Preface

Technical studies were initiated in 2014 to support ongoing planning and future permitting and approval requirements for the George Massey Tunnel Replacement Project. The scope of some supporting studies may consider physical activities and spatial areas that are beyond the scope of the Project assessed under the B.C. Environmental Assessment Act. The results of future studies will be presented in the Environmental Assessment Certificate Application that will be prepared for the Project.
Executive Summary

The B.C. Ministry of Transportation and Infrastructure (Ministry) is proposing the George Massey Tunnel Replacement Project (Project) to meet regional, provincial, and national transportation management goals. The proposed Project involves replacing the George Massey Tunnel (Tunnel) with a new bridge spanning the Fraser River South Arm and Deas Island, decommissioning the Tunnel, and improving Highway 99 between Bridgeport Road in Richmond and Highway 91 in Delta.

To support planning and future permitting and approval requirements for the Project, the Ministry initiated studies to document existing conditions of environmental components that could potentially be affected by the Project. A sediment and water quality study was conducted as part of the environmental program for the Project. The study focused on collecting information on the existing conditions pertaining to the Fraser River South Arm, and the main watercourses within the study area, with emphasis on the characteristics of the riverbed, suspended sediments, and water quality. Information collected in support of this study included a review of existing data and information, as well as new data obtained through sampling and analyses completed in September 2014.

The study results indicate that there are strong spatial patterns, including a strong gradient in sediment texture, between the navigational channel in the Fraser River South Arm and Deas Slough. The sediments in the navigational channel are predominantly sands, while finer textured sediments (clayey silts) accumulate in more quiescent eddies, back channels, and Deas Slough. Sediments in areas that are conducive to the deposition and retention of finer-textured sediments exhibit concentrations of arsenic, chromium, and copper that are higher than freshwater interim sediment quality guidelines stipulated by the Canadian Council of Ministers of the Environment (CCME). These exceedances are, however, a result of natural geological and hydrological processes, including the tendency of these trace elements to adsorb to silts and clays in comparison with coarse silicaceous sands.

The water chemistry data analysis indicates that the water in the study area is of good quality. Although there are instances of elevated metal concentrations of aluminum, chromium, and copper, these elevated levels are attributed to the presence of suspended solids in bulk water samples, and the presence of these analytes in the particulate phase, rather than dissolved phase.
# Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>μg/g</td>
<td>micrograms per gram (parts per million, mass:mass)</td>
</tr>
<tr>
<td>μg/L</td>
<td>micrograms per litre</td>
</tr>
<tr>
<td>B.C. MOE</td>
<td>British Columbia Ministry of Environment</td>
</tr>
<tr>
<td>CWQG</td>
<td>Canadian (CCME) Water Quality Guidelines for the Protection of Aquatic Life</td>
</tr>
<tr>
<td>CCME</td>
<td>Canadian Council of Ministers of the Environment</td>
</tr>
<tr>
<td>CSR</td>
<td>British Columbia Contaminated Sites Regulation</td>
</tr>
<tr>
<td>DDD</td>
<td>Dichlorodiphenyldichloroethane</td>
</tr>
<tr>
<td>DDT</td>
<td>Dichlorodiphenyltrichloroethane</td>
</tr>
<tr>
<td>DO</td>
<td>dissolved oxygen</td>
</tr>
<tr>
<td>DQO</td>
<td>data quality objective(s)</td>
</tr>
<tr>
<td>HEPH</td>
<td>heavy extractable petroleum hydrocarbons</td>
</tr>
<tr>
<td>ISQG</td>
<td>interim sediment quality guidelines (CCME)</td>
</tr>
<tr>
<td>LEPH</td>
<td>light extractable petroleum hydrocarbons</td>
</tr>
<tr>
<td>LSA</td>
<td>local study area</td>
</tr>
<tr>
<td>Ministry</td>
<td>Ministry of Transportation and Infrastructure</td>
</tr>
<tr>
<td>ng/g</td>
<td>nanograms per gram (parts per billion, mass:mass)</td>
</tr>
<tr>
<td>PAH</td>
<td>polycyclic aromatic hydrocarbon(s)</td>
</tr>
<tr>
<td>PCB</td>
<td>polychlorinated biphenyl(s)</td>
</tr>
<tr>
<td>RPD</td>
<td>relative per cent difference</td>
</tr>
<tr>
<td>RSA</td>
<td>regional study area</td>
</tr>
<tr>
<td>SedQC&lt;sub&gt;ss&lt;/sub&gt;</td>
<td>sediment quality standards for sensitive sites (B.C. CSR)</td>
</tr>
<tr>
<td>STD</td>
<td>standard deviation</td>
</tr>
<tr>
<td>TSS</td>
<td>total suspended solids</td>
</tr>
<tr>
<td>Tunnel</td>
<td>George Massey Tunnel</td>
</tr>
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</table>
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>adsorption</td>
<td>Adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface.</td>
</tr>
<tr>
<td>analyte</td>
<td>A substance having chemical constituents that are being identified and measured.</td>
</tr>
<tr>
<td>circumneutral pH</td>
<td>Having a pH of between 6.5 and 7.5.</td>
</tr>
<tr>
<td>clay</td>
<td>Sediment with particle size less than 0.004 mm in diameter.</td>
</tr>
<tr>
<td>coefficient of determination</td>
<td>A statistical measure used to explain how much of the variability of a factor is caused by its relationship to another factor.</td>
</tr>
<tr>
<td>congener</td>
<td>A single, unique well-defined chemical compound in the PCB category.</td>
</tr>
<tr>
<td>gravel</td>
<td>Sediment with particle size greater than two millimetres in diameter.</td>
</tr>
<tr>
<td>non-polar organic contaminant</td>
<td>Organic contaminant that does not exhibit polarity, and therefore does not readily dissolve in water.</td>
</tr>
<tr>
<td>Project disturbance area</td>
<td>All lands and lands under water, except the Project footprint, which are subject to disturbance during Project construction and required for maintenance activities during Project operation.</td>
</tr>
<tr>
<td>redox</td>
<td>A chemical reaction between substances, in which one substance is oxidized (i.e., gains oxygen) and the other is reduced (i.e., loses oxygen).</td>
</tr>
<tr>
<td>refusal</td>
<td>Depth or point at which drilling cannot continue.</td>
</tr>
<tr>
<td>sand</td>
<td>Sediment with particle size ranging from 0.063 mm to two millimetres in diameter.</td>
</tr>
<tr>
<td>silt</td>
<td>Sediment with particle size ranging from 0.004 mm to 0.063 mm in diameter.</td>
</tr>
<tr>
<td>standard deviation</td>
<td>A statistical measure used to quantify the amount of variation or dispersion of a set of data values.</td>
</tr>
<tr>
<td>titration</td>
<td>The slow addition of one solution of a known concentration (called a titrant) to a known volume of another solution of unknown concentration until the reaction reaches neutralization, which is often indicated by a color change.</td>
</tr>
</tbody>
</table>
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1.0 Introduction

This report presents the objectives, methods, and findings of the sediment and water quality study undertaken to support planning as well as future permitting and approval requirements of the George Massey Tunnel Replacement Project (Project).

1.1 Study Background

The B.C. Ministry of Transportation and Infrastructure (Ministry) is proposing the Project to meet regional and provincial transportation management goals. The Ministry initiated studies in early 2014 to understand and document existing conditions of environmental components that could potentially be affected by the Project.

Because studies were conducted prior to the Project scope being finalized, a broader spatial area was considered to accommodate potential refinements in the Project design. This broader scope was established based on a general understanding that the Project would involve modifications of the Highway 99 corridor, including replacement of the George Massey Tunnel (Tunnel) with a clear-span bridge, removal of all or part of the Tunnel, and replacement or upgrade of interchanges and widening of the highway as required.

The Project is expected to involve in-river works during construction associated with decommissioning the Tunnel and Deas Slough Bridge. These works may result in changes in channel morphology of the Fraser River South Arm, immediately upstream and downstream from the Project area during and following construction. These changes have the potential to result in re-distribution of bed sediments through scouring, re-suspension and re-deposition, and lateral transport.

This study was undertaken to describe the conditions and characteristics of sediment and surface water quality in the Project area, and to inform an assessment of potential effects of the Project on fish and fish habitat, as well as agricultural activities (i.e., use of water for irrigation).

1.2 Study Components and Major Objectives

It is well-established that concentrations of trace metals in surficial sediments are greater than those dissolved in the water column (Horowitz 1985). In riverine systems such as the Fraser River, trace metals are predominantly carried via sediment transport. For example, Sekela et al. (1994) noted that suspended sediments in the Fraser River exhibit higher concentrations of polycyclic aromatic hydrocarbon (PAH) and chlorophenolic contaminants during freshet, likely due to re-suspension of bed sediment. To develop an understanding of the potential for riverine contaminant transport in the Project Area, an understanding of the chemical characteristics of bed sediments is required.
Accordingly, this report provides information on the existing sediment (suspended and riverbed) and water quality characteristics and conditions of the main watercourses traversed by Highway 99, within and adjacent to the Project area. The study is based on a review of existing information from previously completed studies, and on a field program conducted by Hemmera in September 2014 to supplement information on areas for which existing information was not available. The study components, major objectives, and a brief overview of objectives are provided in **Table 1-1**.

### Table 1-1 Sediment and Water Quality Study Components and Major Objectives

<table>
<thead>
<tr>
<th>Component</th>
<th>Major Objective(s)</th>
<th>Brief Overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment</td>
<td>Characterize sediment in the study area</td>
<td>• Desktop review of existing data and information to describe existing conditions and identify information gaps.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Field data collection in September 2014 to supplement information gaps; carry out physical and chemical analyses of riverbed and slough bed sediments (top ~20 cm) at 30 sites, plus subsurface samples to a maximum depth of approx. two metres below the sediment-water interface at four of the 30 sites.</td>
</tr>
<tr>
<td>Water quality</td>
<td>Characterize water quality in the study area</td>
<td>• Desktop review of existing data and information to describe existing conditions and identify information gaps.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Field data collection in September 2014 and laboratory analysis of water samples at five locations within the study area to supplement information gaps.</td>
</tr>
</tbody>
</table>

### 1.3 Spatial Scope

The desktop review of existing information focused mainly on recent studies carried out in the Fraser River North Arm, and upstream and downstream of the new bridge on the Fraser River South Arm. Information was also collected from earlier studies pertaining to the other watercourses along the Highway 99 corridor, including the Serpentine and Nicomekl rivers. Deas Slough was also included because the south approach ramp of the new bridge will replace the existing Deas Slough Bridge, and some encroachment of the wetted perimeter may be required for ground improvements and to install foundations.
While the historical information was considered adequate, additional sampling and analyses were considered necessary to adequately describe conditions, particularly in the vicinity of the Tunnel and Deas Sough. Sediment and water quality samples were collected in September 2014 from these locations.

### 1.4 Study Areas

Changes to surface water and sediment quality in the Fraser River due to Project activities are expected to be most prominent in the Project area, immediately adjacent to in-water activities, such as during Tunnel decommissioning. However, due to tidal influences, salt wedge interactions, and river hydrology, there may be changes some distance downstream of the Tunnel. Further, although Project-related changes to surface water and sediment quality are not expected to extend beyond 1.5 km upstream of the Tunnel, it is important to provide regional context for comparison to conditions within the Project area. For this reason, both a local study area (LSA) and a regional study area (RSA) have been defined, and data have been captured and considered for each one.

The LSA comprises the reach on the Fraser River South Arm extending 1.5 km upstream and one kilometre downstream from the Tunnel. The RSA comprises the reach extending seven kilometres upstream from the Tunnel, and downstream to the river mouth at Sturgeon Bank in the Strait of Georgia (see Appendix A, Figure 1).
2.0 Review of Existing Information

The study team reviewed the available information pertaining to sediment and water quality characteristics in the Fraser River North Arm and South Arm, Serpentine River, and Nicomekl River where each is traversed by Highway 99. Information was captured on sediment types, distribution, and quality, sediment contaminant concentrations, and water quality. A comparison of historical data against current applicable regulatory guidelines and standards was also carried out.

Scientific references that provide relevant information on sediment and water quality characteristics of the lower Fraser River include Swain and Holms (1985, 1988), Swain and Walton (1990, 1991, 1993, 1994), Barrie et al. (1998), Brewer et al. (1998), Hall and McLeay (1999), McLaren and Tuominen (1999), Phippen (2001), Han et al. (2006), Erickson et al. (2013), and Environment Canada (2014). The relevant results from these studies are presented in Appendix B, including tables of sample locations and sediment chemistry results collected from these information sources. The following sections summarize the existing conditions for the study area based on the literature review.

2.1 Fraser River South Arm and Deas Slough

The locations of the historical study samples within the Fraser River South Arm and Deas Slough discussed in this section are shown in Appendix A, Figure 2.

2.1.1 Sediment Texture

Sediments within the Fraser River South Arm at Barnston Island, Ewen Slough (in the Fraser River main arm), and Boundary Bay comprise grain sizes of less than two millimetres (Swain and Walton 1991). Grain size by per cent mass at the time of collection was 83.3% silts and clays (<0.063 mm) near Westham Island, and 47.7% fine sands (0.063 to 2.0 mm) in Boundary Bay. This interpretation is consistent with other observations (Phippen 2001) that the majority of the Fraser River South Arm (where Highway 99 traverses the Fraser River) is almost entirely composed of silts (approximately 100% silts or finer in Deas Slough). McLaren and Tuominen (1999) showed that this area consists of sands and muds, while Deas Slough is composed entirely of silts and clays. This information reinforces the general conclusion that side-channel areas or nearshore eddies of the Fraser River tend to accumulate finer-textured clayey and silty sediments, while the higher current areas in the main river channel (and in the designated navigational channel) are characterized by sandy sediments with very limited fines. The locations of samples referenced in these studies are provided in Appendix B.
2.1.2 Evaluation of Sediment Quality

Several reports, as noted below, indicate that bed sediments in some areas of the Fraser River South Arm may contain trace elements, PAHs, and various other non-polar organic contaminants at levels that may exceed sediment quality guidelines. In general, higher concentrations of such substances tend to occur in association with finer-textured, organic-rich sediments, and may reflect broader regional and watershed-scale inputs from globally redistributed sources in most areas of the riverbed.

Swain and Walton (1991) noted that the sediment concentrations of arsenic, copper, chromium, mercury, nickel, and zinc were related to the percentage of very fine sediments in samples collected. Brewer et al. (1998) found exceedances in total PAH concentrations when compared to B.C. *Contaminated Sites Regulation (CSR)*, B.C. Reg. 375/96, Schedule 9 sediment quality standards for sensitive sites standards. Exceedances were also found for pesticides such as total dichlorodiphenyltrichloroethane (DDT) and chlordane, metals such as chromium, and other contaminants including total polychlorinated biphenyl (PCB) congener. Swain and Walton (1991, 1993) found high concentrations exceeding applicable B.C. CSR Schedule 9 standards for PAHs and metals. These include phenanthrene, copper, lead, and zinc. A comparison of the data from these studies to Canadian Council of Ministers of the Environment (CCME) interim sediment quality guidelines (ISQG) (CCME 1999a) was conducted; however, no exceedances were found (see Appendix B).

Historical data collected by Hemmera (2013), Fraser River Pile and Dredge (2013), Balanced Environmental (2013), Duane Brothers (2009), and Port Metro Vancouver (2005) were reviewed to establish the existing conditions in the sediments of the Fraser River South Arm and to decide if additional sampling might be required. Appendix A, Figure 2 shows the sampling locations of these five studies. All data, except those collected from outside of the study area, are provided in Appendix C, Table C1 to Table C4. Descriptions of sampling techniques were not available with the data reports; however, it is assumed that all samples for which the data apply were collected using a surface grab and include the top 15 cm of riverbed or less.

Figure 2-1 through Figure 2-3 present the concentrations of total arsenic, chromium, and copper, respectively, found in sediment samples collected in 2013 by (a) Fraser River Pile and Dredge, (b) Hemmera, and (c) Balanced Environmental. These metals are highlighted in the present report because of the consistently elevated metal concentrations observed in all the data examined. No other parameters analyzed in those three studies were found to exceed CCME guidelines. These results are discussed in the sections below.
2.1.2.1 Arsenic

Arsenic data were collected in 2013 by Fraser Pile and Dredge, Hemmera, and Balanced Environmental. Of the sediment samples collected by Balanced Environmental, the average arsenic concentration was 6.13 mg/kg (standard deviation (STD) = 0.75 mg/kg) within the LSA, and 5.55 mg/kg (STD = 1.4 mg/kg) in the RSA. The average arsenic concentration of 6.13 mg/kg is slightly higher than the CCME ISQG (1999a) of 5.9 mg/kg. Many of the samples collected for the Balanced Environmental study were focused along the shoreline, specifically in Deas Slough (Appendix A, Figure 2). As explained above, finer-grained sediment has settled out and accumulated in Deas Slough due to slow flow. The higher arsenic concentrations from the samples collected in Deas Slough (DS-01 to DS-12) imply that these sediments, on average, comprise finer grain size than those collected from the middle of the Fraser River South Arm (e.g., FR14-1 to FR20-1). Due to the increased surface area of finer material, an associated increase in metal/metalloid concentrations is observed. The average arsenic concentration in the LSA of 6.13 mg/kg is slightly higher than the CCME ISQG (1999a) of 5.9 mg/kg. Due to the larger surface area of fine grains relative to coarser grains, an associated increase in metal/metalloid concentrations is observed.

Samples collected in the LSA and RSA in 2013 by Fraser Pile and Dredge and Hemmera were all below the CCME guideline for arsenic. Only two of the 2013 Hemmera samples, and one of the 2013 Fraser River Pile and Dredge samples, were collected from within the LSA (FR24-1 and FR25-1, FR 16 respectively) and analyzed for metals/metalloids.
Figure 2-1  Arsenic Concentrations in Sediment Samples Collected in 2013 by (a) Fraser River Pile and Dredge, (b) Hemmera, and (c) Balanced Environmental.
2.1.2.2 Chromium

The average total chromium concentration from all samples collected from the study area was below the CCME ISQG of 37.3 mg/kg. The average concentration of samples collected in 2013 by Balanced Environmental in the LSA was 34.24 mg/kg. In the RSA, the average concentration of chromium was greatest in the Balanced Environmental 2013 data (35 mg/kg, STD = 5.44 mg/kg), and lowest in the Fraser Pile and Dredge data (25.46 mg/kg, STD = 3.31 mg/kg). There were more sediment samples with appreciable silt content in the Balanced Environmental 2013 dataset (Table 2-1), and the higher average silt and clay content undoubtedly accounts for the higher average metal/metalloid concentrations.

<table>
<thead>
<tr>
<th>Source</th>
<th>Parameter (mm)</th>
<th>Average Per Cent Per Sample</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
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<td>RSA</td>
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<td></td>
<td></td>
<td>N</td>
<td>Average</td>
<td>STD</td>
<td>N</td>
<td>Average</td>
<td>STD</td>
<td>N</td>
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<td>Fraser Pile and Dredge</td>
<td>Clay (0.004)</td>
<td>1</td>
<td>0.45</td>
<td>N/A</td>
<td>16</td>
<td>0.94</td>
<td>0.62</td>
<td>16</td>
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<td></td>
<td>Silt (0.004 - 0.063)</td>
<td>1</td>
<td>1.41</td>
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<td>16</td>
<td>1.86</td>
<td>2.9</td>
<td>16</td>
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<td>Sand (0.063 - 2.00)</td>
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<td>98.1</td>
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<td>16</td>
<td>96.88</td>
<td>3.6</td>
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<td>Gravel (&gt;2.00)</td>
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<td>&lt;0.10</td>
<td>N/A</td>
<td>16</td>
<td>1.84</td>
<td>2.78</td>
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<td>Duane Brothers</td>
<td>Clay (0.004)</td>
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<td>1</td>
<td>N/A</td>
<td>16</td>
<td>2.79</td>
<td>5.62</td>
<td>16</td>
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<td>Silt (0.004 - 0.063)</td>
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<td>1.56</td>
<td>0.36</td>
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<td>Sand (0.063 - 2.00)</td>
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<td>98</td>
<td>N/A</td>
<td>16</td>
<td>96.6</td>
<td>2.89</td>
<td>16</td>
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<td>0</td>
<td>0</td>
<td>N/A</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Balanced Environmental</td>
<td>Clay (0.004)</td>
<td>12</td>
<td>7.6</td>
<td>3.64</td>
<td>30</td>
<td>4.82</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Silt (0.004 - 0.063)</td>
<td>12</td>
<td>51.5</td>
<td>16.59</td>
<td>30</td>
<td>26.0</td>
<td>29.24</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Sand (0.063 - 2.00)</td>
<td>12</td>
<td>40.9</td>
<td>20</td>
<td>30</td>
<td>69.2</td>
<td>34.88</td>
<td>30</td>
</tr>
<tr>
<td>Hemmera</td>
<td>Clay (0.004)</td>
<td>2</td>
<td>0.1</td>
<td>0</td>
<td>21</td>
<td>1.82</td>
<td>0.6</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Silt (0.004 - 0.063)</td>
<td>2</td>
<td>1.8</td>
<td>0.1</td>
<td>21</td>
<td>3.66</td>
<td>2.42</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Sand (0.063 - 2.00)</td>
<td>2</td>
<td>98.2</td>
<td>0.25</td>
<td>21</td>
<td>96.3</td>
<td>3.09</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Gravel (&gt;2.00)</td>
<td>2</td>
<td>&lt;0.10</td>
<td>0</td>
<td>21</td>
<td>0.27</td>
<td>0.38</td>
<td>21</td>
</tr>
</tbody>
</table>
Figure 2-2  Chromium Concentrations in Sediment Samples Collected in 2013 by Fraser River Pile and Dredge, (b) Hemmera, and (c) Balanced Environmental.
2.1.2.3 Copper

The same trends observed for total arsenic and chromium concentrations in the three studies are also observed with total copper concentrations. The average concentration of total copper in the Balanced Environmental 2013 samples was 28.7 mg/kg (STD = 4.71 mg/kg) for the LSA, and 23.2 mg/kg (STD = 10.07 mg/kg) for the RSA. Both of these average concentrations are well below the CCME ISQG of 35.7 mg/kg; however, there were exceedances of the CCME ISQG for copper at three sites in the RSA, including DS-01, LH13-15, and LHE-01.
Figure 2-3  Copper Concentrations in Sediment Data Collected in 2013 by (a) Fraser River Pile and Dredge, (b) Hemmera, and (c) Balanced Environmental.
2.1.2.4 Total Polychlorinated Biphenyl

The CCME ISQG for total PCBs is 0.0341 µg/g (34.1 ng/g). None of the 2013 samples analyzed for Fraser River Pile and Dredge, Hemmera, or Balanced Environmental exceeded this guideline (Figure 2-4 and Table 2-2).

**Figure 2-4** Total PCB Concentrations in Sediment Samples Collected in 2013 by Balanced Environmental. CCME ISQG is 34.1 ng/g.
### Table 2-2  Riverbed Concentrations of PAHs and Total PCBs Based on Recent Data

<table>
<thead>
<tr>
<th>Source</th>
<th>Parameter (mg/kg)</th>
<th>Number of Samples</th>
<th>LSA</th>
<th>RSA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td>STD</td>
</tr>
<tr>
<td>Fraser Pile and Dredge 2013</td>
<td>Acenaphthene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Acenaphthylene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Anthracene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Benzo(a)anthracene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Benzo(a)pyrene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Benzo(b)fluoranthe</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Benzo(g,h,i)perylene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Benzo(k)fluoranthe</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Chrysene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Dibenz(a,h)anthracene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Fluoranthe</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Fluorene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Indeno(1,2,3-c,d)pyrene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Naphthalene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Phenanthrene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Pyrene</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Total PCBs (ng/g)</td>
<td>0</td>
<td>No PCB data for this sample</td>
<td>-</td>
</tr>
<tr>
<td>Source</td>
<td>Parameter (mg/kg)</td>
<td>Number of Samples</td>
<td>LSA</td>
<td>RSA</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---------------------</td>
<td>-------------------</td>
<td>-------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td>STD</td>
</tr>
<tr>
<td>PMV 2005</td>
<td>Total PAHs</td>
<td>2</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td>Hemmera 2013</td>
<td>Total PCBs (ng/g)</td>
<td>2</td>
<td>0.008</td>
<td>0.003</td>
</tr>
<tr>
<td>Duane Brothers 2009</td>
<td>Total PCBs (ng/g)</td>
<td>1</td>
<td>&lt; detection limit</td>
<td>-</td>
</tr>
<tr>
<td>Balanced Environmental 2013</td>
<td>Total PCBs (ng/g)</td>
<td>5</td>
<td>0.89</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Total PAHs</td>
<td>12</td>
<td>0.99</td>
<td>-</td>
</tr>
</tbody>
</table>
2.1.3 Water Quality

Based on results of previous studies, water quality in the Fraser River South Arm is generally good but may exhibit slightly elevated metal concentrations, with higher ambient copper and iron believed to be a result of a natural condition (Swain and Holms 1985). Exceedances of aluminum and iron were found in samples collected by Phippen (2001) at Ewen Slough, situated near the mouth of the Fraser River main channel. Levels of pH, turbidity, ammonia, nitrite, nitrate and hardness were all comparable to North Arm records and below applicable guidelines.

Environment Canada operates a buoy situated in the Fraser River South Arm (Fraser River Water Quality Buoy) that provides real-time water quality data, including pH and turbidity, which were found to be consistent with historical records (noted above) for these two parameters.

2.2 Fraser River North Arm

2.2.1 Sediment Texture

Bed sediments from sites sampled by Swain and Walton (1991) in the Fraser River North Arm were generally found to be fine-textured, with no portion of the sediment grain size distribution exceeding two millimetres. Bed sediments were, on average, found to be composed of 94.2% silts and clays by mass (<0.063 mm) and 5.8% fine sands (0.063 to 2.0 mm). This information is corroborated by graphical evidence presented by Phippen (2001) that indicates the majority of the North Arm (where it is transected by Highway 99) is composed of silts and some sands/clays. Furthermore, McLaren and Tuominen (1999) show this area as mainly silt and clay. Sample site locations for these studies are provided in Appendix B.

2.2.2 Evaluation of Sediment Quality

Based on results from previous studies, it is evident that elevated concentrations of measured parameters exist in sediment samples from the Fraser River North Arm. Brewer et al. (1998) observed that total PAH concentrations in several samples were higher than CSR Schedule 9 sediment quality criteria standards for sensitive sites. Exceedances of various provincial or CCME sediment quality guidelines were also noted for pesticides such as total DDT, dieldrin, chlordane, and other contaminants such as pentachlorophenol and total PCB congeners. Brewer et al. (1998) found that chromium was the only metal to exceed standards at the time of the study. Results are summarized in Appendix B, Table B2.
2.2.3 Water Quality

The B.C. Ministry of Environment (MOE) report on ambient water quality for the Fraser River, *Ambient Water Quality Assessment and Objectives for the Fraser River Sub-basin from Kanaka Creek to the Mouth* (Swain and Holms 1985) concluded that water quality in the North Arm is good, and is consistent with water quality data from 1979. Acidity was in the range of 7.0 to 8.0 pH. Metal concentrations generally did not exceed water quality criteria or standards for the protection of aquatic life, except for copper and iron. Phippen (2001) reported similar results for water samples collected from McDonald Slough: water samples exhibited circumneutral pH; only concentrations of iron, aluminum, and zinc exceeded their respective water quality guidelines.

Water quality data collected from 1979 to 2004 for the Fraser River at Hope are summarized in documents prepared by B.C. MOE for Environment Canada (Swain 2007) and a report prepared for the Water Protection Branch, B.C. Ministry of Water, Land, and Air Protection (Phippen 2001). Phippen (2001) established monitoring stations in McDonald Slough and Ewen Slough, located in the Fraser River North Arm and main channel, respectively. Both documents provide background water quality information for the Fraser River, in addition to that summarized in Section 2.1.3 and Section 2.2.3, and indicate that, over the 35-year period monitored, there was a temporal trend of increased turbidity and an associated increased fluctuation of total metal concentrations, likely as a result of the relationship between total suspended solids (TSS) and bound metals. A temporal decrease in the concentrations of chloride and various dissolved phase metals was also observed. This was attributed to the emergence of better analytical detection limits through the monitoring period. Lead, zinc, iron and manganese concentrations at McDonald and Ewen sloughs were reported to exceed CCME water quality guidelines. Any incidents of elevated aluminum or chromium concentrations were associated with high levels of TSS. Concentrations of PCBs were very low and therefore not a concern.

2.3 Serpentine River

2.3.1 Sediment Texture

No detailed sediment composition data appear to be available for Serpentine River. The Nicomekl—Serpentine Basin is reported to be composed primarily of clays, silts, and fine sands (Hall and McLeay 1999). The Serpentine River has been periodically dredged since the 1950s to remove silt buildup (City of Surrey 2015).
2.3.2 Evaluation of Sediment Quality

Samples collected by Swain and Walton (1990) from the mouth of the Serpentine River had PAH levels that exceed current CSR Schedule 9 standards for dibenz(a,h)anthracene, anthracene, and phenanthrene. Pesticides such as dichlorodiphenyldichloroethane (DDD) were present, and concentrations of aluminum, calcium, iron, and titanium were high. Similar results were found by Swain and Walton (1994), with anthracene and phenanthrene levels exceeding CSR standards, and DDD being detectable; however, none of these three parameters exceed their respective current CCME ISQG. The numerical results of these two studies are summarized in Appendix B, Tables B4 and B5.

2.3.3 Water Quality

Water quality of the Serpentine River was assessed by Swain and Holms (1988). The results indicate high levels of zinc near the Highway 99 corridor. Lower levels of dissolved oxygen (DO) were found when compared to major rivers such as the Fraser, but the observed DO levels still met applicable criteria for the protection of aquatic life. The pH varied from 6.5 to 9.3. Nitrogen, ammonia, chloride, alkalinity, sodium, and phosphorous parameters were all similar to those in nearby Nicomekl River (see Section 2.4), but could not be compared to water quality guidelines because the accessory data for temperature, salinity, and pH at sampling times could not be identified, since these parameters were not collected by the sampler.

2.4 Nicomekl River

2.4.1 Sediment Texture

Specific sediment characterization data for the Nicomekl River are not available; however, the stratigraphy of the Nicomekl—Serpentine Basin is described as silty clay, silty sand, sandy silts, and sand lenses of fluvial, glaciofluvial, and glaciomarine origin (Hall and McLeay 1999).

2.4.2 Evaluation of Sediment Quality

Sampling and analysis completed by Swain and Walton (1990) for Nicomekl River indicated high PAH concentrations in some sediment samples, and exceedances of CSR sediment standards and CCME ISQG for dibenz(a,h)anthracene. Swain and Holms (1988) found elevated lead concentrations when compared to current B.C. CSR regulatory standards or to CCME ISQG standards. High metal concentrations, similar to those in the Serpentine River, seem to be prevalent in historical sediment samples. A summary of these results is provided in Appendix B, Tables B5 and B6.
2.4.3 Water Quality

Nicomekl River water quality was found by Swain and Holms (1988) to be similar to that of the Serpentine River. Aluminum and zinc concentrations exceeded current CSR water quality guidelines (Appendix B, Table B6). Nitrogen, ammonia, chloride, alkalinity, sodium, and phosphorous parameters were all similar to those in nearby Serpentine River but could not be compared to guidelines because accessory data for temperature, salinity, and pH at sampling times could not be verified, since these parameters were not collected by the sampler. The pH was within the regulatory guideline of 6.5 to 8.5.

2.5 Conclusions from Existing Sediment and Water Quality Studies

Because sediments in side-channel areas or nearshore eddies of the watercourses sampled accumulate finer-textured clayey and silty sediments, these areas also tend to exhibit higher concentrations of potential contaminants. During freshet or disturbance events, sediments can be re-suspended into the water column. Based on the review of existing information, a general summary of sediment and water quality conditions is as follows:

- The Fraser River South Arm exhibits predominantly sandy sediments within the deeper portions of the river channel away from the river bank, while nearshore sediments and those in eddies, sloughs, and side-channels are generally finer textured.
- Sediments of the Fraser River North Arm, Serpentine River, and Nicomekl River are mainly fine sands, silts, and clays.
- Finer-grained bed sediments tend to have higher concentrations of trace elements and organic contaminants such as PAHs, in comparison with coarser-textured, sandy sediments. The potential for re-mobilization and re-distribution of sediment-associated contaminants is dependent, therefore, on the local sediment textural characteristics.
- Serpentine and Nicomekl rivers show historically high levels of metals that are generally interpreted as a result of background geology, with the exception of zinc and aluminum, which may be due to agricultural sources.
- Several of the sampling locations for previous studies reflect areas of known historical accumulations of sediment contaminants, and areas of high fine-particle sediment accumulation.
3.0 New Studies

Additional sediment and water quality samples were collected in 2014 from the Fraser River South Arm, including Deas Slough. While existing historical data were considered generally adequate for describing existing conditions, additional sampling and analyses were considered necessary to address the paucity of pre-existing data on sediment and water quality, specifically in the vicinity of the Tunnel and Deas Sough.

3.1 Field Methods

3.1.1 Sediment Sampling

Sediment samples were collected on September 11 and 12, 2014 (Appendix A, Figure 3). These dates were selected to correspond with low-flow conditions in the Fraser River. Five transects were planned upstream and downstream of the Tunnel, with five stations located along each transect, extending north to southeast across the river. Seven sites were also planned in Deas Slough. The sampling design was developed to better understand the physical and chemical characteristics of bed sediments within the study area. Sediment samples were collected using a combination of vibracore technology and Van Veen surface grabs deployed from a surface vessel.

Sample location coordinates were uploaded to the boat GPS and a handheld Garmin GPS prior to arriving at each site. Electronic field forms were used for data entry and transfer. Site photos were collected and uploaded to electronic field forms (see Appendix D). Field data were also uploaded to and managed in Hemmera’s customized database. Sampling was conducted during low-flow periods identified from Water Survey of Canada hydrographs.

Vibracore sampling is a technique used to sample sediment whereby the vibrating core cutter head and the weight of the core tube advance into the sediment. Vibracoring was the sampling method chosen for vertically characterizing the study area sediment, and was completed at four stations (Appendix A, Figure 3). The maximum possible sampling depth achievable with the vibracore used in this study was approximately two metres. Once the core tube was advanced as far as possible (generally until refusal), the core was withdrawn with the aid of the hoist equipment. The intact and continuous sediment core was removed and deposited into a long tubular clear plastic bag and tied off. Water was slowly decanted through a small hole in the sample bag and the core was then placed in a plastic trough on a table and carefully split open longitudinally using a stainless steel spatula driven perpendicularly into the long axis of the core. After making visual and olfactory observations of sediment stratigraphy, changes in colour or texture, and presence of debris, etc., sediment samples were collected from near the centre of
the core, with care taken to prevent sampling any sediment that may have been in contact with the core barrel. This method limits the potential for cross-contamination of sediment samples or misleading information on the stratigraphy of specific parameters that may result due to carry-down of sediments adjacent to the core barrel.

During vibracore sampling, strong tidal action at the confluence of the Fraser River South Arm and Deas Slough, at Gravesend Reach, combined with strong winds, resulted in wave action that made this sampling technique ineffective. In addition, the coarse-grained sand of the Fraser River South Arm made sediment penetration difficult. As a result, fewer cores were collected than had been planned. A total of four sediment cores (S14-05, S14-26, S14-27, S14-29) were collected, which was considered to be satisfactory since recent data (Fraser River Pile and Dredge 2013, Hemmera 2013, Balanced Environmental 2013) provided good spatial coverage of the study areas. Three of the four successfully collected cores are from Deas Slough, where finer-grained sediments allowed better vibracore performance.

A Van Veen grab sampler is a mechanism with a stainless steel clamshell bucket that is cocked in an open position prior to being lowered into the water. The jaws are triggered to close when the grab hits the substrate. The 0.1 m² stainless steel Van Veen grab used for sampling is generally capable of penetrating the surface sediment and retaining a sediment sample from depths of 25 to 30 cm or less. To the extent possible, sediment was collected from the top 20 cm of sediment from the top access doors in the grab, with care taken to avoid the sampling of sediments directly adjacent to the internal surfaces of the grab. Van Veen samples were collected at 14 stations in the LSA (Appendix A, Figure 3). The team initially attempted to collect Van Veen grab sediment samples from the transect closest to the Tunnel (S14-11 to S14-15). Although multiple casts were executed along this transect, only two sites (S14-13 and S14-14) were successfully sampled due to coarse woody debris accumulated on the riverbed.

All samples were handled in the field in accordance with the B.C. Field Sampling Manual for Continuous Monitoring and the Collection of Air, Air-Emission, Water, Wastewater, Soil, Sediment, and Biological Samples (B.C. MWLAP 2003), and stored in the appropriate non-contaminating containers provided by the commercial analytical laboratory (ALS Environmental Services). All crew members who handled samples wore clean nitrile gloves to protect the sample from contamination. Once labelled, samples were immediately placed in a cooler with ice packs for storage in the field until delivery at the laboratory at the first opportunity.
The analytical data from all sediment samples collected, including field duplicates, as well as the relative per cent difference (RPD) in concentrations between field duplicates are provided in Appendix C, Table C5. Three sets of duplicate samples were collected in addition to the 30 sediment samples collected (10%), following guidelines provided in Standard Methods for the Examination of Water and Wastewater (AWWA 1999) and as recommended in the British Columbia Field Sampling Manual (B.C. MWLAP 2003). The sediment chemistry data were compared with CCME ISQG for freshwater.

3.1.2 Water Quality Sampling

Water samples were collected on September 11 and 12, 2014 at five locations in the middle of the Fraser River South Arm channel and in Deas Slough (Appendix A, Figure 3). Samples were collected from the water column approximately 10 cm below the water surface in the immediate vicinity of the Tunnel and from areas of potential disturbance during bridge construction. The five sites were selected based on their proximity to the anticipated future works.

In situ parameters (pH, temperature, redox, DO, and specific conductivity) were measured with a weighted multi-probe meter. All protocols followed the British Columbia Field Sampling Manual (B.C. MWLAP 2003). Water samples were chemically analyzed by ALS Environmental Services. Dissolved metals and dissolved organic carbon samples were filtered in the lab using a 0.45 μm filter to remove particulate material.

3.2 Laboratory Analysis

Specific analytes tested and associated methodologies used by ALS Environmental Services are listed and discussed below.

3.2.1 Sediment

Sediment samples were analyzed for the following parameters:

- Physical characteristics: per cent moisture, pH, detailed grain-size analyses
- Nutrients: total organic carbon
- Total metals: antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, tin, titanium, uranium, vanadium, and zinc.
- Oil and grease, light extractable petroleum hydrocarbons (LEPH), heavy extractable petroleum hydrocarbons (HEPH).
PAHs: 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, phenanthrene, pyrene, 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, phenanthrene, and pyrene.

PCBs: aroclor 1016, aroclor 1221, aroclor 1232, aroclor 1242, aroclor 1248, aroclor 1254, aroclor 1260, aroclor 1262, aroclor 1268, and total PCBs.

Total carbon and inorganic carbon were determined based on methodologies outlined in Nelson and Sommers (1996) and Loeppert and Suarez (1996), respectively. Metals analysis (including mercury) in sediments was carried out according to procedures for strong acid leachable metals in the British Columbia Environmental Laboratory Manual (B.C. MOE 2013a). Extractable petroleum hydrocarbons were analyzed in accordance with the provincial lab method (B.C. MOE 2013b). Light and heavy extractable hydrocarbons were determined based on methods developed by the B.C. MOE (2013c). Particle-size analysis was performed by both the wet-sieving method and pipette sedimentation method. Analysis of PAHs followed Test Methods for Evaluating Solid Waste SW-846, Methods 3570 and 8270 (U.S. EPA 2007), and PCBs following the methodology of Test Methods for Evaluating Solid Waste SW-846, Methods 3500, 3620, 3630, 3660, 3665, and 8082 (U.S. EPA 2007). Full details on the lab methods can be found in the Certificate of Analysis L1517285 from ALS Environmental Services (Appendix E).

3.2.2 Water Quality

Water samples were analyzed for the following parameters:

- Physical parameters/dissolved anions: conductivity, pH, temperature, DO, TSS, total dissolved solids, hardness, total acidity, and alkalinity (as CaCO₃).
- Nutrients: ammonia nitrogen, nitrate, nitrite, and total phosphate.
- Total and dissolved metals: aluminum, antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, calcium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, phosphorus, selenium, silver, sodium, thallium, titanium, uranium, vanadium, and zinc.
- PAHs: acenaphthene, acenaphthylene, acridine, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, phenanthrene, pyrene, quinoline, and total PAHs.
The lab methods used by ALS for analysis of water include alkalinity by titration using APHA Method 2320 (AWWA 1999); and bromide, chloride, and fluoride using procedures from APHA Method 4110 B (AWWA 1999). Anions were analyzed using Ion Chromatography with Chemical Suppression of Eluent Conductivity and EPA Method 300.0 Determination of Inorganic Anions by Ion Chromatography (Pfaff 1993). Dissolved and total metals were analyzed using inductively coupled plasma mass spectrometry following methodologies from Standard Methods for the Examination of Water and Wastewater and Test Methods for Evaluating Solid Waste SW-846 (AWWA 1999). Ammonia was analyzed by fluorescence (Watson et al. 2005), and phosphorous by colorimetric analysis. PAHs were analyzed using gas chromatography with mass spectrometric detection. Further details on specific methods are provided in the Certificate of Analysis L1517285 (Appendix E).

### Quality Assurance and Quality Control Program

A comprehensive quality assurance/quality control (QA/QC) program was incorporated into the field program and laboratory components of the 2014 sediment and water quality data collection and analysis. The full suite of QA/QC data is presented with the data in Appendix C, Tables C7 and C8, respectively. Duplicate field samples were collected to test the reproducibility of the samples, as well as laboratory quality control data. Duplicate samples were collected at the industry standard rate of 1:10.

Quality assurance criteria for field and laboratory duplicates are ALS Environmental Services’ data quality objectives (DQO) for precision. These state that the relative per cent difference (RPD) needs to be within $20\% + \sqrt{2} \times DL$ multiplied by the detection limit. The square root of two multiplied by the detection limit is added to the RPD to address the variability of the two results near the detection limit, which can have small absolute differences but large relative differences. The DQO for a parameter is met if:

$$\text{RPD} < 20\% + \sqrt{2} \times \text{DL}$$

where

$$\text{RPD} = \frac{|\text{Result1} - \text{Result2}|}{\left(\frac{\text{Result1} + \text{Result2}}{2}\right)}$$

This formula takes into account values that are close to the detection limit and, therefore, have large RPD when the absolute difference is small.

Appendix C, Table C7 provides all the RPD sediment values in the column following the sample data. The RPD between DS091214C and S14-06A were below 20%, with the exception of the gravel portion of the grain size analysis, total organic carbon, and chromium.
All parameters were below 20% between samples DS091214E and S14-13A. Relative per cent differences between DS091114A and S14-26C were generally low, with the exception of sand (1:0.5) and sand (2:1), and total organic carbon. Samples WS14-04 and DS091214B had RPDs greater than 20% in the dissolved fraction of aluminum, iron and TSS. This may be an indicator of filtering error.

3.3.1 Sediment

As noted in the ALS Environmental Services Certificate of Analysis L1516617 (Appendix E), the internal laboratory method blank results indicate that all associated sample results, except for barium in sample L1516617-7 (S14-29B), were at least five times greater than blank values, and are therefore considered reliable. Internal duplicate results indicate eight samples having values outside of the ALS Environmental Services DQO for uranium (Appendix C, Table C5).

3.3.2 Water Quality

The ALS Environmental Services Certificate of Analysis L1517285 (Appendix E) notes that the detection limit was adjusted due to sample matrix effects for fluoride and nitrite in samples WS14-01, WS14-02, WS14-03, WS14-04, and WS14-05. Matrix or sample spike recovery was not accurately calculated due to high analyte background in the sample. Specifically, the sample spike recovery affected samples WS14-01, WS14-02, WS14-03, WS14-04, WS14-05 and DS091214B for parameters orthophosphate, sodium, and calcium. Sample results remain valid despite the adjustment in detection limit, based on other quality control measures such as duplicates, certified reference materials, laboratory control standards, and method blanks.

3.4 Results of New Studies

Analysis of the physical and chemical sediment and water data collected in September 2014 supports the literature review in describing existing riverbed conditions within the LSA. The results are provided in the sections below.

3.4.1 Sediment

Of the 30 samples collected, 14 samples exhibit concentrations of arsenic, chromium, and copper that exceed the CCME ISQG (Figure 3-1). In addition, concentrations of PAHs phenanthrene and pyrene exceed their respective ISQG in four sediment samples, which were also the only samples with PAHs observed above the detection limit of 0.05 mg/kg. Figure 3-1 shows the concentrations of arsenic, chromium, and copper in the sediment samples collected in September, 2014. The sample site locations are shown in Appendix A, Figure 3.
Figure 3-1  Concentrations of Arsenic, Chromium, and Copper in September 2014 Sediment Samples

CCME ISQG = 5.9 µg/g

CCME ISQG - 37.3 µg/g

CCME ISQG - 35.7 µg/g
The average arsenic concentration in sediment samples collected is 5.48 μg/g (STD = 1.76 μg/g), while the maximum observed concentration is 9.13 μg/g (S14-33A). When compared with the CCME ISQG, 14 of the 30 samples collected exceed the CCME ISQG of 5.9 μg/g. These 14 samples were all collected from Deas Slough.

The average chromium concentration across all sites was 35.1 μg/g (STD = 6.67 μg/g), with a maximum concentration of 51.7 μg/g at S14-33A. Twelve of the samples exceed the CCME ISQG of 37.3 μg/g for total chromium. All exceedances in chromium concentrations were found in samples collected from Deas Slough.

Sediment copper concentrations average 24.8 μg/g (STD = 9.4 μg/g), with a maximum concentration of 44.8 μg/g at S14-33A. Only three samples (S14-27C, S14-29B, S14-33A) exhibit a copper concentration greater than the CCME ISQG of 35.7 μg/g. These three samples were collected from Deas Slough.

3.4.1.1 Grain Size Analysis

A detailed analysis was completed on all 30 samples to determine the range of grain sizes found in the study area riverbed sediments. The results are shown in Figure 3-2 as the per cent composition of very fine clay-sized particles (<0.004 mm diameter) to coarse sands (>2 mm diameter).

Figure 3-3 and Figure 3-4 illustrate the grain-size distribution for various core samples. It is evident in these figures that there is a shift in particle composition starting at station S14-02A (Fraser River South Arm) to S14-26A (Deas Slough). The dominant particle size found in the Fraser River South Arm is sand, ranging in diameter from 0.25 to 0.5 mm. The sediment texture shifts to a more diverse and smaller particle size toward and into Deas Slough. The largest per cent of sand and gravel is observed in sample S14-04A, with 1.05% gravel (>2.0 mm diameter). The smallest grain size found is in sample S14-33A with 56.5% silt (0.004 mm diameter) and 29.2% clay (<0.004 mm diameter). The sediment texture of the sample from S14-13A is typical of the most dominant texture of all samples collected, with 80.3% of all sediment falling into the sand category, and a particle diameter range from 0.25 to 0.5 mm. The sample with the largest per cent fraction of sand (80.3% of grains ranged in diameter from 0.25 to 0.5 mm) was collected from S14-13A, located directly beside the Tunnel. The geographic locations of all sample sites are illustrated in Appendix A, Figure 3.
**Figure 3-2**  Per Cent Grain Size in All Samples
Figure 3-3  Grain-Size Distribution for Core Samples (a) S14-26A-E and (b) S14-27A-D
Figure 3-4  Grain-Size Distribution for Core Samples (a) S14-29A-E and (b) S14-05A-B
3.4.1.2 Vertical Characterization of Sediment

The four sediment cores collected from Deas Slough allow for examination of physical and chemical parameters of sediment with depth. Figure 3-3 and Figure 3-4 indicate that grain size is consistent across all depths. In cores S14-26 and S14-05, sands ranging in diameter from 0.063 to 0.125 mm and 0.125 to 0.25 mm, respectively, are the dominant grain sizes. In cores S14-27 and S14-29, grain size is less variable, with silt clearly dominating the sediment grain-size distribution.

3.4.1.3 Vertical Trends in Sediment Chemistry

Total arsenic, chromium and copper concentrations do not exhibit any apparent trend with depth. Figure 3-5 illustrates each core sample (depicted by different colours) by depth. The absence of information on chemical concentration estimates for some cores (e.g., S14-05) at greater depths simply reflects the fact that vibracoring did not result in a recovered sample at this depth.
Figure 3-5  Arsenic, Chromium, and Copper Distribution by Depth in Deas Slough Sediment Cores
3.4.1.4 Covariation of Trace Elements and Sediment Texture

The concentrations of various trace elements in the Fraser River South Arm riverbed and Deas Slough sediments are clearly correlated with the per cent fines (<63 µm: silt + clay fraction) content. This is illustrated in Figure 3-6 for arsenic, chromium, and copper. The relationship between arsenic and per cent of sediment comprising fines is very strong, with a coefficient of determination ($r^2$) of 0.91 out of a possible 1.0. Copper exhibits a similar strong relationship with per cent fines content ($r^2 = 0.93$) while the covariance between chromium and per cent fines composition is only slightly weaker ($r^2 = 0.81$).
Figure 3-6  Linear Regression Analysis between Per Cent Fines (<0.063 mm) and (a) Arsenic, (b) Chromium, and (c) Copper Concentration
3.4.2 Water Quality

General water quality parameters collected during field visits in September 2014 include pH, temperature, DO, and electrical conductivity. All were observed to be within their respective normal ranges. Water temperatures ranged from 16.76°C in the Fraser River South Arm mid-channel to 18.8°C in the middle of Deas Slough, where there is less influence of currents or flow. Dissolved oxygen and pH were observed to not vary appreciably among the five sites. Total suspended solids ranged between 8.8 mg/L at WS14-05 to a maximum of 28.4 mg/L at WS14-03. This reflects the wind and tidal interaction at WS 14-03. A more representative TSS concentration for the RSA in September is characterized at site WS15-02.

Based on tidal predictions for Sand Heads (Vancouver Station #7735), tide height varied by 20 cm between the time of collecting WS14-01 and the time of collecting WS14-03, which is located at the confluence of Woodward Reach and Ladner Reach, at the entrance of Deas Slough (Appendix A, Figure 3). Chloride, sodium, and calcium concentrations clearly indicate that WS14-03 is the area most influenced by the tide during sampling; the highest electrical conductivity and salinity concentrations were measured at this location. This corroborates the conclusions regarding the locally elevated TSS concentrations; i.e., that this sampling location undergoes the greatest mixing of oceanic and fresh water.

Aluminum, chromium, and copper data is presented in Figure 3-7, Figure 3-8, and Figure 3-9 respectively. These three analytes are the only parameters having concentrations that exceed the Canadian Water Quality Guidelines [CWQG] for the Protection of Aquatic Life (CCME 1999b), with the exception of total iron. It is generally accepted that the geological background levels of iron in the Fraser River sediment are higher than the CWQG for the protection of aquatic life (CCME 1999b).

The value of the CWQG for the protection of aquatic life (CCME 1999b) for aluminum is pH-dependent. The average pH in the five water samples collected ranges from 7.07 to 7.84. The CWQG for the protection of aquatic life for aluminum is 100 μg/L if the pH is greater than 6.5. From Figure 3-7, it is evident that total aluminum exceeds the guideline of 100 μg/L in all five samples. The highest aluminum concentration is observed in WS14-01 (699 μg/L). This sample was collected in the Fraser River South Arm at the site furthest upriver in the study area. The complete set of water chemistry data can be found in Appendix C, Table C6.
The CWQG for the protection of aquatic life (CCME 1999b) for chromium is 1 μg/L per litre. **Figure 3-8** provides an overview of the chromium concentrations found in water samples WS14-01 to WS14-05. There are two exceedances of this guideline at site WS14-01 (1.21 μg/L) and WS14-03 (1.25 μg/L). The water samples collected in Deas Slough (WS14-04 and WS14-05) have the lowest concentrations of chromium.

Total copper concentrations in water samples are presented in **Figure 3-9**. Dissolved copper is not included because it does not exceed the CWQG for the protection of aquatic life. The CCME provides an equation that incorporates hardness. The guideline states that if hardness is <120 mg/L, then the guideline is 2 μg/L; if hardness is greater than 180 mg/L, then it is 4 μg/L. If the hardness concentration falls between 82 mg/L and 180 mg/L the following equation is used:

\[
\text{CWQG (μg/L)} = 0.2 \times e^{(0.8545[\ln(\text{hardness})]-1.465)}
\]

Based on this equation, there are two exceedances of the guidelines: WS14-01 (2 μg/L) and WS14-03 (2.2 μg/L). WS14-01 is located mid-channel in the Fraser River South Arm, while WS14-03 is at the mouth of Deas Slough.

**Figure 3-7** Total and Dissolved Aluminum Concentrations in 2014 Water Samples from Study Area
Note: Concentrations of dissolved chromium were below detection limits

Figure 3-8  Total Chromium Concentrations in Grab Samples Collected in 2014 in Study Area

Figure 3-9  Concentrations of Total Copper and Hardness in September 2014 in Water Samples

Total metal analysis incorporates both the dissolved fraction and concentrations present in the particulate fraction of the sample. Other than calcium and magnesium, where concentrations are entirely accounted for in the dissolved fraction, an appreciable portion of the analyte concentration is found in the total minus dissolved (or particulate) fraction. In most cases, this may reflect trace element concentrations in natural minerals contained within suspended particulates that are generally poorly bioavailable, and thus generally non-toxic. Neither PAHs, nor LEPH/HEPH, oil, or grease were detected in any water sample.
4.0 Discussion

4.1 Sediment

Analysis of sediment samples collected in September 2014, in combination with the pre-existing sediment data and information, provide a good understanding of the physical and chemical riverbed characteristics within the study area. The historical data discussed in Section 2.0 and the 2014 data collectively provide insights regarding the bed sediments within the study area. There are strong spatial patterns, with a strong gradient in sediment texture between the navigational channel in the Fraser River South Arm and Deas Slough.

In terms of sediment quality, the only substances that were consistently observed to exceed relevant sediment quality guidelines (i.e., CCME ISQG) in samples collected are arsenic, chromium, and copper. These trace elements occur at higher concentrations in the finer textured (silt + clay) fractions of bed sediments, and their sediment concentrations are strongly correlated with the per cent fines content. Fine-grained sediments (<0.063 mm diameter) preferentially adsorb metals due to high cation exchange capacity, and as a result of higher surface area and adsorption capacity compared with coarse-grained sediments (Ackermann 1980, Salomons and Förstner 1984, Horowitz et al. 1989). This pattern is evident in both historical data and data collected in 2014. This is evident in Figure 3-3, which shows that sediments in or at the mouth of Deas Slough (S14-26 to S14-33) are finer-grained and dominated by clays and silts (0.063 to <0.004 mm).

The relationship between total organic carbon and fine-grained material has also long been established, whereby finer particles hinder oxygen diffusion into the sediments, favouring organic matter conservation through reduced aerobic biodegradation and adsorption of organic particles onto the charged surfaces of clay particles (Tyson 1995). In addition, detrital organic matter has a low bulk density and tends to settle out and be retained only in areas with lower current velocities as the sediment-water interface. The linear regression analysis carried out with particles <0.063 mm, using per cent total organic carbon as the independent variable, results in a strong relationship ($r^2 = 0.76$).

There is no apparent variation in trace element or other analyte concentrations with depth below the riverbed, to a maximum sampling depth of approximately two metres. Clay and silt comprise between 27 and 53 per cent of the total S14-26 core, 73 to 87 per cent of core S14-27, and 67 to 89 per cent of core S14-29. The strength of this evidence for a correlation between per cent fines and trace element concentrations is useful in conjunction with the sediment transport modelling carried out for the Project (NHC 2014) to determine a maximum possible effect...
associated with re-suspension of sediments during Tunnel decommissioning. The sediment concentrations of trace elements and hydrophobic organic contaminants are lower than their respective CCME ISQG, with the exception of samples collected along the southern bank of Sea Reach and in Deas Slough (Appendix A, Figure 3). As such, low risk to water quality as a result of disturbance of existing sediment during tunnel decommissioning is anticipated.

4.2 Water Quality

Data collected from the five 2014 stations indicate that water quality in the Fraser River South Arm is generally good. There are instances of elevated metal concentrations of aluminum, chromium, and copper; however, these occurrences are primarily found in the total phase and can be correlated with the TSS concentrations at the same locations. This indicates that metal concentrations are associated with sediment and dissolved phase trace element concentrations are generally low in comparison with various CWQG for the protection of aquatic life.

Samples collected at stations W14-01 (Fraser River South Arm mid-channel) and W14-03 (mouth of Deas Slough) have the highest TSS concentrations, at 20.2 and 28.4 μg/L respectively, and also include guideline exceedances of aluminum, chromium, and copper. Increased total levels of various trace elements in water with increased TSS is a common trend, where trace elements in the dissolved metals are considered more mobile and more bioavailable. TSS concentrations are expected to fluctuate seasonally, with increased TSS during periods of high flow, such as freshet. This is an important factor to consider during construction. Activities such as densification or stability drilling may re-suspend sediments and increase TSS in the area.
5.0 Closure

This technical data report was prepared and reviewed by the undersigned.

Report prepared by: Hemmera Envirochem Inc.
Report peer reviewed by: Hemmera Envirochem Inc.

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This document represents an electronic version of the original hard copy document, sealed, signed and dated by Debbie Bryant, M.Sc., P.Ag. and Doug Bright, PhD, R.P.Bio. and retained on file. The content of the electronically transmitted document can be confirmed by referring to the original hard copy and file. This document is provided in electronic format for convenience only. Hemmera Envirochem Inc. shall not be liable in any way for errors or omissions in any electronic version of its report document.
6.0 Statement of Limitations

This report has been prepared for the sole benefit of the B.C. Ministry of Transportation and Infrastructure to describe existing conditions of sediment and water quality within a specific study area. This report is based on field studies and desktop studies, and the data presented herein represent sediment and water quality conditions at the time field observation and desktop studies were undertaken.
7.0 References


