Prepared for:

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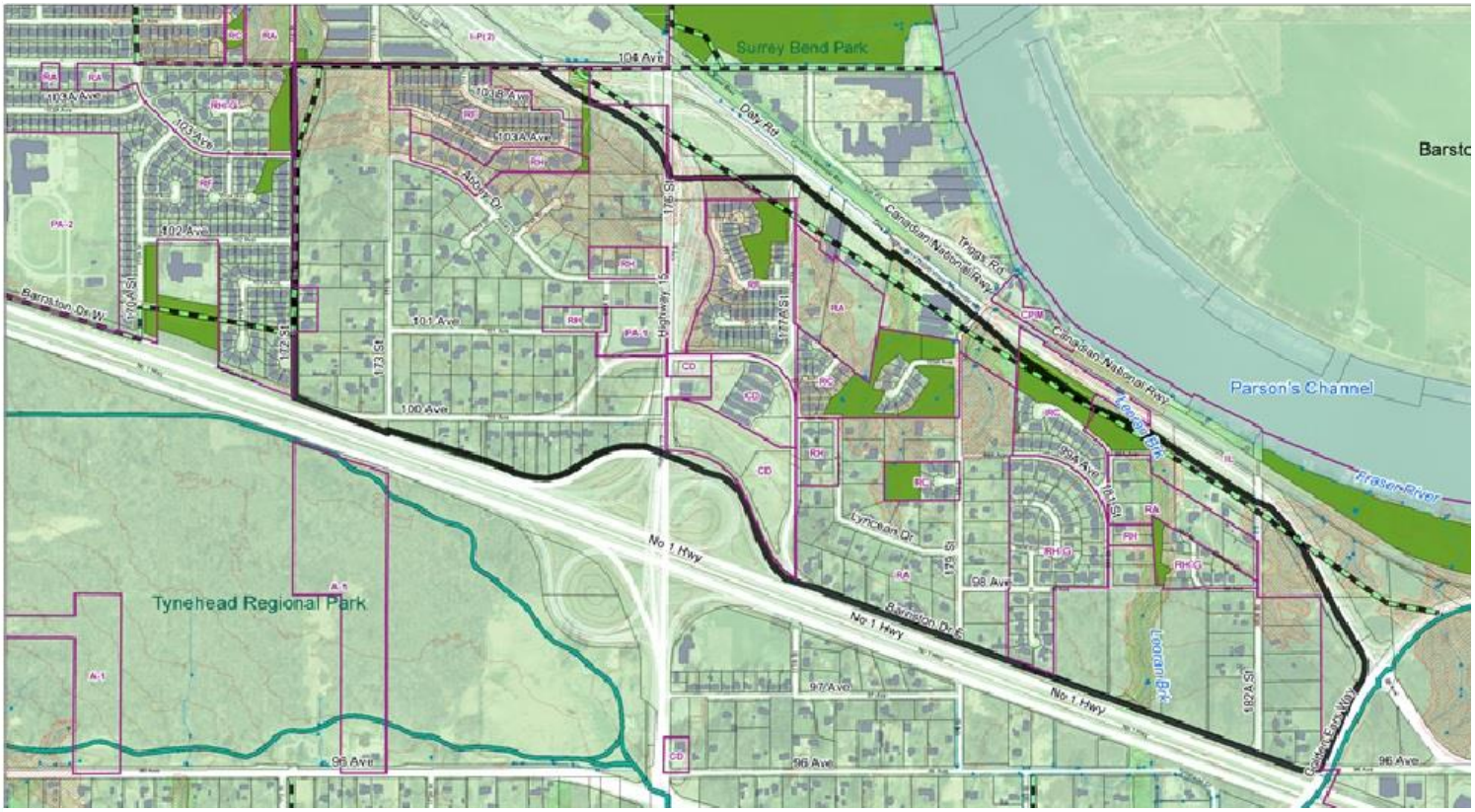
Abbey Ridge Local Area Plan
Stormwater Servicing Strategy
Final Report – 8 December 2016



McElhanney

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2111-03570-00

OQM | Organizational Quality Management Program

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McElhanney

December 09, 2016
Our File: 2111-03570-00

City of Surrey
Engineering Department – Drainage Section
13450 104 Avenue
Surrey, BC V3T 1V8

Attention: Jeannie Lee, M.A.Sc, P.Eng.
Project Engineer

RE: Abbey Ridge Local Area Plan Stormwater Servicing Strategy

McElhanney Consulting Services Ltd. is pleased to provide a signed and sealed copy of the Stormwater Servicing Strategy for the Abbey Ridge Local Area Plan.

The report provides a summary of the analysis completed during the study and outlines the recommended stormwater servicing strategy to allow further development of Abbey Ridge. We believe this strategy is most appropriate for the study area to achieve the objectives for development.

Please contact the undersigned should you have any questions or comments related to this study.

Yours truly,

McELHANNEY CONSULTING SERVICES LTD.

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Executive Summary

The City of Surrey (the City) retained McElhanney Consulting Services Ltd. (McElhanney) to complete a stormwater servicing strategy for the Abbey Ridge Local Area Plan (LAP) area. Currently, Abbey Ridge is not developed to its full potential, with approximately half of the study area slated for rezoning and future development. It is mostly occupied by large acreages and single family residential lots along with some institutional and commercial areas. The future land use plan adopted by the City indicates a mix of single and multi-family residential, commercial, and industrial land uses. This development will increase the imperviousness of the catchment, increasing runoff rates and volumes.

Hydrology and hydraulics analysis of the existing system confirmed various locations where the existing system is undersized to accommodate current and future flows. An in-field erosion and stability assessment of the various existing erosion sites within the watercourses determined two particular sites that are of concern and sensitive to any increase in runoff rates and volumes.

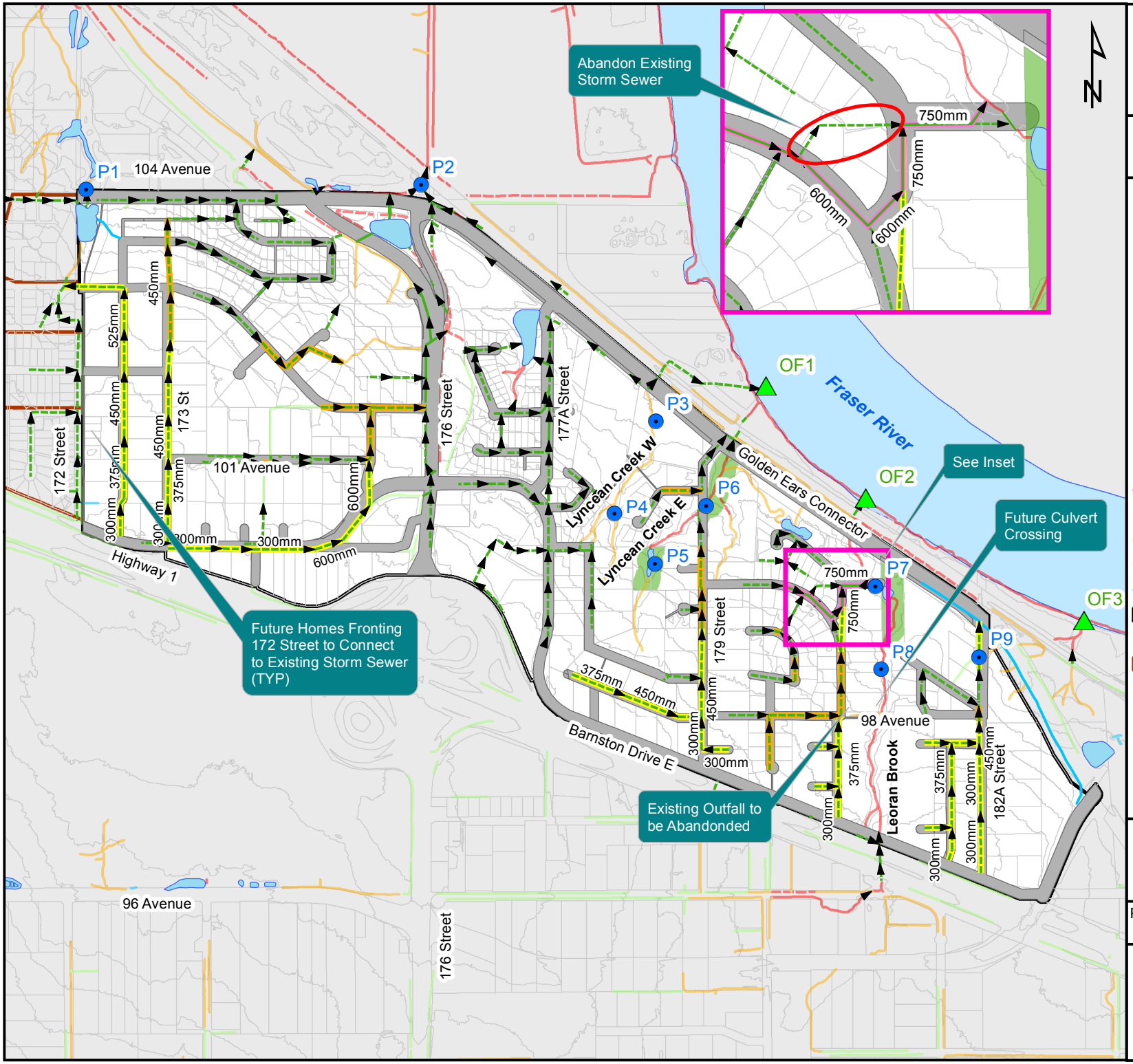
The general approach to the proposed stormwater servicing was to identify required local and trunk sewer upgrades, on-site detention and provide Low Impact Development (LID) systems that promote impervious disconnection, absorption, and some partial infiltration of runoff to reduce discharge rates and volumes to the receiving downstream systems. This approach provides the necessary upgrades and rates / volume controls at key locations to allow for development while providing the required conveyance capacity and drainage level of service for the area.

The proposed conveyance upgrades are shown in *Figure ES-1*. The proposed stormwater controls consist of on-site detention and LIDs placed on private lots and within the road Right-of-Way (ROW). A Statutory Right-of-Way (SRW) would be required at the outlet of the culvert beneath 179 Street along Lyncean Creek (east tributary). *Figure ES-2* shows the locations requiring these controls, and *Table ES-1* presents a summary of the required controls for each zone.

Table ES-1: Pre and Post-development flow at Control Points

Land Use	Zoning	LIDs required
Single Family Residential / Cluster (1-10 UPA)	RH-G, RF, RF-9/12	- Disconnected Roof Leaders directing runoff to splash pads - 450mm enhanced / amended top soil on all pervious areas
Multiple Family Residential (12-30 UPA)	RM-15, RM-30, RM-45	- On-site detention to reduce offsite discharges to 15 and 25 l/s/ha during the 5 year and 100 years events respectively. - 450mm enhanced / amended top soil on all pervious areas
Commercial and Industrial	IL, C-5	- On-site detention to reduce offsite discharges to 15 and 25 l/s/ha during the 5 year and 100 years events respectively. - 450mm enhanced / amended top soil on all pervious areas
Institution, School, Church	PA-1	- On-site detention to reduce offsite discharges to 15 and 25 l/s/ha during the 5 year and 100 years events respectively. - 450mm enhanced / amended top soil on all pervious areas

Storm DCC expenditures benefitting Abbey Ridge are limited to the 106m of 600mm and 123m of 750mm diameter trunk sewer upgrade and associated outfall works within the study area's eastern portion. The estimated construction cost for this item is $660,330, while the projected drainage DCC revenue calculation for the Abbey Ridge Area estimated a revenue of $5,367,522. Based on the total costs of the proposed storm works, we anticipate that storm DCC revenues will be adequate to fund the DCC eligible storm works for the area.



Abbey Ridge
Storm Servicing Concept

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Legend

- Points of Interest
- Outfalls
- Upsized Trunk Sewers
- Upsized Local Sewers
- Existing Water Bodies
- Existing Local Sewers
- Existing Trunk Sewers
- New Local Sewers
- Proposed Road

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- SRWs
- External catchments
- 5m Contours

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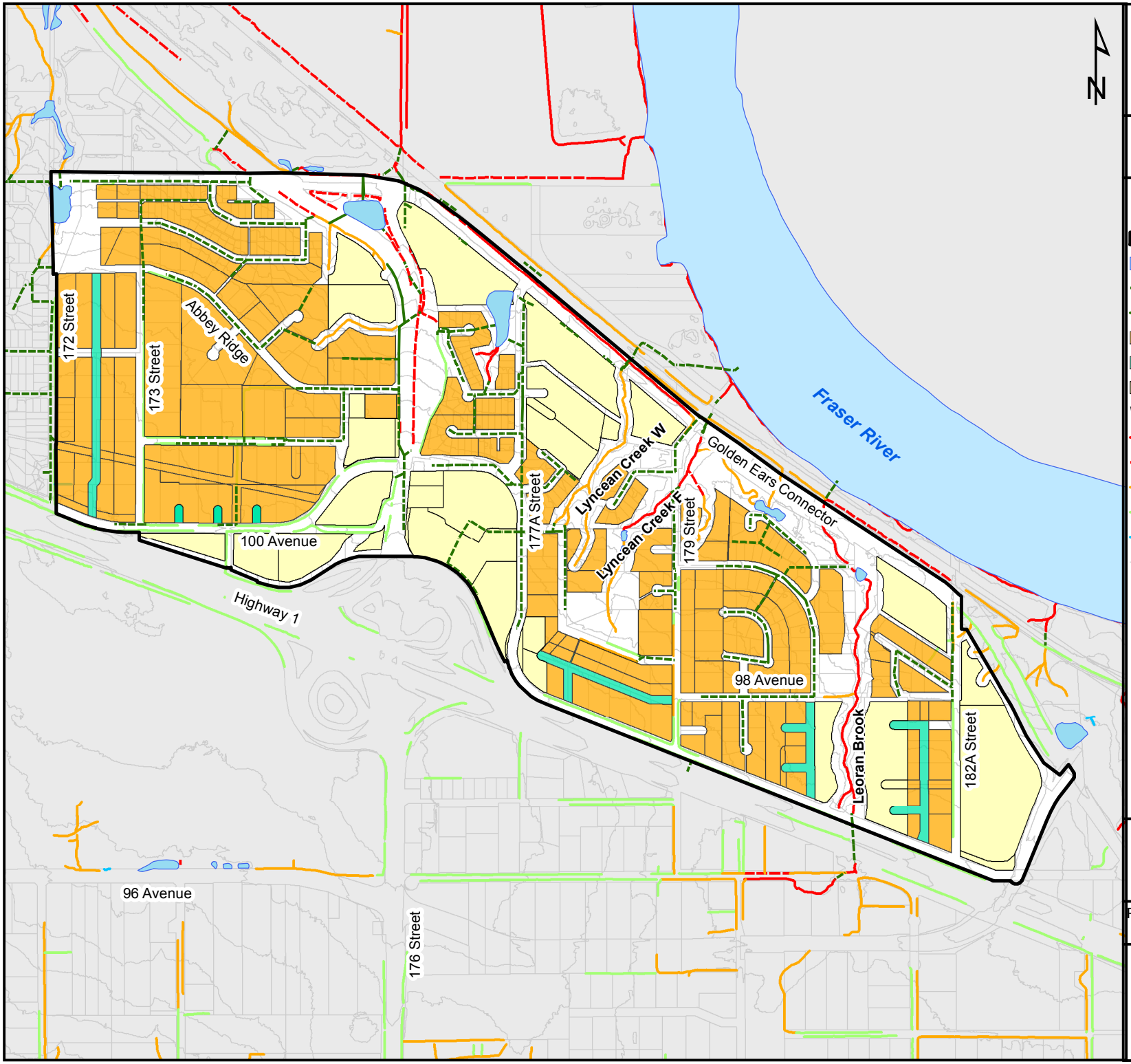
2111-03570-00	December 2016

Proposed Storm Sewers and Upgrades

Figure ES-1



Abbey Ridge
Storm Servicing Concept

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Legend

- Abbey Ridge LAP
- Existing Water Bodies
- Existing Local Sewers
- Existing Trunk Sewers
- On Lot LIDs
- Road ROW LIDs
- On-site Detention

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- 5m Contours

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LID Locations and On-site Detention

Figure ES-2

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Appendix B: Design Storm Hyetographs

Appendix C: Model Results

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1. Introduction

This stormwater servicing study completed by McElhanney was commissioned by the City as a result of a new land use proposed and adopted by the City in late 2015. This study reviewed current and future stormwater uses in preparation for the proposed densification of Abbey Ridge.

In this document you will find:

- The existing watershed conditions within the Abbey Ridge LAP, including topography and terrain, drainage catchments, land use, environmental resources, and anticipated development trends
- A summary of the existing drainage system's performance
- Key constraints and opportunities
- The location of existing and future local and trunk storm sewers and outfalls
- A summary of the geotechnical investigation of slope stability and key erosion sites as it relates to the existing drainage system and proposed upgrades

1.1. Project Background & Objectives

Abbey Ridge is located in northeast Surrey and is bordered by the Fraser River to the northeast, Highway 1 to the south, Port Kells to the east, 104 Avenue to the north, and 172 Street to the west. The primary increase in densification will come from development of existing acreage lots to higher density residential areas. This proposed re-development requires extending the basic stormwater collection system and involves upgrades to some of the larger pipes as flows reach low-lying areas. In addition, several small streams with known erosion concerns drain to lands at the toe of slope, and flooding has historically been a concern within the lowland areas including along Daly Road and lumber mill located between the CN Railway and Fraser River. Therefore, a review of area servicing is needed to confirm that development can proceed without impacting existing lands, both within the development area and in surrounding areas.

The project objective is to identify the stormwater infrastructure needed to service the planned ultimate development land use within the Abbey Ridge LAP area. The recommended servicing must meet or exceed the requirements of the City's current design guidelines and the Bon Accord – North Slope (East) Integrated Stormwater Management Plan (ISMP).

This document recommends Best Management Practices (BMPs) developers shall implement to meet runoff rates, volumes, and water quality objectives for the area. These BMP recommendations provide sufficient detail for consistent implementation by developers. They also provide the City with a reasonable level of confidence that the development will meet area design objectives, which include:

- Managing road runoff and mitigating residential and commercial development impacts in order to maintain pervious surfaces, trees, and infiltration
- Providing clear instructions on suitable mitigation measures to include in the development designs so they meet the ISMP requirements and good design standards
- Obtaining sufficient water quality for the safety of fish and the enjoyment of local waters by residents
- Obtaining acceptance by the City Planning and Engineering Operations departments, residents, and development community

1.2. Background Information

McElhanney reviewed the following background information relevant to the stormwater planning undertaken as part of this study:

- Golden Ears Connector – Detail Design Drawings, MoTI, 2016
- Abbey Ridge Land Use Concept Plan, Stage 1 Preferred Option, City of Surrey, December 2015
- Bon Accord – North Slope (East) Integrated Stormwater Management Plan, Associated Engineering, May 2015
- East Fraser Heights Environmental Assessment Report. 2015. Phoenix Environmental
- Ravine Stability Assessment, Tetra Tech, 2014
- Anniedale-Tynehead Neighbourhood Concept Plan (NCP), City of Surrey, April 2012
- Port Mann / Highway 1 Project Environmental Assessment Certificate Application, September 2007
- South Fraser Perimeter Road Fish Habitat Impact Assessment, Coast River Environmental Services, September 2006
- South Fraser Perimeter Road Environmental Assessment Application, Hemmera, September 2006
- North Bluff Drainage and Slope Stability Assessment, Final Report, Stantec, March 2000

2. Existing Stormwater Servicing

The Abbey Ridge LAP is approximately 183 hectares (ha) in size and is bounded by the Fraser River to the north, 172 Street to the west, Golden Ears Way to the east, and Highway 1 to the south. Located within the Big Bend and Port Kells watersheds, the study area is comprised of single family residential lots, transportation corridors, and industrial, institutional, and commercial areas.

2.1. Study Area

Figure 1 shows the Abbey Ridge LAP area boundaries along with the proposed land use plan adopted by the City. The area's terrain is characterized by three distinct landscapes:

- A gently sloped upland area to the south of the terrain
- A relatively flat lowland area along the north boundary
- A moderately steep transition zone between the upland and the lowland, known commonly as the Surrey escarpment (the majority of the Abbey Ridge LAP area is within this escarpment zone)

The upland area has elevations ranging between 40m and 65m. This area is mostly located in the southwest of the terrain and is sparsely developed with suburban residences. In general, it slopes down to the north and east.

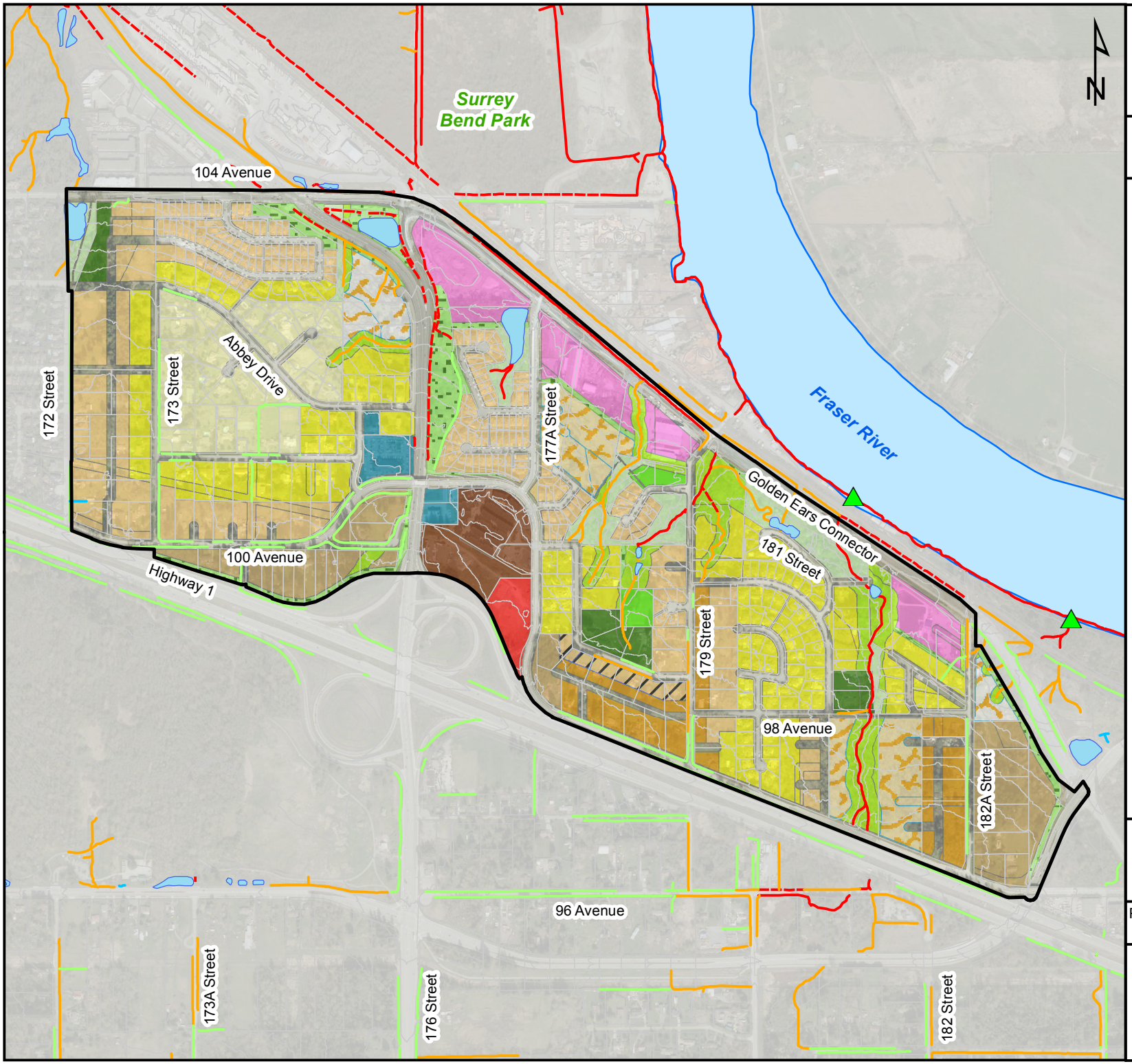
The escarpment zone has elevations ranging between 15m and 55m. Some areas have already been developed with urban residential and transportation corridors. Other areas remain largely undeveloped, especially those adjacent to watercourses. The escarpment slopes down in the northeast direction with slopes as steep as 50%. Some pools have formed in the transition of the escarpment to the lowlands along the watercourses.

Lowlands at the base of the escarpment are located within the Fraser River floodplain and have elevations ranging between 3m and 15m. The area is highly developed with transportation corridors and light impact industry, including the newly constructed Golden Ears Connector. Runoff coming from the uplands and the escarpment zone flows towards the Fraser River through culverts beneath the Golden Ears Connector and CN railway. The lowland areas are not dyked and the 2015 Bon Accord – North Slope ISMP reports that dykes are unlikely to be built in the future. The fluctuating water levels within the Fraser River therefore dictate water levels and performance of the drainage system within the lowland areas, particularly during high winter water levels periods and the spring freshet. The current 200-year flood plain elevation (with 0.6m freeboard) ranges from 5.9m at the western extent of the study area at 172 Street to 6.2m at the eastern extent at 182A Street, as reported by the Fraser River Hydraulics Model Updated Report (March 2008).

2.2. Land Use

Currently, there are 522 residential lots / units within the Abbey Ridge neighbourhood area. The Abbey Ridge neighbourhood area also includes approximately 8.6 ha (21.3ac) of industrial, 2.0 ha (5ac) of institutional and 1.5 ha (3.7ac) of commercial use.

The Port Kells area is an industrial-designated subarea located east of the Abbey Ridge NCP, north of Highway 1. This area is almost entirely zoned Light Impact Industrial (IL) with a small number of Comprehensive Development (CD) spot-zoned parcels for light industrial uses. Based on 2015 air photo data, the Port Kells area appears to be fully utilized with only a small percentage of parcels not having any buildings present.



Abbey Ridge
Storm Servicing Concept

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Legend

- Outfalls
- Abbey Ridge LAP
- Existing Water Bodies

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- 5m Contours

Future land use

- Acreage Residential 1-2 UPA
- Suburban Residential 2-4 UPA Gross
- Urban Transition 4-5 UPA
- Low Density Cluster 4-6 UPA Gross
- Single Family Residential 4-6 UPA
- Medium Density Cluster 10-12 UPA Gross
- Urban Residential 8-10 UPA
- Low Density Multiple Residential 10-15 UPA Gross
- High Density Multiple Residential 25-30 UPA
- Neighbourhood Commercial
- Industrial
- Institutional
- Existing Natural Area
- Future Natural Area
- Existing Neighbourhood Park
- Future Neighbourhood Park
- Landscape Buffer
- External Area

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Abbey Ridge
Local Area Plan

Figure 1

2.3. Climate

According to the City's Design Criteria Manual, the Abbey Ridge LAP lies within the North Rainfall Area and experiences similar rainfall as the Kwantlen Park rainfall gauge.

Table 1 summarizes the 1980-2010 climatic normal data at this station. It can be observed that the average total annual rainfall is 1521.5mm, with 97% of the precipitation in the form of rainfall. On average, 41% of the total yearly rainfall occurs between November and January. The driest months are July and August when only 6% of the average total annual rainfall occurs.

Table 1: Canadian Climate Normals Station Data, 1981-2010, Surrey Kwantlen Park

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Precipitation (mm)	219.2	137.4	142.2	124.8	93.9	73.7	48.1	49.3	68.4	167.4	241.4	196.5	1562.3
Rainfall (mm)	204.4	128.6	139.0	124.7	93.9	73.7	48.1	49.3	68.4	167.1	238.2	186.2	1521.5
Snowfall (mm)	14.8	8.8	3.1	0.2	0.0	0.0	0.0	0.0	0.0	0.3	3.3	10.4	40.8
Greatest Precipitation in 24 hrs (mm)	139.7	65.2	65	51.2	38	46.6	59.9	55.6	57.9	70.9	85	100.8	
Greatest Rainfall in 24 hrs (mm)	139.7	65.2	65	51.2	38	46.6	59.9	55.6	57.9	70.9	85	100.8	
Greatest Snowfall in 24 hrs (mm)	35.6	29	24.6	4	0	0	0	0	0	5	20.8	38	

2.4. Watersheds & Catchments

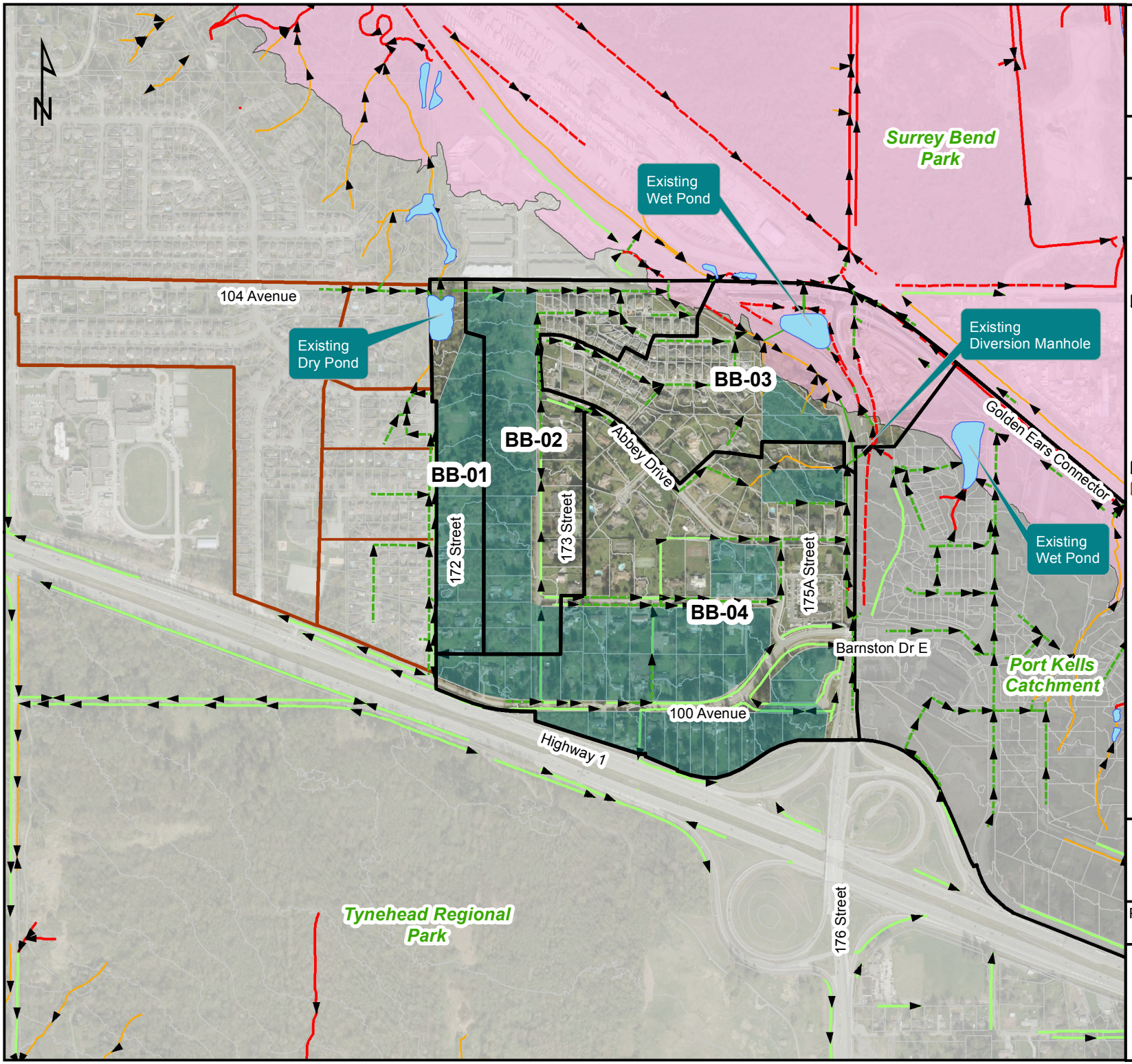
Big Bend Catchment

The two major watersheds within the study area are Big Bend and Port Kells, each containing various sub-catchments. The Big Bend watershed is comprised primarily of urban and suburban residential developments that drains southeast. The piped system discharges to multiple tributaries along the Surrey escarpment that discharge to the lowlands and drain into Surrey Bend Regional Park via Centre Creek. *Figure 2* shows that only the eastern portion of the Big Bend watershed (approx. 75.13 ha), east of 172 Street and south of 104 Avenue is within the Abbey Ridge study area. *Table 2* provides a brief description of the catchments located within the study area.

Approximately half of the Big Bend catchment is already built-out to the zoning identified under the proposed land use plan. Future development will generally occur to the west and south as shown on *Figure 2*.

Table 2: Catchments Conditions, Big Bend Watershed

Name	General Description
BB-01	Sparsely developed, the runoff from this sub-catchment drains northwest to a dry detention pond located at 172 Street and 104 Avenue. This pond also receives runoff from urban residential developments located west of 172nd Street, outside of the Abbey Ridge area. These external sub-catchments are shown in *Figure 2*. The pond discharges through a 1050mm culvert beneath 104 Avenue and drains into one of the tributaries of Centre Creek in Surrey Bend Regional Park.
BB-02	Comprised primarily of suburban residences and an urban land development in the east side of the lowlands. The land slopes down to the north east direction and the runoff is collected by storm sewers along 104 Avenue, 173 Street, and 103B Avenue. These sewers discharge through a 600mm culvert beneath 104 Avenue and drain north into a roadside ditch of Highway 17.
BB-03	This sub-catchment is traversed by two major transport corridors: Highway 17 and the Golden Ears Connector. The area to the east is classified as light impact industrial zone, while the area to the west is comprised of suburban and urban residences. In general, the land slopes downward to the northeast direction, somewhat steeply in the areas to the west and more gently at the industrial zone. The runoff from the residential areas is collected by storm sewers along 103A and 103B Avenues which discharge into a roadside ditch of Highway 17. This ditch conveys the runoff into a pond located between the Golden Ears Connector and Highway 17.
BB-04	The majority of the area in this sub-catchment is comprised of suburban residences. Highway 17 runs north to south in the east side of the catchment. The Korean Central Presbyterian Church is located at 175A Street and Barnston Drive East. The land slopes down to the northeast direction and the runoff is collected by pipes and ditches which eventually drain into the storm sewer along Highway 17. A diversion manhole in this sewer provides base flow to an AO class channel and diverts larger flows to a roadside ditch of Highway 17. This ditch discharges into the wet pond located in sub-catchment BB-03.



Abbey Ridge Storm Servicing Concept

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Legend

- Water Body
- Existing Local Sewers
- Existing Trunk Sewers
- Big Bend Subcatchments
- Areas Slated for Redevelopment

Watercourse/Ditch Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- External Subcatchments
- 200 Year Flood Plain
- 5m Contours

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Big Bend Subcatchments

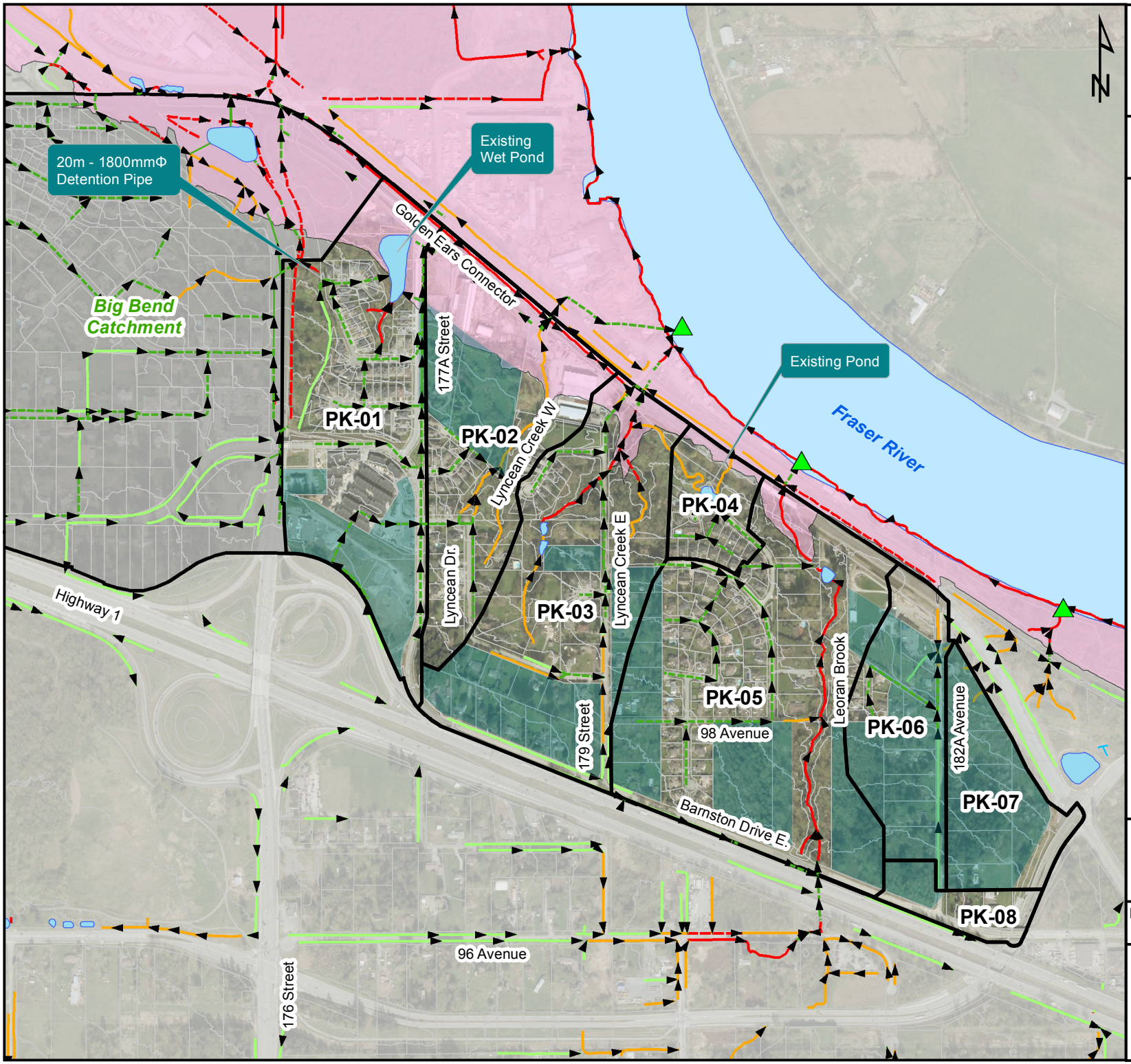
Figure 2

Port Kells Catchment

The Port Kells watershed is made up of two distinct halves. Only the western half (approx. 107.93 ha), from Golden Ears Way, is within the Abbey Ridge area (*Figure 3*) and is sparsely developed with residential and light-industrial land uses. Runoff from these areas drains north to the Fraser River via one of three major watercourses: Lyncean Creek West, Lyncean Creek East, and Leoran Brook. Past studies, including a geotechnical and erosion assessment completed for this study, identify several existing and ongoing erosion locations within these and other local water courses. Erosion risk and mitigation are further discussed in *Section 2.6* of this document. *Table 3* provides a brief description of the catchments located within the study area. Approximately half of the Port Kells catchment is already built out to the zoning identified under the proposed land use plan. Future development will generally occur to the south and eastern areas, in addition to some isolated pockets as shown on *Figure 3*.

Table 3: Catchments Conditions, Port Kells Watershed

Name	General Description
PK-01	The southern area of this sub-catchment is a combination of undeveloped land and multi-family residential developments. North of Barnston Drive East, the area is primarily of urban residential developments. The land slopes down towards the north and northeast directions. Most of the runoff from residential areas is conveyed to the storm sewer along 177A Street. This sewer connects to a 900mm culvert and drains into the roadside ditch of the Golden Ears Connector. The runoff from the undeveloped area north of Barnston Drive and west of the residential developments is collected by a ditch that drains into a 20m-1800mm detention pipe. This pipe also detains the runoff from the properties along 177 Street before discharging into the creek / wetland to the northwest of the sub-catchment.
PK-02	This sub-catchment is suburban and urban residences to the south and an industrial area to the north. In general, the area slopes down to the northeast direction. The runoff from properties along 100 Avenue, 178 Street, and Lyncean Drive is collected by pipes that discharge into Lyncean Creek West.
PK-03	This sub-catchment is crossed by Lyncean Creek East and its tributaries. The area to the north consists primarily of a large private lot that is currently undeveloped, while the area to the south is comprised of suburban residences. In general, the land slopes down to the north and northeast directions, although some areas in the lowlands slopes down to the northwest direction towards Lyncean Creek East. Runoff from the developed areas is collected via pipes and ditches and is conveyed to the storm sewer along 179 Street. This sewer discharges on Lyncean Creek East, upstream of the 1800mm culvert that crosses 179 Street. The properties along 100A Avenue are served by pipes that drain into the sewer that runs along 179 Street. This sewer discharges into a ditch of Daly Road (Golden Ears Connector).
PK-04	This sub-catchment is an urban residential development and vacant lots owned by the City. The land slopes down to the northeast direction and the runoff is collected by a storm sewer network that discharges into a detention pond north of 181 Street. Originally used as detention and then modified by MoTI, it is now part of a wetland system located within the City's land. The pond appears to have two overflow pathways: one flowing north towards a ditch of the Golden Ears Connector and the other flowing west to Lyncean Creek East.
PK-05	This is the largest sub-catchment in the Abbey Ridge LAP. It is crossed by Leoran Brook and is comprised of suburban and urban residential developments to the north and southwest, and vacant lots owned by the Province to the southeast. The land slopes down towards Leoran Brook primarily to the north and northeast directions. Storm sewers in the developed areas discharge on Leoran Brook in two locations: on 98 Avenue and on 99A Avenue. Leoran Brook also receives the runoff from areas south of Highway 1.
PK-06	The area to the south of 98 Avenue slopes down to the north and is comprised of undeveloped areas and suburban residences. The runoff from these areas is collected by a ditch along 182A Avenue. The area to the north of 98 Avenue slopes down to the northeast direction and includes urban residences and a light impact industrial zone in the lowland. The urban residences are served by sewers along 98 Avenue and Parsons Drive, which drain into a storm sewer that runs along a segment of 182A Avenue. In the industrial zone, this sewer becomes an open ditch that drains to the roadside ditches of the Golden Ears Connector.
PK-07	This sub-catchment is largely undeveloped, consisting primarily of suburban residences. The land slopes down to the northeast direction. There are no records of existing stormwater infrastructure in the area.
PK-08	Sparsely developed, this area slopes down to the southeast direction and part of the runoff is collected by a storm sewer along Barnston Drive East. This connects to the storm sewer network along Golden Ears Way.



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Storm Servicing Concept

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Legend

- Outfalls
- Water Body
- Existing Local Sewers
- Existing Trunk Sewers
- Port Kells Subcatchments
- Areas Slated for Redevelopment
- Abbey Ridge LAP

Watercourse/Ditch Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- 200 Year Flood Plain
- 5m Contours

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Port Kells Subcatchments

Figure 3

2.5. Existing Drainage Infrastructure

The drainage infrastructure within the study area is predominantly open channels, storm sewers, culverts, and ditches along roads. *Table 4* summarizes active pipes according to the City's GIS information, including storm sewer pipes and culverts.

Table 4: Summary of Active Pipes in Abbey Ridge LAP

Material	Smallest Size (mm)	Largest size (mm)	Pipe lengths (m)				
			Installation Date				
			Unknown	1970-1985	1986-2000	2001-2016	Total
CMP	600	1800	12.5	0	34.2	372.3	**419**
Concrete	200	1800	264.1	1109.3	1839.2	1743.4	**4956**
PVC	100	675	16.2	201.4	2096.3	3902.2	**6216.1**
PE	375	900	0	0	0	193.5	**193.5**
Unknown	375	900	50.1	61.7	8.3	83.3	**203.4**
TOTAL							**11,988**

Storm sewers in the Big Bend sub-catchments discharge into roadside ditches and then drain through culverts beneath Highway 17 and the CN Railway. The runoff eventually reaches Centre Creek in Surrey Bend Regional Park. In the Port Kells sub-catchments, several storm sewers outfall into wetlands and watercourses, including Lyncean Creek West, Lyncean Creek East, and Leoran Brook. Sewers in sub-catchments PK-01 and PK-02 discharge directly on roadside ditches. Many of these existing storm sewers in both catchments will be maintained and utilized, with some sections upgraded as needed to provide adequate capacity for future development. Proposed storm sewers and upgrade requirements are further discussed in *Section 4.0* of this document.

There are three detention facilities in the Abbey Ridge LAP. Record drawings show that the dry detention pond at 172 Street and 104 Avenue has a capacity of 2,800m^3 at a water elevation of 28.70m (0.60m of freeboard). This pond retains runoff from residential developments west of 172 Street and from open areas in Abbey Ridge. The wet detention pond at the intersection of 104 Avenue and 176 Street (*Figure 2*) is used for water quality improvement, with an estimated capacity of 5,000m^3. The 20m-1800mm pipe at 177 Street and 102 Avenue has a detention capacity of approximately 50m^3. In addition to these detention facilities, there is a wetland area to the west of 177A Street and North of 101A Avenue, and a constructed pond immediately north of 181 Street which receive discharges from storm sewers. The East Fraser Heights Environmental Assessment and Tree Study prepared by Phoenix Environmental Services Ltd describes these ponds as fish habitat compensation sites.

The ongoing construction of the Golden Ears Connector Road includes constructing new drainage infrastructure to improve existing drainage patterns. This includes new culverts, a new bridge over Leoran Brook, and flap gate installation that will prevent peak flows from going through the sewer system at the Teal Jones Lumber Plant. All of these proposed upgrades have been included in our analysis of the proposed drainage scenario.

2.6. Geotechnical Conditions & Erosion Assessment

General Soils Conditions

The preliminary geotechnical assessment completed by Braun Geotechnical Ltd. (Braun) in April 2016 indicates that the Capilano Sediments and Pre-Vashon Deposits underlay the Abbey Ridge area. The Capilano Sediments include marine and glaciomarine stony deposits to stoneless silt loam to clay loam with minor sand and silt. The Pre-Vashon Deposits include Quadra fluvial channel fill and floodplain deposits, cross-bedded sand containing minor silt, and gravel lenses.

This preliminary information indicates that a low to moderate amount of rainfall may currently be lost to sub-surface infiltration and some infiltration should be replicated in the future by development conditions. The Bon Accord ISMP also notes the local physiography is generally not conducive to successful infiltration as only low to moderate infiltration potential exists at the surface due to perched water table conditions resulting from subsurface soils that restrict any deep infiltration. Therefore, infiltration based source controls must be approached with caution. As such, only partial infiltration measures are considered for inclusion into the overall stormwater servicing and LID strategy for future developments. Site specific infiltration rates should be measured during the design of such LID measures, as rates can vary throughout the study area.

Groundwater Considerations

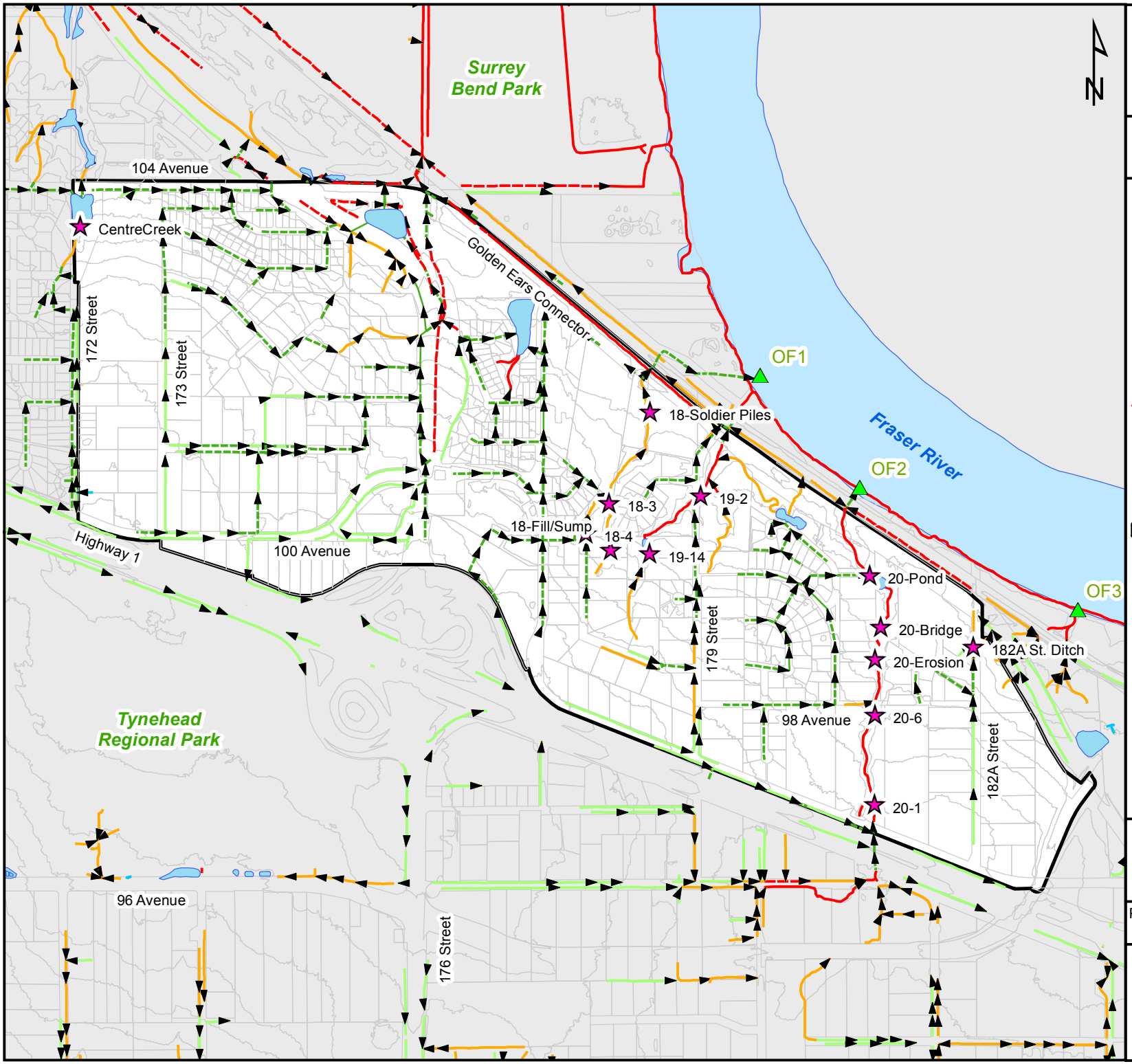
In the past the City has experienced extensive groundwater emergence after homes are constructed on steep slopes, similar to some areas of Abbey Ridge. This is usually a result of structures such as foundations, retaining walls, and roads that are constructed and often cut into high permeable soil lenses. As noted above, localized perched water table conditions exist throughout the Abbey Ridge area which tend to cause lateral movement of infiltrated water within the upper soil layer.

Future developments will need to consider the implications of shallow groundwater movement during design. Site specific geotechnical investigation should further investigate groundwater conditions and provide recommendations for controlling any groundwater emergence.

Erosion Assessment

As part of this assessment, Braun also reviewed the finding of previous studies for the Abbey Ridge area, including the 2000-North Bluff Overview Geotechnical Erosion and Hazard Assessment carried out by Thurber Engineering Ltd. and the 2014-Ravine Stability Assessment prepared by Tetra Tech EBA Inc. These studies identified areas affected by erosion and soil slope instability. Braun conducted a site reconnaissance and prepared an updated assessment of significant changes in the site. They also described current hazard conditions and provided recommendations for additional work.

Most of the areas mentioned in Braun's report are located along Lorean Brook, Lyncean Creek West, and Lyncean Creek East. Braun also reported ongoing erosion in a roadside ditch of 182A Street and in a short reach of Centre Creek. *Figure 4* identifies the location of these erosion sites and *Table 5* summarizes the existing conditions at these locations and describes how these conditions can be improved in the proposed drainage system.



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Legend

- Erosion Site / ID*
- Existing Local Sewers
- Outfalls
- Existing Trunk Sewers
- Existing Water Bodies

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- 5m Contours

* ID per Braun geotechnical report

McElhanney

0 75 150 300 450 (m)

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Project No.	Date
2111-03570-00	December 2016

Erosion Sites

Figure 4

Table 5: Erosion and Hazard Assessment

Location	Site ID[1]	Existing Conditions	Recommendations	Risk	Considerations during Future Development
182A Street	182A St. Ditch	Ongoing erosion of the left bank of ditch along property west of 182A Street. The short timber wall retaining the landscaped private property is in an undermined state.	Extend existing driveway culvert northward and/or provide rip-rap protection.	Low	This existing ditch would eventually be replaced with a closed drainage system as development occurs within the area. In the interim, provide rock rip-rap protection to mitigate against any increase in flows from upstream development.
Leoran Brook	20-1	Minor erosion downstream of new culvert beneath Highway 1.	The banks should be reviewed periodically for potential changes in erosion rates.	Low	None
	20-6	Left bank erosion in reach southeast of 9820 181 Street.	The banks should be reviewed periodically for potential changes in erosion rates.	Low	None
	20-Erosion	Left bank erosion in the middle section of the creek.	The banks should be reviewed periodically for potential changes in erosion rates.	Low	None
	20-Bridge	Woody debris is accumulating under low clearance of amateur footbridge.	The bridge should be removed or replaced. Accumulated debris should be removed.	Low	None
	20-Pond	Man-made pond discharges onto a fish ladder that flows through a culvert installed in ravine fill. Potential risk to downstream highway and Railway crossing in the event of a pond overtopping or damn breach.	The stability of the fish ladder and associated ravine fill should be reviewed. An assessment of the pond structures should be carried out. Develop an operation and inspection plan for the pond.	Medium	Flows to the 99A Ave outfall to Leoron Brook to be maintained at or below existing conditions. The stability of the existing driveway culvert and fish ladder to be reviewed. A new outfall to be installed immediately downstream of the existing Culvert / Fish Ladder as part of the storm upgrade required at 99A Avenue

Location	Site ID[1]	Existing Conditions	Recommendations	Risk	Considerations during Future Development
Lyncean Creek East	19-14	A 7m high dam behind the property at 9999 179 Street creates a pond. A second dam to the north creates another pond. The main pond trash rack is damaged and partially clogged with debris. These dams are located on private property.	Geotechnical exploration and assessment of the existing fills and dams should be undertaken. Develop an operation and inspection plan for the pond.	High	No additional flows to this section of the Creek. Maintain or reduce discharge rates and volumes at this location.
	19-2	Over-steepened rip rap slope at west side of 179 Street culvert crossing (1H: 1.5V). Erosion below the Lock-Block wall causing undermining.	The condition of the rip rap should be reviewed periodically and repairs completed if required. Erosion below the Lock-Block wall should be reviewed and repaired as needed. Additional fill and/or slope reconfiguration should be completed.	Medium	Repairs should be made to the culvert inlet and outlet prior to any increase in flows at this location from upstream development.
Lyncean Creek West	18-Fill / Sump	Dumping of residential garden waste was observed at intersection of 100 Avenue and Lyncean Drive.	Residents should be informed of potential damage if uncontrolled dumping continues.	Low	None
	18-4	Bank erosion above culvert at 100 Avenue and Lyncean Drive.	The replacement of the culvert should be carried out if its current design is considered inadequate.	Low	None
	18-3	A tree located southeast of 17780 100A Avenue has water flowing below it.	The tree should be reviewed by an arborist and removed if deemed unstable.	Low	None
	18-Soldier Piles	Soldier piles had been installed to stabilize the bank at the industrial property at 10095 179 Street.	The slopes should be assessed for long term stability under static and seismic loading conditions.	Low	None
Centre Creek	Centre Creek	Minor erosion in a short reach between 103 and 104 Avenue along 172 Street.	The banks should be reviewed periodically for changing conditions.	Low	None

[1]*See Site ID Location in Figure 4*

In general, a majority of the identified erosion site are considered low risk and continual review and monitoring of these sites is recommended as part of the City's ongoing Ravine and Slope Stability Assessments. There are two erosion sites (ID 20-Pond and 19-14) that are considered particularly sensitive as both sites include a water retaining structure of relatively unknown condition and capacity. These structures are on private property and are not City infrastructure.

Also important to note is that no statutory ROWs are in place along Leoran Brook and Lyncean Creek (East & West tributaries) where these erosion sites are located. Further exacerbation of these erosion sites is of concern to the City as this has the potential to impact private property. This is a key constraint considered in development of the future drainage servicing for the area. Mitigation will primarily consist of either:

- Maintain existing discharge rates and runoff volumes where existing ROWs are not in place and/or access is a constraint to complete restoration of the erosion sites; or
- Provide appropriate rehabilitation of erosion sites where access is available and ROWs can be obtained.

The full report prepared by Braun is included in *Appendix A*.

2.7. Environment

Several recent environmental assessments have been completed in and around the East Fraser Heights / Abbey Ridge study area. A British Columbia Environmental Assessment Act (BCEAA) application submitted for the construction of the South Fraser Perimeter Road (SFPR) included a study of the environmental features and sensitivities in the study area (MOTI 2006). The City conducted detailed baseline environmental studies focused on the East Fraser Heights / Abbey Ridge LAP (Surrey 2015a) and the North Bluff for its ISMP studies (Surrey 2015b). This environmental review of these previous studies and published information was conducted to inform the plans for the water and sewer local area servicing (LAS) for Abbey Ridge.

The City has developed a Biodiversity Conservation Strategy (BCS) which promotes the preservation and maintenance of habitat and species biodiversity (Surrey 2014a). The Surrey's Green Infrastructure Network (GIN) (hubs and corridors) comprise contiguous natural areas including natural areas, parks, streams, riparian areas and natural corridors which serve to provide habitat within the City as an application of the BCS. The City's Ecosystem Development Permit Guidelines (Surrey 2014b), detailed below, are intended to support this biodiversity strategy through application of environmental protection policies outlined in the City's Official Community Plan. Implementation of the City's BCS provides a means to protect riparian and streamside habitat from development while also satisfying the City's requirements to ensure that development complies with the Provincial regulations. Other development permit considerations include development near areas designated as hazardous slopes and tree protection policies. Please note that the construction, maintenance or operation of municipal or public utility works and services are exempt from development permit requirements.

The City's OCP outlines Development Permit Guidelines for Sensitive Ecosystems (Surrey 2014b) identified as green infrastructure areas and streamside areas. Green infrastructure areas have been identified as areas to facilitate biodiversity management and protection of wildlife habitat corridors. Streamside areas are those adjacent to watercourses providing protection of fish habitat.

The Sensitive Ecosystem Development Permit Area and Zoning Streamside Setback provisions of these Development Permit Guidelines (Surrey 2014b), states that any portion of a property that falls within 50 m of a GIN Hub, wildlife corridor, watercourse or biodiversity management area is subject to these provisions.

GIN Hubs are natural areas greater than 10 ha that provide habitat, refuge and movement corridors for wildlife. The BCS objectives for Hubs are to protect these natural areas from development though acquisition of land within each Hub. The objectives for local wildlife corridors are to provide a 10 to 50 m wide natural vegetated corridor to facilitate wildlife movement though an urban environment. These wildlife corridors are often located within the riparian corridors of creeks.

Part 7a – Riparian Protection of Surrey's Zoning Bylaw (Surrey 1993), is to be used to determine the area of riparian protection or 'buffer' required from development adjacent to a stream. For fish bearing creeks these buffers are 15 to 30 m in width, from top of bank, depending on specified conditions.

The study area lies within the Tynehead biodiversity management area. Biodiversity goals for the area include maintenance and enhancement of habitat connectivity of the Abbey Ridge escarpment towards the Fraser River and Surrey Bend Regional Park. Providing riparian buffers around watercourses and enhancing riparian areas to support fish and wildlife are a means to assist in achieving these goals. Retention of forest habitat along the Fraser River is also an objective of the City's Biodiversity Conservation Strategy BCS (BCS 2014a).

Environmental features summarized here for the Abbey Ridge LAP include terrestrial features such as watercourses and wetlands, forest and vegetation communities, wildlife habitat, and species at risk.

Aquatic Habitat Overview

Watercourses and wetlands have been identified and are marked on the Abbey Ridge Land Use Concept plan. Lyncean Creek (east and west) and Leoran Brook are natural streams that flow through the area. A number of unnamed creeks run downslope towards the Fraser River. Many of the watercourses flowing downslope off the Abbey Ridge area are connected to the Fraser River through culverts that convey water under the South Fraser Perimeter Road. Due to this connection with the Fraser River, several watercourses including roadside ditches within the study area have become watercourses that are either fish bearing or provide overwintering habitat for fish.

Watercourses and Wetlands

The City (Surrey 2014) adopted a watercourse classification system categorizing the general productivity of fish habitat in its local watercourses. The East Fraser Heights Environmental Assessment (Surrey 2015a) reviewed the area's watercourse classifications, proposing several recommendations for changes, which the City accepted and included in their COSMOS mapping. *Table 6* provides definitions for the colour coding which is also presented on the City watercourse classification maps and indicated on *Figure 5*. These watercourse classifications for fish productivity are used to develop appropriately sized protective riparian corridors around various watercourses or stream types.

Table 6: Watercourse / stream classification system (Surrey 1995)

Colour Code	Stream Type	Description
Red	Class A (High Productivity) habitat	Inhabited or potentially inhabited by salmonids year round.
Red-Dashed	Class A(O) (High Productivity) habitat	Inhabited by salmonids primarily during the overwintering period or potentially inhabited seasonally with access enhancement.
Yellow	Class B (Moderate Productivity) habitat	Significant food and nutrient value but no fish present.
Green	Class C (Low Productivity) habitat	Insignificant food and nutrient value and no fish present, usually roadside ditches.

Under Part 7a of Surrey's Zoning Bylaw (Surrey 1993), riparian protection or 'buffer' required from development adjacent to a stream have been defined. Generally, all stream types that are classed as fish bearing have 30m setbacks (*Table 7*), unless they are channelized or are roadside ditches. Development occurring within 50m of these watercourses requires a confirmation of the watercourse classification and determination of the appropriate setbacks to apply from top of bank of the watercourse.

Table 7: City of Surrey prescribed riparian setbacks from watercourses modified from the City of Surrey OCP

Development Minimum Distance From Top of Bank		
	Stream Type	
	A or A/O **Fish bearing**	B **Non-fish bearing**
All *Stream* Types (except as shown below):	**30 metres**	**20 metres**
Channelized Stream that has been dyked, diverted or straightened carrying drainage flows from headwaters or significant sources of groundwater, and can include channels that divert irrigation from a *stream* and send overflow water back to a *stream*.	25	15
Ditches: a Stream that is a constructed drainage channel, carrying water that does not originate from a headwater or significant source of groundwater.	10	7
Natural Stream predominantly in its natural state that is not significantly altered by human activity.	30	15
Large Ravines: *Stream* with a narrow, steep-sided valley with a minimum of 60m between the *top of bank* from either side of the *stream*.	15	15

Figure 5 diagrams the watercourses and wetlands within the Abbey Ridge area, provides a stream type colour coding as per *Table 7*, and shows the riparian setbacks for watercourse protection. Roadside ditches, constructed stormwater management ponds and streams, wetlands, natural ravine creeks, and tributaries make up the variety of watercourses in the study area.

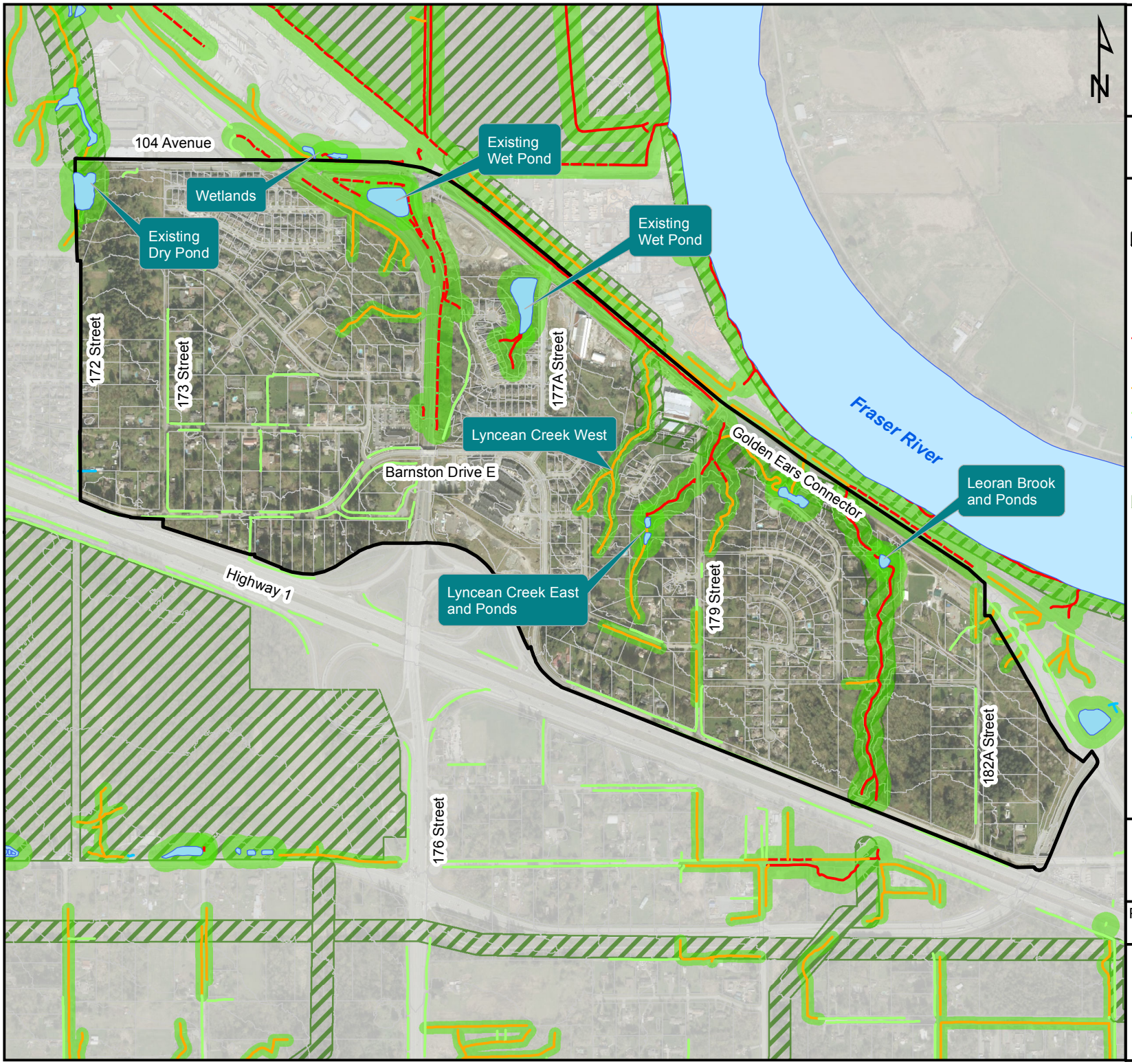
At 172 Street and 104 Avenue, Centre Creek flows northwest out from the Abbey Ridge area. This creek joins with its several tributaries downslope and is culverted under South Fraser Perimeter Road, flowing through Surrey Bend Regional Park before entering the Fraser River (MOE 2016). This creek provides an important wildlife and fisheries corridor and linkage between upslope habitat and the Fraser River. The environmental studies conducted prior to the construction of the South Fraser Perimeter Road (SFPR)

reported that this watercourse, its tributaries, and riparian wetlands provided spawning habitat for coho salmon and juvenile rearing of coastal cutthroat trout.

Numerous other wetlands and wet detention ponds have been developed or enhanced at the base of the Abbey Ridge slope as habitat replacement and compensation that was specified in a Fisheries and Oceans Canada authorization for the construction of the SFPR (Surrey 2015a). Much of this replacement and enhanced habitat provides habitat for salmonids and other fish species. Leoran Brook is a natural fish bearing watercourse supporting populations of cutthroat trout, rainbow trout, and coho salmon. This brook was evaluated in an environmental assessment report which indicated that Leoran Brook provided good rearing habitat (2015a). The study found that spawning potential was limited by low flows and downstream migration obstacles such as culverts and fishway weirs that are impassable during low flow conditions.

Lycean Creek and ponds in and around Barnston Park contain water from seeps, springs, and artesian wells. These springs and seeps are important water sources, conveying water downslope to fish habitat. Most of this creek system's reaches are yellow coded (non-fishbearing) due to natural and manmade fish passage barriers. Banks of some reaches are eroding, which may be mitigated by riparian planting enhancements or through a reduction in storm water inputs into these watercourses (Surrey 2015a,b).

With respect to development, flows in all red and yellow coded watercourses should be maintained at levels set by the City's ISMP and drainage plans (2015b). Water sources, water quality and water quantity are protected by the Province under the *Water Sustainability Act.* No works should be planned within these watercourses and their riparian buffer zones or setbacks except with the permission of the Province.



Abbey Ridge Storm Servicing Concept

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Legend

- Abbey Ridge LAP
- Riparian Set Back Area
- Water Body

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- 5m Contours
- Green Infrastructure Network (GIN)
- External Area

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Aquatic Habitat

Figure 5

Terrestrial Overview

The Abbey Ridge area is characterized by a sloping topography towards the Fraser River to the north, with numerous creeks conveyed off an escarpment down naturally forested ravines. The City's Biodiversity Strategy recommends maintaining the forested character of the slope.

The riparian area of Leoran Brook is designated as a terrestrial corridor connecting fragmented patches of forest habitat within the developed portions of the City to Surrey Bend Regional Park.

Parks and greenbelts have been planned along these corridors and the City has purchased or dedicated land to protect many of these green spaces (*Figure 5*).

Federal Species at Risk

Abbey Ridge lies adjacent to federally designated critical habitat for the Pacific Water shrew (*Sorex bendirii*), a federally designated species at risk under the *Species at Risk Act (SARA) (*Figure 6*).* This small area of habitat at the corner of 172 Street and 104 Avenue (northeast corner of the study area) lies within Abbey Glen Park which is owned by the City. No works can occur within this critical habitat without permits from Environment Canada concerning alterations to the habitat of a Schedule 1 species at risk.

Leoran Brook and Lycean Creek East and West are not indicated as critical habitat for the Pacific Water Shrew. However, there is the potential habitat along these watercourses and riparian areas for this *SARA* listed species. Any works or development impacting these watercourses should have a qualified environmental professional review the site for this species.

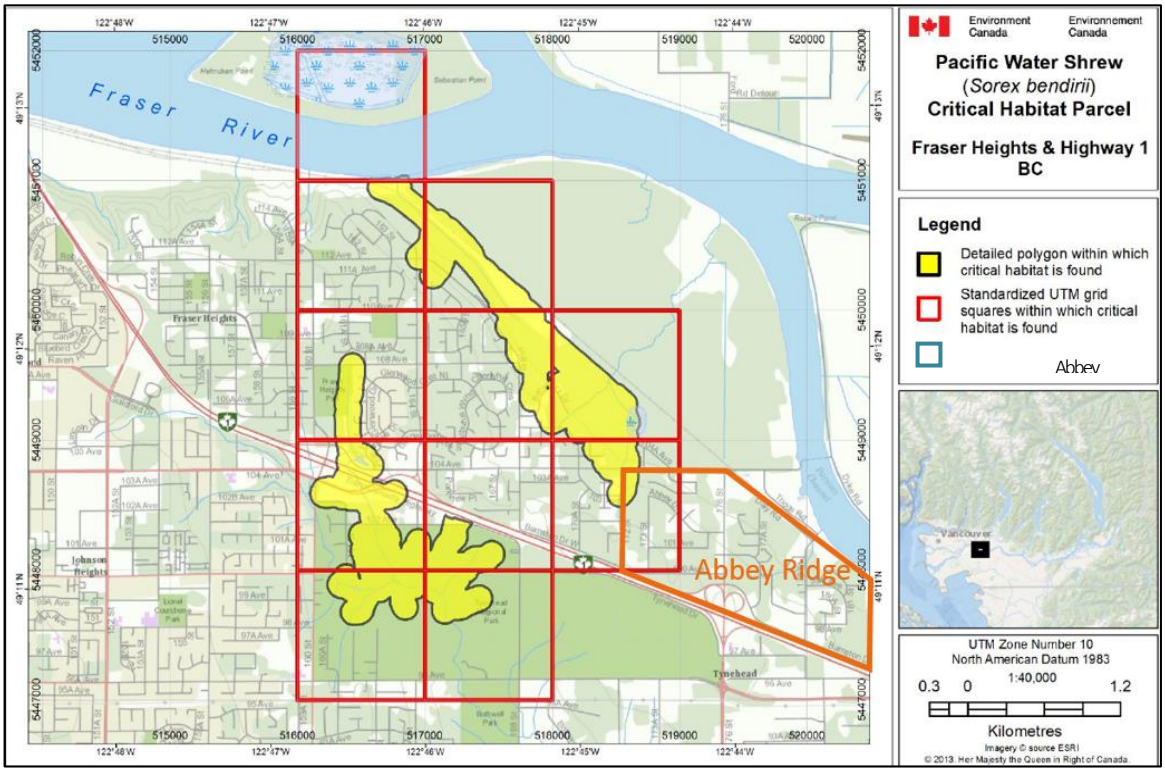


Figure 6: Pacific Water Shrew Critical Habitat Parcel.
The Abbey Ridge LAP touches federally designated critical habitat for the Sorex bendirii.
URL: http://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/rs_pacific_water_shrew_e_final.pdf (EC 2014)

Wildlife Corridors

The City's Green Infrastructure Network (GIN) is a conservation strategy which assists in achieving habitat connectivity for wildlife by identifying terrestrial hubs (forested habitat) and potential wildlife corridors throughout the urban environment. The GIN is included in the City's Biodiversity Conservation Strategy and in land use planning for the City as habitat to be protected from development. The land use plan for Abbey Ridge has provided for one main wildlife corridor through the Abbey Ridge area following Leoran Brook and providing connectivity with the regional hub at Surrey Bend Regional Park (*Figure 5*). Numerous small 'greenbelts' are proposed for some of the lower slope drainages. The Leoran Brook culvert under the SFPR is large enough to accommodate wildlife movement northward providing connectivity of the Abbey Ridge escarpment to the Fraser River and Surrey Bend Regional Park.

Deer, coyotes, raccoon, voles, and squirrel are the primary mammals utilizing these wildlife corridors. Provincially listed species are discussed below. Birds such as the bald eagle, woodpecker, various passerines, and raptors have been observed in the area (Surrey 2015a). The forested slopes and watercourse ravines provide habitat for nesting of various bird species. To comply with the BC *Wildlife Act S 34,* bird nest surveys should be undertaken prior to constructing any land development or municipal projects within 50m of a designated corridor or hub.

Provincial Species at Risk

The Leoran Brook riparian and wildlife corridor provides high potential habitat for provincially listed species such as the Oregon forestsnail and Pacific sideband, Northern red-legged frog, Trowbridge's shrew, and Western Screech-owl (Surrey 2015a). The Leoran Brook corridor, recommended to be 60m wide, provides connectivity between the escarpment and Surrey Bend Regional Park (Surrey 2015a). Though these species are not provided provincially legislated protections, the City's Biodiversity Conservation Strategy provides for the management of these native species through preservation and connectivity of patches of the natural diverse habitats in which these species are found.T

Significant Trees

Trees protected under the City's Tree Protection Bylaw 16100 occur throughout the Abbey Ridge area. Though the bylaw exempts all trees on provincial, federal, Metro Vancouver, and City owned land from the protection provisions of the bylaw, it is mentioned here with respect to construction associated with the land use plan. The tree protection bylaw requires protecting or replacing trees that are removed for residential and commercial development. Priority should be given to retaining forest / tree resources as much as possible to enhance Surrey's GIN.

3. Design Criteria & Analysis

The design criteria for this study is from the City's 2016 Design Criteria Manual and the Bon Accord – North Slope (East) ISMP. General design requirements for the Abbey Ridge LAP include the following:

- In areas where the properties do not have basements, provide a storm sewer system (minor system) with capacity to convey the post-development peak flows from the 1:5-year storm and a major system with enough capacity to accommodate the peak flows from the 1:100-year storm
- In areas where the properties have basements, provide a storm sewer system (minor system) with capacity to convey the post-development peak flows from the 1:100-year storm
- Control the post-development flows and volumes to or below pre-development conditions in areas where erosion is a concern
- Implement LID practices to attenuate post-development peak flows and improve water quality

These general requirements result in the following specific requirements for the Abbey Ridge area:

- Provide a piped system for the major flow in areas that currently have or are expected to have basements
- Use LIDs to control the post development runoff rate and volumes at the various erosion sites
- Provide a drainage strategy that will not overload the culverts crossing the Golden Ears Connector

3.1. Methodology

McElhanney assessed the existing conditions and stormwater infrastructure in the Abbey Ridge LAP by reviewing information available for the study area. This includes background reports, construction record drawings, aerial photos, and the City's GIS database.

Computational modelling was used to determine peak flows from the catchments. PCSWMM version 6.2.2070 was used to simulate the rainfall to runoff process through single event modelling, with five model scenarios developed to compare pre-development, existing and future conditions. *Table 8* describes the purpose of each scenario. These models were built over the Bon Accord / North Slope SWMM-model developed for the 2015 Integrated Stormwater Management Plan of this area.

Table 8: Model Scenarios

Scenario Number	Development Condition	Description
0	Pre-development	Determine pre-development runoff values and establish maximum unit discharges for the future on-site detention.
1	Existing	Analyze the performance of the existing storm sewers under existing conditions and determine existing peak flows (ie baseline conditions)
2	Future	Analyze the performance of the existing storm sewers under future build-out conditions without any upgrades.
3	Future	Analyze and propose the extension and upgrading of the existing storm sewer.
4	Future	Assess the benefits of implementing on-site detention and LID practices within the proposed storm sewer system.

The catchments identified in *Tables 3* and *4* were further divided into multiple sub-catchments. We obtained the average slope of these sub-catchments from a DEM surface built with the City's existing contours. For Scenario

1 (existing conditions), we determined the percentage of total imperviousness by completing a weighted multiplication of the total areas for different land uses (delineated in the aerial photo) and their corresponding imperviousness, as defined in the 2016 City of Surrey's Design Criteria Manual. For Scenarios 2, 3, and 4 (future conditions), we calculated the imperviousness assuming full build out of the Abbey Ridge LAP.

We matched the hydrologic input parameters to those used in the Bon Accord ISMP, which are summarized in *Table 9*.

Table 9: Catchment Modeling Input Parameters

Parameter	Value
Impervious Manning n	0.012
Pervious Manning n	0.24
Impervious Depression Storage	1.3mm / hr
Pervious Depression Storage	3.8mm
Maximum infiltration rate	5mm / hr
Minimum infiltration rate	1.5mm / hr
Decay constant	5.4 1 / hr
Drying time	7 days

3.2. Rainfall Data

The synthetic design storms used for the single event modeling were derived with IDF data from the Kwantlen Park rainfall station. This data was obtained from the City's 2016 Design Criteria Manual. *Appendix B* includes the hyetographs of these design storms, which have durations from 1 hour to 24 hours for 5 and 100-year return periods. *Table 10* shows total rainfall depths for each of the design storms.

Table 10: Design Storms Rainfall Depths (mm)

Duration	Return Period in Years	
	5 year	100 year
1 hours	15.00	23.90
2 hours	21.20	31.90
6 hours	40.30	58.40
12 hours	61.39	94.39
24 hours	85.67	137.90

Appendix C provides more details on model input parameters used.

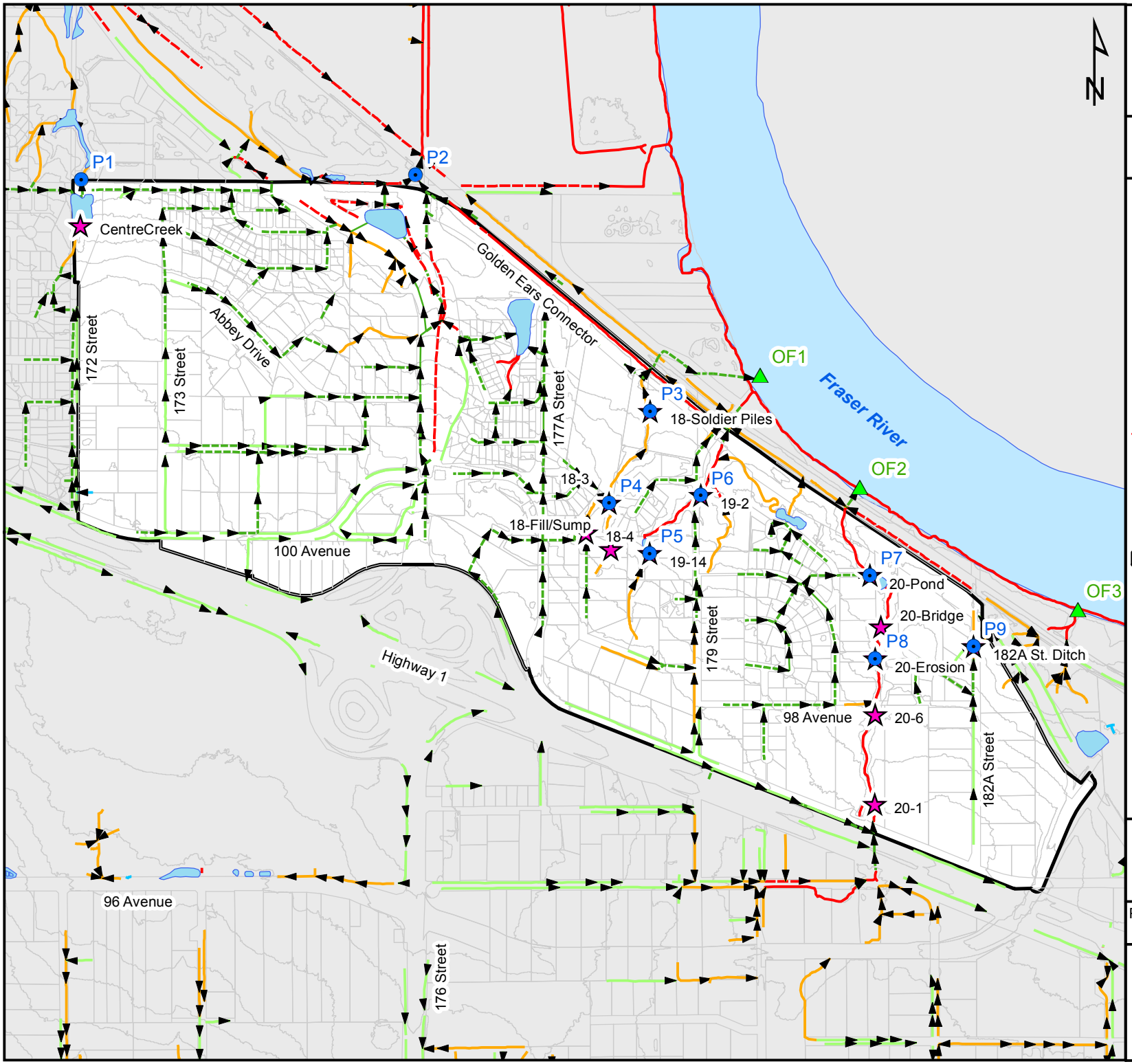
3.3. Baseline Conditions

Baseline conditions were established at several Points of Interest (POI) to compare peak flows and runoff volumes between modeling scenarios. *Figure 7* outlines the location of the POIs for the study area which are generally located at several key erosion sites and along the perimeter of Abbey Ridge where flows exit the study limits.

Results from the existing drainage scenario model were used to establish the pre-development peak flow rates at each POI and are summarized in *Table 11* below.

Table 11: Existing development flow at each Point of Interest

Point of Interest ID	Control Point / Location	5-year 1h (m^3/s)	5-year 24h (m^3/s)	100-year 1h (m^3/s)	100-year 24h (m^3/s)
OF1	Fraser River Outfall	1.27	1.40	1.96	2.00
OF2	Fraser River Outfall	1.33	1.69	1.86	2.44
OF3	Fraser River Outfall	0.81	0.52	1.17	0.87
POI 1	Centre Creek / 104 Avenue	0.32	0.81	0.91	1.40
POI 2	Big Bend Park / 104 Avenue	1.48	1.44	2.73	2.49
POI 3	Erosion Site 18-Soldier Piles	0.32	0.18	0.63	0.30
POI 4	Erosion Site 18-3	0.05	0.03	0.09	0.04
POI 5	Erosion Site 19-14	0.09	0.07	0.18	0.12
POI 6	Erosion Site 19-2	0.46	0.31	0.91	0.54
POI 7	Erosion Site 20-Pond	2.04	1.74	3.60	2.92
POI 8	Erosion Site 20-Erosion	2.02	1.72	3.55	2.87
POI 9	Erosion Site 182A Street Ditch	0.31	0.18	0.59	0.30



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Legend

- Points of Interest
- Erosion Site / ID*
- Existing Local Sewers
- Outfalls
- Existing Trunk Sewers
- Existing Water Bodies

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- 5m Contours

* ID per Braun geotechnical report

McElhanney

0 75 150 300 450 (m)

1:12,000

Project No.	Date
2111-03570-00	December 2016

Points of Interest & Erosion Sites

Figure 7

4. Proposed System

The future development of Abbey Ridge will change the existing land use distribution. These changes will increase the amount of impervious areas, reducing infiltration and increasing surface runoff. *Table 12* below compares the imperviousness between current and future conditions indicating a modest 23% increase in percent imperviousness that is expected to the Abbey Ridge area when full build-out is realized per the approved land use plan.

Table 12: Comparison of % Imperviousness

	Big Bend Catchment	Port Kells Catchment
Existing Development Conditions	47.2%	42.3%
Future Development Conditions	69.3%	66.0%

Our overall approach to determining the proposed drainage system was to assess the existing system's performance and determine necessary upgrades to adequately convey runoff from the study area to the Fraser River. We assumed at the onset of the study that additional detention ponds were not required since a significant portion of the study area is already developed and is in close proximity to the Fraser River.

Hydraulic modeling of the existing drainage system revealed that many of the sewers do not have capacity to accommodate current or increased flows. Therefore, in addition to extending the existing sewer system, many of the installed pipes will have to be replaced to prevent flooding of existing properties, including existing areas with basements. In order to attenuate flows at the POIs shown on *Figure 7*, the development discharges on Leoran Brook and Lyncean Creek East should be limited. In addition, we recommend the use of LID techniques in future roads and developments to reduce volume rates and as the primary erosion mitigation measure in sensitive areas.

4.1. Minor System Conveyance

The minor system, defined by the City as the drainage system component with marginal capacity to convey the five-year return period flow, will generally consist of curb and gutters and catch basins that discharge water to an underground storm sewer system. Future developments will be expected to install storm sewers to service their respective development and connect to the existing storm sewer system.

The design criteria also require that all habitable areas, including basements, be above the 100-year hydraulic grade line. A cursory visual inspection revealed that many existing properties in the Abbey Ridge area have basements. However, the hydraulic modelling of the existing sewer system (Scenario 1 of *Table 7*) showed that many of the installed sewers in these areas do not have capacity to convey the current peak flows from the 100-year return period storm therefore, flooding would occur. This situation is aggravated if the increased runoff from future development is considered (Scenario 2 of *Table 7*).

We recommend upsizing the existing local and trunk sewers, as shown on *Figure 8*. These minimum upgrades are required to prevent flooding of any existing basements by providing in-pipe capacity for the 100-year flow.

Big Bend Catchment

As shown previously on *Figure 2*, future development within the Big Bend catchment will primarily consist of future residential development concentrated along the western and southern perimeters of the catchment with a small pocket located along 176 Street. Future development along 172 Street can be serviced by the existing storm sewer on 172 Street that conveys runoff to the existing detention pond at 104 Avenue and 172 Street. Limited opportunity exists for expansion of this detention facility. However analysis shows some capacity is available to convey some additional flows from Abbey Ridge to this facility provided upstream LIDs are utilized.

LIDs can be used to provide adequate rate control to provide sufficient conveyance capacity up to and downstream of the detention pond to the Fraser River. New storm sewers will be required between 172 Street and 173 Street to convey runoff south towards 104 Avenue. Upgrade of an existing section of local sewer along 173 Street will be required to provide adequate conveyance capacity.

A new storm sewer system would be required along 100 Avenue / Barnston Drive that would convey runoff to 175A Street. Upgrades to the existing system would be required along 175A Street and Abbey Drive due to existing flooding issues and additional flows being generated and conveyed by upstream development. No trunk sewers will be required in this catchment.

All other existing drainage infrastructure was reviewed under the modeling analysis and the majority are shown to have adequate conveyance capacity to meet the design criteria. View the modeling results located under *Appendix C*.

Port Kells Catchment

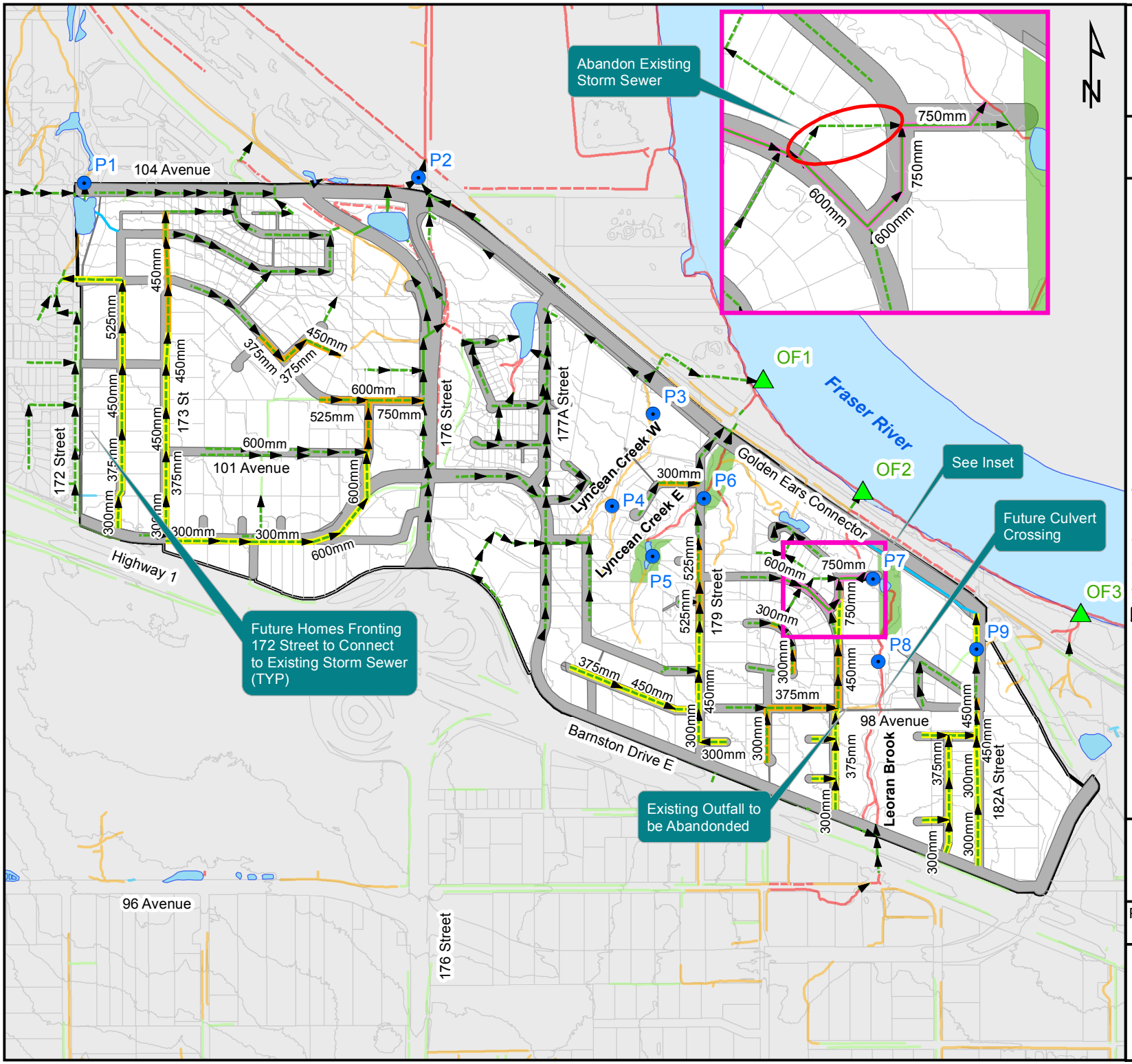
As shown previously on *Figure 3*, future development within the Port Kells catchment will primarily consist of urban residential and low / high multifamily residential with a small pocket of commercial located along the southern half of the catchment along 177A Street, 179 Street, Barnston Drive, and 182A Street.

New storm sewers and upgrades to sections of existing storm sewers will be required throughout the eastern half of the catchment, generally along 98 Avenue, 179 Street, 181 Street, and 182A Street where majority of development will occur. Upgrade to existing local trunk sewers will be required (shown on *Figure 8)* to provide adequate conveyance for existing and future developments in the area.

Upgrade and re-alignment of an existing storm trunk sewer will also be required at 99A Avenue and 181 Street to provide sufficient capacity. The works would include abandonment of the existing trunk sewer behind the existing homes along 99A Avenue / 181 Street. An additional outfall will also be required immediately downstream of the existing fish ladder and culvert structure as the capacity and structural integrity of these structures are questionable.

All other existing outfalls to Lyncean Creek, Leoran Brook and the unnamed yellow coded ditch at 182A Avenue / Golden Ears Connector will be maintained and utilized. It is recommended the existing outfall to Leoran Brook at 98 Avenue be abandoned as a mitigation measure to the ongoing erosion occurring within Leoran Brook. This abandonment will have negligible impact to the existing base flow. A future culvert crossing will also be required along 98 Avenue at Leoran Brook when 98 Avenue is extended through.

All other existing drainage infrastructure was reviewed under the modeling analysis and the majority are shown to have adequate conveyance capacity to meet the design criteria. View the modeling results located under *Appendix C*.



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Legend

- Points of Interest
- Outfalls
- Upsized Local Sewers
- Upsized Trunk Sewers
- Existing Local Sewers
- Existing Trunk Sewers
- New Local Sewers
- Proposed Road
- Existing Water Bodies

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- SRWs
- 5m Contours

McElhanney

0 75 150 300 450 (m)

1:12,000

Project No.	Date
2111-03570-00	December 2016

Proposed Storm Sewers and Upgrades

Figure 8

4.2. Major System Conveyance

Future developments within the Abbey Ridge area must provide for a major flow route along the surface by installing curb and gutter along roadways. This will provide a safe route for flows that exceed the piped system's capacity without flooding adjacent properties. In areas where the piped (minor) system is designed to convey the 100-year storm, a safe surface route must be present to be provided for redundancy. A review of the existing and future overland flow routes were completed under this study to confirm a safe route is available without impact to existing property. In general, a safe route flood route is available along all road corridors to an appropriate outfall. The only exception is the existing cul-de-sac along 174A Street within the Big Bend catchment. Any overland flows would be directed down towards existing private properties. However, this section of storm sewer is recommended for upgrade to provide capacity for the 100-year discharge, and as part of the upgrade, an additional grated inlet at the low-point of the cul-de-sac should be provided to collect any overland flows.

4.3. Existing Detention Facilities

The detention ponds and wetlands described in *Section 2.5* of this document are proposed to operate as is, without any further upgrades or modifications. The inflow volumes at these facilities will be maintained or reduced through the use of on-site detention and LID techniques. A small portion of Abbey Ridge, from 172 Street to 172A Street (north of Highway 1), can be directed to the detention pond at 172 Street and 104 Avenue. This pond was modelled to include this additional area and result show the pond has the capacity to accept the additional flow.

Table 14 presents the existing and post-development inflow volumes at these facilities.

Table 13: Inflow Volume into Existing Detention Facilities

Detention Facility	5-year-24h (Existing) (m^3)	5-year 24h (Future) (m^3)	100-year-24h (Existing) (m^3)	100-year 24h (Future) (m^3)
Dry detention pond at 172 St. and 104 Av.	28,300	28,100	48,900	46,600
Wet detention pond at 104 Av. and 176 St.	30,900	23,500	54,600	39,100
Wetland west of 177A St.	4,380	3,690	7,200	6,000
Pond North of 181 St.	2,860	2,040	5,180	3,710

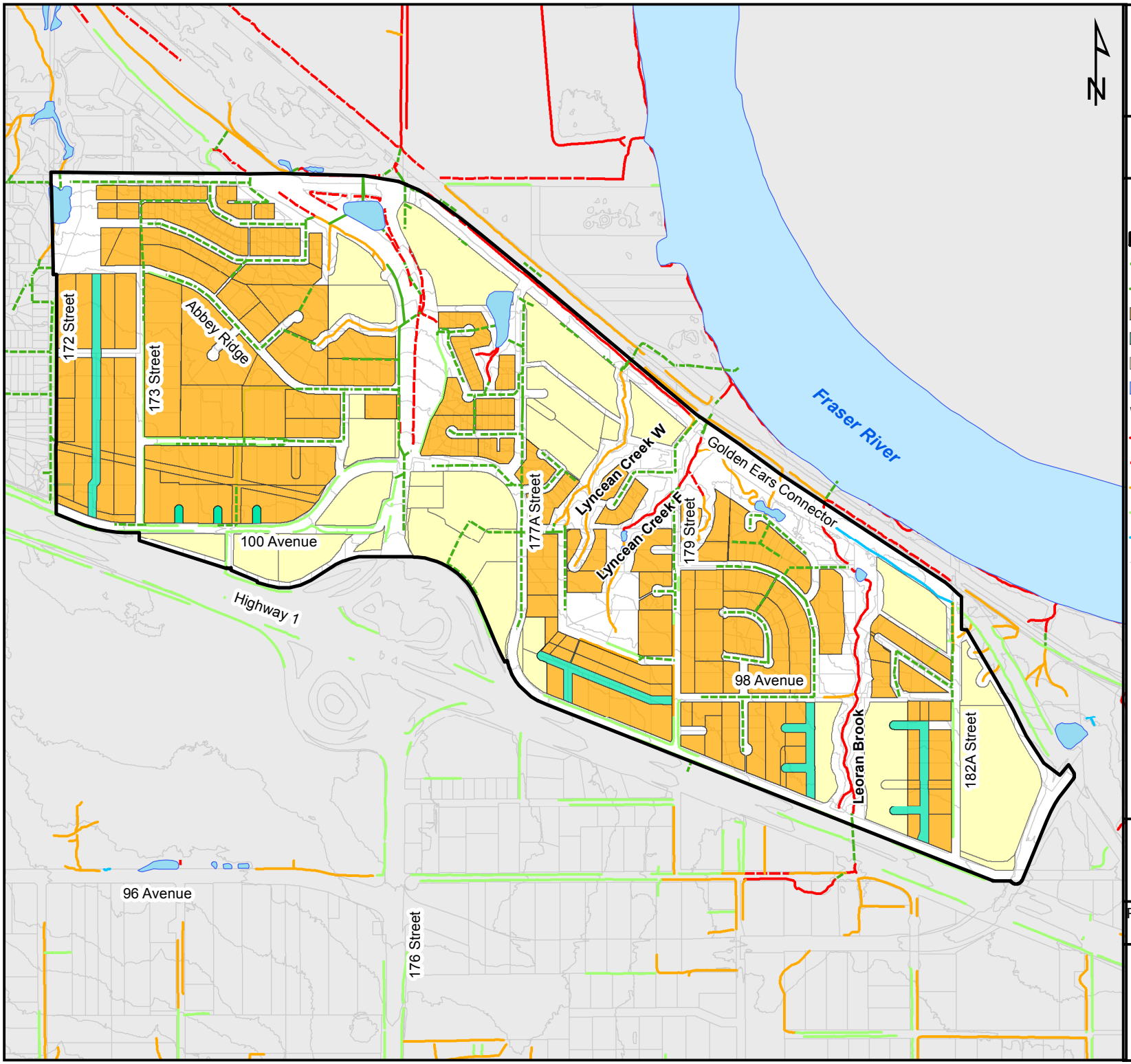
4.4. On-site Detention

All new industrial, institutional, commercial and multiple family residential developments will be required to have on-site detention storage to control offsite discharges to below 15 l/s/ha and 25 l/s/ha during the 5-year and 100-year events respectively. These targets were established through the pre-development model (Scenario 0 in *Table 8*) with the 5-year and 100-year storm events and durations from 1 hour to 24 hours. *Table 13* shows the average unit pre-development flows from the industrial, institutional, commercial and multiple family

residential areas. The 15 l/s/ha and 25 l/s/ha targets will limit the offsite discharges to flow rates below the pre-development runoff during all storm events. *Figure 9* shows the areas where on-site detention is recommended.

Table 14: Average unit pre-development runoff (l/s/ha)

Duration	Return Period in Years	
	5 year	100 year
1 hours	20	47
2 hours	21	46
6 hours	17	26
12 hours	23	42
24 hours	18	32



Abbey Ridge
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Legend

- Abbey Ridge LAP
- Existing Local Sewers
- Existing Trunk Sewers
- On Lot LIDs
- Road ROW LIDs
- On-site Detention
- Existing Water Bodies

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- 5m Contours

McElhanney

0 75 150 300 450 (m)

1:12,000

Project No.	Date
2111-03570-00	December 2016

LID Locations and On-site Detention

Figure 9

4.5. Runoff Rates

Implementing the on-side detention and the LID techniques will also reduce the runoff rates at the various POIs, including within Leoran Brook and Lyncean Creek. *Table 15* presents the existing and post-development runoff rates at these locations.

Table 15: Pre and Post-development flow at Points of Interest

Point of Interest ID	Control Point / Location	5-year-1h (Existing) (m^3/s)	5-year 1h (Future) (m^3/s)	100-year-1h (Existing) (m^3/s)	100-year 1h (Future) (m^3/s)
OF1	Fraser River Outfall	1.27	1.06	1.96	1.72
OF2	Fraser River Outfall	1.33	1.26	1.86	1.77
OF3	Fraser River Outfall	0.81	0.67	1.17	1.33
POI 1	Centre Creek / 104 Avenue	0.32	0.26	0.91	0.75
POI 2	Big Bend Park / 104 Avenue	1.48	0.64	2.73	1.31.
POI 3	Erosion Site 18-Soldier Piles	0.32	0.20	0.63	0.43
POI 4	Erosion Site 18-3	0.05	0.03	0.09	0.08
POI 5	Erosion Site 19-14	0.09	0.08	0.18	0.17
POI 6	Erosion Site 19-2	0.46	0.50	0.91	1.00
POI 7	Erosion Site 20-Pond	2.04	1.89	3.60	3.28
POI 8	Erosion Site 20-Erosion	2.02	1.87	3.55	3.24
POI 9	Erosion Site 182A Street Ditch	0.31	0.37	0.59	0.76

As shown, post-development rates would match closely to pre-development conditions with the exception of OF3, POI 6, and POI 9.

Outfall 3 (OF3) and POI 9 represent flow conditions at the eastern most outfall to the Fraser River and the erosion occurring along the 182A Avenue roadside ditch, respectively. The existing system in this area has sufficient hydraulic capacity to convey future runoff without any flooding. This roadside ditch along 182A Street will be replaced by a storm sewer system as development proceeds along 182A Street. In the interim, temporary erosion protection works such as ditch restoration and placement of rock rip-rap can be utilized to stabilize the erosion occurring at this location until the ditch is replaced with a storm sewer. As such, the increase in discharge rates as shown in *Table 12* above at POI 9 can be accommodated with these temporary works in place.

POI 6 is an erosion site located at the inlet and outlet of the existing culvert along 179 Street along Lyncean Creek (east tributary). The culvert does have the hydraulic capacity to accept the additional increase in discharge and the erosion concern can be mitigated with some minor rehabilitation works. This work includes review and repair of the existing rip-rap at the culvert inlet and placement of additional fill or slope reconfiguration at the culvert outlet. A Statutory Right-of-Way (SRW) would be required at the outlet of the culvert to complete this work.

4.6. Runoff Volume Control

More development will increase runoff volume. While the Bon Accord – North Slope (East) ISMP did not establish runoff volume constraints, the City's current design standards encourage more effective methods to manage post-development flows, runoff volumes, and maintaining base flows in efforts to protect properties and sensitive receiving watercourses.

Using PCSWMM, McElhanney used both single event and continuous simulation to evaluate the water balance and assess the performance of the proposed LIDs.

Single-Event Analysis

Similar to the peak flow analysis, single event modeling was used to determine the effectiveness of LIDs to reduce total runoff volumes from the significant long duration SCS storms throughout the system. *Table 17* compares the total runoff volumes from significant (5-year and 100-year) 24-hour events.

Table 16: Pre- and Post-development volumes at Points of Interest using Single Event Modeling

Point of Interest ID	Control Point / Location	5-year-24h (Existing) (m^3)	5-year 24h (Future) (m^3)	100-year-24h (Existing) (m^3)	100-year 24h (Future) (m^3)
OF1	Fraser River Outfall	49,500	44,800	86,400	79,500
OF2	Fraser River Outfall	69,400	65,000	123,000	114,000
OF3	Fraser River Outfall	14,400	17,300	26,300	30,200
POI 1	Centre Creek / 104 Avenue	27,600	27,200	48,300	47,600
POI 2	Big Bend Park / 104 Avenue	43,400	29,700	81,200	53,800
POI 3	Erosion Site 18-Soldier Piles	4,970	4,200	9,060	7,720
POI 4	Erosion Site 18-3	710	385	1,280	759
POI 5	Erosion Site 19-14	2,890	2,830	4,370	4,310
POI 6	Erosion Site 19-2	9,470	8,580	16,300	14,900
POI 7	Erosion Site 20-Pond	60,100	55,200	105,000	97,100
POI 8	Erosion Site 20-Erosion	59,700	54,700	104,000	96,100
POI 9	Erosion Site 182A Street Ditch	4,950	6,670	8,980	11,700

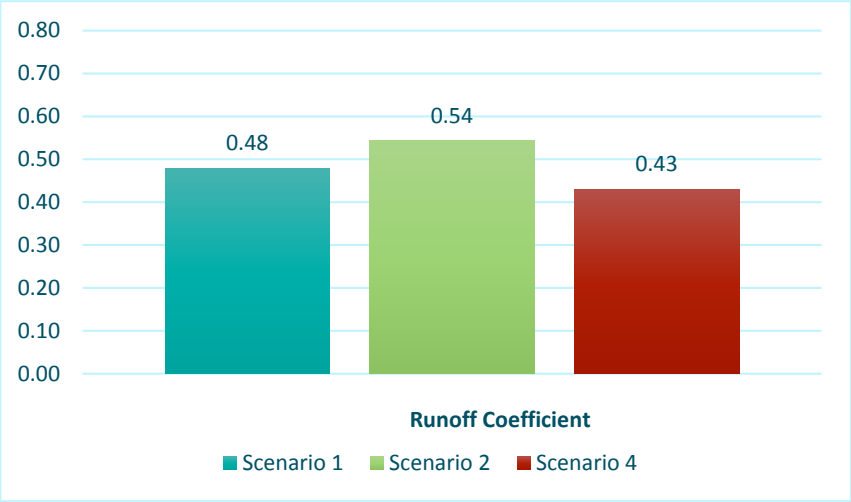
Similar to the comparison of pre- and post-development discharge rates, the total runoff volumes at the POIs in the future will generally be at or below the current conditions, with the exception of OF3 and POI 9. However, as discussed in *Section 4.2*, the existing system in this area has sufficient hydraulic capacity to convey future runoff without any flooding. Temporary erosion protection works are recommended to stabilize the erosion occurring at this location until the ditch is replaced with the ultimate storm sewer.

Continuous Simulation

Continuous simulation based on historical rainfall from a typical year (Surrey Kwantlen Park gauging station) was also used to determine runoff volume and discharge rates for Scenario 1 (existing conditions), Scenario 3 (proposed development with no LIDs), and Scenario 4 (proposed development with LIDs in place).

The rainfall and runoff mass balance from the continuous simulation (represented by the total runoff coefficient) for the LIDs are indicated in *Figure 11*, with the runoff coefficient representing the ratio of runoff to total rainfall volume. This shows that the proposed development with no LIDs increases the overall runoff volume due to increased imperviousness and decreased potential infiltration. However, using the recommended LIDs, the runoff coefficient (and therefore runoff volume) is smaller than the pre-development level.

Figure 10: Runoff Coefficient Comparison from Continuous Simulation



4.7. Proposed LIDs

Attenuation of future runoff rates will also be accomplished through the use of three LID techniques: impervious disconnection, absorbent landscaping and infiltration trenches in roads.

The implementation of these strategies will help to minimize impacts to downstream infrastructure and maintain existing discharge rates and volumes at key vulnerable erosion sites. The recommendation of these LIDs can be separated into two areas for the study: On-Lot LIDs and Road ROW LIDs, as described below.

On Lot LIDs

The simplest non-structural source control is the disconnection of roof leaders from the storm sewer service connections to allow roof runoff onto splash pads directing runoff to the surrounding yard area. The disconnection of roof leaders is an existing criterion for new single family residential developments in Surrey.

The other primary on-lot LID to be implemented for all developments is the use of amended topsoil throughout all landscaped areas of the development. Metro Vancouver's Stormwater Source Control Design Guidelines 2012 describes an absorbent landscape as a layer of soil with vegetation designed to infiltrate the rain that falls on it and from upstream impervious areas. Impervious areas and roof leaders must be disconnected from the storm sewer and drain into the absorbent landscape with only an overflow to the drainage system. The required thickness of the top soil layer is 450mmn which is cited by the Bon Accord – North Slope ISMP study and a maximum of impervious area to absorbent landscape ratio shall be 1.5:1. Additionally, the enhanced topsoil would be applied to all pervious surfaces on the private property and fronting boulevard areas within the municipal ROWs. *Table 17* summarizes the required LID for each zone.

Table 17: Summary of Required LID for Each Zoning

Land Use	Zoning	LIDs required
Single Family Residential / Cluster (1-10 UPA)	RH-G, RF, RF-9/12	Disconnected Roof Leaders directing runoff to splash pads 450mm enhanced / amended top soil on all pervious areas
Multiple Family Residential (12-30 UPA)	RM-15, RM-30, RM-45	450mm enhanced / amended top soil on all pervious areas
Commercial and Industrial	IL, C-5	450mm enhanced / amended top soil on all pervious areas
Institution, School, Church	PA-1	450mm enhanced / amended top soil on all pervious areas

Road ROW LIDs

The road ROW areas also require their own designated LID measures separate from measures located on private property. Road ROW LIDs may include any combination of rain gardens, roadside swales, and infiltration trenches. The total area of road ROW LIDs are a function of the total area being serviced, and through several iterations of modeling/analysis the footprint of the LIDs was determined to be a minimum 5% of the road ROW area.

All pervious and impervious surfaces must be directly connected to the LID such that no uncontrolled runoff enters the piped system. Retention of stormwater runoff from the ROW areas, particularly from impervious road surfaces, is important as significant runoff contribution and pollutant loadings originate from the pavement areas of local roads and rear access lanes in the neighbourhood.

Boulevards within the road ROW provide opportunities to apply the 450mm layer of enhanced / amended topsoil, consistent with the on-lot developments. This installation of topsoil within the ROW would coincide with topsoil placement during construction of the frontage roads for each particular development. The topsoil will help to retain rainfall and promote rainwater absorption within the boulevard.

Two options have been identified to apply source control measures for the road ROW areas.

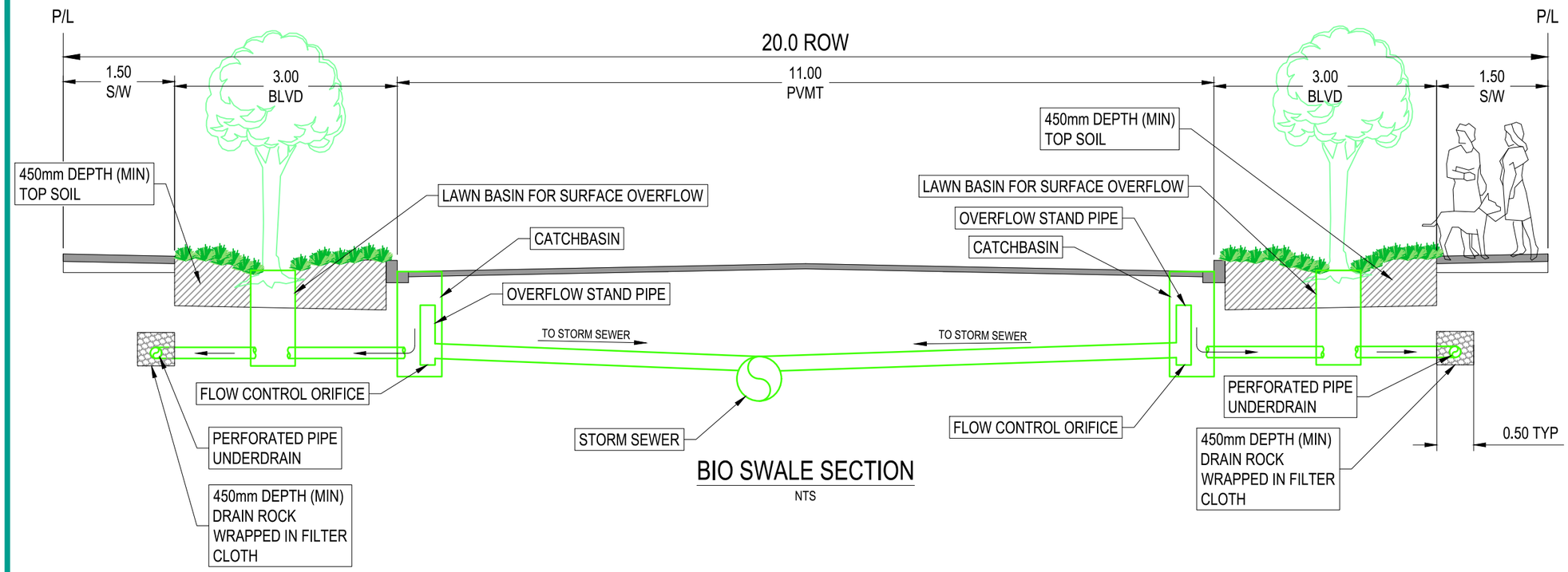
- The first option utilizes a 0.5m wide by 0.45m deep infiltration trench located along both sides of the road ROW to provide retention volume to meet the stormwater retention targets for road ROW areas. Flow control orifices are required to act as an underdrain within the catchbasins to provide a slow release to the storm sewer main. The infiltration trench and flow control catchbasins for a typical 20m road cross section are shown in *Figure 11*.
- The second option is to incorporate the use of an above ground rain garden within the boulevards of the road ROW. *Figure 12* provides detail of how rain gardens could be incorporated into the local road ROW cross-section to provide stormwater retention. Runoff from the roadway area is directed to the rain garden using a curb-cut inlet instead of a traditional catchbasin. An overflow grated drain is provided within the rain garden to discharge overflows to the storm sewer main. In addition, an underflow would be required as previously described.

The rear access lanes located throughout the single family development areas also require an infiltration trench system similar to the local road section described above. The required infiltration trench width, however, is reduced while maintaining the same depth of 0.45m.

An infiltration trench or rain garden covering 5% of the ROW area must be installed in the boulevards and/or curb bump outs. One of the biggest challenges in incorporating LIDs, such as infiltration trenches, is the limitation of installing flat infiltration trenches or rain gardens on steep roadways. From a practicality standpoint, we have assumed infiltration trenches can be located within the road ROW for roadways that have a maximum longitudinal slope of 4%.

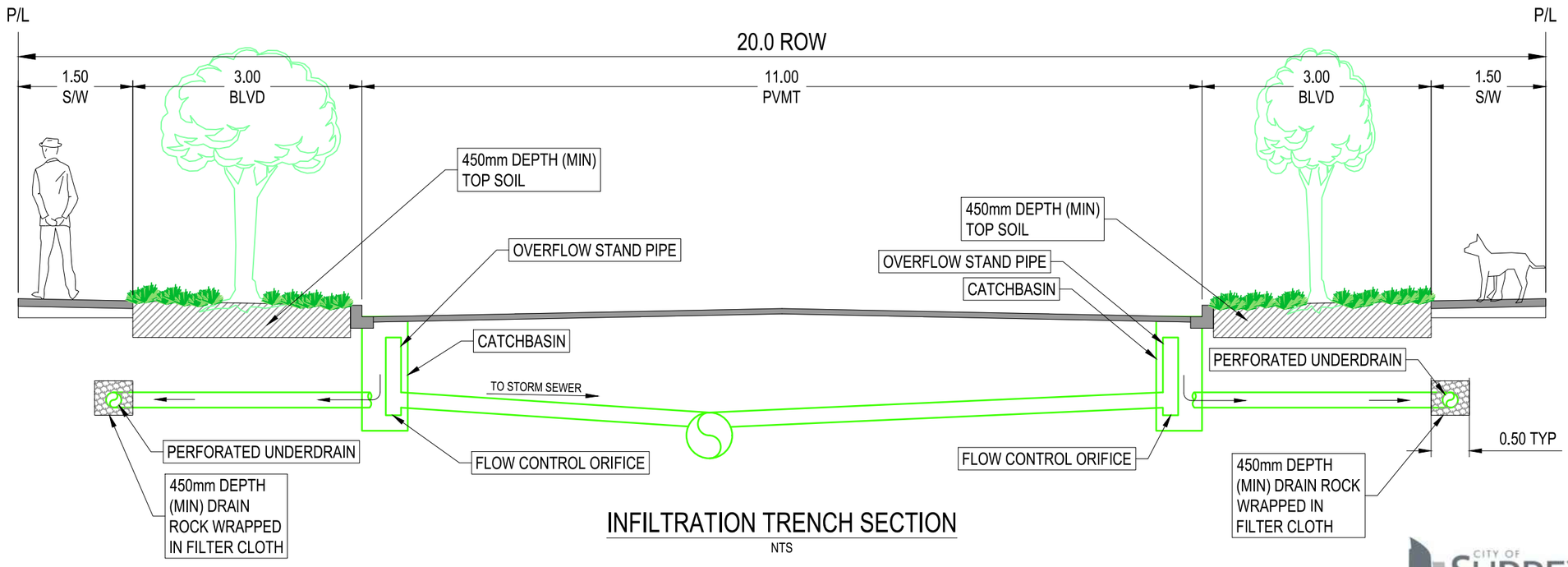
In summary, recommended source control measures for road ROW areas include:

- 450mm layer of enhanced or amended topsoil placed on all pervious areas of the boulevard.
- Sidewalks and pathways graded towards the boulevard.
- Infiltration galleries and/or rain gardens installed within the boulevard and rear lanes that occupies 5% of the road or lane ROW area, assuming a 0.45m deep infiltration trench shall be provided.



BIO SWALE SECTION

NTS



INFILTRATION TRENCH SECTION

NTS

NOTES:

FLOW CONTROL ORIFICE TO BE SIZED TO DRAIN THE DRAIN ROCK RESERVOIR IN 3 - 4 DAYS.

PLAN VIEW AREA OF DRAIN ROCK TO BE 5% MIN. OF TOTAL ROAD ROW AREA

DRAIN ROCK RESERVOIR TO BE 450mm DEEP MIN. AND WRAPPED IN FILTER CLOTH ON ALL SIDES TO PREVENT CLOGGING

UNDERDRAIN TO BE 150mm PERFORATED PVC PIPE WITH INVERT 100mm ABOVE DRAIN ROCK RESERVOIR INVERT

OVERFLOW STAND PIPE OPENING TO BE AT SAME HEIGHT AS TOP OF DRAIN ROCK RESERVOIR

THE DRAIN ROCK RESERVOIR IS TO BE PROTECTED FROM SEDIMENT DURING CONSTRUCTION IN THE ROAD ROW AND ADJACENT PROPERTIES

THE DRAIN ROCK RESERVOIR IS TO BE MIN 300mm FROM THE PROPERTY LINE AND NOT TO CONFLICT WITH THE WATERMAIN, SHALLOW UTILITIES, OR STREET LIGHTING

ABBEY RIDGE
STORMWATER SERVICING

20m ROW LID DETAILS

FIGURE 11

McElhanney

SCALE: NTS AUGUST 2016 2111-03570-0

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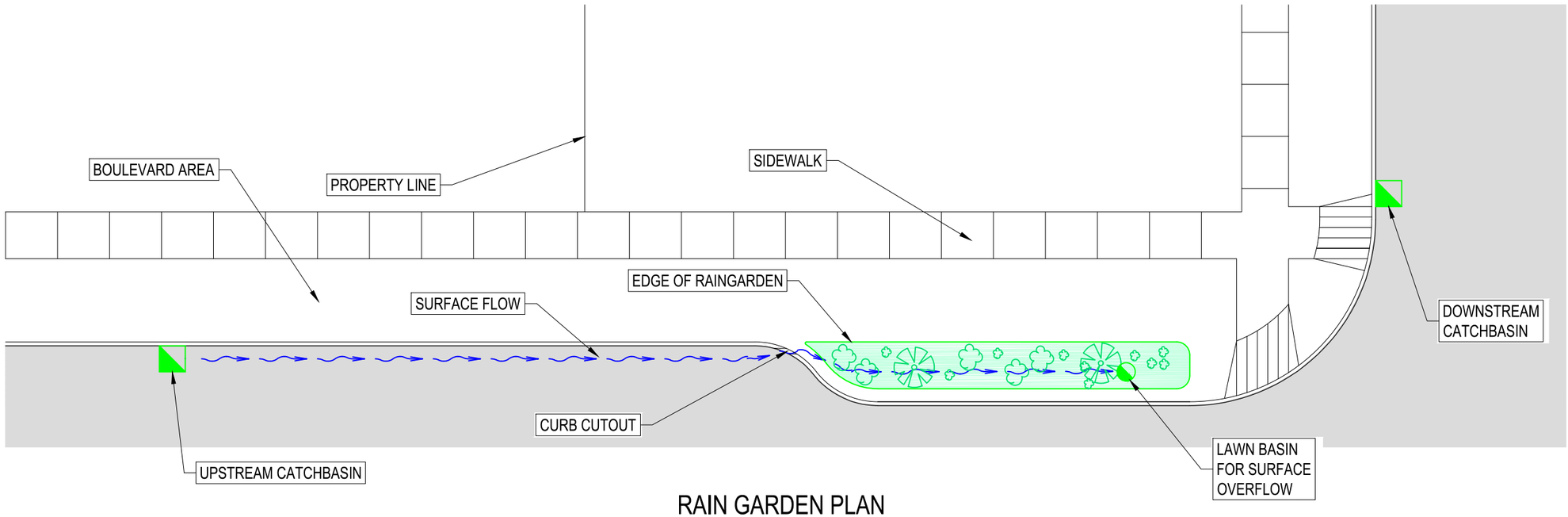
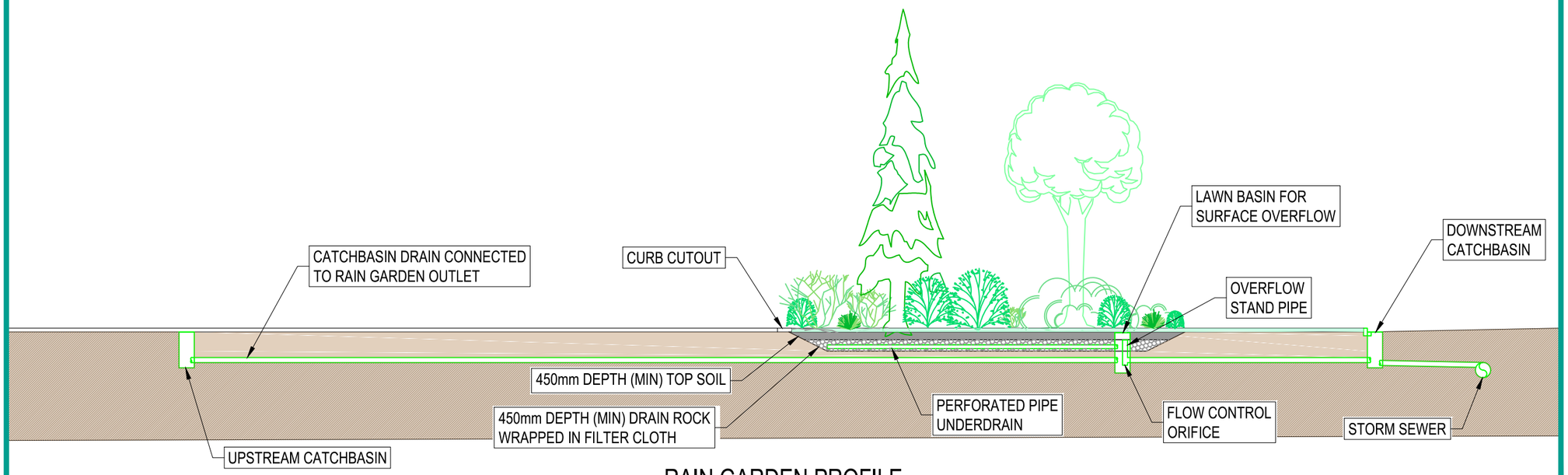


RAIN GARDEN PLAN

NTS



RAIN GARDEN PROFILE

NTS

NOTES:

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ABBEY RIDGE
STORMWATER SERVICING

RAIN GARDEN LID DETAILS

FIGURE 12

McElhanney

SCALE: NTS AUGUST 2016 2111-03570-0

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4.8. Runoff Quality

Runoff from Abbey Ridge will drain into the Fraser River through several smaller watercourses. Stormwater runoff quality is a critical issue for the Fraser River and these small watercourses. As development progresses, the tendency is for increased levels of pollutants to enter the drainage system. Applying LIDs in the Abbey Ridge area will mitigate and bio-remediate some of the pollutant loading into the downstream watercourses. LIDs such as bio-swales, raingardens, and infiltration trenches can provide water quality benefits through settling-out of suspended solids in storage zones of such LIDs and by reducing water volume through absorption, evapotranspiration, and infiltration. Literature and analysis undertaken in past studies have reported similar benefits to LIDs with respect to removal of total suspended solids.

In addition to the recommended source control measures previously described, water quality BMPs that are recommended for use within this neighbourhood include:

- Use of oil / water separators and/or vortex separators for multi-family sites;
- Use of oil-grit traps on catchbasins located with roadways; and
- Regular street sweeping and maintenance to remove sediment at the roadway source.

4.9. Erosion Mitigation

There are several sites in Abbey Ridge where erosion is a potential concern. Braun completed a report detailing each location, which determined that no site required immediate remediation but, that all sites listed should be monitored for signs of bank destabilization and habitat loss.

The primary mitigation measure against the noted erosion occurring throughout the study area is to control the peak discharge rates and total runoff volumes to at or below the current levels at the erosion sites. This should be considered for locations at high risk and/or located within private property with no direct access or statutory ROW.

Table 18 below provides a summary of the erosion sites to be addressed as development proceeds.

Table 18: Erosion Mitigation

Location	Site ID[1]	Existing Conditions	Recommendation during Future Development
182A Street	182A Street Ditch	Ongoing erosion of the left bank of ditch along property west of 182A Street. The short timber wall retaining the landscaped private property is in an undermined state.	This existing ditch would eventually be replaced with a closed drainage system as development occurs within the area. In the interim, rock rip-rap protection can mitigate against any increase in flows from upstream development.
Leoran Brook	20-Pond	Man-made pond discharges onto a fish ladder that flows through a culvert installed in ravine fill. Potential risk to downstream highway and railway crossing in the event of a pond overtopping or damn breach.	Flows to the 99A Avenue outfall to Leoron Brook to be maintained at or below existing conditions. The stability of the existing driveway culvert and fish ladder to be reviewed. A new outfall to be installed immediately downstream of the existing Culvert / Fish Ladder as part of the storm upgrade required at 99A Avenue.
Lyncean Creek East	19-2	Over-steepened rip-rap slope at west side of 179 Street culvert crossing (1H: 1.5V). Erosion below the Lock-Block wall causing undermining.	Repairs should be made to the culvert inlet and outlet prior to any increase in flows at this location from upstream development.

4.10. Right of Way Acquisition

While some stretches of Lyncean Creek West, Lyncean Creek East and Leoran Brook flow through lots owned by the City of Surrey, other stretches flow through private property. This includes some sites where the erosion and hazard assessment (*Section 2.6*) identified some locations as medium and high risk, such as sites 19-14 and 19-2 in Lyncean Creek East (POI 5 and 6), and site 20-pond in Leoran Brook (POI 7). Therefore, the acquisition of a Statutory Right-of-Way (SRWs) for these stretches is recommended. *Table 19* presents a list of the recommended SRWs acquisitions. Their location is shown on *Figure 13*. The recommended SRWs are located in areas identified as *Future Natural Areas* in the Abbey Ridge-Local Area Plan.

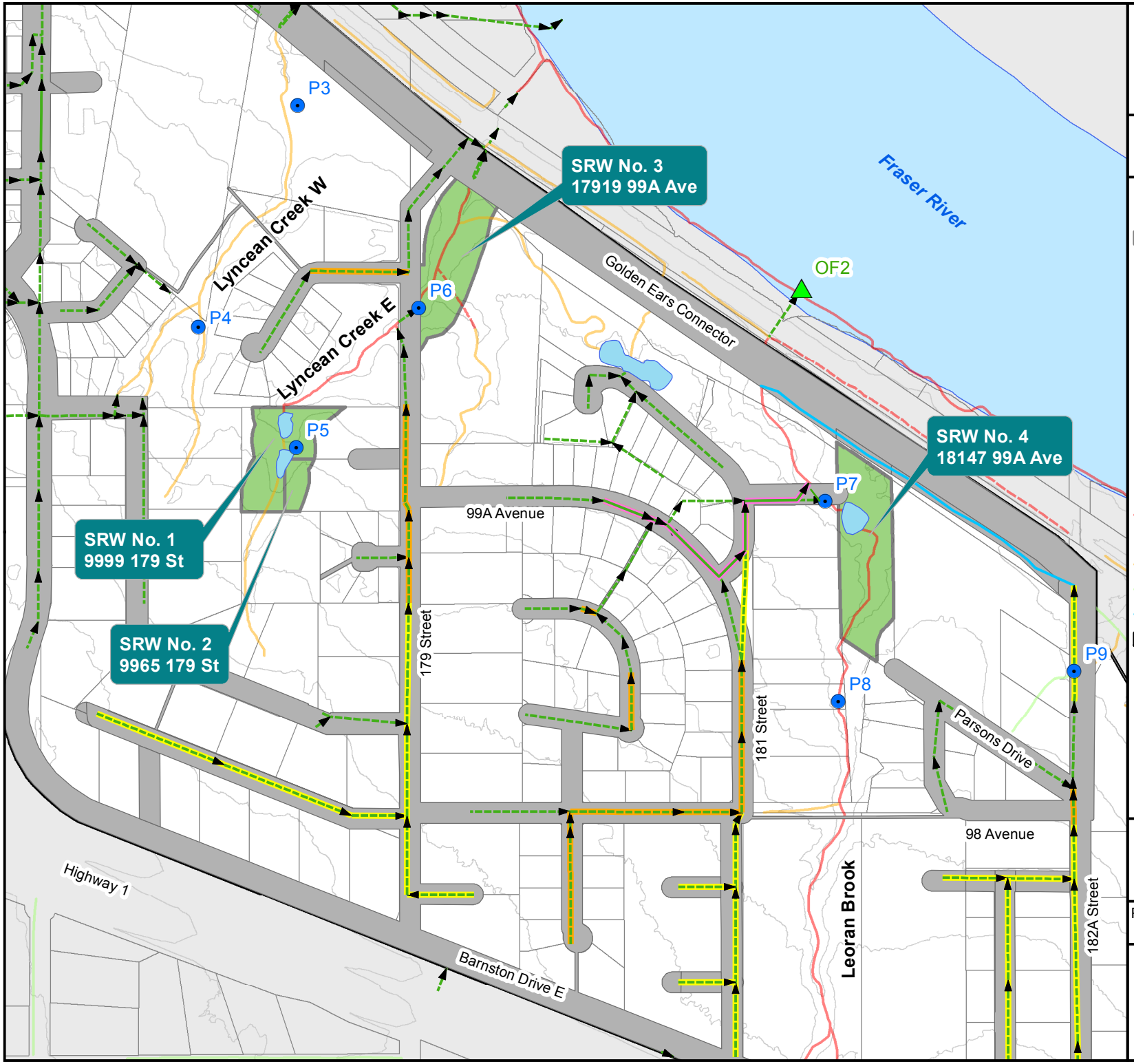
Table 19: Statutory Right-of-Way Acquisition

No.	PID	Address	Location	Area (ha)
1	002-772-400	9965 179 St	Lyncean Creek E	0.11
2	002-772-388	9999 179 St	Lyncean Creek E	0.52
3	011-931-001	17919 99A Ave	Lyncean Creek E	0.75
4	002-519-968	18147 99A Ave	Leoran Brook	0.90

It should be noted that of the four SRW's recommended above, SRW #3 is only one required prior to any development due to the increase in flows and repairs the erosion at the culvert outlet. The other three SRWs are recommendations for the City to facilitate on-going monitoring, maintenance of the existing creek and wet ponds/dams within them.

4.11. Phasing & Implementation

All future drainage infrastructure required to support development of the Abbey Ridge LAP will consist of new or replacement of existing storm sewers, in addition to the Road ROW LIDs at select locations. As build-out of the area proceeds, each development will need to extend the existing drainage system to their development that follows the proposed storm sewer and upgrades recommended by this study. No formal phasing of development will be required to meet the stormwater objectives and upgrade strategy. However, future development will need to be cognizant of the active erosion sites located at 182A Street and 179 Street and ensure appropriate mitigation is applied prior to increasing any flows at these locations.



Abbey Ridge
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Legend

- SRWs
- Points of Interest
- Outfalls
- Upsized Trunk Sewers
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- Existing Local Sewers
- Existing Trunk Sewers
- New Local Sewers
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Watercourse Classification

- Class A
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- Unknown
- Abbey Ridge LAP
- 5m Contours

McElhanney

0 30 60 120 180 (m)

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Project No.	Date
2111-03570-00	December 2016

Recommended
Statutory Right-of-ways

Figure 13

5. Costs & Financing

5.1. Projected Storm DCC Revenue

As the City of Surrey will calculate revenue from DCCs, detailed calculations are excluded from this report.

5.2. Projected Storm DCC Expenditures

Storm DCC expenditures benefitting Abbey Ridge are limited to 106m of 600mm and 123m of 750mm diameter trunk sewer and outfall works located within the Port Kells sub-catchment.

Construction cost estimates include a 15% allowance for engineering and contract administration, and a 30% allowance for contingency. All construction costs are based on current (2016) construction cost data. Construction costs do not include applicable taxes such as GST. *Table 20* presents the Storm DCC Eligible Works for the Abbey Ridge.

Table 20: DCC Eligible Storm Works

Item	Unit	Unit Price	Quantity	Total
600mm Storm	m	1,500.00	106	$ 159,000.00
750mm Storm	m	1,800.00	123	$ 221,400.00
Outfall	LS	75,000.00	1	$ 75,000.00
Total				**$ 455,400.00**
Engineering (12%)				$ 54.648.00
Contingency (15%)				$ 68,310.00
Total				**$ 578,358.00**

5.3. Financial Summary

It should be noted that this financial summary is subject to fluctuations in market conditions related to the rate of development and capital construction costs, ultimate development form and densities, and other variables which may alter projected DCC revenues and/or expenditures. These projections may also change with the adoption of new DCC rates.

Based on the total costs of the proposed storm works, we anticipate that revenues generated from the storm DCC will be adequate to fund the DCC eligible storm works for the area.

6. References

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Appendix A – Geotechnical Report

Foundations, Excavation & Shoring Specialists

April 15, 2016
Our File: 16-6720

Via email: nsandhu@mcelhanney.com

McElhanney Consulting Services Ltd.
2300 – 13450 102nd Avenue
Surrey, BC V3T 5X3

Attn: Mr. Nav Sandhu, P.Eng.

Re: Preliminary Geotechnical Assessment
Abbey Ridge Local Area Servicing, Surrey, BC

Braun Geotechnical
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Foundations

Excavation & Shoring

Slope Stability

Natural Hazards

Pavement Design and Management

Reinforced Soil Walls and Slopes

1.0 INTRODUCTION & PROPOSED PROJECT

As requested, Braun Geotechnical Ltd. has carried out a preliminary geotechnical assessment at an overview level of effort for the above-referenced study site area. The geotechnical work was completed in general accordance with the Braun Geotechnical Ltd. proposal Ref. P16-4883 dated February 9, 2016

The scope of work included:

- Compilation, review, and update of geological, geotechnical and slope hazard mapping information that is available from published, in-house, and Surrey sources. The desk study work included review of Google Earth imagery and historical air photos dating back to the 1940's.
- Field site reconnaissance at select slope areas of potential geotechnical concern identified during the desk study phase.
- Provision of a geotechnical report with preliminary discussion comments and recommendations pertaining to geotechnical related site conditions including highlight of slope areas that may warrant detailed geotechnical assessment and/or avoidance.

The geotechnical assessment is required in support of Local Area Servicing (LAS) for future densification in the Abbey Ridge area of north Surrey. The subject area is bordered by 172nd Street to the west, Highway 1 to the south, Golden Ears Way to the east, and 104 Ave and Daly Road / Golden Ears Connector to the north.

A geotechnical erosion and hazard assessment of the Surrey North Bluff was carried out at an overview level of effort by Thurber Engineering Ltd. (Thurber) and their findings presented in a report dated February 22, 2000. Tetra Tech EBA Inc. (EBA) produced an overview report dated December 24, 2014 which covers all ravines in the City of Surrey. The Abbey Ridge area constitutes a small area entirely within the limits of the previous studies carried out by Thurber and EBA. As such, the purpose of the current assessment was to review the findings of the previous assessments for the Abbey Ridge area, and to provide an updated assessment which considers any significant changes that may have occurred and provide recommendations for additional assessment if deemed necessary.

The previous studies included identification of erosion areas within the creeks by Stantec followed by review of the identified areas by Thurber, and subsequent review of a much larger area of Surrey by EBA. The reviews took into consideration erosion and soil slope instability, and provided priorities for geotechnical repair or site monitoring. The areas of concern were given a high, medium or low priority rating. For consistency, Braun adopted similar qualitative assignments of geotechnical areas of potential concern presented in the Thurber and EBA studies.

It is anticipated that setback requirements for any developments adjacent to the ravines would be carried out by a qualified engineer.

2.0 HAZARD & RISK ASSESSMENT

A hazard is a phenomenon with the potential to cause harm; it is usually represented by a magnitude and recurrence interval (see Table 1). The product of the factors Hazard and Consequence equals Risk. Consequence itself is a product of factors, including 1) whether an event will reach a site, 2) whether elements at risk will be present when the site is affected by the hazard, 3) how vulnerable the elements at risk are to the hazard affecting the site, and 4) the value of the elements at risk, or the number of persons exposed.

Table 1. Qualitative Hazard Frequency Categories.

Qualitative Frequency	Annual Return Frequency	Comments
Very high	>1/20	Hazard is well within the lifetime of a person or typical structure. Clear fresh signs of hazard are present.
High	1/100 to 1/20	Hazard could happen within the lifetime of a person or structure. Events are identifiable from deposits and vegetation, but may not appear fresh.
Moderate	1/500 to 1/100	Hazard within a given lifetime is possible, but not likely. Signs of previous events may not be easily noted.
Low	1/2500 to 1/500	The hazard is of uncertain significance.
Very low	<1/2500	The occurrence of the hazard is remote.

Source: BC MoE (1999)

In Canada and BC there is no legislated guidance for risk tolerance to landslides and associated phenomenon, and the term “safe” has not been legally defined. In considering risk tolerance, an important concept is that risk of loss of life from natural hazards should not add substantially to that from usual life factors combined (i.e. driving, health, recreation, etc.). This consideration may also be extended to risk of property damage or loss.

The Association of Professional Engineers and Geoscientists of BC (APEGBC) document, “Legislated Landslide Assessments for Proposed Residential Development in BC, May, 2010” presented and supported hazard acceptability criteria adopted by Fraser Valley Regional District for hazard risk management (Cave 1993). The criteria are presented as a risk matrix with different development proposals versus different hazard levels for a suite of hazard types.

A hazard acceptability risk matrix considered relevant to the study site area is presented below in Table 2.

Table 2. Hazard acceptability thresholds for various levels of development considering select geologic hazards. See Cave (1993) for full description.

Stream Erosion/ Flooding	>1/10	1/10-1/100	1/100-1/200	1/200-1/500	<1/500
New Building	5	5	4	2	1
Subdivision (densification)	5	5	5	4	1
Sediment flood	**>1/50**	**1/50-1/200**	**1/200-1/500**	**1/500-1/10K**	**<1/10K**
New Building	4	4	3	1	1
Subdivision (densification)	5	5	4	2	1
Property-Scale Landslide	**>1/10**	**1/10-1/100**	**1/100-1/200**	**1/200-1/500**	**<1/500**
New Building	5	5	4	2	1
Subdivision (densification)	5	5	5	4	1

1 - Approval without conditions relating to hazards.
2 – Approval without siting conditions or protective works conditions, but with a registered covenant against title.
3 – Approval, but with siting requirements to avoid the hazard, or with requirements for protective works to mitigate the hazard.
4 – Approval as (3) above, but with a registered covenant against title as well as siting conditions, protective works, or both
5 – Not approvable.

3.0 STUDY AREA DESCRIPTION

Based on surficial geology mapping information from the Canadian Geological Survey, the Abbey Ridge area is underlain by Capilano Sediments and Pre-Vashon Deposits. The Capilano Sediments include marine and glaciomarine stony (including till-like) deposits to stoneless silt loam to clay loam with minor sand and silt normally less than 3m thick but up to 30 to 60m thick, containing marine shells. The Pre-Vashon Deposits include Quadra fluvial channel fill and floodplain deposits, cross-bedded sand containing minor silt and gravel lenses and interbeds, or Quadra marine interbedded fine sand to clayey silt believed to be off shore equivalent to the Quadra fluvial channel fill.

The creeks in the Abbey Ridge area generally flow from the Surrey uplands north towards the Fraser River. The creeks have eroded the above materials to form ravines in many areas.

Mean annual precipitation at Surrey is 1500mm with less than 2% falling as snow. Prolonged, sometimes intense rainfall occurs in fall and winter. Late summer (Aug/Sep) storms may also deliver intense precipitation.

4.0 CLIMATE CHANGE

Climate change is expected to result in an increase in winter temperatures, precipitation intensity and strong storm frequencies (Madsen and Figdor 2007, and others).

A summary of research opinions regarding climate impacts on precipitation is provided below in Table 3, (Sutton, 2011).

Table 3. Summary of climate change impacts on precipitation (Sutton, 2011)

Precipitation Condition	Expected Change Condition	Authors
Short Term (Intense)	-6 percent increase by 2100 -increase in 1990 data compared to pre-1977 data -small increase +/- annual maximums Sept, Oct, Nov, 2100	-Jakob & Lambert, (2009) -Jakob et al, (2003) -Salathe et al, (2010) -Mailhout et al, (2010)
Long Term (Annual)	-10% increase by 2070 to 2100 -1% to 2% annual increase by 2100 -1% to 5% increase by ~2050 -2% to 11% increase by ~2050 -11% to 12% increase by ~2040 & 0% to 21% increase by ~2080	-Jakob & Lambert, (2009) -Mote et al, (2010) -Murdock et al, (2007) -PCIC, (2010) -Elsner et al, (2010)
Seasonal Shift	-winter increase/ summer decrease -winter increase/ summer decrease -winter increase (4% to 14%)/ summer decrease (14% to 33%) -increase in autumn -winter increase or decrease (-2% to 16%)/ summer increase or decrease (-8% to 6%) -increase/ decrease disagreement between models	-Elsner et al, (2010) -Mote et al, (2010) -Murdock et al, (2007) -Salathe et al, (2008) -PCIC, (2010) -Salathe et al (2010)
Climate Oscillations (PDO/ ENSO)[1]	-increase associated with high precipitation -increase in intensity with positive PDO -increase in PDO winter daily maximums -changes in stochasticity complicates predictions	-Jakob et al, (2003) -Murdck et al (2007) -Zhang et al, (2010) -Jakob & Lambert, (2009)

1. Pacific Decadal Oscillations & El-Nino Southern Oscillations

Climate change impact on precipitation is expected to result in a change in rate and magnitude of natural hazards, including floods (Whitfield et al 2003a, b) and landslides (Jakob and Lambert 2009). It is beyond the scope of this report to evaluate the magnitude of the impact of these changed conditions.

However, in view of uncertainty in current understanding of climate change impacts, caution is warranted in application of current precipitation simulation modelling for use in stormwater management designs, including effectiveness of overflow protection measures.

5.0 REFERENCE MATERIAL

Background reports provided in the Surrey RFP documents included the above noted overview reports by Thurber and EBA. These documents, summarized in the following section, were reviewed and those hazards that were identified were noted along with frequency of occurrence and other pertinent details.

Airphotos for the study area were obtained from the Geographical Information Centre at UBC. The airphotos were used to follow up specific events identified in the background review and the field portions of the work. Airphotos were reviewed for 1940, 1949, 1954, 1963, 1969, 1974, 1979, 1986, 1991, 1997, 2002, and 2009.

6.0 UPDATES TO PREVIOUS FINDINGS

This section provides a summary of the findings of the previous studies by Thurber (2000) and EBA (2014), updates previous findings, and makes recommendations for additional work, where required, based on review of recent air photos and on site reconnaissance findings.

Site ID numbers used by EBA are included where EBA completed reviews, and shown on the attached plan. A majority of descriptions of previous work are from the Thurber report. Select photos of the subject areas are attached in Appendix A.

6.1 182A Street Ditch (Thurber ID 182A Street Ditch/ EBA no ID, did not assess)

Previous observations, comments and recommendations by others included:

- Erosion of a ditch channel adjacent to an anchor fence along private property west of 182A Street was observed. A low timber retaining wall was observed to be undermined and slightly damaged. It was considered that additional erosion could impact the private property.
- Exposed natural soils were observed to comprise stiff, fissured pale grey to brown, moist clayey silt with a trace of sand.
- Extension of a driveway culvert northward to limit the localized ditch erosion, or provision of rip-rap armour to the ditch was recommended. This work was given a high priority.

The following observations were made during the recent site reconnaissance:

- The condition of the ditch was similar to that described previously. Soil is exposed on the side slopes of the ditch below the relatively short timber wall on the private property located adjacent and to the west of the ditch. The base of the timber wall is located well above the base of the ditch, and the timber wall is currently in an undermined condition.
- The previous recommendation to extend the culvert to the north was not carried out.
- Further erosion could impact the landscaped areas on the private property, and possibly underground utilities that may be present.
- Many of the landscape ties used to construct the left bank retaining walls appear to be in an advanced state of decay.

Current Hazard Condition

- Ongoing erosion of the left bank of the ditch and advanced decay of the wood retaining wall timbers mean that potential for collapse of portions of the left bank are considered Very High.
- Loss of public and private property along the left bank of the channel at a property scale.
- Channel avulsion is considered likely for left bank collapse during the wet weather season when average ditch flows are near maximum annual levels or during an extended period of heavy rainfall. Avulsion flows could inundate downgradient private and public property.

Recommendations

- Previous recommendations were provided that included extension of an existing driveway culvert northward to limit the localized ditch erosion. This is considered a low cost solution to the hazard and is also recommended by Braun.

6.2 Leoran Brook (Thurber ID Leoran Creek/ EBA ID Drainage # 20)

Previous observations, comments and recommendations by others included:

- In the upper section of Leoran Brook, minor lateral scour at the toe of the slope was observed by Thurber between Barnston Drive and a sediment filled pond just north of a high driveway fill approximately aligned with 99 Ave. Geotechnical hazards noted in the upper portion of Leoran Brook were considered to be small scale or low consequence. Erosion was reviewed by EBA within the left bank area southeast of 9820 181 Street, which they considered to be of medium risk.
- A pond, low earth dam with a culvert outlet, an old concrete fish ladder, and a small pool just upstream of the culvert inlet through deep ravine fill was identified within the mid-section of the creek alignment by Thurber. This area was observed to be landscaped and open, with only small scale erosion concerns. Periodic clean out of the middle section pond was recommended if the private land owner wished to continue to operate the structures.
- The lower section of the creek was forested, with a newer concrete fish ladder below the culvert outlet. Leoran Brook was noted to have eroded its banks at several locations and minor slope stability problems associated with the erosion were observed. A high soil face just north of the fill, possibly excavated with heavy equipment was observed. Downstream, erosion of the base of the ravine slopes and portions of the creek terraces was observed. The lower forested portion of the creek was considered to have the highest potential for erosion, but this area of the creek was not considered to pose a significant geotechnical risk based on the development density at that time (2000).
- Native soils along the ravine slopes were noted to comprise erosion-resistant stiff, fissured, pale grey to brown, moist clayey silt with a trace to some sand and gravel.

The following observations were made during the recent site reconnaissance:

Upper Section

- A new culvert has been installed under Highway 1, and some re-alignment of the creek channel to the north of the culvert has been completed. Beyond the area of realignment, minor erosion of the right and left banks was observed. The ravine slopes and crest areas are generally heavily treed.
- Additional erosion of the left bank area southeast of 9820 181 Street since the time of the EBA review was not observed.

Current Hazard Condition

- Ongoing erosion could impact trees.
- Surface water flow could accelerate erosion of the left bank area southeast of 9820 181 Street.

Recommendations

- Obvious visible evidence of accelerated left or right bank erosion was not identified. However, the area of the downstream channel re-aligned during the recent Hwy 1 full-width culvert crossing should be reviewed periodically for potential changes in erosion rates.
- The area of erosion southeast of 9820 181 Street should be reviewed periodically for changing conditions.

Middle Section

- Left bank erosion/ shallow sloughing, and right bank erosion were observed in the middle section of the creek. An amateur (non-engineered) bridge constructed using steel beams with 2x6 timber decking crossed the channel at a low bank location. The bridge has low clearance (maximum 0.4m clearance at the channel invert), and woody debris is accumulating against the steel beams.
- A large number of trees have toppled into the creek downstream of the bridge, and stream sediments are accumulating in the woody debris.
- The middle section opens up into a pond area with a landscaped perimeter. A high clearance, (likely non-engineered) bridge is present just upstream of the pond. The pond discharges onto a fish ladder that flows through a culvert installed in ravine fill for a driveway crossing.

Current Hazard Condition

- The low clearance bridge and downstream accumulation of woody debris is expected to continue to accumulate debris and may shift the channel. In the event that a channel dam develops, sudden release of water and debris may overload or clog the pond structures located immediately downstream.
- The stability of the ravine fill for the driveway crossing below the pond structure is unknown.

Recommendations

- The creek banks should be reviewed periodically for accelerated erosion. The non-engineered bridge structures should be removed from the channel or replaced.
- Accumulated woody debris should be removed from within the creek channel.
- The stability of the fish ladder and associated ravine fill should be reviewed. Due to the height of the ravine fill the potential head that could be developed behind fill in the event the culvert through the fill becomes clogged would be significant, and in a breach event, the accelerated erosion and associated de-stabilization of existing ravine slopes in a breach event could occur. Current receptors are limited due to low density development below the ravine fill. However, this consequence condition can be expected to change with development densification.
- Geotechnical exploration and stability assessment of the pond structures should be carried out. The findings of the geotechnical study should be used to develop an operation and inspection plan that meets the provincial requirements for management of small dams.

Lower Section

- Below the fish ladder and dam, ravine slopes become setback and Lorean Brook meanders in a wide channel area. The creek flows under a recently constructed bridge for the Golden Ears Connector.

Recommendations

- The lower section of the creek should be reviewed periodically for potential changes in erosion rates.

6.3 Lyncean Creek East (Thurber ID "Unnamed"/ EBA ID Drainage #19)

Previous observations, comments and recommendations by others included:

- Significant erosion within this creek was not observed.
- A pond behind a 7m high dam with a vertical downstream face was located west of 9999 179 Street. It was observed that each face of the dam may have been constructed using driven piles with soil placed between the row of piles. A narrow roadway crossed the dam crest, and another pond was observed downstream of the dam.
- Settlement of the dam crest was evident. The dam was not considered to have been engineered, and the safety of the public and property was a concern should the dam fail suddenly.
- Exposed soil was not observed at this location. However, soils exposed at a nearby construction site indicated that clayey silt and sand is present at depth.
- The risks of erosion associated with a sudden failure of the dam were considered to be severe. It was recommended that the property owner be requested to have a professional engineer complete a dam safety review. This work was given a high priority.

The following observations were made during the recent site reconnaissance:

- The dam behind the property at 9999 179 Street was still present, creating a pond to the south. The dam is approximately 7m high, and a second dam is present to the north creating a second pond. Both dams appear to be non-engineered structures.
- Rip rap placed on the west side of 179 Street where the creek flows under the road appears to be oversteepened as it has a slope of approximately 1H:1.5V (Horizontal to Vertical).
- Portions of a concrete block wall supporting the east side the 179 Street creek crossing are undermined.

Current Hazard Condition

- Stability of the existing dam structures and fill embankments is unknown. A dam breach could be expected to impact residential areas and municipal infrastructure downstream due to flooding/inundation, and accelerating erosion at the toe of ravine slopes and promoting instability.
- Ongoing erosion below the rip rap or erosion below the concrete block wall adjacent to 179 Street could impact the roadway over time.

Recommendations

- Dam breach or embankment failure can be expected to impact downstream residential subdivision development or municipal infrastructure. Geotechnical exploration and assessment of the existing ravine fills / dams should be undertaken to review stability of the embankments. The findings of the geotechnical study should be used to develop an operation and inspection plan that meets the provincial requirements for management of small dams. This work should be given a high priority.
- The condition of the rip-rap should be reviewed periodically, and repairs completed if required.

- Erosion below the lock blocks should be reviewed and repaired as needed. Additional fill and/or slope reconfiguration should be completed to remediate the undermined portions of the wall.

6.4 Lyncean Creek West (Thurber ID "Unnamed"/ EBA ID Drainage #18)

Previous observations, comments and recommendations by others included:

- Minor creek bank erosion just above a small pond created by a low earth dam was observed. A fish ladder was not present, and the overflow CMP culvert appeared to be too steep for fish to traverse. Some soil erosion around the culvert was observed. North of the outlet, the creek was observed to flow to a ditch on the south side of Daly Road.
- Soils exposures were not observed, but it was considered that clayey silt and sand are present at depth.
- Several dams that created ponds behind them were observed west of the creek. However, none discharged into the creek. Breaching of the dams was not considered to pose a significant risk at that time. Removal of the dams was recommended if they did not have environment value. This work was given a low priority.
- EBA noted a culvert with an undermined concrete headwall immediately south of the intersection 100 Ave and Lyncean Drive.
- The creek was noted to flow under a tree located southeast of 17780 100A Avenue.

The following observations were made during the recent site reconnaissance:

- The confluence of two creek tributaries to Lyncean Creek West is located at the approximate alignment of 100A Avenue.
- The west tributary extends south to approximately the intersection of Lyncean Drive and 100 Avenue to a headwall which discharges water into the creek. Dumping of residential garden waste and relatively high, steep slopes were observed in this area. Further, the catch basin at the corner of the adjacent roadway was observed to be plugged with leaves and debris. Surface water appears to have been flowing past the catch basin, north and down the ravine bank, and erosion of the bank above the culvert headwall was observed. The water likely contributed to undermining of the culvert headwall.
- The east tributary extends approximately 125m further south than the west tributary. The ground surface near the creek was observed to be wet and soft, and seepage from the side slopes was observed at many locations. A culverted creek crossing was present just south of the approximate alignment of 100 Avenue. The thickness of fill was approximately 4.5m, and 300mm diameter culverts had been installed near the base of the fill and 3m above the base. An open top concrete sump was installed downstream of the crossing, and discharged to the creek through a PVC pipe extending from the side of the sump down to the base of the creek. A considerable volume of water was discharging out of the slope adjacent to the sump.
- A tree located southeast of 17780 100A Avenue was observed to be in similar condition as described previously, with water flowing below it. The tree is leaning.
- Further downstream, the creek flows through the industrial property located at 10095 179 Street. Within the property, the banks of the creek were observed to be oversteepened. Horizontal steel beams restrained with driven steel piles had been installed to stabilize the

bank. The creek flows into a culvert within the private property and under Daly Road to the north.

Current Hazard Condition

- Uncontrolled disposal of residential garden waste is accumulating substantial debris at the crest of ravine slopes. If allowed to continue unabated, this material can be expected to fail at some point in the future. Previous experience with failures of slope crest debris noted that underlying natural soils may be scoured and accumulated in the slide mass as the material slides downslope thus reducing stability to a condition less stable than pre-development natural slopes condition.
- A catch basin located near the crest of slope at Lyncean Drive and 100 Avenue was observed to be fully clogged. Visible evidence of uncontrolled surface run-off and slope erosion was noted below the catch basin location
- If the culverted crossing just south of the 100 Avenue alignment becomes plugged, potential exists for development of conditions that may promote a dam breach event.
- The leaning tree below which the creek flows southeast of 17780 100A Avenue could impact adjacent properties if it topples.

Recommendations

- Residents should be informed of potential damage that may occur if uncontrolled dumping is allowed to continue. Appropriate signage should be installed.
- The catch basin at the corner of Lyncean Drive and 100 Avenue should be cleared regularly. Erosion of the bank and the culvert headwall to the north should be repaired.
- Details of the culvert at the filled creek crossing just south of the 100 Avenue alignment should be reviewed. Replacement of the culvert should be carried out if the design is inadequate. If deemed adequate, regular maintenance and inspection should be carried out to reduce potential for development of fully plugged condition.
- Details of the sump and water leakage adjacent to the sump should be reviewed.
- The tree located southeast of 17780 100A Avenue should be reviewed by an arborist, and removed if deemed unstable.
- The oversteepened slopes within the private property at 10095 179 Street should be assessed for long term stability under static and seismic loading conditions.

6.5 Centre Creek Tributary Creek, Along 172 St. Alignment, Between 103 and 104 Ave

The following observations were made during the recent site reconnaissance:

- A short reach of a Centre Creek tributary is located within the limits of the study area between 103 and 104 Avenue along the alignment of 172 Street. The side slopes around the creek are relatively steep (~1H:1V) at some locations. Minor to moderate bank erosion was evident. A right bank slump with a volume of approximately 15 cubic metres was observed, and was estimated to be approximately 5 to 10 years old. Downstream from the slump, there were two trees that had toppled at different times to indicate active bank erosion.
- The creek flows north through a culvert under 104 Avenue towards Centre Creek.

Current Hazard Condition

- The erosion and slump are relatively minor, and are not considered to pose a risk to adjacent properties at this time.

Recommendations

- The ravine should be reviewed periodically for changing conditions.
- Review of this tributary channel beyond the study limits noted conditions to indicate that accelerated erosion of the channel and ravine slopes may be occurring. This suggests that development-related changes to the stream basin have resulted in more frequent flooding. A detailed stream channel assessment of Centre Creek is recommended

7.0 ADDITIONAL COMMENTS AND RECOMMENDATIONS

The current preliminary study was completed to obtain a reconnaissance level review of the subject creeks, and update previous assessments. Additional detailed geotechnical assessment is recommended to assess stability of ravine slopes. The detailed assessment would be carried out with a view to focus intrusive exploration efforts at selected locations in order to determine performance expectations of the slopes under both static and seismic conditions.

Detailed stream channel assessments of the selected creeks are recommended to assess the baseline condition of each channel for use in assessing potential impacts of additional development that is expected to occur.

8.0 CLOSURE

This report is prepared for the exclusive use of McElhanney Consulting Services and their designated representatives and may not be used by other parties without the written permission of Braun Geotechnical Ltd. The City of Surrey may also rely upon the contents of this report.

The use of this geotechnical report is subject to the conditions on the attached Report Interpretation and Limitations sheet. The reader's attention is drawn specifically to those conditions, as it is considered essential that they be followed for proper use and interpretation of this report.

We hope the above meets with your requirements. Should any questions arise, please do not hesitate to contact the undersigned.

Yours truly,

Braun Geotechnical Ltd.

Original Signed by Authors

James Wetherill, P.Eng.
Geotechnical Engineer

Braun Geotechnical Ltd

Original Signed by Authors

Sonny Singha, P.Eng.
Geotechnical Engineer

Encl: Report Interpretation and Limitations
Site Plan
Appendix A – Annotated Site Photographs

REPORT INTERPRETATION AND LIMITATIONS

1. STANDARD OF CARE

Braun Geotechnical Ltd. (Braun) has prepared this report in a manner consistent with generally accepted engineering consulting practices in this area, subject to the time and physical constraints applicable. No other warranty, expressed or implied, is made.

2. COMPLETENESS OF THIS REPORT

This Report represents a summary of paper, electronic and other documents, records, data and files and is not intended to stand alone without reference to the instructions given to Braun by the Client, communications between Braun and the Client, and/or to any other reports, writings, proposals or documents prepared by Braun for the Client relating to the specific site described herein.

This report is intended to be used and quoted in its entirety. Any references to this report must include the whole of the report and any appendices or supporting material. Braun cannot be responsible for use by any party of portions of this report without reference to the entire report.

3. BASIS OF THIS REPORT

This report has been prepared for the specific site, development, design objective, and purpose described to Braun by the Client or the Client's Representatives or Consultants. The applicability and reliability of any of the factual data, findings, recommendations or opinions expressed in this document pertain to a specific project at described in this report and are not applicable to any other project or site, and are valid only to the extent that there has been no material alteration to or variation from any of the descriptions provided to Braun. Braun cannot be responsible for use of this report, or portions thereof, unless we were specifically requested by the Client to review and revise the Report in light of any alterations or variations to the project description provided by the Client.

If the project does not commence within 18 months of the report date, the report may become invalid and further review may be required.

The recommendations of this report should only be used for design. The extent of exploration including number of test pits or test holes necessary to thoroughly investigate the site for conditions that may affect construction costs will generally be greater than that required for design purposes. Contractors should rely upon their own explorations and interpretation of the factual data provided for costing purposes, equipment requirements, construction techniques, or to establish project schedule.

The information provided in this report is based on limited exploration, for a specific project scope. Braun cannot accept responsibility for independent conclusions, interpretations, interpolations or decisions by the Client or others based on information contained in this Report. This restriction of liability includes decisions made to purchase or sell land.

4. USE OF THIS REPORT

The contents of this report, including plans, data, drawings and all other documents including electronic and hard copies remain the copyright property of Braun Geotechnical Ltd. However, we will consider any reasonable request by the Client to approve the use of this report by other parties as "Approved Users." With regard to the duplication and distribution of this Report or its contents, we authorize only the Client and Approved Users to make copies of the Report only in such quantities as are reasonably necessary for the use of this Report by those parties. The Client and "Approved Users" may not give, lend, sell or otherwise make this Report or any portion thereof available to any other party without express written permission from Braun. Any use which a third party makes of this Report – in its entirety or portions thereof – is the sole responsibility of such third parties. BRAUN GEOTECHNICAL LTD. ACCEPTS NO RESPONSIBILITY FOR DAMAGES SUFFERED BY ANY PARTY RESULTING FROM THE UNAUTHORIZED USE OF THIS REPORT.

Electronic media is susceptible to unauthorized modification or unintended alteration, and the Client should not rely on electronic versions of reports or other documents. All documents should be obtained directly from Braun.

5. INTERPRETATION OF THIS REPORT

Classification and identification of soils and rock and other geological units, including groundwater conditions have been based on exploration(s) performed in accordance with the standards set out in Paragraph 1. These tasks are judgemental in nature; despite comprehensive sampling and testing programs properly performed by experienced personnel with the appropriate equipment, some conditions may elude detection. As such, all explorations involve an inherent risk that some conditions will not be detected.

Further, all documents or records summarizing such exploration will be based on assumptions of what exists between the actual points sampled at the time of the site exploration. Actual conditions may vary

significantly between the points investigated and all persons making use of such documents or records should be aware of and accept this risk.
The Client and "Approved Users" accept that subsurface conditions may change with time and this report only represents the soil conditions encountered at the time of exploration and/or review. Soil and ground water conditions may change due to construction activity on the site or on adjacent sites, and also from other causes, including climactic conditions.
The exploration and review provided in this report were for geotechnical purposes only. Environmental aspects of soil and groundwater have not been included in the exploration or review, or addressed in any other way.
The exploration and Report is based on information provided by the Client or the Client's Consultants, and conditions observed at the time of our site reconnaissance or exploration. Braun has relied in good faith upon all information provided. Accordingly, Braun cannot accept responsibility for inaccuracies, misstatements, omissions, or deficiencies in this Report resulting from misstatements, omissions, misrepresentations or fraudulent acts of persons or sources providing this information.

6. DESIGN AND CONSTRUCTION REVIEW

This report assumes that Braun will be retained to work and coordinate design and construction with other Design Professionals and the Contractor. Further, it is assumed that Braun will be retained to provide field reviews during construction to confirm adherence to building code guidelines and generally accepted engineering practices, and the recommendations provided in this report. Field services recommended for the project represent the minimum necessary to confirm that the work is being carried out in general conformance with Braun's recommendations and generally accepted engineering standards. It is the Client's or the Client's Contractor's responsibility to provide timely notice to Braun to carry out site reviews. The Client acknowledges that unsatisfactory or unsafe conditions may be missed by intermittent site reviews by Braun. Accordingly, it is the Client's or Client's Contractor's responsibility to inform Braun of any such conditions.
Work that is covered prior to review by Braun may have to be re-exposed at considerable cost to the Client. Review of all Geotechnical aspects of the project are required for submittal of unconditional Letters of Assurance to regulatory authorities. The site reviews are not carried out for the benefit of the Contractor(s) and therefore do not in any way effect the Contractor(s) obligations to perform under the terms of his/her Contract.

7. SAMPLE DISPOSAL

Braun will dispose of all samples 3 months after issuance of this report, or after a longer period of time at the Client's expense if requested by the Client. All contaminated samples remain the property of the Client and it will be the Client's responsibility to dispose of them properly.

8. SUBCONSULTANTS AND CONTRACTORS

Engineering studies frequently requires hiring the services of individuals and companies with special expertise and/or services which Braun Geotechnical Ltd. does not provide. These services are arranged as a convenience to our Clients, for the Client's benefit. Accordingly, the Client agrees to hold the Company harmless and to indemnify and defend Braun Geotechnical Ltd. from and against all claims arising through such Subconsultants or Contractors as though the Client had retained those services directly. This includes responsibility for payment of services rendered and the pursuit of damages for errors, omissions or negligence by those parties in carrying out their work. These conditions apply to specialized subconsultants and the use of drilling, excavation and laboratory testing services, and any other Subconsultant or Contractor.

9. SITE SAFETY

Braun Geotechnical Ltd. assumes responsibility for site safety solely for the activities of our employees on the jobsite. The Client or any Contractors on the site will be responsible for their own personnel. The Client or his representatives, Contractors or others retain control of the site. It is the Client's or the Client's Contractors responsibility to inform Braun of conditions pertaining to the safety and security of the site – hazardous or otherwise – of which the Client or Contractor is aware.
Exploration or construction activities could uncover previously unknown hazardous conditions, materials, or substances that may result in the necessity to undertake emergency procedures to protect workers, the public or the environment. Additional work may be required that is outside of any previously established budget(s). The Client agrees to reimburse Braun for fees and expenses resulting from such discoveries. The Client acknowledges that some discoveries require that certain regulatory bodies be informed. The Client agrees that notification to such bodies by Braun Geotechnical Ltd. will not be a cause for either action or dispute.

000.000000 520000.000000 522000.000000 5450000.000000

Slope Theme Legend

- 0-5%
- 5-15%
- 15-30%
- 30-50%
- 50-70%
- 70-90%
- 90+%

N

0 0.25 0.5 0.75 1

Kilometres

Map Created: April 13 2016
Created By: ES
Datum: NAD 83
Projection: UTM Zone 10

McElhanney

Limits of Study Site

Centre Creek

18-Soldier Piles

18-3

18-4

19-2

19-14

18-Fill/Sump

20-Pond

20-Bridge

182A St. Ditch

20-Erosion

20-6

20-1

Parson's Channel

Dyke Rd

96A Ave

Golden Ears Way

Golden Ears Way

5448000.000000

BRAUN GEOTECHNICAL LTD.

Rev.	Description	Date

Client: McElhanney Consulting Services Ltd.

Project: Abbey Ridge Local Area Servicing
Surrey, BC

Project no.: 16-6720 | Drawn: DD | Design: SS | Checked: JW

Title: SITE ID
LOCATION PLAN

Date: April 13, 2016 | Scale: 1:12500 | Drawing no.: 16-6720-01

Appendix A: Annotated Photos

Photo 1. (WP-182A ST DITCH) 182A Street Ditch. View of left bank decaying and toppling landscape tie retaining walls and wall debris.

Photo 2. **(WP20-1)** Leoran Brook (upper section at Hwy 1). View of right bank erosion and recent instream works (~5 yrs old).

Photo 3. (WP20-6) Leoran Brook (upper section). Left bank erosion (southeast of 9820 181 Street).

Photo 4. **(WP20-EROSION)** Leoran Brook (middle section). View of left bank erosion and woody debris

Photo 5. (WP20-BRIDGE). Leoran Brook (middle section). View of amatuer footbridge crossing with woody debris accumulating under the bridge against the stringers.

Photo 6. (WP20-BRIDGE). Leoran Brook (middle section). View of woody debris accumulation and aggrading stream channel approximately 25m upstream from man-made pond.

Photo 7. (WP20-POND). Leoran Brook (middle section). View of man-made pond. Outfall wier with fish ladder structure visible at centre of image.

Photo 8. (WP19-14). Lyncean Creek East. View of upper pond (access road ravine fill). Culvert trash rack partially clogged with debris

Photo 9 (WP19-14). Lyncean Creek East. View of main pond showing flow from upper pond through access road ravine fill. Main pond trash rack damaged and partially clogged with debris.

Photo 10 (WP19-2). Lyncean Creek East (179 Street culvert crossing). View of 200mm pipe draining northbound roadway scupper and Lock Block retaining wall erosion.

Photo 11. (WP19-2). Lyncean Creek East (179 Street culvert crossing). View of over-steepened rip rap slope at inlet culvert crossing

Photo 12. (WP18-FILL/SUMP). Lyncean Creek West (East Tributary). Small scale stormwater control structure (vandalized) flowing approximalely 5gpm.

Photo 13. (WP18-FILL/SUMP). Lyncean Creek West (East Tributary). Ravine Fill with High/Low Inlet Culverts

Photo 14. (WP18-4). Lyncean Creek West (West Tributary). Undermined Culvert Headwall at 100 Ave & Lyncean Drive.

Photo 15. (WP18-4). Lyncean Creek West (West Tributary). Bank Erosion Above Culvert at 100 Ave & Lyncean Dr.

Photo 16. (WP18-3). Lyncean Creek West. Tree With Water Flowing Below East of 17780 100A Ave

Photo 17. (WP18-SOLDIER PILES). Lyncean Creek West. View of left bank tiered solderpile walls (~300mm steel pipe piles with various metal lagging).

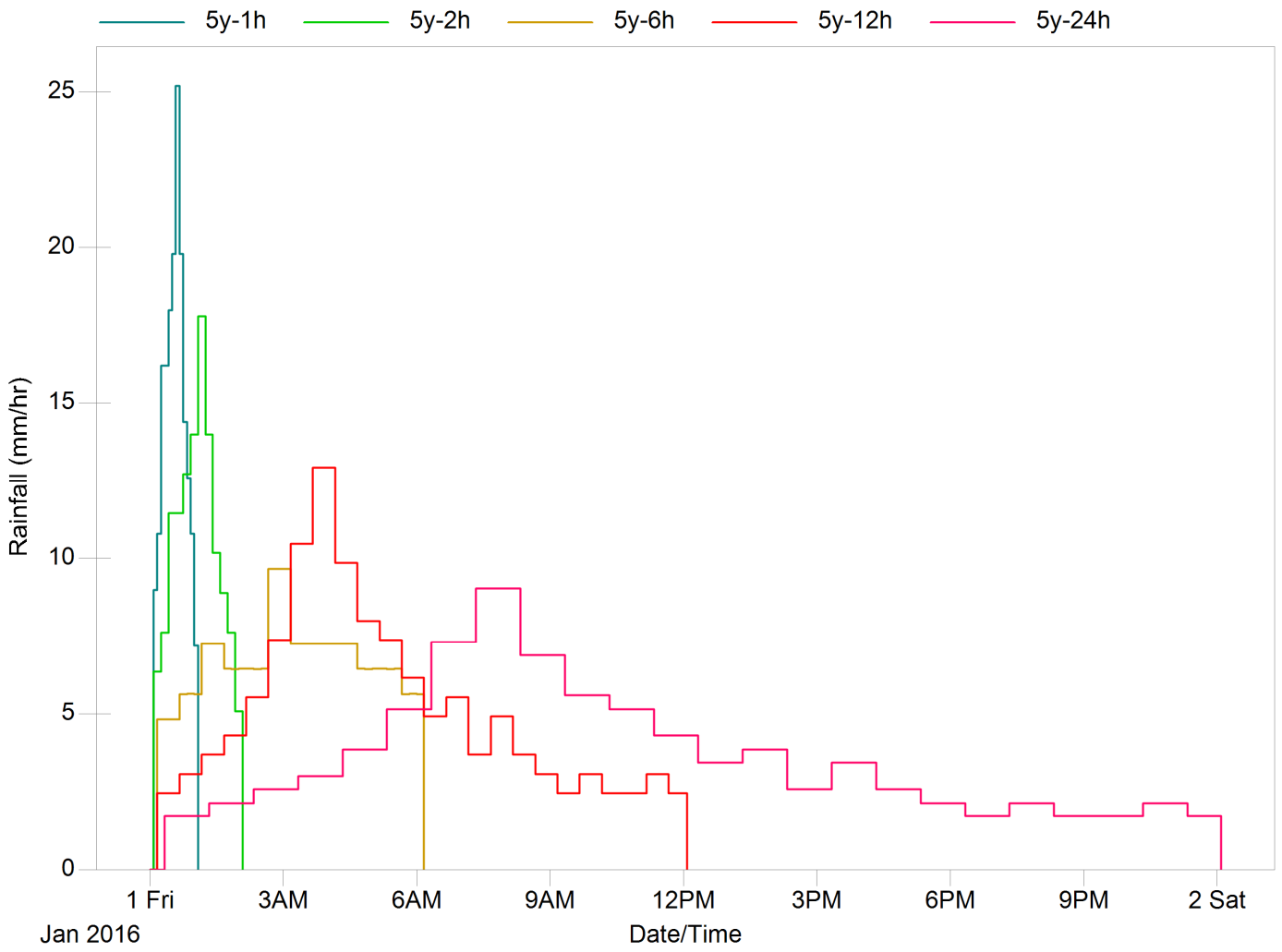
Photo 18. (WP18-SOLDIER PILES). Lyncean Creek West. View of right bank fill and near vertical (excavated) left bank slopes

Photo 19. (WP CENTER CREEK). Centre Creek. Right Bank erosion and slide scar (~15m^3). Age of event ~5-10 yrs

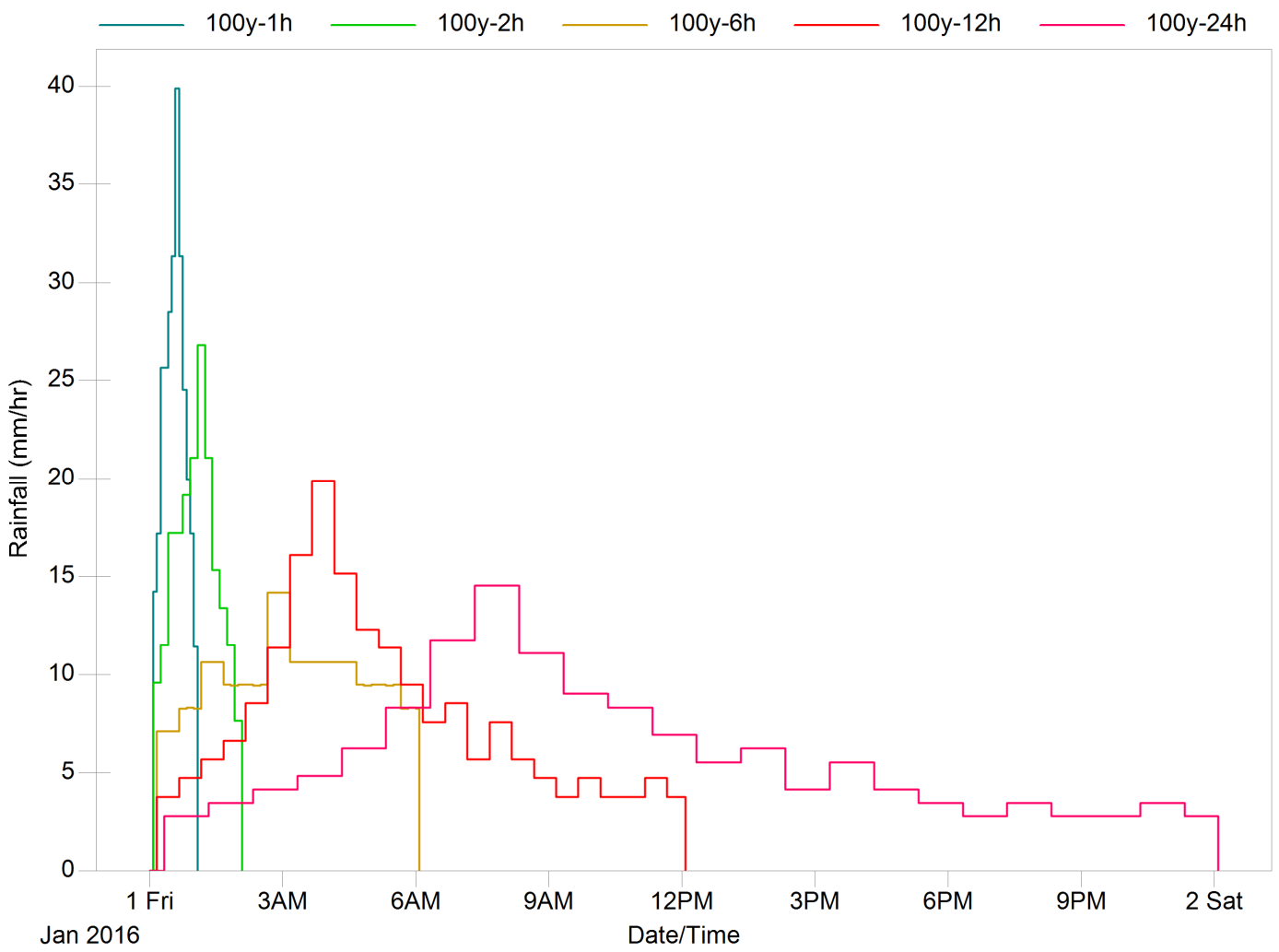
Photo 20 (WP CENTER CREEK). Centre Creek. View of Left Bank erosion and topple of 2 large trees. The older topple ~5-6 yrs ago based on tree top growth, the younger topple recent (<1 yr ago).

Appendix B – Design Storm Hyetographs

5-year Design Storm Hyetographs



100-year Design Storm Hyetographs

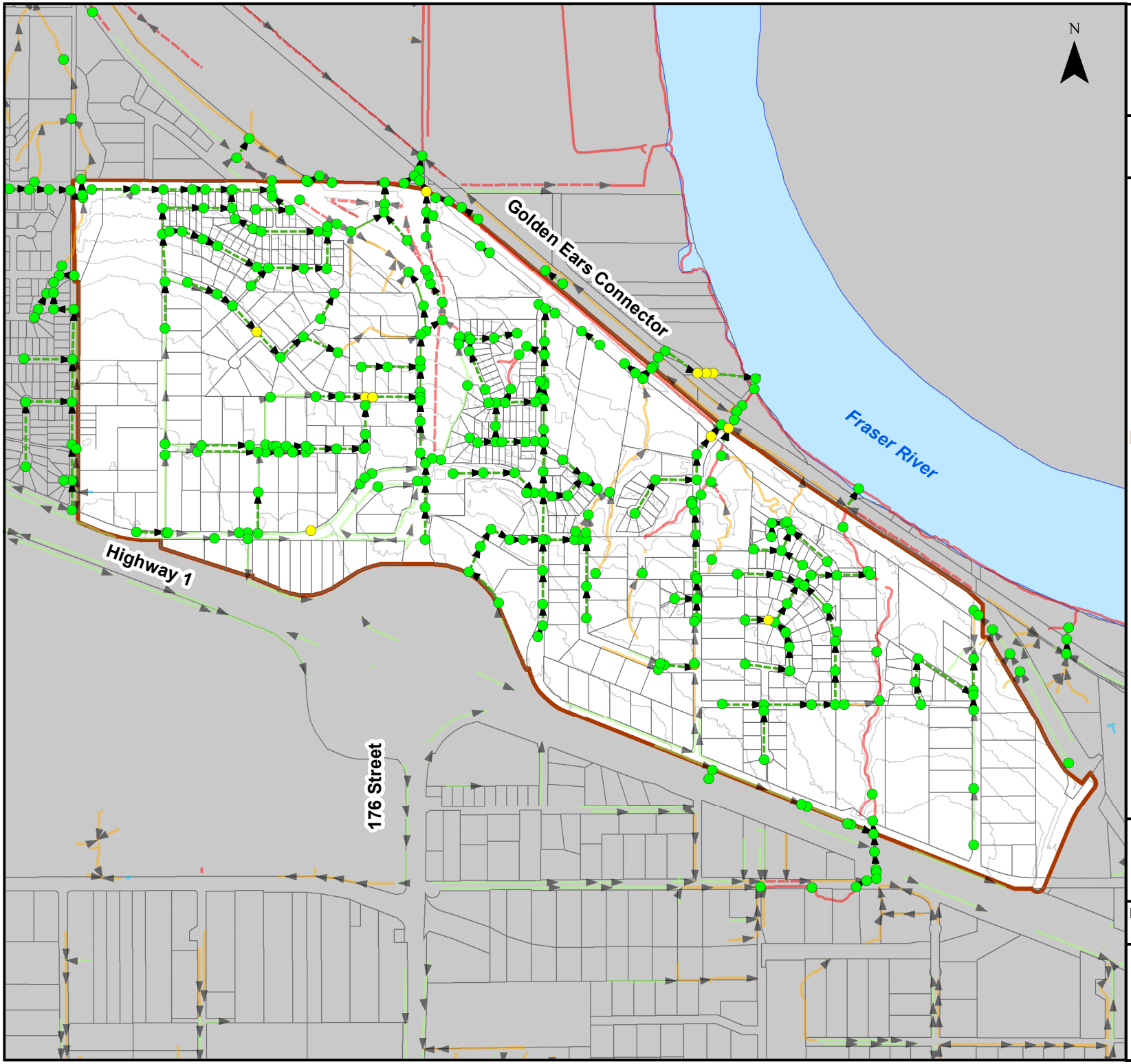


Appendix C – Model Results

PCSWMM Modeling Assumptions

Project Name Surrey - Abbey Ridge Stormwater Servicing
MCSL No. 2111-03570-00
Prepared by: Daniel Archila
Review by: Nav Sandhu
Date: April 15, 2016

Layer	Parameter	Associated Assumptions*
Subcatchment	Rainfall parameters	• Used hyetographs from Kwantlen Park rainfall gauge as per 2016 - City of Surrey Design Criteria Manual
	Catchment area (ha)	• Sub-catchment were delineated using existing contours from the City and considering the existing drainage infrastructure.
	Width (m)	$Width = \frac{Area}{FlowLength}$
	Flow length (m)	$FlowLength = 1.75 * \sqrt{Area}$
	Slope (%)	• The average slope for the sub-catchment areas was obtained from a Civil 3D 2016 surface built with contour information from the City. The slopes were found to be between 7-13%.
	Percent impervious (%)	• The percent of imperviousness for the sub-catchments was defined based on a review of the existing land use and typical imperviousness values used by the City of Surrey: o Commercial, industrial, transportation corridor = 90% o Residential – Acreage = 50% o Residential – Half-Acreage = 55% o Residential – Other = 65% o Institutional (School, Churches) = 80% o Parks, Agricultural, Cemeteries = 20% The percent impervious values were found to be between 29-53%.
	Manning's N for impervious area	• A Manning's "n" roughness value of 0.012 was used for impervious areas.
	Manning's N for pervious area	• A Manning's "n" roughness value of 0.24 was used for pervious areas.
	Infiltration method	• Based on Bon Accord – North Slope Integrated Stormwater Management Plan (2015), the Horton infiltration method was used with the following parameters: o Max infiltration rate (mm/hr) = 5 o Min infiltration rate (mm/hr) = 1.5 o Decay constant (a/hr) = 5.4 o Drying time (days) = 7
	Depression Storage	• Based on Bon Accord – North Slope Integrated Stormwater Management Plan (2015), the following depression storage values were used: o Impervious surface (mm) = 1.3 o Pervious surface (mm) = 3.8



Abbey Ridge
Storm Servicing Concept

CITY OF SURREY
the future lives here.

Legend

- Existing Local Sewers
- Existing Trunk Sewers

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- 5m Contours

Flooding

- Surcharged
- In pipe

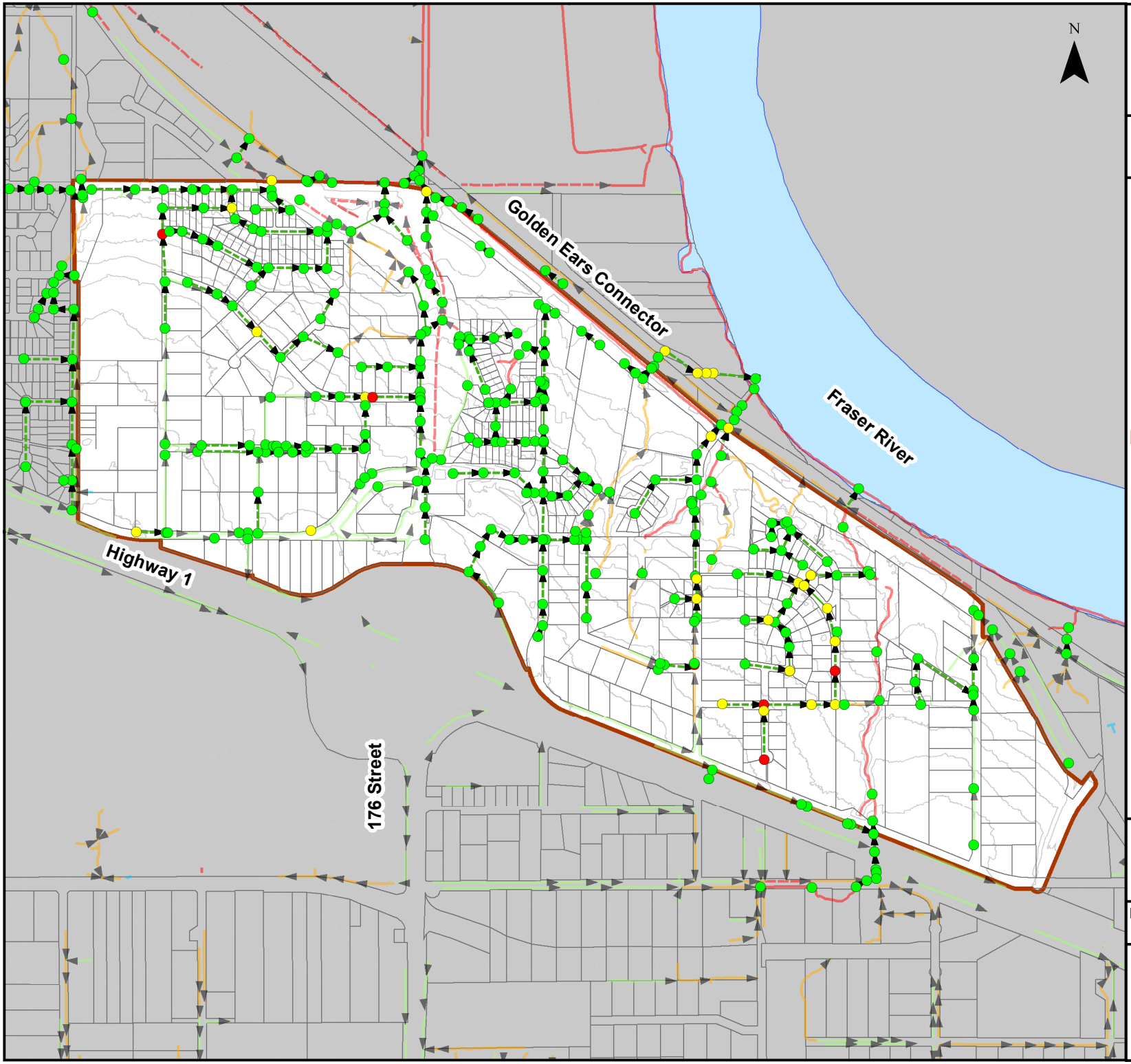
McElhanney

0 75 150 300 450 (m)

1:12,000

Project No.	Date
2111-03570-00	December 2016

Scenario 1
5 year 1 hour storm



Abbey Ridge
Storm Servicing Concept

CITY OF SURREY
the future lives here.

Legend

- Existing Local Sewers
- Existing Trunk Sewers

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- 5m Contours

Flooding

- Flooded
- Surcharged
- In pipe

* ID per Braun geotechnical report

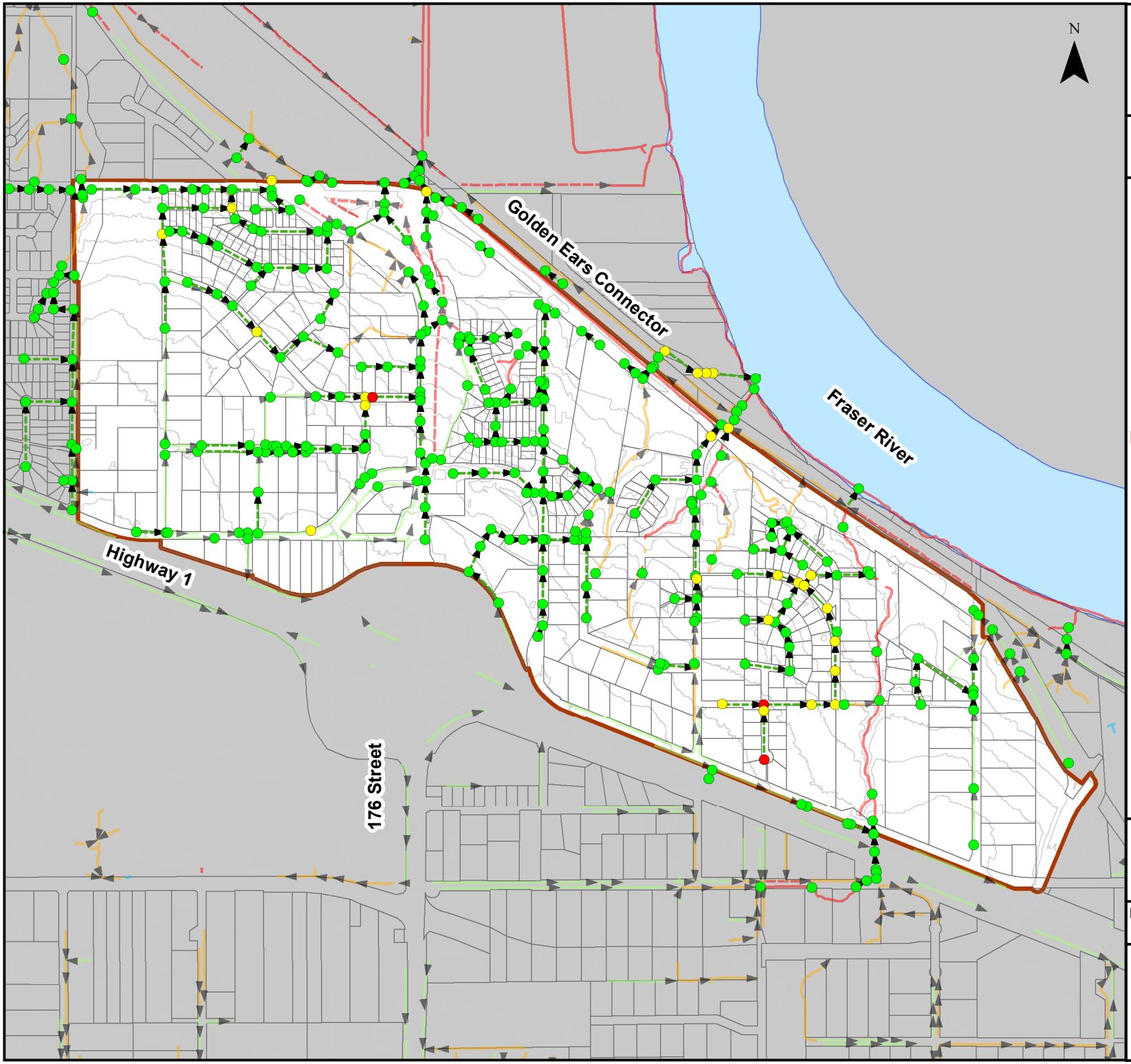
McElhanney

0 75 150 300 450 (m)

1:12,000

Project No.	Date
2111-03570-00	December 2016

Scenario 1
100 year 1 hour storm



Abbey Ridge
Storm Servicing Concept

CITY OF SURREY
the future lives here.

Legend

- Existing Local Sewers
- Existing Trunk Sewers

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- 5m Contours

Flooding

- Flooded
- Surcharged
- In pipe

* ID per Braun geotechnical report

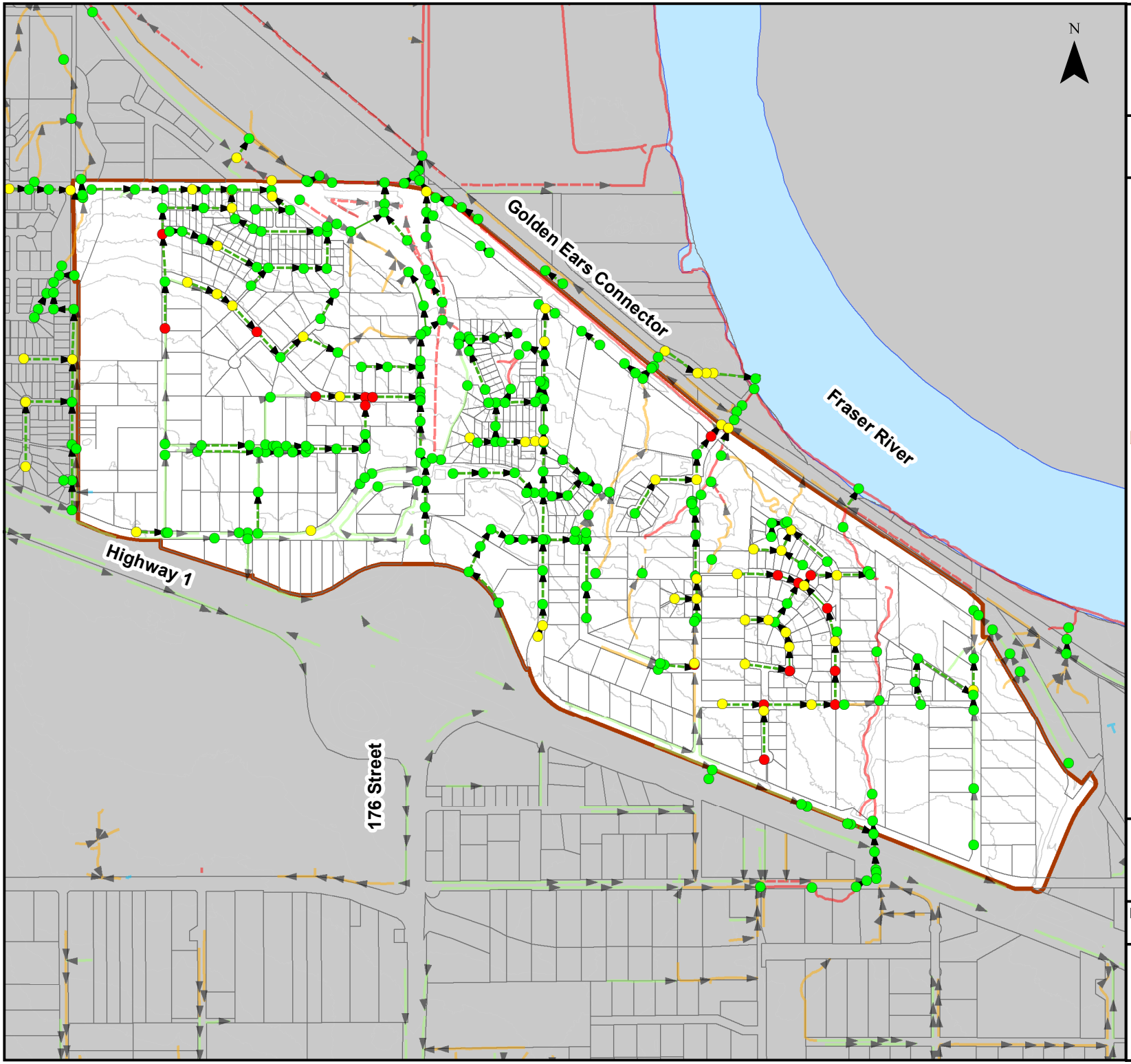
McElhanney

0 75 150 300 450 (m)

1:12,000

Project No.	Date
2111-03570-00	December 2016

Scenario 2
5 year 1 hour storm



Abbey Ridge
Storm Servicing Concept

CITY OF SURREY
the future lives here.

Legend

- Existing Local Sewers
- Existing Trunk Sewers

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- 5m Contours

Flooding

- Flooded
- Surcharged
- In pipe

* ID per Braun geotechnical report

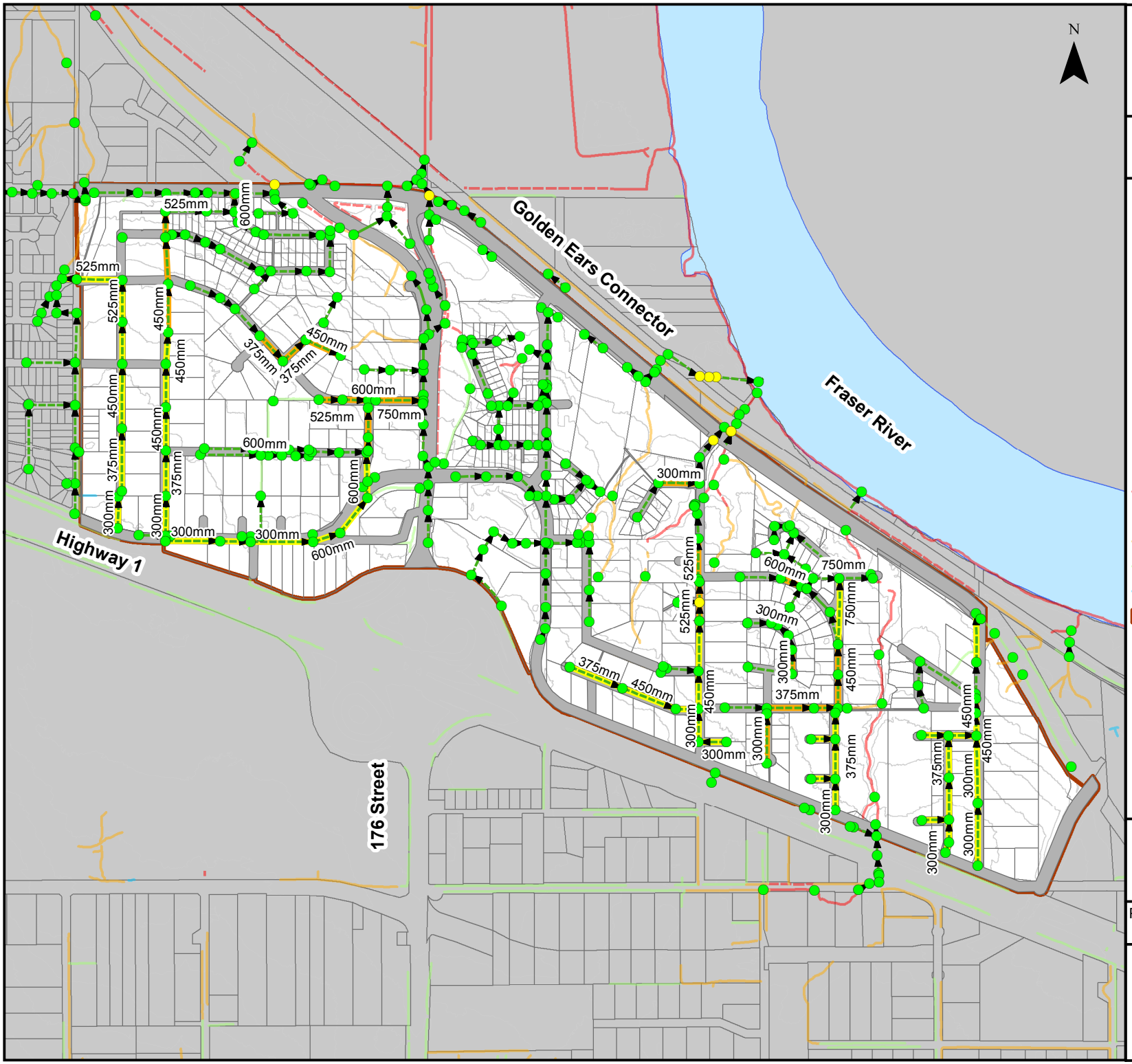
McElhanney

0 75 150 300 450 (m)

1:12,000

Project No.	Date
2111-03570-00	December 2016

Scenario 2
100 year 1 hour storm



Abbey Ridge
Storm Servicing Concept

CITY OF SURREY
the future lives here.

Legend

Flooding

- Surcharged
- In pipe

- Upsized Trunk Sewers
- Upsized Local Sewers
- Existing Local Sewers
- Existing Trunk Sewers
- New Local Sewers
- Proposed Road

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- 5m Contours

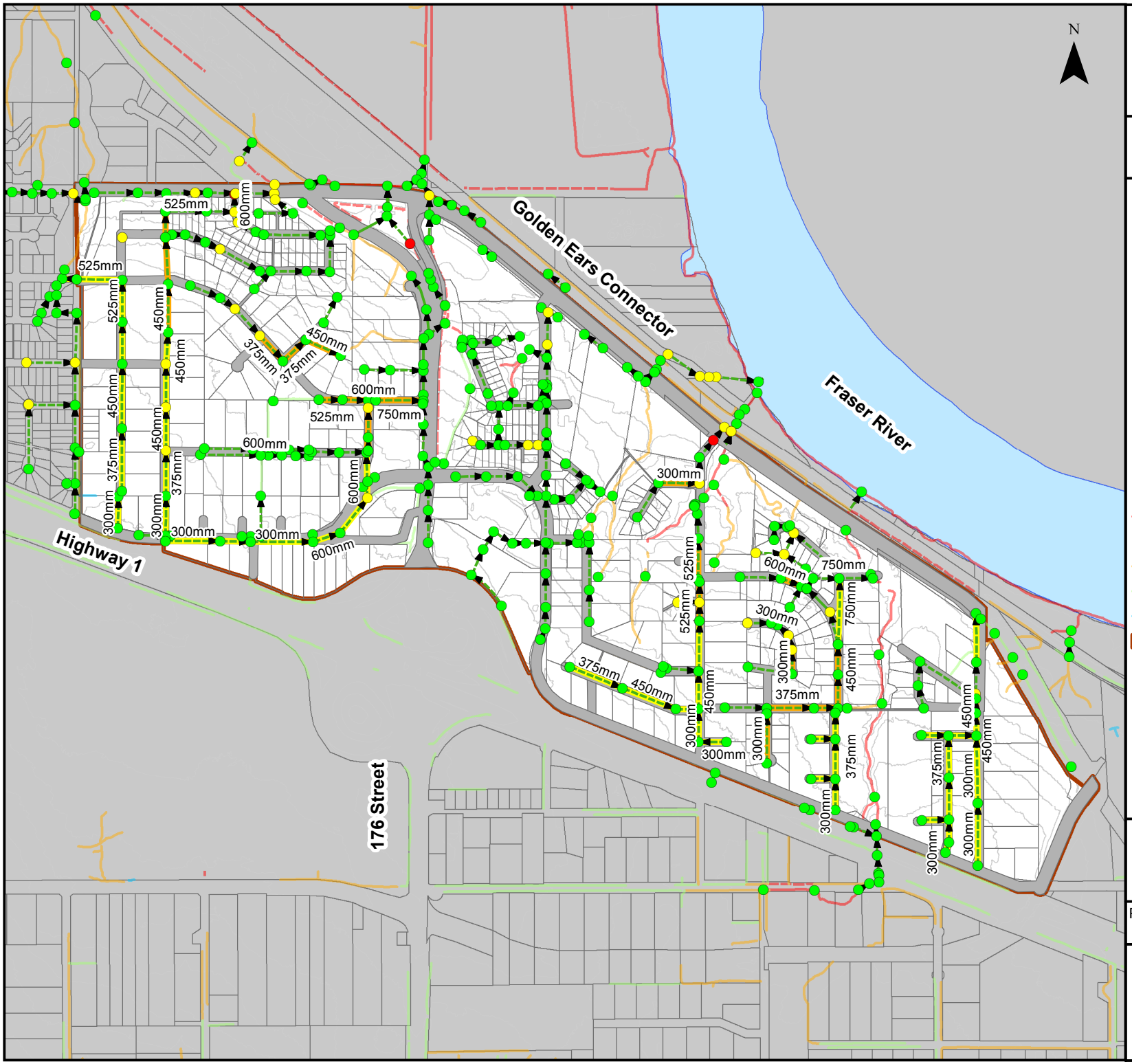
McElhanney

0 75 150 300 450 (m)

1:12,000

Project No.	Date
2111-03570-00	December 2016

Scenario 3
5 year 1 hour



Abbey Ridge
Storm Servicing Concept

CITY OF SURREY
the future lives here.

Legend

Flooding
- Flooded
- Surchaged
- In pipe
- Upsized Trunk Sewers
- Upsized Local Sewers
- Existing Local Sewers
- Existing Trunk Sewers
- New Local Sewers
- Proposed Road

Watercourse Classification
- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- 5m Contours

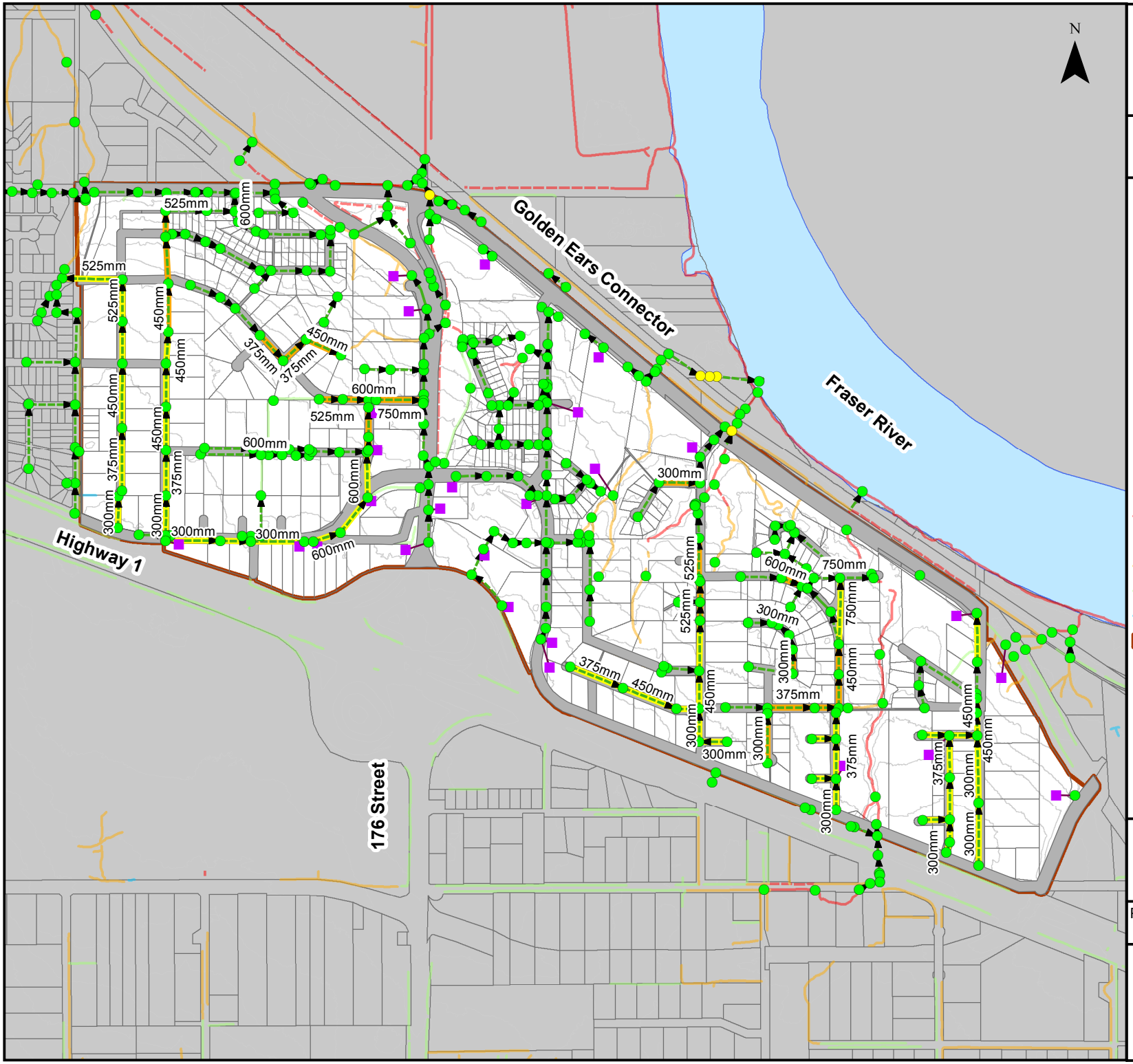
McElhanney

0 75 150 300 450 (m)

1:12,000

Project No.	Date
2111-03570-00	December 2016

Scenario 3
100 year 1 hour



Abbey Ridge
Storm Servicing Concept

CITY OF SURREY
the future lives here.

Legend

Flooding

- Surcharging
- In pipe

- Upsized Trunk Sewers
- Upsized Local Sewers
- Existing Local Sewers
- Existing Trunk Sewers
- New Local Sewers
- Onsite detention
- Proposed Road

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- 5m Contours

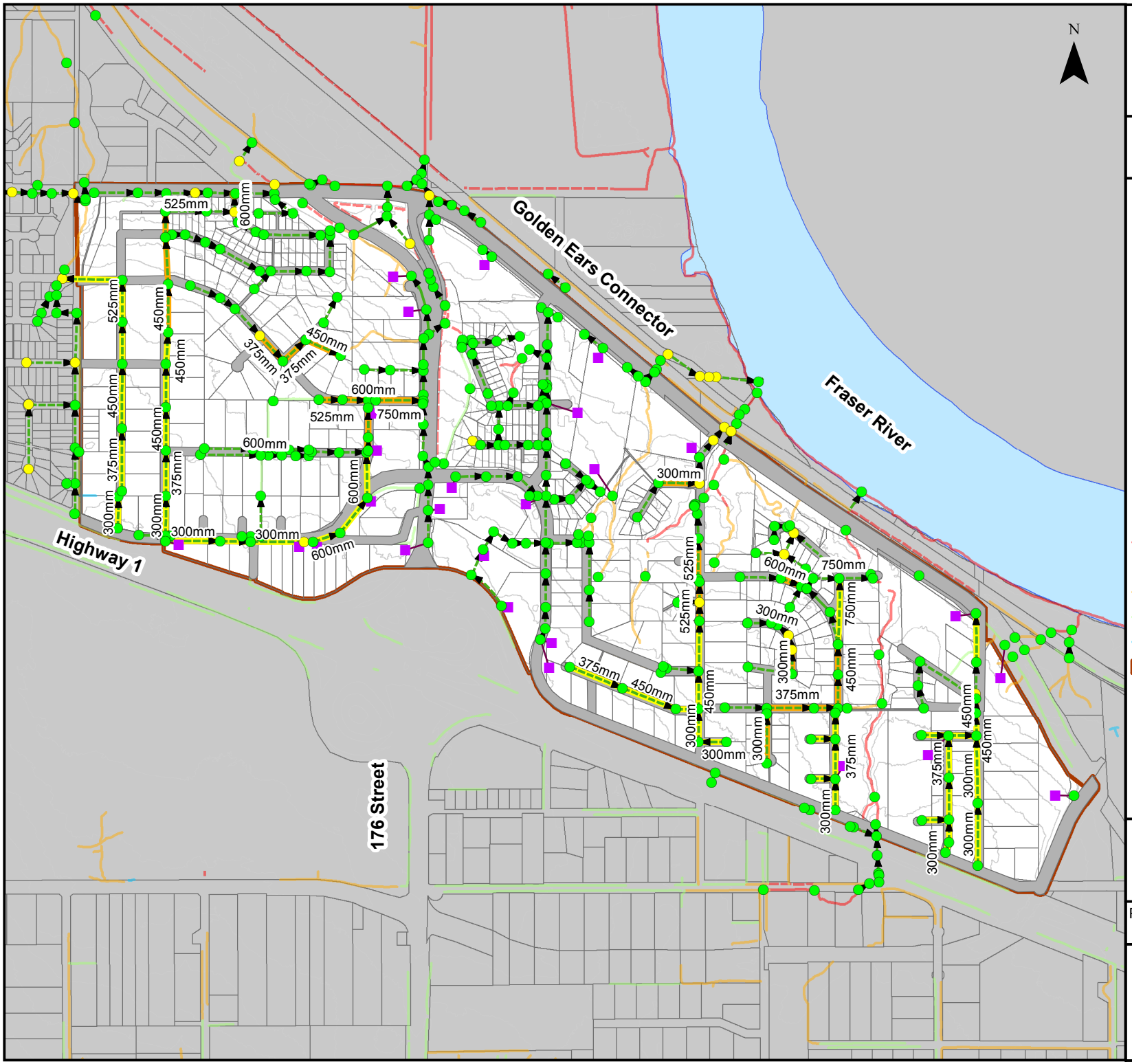
McElhanney

0 75 150 300 450 (m)

1:12,000

Project No.	Date
2111-03570-00	December 2016

Scenario 4
5 year 1 hour



Abbey Ridge
Storm Servicing Concept

CITY OF SURREY
the future lives here.

Legend

Flooding

- Flooded
- Surcharged
- In pipe
- Upsized Trunk Sewers
- Upsized Local Sewers
- Existing Local Sewers
- Existing Trunk Sewers
- New Local Sewers
- Onsite detention
- Proposed Road

Watercourse Classification

- Class A
- Class AO
- Class B
- Class C
- Unknown
- Abbey Ridge LAP
- 5m Contours

McElhanney

0 75 150 300 450 (m)

1:12,000

Project No.	Date
2111-03570-00	December 2016

Scenario 4
100 year 1 hour