Corporation of Delta

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Final Report

# Boundary/Shaw Creek ISMP

January 2012

**Submitted by:**

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January 30, 2012

Rob Racine
The Corporation of Delta
4500 Clarence Taylor Crescent
Delta, B.C.  V4K 3E2

Dear Mr..Racine:

RE: **BOUNDARY/SHAW CREEK ISMP**
**Final Report Submission**
**Our File 0323.059-300**

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We are pleased to submit 14 copies (10 to Delta and 4 to Surrey) and a digital copy of our Final Report for the above-captioned project. This submission incorporates the comments made on the 90% report. It consists of:

- **Hydrotechnical Improvements** including addressing creek erosion and culvert upgrades.
- **Lowlands Drainage Improvement** namely making more efficient use of the East Oliver Bypass.
- **Water Quality Treatment** including education of residents, considering bylaw changes to require WQ treatment of pavement runoff, two wetlands, and WQ monitoring.
- **Volumetric Reduction** including considering bylaw changes to require stormwater capture for impervious surfaces, considering options for disconnected roof leaders in Delta, and a parkette rain garden in Surrey.
- **Flow Rate Control** including requiring detention to pre-development levels for all new development, roadways, and redevelopment.
- **Riparian Protection** including continuing implementation of riparian bylaws and regulations, considering options for relocating a stream away from railway/highway embankments, and improving existing riparian.
- **Instream Restoration and Enhancement** including improving fish passage and enhancing fish habitat.
- **Further Studies and Monitoring** including geotechnical investigation and monitoring, water quality and benthic monitoring and sediment sampling, and fish presence and fish passage investigations.

It was our pleasure to complete this interesting ISMP on behalf of the Corporation of Delta and City of Surrey.

Yours truly,

**KERR WOOD LEIDAL ASSOCIATES LTD.**

**Original Signed By:**

David Zabil, P.Eng.
Project Manager

DZ/
Encl.
cc: Jeannie Lee, City of Surrey

## Statement of Limitations

This document has been prepared by Kerr Wood Leidal Associates Ltd. (KWL) for the exclusive use and benefit of Corporation of Delta/City of Surrey for the Boundary/Shaw Creek Integrated Stormwater Management Plan. No other party is entitled to rely on any of the conclusions, data, opinions, or any other information contained in this document.

This document represents KWL's best professional judgement based on the information available at the time of its completion and as appropriate for the project scope of work. Services performed in developing the content of this document have been conducted in a manner consistent with that level and skill ordinarily exercised by members of the engineering profession currently practising under similar conditions. No warranty, express or implied, is made.

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## Revision History

| Revision # | Date | Status | Revision | Author |
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# Executive Summary

# Executive Summary

The Corporation of Delta (Delta) together with the City of Surrey (Surrey) initiated an integrated stormwater management plan (ISMP) for the Boundary/Shaw Creek watershed, located near the south end of the border between Delta and Surrey. The 930 ha study area includes a largely urbanized upland area, agricultural areas in the lowlands, and a large park (Watershed Park) on the slope between the urban and agricultural areas. The study area includes tributaries Watershed Creek, Briarwood Creek, Shaw Creek, Oliver Slough, and a number of lowland ditches. The area drains generally from north to south into Mud Bay.

The Delta and Surrey Official Community Plans (OCPs) show minimal new development areas, however, redevelopment densification is expected. There are valuable environmental resources within the creek system, and riparian corridors are strong in Watershed Park.

## Key Issues in Watershed

Delta and Surrey identified a number of key issues in the Boundary/Shaw Creek Watershed. The filed investigation program and stakeholder consultation process expanded and confirmed the key issues. Table 1 summarizes the key issues requiring resolution (in no order of importance).

**Table 1: Summary of Key Issues**

| Key Issues |
|---|
| • Effectiveness of Existing Detention Facilities and Hydraulic Structures<br>• Lowland Flooding<br>• Delta Golf Course Flooding at South End<br>• Flooding in Low-lying Portions of Watershed Park near BNSF Railway<br>• Backwatered Storm Sewer Outfall near 63 Ave and 109A St<br>• Erosion in the Stream Channels<br>• Ravine Instabilities and Hazards<br>• Sediment and Debris Accumulation and Potential Blockage of Shaw Creek Highway 10 Culvert<br>• Fish Passage Barriers<br>• Limited Fish Habitat<br>• Poor Water Quality in Streams<br>• Irrigation Water Supply in Farmland during Growing Season |

## The Integrated Stormwater Management Plan for Boundary/Shaw Creek

The Boundary/Shaw Creek ISMP strives to resolve the above issues through the following strategies:

- Detention facility assessment and recommendations.
- Culvert capacity assessment and upgrade program.
- Flooding assessment and improvements to culvert capacity, flow splitter adjustments, pump capacity increase, and East Oliver Bypass connection to Mud Bay.
- Erosion assessment and stabilization projects.
- Ravine stability assessment and proposed future detailed investigations.
- Debris interception and culvert inlet improvement at Shaw Creek Highway 10 culvert.
- Fish habitat and passage improvements.
- Water quality monitoring program and improvements.

- Improve water quality from non-point sources through the medium and long term implementation of stormwater source controls.
- Maintain base flows and low flows into the farmland channels for irrigation.
- Mitigate hydrologic impacts from future development through source controls and stormwater bylaws.

## ISMP Performance Monitoring and Accountability of Plan

In order to measure and track the levels and changes in the health of a watershed, and to provide accountability to the ISMP, a suite of performance parameters has been developed that match the key issues identified above. Table E-2 lists the parameters or "indicators" that should be measured and tracked over time.

The proposed schedule for review of the watershed health indicators should be once every five years. It is suggested that indicators be measured every two years.

**Table 2: Boundary/Shaw Creek Watershed Adaptive Management Indicators**

| | Performance Indicator | Method of Analysis | 2010 | 2015 |
|---|---|---|---|---|
| 1. | Total Impervious Area (% of Watershed Area) | GIS Analysis of Aerial Photos and Assessment Data | 26% | Small increase expected due to development |
| 2. | Effective Impervious Area (% of Watershed Area) | Estimated from surface cover type and source controls implemented | Flow monitoring required to quantify | decrease when source controls implemented |
| 3. | Riparian Forrest Integrity (% of Riparian Area) | GIS Analysis of Aerial Photos | 31% | Same or Increase |
| 4. | Watershed Forest Cover (% of Watershed Area) | GIS Analysis of Aerial Photos | 23% | Same or Increase |
| 5. | Benthic Invertebrates | B-IBI scores based on methods used in this study | mean = 17.0 | 18 |
| 6. | Fish Populations | Density, species composition | No data | Collect Data |
| 7. | Fish Passage Barriers | City/Streamkeepers Records | Full Barriers 1<br>Partial Barriers 4 | Progressive Removal of Non-natural Barriers |
| 8. | Average Summer Water Temperature (°C) | Monitoring (continuous station at Shaw Creek at Old Highway 10) | Range: 10.6 - 18.3<br>Mean: 15.0 | Same or Decrease |
| 9. | Dissolved Oxygen (DO, mg/L) | Field Measurement (during spring/summer baseflow) | Range: 1.5 – 10.8<br>Mean: 7.1 | Same or Increase |
| 10. | Water pH | Monitoring (continuous station at Shaw Creek at Old Highway 10) | Range: 5.7 – 7.5<br>Mean: 6.8 | Same or Trend Toward Neutral |
| 11. | Water Conductivity (μS) | Monitoring (continuous station at Shaw Creek at Old Highway 10) | Range: 83 – 7,590<br>Mean: 505 | Same or Decrease |
| 12. | Turbidity (NTU) | Monitoring (continuous station at Shaw Creek at Old Highway 10) | Range: 0 – 160<br>Mean: 15 | Same or Decrease |
| 13. | Water Quality Fecal Coliforms (MPN/100mL) | Field Sample at Oliver Slough near 112 Street & Lab Testing | 1,600 | < 200 |
| 14. | Sediment Quality | Metals in sediment | See Section 2.4 | Same or Decrease |
| 15. | No. of Erosion Sites | Field Assessment and Designation as Low, Medium, or High Severity and Consequence | See Table 2-2 | Same or Decrease |
| 16. | Lineal km of Roadside Ditches/Swales/Rain Gardens (km) | As-Constructed Drawings / GIS | 16 km | 18 km |

Section 1

# Introduction

# 1. Introduction

The Corporation of Delta (Delta) together with the City of Surrey (Surrey) initiated an integrated stormwater management plan (ISMP) for the Boundary/Shaw Creek watershed, located near the south end of the border between Delta and Surrey (see Figure 2-1 in next section). The 930 ha study area includes a largely urbanized upland area, agricultural lowlands, and a large park (Watershed Park) on the slope between the urban and agricultural areas. The study area includes tributaries Watershed Creek, Briarwood Creek, Shaw Creek, Oliver Slough, and a number of lowland ditches. The area drains generally from north to south into Mud Bay.

The Delta and Surrey Official Community Plans (OCPs) show minimal new development areas, however, redevelopment densification is expected. There are valuable environmental resources within the creek system, and riparian corridors are strong in Watershed Park.

This report fulfills the goals of the ISMP process including:

- document the existing condition of the drainage system and the ecological health of the watershed;
- define how development can proceed with minimal effects on flooding, erosion, water quality, and ecological health;
- identify required remedial and new capital work items; and
- provide a sustainable plan with minimal operational and maintenance costs.

The ISMP process strives to preserve watershed health as a whole, while meeting community needs and allowing development and redevelopment to occur. It allows for trade-offs so that environmental losses in one area within a watershed can be offset by gains in others, thereby meeting the regulatory guiding principle of no-net-loss.

## 1.1 Goals and Objectives

The goal of the Boundary/Shaw Creek study is to develop a comprehensive ISMP that will seek to improve the overall watershed system by minimizing the risk of flooding, preserving aquatic and riparian habitats, and develop effective and affordable watercourse improvements.

Delta and Surrey have developed the following objectives for this study:

- Protect aquatic ecosystems and water resources (surface and ground water) for their fish, wildlife, and ecological values.
- Minimize the risk to life and property associated with flooding.
- Provide or recommend pollution prevention and water quality control approaches.
- Involve the local stakeholders, agencies and public in a consultation process that will provide information on the current system and fully explore a range of options for improving the management of the watershed.
- Develop a comprehensive and cost effective strategy for municipal capital improvements, projects for streamkeeper groups, and improve community awareness of watershed issues.
- Meet Metro Vancouver criteria for ISMP acceptance. Obtain municipal commitment to ISMP implementation and maintenance program.
- Review appropriate streamside setbacks and address any existing or potential conflicts with existing riparian regulations.
- Develop functional preliminary designs for any structural/hydraulic improvements that are required.

The plan is to be cost-effective, scientifically defendable, supported by the public, and endorsed by the environmental agencies.

## 1.2 ISMP Key Issues

The following key issues for the watershed were identified. Refer to Figure 2-1 for orientation.

**Existing Flooding**

Sediment/debris issue in Shaw Creek potentially plugging Highway 10 culvert resulting in road overtopping and flooding;

**Sediment/debris in Shaw Creek at upstream end of Highway 10 culvert**

**Sediment/debris in Shaw Creek between 120 Street and Highway 10**

**Debris Jams in Shaw Creek between 120 Street and Highway 10**

**Debris Jams in Shaw Creek between 120 Street and Highway 10**

- Flooding of the south portion of Delta Golf Course (causes may include: located in floodplain, lack of pump station on the golf course);
- Storm sewer near 63 Ave and 109A St backwatered by Watershed Creek water levels;
- Flooding of farmlands west of Highway 91 (causes may include: located in floodplain, runoff from uplands, hydraulic constrictions in conveyance system); and

- Lower part of Watershed Park (located in floodplain, inadequate flood conveyance to Oliver Pump Station, runoff from uplands).

**Irrigation**

- Desire to increase irrigation water supply to farmland in the growing season.

**Existing Erosion**

- Erosion and ravine instabilities and hazards;

**Bank Erosion in Shaw Creek downstream of Highway 10 culvert**

**Bank Erosion in Shaw Creek downstream of Highway 10 culvert**

- Severe erosion and unstable obstructions observed in Shaw Creek between 120 Street and Highway 10; and
- Erosion at the top end of Shaw Creek at storm sewer outfall and through the 6007 Scott Road property including bank stabilization needs.

**Environmental**

- Fish passage barriers;

- Limited spawning and rearing habitat capacity; and

- Poor water quality in upland creeks and lowland ditches and sloughs (high summer water temperatures, high turbidity/TSS, high nutrients in lowlands, fecal coliforms, high metals).

**Poor Water Quality in Shaw Creek**

**Poor Water Quality in Watershed Creek**

**Effectiveness of Existing Infrastructure**

- Capacity and condition assessment of hydraulic structures; and
- Performance evaluation of existing stormwater detention systems and possible improvement.

## 1.3 Scope of Assignment

The following table summarizes the major tasks involved in undertaking this study.

**Table 1-1: Engineering Work Program**

| Major Tasks | | |
|---|---|---|
| Phase 1 | 1. | Project Initiation |
| | 2. | Background Information Review |
| Phase 2 | 3. | Hydrogeology and Geotechnical Assessment |
| | 4. | Land Use Assessment |
| | 5. | Drainage System and Erosion Inventory |
| | 6. | Environmental Inventory and Assessment |
| Phase 3 | 7. | Hydrology/Hydraulic Analysis |
| | 8. | Ecological Health Analysis |
| | 9. | Project Summary and 50% Report |
| Phase 4 | 10. | Mitigation Alternatives |
| Phase 5 | 11. | Develop Strategy, Plan, and Report |

## 1.4 Stormwater and Drainage Criteria

**Table 1-2: Summary of Stormwater Criteria**

| Application | | Criteria/Methodology |
|---|---|---|
| Flood and Erosion Protection | Minor drainage system | • 10-year return period design event typically.[1]<br>• 5-year return period design event for low density residential areas; 25-year return period design event for high value commercial or industrial development.[1]<br>• 5-year return period design event.[2] |
| | Major drainage system (Rural, Urban, Commercial Industrial) | • 100-year return period design event for floodway routing.[1, 2]<br>• 25-year return period design event for dyked or reclaimed land.[1]<br>• 100-year return period design event for culverts with less than 3 meter span on BC Ministry of Transportation roads.[3] |
| Agricultural Criteria | ARDSA Criteria | • Limit flooding to 5 days during a 10-year 5-day winter storm.<br>• Limit flooding to 2 days during a 10-year 2-day growing season storm.<br>• Provide 1.2 m of freeboard during baseflows between storm events. |
| Erosion & Environmental Protection | Volume Reduction (Source Controls) | • On-site rainfall capture (runoff volume reduction) for 6-month 24-hour storm (72% 2-year 24-hour storm).[4] |
| | Water Quality Treatment | • 6-month 24-hour storm (72% 2-year 24-hour storm).[4] |
| | Rate Control (Detention / Diversion) | • Control post-development flows to pre-development levels for 6-month, 2-year, and 5-year 24-hour event.[4]<br>• On fish bearing streams restrict post-development flows to pre-development levels for all storms up to and including the 10-year storm.[1]<br>• Limit flows to more stringent of the following criteria: Control the 5-year post-development flow to: 50% of the 2-year post development rate; or the 5-year pre-development rate.[2] |
| | Riparian | • Establish riparian setbacks to comply with Delta Streamside Protection and Enhancement Areas Bylaw[5] and Riparian Areas Regulation. |

[1] Corporation of Delta Stormwater Management Design Manual, February 1989, Revised January 1994.
[2] City of Surrey Design Criteria Manual, May 2004.
[3] BC Ministry of Transportation supplement to TAC Geometric Design Guide, 2007.
[4] DFO Urban Stormwater Guidelines and BMPs for the Protection of Fish and Fish Habitat, 2001.
[5] Corporation of Delta Development Permit Area to Establish Streamside Protection and Enhancement Areas Bylaw No. 6349, 2005.

## 1.5 Stakeholder Consultation Program

The stakeholder consultation included meetings with the municipalities, an Open House public meeting, and questionnaires seeking input on the key issues and potential solutions. Stakeholders included:

- municipal advisory committees;
- streamkeeper volunteer groups;
- residents;
- Burlington Northern Santa Fe (BNSF) Rail;
- Ministry of Transportation and Infrastructure (MOT);
- Metro Vancouver;
- Ministry of Agriculture and Lands;
- Fisheries and Oceans Canada (DFO);
- BC Ministry of Environment (MOE);
- Delta Farmers' Institute; and
- Delta Golf Course.

This ISMP was developed under of the direction the Corporation of Delta and the City of Surrey. The contents of the final report including the alternatives and the projects proposed in the Plan were selected in consultation with the municipalities.

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## Section 2

# Boundary/Shaw Creek Watershed

# 2. Boundary/Shaw Creek Watershed

## 2.1 Background Material

Table 2-1 summarizes the background information reviewed as part of this study.

**Table 2-1: Summary of Background Material**

| Date | Title |
|---|---|
| January 1987 | East Delta Drainage and Irrigation Study, K. Wilson, P.Eng., Ministry of Environment and Parks |
| May 1993 | Corporation of Delta East Delta Drainage and Irrigation Study Design Report, Dayton and Knight Consulting Engineers |
| December 1994 | Proposed West Newton Plan, Land Use Map, City of Surrey |
| February 1999 | Panorama Ridge Drainage and Slope Stability Assessment, Volumes 1 to 3, Stanley Consulting Group |
| November 1999 | Panorama Ridge Functional Review of Existing Drainage Concerns (54 Avenue), Stantec Consulting |
| February 2000 | Drawings of East Oliver Bypass Ponds, Kerr Wood Leidal Associates |
| May 2000 | Update to Panorama Ridge Drainage and Slope Assessment Final Report, Stantec Consulting |
| July 2001 | Tender Drawings of East Oliver Bypass Ponds, Kerr Wood Leidal Associates |
| July 2002 | Corporation of Delta Long Range Drainage Plan, New East Consulting Services |
| June 2004 | Assessment of a Well to Supply a Public Fountain, Gartner Lee Ltd. |
| April 2005 | Eugene Creek 90% Design Submission Drawings Package, McElhanney Consulting Services |
| September 2008 | Preliminary Report to the City of Surrey for Eugene Creek Channel Diversion, McElhanney Consulting Services |

## 2.2 Drainage

The Boundary/Shaw Creek study area is located in both the Delta and Surrey, with approximately 75% of the watershed within Delta (see Figure 2-1). The study area is approximately bounded by 68 Avenue to the north, Mud Bay to the south, 112 Street to the west and 128 Street to the east. The Cougar Creek and the Eugene Creek watersheds are immediately north and east of the study area, respectively.

- Study area is approximately 930 ha with the Surrey area (220 ha) largely developed and the Delta area (710 ha) mostly undeveloped or agricultural land.
- Drainage direction is generally toward the south, via storm sewers, culverts, creeks, and ditches.
- Study area drainage discharges into Mud Bay via the Oliver Pump Station.
- Uplands rate controls includes two detention facilities in Surrey (Boundary Park Pond and 6455 121 Street tank).

- Lowland flow control includes the East Oliver Bypass series of lowland storage ponds/wetlands with a flow splitter (see photo to right) that regulates the flows into the farmlands west of Highway 91 (other irrigation control structures exist in the lowlands outside the study area).

Refer to Figures 2-1 and 2-2 for the study area extents and drainage system overview.

## Field Inventory

Field inventories were completed between May 20 and June 8, 2010 for Watershed Park as well as the area south of Highway 10 and north of Ladner Trunk Road. The creek bed was traversed on foot and locations of interest were identified and recorded with a Trimble GeoXT handheld global positioning system (GPS) receiver. Measurements, photographs and additional observations were recorded as attributes associated with these positions to create a comprehensive geographical information system (GIS) database. Figure 2-3 shows the field inventory and locations of interest.

Field inventory work included gathering information on creek crossings, channel cross-sections, erosion, deposition, obstructions and a condition assessment of hydraulic structures. Sites of significant erosion were identified and assigned a relative severity level of low, moderate or high, based on a visual assessment that took into account the following parameters:

- total height of eroded bank;
- apparent rate of erosion; and
- apparent capacity of bank material to resist further erosion.

In addition to rating the severity of these sites, the potential consequences of the erosion activity was also evaluated and assigned a relative risk level of low, medium or high. This was based on a visual assessment that took into account the perceived level of risk to human life, property damage or destruction and wildlife habitat. Tables 2-2 and 2-3 summarize the erosion and obstruction locations. In general, the following observations were made:

- Severe erosion was noted along Shaw Creek between 120 Street and Old Highway 10 (Delta Golf Course access road).
- Consequences of the most severe erosion site were low as there are no nearby structures.

- One major erosion site noted adjacent to Highway 10 embankment which if left unaddressed would threaten the highway in the future (E-11).
- Erosion at the toe of the ravine southeast of Highway 10 may undermine toe increasing likelihood of slope instability and pose a risk to homes on Panorama Ridge.

- Unstable obstructions such as debris jam, large woody debris, and sediment was noted in Shaw Creek upstream of Highway 10. These pose the risk of culvert blockage and should be monitored, anchored, or removed.

See Appendix A for photo overviews of the field inventory.

**Table 2-2: Summary of Observed Severe Erosion Sites**

| ID | Location | Severity | Consequence | Length (m) | Depth (m) | Comment |
|---|---|---|---|---|---|---|
| | | | | | | |
| E-1 | RIGHT BANK | MODERATE | LOW | 26 | 0.5 - 0.75 | |
| E-2 | BOTH | LOW | LOW | 15 | 0.5-1 | |
| E-3 | LEFT BANK | MODERATE | LOW | 10 | 0.5-1 | MULTIPLE SITES WITHIN 50 m |
| E-4 | LEFT BANK | MODERATE | MODERATE | 6 | 2-4 | |
| E-5 | LEFT BANK | MODERATE | LOW | 10 | 1-2 | |
| E-6 | LEFT BANK | HIGH | LOW | 15 | 2-4 | |
| E-7 | LEFT BANK | HIGH | LOW | 40 | 4-8 | |
| E-8 | RIGHT BANK | HIGH | LOW | 20 | 1.5-4 | |
| E-9 | RIGHT BANK | MODERATE | HIGH | 15 | 2-4 | |
| E-10 | LEFT BANK | LOW | LOW | 10 | .5-1 | |
| E-11 | RIGHT BANK | HIGH | HIGH | 20 | 2-5 | ALSO DEBRIS BARRIER & GRAVEL DEPOSITION |
| E-12 | RIGHT BANK | MODERATE | HIGH | 40 | 2-5 | LEFT BANK EROSION 1M DEPTH |

Severity Ratings based on erosion area: Low = less than 10 $m^2$, Moderate = 10 to 50 $m^2$; High = greater than 50 $m^2$
Consequence Ratings: High = roads or buildings at risk, Moderate = private property at risk, Low = all others

Refer to Figure 2-3 for location of sites

O:\0300-0399\323-059\300-Report\Final Report\[Table 2-2 ErosionSites.xls]wk-Table_Combined

**Table 2-3: Summary of Observed Major Channel Obstructions**

| ID | Cause | Stability | Type | Downstream Drop (m) | Comment |
|---|---|---|---|---|---|
| O-1 | NATURAL | STABLE | FALLEN TREE | 0 | .5 m DIAMETER |
| O-2 | NATURAL | STABLE | FALLEN LOGS | 0 | |
| O-3 | NATURAL | UNSTABLE | BRANCHES/DEBRIS | 0 | CAUSES CREEK DIVERSION |
| O-4 | NATURAL | UNSTABLE | BRANCHES/DEBRIS | 0 | |
| O-5 | NATURAL | STABLE | BOULDERS | 0.3 | DEPOSITION/PROTECTION |
| O-6 | ANTHROPOGENIC | STABLE | 950 CONC BARREL | 0 | |
| O-7 | NATURAL | STABLE | BOULDERS | 0.5 | BOULDERS & LOG |
| O-8 | NATURAL | UNSTABLE | LOGS & DEBRIS | 1 | MODERATE EROSION LEFT & RIGHT BANK 1-2.5M |
| O-9 | NATURAL | STABLE | BOULDERS | 0.5 | |
| O-10 | NATURAL | UNSTABLE | DEBRIS | 0 | |
| O-11 | NATURAL | UNSTABLE | FALLEN TREE/DEBRIS | 0 | MODERATE EROSION BOTH BANKS |
| O-12 | NATURAL | STABLE | DEBRIS | 1 | |
| O-13 | NATURAL | UNSTABLE | LOGS | .5 | |
| O-14 | ANTHROPOGENIC | FIXED | TIMBER DAM | 0 | |
| O-15 | ANTHROPOGENIC | STABLE | OLD DAM? | .5 | |
| O-16 | NATURAL | STABLE | BOULDERS | .25 | |

Refer to Figure 2-3 for location of sites

O:\0300-0399\323-059\300-Report\Final Report\[Table 2-3 ObstructionSites.xls]wk-Table_Combined

## 2.3 Land Use

The historic, existing, and future land uses were identified in the study area in order to estimate imperviousness values and how they have changed and how they are predicted to change in the future. Aerial photographs and land use information were received from Surrey and Delta.

### Existing Land Use

**Table 2-4: Existing Land Use**

| Delta | Surrey |
|---|---|
| Agricultural<br>Parks/recreation<br>Single family residential<br>Some commercial along Scott Road<br>Two schools | Mainly residential<br><br>Some commercial along Scott Road |
| As per 2008 airphoto | |

Refer to Figure 2-4 for existing land use and associated impervious percentages.

### Future Land Use – OCP

- Very few zoning changes.
- Mainly redevelopment at higher impervious percentages.
- Potential for higher density along Scott Road.

Refer to Figure 2-5 for proposed land use. Table 2-5 summarizes the imperviousness values for each municipality and study area overall for the existing and future land uses.

**Table 2-5: Existing and Future Total Impervious Areas**

| Existing Land Use | | | Future Land Use (Estimated 2030) | | |
|---|---|---|---|---|---|
| Delta Area Only | Surrey Area Only | Total Study Area | Delta Area Only | Surrey Area Only | Total Study Area |
| 18% | 49% | 26% | 24% | 58% | 32% |

### Historic Land Use

Pre-development conditions were examined to assess how the stormwater flows have changed over the past three decades. The Terms of Reference noted a 1950 Delta and 1973 Surrey land use for this purpose. The 1974 for Delta and 1976 for Surrey aerial photography is shown on Figure 2-6 as those are the best quality photos provided by the municipalities. However, it was observed that there was little change in imperviousness between the 1950s and the 1970s. The aerial photography made available did not cover the entire study area and therefore a 5% imperviousness was assumed for the historic rural development.

## 2.4 Environmental Inventory and Assessment

An environmental inventory was undertaken to summarize watershed conditions and trends, and information on water and sediment quality, benthic invertebrate communities, aquatic species and habitats, vegetation and land cover patterns, and terrestrial habitats and wildlife use. In addition, habitat restoration sites and enhancement strategies were also identified.

### Water Quality

Water quality sampling was undertaken on September 15, and 16, 2010. While one-time water quality sampling provides a limited snap-shot of parameter concentrations, it is a useful way to screen for issues of potential concern that should be managed as part of the ISMP. Because of a limited budget for sampling, water and sediment sampling did not include the replication (e.g., 5 samples in 30 days) or broader spatial sampling needed to more rigorously characterize environmental contaminants and for proper comparisons to appropriate federal or provincial guidelines. However, it is still useful to undertake such comparisons as a screening-level analysis to flag issues of concern, and as part of a weight-of-evidence approach used in ISMPs. Sampling consisted of:

1. in-situ measurements of general water quality parameters (temperature, specific conductivity, DO, pH, oxygen reduction potential (ORP), and turbidity) (28 sites in total);
2. discrete (grab) sampling for nutrients (nitrate, ammonia nitrogen, and orthophosphate), alkalinity, total suspended solids (TSS), fecal coliforms, and total metals (6 sites in total); and
3. continuous temperature monitoring at one site in the lowlands (downstream of 112$^{th}$ St near confluence with Big Slough) and one site in Shaw Creek (downstream of Old Highway 10) (operated June to September 2010).

Lab analyses were performed by ALS Environmental. Sampling sites are illustrated in Figure 2-7.

- General water quality parameter sampling results:
  - Water temperature: range = 10.63–18.32ºC, mean = 15.04ºC;
  - Dissolved oxygen: range = 1.53–10.76 mg/L, mean = 7.07 mg/L;
  - Specific conductivity: range = 83–7590 µS/cm, mean = 505 µS/cm;
  - pH: range = 5.72–7.49, mean = 6.81;
  - Total dissolved solids (TDS): range = 0.057–4.933, mean = 0.327;
  - Turbidity: range = -0.19–160.0 NTU; mean = 14.64 NTU; and
  - Oxygen reduction potential (ORP): range = -20.9–405.7, mean = 85.7.
- Watershed Creek and downstream ditches had lower water temperatures, likely due to the influx of groundwater from artesian wells in Watershed Park.
- Dissolved oxygen and pH were typically lower and specific conductivity was higher in lowland versus upland watercourses.
- Oliver Slough (at 112$^{th}$ St) had higher specific conductivity and TDS than other sampling sites.
- Elevated nitrate levels were observed in Briarwood Creek (upstream of Watershed Park slope culvert), near to but not exceeding the Canadian Council of Ministers of the Environment (CCME) guidelines for aquatic life (possibly naturally high in groundwater).
- Ammonia nitrogen and orthophosphate levels were highest in Oliver Slough near 112$^{th}$ St (possibly from agricultural runoff). No guidelines exist for these nutrients.

- Fecal coliform bacteria levels were 1600 MPN/100 ml at Oliver Slough near 112th St, well above the BC AWQG for primary contact recreation of 200 MPN/100 ml (guideline is for 5 samples in 30 days). All other sites were well below this guideline.
- Iron, aluminum, and cadmium levels were above the BC Approved Water Quality Guidelines (BC AWQGs) at one or more sites. Copper and chromium levels may also be above provincial guidelines[1].Shaw Creek (multiple sites) and Oliver Slough (at 112th St) showed the most evidence of metals concentrations at or slightly above BC AWQG's.
- It should be noted that levels of nutrients, fecal coliform, and metals in the water were assessed only from a single sample at each site. Further assessment to identify the extent of issues is needed.
- The upstream continuous temperature logger showed summer water temperatures in 2010 exceeded the BC AWQG for salmonids (maximum 17ºC for Coho and Cutthroat Trout) in Shaw Creek for 8.4 days in July 2010 and 10.3 days in August 2010. Based on the temperature differences measured in September 2010 during in-situ sampling, it is expected that Watershed Creek does not exceed this guideline on a regular basis. Data from the downstream logger (downstream of 112th St) was not available because of theft of the logger prior to the data being downloaded.

Full water quality sampling data can be found in Appendix B.

**Link to Watershed Health**

In the Shaw Creek ISMP study area, good water quality is important to protecting aquatic life and ecosystems, as well as a clean irrigation water source. In general, water quality sampling results were as expected for the level of urbanization in these watersheds and similar to other developed watersheds in Metro Vancouver. From the above analysis, priority water quality issues related to these uses are:

- Poor water quality in Shaw Creek, minor sloughs, and other lowland watercourses (including metals, nutrients, fecal coliforms, and dissolved oxygen levels), particularly Oliver Slough; and
- High summer water temperatures in Shaw Creek.

## Sediment Quality

Sediment quality sampling was undertaken on September 15, 2010. Sediment samples are also useful for long-term monitoring of stream condition because they are much less variable than water quality measurements. Sediment samples were taken at five sites (same as grab water quality samples minus one lowland site which could not be sampled) and tested for total metals. Where possible, each sample was a composite of surface and shallow sub-surface fine sediment collected from 10–15 sites from within the active stream channel. Sampling sites are illustrated in Figure 2-7.

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[1] The BC AWQG for copper is for mean of 5 samples in 30 days and BC AWQG for chromium is for trivalent chromium and hexavalent chromium separately, rather than for instantaneous total levels of this metal. In the case of total copper, instantaneous levels measured exceeded the mean guideline in Oliver Slough. For chromium, total chromium levels were above the value for hexavalent chromium and below the value for trivalent chromium in Oliver Slough. As a result, it is not possible to say with certainty whether these guidelines have been exceeded. Additional sampling and lab tests would be required.

- Arsenic levels were above the BC Working Water Quality Guidelines in Briarwood Creek (upstream of Watershed Park slope culvert) and Oliver Slough (at 112th St).
- Cadmium, chromium, and copper, and zinc levels were above the CCME's Probable Effect Levels (PELs)[2] for aquatic life in Oliver Slough (at 112th St).
- Nickel levels were above BC Working Water Quality Guidelines (BC WWQGs) in Shaw Creek (at Scott Road), Briarwood Creek (upstream of Watershed Park slope culvert), and Oliver Slough (at 112th St), zinc levels were above the BC WWQGs in Briarwood Creek, and chromium levels were above the BC WWQGs in Oliver Slough (at 112th St).
- It should be noted that levels of metals in sediments were assessed only from a single sample at each site, and in some cases this level of sampling is insufficient for comparison to appropriate guidelines (i.e., mean value based on 5 samples in 30 days required). Further assessment is needed.

Full sediment quality sampling data can be found in Appendix B.

**Link to Watershed Health**

Sediment quality is an indicator of the cumulative impacts of water pollution on watershed health. Similar to water quality, sediment quality sampling results were generally as expected given the land uses present in the watershed. From the above analysis, priority watershed health issues indicated by the sediment quality results are:

- High metal concentrations in Oliver Slough.

## Benthic Invertebrates

Benthic invertebrates (streambed insects) are useful indicators of a stream's biological condition and can be monitored over time to track changes in stream or watershed health. Benthic invertebrate community sampling provides an integrated measure of cumulative effects of watershed changes, such as urbanization, not consistently captured by water quality measurements. Standardized methods used in Metro Vancouver (see EVS, 2003 provide replication and are robust against variability and outlier values (Page et al., 2008).

Benthic invertebrate sampling was undertaken on September 15, 2010 at four stations (two in Shaw Creek, one in Briarwood Creek, one in Watershed Creek). Each station consisted of a single composite sample of three Serber sampler placements (3 min substrate disturbance each) within the same or adjacent riffles. Sampling followed the field sampling protocol described in the GVRD Benthic Macroinvertebrate B-IBI Guide (EVS, 2003) (although 1-2 samples were taken within each stream, rather than four samples within one 500 m sampling reach in a single stream). Sample processing, subsampling, taxonomic identification, and B-IBI scoring (used as an index of watershed health) was completed by Rhithron Associates (Missoula, MT). Sampling sites are illustrated in Figure 2-7.

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[2] Probably Effects Levels (PELs) are defined as "levels which, if exceeded, will cause severe effects on aquatic life" (Nagpal et al., 2006). PELs are typically 3–5 times higher than provincial or federal sediment quality guidelines, and indicate more severe levels of contamination.

- The sampling results indicate that the biological condition of Shaw Creek has been heavily impacted by human disturbance within the watershed. However, this result is similar to other Metro Vancouver watersheds with similar levels of development and is not unexpected given the high levels of urbanization and high total impervious area within the upper watershed, poor water quality in some areas, and low riparian forest integrity outside of Watershed Park (see Watershed and Riparian Forest Cover Assessment section).
- B-IBI scores across the four sampling sites ranged from 16 to 18 (Table 2-6)[3]. The overall mean B-IBI score for the watershed is 17.0 (SD 1.2).
- Across all four sites, mean taxa richness was 10.8 (SD 4.9, min 6, max 15). Variability in taxa richness accounts for the variability observed in B-IBI scores between sites.

Full taxonomic data and individual B-IBI scores are available in Appendix B.

**Table 2-6: Benthic Invertebrate Sampling Results**

| Metric | Shaw C-1 | | Shaw C-2 | | Briarwood | | Watershed | | Mean | |
|---|---|---|---|---|---|---|---|---|---|---|
| Site | Value | Score | Value | Score | Value | Score | Value | Score | Value | Score |
| Taxa richness | 15 | 3 | 7 | 1 | 6 | 1 | 15 | 3 | 10.75 | 1 |
| E richness | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1.25 | 1 |
| P richness | 0 | 1 | 0 | 1 | 0 | 1 | 2 | 1 | 0.5 | 1 |
| T richness | 2 | 1 | 0 | 1 | 0 | 1 | 2 | 1 | 1 | 1 |
| Intolerant taxa richness | 0 | 1 | 0 | 1 | 0 | 1 | 2 | 1 | 0.5 | 1 |
| Clinger richness | 3 | 1 | 1 | 1 | 0 | 1 | 5 | 1 | 2.25 | 1 |
| Long-lived richness | 1 | 1 | 0 | 1 | 1 | 1 | 2 | 1 | 1 | 1 |
| % tolerant | 7.51 | 5 | 2.49 | 5 | 1.06 | 5 | 1.91 | 5 | 3.24 | 5 |
| % predator | 3.76 | 1 | 27.07 | 5 | 19.58 | 3 | 1.20 | 1 | 12.90 | 3 |
| % dominance (3) | 84.74 | 1 | 80.39 | 1 | 94.18 | 1 | 75.84 | 3 | 83.79 | 1 |
| **Sample Score** | **16** | | **18** | | **16** | | **18** | | | |
| **Site Score** | | | | | | | | | | **16** |
| **Mean BIBI** | **17.0 (SD = 1.2)** | | | | | | | | | |

### Link to Watershed Health

B-IBI is an overall indicator of watershed health, representing the cumulative impacts of upstream development on aquatic ecosystems (e.g., changes in flow regime, water quality, instream habitat). The B-IBI index operates on a scale of 10 to 50 with 10 representing a degraded watershed and 50 representing a pristine, old growth forest watershed. Typically undeveloped watersheds in the Lower Mainland score a maximum of 40 points. The B-IBI scores measured in the tributaries in the study area

[3] Under the 10-metric B-IBI scoring system, for each metric, each sample is given a score from 1 to 5. Therefore, the minimum possible B-IBI score is 10 and the maximum score is 50 (Page et al., 2008).

indicate a high level of human disturbance but are typical of watersheds with this level of development (see Section 3.3).

## Fish Communities

Fish species present in creeks and ditches were assessed using information from a Delta-wide inventory from 2000–2003 (Rithaler and Rithaler, 2003), and the provincial Fisheries Information Summary System (FISS) database, and reports from fish salvages associated with recent instream work. No new fish sampling was undertaken as part of the ISMP.

- The known fish community in the study area consists of three salmonid species, five native non-salmonid species, and five exotic species (Table 2-7).
- Coho, chum, and cutthroat trout use the lower and transitional reaches of Watershed and Shaw creeks for spawning and rearing. Lowland ditches are used for rearing and migration to and from the Oliver Pump Station and access to Mud Bay. Chinook may also periodically move in from Boundary Bay to rear.
- Oliver Slough is also documented as fish-bearing with Coho and Cutthroat trout present in the Slough and its connected ditches (FISS, 2011). However, due to poor summer water quality, use is likely to be highly seasonal and restricted to winter months.
- Twenty-five thousand chum fry have been released annually into Watershed Creek since 2002 (Delta Parks, 2006). A small number of adults have returned to spawn. Chum salmon were likely historically present within the study area but disappeared when lowland areas were initially dyked.
- The only confirmed fish Species at Risk from the study area are Cutthroat Trout, *clarkii* subspecies (S3S4; blue-listed in BC).
- Other fish species may be periodically present in the study watersheds as a result of exchange with Mud Bay.

Fish presence (salmonids only) in the watercourses is illustrated in Figure 2-8.

### Link to Watershed Health

Fish communities are an important component of aquatic ecosystems and salmonids, in particular, are part of important commercial and recreational fisheries within the lower Fraser River area. While native fish diversity in the study area is still relatively high, the abundance of native species, and salmonids in particular, is likely much lower than historical levels. Colonization by tolerant and predatory non-native fish species is both an indicator of and a concern to watershed health.

**Table 2-7: Fish Species Presence**

| Species | | | Source(s) | Notes |
|---|---|---|---|---|
| CO | Coho Salmon | *Oncorhynchus kisutch* | Rithaler and Rithaler, 2003; FISS, 2011 | Anadromous; overwinters as fry |
| CM | Chum Salmon | *Oncorhynchus keta* | Delta Parks Dept., pers. comm. | 25,000 fry released annually (2002–10); few adults returning to spawn |
| CT | Cutthroat Trout | *Oncorhynchus clarki* | Rithaler and Rithaler, 2003; FISS, 2011 | Species at Risk (blue-listed in BC); Resident likely; anadromous may also be present |
| CH | Chinook Salmon | *Oncorhynchus tshawytscha* | FISS, 2011 | Sampled during fish sampling for golf course development; likely juveniles moving in/out from Boundary Bay |
| CAS | Prickly Sculpin | Cottus asper | Rithaler and Rithaler, 2003; FISS, 2011 | Found in more natural watercourses in study area |
| TSB | Threespine Stickleback | Gasterosteus aculeatus | Rithaler and Rithaler, 2003; FISS, 2011 | Very common and abundant throughout study area |
| BMC | Brassy Minnow | *Hybognathus hankinsoni* | Rithaler and Rithaler, 2003 | Found in more natural watercourses in study area |
| PCC | Peamouth Chub | *Mylocheilus caurinus* | Rithaler and Rithaler, 2003; FISS, 2011 | Found at single site in north end of Oliver Slough |
| BCB | Black Crappie* | *Pomoxis nigromaculatus* | Rithaler and Rithaler, 2003 | Found at single site in north end of Oliver Slough |
| RSC | Redside Shiner | *Richardsonius balteatus* | Rithaler and Rithaler, 2003 | Found at single site in Lorne Ditch at 112th St |
| BNH | Brown Catfish* | *Ameiurus nebulosus* | Rithaler and Rithaler, 2003; FISS, 2011 | Found at single site in north end of Oliver Slough |
| GC | Goldfish* | *Carassius auratus* | Rithaler and Rithaler, 2003; P. Lilley, pers. obs. | Found in Shaw Creek in Watershed Park |
| CP | Carp* | *Cyprinus carpio* | Rithaler and Rithaler, 2003; FISS, 2011 | Found in Shaw Creek above Highway 91 |
| PMB | Pumpkinseed Sunfish* | *Lepomis gibbosus* | Rithaler and Rithaler, 2003 | Found in 112th St Ditch south of Highway 10 and north end of Oliver Slough |
| * denotes a introduced (non-native) species | | | | |

## Amphibians

Three amphibian species (one native, two introduced) have also been found to inhabit aquatic areas within the study area (Table 2-8).

- Northwestern Salamanders are one of the more common amphibian species in our region. Mesic forests are the main terrestrial habitat. Breeding habitats include ponds, wetlands, lakes, road ditches, and slow moving creeks.
- Green Frogs and Bullfrogs prefer warmer water temperatures and are known to have detrimental effects on native amphibian populations, mainly through predation.

**Table 2-8**: **Amphibian Species Presence**

| Species | | Source(s) | Notes |
|---|---|---|---|
| Northwestern Salamander | *Ambystoma gracile* | Rithaler and Rithaler, 2003 | Found frequently in open wetlands, ditches, and sloughs |
| Green Frog* | *Rana clamitans* | Rithaler and Rithaler, 2003 | Found in open wetlands, ditches, and sloughs |
| Bullfrog* | *Rana catesbeiana* | Rithaler and Rithaler, 2003 | Found in ditches and sloughs south of Highway 10 |
| * denotes a introduced (non-native) species | | | |

**Link to Watershed Health**

The presence of only one native amphibian species and two non-native amphibian species indicate that wetlands in the study area have been degraded such that they are not able to sustain highly diverse native amphibian communities and that conditions favour invasive species.

## Instream Fish Habitat

Fish habitat characteristics (channel conditions, substrates, complexity, etc.) were assessed during field visits in May and September 2010. To understand the distribution of different habitat types, conditions were assessed at representative reach points (data found in Appendix B) with reaches shown in Figure 2-9.

- In general, the lowland portion of the study area has been dyked and channelized due to agricultural development. This area likely supported a complex of wetlands and interconnected channels historically. Thus, much of the historical lowland rearing habitat capacity of the watershed has been lost.
- The middle reaches in the gradient transition between lowland and upland areas historically contained the best quality fish habitat. Watercourses in the western portion of Watershed Park and in the lower reaches in the Shaw Creek ravine contain more gravel and cobble substrates suitable for spawning and rearing.
- The upper or headwater reaches of all watercourses in the ISMP study area have been culverted and developed. As a result, the overall amount of spawning habitat in the ISMP study area is limited.
- Currently, the best spawning and rearing habitat for salmonids can be found: (1) in Watershed Creek (between the BNSF railway culvert and Kittson Parkway); (2) in Shaw Creek (between the BNSF railway culvert to the bottom of the clay ravine north of Highway 10; (3) in the 60$^{th}$ Ave Ditch. Unfortunately, due to fish passage barriers, this habitat is not all available to anadromous species (see section below).
- Instream fish habitat was improved within Watershed Creek in 2006. A large oxbow adding 80 m of rearing habitat and three large riffles for chum spawning was created on the portion of Watershed Creek immediately upstream of the BNSF Railway culvert crossing within the lowland portion of Watershed Park.

**Link to Watershed Health**

Historical instream fish habitat has been degraded in the upland reaches, where spawning habitats have been culverted and replaced by development, and in the lowlands, where rearing and overwintering habitats (for species moving in from Boundary Bay) have been dyked and channelized. Although likely not a highly productive watershed historically (due to the limited size of upland spawning areas), the productive capacity of the watershed has been diminished.

## Fish Barriers

The following structures or crossings may present barriers to fish passage (see Figure 2-8):

- Oliver Pump Station: Although some fish likely do make it through the current floodbox, fish passage is likely impeded. Four new Archimedes screw pumps have been installed as part of a pump station upgrade in 2011 (R. Racine, pers. comm.) and will improve fish passage.
- Irrigation weir/dam on Lorne Ditch just west of 112$^{th}$ St (May–October) (Figure 2-8): An irrigation weir is used during the growing season to maintain water levels within the 112$^{th}$ St and associated ditches. As a result, during the dry season, all flow is diverted south down the 112$^{th}$ St Ditch. Access to Big Slough via Lorne Ditch is blocked and water levels vary by 60 cm on either side of the dam.
- 112$^{th}$ St Ditch, south of Lorne Ditch (October–May): When the irrigation weir is not in place, Rithaler and Rithaler (2003) reports that the 112$^{th}$ St Ditch channel is elevated and fish may not be able to pass through this section. Spawner access is still available to upstream areas via Big Slough and Lorne Ditch.
- Shaw Creek culvert under Highway 91 (CUL_236): This round culvert is 85 m long with a 0.9% slope. DFO's Land Development Guidelines for the Protection of Aquatic Habitat recommend that culvert slope not exceed 0.5% for culverts greater than 24 m in length (DFO, 2002). Further assessment of fish passage through this culvert is needed (see below).
- Watershed Creek culvert under the BNSF Railway (CUL_14): This round culvert is 25 m long with a 2.5% slope. Although this exceeds the recommended 0.5% slope threshold, the culvert does have a natural bottom and flows are typically maintained by influx from the artesian wells upstream. Further assessment of fish passage through this culvert is needed (see below).

- Historic weir within the Shaw Creek ravine south of Highway 10 (Figure 2-8): This old timber weir is located approximately 200 m upstream of Old Highway 10 and creates a cascading waterfall that obstructs fish passage to an additional 70-80 m of fish habitat below the upper Highway 10 culvert (which is a further barrier to fish passage).

Further work to assess culverts (listed in ascending level of effort) would be prescribed as:

1. Field visit to measure water widths and depths, high water mark (if visible), and outfall drops (if any).
2. Examination of water velocities through the culvert - would likely need to measure at different times of year but, most importantly, under range of conditions during the spawning and juvenile migration periods.
3. Fish sampling to identify fish presence on either side of the culvert.

Standard procedures for culvert inspections for fish passage can be found in Parker (2000):
http://www.env.gov.bc.ca/wld/documents/wrp/wrtc_11.pdf

**Link to Watershed Health**

The presence of several fish barriers (1 full, 4 partial) has lowered the productivity of the study area because access to some of the spawning and rearing habitat in the watersheds have been restricted. Potential exists to improve access to some of these areas through removing or modifying barriers.

## Watershed and Riparian Forest Cover Assessment

A desktop evaluation of watershed and riparian forest cover was undertaken to assess the amount and distribution of tree canopy cover within different regions of the study area and identify areas for potential riparian forest restoration. Forest cover was digitized on 2008 orthophotos. A standard 30 m buffer on either side of the stream centrelines (60 m total width) across all permanent streams was used to assess riparian forest integrity (RFI) across the study watersheds. Refer to Figure 2-9 for the locations of existing riparian corridors

- Approximately 23.1% (215.6 ha) of the Shaw Creek ISMP study area is forested. Two-thirds of this forest cover is located within Watershed Park and the Shaw Creek ravine south of Highway 10 (66.5%; 143.4 ha). The remainder is scattered throughout the study area in small forest patches in the lowland areas, smaller public parks, street medians, and private yards.
- Across the seven catchments which make up the study area, watershed forest cover ranged from 54.6% (Watershed Creek Tributary) to 6.9% (Southeast Catchment) (Table 2-9).
- Watershed forest cover was 27.0% in the Delta portion of the study area versus 10.8% in the Surrey portion. Watershed forest cover was 10.0% in the ALR portion of the study area versus 32.9% in the non-ALR portion.
- RFI in the major creeks that drain into the lowlands varies from 50.9% (Shaw Creek) to 96.6% (Briarwood Creek) (Table 2-9). Riparian forest integrity in the lowlands is much lower. The lowland ditches and sloughs have approximately 10% RFI.
- RFI is 11.8% in the ALR portion of the study area and 76.9% in the non-ALR portion of the study area.
- Overall, RFI across the study area was 31.0% which is low largely due to the lack of riparian along the lowland watercourses.

**Link to Watershed Health**

Watershed forest cover plays an important role in maintaining natural watershed hydrology through rainfall interception, capture, and evapotranspiration. The low watershed forest cover in the study area, while comparable to many Metro Vancouver watersheds with similar levels of development, means that these significant hydrologic functions have been lost during development and mitigation is required. Riparian forest cover protects streams by providing cooling shade, stabilizing banks, and supplying instream wood debris. Riparian forest integrity in this watershed is lower than most Metro Vancouver watersheds with similar levels of development, and is a particular problem in the lowlands.

**Table 2-9**: **Watershed Health Indicators – Watershed and Riparian Forest Cover**

| Watershed/ Land Area | Total Area (ha) | Watershed Forest Cover (ha) | Watershed Forest Cover (%) | Riparian Forest Cover (ha) | Riparian Forest Integrity (RFI) (%) |
|---|---|---|---|---|---|
| Watershed Ck | 137.0 | 53.6 | 39.2 | 6.7 | 84.2 |
| Watershed Ck Tributary | 66.5 | 54.3 | 81.7 | 6.4 | 88.1 |
| Briarwood Ck | 102.7 | 38.5 | 37.5 | 3.1 | 96.6 |
| Shaw Ck | 235.7 | 35.5 | 15.0 | 5.5 | 50.9 |
| Southeast Catchment | 22.7 | 6.9 | 30.2 | 0.0 | 0.0 |
| Lowlands West | 297.5 | 15.7 | 5.3 | 3.6 | 7.8 |
| Lowlands East | 69.3 | 11.0 | 15.9 | 1.4 | 13.0 |
| Delta Portion | 711.3 | 191.9 | 27.0 | 26.4 | 31.9 |
| Surrey Portion | 220.1 | 23.7 | 10.8 | 0.1 | 3.1 |
| ALR Portion | 396.3 | 39.7 | 10.0 | 7.2 | 11.8 |
| Non-ALR Portion | 535.1 | 175.9 | 32.9 | 19.4 | 76.9 |
| **Total Study Area** | **931.4** | **215.6** | **23.1** | **26.5** | **31.0** |

## Terrestrial Species and Habitat

Terrestrial species and their habitats were assessed using existing information supplemented by minor amounts of field work:

- The only confirmed terrestrial Species at Risk from the study area is Great Blue Heron, *fannini* subspecies S2S3B, S4N; Special Concern under SARA; blue-listed in BC). Additional Species at Risk that may potentially inhabit the study area based on typical habitat associations and/or that have known occurrence records within close proximity to the study area (e.g., Burns Bog) are shown in Table 2-10.
- Two red-listed ecological communities at risk in BC have been provisionally identified in the study area: (1) red alder / skunk cabbage (S2; in wet lowland areas of Watershed Park); and (2) Douglas-fir / dull Oregon-grape (S2; upland forest areas in Watershed Park with richer soils) (Table 2-11). These communities are at risk in BC due to their increasing rarity within the lower Fraser Valley and sensitivity to disturbance from development. Both habitat types are largely protected within public parklands although small unprotected fragments may exist in lowland areas.
- In addition to watercourses and riparian areas, other ecologically-important features include all types of wetlands (swamps, shrub-swamps, and sloughs), mature forest patches, old fields, seasonally-flooded fields, and scattered large trees. These features are important either for their inferred ecological value or the presence of one or more ecological communities or species of conservation concern.

### Link to Watershed Health

The presence of biodiversity is an indicator of terrestrial ecosystem health. The presence of at least one Species at Risk and two sensitive ecological communities in the study area indicates that remaining natural areas (wetlands and riparian areas, large forest patches) still maintain some function as important habitat reservoirs for biodiversity.

**Table 2-10: Confirmed and Potential Species at Risk**

| Common Name | Scientific Name | Conservation Status | | | | Status and habitat in Shaw Creek watershed | Reference(s) |
|---|---|---|---|---|---|---|---|
| | | Global Rank | Prov Rank | COSEWIC | BC List | | |
| **Fish** | | | | | | | |
| Cutthroat Trout, *clarkii* subspecies | *Oncorhynchus clarkii clarkii* | G4T4 | S3S4 | - | Blue | Confirmed present in Watershed Creek and 112th St Ditch, likely some are anadromous | Rithaler and Rithaler, 2003 |
| **Amphibians and Reptiles** | | | | | | | |
| Red-Legged Frog | *Rana aurora* | G4 | S3S4 | SC (2004) | Blue | Possible; not found in 2000–03 sampling (Rithaler and Rithaler, 2003) but could be present in forested lowlands in parts of Watershed Park | |
| **Birds** | | | | | | | |
| Great Blue Heron, *fannini* subspecies | *Ardea herodias fannini* | G5T4 | S2S3B, S4N | SC (2008) | Blue | Forages along most waterways in study area; no occupied breeding sites currently known | |
| Green Heron | *Butorides virescens* | G5 | S3S4B | - | Blue | Possible breeder in forested or shrub wetlands | |
| American Bittern | *Botaurus lentiginosus* | G4 | S3B | - | Blue | Possible breeder in forested or shrub wetlands | |
| Barn Owl | *Tyto alba* | G5 | S3 | SC (2001) | Blue | Possible breeder in barns and other structures | |
| **Mammals** | | | | | | | |
| Olympic Shrew | *Sorex rohweri* | G4G5 | S1S2 | | Red | Unlikely; known from Burns Bog (only known population in BC) | |
| Pacific Water Shrew | *Sorex bendrii* | G4 | S1S2 | E (2006) | Red | Possible in Watershed Park lowlands | |
| Trowbridge's Shrew | *Sorex trowbridgii* | G5 | S3S4 | - | Blue | Probable in forested areas of Watershed Park | |
| Southern Red-backed Vole | *Scapanus townsendii* | G5 | S1 | E (2003) | Red | Unlikely; known from Burns Bog pine forest (only known population in BC) | |
| **Invertebrates** | | | | | | | |
| Dun Skipper | *Euphyes vestris* | G5 | S3 | T (2006) | Blue | Possible; known from Burns Bog at Highway 91 near 72nd Ave | |
| Autumn Meadowhawk | *Sympetrum vicinum* | G5 | S3S4 | - | Blue | Possible; known from nearby areas of Burns Bog | |
| Blue Dasher | *Pachydiplax longipennis* | G5 | S3S4 | - | Blue | Known from several wetland areas in south Surrey; becoming more common in lower mainland | |
| **Vascular Plants** | | | | | | | |
| Vancouver Island Beggarticks | *Bidens amplissima* | G3 | S3 | SC (2001) | Red | Found in Delta along Fraser River and in Elgin Heritage Park, Surrey | |

**Table 2-11: Provisionally Identified Ecosystems at Risk**

| Common Name | Scientific Name | Conservation Status | | | Locations |
|---|---|---|---|---|---|
| | | Global Rank | Prov Rank | BC List | |
| red alder / skunk cabbage | *Alnus rubra / Lysichiton americanus* | GNR | S2 | Red | Wet lowland areas of Watershed Park |
| Douglas-fir / dull Oregon-grape | *Pseudotsuga menziesii / Mahonia nervosa* | G2 | S2 | Red | Upland forest areas in Watershed Park with richer soils, particularly southern areas above Highway 10 |

## 2.5 Hydrogeology/Geotechnical

Hydrogeological and geotechnical hazard assessments were conducted and the following observations were made.

- Poor draining till and silt & clay soils in uplands.
- Poor draining peat and silt & clay soils in a majority of the lowlands.
- Small area of well draining gravel & sand in the Watershed Creek headwaters.
- Groundwater table in the lowlands is generally high.
- Artesian wells present at the toe of the uplands in Watershed Park.

Infiltration rates were estimated for the poorly draining uplands soils (1.5 mm/hr), for the well draining gravel and sand soils (210 mm/hr) and for the lowlands soils (0 mm/hr due to high groundwater table and saturated soils). A soils map of the study area is included as Figure 2-10.

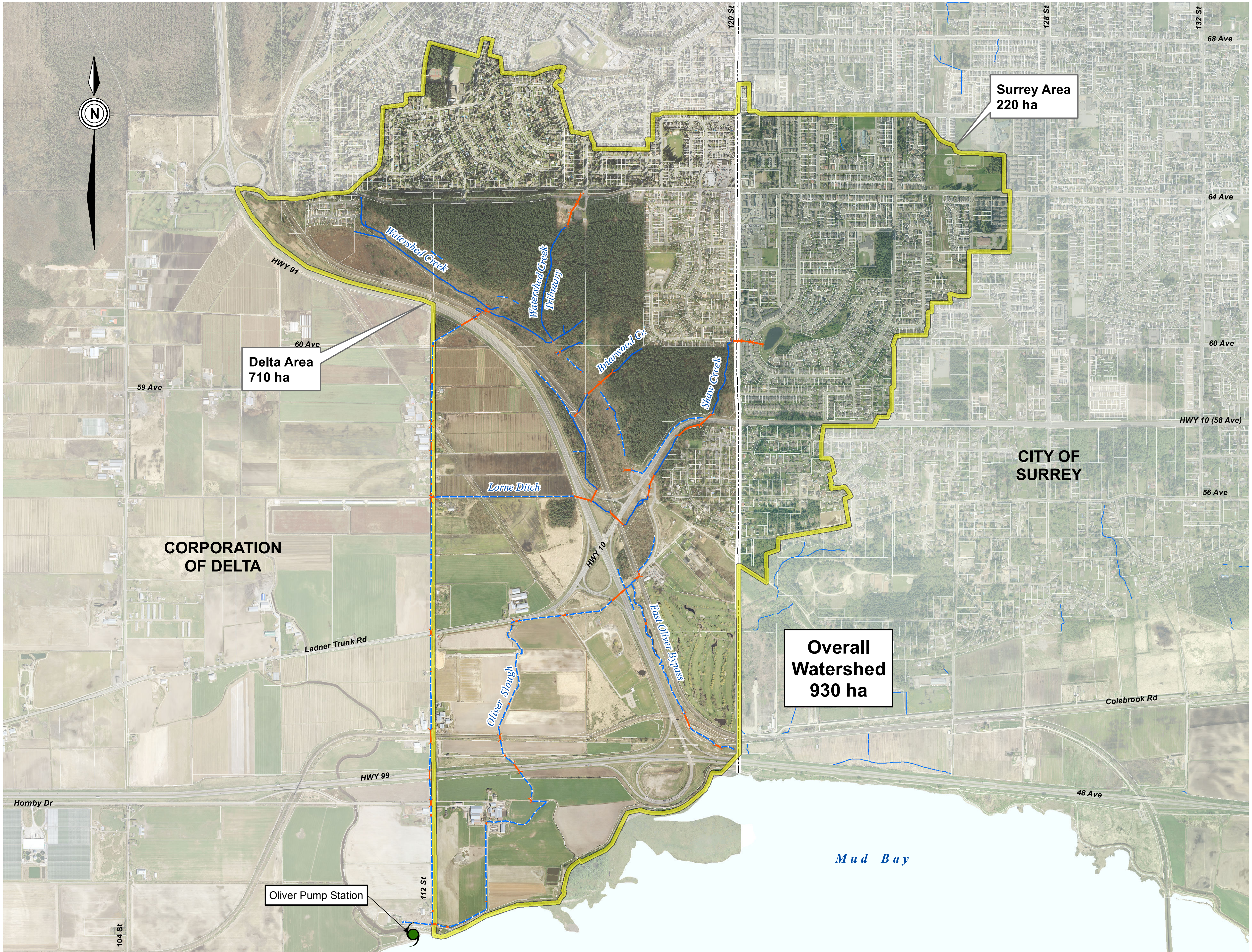
### Erosion and Ravine Instability

Trow performed a geotechnical hazard assessment (see Appendix C) and noted the following:

- Numerous erosion sites mainly in Shaw Creek (4 severe locations – see Figure 2-3).
- Historic slope instability noted along Shaw Creek in Watershed Park and below the Panorama Ridge subdivision. Potential for future failures exists.
- Continued erosion of the Highway 10 embankment adjacent to Shaw Creek may pose a risk to the highway over time.
- Erosion at the toe of steep slopes may pose a risk to the Panorama Ridge lots at the top of the Shaw Creek ravine along the southeast side of Highway 10. Toe should be protected by riprap.
- Monitoring of slope movement below Panorama Ridge along Shaw Creek is recommended.

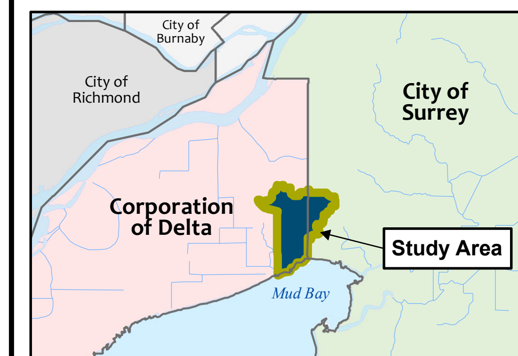
Further detailed geotechnical investigations are needed to provide specific recommendations.

**Corporation of Delta**
**Boundary/Shaw**
**Integrated Stormwater Management Study**




## Legend

- Study Boundary
- Municipal Boundary
- Culvert
- Ditch
- Creek




Location Map

Topographic, cadastral data and 2008 orthophoto provided by The Corporation of Delta and City of Surrey.

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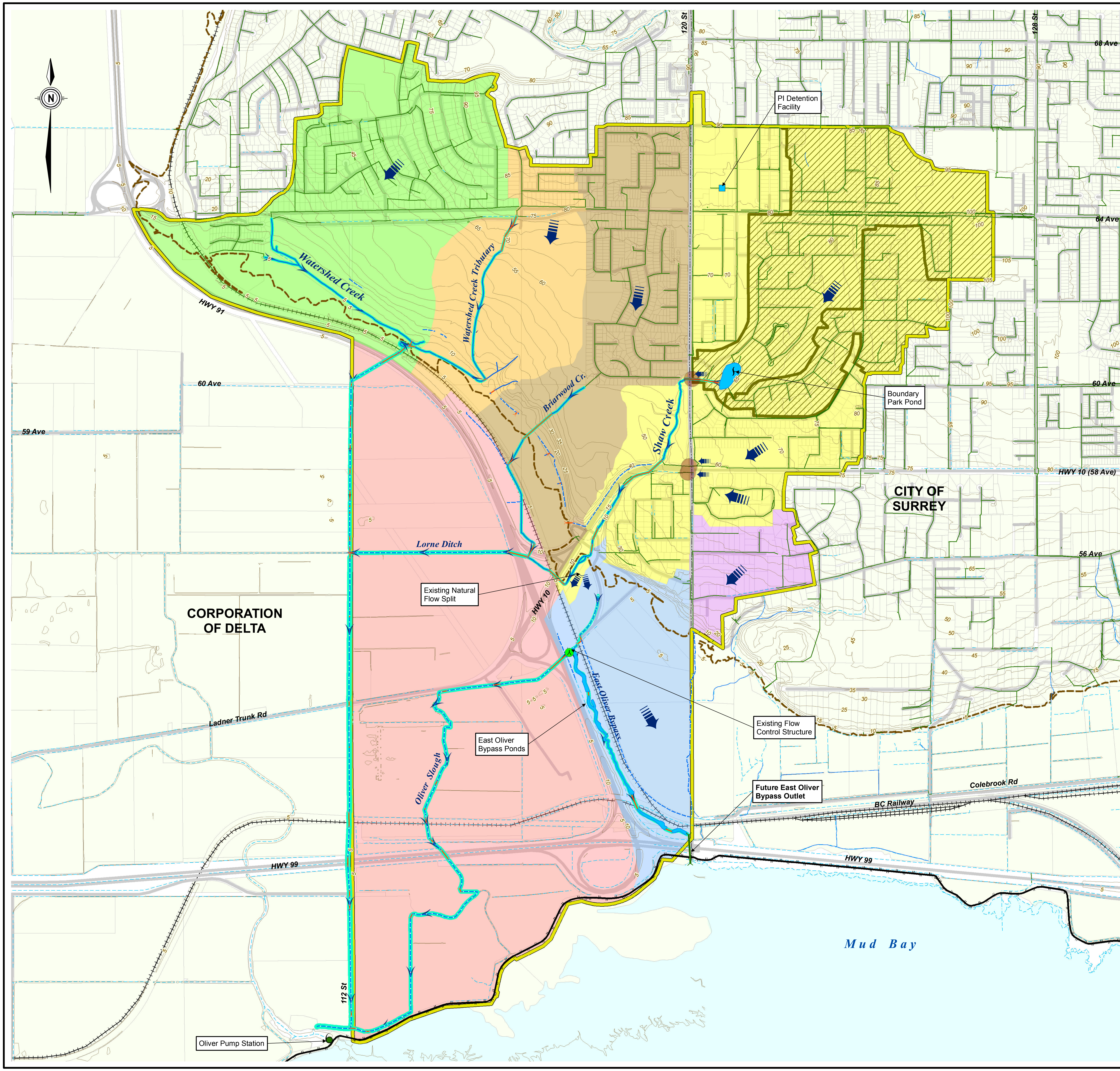
| 323-059 | January 2012 |

# 2008 Air Photo of Study Area

**Figure 2-1**

Path: O:\0300-0399\323-059\430-GIS\MXD-Rpt\323059Fig2-1_Airphoto.mxd Date Saved: 1/27/2012 9:09:34 AM
Author: jlau




Corporation of Delta
Boundary/Shaw
Integrated Stormwater Management Study

## Legend

- Study Boundary
- Municipal Boundary
- Contour (5m Interval)
- Lowland Boundary (5m)
- Railway
- Existing Dyke
- Storm Main
- Ponds/Wetland
- Culvert
- Ditch
- Creek
- Major Drainage Path
- Pond Subcatchment
- Cross Boundary Flow Location
- Overland Flow Direction

**Subcatchment**

- Watershed Creek
- Unnamed Tributary
- Briarwood Creek
- Shaw Creek
- Southeast Catchment
- Lowlands East
- Lowlands West

Topographic, cadastral data provided by The Corporation of Delta and City of Surrey.

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# Drainage Overview

Figure 2-2

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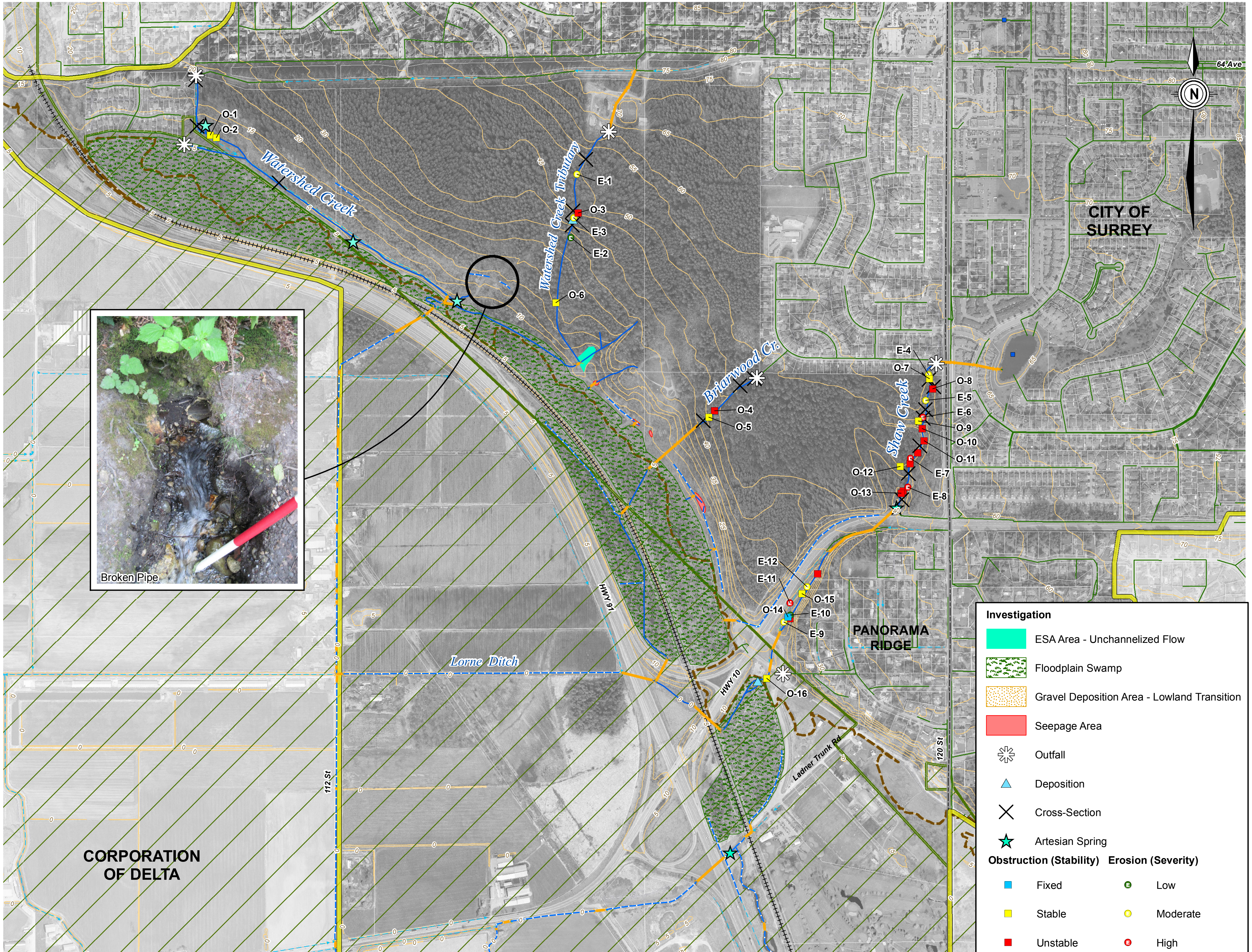
Corporation of Delta
Boundary/Shaw
Integrated Stormwater Management Study




## Legend

- Study Boundary
- Municipal Boundary
- Contour (5m Interval)
- Lowland Boundary (5m)
- Storm Main
- Culvert
- Ditch
- Creek
- ALR Boundary

Topographic, cadastral data nad 2008 orhtophoto provided by The Corporation of Delta and City of Surrey.

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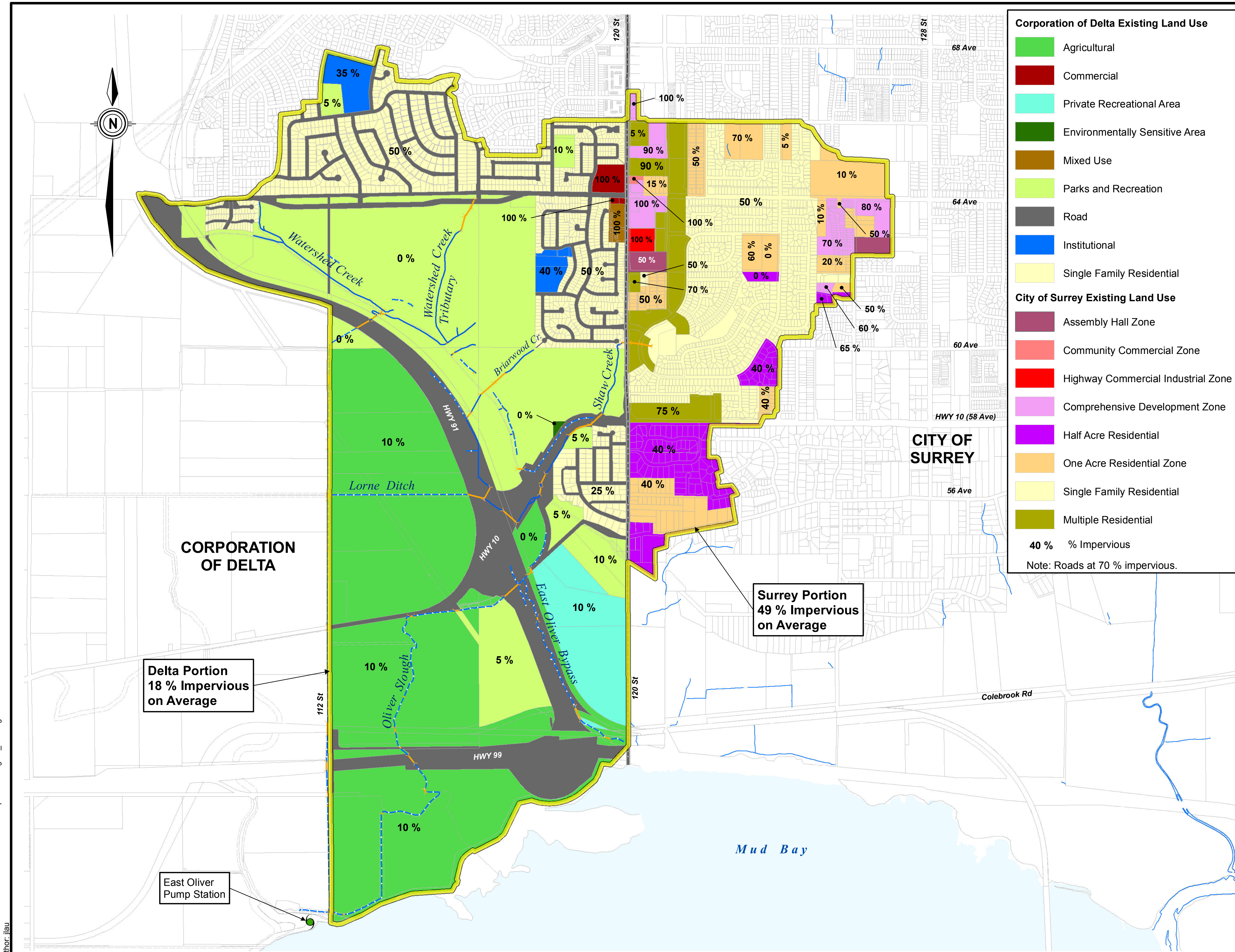
Project No. 323-059

Date January 2012

# Erosion and Obstruction Inventory (May 2010)

Figure 2-3

Path: O:\0300-0399\323-059\430-GIS\MXD-Rpt\323059Fig2-3_Inventory.mxd Date Saved: 1/27/2012 9:13:14 AM
Author: jlau




Path: O:\0300-0399\323-059\430-GIS\MXD-Rp\323059Fig2-4_ExistingLanduse.mxd Date Saved: 1/27/2012 9:14:25 AM
Author: jlau

**Corporation of Delta/City of Surrey Boundary/Shaw Integrated Stormwater Management Study**

## Legend

- Study Boundary
- Municipal Boundary
- Culvert
- Ditch
- Creek

Topographic, cadastral and land use data provided by The Corporation of Delta and City of Surrey.

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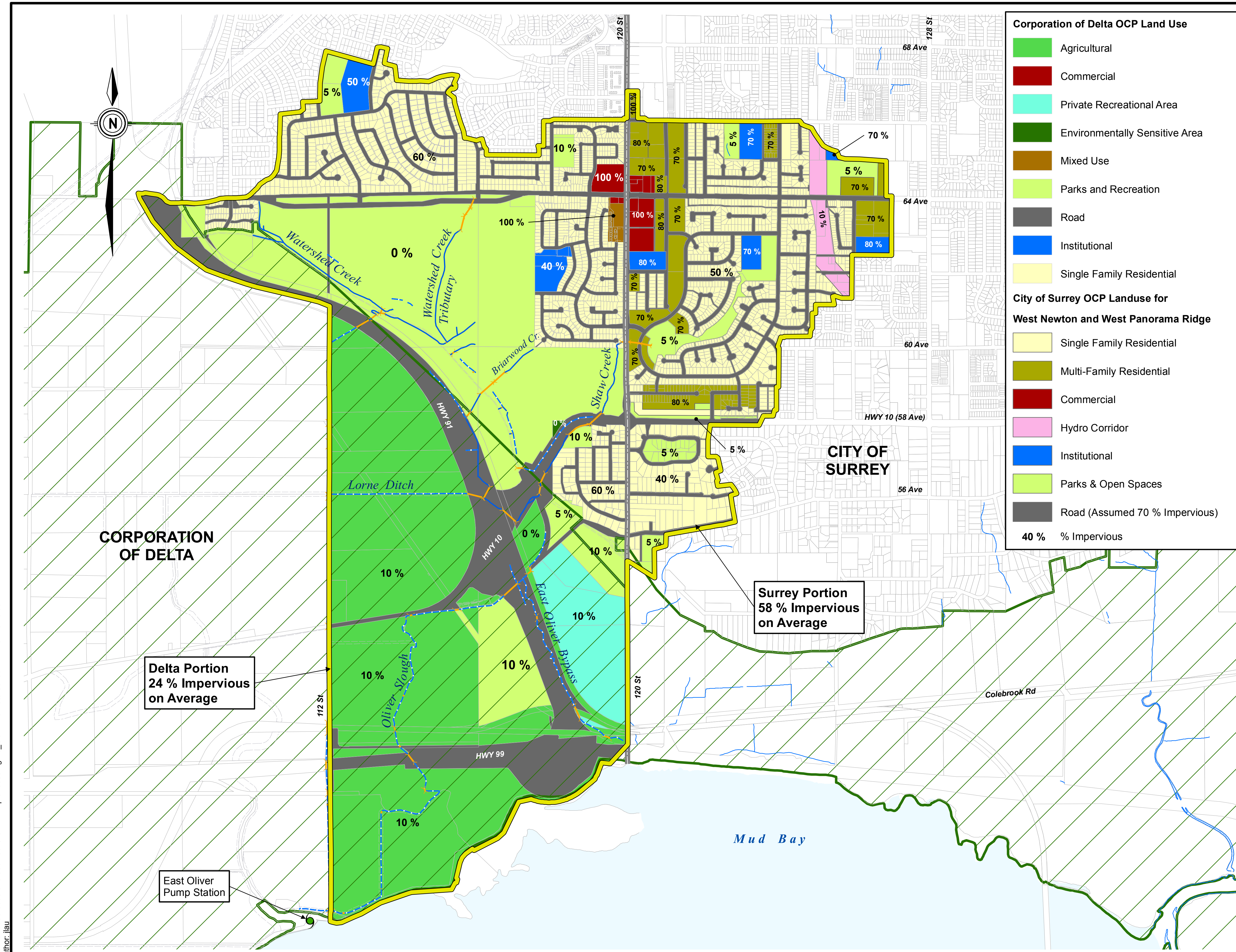
# Existing Land Use

**Figure 2-4**




Corporation of Delta/City of Surrey Boundary/Shaw Integrated Stormwater Management Study

## Legend

- Study Boundary
- Municipal Boundary
- Culvert
- Ditch
- Creek
- ALR Boundary

Topographic, cadastral and land use data provided by The Corporation of Delta and City of Surrey.

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# Future Land Use (OCP)

Figure 2-5

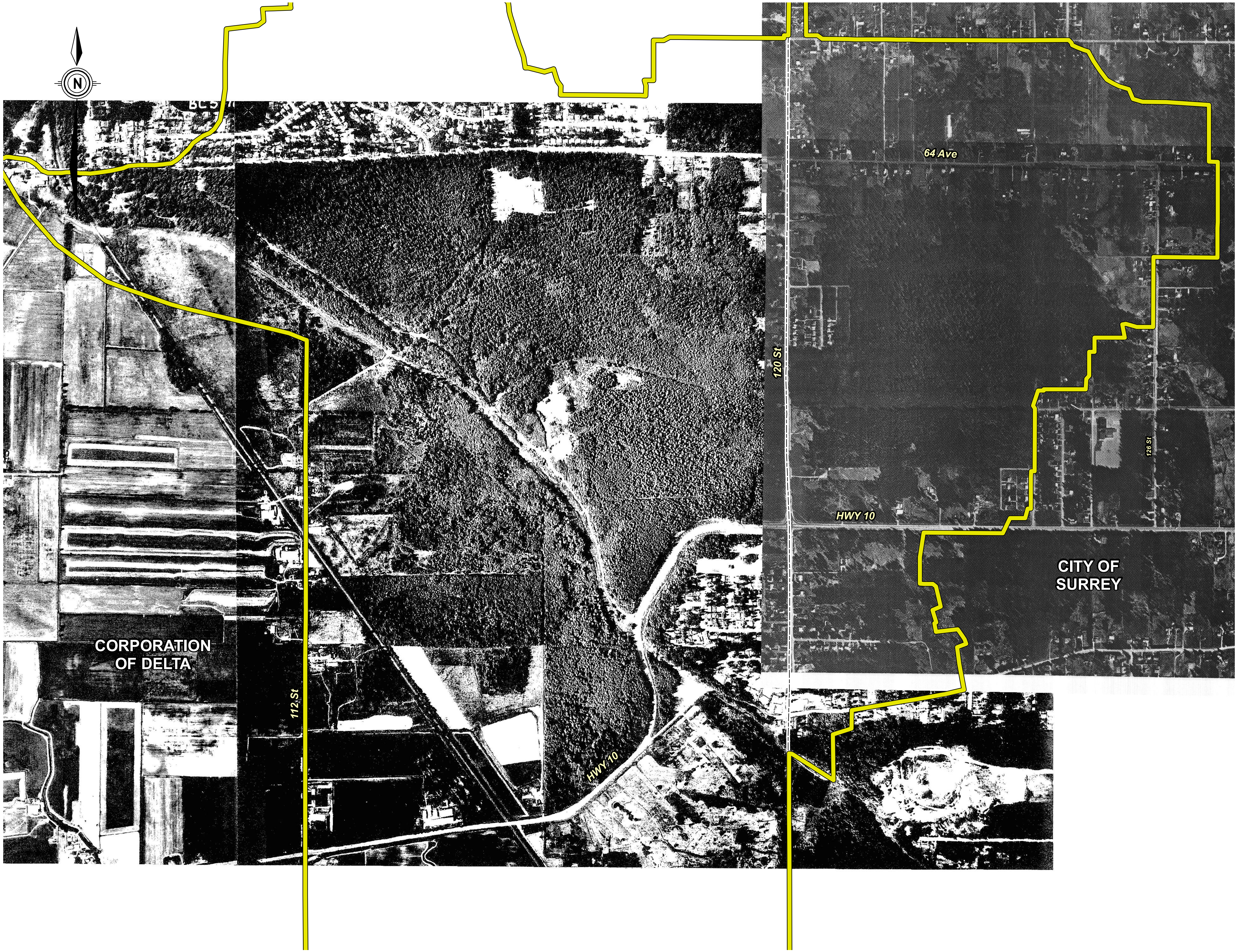
Path: O:\0300-0399\323-059\430-GIS\MXD-Rpt\323059Fig2-5_OCP.mxd Date Saved: 1/27/2012 9:16:05 AM
Author: jlau

**Corporation of Delta**
**Boundary/Shaw**
**Integrated Stormwater Management Study**

## Legend

Study Boundary

Municipal Boundary




Aerial photos provided by The Corporation of Delta and City of Surrey.

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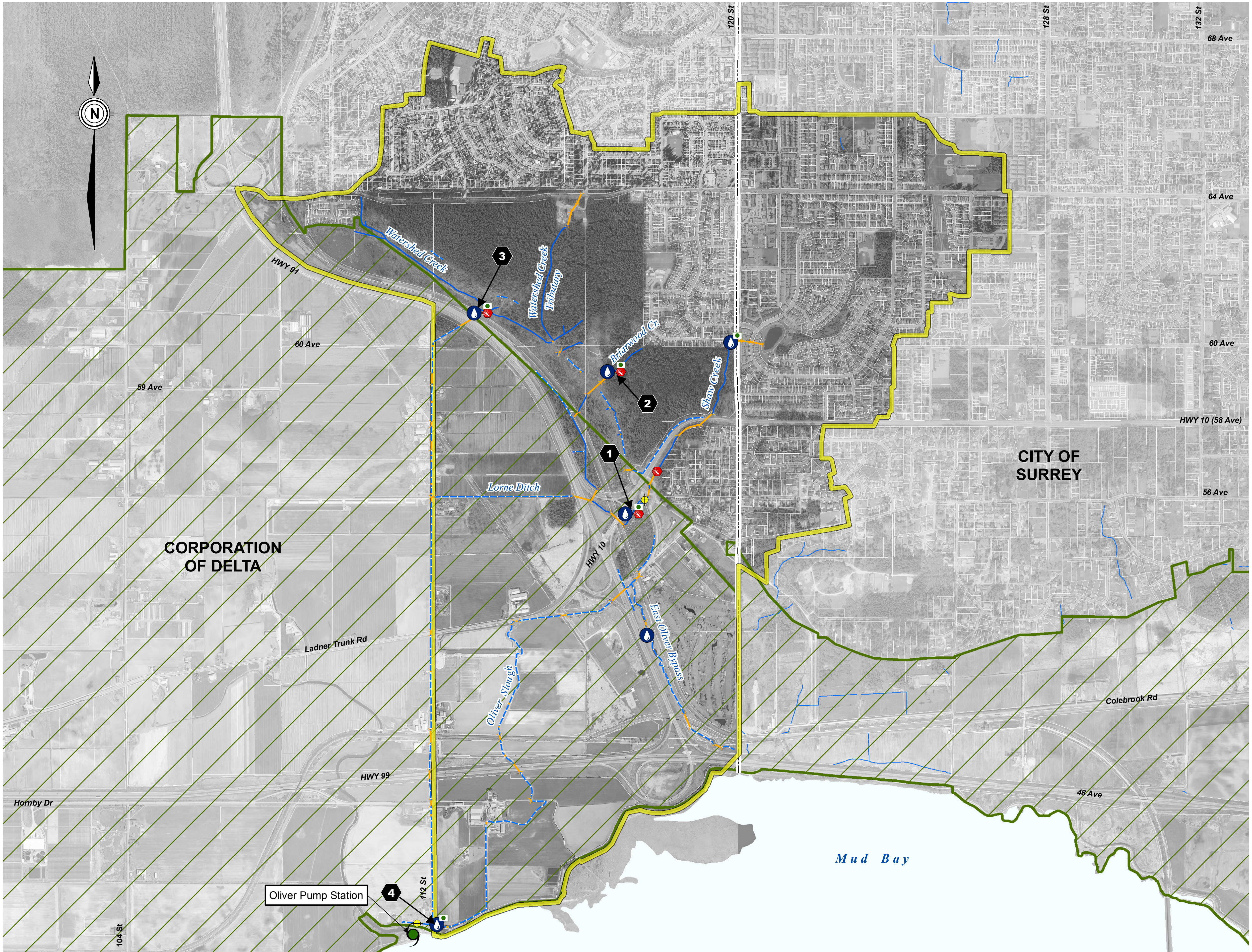
# Pre-development Land Use – Delta 1974/Surrey 1976

**Figure 2-6**


Path: O:\0300-0399\323-059\430-GIS\MXD-Rp\323059Fig2-6_AerialLanduseComparison.mxd Date Saved: 1/27/2012 9:16:57 AM
Author: jlau




## Corporation of Delta
## Boundary/Shaw
## Integrated Stormwater Management Study

**Legend**

- Study Boundary
- Municipal Boundary
- ALR Boundary

**Watercourse (Type)**

- Culvert
- Ditch
- Creek
- Benthic sites
- Water Quality Sites
- Temperature Probe
- Sediment Sampling Location
- Watershed Health Tracking System Locations

Topographic, cadastral data and 2008 orthophoto provided by The Corporation of Delta and City of Surrey.

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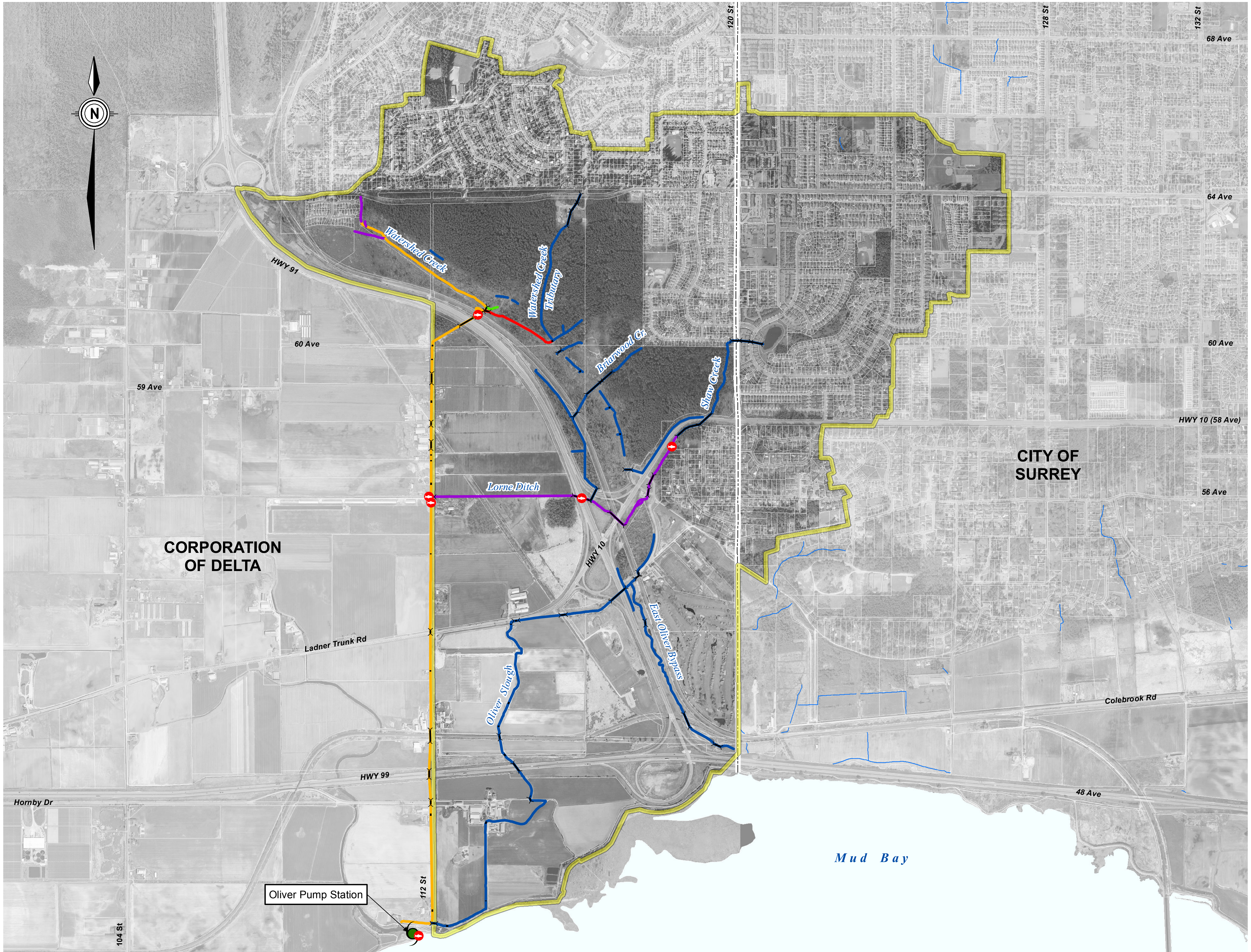
# Sampling Site Locations

**Figure 2-7**

Path: O:\0300-0399\323-059\430-GIS\MXD-Rp\323059Fig2-7_SamplingSites.mxd Date Saved: 1/27/2012 9:17:40 AM
Author: jlau




**Corporation of Delta**
**Boundary/Shaw**
**Integrated Stormwater Management Study**

## Legend

- Study Boundary
- Municipal Boundary
- Culvert
- Fish Passage Barrier

**Salminoid Presence**

- Absent
- Present - (CO)
- Present - (CO, CT)
- Present - (CO, CM, CT)
- Unknown

**Fish Type:**

CO - Coho
CM - Chum
CT - Cut Throat Trout

Topographic, cadastral data and 2008 orthophoto provided by The Corporation of Delta and City of Surrey.

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| Project No. | Date |
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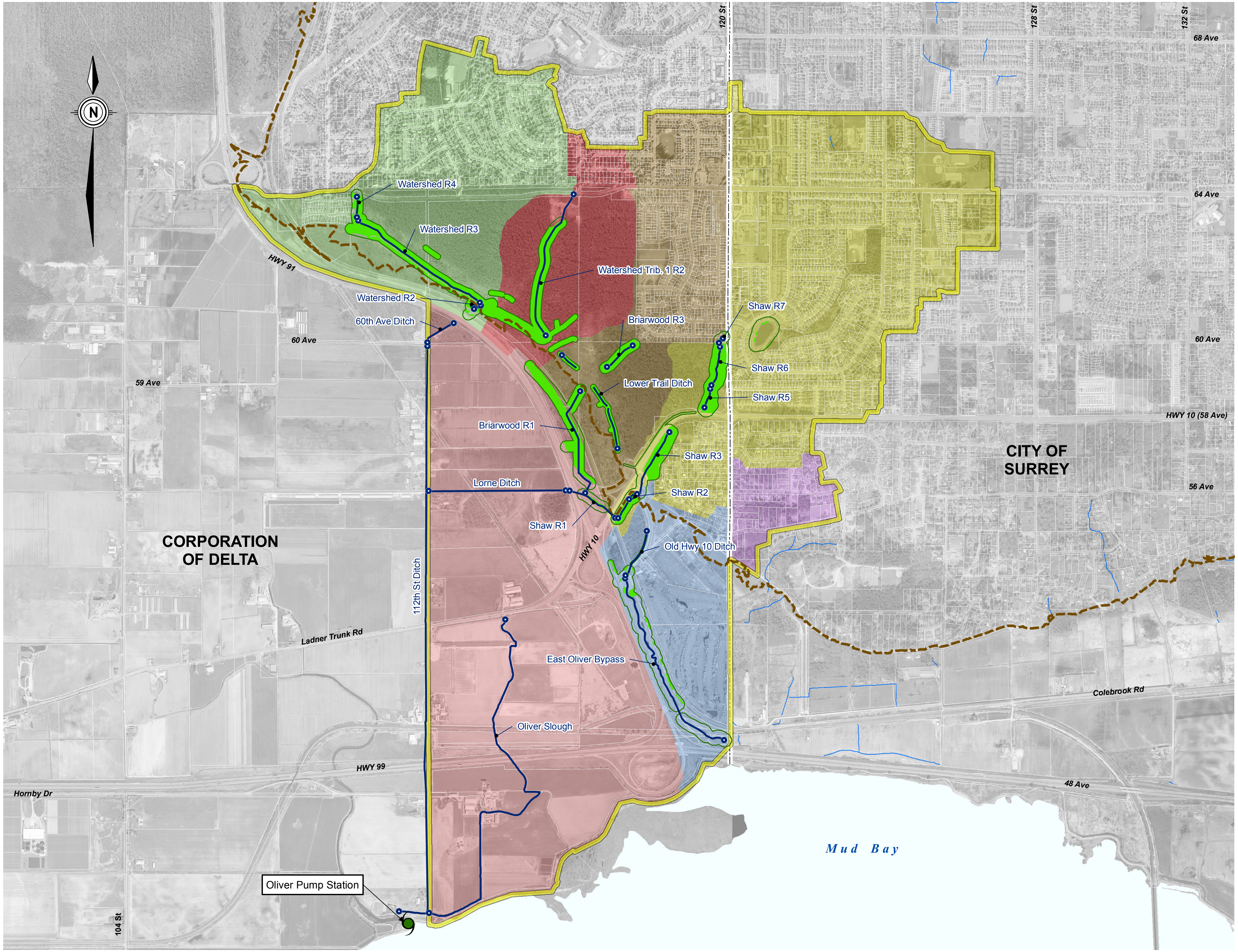
# Fish Communities

**Figure 2-8**

Path: O:\0300-0399\323-059\430-GIS\MXD-Rpt\323059Fig2-8_FishCommunity.mxd Date Saved: 1/27/2012 9:18:15 AM
Author: jlau




**Corporation of Delta**
**Boundary/Shaw**
**Integrated Stormwater Management Study**

## Legend

- Study Boundary
- Municipal Boundary
- Lowland Boundary (5m)
- Culvert
- 30 m RFI Assessment Area
- Forest Cover
- Representative Reach

**Subcatchment**

- Watershed Creek
- Unnamed Tributary
- Briarwood Creek
- Shaw Creek
- Southeast Catchment
- Lowlands East
- Lowlands West

Topographic, cadastral data and 2008 orthophoto provided by The Corporation of Delta and City of Surrey.

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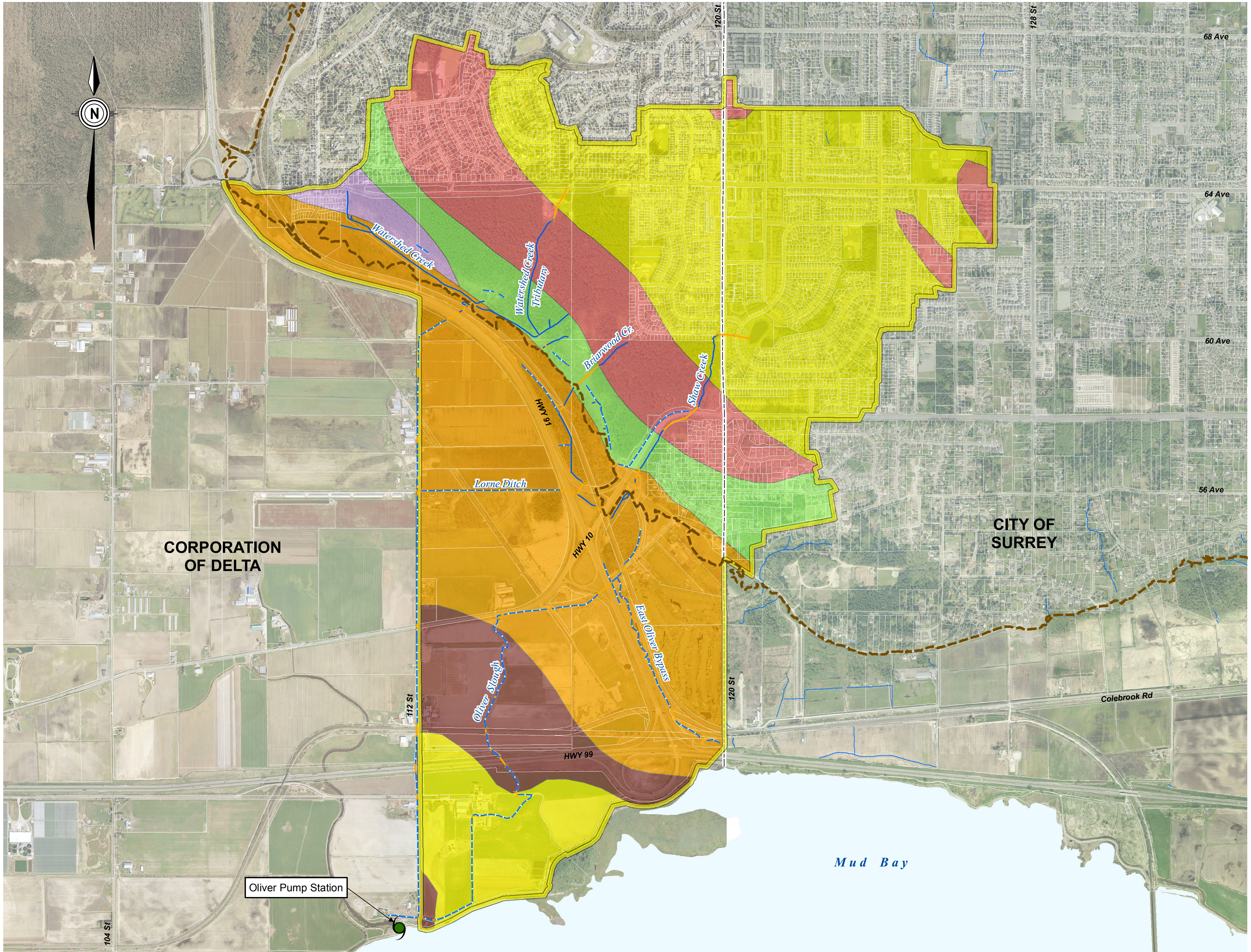
| 323-059 | January 2012 |

# Existing Riparian Corridors and Representative Reaches

**Figure 2-9**

Path: O:\0300-0399\323-059\430-GIS\MXD-Rp\323059Fig2-9_ExistingRiparian.mxd Date Saved: 1/27/2012 9:19:09 AM
Author: jlau

Path: O:\0300-0399\323-059\430-GIS\MXD-Rp\323059Fig2-10_SoilsMap.mxd Date Saved: 1/27/2012 9:20:19 AM
Author: jlau




**Corporation of Delta**
**Boundary/Shaw**
**Integrated Stormwater Management Study**

## Legend

- Study Boundary
- Municipal Boundary
- Culvert
- Ditch
- Creek
- Lowland Boundary (5 m Contour)

**Soil Material (Infiltration mm/hr)**

- Gravel and Sands (210 mm/hr)
- Peat (0 mm/hr*)
- Sand and Silt (0 mm/hr*)
- Silt and Clay (1.5 mm/hr*)
- Steepland Sediments (1.5 mm/hr)
- Till (1.5 mm/hr)

*** No Infiltration in Saturated Lowlands**

2008 orthophoto provided by The Corporation of Delta and The City of Surrey.
Surficial Geology Information: Natural Resource Canada and the Geological Survey of Canada

This information is not warranted as to its accuracy by Kerr Wood Leidal Associates and is provided for illustrative purposes only.

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| Project No. | Date |
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| 323-059 | January 2012 |

# Soils Map

**Figure 2-10**

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Section 3

# Watershed Analysis

# 3. Watershed Analysis

## 3.1 Hydrologic/Hydraulic Models

### XP-SWMM and MIKE11 Model Development

The hydrologic and hydraulic models were developed for previous work done for Delta and were updated for this project. Two models were developed for the Boundary/Shaw watershed, XP-SWMM for hydrology (RUNOFF) and upland hydraulics (EXTRAN) and MIKE11 for lowland hydraulics. XP-SWMM RUNOFF uses inputs such as rainfall and catchment characteristics (area, slope, soil type, etc.) to estimate catchment flows. XP-SWMM EXTRAN and MIKE 11 use hydraulic system inputs (culvert/pipe/channel characteristics) to simulate flow routing, water levels, and flooding.

The models were not calibrated as no recorded flow data was available. The infiltration and groundwater parameters used in the models were based on KWL's database of calibrated model parameters for similar soil conditions in the Lower Mainland. Flow monitoring could be initiated prior to detailed design of any new drainage structures or upgrades in order to validate the model.

Details of the model development and validation are provided in Appendix D.

### Design Storms

The drainage system analysis required the creation of three sets of design storms for the various scenarios that were modelled.

- The drainage system analysis was performed using design storms from the Surrey *Design Criteria Manual* (2004) for the Municipal Hall station:
  - the 2-year, 5-year, 10-year, and 100-year return period events for the 12-, 24-, and 48-hour durations;
  - the 6-month 24-hour event (72% of the 2-year 24-hour event); and
  - the ARDSA 10-year return period 2- and 5-day events.. These were used to determine whether the ARDSA criteria are met in the lowland areas.

  The rainfall amounts for each of the design storms are presented in Table D-1 in Appendix D.

### Continuous Simulation

Continuous simulation modelling was performed for the pre-development, existing land use conditions with existing flow control, and future land use conditions with existing flow control for the period of 1991 to 2009.

- Rainfall from the GVRD DT34 rain gauge, located in North Delta at 8544 116$^{th}$ Street, was used to perform continuous simulation.
- The period of data available for this gauge is November 1, 1991 to December 31, 2009 and the data was obtained from Metro Vancouver.

The results were extracted and flow durations calculated to create the exceedance duration curves (Figures D-11 to D-13 in Appendix D). These curves were used in the detention facility analysis and to analyze the hydrologic impacts of future densification. The XP-SWMM models were also used to simulate the watershed response during recent large rainfall events in the last five years plus the October and November events of 2003 to quantify the impacts of development.

## 3.2 Results of Hydrologic/Hydraulic Modelling

### Peak Flow Estimates at Strategic Locations

The XP-SWMM models were used to simulate the hydrology and upland hydraulics and to determine peak flows at strategic locations in the watershed. Flow hydrographs from the XP-SWMM models were used as inputs to the MIKE11 models (described below). The models simulated the East Oliver Bypass Ponds not connected to Mud Bay to represent the case as of 2010. Flows were estimated for the 6-month, 2-year, 5-year, 10-year and 100-year storms for the following three scenarios:

- Existing land use conditions without flow control;
- Existing land use conditions with existing flow control (existing detention and structures); and
- Future land use conditions with existing flow control.

Peak flow estimates are shown in Tables 3-1 to 3-3 below. As shown, the Watershed Creek, Watershed Creek Tributary, and Briarwood Creek flows are not influenced by the flow control as no detention or flow split structures are present in these areas. Furthermore, if left unmitigated, the future land use would increase 2-year to 100-year peak flows by approximately 5% to 10% and the 6-month flows by 20% to 40%.

**Table 3-1: Flows at Strategic Locations for Existing Land Use with Existing Flow Control**

| Location | Peak Instantaneous Flow Estimate ($m^3/s$) | | | | |
|---|---|---|---|---|---|
| | 6-month[1] | 2-year | 5-year | 10-year | 100-year |
| Watershed Creek at BNSF Rail | 0.59 | 1.77 | 2.47 | 2.95 | 4.48 |
| Watershed Cr Tributary at mouth | 0.29 | 0.88 | 1.26 | 1.50 | 2.26 |
| Briarwood Creek at BNSF Rail | 0.42 | 1.21 | 1.71 | 2.08 | 3.24 |
| Shaw Creek at 120 Street Outfall | 0.77 | 1.92 | 2.65 | 3.35 | 4.92 |
| Shaw Flow Split to Lorne Ditch | 0.82 | 1.78 | 2.29 | 2.50 | 3.18 |
| Shaw Flow Split to Oliver Slough | 0.07 | 0.15[2] | 0.19[2] | 0.24[2] | 0.32[2] |
| Shaw Flow Split to East Oliver Bypass Ponds | 0.13 | 0.50 | 0.68 | 0.76 | 0.97 |

[1] Only the 24-hour storm was simulated for the 6-month return period.
All flows are governed by the 12-hour design storm except:
[2] 48-hour duration governs

**Table 3-2: Flows at Strategic Locations for Existing Land Use with No Flow Control**

| Location | Peak Instantaneous Flow Estimate ($m^3/s$) | | | | |
|---|---|---|---|---|---|
| | 6-month[1] | 2-year | 5-year | 10-year | 100-year |
| Watershed Creek at BNSF Rail | 0.59 | 1.77 | 2.47 | 2.95 | 4.48 |
| Watershed Cr Tributary at mouth | 0.29 | 0.88 | 1.26 | 1.50 | 2.26 |
| Briarwood Creek at BNSF Rail | 0.42 | 1.21 | 1.71 | 2.08 | 3.24 |
| Shaw Creek at 120 Street Outfall | 1.16 | 3.02 | 4.13 | 4.80 | 6.79 |
| Shaw Flow Split to Lorne Ditch | 1.09 | 2.27 | 2.58 | 2.76 | 3.42 |
| Shaw Flow Split to Oliver Slough | 0.11 | 0.29[2] | 0.40[2] | 0.53[2] | 0.81[2] |
| Shaw Flow Split to East Oliver Bypass Ponds | 0.15 | 0.40 | 0.45 | 0.48 | 0.57 |

[1] Only the 24-hour storm was simulated for the 6-month return period.
All flows are governed by the 12-hour design storm except:
[2] 48-hour duration governs

**Table 3-3: Flows at Strategic Locations for Future Land Use with Existing Flow Control**

| Location | Peak Instantaneous Flow Estimate ($m^3/s$) | | | | |
|---|---|---|---|---|---|
| | 6-month[1] | 2-year | 5-year | 10-year | 100-year |
| Watershed Creek at BNSF Rail | 0.70 | 1.90 | 2.62 | 3.16 | 4.68 |
| Watershed Cr Tributary at mouth | 0.32 | 0.88 | 1.26 | 1.51 | 2.26 |
| Briarwood Creek at BNSF Rail | 0.51 | 1.35 | 1.94 | 2.32 | 3.46 |
| Shaw Creek at 120 Street Outfall | 0.99 | 2.09 | 2.84 | 3.43 | 5.12 |
| Shaw Flow Split to Lorne Ditch | 1.04 | 2.00 | 2.45 | 2.63 | 3.39 |
| Shaw Flow Split to Oliver Slough | 0.08 | 0.16[2] | 0.20[2] | 0.24[2] | 0.32[2] |
| Shaw Flow Split to East Oliver Bypass Ponds | 0.21 | 0.58 | 0.74 | 0.81 | 1.02 |

[1] Only the 24-hour storm was simulated for the 6-month return period.
All flows are governed by the 12-hour design storm except:
[2] 48-hour duration governs

Unit peak flows from the model were checked against unit flows estimated for similar creeks in the Lower Mainland. Table 3-4 shows the unit peak flow comparison.

**Table 3-4: Unit Peak Flow Comparison**

| Location | Peak Flow (L/s/ha) | | | |
|---|---|---|---|---|
| | 2-year | 5-year | 10-year | 100-year |
| *Residential Catchment* | | | | |
| Shaw Creek ISMP | 16.7 | 22.4 | 26.0 | 36.6 |
| Quibble Creek 619ha 44% TIA (Surrey) – calibrated model | 14 | 24 | - | 48 |
| Upper Serpentine 199ha 66% TIA (Surrey) – calibrated model | 19 | 29 | - | 45 |
| Surrey Design Criteria Manual - Table 5.3 (j) – SFR Runoff Design Value | 17 | - | - | - |
| | | | | |
| *Largely Undeveloped Catchment* | | | | |
| Shaw Creek ISMP | 8.4 | 12.1 | 14.6 | 23.6 |
| Mackay Creek 363ha 8% TIA (North Vancouver) - recorded | 15.4 | 22.9 | 28.3 | 48.3 |
| MacDonald Creek 394ha 9% TIA (West Vancouver) – calibrated model | 20 | - | 44 | 66 |
| Partington Creek 442ha 3% TIA (Coquitlam) – calibrated model | 15 | 23 | 24 | 39 |
| Clayburn Creek 1580ha 7% TIA (Abbotsford) - calibrated model | 5.9 | 6.1 | 8.1 | 15.1 |
| Morgan Creek 186ha 16% TIA (Surrey) – calibrated model | 6 | 8 | - | 16 |
| Archibald Creek 220ha 16% TIA (Surrey) – calibrated model | 6 | 12 | - | 24 |
| Surrey Design Criteria Manual - Table 5.3 (j) – Forested Runoff Design Value | 5 | - | - | - |

In general, the unit flows from the model were inline with the estimates for similar creeks.

Refer to Figure D-1 in Appendix D for the catchments and modelling schematic.

## Capacity Assessment

A culvert capacity assessment was performed to determine if any culverts were undersized and required upgrading. The assessment criteria were:

- For culverts under major roads (Highways 10, 91 and 99) or the railway, the culverts were evaluated using the 100-year peak flow (as per MOT and Delta criteria) limiting the surcharge time to 30 minutes.
- For culverts under minor crossings, the culverts were evaluated using the 10-year peak flow (as per Delta criteria) limiting the surcharge time to 30 minutes.
- For lowland culverts under minor crossings, the culverts were evaluated using the 10-year peak flow and a maximum head loss of 250 mm over the length of the culvert (as per Delta criteria).

The results indicated:

- Ten culverts, shown on Figure 3-1, did not meet the criteria for both the existing and future land use flows. Two creek crossings were surcharged during the 100-year event, and eight were surcharged in the 10-year event.

- Refer to Tables D-2 to D-5 in Appendix D for the results of the analysis for all culverts.

## Detention Facility Assessment

A detention facility assessment was performed to determine the effectiveness of the existing flow control facilities and to determine modifications that would improve their effectiveness using both design events and continuous simulation. Figures D-3 to D-10 in Appendix D show the detention pond hydrographs and Figure D-11 shows the Shaw Creek exceedance duration curve which is influenced by the Boundary Park Pond. Figure 2-2 shows the facility locations.

- Boundary Park Pond is being fully utilized but it is not quite able to detain the 2-year and larger peak flows to pre-development values (see red and green hydrographs on Figures D-4 to D-6 in Appendix D). There is room for improvement by adjusting the outlet control structure (see blue hydrograph on Figures D-4 to D-6); however testing showed that this would result in an increase in exceedance duration of frequent small flows.
- Boundary Park Pond reduces the flow energy to half way between undetained existing land use and historic land use flows in Shaw Creek (see Figure D-11 in Appendix D). This is reasonable as only a portion of the Shaw Creek catchment is serviced by the pond.
- Improving the Boundary Park Pond outlet has limited effect on flow energy. A larger detention volume and capture source controls would be needed for additional benefit.
- Detention Tank P1 (6455 121 St) is not being fully utilized. An orifice is needed to improve its performance. The detention volume is insufficient to reduce peak flows to pre-development even with improvements to the control structure (see Figures D-7 to D-10 in Appendix D).
- East Oliver Bypass Ponds are currently acting as offline detention to effectively reduce peak flows into the lowlands as follows:
  - 10-year 12-hour: 0.77 $m^3/s$ reduced to 0.06 $m^3/s$ (92% reduction)
  - 10-year 24-hour: 0.75 $m^3/s$ reduced to 0.11 $m^3/s$ (85% reduction)
  - 10-year 48-hour: 0.72 $m^3/s$ reduced to 0.15 $m^3/s$ (79% reduction)
  - 100-year 12-hour: 0.89 $m^3/s$ reduced to 0.11 $m^3/s$ (88% reduction)
  - 100-year 24-hour: 0.85 $m^3/s$ reduced to 0.15 $m^3/s$ (82% reduction)
  - 100-year 48-hour: 0.79 $m^3/s$ reduced to 0.25 $m^3/s$ (68% reduction)

  Their effectiveness at reducing flows to the lowlands will be further improved when the East Oliver Bypass works are completed by interconnection to Eugene Creek/Mud Bay. The East Oliver bypass 100-year peak water level is approximately 1.76 m Geodetic.

## Lowland Flooding Assessment

The MIKE11 software was used to model the lowland drainage system and determine maximum flood levels, flood durations and freeboard during baseflow for the lowland cells for the ARDSA 10-year 2-day growing season and 10-year 5-day winter events. A designated ground elevation which represents the $5^{th}$ percentile of land elevations in the cell (i.e. 95% of the land in the cell is higher than this elevation) was estimated for each cell. The catchment flow hydrographs were generated using the XP-SWMM model and input into the MIKE11 model. The criteria used for evaluation is presented in Table 1-2.

ARDSA events were run for the existing land use conditions with existing flow control and the future land use conditions with existing flow control. Peak water levels, flood durations, freeboard and designated ground elevations are shown in Tables 3-5 and 3-6 below and in Figure 3-2.

**Table 3-5: 10-Year 2-Day Peak Water Levels and Flooding Durations for the Lowland Cells**

| Cell ID | Designated Ground Elevation (m) | Existing Land Use | | Future Land Use | |
|---|---|---|---|---|---|
| | | Max. Flood Level (m) | Flood Duration (Days) | Max. Flood Level (m) | Flood Duration (Days) |
| 31E | 0.4 | 0.44 | 0.3 | 0.45 | 0.3 |
| 27E | 0.3 | 0.49 | 0.5 | 0.49 | 0.5 |
| 28E | 0.6 | 0.47 | 0 | 0.47 | 0 |
| 12E | 0.4 | 0.48 | 0.3 | 0.48 | 0.3 |
| Golf Course | 1.2 | 1.30 | 0.8 | 1.32 | 0.9 |

**Table 3-6: 10-Year 5-Day Peak Water Levels and Flooding Durations for the Lowland Cells**

| Cell ID | Freeboard (m) | Existing Land Use | | Future Land Use | |
|---|---|---|---|---|---|
| | | Max. Flood Level (m) | Flood Duration (Days) | Max. Flood Level (m) | Flood Duration (Days) |
| 31E | 0.95 | 0.48 | 0.4 | 0.48 | 0.4 |
| 27E | 1.35 | 0.50 | 0.9 | 0.50 | 0.9 |
| 28E | 1.65 | 0.48 | 0 | 0.48 | 0 |
| 12E | 1.70 | 0.49 | 0.3 | 0.49 | 0.3 |
| Golf Course | 1.70 | 1.37 | 0.9 | 1.39 | 0.9 |
| Shading indicates that the Cell fails the ARDSA freeboard during baseflow criterion. | | | | | |

The existing and future land use conditions models indicate the following:

- The existing 6 $m^3$/s Oliver Pump Station and floodboxes are adequate to meet the ARDSA flooding duration criteria in all of the lowland cells in the study area.
- The ARDSA freeboard (>1.2m) during baseflow criterion is met in four of the five lowland cells. Cell 31E does not meet the freeboard criterion (0.95m). To meet the freeboard criterion in Cell 31E, the 112 Street ditch and all culverts including Highway 10, Highway 99, and the Railway would have to be lowered. This would require the cooperation of the Ministry of Transportation and the Railway Authority. Through discussions with Delta it was determined that servicing Cell 31E for additional freeboard would not be pursued.
- Delta Golf Course flooding meets the ARDSA flooding duration and freeboard criteria.
- Future land use conditions with no drainage improvements in general do not make the depth and duration of flooding measurably worse (in the Delta Golf Course the 10-year water level may increase by 2 cm)
- With the existing drainage configuration, less than 1/4 of 10-year Shaw Creek flow is going to the East Oliver Bypass ponds. Connecting the Bypass ponds at the south end to the Eugene Creek outlet into Mud Bay would increase the amount of flow passing through the ponds thereby reducing the peak flows to the farmland.

- Delta has recently upgraded the Oliver Pump Station capacity from 6 $m^3/s$ to 9 $m^3/s$ by adding four fish-friendly Archimedes screw pumps. This upgrade occurred after the analysis was performed and therefore the results do not account for the resulting improved level of service. The existing pump ON/OFF levels are -0.8 m/-1.1 m. If possible, it is recommended that the ON/OFF levels for this new pump are set to -1.2 m/-1.6 m Geodetic for the winter condition so that the land west of 112 Street that drains towards the pump station (DGE = -0.2 m Geodetic) will receive 1.2 m of freeboard during baseflow. Higher ON/OFF pump settings would be used in the growing season to increase water available for irrigation.

The lowlands flooding with irrigation controls in place was to be assessed. However, there are no irrigation structures within the study boundary and the Oliver Pump Station settings are identical in the winter and growing seasons. KWL was informed that there are baffles installed from June to November at the Oliver Pump Station, however, no height details were available. Furthermore, the irrigation structure near 112 Street and Lorne Ditch is just outside the study area boundary and was not assessed. The only other structure present is the East Oliver Bypass control structure whose settings do not change from season to season.

## Hydrologic Impacts of Future Densification

The results of the XP-SWMM model continuous simulation and exceedance duration curves for the pre-development, existing, and future land use scenarios (Figures D-11 to D-13 in Appendix D) indicated that unmitigated future land use densification would increase the flow in Shaw, Watershed, and Briarwood Creeks, mainly for infrequent large storms and rare large floods. A 20% to 40% increase above pre-development values was also noted in the 6-month to 5-year flows for a given flow duration. This shows the need for stormwater measures to mitigate these impacts to not exacerbate erosion and avoid degradation of aquatic habitat.

The existing erosion in the portion of Shaw Creek between Highway 10 and the Panorama Ridge development should be monitored and critical locations stabilized to prevent future impacts to the Highway 10 embankment and the Panorama Ridge development.

## Watershed Performance during Recent Large Storms

The XP-SWMM models were also run to simulate the watershed response during recent large rainfall events. The results of these simulations are presented in Appendix D. The large events were run for the pre-development, existing, and future land use conditions with existing flow control.

- Six events were extracted from the continuous simulation models and presented for the Watershed Creek at BNSF Railway and Shaw Creek at 120 Street Outfall locations (see Figures D-14 to D-25 in Appendix D).
- The hydrographs show that the existing and future land use condition scenarios are similar in their response to the storms. The existing and future peak flows are higher than the pre-development peak flow especially during large dry initial condition events.

## 3.3 Watershed Health Tracking System

The watershed health was estimated using the Watershed Health Tracking System (WHTS) which uses the indicators of impervious percentage and riparian forest integrity to estimate the benthic index of biotic integrity (B-IBI) score. Figures 3-3 and 3-4 show the WHTS graphs for a number of locations in the study area as shown on Figure 2-8. Site 5 does not represent a single physical location but rather the sum of the entire non-ALR area. This point was included on the WHTS because neither the Delta Streamside Protection and Enhancement Areas Bylaw or the Riparian Areas Regulation apply to ALR land or agricultural operations and therefore Site 5 represents the portion of the study area where riparian protection is mandatory.

The B-IBI samples collected, as discussed in Section 2.5, resulted in the scores shown in Table 3-6. There was general agreement between the measured score and that predicted by the WHTS from impervious area and riparian forest integrity.

**Table 3-7: Measured and Predicted B-IBI Scores**

| Sampling Location | 2010 B-IBI Score | |
|---|---|---|
| | Measured | WHTS Predicted |
| 1. Shaw Creek at Old Highway 10 | 16 | 14 |
| 2. Briarwood Creek upstream of Culvert CUL_372 | 16 | 15 |
| 3. Watershed Creek near BNSF Railway | 18 | 20 |
| See Figure 2-8 for sampling locations. | | |

The land use analysis shows that imperviousness is predicted to increase by approximately 10%. Upland riparian corridors are expected to remain in the current condition as they are protected by the riparian bylaws and regulations currently in place. Measures will be proposed to mitigate the watershed heath impacts and perhaps to improve stream health in certain areas.

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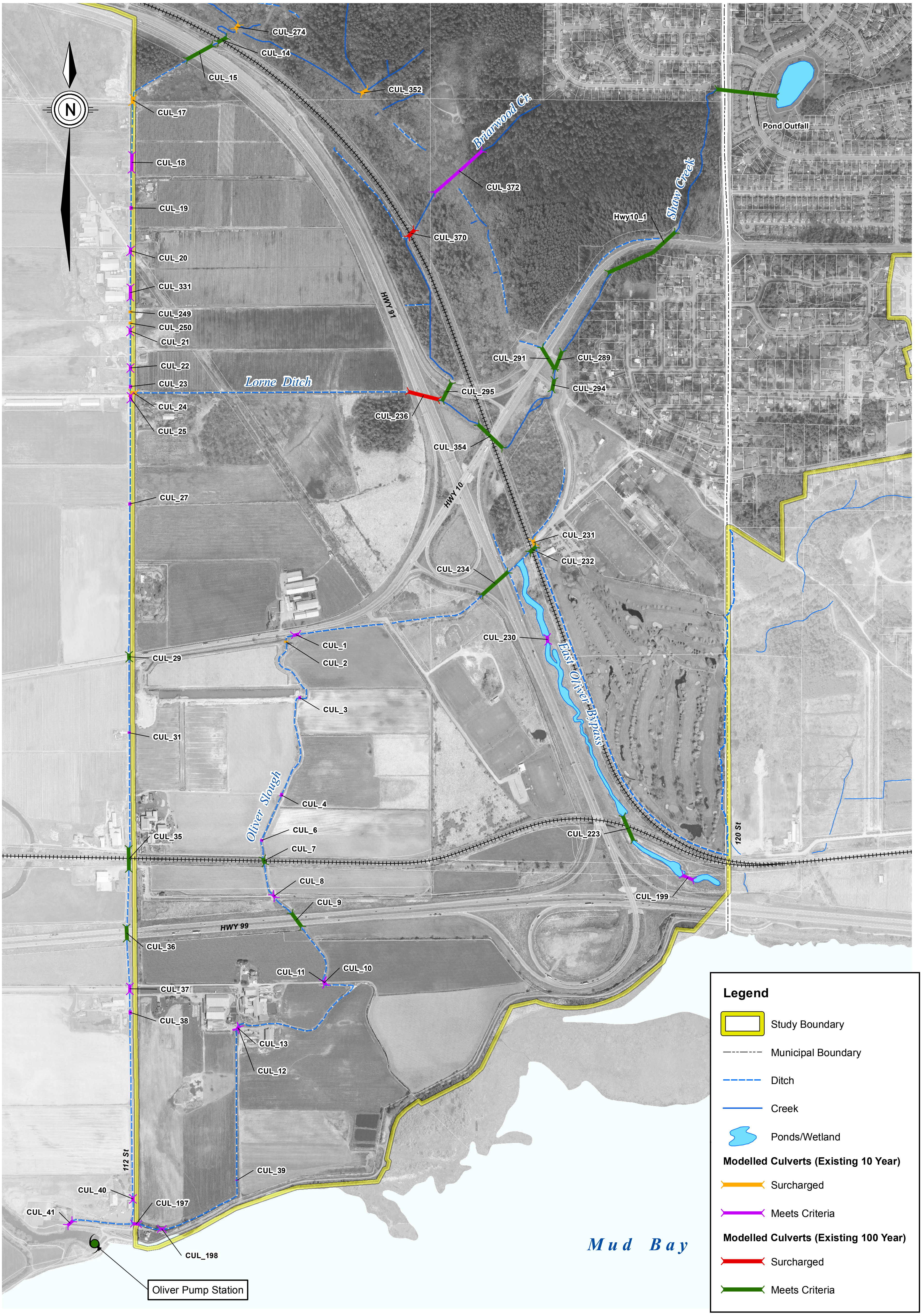
Author: jlau

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| Project No. | Date |
|---|---|
| 323-059 | January, 2012 |

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# Hydrotechnical Modelling Results - Existing and Future 10-Year and 100-Year Conveyance

**Figure 3-1**

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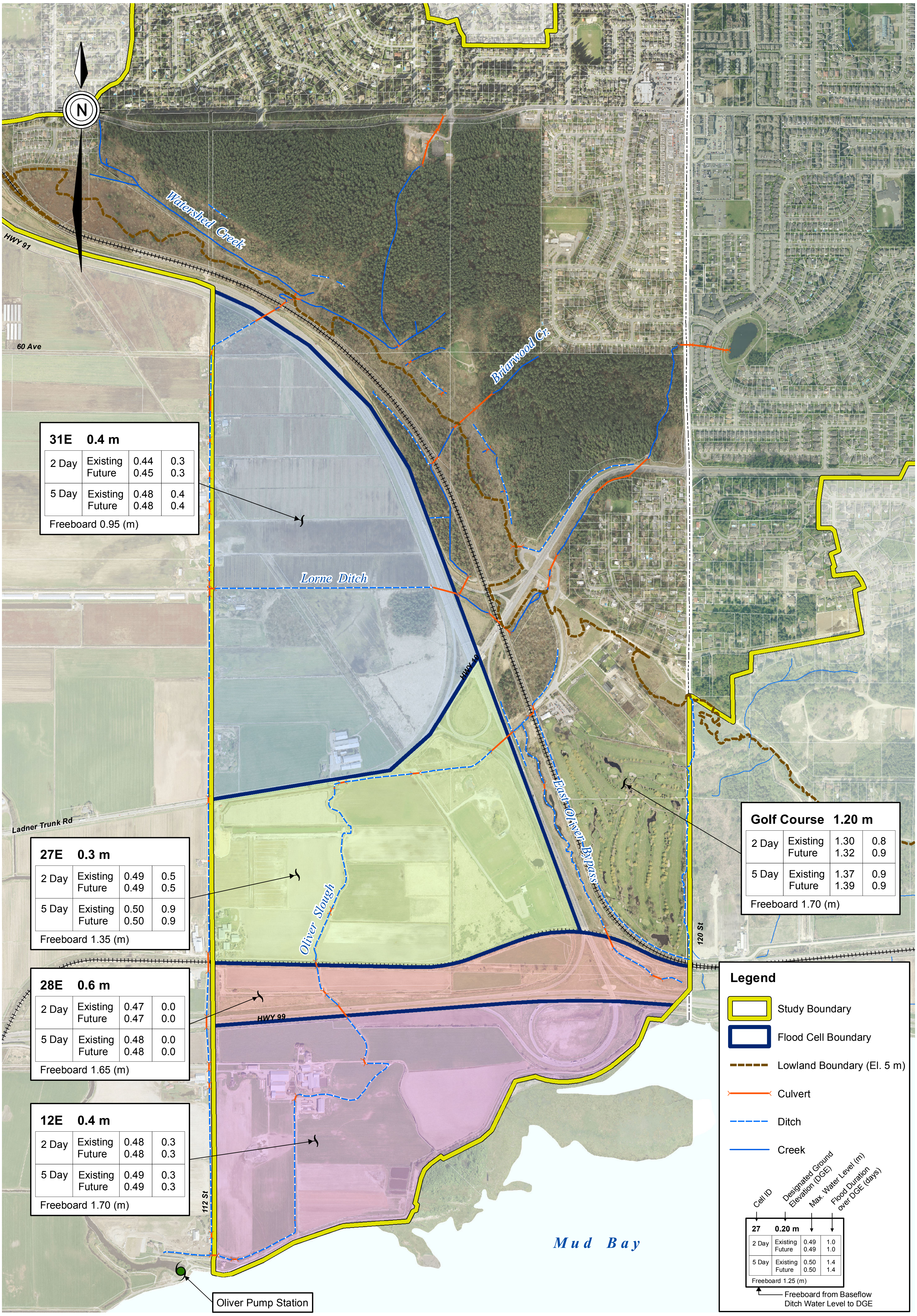
Author: jlau

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| Project No. | Date |
|---|---|
| 323-059 | January, 2012 |

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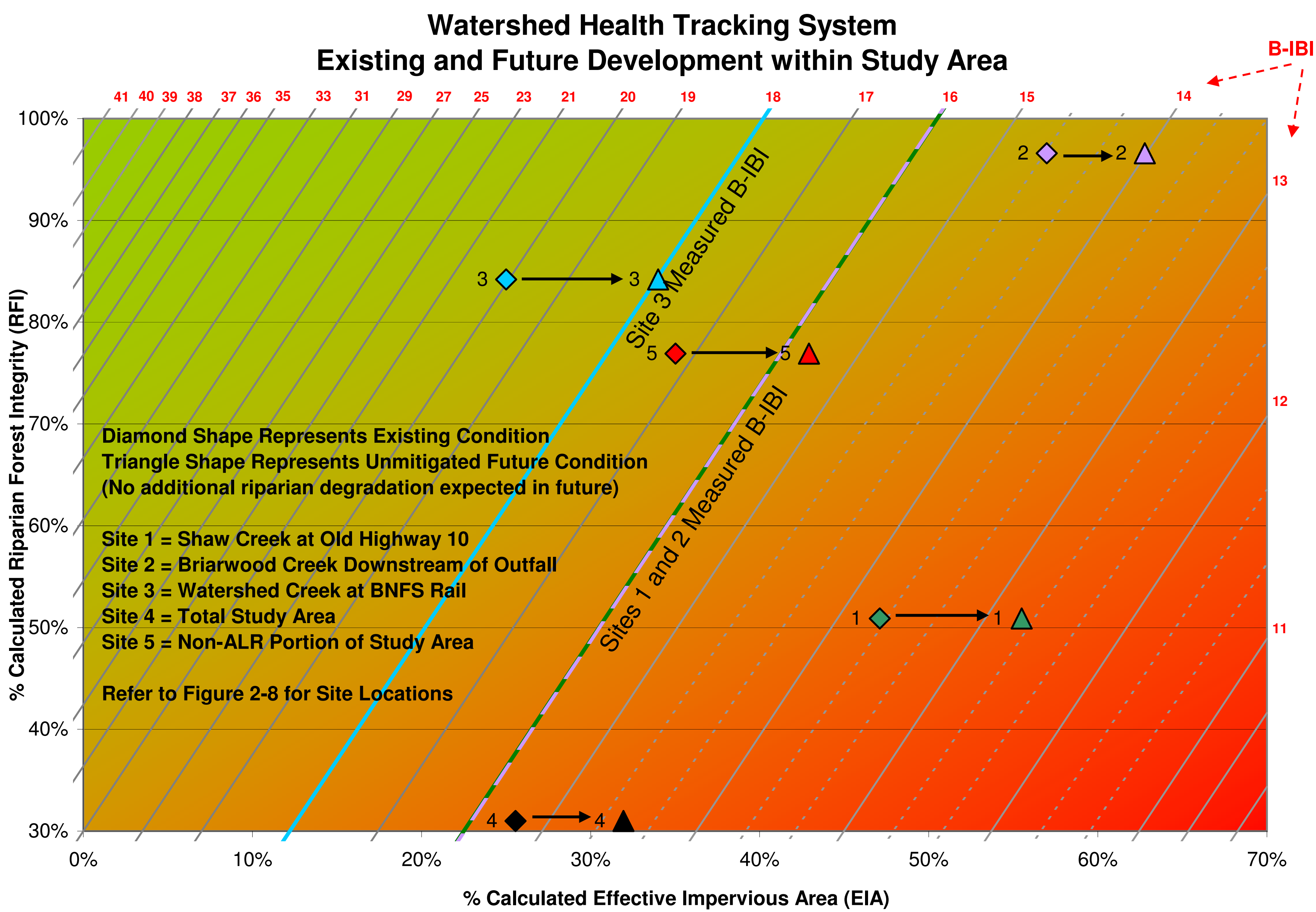
# ARDSA Lowland Flooding Extents and Durations

Figure 3-2

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O:\0300-0399\323-059\400-work\WHTS\WHTS_ShawCr_v2.xls[Fig_3-4]

**Figure 3-3**

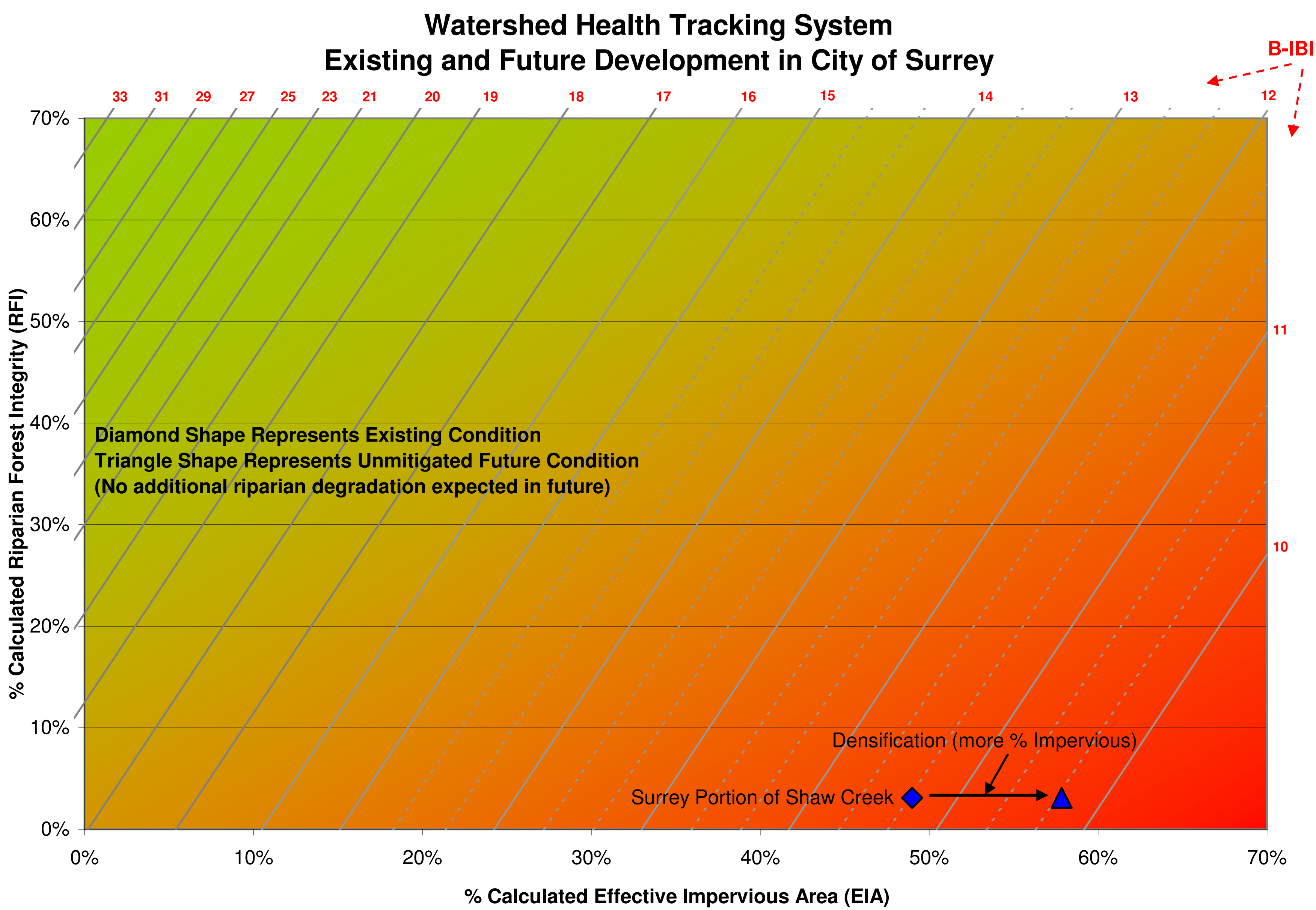


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**Figure 3-4**

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Section 4

# Mitigation Alternatives

# 4. Mitigation Alternatives

## 4.1 Introduction

Alternatives were developed to address the key issues and mitigate the potential impacts of future development and also to improve the watershed health by partially mitigating the impacts of past development. Comments from stakeholders were also used to identify projects. The hydrotechnical upgrades identified in Section 4.2 are necessary to protect property and infrastructure. The projects identified in Section 4.3 are required as a minimum to offset the impacts of future development to meet the no-net-loss of watershed health goal. The alternatives identified in Section 4.4 could be implemented to improve the watershed health above current conditions or to make up for any shortcomings in implementation of the required projects in Section 4,3. The projects listed in Section 4.4 should be viewed as potential or possible projects that vary in benefit and will not all be recommended in the proposed plan. Table 4-1 and Figures 4-1 and 4-2 summarize the alternatives considered.

## 4.2 Required Hydrotechnical Upgrades

A number of undersized culverts and priority works were identified. The proposed hydrotechnical upgrades (see Table 4-1 for details) are shown on Figure 4-1 and include:

- MOT should construct bank protection on the right bank (looking downstream) of Shaw Creek at Highway 10 south side major erosion spot (E-11).
- Delta to inspect riprap at the top end of Shaw Creek near 6007 Scott Road following all greater than 2-year rainfall events and maintain as required to fill any spots left unprotected by riprap movement and protect concrete wall toe and concrete outfall edge. Alternatively, replace riprap with a larger size that will not move during the peak design flow or construct an energy dissipater in order to reduce the flow velocities.
- MOT should construct an improved inlet and new trash rack at the Hwy 10 Shaw Creek culvert with wider bar spacing and debris interceptor upstream. This will reduce the likelihood of inlet blockage and Highway 10 overtopping.
- Delta to confirm whether accumulation is a problem at the u/s end of Briarwood Creek culvert CUL_372 and if so, remove accumulated debris more frequently to reduce the likelihood of inlet blockage and flows traveling overland down the steep bank causing erosion. Inspect monthly and after storm events. Alternatively, replace existing inlet with a standard headwall and trash rack to reduce the amount of debris accumulating on the existing grill.
- Delta to complete the construction of the East Oliver Bypass backwater berms near the Delta Golf Course as per the 2001 detailed design drawings..
- Delta to upgrade culvert CUL_274 in Watershed Park to 1,350 mm diameter pipe to prevent path from overtopping.
- Delta to upgrade culvert CUL_352 in Watershed Park to 1,050 mm diameter pipe to prevent path from overtopping.

The above list includes upgrading only 2 of the 10 culverts identified as being undersized for both the existing and future land use flows (see Tables D-2 to D-5 in Appendix D). The capacity issues for the other culverts (CUL_2, CUL_17, CUL_24, CUL_231, CUL_236, CUL_249, CUL_250, and CUL_370) may be addressed with detention and diversion works described in the alternative section below or the culverts should be replaced at the end of their design life.

## 4.3 Mitigate Impacts of Future Development

In order to meet the no-net-loss requirement of an ISMP, future development impacts need to be mitigated. This mitigation can be performed at the source or with compensation works elsewhere in the watershed. The developable portions of the watershed are already largely developed and any future densification would be from re-development. Compensation works for redeveloping parcels are an option once the potential impacts can be quantified and projects from Section 4.4 could be used to offset redevelopment impacts. However, it is difficult to estimate how much of the area will redevelop and therefore difficult to estimate the required amount of compensation works. Therefore, for the purpose of this ISMP, developers in both Surrey and Delta should apply the following source controls to allow development while not making conditions worse in the downstream creeks or in the farmlands before considering compensation works (see Figure 4-2):

- Apply volume reduction source controls on all new development and redevelopment including roadways for all areas changing from pervious to impervious in upland areas. The types of source controls for volume reduction are discussed in Appendix E. Capture 6-month 24-hour storm (40 mm) to meet the DFO Guideline and not make creek erosion worse. It can be shown that a forested catchment in the study area, even one underlain by poorly drained soils, is able to capture 40 mm of rainfall or approximately 90% or rainfall annually, resulting in only 10% runoff annually. Figure 4-3 shows the WHTS for the improvement alternatives. The line labeled “Redev. Source Controls” represents this item.
- Treat runoff from new paved surfaces, including municipal roadways, resulting from a 6-month 24-hour storm (or 90% of annual flows) to remove pollutants. The types of source controls for water quality treatment are discussed in Appendix E. This level of treatment will meet the DFO Guideline.
- Because the entire study area drains to fish bearing streams, restrict post-development flows to pre-development levels for all storms up to and including the 5-year storm on all new development and roadways and redevelopment as per the Surrey Design Criteria Manual and the DFO Guidelines. The Delta Stormwater Management Design Manual requires a further detention of the 10-year return period flows for Development in Delta. .
- Protect existing riparian areas as per the Delta Streamside Protection and Enhancement Areas (SPEA) Bylaw or the Riparian Areas Regulation (RAR). Future land use changes are not expected to result in additional riparian loss as the creeks are not in developable areas. However, losses not associated with development land use change may occur. Quantify any riparian loss within 30 m of permanent streams due to narrower-than-30 m setbacks, new creek crossings, new streamside trails, and riparian clearing on land uses where the SPEA Bylaw or RAR does not apply (for example Agriculture). Look for reforestation opportunities to compensate for any such losses.
- Replant riparian areas that are currently not forested to compensate for the any shortcomings in source controls applied to future densification. Assume 1 ha of replanting by Delta at upstream end of East Oliver Bypass as shown in Figure 4-2 to compensate for this.

## 4.4 Improve Watershed Health

The works listed in Sections 4.2 and 4.3 address existing hydrotechnical issues and mitigate the impacts of future development to achieve a no-net-loss in the watershed. There are a number of other issues in the watershed that were identified that are a result of existing conditions in the watershed (past development, agricultural use, riparian encroachment, etc.) that could be addressed to go beyond no-net-loss and in fact improve the watershed health. The alternatives for addressing these issues are divided into six categories as shown in Table 4-1 and presented below. The potential projects are shown on Figure 4-2. Figure 4-3 shows the WHTS for the improvement alternatives. The projects listed in this section should be viewed as potential or possible projects that vary in benefit and will not all be recommended in the proposed plan.

## Lowlands Drainage Improvement

Lowland owners have noted that the amount of flow entering the lowlands from the uplands has increased resulting in lower levels of service for drainage and that irrigation water is needed in the growing season. This is not unusual given that development (impervious surfaces) increases runoff and reduces the amount of evaporation and infiltration. Reduced infiltration decreases baseflows in the creeks which would be used for irrigation in the lowlands.

Even though the agricultural drainage assessment showed that the existing level of service met the ARDSA criteria for flooding in all cells and for freeboard in most cells, the following improvements (shown in orange on Figure 4-2) could be or have recently been implemented to further improve the lowlands drainage and irrigation:

- Delta will connect the East Oliver Bypass to Mud Bay and adjust the flow split between Oliver Slough and the bypass if necessary (see Figure 4-1). Maintain baseflows to Oliver Slough and divert peak flows to the bypass. This project is underway.
- Delta has increased the Oliver Pump Station capacity from 6 $m^3$/s to 9 $m^3$/s (see Figure 4-1). This project was completed in 2011.

A. Consider constructing a 900 mm dia. culvert under the railway and a channel from the downstream end of the culvert to the East Oliver Bypass to take more of the Shaw Creek high flows into the East Oliver Bypass and out to Mud Bay. A flow split structure on the upstream end of the culvert would send baseflows and low flows to Lorne Ditch and high flows to the bypass. This would likely bring culverts CUL_2, CUL_24, CUL_231, and CUL_236 closer to meeting (or in compliance with) the capacity criteria.

## Riparian Reforestation

Riparian forest integrity (RFI) is one of the major indicators of watershed health as shown on the WHTS discussed in Section 3.3. While a majority of the upland creek riparian areas are within Watershed Park and forested, there are a number of riparian reforestation opportunities in the study area (shown in green on Figure 4-2) including the following:

B. Add to the riparian planting along the East Oliver Bypass.

C. Add to riparian trees around Boundary Park Pond on the south, west, and east sides to provide shade to the pond and increase the riparian forest by 2,880 $m^2$.

D. Consider relocating Briarwood Creek away from roadways/railway in the section between Highway 91 and the BNSF railway to gain intact riparian on both sides of streams increasing the riparian by 2,800 $m^2$.

The line labeled “Riparian Reforestation” on Figure 4-3 represents the above four items.

E. Delta could encourage planting trees along the lowland ditches by working with the Environmental Farm Plan Program to increase the RFI by up to 5% in the watershed. The line labeled "Environmental Farm Practices" on Figure 4-3 represents this item.

The Environmental Farm Plan (EFP) is a voluntary program that farmers and ranchers can use to identify both environmental strengths and potential risks on their land. EFPs will help protect water quality, water quantity and biodiversity in the watershed. Because the Riparian Areas Regulation does not apply to agricultural lands, the EFP outlines practices for managing livestock access to watercourses and improving riparian vegetation to prevent bank erosion and improve fish habitat. The EFP program is initiated by Agriculture and Agra-Food Canada and is implemented at the provincial level through the BC Ministry of Agriculture and Lands (MAL), and the BC Agriculture Council. Please refer to the following website: http://www.bcac.bc.ca/efp_documents.htm

## Water Quality Improvement

The environmental inventory and sampling has identified a number of water quality issues in the watercourses. Further monitoring would be required to more conclusively identify and quantify pollutants. A number of projects could be initiated to identify pollutants and treat the water quality of outflows into the creeks (shown in blue on Figure 4-2) including:

F. Evaluate benefits of a water quality treatment wetland at top end of Watershed Creek and pipe residential runoff into it to treat runoff from a 76 ha residential catchment in Delta (80% removal of TSS).

G. Delta could monitor water quality at the outfall into the top end of the Watershed Creek tributary (at former Works Yard) to determine if there is a need for treatment. Monitor runoff from an 8.3 ha residential catchment in Delta.

H. Delta could monitor water quality at the outfall into the top end of Briarwood Creek to determine if there is a need for treatment. Monitor runoff from a 60 ha developed area in Delta.

I. Delta could monitor water quality at the outfall into the top end of Shaw Creek to determine if there is a need for treatment. Monitor runoff from the Surrey portion of the Shaw Creek catchment.

J. Consider constructing a small linear wetland along the south side of Highway 10 immediately west of Scott Road and daylight 600 mm and 300 mm storm sewers into it to partially treat runoff from an 8 ha residential catchment in Surrey (est. 40% removal of TSS).

K. Further education of residents in the catchment on the use of BMP's (ie. environmentally friendly soaps for car washing.) Also confirm that commercial facilities are discharging to sanitary and not storm sewer in order to reduce the soapy water in creeks.

E. Encourage the Environmental Farm Plan Program in order to reduce fertilizers and pesticides entering lowland channels.

L. Consider a policy to retrofit existing streets with roadside source controls (rain gardens or grassed swales) at time of redevelopment in upland areas to treat runoff from up to 40 km (Surrey) and 29 km (Delta) of roadway (80% removal of TSS). Homeowners would maintain these as part of the required boulevard maintenance.

M. Develop a policy to encourage retrofit of large parking areas by directing pavement runoff to rain gardens (e.g. Safeway parking lot and Sunrise Baptist Church and GM Dealership pavement area retrofits would reduce the EIA of 3 ha of pavement from 100% to 10%).

## Detention and Diversion to Reduce Existing Erosion

Erosion, due in part to existing development, occurs in the steep sections of creeks, especially Shaw Creek. In order to reduce this erosion, the peak flows and volumes of flows could be reduced by detaining runoff or diverting flows away from Shaw Creek with the following potential alternatives (shown in pink on Figure 4-2):

N. Evaluate benefits of constructing a high flow piped diversion from the top of Shaw Creek south on Scott Road and outlet to Mud Bay to greatly reduce the existing erosion in Shaw Creek. This would likely negate the need for riprap maintenance at the top end of Shaw Creek and the need to upgrade culverts CUL_2, CUL_24, CUL_231, and CUL_236. It may also reduce the upland flows to the Delta Golf Course reducing flooding at its south end. The pipe would need to convey approximately 1 $m^3$/s in a 10-year event which equates to a 750 mm diameter pipe at 2% grade. The line labeled “Shaw Creek Diversion” on Figure 4-3 represents this item.

## Volumetric Reduction to Mitigate Existing Development Flows

Traditional development alters the flows in the creeks by increasing the peak flows, the runoff volumes, and the frequency of flows. The existing development outflows into the creek could be improved by reducing the effective impervious area (EIA) with the following alternatives (shown in yellow on Figure 4-2):

M. Develop a policy to encourage retrofit of large parking areas by directing pavement runoff to rain gardens (e.g. Safeway parking lot and Sunrise Baptist Church and GM Dealership pavement area retrofits would reduce the EIA of 3 ha of pavement from 100% to 10%).

O. Consider a rain garden in the parkette leading to the Boundary Park Pond and daylight the Boundary Drive East storm sewer into it. This would reduce the EIA of a 9 ha residential area from 60% to 10%. The line labeled “Regional Rain Gardens” on Figure 4-3 represents the above two items.

P. Develop a policy to construct full volume reduction source controls during redevelopment/ densification to not only maintain EIA at existing values but reduce the EIA to less than existing on-site values to reduce the overall study area EIA to less than existing (2010) values. The line labeled “Retrofit Lots” on Figure 4-3 represents this item.

Q. Evaluate volunteer program to help homeowners install rain barrels on existing single family development in Surrey to reduce potable water usage and increase rainfall capture.

R. Allow disconnected roof leaders directing roof runoff to landscaped areas on existing single family development in Delta and initiate a volunteer program to help homeowners do so. This would reduce the EIA of approximately 120 ha of residential area by approximately 30%.

S. Surrey and Delta could initiate a volunteer program to help home owners plant trees on their properties to increase evapotranspiration and reduce runoff volumes to creeks.

L. Surrey and Delta could develop and implement policy to retrofit existing streets with roadside source controls in upland areas to reduce the EIA from 100% to 10% of approximately 70 ha of roadway in the study area. This is the same policy referred to in the water quality section as source controls would provide both capture and treatment. The line labeled “Retrofit Roads” on Figure 4-3 represents this item.

### Fish Habitat Improvements

A number of instream works could be undertaken to improve the conditions for fish including (shown in purple on Figure 4-2):

- Delta connecting the East Oliver Bypass to Mud Bay will provide rearing habitat for juvenile salmon moving in from the Bay (see Figure 4-1).

T. MOT could remove a fish passage obstruction (old weir) in Shaw Creek along south side of Highway 10 to improve fish access to 70 to 80m of channel.

U. BNSF and MOT, could improve fish passage through the Watershed Creek culvert under railway (CUL_14) and the Shaw Creek culvert under Highway 91 (CUL_236) by adding fish baffles or rock weir. This would improve fish access to approximately 2 km of channel.

V. MOT could create fish habitat along Shaw Creek between Old Highway 10 and the BNSF Railway to enhance 150 m of channel.

## 4.5 Evaluation of Potential Projects

The hydrotechnical upgrades listed in Section 4.2 and the mitigation measures listed in Section 4.3 mitigate the impacts of future development and address existing conveyance capacity issues. These are required to meet the no-net-loss in the watershed. The various projects listed in Section 4.4 go beyond a no-net-loss to improve the conditions in the watershed offsetting impacts of existing and historic development.

It is difficult to compare the costs/benefits of the various optional projects because they achieve different types of improvement benefits that cannot be readily converted to a common value system. Some improve water quality while others reduce runoff or provide riparian benefits. Through discussions with Surrey and Delta, however, the projects were assigned a timeline and importance which results in a prioritization. A capital cost was also estimated for the construction projects as shown in Table 4-1.

The Green Growth Index (GGI) was adapted to evaluate the potential projects using the leaf/branch/tree rating system where a leaf represents some benefit, a branch represent more benefit, and a tree represents the most benefit. These symbols were incorporated in Table 4-1.

The various options and projects were discussed with Surrey and Delta and the majority of them were selected to be incorporated into the ISMP as presented in the next section.

**Table 4-1: Issues and Improvement Alternatives**

| Key Issue | Potential Project | Benefit | Capital Cost Estimate | Timeline | Priority | Action By | GGI | Comment | Recommen-ded (Y/N) | Identified By |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Erosion and Sedimentation*** *- See Figure 4-1 for Locations* | | | | | | | | | | |
| Major Creek Bank Erosion | Construct bank protection on right bank of Shaw Creek at Highway 10 south side major erosion spot (E-11). | Protect Hwy 10 embankment at major scour. | $ 40,000 | Short Term | High | MOT | | | Y | KWL/Trow |
| Riprap Movement and Scour at Lock Block Wall | Inspect riprap at the top end of Shaw Creek directly d/s of Boundary Pond outfall at Scott Rd following all greater than 2-year rainfall events and maintain as required. | Fill any spots left unprotected by riprap movement and protect concrete wall toe and concrete outfall edge. | $ - | Short Term | Medium | Delta | | Recommended option (potential cost share with Surrey) | Y | Stakeholders |
| | Or Replace riprap with larger size. | Protect toe of lock block wall and end of outfall headwall and prevent riprap movement. | $ 70,000 | Medium Term | | | | Difficult due to access | N | |
| | Or Construct an energy dissipator. | Reduce flow velocity to below existing riprap erosion threshold. | $ 340,000 | Short Term | | | | Costly solution | N | |
| Debris Accumulation and Inlet Capacity | Improve inlet and new trash rack at Hwy 10 Shaw Creek with wider bar spacing and debris interceptor upstream. | Reduce the likelihood of inlet blockage and Highway 10 overtopping. | $ 100,000 | Medium Term | Medium | MOT | | | Y | Delta |
| Debris Accumulation | Confirm if accumulation is a problem and if so, remove debris more frequently at u/s end of Briarwood Creek culvert CUL_372. Inspect monthly and after storm events. | Reduce the likelihood of inlet blockage and flows traveling overland down the steep bank (erosion). | $ - | Short Term | | Delta | | | Y | KWL |
| | Or Replace existing inlet with a standard headwall and trash rack to reduce the amount of debris accumulating on the existing rack. | Reduce the likelihood of inlet blockage and flows traveling overland down the steep bank (erosion). | $ 60,000 | Medium Term | To be determine d | | | Monitor accumulation first | N | |
| ***Hydrotechnical Improvements (Requirement)*** *- See Figure 4-1 for Locations* | | | | | | | | | | |
| Golf Course Flooding | Complete the construction of the East Oliver Bypass backwater berms near the Delta Golf Course as per the 2001 detailed design drawings. | Prevent existing major event overflows and future minor event overflows if more water is directed towards the Bypass. | $ 60,000 | Medium Term | Medium | Delta | | This might not be needed if new culvert is installed under railway (see below). | Y | KWL |
| Culvert Capacity | Upgrade two high head loss culverts in Watershed Park. Upgrade culverts CUL_274 to 1,350 mm & CUL_352 to 1,050 mm dia. pipes (Figure 3-1). | Prevent path overtopping in Watershed Park & meet Delta criteria. | $ 80,000 | Medium Term | Low | Delta | | Path estimated to overtop annually with existing pipe sizes. | Y | KWL |
| | Allow culverts CUL_17, CUL_249 and CUL_250 to surcharge in the near term and replace at end of life with larger sizes (Figure 3-1). | Meet the Delta capacity criteria. | $ - | Long Term | Low | Delta | | | Y | KWL |
| | Allow culverts CUL_2, CUL_24 and CUL_231 to surcharge in the near term and replace at end of life with larger sizes (Figure 3-1). | Meet the Delta capacity criteria. | $ - | | Low | Delta | | Culverts would have sufficient capacity if diversion constructed (see below) | Y | KWL |
| | Allow culvert CUL_236 to surcharge in the near term and replace at end of life with larger size (Figure 3-1). | Meet the MOT capacity criteria. | $ - | | Low | MOT | | CUL_236 would have sufficient capacity if diversion constructed (see below) | Y | KWL |
| | Allow culvert CUL_370 to surcharge in the near term and replace at end of life with larger size (Figure 3-1). | Meet the Delta capacity criteria. | $ - | | Low | BNSF | | | Y | KWL |

Note: GGI is the adapted rating system of Delta's Green Growth Index that shows the relative amount of environmental benefit of the works. A leaf sysmbol represents some benefit, a branch represents more benefit, and a tree represents the most benefit.

**Table 4-1: Issues and Improvement Alternatives**

| Key Issue | Potential Project | Benefit | Capital Cost Estimate | Timeline | Priority | Action By | GGI | Comment | Recommen-ded (Y/N) | Identified By |
|---|---|---|---|---|---|---|---|---|---|---|
| *Hydrologic Mitigation of Future Development/Densification (Requirement)* - *See Figure 4-2* | | | | | | | | | | |
| Reduce Erosive Flows from Development | Implement policy to apply volume reduction source controls on all new development / redevelopment including roadways. Capture 6-month 24-hour storm (40 mm) to meet the DFO Guideline & mitigate creek erosion. | Restore pre-development hydrology on densifying parcels and roads to minimize EIA increase of additional impervious surfaces. | Developer | At Time of Dev. | High | Surrey Delta | | An option would be to stabilize the steep sections of Shaw and Briarwood Creeks but this would have negative impacts on creeks. | Y | KWL |
| Treat Water Quality from Development | Treat runoff from new paved surfaces, including municipal roadways to remove pollutants using biofiltration or manufactured systems (swales, rain gardens, oil/grit separators, etc. ). | Remove pollutants from proposed additional travelled surfaces to meet DFO WQ Guideline. | Developer | At Time of Dev. | High | Surrey Delta | | An option would be to construct regional WQ facilities but this would require land. | Y | KWL |
| Reduce Peak Flows from Development | Detain post-development flows to pre-development levels for all storms up to and including the 10-year storm for all new development, new roadways, and redevelopment using onsite detention facilities. | Maintain the peak flows at existing levels to meet the DFO, Delta, and Surrey requirements. | Developer | At Time of Dev. | High | Surrey Delta | | An option would be to construct regional detention facilities or stabilize the steep sections of Shaw and Briarwood Creeks. | Y | KWL |
| Development within Riparian Areas | Protect existing riparian areas as per RAR. Quantify any riparian loss within 30m of permanent streams due to narrower-than-30m RAR setbacks, new creek crossings, new streamside trails, and riparian clearing on land uses where RAR does not apply (Agriculture). | Maintain existing level of watershed health by ensuring no-net-loss of riparian area. Future land use changes are not expected to result in additional riparian loss. | $ - | Ongoing | Medium | Surrey Delta | | Delta SPEA Bylaw and RAR do not apply to ALR. | Y | KWL |
| Riparian Planting Compensation for Densification | Replant riparian areas that are currently not forested to compensate for riparian losses using a 1-for-1 compensation ratio if performed before the loss incurred or 2-for-1 compensation ratio if performed after loss incurred. | Densification with source controls may still increase EIA and 1 ha of riparian replanting at the upstream end of the East Oliver Bypass would offset shortfalls (WHTS Figure 4-5). | $30,000 by Delta, remainder by developer | Ongoing | Medium/ High | Delta | | Plant in short term so vegetation matures before densification health loss occurs. | N | KWL |

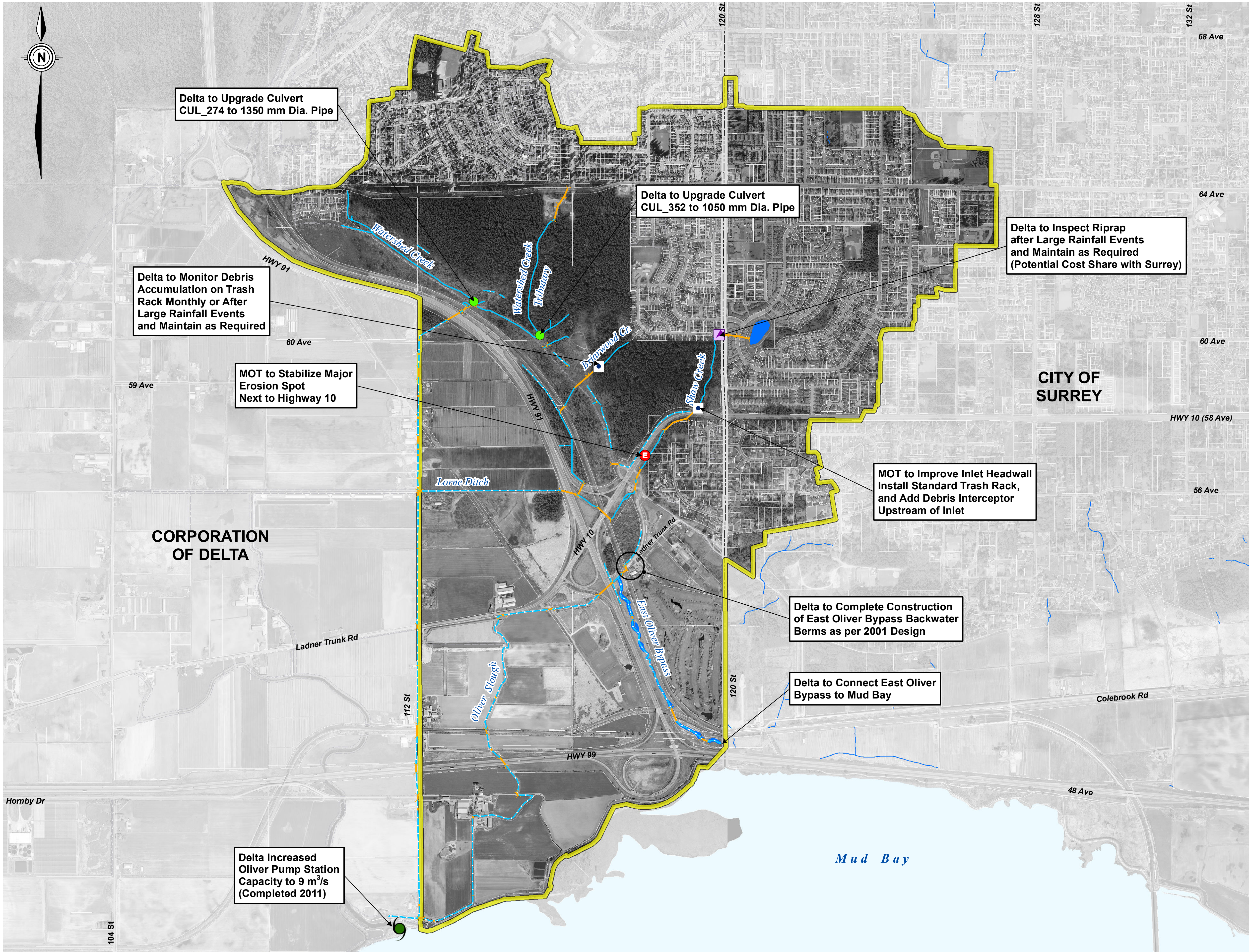
**Table 4-1: Issues and Improvement Alternatives**

| Key Issue | Potential Project | Benefit | Capital Cost Estimate | Timeline | Priority | Action By | GGI | Comment | Recommen-ded (Y/N) | Identified By |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Watershed Health Improvement (Optional)*** *- See Figure 4-2 for Locations* | | | | | | | | | | |
| Lowlands Drainage Improvement | Connect the East Oliver Bypass to Mud Bay and adjust the flow split between Oliver Slough and bypass if necessary (Figure 4-1). | Reduce peak flows into the farmlands and flooding duration to better-than-ARDSA level of service. | Unknown | Underway | | Delta | | | Y | Delta |
| | Increase Oliver Pump Station capacity from 6 $m^3/s$ to 9 $m^3/s$ (Figure 4-1). | Reduce flooding duration in farmlands to better-than-ARDSA level of service and improve fish passage. | Unknown | Completed | | Delta | | Completed in 2011. | Y | Delta |
| | Consider constructing 900 mm dia. pipe under railway to convey more high flows from Shaw Creek into the East Oliver Bypass and away from Lorne Ditch. | Further reduce peak flows and flooding duration in farmlands to better-than-ARDSA level of service (est. 25% more flows to Bypass). This would likely help culverts CUL_2, CUL_24, CUL_231, and CUL_236 meet the criteria. | $ 180,000 | Medium Term | Medium | Delta | | Utilize Bypass capacity. Work with BNSF. | Y | KWL |
| Riparian Reforestation | Add to the East Oliver Bypass riparian planting, ensure maintenance access is preserved. | Potential to increase RFI by up to 15%. | $40/m2 | Medium Term | Medium | Delta | | This could perhaps be done as compensation for impacts of other projects over time. | Y | KWL |
| | Work with Environmental Farm Plan Program to selectively plant a 2m to 5m setback from lowland watercourses. | Selected planting along ditches could increase RFI by up to 5%. | $ - | Ongoing | Low | Delta | | There may be resistance to this. | Y | KWL |
| | Add riparian trees around Boundary Park Pond to provide shade on west, east, and south sides. | Approx. 2,880 $m^2$ of area planted increasing RFI by 1%. | $ 120,000 | Long Term | Low | Surrey | | There may be resistance unless residents informed of benefits. | N | KWL |
| | Consider relocating stream in MOT ROW away from roadways/railway to gain intact riparian on both sides of stream (Figure 4-2). | Approx. 2,800 $m^2$ of riparian area gained increasing RFI by 1%. | $ 50,000 | Medium Term | Low | MOT | | Work with Streamkeepers. | Y | KWL |
| Fish Habitat Improvements | Remove fish passage obstruction (old weir) in Shaw Creek along south side of Highway 10 in MOT ROW. | Improve fish access to 70-80 m of channel. | $ 20,000 | Medium Term | Low | MOT | | Work with Streamkeepers. | Y | Raincoast |
| | Add fish baffles or rock weir to improve fish passage through Watershed Creek culvert under railway (CUL_14) & Shaw Creek culvert under Highway 91 (CUL_236). | Improve fish access to approximately 2 km of channel. | $ 70,000 | Long Term | Medium | MOT and BNSF | | Work with Streamkeepers. | Y | Raincoast |
| | Create fish habitat along Shaw Creek between Old Highway 10 and BNSF Railway in MOT ROW. | Enhance 150 m of channel. | $ 40,000 | Long Term | Low | MOT | | Work with Streamkeepers. | Y | Delta |
| Improve Water Quality | Evaluate benefits of WQ treatment wetland at top end of Watershed Creek and pipe residential runoff into it. | Treat runoff from a 76 ha residential catchment in Delta (80% removal of TSS). | $ 450,000 | Long Term | Low | Delta | | | Y | KWL |
| | Monitor WQ at top end of Watershed Creek tributary at outfall at former Works Yard to determine need for treatment. | Monitor runoff from an 8.3 ha residential catchment in Delta. | | Long Term | Low | Delta | | | Y | KWL |
| | Monitor WQ at top end of Briarwood Creek to determine need for treatment. | Monitor runoff from 60 ha developed area in Delta. | | Long Term | Low | Delta | | High turbidity measured in Briarwood Creek. | Y | KWL |
| | Monitor WQ at top end of Shaw Creek to determine need for treatment. | Monitor runoff from Surrey portion of catchment. | | Long Term | Low | Delta | | Potential cost share with Surrey. | Y | KWL |
| | Consider constructing small linear wetland along south side of Highway 10 west of Scott Road in MOT ROW and daylight 600 mm & 300 mm storm sewers into it. | Partially treat runoff from an 8 ha residential catchment in Surrey (est. 40% removal of TSS). | $ 100,000 | Medium Term | Low | MOT | | Work with Streamkeepers. | Y | KWL |
| | Further education of residents on the use of BMPs (e.g. environmentally friendly soaps for car washing.) Confirm commercial facilities are discharging wash water to sanitary and not storm sewer. | Reduce the soapy water in creeks. | $ - | Short Term | High | Delta Surrey | | | Y | Stakeholders |
| | Encourage Environmental Farm Plan Program. | Reduce fertilizers and pesticides . | $ - | Ongoing | High | Delta | | | Y | KWL |
| | Consider a policy to retrofit existing streets with roadside source controls (rain gardens or grassed swales) at time of redevelopment in upland areas. Homeowners to maintain as part of boulevard maintenance. | Treat runoff from up to 40 km (Surrey) and 29 km (Delta) of roadways (80% removal of TSS) | Developer | At Time of Dev. | High | Surrey Delta | | Very long term strategy as roads are redeveloped. | Y | KWL |

**Table 4-1: Issues and Improvement Alternatives**

| Key Issue | Potential Project | Benefit | Capital Cost Estimate | Timeline | Priority | Action By | GGI | Comment | Recommen-ded (Y/N) | Identified By |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Watershed Health Improvement (Optional) Continued*** *- See Figure 4-2 for Locations* | | | | | | | | | | |
| Mitigate Existing Development Hydrology through Detention/Diversion of Peak Flows | Add orifice outlet to Detention Tank P1 at 6455 121 Street. | Make use of available detention volume. | $ 10,000 | Short Term | Low | Surrey | | Limited benefit. | N | KWL |
| | Evaluate benefits of constructing a diversion pipe south on 120 Street and outlet to Mud Bay. | Greatly reduce the existing erosion in Shaw Creek. Likely negate need for riprap maintenance at top end of Shaw Creek, need to upgrade culverts CUL_ 2, CUL_24, CUL_231, and CUL_236, and reduce Golf Course flooding at south end. | $ 2,200,000 | Long Term | Low | Surrey | | | N | Stakeholders/ KWL |
| Mitigate Existing Development Hydrology through Volumetric Reduction | Consider a rain garden in parkette leading to Boundary Park Pond and daylight Boundary Drive East storm sewer into it. | Reduce the EIA of a 9 ha residential area from 60% to 10%. Total study area EIA reduced by 0.5%. | $ 340,000 | Long Term | Low | Surrey | | | Y | Surrey |
| | Develop policy to construct source controls during redevelopment to reduce EIA to less than existing values (e.g. during densification of 50% imp SFR area to 60% imp, reduce EIA to less than 50%). | Reduce overall EIA to less than 2010 values. | Developer | Ongoing | High | Surrey Delta | | Very long term strategy as lots are redeveloped. Consider incentives to maximize EIA reduction. | N | KWL |
| | Develop policy to encourage retrofit of large parking areas by directing pavement runoff to rain gardens (Safeway parking lot and Sunrise Baptist Church/GM Dealership pavement) | Reduce the EIA of a 3 ha of pavement from 100% to 10%. Total study area EIA reduced by 0.5%. | $160,000/ha | Medium Term | Low | Surrey Delta | | | N | Stakeholders |
| | Evaluate a volunteer program to help homeowners install rain barrels on existing single family development in Surrey. | Reduce potable water usage and increase rainfall capture. | $ - | Short Term | Medium | Surrey | | Delta has a rain barrel program. | N | KWL |
| | Allow disconnected roof runoff directed to landscaped areas on existing single family development in Delta and initiate volunteer program to help homeowners do so. | Reduce EIA of approx. 120 ha of residential area by 30%. Total study area EIA reduced by 4%. | $ - | Short Term | Medium | Delta | | Surrey already has disconnected roof leaders policy. | Y | KWL |
| | Initiate volunteer program to help homeowners plant trees on their properties. | Increase evapotranspiration reducing volumes to creeks & erosion. | $ - | Short Term | Medium | Surrey Delta | | | N | KWL |
| | Consider options to retrofit existing streets with roadside source controls in upland areas. | Reduce EIA of 70 ha of roadway from 100% to 10%. Total study area EIA reduced by 7%. | Developer | At Time of Dev. | High | Surrey Delta | | Very long term strategy as roads are redeveloped. | Y | KWL |

Corporation of Delta/City of Surrey
Boundary/Shaw
Integrated Stormwater Management Study




## Legend

- Study Boundary
- Municipal Boundary
- Ponds/Wetlands
- Culvert
- Ditch
- Creek

Topographic, cadastral data and 2008 orthophoto provided by The Corporation of Delta and City of Surrey.

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| Project No. | Date |
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| 323-059 | January 2012 |

# Proposed Hydrotechnical Upgrades

**Figure 4-1**

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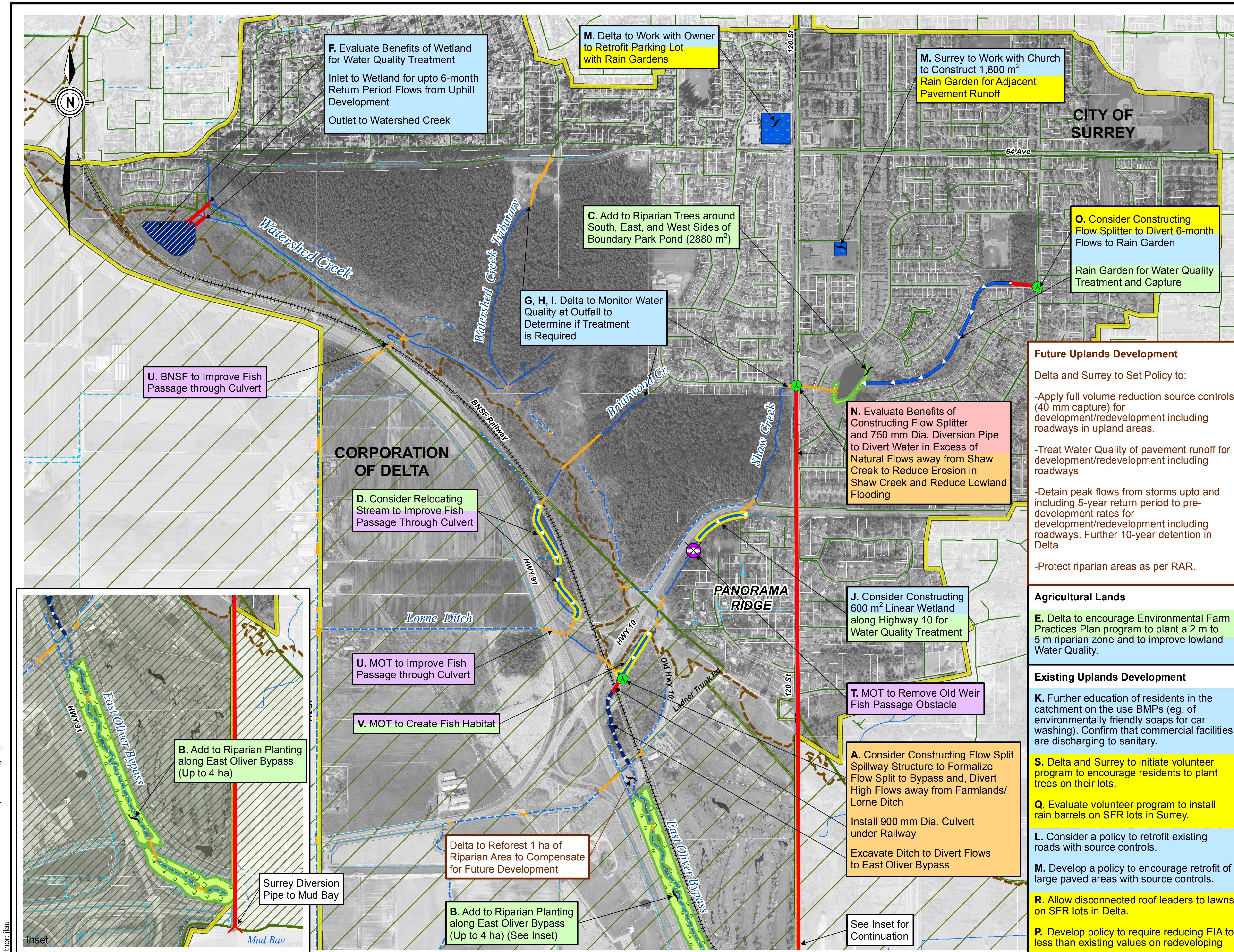


**Corporation of Delta**
**Boundary/Shaw**
**Integrated Stormwater Management Study**

## Legend

- Study Boundary
- Municipal Boundary
- Lowland Boundary (5m)
- Storm Main
- Existing Culvert
- Existing Ditch
- Existing Creek
- ALR Boundary
- Required Works

**Enhancement Alternatives**

- Lowlands Drainage Improvements
- Riparian Reforestation
- Water Quality Improvement
- Detention and Diversion to Reduce Erosion
- Volumetric Reduction to Mitigate Existing Development
- Fish Habitat Improvements

Topographic, cadastral data nad 2008 orhtophoto provided by The Corporation of Delta and City of Surrey.

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consulting engineers



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| 323-059 | January 2012 |

# Watershed Health Improvement Alternatives

**Figure 4-2**

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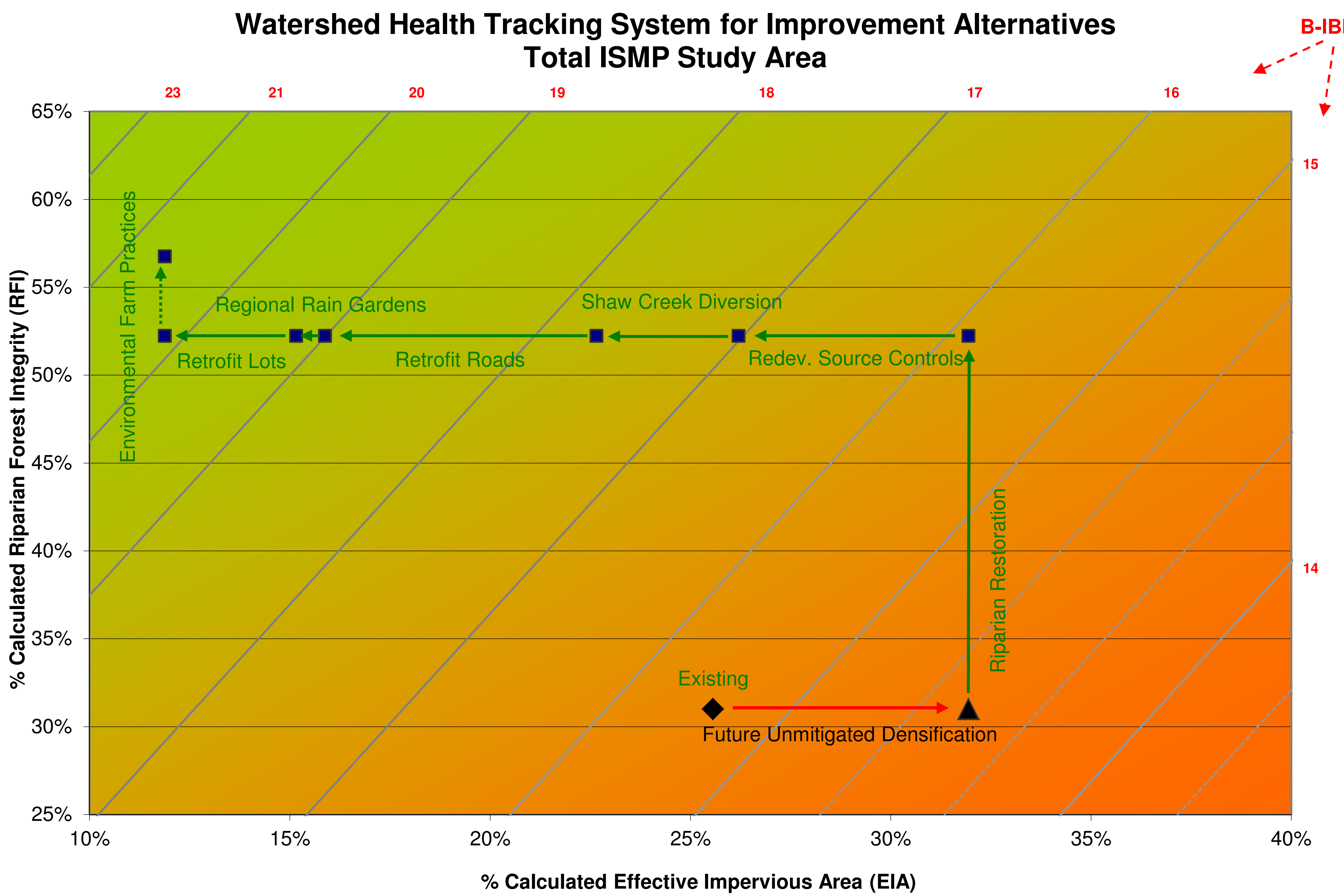


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Figure 4-3

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Section 5

# Proposed Shaw Creek ISMP

# 5. Proposed Shaw Creek ISMP

## 5.1 Introduction

The overall strategy for the Shaw Creek ISMP study area consists of many components for flood management and environmental protection and enhancement as summarized in the following sections. The strategy was developed by incorporating preferred elements from the alternatives.

The ISMP Strategy is depicted in plan view on three figures and described in this section:

- **Figure 5-1: Short Term Projects** that address safe flood conveyance for both existing and future conditions and also shows works currently underway and recently completed outside of this ISMP.
- **Figure 5-2: Medium Term Projects** that address lower priority nuisance impacts, some of the impacts from existing and past development, and riparian improvements.
- **Figure 5-3: Long Term Projects** that address some of the impacts from existing and past development and long term improvements to fish habitat.

The sizing of facilities in the ISMP is conceptual in nature and should be thoroughly assessed during pre-design. The capital cost estimates are summarized into four timeline categories, 1) Short Term, 2) Medium Term, 3) Long term, and 4) Ongoing. They are also summarized into the four groups 1) Delta, 2) Surrey, 3) MOT, and 4) BNSF. Developer costs are not estimated (see Table 5-1).

## 5.2 Required Hydrotechnical Improvements

A number of undersized culverts and priority works were identified. The proposed hydrotechnical upgrades were listed in Section 4.2 and are prioritized below.

### Short Term Projects

The following short term projects are shown on Figure 5-1:

1. MOT to construct bank protection on right bank of Shaw Creek at Highway 10 south side major erosion spot (E-11).
2. Delta to inspect riprap at the top end of Shaw Creek following all greater than 2-year rainfall events and maintain as required to fill any spots left unprotected by riprap movement and protect concrete wall toe and concrete outfall edge. This project could potentially be cost shared with Surrey.
3. Delta to confirm whether debris accumulation is a problem at the upstream end of Briarwood Creek culvert CUL_372 and if so, remove accumulated debris more frequently to reduce the likelihood of inlet blockage and flows traveling overland down the steep bank causing erosion. Inspect monthly and after storm events.

### Medium Term Projects

The following medium term projects are shown on Figure 5-2:

4. Possible upgrade of culvert CUL_352 under path in Watershed Park to 1,050 mm diameter pipe.

## Table 5-1: ISMP Class D Capital Cost Estimate

| ISMP Component | Timeline | Class D Cost Estimates | |
|---|---|---|---|
| **Hydrotechnical Improvements** | | | |
| 1. Construct bank protection on right bank of Shaw Creek at Highway 10 south side major erosion spot (E-11). | Short Term | $40,000 | |
| 2. Inspect riprap at the top end of Shaw Creek following all greater than 2-year rainfall events and maintain as required to fill any spots left unprotected by riprap movement and protect concrete wall toe and concrete outfall edge. | | $0 | |
| 3. Confirm whether accumulation is a problem at the u/s end of Briarwood Creek culvert CUL_372 and if so, remove accumulated debris more frequently to reduce the likelihood of inlet blockage. Inspect monthly and after storm events. | | $0 | |
| 4. Possible upgrade of culvert CUL_352 in Watershed Park to 1050mm diameter pipe. | Medium Term | $40,000 | |
| 5. Review improved inlet and trash rack options at Hwy 10 Shaw Creek with wider bar spacing and debris interceptor upstream. This will reduce the likelihood of inlet blockage and Highway 10 overtopping. | | $100,000 | |
| 6. Complete the construction of the East Oliver Bypass backwater berms near the Delta Golf Course as per the 2001 detailed design drawings. | | $60,000 | |
| 7. Possible upgrade of culvert CUL_274 in Watershed Park to 1350mm diameter pipe. | | $40,000 | **Hydrotech. Subtotal** |
| 8. Delta, MOT, and BNSF to replace the following culverts with the larger sizes noted at the end of the design life of the existing culverts: CUL_2, CUL_17, CUL_24, CUL_231, CUL_236, CUL_249, CUL_250, and CUL_370. Cost for end of life upgrades not included. | Long Term | $0 | **$280,000** |
| **Lowlands Drainage Improvements** | | | |
| 9. Consider constructing a 900 mm dia. culvert under the railway and a channel to the East Oliver Bypass to divert more of the Shaw Creek high flows away from the lowlands and out to Mud Bay. | Medium Term | $220,000 | **$220,000** |
| **Water Quality Treatment** | | | |
| 10. Further education of residents on the use of BMPs (e.g. environmentally friendly soaps for car washing). Confirm that commercial facilities are discharging to sanitary and not storm sewer in order to reduce the soapy water in creeks. | Short Term | $0 | |
| 11. Consder options for treatment of runoff from new paved surfaces, including municipal roadways, resulting from a 6-month 24-hour storm (or 90% of annual flows) to remove pollutants. | At Time of Development and Ongoing | | |
| 12. Incorporate stormwater BMPs when retrofitting existing streets with roadside source controls (rain gardens or grassed swales) at time of redevelopment in upland areas to treat runoff from up to 40 km (Surrey) and 29 km (Delta) of roadways. | | | |
| 13. Encourage the Environmental Farm Plan Program in order to reduce fertilizers and pesticides in lowland channels. | | $0 | |
| 14. A small linear wetland is suggested along the south side of Highway 10 immediately west of Scott Road. Daylight 600 mm and 300 mm storm sewers into it to partially treat runoff from an 8 ha residential catchment in Surrey (est. 40% removal of TSS). | Medium Term | $100,000 | |
| 15. A water quality treatment wetland should be considered at top end of Watershed Creek. Pipe residential runoff into it to treat runoff from a 76 ha residential catchment (80% removal of TSS). | Long Term | $450,000 | |
| 16. Monitor water quality at the top end of the Watershed Creek Tributary (at former Works Yard outfall) to determine if there is a need for treatment. Monitor runoff from an 8.3 ha residential catchment in Delta. This is the first year cost and subsequent years would cost approximately $6000/yr. | | $14,000 | |
| 17. Monitor water quality at the outfall into the top end of Briarwood Creek to determine if there is a need for treatment. Monitor runoff from a 60 ha developed area in Delta. This is the first year cost and subsequent years would cost approximately $6000/yr. | | $14,000 | **WQ Treat. Subtotal** |
| 18. Monitor water quality at the outfall into the top end of Shaw Creek to determine if there is a need for treatment. Monitor runoff from the Surrey portion of the Shaw Creek catchment. This is the first year cost and subsequent years would cost approximately $6000/yr. | | $14,000 | **$592,000** |
| **Volumetric Reduction to Mitigate Frequently Occurring Flows and Sustain Baseflows** | | | |
| 19. Require volume reduction source controls on all new development and redevelopment including roadways for all areas changing from pervious to impervious. Capture 6-month 24-hour storm (40 mm) with source controls. | At Time of Development and Ongoing | | |
| 20. Review options for retrofitting existing streets with roadside source controls in upland areas to reduce the EIA of approximately 70 ha of roadway in the study area. This is the same policy referred to in the water quality section. | | | |
| 21. Create a rain garden in the parkette leading to the Boundary Park Pond and daylight the Boundary Drive East storm sewer into it. This would reduce the EIA of a 9 ha residential area from 60% to 10%. | Long Term | $340,000 | **Vol. Red. Subtotal** |
| 22. Review options for disconnected roof leaders directing roof runoff to landscaped areas on existing single family development and initiate a volunteer program to help homeowners do so. | | $0 | **$340,000** |
| **Flow Rate Control to meet DFO Guidelines, and Surrey and Delta Bylaws** | | | |
| 23. Restrict post-development flows to pre-development levels for all storms up to and including the 5-year storm (plus 10-year in Delta) on all new development and roadways and redevelopment. | At Time of Development | | |
| **Riparian Protection and Enhancement** | | | |
| 24. Continue with implementation of Delta SPEA Bylaw and Riparian Areas Regulation. Look for offsetting riparian replanting opportunities within the watershed to compensate for areas where the Riparian Areas Regulation (RAR) does not apply (see Item 27 below). | At Time of Development and Ongoing | | |
| 25. Encourage Environmental Farm Plan Program to incorporate riparian plantings (e.g. 2m riparian width) along lowland watercourses to increase the study area RFI. | | $0 | |
| 26. Improve the riparian along the East Oliver Bypass. | Medium Term | $40/m2 | **Riparian Subtotal** |
| 27. Consider options to relocate Briarwood Creek away from railway and highway between Highway 91 and the BNSF railway to gain intact riparian on both sides of streams increasing the riparian by 2800 m2. | | $50,000 | **$50,000** |
| **Restoration and Enhancement for Fish** | | | |
| 28. Remove a fish passage obstruction (old weir) in Shaw Creek along south side of Highway 10 to improve fish access to 200m of channel. | Medium Term | $20,000 | |
| 29. Improve fish passage through the Watershed Creek culvert under railway (CUL_14) by adding fish baffles or rock weir. | Long Term | $35,000 | **Fish Habitat Subtotal** |
| 30. Improve fish passage through the Shaw Creek culvert under Highway 91 (CUL_236) by adding fish baffles or rock weir. | | $35,000 | |
| 31. Create fish habitat along Shaw Creek between Old Highway 10 and the BNSF Railway to enhance 150 m of channel. | | $40,000 | **$130,000** |
| **TOTAL CAPITAL COST Excluding Developer Costs (Excluding HST)** | | **$1,612,000** | |
| | | **Breakdown by Group** | |
| | **Total Delta Cost** | **$852,000** | |
| | **Total Surrey Cost** | **$340,000** | |
| | **Total MOT Cost** | **$385,000** | |
| | **Total BNSF Cost** | **$35,000** | |
| | **Total Developer Cost** | **not estimated** | |
| | | **Breakdown by Timeline** | |
| | **Total Short Term Cost** | **$40,000** | |
| | **Total Medium Term Cost** | **$630,000** | |
| | **Total Long Term Cost** | **$942,000** | |

**Refer to Figures 5-1 to 5-3**

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5. MOT to review improved inlet and trash rack options on Shaw Creek at Highway 10 with wider bar spacing and debris interceptor upstream, to reduce the likelihood of inlet blockage and Highway 10 overtopping.
6. Delta to complete the construction of the East Oliver Bypass backwater berms near the Delta Golf Course as per the 2001 detailed design drawings.
7. Possible upgrade of culvert CUL_274 under path in Watershed Park to 1,350 mm diameter pipe.

### Long Term Projects

The following long term projects are shown on Figure 5-3:

8. Delta, MOT, and BNSF to replace the following culverts with the larger sizes noted at the end of the design life of the existing culverts:
   - CUL_2 – Existing: 600 mm ∅ conc, Proposed: to be determined once East Oliver Bypass flow split finalized (Delta)
   - CUL_17 – Existing 1200 mm ∅ CMP, Proposed: 1,500 mm ∅ CMP (Delta)
   - CUL_24 – Existing: 1.8 m x 1.2 m conc box, Proposed: to be determined once East Oliver Bypass flow split finalized (Delta)
   - CUL_231 – Existing: 900 mm CMP, Proposed: to be determined once East Oliver Bypass flow split finalized (Delta)
   - CUL_236 – Existing: 2,000 mm ∅ CMP, Proposed: to be determined once East Oliver Bypass flow split finalized (MOT)
   - CUL_249 – Existing 600 mm ∅ conc, Proposed: 750 mm ∅ CMP (Delta)
   - CUL_250 – Existing 600 mm ∅ conc, Proposed: 750 mm ∅ CMP (Delta)
   - CUL_370 – Existing: 1,200 mm ∅, Proposed: 2,000 mm ∅ CMP (BNSF)

## 5.3 Lowlands Drainage Improvement

The following improvements would further improve lowlands drainage and irrigation:

### Recently Completed and Upcoming Work by Others in the Study Area

**Oliver Pump Station Capacity**

Delta increased the Oliver Pump Station capacity from 6 $m^3$/s to 9 $m^3$/s. Completed in 2011. If possible, the ON/OFF switch elevations for the new pump should be set so that their average value is El. -1.4m Geodetic in order to provide 1.2m of freeboard to the adjacent lowlands.

**East Oliver Bypass Completion**

Delta to complete the East Oliver Bypass by connecting it to Mud Bay and adjusting the flow split between the agricultural land to the west and the bypass if necessary (see Figure 5-1).

### Medium Term Projects

The following medium term projects are shown on Figure 5-2:

9. Consider constructing a 900 mm diameter culvert under the railway and a channel from the downstream end of the culvert to the East Oliver Bypass to divert more of the Shaw Creek high flows away from the lowlands and out to Mud Bay. A flow split structure on the upstream end of the culvert would send baseflows and low flows to Lorne Ditch and high flows to the bypass.

## 5.4 Water Quality Treatment

The environmental inventory and sampling has identified a number of water quality issues in the watercourses. Further monitoring would be required to more conclusively identify and quantify pollutants. The following projects will be initiated to identify pollutants and treat the water quality of outflows into the creeks:

### Short Term Projects

The following short term projects are shown on Figure 5-1:

10. Further education of residents on the use of BMP's (e.g. environmentally friendly soaps for car washing). Confirm that commercial facilities are discharging to sanitary and not storm sewer in order to reduce the soapy water in creeks.

### Developer, DCC, and Ongoing Projects

The following are developer, DCC, and ongoing projects:

11. Consider options for treatment of runoff from new paved surfaces, including municipal roadways, resulting from a 6-month 24-hour storm (or 90% of annual flows) to remove pollutants (see Appendix E for typical BMPs).
12. Incorporate stormwater BMP's when retrofitting existing streets with roadside source controls (rain gardens or grassed swales) at time of redevelopment in upland areas to treat runoff from up to 40 km (Surrey) and 29 km (Delta) of roadway (80% removal of TSS) (see Appendix E for typical BMPs). Homeowners would maintain these as part of the required boulevard maintenance.
13. Delta to encourage the Environmental Farm Plan Program in order to reduce fertilizers and pesticides in lowland channels.

### Medium Term Projects

The following medium term projects are shown on Figure 5-2:

14. A small linear wetland is suggested along the south side of Highway 10 immediately west of Scott Road. Daylight 600 mm and 300 mm storm sewers into it to partially treat runoff from an 8 ha residential catchment in Surrey (est. 40% removal of TSS).

### Long Term Projects

The following long term projects are shown on Figure 5-3:

15. A water quality treatment wetland should be considered at top end of Watershed Creek. Pipe residential runoff into it to treat runoff from a 76 ha residential catchment (80% removal of TSS).
16. Selectively monitor water quality at the outfall into the top end of the Watershed Creek Tributary (at former Works Yard) to determine if there is a need for treatment. Monitor runoff from an 8.3 ha residential catchment in Delta.
17. Selectively monitor water quality at the outfall into the top end of Briarwood Creek to determine if there is a need for treatment. Monitor runoff from a 60 ha developed area in Delta.
18. Selectively monitor water quality at the outfall into the top end of Shaw Creek to determine if there is a need for treatment. Monitor runoff from the Surrey portion of the Shaw Creek catchment.

## 5.5 Volumetric Reduction for Environmental Protection

In order to meet the no-net-loss requirement of an ISMP, future development impacts need to be mitigated. Volumetric reduction is one step in addressing development impacts. Existing development impacts can also be mitigated in part with volumetric reduction. The following volumetric reduction projects are proposed:

### Developer, DCC, and Ongoing Projects

The following are developer, DCC, and ongoing projects:

19. Require volume reduction source controls capable of capturing the 6-month 24-hour storm (40 mm) on all new development and redevelopment including roadways for all areas changing from pervious to impervious (see Appendix E for typical BMPs).
20. Review options for retrofitting existing streets with roadside source controls in upland areas to reduce the EIA of approximately 70 ha of roadway in the study area (see Appendix E for typical BMPs). This is the same policy referred to in the water quality section as source controls would provide both capture and treatment.

### Long Term Projects

The following long term projects are shown on Figure 5-3:

21. Create a rain garden in the parkette leading to the Boundary Park Pond and daylight the Boundary Drive East storm sewer into it. This would reduce the EIA of a 9 ha residential area from 60% to 10%.
22. Delta to review options for disconnected roof leaders directing roof runoff to landscaped areas on existing single family development in Delta where impacts to neighbouring properties and adjacent steep slope areas can be avoided. Initiate a volunteer program to help homeowners do so. This would reduce the EIA of approximately 120 ha of residential area by approximately 30%.

## 5.6 Flow Rate Control

In order to meet the no-net-loss requirement of an ISMP, future development impacts need to be mitigated. Flow rate control is the second step in addressing development impacts. The following volumetric reduction projects are proposed:

### Developer and DCC Projects

The following are developer and DCC projects:

23. Restrict post-development flows to pre-development levels for all storms up to and including the 5-year storm on all new development and roadways and redevelopment as per the Surrey Design Criteria Manual and DFO Guidelines. The Delta Stormwater Management Design Manual requires a further detention of the 10-year return period flows for development in Delta.

## 5.7 Protect Riparian Setbacks

Riparian forest integrity is one of the major indicators of watershed health as shown on the WHTS discussed in Section 3.3. There are a number of riparian reforestation opportunities in the study area including the following:

### Developer, DCC, and Ongoing Projects

The following are developer, DCC, and ongoing projects:

24. Continue with implementation of Delta SPEA Bylaw and Riparian Areas Regulation.. Look for offsetting riparian replanting opportunities within the watershed to compensate for areas where the RAR does not apply (see Item 27 below).
25. Encourage Environmental Farm Plan Program to incorporate riparian plantings (e.g. 2 m riparian width) to increase the study area RFI.

### Medium Term Projects

The following medium term projects are shown on Figure 5-2:

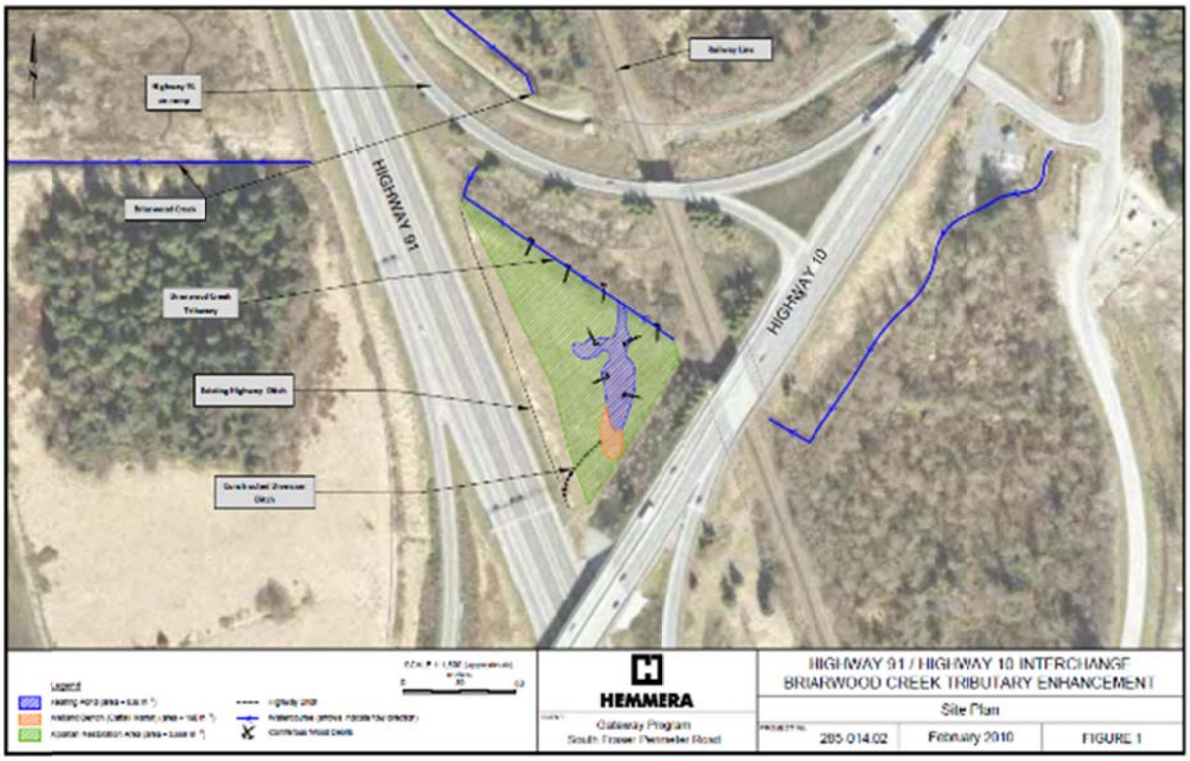
26. Improve the riparian along the East Oliver Bypass.
27. Consider options to relocate Briarwood Creek away from roadways/railway between Highway 91 and the BNSF railway to gain intact riparian on both sides of streams increasing the riparian by 2800 $m^2$.

## 5.8 Restoration and Enhancement for Fish

### Recently Completed and Upcoming Work by Others

**Shaw Creek (Briarwood Creek Tributary) Enhancement**

This project is located Shaw Creek between Highway 91 and the BNSF Railway, adjacent to the Highway 10 to Highway 91 on-ramp. The work will involve rearing habitat creation (Aquatic habitat created = 838 $m^2$) and riparian enhancement (riparian habitat created = 5,849 $m^2$) within a grass-covered highway interchange that is routinely maintained. The primary objective will be to improve existing habitat within the watercourse and create overwintering habitat for juvenile salmonids (coho salmon and cutthroat trout). Proposed works primarily entail the construction of one off-channel rearing pond (3-5 m deep), which will be excavated in-the-dry, and creating/enhancing riparian habitat by removing Himalayan blackberry and planting grass covered areas with native shrubs and trees. The rearing pond and enhanced adjacent riparian area are also expected to provide improved habitat values for other wildlife species (e.g., amphibians and waterfowl). The pond, outlet channel and existing channel will be complexed with anchored coarse woody debris (CWD) and root wads (mainstem and secondary stems attached), and large boulders (see Figure 5-1). This work is part of fish habitat compensation associated with construction of the South Fraser Perimeter Road through Delta.

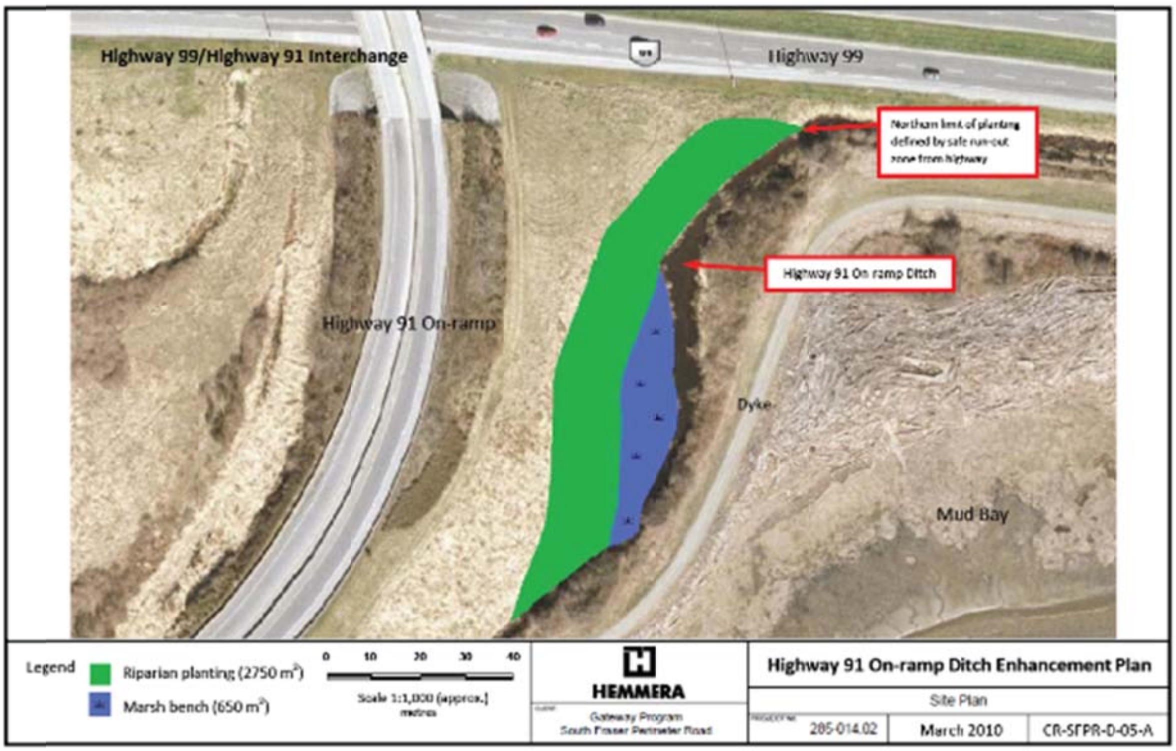



### The Corporation of Delta and the Pacific Salmon Foundation Rearing Channel

An 80 m rearing channel in the shape of a horseshoe was created in a low lying area adjacent to Watershed Creek. The rearing channel has three 15 m gravel riffles, each with a 10 cm drop to provide spawning habitat. Large woody debris and boulders were placed for cover and bank stabilization. Seven 3 m Douglas Fir trees were planted along the channel edge to help provide shade and cover and moderate the water temperatures during the warmer calendar days. Two gravel trails furnished with trail benches lead to the stream to provide access for future public fish releases. Four interpretive signs installed along the stream edge provide information about the chum salmon life cycle and the benefits of the stream restoration improvements (see Figure 5-1).

**Highway 91 On-ramp Ditch Enhancement**

The proposed restoration/enhancement works will occur within vacant areas between the ditch and the side slope of the fill associated with the southern approach to the Hwy 99 Overpass. This is an area that is not only vacant but also experiences ongoing maintenance by MOT (i.e., mowing to within 0.5 to 1.0 m of the high water mark on the western side of the ditch channel). A marsh bench (cattails) would be constructed alongside the ditch, to provide enhanced channel complexity. An excavation depth of approximately 1.0 to 1.5 m is anticipated to be required, to achieve the appropriate invert for marsh plant persistence and consistent inundation. Riparian vegetation, consisting of native shrubs and trees, would be planted within the vicinity of the enhanced channel and adjacent reaches of the ditch. The works will more likely benefit resident rather than migratory fish (e.g., threespine stickleback, prickly sculpin, etc.). Aquatic habitat created = 650 $m^2$ (marsh bench). Riparian habitat created = 2,750 $m^2$ (see Figure 5-1). This project is part of fish habitat compensation associated with construction of the South Fraser Perimeter Road through Delta.




## Medium Term Projects

The following medium term projects are shown on Figure 5-2:

28. MOT to remove a fish passage obstruction (old weir) in Shaw Creek along south side of Highway 10 to improve fish access to 200 m of channel.

### Long Term Projects

The following long term projects are shown on Figure 5-3:

29. BNSF to improve fish passage through the Watershed Creek culvert under railway (CUL_14) by adding fish baffles or rock weir.
30. MOT to improve fish passage through the Shaw Creek culvert under Highway 91 (CUL_236) by adding fish baffles or rock weir. Projects 29 and 30 will improve fish access to approximately 2 km of channel, including some of the above mentioned projects underway.
31. MOT to create fish habitat along Shaw Creek between Old Highway 10 and the BNSF Railway to enhance 150 m of channel.

## 5.9 Further Studies and Monitoring Program

### Detailed Geotechnical Investigations

The geotechnical hazard assessment performed by Trow identified the need for further study of the following:

- Monitoring of slope movement below Panorama Ridge along Shaw Creek
- Identifying areas along the Shaw Creek left (south) bank where riprap is needed to prevent future slope instability below the Panorama Ridge residential areas.

### Ongoing Benthic, Water Quality, and Sediment Sampling

To monitor the success of mitigation measures and measures to improve watershed health as outlined in the ISMP, ongoing benthic sampling of the same sites that were used in the ISMP is recommended. To establish trends over time, sites should be monitored approximately once every two years. At the time of the benthic sampling, water and sediment samples should be taken and analyzed to quantify long term trends of pollutants in the water and sediment. The cost of benthic, water, and sediment sampling would be approximately $7,000 per year for the four locations used in this study.

### Detailed Fish Presence and Fish Passage Investigations

Fish presence and distributions within the ISMP study area, especially in the lowlands, is not well-known. Therefore, further fish sampling and a fish utilization study, particularly of the minor lowland watercourses (minor sloughs, ditches, etc.), is recommended.

In addition, some culverts have been identified as potential barriers to fish passage based on general characteristics (length, slope, etc.) but further investigation is needed to assess whether they actually present a barrier to fish.

### ISMP Performance Monitoring and Accountability of Plan

In order to measure and track the levels and changes in the health of a watershed, and to provide accountability to the ISMP, a suite of performance parameters has been developed that match the key issues identified above. Table 5-2 lists the parameters or “indicators” that should be measured and tracked over time.

The proposed schedule for review of the watershed health indicators should be once every five years. It is suggested that indicators be measured every two years.

**Table 5-2: Boundary/Shaw Creek Watershed Adaptive Management Indicators**

| Performance Indicator | | Method of Analysis | 2010 | 2015 |
|---|---|---|---|---|
| 1. | Total Impervious Area (% of Watershed Area) | GIS Analysis of Aerial Photos and Assessment Data | 26% | Small increase expected due to development |
| 2. | Effective Impervious Area (% of Watershed Area) | Estimated from surface cover type and source controls implemented | Flow monitoring required to quantify | decrease when source controls implemented |
| 3. | Riparian Forrest Integrity (% of Riparian Area) | GIS Analysis of Aerial Photos | 31% | Same or Increase |
| 4. | Watershed Forest Cover (% of Watershed Area) | GIS Analysis of Aerial Photos | 23% | Same or Increase |
| 5. | Benthic Invertebrates | B-IBI scores based on methods used in this study | mean = 17.0 | 18 |
| 6. | Fish Populations | Density, species composition | No data | Collect Data |
| 7. | Fish Passage Barriers | City/Streamkeepers Records | Full Barriers 1<br>Partial Barriers 4 | Progressive Removal of Non-natural Barriers |
| 8. | Average Summer Water Temperature (°C) | Monitoring (continuous station at Shaw Creek at Old Highway 10) | Range: 10.6 - 18.3<br>Mean: 15.0 | Same or Decrease |
| 9. | Dissolved Oxygen (DO, mg/L) | Field Measurement (during spring/summer baseflow) | Range: 1.5 – 10.8<br>Mean: 7.1 | Same or Increase |
| 10. | Water pH | Monitoring (continuous station at Shaw Creek at Old Highway 10) | Range: 5.7 – 7.5<br>Mean: 6.8 | Same or Trend Toward Neutral |
| 11. | Water Conductivity (µS) | Monitoring (continuous station at Shaw Creek at Old Highway 10) | Range: 83 – 7,590<br>Mean: 505 | Same or Decrease |
| 12. | Turbidity (NTU) | Monitoring (continuous station at Shaw Creek at Old Highway 10) | Range: 0 – 160<br>Mean: 15 | Same or Decrease |
| 13. | Water Quality Fecal Coliforms (MPN/100mL) | Field Sample at Oliver Slough near 112 Street & Lab Testing | 1,600 | < 200 |
| 14. | Sediment Quality | Metals in sediment | See Section 2.4 | Same or Decrease |
| 15. | No. of Erosion Sites | Field Assessment and Designation as Low, Medium, or High Severity and Consequence | See Table 2-2 | Same or Decrease |
| 16. | Lineal km of Roadside Ditches/Swales/Rain Gardens (km) | As-Constructed Drawings / GIS | 16 km | 18 km |

# 5.10 Capital Cost Estimates and Funding

## Capital Cost Estimate

The sizing of facilities in the ISMP is conceptual in nature and should be thoroughly assessed during pre-design. The capital cost estimates of the overall proposed works in the ISMP are summarized in Table 5-2. The detailed cost estimates are included in Appendix F.

### Class 'D' Cost Estimate and Assumptions

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

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

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

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

HST has not been included in the estimated project costs. The unit prices reflect KWL's recent experience with similar work, and therefore represent the best prediction of actual (2011) costs as of the date prepared. Actual tendered costs would depend on such things as market conditions generally, remoteness factor, the time of year, contractors' work loads, any perceived risk exposure associated with the work, and unknown conditions.

### Funding Strategies

The cost estimates in Table 5-2 are summarized into four timeline categories, 1) Short Term, 2) Medium Term, 3) Long term, and 4) Ongoing. They are also summarized into four groups, 1) Delta, 2) Surrey, 3) MOT, and 4) Streamkeepers. Developer costs are not estimated.

- Funding opportunities from senior governments should be pursued for some of the items for example:
- Fish barrier removals and habitat improvements – Wildlife Habitat Canada Conservation Grant;
- Riparian enhancement and conservation areas – Environment Canada Habitat Stewardship Program; and
- Conveyance upgrades – Infrastructure grant programs.

## 5.11 Operation and Maintenance

Regular drainage system and stormwater facility maintenance is required to effectively convey design flows, minimize flooding and erosion, and mitigate the impacts of development. The following inspection and maintenance procedures are recommended.

**Inspection**: The Boundary/Shaw Creek drainage systems should be inspected annually during low flow conditions, ideally in the spring so that identified problems can be undertaken during the dry summer months. The primary purpose of the inspection is to assess the condition of the conveyance facilities including creek channels for erosion locations and hydraulic structures, and identify the need for maintenance. The annual inspection should include all open channels, culverts, ponds, diversions, flow splitters, and floodboxes. An overall drainage system inspection should also be completed after major storm events.

**Vegetation Maintenance**: Access to ditches and the conveyance ditches themselves should be maintained to prevent the growth of weeds, small trees and bushes. The hydraulic conveyance capacities of the ditches must be maintained. Ditch maintenance should occur annually.

**Sediment Removal**: Silt accumulation in the lowland drainage system can be expected due to the flat topography. The sediment should be removed when it affects the conveyance capacities of the drainage system and has an impact on water levels. Removal of sediment should be undertaken on a required basis (4 years).

**Debris Control**: Debris blockages at hydraulic structures can cause flooding problems. Regular debris removal (at least annually) from the ditches, culverts and floodboxes is necessary.

**Pump Station**: Undertake pump maintenance, as recommended by manufacturers, maintain and clean bar screens and trash racks.

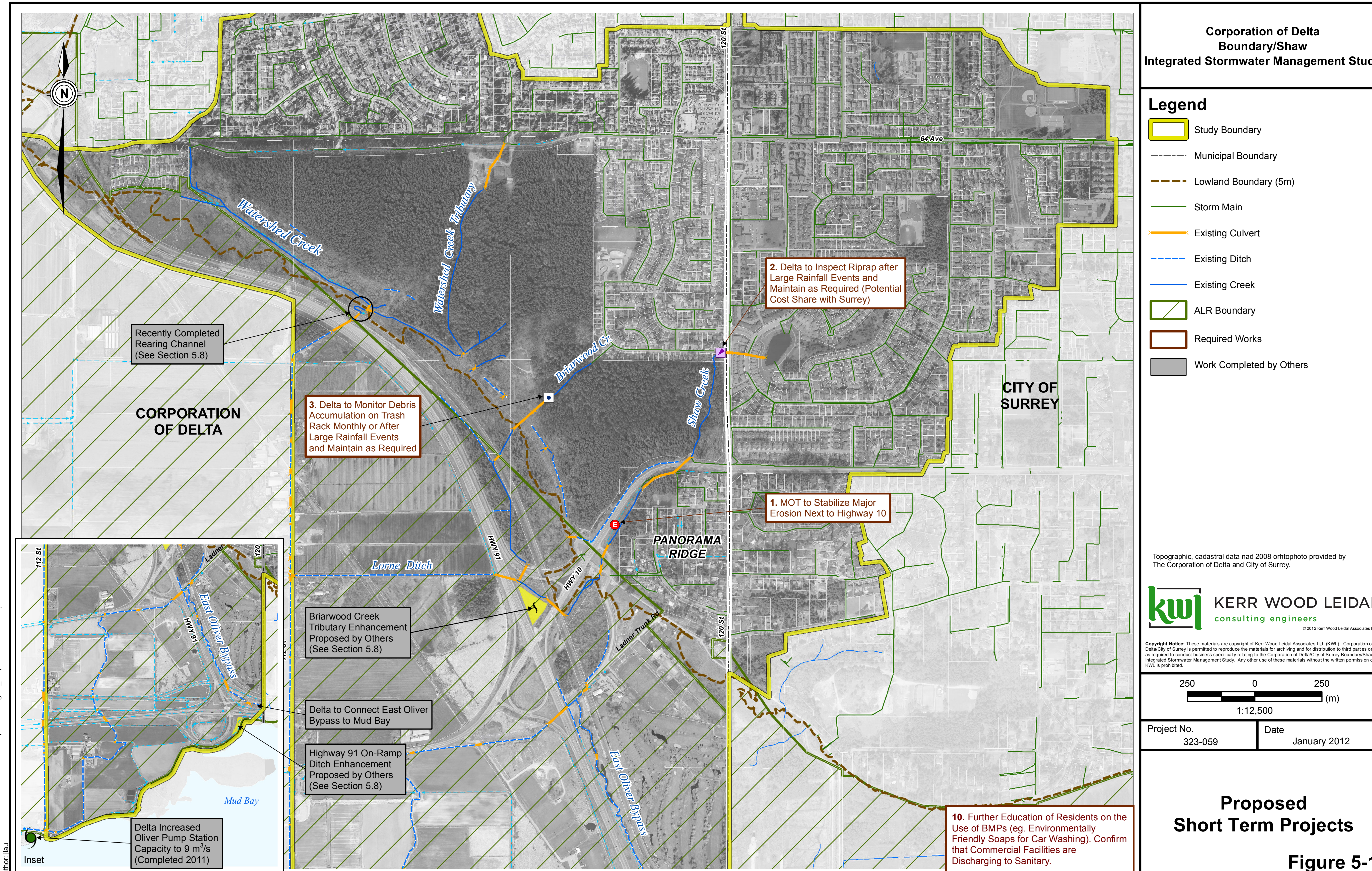
**Wet Pond**: Inspect periodically during wet weather to observe function, clean sediment forebay every 5 to 7 years or when 50% capacity has been lost, remove accumulated sediment form pond bottom when 10 to 15% of pool volume is lost, inspect hydraulic and structural facilities annually and mow side-slopes, embankments and spillways as required to prevent over growth.

**Detention Tanks**: Inspect annually and remove floating debris and oil.

**Wetlands**: Inspect annually and after each major storm event. At beginning of wet season remove trash and floatables and unclog outlet structures.

**Grassed Swales**: Inspect routinely especially after large storm events. Correct erosion problems as necessary, mow to keep grass in the active growth phase, remove clippings to prevent clogging of outlets, and remove trash and debris.

**Bioretention with Underdrain**: Remove leaves each fall, inspect overflow, hydraulic and structural facilities annually.




**Corporation of Delta**
**Boundary/Shaw**
**Integrated Stormwater Management Study**

Topographic, cadastral data nad 2008 orhtophoto provided by The Corporation of Delta and City of Surrey.

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consulting engineers



| Project No. | Date |
|---|---|
| 323-059 | January 2012 |

# Proposed Short Term Projects

**Figure 5-1**

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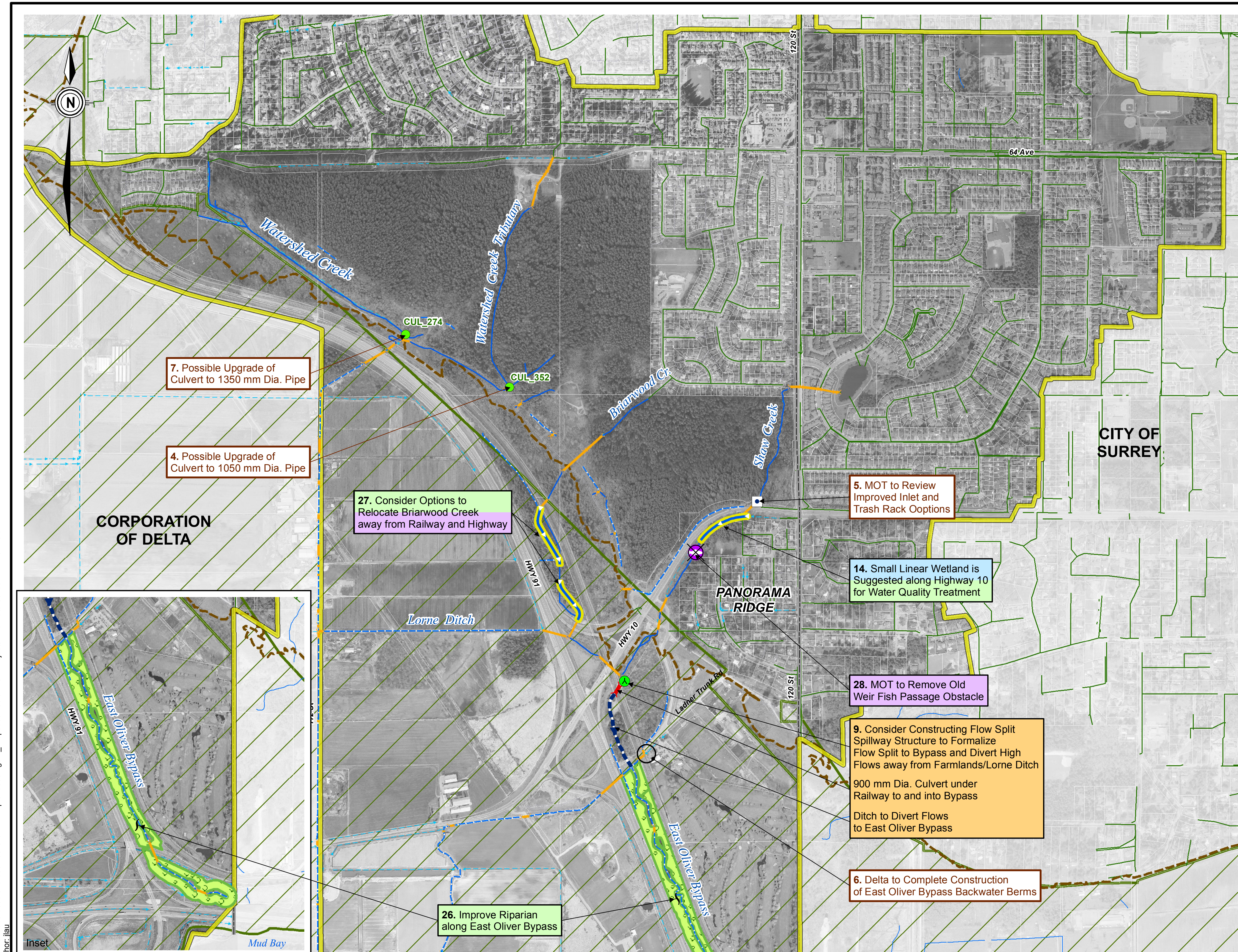


**Corporation of Delta**
**Boundary/Shaw**
**Integrated Stormwater Management Study**

## Legend

- Study Boundary
- Municipal Boundary
- Lowland Boundary (5m)
- Storm Main
- Existing Culvert
- Existing Ditch
- Existing Creek
- ALR Boundary
- Required Works

**Enhancement Alternatives**

- Lowlands Drainage Improvements
- Riparian Reforestation
- Water Quality Improvement
- Fish Habitat Improvements

Topographic, cadastral data nad 2008 orhtophoto provided by The Corporation of Delta and City of Surrey.

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| Project No. | Date |
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| 323-059 | January 2012 |

# Proposed Medium Term Projects

**Figure 5-2**

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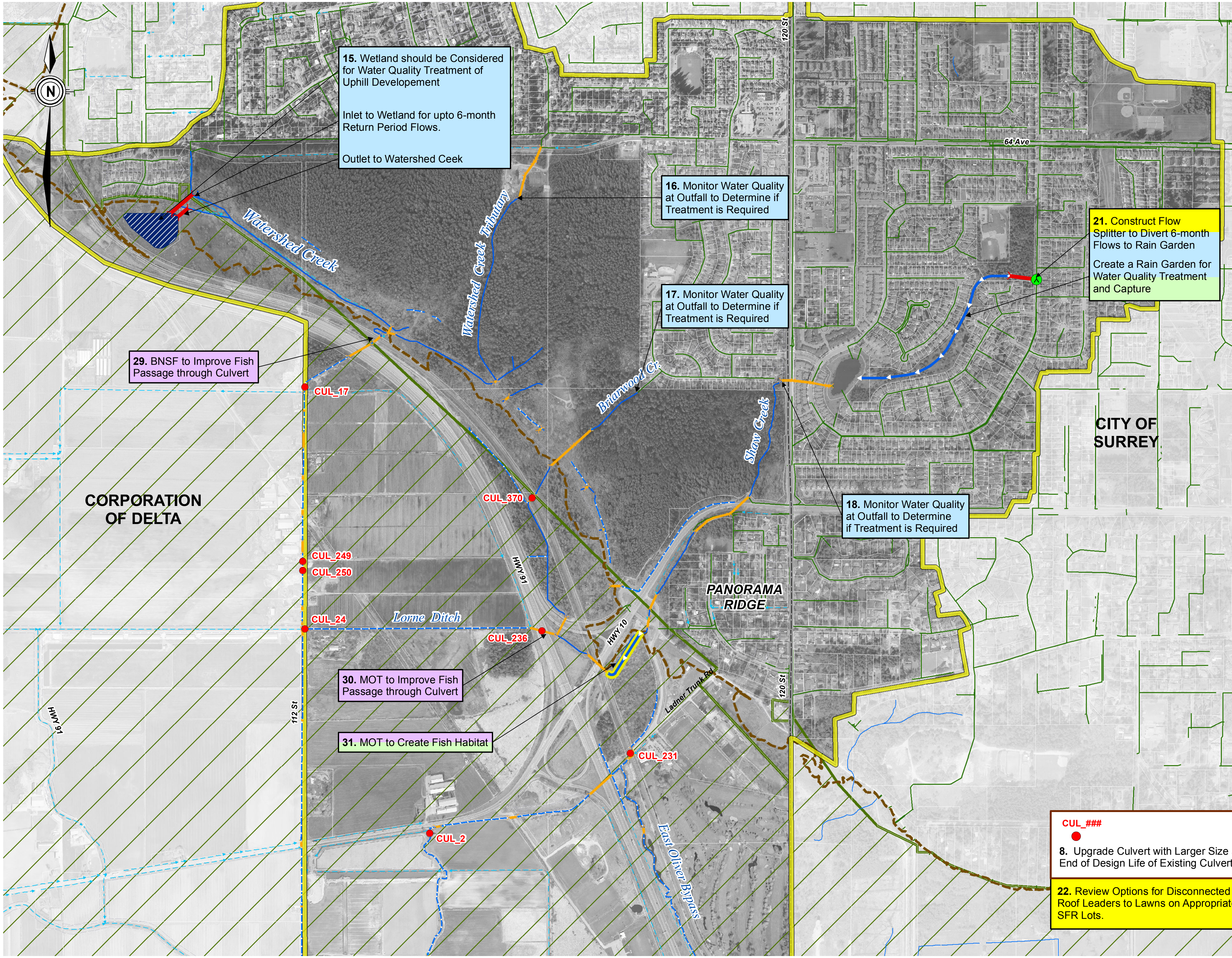
**Corporation of Delta**
**Boundary/Shaw**
**Integrated Stormwater Management Study**

## Legend

- Study Boundary
- Municipal Boundary
- Lowland Boundary (5m)
- Storm Main
- Existing Culvert
- Existing Ditch
- Existing Creek
- ALR Boundary
- Required Works

**Enhancement Alternatives**

- Riparian Reforestation
- Water Quality Improvement
- Volumetric Reduction to Mitigate Existing Development
- Fish Habitat Improvements

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| 323-059 | January 2012 |

# Proposed Long Term Projects

**Figure 5-3**

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Section 6

# Summary and Recommendations

# 6. Summary and Recommendations

## 6.1 Summary

### Introduction

- The Boundary/Shaw Creek ISMP employed a multi-disciplinary approach including stormwater engineering, and environmental protection.
- The study included consultation of Municipal Advisory Committees, City Council and the public.
- Two main watershed goals directed the IWMP: Protect aquatic ecosystems and water resources and minimize the risk to life and property associated with flooding.
- Key ISMP issues included existing flooding, irrigation, erosion, and environmental issues such as fish passage barriers and poor water quality.
- Applicable stormwater criteria included Delta and Surrey 10-year minor and 100-year major conveyance standards and detention criteria, BC Ministry of Transportation design guide, DFO Guidelines for 6-month volume reduction, 6-month to 5-year detention, and water quality treatment of 90% of annual runoff, and the Riparian Area Regulation for riparian protection.

### Boundary/Shaw Creek Watershed

**Land Use**

- The historic, existing and future land uses were summarized. The existing land use is largely developed in the Surrey area (220 ha at 49% impervious) and mostly undeveloped or agricultural land in the Delta area (710 ha at 18% impervious). The future land use has very few zoning changes and mainly has redevelopment at higher impervious percentages (Surrey 58% impervious and Delta 24% impervious).

**Drainage Inventory**

- The Boundary/Shaw Creek watershed is 930 ha and drains to Mud Bay via the Oliver Pump Station. There are three significant watercourses in the watershed: Shaw Creek, Watershed Creek and Briarwood Creek. Watershed Creek has one significant tributary.
- There is an existing erosion problem in Shaw Creek between 120 Street and Highway 10 and existing flooding problems in the south portion of Delta Golf course, the lower part of Watershed Park, and the farmlands west of Highway 91.
- Irrigation water supply of the farmland is necessary in the growing season.
- A drainage inventory included investigations on creek crossings, channel cross-sections, erosion, deposition, obstructions and a condition assessment of hydraulic structures. Severe erosion was noted along Shaw Creek between 120 Street and Old Highway 10.

**Environmental Inventory and Assessment**

- Water quality sampling shows elevated nitrate levels in Briarwood Creek near to Canadian Council of Ministers of the Environment guidelines and levels of iron, aluminum, and cadmium above BC

Approved Water Quality Guidelines at one or more sites. Because of the limited amount of water quality sampling undertaken, comparison to guidelines is for the purpose of flagging issues of potential concern only. Further sampling to identify the extent of issues is recommended.

- Continuous temperature logging showed summer water temperatures in 2010 exceeded the BC Approved Water Quality Guidelines for salmonids in Shaw Creek for 8.4 days in July and 10.3 days in August.
- Sediment quality sampling showed elevated arsenic, cadmium, chromium, copper, zinc and nickel levels in several sample sites.
- The biological condition of Boundary/Shaw Creek has been heavily impacted by human disturbances in the watershed as reflected in the 2010 B-IBI score of 17.0 and a mean taxa richness of 10.8. This result was not unexpected given the high levels of urbanization and total impervious area within the upper watershed and low riparian forest integrity.
- The study area supports a known fish community with three salmonid species, five native non-salmonid species, and five exotic species. Coho, Chum and Cutthroat trout use the lower and transitional reaches of Watershed and Shaw Creeks for spawning and rearing. Lowland ditches are used for rearing and migration to and from the Oliver Pump Station and access to Mud Bay. Chinook may also periodically move in from Boundary Bay to rear.
- Instream fish habitat includes the lowland portion that has been dyked and channelized, the middle reaches that contain more gravel and cobble substrates suitable for spawning and rearing, and the upper reaches that have been culverted and developed. The best spawning and rearing habitat for salmonids is found in Watershed and Shaw Creeks. This habitat may not be available due to fish passage barriers.
- Six structures or crossings were identified as possible barriers to fish passage.
- Approximately 23% of the watershed is forest, with 27% riparian forest cover.
- Wildlife use in the watershed is diverse including species of conservation significance.
- Confirmed Species at Risk are Cutthroat Trout, *clarkii* subspecies and Great Blue Heron, *fannini* subspecies. Two red-listed ecological communities at risk in BC have been provisionally identified in the study area: red alder / skunk cabbage and Douglas-fir / dull Oregon-grape.

**Geotechnical/Hydrogeological Assessment**

- The hydrogeological assessment revealed mostly poor draining soils in the majority of the study area with a small area of well draining gravel and sand in the Watershed Creek headwaters. Groundwater tables in the lowlands are generally high and artesian wells are present at the toe of the uplands in Watershed Park.
- The geotechnical hazard assessment revealed numerous erosion sites mainly in Shaw Creek and historic slope instability along Shaw Creek in Watershed Park and below the Panorama Ridge subdivision. Monitoring of slope movement below Panorama Ridge along Shaw Creek is recommended.

## Watershed Analysis

### Hydrologic and Hydraulic Modelling

- Previously-developed XP-SWMM and MIKE 11 models were updated with more detailed information and validated.
- Three sets of design storms were created: the 2-, 5-, 10-, and 100-year return period 12-, 24-, and 48-hour duration events, the 6-month 24-hour event, and the ARDSA 10-year 2- and 5-day events taken from the Surrey *Design Criteria Manual* (2004) for the Municipal Hall Station.
- Continuous simulation modelling was performed using rainfall from 1991 to 2009 from the GVRD DT34 rain gauge. Results were used to create exceedance duration curves. The models were run for three scenarios: existing land use conditions without flow control, existing land use conditions with existing flow control, and future land use conditions with existing flow control. Results showed that there was little difference between the existing and future land uses. Both had higher peak flows for longer durations that the pre-development case. The Boundary Park Pond appears to be mitigating approximately half of the land use impacts in Shaw Creek.
- Peak flows for design events were estimated at strategic locations within the watershed for all three scenarios.
- The future land use, if left unmitigated, would increase 2-year to 100-year peak flows by approximately 5% to 10% and the 6-month flows by 20% to 40%. Watershed Creek, Watershed Creek Tributary, and Briarwood creek flows are not influenced by flow control as no detention or flow split structures are present in those areas.
- Exceedance duration curves developed from continuous simulation indicated that the future land use densification increase the flows and flow durations in Shaw, Watershed and Briarwood Creeks.
- A culvert capacity assessment was performed. Culverts under major roads or the railway were checked using the 100-year peak flow limiting the surcharge time to 30 minutes. Upland culverts under minor crossings were checked using the 10-year peak flow limiting surcharge time to 30 minutes. Lowland culverts under minor crossings were checked using the 10-year peak flow and a maximum head loss of 250 mm over the length of the culvert. Results indicate that ten culverts do not meet the criteria for both the existing and future land use flows. There are two surcharged creek crossings during the 100-year event and eight surcharged creek crossings in the 10-year event.
- A detention facility assessment was performed to determine the effectiveness of the existing flow control facilities and determine changes that would improve their effectiveness. Outlet adjustments to the Boundary Park Pond would provide some improvement and Detention Tank P1 is too small to benefit from outlet adjustment. The East Oliver Bypass Ponds reduce peak flows by 70 to 90% and will further reduce peak flows to the lowlands when completed and connected to Mud Bay.
- The ARDSA criteria were largely met in the lowland agricultural areas with the exception of freeboard in Cell 31 (the land bounded by Highway 10, Highway 91, and 112 Street).

### Watershed Health Tracking System

- The Watershed Health Tracking System shows general agreement between the measured scores (16 to 18) and the scores predicted form impervious area and riparian forest integrity (14 to 20). The watershed health is as would be expected for a watershed with this level of development and would benefit from improvements.

## Mitigation Alternatives

- Alternatives were developed and explored with Delta and Surrey to address the existing issues and mitigate the potential impacts of future development.
- Hydrotechnical upgrades to protect property and infrastructure were identified.
- To meet the no-net-loss requirement of an ISMP, future development impacts need to be mitigated. Developers in both Surrey and Delta should apply source controls to allow development while not making conditions worse in the downstream creeks or farmlands.
- To go beyond the no-net-loss requirement of an ISMP and in fact improve the watershed, a number of existing issues could be addressed. Six categories of alternatives are identified.
    - **Lowland drainage improvements** to improve the lowland drainage and irrigation.
    - **Riparian reforestation** to improve watershed health.
    - **Water quality improvements** to improve identify pollutants and treat the water quality of outflows into the creek.
    - **Detention and diversion alternatives** to reduce existing erosion.
    - **Volumetric reduction alternatives** to reduce existing development flows.
    - **Fish habitat improvements** to improve the conditions for fish in the creeks.
- The potential projects were discussed with Delta and Surrey and evaluated based on cost and qualitative benefit. The projects were assigned a timeline and importance which results in a prioritization. The majority of the options were selected to be incorporated into the ISMP.

## Proposed Shaw/Boundary Creek ISMP Strategy

The ISMP strategy is summarized in four timeline categories: Short term, medium term, long term and ongoing with capital cost estimates provided for each (see Table 5-1 and Figures 5-1 to 5-3).

- **Required hydrotechnical improvements** include three short term projects ($40,000), four medium term projects ($240,000), and one long term projects ($0).
- **Lowland drainage improvements** to further improve the lowlands drainage and irrigation include one medium term project ($220,000).
- **Water quality treatment** to improve instream conditions for fish includes one short term project ($0), three ongoing projects ($0), one medium term project ($100,000), and four long term projects ($492,000).
- **Volumetric reduction** for environmental protection includes two ongoing projects ($0) and two long term projects ($340,000).
- **Flow rate control** to meet bylaws and guidelines includes one ongoing project ($0).
- **Riparian protection and enhancement** for improving watershed health includes two ongoing projects ($0) and two medium term projects ($50,000).
- **Restoration and enhancement for fish** includes one medium term project ($20,000) and three long term projects ($110,000).

- Further studies and monitoring are recommended for the Boundary/Shaw Creek study area to investigate the geotechnical hazards along Shaw Creek, to continue benthic sampling, to document fish presence and fish passage through culverts, and to measure the performance of the ISMP.
- The total capital cost of the ISMP projects is up to $1.6 million of which $0.4M to $0.85M is attributable to Delta projects, $0.34M to Surrey projects, $0.38M to MOT projects, and $35k to BNSF projects. Short term cost projects are valued at $40,000, medium term projects at $630,000, and long term projects at $940,000. Funding opportunities from senior governments may be pursued for some of these projects.
- Additional regular drainage system maintenance was recommended.

## 6.2 Recommendations

Based on the above summary, it is recommended that Delta and Surrey:

1. Adopt the goal of net gain of ecological health for Boundary/Shaw Creek watershed as a whole.
2. Initiate a monitoring program to collect benthic samples, water quality samples, and sediment samples. Undertake further fish presence and fish passage investigations. Track the performance of the ISMP by comparing trends in indicators as shown in Table 5-1.
3. Implement the proposed short term projects and improvements first, followed in turn by the medium and long term projects and improvements.
4. Develop and implement policy requiring volume reduction source controls and detention on all new development and redevelopment.
5. Continue with roadside source controls BMP's in upland areas and review policy options.
6. Review implications of a roof leader disconnection program that directs roof runoff to landscaped areas and consider a volunteer program to assist home owners to do so.
7. Expand and enhance education program for residents in the catchment on the use of local BMPs (e.g. environmentally friendly soaps for car washing, fertilizer/pesticide usage, benefits of trees, and protection of riparian areas).
8. Initiate a detailed geotechnical study to monitor the slope movement and identify the need for bank protection to minimize risk of slope instability below Panorama Ridge along the left (south) bank of Shaw Creek.
9. Continue with and possibly expand maintenance programs required to protect infrastructure and facilities to promote their proper and effective function. Maintain source controls to meet watershed health targets.

## 6.3 Report Submission

Prepared by:

**KERR WOOD LEIDAL ASSOCIATES LTD.**

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***Original Signed and Sealed by:***

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Reviewed by:

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Crystal Campbell, P.Eng.
Technical Review

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## Appendix A

# Drainage Inventory

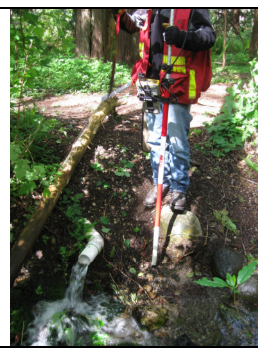
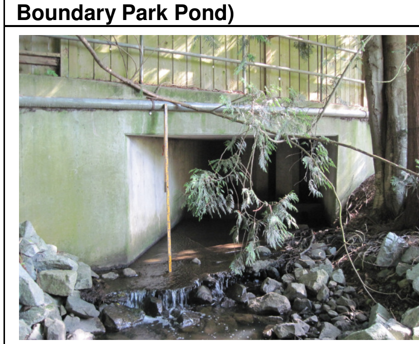
# Appendix A

**Figure A-1: Photo Overview of Boundary / Shaw Creek – Upland Culverts and Bridges (Page 1)**

| | | |
|---|---|---|
| **Bridge in Watershed Park** | **Bridge in Watershed Park** | **Inlet of Culvert CUL_372 on Briarwood Creek** |
|  |  |  |
| **Inlet to culvert under HWY 10** | **Inlet to culvert under HWY 10 east ramp to Ladner Trunk Road** | **Outlet to culvert under HWY 10 East ramp to Ladner Trunk Road** |
|  |  |  |
| **Inlet to culvert under Railway at HWY 10 overpass** | **Outlet to culvert under Railway at HWY 10 overpass** | **2 storm outfalls east of 63A Street (outfall to watercourse in Watershed Park)** |
|  |  |  |

# Appendix A

**Figure A-1: Photo Overview of Boundary / Shaw Creek – Upland Culverts and Bridges (Page 2)**

| | | |
|---|---|---|
| **Broken pipe in artesian well area** | **Outlet of culvert under path (culvert drains flow from artesian wells)** | **Pond area created by artesian wells** |
|  |  |  |
| **Inlet to culvert under railway (culvert drains flow from artesian wells)** | **Outfall south-east of 63 Street (Well)** | **Outfall from Briarwood Cres.** |
|  |  |  |
| **Storm sewer outfall (120 street sewer, Boundary Park Pond)** | **Storm sewer outfall (120 street sewer, Boundary Park Pond)** | |
|  |  | |

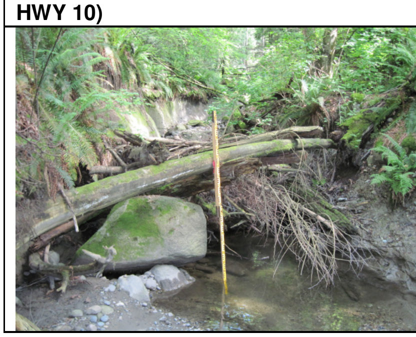
# Appendix A

### Figure A-2: Photo Overview of Boundary / Shaw Creek - Major Erosion Sites

| **Erosion downstream of work yard on 64 street** | **Erosion downstream of Boundary Park outfall** | **Erosion further downstream of Boundary Park outfall** |
|---|---|---|
|  |  |  |
| **Erosion further downstream of Boundary Park outfall (half way between outfall and HWY 10)** | | **Erosion site downstream of HWY 10 culvert and upstream of ramp to Ladner Trunk Road** |
|  |  |  |
| **Erosion, Debris Barrier, and Gravel Deposit downstream of HWY 10 culvert and upstream of ramp to Ladner Trunk Road** | **Erosion site downstream of HWY 10 culvert and upstream of ramp to Ladner Trunk Road** | |
|  |  | |

# Appendix A

**Figure A-3: Photo Overview of Boundary / Shaw Creek - Watercourse Obstructions**

| | | |
|---|---|---|
| **Obstruction downstream of Briarwood Cres. outfall** | **Obstruction downstream of Boundary Park outfall** | |
|  |  |  |
| **Obstruction further downstream of Boundary Park outfall (half way between outfall and HWY 10)** | | **Obstruction further downstream of Boundary Park outfall (Closer to HWY 10)** |
|  |  |  |
| **Obstruction further downstream of Boundary Park outfall (Closer to HWY 10)** | **Obstruction site downstream of HWY 10 culvert and upstream of ramp to Ladner Trunk Road** | |
|  |  |  |

KERR WOOD LEIDAL
consulting engineers

## Appendix B

# Environmental Inventory and Assessment

# Contents

## Appendix B-1.

In-situ water quality parameter sampling data for Shaw Creek ISMP study area streams (September 2010).

| ID | Catchment | Location Description | Date | Time | UTM-E (NAD27) | UTM-N (NAD27) | Temp (ºC) | Cond (µS/cm) | SpCond (µS/cm) | DO (%) | DO (mg/l) | pH pH | TDS (mg/l) | Turbidity (NTU) | ORP ORP | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Shaw | Shaw Ck south of Highway 10, approx. 130 m d/s of lower culvert at Old Hwy 10 interchange, 75 m u/s of BNSF railway culvert | 15-Sep-10 | 10:15 | 507641 | 5440988 | 15.37 | 118 | 145 | 85.8 | 8.57 | 6.92 | 0.094 | 4.05 | 22.2 | SHAW C-1 benthic site |
| 2 | Shaw | Shaw Ck u/s of railway culvert | 15-Sep-10 | 11:01 | 507601 | 5440928 | 15.34 | 119 | 146 | 86.5 | 8.65 | 6.81 | 0.095 | 4.72 | 62.8 | |
| 3 | Shaw | Shaw Ck u/s of Highway 91 culvert | 15-Sep-10 | 11:14 | 507421 | 5441058 | 15.00 | 133 | 165 | 80.3 | 8.03 | 6.71 | 0.108 | 2.58 | 36.5 | at confluence with Briarwood Ck; no fish observed in pools here |
| 4 | Shaw | Shaw Ck d/s of railway culvert | 15-Sep-10 | 11:24 | 507525 | 5440993 | 15.35 | 128 | 157 | 85.4 | 8.50 | 6.60 | 0.102 | 4.72 | 7.3 | |
| 5 | Briarwood | Briarwood Ck along regional greenway trail | 15-Sep-10 | 11:38 | 507394 | 5441174 | 12.90 | 241 | 314 | 15.1 | 1.53 | 6.54 | 0.204 | 160.0 | -20.7 | |
| 6 | Shaw | Shaw Ck within Highway 10/Old Highway 10 interchange | 15-Sep-10 | 11:53 | 507734 | 5441138 | 15.87 | 119 | 145 | 93.7 | 9.26 | 7.08 | 0.094 | 2.34 | 0.2 | Salamander sp. seen briefly in pool at sampling site |
| 7 | Shaw | Shaw Ck 20 m d/s of Highway 10/Old Highway 10 interchange | 15-Sep-10 | 12:04 | 507715 | 5441063 | 16.12 | 120 | 145 | 93.9 | 9.22 | 7.11 | 0.094 | 4.05 | 26.9 | |
| 8 | Shaw | Shaw Ck 25 m u/s of Ladner Trunk Rd | 15-Sep-10 | 12:16 | 507774 | 5441214 | 15.96 | 119 | 144 | 76.9 | 7.60 | 7.02 | 0.093 | 3.33 | 45.2 | SHAW C-2 benthic site |
| 9 | Shaw | Shaw Ck immed. d/s of Scott Road/120 St culvert | 15-Sep-10 | 12:51 | 508166 | 5441899 | 17.04 | 104 | 122 | 95.2 | 9.19 | 7.00 | 0.080 | 9.86 | 98.4 | SHAW SCOTT water quality/sediment site |
| 10 | Briarwood | Briarwood Ck immed. u/s of of Watershed Park slope culvert | 15-Sep-10 | 13:16 | 507546 | 5441744 | 17.56 | 175 | 204 | 98.2 | 9.33 | 7.16 | 0.132 | 4.82 | 88.6 | BRIARWOOD C-1 benthic site |
| 11 | Briarwood | Briarwood Ck immed. d/s of Briarwood Cres storm outfall | 15-Sep-10 | 13:51 | 507690 | 5441864 | 17.58 | 175 | 203 | 94.2 | 8.99 | 7.12 | 0.135 | 2.58 | 66.9 | |
| 12 | Watershed | Watershed Ck 5 m u/s of railway culvert | 15-Sep-10 | 14:15 | 506838 | 5442056 | 10.96 | 133 | 181 | 77.0 | 8.48 | 6.84 | 0.118 | 2.03 | 98.0 | WATERSHED C-1 benthic site |
| 13 | Lowlands West | Oliver Slough immed. u/s of 112 St culvet | 15-Sep-10 | 15:08 | 506605 | 5438806 | 16.06 | 673 | 811 | 52.5 | 5.13 | 6.60 | 0.525 | 9.02 | 44.7 | LOW-W water quality/sediment site |
| 14 | Lowlands East | East Oliver Bypass east of Highway 91, north of Highway 99 | 15-Sep-10 | 16:04 | 507720 | 5440343 | 18.32 | 285 | 327 | 90.6 | 8.51 | 7.28 | 0.212 | 1.81 | 67.8 | LOW-E water quality site |
| 15 | Watershed | Watershed Ck immed. d/s of Kittison Pkwy | 16-Sep-10 | 9:22 | 506201 | 5442665 | 16.77 | 116 | 137 | 96.3 | 9.43 | 7.49 | 0.089 | 3.27 | 79.5 | |
| 16 | Watershed Trib. | Unnamed trib. 10 d/s of Watershed Park maintenance yard | 16-Sep-10 | 9:34 | 507226 | 5442428 | 14.59 | 78 | 98 | 78.6 | 7.99 | 7.16 | 0.063 | -0.19 | 124.6 | |
| 17 | Shaw | Boundary Park Stormwater Pond | 16-Sep-10 | 9:48 | 508344 | 5441902 | 17.42 | 104 | 122 | 103.8 | 9.97 | 7.37 | 0.079 | 9.95 | 111.8 | |
| 18 | Shaw | Shaw Ck 20 m u/s of Highway 10 culvert | 16-Sep-10 | 9:58 | 508076 | 5441546 | 16.66 | 74 | 83 | 90.1 | 8.76 | 7.02 | 0.057 | 10.33 | 134.9 | |
| 19 | Watershed | Watershed Park groundwater-fed trib. immed. d/s of Lower Trail culvert | 16-Sep-10 | 10:20 | 507519 | 5441548 | 10.63 | 157 | 216 | 96.7 | 10.76 | 7.23 | 0.141 | 0.64 | 123.1 | |
| 20 | Lowlands East | Ditch across from Delta Golf Course entrance | 16-Sep-10 | 10:37 | 507715 | 5440730 | 14.12 | 162 | 208 | 15.7 | 1.61 | 6.65 | 0.124 | 8.33 | 86.0 | water stagnant; ditch was RCG-infested |
| 21 | Lowlands West | Lorne Ditch immed. u/s of 112 St | 16-Sep-10 | 10:51 | 506590 | 5441077 | 14.63 | 158 | 197 | 23.4 | 2.37 | 6.39 | 0.128 | 3.16 | 405.7 | irrigation dam 10 m west of 112 St is 2 foot drop |
| 22 | Lowlands West | 60 Ave Ditch d/s of 6015 112 St driveway crossing | 16-Sep-10 | 11:10 | 506582 | 5441872 | 10.91 | 137 | 188 | 82.6 | 9.12 | 6.87 | 0.122 | 2.13 | 280.6 | water flowing at this location; good potential spawning habitat (gravels, etc.) |
| 23 | Lowlands West | Private E-W ditch north of 5860 112 St | 16-Sep-10 | 11:34 | 506591 | 5441665 | 14.77 | 166 | 206 | 18.6 | 1.89 | 5.72 | 0.134 | 0.56 | 120.7 | |
| 24 | Lowlands West | 112 St Ditch at concrete footbridge in front of 5655 112 St | 16-Sep-10 | 11:42 | 506575 | 5441181 | 12.78 | 160 | 209 | 62.7 | 6.71 | 6.22 | 0.136 | 2.73 | 237.5 | ditch has muddy bottom |
| 25 | Lowlands West | 112 St Ditch 25 m u/s of Ladner Trunk Rd | 16-Sep-10 | 11:54 | 506571 | 5440401 | 13.96 | 168 | 213 | 73.9 | 7.62 | 6.60 | 0.138 | 5.36 | -20.9 | |
| 26 | Lowlands West | Ditch E of 112 St S of Ladner Trunk Rd at u/s end of box culvert to W side ditch | 16-Sep-10 | 12:06 | 506589 | 5440298 | 16.11 | 336 | 405 | 30.7 | 3.01 | 6.21 | 0.263 | 10.5 | 40.3 | flow is W along S side of Ladner Trunk Rd then turns S then through box culvert |
| 27 | Lowlands West | Oliver Slough S of Highway 99 | 16-Sep-10 | 12:26 | 507107 | 5439528 | 16.32 | 6333 | 7590 | 52.2 | 4.94 | 6.44 | 4.933 | 106.6 | -18.7 | |
| 28 | Lowlands West | 112 St Ditch immed u/s of 4455 112 St driveway culvert | 16-Sep-10 | 12:39 | 506582 | 5438882 | 15.26 | 247 | 304 | 61.6 | 6.16 | 7.36 | 0.192 | n/a | 34.3 | ditch too steep to sample; salinity = 0.14 |
| | | | | | | **mean** | 15.16 | 394 | 478 | 71.9 | 7.19 | 6.84 | 0.310 | 14.0 | 85.2 | |
| | | Coordinates in UTM NAD27. | | | | **min** | 10.63 | 74 | 83 | 15.1 | 1.53 | 5.72 | 0.057 | -0.19 | -20.9 | |
| | | | | | | **max** | 18.32 | 6333 | 7590 | 103.8 | 10.76 | 7.49 | 4.933 | 160.0 | 405.7 | |
| | | | | | | **count** | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 27 | 28 | |

## Appendix B-2.

Bacteriological, anion, nutrient, and metal concentrations in water samples from Shaw Creek ISMP study areas streams (September 2010).

**RESULTS OF ANALYSIS**

| Sample ID<br>Date Sampled<br>Time Sampled | Units | Detection Limits | SHAW C-1<br>15-SEP-10<br>10:27 | SHAW SCOTT<br>15-SEP-10<br>12:50 | BRIARWOOD C-1<br>15-SEP-10<br>13:15 | WATERSHED C-1<br>15-SEP-10<br>14:10 | LOW-W<br>15-SEP-10<br>14:59 | LOW-E<br>15-SEP-10<br>16:00 | BC Approved (A) and Working (W)<br>Water Quality Guidelines<br>(2006)<br>**BCWQ 2006** | CCME Water Quality Guidelines<br>for the Protection of Aquatic Life<br>(December 2007)<br>**CCME 2007** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Bacteriological Tests** | | | | | | | | | | |
| Coliform Bacteria - Fecal | MPN/100mL | 2 | 49 | 49 | 49 | 23 | 1600 | 33-46 | 200 | 200 |
| Coliform Bacteria - Total | MPN/100mL | 2 | 920 | >1600 | 350 | 920 | >1600 | 240-350 | | |
| **Anions and Nutrients** | | | | | | | | | | |
| Alkalinity, Total (as CaCO3) | mg/L | 2.0 | 43.2 | 35.2 | 46.1 | 74.2 | 64.3 | 115 | | |
| Ammonia as N | mg/L | 0.0050 | 0.0596 | 0.0052 | <0.0050 | 0.0152 | 0.280 | <0.0050 | | |
| Nitrate (as N) | mg/L | 0.0050 | 0.772 | 0.883 | 2.56 | 0.582 | 0.632 | <0.0050 | | 2.9 |
| Ortho Phosphate as P | mg/L | 0.0010 | <0.0010 | 0.0191 | 0.0076 | 0.0553 | 0.121 | <0.0010 | | |
| **Total Metals** | | | | | | | | | | |
| Aluminum (Al)-Total | mg/L | 0.0050 | 0.295 | 0.206 | <0.040 | <0.040 | 0.373 | <0.020 | | 0.005 @ pH<6.5; 0.1@ pH>6.5 |
| Antimony (Sb)-Total | mg/L | 0.00050 | <0.00050 | 0.00057 | <0.00050 | <0.00050 | <0.00050 | <0.00050 | 0.02 (W) | |
| Arsenic (As)-Total | mg/L | 0.00050 | 0.00146 | 0.00163 | 0.00382 | 0.00350 | <0.0040 | <0.00050 | 0.005 (W) | 0.005 |
| Barium (Ba)-Total | mg/L | 0.020 | <0.020 | <0.020 | 0.024 | <0.020 | <0.020 | <0.020 | 5 (W) | |
| Beryllium (Be)-Total | mg/L | 0.0010 | <0.0010 | <0.0010 | <0.0010 | <0.0010 | <0.0010 | <0.0010 | 0.0053 (W) | |
| Boron (B)-Total | mg/L | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | 0.12 | <0.10 | | |
| Cadmium (Cd)-Total | mg/L | 0.000017 | 0.000021 | 0.000019 | <0.000017 | <0.000017 | 0.000068 | <0.000017 | 0.00001 (b) (W) | 0.000017 |
| Calcium (Ca)-Total | mg/L | 0.10 | 15.9 | 14.1 | 16.8 | 19.7 | 30.2 | 32.2 | | |
| Chromium (Cr)-Total | mg/L | 0.0010 | 0.0011 | 0.0013 | <0.0010 | 0.0010 | 0.0019 | <0.0010 | 0.001 Cr(VI); 0.0089 Cr(III) (W) | 0.001 Cr(VI); 0.0089 Cr(III) |
| Cobalt (Co)-Total | mg/L | 0.00030 | <0.00030 | <0.00030 | <0.00030 | <0.00030 | 0.00223 | <0.00030 | 0.110 (A) | |
| Copper (Cu)-Total | mg/L | 0.0010 | 0.0037 | 0.0054 | 0.0031 | <0.0010 | 0.0038 | <0.0010 | 0.003 to 0.007 mg/L [(0.094(hardness)+2) (A)] | 0.002 @ CaCO3 = 0-120 mg/L |
| Iron (Fe)-Total | mg/L | 0.030 | 0.835 | 0.408 | 0.161 | 0.071 | 3.64 | 0.106 | 0.3 (W) | 0.3 |
| Lead (Pb)-Total | mg/L | 0.00050 | 0.00079 | 0.00080 | <0.00050 | <0.00050 | <0.00050 | <0.00050 | 0.018 mg/L at 30 mg/L $e^{[1.273 \ln(hardness)-1.460]}$ (A) | 0.001 @ CaCO3 = 0-60 mg/L |
| Lithium (Li)-Total | mg/L | 0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | 0.0056 | 0.0057 | 5 (W) | |
| Magnesium (Mg)-Total | mg/L | 0.10 | 2.72 | 2.08 | 3.50 | 6.83 | 19.6 | 14.2 | | |
| Manganese (Mn)-Total | mg/L | 0.00030 | 0.0758 | 0.0339 | 0.00287 | 0.0124 | 0.248 | 0.180 | 0.8 - 1.1 @ CaCO3 = 25-50 mg/L (A) | |
| Mercury (Hg)-Total | mg/L | 0.000010 | <0.000010 | <0.000010 | <0.000010 | <0.000010 | <0.000010 | <0.000010 | 0.0001 (A) | |
| Molybdenum (Mo)-Total | mg/L | 0.0010 | <0.0010 | <0.0010 | <0.0010 | <0.0010 | 0.0011 | <0.0010 | 2 (A) | 0.073 |
| Nickel (Ni)-Total | mg/L | 0.0010 | <0.0010 | 0.0010 | <0.0010 | <0.0010 | 0.0087 | 0.0045 | 0.025 @ CaCO3 = 0-60 mg/L (W) | 0.025 @ CaCO3 = 0-60 mg/L |
| Potassium (K)-Total | mg/L | 2.0 | <2.0 | <2.0 | 2.5 | <2.0 | 8.5 | 3.4 | | |
| Selenium (Se)-Total | mg/L | 0.0010 | <0.0010 | <0.0010 | <0.0010 | <0.0010 | <0.0040 | <0.0010 | 0.001 (A - drinking water) | 0.001 |
| Silver (Ag)-Total | mg/L | 0.000020 | <0.000020 | <0.000020 | <0.000020 | <0.000020 | <0.000020 | <0.000020 | 0.0001 @ CaCO3 < 100 mg/L (A) | 0.0001 |
| Sodium (Na)-Total | mg/L | 2.0 | 8.0 | 6.1 | 14.3 | 7.4 | 90.7 | 16.3 | | |
| Thallium (Tl)-Total | mg/L | 0.00020 | <0.00020 | <0.00020 | <0.00020 | <0.00020 | <0.00020 | <0.00020 | 0.0003 (W) | 0.0008 |
| Tin (Sn)-Total | mg/L | 0.00050 | <0.00050 | <0.00050 | <0.00050 | <0.00050 | <0.00050 | <0.00050 | | |
| Titanium (Ti)-Total | mg/L | 0.010 | 0.012 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | | |
| Uranium (U)-Total | mg/L | 0.00020 | <0.00020 | <0.00020 | <0.00020 | 0.00057 | 0.00036 | <0.00020 | | |
| Vanadium (V)-Total | mg/L | 0.0010 | 0.0014 | 0.0010 | <0.0010 | 0.0047 | <0.0040 | <0.0010 | | |
| Zinc (Zn)-Total | mg/L | 0.0050 | 0.0114 | 0.0207 | 0.0066 | <0.0050 | 0.0141 | <0.0050 | 0.033 @ CaCO3 = 0-90 mg/L (A) | |
| **Physical Tests** | | | | | | | | | | |
| Hardness (as CaCO3) | mg/L | 0.50 | 50.9 | 43.7 | 56.3 | 77.4 | 156 | 139 | | |
| Total Suspended Solids | mg/L | 3.0 | 27.1 | 11.8 | <3.0 | <3.0 | 17.8 | 7.8 | | |

noticeably higher levels at site(s) compared with other sites in the study area

| Sampling Sites | UTM-E | UTM-N | Location Description |
|---|---|---|---|
| SHAW C-1 | 507641 | 5440988 | Shaw Ck south of Highway 10, approximately 130 m d/s of lower culvert at Old Highway 10 interchange, 75 m upstream of BNSF railway culvert |
| SHAW SCOTT | 508166 | 5441899 | Shaw Ck, immediately d/s of Scott Road/120 St culvert |
| BRIARWOOD C-1 | 507546 | 5441744 | Briarwood Ck, immediately u/s of inlet to steep gradient culvert in Watershed Park |
| WATERSHED C-1 | 506838 | 5442056 | Watershed Ck, 5 m u/s of BNSF railway culvert |
| LOW-W | 506605 | 5438806 | Oliver Slough, immediately u/s of 112 St culvert; representative of lowlands west of Highway 91 |
| LOW-E | 507720 | 5440343 | East Oliver Bypass, east of Highway 91; representative of lowlands east of Highway 91 |

Coordinates in NAD27 Ground.

## Appendix B-3.

Metal concentrations in sediment samples from Shaw Creek ISMP study area streams (September 2010).

**RESULTS OF ANALYSIS**

| Sample ID | | | SHAW C-1 | SHAW SCOTT | BRIARWOOD C-1 | WATERSHED C-1 | LOW-W | BC Working Sediment Quality Guidelines - Freshwater (August 2006) | | CCME Sediment Quality Guidelines - Freshwater (Update 2002) | | Other Comparative Values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date Sampled | | | 15-SEP-10 | 15-SEP-10 | 15-SEP-10 | 15-SEP-10 | 15-SEP-10 | | | | | | | |
| **Metals** | Units | Detection Limits | | | | | | **ISGQ BC 2006** | **PEL BC 2006** | **ISGQ CCME 2002 (Aquatic Life)** | **PEL CCME 2002 (Aquatic Life)** | **Still Creek Subbasin 1995 (median)** | **Brunette River Subbasin 1995 (median)** | **Oh (2003) thesis Table 2-3** |
| Antimony (Sb) | mg/kg | 10 | <10 | <10 | <10 | <10 | <10 | | | | | | | |
| Arsenic (As) | mg/kg | 5.0 | <5.0 | <5.0 | 12.1 | <5.0 | 10.7 | 5.9 | 17 | 5.9 | 17.0 | | | |
| Barium (Ba) | mg/kg | 1.0 | 43.8 | 35.4 | 44.0 | 21.2 | 72.6 | | | | | | | |
| Beryllium (Be) | mg/kg | 0.50 | <0.50 | <0.50 | <0.50 | <0.50 | 2.69 | | | | | | | |
| Cadmium (Cd) | mg/kg | 0.50 | <0.50 | <0.50 | <0.50 | <0.50 | 5.66 | 0.6 | 3.5 | 0.6 | 3.5 | 141 | 103 | |
| Chromium (Cr) | mg/kg | 2.0 | 19.1 | 23.9 | 30.8 | 9.6 | 53.8 | 37.3 | 90 | 37.3 | 90.0 | | | |
| Cobalt (Co) | mg/kg | 2.0 | 4.6 | 5.8 | 7.2 | 4.9 | 14.6 | | | | | | | 18 |
| Copper (Cu) | mg/kg | 1.0 | 12.1 | 25.1 | 33.8 | 15.1 | 257 | 35.7 | 197 | 35.7 | 197.0 | 130 | 51 | 33-210 |
| Lead (Pb) | mg/kg | 30 | <30 | <30 | <30 | <30 | <30 | 35 | 91 | 35.0 | 91.3 | 130 | 55 | 10-223 |
| Mercury (Hg) | mg/kg | 0.050 | <0.050 | <0.050 | 0.123 | <0.050 | 0.086 | 0.170 | 0.486 | | | | | |
| Molybdenum (Mo) | mg/kg | 4.0 | <4.0 | <4.0 | <4.0 | <4.0 | 7.4 | | | | | | | |
| Nickel (Ni) | mg/kg | 5.0 | 13.5 | 16.7 | 16.9 | 7.7 | 67.9 | 16 | 75 | | | 17 | 12 | 32-340 |
| Selenium (Se) | mg/kg | 2.0 | <2.0 | <2.0 | <2.0 | <2.0 | <2.2 | 5 | | | | | | |
| Silver (Ag) | mg/kg | 2.0 | <2.0 | <2.0 | <2.0 | <2.0 | <2.0 | 0.5* | | | | | | |
| Tin (Sn) | mg/kg | 5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | | | | | | | |
| Vanadium (V) | mg/kg | 2.0 | 40.5 | 36.7 | 41.7 | 40.4 | 54.6 | | | | | | | |
| Zinc (Zn) | mg/kg | 1.0 | 62.6 | 74.0 | 124 | 43.5 | 361 | 123 | 315 | 123.0 | 315.0 | 251 | 128 | 159-983 |
| **Physical Tests** | | | | | | | | | | | | | | |
| pH | | | 7.20 | 7.86 | 7.54 | 7.44 | 7.02 | | | | | | | |

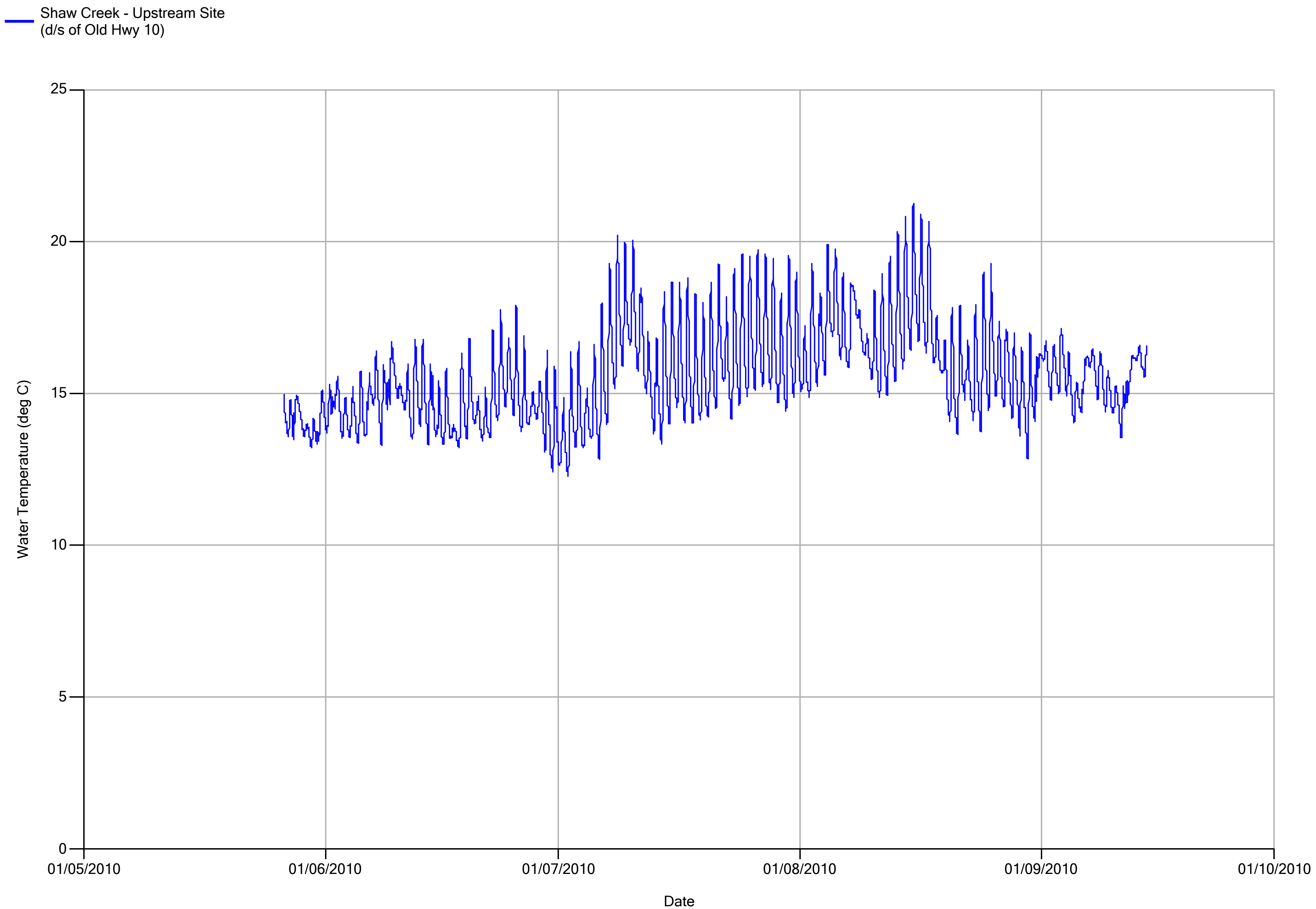
*Ontario sediment quality guideline

noticeably higher levels at site(s) compared with other sites in the study area

| **Sampling Sites** | **UTM-E** | **UTM-N** | **Location Description** |
|---|---|---|---|
| SHAW C-1 | 507641 | 5440988 | Shaw Ck south of Highway 10, approximately 130 m d/s of lower culvert at Old Highway 10 interchange, 75 m upstream of BNSF railway culvert |
| SHAW SCOTT | 508166 | 5441899 | Shaw Ck, immediately d/s of Scott Road/120 St culvert |
| BRIARWOOD C-1 | 507546 | 5441744 | Briarwood Ck, immediately u/s of inlet to steep gradient culvert in Watershed Park |
| WATERSHED C-1 | 506838 | 5442056 | Watershed Ck, 5 m u/s of BNSF railway culvert |
| LOW-W | 506605 | 5438806 | Oliver Slough, immediately u/s of 112 St culvert; representative of lowlands west of Highway 91 |
| LOW-E | 507720 | 5440343 | East Oliver Bypass, east of Highway 91; representative of lowlands east of Highway 91 |

Coordinates in NAD27 Ground.

# Shaw Creek: Raw Water Temperature 2010



**Analysis of biological samples:**
**Technical summary of methods and quality assurance procedures**
**Prepared for Raincoast Applied Ecology**
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## METHODS

*Sample processing*

Four macroinvertebrate samples from the Shaw Creek ISMP Project were delivered to Rhithron's laboratory facility in Missoula, Montana on December 10, 2010. All samples arrived in good condition. An inventory document containing sample identification information was provided by the Raincoast Applied Ecology (RAE) Project Manager. Upon arrival, samples were unpacked and examined, and checked against the RAE inventory. An inventory spreadsheet was created and sent to the RAE Project Manager. This spreadsheet included project code and internal laboratory identification numbers and was verified by the RAE Project Manager prior to upload into the Rhithron database.

Samples were preserved in formalin. Upon arrival all samples were rinsed to remove formalin preservative. Samples were re-preserved in 95% ethanol. Standard sorting protocols were applied to achieve representative subsamples of a minimum of 400 organisms. Caton sub-sampling devices (Caton 1991), divided into 30 grids, each approximately 5 cm by 6 cm were used. Each individual sample was thoroughly mixed in its jar(s), poured out and evenly spread into the Caton tray, and individual grids were randomly selected. The contents of each grid were examined under stereoscopic microscopes using 10x-30x magnification. All aquatic invertebrates from each selected grid were sorted from the substrate, and placed in 95% ethanol for subsequent identification. Grid selection, examination, and sorting continued until at least 400 organisms were sorted. All unsorted sample fractions were retained and stored at the Rhithron laboratory.

Organisms were individually examined by certified taxonomists, using 10x – 80x stereoscopic dissecting scopes (Leica S8E and S6E) and identified to target taxonomic levels consistent with Washington LPTL (Plotnikoff and White 1996) protocols and data generated for previous RAE projects, using appropriate published taxonomic references and keys.

Identification, counts, life stages, and information about the condition of specimens were recorded on bench sheets. Organisms that could not be identified to the taxonomic targets because of immaturity, poor condition, or lack of complete current regionally-applicable published keys were left at appropriate taxonomic levels that were coarser than those specified. To obtain accuracy in richness measures, these organisms were designated as "not unique" if other specimens from the same group could be taken to target levels. Organisms designated as "unique" were those that could be definitively distinguished from other organisms in the sample. Identified organisms were preserved in 95% ethanol in labeled vials, and archived at the Rhithron laboratory.

Representatives of each unique identified taxon were placed in labeled vials. Each reference specimen was internally verified by three Rhithron taxonomists. Specimens added to the collection and their verifications were continuously tracked on a reference collection form.

*Quality control procedures*

Quality control procedures for initial sample processing and subsampling involved checking sorting efficiency. These checks were conducted on 100% of the samples by independent observers who microscopically re-examined at least 20% of sorted substrate from each sample. Quality control procedures for each sample proceeded as follows:

The quality control technician poured the sorted substrate from a processed sample out into a Caton tray, redistributing the substrate so that 20% of it could be accurately lifted out by removing entire grids in a random fashion. Grids were selected, and re-examined until 20% of the substrate was re-sorted. All organisms that were missed were counted and this number was added to the total number obtained in the original sort. Sorting efficiency was evaluated by applying the following calculation:

$$SE = \frac{n_1}{n_1 + n_2} \times 100$$

where: SE is the sorting efficiency, expressed as a percentage, $n_1$ is the total number of specimens in the first sort, and $n_2$ is the total number of specimens expected in the second sort, based on the results of the re-sorted 20%.

Quality control procedures for taxonomic determinations of invertebrates were performed on a random selection of samples from the City of North Vancouver, City of Surrey, Metro Vancouver and Maple Creek ISMP Fall 2010 projects. The 10% minimum requirement was fulfilled within those projects.

Six taxonomists independently reviewed the reference collection to verify consistency of identifications.

*Data analysis*

Taxa lists and counts for each sample were constructed. Metric calculations and scoring for the B-IBI for Puget Sound Lowlands streams (Karr and Chu 1999) were performed using Rhithron's customized database software. A sites-by-taxa and sites-by-metrics data matrix was compiled in Microsoft Excel XP.

## RESULTS

*Quality Control Procedures*

Results of quality control procedures for subsampling are given in Table 1. Sorting efficiency averaged 95.05% and data entry efficiency averaged 100% for the project. These similarity statistics fall within acceptable industry criteria (Stribling et al. 2003).

*Data analysis*

Taxa lists and counts and metric summary pages for each sample are given in the Appendix. Electronic spreadsheets containing macroinvertebrate identifications and metric values and scores were provided to the RAE Project Manager via email. The complete verified reference collection was held at the Rhithron laboratory and will be delivered to the RAE Project Manager upon completion of all City of Surrey projects.

**Table 1.** *Results of internal quality control procedures for subsampling and taxonomy.* Shaw Creek ISMP, Fall 2010.

| RAI Sample ID | Station name | Client ID | Sorting efficiency |
|---|---|---|---|
| RAE10CS2082 | Shaw Creek C1 | C1-1 | 96.66% |
| RAE10CS2083 | Shaw Creek C2 | C2-1 | 97.26% |
| RAE10CS2084 | Briarwood Creek | | 91.84% |
| RAE10CS2085 | Watershed Creek | | 94.42% |

## REFERENCES


Bray, J. R. and J. T. Curtis. 1957. An ordination of upland forest communities of southern Wisconsin. Ecological Monographs 27: 325-349.

Caton, L. W. 1991. Improving subsampling methods for the EPA's "Rapid Bioassessment" benthic protocols. Bulletin of the North American Benthological Society. 8(3): 317-319.

Karr, J. R. and E. W. Chu. 1999. *Restoring Life in Running Waters*. Island Press.

Plotnikoff, R.W. and J. S. White. 1996. Taxonomic Laboratory Protocol for Stream Macroinvertebrates Collected by the Washington State Department of Ecology. Washington State Department of Ecology, Environmental Assessment Publication No. 96-323.

Stribling, J.B., S.R Moulton II and G.T. Lester. 2003. Determining the quality of taxonomic data. J.N. Am. Benthol. Soc. 22(4): 621-631.

**APPENDIX**

**Taxa lists and metric summaries**

**Shaw Creek ISMP**

**Fall 2010**

# Taxa Listing

Project ID: RAE10CS2
RAI No.: RAE10CS2082

RAI No.: RAE10CS2082
Sta. Name: Shaw Creek C1
Client ID: C1-1
Date Coll.: 9/15/2010
No. Jars: 1
STORET ID: Shaw Creek ISMP

| Taxonomic Name | Count | PRA | Unique | Stage | Qualifier | BI | Function |
|---|---|---|---|---|---|---|---|
| Non-Insect | | | | | | | |
| Nematoda | 8 | 1.88% | Yes | Unknown | | 5 | UN |
| Oligochaeta | 125 | 29.34% | Yes | Unknown | | 10 | CG |
| Turbellaria | 4 | 0.94% | Yes | Unknown | | 4 | PR |
| Asellidae | | | | | | | |
| *Caecidotea* sp. | 32 | 7.51% | Yes | Unknown | | 8 | CG |
| Crangonyctidae | | | | | | | |
| *Crangonyx* sp. | 26 | 6.10% | Yes | Unknown | | 6 | CG |
| Sphaeriidae | | | | | | | |
| Sphaeriidae | 1 | 0.23% | Yes | Unknown | | 8 | CF |
| Ephemeroptera | | | | | | | |
| Baetidae | | | | | | | |
| *Baetis* sp. | 1 | 0.23% | No | Larva | Early Instar | 5 | CG |
| *Baetis tricaudatus* | 11 | 2.58% | Yes | Larva | | 4 | CG |
| Trichoptera | | | | | | | |
| Hydropsychidae | | | | | | | |
| *Parapsyche* sp. | 1 | 0.23% | Yes | Larva | Early Instar | 0 | PR |
| Rhyacophilidae | | | | | | | |
| *Rhyacophila narvae* | 1 | 0.23% | Yes | Larva | | 0 | PR |
| Diptera | | | | | | | |
| Ceratopogonidae | | | | | | | |
| Ceratopogoninae | 2 | 0.47% | Yes | Larva | | 6 | PR |
| Empididae | | | | | | | |
| *Neoplasta* sp. | 6 | 1.41% | Yes | Larva | | 5 | PR |
| Simuliidae | | | | | | | |
| *Simulium* sp. | 2 | 0.47% | Yes | Larva | | 6 | CF |
| Tipulidae | | | | | | | |
| *Dicranota* sp. | 1 | 0.23% | Yes | Larva | | 3 | PR |
| *Limnophila* sp. | 1 | 0.23% | Yes | Larva | | 3 | PR |
| Chironomidae | | | | | | | |
| Chironomidae | | | | | | | |
| Chironomidae | 184 | 43.19% | Yes | Larva | | 10 | CG |
| Chironomidae | 20 | 4.69% | No | Pupa | | 10 | CG |
| Sample Count | 426 | | | | | | |

# Taxa Listing

Project ID: RAE10CS2
RAI No.: RAE10CS2083

RAI No.: RAE10CS2083 | Sta. Name: Shaw Creek C2
Client ID: C2-1
Date Coll.: 9/15/2010 | No. Jars: 1 | STORET ID: Shaw Creek ISMP

| Taxonomic Name | Count | PRA | Unique | Stage | Qualifier | BI | Function |
|---|---|---|---|---|---|---|---|
| Non-Insect | | | | | | | |
| Oligochaeta | 97 | 26.80% | Yes | Unknown | | 10 | CG |
| Turbellaria | 98 | 27.07% | Yes | Unknown | | 4 | PR |
| Asellidae | | | | | | | |
| *Caecidotea* sp. | 9 | 2.49% | Yes | Unknown | | 8 | CG |
| Crangonyctidae | | | | | | | |
| *Crangonyx* sp. | 96 | 26.52% | Yes | Unknown | | 6 | CG |
| Ephemeroptera | | | | | | | |
| Baetidae | | | | | | | |
| *Baetis tricaudatus* | 50 | 13.81% | Yes | Larva | | 4 | CG |
| Diptera | | | | | | | |
| Simuliidae | | | | | | | |
| *Simulium* sp. | 2 | 0.55% | Yes | Larva | | 6 | CF |
| *Simulium* sp. | 1 | 0.28% | No | Pupa | | 6 | CF |
| Chironomidae | | | | | | | |
| Chironomidae | | | | | | | |
| Chironomidae | 8 | 2.21% | Yes | Larva | | 10 | CG |
| Chironomidae | 1 | 0.28% | No | Pupa | | 10 | CG |
| Sample Count | 362 | | | | | | |

# Taxa Listing

Project ID: RAE10CS2
RAI No.: RAE10CS2084

RAI No.: RAE10CS2084 Sta. Name: Briarwood Creek
Client ID:
Date Coll.: 9/15/2010 No. Jars: 1 STORET ID: Shaw Creek ISMP

| Taxonomic Name | Count | PRA | Unique | Stage | Qualifier | BI | Function |
|---|---|---|---|---|---|---|---|
| Non-Insect | | | | | | | |
| Amphipoda | 6 | 3.17% | Yes | Unknown | Damaged | 4 | CG |
| Oligochaeta | 131 | 69.31% | Yes | Unknown | | 10 | CG |
| Turbellaria | 37 | 19.58% | Yes | Unknown | | 4 | PR |
| Planorbidae | | | | | | | |
| *Promenetus* sp. | 2 | 1.06% | Yes | Unknown | | 6 | SC |
| Ephemeroptera | | | | | | | |
| Baetidae | | | | | | | |
| Baetidae | 2 | 1.06% | No | Larva | Damaged | 4 | CG |
| *Baetis tricaudatus* | 1 | 0.53% | Yes | Larva | | 4 | CG |
| Chironomidae | | | | | | | |
| Chironomidae | | | | | | | |
| Chironomidae | 10 | 5.29% | Yes | Larva | | 10 | CG |
| Sample Count | 189 | | | | | | |

# Taxa Listing

Project ID: RAE10CS2
RAI No.: RAE10CS2085

RAI No.: RAE10CS2085
Sta. Name: Watershed Creek
Client ID:
Date Coll.: 9/15/2010
No. Jars: 1
STORET ID: Shaw Creek ISMP

| Taxonomic Name | Count | PRA | Unique | Stage | Qualifier | BI | Function |
|---|---|---|---|---|---|---|---|
| Non-Insect | | | | | | | |
| Amphipoda | 6 | 1.44% | No | Unknown | Damaged | 4 | CG |
| Oligochaeta | 54 | 12.92% | Yes | Unknown | | 10 | CG |
| Asellidae | | | | | | | |
| *Caecidotea* sp. | 1 | 0.24% | Yes | Unknown | | 8 | CG |
| Crangonyctidae | | | | | | | |
| *Crangonyx* sp. | 109 | 26.08% | Yes | Unknown | | 6 | CG |
| Planariidae | | | | | | | |
| *Polycelis coronata* | 9 | 2.15% | Yes | Unknown | | 1 | OM |
| Planorbidae | | | | | | | |
| *Promenetus* sp. | 7 | 1.67% | Yes | Unknown | | 6 | SC |
| Sphaeriidae | | | | | | | |
| Sphaeriidae | 3 | 0.72% | Yes | Unknown | | 8 | CF |
| Ephemeroptera | | | | | | | |
| Baetidae | | | | | | | |
| *Baetis* sp. | 18 | 4.31% | No | Larva | Early Instar | 5 | CG |
| *Baetis bicaudatus* | 6 | 1.44% | Yes | Larva | | 2 | CG |
| *Baetis tricaudatus* | 154 | 36.84% | Yes | Larva | | 4 | CG |
| Plecoptera | | | | | | | |
| Nemouridae | | | | | | | |
| *Malenka* sp. | 1 | 0.24% | Yes | Larva | | 1 | SH |
| *Zapada cinctipes* | 17 | 4.07% | Yes | Larva | | 3 | SH |
| Trichoptera | | | | | | | |
| Hydropsychidae | | | | | | | |
| *Parapsyche almota* | 1 | 0.24% | Yes | Larva | | 3 | PR |
| Limnephilidae | | | | | | | |
| *Ecclisomyia* sp. | 1 | 0.24% | Yes | Larva | | 4 | CG |
| Diptera | | | | | | | |
| Simuliidae | | | | | | | |
| *Simulium* sp. | 14 | 3.35% | Yes | Larva | | 6 | CF |
| *Simulium* sp. | 3 | 0.72% | No | Pupa | | 6 | CF |
| Tipulidae | | | | | | | |
| *Dicranota* sp. | 4 | 0.96% | Yes | Larva | | 3 | PR |
| Chironomidae | | | | | | | |
| Chironomidae | | | | | | | |
| Chironomidae | 1 | 0.24% | No | Pupa | | 10 | CG |
| Chironomidae | 9 | 2.15% | Yes | Larva | | 10 | CG |
| Sample Count | 418 | | | | | | |

# Metrics Report

**Project ID:** RAE10CS2
**RAI No.:** RAE10CS2082
**Sta. Name:** Shaw Creek C1
**Client ID:** C1-1
**STORET ID:** Shaw Creek ISMP
**Coll. Date:** 9/15/2010

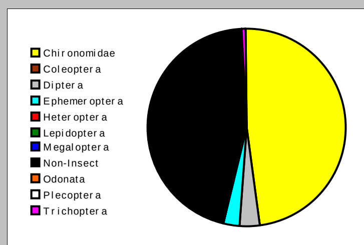
## *Abundance Measures*

| | | |
|---|---|---|
| **Sample Count:** | 426 | |
| **Sample Abundance:** | 555.65 | 76.67% of sample used |

**Coll. Procedure:**
**Sample Notes:**

## *Taxonomic Composition*

| Category | R | A | PRA |
|---|---|---|---|
| Non-Insect | 6 | 196 | 46.01% |
| Odonata | | | |
| Ephemeroptera | 1 | 12 | 2.82% |
| Plecoptera | | | |
| Heteroptera | | | |
| Megaloptera | | | |
| Trichoptera | 2 | 2 | 0.47% |
| Lepidoptera | | | |
| Coleoptera | | | |
| Diptera | 5 | 12 | 2.82% |
| Chironomidae | 1 | 204 | 47.89% |

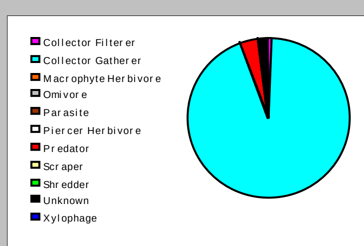



## *Dominant Taxa*

| Category | A | PRA |
|---|---|---|
| Chironomidae | 204 | 47.89% |
| Oligochaeta | 125 | 29.34% |
| Caecidotea | 32 | 7.51% |
| Crangonyx | 26 | 6.10% |
| Baetis tricaudatus | 11 | 2.58% |
| Nematoda | 8 | 1.88% |
| Neoplasta | 6 | 1.41% |
| Turbellaria | 4 | 0.94% |
| Simulium | 2 | 0.47% |
| Ceratopogoninae | 2 | 0.47% |
| Sphaeriidae | 1 | 0.23% |
| Rhyacophila narvae | 1 | 0.23% |
| Limnophila | 1 | 0.23% |
| Dicranota | 1 | 0.23% |
| Baetis | 1 | 0.23% |

## *Functional Composition*

| Category | R | A | PRA |
|---|---|---|---|
| Predator | 7 | 16 | 3.76% |
| Parasite | | | |
| Collector Gatherer | 5 | 399 | 93.66% |
| Collector Filterer | 2 | 3 | 0.70% |
| Macrophyte Herbivore | | | |
| Piercer Herbivore | | | |
| Xylophage | | | |
| Scraper | | | |
| Shredder | | | |
| Omivore | | | |
| Unknown | 1 | 8 | 1.88% |

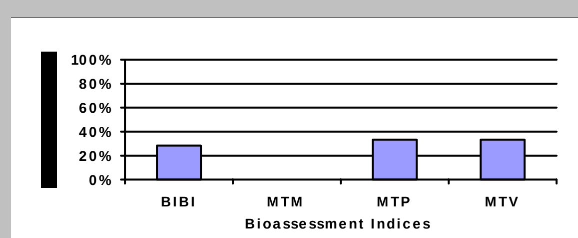



## *Metric Values and Scores*

| Metric | Value | BIBI | MTP | MTV | MTM |
|---|---|---|---|---|---|
| *Composition* | | | | | |
| Taxa Richness | 15 | 1 | 1 | | 0 |
| Non-Insect Percent | 46.01% | | | | |
| E Richness | 1 | 1 | | 0 | |
| P Richness | 0 | 1 | | 0 | |
| T Richness | 2 | 1 | | 1 | |
| EPT Richness | 3 | | 1 | | 0 |
| EPT Percent | 3.29% | | 0 | | 0 |
| Oligochaeta+Hirudinea Percent | 29.34% | | | | |
| Baetidae/Ephemeroptera | 1.000 | | | | |
| Hydropsychidae/Trichoptera | 0.500 | | | | |
| *Dominance* | | | | | |
| Dominant Taxon Percent | 47.89% | | 1 | | 0 |
| Dominant Taxa (2) Percent | 77.23% | | | | |
| Dominant Taxa (3) Percent | 84.74% | 1 | | | |
| Dominant Taxa (10) Percent | 98.59% | | | | |
| *Diversity* | | | | | |
| Shannon H (loge) | 1.508 | | | | |
| Shannon H (log2) | 2.176 | | 1 | | |
| Margalef D | 2.332 | | | | |
| Simpson D | 0.312 | | | | |
| Evenness | 0.114 | | | | |
| *Function* | | | | | |
| Predator Richness | 7 | | 3 | | |
| Predator Percent | 3.76% | 1 | | | |
| Filterer Richness | 2 | | | | |
| Filterer Percent | 0.70% | | | 3 | |
| Collector Percent | 94.37% | | 1 | | 0 |
| Scraper+Shredder Percent | 0.00% | | 0 | | 0 |
| Scraper/Filterer | 0.000 | | | | |
| Scraper/Scraper+Filterer | 0.000 | | | | |
| *Habit* | | | | | |
| Burrower Richness | 3 | | | | |
| Burrower Percent | 49.53% | | | | |
| Swimmer Richness | 1 | | | | |
| Swimmer Percent | 2.82% | | | | |
| Clinger Richness | 3 | 1 | | | |
| Clinger Percent | 0.94% | | | | |
| *Characteristics* | | | | | |
| Cold Stenotherm Richness | 0 | | | | |
| Cold Stenotherm Percent | 0.00% | | | | |
| Hemoglobin Bearer Richness | | | | | |
| Hemoglobin Bearer Percent | | | | | |
| Air Breather Richness | 2 | | | | |
| Air Breather Percent | 0.47% | | | | |
| *Voltinism* | | | | | |
| Univoltine Richness | 10 | | | | |
| Semivoltine Richness | 1 | 1 | | | |
| Multivoltine Percent | 53.52% | | 2 | | |
| *Tolerance* | | | | | |
| Sediment Tolerant Richness | 3 | | | | |
| Sediment Tolerant Percent | 29.81% | | | | |
| Sediment Sensitive Richness | 0 | | | | |
| Sediment Sensitive Percent | 0.00% | | | | |
| Metals Tolerance Index | 4.681 | | | | |
| Pollution Sensitive Richness | 0 | 1 | | 0 | |
| Pollution Tolerant Percent | 7.51% | 5 | | 2 | |
| Hilsenhoff Biotic Index | 9.096 | | 0 | | 0 |
| Intolerant Percent | 0.47% | | | | |
| Supertolerant Percent | 84.98% | | | | |
| CTQa | 85.308 | | | | |

## *Bioassessment Indices*

| BioIndex | Description | Score | Pct | Rating |
|---|---|---|---|---|
| BIBI | B-IBI (Karr et al.) | 14 | 28.00% | |
| MTP | Montana DEQ Plains (Bukantis 1998) | 10 | 33.33% | Moderate |
| MTV | Montana Revised Valleys/Foothills (Bollman 1998) | 6 | 33.33% | Moderate |
| MTM | Montana DEQ Mountains (Bukantis 1998) | 0 | 0.00% | Severe |



# Metrics Report

**Project ID:** RAE10CS2
**RAI No.:** RAE10CS2083
**Sta. Name:** Shaw Creek C2
**Client ID:** C2-1
**STORET ID:** Shaw Creek ISMP
**Coll. Date:** 9/15/2010

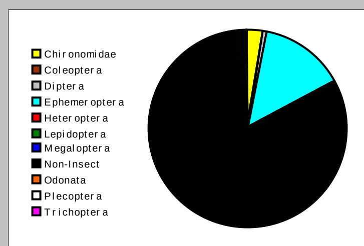
## *Abundance Measures*

| | | |
|---|---|---|
| **Sample Count:** | 362 | |
| **Sample Abundance:** | 362.00 | 100.00% of sample used |

**Coll. Procedure:**
**Sample Notes:**

## *Taxonomic Composition*

| Category | R | A | PRA |
|---|---|---|---|
| Non-Insect | 4 | 300 | 82.87% |
| Odonata | | | |
| Ephemeroptera | 1 | 50 | 13.81% |
| Plecoptera | | | |
| Heteroptera | | | |
| Megaloptera | | | |
| Trichoptera | | | |
| Lepidoptera | | | |
| Coleoptera | | | |
| Diptera | 1 | 3 | 0.83% |
| Chironomidae | 1 | 9 | 2.49% |

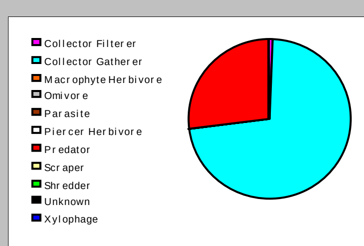



## *Dominant Taxa*

| Category | A | PRA |
|---|---|---|
| Turbellaria | 98 | 27.07% |
| Oligochaeta | 97 | 26.80% |
| Crangonyx | 96 | 26.52% |
| Baetis tricaudatus | 50 | 13.81% |
| Chironomidae | 9 | 2.49% |
| Caecidotea | 9 | 2.49% |
| Simulium | 3 | 0.83% |

## *Functional Composition*

| Category | R | A | PRA |
|---|---|---|---|
| Predator | 1 | 98 | 27.07% |
| Parasite | | | |
| Collector Gatherer | 5 | 261 | 72.10% |
| Collector Filterer | 1 | 3 | 0.83% |
| Macrophyte Herbivore | | | |
| Piercer Herbivore | | | |
| Xylophage | | | |
| Scraper | | | |
| Shredder | | | |
| Omivore | | | |
| Unknown | | | |

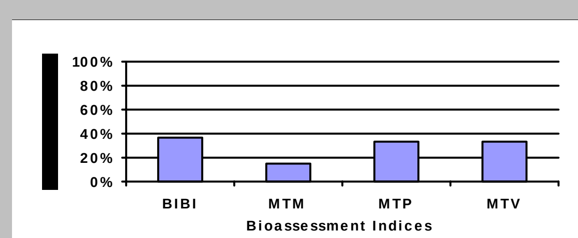



## *Metric Values and Scores*

| Metric | Value | BIBI | MTP | MTV | MTM |
|---|---|---|---|---|---|
| *Composition* | | | | | |
| Taxa Richness | 7 | 1 | 0 | | 0 |
| Non-Insect Percent | 82.87% | | | | |
| E Richness | 1 | 1 | | 0 | |
| P Richness | 0 | 1 | | 0 | |
| T Richness | 0 | 1 | | 0 | |
| EPT Richness | 1 | | 0 | | 0 |
| EPT Percent | 13.81% | | 1 | | 0 |
| Oligochaeta+Hirudinea Percent | 26.80% | | | | |
| Baetidae/Ephemeroptera | 1.000 | | | | |
| Hydropsychidae/Trichoptera | 0.000 | | | | |
| *Dominance* | | | | | |
| Dominant Taxon Percent | 27.07% | | 3 | | 2 |
| Dominant Taxa (2) Percent | 53.87% | | | | |
| Dominant Taxa (3) Percent | 80.39% | 1 | | | |
| Dominant Taxa (10) Percent | 100.00% | | | | |
| *Diversity* | | | | | |
| Shannon H (loge) | 1.540 | | | | |
| Shannon H (log2) | 2.222 | | 1 | | |
| Margalef D | 1.019 | | | | |
| Simpson D | 0.236 | | | | |
| Evenness | 0.169 | | | | |
| *Function* | | | | | |
| Predator Richness | 1 | | 0 | | |
| Predator Percent | 27.07% | 5 | | | |
| Filterer Richness | 1 | | | | |
| Filterer Percent | 0.83% | | | 3 | |
| Collector Percent | 72.93% | | 2 | | 1 |
| Scraper+Shredder Percent | 0.00% | | 0 | | 0 |
| Scraper/Filterer | 0.000 | | | | |
| Scraper/Scraper+Filterer | 0.000 | | | | |
| *Habit* | | | | | |
| Burrower Richness | 1 | | | | |
| Burrower Percent | 2.49% | | | | |
| Swimmer Richness | 1 | | | | |
| Swimmer Percent | 13.81% | | | | |
| Clinger Richness | 1 | 1 | | | |
| Clinger Percent | 0.83% | | | | |
| *Characteristics* | | | | | |
| Cold Stenotherm Richness | 0 | | | | |
| Cold Stenotherm Percent | 0.00% | | | | |
| Hemoglobin Bearer Richness | | | | | |
| Hemoglobin Bearer Percent | | | | | |
| Air Breather Richness | 0 | | | | |
| Air Breather Percent | 0.00% | | | | |
| *Voltinism* | | | | | |
| Univoltine Richness | 4 | | | | |
| Semivoltine Richness | 0 | 1 | | | |
| Multivoltine Percent | 43.37% | | 2 | | |
| *Tolerance* | | | | | |
| Sediment Tolerant Richness | 1 | | | | |
| Sediment Tolerant Percent | 26.80% | | | | |
| Sediment Sensitive Richness | 0 | | | | |
| Sediment Sensitive Percent | 0.00% | | | | |
| Metals Tolerance Index | 4.388 | | | | |
| Pollution Sensitive Richness | 0 | 1 | | 0 | |
| Pollution Tolerant Percent | 2.49% | 5 | | 3 | |
| Hilsenhoff Biotic Index | 6.403 | | 1 | | 0 |
| Intolerant Percent | 0.00% | | | | |
| Supertolerant Percent | 31.77% | | | | |
| CTQa | 102.000 | | | | |

## *Bioassessment Indices*

| BioIndex | Description | Score | Pct | Rating |
|---|---|---|---|---|
| BIBI | B-IBI (Karr et al.) | 18 | 36.00% | |
| MTP | Montana DEQ Plains (Bukantis 1998) | 10 | 33.33% | Moderate |
| MTV | Montana Revised Valleys/Foothills (Bollman 1998) | 6 | 33.33% | Moderate |
| MTM | Montana DEQ Mountains (Bukantis 1998) | 3 | 14.29% | Severe |




**Tuesday, March 08, 2011**

# Metrics Report

**Project ID:** RAE10CS2
**RAI No.:** RAE10CS2084
**Sta. Name:** Briarwood Creek
**Client ID:**
**STORET ID:** Shaw Creek ISMP
**Coll. Date:** 9/15/2010

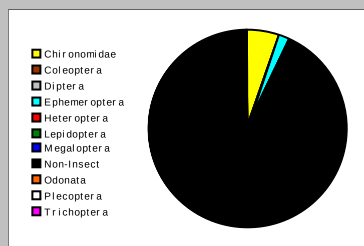
### *Abundance Measures*

**Sample Count:** 189
**Sample Abundance:** 189.00 100.00% of sample used

**Coll. Procedure:**
**Sample Notes:**

### *Taxonomic Composition*

| Category | R | A | PRA |
|---|---|---|---|
| Non-Insect | 4 | 176 | 93.12% |
| Odonata | | | |
| Ephemeroptera | 1 | 3 | 1.59% |
| Plecoptera | | | |
| Heteroptera | | | |
| Megaloptera | | | |
| Trichoptera | | | |
| Lepidoptera | | | |
| Coleoptera | | | |
| Diptera | | | |
| Chironomidae | 1 | 10 | 5.29% |

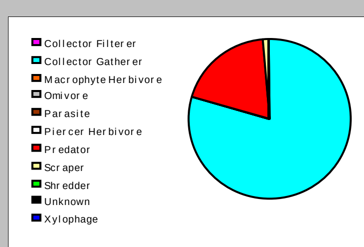



### *Dominant Taxa*

| Category | A | PRA |
|---|---|---|
| Oligochaeta | 131 | 69.31% |
| Turbellaria | 37 | 19.58% |
| Chironomidae | 10 | 5.29% |
| Amphipoda | 6 | 3.17% |
| Promenetus | 2 | 1.06% |
| Baetidae | 2 | 1.06% |
| Baetis tricaudatus | 1 | 0.53% |

### *Functional Composition*

| Category | R | A | PRA |
|---|---|---|---|
| Predator | 1 | 37 | 19.58% |
| Parasite | | | |
| Collector Gatherer | 4 | 150 | 79.37% |
| Collector Filterer | | | |
| Macrophyte Herbivore | | | |
| Piercer Herbivore | | | |
| Xylophage | | | |
| Scraper | 1 | 2 | 1.06% |
| Shredder | | | |
| Omivore | | | |
| Unknown | | | |

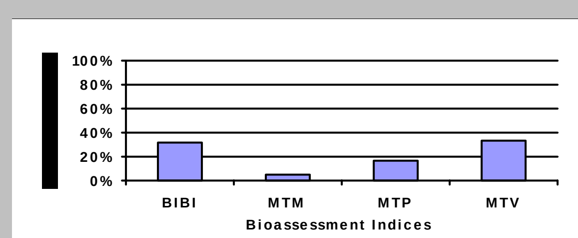



### *Metric Values and Scores*

| Metric | Value | BIBI | MTP | MTV | MTM |
|---|---|---|---|---|---|
| *Composition* | | | | | |
| Taxa Richness | 6 | 1 | 0 | | 0 |
| Non-Insect Percent | 93.12% | | | | |
| E Richness | 1 | 1 | | 0 | |
| P Richness | 0 | 1 | | 0 | |
| T Richness | 0 | 1 | | 0 | |
| EPT Richness | 1 | | 0 | | 0 |
| EPT Percent | 1.59% | | 0 | | 0 |
| Oligochaeta+Hirudinea Percent | 69.31% | | | | |
| Baetidae/Ephemeroptera | 1.000 | | | | |
| Hydropsychidae/Trichoptera | 0.000 | | | | |
| *Dominance* | | | | | |
| Dominant Taxon Percent | 69.31% | | 0 | | 0 |
| Dominant Taxa (2) Percent | 88.89% | | | | |
| Dominant Taxa (3) Percent | 94.18% | 1 | | | |
| Dominant Taxa (10) Percent | 100.00% | | | | |
| *Diversity* | | | | | |
| Shannon H (loge) | 0.913 | | | | |
| Shannon H (log2) | 1.318 | | 0 | | |
| Margalef D | 0.956 | | | | |
| Simpson D | 0.531 | | | | |
| Evenness | 0.140 | | | | |
| *Function* | | | | | |
| Predator Richness | 1 | | 0 | | |
| Predator Percent | 19.58% | 3 | | | |
| Filterer Richness | 0 | | | | |
| Filterer Percent | 0.00% | | | 3 | |
| Collector Percent | 79.37% | | 2 | | 1 |
| Scraper+Shredder Percent | 1.06% | | 0 | | 0 |
| Scraper/Filterer | 0.000 | | | | |
| Scraper/Scraper+Filterer | 0.000 | | | | |
| *Habit* | | | | | |
| Burrower Richness | 1 | | | | |
| Burrower Percent | 5.29% | | | | |
| Swimmer Richness | 1 | | | | |
| Swimmer Percent | 0.53% | | | | |
| Clinger Richness | 0 | 1 | | | |
| Clinger Percent | 0.00% | | | | |
| *Characteristics* | | | | | |
| Cold Stenotherm Richness | 0 | | | | |
| Cold Stenotherm Percent | 0.00% | | | | |
| Hemoglobin Bearer Richness | 1 | | | | |
| Hemoglobin Bearer Percent | 1.06% | | | | |
| Air Breather Richness | 0 | | | | |
| Air Breather Percent | 0.00% | | | | |
| *Voltinism* | | | | | |
| Univoltine Richness | 2 | | | | |
| Semivoltine Richness | 1 | 1 | | | |
| Multivoltine Percent | 26.46% | | 3 | | |
| *Tolerance* | | | | | |
| Sediment Tolerant Richness | 2 | | | | |
| Sediment Tolerant Percent | 70.37% | | | | |
| Sediment Sensitive Richness | 0 | | | | |
| Sediment Sensitive Percent | 0.00% | | | | |
| Metals Tolerance Index | 4.026 | | | | |
| Pollution Sensitive Richness | 0 | 1 | | 0 | |
| Pollution Tolerant Percent | 1.06% | 5 | | 3 | |
| Hilsenhoff Biotic Index | 8.497 | | 0 | | 0 |
| Intolerant Percent | 0.00% | | | | |
| Supertolerant Percent | 74.60% | | | | |
| CTQa | 99.000 | | | | |

### *Bioassessment Indices*

| BioIndex | Description | Score | Pct | Rating |
|---|---|---|---|---|
| BIBI | B-IBI (Karr et al.) | 16 | 32.00% | |
| MTP | Montana DEQ Plains (Bukantis 1998) | 5 | 16.67% | Severe |
| MTV | Montana Revised Valleys/Foothills (Bollman 1998) | 6 | 33.33% | Moderate |
| MTM | Montana DEQ Mountains (Bukantis 1998) | 1 | 4.76% | Severe |




**Tuesday, March 08, 2011**

# Metrics Report

**Project ID:** RAE10CS2
**RAI No.:** RAE10CS2085
**Sta. Name:** Watershed Creek
**Client ID:**
**STORET ID:** Shaw Creek ISMP
**Coll. Date:** 9/15/2010

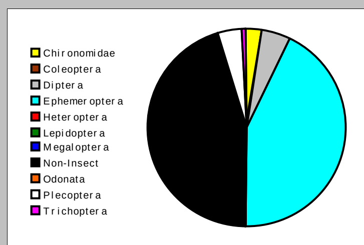
## *Abundance Measures*

| | | |
|---|---|---|
| **Sample Count:** | 418 | |
| **Sample Abundance:** | 1,140.00 | 36.67% of sample used |

**Coll. Procedure:**
**Sample Notes:**

## *Taxonomic Composition*

| Category | R | A | PRA |
|---|---|---|---|
| Non-Insect | 6 | 189 | 45.22% |
| Odonata | | | |
| Ephemeroptera | 2 | 178 | 42.58% |
| Plecoptera | 2 | 18 | 4.31% |
| Heteroptera | | | |
| Megaloptera | | | |
| Trichoptera | 2 | 2 | 0.48% |
| Lepidoptera | | | |
| Coleoptera | | | |
| Diptera | 2 | 21 | 5.02% |
| Chironomidae | 1 | 10 | 2.39% |

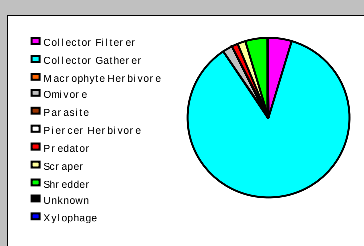



## *Dominant Taxa*

| Category | A | PRA |
|---|---|---|
| Baetis tricaudatus | 154 | 36.84% |
| Crangonyx | 109 | 26.08% |
| Oligochaeta | 54 | 12.92% |
| Baetis | 18 | 4.31% |
| Zapada cinctipes | 17 | 4.07% |
| Simulium | 17 | 4.07% |
| Chironomidae | 10 | 2.39% |
| Polycelis coronata | 9 | 2.15% |
| Promenetus | 7 | 1.67% |
| Baetis bicaudatus | 6 | 1.44% |
| Amphipoda | 6 | 1.44% |
| Dicranota | 4 | 0.96% |
| Sphaeriidae | 3 | 0.72% |
| Parapsyche almota | 1 | 0.24% |
| Malenka | 1 | 0.24% |

## *Functional Composition*

| Category | R | A | PRA |
|---|---|---|---|
| Predator | 2 | 5 | 1.20% |
| Parasite | | | |
| Collector Gatherer | 7 | 359 | 85.89% |
| Collector Filterer | 2 | 20 | 4.78% |
| Macrophyte Herbivore | | | |
| Piercer Herbivore | | | |
| Xylophage | | | |
| Scraper | 1 | 7 | 1.67% |
| Shredder | 2 | 18 | 4.31% |
| Omivore | 1 | 9 | 2.15% |
| Unknown | | | |

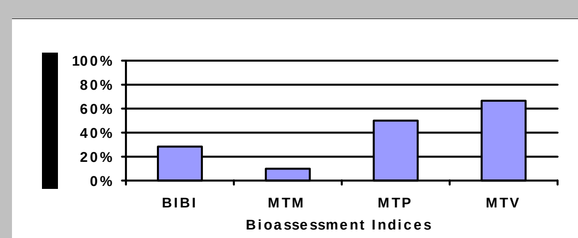



## *Metric Values and Scores*

| Metric | Value | BIBI | MTP | MTV | MTM |
|---|---|---|---|---|---|
| *Composition* | | | | | |
| Taxa Richness | 15 | 1 | 1 | | 0 |
| Non-Insect Percent | 45.22% | | | | |
| E Richness | 2 | 1 | | 1 | |
| P Richness | 2 | 1 | | 2 | |
| T Richness | 2 | 1 | | 1 | |
| EPT Richness | 6 | | 2 | | 0 |
| EPT Percent | 47.37% | | 2 | | 1 |
| Oligochaeta+Hirudinea Percent | 12.92% | | | | |
| Baetidae/Ephemeroptera | 1.000 | | | | |
| Hydropsychidae/Trichoptera | 0.500 | | | | |
| *Dominance* | | | | | |
| Dominant Taxon Percent | 36.84% | | 2 | | 1 |
| Dominant Taxa (2) Percent | 62.92% | | | | |
| Dominant Taxa (3) Percent | 75.84% | 1 | | | |
| Dominant Taxa (10) Percent | 95.93% | | | | |
| *Diversity* | | | | | |
| Shannon H (loge) | 1.709 | | | | |
| Shannon H (log2) | 2.465 | | 2 | | |
| Margalef D | 2.347 | | | | |
| Simpson D | 0.256 | | | | |
| Evenness | 0.111 | | | | |
| *Function* | | | | | |
| Predator Richness | 2 | | 0 | | |
| Predator Percent | 1.20% | 1 | | | |
| Filterer Richness | 2 | | | | |
| Filterer Percent | 4.78% | | | 3 | |
| Collector Percent | 90.67% | | 1 | | 0 |
| Scraper+Shredder Percent | 5.98% | | 1 | | 0 |
| Scraper/Filterer | 0.350 | | | | |
| Scraper/Scraper+Filterer | 0.259 | | | | |
| *Habit* | | | | | |
| Burrower Richness | 1 | | | | |
| Burrower Percent | 2.39% | | | | |
| Swimmer Richness | 2 | | | | |
| Swimmer Percent | 42.58% | | | | |
| Clinger Richness | 5 | 1 | | | |
| Clinger Percent | 8.85% | | | | |
| *Characteristics* | | | | | |
| Cold Stenotherm Richness | 2 | | | | |
| Cold Stenotherm Percent | 1.67% | | | | |
| Hemoglobin Bearer Richness | 1 | | | | |
| Hemoglobin Bearer Percent | 1.67% | | | | |
| Air Breather Richness | 1 | | | | |
| Air Breather Percent | 0.96% | | | | |
| *Voltinism* | | | | | |
| Univoltine Richness | 9 | | | | |
| Semivoltine Richness | 2 | 1 | | | |
| Multivoltine Percent | 47.13% | | 2 | | |
| *Tolerance* | | | | | |
| Sediment Tolerant Richness | 3 | | | | |
| Sediment Tolerant Percent | 15.55% | | | | |
| Sediment Sensitive Richness | 0 | | | | |
| Sediment Sensitive Percent | 0.00% | | | | |
| Metals Tolerance Index | 4.626 | | | | |
| Pollution Sensitive Richness | 2 | 1 | | 2 | |
| Pollution Tolerant Percent | 1.91% | 5 | | 3 | |
| Hilsenhoff Biotic Index | 5.483 | | 2 | | 0 |
| Intolerant Percent | 3.83% | | | | |
| Supertolerant Percent | 16.27% | | | | |
| CTQa | 72.833 | | | | |

## *Bioassessment Indices*

| BioIndex | Description | Score | Pct | Rating |
|---|---|---|---|---|
| BIBI | B-IBI (Karr et al.) | 14 | 28.00% | |
| MTP | Montana DEQ Plains (Bukantis 1998) | 15 | 50.00% | Moderate |
| MTV | Montana Revised Valleys/Foothills (Bollman 1998) | 12 | 66.67% | Slight |
| MTM | Montana DEQ Mountains (Bukantis 1998) | 2 | 9.52% | Severe |




Tuesday, March 08, 2011

## **Appendix B-6.** Reach Summary Data.

**Table B6-1: Summary of Channel and Substrate Characteristics in the Shaw Creek ISMP study area**

| Reach | Length (m) | Bankfull Width (m) | Wetted Width (m) | Riffle Depth (cm) | Gradient (%) | Embeddedness (%) | %Boulder | %Cobble | %Large Gravel | %Small Gravel | %Fines |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 112 St Ditch | 3219 | 1.2 | 1.2 | n/a | < 0.5 | n/a | 0 | 0 | 0 | 0 | 100 |
| Lorne Ditch | 759 | 2.3 | 2.3 | n/a | < 0.5 | n/a | n/a | n/a | n/a | n/a | n/a |
| 60 Ave Ditch | 203 | 1.6 | 1.6 | 12 | < 0.5 | 30 | 0 | 15 | 30 | 30 | 25 |
| Oliver Slough | 2342 | 4 | 4 | >30 | < 0.5 | n/a | 0 | 0 | 0 | 0 | 100 |
| Gourley Ditch | 702 | | | | < 0.5 | | | | | | |
| East Oliver Bypass | 1157 | 10 | 10 | >30 | < 0.5 | n/a | n/a | n/a | n/a | n/a | n/a |
| Old Hwy 10 Ditch | 294 | 2.5 | 2 | n/a | < 0.5 | n/a | 0 | 0 | 0 | 0 | 100 |
| Shaw R1 | 311 | 2.3 | 1.5 | 10 | 2-3 | 10 | 0 | 0 | 0 | 0 | 100 |
| Shaw R2 | 233 | 2.2 | 1.9 | 4 | 5 | 30 | 2.5 | 35 | 35 | 20 | 7.5 |
| Shaw R3 | 406 | 7.5 | 2.5 | 6 | 5-10 | 15 | 2.5 | 15 | 45 | 35 | 2.5 |
| Shaw R4 | 215 | | | | 20-30 | | | | | | |
| Shaw R5 | 130 | 4.6 | 1.9 | 6 | 5-10 | 30 | 15 | 35 | 20 | 20 | 10 |
| Shaw R6 | 241 | 6 | 0.9 | 6 | 5-7 | 20 | 10 | 20 | 30 | 30 | 10 |
| Shaw R7 | 60 | 2.5 | 2 | 8 | 5 | 20 | 50 | 35 | 10 | 2.5 | 2.5 |
| Shaw R8 | 166 | | | | 2-3 | | | | | | |

**Table B6-2: Summary of Channel and Substrate Characteristics in the Shaw Creek ISMP study area**

| Reach | Length (m) | Bankfull Width (m) | Wetted Width (m) | Riffle Depth (cm) | Gradient (%) | Embeddedness (%) | %Boulder | %Cobble | %Large Gravel | %Small Gravel | %Fines |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Briarwood R1 | 640 | 1.6 | 0.9 | 11 | < 0.5 | n/a | 0 | 0 | 0 | 0 | 100 |
| Briarwood R2 | 175 | | | | 35-40 | | | | | | |
| Briarwood R3 | 204 | 2.6 | 1.5 | 5 | 5-7 | 30 | 20 | 20 | 30 | 25 | 5 |
| Lower Trail Ditch | 532 | 0.7 | 0.3 | 1 | 0 | 15 | 0 | 0 | 0 | 70 | 30 |
| Watershed R1 | 121 | | | | < 0.5 | | | | | | |
| Watershed R2 | 116 | 1.5 | 1.1 | 5 | 5 | 10 | 5 | 15 | 40 | 35 | 5 |
| Watershed R3 | 818 | | | | 0.5-2 | | | | | | |
| Watershed R4 | 132 | | | | 7-10 | | | | | | |
| Watershed Trib. 1 R1 | 411 | | | | < 0.5 | | | | | | |
| Watershed Trib. 1 R2 | 850 | 0.8 | 0 | 0 | 7 | 10 | 0 | 5 | 40 | 50 | 5 |
| Watershed Trib. 2 | 169 | | | | < 0.5 | | | | | | |

**Table B6-3: Summary of Channel Characteristics, Complexity, Erosion, and Fish Presence in the Shaw Creek ISMP study area**

| Reach | % culverted | % channelized | LWD per 100m | Erosion* | Fish Presence | Salmonid Presence | **Fish Species** (see codes in text) |
|---|---|---|---|---|---|---|---|
| 112 St Ditch | 10% (339 m) | 90 % (2880 m) | < 1 | Moderate | Present | Present | CO, CM, CT, TSB, BMC |
| Lorne Ditch | 19% (135 m) | 81% (624 m) | < 1 | Minor | Present | Present | CO, CT? |
| 60 Ave Ditch | 5% (10 m) | 95% (193 m) | < 1 | Minor | Present | Present | CO, CM, CT, CAS, TSB, PMB, RSC |
| Oliver Slough | 6% (157 m) | 94% (2185 m) | < 1 | Moderate | Present | Absent | TSB |
| Gourley Ditch | 19% (135 m) | 81% (567 m) | < 1 | - | Present | Absent | TSB, PCC, BCB, BNH, PMB |
| East Oliver Bypass | 11% (124 m) | 89% (1033 m) | < 1 | Minor | Present | Absent | TSB, BMC |
| Old Hwy 10 Ditch | 10% (29 m) | 90% (265 m) | 1 to 3 | Minor | Unknown | Absent | Unknown |
| Shaw R1 | 57% (177 m) | 43% (134 m) | < 1 | Moderate | Present | Present | CO, CT?, TSB, BMC |
| Shaw R2 | 0% | 51% (118 m) | 1 to 3 | Minor | Present | Present | CO, CT?, CAS, TSB, BMC, CP |
| Shaw R3 | 20% (81 m) | 7% (30 m) | 1 to 3 | Major | Present | Present | CO, CT?, CAS, CP |
| Shaw R4 | 100% (215 m) | n/a | n/a | n/a | Absent | Absent | None |
| Shaw R5 | 0% | 0% | 1 to 3 | Moderate | Present | Absent | GC, CP |
| Shaw R6 | 0% | 0% | 2 to 5 | Major | Present | Absent | GC, CP |
| Shaw R7 | 0% | 0% (modified) | < 1 | Historic/none | Present | Absent | GC, CP |
| Shaw R8 | 100% (166 m) | n/a | n/a | n/a | Absent | Absent | None |

* note that the erosion rating is related to fish habitat concerns and is not as detailed as Section 2.2.

**Table B6-4: Summary of Channel Characteristics, Complexity, Erosion, and Fish Presence in the Shaw Creek ISMP study area**

| Reach | % culverted | % channelized | LWD per 100m | Erosion* | Fish Presence | Salmonid Presence | **Fish Species** (see codes in text) |
|---|---|---|---|---|---|---|---|
| Briarwood R1 | 14% (92 m) | 86 % (549 m) | 2 to 5 | Minor | Present | Absent | TSB |
| Briarwood R2 | 100% (175 m) | n/a | n/a | n/a | Absent | Absent | None |
| Briarwood R3 | 0% | 0% (modified) | 2 to 4 | Minor | Unknown | Absent | Unknown |
| Lower Trail Ditch | 5% (28 m) | 82% (435 m) | 3 to 6 | Minor | Absent | Absent | None |
| Watershed R1 | 88% (107 m) | 12% (14 m) | < 1 | n/a | Present | Present | CO, CM, CT, TSB |
| Watershed R2 | 19% (22 m) | 0% | 1 to 3 | Minor | Present | Present | CO, CM, CT, TSB |
| Watershed R3 | 0% | 100% (818 m) | 2 to 5 | Moderate | Present | Present | CO, CM, CT, TSB |
| Watershed R4 | 0% | 0% | 1 to 3 | Minor | Present | Present | CO, CT |
| Watershed Trib. 1 R1 | 8% (32 m) | 69% (285 m) | 1 to 3 | Minor | Unknown | Unknown | Unknown |
| Watershed Trib. 1 R2 | 21% (179 m) | 0% | 2 to 5 | Moderate | Absent | Absent | None |
| Watershed Trib. 2 | 0% | 100% (169 m) | 1 to 3 | Minor | Present | Present | CO, CT, TSB |

* note that the erosion rating is related to fish habitat concerns and is not as detailed as Section 2.2.

**Figure B7-1: Photos of Representative Channel Conditions in Shaw Creek ISMP Study Area**

112 St Ditch

Lorne Ditch

60 Ave Ditch

Oliver Slough

East Oliver Bypass

Old Hwy 10 Ditch

Shaw R1

Shaw R2

Shaw R3

Shaw R4
(culvert inlet)

Shaw R5

Shaw R6

**Figure B7-2: Photos of Representative Channel Conditions in Shaw Creek ISMP Study Area**

Shaw R7

Shaw R8

Boundary Park Pond

Briarwood R1

Briarwood R2
(culvert inlet)

Briarwood R3

Lower Trail Ditch

Watershed R1
(culvert inlet)

Watershed R2

Watershed R4

Watershed Trib. 1 R2

# Appendix B-8. RFI Method Summary.

The 30 m buffer width was selected to provide a generalized and consistent assessment method of the area where riparian-stream channel interactions are potentially strongest. A 30 m buffer is used for RFI assessments because it has been found to be most strongly correlated with other measures of stream health (May et al., 1999). It is not meant to prescribe an appropriate setback to development and supersede or conflict with the Riparian Area Regulation (RAR), municipal stream protection bylaws, or other riparian protection measures. The use of permanent streams only increases data consistency for areas where the stream network mapping is variable (Page et al., 1999). Where possible, culverted stream sections were also included to represent the entire historical stream network within the watershed. This was not possible in headwater sections of the study area where it is difficult to infer whether permanent watercourses would have been historically present.

KERR WOOD LEIDAL
consulting engineers

Appendix C

# Geotechnical Report

Trow

7025 Greenwood St.
Burnaby, BC
V5A 1X7

Tel: (604) 874-1245
Fax: (604) 874-2358

*Buildings*

*Environment*

*Geotechnical*

*Infrastructure*

*Materials & Quality*



September 14, 2010 Reference: VAN-00010608

Kerr Wood Leidel Associates Inc.
200-4185A Still Creek Drive
Burnaby, BC, V5C 6G9 Via E-Mail: dzabil@kwl.ca

Attention: Mr. David Zabil, M.A.Sc., P.Eng.

***Geotechnical Review***
***Shaw Creek, Delta, BC***

Dear Mr. Zabil:

## 1.0 INTRODUCTION

As requested, Trow Associates Inc. (Trow) has completed a geotechnical review of the Shaw Creek channel and adjacent slopes within Watershed Park, Delta, BC (see attached Map 1). The purpose of our review was to characterize the subject site with regards to slope stability, stream erosion and soils and to present options for mitigative measures where appropriate.

There is an inherent level of uncertainty associated with the prediction of long term stability of natural slopes, particularly in seismically active terrain as is present in this case. This uncertainty combined with the lack of long term historical records and information on subsurface soil conditions significantly limits our ability to complete a quantitative assessment of slope stability within the subject site. Therefore we are presenting a qualitative assessment of geologic hazards, which may influence nearby development, based on our characterization of the site.

Our characterization was based on the following information sources:

- Published surficial geology information from GSC Map 1448A (1:50,000);
- Aerial photographs of the general area dated from 1949 to 2004;
- Regional topographic contour map provided by Kerr Wood Leidel;
- Information from previous Trow projects in the general vicinity of Watershed Park;
- Site reconnaissance of Shaw Creek conducted by Trow personnel.

## 2.0 SITE DESCRIPTION

The study area contains Shaw Creek which flows from north to south in a channel incised into the subgrade soils up to about 5 m deep. The channel ranges in width from about 5 m to 10 m and maintains a generally consistent gentle grade with numerous bends. The study area has been divided into a northern portion and a southern portion on either side of Highway 10 (see attached Map 2).

The creek is sub-parallel to 120$^{th}$ Street in the northern portion (see attached Map 3) and sub-parallel to Highway 10 in the southern portion (see Map 4). The northern portion of the creek ranges from about 40 m to 100 m horizontal distance from 120$^{th}$

Street and the southern portion ranges from about 15 m to 40 m horizontal distance from Highway 10. The creek flows under Highway 10 for a distance of about 170 m from the north portion to the south portion, through a culvert.

A trash gate was located at the intake of the culvert located at the southern end of the north portion of the creek channel and two separate stockpiles; one containing organics and wood debris and the other boulders, cobbles and gravel (likely removed from the trash gate), were noted in the area.

Indications of a previous dirt road with creek crossings were noted along the west side of the southern portion of the creek. This roadway has been abandoned with creek crossings removed long ago, as there were no indications of creek crossings observed in aerial photographs dating back to 1949. Erosion generally did not appear to be prevalent in areas of presumed former creek crossings where minimal rip rap had been placed; however, some minor slope failures due to erosion of the underlying soils were noted in these areas. In some areas, the old roadway had been undermined by the creek resulting in parts of the roadway sloughing into the creek channel.

There were no structures noted, either between the creek and 120$^{th}$ Street or in close proximity to the west side of the creek within the northern portion of the study area with the exception of single family residential dwellings on either side of the creek channel immediately south of an outlet for a box culvert at the northern end of the study area. In the area of these residential dwellings, as the creek outlets from the box culvert, there is a sharp bend in the creek channel to the west followed closely by another sharp bend back to the south. Protection measures to protect the properties from erosion by the creek on the outside banks of these bends were in place. A lock block wall, 2.25 m in height was located on the west side of the creek and rip rap consisting of boulders with a size of approximately 600 mm diameter had been placed on the east side.

Near the middle and southern parts of the southern portion of the creek channel, residential development was located behind the crest of a slope originating at the creek channel and cresting near the backyards of some of the residences east of the channel. The horizontal distance from the creek channel to the backyards of these residences ranges from about 30 m to 50 m with an elevation difference of about 15 m. The slope is generally moderately inclined with some localized steeply inclined areas, particularly near the crest of the slope. In the southern portion of the study area, the slope between Highway 10 and the creek is a gently inclined slope increasing in steepness as it approaches the creek channel, with near vertical creek banks. The overall elevation difference from the creek channel to the highway appears to be about 5 m.

The study area lies within an area of Vashon Drift deposits. The banks of the creek generally consist of very dense gravelly sand with some silt (till-like) soils overlain with loose to compact gravelly sand with some cobbles, boulders and trace to some silt. Based on the exposed soils within the creek channel banks, the overlying gravelly sand varies in thickness from less than 1 m up to about 5 m. Within the creek channel, the till-like soils generally have a near vertical inclination, with the overlying soils being inclined from about 1H: 1V to near vertical adjacent to the creek. In general, the till-like soils were more prevalent in the northern portion of the study area, with exposed heights of up to about 4 m. Overhangs of the overlying gravelly sand layer were noted near the creek in areas where tree root masses have provided sufficient binding of the soils. In addition, fallen trees with root masses and other debris were noted within the creek channel in several locations, particularly within the northern portion of the creek channel.

Along the east bank of the southern portion of the study area, undulating topography was observed near the creek and within gullies and bowls above the creek banks. The bowls were up to about 20 m wide and the crests were noted to be located near the western property boundaries of the residential lots located above the slope. Depositional fans were noted at the base of some of the gullies and bowls.

Vegetation along the creek consists of widely spaced deciduous and coniferous trees with trunk diameters up to about 200 mm. In numerous areas trees were noted to have curved trunks or were leaning towards the creek. Ferns and thick underbrush were noted within the gullies and bowls along the eastern side of the creek.

## 3.0 DISCUSSION

The study area has been divided into a northern portion and a southern portion on either side of Highway 10 (see Map 2). The northern portion of the creek is generally removed from roadways or developments except near the southern end where the creek crosses Highway 10 through a culvert and the northern end where two residential dwellings were located. Development near the southern portion of the creek includes Highway 10 to the west and residential development to the east.

**3.1 Northern Portion** – The creek banks are generally comprised of very dense till-like soils overlain with gravelly sand in the northern portion of the study area. These very dense soils are somewhat resistant to erosion, causing the erosion process to occur much more gradually that with most other soil types. In several locations along the creek, the continuing erosion process of the creek banks has resulted in the undermining of the loose to compact granular soils overlying the till-like soils and trees at the crests of the channel banks. The undermining of the trees has resulted in several areas where trees have fallen into the creek channel along with the root mass. The presence of fallen trees within the creek channel, with the accompanying accumulated debris upstream of the fallen trees, may create blockages of the creek in the future. A sudden release of such a blockage, at a time of high water flow, may overwhelm the culvert capacity downstream, particularly when combined with the associated additional debris which may create a blockage at the culvert.

We understand that in the recent past debris has clogged the intake for the culvert, where the creek flows under Highway 10 from the north, and backed up the creek such that overflowing water affected the highway. The presence of the stockpiles of debris, likely removed from the trash gate, indicates that blockage of the culvert may have occurred in the recent past.

Surficial movement of the slopes above the creek banks were noted, as indicated by undulating topography and curved or leaning trees. It is considered likely that the sliding material would be confined to the soils overlying the till-like soils limiting the extent and depth of such slope failures. However, such movement may result in soil and vegetation sliding into the creek channel, creating similar issues to those described above.

**3.2 Southern Portion** – The banks of the creek appear to consist of varying types of soil, including very dense till-like soils, compact gravelly sand and laminated sand with some silt. As expected, areas of till-like soils appear to have experienced less erosion than the other soil types; however erosion has resulted in some undermined soils and trees in several areas. The extent to which the undermining has occurred does not appear to be as extensive as that observed in the northern portion, likely due to the lower height of the till-like soils with the overlying gravel and sand exposed to erosion by the creek. These less dense soils are less capable of maintaining the very steep inclinations of the till-like soils; hence, overhangs are prevented from developing. The overall slope inclination from the creek to the highway over a distance of approximately 25 m is about 6H: 1V. The rate of erosion of the west creek bank appears to be about 1 m since the dirt road was constructed, which based on interpretation of aerial photographs is about 50 years ago.

The leaning and curved trees, undulating topography, gullies and bowls on the east side of the creek channel are all indicative of historic slope instabilities. The steeply inclined areas near the crests of the slopes within the bowls are likely head scarps of such slope failures as charaterized by their curved shape. Of particular interest is large failure scarps located near the back of the properties located along Fairlight Crescent where a depositional fan created by the slope failure(s) has been reshaped into a BMX bike area. Thick vegetation and garden refuse prevented a thorough visual review of the slopes during our site reconnaissance to assess the size of the possible slope failures or to assess the surficial soils in the area. A review of aerial photographs dating back to 1949 indicate that the slope failure(s) occurred prior to that date; however, vegetation within the bowl area prior to the residential development differs from that found in the surrounding area, indicating that the failure may have been relatively recent relative to the time of the aerial photograph. The presence of ferns and other wet soil type vegetation within the bowls and gullies indicate that these areas are likely zones with higher water tables or more saturated soils, likely contibuting to the instabilities of these slopes. Continued movement or remobilization of these slopes may influence the private properties located at the crest of the slope.

## 4.0 RECOMMENDATIONS

Recommendations for the mitigation of affects of erosion of the creek banks and slope instabilities where such activity is occurring or is likely to occur, is provided below.

**4.1 Northern Portion** – Creek banks within the northern portion of the study area (north of Highway 10) are generally comprised of very dense till-like soils which are somewhat resistant to erosion by the creek; however, the erosion that has occurred over time has is created overhangs resulting in trees falling into the creek channel. This debris may cause blockages within the creek channel with sudden releases of water and debris being possible. The result of such action may cause blockages of the culvert near Highway 10 and flooding of the adjacent highway as has occurred in the past when the trash gate was blocked. We recommend that the creek channel, including the trash gate for the culvert, be reviewed on a regular basis (approximately every 6 months) to identify such blockages. No blockages were identified within the channel during our field reconnaissance.

As there are no developments or roadways with the exception of the two residences at the north end of this portion of the study area, the continuing erosion of the creek beds does not present a risk to buildings or roadways. The two existing residences appear to have sufficient protection from erosion with the existing rip rap slope covering and lock block walls.

The slope instabilities in the northern portion appear to generally be comprised of surficial movement related to undermining of the slope by the creek. These slope instabilities are not in close proximity to buildings or infrastructure and as such are not considered likely to affect developments.

**4.2 Southern Portion** – Highway 10 is located near the crest of the slopes on the west side of the creek channel. Though no significant slope stability issues were noted on the west side of the creek channel erosion of the banks along this side of the creek channel has resulted in small failures in various locations and in some instances has resulted in the loss of portions of the abandoned dirt road. The relatively gentle overall inclination of the slope between the highway and the creek creates a situation where a significant slope failure is unlikely; however, continued erosion of the west creek bank may influence the highway over time. We recommend continued monitoring of the west creek bank to identify areas of ongoing erosion which may eventually influence the highway.

Portions of the slope on the east side of the creek channel appear to have experienced historic slope failures, particularly in the southern areas near the residential development. The significance of these slope failures appear to vary between surficial sloughs to large scale (20 m across) failures. Presently the toes of the more significant failure areas are protected from erosion by depositional fans which currently prevent further toe erosion of the slopes; however should these fans be eroded away in the future, continued erosion at the toe of the slopes could further destabilize these slopes. We recommend that rip rap be placed along the creek banks in areas where potentially unstable slopes may influence residential developments above the slopes, in order to mitigate erosion of the toes of these slopes. Monitoring of slope movement below the residences should be implemented to determine whether the slope is currently active.

In order to provided a quantitative analysis of the slope stability in this area with a factor of safety for static and seismic conditions, subsurface exploration would be required to characterize the soil stratigraphy and water table. To acquire such information bore holes would likely be required, and was beyond the scope of this report.

## 5.0 CLOSURE

As there was no subsurface investigation conducted, we have provided a qualitative assessment of the existing slope stability based on our characterization of the subject site including recent and historical slope failures. Our characterization of the subject site is based on site reconnaissance, topographic plan maps, surficial geology plans and Trows' experience with similar sites throughout British Columbia.

The above noted and attached information is provided for the exclusive use of our client and their designated consultants and agents and may not be used by other parties without the written consent of Trow Associates Inc. The attached "Interpretation and Use of Study and Report" forms an integral part of this report and must be included with any copies of this report.

Yours truly,

**Trow Associates Inc.**

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
E. G. SYKES
Sept 15, 2010

Evan Sykes, P.Eng.
Senior Engineer

**Reviewed by:**

Ben Weiss, P.Eng.
Senior Engineer

Enclosures:
- Interpretation and Use of Study and Report
- Photos
- Location Plan (Map 1)
- Overall Site Plan (Map 2)
- Northern Portion Site Plan (Map 3)
- Southern Portion Site Plan (Map 4)

*ES/es*

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# INTERPRETATION & USE OF STUDY AND REPORT

## 1. STANDARD OF CARE

This study and Report have been prepared in accordance with generally accepted engineering consulting practices in this area. No other warranty, expressed or implied, is made. Engineering studies and reports do not include environmental consulting unless specifically stated in the engineering report.

## 2. COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report which is of a summary nature and is not intended to stand alone without reference to the instructions given to us by the Client, communications between us and the Client, and to any other reports, writings, proposals or documents prepared by us for the Client relative to the specific site described herein, all of which constitute the Report.

IN ORDER TO PROPERLY UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. WE CANNOT BE RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

## 3. BASIS OF THE REPORT

The Report has been prepared for the specific site, development, building, design or building assessment objectives and purpose that were described to us by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the document are only valid to the extent that there has been no material alteration to or variation from any of the said descriptions provided to us unless we are specifically requested by the Client to review and revise the Report in light of such alteration or variation.

## 4. USE OF THE REPORT

The information and opinions expressed in the Report, or any document forming the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT OUR WRITTEN CONSENT. WE WILL CONSENT TO ANY REASONABLE REQUEST BY THE CLIENT TO APPROVE THE USE OF THIS REPORT BY OTHER PARTIES AS "APPROVED USERS". The contents of the Report remain our copyright property and we authorise only the Client and Approved Users to make copies of the Report only in such quantities as are reasonably necessary for the use of the Report by those parties. The Client and Approved Users may not give, lend, sell or otherwise make the Report, or any portion thereof, available to any party without our written permission. Any use which a third party makes of the Report, or any portion of the Report, are the sole responsibility of such third parties. We accept no responsibility for damages suffered by any third party resulting from unauthorised use of the Report.

## 5. INTERPRETATION OF THE REPORT

a. Nature and Exactness of Descriptions: Classification and identification of soils, rocks, geological units, contaminant materials, building envelopment assessments, and engineering estimates have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature and even comprehensive sampling and testing programs, implemented with the appropriate equipment by experienced personnel, may fail to locate some conditions. All investigations, or building envelope descriptions, utilizing the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarising such investigations will be based on assumptions of what exists between the actual points sampled. 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. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. Where special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

b. Reliance on Provided information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to us. We have relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, we cannot accept responsibility for any deficiency, misstatement or inaccuracy contained in the report as a result of misstatements, omissions, misrepresentations or fraudulent acts of persons providing information.

c. To avoid misunderstandings, Trow Associates Inc. (Trow) should be retained to work with the other design professionals to explain relevant engineering findings and to review their plans, drawings, and specifications relative to engineering issues pertaining to consulting services provided by Trow. Further, Trow should be retained to provide field reviews during the construction, consistent with building codes guidelines and generally accepted practices. Where applicable, the field services recommended for the project are the minimum necessary to ascertain that the Contractor's work is being carried out in general conformity with Trow's recommendations. Any reduction from the level of services normally recommended will result in Trow providing qualified opinions regarding adequacy of the work.

## 6.0 ALTERNATE REPORT FORMAT

When Trow submits both electronic file and hard copies of reports, drawings and other documents and deliverables (Trow's instruments of professional service), the Client agrees that only the signed and sealed hard copy versions shall be considered final and legally binding. The hard copy versions submitted by Trow shall be the original documents for record and working purposes, and, in the event of a dispute or discrepancy, the hard copy versions shall govern over the electronic versions. Furthermore, the Client agrees and waives all future right of dispute that the original hard copy signed version archived by Trow shall be deemed to be the overall original for the Project.

The Client agrees that both electronic file and hard copy versions of Trow's instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Trow. The Client warrants that Trow's instruments of professional service will be used only and exactly as submitted by Trow.

The Client recognizes and agrees that electronic files submitted by Trow have been prepared and submitted using specific software and hardware systems. Trow makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.


**TROW ASSOCIATES INC.**
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| | |
|---|---|
| CLIENT | KERR WOOD LEIDAL |
| PROJECT | SHAW CREEK ISMP DELTA, B.C. |
| TITLE: | LOCATION PLAN |

| PROJECT NO. | DFTR. | DSGN. | CHK. | DATE | SCALE: | DWG NO. |
|---|---|---|---|---|---|---|
| VAN 00010608 | MG | EGS | BW | 2010-09-10 | NTS | MAP 1 |

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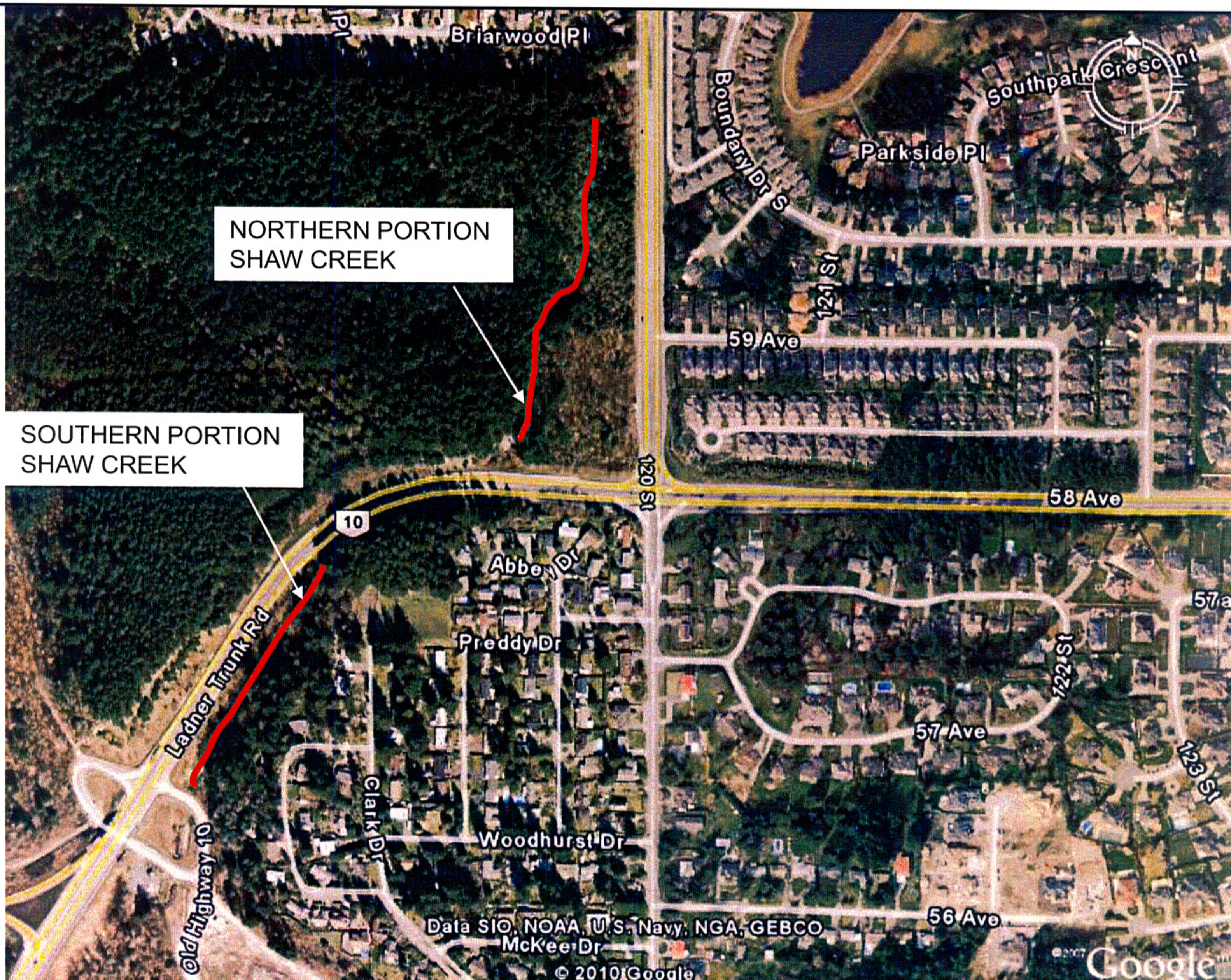


| TROW ASSOCIATES INC. 7025 Greenwood Street, Burnaby, British Columbia, V5A 1X7 Telephone: 604-874-1245 Fax: 604-874-2358 | CLIENT: KERR WOOD LEIDAL | | | | TITLE: OVERALL SITE PLAN | | |
|---|---|---|---|---|---|---|---|
| | PROJECT: SHAW CREEK ISMP DELTA, B.C. | | | | | | |
| | PROJECT NO. VAN 00010608 | DFTR. MG | DSGN. EGS | CHK. BW | DATE 2010-09-10 | SCALE: 1:5000 APPROX. | DWG NO. MAP 2 |

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| | |
|---|---|
| CLIENT | KERR WOOD LEIDAL |
| PROJECT | SHAW CREEK ISMP DELTA, B.C. |
| TITLE: | NORTHERN PORTION SITE PLAN |
| PROJECT NO. | VAN 00010608 |
| DFTR. | MG |
| DSGN. | EGS |
| CHK. | BW |
| DATE | 2010-09-10 |
| SCALE: | 1:3000 APPROX. |
| DWG NO. | MAP 3 |

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| CLIENT | | | | TITLE: | | |
|---|---|---|---|---|---|---|
| KERR WOOD LEIDAL | | | | SOUTHERN PORTION SITE PLAN | | |
| PROJECT: SHAW CREEK ISMP DELTA, B.C. | | | | | | |
| PROJECT NO. | DFTR. | DSGN. | CHK. | DATE | SCALE: | DWG NO. |
| VAN 00010608 | MG | EGS | BW | 2010-09-10 | 1:3000 | MAP 4 |

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## NORTHERN PORTION

File: Van-00010608
Date: Sept. 10, 2010

Photo 1 – Erosion Resulting in Overhang

Photo 2 – Tree Fallen Into Creek Channel

Photo 3 – North Culvert

Photo 4 – Lock Block Wall Mitigating Erosion

## NORTHERN PORTION

PHOTO 5 – Rip Rap Mitigating Erosion

PHOTO 6 – Fallen Tree and Wood Debris

PHOTO 7 – Soughing Slope with Associated Leaning/ Curved Trees

PHOTO 8 – Fallen Undermined Trees

## NORTHERN PORTION



PHOTO 9 – Undulating Topography
Indicating Slope Movement

PHOTO 10 – South Culvert

PHOTO 11– Cobbles and Boulder Material
Removed from Trash Gate (Culvert Entrance)

PHOTO 12 – Vegetation and Wood Debris
Removed from Trash Gate (Culvert Entrance)

## SOUTHERN PORTION

PHOTO 13 – Curved Trees Indicating Slope Movement

PHOTO 14 – Gully East Side of Creek Channel

PHOTO 15 – Abandoned Dirt Road – Note Slough Resulting From Undermining

PHOTO 16 – BMX Track on Depositional Fan Below Residential Development

## SOUTHERN PORTION

PHOTO 17 – Depositional Fan

PHOTO 18 – Slide Scarp Below Residential Lot – Note Heavy Brush/Waste Covering Slope

PHOTO 19 – Depositional Fan Providing Erosion Mitigation

PHOTO 20 – Rip Rap Placed for Creek Crossing

## SOUTHERN PORTION

PHOTO 21 – Eroded Rip Rap Bank From Abandoned Road Crossing

PHOTO 22 – Rip Rap Bank From Abandoned Road Crossing

PHOTO 23 – Leaning Trees and Undulating Topography Indicative of Slope Movement

PHOTO 24 – Slide Scarp Near Residential Development

Appendix D

# Hydrologic/Hydraulic Modelling

# Appendix D – Hydrologic/Hydraulic Modelling

## Contents



## Figures

# Appendix D – Hydrologic/Hydraulic Modelling

## Tables

# Appendix D – Hydrologic/Hydraulic Modelling

## 1. Hydrologic and Hydraulic Modelling

### 1.1 Introduction

This appendix outlines the development of the detailed hydrologic and hydraulic model of the Boundary/Shaw Creek Drainage Basin.

### 1.2 XP-SWMM and MIKE 11 Model Development

The drainage system is shown in Figure D-1 and includes portions of both Delta and Surrey. For this study, the Boundary/Shaw Creek basin is separated into two major sections for assessment, uplands area and lowlands area.

Hydrologic and hydraulic models developed for previous work done for Delta were updated for this project. Two models were developed for the Boundary/Shaw watershed, XP-SWMM for hydrology (RUNOFF) and upland hydraulics (EXTRAN) and MIKE11 for lowland hydraulics. XP-SWMM RUNOFF uses inputs such as rainfall and catchment characteristics (area, slope, soil type, etc.) to estimate catchment flows. XP-SWMM EXTRAN and MIKE 11 use hydraulic system inputs (culvert/pipe/channel characteristics) to simulate flow routing, water levels, and flooding.

### 1.3 XP-SWMM Overview

The East Delta flood analysis model that was developed for the 2007 Delta Flood Management Study was used as a base for the XP-SWMM modelling. This model used the XP-SWMM RUNOFF module to generate the flow hydrographs for the MIKE 11 model.

The East Oliver Bypass models were developed for the design of the East Oliver Bypass Ponds. This model was developed by KWL in 2001 and included both RUNOFF and EXTRAN modules.

Both of these models were combined to form the base of the Boundary/Shaw Creek watershed model. The East Delta model was used for the lowland and lumped catchment runoff, while the Bypass model was used to add details of existing detention and flow control structures into the XP-SWMM hydraulics layer.

The hydrologic and hydraulic model was developed with the aid of the Corporation of Delta and City of Surrey GIS databases and with information gathered during the drainage inventory.

#### XP-SWMM Model Catchments

The East Delta watershed was discretized into sub-catchments using contours, field watercourse information, and existing drainage information. The major model sub-catchments for the Boundary/Shaw Creek study area are shown on Figure D-1.

In total, 52 catchments were created and imported into the XP-SWMM model. Catchments were assigned the following attributes:

- areas;
- slopes, using contour information;

# Appendix D – Hydrologic/Hydraulic Modelling

- impervious percentage values; and
- infiltration and groundwater parameters.

**Impervious Percentage**

Existing land use impervious percentages were estimated based on the land use type visible in the aerial photography and typical impervious percentage values.

The future land use impervious percentages were derived using the OCP zoning information and Panorama Ridge and West Newton local area plans combined with typical impervious percentage values.

**Soil Parameters**

The groundwater portion of XP-SWMM – RUNOFF was used to estimate the groundwater and interflow portions of the runoff hydrograph. Figure 2-4 shows the surficial geology that was used to determine soil parameters. The majority of the watershed is silt-clay soils and peat, with some till, steepland sediments, sand and silt, and gravel and sand soils.

The infiltration and groundwater parameters used in the models were based on KWL's database of calibrated model parameters for similar soil conditions.

## Model Update

The RUNOFF portion of the XP-SWMM model was updated with the following information:

- Catchment areas were refined and updated;
- Eugene Creek catchments were added;

The EXTRAN portion of the XP-SWMM model was modified to include a portion of the lowland area also modelled in MIKE11 at the request of the Corporation of Delta. The hydraulics model was updated with the following information:

- Added two detention ponds located in Surrey;
- Added Shaw Creek channel details up to Scott Rd.
- Added Briarwood Creek, Watershed Creek, and Watershed Creek Tributary;
- Added golf course ditch and storage areas;
- Added Eugene Creek floodboxes and culverts at lower end of golf course;
- Upland culverts on Shaw Creek, Briarwood Creek, Watershed Creek, and Watershed Creek Tributary; and
- Added the East Oliver Bypass ponds and flow control structure.

## Model Validation

The available recorded information for model validation consisted of measured Boundary Park Pond water levels. No flow information on the creeks was available. The XP-SWMM model was validated against the pond water levels recorded in 2010. The rainfall during the monitored period (March to July 2010) included a number of small storm events, all less than 2-year return period. Figure D-2 shows the validation results.

# Appendix D – Hydrologic/Hydraulic Modelling

The model appears to overestimate the peak water levels by up to 0.34m (2 May 2010) but appears to be able to replicate the drawdown curve well. The control structure at the pond outlet is a weir with sloping sides (the width increases with depth) for which a rating curve was developed in a previous study. The model produces conservative pond water levels and no adjustment was made prior to performing design storm or continuous simulation.

## 1.4 Mike 11 Overview

The MIKE 11 East Delta flood analysis model that was developed for the 2007 Delta Flood Management Study was used as a base for the lowland modelling. The model incorporates East Delta's network of lowland drainage ditches, culverts, pump stations, and other drainage structures, as well as flood storage and overland conveyance mechanisms. This conceptual model uses unsteady hydraulic analysis to simulate the response (flow and water level) of the East Delta drainage system to storms between several hours and several days long.

The East Delta MIKE 11 model area encompasses the south-eastern quadrant of Delta, extending from 72nd Street (near Boundary Bay Airport) in the west to the toe of the upland area in the east, and from Burns Bog in the north to Mud Bay in the south. The boundaries of the model are generally set to include all areas that are tributary to Oliver pump station, the Beharrel pump station and the Airport pump station.

### Data Collection

The hydraulic model requires various scales of topographic and infrastructure data to build the computational framework. East Delta is an expansive area (11 km by 6 km, including Shaw Creek Catchment) with generally older agricultural development and large drainage structures. Given the age and land use in the area, the existing database of as-constructed information is generally poor; most of the available data has been collected in the past 5 to 10 years by the Delta survey and operations staff. Additionally, typical high water levels and the large scale of the drainage ditches and culverts make collection of topographic information difficult.

To develop the model, the area was initially delineated using two primary sources of information:

- the Delta DEM; and
- infrastructure mapping from the Delta GIS system.

Achieving an accurate representation of the drainage ditches and culverts required more detailed survey information. The Delta survey department supplied GPS survey information for road centrelines and some isolated areas of survey of culverts and ditches. Road centreline information was used to identify cell boundaries and potential overflow areas. Other information supplied by Delta was generally limited to Centre Slough and parts of 104th Street. A survey was done to obtain all other necessary information.

The model network was built to include only major drainage ditches and culverts. Each culvert was assigned a unique identifier. Ditch cross-sections were obtained by survey and were surveyed at intervals required for modelling (i.e. with greater resolution in rapidly changing geometry, and less resolution in uniform reaches).

# Appendix D – Hydrologic/Hydraulic Modelling

All other required data was obtained from Delta record drawings, pump curves, floodbox and pump station inventory manuals, and drainage operation manuals.

Additional drainage inventory work was undertaken in the Shaw Creek study area. The drainage inventory survey was completed between May 20 and June 8, 2010 for Watershed Park as well as the area south of Highway 10 and north of Ladner Trunk Road. To accomplish this, the creek bed was traversed on foot and locations of interest were identified and recorded with a Trimble GeoXT handheld global positioning system (GPS) receiver. Measurements, photographs and additional observations were recorded as attributes associated with these positions to create a comprehensive geographical information system (GIS) database. The goals of the inventory field work program were to identify:

- Locations of significant erosion and to rate these sites based on relative severity and potential risk;
- natural and anthropogenic channel obstructions and to rate these obstructions based on relative stability;
- locations of significant deposition;
- drainage control structures; and
- drainage pathways within Watershed Park.

See Appendix A for photo overviews of the field inventory.

## Channel Sections

Typical creek channel sections were measured during the field visits. Section properties such as bank height, bed width and material, and bank material were recorded. This information was incorporated into the hydrologic/hydraulic model.

## Model Construction

The model was constructed in North American Datum 1927 (NAD 27) UTM horizontal coordinate system, the spatial coordinate system used by the Delta GIS and engineering system. To simplify the spatial analyses, all model structures (ditches, culverts, etc.) were input into the model with approximately accurate spatial locations.

## Model Update

The East Delta flood analysis model was updated with more detailed information in the area east of Highway 91. Updates included the including:

- Added typical channel cross-sections and storage areas for Briarwood Creek, Watershed Creek, and Watershed Creek Tributary,
- Updated and added additional culverts; and
- Added golf course ditch and storage areas.

# Appendix D – Hydrologic/Hydraulic Modelling

## 1.5 Boundary Conditions

### Rainfall Input

The design storms used in analysis were those contained in the Surrey *Design Criteria Manual* (2004). The 48-hour rainfall totals were estimated based on the IDF curve on Figure 5.4 of the manual and the 24-hour storm distribution was used for the 48-hour storm as well as the 24-hour storm. The 12-, 24-, and 48-hour design storms were used for the culvert capacity and detention facility assessments.

The RFP initially asked that Chicago storms be used for the analysis in the Delta portion of the study area, however it was found that the intensity in these storms were too high and resulted in unrealistically-high peak flows. Delta staff agreed to use the Surrey design storms throughout the study area.

The lowland areas were analysed under the Agri-food Regional Development Subsidiary Agreement (ARDSA) using the ARDSA design storms from the Surrey *Design Criteria Manual* (2004). The model was also run for the 10-year 2-day and 10-year 5-day storms to determine whether the ARDSA criteria are met in the lowland areas and to evaluate the lowland culverts. The 5-day winter and 2-day growing season storms reflect actual recorded storm events modified to reflect the specified return period rainfall intensities for all durations from 1 hour to 5 days.

Table D-1 shows precipitation totals for all events and the ARDSA storms.

**Table D-1: Total Precipitation Amounts for Climate Stations**

| Duration | Total Rainfall (mm) | | | | |
|---|---|---|---|---|---|
| | 6-month | 2-year | 5-year | 10-year | 100-year |
| **Surrey Municipal Hall** | | | | | |
| 12-hour | - | 39.2 | 47.3 | 52.6 | 69.4 |
| 24-hour | 40.5 | 56.2 | 67.7 | 75.3 | 99.1 |
| 48-hour | - | 81.6 | 96.0 | 115.2 | 172.8 |
| **ARDSA Storms** | | | | | |
| 2-day | - | - | - | 84.02 | - |
| 5-day | - | - | - | 143.36 | - |
| | | | | | |
| Design storms were developed for the 6-month, 2-year, 5-year, 10-year, and 100-year return periods. ARDSA Storms are from the City of Surrey Design Criteria Manual, 2004, 2-Day Surrey Municipal Hall and 5-day Pitt Meadows STP | | | | | |

Rainfall from the GVRD DT34 rain gauge for 1991 to 2009 was used to perform continuous simulation. The 5 minute rainfall data was obtained from the Metro Vancouver for this time period. The GVRD DT34 gauge is located in North Delta at 8544-116th Street. The period of data available for this gauge is November 1, 1991 to December 31, 2009.

# Appendix D – Hydrologic/Hydraulic Modelling

### Water Level Boundaries

The outlets to Mud Bay include floodboxes and pump stations and were simulated using water level boundary conditions. The tidal signal used on the boundary of these outlets was consistent with the design water level time series that KWL and UMA used previously for the modelling of the Nicomekl River and Serpentine River. This tidal series represents a normal high tide series for a winter condition in Boundary Bay, and does not include other components such as storm surge.

## 1.6 Results Analysis

The modelling results are presented in Section 3 of the main body.

### Capacity Assessment

A culvert capacity assessment was preformed for the culverts in the study area to determine if any culverts were undersized and required upgrading. Tables D-2 to D-5 show the results of the analysis for all the culverts in the study area. Modelling results indicate that the same ten culverts do not meet the criteria for both the existing and future land use flows. There are two surcharged creek crossings during the 100-year event, and eight surcharged creek crossings in the 10-year event.

### Detention Facility Assessment

A detention facility assessment was preformed to determine the effectiveness of the existing flow control facilities and to determine improvements that would improve the effectiveness. Three scenarios were simulated to perform this assessment:

- Pre-development land use conditions,
- Future land use conditions with existing flow control, and
- Future land use conditions with improved flow control.

Changes to the outlet control structures were made in the "Improved Flow Control" models to reduce the peak flows downstream of the facilities. Figures D-3 to D-6 show the Boundary Park detention pond hydrographs for the 6-month, 2-year, 5-year, and 10-year 24-hour events. As shown, the Boundary Park Pond outlet could be modified so that the pond outflows better match the pre-development flows in the 2-year to 10-year events while limiting the peak 10-year pond level to 65.1m Geodetic, approximately 5cm higher than the water level reached with the existing outlet. This modification involves replacing the existing weir structure with two orifices and an overflow.

Figures D-7 to D-10 show the Detention Tank P1 detention pond hydrographs. As shown, adding an orifice to the Detention Tank P1 outlet could slightly reduce the peak 6-month event flow, however, there is insufficient storage volume to reduce the larger events.

### Hydrologic Impacts of Future Densification

XP-SWMM was used to perform a continuous model simulation using rainfall from the GVRD DT34 rain gauge for 1991 to 2009 and exceedance duration curves were created.

Exceedance duration curves for the pre-development, existing land use with existing flow control, and future land use with existing flow control scenarios are shown in Figures D-11 to D-13 for Shaw,

# Appendix D – Hydrologic/Hydraulic Modelling

Briarwood, and Watershed Creeks. Figure D-11 also shows the existing land use with no flow control and future land use with improved flow control scenarios for Shaw Creek. The Boundary Park Pond and Detention Tank P1 storage volumes were removed in the "No Flow Control" scenario and the outlets were adjusted in the "Improved Flow Control" scenario as described in the Detention Facility Assessment section.

Exceedance duration curves show the duration of any given flow rate over the simulation period. In catchments that have been developed, the curves often show higher flows for a given duration under the developed condition, while pre-developed conditions often have lower flows for the same duration.

The curves indicated that the land use densification increases the flow in Shaw, Watershed, and Briarwood Creeks, mainly in infrequent large flows and rare large flows. For Shaw Creek, the difference between the exiting land use with and without flow control results shows the significant benefit of the Boundary Park Pond on peak flow reduction. The small difference between the future land use with existing and improve flow control results shows that the potential improvements to be realized by the outlet structure improvements are limited. Greater storage volumes would be required to realize a larger benefit.

## Watershed Performance during Recent Large Storms

The XP-SWMM models were used to simulate the watershed response during recent large rainfall events in the last five years plus the October and November events of 2003. The large events were run for the following three scenarios:

- Pre-development land use conditions,
- Existing land use conditions with existing flow control, and
- Future land use conditions with existing flow control.

Figures D-14 to D-19 show the flow hydrographs for Shaw Creek at 120 Street and Figures D-20 to D-25 show Watershed Creek at the BNSF railway. The hydrographs show that the existing with flow control and future with flow control scenarios are similar in their reaction to the storms. The existing and future peak flows are higher then the pre-development peak flow especially during the large dry initial conditions storms (September 2006 and October 2006).

**Table D-2: Culvert Assessment for Existing Land Use 100-Year Flow**

| Culvert ID | Diameter | Material | Pipe Capacity | Capacity Inlet Controlled to d/D=1.0 | 100-Year Peak Flow | Surcharge Time | Meets Criteria | Notes |
|---|---|---|---|---|---|---|---|---|
| | (m) | | ($m^3$/s) | ($m^3$/s) | ($m^3$/s) | (min) | (Y/N) | |
| Boundary Park Pond Outfall | 1.50 | CONC | 4.36 | 3.90 | 4.92 | 0 | Y | SWMM FLOW |
| Hwy10_1 | 1.50 | PVC | 13.69 | 3.90 | 5.21 | 0 | Y | SWMM FLOW |
| CUL_289 | 1.60 | CMP | 36.49 | 4.50 | 5.75 | 0 | Y | SWMM FLOW |
| CUL_291 | 0.60 | CMP | 1.97 | 0.40 | 0.70 | 0 | Y | SWMM FLOW |
| CUL_294 | 1.60 | CMP | 4.50 | 4.50 | 6.28 | 0 | Y | SWMM FLOW |
| CUL_232 | 0.90 | CMP | 2.17 | 1.10 | 0.88 | 0 | Y | MIKE11 FLOW |
| CUL_14 | 1.80 | CMP | 15.09 | 6.00 | 5.20 | 0 | Y | MIKE11 FLOW |
| CUL_15 | 2.40 | CMP | 14.54 | 10.20 | 5.17 | 0 | Y | MIKE11 FLOW |
| CUL_370 | 1.20 | | 10.37 | 2.20 | 4.31 | 315 | N | MIKE11 FLOW |
| CUL_295 | 1.80 | CMP | 7.24 | 6.00 | 4.45 | 0 | Y | MIKE11 FLOW |
| CUL_354 | 1.50 | CMP | 2.08 | 3.90 | 3.70 | 0 | Y | MIKE11 FLOW |
| CUL_236 | 2.00 | CMP | 13.2 | 7.00 | 7.69 | 135 | N | MIKE11 FLOW |
| CUL_234 | 0.90 | CMP | 0.91 | 1.10 | 0.25 | 0 | Y | MIKE11 FLOW |
| CUL_9 | 1.40 | CMP | 15.05 | 3.50 | 0.57 | 0 | Y | MIKE11 FLOW |
| CUL_7 | 1.20 | CMP | 2.29 | 2.20 | 0.52 | 0 | Y | MIKE11 FLOW |
| CUL_223 | 1.20 | CONC | 0.04 | 2.20 | 0.58 | 0 | Y | MIKE11 FLOW |
| CUL_35 | 1.60 | CMP | 1.13 | 4.50 | 1.25 | 0 | Y | MIKE11 FLOW |
| CUL_29 | 1.20 | CONC | 6.40 | 2.20 | 1.32 | 0 | Y | MIKE11 FLOW |
| CUL_36 | 1.60 | CMP | 6.18 | 4.50 | 1.63 | 0 | Y | MIKE11 FLOW |

Shaded entries do not meet the criteria
See Figure 3-2 for locations.

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**Table D-3: Culvert Assessment for Future Land Use 100-Year Flow**

| Culvert ID | Diameter | Material | Pipe Capacity | Capacity Inlet Controlled to d/D=1.0 | 100-Year Peak Flow | Surcharge Time | Meets Criteria | Notes |
|---|---|---|---|---|---|---|---|---|
| | (m) | | ($m^3$/s) | ($m^3$/s) | ($m^3$/s) | (min) | (Y/N) | |
| Boundary Park Pond Outfall | 1.50 | CONC | 4.36 | 3.90 | 5.12 | | Y | SWMM FLOW |
| Hwy10_1 | 1.50 | PVC | 13.69 | 3.90 | 5.42 | | Y | SWMM FLOW |
| CUL_289 | 1.60 | CMP | 36.49 | 4.50 | 6.02 | | Y | SWMM FLOW |
| CUL_291 | 0.60 | CMP | 1.97 | 0.40 | 0.70 | | Y | SWMM FLOW |
| CUL_294 | 1.60 | CMP | 4.50 | 4.50 | 6.58 | | Y | SWMM FLOW |
| CUL_232 | 0.90 | CMP | 2.17 | 1.10 | 0.89 | | Y | MIKE11 FLOW |
| CUL_14 | 1.80 | CMP | 15.09 | 6.00 | 5.43 | | Y | MIKE11 FLOW |
| CUL_15 | 2.40 | CMP | 14.54 | 10.20 | 5.39 | | Y | MIKE11 FLOW |
| CUL_370 | 1.20 | | 10.37 | 2.20 | 4.48 | 315 | N | MIKE11 FLOW |
| CUL_295 | 1.80 | CMP | 7.24 | 6.00 | 4.61 | | Y | MIKE11 FLOW |
| CUL_354 | 1.50 | CMP | 2.08 | 3.90 | 3.78 | | Y | MIKE11 FLOW |
| CUL_236 | 2.00 | CMP | 13.2 | 7.00 | 7.88 | 165 | N | MIKE11 FLOW |
| CUL_234 | 0.90 | CMP | 0.91 | 1.10 | 0.26 | | Y | MIKE11 FLOW |
| CUL_9 | 1.40 | CMP | 15.05 | 3.50 | 0.56 | | Y | MIKE11 FLOW |
| CUL_7 | 1.20 | CMP | 2.29 | 2.20 | 0.49 | | Y | MIKE11 FLOW |
| CUL_223 | 1.20 | CONC | 0.04 | 2.20 | 0.59 | | Y | MIKE11 FLOW |
| CUL_35 | 1.60 | CMP | 1.13 | 4.50 | 1.25 | | Y | MIKE11 FLOW |
| CUL_29 | 1.20 | CONC | 6.40 | 2.20 | 1.32 | | Y | MIKE11 FLOW |
| CUL_36 | 1.60 | CMP | 6.18 | 4.50 | 1.63 | | Y | MIKE11 FLOW |

Shaded entries do not meet the criteria
See Figure 3-2 for locations.

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**Table D-4: Culvert Assessment for Existing Land Use 10-Year Flow**

| | | | | | | For Inlet Control | | For Outlet Control | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Diameter | Material | Pipe Capacity | Capacity Inlet Controlled to d/D=1.0 | Outlet Controlled | 10-Year Peak Flow | Surcharge Time | 10-Year Peak Flow | Head Loss | Meets Criteria |
| | (m) | | ($m^3/s$) | ($m^3/s$) | (Y/N) | ($m^3/s$) | (min) | ($m^3/s$) | (m) | (Y/N) |
| CUL_41 | 1.80 | CMP | 13.90 | 6.0 | Y | 3.04 | | 3.04 | 0.02 | Y |
| CUL_40 | 1.20 | CMP | 5.41 | 2.2 | Y | 1.41 | | 1.41 | 0.01 | Y |
| CUL_38 | 1.50 | CMP | 8.62 | 3.9 | Y | 1.27 | | 1.27 | 0.01 | Y |
| CUL_37 | 1.50 | CMP | 1.97 | 3.9 | Y | 1.26 | | 1.26 | 0.01 | Y |
| CUL_31 | 1.30 | WOODSTV | 4.55 | 3.0 | Y | 1.03 | | 1.03 | 0.01 | Y |
| CUL_27 | 0.90 | CONC | 2.96 | 1.1 | Y | 0.78 | | 0.78 | 0.11 | Y |
| CUL_25 | 0.90 | CONC | 1.70 | 1.1 | Y | 0.80 | | 0.80 | 0.12 | Y |
| CUL_24 | 1.80 | CON | 9.79 | 6.0 | Y | 5.77 | | 5.77 | 0.40 | N |
| CUL_23 | 0.75 | CMP | 0.28 | 0.7 | Y | 0.67 | | 0.67 | 0.16 | Y |
| CUL_22 | 1.05 | STL | 2.75 | 1.6 | Y | 0.66 | | 0.66 | 0.03 | Y |
| CUL_21 | 0.75 | CONC | 0.94 | 0.7 | Y | 0.66 | | 0.66 | 0.15 | Y |
| CUL_249 | 0.60 | CONC | 0.98 | 0.4 | Y | 0.67 | 3045 | 0.67 | 0.41 | N |
| CUL_331 | 1.20 | CONC | 0.04 | 2.2 | Y | 0.69 | | 0.69 | 0.03 | Y |
| CUL_20 | 1.05 | CMP | 4.77 | 1.6 | Y | 0.74 | | 0.74 | 0.04 | Y |
| CUL_19 | 1.05 | CMP | 2.53 | 1.6 | Y | 0.74 | | 0.74 | 0.02 | Y |
| CUL_18 | 1.05 | CMP | 1.50 | 1.6 | Y | 0.74 | | 0.74 | 0.06 | Y |
| CUL_17 | 1.20 | CMP | 4.38 | 2.2 | Y | 3.39 | 870 | 3.39 | 0.20 | N |
| CUL_250 | 0.60 | CONC | 0.17 | 0.4 | Y | 0.67 | 3420 | 0.67 | 0.38 | N |
| CUL_1 | 1.20 | CONC | 2.75 | 2.2 | Y | 0.19 | | 0.19 | 0.00 | Y |
| CUL_2 | 0.60 | CONC | 0.59 | 0.4 | Y | 0.45 | 2610 | 0.45 | 0.06 | N |
| CUL_3 | 1.40 | CMP | 1.81 | 3.5 | Y | 0.45 | | 0.45 | 0.00 | Y |
| CUL_4 | 1.05 | CONC | 2.51 | 1.6 | Y | 0.47 | | 0.47 | 0.01 | Y |
| CUL_6 | 1.50 | CMP | 5.00 | 3.9 | Y | 0.49 | | 0.49 | 0.00 | Y |
| CUL_8 | 1.20 | CMP | 2.35 | 2.2 | Y | 0.52 | | 0.52 | 0.01 | Y |
| CUL_10 | 1.00 | CMP | 0.20 | 1.4 | Y | 0.88 | | 0.88 | 0.03 | Y |
| CUL_11 | 1.00 | CMP | 0.53 | 1.4 | Y | 0.88 | | 0.88 | 0.03 | Y |
| CUL_12 | 1.05 | CMP | 1.15 | 1.6 | Y | 0.81 | | 0.81 | 0.02 | Y |
| CUL_13 | 1.05 | CMP | 1.82 | 1.6 | Y | 0.81 | | 0.81 | 0.02 | Y |
| CUL_39 | 1.05 | CONC | 4.09 | 1.6 | Y | 1.48 | | 1.48 | 0.09 | Y |
| CUL_197 | 1.20 | CMP | 3.91 | 2.2 | Y | 1.55 | | 1.55 | 0.05 | Y |
| CUL_198 | 1.20 | CMP | 3.91 | 2.2 | Y | 1.53 | | 1.53 | 0.05 | Y |
| CUL_230 | 1.20 | CONC | 1.23 | 2.2 | Y | 0.55 | | 0.55 | 0.00 | Y |
| CUL_231 | 0.90 | CMP | 2.33 | 1.1 | Y | 1.32 | 130 | 1.32 | | N |
| CUL_199 | 1.20 | CONC | 3.06 | 2.2 | Y | 0.18 | | 0.18 | 0.00 | Y |
| CUL_274 | 0.45 | CMP | 0.00 | 0.2 | Y | 2.85 | 1395 | 2.85 | | N |
| CUL_352 | 0.25 | | 0.18 | 0.1 | N | 1.53 | 1890 | 1.53 | | N |
| CUL_372 | 1.50 | | 31.00 | 3.9 | N | 2.02 | | 2.02 | | Y |

Shaded entries do not meet the criteria. See Figure 3-1 for locations.
Bold entries were also checked for 100-year flow conveyance (see Tables B-1 and B-2).

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**Table D-5: Culvert Assessment for Future Land Use 10-Year Flow**

| | | | | | | For Inlet Control | | For Outlet Control | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Diameter | Material | Pipe Capacity | Capacity Inlet Controlled to d/D=1.0 | Outlet Controlled | 10-Year Peak Flow | Surcharge Time | 10-Year Peak Flow | Head Loss | Meets Criteria |
| | (m) | | ($m^3$/s) | ($m^3$/s) | (Y/N) | ($m^3$/s) | (min) | ($m^3$/s) | (m) | (Y/N) |
| CUL_41 | 1.80 | CMP | 13.90 | 6.0 | Y | 3.05 | | 3.05 | 0.02 | Y |
| CUL_40 | 1.20 | CMP | 5.41 | 2.2 | Y | 1.42 | | 1.42 | 0.01 | Y |
| CUL_38 | 1.50 | CMP | 8.62 | 3.9 | Y | 1.28 | | 1.28 | 0.01 | Y |
| CUL_37 | 1.50 | CMP | 1.97 | 3.9 | Y | 1.27 | | 1.27 | 0.01 | Y |
| CUL_31 | 1.30 | WOODSTV | 4.55 | 3.0 | Y | 1.03 | | 1.03 | 0.01 | Y |
| CUL_27 | 0.90 | CONC | 2.96 | 1.1 | Y | 0.79 | | 0.79 | 0.11 | Y |
| CUL_25 | 0.90 | CONC | 1.70 | 1.1 | Y | 0.80 | | 0.80 | 0.12 | Y |
| CUL_24 | 1.80 | CON | 9.79 | 6.0 | Y | 6.05 | 315 | 6.05 | 0.44 | N |
| CUL_23 | 0.75 | CMP | 0.28 | 0.7 | Y | 0.67 | | 0.67 | 0.16 | Y |
| CUL_22 | 1.05 | STL | 2.75 | 1.6 | Y | 0.66 | | 0.66 | 0.03 | Y |
| CUL_21 | 0.75 | CONC | 0.94 | 0.7 | Y | 0.66 | | 0.66 | 0.15 | Y |
| CUL_249 | 0.60 | CONC | 0.98 | 0.4 | Y | 0.67 | 1875 | 0.67 | 0.41 | N |
| CUL_331 | 1.20 | CONC | 0.04 | 2.2 | Y | 0.69 | | 0.69 | 0.03 | Y |
| CUL_20 | 1.05 | CMP | 4.77 | 1.6 | Y | 0.74 | | 0.74 | 0.04 | Y |
| CUL_19 | 1.05 | CMP | 2.53 | 1.6 | Y | 0.75 | | 0.75 | 0.02 | Y |
| CUL_18 | 1.05 | CMP | 1.50 | 1.6 | Y | 0.75 | | 0.75 | 0.06 | Y |
| CUL_17 | 1.20 | CMP | 4.38 | 2.2 | Y | 3.49 | 840 | 3.49 | 0.20 | N |
| CUL_250 | 0.60 | CONC | 0.17 | 0.4 | Y | 0.67 | 3390 | 0.67 | 0.38 | N |
| CUL_1 | 1.20 | CONC | 2.75 | 2.2 | Y | 0.19 | | 0.19 | 0.00 | Y |
| CUL_2 | 0.60 | CONC | 0.59 | 0.4 | Y | 0.45 | 2610 | 0.45 | 0.06 | N |
| CUL_3 | 1.40 | CMP | 1.81 | 3.5 | Y | 0.45 | | 0.45 | 0.01 | Y |
| CUL_4 | 1.05 | CONC | 2.51 | 1.6 | Y | 0.47 | | 0.47 | 0.01 | Y |
| CUL_6 | 1.50 | CMP | 5.00 | 3.9 | Y | 0.50 | | 0.50 | 0.00 | Y |
| CUL_8 | 1.20 | CMP | 2.35 | 2.2 | Y | 0.52 | | 0.52 | 0.01 | Y |
| CUL_10 | 1.00 | CMP | 0.20 | 1.4 | Y | 0.88 | | 0.88 | 0.03 | Y |
| CUL_11 | 1.00 | CMP | 0.53 | 1.4 | Y | 0.88 | | 0.88 | 0.03 | Y |
| CUL_12 | 1.05 | CMP | 1.15 | 1.6 | Y | 0.81 | | 0.81 | 0.02 | Y |
| CUL_13 | 1.05 | CMP | 1.82 | 1.6 | Y | 0.81 | | 0.81 | 0.02 | Y |
| CUL_39 | 1.05 | CONC | 4.09 | 1.6 | Y | 1.48 | | 1.48 | 0.09 | Y |
| CUL_197 | 1.20 | CMP | 3.91 | 2.2 | Y | 1.55 | | 1.55 | 0.05 | Y |
| CUL_198 | 1.20 | CMP | 3.91 | 2.2 | Y | 1.53 | | 1.53 | 0.05 | Y |
| CUL_230 | 1.20 | CONC | 1.23 | 2.2 | Y | 0.55 | | 0.55 | 0.00 | Y |
| CUL_231 | 0.90 | CMP | 2.33 | 1.1 | Y | 1.48 | 150 | 1.48 | | N |
| CUL_199 | 1.20 | CONC | 3.06 | 2.2 | Y | 0.20 | | 0.20 | 0.00 | Y |
| CUL_274 | 0.45 | CMP | 0.00 | 0.2 | Y | 3.03 | 1305 | 3.03 | | N |
| CUL_352 | 0.25 | | 0.18 | 0.1 | N | 1.53 | 1890 | 1.53 | | N |
| CUL_372 | 1.50 | | 31.00 | 3.9 | N | 2.26 | | 2.26 | | Y |

Shaded entries do not meet the criteria. See Figure 3-1 for locations.
Bold entries were also checked for 100-year flow conveyance (see Tables B-1 and B-2).

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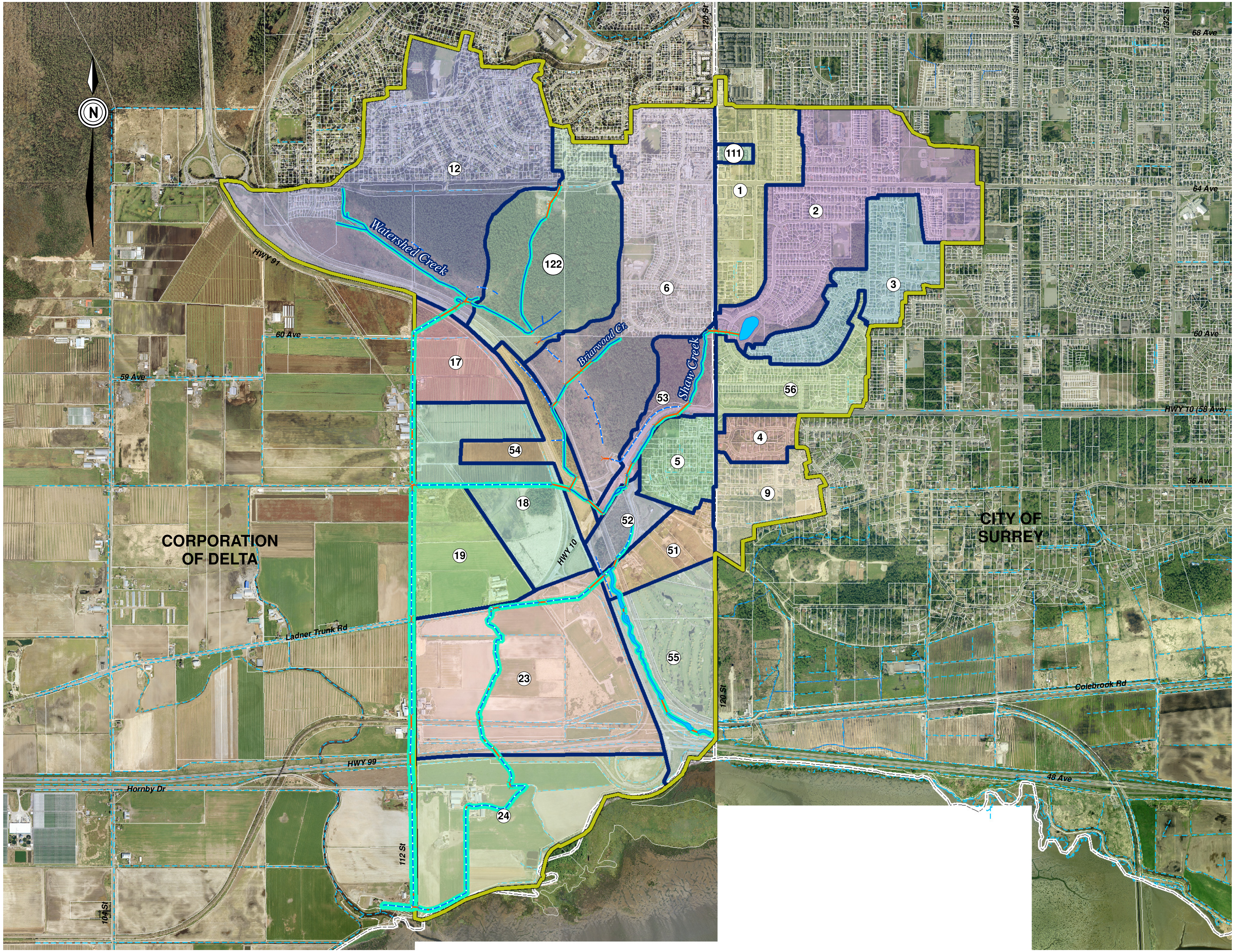
# Appendix D – Hydrologic/Hydraulic Modelling

The rainfall data shows the following recent large events and their approximate return period and duration (see Table D-6).

**Table D-6: Large Precipitation Events 2003-2009**

| Date | Return Period | Duration | Rain Depth |
|---|---|---|---|
| October 16, 2003 | 2- to 5-year<br>10- to 25-year<br>>100-year<br>>100-year | 2-hour<br>6-hour<br>12-hour<br>24-hour | 22 mm<br>51.6 mm<br>91 mm<br>132 mm |
| November 28, 2003 | 10-year<br>25-year<br>50-year | 6-hour<br>12-hour<br>24-hour | 47.2 mm<br>75.6 mm<br>93.2 mm |
| January 17, 2005 | 10-year<br>10- to 25-year<br>25-year | 12-hour<br>24-hour<br>48-hour | 66 mm<br>80.6 mm<br>129.2 mm |
| September 14, 2006 | 2-year<br>2-year<br>5-year<br>2- to 5-year | 15-minute<br>30-minute<br>1-hour<br>2-hour | 7.2 mm<br>11 mm<br>19.2 mm<br>23 mm |
| October 17, 2006 | 25-year | 5-minute | 7 mm |
| March 11 2007 | 10- to 25-year<br>10-year<br>5- to 10-year | 24-hour<br>48-hour<br>72-hour | 81.6 mm<br>114.6 mm<br>120.4 mm |
| Events may span multiple return periods and durations during the course of a storm | | | |

Hydrographs for these events were created for Shaw and Watershed Creeks (See Figures D-14 to D-25). The hydrographs show that the existing with flow control and future with flow control scenarios are similar in their reaction to the storms. The existing and future peak flows are higher than the pre-development peak flow and the future scenario has slightly higher peak flows than the existing scenario.




## Corporation of Delta
## Boundary/Shaw
## Integrated Stormwater Management Study

### Legend

- Study Boundary
- Municipal Boundary
- (ID) Subcatchments
- Culvert
- Ditch
- Creek
- Modelled Conveyance System

2008 Orthophoto and cadastral data provided by The Corporation of Delta and City of Surrey.
ALR source from Agricultural Land Commission

KERR WOOD LEIDAL associates limited
CONSULTING ENGINEERS



500 0 500
Scale in Metres 1:20,000

| Project No. | Date |
| --- | --- |
| 323-059 | August 2011 |

# Catchments and Modelling Schematic

**Figure D-1**

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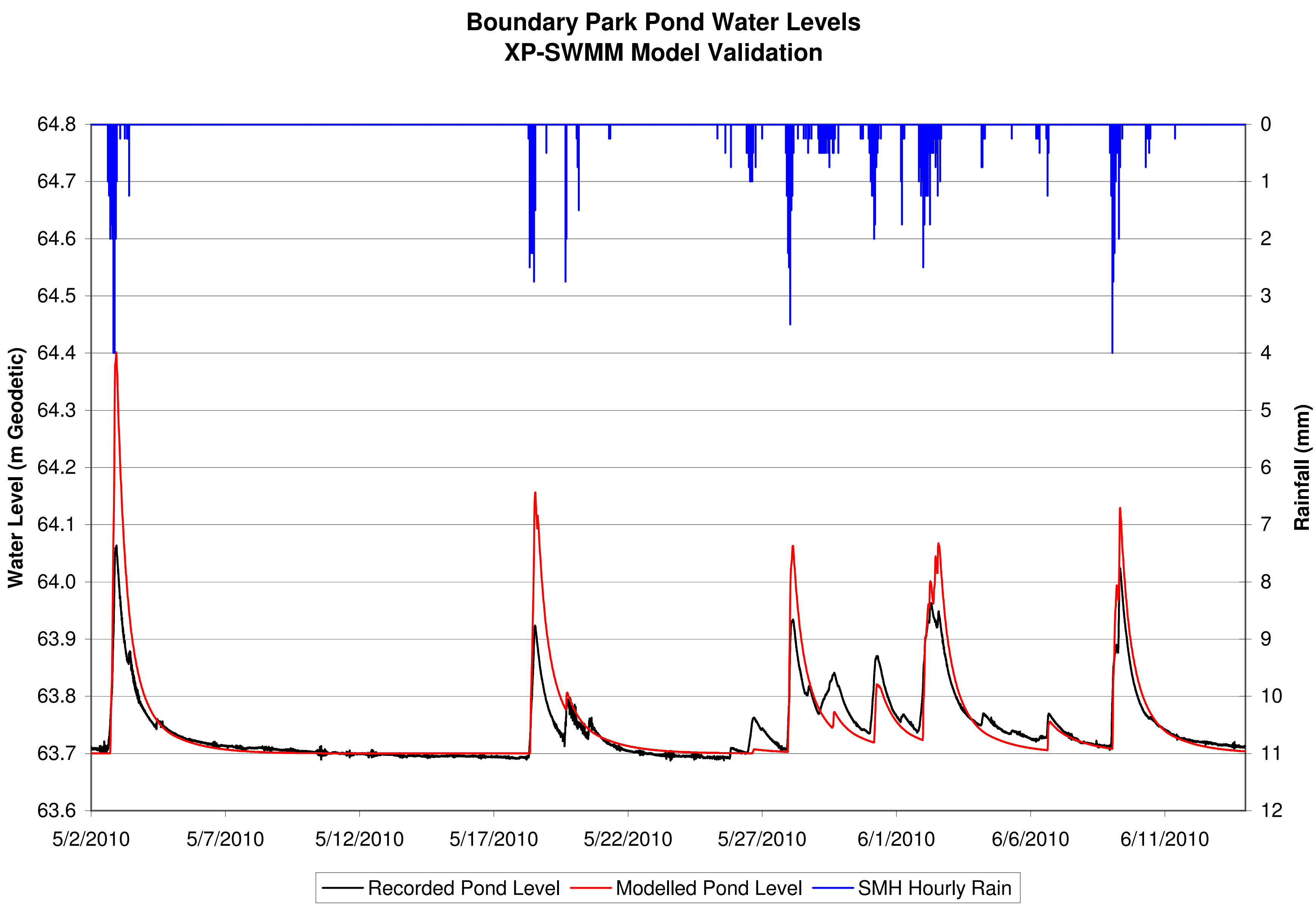


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**Figure D-2**

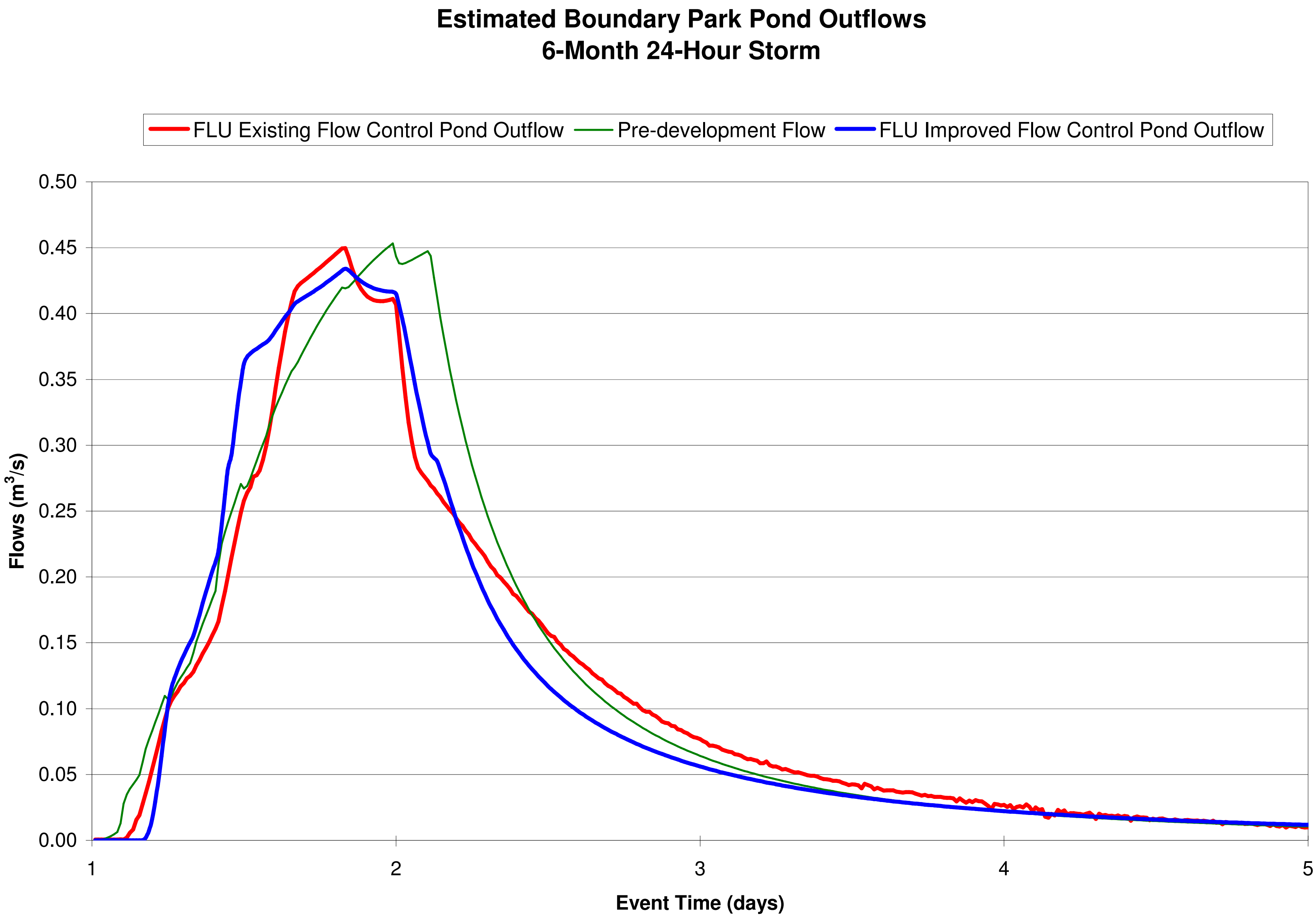


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**Figure D-3**

## Estimated Boundary Park Pond Outflows
## 2-Year 24-Hour Storm

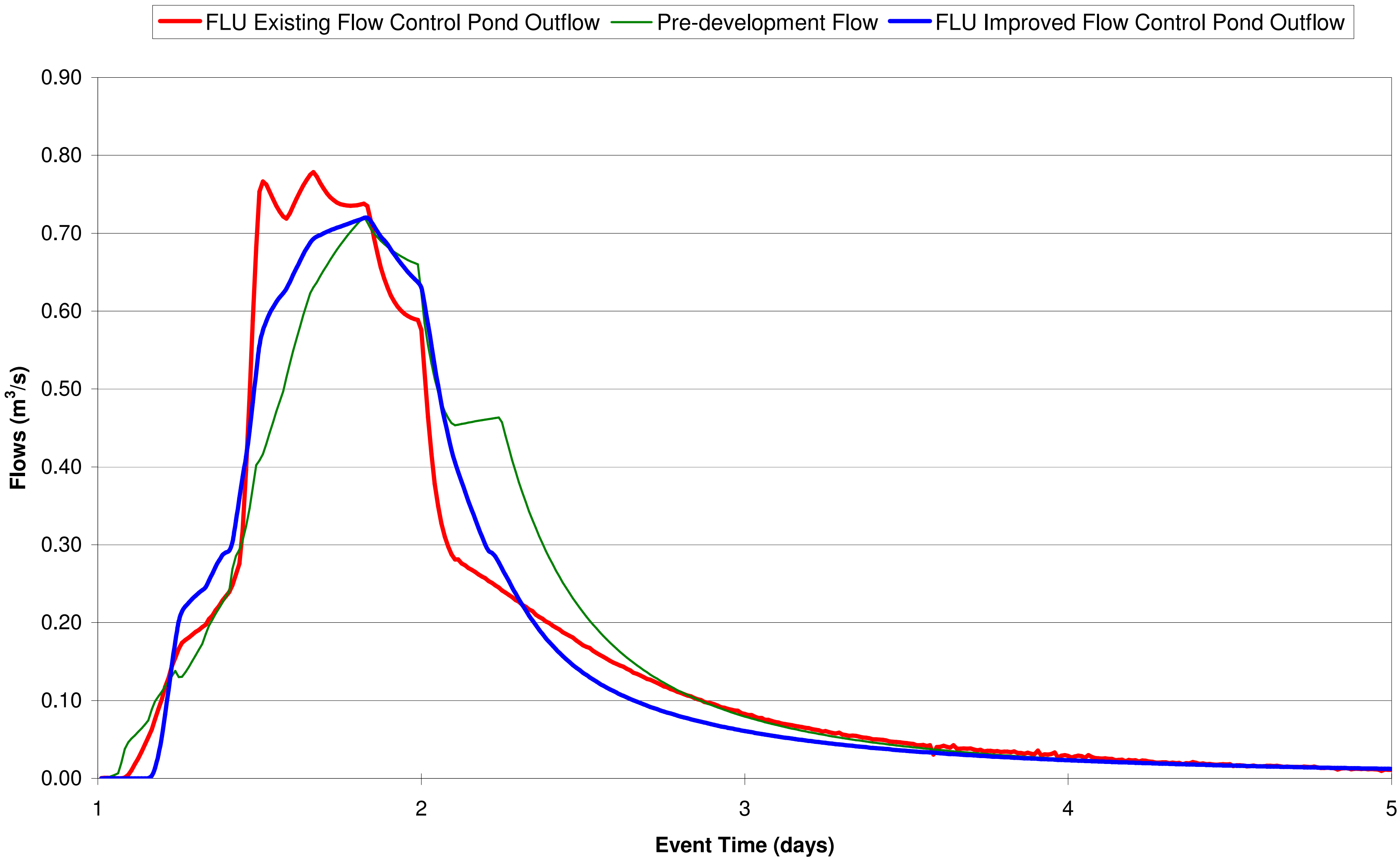


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**Figure D-4**

## Estimated Boundary Park Pond Outflows
## 5-Year 24-Hour Storm

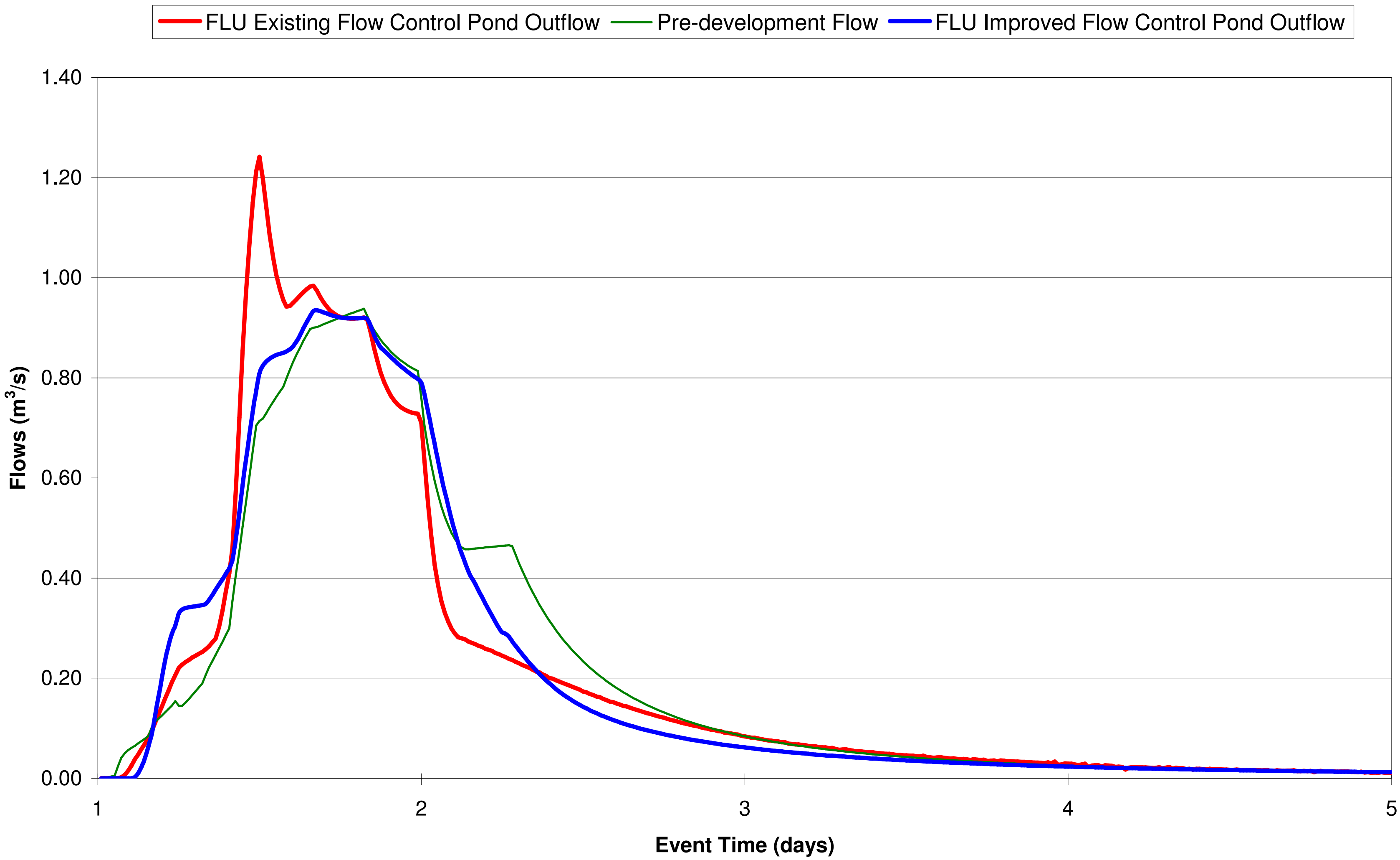


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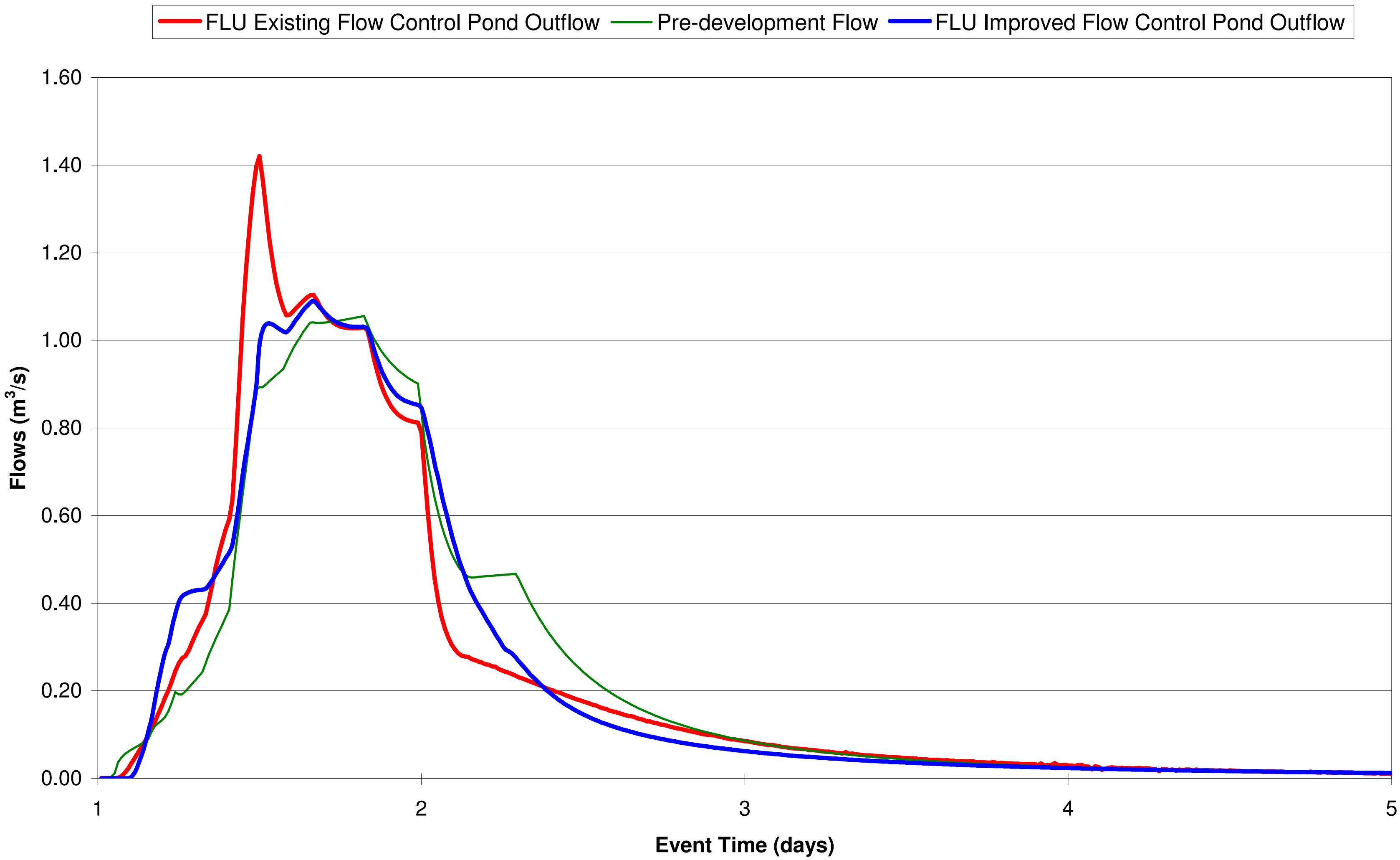
**Figure D-5**

## Estimated Boundary Park Pond Outflows
## 10-Year 24-Hour Storm

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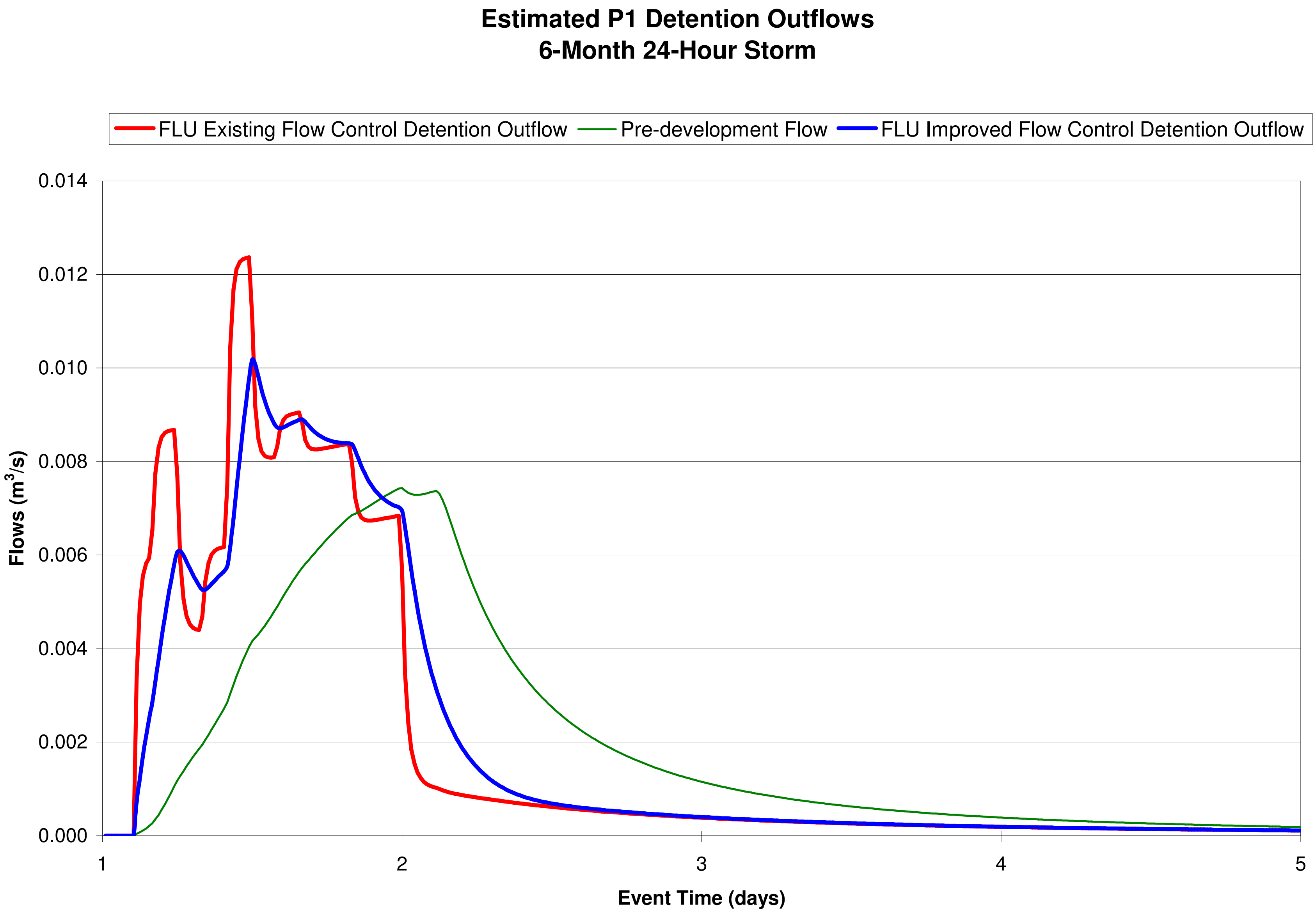


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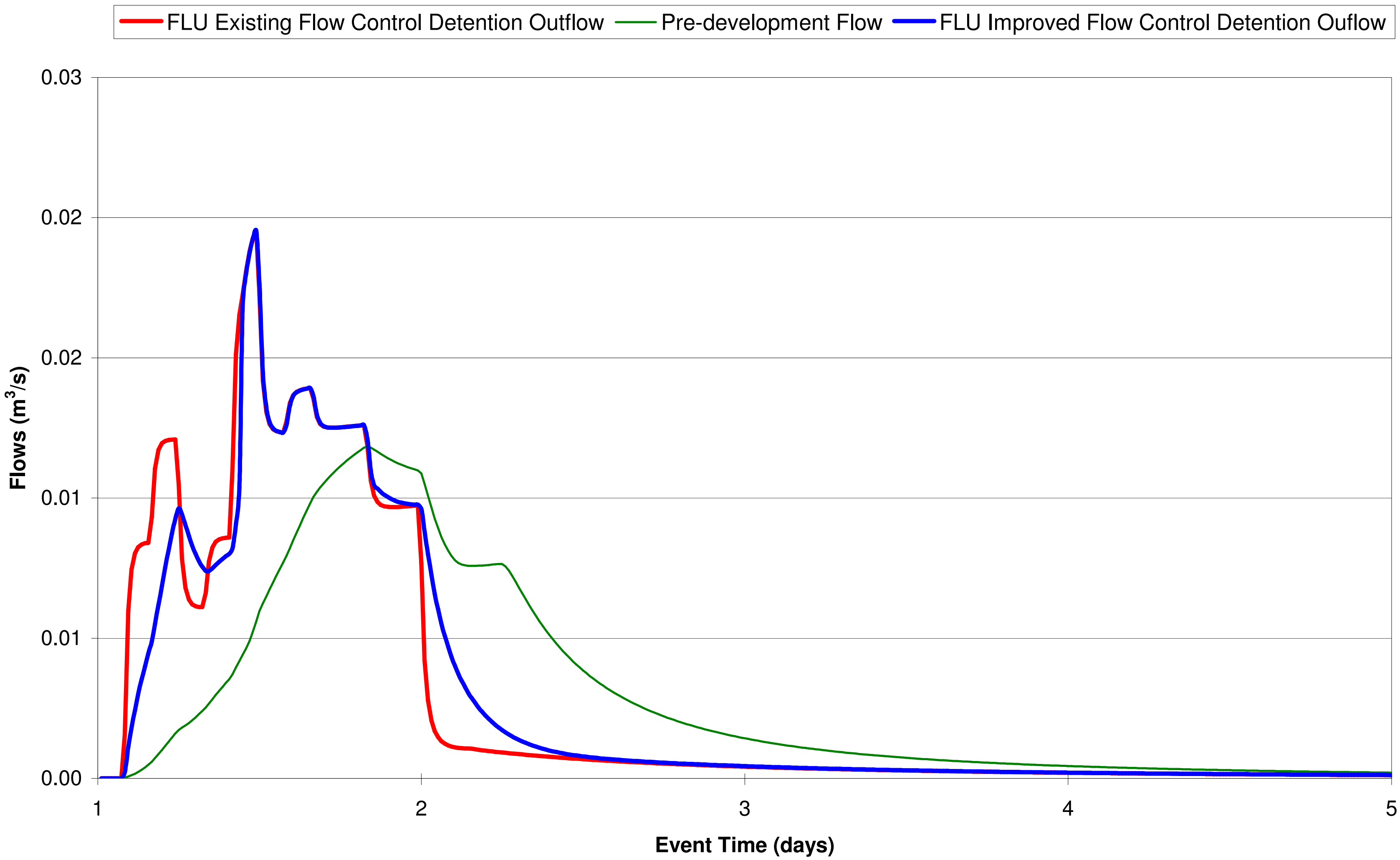
**Figure D-7**

## Estimated P1 Detention Outflows
## 2-Year 24-Hour Storm

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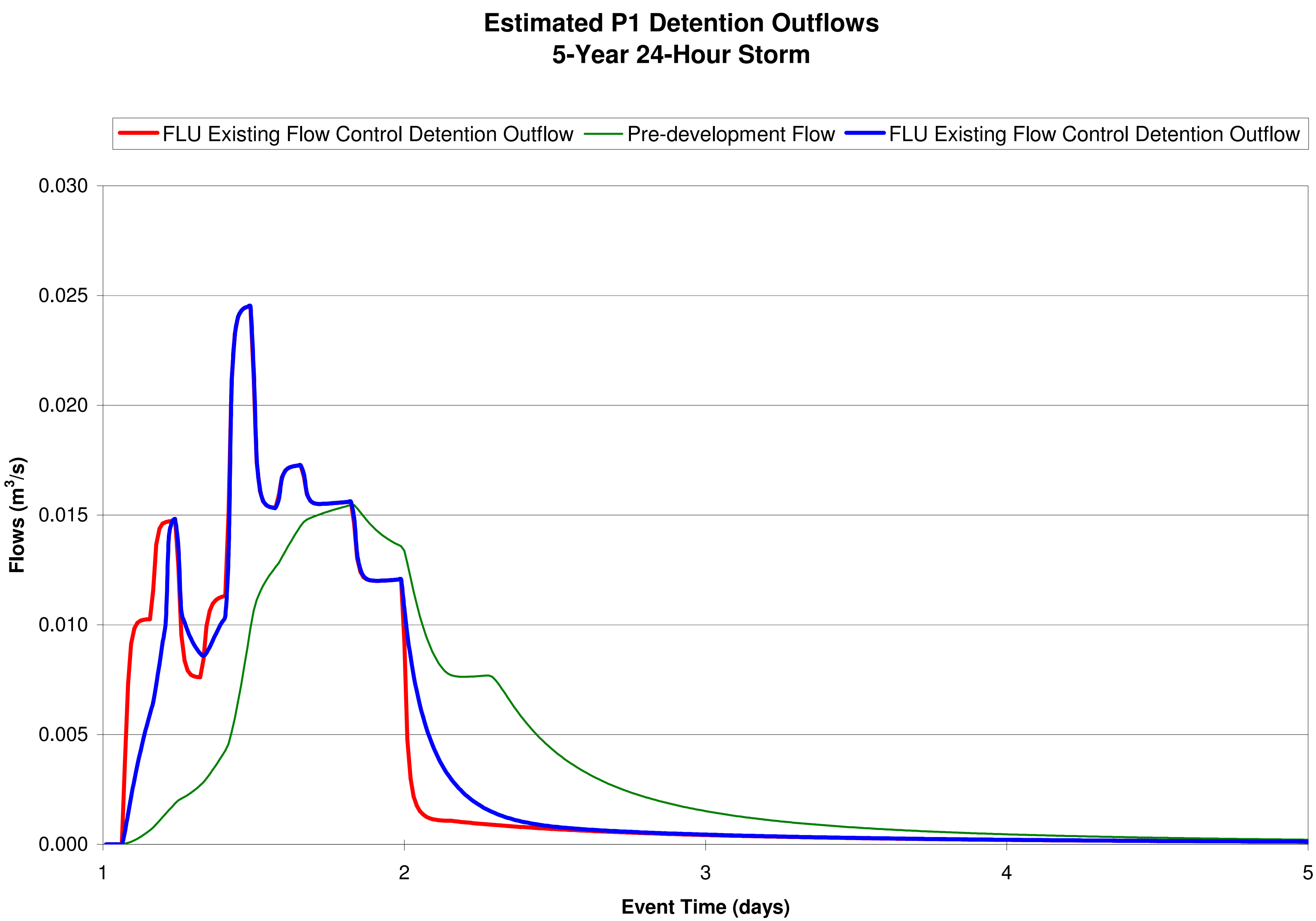


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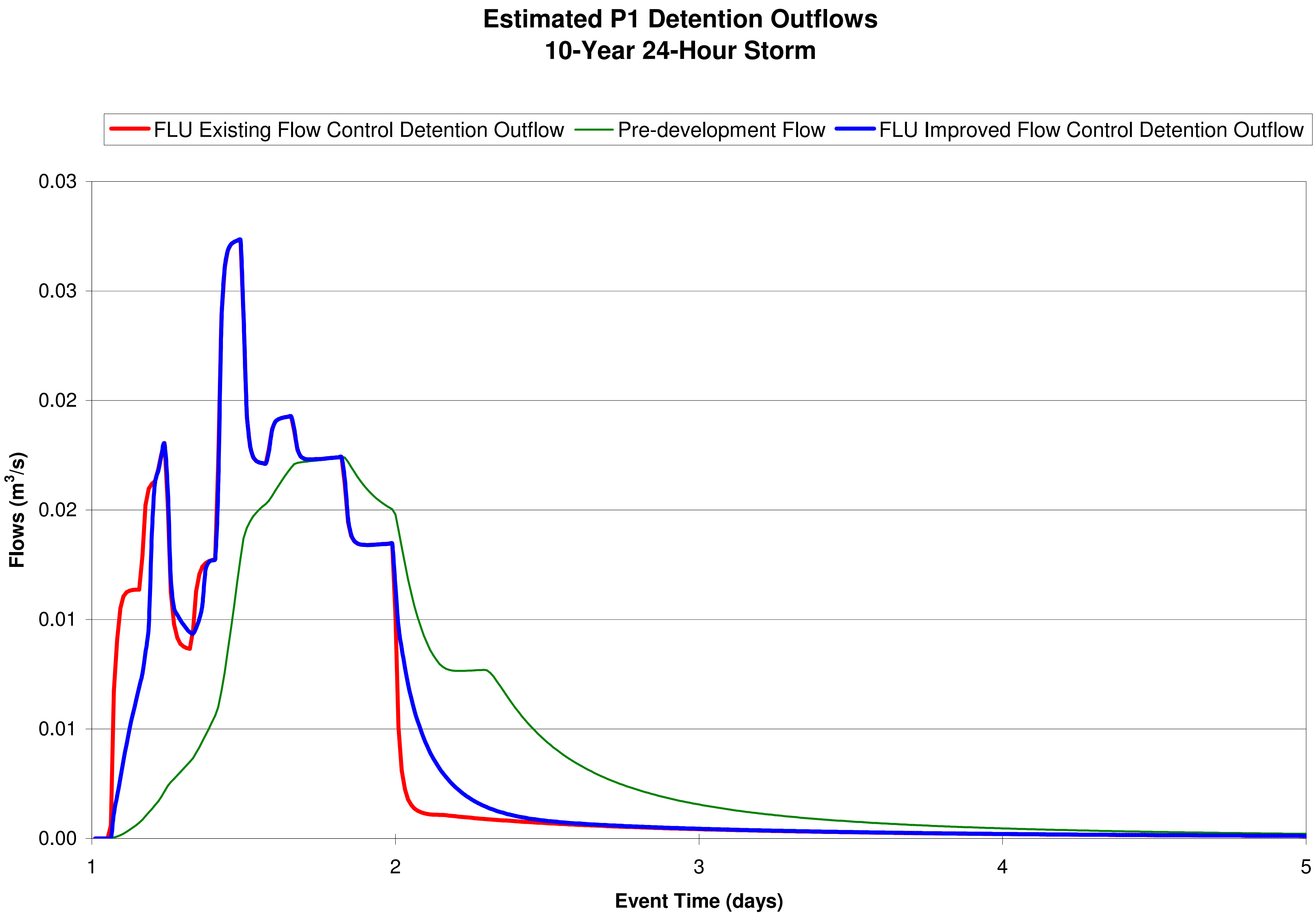


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**Figure D-10**

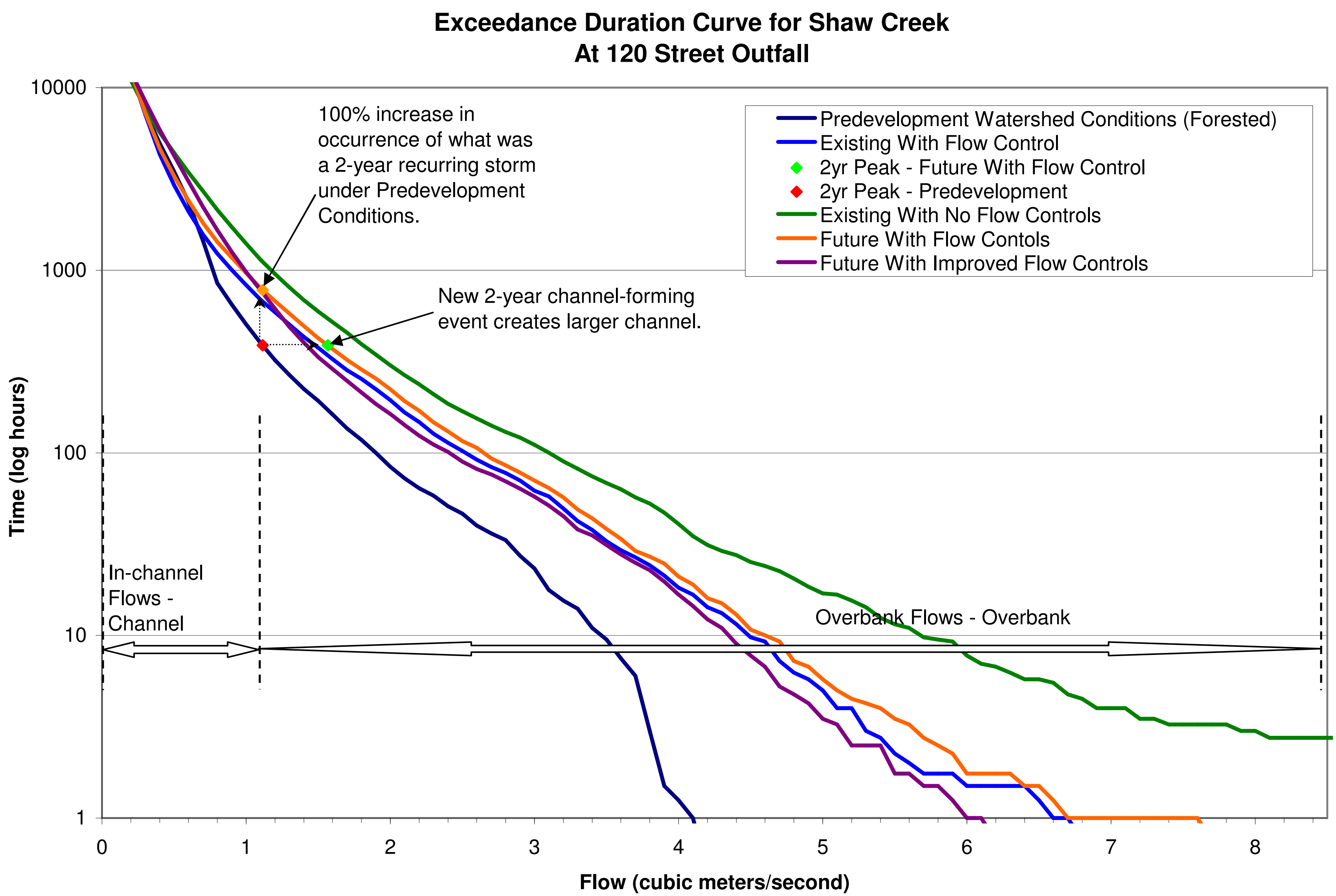


Figure D-11

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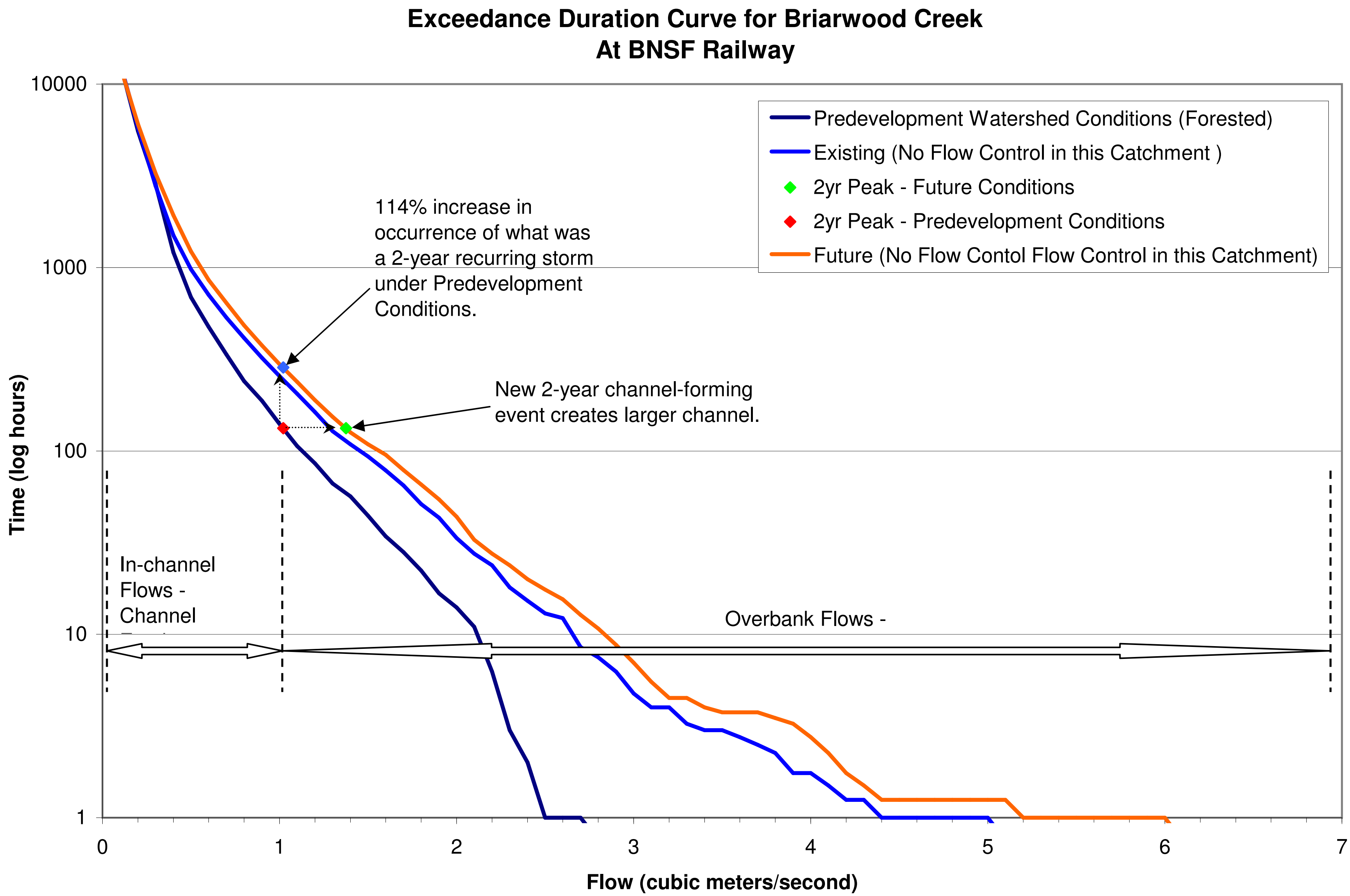


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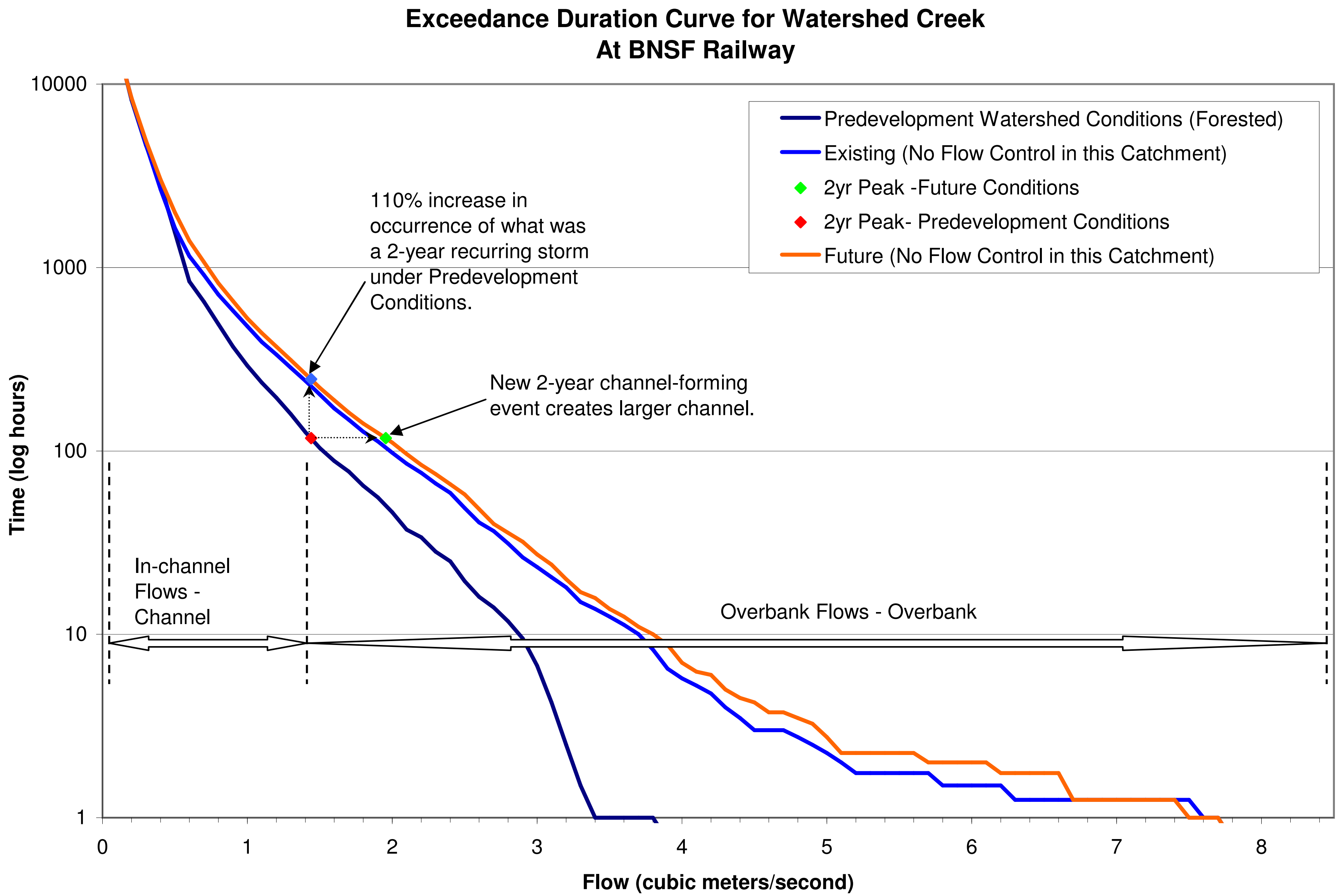


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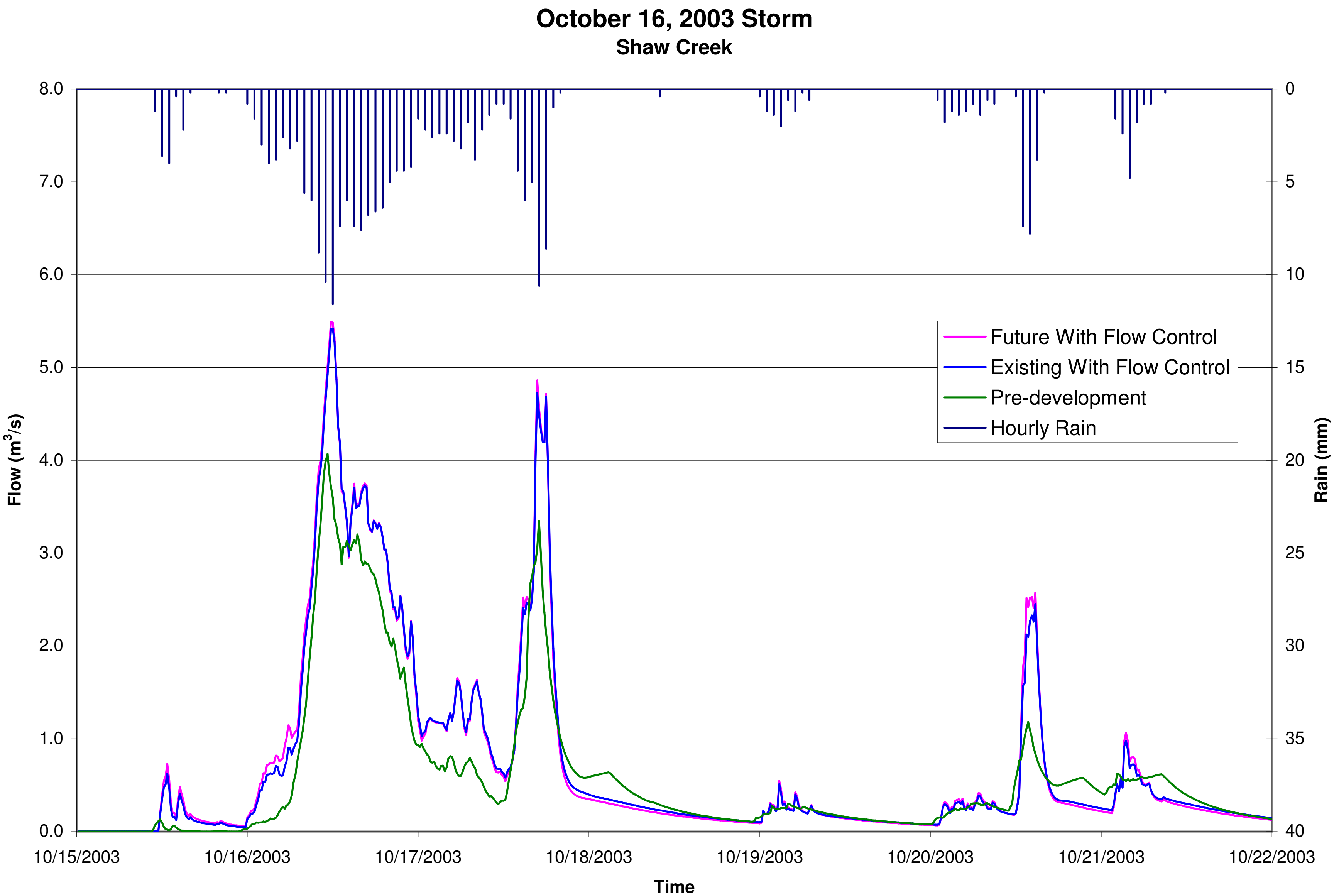


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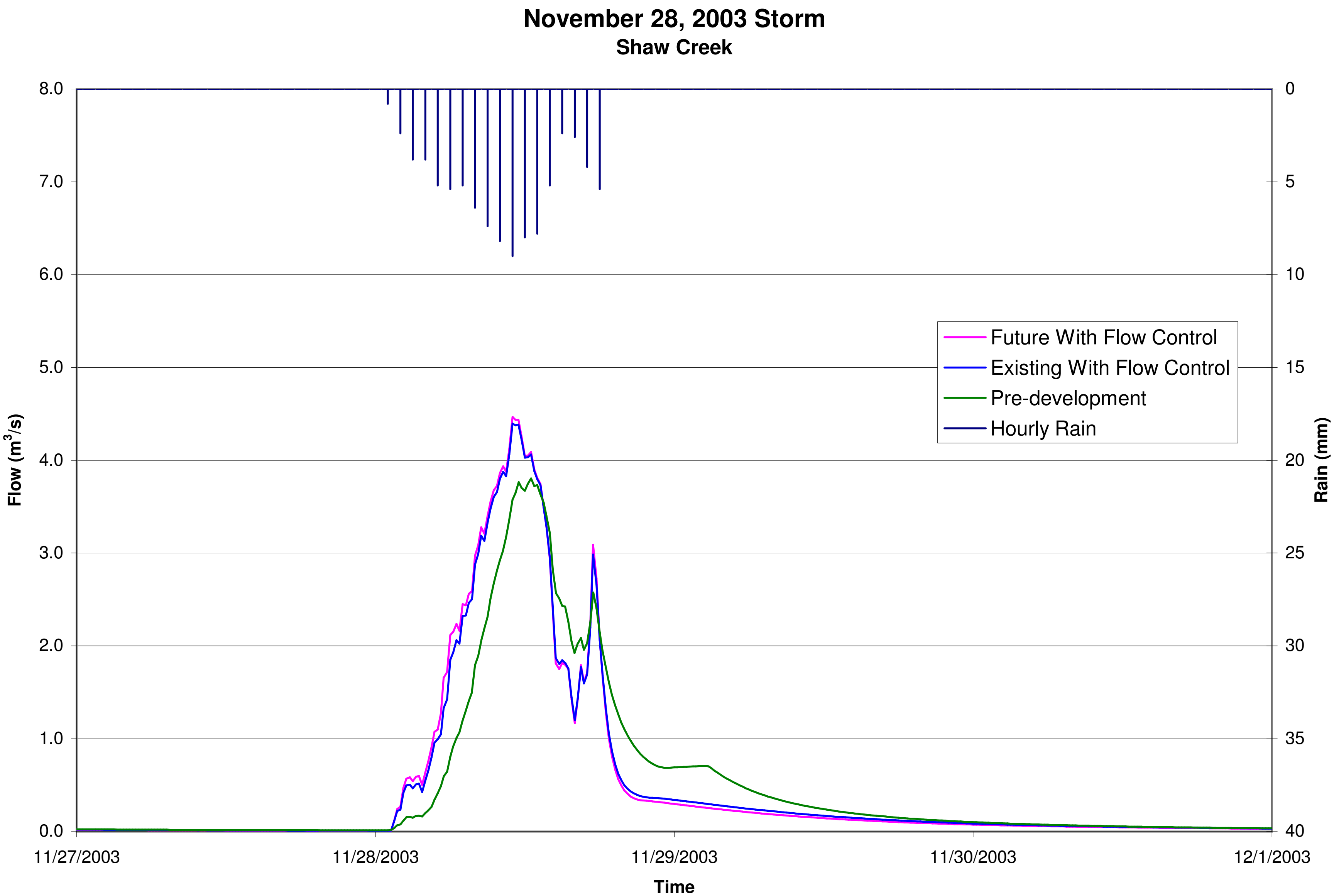


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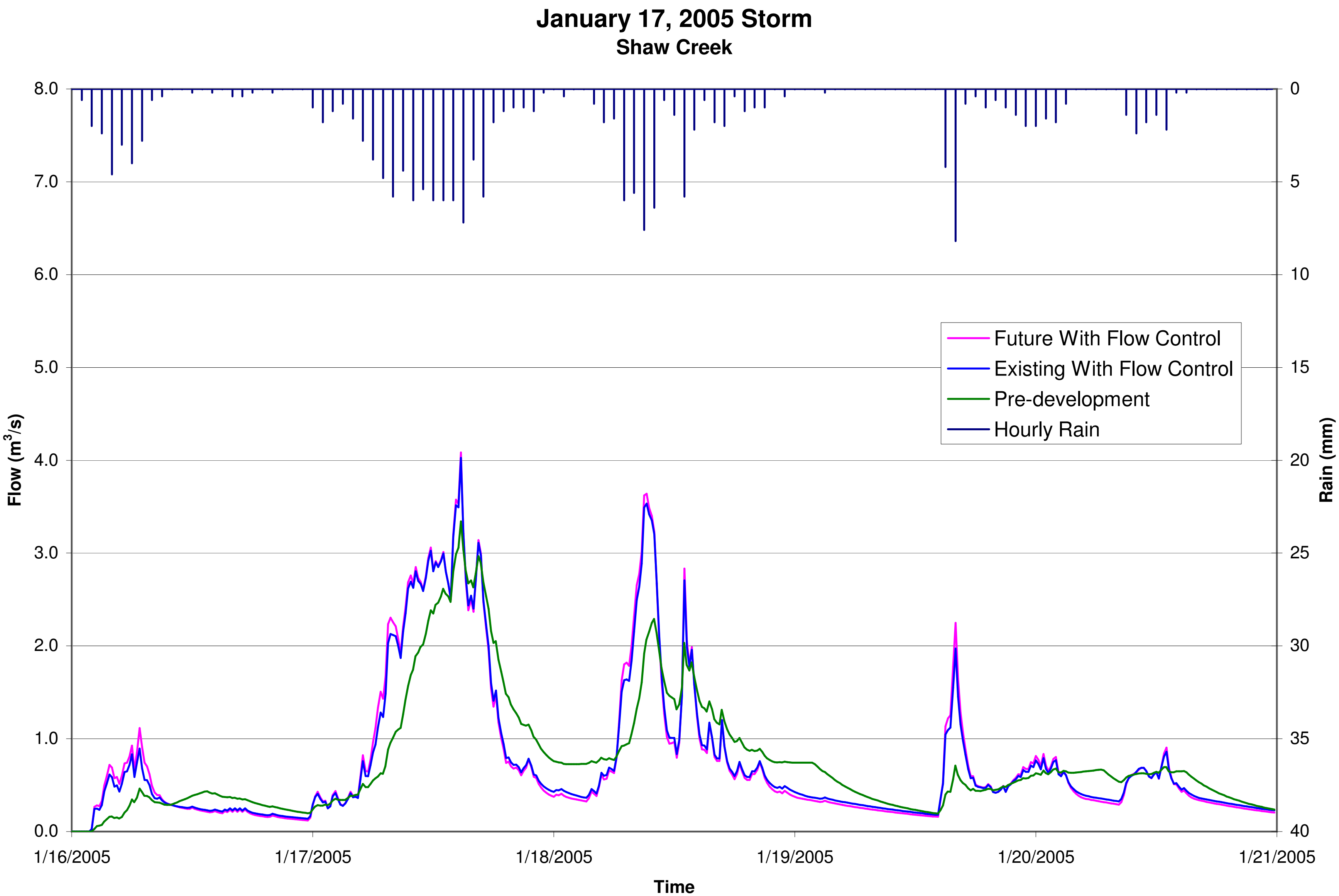
**Figure D-15**

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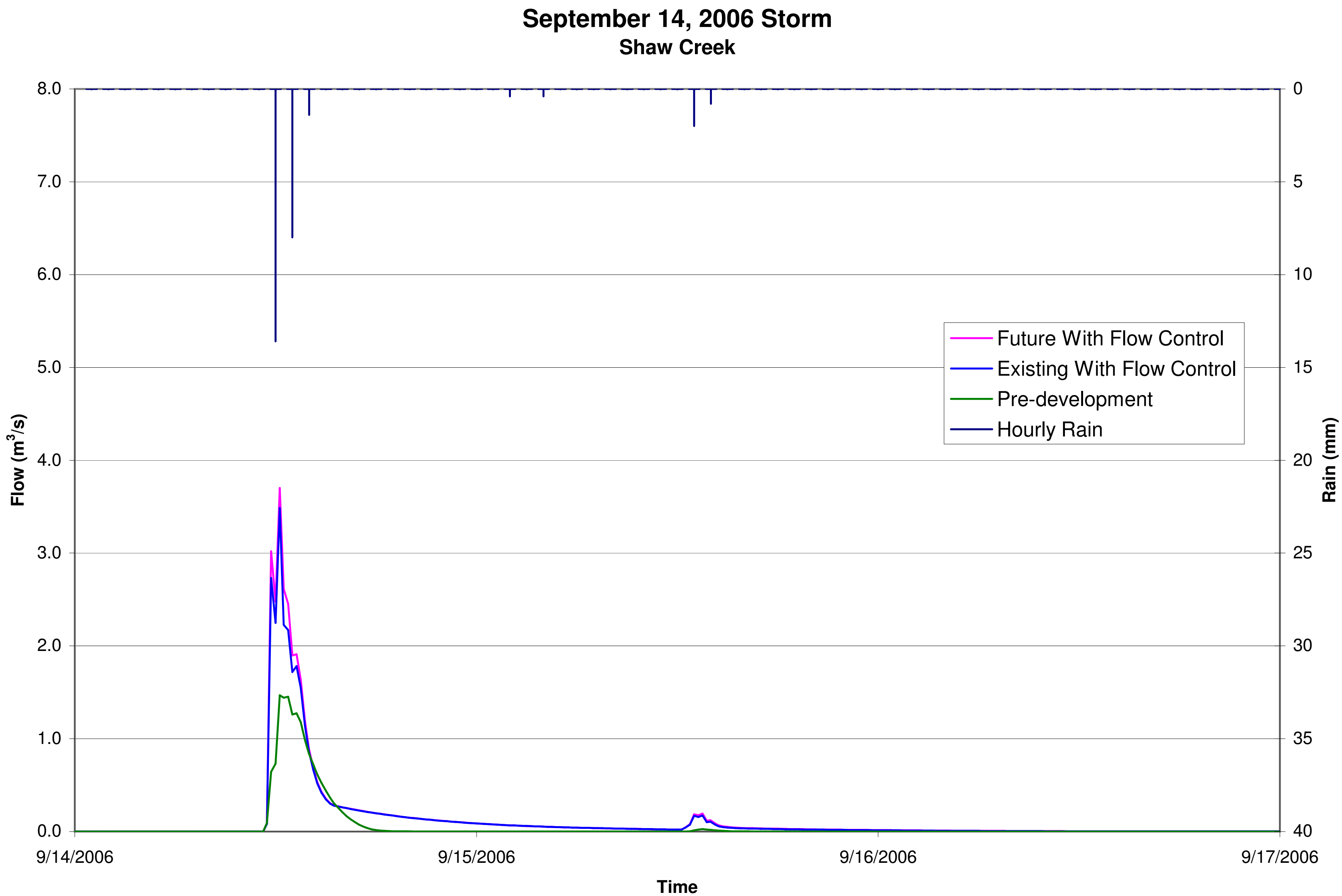


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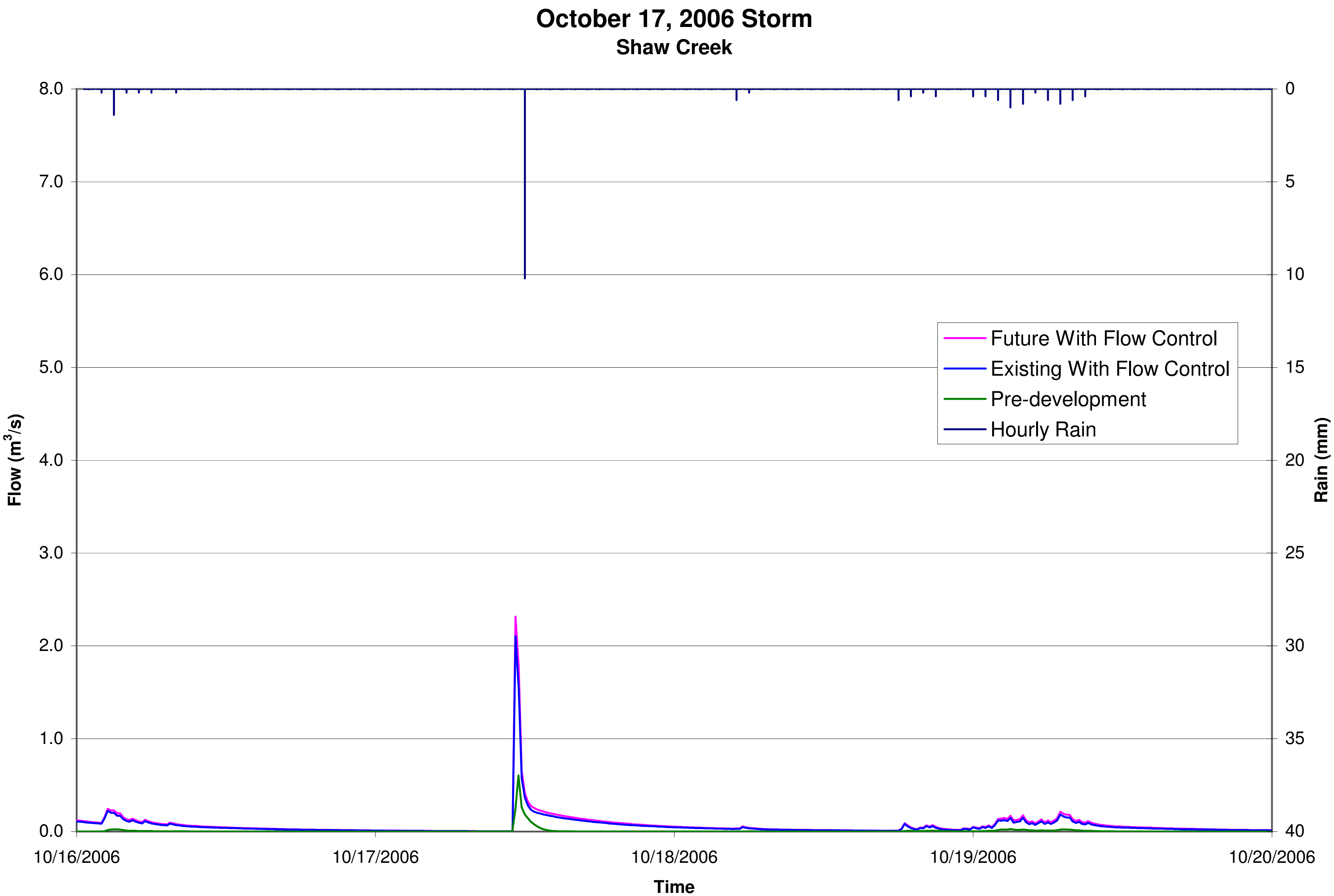


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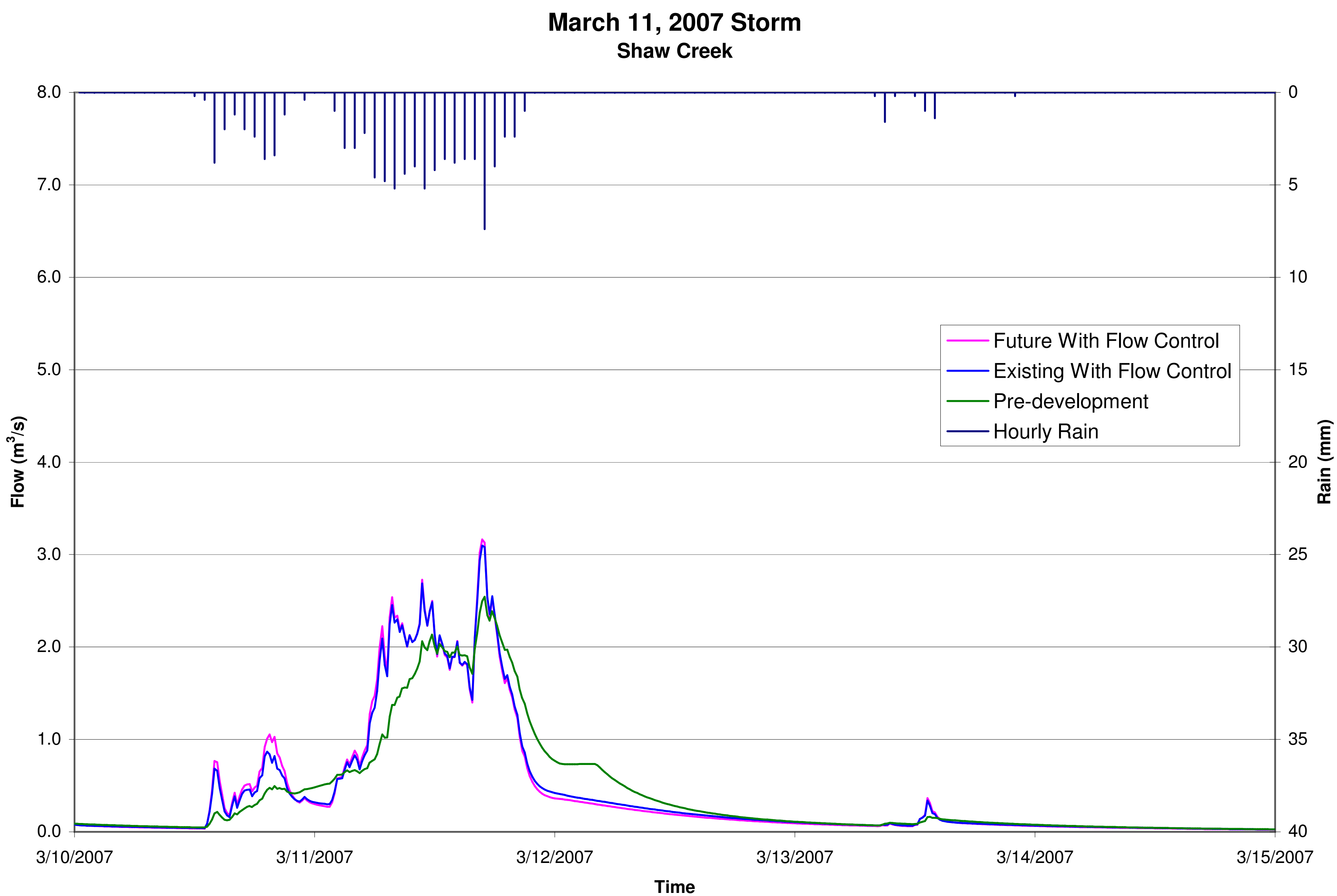


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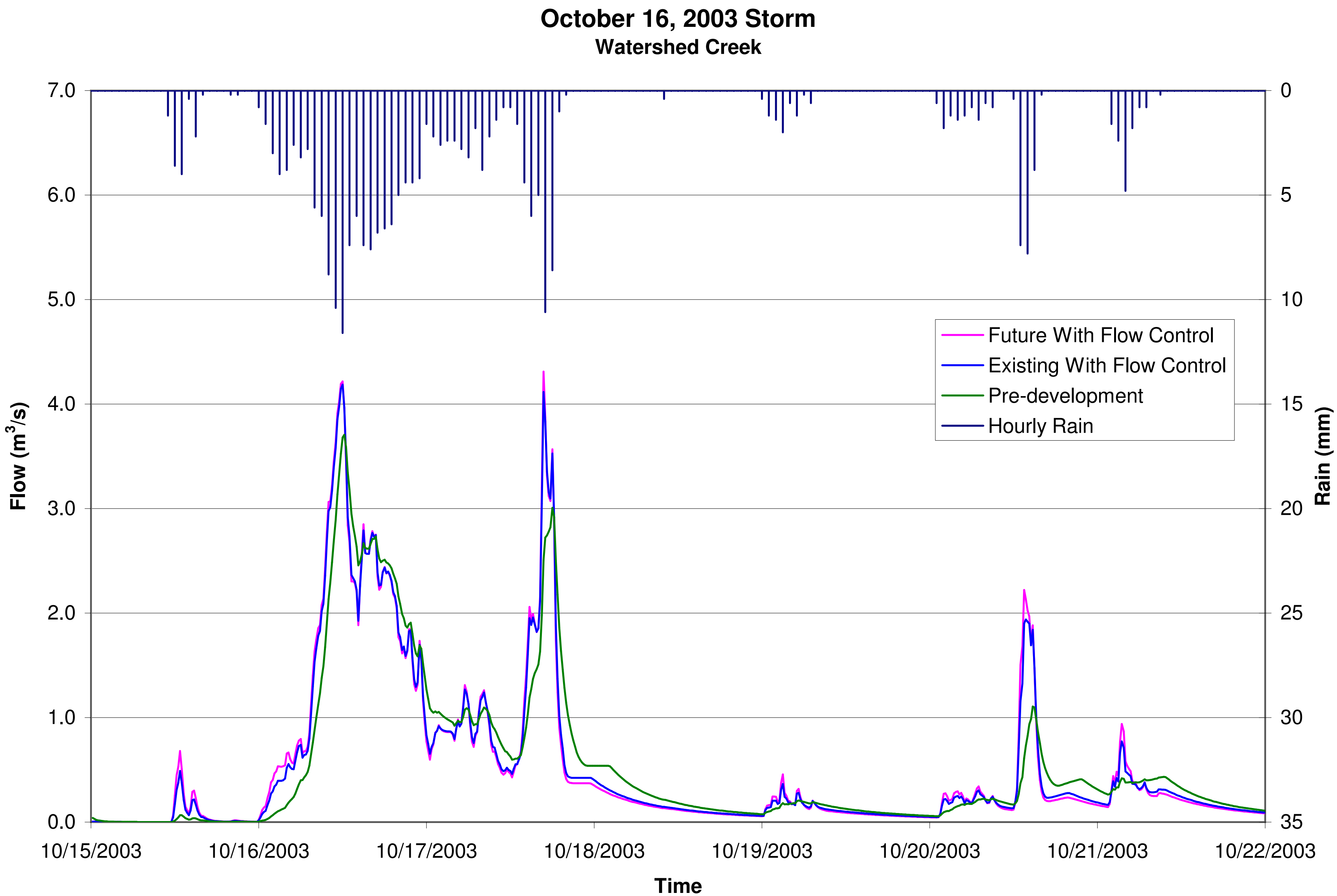


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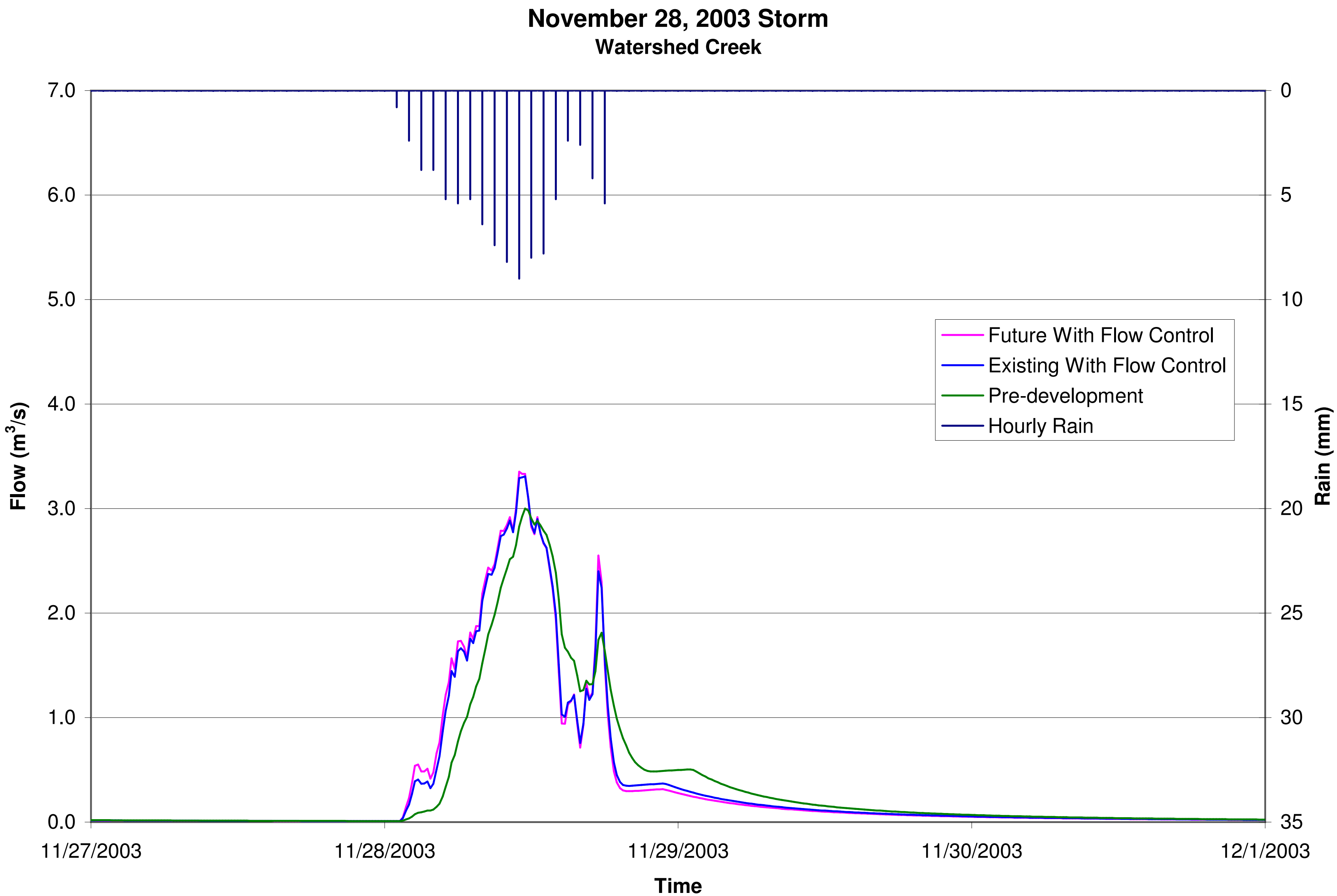


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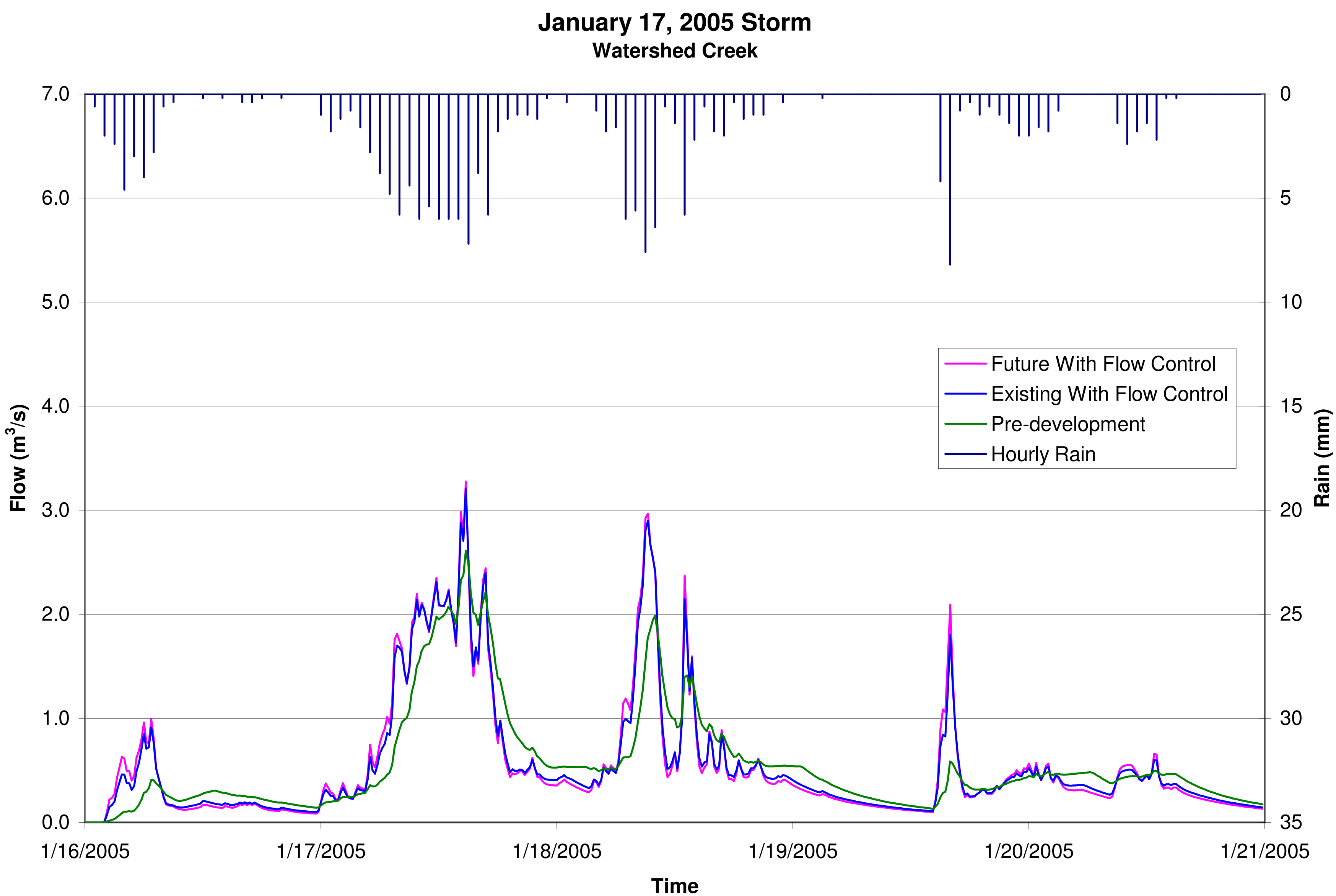


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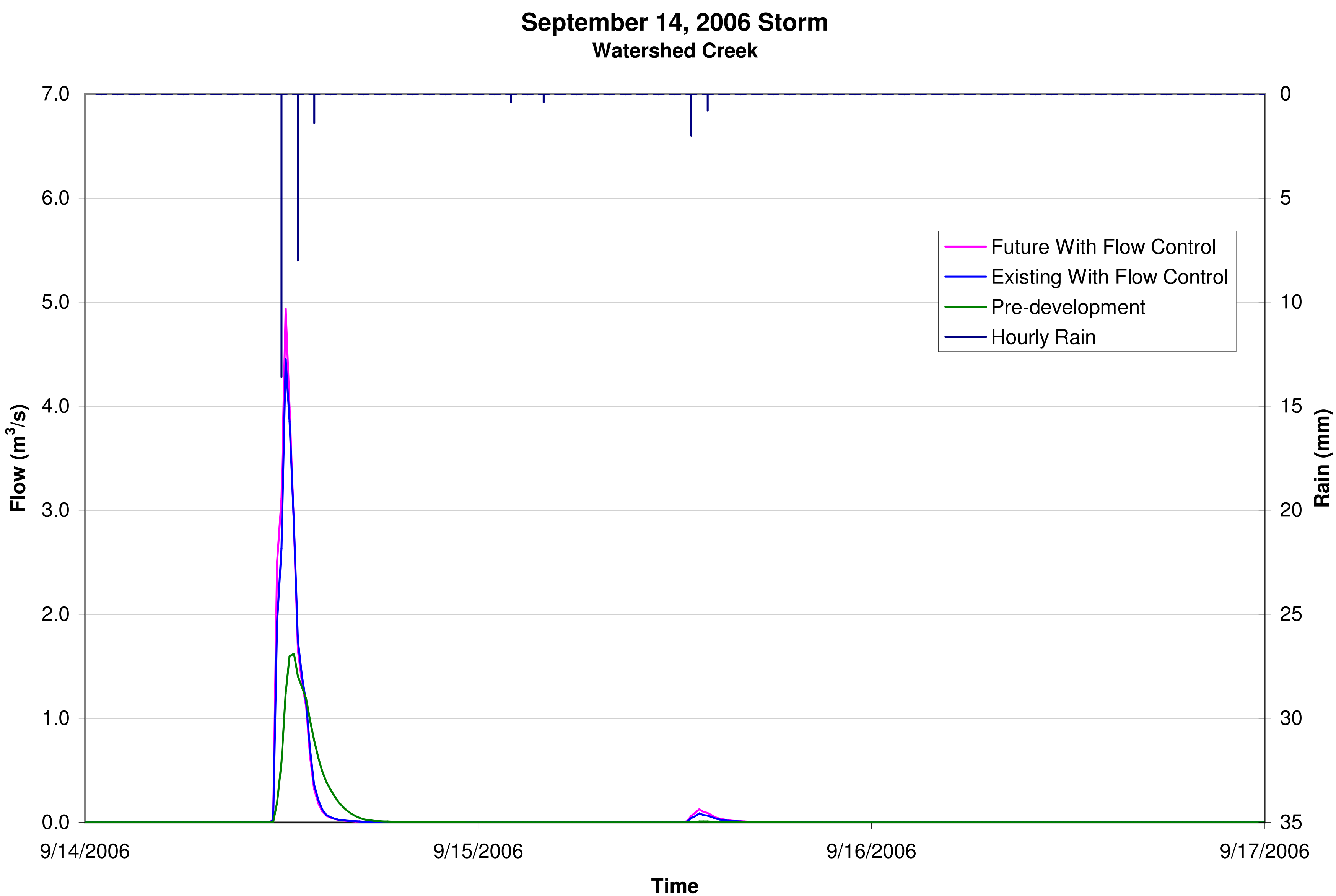


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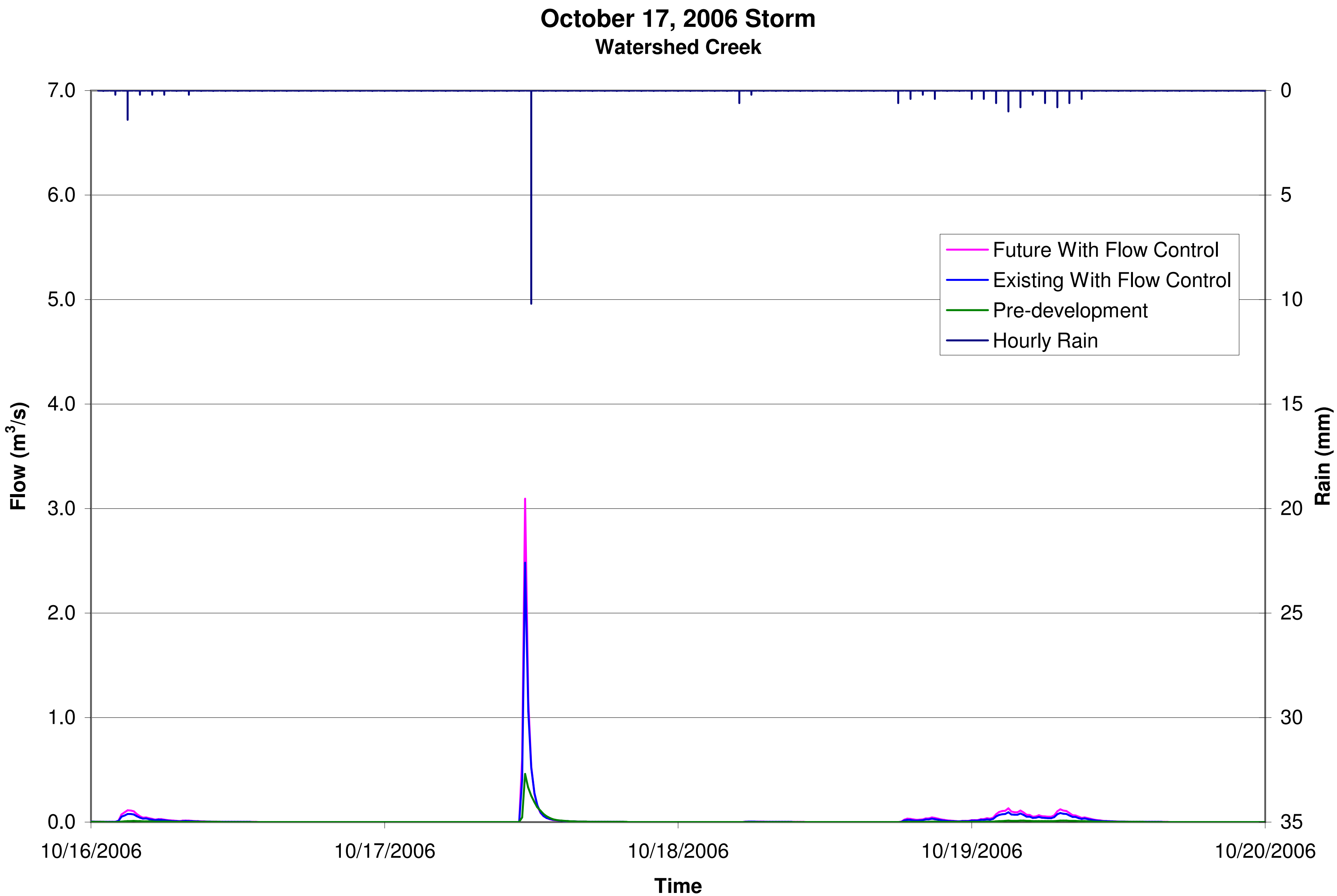


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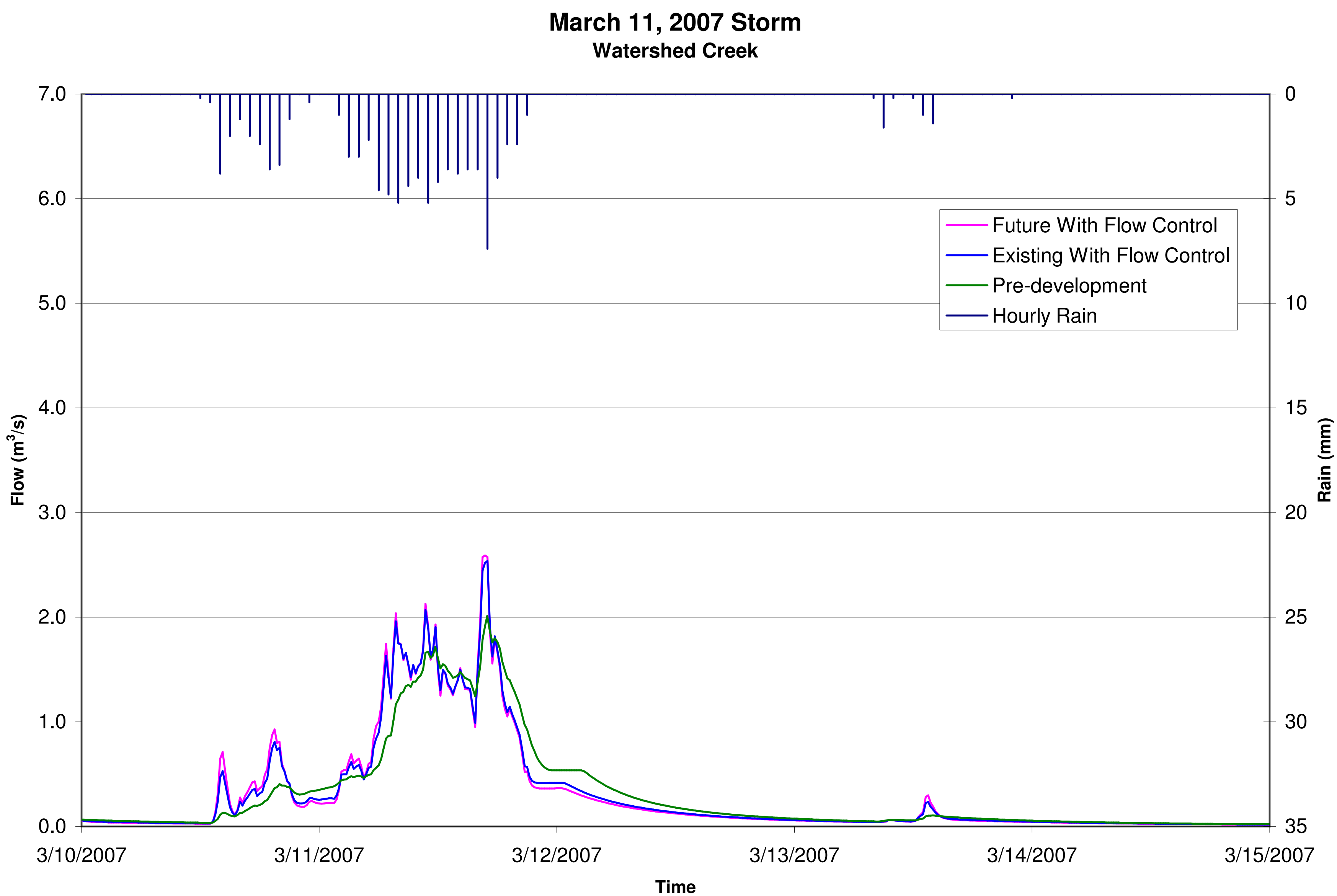


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**Figure D-25**

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## Appendix E

# Measures to Mitigate Environmental Hydrologic Impacts of Development

# Appendix E – Mitigation Measures

## Measures to Mitigate
## Environmental Hydrologic Impacts of Development

## Contents

# Appendix E – Mitigation Measures

## 1. Low Impact Development Practices

### Introduction

Low Impact Development (LID) is a design with nature approach that reduces a development's ecological footprint. LID concepts embodied at the planning stage, often affords more opportunities to reduce the overall negative effects of development and reduce costs. Requirements for expensive traditional stormwater infrastructure may also be reduced as less runoff will be generated.

There are many best management practices (BMPs) commonly used in LID, however it is not always possible to incorporate all of them into a development, and even with adoption of all available LID options, there will still be changes to the hydrologic regime relative to the pre-development conditions and some additional measures or facilities will often be required. LID practices are most effective in mitigating adverse stormwater effects when used in combination with other BMPs, such as constructed source controls and detention. The *Puget Sound Action Team's* LID Technical Guidance Manual[1] is an excellent resource for LID planning and design.

### Reduced Road Widths

Traditional road pavement widths may be larger than they need to be, particularly for streets that are residential access only, and not thoroughfares. Road widths can be narrowed to a minimum that allows necessary traffic flow, but that discourages excess traffic and excess speed, both of which are beneficial in a family- and pedestrian-oriented neighbourhood. Road widths do, however, need to meet the community's needs for utility and emergency vehicle access and these requirements will often determine acceptable minimum road widths.

### Reduced Building Footprints

Building footprints, and impervious roof area, may be reduced without compromising floor area by increasing building height. This also allows greater flexibility to develop layouts that preserve naturally vegetated areas and provide space for infiltration facilities. Some relaxation of building height restrictions may be necessary to allow this type of design.

### Reduced Parking Standards

Reducing the required number of parking spaces for a development reduces the impervious area and encourages pedestrian and public transit-friendly communities. Reducing the required parking spaces also reduces development costs.

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1 Low Impact Development Technical Guidance Manual for Puget Sound, 2005. http://www.psparchives.com/our_work/stormwater/lid.htm

# Appendix E – Mitigation Measures

### Limiting Surface Parking

Limiting surface parking and restricting parking to below building roof areas, also directly reduces the impervious area in a development.

### Pervious Parking Surfaces

Use of pervious paving materials rather than impervious concrete or asphalt can reduce the runoff generated from parking areas. Pervious materials may include pavers, reinforced clean crushed gravel, reinforced turf, or engineered permeable pavements.

**Reinforced Clean Crushed Gravel**

**Pavers**

### Building Compact Communities

A complete and compact development plan preserves more natural watershed features and significantly reduces imperviousness. In some cases, compact communities have up to 75% less roadway pavement per dwelling unit, and parking needs are reduced because local services are more accessible by pedestrians and via public transit.

### Preserving Naturally Significant Features

Preservation of natural areas in a watershed is always an important consideration, which can provide recreational as well as environmental benefits but some natural areas perform special aquatic ecosystem functions and as such are vital to maintaining watershed health. These areas, which include riparian forests, wetlands, floodplains and natural infiltration depressions with highly permeable soils, are particularly important to inventory and protect from alteration.

## 2. Stormwater Source Control Technologies

Stormwater source controls reduce the runoff that is discharged to the stream network by managing the water balance at the site level. Source controls play a key role in achieving Rainwater Management Criteria for volume reduction, water quality treatment, and runoff control and can be very effective at reducing runoff volumes and peak runoff rates from events smaller than the 50% of 2-year storm. Though they do provide some flow-detention benefits for the 2-year storms, source controls have limited ability to reduce peak runoff rates from large storms and must be designed with adequate overflow

# Appendix E – Mitigation Measures

capacity. Additional stormwater infrastructure must be provided to safely convey stormwater offsite for the larger events.

Several standard source control technologies are described below. The *Metro Vancouver Stormwater Source Control Design Guidelines*[2] is an excellent reference for source control BMP design advice.

## Absorbent Landscaping

Natural topsoil is generally permeable. The vegetation on topsoil provides a layer of organic matter which is mixed into the soil by worms and micro-organisms, creating voids, which allow rain water to percolate through, and making the soil more structurally capable of providing storage in the void spaces when saturated.

Standard construction practice is often to strip the existing topsoil, compact or excavate a site surface to the desired grade, and then cover it with a thin layer of imported topsoil. Although lawns and other ornamental landscaping will establish a vegetated surface, both the original surface and subsurface flows and storage capacities have been altered and surface runoff will be increased. Instead of stripping and removing, original topsoil it should be replaced on the site and augmented with organic matter and sand to improve soil structure and increase macropore development.

To increase absorbency, surface soils should have a minimum organic content to facilitate plant growth and a soil depth sufficient to meet the 50% of 2-year rainfall capture target. Increased soil depths also provide retention for runoff from adjacent hard surfaces. Surface vegetation should include herbaceous groundcovers with a thickly matted rooting zone, deciduous trees, or evergreens.

Some maintenance over the long term is required for the absorbent landscape to continue to provide stormwater benefits. Maintenance activities may include replacing soils that have eroded and replanting dead or dying vegetation.

**Absorbent Landscaping**

**Absorbent Landscaping**

2 Metro Vancouver, Stormwater Source Control Design Guidelines, 2005 http://www.gvrd.bc.ca/sewerage/stormwater_reports.htm

# Appendix E – Mitigation Measures

## Surface Infiltration Facilities

Rainfall runoff is stored at or near the surface in a layer of absorbent soil, sand, gravel, or rock, and/or on the ground surface in a ponding area. The stored runoff that infiltrates into the soil becomes interflow and augments groundwater in the sub-surface.

Surface infiltration facilities can look like normal vegetated swales or ponds, and can be aesthetically landscaped and integrated into the design of open spaces. They include bioretention facilities and rain gardens. Both surface and sub-surface infiltration facilities can be effective at the lot level, as well as at the neighbourhood level, where individual lot sizes or layouts don't support on-lot facilities or where more permeable soils or groundwater recharge areas are located off-site. Surface infiltration facilities can, depending on their design, provide some level of water quality treatment as well.

Surface infiltration can be combined with detention, where the detention release rate allows sufficient time for infiltration through the pond. Infiltration facilities are highly dependent on the hydrologic properties of the sub-surface soils.

Surface infiltration can also be promoted by the used of permeable pavers or other pervious surfacing materials.

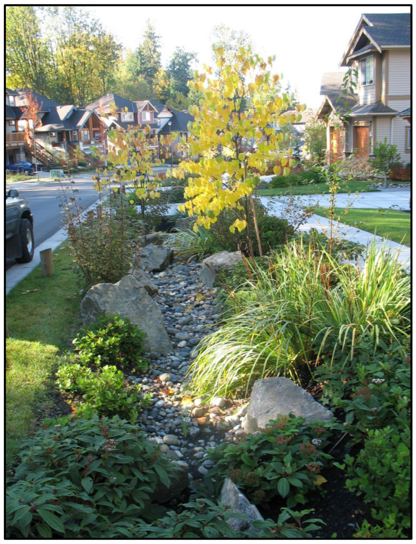
**Surface Infiltration Swale**

## Bio-Retention Facilities

If infiltration rates are low, such as is likely in clay and till soils, bio-retention facilities can be designed to store the volume reduction target in soil and rock trench voids and infiltrate it slowly over time.

Where applicable, a retention facility may also be designed as a baseflow augmentation facility that retains the design capture volume in a tank or pond and releases it at baseflow rates. These rates are very low, and are based on measured summer baseflows in a watercourse divided by the contributing watershed area, and then applied to the area of the site contributing runoff. Baseflow augmentation facilities discharge the capture volume to the downstream stormwater system or watercourse at a maximum of the determined baseflow rates. Any volumes above the capture volume must be allowed to bypass the baseflow augmentation facility.

# Appendix E – Mitigation Measures



**Bio-Retention Swale**

**Bio-Retention Swale**

## Sub-surface Infiltration Facilities

A similar design process is used for sub-surface infiltration as for surface infiltration facilities. The main advantage of sub-surface facilities is that they often have vertical walls and do not require as much dedicated ground area, allowing them to be located beneath paved impervious areas.

Sub-surface facilities must be located at least 0.5 m above the level of the water table so that they can discharge through the sides and bottom of the structure and will not merely store infiltrated groundwater. Generally, the deeper an infiltration facility is located, the less-effective it will be. Subsurface infiltration facilities can be as simple as a trench filled with clean, free-draining rock that is protected from soil by a permeable membrane. There are numerous products available commercially for subsurface infiltration as well.

**Sub-Surface Infiltration**

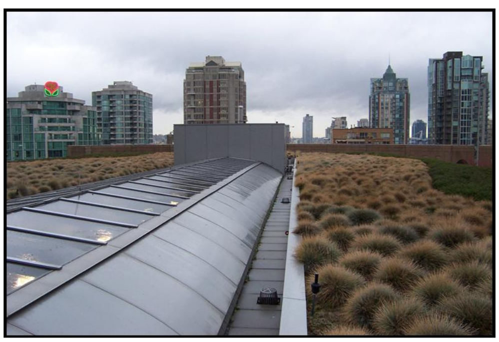
# Appendix E – Mitigation Measures

## Green Roofs

Installing a green roof rather than a conventional impervious roof can significantly reduce the volume and rate of runoff from a building lot particularly for the smaller, more frequent storm events.

A green roof is essentially a roof with a layer of absorbent soil and vegetation on top of a drainage collection layer or system. Rainfall is absorbed or stored by the soil and vegetation for later evapotranspiration. The green roof has a limited storage capacity, so any excess rainfall percolates through and is collected by a drainage system. The excess rainfall is then routed to the ground for detention and conveyance.

Green roofs are more expensive to build as they have structural costs as well as landscaping costs and do require maintenance to ensure their ongoing functionality. However, when compared with land costs for alternate facilities in high density urban areas, the costs for a green roof may be favourable. Green roofs also have other benefits, in addition to stormwater benefits, that can include heating or cooling cost savings by insulating the building, aesthetic benefits, air quality benefits, and reduced solar gain that decreases the urban heat island effect. Green roofs should only be designed and constructed by qualified professionals as structural engineering, building envelope and landscape design as well as stormwater engineering are all critical components. Green roofs are the preferable source control in areas where ground surface controls are not possible. For more information on green roofs readers are referred to the *Green Roofs for Healthy Cities* website.



**Green Roof**

**Green Roof**

## Rainwater Re-use

Rainwater re-use is commonly afforded by residential rain barrels which are effectively retention facilities for roof runoff. Limitations of rain barrels are that rainfall is seldom a reliable source for water during the dryer seasons and rain barrels are often not large enough to store the 50% of 2-year capture target. The most significant reductions in runoff volume from re-use are achieved by capturing and re-using rainwater for indoor grey-water uses, or for commercial and industrial applications with high water consumption rates or where water supplies are limited. Recycling rainwater reduces demands from surface waters and reservoirs and can reduce supply infrastructure costs. Rainwater re-use can also be combined with infiltration facilities.

# Appendix E – Mitigation Measures


**Re-Use Tank**

**Re-Use Rain Barrel**

## Water Quality Best Management Practices

Changes in land use, loss of natural biofiltration capacity, increases in impervious area, and pollutant laden runoff associated with urban development can contribute to reduced water quality which impacts fish and fish habitat. BMPs designed to capture and treat runoff need to be incorporated into RWMPs.

Water Quality BMPs are physical, structural or management practices that reduce or prevent water quality degradation. Many of these are the same as, or similar to those used for runoff volume reduction and rate control and but have ancillary benefits for water quality. Source control remains the key means of reducing introduction of toxic and hazardous materials or organic and inorganic contaminants, originating from land and water use or as a result of commercial or industrial spills. Without source control, runoff water quality is limited by the effectiveness of treatment technology.

Treatment controls are point-source water quality management measures. They are generally constructed facilities and are often individual installations incorporated into the stormwater management infrastructure. They should be designed on a site-specific basis, after examining all alternative treatment technologies, and selecting the best available options based on cost and effectiveness. These controls should be designed and constructed by appropriately qualified environmental professionals.

## Water Quality Best Practical Technologies

Several technologies have the ability to provide both water quality benefits and runoff control. Water quality benefits are derived from contaminant removal mechanisms that use biological and physical processes. Runoff control is accomplished by improving stormwater detention and retention which reduces peak runoff discharge rates and volumes.

## Biofilters

Biofilters are vegetated filter strips, swales and rain gardens that remove deleterious substances, notably particulate contaminants, though some combination of physical (e.g.: adsorption) and biological

# Appendix E – Mitigation Measures

(biodegradation) removal mechanisms. Biofilter technology is suitable for sheet flow runoff, typical of large linear impervious developments like roadways and parking lots.

## Urban Forests and Leave Strips

Depending on the extent of tree canopy and ground cover retained, runoff reduction and pollutant removal can be achieved by maintaining natural well functioning urban forested areas. The contaminant removal processes forests and natural vegetation provide include: filtration, adsorption, absorption, and biological uptake and conversion by plant life. Urban forests also provide habitat refuges for many species whose habitats have been fragmented while riparian leave strips along watercourses, provide critical fish and wildlife habitat.

## Infiltration Systems

Infiltration systems generally require pre-treatment for water quality to prevent clogging and binding-off of the permeable materials and contamination of underlying aquifers. Physical removal of deleterious substances by filtration and adsorption, as well as conversion of soluble pollutants by bacteria, also occurs within the infiltrating soils.

## Constructed Wetlands

Physical, biological and chemical processes combine in wetlands to remove contaminants and either surface or subsurface flow wetlands can be constructed specifically to treat stormwater runoff. Constructed wetlands also offer retention benefits and can create preferred habitats for aquatic and terrestrial wildlife species. **The use of existing natural wetlands to treat stormwater however is not an acceptable practice**.

**Small Wetland**

**Wetland**

## Wet Detention Ponds

Permanent wet ponds remove pollutants and other deleterious substances through physical processes such as sedimentation, filtration, absorption and adsorption and through biological mechanisms such as: uptake and conversion by plants, and microbial degradation. Wet ponds can also detain flows thereby contributing to rate control and volume reduction objectives. General design parameters need

# Appendix E – Mitigation Measures

to include: vegetation types (floating, emergent and submergent vegetation), water depth and ponding area, and will often require consideration of detailed pond specific operational parameters.

**Wet Detention Pond**

**Wet Detention Pond**

## Oil and Grit Separators

Oil and grit separators are suitable for spill control and removal of floatable petroleum-based contaminants as well as coarse grit and sediment from small areas, such as gas stations, automotive service areas and parking lots. Oil and grit separators have limited application in large-scale stormwater runoff applications, and should be limited to small area generation sites.

**Oil Grit Separator**

**Oil Grit Separator**

## Construction Best Practices

Construction Best Practices for instream stormwater management works include timing of the works to minimize impacts. Timing windows should be adhered to in order to minimize impacts to fish and wildlife and specifically to avoid sensitive periods for certain life history stages of fish (e.g.; adult spawning, egg and alevin intergravel incubation). Where information is available on critical life history stages and timing for any identified Species at Risk, these times should also be avoided. Clearing should only be undertaken immediately in advance of work, and only during vegetation clearing timing windows, where these have been identified for protection of nesting birds. To the extent possible, work should be restricted to cells and undertaken in a systematic manner to limit the area disturbed at any given time. Works should only be undertaken during favourable weather conditions and low water conditions.

# Appendix E – Mitigation Measures

Measures must be taken to prevent the release, from any work site, of silt, sediment, sediment-laden water, raw concrete, concrete leachate, or any other *deleterious substance* into any ditch, watercourse, stream, or storm sewer system. The work area should be isolated from flowing water as much as possible and diversions around the site should be provided for overland flow paths. Ensuring that all equipment used on-site is in good working order, and having a ready spill containment kit and staff trained in its use, are also critical measures.

For further information on managing erosion and sediment discharges during construction, see the Erosion and Sediment Control section of the *Land Development Guidelines and the Standards and Best Practices for Instream Works*.[3]

## 3. Stormwater Detention Systems

The rainwater detention objective is to limit the post-development runoff to the pre-development rate, volume, and approximate shape of the hydrograph for the 50% MAR, and 2-year/24-hour storm events and to maintain, as closely as possible, the natural pre-development flow pattern in the receiving watercourse.

These detention levels have been adopted to address increases in impervious areas in developments and the environmental impacts (e.g. stream erosion, sedimentation; loss of riparian habitat, changes in stream morphology, etc.) that are occurring due to the more frequent, smaller storm events being rapidly conveyed off hard surfaces into fish bearing waters.

## 4. Infiltration Systems

Stormwater infiltration systems can provide many benefits to urban streams. Infiltration systems can retain runoff, recharge groundwater and control peak flows. The soil, through which the stormwater runoff passes, also acts as a filter removing a large percentage of the common pollutants normally discharged to the stream or creek. Infiltration can recharge local groundwater which in turn feeds smaller streams and creeks through seepage. Groundwater which is slowly discharged back into streams and can constitute all or part of a stream's baseflow. This baseflow can be critical for fish and fish habitat during extended periods of little or no precipitation and runoff. It maintains preferred spawning conditions for several salmon species which key on groundwater seepage areas for spawning and egg incubation.

In areas with well-draining soils, stormwater runoff from a site can be collected and discharged into an infiltration system where there are no conventional stormwater removal systems, or infrastructure, which reduces the costs of providing offsite conveyance.

[3] BC Ministry of Water, Land and Air Protection's *Standards and Best Practices for Instream Works* (draft March 2004) http://wlapwww.gov.bc.ca/sry/iswstdsbpsmarch2004.pdf.

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## Appendix F

# Capital Cost Estimates

**Appendix F: Capital Cost Estimates - Environmental**

| | Item | Costs[1] | Quantity | Unit Cost | Comment |
|---|---|---|---|---|---|
| 9 | High flow pipe to E. Oliver Bypass | | | | |
| | 900mm dia culvert pipe jacked | $176,400 | 30 m | $3,500 | per m supply and install cost |
| | Ditch creation (2 sq.m. xs area) | $23,100 | 250 m | $55 | per m includes clearing for the ditch |
| | riprap spillway / sidechannel weir | $16,800 | 1 ea | $10,000 | assume 2 days of machine time and 25 m3 of riprap |
| | Subtotal | **$220,000** | | | |
| 14 | Highway 10 WQ treatment wetland (1m deep) | **$100,000** | 600 m2 | $95 | per m2 assumes $35/m2 for soil removal, $50/m2 reveg, $10/m2 other |
| 15 | Watershed Creek WQ treatment wetland (1m deep) | | | | |
| | Berm (1.3m high, 2m wide crest, 3:1 slopes) | $231,941 | 600 m | $230 | per m using import pitrun ($30/m3 supply and place) |
| | storm sewer (750mm) | $184,800 | 200 m | $550 | per m supply and install cost |
| | manhole (1200mm) | $12,432 | 2 ea | $3,700 | ea supply and install |
| | outlet headwall | $6,720 | 1 ea | $4,000 | ea supply |
| | crew for headwall | $13,440 | 2 days | $4,000 | per day |
| | | **$450,000** | | | |
| 21 | Boundary Park rain garden | | | | |
| | rain garden | $302,400 | 600 m | $300 | per m labour + material |
| | storm sewer (300mm) | $33,600 | 100 m | $200 | per m supply and install cost |
| | outlet headwall | $5,880 | 1 ea | $3,500 | assume a day of machine time and $2000 headwall |
| | Subtotal | **$340,000** | | | |

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| | Item | Costs[1] | Quantity | Unit Cost | Comment |
|---|---|---|---|---|---|
| 27 | Stream relocation (0.5 m deep, 0.5 m bottom width, 2:1 slopes) | | | | move 30 m over away from railway and fill and reforest existing channel |
| | clearing (4 m wide) | $6,720 | 1000 m2 | $4 | per m2 |
| | Excavation | $10,500 | 250 m | $25 | per m assumes that material is side case in trees, a small excavator is used for 6 days ($1000/day) |
| | habitat features | $12,600 | 1 ea | $7,500 | ea supply and install |
| | Restoration of old channel | $21,000 | 250 m | $50 | per m assumes minimal soil and then light vegetation |
| | Subtotal | **$50,000** | | | |
| 28 | Remove Shaw Creek fish passage obstruction (weir in creek) | | | | |
| | weir removal / flow diversion | $12,600 | 1 ea | $7,500 | pumping creek around site and removal of weir (1 day) |
| | riprap restoration | $8,400 | 1 ea | $5,000 | Supply and place about 20 m3 of riprap ($75/m3) plus 2 days of excavator (1500/day) |
| | Subtotal | **$20,000** | | | |
| | Improve fish passage through culverts | | | | |
| 29 | Watershed Creek CUL_14 Under BNSF Railway 1800mm CSP too steep (25 m at 2.5%) | $33,600 | 1 ea | $20,000 | allowance for rock weirs or baffles |
| 30 | Shaw Creek CUL_236 Under Hwy 91 1800mm CSP too long (85 m at 0.9%) | $33,600 | 1 ea | $20,000 | allowance for rock weirs or baffles |
| | Subtotal | **$70,000** | | | |
| 31 | Create Shaw Creek fish habitat | | | | |
| | create channel (0.5 m deep, 1 m bottom width, 2:1 slopes) | $22,680 | 150 m | $90 | per m assumes material is disposed of off-site and clearing of the channel |
| | spawning gravel (0.3m deep for 1 m width) | $3,402 | 45 m3 | $45 | per m3 supply and place |
| | habitat features | $12,600 | 1 ea | $7,500 | ea supply and install |
| | Subtotal | **$40,000** | | | |

Note: 1. Costs include 2% bonding/insurance, 6% mob/demob, 20% engineering, and 40% contingency.

**Appendix F: Capital Cost Estimates - Hydrotechnical**

| | Item | Costs[1] | Quantity | Unit Cost | Comment |
|---|---|---|---|---|---|
| 1 | Construct bank protection on right bank of Shaw Creek at Highway 10 south side major erosion spot (E-11) | **$40,000** | 1 ea | $20,000 | assume 4 days of machine time and 50 m3 of riprap |
| 2 | Monitor Riprap movement and erosion at the top end of Shaw Creek | **$0** | | | no capital cost only maintenance |
| 3 | Monitor and remove accumulated debris at Briarwood culvert more frequently (perhaps monthly and after storm events) | **$0** | | | no capital cost only maintenance |
| 4 | Upgrade culvert CUL_352 in Watershed Park to 1050mm diameter pipe. | **$40,000** | 1 ea | $20,000 | per path culvert supply and install |
| 5 | Improved inlet and new trash rack at Hwy 10 Shaw Creek with wider bar spacing and debris interceptor upstream. | $60,077 | 1 ea | $35,760 | headwall cost x4 supply and install |
| | | $84,000 | 1 ea | $50,000 | debris interceptor |
| | | $16,800 | 1 ea | $10,000 | sediment basin excavation |
| | Subtotal | **$100,000** | | | |
| 6 | Complete construction of East Oliver Bypass backwater berms near Delta Golf Course. | **$60,000** | 70 m | $500 | per lin m using import pitrun ($30/m3 supply and place) |
| 7 | Upgrade culvert CUL_274 in Watershed Park to 1350mm diameter pipe. | **$40,000** | 1 ea | $20,000 | per path culvert supply and install |
| 8 | Allow culverts CUL_2, CUL_17, CUL_24, CUL_231, CUL_236, CUL_249, CUL_250, and CUL_370 to surcharge in the near term and replace at end of life with | **$0** | | | additional cost of larger size not estimated. Replacement cost part of asset management budget. |

Note: 1. Costs include 2% bonding/insurance, 6% mob/demob, 20% engineering, and 40% contingency.

**Appendix F: Capital Cost Estimates - Monitoring**

| Item | | Costs[1] | Quantity | Unit Cost | Comment |
|---|---|---|---|---|---|
| 16 | Monitor WQ at top end of Watershed Creek Tributary at former Works Yard outfall (first year cost) | | | | |
| | new probe | $8,000 | 1 ea | $8,000 | per probe |
| | data downloading and probe calibration | $3,000 | 1 yr | $3,000 | per yr for data downloading, probe calibration, etc (based on 40 day cycle) |
| | batteries and solutions | $400 | 1 yr | $400 | per yr for batteries + solutions |
| | data collation and summary memo | $2,500 | 1 yr | $2,500 | per year for basic yearly data collation, cleaning, and reporting (memo) |
| | | **$14,000** | | | |
| 17 | Monitor WQ at top end of Briarwood Creek (first year cost) | | | | |
| | new probe | $8,000 | 1 ea | $8,000 | per probe |
| | data downloading and probe calibration | $3,000 | 1 yr | $3,000 | per yr for data downloading, probe calibration, etc (based on 40 day cycle) |
| | batteries and solutions | $400 | 1 yr | $400 | per yr for batteries + solutions |
| | data collation and summary memo | $2,500 | 1 yr | $2,500 | per year for basic yearly data collation, cleaning, and reporting (memo) |
| | | **$14,000** | | | |
| 18 | Monitor WQ at top end of Shaw Creek (first year cost) | | | | |
| | new probe | $8,000 | 1 ea | $8,000 | per probe |
| | data downloading and probe calibration | $3,000 | 1 yr | $3,000 | per yr for data downloading, probe calibration, etc (based on 40 day cycle) |
| | batteries and solutions | $400 | 1 yr | $400 | per yr for batteries + solutions |
| | data collation and summary memo | $2,500 | 1 yr | $2,500 | per year for basic yearly data collation, cleaning, and reporting (memo) |
| | | **$14,000** | | | |

O:\03 1. Monitoring costs do not include travel time or mileage.

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