this pool has low hydraulic and habitat complexity, with hardpan substrate and no vegetative or LWD cover. The remainder of the reach upstream of this pool (HU G3-3) has no riffles or pools and is severely lacking in habitat complexity (Photos 37 and 38), as described below. Stickleback were observed in HU G3-3 however no salmonids were observed upstream of km 1+595.

This reach is within a mixed deciduous/coniferous second-growth forest, with vegetation dominated by grand fir, Douglas fir, Western hemlock, Western red cedar, sitka spruce, bigleaf maple, red alder, snowberry, dull Oregon grape, sword fern, lady fern, slough sedge, skunk cabbage, Pacific ninebark, salmonberry, nootka rose, and thimbleberry. The riparian depths on both banks is between 12-100 m, with a pedestrian path immediately beside the bank in several locations. Residential properties are close to the right bank surrounding Balsam Avenue and Cedar Avenue, narrowing the riparian depth in these areas. There is a 25 m by 7 m trampled area with a denuded understory along the right bank at approximately km 1+060 (Photo 44), where a drainage pipe outlets into the creek creating an artificial waterfall feature (Photo 45). The banks are covered in invasive English ivy throughout much of Reach 3 (e.g. Photo 46). Additional invasive species observed along the banks of this reach include English holly, yellow archangel, Himalayan blackberry, Policeman's helmet, spurge laurel, periwinkle, and morning glory.

The upper 293 m of Reach 3 (HU G3-3) is one long glide, with no pools or riffles (Photos 37 and 38). There is no bed or habitat complexity, with eroding hardpan comprising a large portion of the substrate (30%). Cobbles are the dominant substrate in this reach (45%), overtopping the hardpan with 15% gravels and 10% boulders. The bed substrate in the upstream portion of this HU is almost entirely exposed and eroding hardpan with cobbles and boulders on top, from km 1+685 to Dogwood Avenue. No fine material was observed within this HU. English ivy is pervasive along the banks in this section of the reach. Stickleback were observed within this HU, however no salmonids were observed due to the lack of pools, complexity, cover, and rearing habitat. One small gravel bar was observed along the left bank at km 1+750 (Photo 47), however there were still no pool or riffle habitats in this section of the reach. This portion of the reach is very urbanized and altered, with a walking bridge across the creek, multiple drainage pipes out-letting into the creek, a fence along the edge of a backyard beside the creek, and revetments along a residential property to slow bank erosion (Photo 48). There is a more defined riffle beneath the Dogwood Avenue bridge, upstream of HU G3-3.

<u>Habitat Assessment Results</u>
Reach 3 shows a *Good* rating for % crown cover, however there is less in-stream cover than observed in Reaches 1 and 2; % in-stream cover receives a *Fair* rating in Reach 3. The riparian depth is narrower (between 15-50 m) along the right bank than in Reach 2, with houses located closer to the creek. The riparian depth on the left bank is wider at 30-50 m. Substrates are *Good* for % gravel % fines, with the least amount of fines compared to the other five reaches. This reach had *Poor* percent wetted area, with large, exposed gravel bars throughout the glide and riffle habitat units. Overall, Reach 3 receives a *Fair*

rating (Table 12). It should be noted that enhancement work has been done in this reach, including the construction of riffles, installation of LWD/boulder complexes, and addition of spawning gravel. Since only 37% of the entire reach was assessed according to the modified FHAP/USHP methodology (Figure 9), the overall reach score does not account for all restoration work completed in the reach and should be considered in conjunction with the reach descriptions and visual observations made while assessing the remainder of the reach.

Table 12. Habitat Ratings for Reach 3

Habitat Parameter	Reach 3	Ratings	
% Pool Area	n/a	n/a	-
LWD/BFW	0.31	5	Poor
% Stream Cover	14.44	3	Fair
Average % Fines	6.67	1	Good
Average % Gravel	57.22	1	Good
% Wetted Area	56.24	5	Poor
% Crown Cover	52.22	1	Good
Erosion Sites	n/a	n/a	-
Obstructions	n/a	n/a	-
Alteration Sites	n/a	n/a	-
Totals		**16**	Fair

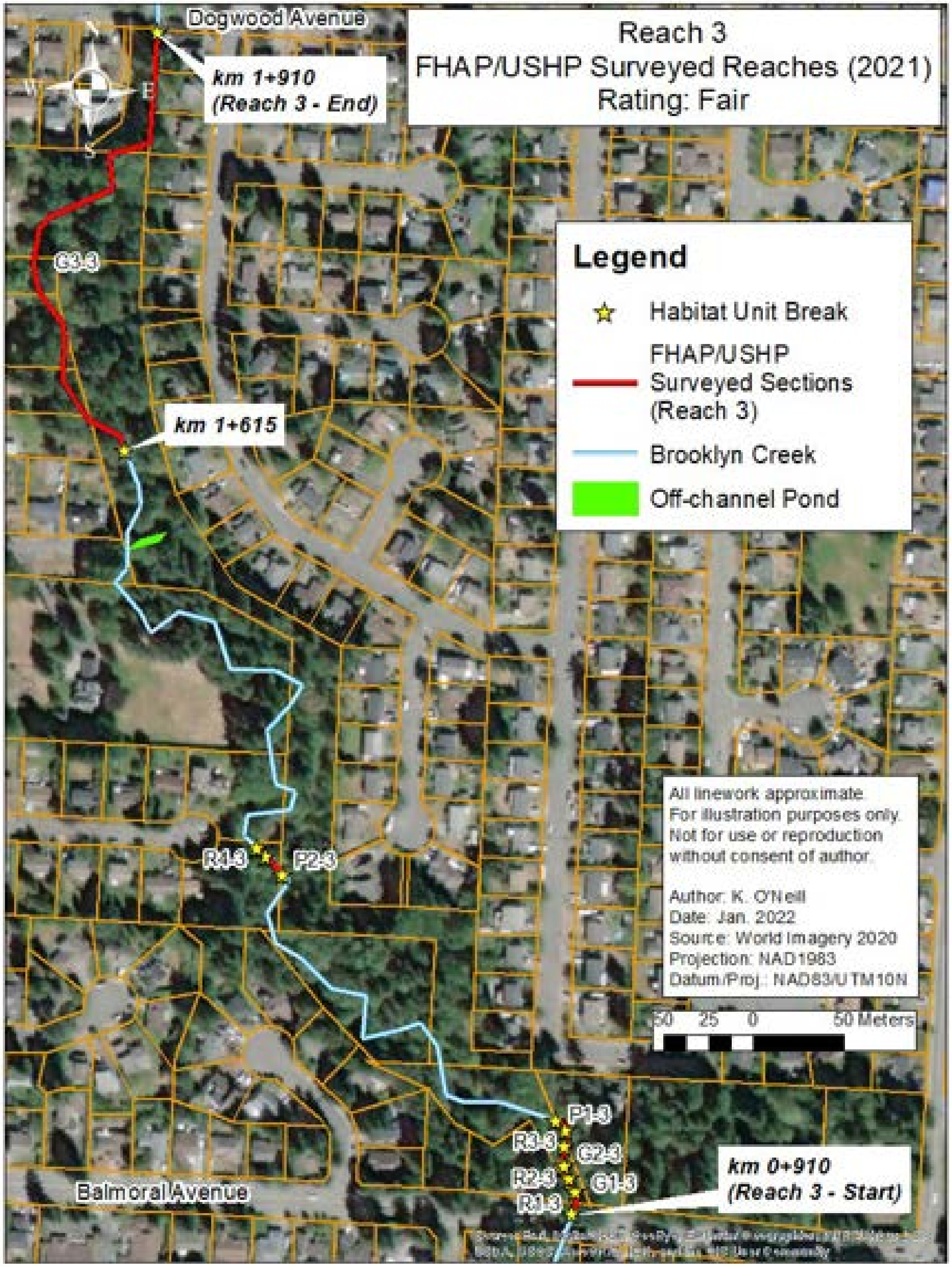


Figure 9. Modified FHAP/USHP Surveyed Habitat Units in Reach 3. Note: Overall reach is rated as fair based on FHAP/USHP measurements and visual assessments, however the upper 293 m section of the reach (HU G3-3) is very different and is considered poor for fish habitat.

Photos 35 & 36. Retaining wall constructed by property owner along eroding left bank in HU G2-3 (above left; Aug. 20, 2021). Riprap armoured right bank preventing pedestrian path from eroding into stream in lower portion of Reach 3. Steep ravine bank to the west of the walking path. Recommend riparian planting between riprap wall and pedestrian path. Dense English ivy along left bank (above right; Aug. 25, 2021).

Photos 37 & 38. Eroded hardpan substrate and banks in upper portion of Reach 3 (above left; Aug. 25, 2021). Cutbanks and exposed roots in upper portion of Reach 3 (above right; Aug. 25, 2021).

Photos 39 & 40. Steep and eroded bank in Reach 3 (above left; Aug. 25, 2021). Off-channel pond at km 1+555 that appears to hold water during high flow winter months; filled with slough sedge and skunk cabbage (above right; Aug. 25, 2021).


Photos 41 & 42. Gravel bar with potential spawning opportunities at approximately km 1+175 (above left; Aug. 25, 2021). Deep pool habitat with overhanging vegetation and cutbanks providing cover for salmonids at approximately km 1+160. Juvenile cutthroat trout and coho observed in this pool (above right; Aug. 25, 2021).


Photos 43 & 44. Last pool observed in upstream section of reach (at km 1+615); no pools or riffles upstream to Dogwood Avenue. Pool lacks hydraulic and habitat complexity and substrates and banks are composed of eroding hardpan. (above left; Aug. 25, 2021). Denuded area to be planted and fenced along right bank at km 1+060 (above right; Aug. 25, 2021).


Photos 45 & 46. Artificial waterfall feature on left bank from drainage pipe outletting at km 1+060 (above left; Aug. 25, 2021). English ivy covering steep left bank and climbing up trees between km 1+080 – 1+088 (above right; Aug. 25, 2021).

Photos 47 & 48. Small gravel bar along left bank at km 1+570 (in HU G3-3; above left; Aug. 25, 2021). Fencing and bank revetments along right bank in HU G3-3 (above right; Aug. 25, 2021).

Previous Enhancement Conducted in Reach

There are many constructed riffles in Reach 3, between Balmoral Avenue (km 0+915) and km 1+495. These riffle/pool complexes, along with the spawning platforms and bank revetment work were conducted as part of the Brooklyn Creek Channel Enhancement Project. Channel enhancement work in Reach 3 was conducted between 2010-2012 (Figure 2). Spawning platforms were constructed upstream of these constructed riffles, however a large proportion of the gravels have washed downstream during high flow winter events. LWD/boulder complexes were installed in many of the pools upstream of the constructed riffles. The majority of these are intact and in good condition, however rotting is beginning to occur on some of the logs; these structures should be inspected frequently and replaced as required. Sixteen constructed riffles were observed and assessed as part of the 2021 study. The condition and functionality of each of these constructed riffles is shown in Appendix B.

No restoration has been conducted in the upper reach, between km 1+495 and Dogwood Avenue. The mid and upper portions of this section of Reach 3 are within the Brooklyn Creek Greenway, however the majority is on private properties to the west east, zoned residential low density (R1.1) in the Town of Comox. Riparian planting has been conducted in multiple locations along the banks of Reach 3.

Recommended Enhancement

Potential restoration opportunities within Reach 3 include the addition of spawning gravels, repair/installation of constructed riffles, repair/installation of LWD complexes, and riparian enhancement (native species planting and removal of invasive species), and off-channel creation. Specific enhancement recommendations including locations are described below.

Addition of Spawning Gravels

Spawning gravels should be placed throughout, since it appears that spawning gravels that have been added during previous restoration projects have washed downstream during high flow events. Specifically, gravel should be re-seeded on most of the existing constructed riffles, as well as in the pools upstream of these constructed riffles. Access routes for the placement of spawning gravels can follow the same routes used during the initial installation of these constructed riffles.

Repair of Constructed Riffles

Many of the constructed riffles need to be repaired, including re-seeding the riffles with gravel and pitrun that has migrated downstream, increasing the height of the riffle crest for riffles that are not properly backwatering the pool upstream, and lengthening the tail-out of riffles to decrease their slope, allowing for improved low flow passage. The priority constructed riffles to be repaired are discussed in Appendix B. Photos of each of these constructed riffles are presented in Appendix B.

Riffle/Pool Creation

Several areas should be enhanced with constructed riffles to create a riffle-pool morphology. Recommended areas for the construction of additional riffles are as follows:

1) Riffle-pool complexes should also be created in the upper section of Reach 3 (between km 1+615 and 1+908), where the stream bed is composed entirely of eroded hardpan with cobbles and boulders and there is no habitat or hydraulic complexity (Photos 37 and 38). This will help to create pools for salmonids to take refuge in during the summer months. LWD and boulder complexes should be installed in the pools once they are created, providing cover and bank stability. These restoration actions are a priority since this 293 m section of Reach 3 is one of the worst in terms of fish habitat in the entirety of the assessed reaches.
2) A riffle should be constructed at km 1+080, downstream of CR3.5 (under the walking bridge) to backwater CR3.5. The constructed riffle 3.5 is currently too steep and is serving as a low-flow barrier to salmonids, therefore this riffle should be backwatered to allow for upstream passage. Alternatively, the tail-out of CR3.5 could be lengthened instead of constructing an additional riffle downstream to lower the slope and allow for upstream passage.
3) Two riffle-pool complexes could be constructed in the mainstem between km 1+525 to 1+595 if a machine will already be in the area to dig out and deepen the off-channel pond along the left bank. This section would benefit from constructed riffles since the channel morphology is primarily one long glide with low flows and no rearing habitat.

Repair/Installation of LWD Complexes

Several LWD structures are rotting or are no longer serving as cover in low flows and should be repaired to remain functional. These are as follows:

1) A ballasted LWD/boulder complex previously installed along the right bank at km 1+030 (upstream of CR3.3) is beginning to rot (Photo 49), however it is still well established into the bank. If soil is being brought to this section of the reach to enhance the riparian area between the pedestrian trail and the stream (see riparian planting recommendations below), then additional soil can be used to backfill the bank behind the LWD structure and further anchor it into the bank with roots.
2) A constructed LWD structure along the right bank at km 1+037 is rotting and is perched above the low water level during the summer months (Photo 50), therefore it only functions as cover during the high flow winter months. This LWD structure was constructed into the rip-rap armoured bank, directly adjacent to the pedestrian trail. Additional LWD pieces should be installed closer to the stream bed below the existing LWD structure, to provide cover and hydraulic complexity in the pool during the low flow summer months. Soil or pit run should be used to backfill this LWD structure to further anchor it into the rip-rap bank, alongside riparian planting (see below).
3) There are two LWD structures along the right bank across from the artificial waterfall (km 1+060). The farther downstream structure is rotting (Photo 51) and could be supplemented with an additional stump or root wad to re-create the in-stream portion of this LWD feature.
4) A constructed LWD structure along the left bank in the pool at km 1+290 is rotting but is still well established into the bank and will likely remain in place (Photo 52). A larger LWD structure

would be beneficial in this pool if enhancement work is already being done in this area (e.g. riffle maintenance) to provide enhanced cover and hydraulic complexity in the deep pool (> 1 m residual depth during the site visit in August 2021).

Photos 49 & 50. LWD structure along right bank at km 1+030 beginning to rot – soil could be used to backfill bank behind structure to further anchor it into bank (above left; Aug. 25, 2021). LWD structure holding up right bank and above low water level at km 1+037 – could install additional LWD structures closer to low water mark (above right; Aug. 25, 2021).

Photos 51 & 52. LWD structure along right bank at km 1+060 beginning to rot – could be supplemented with an additional stump or root wad (above left; Aug. 25, 2021). Rotting LWD structure along right bank in pool at km 1+290 – good candidate pool for larger LWD (above right; Aug. 25, 2021).

Riparian Enhancement

Several areas that are currently trampled and denuded could use decompaction, riparian planting, and/or protection with split rail fences. These specific areas are as follows:

1) The pedestrian trail is directly adjacent to the right bank at km 1+037, with riprap armouring the bank and keeping the pedestrian trail in place. There is a steep ravine to the west of the trail, therefore the trail cannot be moved farther away from the stream's edge. A 1 m wide row of native ferns, salmonberry, and Pacific ninebark could be planted between the pedestrian trail and the rip-rap armoured wall to minimize future bank erosion and provide vegetative cover along the right bank of the pool (Photo 36). Soil will need to be added to this area, which will also help to anchor the LWD structure into the bank (as described above).

2) There is a steep ravine slope to the west of the stream from approximately km 1+037 and 1+052, between the pedestrian trail and the residential development at the top of the ravine (Photo 53). This slope is eroding and is lacking in vegetative cover. Small terraces could be constructed along the ravine with horizontal wood ledges/walls to create flat zones for planting. Native topsoil should be added to these terraces and they should be planted with native species such as sword fern, lady fern, dull-oregon grape, salmonberry, snowberry, Pacific ninebark, Western red cedar, Douglas fir, and Bigleaf maple. This would minimize erosion and would provide wildlife habitat and shading/litter drop opportunities to the stream.
3) A denuded 25 m x 7 m area adjacent to the right bank of the stream at km 1+060 has been trampled and is lacking in understory species (Photo 44). This denuded area is across from the artificial waterfall feature where a drainage pipe outlets into the left bank of the stream. This area is severely compacted and may need machinery to de-compact the soil, followed by soil amendments to prepare the soil for planting. Species to be planted could include sword fern, lady fern, dull-oregon grape, salmonberry, snowberry, Pacific ninebark, Western red cedar, Douglas fir, and Bigleaf maple. There are multiple pieces of coarse woody debris on the ground in this area, therefore riparian planting would improve wildlife habitat. A narrow trail would need to be created to allow pedestrians to access the artificial waterfall for photos. This trail should be fenced using split rail fencing to protect the planted vegetation.
4) The right bank at km 1+105, immediately upstream of the walking bridge is very steep and is lacking understory species (Photo 54). Small terraces could be constructed along the slope with horizontal wood ledges/walls to create flat zones for planting. Native topsoil should be added to these terraces and they should be planted with native species that can tolerate full shade conditions such as sword fern, lady fern, dull-oregon grape, salmonberry, snowberry, Pacific ninebark, Western red cedar, Douglas fir, and Bigleaf maple. This would minimize erosion and would provide wildlife habitat and shading/litter drop opportunities to the stream. The left bank along this section of stream is severely compacted and denuded and requires decompaction, native species planting, the addition of woody debris, and split rail fencing to prevent pedestrians from accessing the stream in this location.
5) A denuded 15 m x 6 m area adjacent to the left bank of the stream between km 1+422 and 1+455 has been trampled and is lacking in understory species (Photo 55). This area should be de-compacted, amended with native topsoil, planted with native species, and fenced with split-rail fencing to protect the planted vegetation.
6) Native trees and tall shrubs (e.g. Douglas fir, Bigleaf maple, Pacific ninebark, salmonberry, and snowberry) should be planted along the right bank between CR3.15 (km 1+465) and CR3.16 (km 1+491) to enhance the riparian area and provide additional cover in the pool between the two constructed riffles (Photo 56).

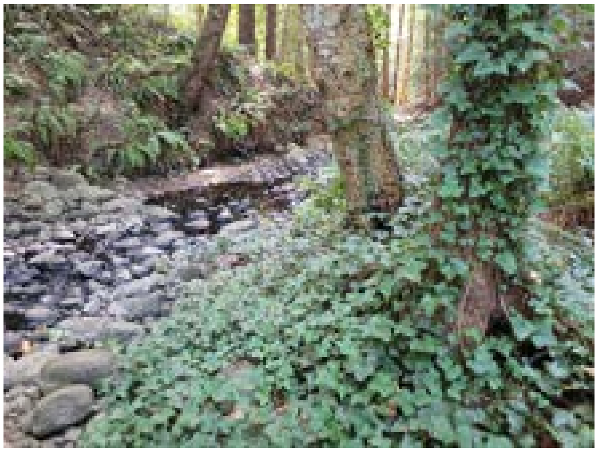

Photos 53 & 54. Steep ravine bank along right bank of stream between approximately km 1+037 and 1+052 that could use terraces and planting to stabilize slope and provide cover/shade to stream (above left; Aug. 25, 2021). Steep right bank at km 1+105 that could use terraces and planting to stabilize slope and provide cover/shade to stream (above right; Aug. 25, 2021).


Photos 55 & 56. Denuded left bank lacking understory plants between km 1+422 and 1+455 – recommend planting and fencing (above left; Aug. 25, 2021). Grassy area between km 1+465 and km 1+491 that should be planted with taller shrubs and trees to enhance riparian area (above right; Aug. 25, 2021).

Invasive species are pervasive in this reach and should be removed from the banks where possible. Areas where invasive species are the densest and should be prioritized are as follows:

1) km 1+030 – 1+040– English ivy should be removed from left bank (Photo 36).
2) km 1+080 – 1+088 – English ivy should be removed from left bank (Photo 46).
3) km 1+132 – English ivy should be removed from right bank (Photo 57).
4) km 1+150 – English ivy and English holly should be removed from right bank (Photo 58).
5) km 1+174 – 1+204 – English ivy, English holly, and yellow archangel should be removed from both banks; English ivy is covering bank and tree trunks in this area.
6) km 1+223 – English ivy and English holly should be removed from right bank (Photo 59).
7) km 1+260 – 1+290 – English ivy and Himalayan blackberry should be removed from both banks (Photo 60).
8) km 1+455 – Yellow archangel should be removed from right bank.
9) km 1+490 – Himalayan blackberry, Policeman’s helmet (Photo 61), morning glory, and yellow archangel should be removed from left bank.

10) km 1+525 – km 1+550 – English ivy and Himalayan blackberry should be removed from both banks (Photo 62).
11) km 1+685 – English ivy should be removed from left bank (Photo 63).
12) km 1+805 – Spurge laurel and English holly should be removed from both banks (Photo 64).




Photos 57 & 58. Dense English ivy along left bank at km 1+132 (CR3.6; above left; Aug. 25, 2021). Dense English ivy along right bank at km 1+150 (above right; Aug. 25, 2021).


Photos 59 & 60. Dense English ivy along right 1+223 (above left; Aug. 25, 2021). English ivy and Himalayan blackberry along both banks between km 1+260 – 1+290 (above right; Aug. 25, 2021).


Photos 61 & 62. Policeman's helmet and Himalayan blackberry along left bank at km 1+490 (above left; Aug. 25, 2021). English ivy and Himalayan blackberry along both banks between km 1+525– 1+550 (above right; Aug. 25, 2021).


Photos 63 & 64. Dense English ivy along left bank at km 1+685 (above left; Aug. 25, 2021). Spurge laurel and English holly along left bank at km 1+805 (above right; Aug. 25, 2021).

Off-channel Pond Enhancement

The off-channel pond at km 1+555 could be dug deeper to provide overwintering habitat for salmonids since the mainstem in this area is relatively straight and lacks hydraulic complexity, making it challenging for overwintering during high flow events. This pond would also help to store water, dissipating flows in the mainstem and reducing erosion downstream.

5.3.5 **Reach 4 (km 1+910 – 2+145)**

<u>Description</u>

Reach 4 extends between Dogwood Road and Noel Avenue, for a distance of 235 km. There is a constructed fish ladder upstream of the culvert at Dogwood Avenue which may be acting as a barrier under some flow conditions (Photo 65). The outlet drops were often greater than 50% of the depth of the pools beneath each of the steps during the August 26th site visit. Further assessments will be done of this fish ladder to determine if it is causing fish passage issues during low flows.

The pedestrian trail is adjacent to the right bank of Reach 4 between Dogwood Road and the pedestrian bridge at km 1+970 (Photo 66), after which it continues along the left bank between the walking bridge and Noel Avenue, to the west of Phil and Jennie Gaglardi Academy. This reach is straight with relatively homogeneous channel widths (Photo 66), having been channelized and straightened in the 1960s to accommodate the space requirements of the neighbouring school to the east (which was the Brooklyn Elementary School at that time; CEL 2018). Additionally, a historical wetland to the east was drained around the same time as the straightening of the channel, to create the school playing fields (CEL 2018). The modified FHAP/USHP methodology was conducted on two HUs within this reach, for a total of 22 m (9% of the entire reach; Figure 10). The gradient of this reach continues to be low, with an average gradient between the two HUs of 1.5%.

The channel characteristics are distinct between the section of the reach between Dogwood Avenue and the walking bridge, and the section of the reach between the walking bridge and Noel Avenue. The section between Dogwood Avenue and the walking bridge is characterized by a straight and eroded channel that was historically dredged and lacks habitat complexity. There are significant signs of erosion with undercut banks and exposed roots along the entire length of the channel up to the walking bridge (Photo 66). There are no pools providing rearing habitat for salmonids, and no fish were observed within this section of the creek with the exception of one dead salmonid (unidentified species). The substrate is primarily composed of gravel and cobbles, with few boulders and limited fines; the substrate in this channel may provide good spawning opportunities. The riparian depths are very narrow (3-5 m) and vegetation is sparse, predominantly composed of red alder, salmonberry, lady fern, and Western red cedar. Invasive Himalayan blackberry is growing along the banks of this section of the reach.

The section between the walking bridge and Noel Avenue is also straightened and dredged, however it was filled with in-stream vegetation at the time of the site assessment on August 26th, 2021 (Photo 67). Vegetation within the channel included small-flowering bullrush, willow species, sedge species, cattails, and duckweed. Large mats of green algae were also observed on the water's surface in this section of the reach during the August 26th site visit (Photo 68). Riparian vegetation along the left bank of this section of Reach 4 were planted in 2015 and included red alder, bitter cherry and willow species (Photo 69). Invasive Himalayan blackberry was growing along the left bank of the channel. The right bank of this section of the reach is armoured with small riprap, since a residential building is immediately adjacent to the creek (Photo 69). Several drainage pipes were observed outletting into the right bank of Reach 4.

On September 2nd, 2021, a sewage leak originating from Town of Comox infrastructure was identified immediately downstream of the Noel Avenue crossing. This leak accounted for the low DO readings, dead fish observed, and dense in-stream vegetation. This leak was repaired and remediation/restoration works were completed in the channel, as described in the previous enhancement work section below. Fish utilization in this reach affected by the sewage spill is expected to recover with the improvement in water quality.

<u>Habitat Assessment Results</u>
Reach 4 shows a *Good* rating for % crown cover, however the in-stream cover is only rated as *Fair*, due to the lack of habitat complexity and features providing in-stream cover for salmonids. The riparian depth is very narrow along the majority of this reach, with depths between 15-25 m in the section of the reach between Dogwood Road and the walking bridge, and only 3-5 m in the straightened section of the creek between the walking bridge and Noel Avenue. Substrates are *Fair* for both % gravel and % fines. This reach has a lack of LWD, with only 0.21 pieces of LWD/bankfull width between the two HUs assessed. Only one piece of LWD was observed between the walking bridge and Dogwood Avenue, and

several LWD complexes have been installed in the section of the reach between the walking bridge and Noel Avenue. This reach had *Poor* percent wetted area, with limited pool habitat throughout the 235 m reach. Overall, Reach 4 receives a *Fair* rating (Table 13). Enhancement work has been done in this reach, including the construction of riffles, installation of LWD/boulder complexes, and addition of spawning gravel. Only two habitat units were assessed in this reach (Figure 10), and these units were a constructed riffle and upstream glide, which were functioning better than the majority of the reach upstream and downstream.

Note: A sewage spill from Town of Comox infrastructure was observed at the Noel Avenue crossing on September 2nd, 2021, after the assessment of Reach 4 had been conducted. As part of the remediation of the spill, contaminated in-stream vegetation was removed, spawning gravel was replaced and riparian plants along the left bank were removed and then re-planted in the portion of the reach between Noel Avenue and the walking bridge. As such, the quality of this reach has been improved since the fish habitat assessment conducted in August 2021.

Table 13. Habitat Ratings for Reach 4

Habitat Parameter	Reach 4	Ratings	
% Pool Area	n/a	n/a	-
LWD/BFW	0.21	5	Poor
% Stream Cover	15.50	3	Fair
Average % Fines	10.00	3	Fair
Average % Gravel	35.00	3	Fair
% Wetted Area	62.28	5	Poor
% Crown Cover	60.00	1	Good
Erosion Sites	n/a	n/a	-
Obstructions	n/a	n/a	-
Alteration Sites	n/a	n/a	-
Totals		**20**	Fair

Figure 10. Modified FHAP/USHP Surveyed Habitat Units in Reach 4.

Photos 65 & 66. Constructed fish ladder upstream of Dogwood Avenue acting as low flow barrier to salmonids (above left; Aug. 26, 2021). Pedestrian bridge at km 1+970 in Reach 4; pedestrian path along right bank in this section of Reach 4 (above right; Aug. 26, 2021).

Photos 67 & 68. Straightened channel between pedestrian bridge and Noel Avenue filled with in-stream vegetation (above left; Aug. 26, 2021). Green algae mats and duckweed on the surface of the channel between the pedestrian bridge and Noel Avenue (above right; Aug. 26, 2021).

Photos 69. Planted riparian vegetation along left bank of Reach 4, immediately downstream of Noel Avenue channel in-filled with vegetation (above; Aug. 26, 2021).

Previous Enhancement Conducted in Reach

Various restoration projects have been conducted in Reach 4 between the walking bridge and Noel Avenue starting in 2015. The channel planform was modified in 2015, re-instating a meandering channel with pool/riffle sequences (CEL 2018). Two riffles were constructed (CR4.2 and CR4.3) and 10-12 LWD pieces/stumps were constructed/installed within the 150 m stretch of creek in 2015 (Figure 11). The riparian area was enhanced beside the upper portion of the creek, since it was covered in invasive species such as English ivy and Himalayan blackberry prior to the 2015 restoration work. Additionally, pedestrian access between Brooklyn Greenway and Noel Avenue was enhanced parallel to the creek, including riparian planting (CEL 2018). The constructed riffle that was assessed in 2021 according to the modified FHAP/USHP methodology (R1-4) was constructed in 2016 (called CR4.1 in Appendix B) had good gradient and low flow passage, no scouring was observed, and adequate gravels topped the riffle (Photo 70). The two constructed riffles upstream of CR4.1 were also assessed during the 2021 study: the riffle at km 2+015 was in good condition with adequate gravels and cobbles, however the riffle at km 2+075 only consisted of boulders, with all gravels stripped away during high flow events. These riffles were covered in in-stream vegetation and were difficult to properly assess, therefore they were not scored on the constructed riffle scorecard in Appendix B.

Before and after mainstem realignment looking upstream from lower segment

Figure 11. Photos of the reach between Noel Avenue and the pedestrian walking bridge before and after restoration work in 2015.

Between 2016-2018, off-channel pond habitat was created in the southeastern section of the school's property, where the historical wetland had been located (CEL 2018). The constructed off-channel pond is 60 m long, with a 75 m outlet channel connecting it to the Brooklyn Creek mainstem just upstream of the walking bridge (CEL 2018; Photo 71). The creation of this off-channel pond provided approximately 1,200 m^2 of salmonid rearing habitat to the watershed, and juvenile coho were observed using the habitat in 2016 (CEL 2018). Native vegetation was planted around the pond as well as along the banks of the channel connecting the pond to the Brooklyn Creek mainstem (CEL 2018). A flow augmentation structure was also installed in the eastern town corridor in 2017-2018 to supply groundwater flow to the off-channel pond throughout the entire year (CEL 2018).

Unplanned restoration was conducted between the Noel Avenue culvert and 70-75 m downstream due to a sewage spill into Brooklyn Creek, identified on September 2nd, 2021. Contaminated material including sediments and in-stream vegetation were removed from the reach on September 3rd, 2021. A total of 18 m^3 of coho spawning gravel was placed in the remediated reach on September 23rd and native species planting was conducted along the left bank of the remediated reach on November 15, 2021.


Photos 70 & 71. CR4.1 (HU R1-4) looking downstream; in good condition (above left; Aug. 26, 2021). Straightened channel between pedestrian bridge and Noel Avenue filled with in-stream vegetation (above left; Aug. 26, 2021). Constructed channel connecting the off-channel pond to Brooklyn Creek during high flow events (above right; Aug. 26, 2021).

<u>Recommended Enhancement</u>

The section of Reach 4 between Noel Avenue and the walking bridge was recently remediated due to the sewage spill, with the replacement of spawning gravels and planting of native species along the left bank. The only constructed riffle within this section (at km 2+075) that was not functioning as well as it could have been during the August 2021 assessment (lack of gravels) has been improved with the placement of spawning gravels in the channel. The riffle/pool channel morphology is functioning well and there are several LWD complexes providing cover for salmonids. As such, we do not recommend any further restoration work in the upper section of Reach 4 at this time.

In general, this reach is a low priority for restoration since enhancement work was done in this reach between 2015 and 2021, with the construction of riffles, placement of spawning gravels, riparian planting, and installation of LWD structures. Restoration opportunities for this reach could include the construction of riffles in the section of Reach 4 between Dogwood Avenue and the walking bridge, to create pool habitat, and the installation of LWD/boulder complexes in the pools.

5.3.6 **Reach 5 (km 2+145 – 3+160)**

Description

Reach 5 extends between Noel Avenue to Guthrie Road, for a distance of approximately 1 km. The 425 m section of Reach 5 between Noel Avenue and Salish Park (between km 2+145 and 2+570) lies within a residential area, with houses backing onto the creek. The 590 m section of Reach 5 between km 2+570 to 3+160 lies within Salish Park, where residences are further from the creek and there is additional protection of the watercourse. A walking trail extends beside the creek through Salish Park. This reach has been assessed in detail in the past, therefore the modified FHAP/USHP methodology was only conducted on one 21 m long HU (2% of the entire reach; Figure 12). The gradient of the HU that was assessed in August 2021 was 0%.

A 21 m long HU (G1-5) was assessed between km 2+472 and 2+493, approximately 10 m downstream of the Salish Street crossing. Several salmonids (juvenile coho and cutthroat trout) were observed in this section of the Reach. In-stream vegetation such as skunk cabbage, slough sedge, small-flowering bullrush, and water parsley were observed along the channel edges (Photo 72). This section of the creek is highly modified and altered due to residential development, encroachments into the active channel and riparian fragmentation (Photo 73). However, there is a large weeping willow along the left bank of this habitat unit (Photo 73), as well as red alder, bigleaf maple, and a young western red cedar providing moderate overhead cover (25%) in this habitat unit. Understory species in this habitat unit included salmonberry, sword fern, and lady fern. Exposed roots are present along the banks indicating flashiness and erosion (Photo 74). A retaining wall has been built in the landscaped area along the right bank, with planted bamboo along the base of the wall (Photo 75), and the bank has been armoured in several places along the left bank with riprap (Photo 73). As the creek bisects most properties along this stream segment, it is not uncommon for landowners to install foot bridges and retaining walls (Photo 75). The riparian depth was slightly wider immediately downstream of the assessed HU to Pritchard Road (Photo 76). Overall the riparian depth is less than 30 m on both banks for the portion of this reach that lies within the residential area between Noel Avenue and Salish Park.

A portion of the channel within Salish Park was walked, to visually assess the condition of previous restoration/enhancement work (as described in the previous enhancement work section below). The section of the channel in Salish Creek has good overhead and in-stream cover (Photo 77), good pool depths, an adequate number of LWD pieces in the channel (both natural and installed LWD complexes), and several constructed riffles that appear to be in good condition and functioning as intended (Photos 78 – 80). These riffles were not assessed in details as with the riffles in Reaches 1-4, however they appear to provide adequate low flow passage, no scouring or erosion was evident, and there were still gravels between the boulders of the constructed riffles. Juvenile coho were observed in several of the pools within Salish Park. A stormwater retention pond was constructed in 2005 to filter and retain water during high flow events (Photo 81). It appears to be functioning well.

Habitat Assessment Results

Since only one HU was assessed in Reach 5, the ratings are based on the glide unit that was assessed (G1-5) and are not averaged for the reach. As such, this rating should be considered in conjunction with the reach description based on visual assessments.

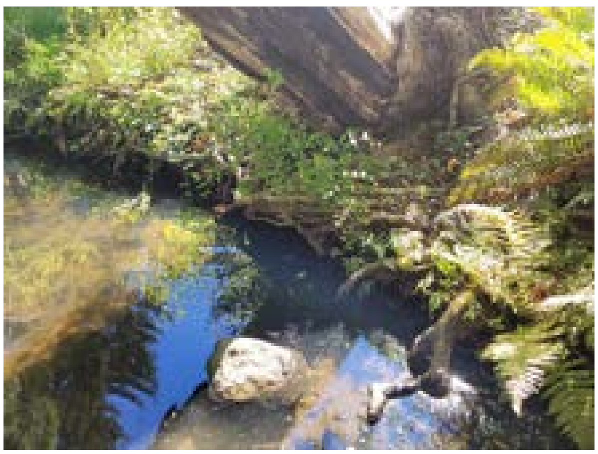
The HU within Reach 5 shows a *Good* rating for % crown cover and in-stream cover, despite the narrow riparian depth due to adjacent houses. Substrates are *Fair* for both % gravel and % fines and the HU had a *Fair* % wetted area. Overall, this HU in Reach 5 is rated as *Fair* (Table 14). Only one habitat unit was assessed in Reach 5 (Figure 12) – the section of Reach 5 between Noel Avenue and Salish Park has several limiting factors to salmonid productivity such as narrow riparian area and overhead canopy, lack of habitat complexity, and bank erosion causing a high percentage of fines into the creek and bank instability. The section of Reach 5 in Salish Park has good fish habitat and fewer limiting factors to salmonid productivity with a riffle-pool morphology, spawning opportunities, good overhead and in-stream cover, and increased habitat complexity.

Table 14. Habitat Ratings for Reach 5

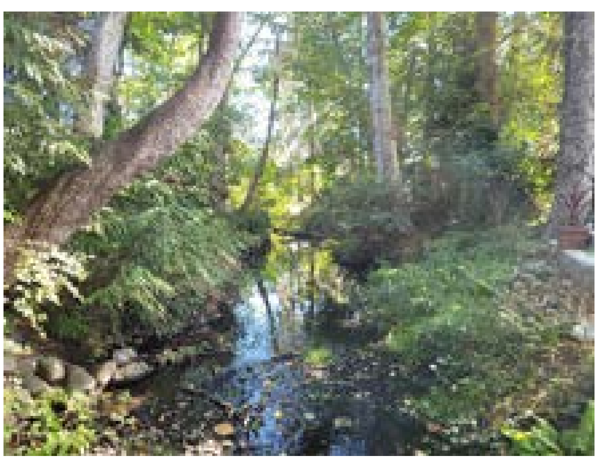
Habitat Parameter	Reach 5	Ratings	
% Pool Area	n/a	n/a	-
LWD/BFW	0.00	5	Poor
% Stream Cover	30.00	1	Good
Average % Fines	10.00	3	Fair
Average % Gravel	40.00	3	Fair
% Wetted Area	72.73	3	Fair
% Crown Cover	25.00	1	Good
Erosion Sites	n/a	n/a	-
Obstructions	n/a	n/a	-
Alteration Sites	n/a	n/a	-
Totals		**16**	Fair

Figure 12. Modified FHAP/USHP Surveyed Habitat Units in Reach 5.


Photos 72 & 73. CR4.1 Skunk cabbage, small-flowering bullrush, and water parsley along banks of HU G1-5 (above left; Sept. 2021Residential development right to streams edge on both right and left banks in HU G1-5; looking downstream. Rip-rap armoured wall along left bank and retaining wall with planted bamboo along right bank (above right; Sept. 2021).




Photos 74 & 75. Cutbanks with exposed roots along right bank in HU G1-5 indicating high flows causing erosion during the winter months (above left; Sept. 2021). Looking downstream of HU G1-5 at bridge constructed over channel; skunk cabbage and water parsley in channel (above right; Sept. 2021).




Photos 76 & 77. Cutbanks with exposed roots along right bank in HU G1-5 indicating high flows causing erosion during the winter months (above left; Sept. 2, 2021). Good riparian cover in section of Reach 5 in Salish Park (above right; Sept. 2021).

Photos 78 & 79. Constructed riffles in the Salish Park section of Reach 5 – both in good condition with no maintenance required (above left and right; Sept. 2, 2021).

Photos 80 & 81. Constructed riffle in the Salish Park section of Reach 5 –in good condition with no maintenance required (above left; Sept. 2, 2021). Stormwater detention pond in Salish Park functioning well (above right; Sept. 2, 2021).

<u>Previous Enhancement Conducted in Reach</u>

The Brooklyn Creek Stormwater Management Project was developed in the late 1990s, and included two phases that were largely conducted within Reach 5:

- Phase 1: Stormwater upgrades including work on the stormwater diversion pipeline at the Pritchard Road crossing and the stormwater outfall at the outlet of Brooklyn Creek in the estuary.
- Phase 2 (2005): Construction of a high flow diversion channel (including a fish screen) at Pritchard Road, construction of the stormwater retention pond in Salish Park, and channel enhancement works in Salish Park. Channel enhancement works in Salish Park included the construction of six riffles with spawning platforms, the removal of small woody debris blockages, and the use of bioengineering methods to reduce erosion and increase rearing habitat.

The constructed riffles in Reach 5 were not assessed to the same degree as in Reaches 1-4, and have therefore not been included in Appendix B. The constructed riffles that were observed in Salish Park were in good condition and functioning as intended, with adequate flow, no scouring around banks, and gravels topping the riffles (Photos 78-80). The pool depths in this section of the Reach were good at the time of the September 2nd, 2021 visit, with in-stream and overhanging cover and adequate LWD present in the channel.

Recommended Enhancement
No additional enhancement work is recommended within the Salish Park section of Reach 5, since this section of the creek is providing good fish habitat and the previous enhancement works are functioning as intended. The section of Reach 5 between Noel Avenue and Salish Park could use stream enhancement measures such as riffle construction, the addition of spawning gravels, installation of LWD/boulder complexes, and riparian planting.

5.3.7 **Reach 6 (km 3+160 – 4+535)**

Description
Reach 6 is a 1,375 m long stretch of Brooklyn Creek, located entirely within agricultural land on Birkdale Farm, between km 3+160 and 4+535. There are multiple access road crossings along this reach, and no public access or parks. The modified FHAP/USHP methodology was conducted on three HUs in this reach, split between the southern, mid, and northern sections of the reach for a total distance of 60 m (4% of the entire reach; Figure 13). The average gradient of the three HUs in this reach is very low, at 0.33%.

The creek through Birkdale Farm was flowing at the time of the August 26th and September 2nd/3rd, 2021 site visits. According to the property owner, the creek typically runs dry throughout the summer months, beginning to flow again at the start of the rainy season in the fall. The reason for flow during summer 2021 is unknown. The channel has low habitat complexity with substrates primarily composed of fine sands and silts (Photo 82). Several locations assessed had cobble/boulder/gravel riffles (Photo 83), however the majority of assessed portions of the reach were glides with few pools and riffles observed. Pockets of gravel were observed, however gravel was not a dominant substrate type. Bank erosion with exposed roots and undercut banks was evident in all of the locations that were assessed on Reach 6 (Photos 82 – 83 and 85 – 89). Although evidence of flooding was not observed during the summer field surveys, flooding has been occurring during the rains in fall 2021 according to the property owner, overtopping the banks in several locations where flood conveyance is being impaired by instream vegetation. The riparian depth is narrow (3-4 m) on both banks throughout the entirety of Reach 6 (Photo 84). There were no large trees in the riparian areas of Reach 6, with red alders and willows comprising the majority of trees, only reaching to a height of approximately 4 m (Photo 84). This means that there is limited succession in the riparian area, with the majority of species consisting of shrubs (such as red-osier dogwood, Pacific ninebark, snowberry, salmonberry, and hardhack) and invasive species (such as cutleaf and Himalayan blackberry).

Visual assessments and modified FHAP/USHP assessments were conducted in three separate areas of Reach 6, in the southeastern portion near Guthrie Road, the middle portion near the access road crossing, and the northwestern portion near Anderton Road. The channel is wider with more bank erosion in the southeastern section (between km 3+230 to 3+250), with fine mucky substrates (Photo 85). Cover in this section was good (75%), with dense overhanging vegetation providing shade and litter fall (Photo 85). A large, covered pipe extends into the channel from the left bank (Photo 86). The middle section, immediately upstream of the road crossing (between km 3+665 to 3+705) narrows compared to the downstream section, with the substrate composed of coarse sand and gravel mixed with fines (Photo 87). The gradient in this section is slightly higher than the upstream and downstream sections, at

1%. Cobbles/small boulders are present along the channel bed in this section (Photo 83). A high flow bench was visible along the right bank. This section also has dense overhanging vegetation such as red-osier dogwood, with invasive Himalayan blackberry overtaking the riparian area. A pipe was also observed entering the channel in this section, draining the fields. Finally, the northwestern section that was surveyed (between km 4+335 and 4+345) consists of good pool habitat with overhanging and in-stream cover. Several willows are growing in the channel in this location, spanning the creek and causing channel braiding (Photo 88). A plunge pool was observed downstream of one of the in-stream willows, and a salmonid (unidentified species) was observed in this pool during the August 26th site visit (Photo 89). Less invasive blackberry plants were observed in the riparian area in this section due to the shading from the willows and red alders.

Habitat Assessment Results

Reach 6 shows a *Good* rating for % crown cover and in-stream cover, however all other parameters are rated as *Poor* (Table 15). There were few pools noted and a lack of LWD observed within the channel. Substrates consisted primarily of fines, with few gravels and cobbles observed in the sections that were surveyed. The % wetted area was low, as was observed in the other five reaches due to the low flows in the summer months. Although the % crown cover was rated as good, this was predominantly provided by shrubs and smaller trees such as red alder and willow. There were no large conifers providing shade, stabilization, and succession opportunities along the narrow riparian strip adjacent to the creek. Overall, Reach 6 receives a *Poor* rating (Table 15), based on both the three habitat units assessed (Figure 13) as part of the modified FHAP/USHP survey, as well as visual assessments in multiple locations along the reach.

Table 15. Habitat Ratings for Reach 6

Habitat Parameter	Reach 6	Ratings	
% Pool Area	n/a	n/a	Poor
LWD/BFW	0.12	5	Poor
% Stream Cover	33.33	1	Good
Average % Fines	88.33	5	Poor
Average % Gravel	2.50	5	Poor
% Wetted Area	54.86	5	Poor
% Crown Cover	80.00	1	Good
Erosion Sites	n/a	n/a	-
Obstructions	n/a	n/a	-
Alteration Sites	n/a	n/a	-
Totals		**22**	Poor

Figure 13. Modified FHAP/USHP Surveyed Habitat Units in Reach 6.


Photos 82 & 83. Approx. km 3+700; substrates are primarily composed of fines, banks are eroded, and shrubs are providing overhanging vegetation (above left; Aug. 26, 2021). Cobble, boulders, and gravel riffle in HU G1-6 at approximately km 3+690 (above right; Aug. 26, 2021).


Photos 84 & 85. Narrow riparian strip primarily composed of red alders, willows, and understory shrubs (above left; Aug. 26, 2021). Looking downstream in wider section of stream in southeastern portion of Reach 6 (HU G2-6; at approximately km 3+260); composed of fine substrates. Stream is covered with dense overhanging vegetation (above right; Aug. 26, 2021).


Photos 86 & 87. Covered pipe extending into left bank of G2-6 (km 3+260; above left; Aug. 26, 2021). Narrower channel in HU G6-1 (at approximately km 3+670) with substrates primarily composed of fines and gravels (above right; Aug. 26, 2021).

Photos 88 & 89. Willows growing in centre of channel at approximately km 4+350 are causing channel to braid, creating isolated shallow depressions of water adjacent to the main channel; looking upstream (above left; Aug. 26, 2021). Plunge pool immediately downstream of braided portion of channel where willows are growing, looking upstream. Juvenile cutthroat trout observed in pool on Aug. 26, 2021. Pool has good overhanging and riparian cover (above right; Aug. 26, 2021).

Previous Enhancement Conducted in Reach

No restoration/enhancement work has been conducted in this reach in the past. The property owner has conducted work in the creek in the past to prevent erosion and flooding concerns due to the high flows in the winter months. This includes bank armouring with riprap downstream of the access road crossing at km 3+655 where erosion concerns have been noted in the past.

Recommended Enhancement

Potential restoration opportunities within this reach include the construction of riffles to backwater pools and oxygenate water, adding spawning gravels, and enhancing the riparian area by planting trees and removing invasive species. Specific enhancement recommendations including locations are described below.

Addition of Spawning Gravels

There was a lack of spawning gravels observed in Reach 6 during the assessment. The gradient of the channel is sufficient for spawning gravels, therefore we recommend that spawning gravels be placed in existing glides and upstream and downstream of constructed riffles (see below) to improve spawning opportunities in the reach.

Riffle/Pool Creation

Riffles should be constructed in several sections of the reach to backwater and deepen pools and oxygenate water. Additionally, these constructed riffles would provide a spawning platform with the addition of gravels to increase spawning potential in the upper portion of the watershed. The lack of pools and therefore summer rearing/overwintering habitat will be remedied with the creation of riffles with pools between them. Exact locations for the construction of riffles will be determined with a more detailed assessment at a later date.

Riparian Enhancement

Finally, the riparian areas along Reach 6 are narrow and are primarily composed of small trees and shrubs overgrown with invasive species. We recommend that trees be planted within the riparian area to provide additional bank stability and shade out the invasive blackberry species. We will work with the property owner to determine numbers and species that will enhance the riparian area without having an adverse impact on agricultural operations. The willow trees growing in the channel in the northwestern section of the reach may be removed at the time of restoration/enhancement work to prevent further erosion and channel braiding, and improve flood conveyance.

6 Discussion and Recommended Enhancement Summary

The limiting factors for fish production identified by the 2021 assessments were used to derive proposed restoration projects for the Brooklyn Creek watershed. Habitat deficiencies and recommended enhancement projects, including expected benefits, identified in Section 5.3 are summarized in Table 16 and Figures 14 to 19. Recommended enhancements, shown in Table 16 include two categories of restoration projects described below.

Type 1: Structures that alter the channel plan and profile for less than 5 bankfull widths, producing a local effect on the streambed and banks. Examples include: riparian planting; LWD jam removal, and installation of groundwater wells. Type 1 activities also include site assessments.

- <u>Invasive plant removal/native planting</u>: Removing invasive plant species and restoring a suitable assemblage of native plants along the riparian corridor is expected to improve habitat complexity and increase channel stability. Fill planting integrated with LWD/Boulder and bank revetment work will also reduce shear stress and help establish a stable root mat.

Type 2: Alteration of the plan profile of a stream that produces a geomorphological disturbance over a reach length greater than 5 bankfull widths. Examples include: larger scale features including bank revetment using LWD; pool/riffle sequence construction using boulders & LWD (including repairing/maintain existing constructed riffles and LWD/boulder structures); spawning gravel placement.

- <u>Riffle/spawning platform</u>: Rock riffle sequences are expected to have a moderating effect on high flows as shear stress is tempered by the decrease in water surface slope (Newbury et al. 1997). Properly built rock riffles are also expected to address limiting factors to fish production by creating stable pool habitat, re-aerating flows, providing substrate for benthic invertebrates and sustaining spawning gravel. Preliminary design concepts for pool complexes including riffle, spawning gravel and LWD placement is described further in Appendix C.
- <u>LWD/Boulder complexing</u>: LWD complexes are often positioned upstream of rock riffle features to provide the necessary hydraulic complexity to maintain function of constructed pool habitats, and are expected to stabilize the channel by reducing flow velocities and localizing erosive energy to the bed. LWD complexes also offer important shelter and feeding habitat for juvenile salmonids. A preliminary design concept for a ballasted LWD feature is described further in Appendix C.

Type 3: Side-channel/pond development. An example includes: off channel fish habitat development.

- <u>Off channel development:</u> A side-channel would be expected to increase the productivity and survival of anadromous and resident salmonids by serving as year-round juvenile rearing for coho and cutthroat trout, while increasing flood capacity and relieving impacts associated with heavy flows.

<u>**The level of detail in this habitat assessment report is intended to identify opportunities for recommended restoration based on observed limitations to productivity; whereas site specific**</u>

enhancement projects requiring instream modification should be directed by a Qualified Environmental Professional (QEP) and be preceded by a detailed Level 2 Assessment used to identify appropriate rehabilitation activities.

Outcomes of a Level 2 assessment may include the following information: habitat unit morphology showing thalweg (longitudinal profile) and cross sections, fish abundance estimates, a site plan showing locations of proposed enhancement features, enhancement feature design typicals, and estimated costs. The results of a Level 2 Assessment are used to clarify the scope and objectives of enhancement activities at specific locations, and to provide necessary detailed site information to inform construction prescriptions (Johnston & Slaney 1996).

The Level 2 Assessment should include consideration for a suitable post-enhancement work monitoring period to observe and report on the function of installed features and to determine if any maintenance or upgrading is necessary. Volunteer assistance under the direction of a QEP would be a great benefit to the collection of pre- and post-enhancement data and help solidify the relationship between local stewards and the watershed; it would also offer the opportunity for volunteers to be trained in techniques such as surveying and fisheries assessment methods. Non-technical volunteers would also be useful for activities such as riparian vegetation planting and spawning gravel installation. Procedures for *Stream Rehabilitation Project Monitoring for Volunteer Groups* are available from Michalski et al. (2005).

Table 16. Enhancement candidate sites organized by reach that include a description of habitat deficiencies, proposed enhancement projects, expected benefits, and project type categorization.

Reach	ID	Location of the site (Figures 14 - 19)	Potentially Limiting Factor(s)	Proposed Enhancement Project	Expected Benefit	Project Type
1	1a	km 0+230 – 0+240	Dense patches of invasive species along right bank	Removal of invasive species (Himalayan blackberry, English ivy, Japanese knotweed)	Enhance riparian function	1
	1b	1 constructed riffle is low priority for maintenance work (CR1.1) – km 0+225	Riffle crest does not properly backwater pool upstream	Build up crest of riffle to deepen pool upstream	Increase pool depth	2
2	2a	km 0+260 – 0+910	Lack of spawning gravels upstream and downstream of previously constructed riffles	Place spawning gravels upstream and downstream of constructed riffles	Enhance spawning opportunities with additional gravel	2
	2b	10 constructed riffles are high priority for maintenance work (CR2.1 – CR2.4, CR2.6 – CR2.8, and CR2.10) 2 constructed riffles are moderate priority for maintenance work (CR2.5 and CR2.9) See Appendix B for chainages of constructed riffles	Function of existing constructed riffles impaired by lack of gravels and scouring and erosion. Potential barriers to upstream fish passage in summer. Pools between riffles infilled with gravels from constructed riffles.	Repair constructed riffles in order or priority (high priority riffles before moderate priority riffles) – add gravels, re-embed toe rocks, raise crest to backwater pools between riffles, etc.	Improve fish passage, enhance spawning opportunities, increase pool depths, create areas of localized scour to displace fine materials and expose gravel substrates.	2

Reach	ID	Location of the site (Figures 14 - 19)	Potentially Limiting Factor(s)	Proposed Enhancement Project	Expected Benefit	Project Type
	2c	km 0+690	Limited riparian cover	De-compact and amend soil along right bank, plant native species	Enhance riparian function	1
	2d	km 0+260 – 0+910	Dense patches of invasive species along banks	Spot treatments throughout reach to remove invasive species (Himalayan blackberry, English ivy, yellow archangel, lemon balm, spurge laurel)	Enhance riparian function	1
	2e	km 0+418 – 0+435	Limited suitable juvenile over-wintering habitat and flow dissipation	Re-connect historical 35 m long side channel	Increased rearing and over-winter habitat for juvenile salmonids, flow dissipation during high flows	3
	2f	km 0+615 – 0+690	Limited suitable juvenile over-wintering habitat and flow dissipation	Re-connect historical 65 m long side channel	Increased rearing and over-winter habitat for juvenile salmonids, flow dissipation during high flows	3
	2g	km 0+915	Juvenile migration. Surface flow disconnection at low flows	Seal bottom of existing fish ladder at Balmoral crossing	Improved fish passage	2
	2h	km 0+915	Juvenile and adult migration. Provincial and Federal fish passage design criteria not being met by existing 1.8 m ø x 31 m long CSP at 1.5% slope	Add 6 – 8 baffles to existing culvert crossing at Balmoral Road	Improved fish passage	2
3	3a	km 0+910 – 1+910	Lack of spawning gravels upstream and downstream of previously constructed riffles	Place spawning gravels upstream and downstream of constructed riffles	Enhance spawning opportunities with additional gravel	2
	3b	7 constructed riffles are high priority for maintenance work (CR3.5, CR3.7, CR3.9-CR3.10, CR3.13, and CR3.15-CR3.16) 2 constructed riffles are moderate priority for maintenance work (CR3.1 and CR3.12) 4 constructed riffles are low priority for maintenance work (CR3.3-CR3.4, CR.3.6, and CR3.8) See Appendix B for chainages of constructed riffles	Function of existing constructed riffles impaired by lack of gravels and scouring and erosion. Potential barriers to upstream fish passage in summer. Pools between riffles infilled with gravels from constructed riffles.	Repair constructed riffles in order or priority (high priority riffles before moderate priority riffles, before low priority riffles) – add gravels, re-embed toe rocks, raise crest to backwater pools between riffles, etc.	Improve fish passage, enhance spawning opportunities, increase pool depths, create areas of localized scour to displace fine materials and expose gravel substrates.	2

Reach	ID	Location of the site (Figures 14 - 19)	Potentially Limiting Factor(s)	Proposed Enhancement Project	Expected Benefit	Project Type
	3c	km 1+615 – 1+908	Lack of spawning habitat and pool area	Pool complexes w/ riffle, spawning platform, & LWD	Increased spawning habitat, and % pool area	2
	3d	km 1+080	CR3.5 upstream too steep; barrier to upstream fish passage	Construct new riffle downstream of CR3.5 to backwater riffle or increase tail-out of 3.5 to decrease slope	Improve fish passage	2
	3e	km 1+525 – 1+595	Lack of spawning habitat and pool area	Pool complexes w/ riffle, spawning platform, & LWD	Increased spawning habitat, and % pool area	2
	3f	km 1+030	Limited LWD/boulder cover, bank erosion	Backfill right bank to protect rotting LWD structure	Increase pool cover/complexity and stabilize bank	2
	3g	km 1+037	Limited LWD/boulder cover, bank erosion, limited riparian cover	Install LWD structure closer to stream bed; backfill right bank to protect rotting LWD structure, plant 1 m wide strip of native shrubs between pedestrian trail and rip-rap armoured bank.	Increase pool cover/complexity and stabilize bank; enhance riparian function	1 & 2
	3h	km 1+060	Limited LWD/boulder cover; limited riparian cover	Install additional stump or root wad beside existing rotting LWD structure; de-compact and amend soil along right bank, plant native species, and install split rail fencing to protect planted area	Increase pool cover/complexity; enhance riparian function	1 & 2
	3i	km 1+290	Limited LWD/boulder cover	Install larger LWD/boulder complex	Increase pool cover/complexity	2
	3j	km 1+037 – 1+052	Steep ravine slope to west of stream that is eroding and lacks vegetative cover	Construct terraces along slope, add soil to terraces, and plant native species along flat benches	Stabilize slope and enhance riparian function	1
	3k	km 1+105	Steep and eroding right bank lacking vegetative cover	Construct terraces along slope, add soil to terraces, and plant native species along flat benches	Stabilize slope and enhance riparian function	1
	3l	km 1+422 – 1+455	Limited riparian cover along left bank	De-compact and amend soil along right bank, plant native species, and install split rail fencing to protect planted area	Enhance riparian function	1
	3m	km 1+465 – 1+491	Limited riparian cover along right bank	Plant native trees and shrubs	Enhance riparian function	1
	3n	Throughout reach (see Section 5.3.4 for detailed list of locations)	Dense patches of invasive species along banks	Removal of various invasive species	Enhance riparian function	1

Reach	ID	Location of the site (Figures 14 - 19)	Potentially Limiting Factor(s)	Proposed Enhancement Project	Expected Benefit	Project Type
	3o	km 1+555	Limited suitable juvenile over-wintering habitat and flow dissipation	Dig off-channel pond deeper	Increased rearing and over-winter habitat for juvenile salmonids, flow dissipation during high flows	3
4	4a	km 1+910 – 1+970	Lack of spawning habitat, habitat and hydraulic complexity, and pool area	Pool complexes w/ riffle, spawning platform, & LWD	Increased spawning habitat, and % pool area	2
	4b	km1+910	Juvenile and adult migration	Evaluate feasibility to amend the ladder or/and integrate channel enhancement	Improved fish passage	2
5	5a	Noel Ave. to Salish Park	Lack of spawning habitat, habitat and hydraulic complexity, and pool area	Pool complexes w/ riffle, spawning platform, & LWD	Increased spawning habitat, and % pool area	2
6	6a	Existing glides and upstream of CRs	Lack of spawning gravels throughout reach	Place spawning gravels upstream and downstream of constructed riffles	Enhance spawning opportunities with additional gravel	2
	6b	Specific locations to be determined	Lack of spawning habitat, habitat and hydraulic complexity, and pool area	Pool complexes w/ riffle, spawning platform, & LWD	Increased spawning habitat, and % pool area	2
	6c	Throughout reach (specific locations to be determined)	Limited tree cover, dense invasive species	Plant larger trees and shrubs along riparian strips	Enhance riparian function	1

Figure 14. Reach 1 overview showing general locations of recommended enhancement projects.

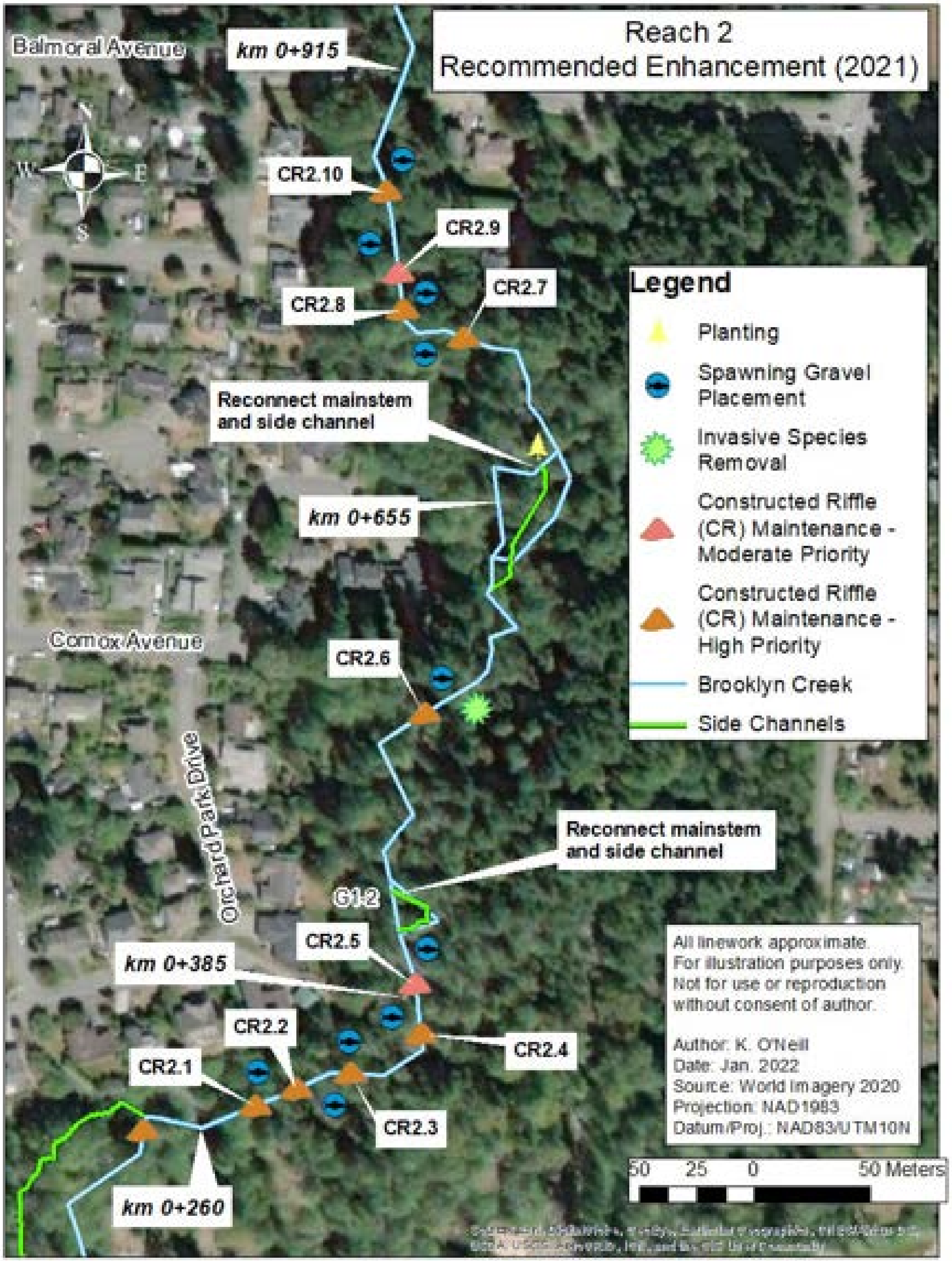


Figure 15. Reach 2 overview showing general locations of recommended enhancement projects. Invasive species removal should be conducted throughout reach (especially in areas where other enhancement/maintenance work is conducted) – invasive species removal symbol symbolizes entire reach.

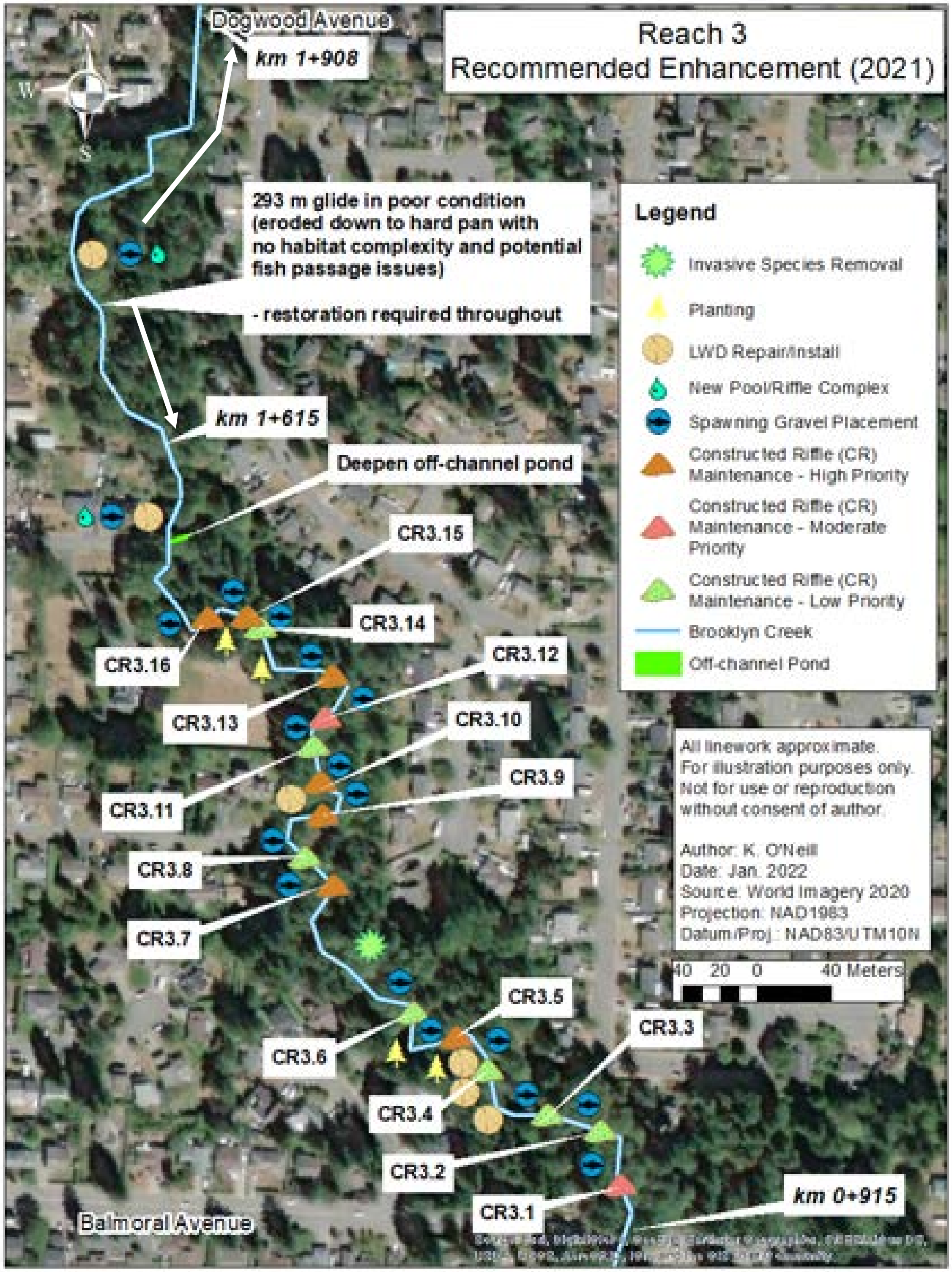


Figure 16. Reach 3 overview showing general locations of recommended enhancement projects. Invasive species removal should be conducted throughout reach (especially in areas where other enhancement/maintenance work is conducted) – invasive species removal symbol symbolizes entire reach.

Figure 17. Reach 4 overview showing general locations of recommended enhancement projects.

Figure 18. Reach 5 overview showing general locations of recommended enhancement projects.

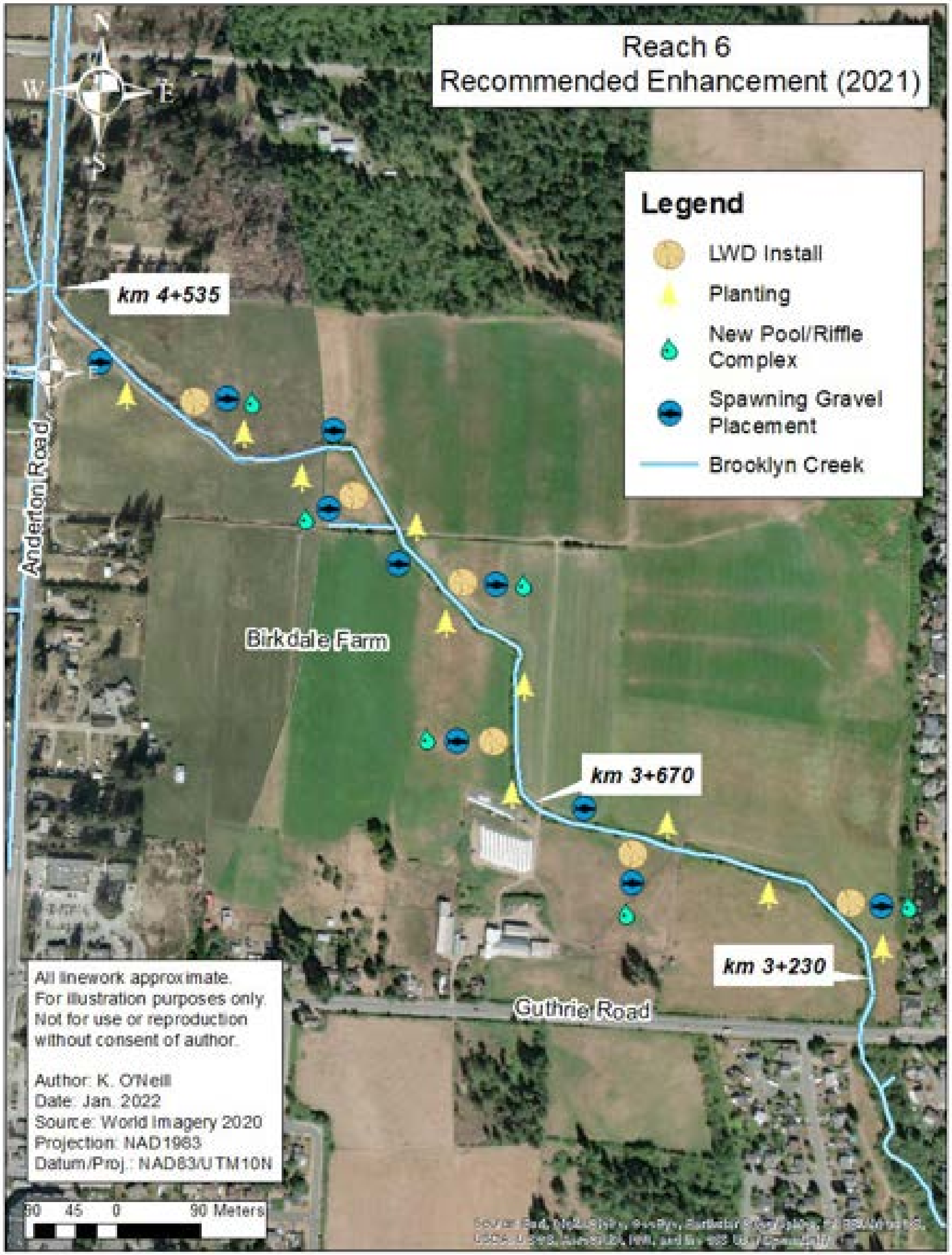


Figure 19. Reach 6 overview showing recommended enhancement projects. Locations are approximate and need to be determined at a later date.

6.1 High Priority Fish Habitat Enhancement Projects in Brooklyn Creek watershed

The prioritization of enhancement projects should be based on the BCWS' current needs and capacities and should be discussed with their chosen QEP in the period leading up to any Level 2 Assessment efforts. Sites identified as the best candidates for enhancement have been selected based on potential limiting factors to fish production described in Section 5.3 as well as consideration for the following:

- Access: including road and driveways, previously cleared vegetation such as farmers fields, old logging roads;
- Location: within watershed likely to support existing or potential spawning habitat;
- Lack of downstream obstructions: including backwatering from structures such as bridges and culverts;
- Year-round flows: that are dependable for sustaining the function of enhancements to juvenile rearing/over-wintering and adult spawning habitat;
- Suitability: where habitat units with identified deficiencies are only targeted for enhancements that are likely to result in the greatest net benefit. For example, channels expected to benefit from LWD/boulder complexes must have a sufficient average width to avoid causing a channel constriction.

Based on consideration for the above criteria, Table 17 shows a prioritized list of habitat enhancement projects organized by reach (in order of downstream reaches to upstream reaches for each priority level), colour-coded by priority level.

Table 17. Enhancement priorities organized by reach and highlighted according to priority in the overall assessment area. See Table 16 for descriptions and chainages of project components.

ID (Table 16)	Priority Level	Enhancement Action	Rationale
2b* (10 high priority constructed riffles)	High	Gravel nourishment, re-embed toe rocks, raise crest to backwater upstream pools	Potential barrier to fish passage, limited spawning opportunities, limited pool depths
2g	High	Repair existing ladder	Restore juvenile fish passage
3b* (7 high priority constructed riffles)	High	Gravel nourishment, re-embed tow rocks, raise crest to backwater upstream pools	Potential barrier to fish passage, limited spawning opportunities, limited pool depths
3c	High	Create riffle/pool complexes with spawning platforms, and install LWD structures	Channel eroded down to hardpan, no riffle or pool habitat, complete lack of hydraulic or habitat complexity resulting in no rearing or spawning opportunities, difficult fish passage
3d	High	Construct riffle downstream of CR3.5 or decrease slope of CR3.5	Constructed riffle too steep for fish passage (potential barrier to fish passage)

ID (Table 16)	Priority Level	Enhancement Action	Rationale
6a	High	Gravel nourishment throughout reach	High percent fines, limited spawning opportunities
6b	High	Create riffle/pool complexes with spawning platforms, and install LWD structures	Limited riffle/pool habitat, limited hydraulic/habitat complexity resulting in a lack of rearing and spawning opportunities
6c	High	Plant native trees and shrubs	Limited tree cover (e.g. for shade, bank stabilization, etc.), high proportion of riparian area composed of invasive species
2a	Moderate	Gravel nourishment	Limited spawning opportunities
2b* (2 moderate priority constructed riffles)	Moderate	Gravel nourishment, raise crest to backwater upstream pools	Limited spawning opportunities, limited pool depths
3b* (2 moderate priority constructed riffles)	Moderate	Gravel nourishment, raise crest to backwater upstream pools	Limited spawning opportunities, limited pool depths
2c	Moderate	De-compact and amend soil, plant native trees and shrubs, and fence off trampled/denuded area	Limited riparian cover
2d	Moderate	Remove invasive species	Dense patches of invasive species limiting native plant growth
2e	Moderate	Re-connect historical channel to mainstem	Lack of overwintering habitat, limited hydraulic complexity, flashy high flows in winter causing erosion
2f	Moderate	Re-connect historical channel to mainstem	Lack of overwintering habitat, limited hydraulic complexity, flashy high flows in winter causing erosion
2h	Moderate	Crossing improvement	Improve fish passage
3a	Moderate	Gravel nourishment	Limited spawning opportunities
3e	Moderate	Create riffle/pool complexes with spawning platforms, and install LWD structures	Limited riffle/pool habitat, limited hydraulic/habitat complexity resulting in a lack of rearing and spawning opportunities
3j	Moderate	Construct terraces along slope, add soil to terraces and plant native species	Steep and eroding slope, limited riparian cover

ID (Table 16)	Priority Level	Enhancement Action	Rationale
3k	Moderate	Construct terraces along slope, add soil to terraces and plant native species	Steep and eroding slope, limited riparian cover
3l	Moderate	De-compact and amend soil, plant native trees and shrubs, and fence off trampled/denuded area	Limited riparian cover
3m	Moderate	Plant native trees and shrubs	Limited riparian cover
4a	Moderate	Create riffle/pool complexes with spawning platforms, and install LWD structures	Limited riffle/pool habitat, limited hydraulic/habitat complexity resulting in a lack of rearing and spawning opportunities
4b	Moderate	Amend existing ladder or/and integrate with 4a	Restore adult and juvenile fish passage
5a	Moderate	Create riffle/pool complexes with spawning platforms, and install LWD structures	Limited riffle/pool habitat, limited hydraulic/habitat complexity resulting in a lack of rearing and spawning opportunities
1a	Low	Remove invasive species	Dense patches of invasive species limiting native plant growth
1b (1 low priority constructed riffle)	Low	Raise riffle crest to backwater upstream pool	Limited pool depth
3b* (4 low priority constructed riffles	Low	Gravel nourishment	Limited spawning opportunities
3f	Low	Backfill bank to protect rotting LWD structure	Eroding and unstable bank, lack of pool cover
3g	Low	Backfill bank to protect rotting LWD structure, install additional LWD structure closer to stream bed, plant native shrubs between trail and bank	Eroding and unstable bank, lack of pool cover, limited riparian cover
3h	Low	Install stump or rootwad beside existing LWD structure, de-compact and amend soil, plant native trees and shrubs, and fence off trampled/denuded area	Existing LWD structure rotting, lack of pool cover/habitat complexity, limited riparian cover
3i	Low	Install larger LWD structure	Lack of pool cover/habitat complexity

ID (Table 16)	Priority Level	Enhancement Action	Rationale
3n	Low	Remove invasive species	Dense patches of invasive species limiting native plant growth

* The constructed riffles have varying priority levels based on their condition and functionality (see Appendix B) – these should be repaired according to their priority level (high, moderate, and low).

It should be noted that in setting up a prioritized list some interrelationships between project components may not be accurately reflected. For example, LWD/Boulder complexes are often installed in conjunction and alternating with establishing riffle/spawning platforms; and invasive vegetation removal is connected with native riparian planting that may also include restoration of temporary machine access routes. These priorities should be considered a general guideline when determining which projects to proceed with and will ultimately be determined according to the project team's goals and budget.

7 Closure

We trust that this report has met the project objectives for a comprehensive review and assessment of existing salmonid habitat conditions in the Brooklyn Creek watershed, and that the recommendations made herein will serve to continue enhancing and restoring the system.

Please contact the undersigned with any queries.

Current Environmental Ltd.

Kate O'Neill, Environmental Scientist
January 10, 2021

Rupert Wong, R.P.Bio.

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Appendix A. Raw Quantitative Data of Assessed Reaches

Reach 1:

	Habitat Type	Start (chainage at start)	Finish (chainage at end)	Unit Length	Wetted Width	Pool Area	Wetted Reach Area	Habitat unit Depth (m)	Percent Gradient	Bankfull Width(m)	Average Percent Wetted Area	Substrate Percent Bed	Bld	Cob	Grv	Fine	Percent Instream Cover Bold	LWD	Cutbk	OverVg	InVg	Percent Crown Cover	Large Woody Debris	LWD/bank-full channel width	Erosion Sites (length)	Altered Stream Sites (length)	Obstructions (number)	Off-Channel Habitat (length)	Off-Channel Habitat (width)	Off-Channel Habitat (bank side)	Comments
G1-1	Glide	165.00	184.00	19.00	1.30	n/a	24.70	0.07	1.00	5.85	22.22	0	0	10	70	20	0	10	5	0	0	90.00	17	5.23	n/a	n/a	n/a	200	5	right	
R1-1	Riffle	184.00	188.00	4.00	1.80	n/a	7.20	0.03	5.00	5.50	32.73	0	0	10	70	20	0	0	3	8	0	90.00	0	0.00	n/a	n/a	n/a	0	0	0	
P1-1	Pool	188.00	202.00	14.00	4.30	n/a	60.20	0.18	0.00	4.40	97.73	0	0	5	50	45	0	0	15	10	0	90.00	2	0.63	n/a	n/a	n/a	0	0	0	
R2-1	Riffle	202.00	218.00	16.00	3.10	n/a	49.60	0.06	1.50	4.40	70.45	0	0	0	90	10	0	0	8	40	0	60.00	0	0.00	n/a	n/a	n/a	0	0	0	
P2-1	Pool	218.00	225.50	7.50	4.90	n/a	36.75	0.42	0.00	7.60	64.47	0	0	5	80	15	0	15	0	35	0	80.00	3	3.04	n/a	n/a	n/a	0	0	0	
R3-1	Riffle	225.50	230.50	5.00	1.80	n/a	9.00	0.08	3.00	6.00	30.00	0	30	40	30	0	15	0	0	15	0	80.00	0	0.00	n/a	n/a	n/a	0	0	0	
G2-1	Glide	230.50	243.60	13.10	2.82	n/a	36.94	0.14	1.00	4.00	70.50	0	15	10	75	0	2	0	0	50	0	20.00	0	0.00	n/a	n/a	n/a	0	0	0	
P3-1	Pool	243.60	249.40	5.80	2.90	n/a	16.82	0.28	0.00	4.70	61.70	0	0	0	80	20	0	0	5	0	0	90.00	0	0.00	n/a	n/a	n/a	0	0	0	
	Reach Totals and Averages			84.40	2.87	n/a	241.81	0.16	1.44	5.31	53.99	0	6	10	68	16.25	2	3	4	20	0	75.00	22	1.38	n/a	n/a	n/a	200.00	6	n/a	

Reach 2:

	Habitat Type	Start (chainage at start)	Finish (chainage at end)	Unit Length	Wetted Width	Pool Area	Wetted Reach Area	%Pool Area	Habitat unit Depth (m)	Percent Gradient	Bankfull Width(m)	Average Percent Wetted Area	Substrate Percent Bed	Bld	Cob	Grv	Fine	Percent Instream Cover Bold	LWD	Cutbk	OverVg	InVg	Percent Crown Cover	Large Woody Debris	LWD/bank-full channel width	Erosion Sites (length)	Altered Stream Sites (length)	Obstructions (number)	Off-Channel Habitat (length)	Off-Channel Habitat (width)	Off-Channel Habitat (bank side)	Comments
P1-2	Pool	0+385	0+391.2	6.20	5.40	n/a	33.48	n/a	0.38	0.00	6.00	90.00	0	3	3	85	10	0	0	5	20	0	15.00	3	2.90	n/a	n/a	n/a	0	0	0	
R1-2	Riffle	0+391.2	0+396.5	5.30	1.40	n/a	7.42	n/a	0.08	6.00	8.50	16.47	0	90	0	10	0	90	0	0	5	0	10.00	0	0.00	n/a	n/a	n/a	0	0	0	
G1-2	Glide	0+396.5	0+450.5	54.00	1.30	n/a	70.20	n/a	0.04	1.50	7.00	18.57	0	0	0	80	20	0	0	2	25	0	40.00	4	0.52	n/a	n/a	n/a	34	5	left	Historical - no longer connected
G2-2	Glide	0+655	0+669.3	14.30	2.80	n/a	40.04	n/a	0.24	0.00	5.30	52.83	0	5	5	75	15	0	5	10	0	0	20.00	5	1.85	n/a	n/a	n/a	0	0	0	
R2-2	Riffle	0+669.3	0+697.8	28.50	1.70	n/a	48.45	n/a	0.04	2.00	6.80	25.00	0	0	5	90	5	0	2	2	0	0	60.00	4	0.95	n/a	n/a	n/a	63	3	left	Historical - no longer connected
G3-2	Glide	0+697.8	0+731.9	34.10	2.00	n/a	68.20	n/a	0.07	1.00	5.50	36.36	0	0	20	70	10	0	0	5	0	0	50.00	0	0.00	n/a	n/a	n/a	0	0	0	
R3-2	Riffle	0+731.9	0+744.7	12.80	2.00	n/a	25.60	n/a	0.06	3.00	4.80	41.67	0	20	60	10	10	15	2	0	0	0	30.00	3	1.13	n/a	n/a	n/a	0	0	0	
	Reach Totals and Averages			155.20	2.37	n/a	368.05	n/a	0.18	1.93	6.27	37.81	0	17	13	60	10.00	15	1	3	7	0	32.14	19	0.77	n/a	n/a	n/a	97	8	n/a	

Reach 3:

	Habitat Type	Start (chainage at start)	Finish (chainage at end)	Unit Length	Wetted Width	Pool Area	Wetted Reach Area	%Pool Area	Habitat unit Depth (m)	Percent Gradient	Bankfull Width(m)	Average Percent Wetted Area	Substrate Percent Bed	Bld	Cob	Grv	Fine	Percent Instream Cover Bold	LWD	Cutbk	OverVg	InVg	Percent Crown Cover	Large Woody Debris	LWD/bank-full channel width	Erosion Sites (length)	Altered Stream Sites (length)	Obstructions (number)	Off-Channel Habitat (length)	Off-Channel Habitat (width)	Off-Channel Habitat (bank side)	Comments
R1-3	Riffle	0+915	0+927.9	12.90	2.00	n/a	25.80	n/a	0.04	3.00	5.30	37.74	0	0	0	100	0	0	0	2	2	0	70.00	1	0.41	n/a	n/a	n/a	0	0	0	
G1-3	Glide	0+927.9	0+936.70	8.80	3.10	n/a	27.28	n/a	0.09	0.50	6.70	46.27	0	10	5	85	0	10	0	0	5	0	30.00	2	1.52	n/a	n/a	n/a	0	0	0	
R2-3	Riffle	0+936.7	0+944	7.30	3.80	n/a	27.74	n/a	0.11	5.00	6.90	55.07	0	20	40	40	0	2	0	0	15	0	15.00	0	0.00	n/a	n/a	n/a	0	0	0	
G2-3	Glide	0+944	0+955.4	11.40	3.40	n/a	38.76	n/a	0.18	0.00	5.30	64.15	0	15	10	70	5	0	5	2	0	0	30.00	6	2.79	n/a	n/a	n/a	0	0	0	
R3-3	Riffle	0+955.4	0+963.7	8.30	2.70	n/a	22.41	n/a	0.03	3.00	9.40	28.72	0	3	3	95	0	0	0	0	0	0	20.00	0	0.00	n/a	n/a	n/a	0	0	0	
P1-3	Pool	0+963.7	0+973.6	9.90	5.70	n/a	56.43	n/a	0.32	0.00	6.20	91.94	0	0	0	60	40	0	15	5	0	0	40.00	5	3.13	n/a	n/a	n/a	0	0	0	
P2-3	Pool	1+240	1+253.5	13.50	4.70	n/a	63.45	n/a	0.46	0.00	5.50	85.45	10	0	35	40	15	0	0	10	5	0	95.00	1	0.41	n/a	n/a	n/a	0	0	0	
R4-3	Riffle	1+253.5	1+260.6	7.10	3.20	n/a	22.72	n/a	0.07	4.00	4.50	71.11	0	70	20	10	0	25	0	0	15	0	90.00	0	0.00	n/a	n/a	n/a	0	0	0	
G3-3	Glide	1+615	1+908	293.00	2.45	n/a	717.85	n/a	0.05	1.00	5.41	45.29	30	10	45	15	0	5	0	0	7	0	80.00	4	0.07	n/a	n/a	n/a	0	0	0	
	Reach Totals and Averages			372.20	3.45	n/a	1284.09	n/a	0.11	1.83	6.13	56.24	4	14	18	57	6.67	5	2	2	5	0	52.22	19	0.31	n/a	n/a	n/a	0	0	0	

Reach 4:

	Habitat Type	Start (chainage at start)	Finish (chainage at end)	Unit Length	Wetted Width	Pool Area	Wetted Reach Area	%Pool Area	Habitat unit Depth (m)	Percent Gradient	Bankfull Width(m)	Average Percent Wetted Area	Substrate Percent Bed	Bld	Cob	Grv	Fine	Percent Instream Cover Bold	LWD	Cutbk	OverVg	InVg	Percent Crown Cover	Large Woody Debris	LWD/bank-full channel width	Erosion Sites (length)	Altered Stream Sites (length)	Obstructions (number)	Off-Channel Habitat (length)	Off-Channel Habitat (width)	Off-Channel Habitat (bank side)	Comments
R1-4	Riffle	1+985	1+995	10.00	1.73	n/a	17.30	n/a	0.05	3.00	3.13	55.27	0	30	50	20	0	5	0	0	3	0	95.00	0	0.00	n/a	n/a	n/a	0	0	0	
G1-4	Glide	1+995	2+007.1	12.10	4.05	n/a	49.01	n/a	0.23	0.00	6.15	65.85	0	0	30	50	20	0	0	0	3	20	25.00	1	0.51	n/a	n/a	n/a	135	9	left	
	Reach Totals and Averages			22.10	2.89	n/a	63.87	n/a	0.14	1.50	4.64	62.28	0	15	40	35	10.00	3	0	0	3	10	60.00	1	0.21	n/a	n/a	n/a	135	9	n/a	

Reach 5:

	Habitat Type	Start (chainage at start)	Finish (chainage at end)	Unit Length	Wetted Width	Pool Area	Wetted Reach Area	%Pool Area	Habitat unit Depth (m)	Percent Gradient	Bankfull Width(m)	Average Percent Wetted Area	Substrate Percent Bed	Bld	Cob	Grv	Fine	Percent Instream Cover Bold	LWD	Cutbk	OverVg	InVg	Percent Crown Cover	Large Woody Debris	LWD/bank-full channel width	Erosion Sites (length)	Altered Stream Sites (length)	Obstructions (number)	Off-Channel Habitat (length)	Off-Channel Habitat (width)	Off-Channel Habitat (bank side)	Comments
G1-5	Glide	2+472	2+492.7	20.70	2.80	n/a	57.96	n/a	0.17	0.00	3.85	72.73	0	10	40	40	10	10	0	0	20	0	25	0	0.00	n/a	n/a	n/a				
	Reach Totals and Averages			20.70	2.80	n/a	57.96	n/a	0.17	0.00	3.85	72.73	0	10	40	40	10.00	10	0	0	20	0	25.00	0	0	n/a	n/a	n/a	0	0	0	

Reach 6:

	Habitat Type	Start (chainage at start)	Finish (chainage at end)	Unit Length	Wetted Width	Pool Area	Wetted Reach Area	%Pool Area	Habitat unit Depth (m)	Percent Gradient	Bankfull Width(m)	Average Percent Wetted Area	Substrate Percent Bed	Bld	Cob	Grv	Fine	Percent Instream Cover Bold	LWD	Cutbk	OverVg	InVg	Percent Crown Cover	Large Woody Debris	LWD/bank-full channel width	Erosion Sites (length)	Altered Stream Sites (length)	Obstructions (number)	Off-Channel Habitat (length)	Off-Channel Habitat (width)	Off-Channel Habitat (bank side)	Comments
G1-6	Glide	3+670	3+690	20.00	1.38	n/a	27.60	n/a	0.09	1.00	2.40	57.50	5	3	20	3	70	0	0	5	70	0	75.00	0	0.00	n/a	n/a	n/a	0	0	0	
G2-6	Glide	3+230	3+260	30.00	2.40	n/a	72.00	n/a	0.27	0.00	4.70	51.06	0	0	0	5	95	0	0	0	10	0	70.00	2	0.31	n/a	n/a	n/a	0	0	0	
P1-6	Pool	4+335	4+345.2	10.20	2.20	n/a	22.44	n/a	0.34	0.00	3.80	57.89	0	0	0	0	100	0	0	0	15	0	95	0	0.00	n/a	n/a	n/a	0	0	0	
	Reach Totals and Averages			60.20	1.99	n/a	120.00	n/a	0.23	0.33	3.63	54.86	2	1	7	3	88.33	0	0	2	32	0	80.00	2	0.12	n/a	n/a	n/a	0.00	0	0	

Appendix B. Previously Constructed Riffle Scorecard

Constructed riffles were assessed for Reaches 1 – 4. These riffles were constructed between 2008 and 2016 (Figure 2) and are in varying states of disrepair. Each riffle was scored between 1 to 5, with 5 being the highest functionality. Lower riffle scores indicate a poorer condition, resulting in a higher priority for repairs/maintenance. Locations of constructed riffles including their associated IDs are shown in Figures 14 to 19.

The scoring system for constructed riffles is as follows:

1-2 = high priority maintenance level
3 = moderate priority maintenance level
4-5 = low priority maintenance level
All riffles that are potentially causing low flow barriers to salmonids (water is not flowing on top of the riffle face), have been listed as high priority regardless of the score.

Constructed Riffle ID	Chainage	Properly Functioning Riffle Feature					Score (# of checkmarks)	Priority Maintenance Level
		Toe rocks embedded	No scouring around banks of riffle	Adequate gravels seeding top of riffle	Water flows on top of riffle face	Riffle crest properly backwaters pool upstream		
Reach 1								
CR1.1	km 0+225	✓	✓	✓	✓	×	4	Low
Reach 2								
CR2.1	km 0+260	✓	×	×	×	×	1	High
CR2.2	km 0+305	✓	✓	×	×	×	2	High
CR2.3	km 0+330	✓	✓	×	×	×	2	High
CR2.4	km 0+370	✓	✓	×	×	×	2	High
CR2.5	km 0+395	✓	✓	×	✓	×	3	Moderate
CR2.6	km 0+530	×	×	×	×	×	0	High
CR2.7	km 0+775	×	✓	×	×	✓	3	High
CR2.8	km 0+805	×	✓	×	×	×	1	High
CR2.9	km 0+820	✓	✓	×	✓	×	3	Moderate
CR2.10	km 0+855	✓	×	×	×	✓	2	High
Reach 3								
CR3.1	km 0+940	✓	✓	×	✓	×	3	Moderate

Constructed Riffle ID	Chainage	Properly Functioning Riffle Feature					Score (# of checkmarks)	Priority Maintenance Level
		Toe rocks embedded	No scouring around banks of riffle	Adequate gravels seeding top of riffle	Water flows on top of riffle face	Riffle crest properly backwaters pool upstream		
CR3.2	km 0+978	✓	✓	✓	✓	✓	5	No maintenance required
CR3.3	km 1+008	✓	✓	×	✓	✓	4	Low
CR3.4	km 1+055	✓	✓	×	✓	✓	4	Low
CR3.5	km 1+088	✓	✓	×	×	✓	3	High
CR3.6	km 1+132	✓	✓	×	✓	✓	4	Low
CR3.7	km 1+238	✓	✓	×	×	✓	3	High
CR3.8	km 1+258	✓	✓	×	✓	✓	4	Low
CR3.9	km 1+296	✓	✓	×	×	✓	3	High
CR3.10	km 1+332	✓	✓	×	×	✓	3	High
CR3.11	km 1+350	✓	✓	✓	✓	✓	5	No maintenance required
CR3.12	km 1+371	✓	✓	×	✓	×	3	Moderate
CR3.13	km 1+400	✓	✓	×	×	✓	3	High
CR3.14	km 1+455	✓	✓	✓	✓	✓	5	No maintenance required
CR3.15	km 1+465	✓	✓	×	×	✓	3	High
CR3.16	km 1+491	✓	✓	×	×	×	2	High
Reach 4								
CR4.1	km 1+990	✓	✓	✓	✓	✓	5	Low
CR4.2	km 2+017	Could not be assessed since covered in dense in-stream vegetation at time of assessment					n/a	n/a
CR4.3	km 2+077	Could not be assessed since covered in dense in-stream vegetation at time of assessment					n/a	n/a

Photos of Constructed Riffles

CR1.1 – looking upstream (Aug. 19, 2021)

CR2.1 – looking upstream (Aug. 19, 2021)

CR2.2 – looking downstream (Aug. 19, 2021)

CR2.3 – looking downstream (Aug. 19, 2021)

CR2.4 – looking upstream (Aug. 19, 2021)

CR2.5 – looking upstream (Aug. 19, 2021)

CR2.6 – looking downstream (Aug. 20, 2021)

CR2.7 – looking upstream (Aug. 20, 2021)

CR2.8 – looking upstream (Aug. 20, 2021)

CR2.9 – looking upstream (Aug. 20, 2021)

CR2.10 – looking upstream (Aug. 20, 2021)

CR3.1 – looking upstream (Aug. 20, 2021)

 CR3.2 – looking toward right bank (Aug. 25, 2021)	 CR3.3 – looking upstream (Aug. 25, 2021)
 CR3.4 – looking upstream (Aug. 25, 2021)	 CR3.5 – looking upstream (Aug. 25, 2021)

CR3.6 – looking upstream (Aug. 25, 2021)

CR3.7 – looking upstream (Aug. 25, 2021)

CR3.8 – looking downstream (Aug. 25, 2021)

CR3.9 – looking upstream (Aug. 25, 2021)

CR3.10 – looking upstream (Aug. 25, 2021)

CR3.11 – looking upstream (Aug. 25, 2021)

CR3.12 – looking upstream (Aug. 25, 2021)

CR3.13 – looking upstream (Aug. 25, 2021)

 CR3.14 – looking downstream (Aug. 25, 2021)	 CR3.15 – looking upstream (Aug. 25, 2021)
 CR3.16 – looking downstream (Aug. 25, 2021)	 CR4.1 – looking downstream (Aug. 26, 2021)

 CR4.2 – looking upstream (Aug. 26, 2021)	 CR4.3 – looking upstream (Aug. 26, 2021)

Appendix C. Preliminary Design Concepts

- Rock Riffle
- Riffle and LWD Configuration
- LWD Complex

1. PLAN: build riffle crest across the stream with large diameter boulders; back up with next largest stone downstream.

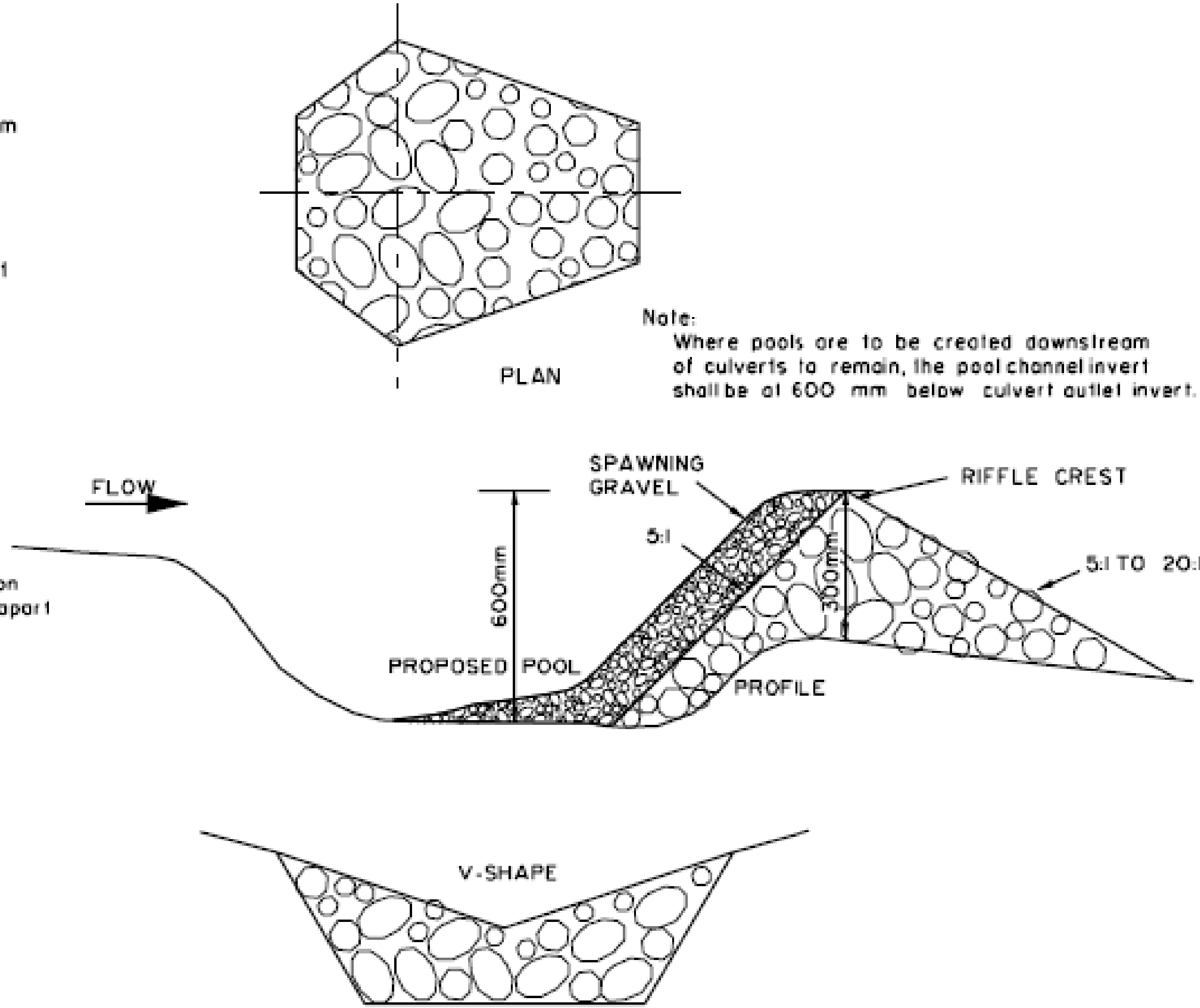
2. PROFILE: construct downstream face of riffle at a shallow slope that mimics local natural riffles (5:1 to 20:1).

3. SECTION: V-shape the crest and face downwards to the centre of the riffle (0.3 to 0.6 m). Pool to be 0.6 m deep x 1.0 m wide x 6.0 m long

4. SURFACE: place large rocks randomly on the downstream face 20 to 30 cm apart to dissipate energy and create low flow fish passage channels.

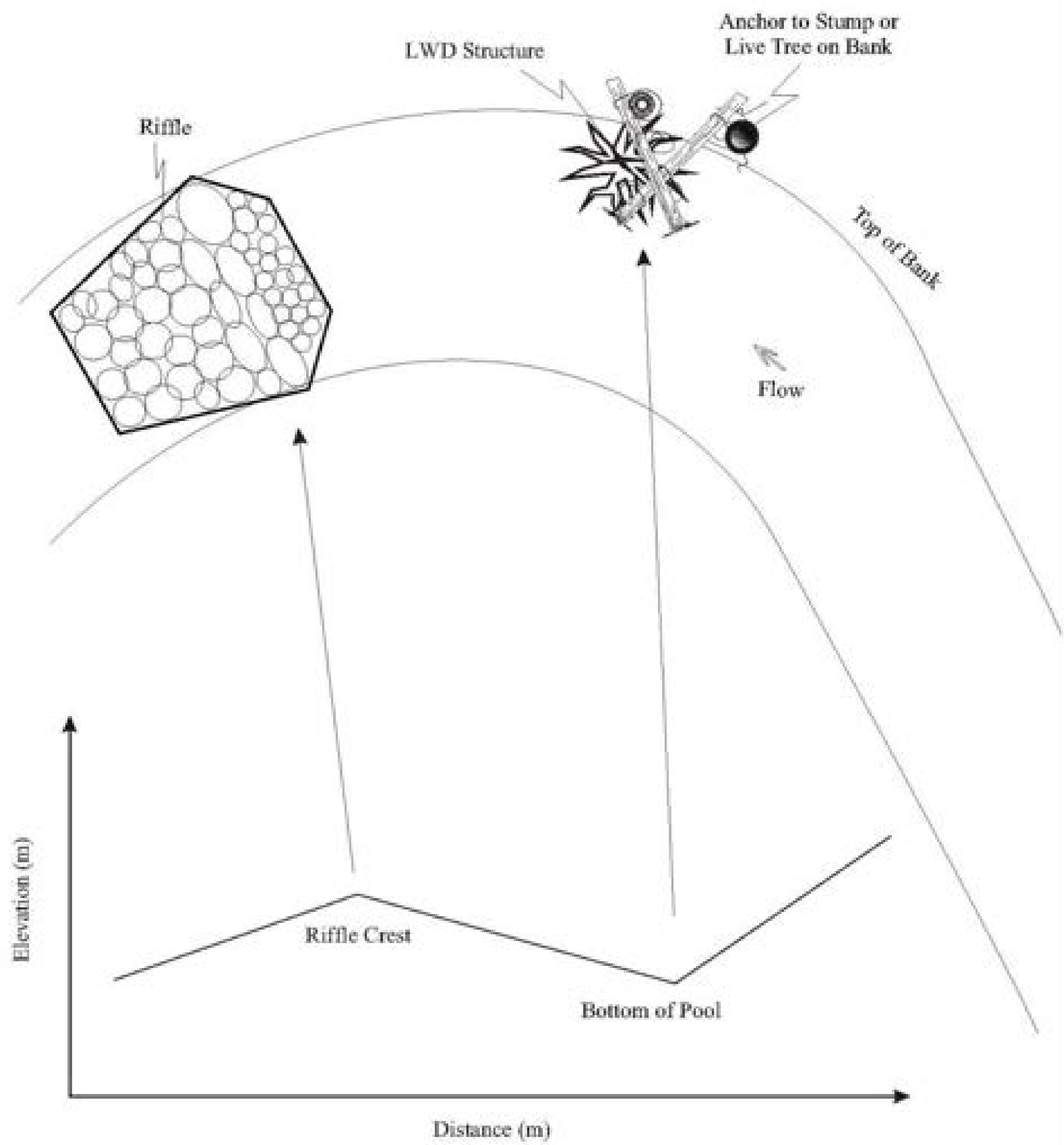
5. BANKS: rip-rap both banks with embedded boulders and cobbles to the floodplain level.

6. Place spawning gravel 200 mm thick.



TYPICAL ROCK RIFFLE, POOL
& SPAWNING GRAVEL DETAIL
N.T.S.

SECTION

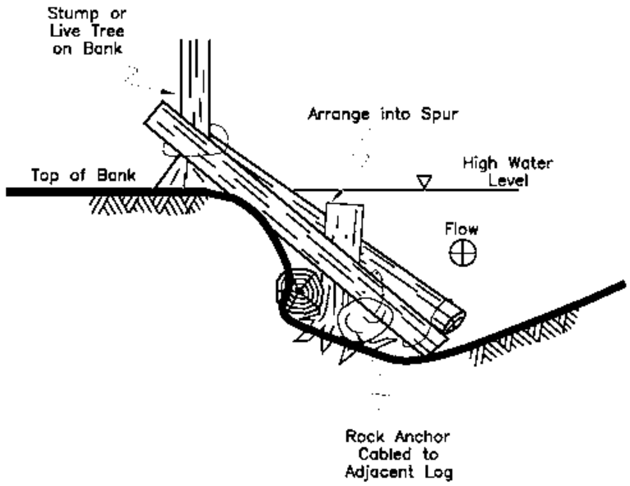


PLAN AND PROFILE

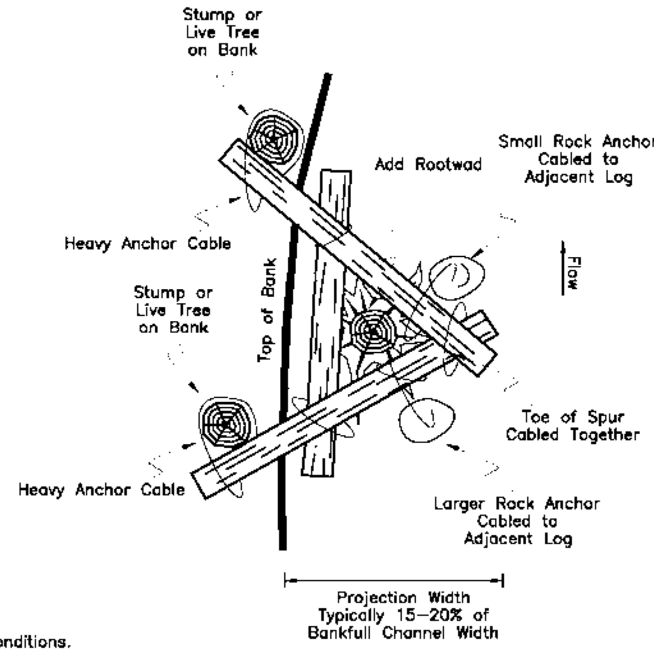
Typical location of LWD complex installation relative to rock riffle

adapted from LGL (2002)	**NOT TO SCALE**

Cross Section



Plan



Construction Notes:

1) Use LWD pieces at least 0.5m diameter and length suited to site conditions.
2) Number and size of rock anchors depends on predicted maximum flow, maximum flow velocity and number and size of LWD used.
3) All cables should be tight.
4) Logs with rootwads attached to be used where available.
5) To maximize the scour potential of each spur space spurs 4–6x the projection width apart along bank or base on site conditions.
6) Limit spur projection width to 15–20% of channel width or base on site conditions.

NHCV 3481–001

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Typical Plan and Cross Section LWD spur complex

northwest hydraulic consultants