Peace Project Water Use Plan

Industry and Taylor Water Quality Assessment

Implementation Year 3

Reference: GMSWORKS-10

Study Period: 2011

Knight Piésold Consulting

April 3, 2012

BC HYDRO
PEACE PROJECT WATER USE PLAN

GMSWORKS #10 – INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

YEAR THREE REPORT

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VA103-14/30-1
Rev 1
April 3, 2012

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PEACE PROJECT WATER USE PLAN

GMSWORKS #10 – INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

YEAR THREE REPORT
(REF. NO. VA103-14/30-1)

Rev	Description	Date	Approved
1	Issued in Final	April 3, 2012	[illegible]
0	Issued in Final	March 20, 2012	SRM

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PEACE PROJECT WATER USE PLAN

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EXECUTIVE SUMMARY

BC Hydro regulates the flow of the Peace River at the WAC Bennett and Peace Canyon Dams, located near Hudson's Hope, BC. The flow regulation had a major impact on the distribution of flows throughout the year with flows decreased during the spring freshet period and increased during the low flow winter period. As a consequence of reduced flood flows, the competence of the river to move bedload has reduced, resulting in a series of morphological changes downstream of the dams, where bed aggradation downstream of tributary confluences is probably the most noticeable change. The dams also interrupted the suspended sediment input from the upper watershed, and an estimated 2.5 million tonnes per year is now trapped in the reservoirs (Church, 2011), which resulted in a decrease of suspended sediments upstream of the Pine River confluence by approximately 65%.

Industrial and municipal users of the Peace River water at Taylor, BC – located approximately 100 km downstream of the Peace Canyon Dam, near the Pine River confluence – have reported ongoing problems with hydraulic function and water quality in their river intakes. It has been suggested that Peace River flow regulation has modified sedimentation patterns in the vicinity of the intakes, with negative consequences on hydraulic function and water quality. In particular, the balance between flows in the Peace and Pine Rivers has been identified as a potential control on sedimentation and water quality conditions at the intake sites. In response to these concerns, the Consultative Committee of the Peace Project Water Use Plan has initiated the Industry and Taylor Water Quality Assessment (GMSWORKS #10).

Knight Piésold Ltd. (KPL) has undertaken three years of study, which included a review of available information, interviews with industrial and municipal stakeholders, site reconnaissance, and collection of field data related to bathymetric surveys, turbidity profiles, suspended sediment concentrations, and sampling of the dredged material from the river intake. It has been found in this study that the intakes have been incrementally affected by flow regulation in the Peace River, in part due to the reduced bedload transport competence of the river. This has caused a general rise in the bed elevation of the Peace River downstream of the Pine River, and has permitted the deposition of fine sediment along the channel margins where the intakes are located. The balance between the Peace and Pine River flows is found not to be a relevant factor related to sedimentation, and the more turbid Pine River water is found not to reach the intake sites under any flow conditions.

The Spectra Energy intake forebay was found to infill with suspended sediments carried by the Peace River, primarily with fine sands that represent the coarsest fraction of the suspended load. In suspension, these sediments are most concentrated in the lower part of the water column, so the aggradation of the Peace River bed near the intake (due to river regulation) may have contributed to an increased input of these materials into the forebay, despite the overall reduction in Peace River suspended sediment load

due to upstream dam construction. There is no practical solution to reverse the ongoing aggradation process in the Peace River below the Pine River confluence.

The sedimentation was found not to be the major cause for the reduced capacity of the District of Taylor groundwater wells. Rather, the reduced functionality appears to be related to the poor water quality at the base of the shallow aquifer, and biological growth and iron precipitation of the well screens.

The Peace River water temperature was identified by stakeholders as a water quality problem that affects the use of river water for cooling. However, Peace River regulation already causes summer water temperatures in the river to be lower than they would be otherwise, due to deep water withdrawal from the reservoir. Furthermore, it was determined during stakeholder interviews that the only industry with significant cooling problems (Canfor Taylor Pulp) uses warm wastewater from another industry (Spectra Energy), not raw river water. There is no apparent connection between BC Hydro's operations and the temperature of the Spectra Energy effluent.

In consideration that all the questions posed in the Terms of Reference have been answered, KPL proposes that this study concludes with this report.

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SECTION 1.0 - INTRODUCTION

BC Hydro regulates the flow of the Peace River at the WAC Bennett and Peace Canyon Dams, located near Hudson's Hope, BC. Industrial and municipal users of river water at Taylor, BC – located approximately 100 km downstream of the Peace Canyon Dam – have reported ongoing problems with hydraulic function and water quality in their river intakes. It has been contemplated that Peace River flow regulation has modified sedimentation patterns in the vicinity of the intakes, with negative consequences on hydraulic function and water quality. Warm water temperatures have also been cited as a concern as they pertain to the use of river water for industrial cooling. In response to these concerns, the Consultative Committee of the Peace Project Water Use Plan has initiated the Industry and Taylor Water Quality Assessment (GMSWORKS #10, BC Hydro 2008).

Knight Piésold Ltd. (KPL) undertook three years of study for GMSWORKS #10 between 2009 and 2011. KPL was able to answer some of the questions posed in the Terms of Reference for GMSWORKS #10 in Year One based on field inspection and stakeholder interviews in September 2009, while answers to the remainder of the questions were deferred until more field data could be collected in Years Two and Three, including field programs during the 2010 and 2011 spring freshets. The review of existing information that was undertaken in Year One also revealed that some of the questions posed in the Terms of Reference did not accurately reflect the physical arrangement of sites in the study and did not adequately consider all of the potential effects of river regulation on sedimentation issues. Therefore, KPL presented a set of refined questions at the end of Year One to guide further studies in Years Two and Three.

The results of the three years of study are presented in this report along with answers to all of the original questions posed in the Terms of Reference. The study area is described in Section 2, while the Terms of Reference and the summary of the intermediate results of the Year One study are in Section 3. The intermediate results of the Year Two study and the study approach for the Year Three are in Section 4.

The remainder of the report (Sections 5 through 9) contains information and data compilation for all three years of the study period. Some of this information was already presented in the reports of the study in Years One and Two; however, most of the sections were updated with new information. The effects of flow regulation on the Peace River hydrology and water temperatures are discussed in Section 5, while changes to channel morphology and to bedload transport are discussed in Section 6. Current and pre-regulation suspended sediment loads and Peace River turbidity are described in Section 7. Information and findings related to the Spectra Energy Intake and to the District of Taylor wells are presented in Sections 8 and 9, respectively. In Section 10 the conclusions of this study are discussed and answers to the questions posed in the Terms of Reference (BC Hydro, 2008) and to additional questions defined by KPL are provided.

1.1 STAKEHOLDER CONCERNS

Stakeholders that expressed concerns with various aspects of the Peace River water quality include the District of Taylor, Spectra Energy, and Canfor Corporation.

The main problems reported by the District of Taylor relate to water quantity and the hydraulic function of their groundwater wells, which provide freshwater to the municipality. The production wells currently in use were installed in 1999 and in 2009.

The Spectra Energy river intake was commissioned in 1957 and has operated continuously since then. The water is used in their nearby McMahon Gas Plant as a cooling agent and as feed-water for an on-site electricity/steam cogeneration operation owned by Alta Gas. The most important concern with the river intake is accumulation and settling of sediments in the intake forebay, and the high concentration of suspended sediments in the intake water, which causes wear on system components.

The Canfor Corporation has operated a pulp mill (Canfor Taylor Pulp) since 1987 at a site immediately to the east of the McMahon Gas Plant. Canfor does not have its own river intake, but uses waste water from the McMahon Gas Plant for cooling and pulp processing.

Summary comments that were obtained through interviews between KPL employees and stakeholder representatives include:

1) The industrial stakeholders reported their problems to BC Hydro first and are experiencing more severe difficulties than the District of Taylor.
2) None of the stakeholders presented a clear hypothesis regarding the role of current BC Hydro operations in their water intake problems.
3) All of the stakeholders are concerned that future construction of the Site C dam could impair their water intake function and water quality, primarily during the construction period.

1.2 INFORMATION FROM OTHER STUDIES

Dr. Michael Church is an emeritus professor in the Department of Geography, the University of British Columbia. He has been studying the Peace River and the morphological changes since regulation for the last 40 years. His work provided valuable information that supported this study (BC Hydro, 1976; Church and Kellerhals, 1989; Ayles, 2001; Church, 2005; Church 2011).

Other sources of information were baseline studies for a potential future BC Hydro hydroelectric facility site referred to as Site C. The proposed Site C is located on the Peace River approximately 19 km upstream of Taylor, just downstream of the Moberly River confluence. The baseline studies conducted in the 1970s and from 2009 to present were also used in this report (BC Hydro, 1976; Golder, 2009a and 2009b; Knight Piésold, 2011b and 2011c).

SECTION 2.0 - STUDY AREA

2.1 PHYSICAL SETTING

The headwaters of the Peace River lie in the Omineca and Rocky Mountain ranges of north-central British Columbia (Holland, 1976). The WAC Bennett Dam is located in a canyon where the river flows eastward through the Rocky Mountain range. The dam, which is located approximately 27 km upstream of Hudson's Hope, impounds the Williston Reservoir. The Peace Canyon Dam, located approximately 7 km upstream of Hudson's Hope, impounds the much smaller Dinosaur Reservoir, which has limited active storage. Downstream of the dams, the Peace River flows eastward and northeastward across the Alberta Plateau toward Lake Athabasca in northeastern Alberta.

The community of Taylor is located on the north (left) bank of the Peace River and approximately 100 km downstream of Dinosaur Reservoir, as shown on Figure 2.1. The Pine River flows into the Peace River immediately upstream of Taylor. The two other major tributaries that flow into the Peace River between the Peace Canyon Dam and Taylor are the Halfway and the Moberly Rivers. These major tributaries both have their headwaters on the eastern slopes of the Rocky Mountains and flow across the Alberta Plateau to join the Peace River. The Peace River is incised approximately 200 m beneath the general surface of the plateau between the dams and Taylor. The major tributaries are similarly incised in their lower reaches as they approach the Peace River.

2.2 GMSWORKS #10 STUDY AREA

The two intakes under investigation in this study are the municipal water intake for the District of Taylor, which actually consists of a cluster of groundwater wells located on an island/bar feature near the north (left) bank of the Peace River, and a surface water intake for the Spectra Energy (Spectra) natural gas processing plant located on the north bank of the river.

The District of Taylor wells are located on a small island/bar feature near the north side of the Peace River, immediately upstream of the Pine River confluence. The District of Taylor pumphouse is located on the north bank of the Peace River approximately 0.3 km downstream of the confluence. The Spectra intake is located on the north bank of the Peace River approximately 1.8 km downstream from the confluence. The powerline and the Highway 97 crossings are located approximately 1.5 km and 2.0 km downstream of the confluence, respectively, and were used to define a 0.5-km section of river encompassing the Spectra intake. The locations of these key sites are shown on Figure 2.2, including the Peace/Pine River confluence. Also shown on the figure are the two locations where turbidity transect were measured. These transects were used to assess the mixing of Peace and Pine River sediment plumes.

Additional sources of information used in this study that are also shown on Figure 2.2 include a Water Survey of Canada (WSC) gauging station and transect "S10" where cross-section surveys were repeated several times since 1968. The WSC gauging station 07FD002 has been in operation since 1944 and is located near the north bank of the Peace River on the Highway 97 bridge pier. The repeated cross-section surveys at S10 provided insight on morphological changes experienced since river regulation.

SECTION 3.0 - TERMS OF REFERENCE AND YEAR ONE STUDY REVIEW

In this section the Terms of Reference and the study questions as presented by BC Hydro (2008) are reviewed. The Year One study approach, followed by the Year One preliminary study results and the refined hypothesis to guide further studies are also presented. The details of the Year One study were presented in a KPL Report VA103-14/16-1 (KPL, 2010a).

3.1 TERMS OF REFERENCE

3.1.1 Background Information and Hypotheses

The Terms of Reference (ToR) for GMSWORKS #10 contain the following background information and hypotheses (BC Hydro, 2008):

1) The industrial and municipal intakes are located on or near the north (left) bank of the Peace River, near the confluence of the Pine River, which enters the Peace River from the south. The ToR refers to the intakes being situated on islands, but only the municipal wells are situated on a bar/island feature that is separated from the main river bank by an ephemeral side channel, while the Spectra intake is situated on the north river bank, not on an island.
2) The stakeholder concerns relate to sediment deposition, which affects the hydraulic function of intakes; suspended sediment concentration, which affects the maintenance requirements of water users; and water temperature, which affects the cooling efficiency of the water.
3) The ToR hypothesizes that sedimentation problems at the intakes appear to be related to the ratio of spring freshet flows in the Peace and Pine Rivers, such that the more sediment-laden Pine River water negatively affects the intakes when Peace River flows are relatively low during the natural spring freshet.
4) No hypothesis was presented regarding the ratio of river flows and water temperature.

The Terms of Reference specify that a five-year study should be initiated to gather information in support of answering the study questions listed below.

3.1.2 Study Questions

The goals of GMSWORKS #10, as per the ToR, are to answer the following questions (BC Hydro, 2008):

1) What physical evidence of sedimentation is there at the water intakes on the islands (*sic*)?
2) What is causing the sedimentation?
    a) What morphological changes are occurring at the Peace-Pine confluence since Peace River regulation?
    b) When, how often, and at what relative Pine River and Peace River flows does sedimentation occur on the islands (*sic*) containing the intakes?
    c) Does turbid Pine River water reach the intakes? If so, for what time period and at what concentration is sedimentation an issue?

3) If sedimentation at the intakes is observed, what is the suspected cause of the sedimentation and what evidence is available to support this hypothesis?
4) Assuming that turbid Pine River water is the cause of the sedimentation, what Peace River flow, at Taylor, would be required to deflect Pine River flows toward the centre of the Peace River and away from the intakes?
   a) Would higher Peace River flows substantially reduce the sedimentation on the water intake facilities and reduce the direct impact on the community?
5) Would increased discharge from the Peace Canyon Dam reduce the summer water temperatures in Peace River?

3.2 YEAR ONE STUDY APPROACH

KPL undertook the following approach in Year One (2009) of GMSWORKS #10:

1) Review existing information and provide an overview of hydrology, sediment transport, and water temperature in the study area.
2) Clarify the nature of the water intake concerns by interviewing stakeholders and making a site reconnaissance in September 2009.
3) Prepare preliminary answers to the questions posed in the ToR, and refine the current hypotheses relating river regulation to the observed problems.
4) Prepare a plan for field investigations in Year Two (2010) to test the revised hypotheses, including a field program for the 2010 spring freshet.

3.3 YEAR ONE RESULTS

The preliminary answers to the questions posed in the GMSWORKS #10 ToR are as follows (KPL, 2010a):

1) *What physical evidence of sedimentation is there at the water intakes on the islands* (sic)*?*

   The District of Taylor groundwater wells are situated on an island/bar feature directly opposite from the Pine River confluence. The bed material consists of formerly mobile cobbles and gravel that are now coated in fine sediment.

   The Spectra Energy surface intake facility is situated on the north (left) bank of the Peace River approximately 1.8 km downstream of the Pine River confluence. Fine sediment accumulates in the intake forebay and is dredged on an annual basis. The average bed elevation of the Peace River has aggraded in this reach by 0.9 to 1.3 m since regulation, as determined by historical channel surveys of cross-section S10 and an analysis of water levels at the nearby WSC Gauge 07FD002. Gravel bars and shoals are continuing to expand between the confluence and the intake site.

2) *What is causing the sedimentation?*

   a) *What morphological changes are occurring at the Peace-Pine confluence since Peace River regulation?*

      The primary cause of the observed sedimentation is the reduced bedload transport competence of the Peace River due to regulation. This has caused formerly mobile bed material upstream of the Pine River confluence to become immobile and to become covered with vegetation and fine sediment. Downstream of the Pine River confluence, regulation has caused the bedload material delivered by the Pine River to build up the elevation of the bed of the Peace River channel. The accumulation of bedload material has also caused the lower Pine River to become laterally unstable and to build a progradational alluvial fan that constricts the width of the Peace River at the confluence.

   b) *When, how often, and at what relative Pine River and Peace River flows does sedimentation occur on the islands* (sic) *containing the intakes?*

      The District of Taylor wells are located directly opposite from the Pine River confluence. Sedimentation at this site is not affected by the instantaneous ratio of the Peace and Pine River flows, but is due to reduced flows in the Peace River.

      The accumulation of bed material in the Peace River at the Spectra intake site is not related to the instantaneous ratio of Peace and Pine River flows, but to the overall capacity of the regulated Peace River to transport the bedload. Based on the available information in Year One, it was not possible to determine whether the sedimentation in the Spectra intake forebay is caused by the deposition of bedload or suspended sediment load carried by the rivers, and more detailed field studies were recommended for Year Two (2010).

   c) *Does turbid Pine River water reach the intakes? If so, for what time period and at what concentration is sedimentation an issue?*

      The District of Taylor wells are located directly opposite from the Pine River confluence and are not affected by the Pine River suspended sediment inflow. The turbid Pine River water does not reach the wells under any flow conditions, because at this location the Peace River flows are pushed against the north bank.

      It also appears unlikely that the Pine River sediment plume reaches the Spectra intake site under typical freshet flow conditions. However, this has been difficult to assess definitively considering the available information in Year One, so more detailed field studies have been recommended for Year Two (2010).

3) *If sedimentation at the intakes is observed, what is the suspected cause of the sedimentation and what evidence is available to support this hypothesis?*

The reduced bedload transport competence of the Peace River due to flow regulation has caused formerly mobile bed material upstream of the Pine River confluence to become immobile and to become covered with vegetation and fine sediments, as observed on the bar/island where the municipal wells are located. Downstream of the Pine River confluence including the Peace River at the Spectra intake, regulation has caused the bedload material delivered by the Pine River to build up the elevation of the Peace River channel.

The observed sedimentation at the municipal wells and the Spectra intake may also be related to increased suspended sediment concentrations in the Peace River in the spring and summer. The decreased seasonal flows from the upper watershed are still competent to move the sediment in suspension, while the inputs of fine sediment to the river downstream of the dams are unchanged. This combination of decreased flows and unchanged sediment inputs results in increased suspended sediment concentrations in the Peace River compared to pre-regulation conditions.

The observed sedimentation at both the District of Taylor wells and at the Spectra intake is related to reduced bedload transport competence and the increased suspended sediment concentrations in the Peace River. However, it was not conclusive after Year One of the study whether this sedimentation was the primary reason for reduced functionality of the wells and the intake, and more detailed studies were recommended for Year Two (2010).

4) *Assuming that turbid Pine River water is the cause of the sedimentation, what Peace River flow, at Taylor, would be required to deflect Pine River flows toward the centre of the Peace River and away from the intakes?*

   a) *Would higher Peace River flows substantially reduce the sedimentation on the water intake facilities and reduce the direct impact on the community?*

   The underlying assumption of question 4) regarding the effect of turbid water from the Pine River causing the sedimentation is likely not valid. Higher Peace River flows would be unable to substantially mobilize the accumulated Peace River bed material, cleanse the bed material of fine sediments and restore pre-regulation channel morphology, as evidenced by the absence of such effects during the prolonged high flows of 1996. However, higher Peace River flows in the spring and summer would likely reduce the concentration of suspended sediments in the river. Based on the results of the Year One study it was not possible to make final conclusions whether sedimentation was the primary cause of the reduced functionality of the municipal wells. Similarly, it was inconclusive whether suspended load or bedload was the primary cause of sedimentation at the Spectra intake.

5) *Would increased discharges from Peace Canyon Dam reduce the summer water temperatures in Peace River?*

BC Hydro's operations already cause summer water temperatures in the Peace River to be cooler than they would be naturally, due to the release of cold water from the deep sections of the reservoirs. Increased summer discharges from the Peace Canyon Dam would likely reduce summer water temperatures in the Peace River even further.

However, it was determined during stakeholder interviews that the only industry with significant cooling problems is the Canfor Taylor Pulp, which uses warm wastewater from Spectra Energy, and not raw river water. There is no apparent connection between BC Hydro's operations and the temperature of the Spectra Energy effluent; therefore, it is recommended that no further consideration be given to water temperature issues.

3.4 YEAR ONE REVISED HYPOTHESES

A set of alternate hypotheses was developed at the end of Year One to guide further investigations. The alternate hypotheses are phrased as questions, similar to the format of the original guiding questions from the ToR.

1) Is sediment deposition at the Spectra Energy intake facility caused by the general increase in Peace River bed elevation in that reach of the river, and by the sheltered hydraulic conditions at the intake that promote suspended sediment deposition?

2) Does the mixing of the Peace and Pine River sediment plumes take place upstream of the Spectra Energy intake facility during freshet flow conditions, despite the relative reduction in Peace River flows? Or does the Pine River plume stay attached to the bank opposite the intake until well downstream of the Highway 97 bridge?

3) Are suspended sediment concentrations in the Peace and Pine Rivers substantially different? Does the mixing of the Peace and Pine River sediment plumes play a key role in determining water quality at the Spectra Energy intake?

4) Has fine sediment deposition on the bar/island feature at the District of Taylor well site reduced the porosity and hydraulic conductivity of the alluvium surrounding the wells? Or is well function related to maintenance issues such as screen fouling?

SECTION 4.0 - YEAR TWO STUDY REVIEW AND YEAR THREE STUDY APPROACH

In this section a brief summary of the study approach and preliminary study results for Year Two, followed by recommendations for further studies and the study approach in Year Three are presented. The details of the Year Two study were presented in a KPL Report VA103-14/16-2 (KPL, 2011a).

4.1 YEAR TWO STUDY APPROACH

The Study approach for Year Two (2010) consisted of the following data collection and analysis tasks (KPL, 2010b):

1) Update the historical channel change analyses presented by Ayles (2001):
    a) Re-survey existing river cross-sections and compare to previous results.
    b) Update the specific gauge analysis of the Water Survey of Canada gauging station on the Peace River near Taylor (Gauge 07FD002).
2) Suspended sediment mixing:
    a) Map the two-dimensional distribution of water depth, velocity, turbidity, and suspended sediment concentration in the vicinity of the Peace/Pine River confluence during freshet conditions to assess mixing.
    b) Use the results from baseline sediment gauging stations in the Peace and Pine Rivers above the confluence to characterize the concentration and grain size of incoming sediment during freshet conditions. These stations have been installed by KPL on behalf of BC Hydro as part of baseline studies for the proposed Site C Clean Energy Project.
3) Spectra intake:
    a) Survey the bathymetry in the Spectra intake forebay area and in the adjacent river channel.
    b) Sample the bed material in the Spectra intake forebay, ideally during dredging, and compare to the adjacent river bed material.
4) District of Taylor wells:
    a) Survey the elevations of the District of Taylor well heads.
    b) Acquire and examine well construction, maintenance, and operation records from the District of Taylor to assess the historical timing of well function problems.
    c) If warranted, make recommendations for a well inspection to determine whether the well problems are due to screen fouling as opposed to changes in the surrounding alluvium.

The goal of these studies was to clarify the nature of suspended sediment mixing downstream of the Peace/Pine River confluence, to relate the elevations of well and intake structures to river bed and water level elevations, and ultimately to test the revised hypotheses that were developed at the end of Year One.

4.2 YEAR TWO RESULTS

The preliminary answers to the revised questions posed in the Year One Report are as follows (KPL, 2010a):

1) *Is sediment deposition at the Spectra Energy intake facility caused by the general increase in Peace River bed elevation in that reach of the river, and by the sheltered hydraulic conditions at the intake that promote suspended sediment deposition?*

   The Spectra Energy intake (installed in 1957) was situated at least 3 m above the thalweg elevation (the lowest point in the river channel) of the Peace River prior to the onset of regulation in 1968. The thalweg rapidly infilled in the first few years following regulation due to decreased flows and reduced bedload transport competence of the Peace River. From 1975 onward, the intake was situated only about 1 m (or less) above the thalweg and was lower than the average bed elevation of the river. This change in relative elevations may contribute to the deposition of fine bedload (sand) and suspended sediment in the intake forebay. Dredging of the forebay to lower elevations (potentially lower than the thalweg bed) inevitably leads to renewed deposition, which explains why routine annual dredging has been required.

   The following sources of information will provide additional insights to this issue:

   a) A volumetric estimate and grain-size analysis of the October 2010 dredgeate that was removed and stockpiled on site, and a comparison to the grain-size characteristics of the Peace River sediment load. This comparison will indicate whether the Peace River sediment load is capable of providing the material that accumulates in the forebay.
   b) An updated post-dredge survey of the intake forebay bathymetry to be conducted in the early spring of 2011, the development of a bathymetric contour map of the adjacent river reach between the powerline and highway crossings based on the June 2010 bathymetric survey data, and an updated comparison of the forebay and river bed elevations. This comparison will provide a visual representation of the river bed bathymetry to better support the discussion of relative bed elevations in the forebay and river bed.

2) *Does the mixing of the Peace and Pine River sediment plumes take place upstream of the Spectra Energy intake facility during freshet flow conditions, despite the reduction in Peace River flows? Or does the Pine River plume stay attached to the bank opposite the intake until well downstream of the Highway 97 bridge?*

   Based on the field work undertaken in 2010, the suspended sediment plumes of the two rivers were observed to remain mostly unmixed between the confluence and the intake under a wide range of relative flow conditions, even though the Pine River plume appeared to encroach far into the Peace River channel at the confluence. Some mixing occurred along the transition between the two plumes, but the plumes retained their original characteristics near either bank of the Peace River in the vicinity of the Spectra Energy intake. Further field work to be undertaken in the Year Three (2011) of the study.

3) *Are suspended sediment concentrations in the Peace and Pine Rivers substantially different? Does the mixing of the Peace and Pine River sediment plumes play a key role in determining water quality at the Spectra Energy intake?*

   The estimation of long-term suspended sediment concentrations and loads in the Peace and Pine Rivers is underway as part of baseline studies for the proposed Site C Clean Energy Project. Turbidity and suspended sediment concentration tended to be substantially higher in the Pine River than in the Peace River during the 2010 spring freshet. However, mixing of the two river plumes does not appear to play a key role in determining water quality at the Spectra Energy intake. Rather, Pine River water appears unlikely to affect the Spectra Energy intake under almost any relative flow conditions. Further field work to be undertaken in the Year Three (2011) of the study.

4) *Has fine sediment deposition on the bar/island feature at the District of Taylor well site reduced the porosity and hydraulic conductivity of the alluvium surrounding the wells? Or is well function related to maintenance issues such as screen fouling?*

   It was learned in Year Two that the existing wells have only been in operation since 1999. Since the pre-regulation (pre-1968) time period is not represented in the history of the wells, there appears to be little justification for the hypothesis that the degradation in performance of these wells is related to regulation. Further, a report by Golder (2009) suggested that the decrease in well function may be a result of well screen fouling.

4.3 YEAR TWO RECOMMENDATIONS FOR FURTHER STUDIES

Based on the results of Years One and Two of the BC Hydro GMSWORKS #10 study, a limited additional work program was recommended for Year Three. There appears to be little justification for continuing with Years Four and Five of the original five-year study program. The proposed scope of work for Year Three consists of the following:

1) Spectra Energy Intake Sedimentation: The results of this study to date suggest that Peace River regulation may have had an effect on sedimentation at the Spectra Energy Intake forebay. The following sources of information will provide additional insights to this issue:

   a) A volumetric estimate and grain-size analysis of the October 2010 dredgeate material that was removed and stockpiled on site, and a comparison to the grain-size characteristics of the Peace River sediment load. This comparison will indicate whether the Peace River sediment load is capable of providing the material that accumulates in the forebay.

   b) An updated post-dredge survey of the intake forebay bathymetry in the early spring of 2011, the development of a bathymetric contour map of the adjacent river reach between the powerline and highway crossings based on the July 2010 bathymetric survey data, and an updated comparison of the forebay and river bed elevations. This comparison will provide a visual representation of the river bed bathymetry to better support the discussion of relative bed elevations in the forebay and river bed.

2) District of Taylor Water Wells: There is no evidence that the reduced functionality of the wells is due to Peace River regulation considering that the wells were installed in 1999. Furthermore, a report by Golder (2009) suggests that the reduced functionality is due to well screen fouling originating from biological growths and iron precipitation. No further work is recommended on this issue.

4.4 YEAR THREE STUDY APPROACH

The study approach for the Year Three (2011) of GMSWORKS #10 consisted of the following data collection and analysis tasks:

1) Spectra intake
    a) Obtain a sample of the dredgeate from the Spectra forebay and obtain the grain size distribution for the sample.
    b) Compare the grain size distribution of the dredgeate to the grain size distributions of the suspended sediment loads in the Peace River.
    c) Develop a bathymetric contour map of the Peace River reach adjacent to the Spectra intake based on the June 2010 bathymetric survey data.
    d) Undertake a post-dredge survey of the Spectra forebay in the spring of 2011 and compare the forebay bathymetry to the adjacent Peace River reach bathymetry.
2) District of Taylor municipal wells
    a) Based on the findings in the Year Two of the study, no further work is to be undertaken on this issue.
3) Compile all existing information collected in Years One and Two and update with new data where appropriate.
4) Prepare a summary report for the entire study period.

SECTION 5.0 - HYDROLOGY

In this section hydrologic information relevant to this study, river regulation effects, and water temperatures are discussed. Most of this information was presented in the Year One Report (KPL, 2010a); however the Figures and Tables were updated to include the most recent data.

5.1 GAUGING STATIONS

The Water Survey of Canada (WSC) records flows in the Peace River at Hudson's Hope (Gauge 07EF001), 10 km above the Pine River confluence (Gauge 07FA004), and 2 km below the Pine River confluence near Taylor (Gauge 07FD002). The locations of the latter two gauging stations are shown on Figure 5.1, while the locations of the District of Taylor wells and the Spectra Energy intake are also shown for reference. The lowermost gauging station on the Pine River is located at East Pine (Gauge 07FB001), approximately 88 km upstream of the Peace River confluence. The periods of record, drainage areas, and mean annual discharges at these gauging stations are provided in Table 5.1. The mean annual discharge values are based on the common period of record for all four stations, which extends from 1980 to 2010, and excludes the year 1986 due to an incomplete record at WSC Gauge 07FA004 in that year.

The incremental drainage area between the Pine River gauging station (Gauge 07FB001) and the confluence with the Peace River is approximately 1,700 km^2, or 12% of the total drainage area at the mouth. However, this part of the watershed lies entirely on the Alberta Plateau and contributes only about 2% of the annual runoff volume at the mouth during most of the year, and 3 % in the highest-flow months of May and June. The relatively small incremental increase in runoff is explained by the much greater unit runoff in the Rocky Mountain headwaters of the watershed. Therefore, the Pine River flows at the mouth have been estimated using the record from Gauge 07FB001, adjusted by 3% to account for the incremental drainage area between the gauge and the mouth. Peace River flows above the confluence can then be estimated by subtracting the Pine River flows from the Peace River flows at Taylor, for the period before the WSC gauge 07FA004 was established. The Pine River record starts in 1961, but has only three complete years of record prior to Peace River regulation in 1967. For that reason it is mainly useful for assessing spring and summer flows in the pre-regulation period rather than annual flows.

5.2 RIVER REGULATION EFFECTS

The WAC Bennett Dam was commissioned in 1967 after which time annual flows in the Peace River were considerably reduced compared to the pre-filling period for a period of four years (1968 through 1971) as Williston Reservoir was filled. Coincidental with the reservoir filling time was a period of draught conditions in the region, which also impacted the annual flows downstream of the dam. From 1972 onward, annual flows were not significantly affected but the seasonal pattern of flows was rearranged based on the timing of hydroelectric energy demand and the ability to store seasonal runoff in the reservoir. The Peace Canyon Dam was constructed after Williston Reservoir was filled, but has a negligible effect on the Peace River flow regime due to the limited storage capacity in Dinosaur Reservoir.

The annual hydrographs of the Peace River at Hudson's Hope and Taylor (WSC Gauges 07EF001 and 07FD002, respectively) are shown on Figure 5.2 for pre- and post-regulation periods. The pre-regulation hydrographs for both stations exhibit typical patterns for a river with a mountainous boreal-zone watershed, in which annual runoff is dominated by snowmelt and, to a lesser extent, by summer rainfall. The hydrographs feature low winter flows, rapidly rising flows in the spring with a pronounced maximum in June, followed by declining flows through the summer and autumn. The post-regulation hydrographs display markedly different patterns, with much more uniform flows year-round. Immediately downstream of the dams at Hudson's Hope, the post-regulation hydrograph typically features maximum flows in the winter when the demand for hydroelectricity is greatest, and minimum flows in the summer when the lowest demand occurs. Further downstream near Taylor, the post-regulation hydrograph includes a reduced peak in the late spring due to tributary inflows, but it is still much different than the pre-regulation hydrograph. The range in water levels between the maximum and minimum mean monthly flows during the post-regulation period at the Taylor gauge (07FD002) is around 1 m. For the same gauge, the extreme range in instantaneous water levels from 2010 to 2012, the period for which continuous data are available from the real-time website, is 2.4 m (WSC, 2012). In comparison, the same information provided in the Year One Report reflected real-time water levels between 2007 and 2009, for which period the extreme range in instantaneous water levels was 2.5 m.

The average annual hydrographs for the Peace and Pine Rivers near the confluence are shown on Figure 5.3, for the common post-regulation period of record from 1980 through 2010 (excluding 1986). The hydrograph for the Peace River above the Pine River confluence (Gauge 07FA004) has an intermediate pattern between the Peace River at Hudson's Hope (Gauge 07EF001) and near Taylor (Gauge 07FD002). Pine River inflows are primarily responsible for the modest spring peak at Taylor. In the Pine River, the highest mean monthly flow occurs in June, at which time the Pine River flow averages 60% of the Peace River flow upstream of the confluence. For comparison, the mean monthly June flow in the Pine River averaged 17% of the Peace River flow upstream of the confluence prior to regulation (1961-1967). Complicating matters, however, is the fact that average June flows in the Pine River have decreased by 26% between these two periods (1961-1967 and 1980-2010), which is reflective of a regional pattern of reduced snowpack accumulation since the mid-1970s (Church, 2005). Had this not occurred June flows in the Pine River would be even larger relative to flows in the Peace River in the post-regulation period, since June flows in the Peace River are independent of snowpack conditions.

Annual maximum daily discharge records for the Peace and Pine Rivers near the confluence are shown on Figure 5.4 for the period from 1961 to 2010. The mean annual maximum daily discharge in the Peace River above the Pine River confluence (Gauge 07FA004) has declined from 6,683 m^3/s in 1961 to 1967, to 2,328 m^3/s in 1980 to 2010 (excluding 1986), a reduction of 65%. It should be noted, however, that the annual maximum daily values in the Pine River (Gauge 07FB001) declined by 28% between these same two periods, similar to the pattern noted above for mean June flows. This is also reflective of the regional pattern of reduced snowpack accumulation since the mid-1970s (Church, 2005). The net result is that the ratio of the Pine to Peace River annual maximum daily discharges increased since regulation from 31% to 64%.

Figure 5.5 represents the exceedence curve for Pine to Peace River daily flow ratios and was developed based on the common period of record from 1980 to 2010 for the two relevant WSC gauges: Peace above Pine (07FA004) and Pine at East Pine (07FD002). The Pine River at the mouth was calculated by adjusting the flows measured at 07FD002 by 3%, as discussed in Section 5.1. For the common period of record, the maximum ratio of 3.9 occurred on July 15, 1982, when the Pine and Peace River discharges were 2493 m^3/s and 639 m^3/s, respectively. It is worth noting that the Pine to Peace River flow ratio of 2 was exceeded nine times, while the flow ratio of 3 was exceeded only two times during the thirty years of record. The minimum flow ratio of 0.01 occurred on April 4, 2002, when Pine and Peace discharges were 21 m^3/s and 2020 m^3/s, respectively. The average flow ratio for the period from 1980 to 2010 was 0.2.

5.3 WATER TEMPERATURE

Water temperatures have been measured in the Peace and Pine Rivers as part of Site C baseline studies in the 1970s (BC Hydro, 1976) and more recently in 2007 and 2008 (Golder, 2009a and 2009b).

In the earlier study (BC Hydro, 1976), a series of manual measurements were taken upstream of the confluence in each river between May and August, 1975. The results are presented on Figure 5.6. Temperatures in the Pine River generally increased from 4ºC in early May to 15ºC in mid-August, although departures of several degrees from a uniform trend occurred at various times. Temperatures in the Peace River started at a similar value in early May, were slower to warm up, but then reached similar values in the summer. Overall, the number of sample points is limited, the sample dates did not always coincide, and only general comments could be made on the basis of this dataset.

In the later study by Golder (2009a, 2009b) continuous temperature records were collected year-round in 2007 and 2008 at sites upstream of the confluence in each river. The average monthly temperatures for May through September of each year are presented on Figure 5.7. Temperatures in the Peace and Pine Rivers are similar in May and June, but summer temperatures are markedly cooler in the Peace River. Temperatures in the Peace River averaged 3ºC to 5ºC cooler than the Pine River temperatures in July and August. In the Peace River, summer temperatures averaged between 11ºC and 13ºC, as compared to 15ºC to 17ºC in the Pine River. By September, temperatures were similar in the two rivers again at around 11ºC to 12ºC. The cooler summer temperatures in the Peace River are presumably caused by the discharge of colder water from deep within the reservoirs. The influence of this cold water is most pronounced in the summer when other flow sources are at their warmest.

SECTION 6.0 - HISTORICAL CHANNEL CHANGE

In this section the sediment sources and the effects of river regulation on the Peace River morphology are reviewed. Further details are provided with respect to the channel changes near the Pine River confluence through a historical air photo review, a review of repeated cross-section surveys, and a specific gauge analysis for the WSC gauge 07FD002. The sediment source, river regulation effects and the historical air photos were discussed in the Year One Report, while cross-section surveys and the specific gauge analysis were discussed in the Year Two report.

6.1 SEDIMENT SOURCES

Prior to regulation, the natural sediment yield from the upper part of the Peace River watershed in the Rocky Mountains was much lower than in the lower part of the watershed on the Alberta Plateau. This is a typical pattern in large river basins in Canada, where the majority of sediment is generated from deep Pleistocene deposits of surficial materials laid down by meltwater and ice, as opposed to the contemporary erosion of mountains (Church *et al*, 1989). The Peace River has incised approximately 200 m into the plateau, where it has mainly cut through glacio-lacustrine deposits of clay and silt, with some inter-bedded glaciofluvial deposits of gravel and sand and a capping layer of glacial till (Mathews, 1978; Hartman and Clague, 2008). The river has cut down through the complete depth of these surficial materials, which ranges between 50 m to 150 m, along its course between the dams and Taylor. Beneath the surficial materials, the river has incised into the underlying shale bedrock.

The surficial deposits along the Peace River were overridden and consolidated by the Laurentide continental ice sheet during the most recent glacial episode that ended around 10,000 years ago. The glacio-lacustrine deposits along the incised valley walls of the Peace River and its tributaries are now highly unstable due to the steepness of the slopes, the decompression of the over-consolidated clays, and the poor drainage conditions in such fine-textured materials (Fletcher *et al*, 2002; Hartman and Clague, 2008). As a result, earthflows and landslides are common along the valley walls, which deliver large quantities of fine sediment to the river channels, particularly during wet conditions in the spring and summer (Photos 1 and 2). The weakly lithified shale bedrock is also prone to rapid weathering and erosion and contributes significant quantities of coarse and fine material to the Peace River and its tributaries. Shale tends to break down rapidly into fine-textured clasts or constituent clay minerals once exposed to fluvial conditions.

Gravel is supplied in relatively small quantities to the Peace River and its tributaries by the erosion of glaciofluvial and alluvial deposits along the main channels and by mountain sources in the tributary headwaters. Bedload transport of gravel and sand in the Peace River has always been much lower in magnitude than the transport of suspended sediment (clay, silt and fine sand), probably around 1% by mass or less (Church, 2005). Prior to dam closure, the bed material of the Peace River consisted primarily of cobble and gravel as far downstream as the town of Peace River, Alberta. This indicates that all finer materials were readily transported by the river and were not found in appreciable deposits on the riverbed until further downstream.

6.2 RIVER REGULATION EFFECTS

Topographic/bathymetric surveys have been repeated over the past several decades at 35 marked cross-sectional transects along the Peace River by Dr. Michael Church, professor emeritus in the Department of Geography, the University of British Columbia (UBC). These transects are located between the Peace Canyon Dam and the BC/Alberta border. The earliest surveys started in 1968, and additional transects were added in 1975. The objective of the survey program was to document channel changes following the commissioning of the WAC Bennett Dam in 1967. The cross-section profiles surveyed between 1968 and 1998 were presented and temporal trends were discussed in a Master's thesis by Ayles (2001). The largest changes in river bed elevations were documented in the vicinity of the Halfway and Pine River confluences, which are the two largest tributaries to the Peace River between the Peace Canyon Dam and the BC/Alberta border.

Following dam commissioning, the reduction in spring freshet flows has had the following effects (Church, 2005):

1) The width of the Peace River channel has decreased as vegetation encroached into marginal areas that are no longer flooded on a regular basis. For example, the alluvial banks and bars upstream of the confluence with the Pine River are generally stable with most bars covered with grassy or deciduous vegetation, which indicates relatively minor rates of mobilization and deposition. The bars exist because of bed material transport prior to regulation, and have been largely transformed into relict features (Photo 3).

2) The lower reaches of tributaries have degraded (eroded vertically) due to reduced backwatering as a result of lower Peace River flows during freshet flows. This is providing extra bedload material to the tributary confluences as the tributary channel profiles adjust.

3) At tributary mouths, bedload material has accumulated due to the reduced competence of the Peace River and the extra bedload supply caused by tributary degradation. This has resulted in local aggradation, lateral channel instability, and tributary fan/delta expansion into the Peace River. For example, a large cobble-gravel bar extends into the Peace River channel at the mouth of the Pine River, indicative of the bedload delivered by the Pine River, which the Peace River is no longer capable of transporting (Photos 4 and 5). The rate of fan/delta expansion is expected to be the greatest in the first few years to decades following Peace River regulation, but may decrease over time as the tributary channels adjust to the new downstream water level regime.

4) The ability of the Peace River to transport suspended sediment (mostly silt and clay) has not been reduced, but concentrations have increased during the spring and summer because the sediment inputs from the lower part of the watershed are now transported within a smaller volume of flow during this part of the year. The suspended sediment concentrations have decreased during the rest of the year, because the flows are increased in the fall and the winter, while the sediment inputs are lower in these periods.

A large, prolonged flow release from the Williston Reservoir with flows continually exceeding 2000 m^3/s that lasted 73 days was undertaken in 1996 to lower the reservoir as a result of dam safety concerns.

The maximum daily discharge of 5720 m^3/s recorded in the Peace River upstream of the Pine River confluence (Gauge 07FA004) in 1996 was approximately 86% of the mean annual maximum daily discharge prior to regulation (based on records from 1961 to 1967). The 1996 flows had a negligible effect on mobilizing bed material or restoring channel width, which indicates that operational strategies to restore bedload transport and channel morphology in the Peace River are not practical (Church, 2005).

6.3 CHANNEL MORPHOLOGY AT THE PINE RIVER CONFLUENCE

6.3.1 Historical Air Photo Review

A historical air photo sequence of the study area is provided on Figure 6.1. Information about the air photos, including dates and river flows, is provided in Table 6.1. Prior to dam commissioning in 1967, the Pine River approached the Peace River in a relatively straight and stable channel, at an angle of approximately 45 degrees from the upstream Peace River channel. An island complex on the south (right) bank of the Peace River immediately downstream of the confluence was likely related to the delivery of bedload sediment from the Pine River, indicating that the bedload input sometimes exceeded the transport capacity of the Peace River prior to regulation. Following dam commissioning, the effects of increased bedload deposition in the vicinity of the confluence are evident. These effects include an increased area of bars in the Peace and lower Pine Rivers, increased lateral instability in the lower Pine River as the flow is forced to shift by the growing bars, and a constriction of the Peace River channel width at the confluence. These effects have also caused the approach angle of the Pine River to change over time, such that it now approaches the Peace River at a nearly perpendicular angle. The rate of lateral channel change appears to have diminished in the past decade or two, consistent with an adjustment of the Pine River channel profile to the new Peace River regime.

A bridge was present across the lower Pine River for short (unknown) period of time in the 1950s (NHC, 1990). The approach roads and bridge were constructed sometime after 1956, as indicated by the 1956 air photo on Figure 6.1, but the bridge is no longer present in 1967. The rock armour on the abandoned bridge approach on the north (left) bank of the Pine River may have contributed to lateral channel instability in that area (NHC, 1990), but probably to a lesser extent than flow regulation in the Peace River.

Photos 6 through 9 taken during a field reconnaissance trip by KPL in September 2009 further illustrate the instability of the lower Pine River. The banks continue to erode rapidly during high flow events, as evidenced by the freshly cut bank faces and exposed roots of floodplain vegetation (Photo 6). Most of the bank erosion occurs in alluvial floodplains where overbank silt deposits overlie riverbed gravels (Photo 7). However, glacio-fluvial, glacio-lacustrine and shale bedrock exposures have also been subject to recent erosion (Photo 8). Gravel bars in the lower Pine River are extensive and unvegetated, indicating active deposition (Photo 9). The extensive bank erosion in the lower Pine River is attributed to lateral channel instability and migration as a result of the increased deposition of bedload materials in the vicinity of the confluence, which in turn is due to the reduced bedload transport competence in the Peace River.

The air photos taken in 1967, 1976, 1987 and 1997 have lighting and turbidity conditions that are most suitable for the identification of suspended sediment plumes at the river surface. In August 1967, June 1976, June 1987, and August 1997, the Pine River flows on the photo dates were 11%, 75%, 58% and 34% of the Peace River flows, respectively (Pine to Peace River flow ratios also shown in Table 6.1). The Pine River plume clearly remained along the south (right) bank of the Peace River downstream of the confluence to the Highway 97 bridge and further downstream. The July 1996 air photos were taken during the large flow release related to dam safety concerns at the WAC Bennett Dam. No Pine River plume can be seen due to extensive backwater influence in the lower Pine River. The differences in seasonal timing and relative river flows at the time that the historical air photos were taken makes it difficult to accurately assess changes in plume mixing patterns, so turbidity measurement were undertaken during field studies in Year Two and Three to further evaluate the mixing patterns, which will be discussed in more detail in Section 8 of this report. However, based on the air photos it appears that the Pine River plume does not fully mix with the Peace River plume upstream of the Highway 97 bridge under the observed flow conditions.

6.3.2 Historical Cross-Section Surveys

The survey data and interpretations contained within this section are based on Master's thesis by Ayles (2001), and on the original cross-section data provided by Dr. Church. The cross-sections surveyed in 2005 were added to the cross-sections reported in Ayles (2001) in the current study. Dr. Church and C. Ayles found that the Peace River bed elevations have aggraded downstream of the Pine River confluence since 1968 (presumably due to the reduced bedload transport competence and capacity of the Peace River under the regulated flow regime). The channel aggradation is thought to be the result of Pine River bedload deposition in the Peace River channel. This material used to be transported more readily down the Peace River during peak flows under the natural flow regime, but has tended to accumulate in the Peace River since regulation. Aggradation in the Peace River below the Pine River confluence has progressed downstream over time as the depositional zone has expanded.

The two sets of cross-section data that support the above assessment are summarized below:

1) Section "S10" is located 2.0 km downstream of the Pine River confluence at the Highway 97 bridge near Taylor (location shown on Figures 2.2 and 5.1). Rapid aggradation occurred at Section S10 between 1968 and 1975. The thalweg elevation, located close to the north side of the channel, changed from 396.5 m to 398.7 m (a rise of 2.2 m), and elsewhere on the cross-section a maximum aggradation depth of 3.2 m was recorded. The aggradation continued at a slower rate through the 1970s and 1980s and appeared to have stabilized by the 1990s, as shown on Figure 6.2. The latest thalweg elevation surveyed in 2005 is at elevation 398.9 m, a rise of 2.4 m with respect to the 1968 thalweg.

2) Section "125" is located 3.5 km downstream of the confluence and 1.5 km downstream of the Highway 97 bridge (location shown on Figure 5.1). This cross-section was first surveyed in 1975, so the initial channel response following dam closure was not recorded. However, ongoing aggradation has been recorded at this section up until 2005, and the amount of aggradation between 1998 and 2005 seems unusually high and is close to 2 m in some sections (Figure 6.3).

6.3.3 Specific Gauge Analysis

Specific gauge analysis is a technique used to analyze changes over time in the stage-discharge relation at a given site on a river. Such changes are indicative of changes in the hydraulic controls that govern the stage-discharge relation at the site of interest, primarily channel geometry and channel roughness in the downstream reach that influences water levels at the site. A specific gauge analysis tracks the river stage (water level) associated with a specific selected discharge over period of gauge record, based on sequential stage-discharge rating tables. If the stage values associated with the specific discharge are found to increase over time, for example, this is indicative of increased channel bed elevation, constricted channel geometry, increased channel roughness, or some combination of these factors. The precise cause of the altered stage-discharge relation cannot be determined from a specific gauge analysis. Rather, the analysis provides supplementary information that can be used in conjunction with other sources of information (such as channel cross-section surveys) to make inferences about river channel changes over time.

The Water Survey of Canada (WSC) has operated the streamflow gauging station 07FD002 at the Highway 97 crossing near Taylor since 1944. Ayles (2001) presented a specific gauge analysis that tracked the river stage (water level) associated with a specific selected discharge over the period of gauge record, based on sequential stage-discharge rating tables developed by the WSC. The specific gauge analysis by Ayles (2001) was based on 32 stage-discharge rating tables covering the period of gauge record from 1944 through 1999. The WSC developed another three rating tables between 1999 and 2010. These rating tables have been obtained and used to update the analysis of Ayles (2001). New rating tables were developed by the WSC each time a significant shift in stage-discharge relationship at the gauge site was identified. The relatively large number of rating tables is indicative of the instability in the stage-discharge relationship at this gauge site. A new rating table was developed approximately every 2 years, on average, over the period of gauge record.

The specific discharge is typically chosen to be indicative of a flow somewhat less than the bankfull flow to avoid breaks in the rating curve at overbank flows, but sufficiently high to avoid localized channel changes that affect the stage-discharge relation only at low flows. Ayles (2001) selected a discharge value of 4,515 m^3/s (equivalent to 0.6 times the pre-regulation mean annual flood of 7,525 m^3/s) for the specific gauge analysis at 07FD002. This flow is less than bankfull but represents a relatively high flow condition in the regulated flow regime (the annual maximum daily discharge exceeded this value in only four years between 1968 and 2010). The stage values corresponding to this discharge value on sequential rating tables are plotted on Figure 6.4. Each rating table has a specific period of application, so all transitions between rating tables appear as step-wise shifts on the figure. A new gauge datum was established in 1960, so the stage values prior to 1960 are plotted relative to the left-hand y-axis, and the stage values from 1960 onward are plotted relative to the right y-axis. The absolute stage values are not relevant to this analysis; the purpose of Figure 6.4 is to display the changes in stage over time.

The stage-discharge relationship at WSC gauging station 07FD002 was unsteady prior to the onset of river regulation in 1968. The stage associated with the specific discharge of 4,515 m^3/s rose by 0.5 m between 1945 and 1949, then declined by 0.4 m between 1953 and 1956, followed by another rise of 0.3 m between 1960 and 1964. These changes are attributed to natural variability in channel morphology in the Peace River, likely related to occasional large bedload inputs from tributaries (particularly the Pine

River) and occasional large floods in the Peace River. Following the onset of regulation in 1968, the cyclical pattern of stage changes ceased and was replaced by a small rise in stage soon after regulation (a rise of 0.2 m between 1972 and 1974), followed by a larger rise in stage following the high flows of 1996 for the drawdown of Williston Reservoir (a rise of 0.4 m). The small increase in stage in the early 1970s coincides with the surveyed aggradation at nearby cross-section S10 (location indicated on Figure 5.1). The larger increase in stage in the 1990s coincides with the surveyed aggradation at cross-sections further downstream, such as cross-section 125 (Figure 5.1), indicating that water levels at Taylor continued to be affected by the downstream extension of Pine River bed material deposits in the Peace River. Taken together, these results show that the Peace River was naturally dynamic prior to regulation, with cycles of river channel changes that caused water level shifts on the order of 0.5 m at a specific discharge. Following regulation, these cyclical river channel changes have been replaced by a unidirectional change with water levels rising by around 0.6 m over time. The specific gauge analysis supports the conclusion that the Peace River bed has been aggrading downstream of the Pine River confluence due to the build-up of Pine River bedload material – not just at the surveyed cross-section locations, but throughout a sufficient portion of the river channel to cause the observed changes in water level at Taylor.

SECTION 7.0 - SUSPENDED SEDIMENT TRANSPORT IN THE PEACE AND PINE RIVERS

In this section the data related to suspended sediment transport and to turbidity profiles collected in the Peace and Pine Rivers is reviewed. The information presented in the Year One and Two Reports was updated with the new information collected during the 2010/2011 KPL suspended sediment field program.

7.1 SUSPENDED SEDIMENT LOAD IN THE PEACE AND PINE RIVERS

7.1.1 Annual Load

The suspended sediment input from the Peace River watershed upstream of the WAC Bennett and Peace Canyon dams is proportionally much less than the sediment inputs from the rest of the watershed. As discussed in Section 6.1, the headwaters of the Peace River lie in the Omnieca and Rocky Mountain ranges and contribute more flow and less sediment per unit area than the lower parts of the watershed that cut through the Alberta Plateau. Church (2011) estimates that the input of suspended sediments from the upper watershed is approximately equivalent to 2.5 million tonnes per year, or 37 t/km^2/yr. It is assumed that post-regulation most of the sediment from the upper watershed settles in the large Williston reservoir and that the outflows from the Peace Canyon Dam contain negligible amounts of suspended sediment compared to suspended sediment loads carried by other tributaries.

Suspended sediment concentrations have been sampled in the Peace and Pine Rivers as part of Site C baseline studies in the 1970s (BC Hydro, 1976) and more recently by Golder and KPL (Golder 2009a, 2009b, KPL 2011b). KPL used these data to develop estimates of mean annual suspended sediment load (for the period 2000-2009) in the major Peace River tributaries and at WSC gauging station 08FA004 on the Peace River mainstem (KPL 2012). The results are presented in Table 7.1. These results differ from those presented in the Year One report, which were developed by BC Hydro (1976) using a more limited sample dataset and a different period of flow record.

The estimated mean annual suspended sediment load in the Peace River above the Pine River confluence (WSC Gauge 07FA004) is 1.36 million tonnes per year. The entire suspended sediment load is assumed to be provided by the drainage area below the Peace Canyon Dam (95 t/km^2/yr.). If the upstream dams were not in place, the mean annual load would have been 3.9 million tonnes per year.

The estimated mean annual suspended sediment load in the Pine River is 2.2 million tonnes per year (160 t/km^2/yr.) In the post-regulation regime, this load is 1.6 times greater than the Peace River load above the confluence. In the pre-regulation regime (disregarding natural variability in flow and sediment transport), this load would equate to 0.6 of the Peace River load.

7.1.2 Concentration and Grain Size

The Pine River suspended sediment load is transported by a smaller flow than the Peace River, so suspended sediment concentrations in the Pine River are higher on average than in the Peace River. The Pine River transports 1.6 times more suspended sediment than the Peace River (2000-2009) with a mean annual flow of 0.15 of the Peace River mean annual flow (Table 5.1), meaning that the average concentration in the Pine River is about 10 times greater than the Peace River, using a mass balance approach (as opposed to a temporal average of instantaneous conditions).

Grain size analyses on the samples indicated that the suspended sediment in the Pine River was coarser than in the Peace River. The suspended sediment loads in both rivers are dominated by silt-sized material, but the Pine River transports proportionately more sand and less clay than the Peace River.

The Peace River samples contained 26-43% clay (average: 33%), 52-66% silt (average: 61%), and 1-13% sand (average: 5%). The Pine River samples contained 11-33% clay (average: 24%), 56-67% silt (average: 61%), and 2-33% sand (average: 15%).

7.2 TURBIDITY TRANSECTS

7.2.1 Methods

The mixing of the Peace and Pine River suspended sediment plumes was assessed by the collection of near-surface turbidity data on two cross-sectional transects located downstream of the Peace/Pine River confluence, on three separate dates during the 2010 spring freshet, and once during the 2011 spring freshet. The turbidity transects were located at the District of Taylor pumphouse and at the powerline crossing located near the Spectra intake (Figure 2.2), approximately 0.3 km and 1.5 km downstream of the confluence, respectively. It was shown during the 2010/2011 KPL suspended sediment sampling program that turbidity is strongly correlated to suspended sediment concentration in the Peace and Pine Rivers (KPL, 2011b), so the turbidity data collected along the two transects are considered a good indication of suspended sediment mixing. Channel bed profiles and horizontal positioning were obtained using an Acoustic Doppler Current Profiler (ADCP) shown on Photo 10, while the turbidity data was collected using an Analite NEP 160 turbidity sensor shown on Photo 11.

Additional turbidity transects were collected during the 2011 KPL suspended sediment sampling program that provide additional insight on the mixing processes in the Peace and Pine Rivers. These include repeated turbidity transects in the Peace and Pine Rivers, as well as one transect on the Peace River 20.4 km downstream of the Pine River confluence. The results for these turbidity transects will be discussed in Section 7.2.2.2.

7.2.2 Pine to Peace River Flow Ratios

Two turbidity transects were collected at two locations downstream of the Pine River confluence on May 15 and May 29, 2010. One turbidity transect was collected on June 3, 2010 and on May 19, 2011 at the powerline location only, when there was an instrumentation problem experienced while collecting data at the pumphouse transect. On each date, there was a different combination of flows in the two rivers (Figure 7.1), but turbidity (i.e. suspended sediment concentration) was always greater in the Pine River than the Peace River upstream of the confluence.

The following observations can be made for the dates when the turbidity transects were recorded:

- May 15, 2010: The Pine River flow was 0.42 times the Peace River flow above the confluence. This was the lowest ratio of Pine to Peace River flows observed during the collection of turbidity transect data. Even at this relatively low flow ratio, the turbid Pine River plume extended more than halfway across the Peace River channel toward the north (left) bank immediately below the confluence (near the pumphouse). Based on the exceedence curve shown on Figure 7.1, the Pine River discharge is 42% or higher than the Peace River flow 13.8% or less of the time (50 days a year).

- May 29, 2010: The Pine River flow was 1.31 times the Peace River flow above the confluence. At this ratio of Pine to Peace River flows, the visibly more turbid Pine River plume extended closer to the north (left) bank of the Peace River immediately below the confluence, but did not reach the north bank. Figure 7.1 illustrates that the Pine River flows are more than 1.31 times higher than Peace River flows for only 1.45% of the time.
- June 3, 2010: The Pine River flow was 1.12 times the Peace River flow above the confluence. This was an intermediate condition between the two previous data collection events and this flow ratio is exceeded 2.5% of the time (Figure 7.1).
- May 19, 2011: The Pine River flow was 1.27 times the Peace River flow above the confluence (exceeded 1.55% of the time based on Figure 7.1). This event was close to the maximum flow ratio recorded in 2010 and the turbid Pine River plume again extended more than half way across the Peace River channel, but did not extend all the way to the north bank. Rather, the Pine River pushes the Peace River water closer to the north bank.

In comparison, the Pine to Peace River flow ratios shown on the historic air photos on Figure 6.1 range between 0.07 during the 1996 high flow releases from the WAC Bennett Dam and 0.75 in 1976 when the Pine River flow was the largest as compared to the Peace River upstream of the confluence. Based on Figure 7.1, the 0.07 flow ratio from 1996 is exceeded 51.1% of the time, while the 0.75 ratio from 1976 is exceeded 6.6% of the time. The second lowest flow ratio of 0.11 visible on the 1967 air photo is exceeded 38.2% of the time, while the 1987 flow ratio of 0.58 is exceeded 9.7% of the time.

Based on the exceedence curve shown on Figure 7.1, the Pine River plume visible on the historic air photos or measured in 2010 and 2011 is representative of medium to high Pine to Peace River flow ratios, with the highest ratio of 1.31 being exceeded only 1.45% of the time, which is equivalent to 5.3 days in a year. The Pine River plume was visibly attached to the right bank of the Peace River at least 1.5 km downstream of the confluence or farther on all examined dates. This is due to the channel geometry downstream of the confluence and lack of structures that would encourage intense and immediate turbulent mixing between the two river plumes. For this reason, the Peace River flow is pushed against the north river bank, and hence, the Peace River turbidity is observed along that bank. During the highest measured Pine to Peace River ratio of 1.31, it was observed that the Pine River plume extended up to 55 m from the north bank. At Pine to Peace River ratios higher than 1.31, it is reasonable to expect that this distance may decrease further, and at extreme ratios it is conceivable, but not very likely that the Pine River plume may reach the north bank. As discussed in Section 5.2, the Pine to Peace River flow ratio of 2 was exceeded nine times, while the flow ratio of 3 was exceeded only two times during the thirty years of record.

7.2.3 Turbidity Transect Results

The results of the turbidity data collected at the two transects just downstream of the Pine River confluence are presented on Figures 7.2 through 7.7 and discussed in Section 7.2.3.1, while Figures 7.8 and 7.9 show turbidity profiles at two other locations on the Peace River and are discussed in Section

7.2.3.2. The dates, locations and flows recorded during turbidity transect measurements are shown in Table 7.2.

7.2.3.1 Turbidity Profiles Near the Pine/Peace River Confluence

On May 15, 2010, a sharp distinction in turbidity could be seen at the pumphouse transect immediately downstream of the confluence (Figure 7.2) between Pine River water (with a turbidity of 60 to 80 NTU) and Peace River water (with a turbidity of less than 10 NTU). The turbidity transition was located approximately 75 m from the north (left) bank of the Peace River. Further downstream at the powerline crossing on the same date (Figure 7.3), the turbidity profile was more gradual with a strong turbidity gradient present across the channel, ranging from less than 10 NTU near the north (left) bank to greater than 60 NTU near the south (right) bank. The implication is that some mixing had taken place along the transition zone between the two plumes, but the two plumes were still far from fully mixed and had largely retained their original characteristics close to either bank.

On May 29, 2010, another sharp distinction in turbidity could be seen at the pumphouse transect (Figure 7.4) between Pine River water (with a turbidity of 150 to 275 NTU) and Peace River water (with a turbidity of around 50 NTU). This time the turbidity transition was located approximately 55 m from the north (left) bank of the Peace River. Further downstream at the powerline crossing on the same date (Figure 7.5), the distinct turbidity transition was not observed, but a strong turbidity gradient was still present across the channel. Turbidity at the powerline crossing ranged from around 50 NTU near the north (left) bank to around 275 NTU near the south (right) bank. Again, some mixing had taken place along the transition zone between the two plumes, but the two plumes were still far from fully mixed and had retained their original turbidity characteristics close to either bank.

The June 3, 2010 turbidity transect at the pumphouse could not be plotted because there was a problem with the ADCP data required for horizontal positioning. However, a sharp transition between the two river plumes was observed in the field. The Pine River plume had a turbidity of around 120 NTU, while the Peace River plume had a turbidity of around 40 NTU. Further downstream at the powerline crossing on the same date (Figure 7.6), a strong turbidity gradient was present across the channel. Turbidity at the powerline crossing ranged from around 40 to 50 NTU near the north (left) bank to around 120 NTU near the south (right) bank. Again, some mixing had taken place along the transition zone between the two plumes, but the two plumes were still far from fully mixed and had retained their original turbidity characteristics close to either bank.

The May 19, 2011 turbidity transect was collected at the powerline location, while the transect collected at the pumphouse resulted in erroneous data due to instrument malfunction and is not shown on a figure. The turbidity and the flow recorded on this date were the highest for all dates when turbidity profiles were measured at these locations. The turbidity at the powerline crossing ranged from about 750 to 800 NTU near the north (left) bank to over 1500 NTU near the south (right) bank (Figure 7.7). There is a visible transition between the two plumes approximately 85 m from the north bank and there is evidence that some mixing had taken place, but the two plumes are not fully mixed and the turbidity along the right (Pine River) bank is markedly higher.

7.2.3.2 Turbidity Profiles at Other Peace River Locations

Four turbidity transects were collected on the Peace River above Pine River near WSC gauge 07FA004 located approximately 10.2 km upstream of the Pine River confluence and 6.3 km downstream of the Moberly River confluence, near the community of Old Fort (Figure 7.8). Flows ranged between about 700 and 1,300 m^3/s at the time of transect measurements. Each turbidity transect has a higher value on the left bank than on the right bank, with a relatively gradual decline in turbidity across the channel, indicating that the Peace River is not completely mixed transversely at this location. The higher turbidity along the left bank is due to the fact that most of the tributaries bringing in suspended sediment loads between the Peace Canyon Dam and this location join the Peace River from the left side (Lynx Creek, Farrell Creek, Halfway River, and Cache Creek). The Halfway River is by far the largest contributor of suspended sediments and it is worth noting that its confluence is over 39 km upstream of this location. The only larger tributary along the right bank upstream of this location is the Moberly River, but its sediment contribution was relatively low compared to the other tributaries at the time of the transect measurements. The suspended sediment yield in the Moberly River is lower than the sediment yields in other nearby tributaries, which is likely due to sediment trapping by the Moberly Lake.

The Peace above Beatton transect is located 1.1 km upstream of the Beatton River confluence and 20.4 km downstream of the Pine River confluence. The turbidity is higher on the right bank (Figure 7.9), likely due to high suspended sediment load from the Pine River. Similar to the results for the Peace River above Pine River transect shown on Figure 7.9, this figure indicates that the Peace River is not fully mixed transversely and that the impact of turbid inflows from the large tributaries like the Halfway and the Pine Rivers could be detected for tens of kilometres downstream of their confluences.

SECTION 8.0 - SPECTRA INTAKE

In this section an overview of the Spectra intake arrangement and conditions is provided along with the findings of this study that are relevant for answering the questions posed in the ToR (BC Hydro, 2008).

8.1 OVERVIEW

Spectra Energy withdraws river water through a surface intake structure situated on the north (left) bank of the Peace River (Photos 12 and 13), located approximately 1.8 km downstream of the Pine River confluence and 0.2 km upstream of the Highway 97 bridge. The river intake was commissioned in 1957 and has operated continuously since. The water is used in the nearby McMahon Gas Plant as a cooling agent for their natural gas processing operations, and as feed-water for an on-site electricity/steam cogeneration operation owned by Alta Gas.

The Canfor Corporation (Canfor) operates a pulp mill (Canfor Taylor Pulp) at a site immediately to the east of the McMahon Gas Plant. Canfor does not have its own river intake. Instead, it uses waste water from the McMahon Gas Plant for cooling and pulp processing purposes and is for that reason reviewed within this section. The mill has been in operation since 1987.

8.2 SITE VISIT AND STAKEHOLDER INTERVIEWS

Craig Nistor, P.Geo., and Mediha Hodzic, E.I.T., of KPL made a site visit to the study area on September 8-9, 2009 to inspect the river intakes and interview the stakeholders. The area of investigation extended from the Highway 97 bridge to the Moberly River confluence on the Peace River (a channel distance of 19 km), and the lower 3 km on the Pine River. The locations of the meetings and the personnel involved are summarized below. The interview meeting minutes were provided in Appendix A of the Year One Report (KPL, 2010a).

1) Spectra Energy Office
    a. Don Lacey, Spectra Director of Operations
    b. Glen Lawrence, Spectra Chief Engineer
    c. Darren Wait, Spectra Area Business Leader

2) Spectra Energy Intake Site
    a. Derek Hutchings, Spectra Staff Member

3) Canfor Office via Telephone
    a. Hal Bulmer, Canfor Production Manager

8.2.1 Spectra Energy

The boat-based reconnaissance was carried out between 09:30 and 12:00 MST on September 9, 2009. The river discharges at the time were approximately 80 m^3/s in the Pine River and 925 m^3/s in the Peace River upstream of the confluence. These flows represent 65% and 76% of the mean monthly values for

September for the post-regulation period, respectively (as defined by the period 1980-2010). The water in both rivers was slightly turbid, but the river bed could be seen at depths of up to 1 m or more. According to the interviewed stakeholders and the boat operator, the river was more clear than it had been throughout the past few months. The following observations specific to the Spectra intake were made during the site visit:

1) The Spectra intake facility is situated in a slight embayment on the north (left) bank of the Peace River, where suspended sediment would be expected to deposit due to a back eddy and calmed flow conditions that typically form under this type of sheltered conditions (Photos 12 and 13).

2) A shoal (submerged bar) of finer gravel exists in the middle of the Peace River channel immediately opposite of the Spectra intake (Photo 14), representing bedload material that has moved a short distance down the Peace River channel from the Pine River confluence, and has deposited due to the lack of transport competence. The water depth over this shoal was less than 0.5 m during the site reconnaissance.

3) Two aggregate mines are located along the north (left) bank of the Peace River between the District of Taylor wells and Spectra Energy intake sites. One of the mines uses a series of settling ponds immediately adjacent to the river channel for settling fine sediment out of its site runoff water (Photo 15). The river bank along this area has been eroding in the past few years and a series of rock and rubble spurs have been constructed to resist the erosion. This problem may be related to the constriction of the Peace River at the Pine River confluence. Both the settling ponds and the additional erosion of the Peace River left bank a short distance upstream of the Spectra intake are likely contributing additional fine sediments into the river that can potentially end up in the forebay.

The Spectra intake was constructed in 1957, or 10 years prior to dam commissioning. The interviewed staff assume that high sediment concentration in the water has always been a problem. The intake opening measures approximately 5 m high by 4 m wide. Annual dredging is required to remove accumulated fine sediments that block the lower half of the opening. The main problems reported by Spectra Energy relate to this accumulation of fine sediment in the forebay of the intake facility, which impairs hydraulic function and encourages sediment entrainment into the intake water. Furthermore, the high concentration of suspended sediment in the intake water causes wear on system components, requires frequent and costly maintenance of sediment-clogged components, and reduces cooling efficiency. However, the temperature of the river water is a secondary consideration as it relates to cooling efficiency for the Spectra Energy.

The dredgeate from the Spectra intake has not been quantitatively characterized in the past, but is generally described by Spectra staff as being fine textured (i.e. presumably sand and silt, but not gravel). Spectra does not maintain water quality records, but staff were able to state that miscellaneous measurements of intake water turbidity have been as high as 5,000 NTU on occasion. The staff were unable to identify from memory any seasonal patterns in intake water turbidity or sediment-related maintenance issues. The sediment that is removed from the plant equipment during periodic maintenance is described as mainly silt and clay.

The interviewed staff did not provide a clear hypothesis regarding the role that BC Hydro's operations might play in these problems, and they specifically rejected the hypothesis that the ratio of Peace and Pine River freshet flows may be important. Their general comment was that both the Peace and Pine Rivers are naturally very sediment-laden, sedimentation has always been an ongoing problem, and that suspended sediment in the Peace River is likely the main source of the problem.

8.2.2 Canfor Corporation

The main problem reported by Canfor relates to water temperature, which affects cooling efficiency. Sediment concentration is a secondary concern as it relates to water quality for pulp processing. Canfor receives warm wastewater from Spectra's plant, and Canfor feels that the high temperature is directly related to Spectra's operations – especially the cogeneration operation – rather than the temperature of the raw river water. Thus, Canfor does not consider BC Hydro's operations to be a significant source of their temperature problem. Sediment concentration in the wastewater is not of particular concern to Canfor because most of the sediment is filtered out within Spectra's plant. Considering that Canfor does not have a direct river intake and that it uses waste water from Spectra, there will be no further discussions related to their reported water temperature issues in this report.

8.3 SPECTRA FOREBAY SURVEYS

Three bathymetric profiles were surveyed by KPL staff using an Acoustic Doppler Current Profiler (ADCP) in the Spectra Energy intake forebay area. Profiles were surveyed in the inner forebay area directly in front of the intake screen and in the middle part of the forebay on June 1, 2010 and May 3, 2011. For these two profiles, the ADCP raft was pulled across the forebay using a hand line. A third profile was surveyed along the outside of the log boom on June 3, 2010. For this profile, the ADCP was towed alongside a jet boat and the profile was not resurveyed in 2011. The locations of all three transects are shown on Figure 8.1.

All surveys were made with reference to the river water level at the time of survey (i.e. depth measurements relative to the current water level). The water level during each survey was measured relative to a temporary reference mark on the upstream wing wall of the forebay. The geodetic elevation of this temporary reference mark was surveyed by Capella Geomatics Inc. on October 23, 2010. All surveyed water levels and forebay bed elevations were adjusted to geodetic datum based on the surveyed reference mark elevation.

The June 1, 2010 survey occurred during the falling limb of the 2010 spring freshet hydrograph and additional infilling would have occurred before the forebay was dredged in October 2010. Some infilling also likely occurred between the time the forebay was dredged in October 2010 and resurveyed on May 3, 2011, prior to the peak of the 2011 freshet. The surveyed bathymetric profiles of the intake forebay are presented on Figures 8.2 through 8.4. The average bed elevation at the intake opening (inner forebay profile) was close to 400.0 m in 2010, and visibly lower and as low as 399.5 m in 2011, as shown on Figure 8.2. The bed elevation in the middle part of the forebay averaged around 400.5 m in 2010 and was not visibly lower for most of the transect in 2011, as shown on Figure 8.3. The river bed elevation along the log boom in front of the forebay mostly ranged between 400.0 m and 400.5 m, as shown on Figure 8.4.

One possible explanation for similar mid forebay transects in 2010 and 2011 is that there was deposition occurring in the period between the forebay dredging in October 2010 and the resurvey in May 2011. Another possible explanation is that the dredging may have been more intensive directly in front of the intake opening, and not as much in the mid forebay area.

Boat-based bathymetric surveys of the Peace River in the vicinity of the Spectra intake were conducted by Capella Geomatics Inc. in June 2010. The bed elevations in the intake forebay were approximately the same or somewhat lower than the general bed elevation in the adjacent river channel, as shown with the contour plot on Figure 8.5 and cross-sections on Figure 8.7. The average river bed elevation between the powerline crossing and the Highway 97 bridge in July 2010 was 401.1 m, or 1.1 m higher than the bed elevation at the intake opening (400.0 m).

The Peace River thalweg (the lowest point in the river channel) is closer to the right bank at the powerline crossing (Figure 8.6), and gradually shifts towards the left bank by the Highway 97 bridge (Figure 8.8). The bed elevations in the intake forebay were somewhat higher than the river thalweg elevation in July 2010. The extreme minimum elevation between the powerline crossing and the Highway 97 bridge was 398.7 m (XS 1 on Figure 8.6), and the thalweg elevation at Section S10 was 399.5 m (approximately equivalent to XS 10 on Figure 8.8). These elevations are 1.3 m and 0.5 m lower, respectively, than the bed elevation at the inner forebay (400.0 m). For comparison, the 1968 thalweg elevation at Section S10 was 396.5 m, or 3.5 m lower than the 2010 bed elevation at the intake opening. The thalweg at Section S10 during the last cross-sectional survey in 2005 was at 398.9 m, which indicates that the aggradation is ongoing and that an additional 0.6 m of deposition occurred in this area between 2005 and 2010.

The general conclusion to be drawn from the comparison of elevations above is that the Spectra Energy intake was initially situated at least 3 m above the thalweg elevation of the Peace River prior to regulation, and that the thalweg rapidly infilled in the first few years following regulation. From 1975 onward, the intake was situated only about 1 m (or less) above the thalweg elevation and was lower than the average bed elevation of the river. This may encourage migration of bedload transported by the Peace River into the Spectra forebay. More insight on the type of material (i.e. bed load vs. suspended load) deposited in the forebay can be obtained from the grain size analysis of the dredged material discussed in the next section.

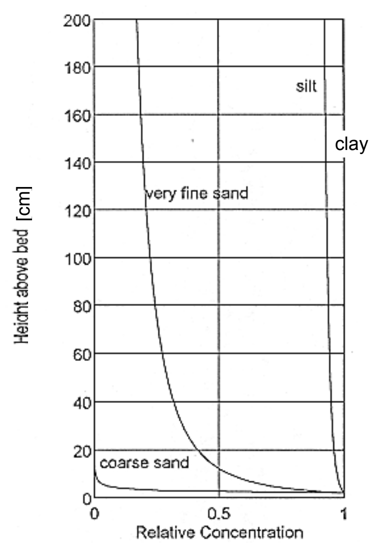
8.4 FOREBAY DREDGING

The Spectra intake forebay was dredged in early October 2010. The occurrence and timing of this work was not communicated to KPL prior to the end of the 2010 field season, so no inspection or sampling of the dredgeate was undertaken. Information on the target bed elevation or the volume of material dredged was not available from Spectra.

The Spectra intake forebay was dredged again in October 2011 and KPL obtained two samples that were sent to a lab for grain size distribution (GSD) analysis (Photos 16 and 17). Figure 8.9 shows GSD curves for the material dredged from the forebay along with GSD curves for water samples collected in the Peace River above Pine River at the WSC gauge 07FA004. The Peace River samples were collected in May and June 2010/2011 and are representative of the suspended sediments carried by the river during the freshet period that have the potential of being deposited in the Spectra forebay.

The forebay GSD indicates that most of the settled material (approximately 72%) falls in the sand category (sizes between 62 and 250 µm), of which the majority, or approximately 64%, is in the size range 125 to 250 µm. There is only about 7% clay (< 4 µm) and 18% silt (between 4 and 62 µm) represented in the dredgeate. The Peace River suspended sediment samples contain 30-45% clay (< 4 µm), 18-44% silt (between 4 and 62 µm), and 1-12% sand (> 62 µm). Comparison of the Peace River and dredgeate GSD curves indicates that most of the material that settles in the forebay corresponds with the coarse end of the sediment that is transported in suspension. Only 3% of the dredgeate is coarser than the suspended sediment and so must have been transported as bedload. The forebay area is reasonably small and the velocities are sufficient to keep most of the finer material (clay and silt) that gets into the forebay in suspension. These fine sediments get drawn further into the intake and cause wear on system components.

The distribution of suspended sediments varies through the water column. The highest concentration is experienced closer to the channel bed containing both the fine wash load (fine sand, silt and clay), and some of the bed material load (sand). As illustrated in Sketch 1, the concentration of sands varies considerably through the water column, while silts and clays tend to be more evenly distributed throughout the entire depth.



Sketch 1. Concentration of suspended sediments throughout the water column for different particle-sizes (Source: http://www2.ocean.washington.edu/oc540/lec02-27/)

The turbidity transect analysis indicates that the Peace River water is pushed against the north bank and that the Peace and Pine suspended sediment plumes do not mix transversely between the Pine River confluence and the Spectra intake. Based on Figure 8.9, it can be concluded that most of the settled sediment in the Spectra forebay is also represented in the Peace River suspended sediment load. A simple annual mass balance yields the following: the average annual sediment load in the Peace River above the Pine River confluence is 1,356,830 tonnes/yr (Table 7.2), of which an average of 5% or 67,842 tonnes/yr is suspended sand (Section 7.1.2). Spectra representatives indicated that the approximate annual dredging depth is about 8 ft or 2.4 m at the intake opening (Appendix A in Year One Report, KPL, 2010a). If a conservative assumption was made that the entire forebay area of 512 m^2 infills and is dredged to this amount, the dredged volume would be equivalent to 1229 m^3/yr or 1475 tonnes/yr (assuming a non-settled sand density of 1.2 tonnes/m^3). This amount is equivalent to only 2.2% of the suspended sand moving in the Peace River. The above analysis confirms that there is sufficient amount of sand moving in suspension in the Peace River to infill the Spectra forebay on an annual basis.

The amount of suspended sediments being transported by the Peace River has decreased downstream of the dams in the post-regulation period due to the settling effect of the reservoirs. The sediment input from the Peace River headwaters upstream of the WAC Bennett Dam is estimated at 2.5 million tonnes per year (Church, 2011), which is now trapped in the Williston reservoir. When compared to the current suspended sediment load of 1.36 million tonnes per year downstream of the reservoirs and upstream of the Pine River confluence (Table 7.2), it can be seen that the pre-regulation sediment input upstream of the Pine River confluence is reduced by approximately 65%. Based on this, it is reasonable to expect that much less sedimentation is occurring in the Spectra forebay post-regulation, as compared to pre-regulation. However, river regulation also changed the timing of suspended sediment concentrations, so the seasonal amounts of sedimentation have changed: more in freshet, less in the rest of the year. Consequently, the Spectra intake likely experiences more of a sediment pulse during the freshet than would have in the pre-regulation period, but the annual loads are still much reduced as compared to the pre-regulation period.

Considering the lack of information related to the Spectra forebay sedimentation in the pre-regulation period, it is not possible to determine whether the frequency and quantity of accumulated sediments in the forebay got worse due to flow regulation. It would be reasonable to expect that the conditions in the forebay improved due to lower suspended sediment loads carried by the Peace River, while the Peace River bed aggradation in the vicinity of the forebay may encourage additional migration of bedload material into the forebay. However, the amount of beadload material in the forebay is very low and represents only about 3% of the dredged material.

SECTION 9.0 - DISTRICT OF TAYLOR WELLS

In this section an overview of the District of Taylor wells is provided along with the findings of this study that are relevant for answering the questions posed in the ToR (BC Hydro, 2008) related to concerns about the decreased hydraulic function of the wells.

9.1 OVERVIEW

The District of Taylor withdraws water via a series of five shallow groundwater wells that were drilled from 1999 onwards (Golder, 2009c). The wells are situated on an island/bar complex near the north (left) bank of the Peace River, located directly opposite from the Pine River confluence and 2.0 km upstream of the Highway 97 bridge. The District of Taylor pumphouse is located on the north bank of the Peace River approximately 0.3 km downstream of the confluence. The water is used to provide a potable water supply to the community, including potable water for local industries (i.e. Spectra and Canfor). Prior to 1980, the District of Taylor intake was not located on this bar/island complex, but the District withdrew river water from a site located approximately 500 m downstream (NHC, 1990).

9.2 SITE VISIT AND STAKEHOLDER INTERVIEWS

Craig Nistor, P.Geo., and Mediha Hodzic, E.I.T., of KPL made a site visit to the study area on September 8-9, 2009 to interview the stakeholders and inspect the stakeholder facilities. The location of the meeting and the personnel involved is summarized below. The interview meeting minutes were provided in Appendix A of the Year One Report (KPL, 2010a).

1) District of Taylor Well Site
    a. Ray Ensz, District of Taylor Staff Member

The District of Taylor wells are situated on one of the vegetated bar/island complexes located across from the Pine River confluence that has stabilized due to regulation (Photos 18 and 19). The cobble bar material that represents the formerly mobile bed material of the Peace River is now coated with fine sediment. The fine sediment may have potentially infiltrated into the former void spaces of the cobbles to some depth beneath the surface, and may have potentially reduced the porosity and hydraulic conductivity of the alluvium surrounding the District's wells. However, it is unknown whether fine sediment has infiltrated the alluvium to sufficient depth to affect well function.

The main problems reported by the District of Taylor relate to water quantity and the hydraulic function of their groundwater wells. The wells are around 4.5 m to 5.5 m deep, and not all produce water. The date of installation was not provided during the stakeholder interview. Two test wells have been installed in 2008, with plans to develop the one that shows the best results as a new permanent well. The interviewed staff member did not provide a clear hypothesis regarding the role that BC Hydro's operations may play in well performance. Furthermore, the ratio of Peace and Pine River freshet flows does not appear relevant at this site as it is unlikely to be influenced by Pine River water under any flow conditions.

9.3 STUDY FINDINGS

During Year One of the study, KPL visited the District of Taylor wells and discussed the stakeholder concerns with a District of Taylor representative, as discussed in Section 9.2. Based on those findings, KPL refined the study questions related to the reduced functioning of the District of Taylor wells to consider the following two alternatives (or a combination of the two):

1) Has fine sediment deposition on the bar/island feature at the District of Taylor well site reduced the porosity and hydraulic conductivity of the alluvium surrounding the wells?

2) Or is well function related to well operation and maintenance issues such as screen fouling?

The Year Two study plan included a review of well construction, maintenance, and operations records to assess the historical timing of well function problems, and if warranted, recommendations for a well inspection to determine whether the well problems are due to screen fouling as opposed to changes in the surrounding alluvium.

During the course of Year Two, the following information was obtained that affected the study plan:

1) The District of Taylor provided KPL with a report by Golder Associates (2009c) regarding the drilling and testing of a new well (TPW09-1) on the bar/island feature. This document provided useful information about the shallow aquifer adjacent to the Peace River, the installation dates of the existing wells, and a brief assessment of past problems in the existing wells.

2) The District of Taylor was unable to provide KPL with well construction, maintenance, or operations records for the existing wells that would support an independent assessment of potential river regulation effects on historical well function.

3) The District of Taylor suggested an alternative hypothesis that was not in agreement with the assessment by Golder Associates.

The Golder Associates report (2009c) described the aquifer in which the District of Taylor wells are located as being comprised primarily of alluvial sand and gravel with a thickness of approximately 8 m. The underlying shale bedrock is relatively tight, but low flows through the bedrock do introduce poor quality water to the base of the aquifer. Ideally, the well intakes would be set above the base of the aquifer to avoid the poor quality water, but the shallow thickness of the aquifer dictates that the existing and new wells needed to extend down to the bedrock contact to obtain sufficient capacity.

The Golder Associates report (2009c) stated that there were five known production wells and one test well on the bar/island feature prior to the commencement of their work in 2008. Four of the production wells and the test well were installed in 1999, and the fifth production well was installed at a later date (Golder, 2009c). Golder Associates installed two new test wells in 2008 and a new production well in September 2009 (soon after the first site visit by KPL staff in Year One). None of the production wells pre-dates the onset of river regulation in 1968.

The historical capacity problems with the existing wells, according to Golder Associates, are likely related to biological growth and iron precipitation on the well screens. These problems might be alleviated, according to Golder Associates, by pumping the wells continuously instead of intermittently to avoid the mixing of oxygen-rich waters in the upper part of the aquifer with anoxic waters rich in iron and manganese in the lower part of the aquifer, thereby reducing precipitation on the well screens. There was no indication that the aquifer or well screen conditions are in any way related to Peace River regulation.

The Golder Associates report (2009c) observed that water turbidity in the new well declined to a relatively low level soon after completion, but still slightly exceeded water quality standards. They speculated that the water would continue to clear up and that turbidity would not be an ongoing problem. This was based on a stated assumption that well turbidity was not directly correlated to river turbidity, but they recommended an ongoing monitoring program to verify this assumption.

In April 2010, Mr. Gord Davies of the District of Taylor verbally provided the following new, alternative hypothesis regarding the past well function problems: groundwater levels in the aquifer have been lowered due to lowered water levels in the Peace River. Overall, BC Hydro's operations on the Peace River have not caused any change in mean annual discharge, and the main geomorphic changes that have been documented are localized increases in river bed elevation. Both of these points contradict a general decrease in river water levels due to BC Hydro's operations. Furthermore, river regulation has caused a substantial increase in mean monthly discharge and water level during the former low-flow autumn and winter months, and a reduction in mean monthly discharge and water level only during the former high-flow months of May through August. Therefore, the hypothesis that lowered river levels have caused a general decrease in aquifer levels does not appear to be valid.

SECTION 10.0 - CONCLUSIONS

BC Hydro regulates the flow of the Peace River at the WAC Bennett and Peace Canyon Dams, located near Hudson's Hope, BC. The flow regulation had a major impact on the distribution of flows throughout the year with flows decreased during the spring freshet period and increased during the winter low flow period. As a consequence of reduced flood flows, the competence of the river to move bedload has reduced, resulting in a series of morphological changes downstream of the dams, where bed aggradation downstream of tributary confluences is probably the most noticeable change. The dams also interrupted the suspended sediment input from the upper watershed, and an estimated 2.5 million tonnes per year is now trapped in the reservoirs (Church, 2011), which resulted in a decrease of suspended sediments upstream of the Pine River confluence by approximately 65%.

KPL undertook a three year study to determine the cause of ongoing problems with hydraulic function and water quality that were reported by industrial and municipal users of river water at Taylor, BC. The Consultative Committee of the Peace Project Water Use Plan has initiated the Industry and Taylor Water Quality Assessment (GMSWORKS #10) in response to these concerns. The Terms of Reference identified a number of relevant questions to guide the study as listed below (indicated in bold italics). In addition to these original questions, KPL identified several more questions to clarify some of the issues and guide the studies during the rest of the study period. These additional questions will be embedded with the original study questions as appropriate (indicated in italics).

1) ***What physical evidence of sedimentation is there at the water intakes on the islands*** **(sic)*****?***

The District of Taylor groundwater wells are situated on an island/bar complex directly opposite from the Pine River confluence. The bed material on this bar/island consists of formerly mobile cobbles and gravel that is now coated in fine sediment. The primary reason for the deposition of fine sediments is the reduced competence of the regulated Peace River to transport the formerly mobile bed material including sand.

The Spectra Energy surface intake facility is situated on the north (left) bank of the Peace River approximately 1.8 km downstream of the Pine River confluence. Fine sediment accumulates in the intake forebay and is dredged on an annual basis. The average bed elevation of the Peace River has aggraded in this reach by 0.9 to 1.3 m since regulation, as determined by historical channel surveys of cross-section S10 and an analysis of water levels at the nearby WSC Gauge 07FD002. Gravel bars and shoals are continuing to expand between the confluence and the intake site, and further downstream. However, the forebay area of the Spectra intake experiences settling of finer sediments primarily carried by the Peace River in suspension, and annual dredging is required to maintain the forebay bed elevation at operational levels.

2) ***What is causing the sedimentation?***

   a) ***What morphological changes are occurring at the Peace-Pine confluence since Peace River regulation?***
   The competence of the Peace River to transport bedload has reduced due to regulation. This has caused formerly mobile bed material upstream of the Pine River confluence to become

immobile and to become covered with vegetation and fine sediments. At the Pine River confluence, a prograding alluvial fan of Pine River bedload material constricts the width of the Peace River channel. Downstream of the Pine River confluence, regulation has caused the bedload material delivered by the Pine River to build up the elevation of the Peace River channel. The aggradation in the Peace River is evident to approximately 7 km downstream of the Pine River confluence (Church, 2011)

b) ***When, how often, and at what relative Pine River and Peace River flows does sedimentation occur on the islands* (sic) *containing the intakes?***

The District of Taylor wells are located directly opposite from the Pine River confluence. Sedimentation at this site is **not** affected by the instantaneous ratio of the Peace and Pine River flows, but is due to reduced freshet flows in the Peace River.

The accumulation of gravel bed material in the Peace River near the Spectra intake site is **not** related to the instantaneous ratio of Peace and Pine River flows, but to the overall ability of the regulated Peace River to transport the bedload.

The accumulation of suspended sediments in the Spectra intake forebay is **not** related to the instantaneous ratio of flows in the two rivers. The Peace and Pine River waters do not mix transversely before they get to the intake, so the water and suspended sediments in the forebay have the same characteristics of the Peace River above the Pine River confluence. The suspended sediment load of the Peace River has decreased by 65% due to regulation, but the river still transports enough sand in suspension to cause the observed deposition in the forebay each year.

c) ***Does turbid Pine River water reach the intakes? If so, for what time period and at what concentration is sedimentation an issue?***

No, the turbid Pine River water does not reach the municipal wells or the Spectra intake under typical flow conditions.

The District of Taylor wells are located directly opposite from the Pine River confluence and are not affected by the Pine River suspended sediment inflow. The turbid Pine River water does not reach the wells under any flow conditions, because at this location the Peace River flows are pushed against the north bank.

It also appears unlikely that the Pine River sediment plume reaches the Spectra intake site under typical flow conditions.

KPL: Does the mixing of the Peace and Pine River sediment plumes take place upstream of the Spectra Energy intake facility during freshet flow conditions, despite the reduction in Peace River flows? Or does the Pine River plume stay attached to the bank opposite the intake until well downstream of the Highway 97 bridge?

No, the suspended sediment plumes of the two rivers were observed to remain mostly unmixed between the confluence and the intake under a wide range of relative flow conditions, even though the Pine River plume appeared to encroach far into the Peace River channel at the confluence. This observation is based both on analysis of historic air photos and on field measurements of turbidity transects. Turbidity transect records confirmed that the Pine River suspended sediment plume did not encroach on the north bank even at the highest measured Pine to Peace River flow ratio of 1.31, which is exceeded less than 1.45% of the time (or 5.3 days per year). Rather, it is Peace River water that gets pushed towards the north bank that reaches the Spectra intake. At Pine to Peace River flow ratios higher than 1.31, it is reasonable to expect that the Pine River plume extends farther into the Peace River, and at extreme ratios it is conceivable, but not very likely that the Pine River plume may reach the north bank. The Pine to Peace River flow ratio of 2 was exceeded nine times, while the flow ratio of 3 was exceeded only two times during the thirty years of record. Typically, some mixing occurs along the transition between the two plumes, but the plumes retain their original characteristics near either bank of the Peace River in the vicinity of the Spectra intake. Turbidity transects measured elsewhere on the Peace River indicate that the river remains transversely unmixed for several tens of kilometres downstream of major tributaries like the Pine and Halfway Rivers.

KPL: Are suspended sediment concentrations in the Peace and Pine Rivers substantially different? Does the mixing of the Peace and Pine River sediment plumes play a key role in determining water quality at the Spectra Energy intake?

Yes, suspended sediment concentrations are generally higher in the Pine River than in the Peace River. The Pine River transports 1.6 times as much suspended sediment as the Peace River with 0.15 times as much flow, meaning that the average concentration in the Pine River (from a mass balance approach) is approximately 10 times greater than in the Peace River.

Mixing of the two river plumes does **not** appear to play a key role in determining water quality at the Spectra intake (as discussed in 2c). Rather, Pine River water appears unlikely to affect the Spectra intake under any relative flow conditions. It is the quality of the Peace River water that primarily affects the water quality and the sedimentation in the Spectra forebay.

3) If sedimentation at the intakes is observed, what is the suspected cause of the sedimentation and what evidence is available to support this hypothesis?

The reduced bedload transport competence of the Peace River due to flow regulation has caused formerly mobile bed material upstream of the Pine River confluence to become immobile and to become covered with vegetation and fine sediments, as observed on the bar/island where the municipal wells are located.

Downstream of the Pine River confluence including the Peace River at the Spectra intake, regulation has caused the bedload material delivered by the Pine River to build up the elevation of the Peace River channel.

Most of the deposited material in the Spectra intake forebay (about 97%) originates from the suspended sediments carried by the Peace River. They settle out of suspension in the relatively still hydraulic conditions in the forebay.

KPL: Is sediment deposition at the Spectra Energy intake facility caused by the general increase in Peace River bed elevation in that reach of the river, and by the sheltered hydraulic conditions at the intake that promote suspended sediment deposition?

Yes, the sediment deposition at the Spectra intake is most likely due to both the increase in the Peace River bed elevation and to the sheltered hydraulic conditions that promote suspended sediment settling.

The Spectra Energy intake (installed in 1957) was initially situated at least 3 m above the thalweg elevation (the lowest point in the river channel) of the Peace River prior to the onset of regulation in 1968. The thalweg rapidly infilled in the first few years following regulation due to decreased flows and reduced bedload transport competence of the Peace River. From 1975 onward, the intake was situated only about 1 m (or less) above the thalweg and was lower than the average bed elevation of the river near the Spectra forebay. This change in relative elevations likely contributes to the deposition of fine bedload (sand) and suspended sediment in the intake forebay.

The analysis of the Peace River suspended sediment loads along with the grain size distribution curves for the dredgeate and the Peace River confirms that most of the deposited material is carried in suspension in sufficient quantities to cause the observed deposition in the Spectra forebay which requires annual dredging. The coarser end of the suspended sediment load typically moves closer to the river bed. This material, along with fine bedload that was found in the forebay in very small quantities (less than 3%) is likely entering the forebay more readily considering the aggraded Peace River bed at the Spectra forebay. Dredging of the forebay to lower elevations (potentially lower than the thalweg bed) inevitably leads to renewed deposition, which explains why routine annual dredging has been required.

4) Assuming that turbid Pine River water is the cause of the sedimentation, what Peace River flow, at Taylor, would be required to deflect Pine River flows toward the centre of the Peace River and away from the intakes?

The underlying assumption regarding the effect of turbid water from the Pine River causing the sedimentation is **not** valid. The turbid Pine River water is not the primary cause of sedimentation and likely does not contribute in any measurable quantity to the sedimentation problem, as discussed under question 2d. Two of the turbidity transects were measured during the 2010 and 2011 spring freshets at high Pine to Peace River flow ratios that are exceeded less than 1.45% and 2.5% of the time, respectively. On both occasions the Pine River water encroached far across the Peace River at the confluence, but a distinct boundary between the waters of the two rivers was still observed about 55 to 80 m away from the north bank.

a) ***Would higher Peace River flows substantially reduce the sedimentation on the water intake facilities and reduce the direct impact on the community?***

No, higher Peace River flows would be unable to substantially mobilize the accumulated Peace River bed material and restore pre-regulation channel morphology, as evidenced by the absence of such effects during the prolonged high flows of 1996. Higher Peace River flows in the spring and summer would likely reduce the concentration of suspended sediments in the river, but this would not change the suspended sediment load in the river on an annual basis nor would it substantially reduce the sedimentation.

KPL: Has fine sediment deposition on the bar/island feature at the District of Taylor well site reduced the porosity and hydraulic conductivity of the alluvium surrounding the wells? Or is well function related to maintenance issues such as screen fouling?

No, sediment deposition on the bar/island does not appear to be the primary cause of the reduced well capacity. The existing wells have only been in operation since 1999. Since the pre-regulation (pre-1968) time period is not represented in the history of the wells, there appears to be little justification for the hypothesis that the degradation in performance of these wells is related to regulation.

Yes, the decrease in well function is likely a result of maintenance issues and well screen fouling, as suggested in a report by Golder (2009c).

KPL: If Peace River regulation has resulted in lower aquifer levels, has this affected well productivity?

No, it is unlikely that the Peace River regulation has caused a general decrease in river levels or a consequent decrease in aquifer levels. The reduced well capacity appears to be caused by biological growth and iron precipitation on the well screens and not by sedimentation, as has suggested by Golder (2009c).

5) ***Would increased discharges from Peace Canyon Dam reduce the summer water temperatures in Peace River?***

Yes, increased discharges from the Peace Canyon Dam would likely reduce summer water temperatures in the Peace River even further. BC Hydro's operations already cause summer water temperatures in the Peace River to be cooler than they would be naturally, due to the release of cold water from the deep sections of the reservoirs. However, it was determined during stakeholder interviews that the only industry with significant cooling problems is the Canfor Taylor Pulp, which uses warm wastewater from Spectra Energy, and not raw river water. There is no apparent connection between BC Hydro's operations and the temperature of the Spectra Energy effluent.

In consideration that all the questions posed in the Terms of Reference have been answered, KPL proposes that this study concludes with this report.

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SECTION 12.0 - CERTIFICATION

This report was prepared, reviewed and approved by the undersigned.

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
Dr. V. MARTIN
29814

Apr. 3, 2012

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President

Knight Piésold CONSULTING

TABLE 5.1

BC HYDRO
GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

REGIONAL STREAMFLOW GAUGING STATIONS

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Station Name	Station ID	Start Year	End Year	Complete Years of Record	Drainage Area (km^2)	Mean Annual Discharge (m^3/s)	Mean Annual Unit Runoff ($l/s/km^2$)
Peace River at Hudson's Hope	07EF001	1917	2010	55	73,164	1,169	16.0
Peace River above Pine River	07FA004	1979	2010	30	87,131	1,273	14.6
Peace River near Taylor	07FD002	1944	2010	56	100,733	1,458	14.5
Pine River at East Pine	07FB001	1961	2010	46	12,108	182	15.0
Pine River at the Mouth	--	--	--	--	13,499	188	13.9

M:\1\03\00014\30\A\Data\Hydrology\[Summary Tables.xlsx]Table 5.1

NOTES:

1. STATION DATA OBTAINED FROM WSC WEBSITE: WWW.WSC.EC.GC.CA.
2. MEAN ANNUAL DISCHARGE AND UNIT RUNOFF BASED ON COMMON PERIODS OF RECORD FROM 1980-2010, EXCLUDING 1986.
3. MEAN ANNUAL DISCHARGE AT THE MOUTH OF THE PINE RIVER HAS BEEN COMPUTED BY ADJUSTING THE PINE RIVER FLOWS AT 07FB001.
4. DRAINAGE AREAS OBTAINED FROM BC HYDRO.

0	20FEB'12	ISSUED WITH REPORT VA103-14/30-1	AA	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

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TABLE 6.1

BC HYDRO
GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

RECORD OF AIR PHOTOS USED FOR CHANNEL MORPHOLOGY ANALYSIS

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Roll Number	Photo Number	Scale	Date	Colour or B&W	Daily Discharge (m^3/s)			Ratio of Pine River/Peace River above Pine River
					Pine River at the Mouth	Peace River above Pine River	Peace River near Taylor	
A8109	65 - 73	1:20,000	June 18, 1945	B&W	--	--	2970	-
A8148	19, 20, 22 - 26	1:20,000	June 24, 1945	B&W	--	--	3170	-
A8151	48 - 51	1:20,000	June 24, 1945	B&W	--	--	3170	-
BC2171	40, 41, 114, 115	1:40,000	July 30, 1956	B&W	--	--	1740	-
BC5269	32, 33, 40, 41	1:32,000	August 15, 1967	B&W	114	*1056*	1170	0.11
BC7278	57-61, 128, 129	1:16,000	August 3, 1970	B&W	171	*517*	688	0.33
BC7837	53, 58, 59	1:20,000	June 8, 1976	B&W	936	*1254*	2190	0.75
BR81043	58, 59, 91 - 99	1:10,000	July 10, 1981	B&W	140	578	714	0.24
30BC87018	174, 175	1:15,000	June 8, 1987	B&W	796	1380	2600	0.58
15BCB96015	113 - 115, 156 - 159	1:40,000	July 14, 1996	B&W	379	5460	5720	0.07
30BCC97159	100 - 105, 113 - 116	1:15,000	August 24, 1997	Colour	162	470	587	0.34
15BCC05129	55 - 57	1:30,000	September 5, 2005	Colour	98	844	916	0.12

M:\1\03\00014\30\A\Data\Hydrology\[Summary Tables.xlsx]Table 6.1

NOTES:
1. PINE RIVER FLOWS AT THE MOUTH ESTIMATED BY ADJUSTMENT OF FLOWS FROM THE PINE RIVER AT EAST PINE (WSC GAUGE 07FB001).
2. PEACE RIVER FLOWS ABOVE THE PINE RIVER TAKEN FROM WSC GAUGE 07FA004 (1979-2010), OR ESTIMATED BY SUBTRACTION OF ADJUSTED PINE RIVER FLOWS AT THE MOUTH FROM PEACE RIVER FLOWS NEAR TAYLOR (07FD002). ESTIMATED VALUES ARE ITALIZED.
3. PEACE RIVER FLOWS NEAR TAYLOR TAKEN FROM WSC GAUGE 07FD002.

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REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

TABLE 7.1

BC HYDRO
GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

ESTIMATED SUSPENDED SEDIMENT YIELD IN THE PEACE RIVER AND TRIBUTARIES
2010 AND 2011 KPL STUDIES

Print 3/1/12 15:23

Location	Effective Drainage Area (km^2)	Annual Suspended Sediment Load (tonnes/yr)	Annual Suspended Sediment Yield (tonnes/km^2/yr)
Peace River at Hudson's Hope	~ 0	~ 0	~ 0
Peace River at WSC Gauge 07FA004	14,314	1,356,830	95
Halfway River at the Mouth	9,389	1,016,700	108
Moberly River at the Mouth	1,851	103,000	56
Pine River near the Mouth	13,499	2,161,800	160

M:\1\03\00014\30\A\Data\Hydrology\[Summary Tables.xlsx]Table 7.1

NOTES:

1. DATA OBTAINED FROM THE 2010/2011 KPL SUSPENDED SEDIMENT SAMPLING PROGRAM ON THE PEACE RIVER AND TRIBUTARIES.
2. ANNUAL SUSPENDED SEDIMENT LOAD IS CALCULATED FOR THE PERIOD FROM 2000 TO 2009.
3. DRAINGE AREAS WERE REVISED BY BC HYDRO IN 2011.
4. PEACE RIVER AT WSC GAUGE 07FA004 IS 10.2 km UPSTREAM OF THE CONFLUENCE WITH THE PINE RIVER.

0	20FEB'12	ISSUED WITH REPORT VA103-14/30-1	AA	VM	JPH
REV	DATE	DESCRIPTION	DESIGN	CHK'D	APP'D

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TABLE 7.2

BC HYDRO
GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

PEACE RIVER TURBIDITY TRANSECTS ABOVE AND BELOW TRIBUTARY CONFLUENCES

Print Apr/03/12 11:38:31

Transect ID and Description	Upstream Tributary Confluence		Downstream Tributary Confluence		Date	Discharge (m³/s)
	Tributary	Transect Distance below Confluence (km)	Tributary	Transect Distance above Confluence (km)		
Peace River above Pine River	Moberly River	6.3	Pine River	10.2	5-May-11	1274
					19-May-11	1298
					6-Jun-11	715
					22-Jun-11	835
Pine River	Distance to Peace River Confluence (km)			14	3-May-11	146
					21-May-11	1152
					7-Jun-11	862
District of Taylor Pumphouse	Pine River	0.3	Beatton River	21.1	15-May-10	1090
					29-May-10	1570
Powerline Crossing	Pine River	1.8	Beatton River	19.7	15-May-10	1090
					29-May-10	1570
					3-Jun-10	1300
					19-May-11	3025
Peace River above Beatton River	Pine River	20.4	Beatton River	1.1	1-May-11	1275

M:\1\03\00014\30\A\Data\Spectra Intake\[Turbidity Transect Tables.xlsx]Table

NOTES:

1. 2011 DISCHARGE VALUES ARE BASED ON ADCP MEASUREMENTS COLLECTED DURING THE 2011 KPL SUSPENDED SEDIMENT SAMPLING PROGRAM.
2. 2010 DISCHARGE VALUES ARE DAILY AVERAGE DISCHARGES FROM THE WSC STATION PEACE ABOVE TAYLOR.

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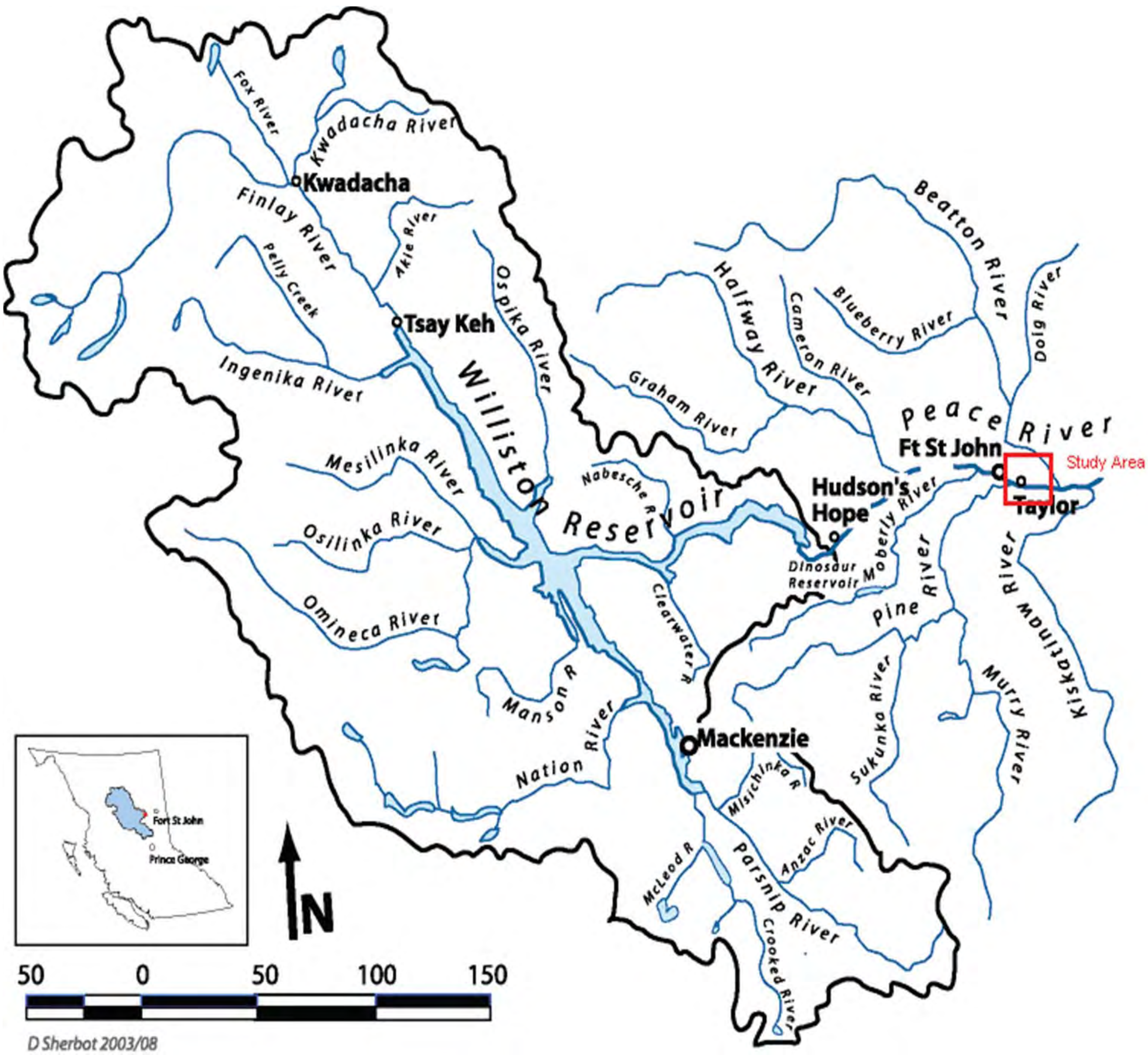
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D



NOTES:

1. LOCATION MAP PROVIDED BY BC HYDRO (TERMS OF REFERENCE, 2008).

0	21FEB'12	ISSUED WITH REPORT	CN	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

LOCATION MAP

Knight Piésold CONSULTING

P/A NO.	REF. NO.	
VA103-14/30	1	
FIGURE 2.1		REV 0

NOTES:

1. GOOGLE EARTH AIR PHOTO DATE: JULY 27, 2009.
2. AIR PHOTO SCALE AS PRESENTED: 1:12,500 (APPROX).
3. PINE/PEACE FLOW RATIO ON AIR PHOTO DATE: 0.020.

LEGEND:

HISTORICAL CROSS-SECTION LOCATION:

TURBIDITY TRANSECT LOCATIONS:

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	21FEB'12	ISSUED WITH REPORT	CJN	DJG	JPH

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

STUDY AREA MAP

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P/A NO. VA103-14/30

REF. NO. 1

FIGURE 2.2

REV 0

LEGEND:

GENERAL

- COMMUNITY
- WATER SURVEY OF CANADA (WSC) GAUGING STATION
- DISTRICT OF TAYLOR WELLS
- SPECTRA ENERGY INTAKE
- HISTORIC CROSS-SECTION

NOTES:

1. BASE MAP: (C) MICROSOFT BING MAPS.
2. COORDINATE GRID IS IN METRES. COORDINATE SYSTEM: NAD 1983 UTM ZONE 10N.
3. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:40,000 FOR 11X17 (TABLOID) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.

REV	DATE	DESCRIPTION	DESIGNED	DRAWN	CHK'D	APP'D
0	20FEB'12	ISSUED WITH REPORT	VM	AMD	CJN	JPH

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

WSC GAUGING STATIONS, TAYLOR WELLS AND SPECTRA ENERGY INTAKE LOCATIONS

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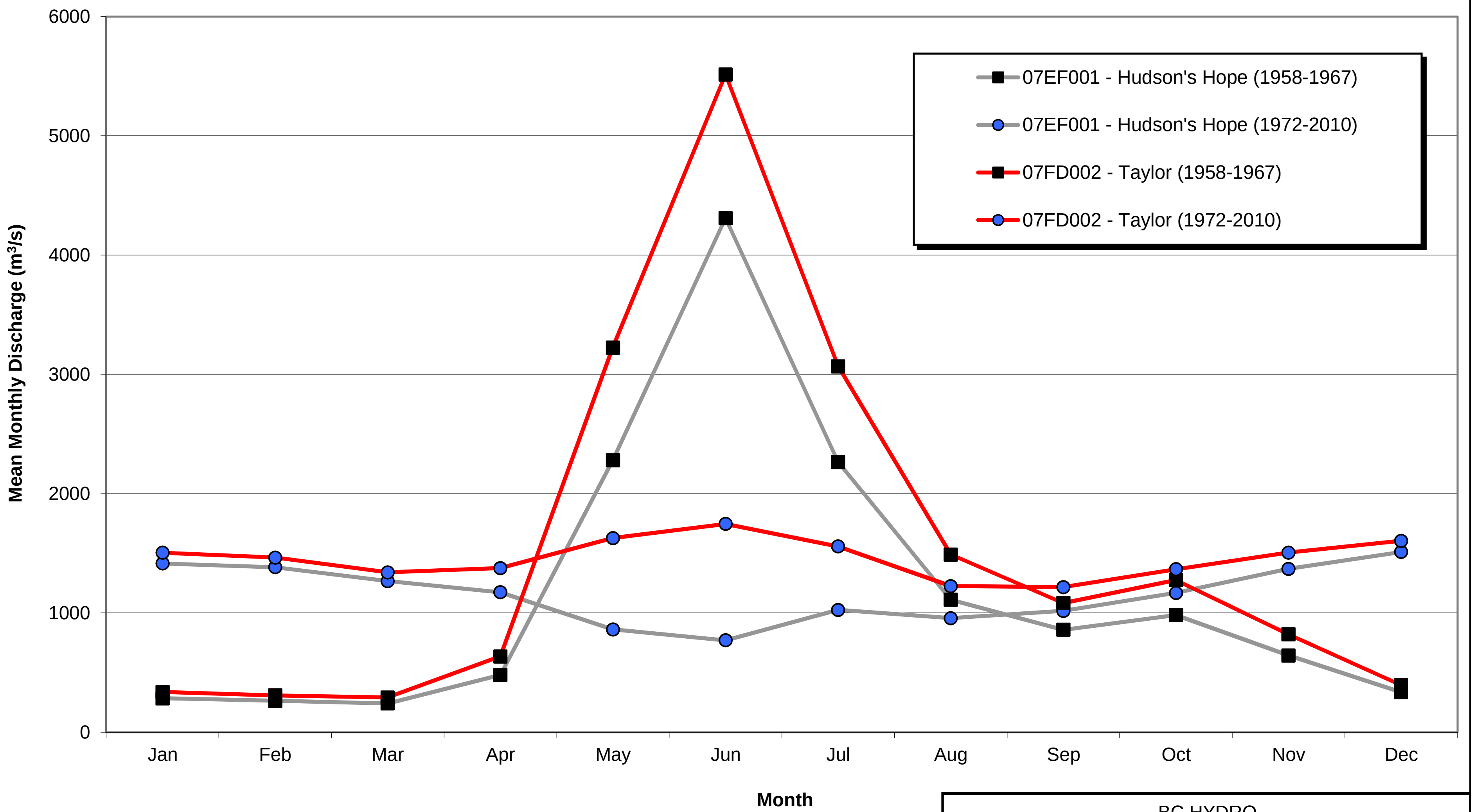
P/A NO.	REF NO.
VA103-14/30	1

FIGURE 5.1 REV 0

KP FIGURE SAVED: M:\1\03\00014\30\A\GIS\Figs\Site\C_WSC_Gauging_Stations.mxd; Mar 02, 2012 8:46:30 AM adinca



NOTES:

1. THE WAC BENNETT DAM WAS COMMISSIONED IN 1967. THE WILLISTON RESERVOIR WAS FILLED PRIMARILY DURING THE PERIOD 1968-1971.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

MEAN MONTHLY DISCHARGE IN THE PEACE RIVER BEFORE AND AFTER REGULATION

Knight Piésold CONSULTING

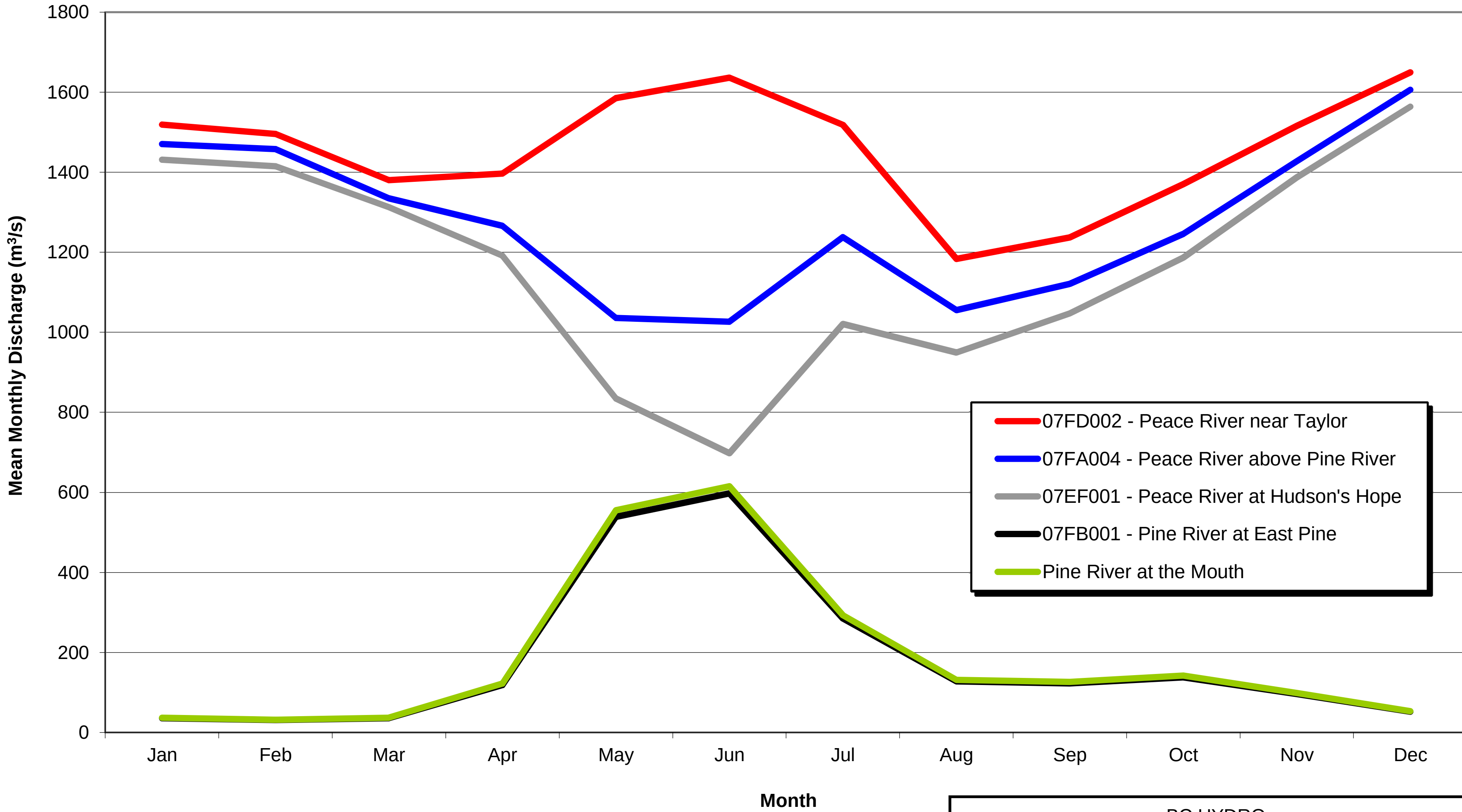
P/A NO. VA103-14/30

REF. NO. 1

FIGURE 5.2

REV 0

0	20FEB'12	ISSUED WITH REPORT	AA	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D



NOTES:

1. MEAN MONTHLY DISCHARGE AT THE MOUTH OF THE PINE RIVER HAS BEEN COMPUTED BY ADJUSTING THE FLOW MEASURED AT PINE RIVER AT EAST PINE (07FB001) .
2. DISCHARGE DATA FOR 1986 WERE EXCLUDED FROM THE ANALYSIS AT ALL STATIONS BECAUSE THE RECORD AT PEACE RIVER NEAR TAYLOR (07FA004) WAS INCOMPLETE.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

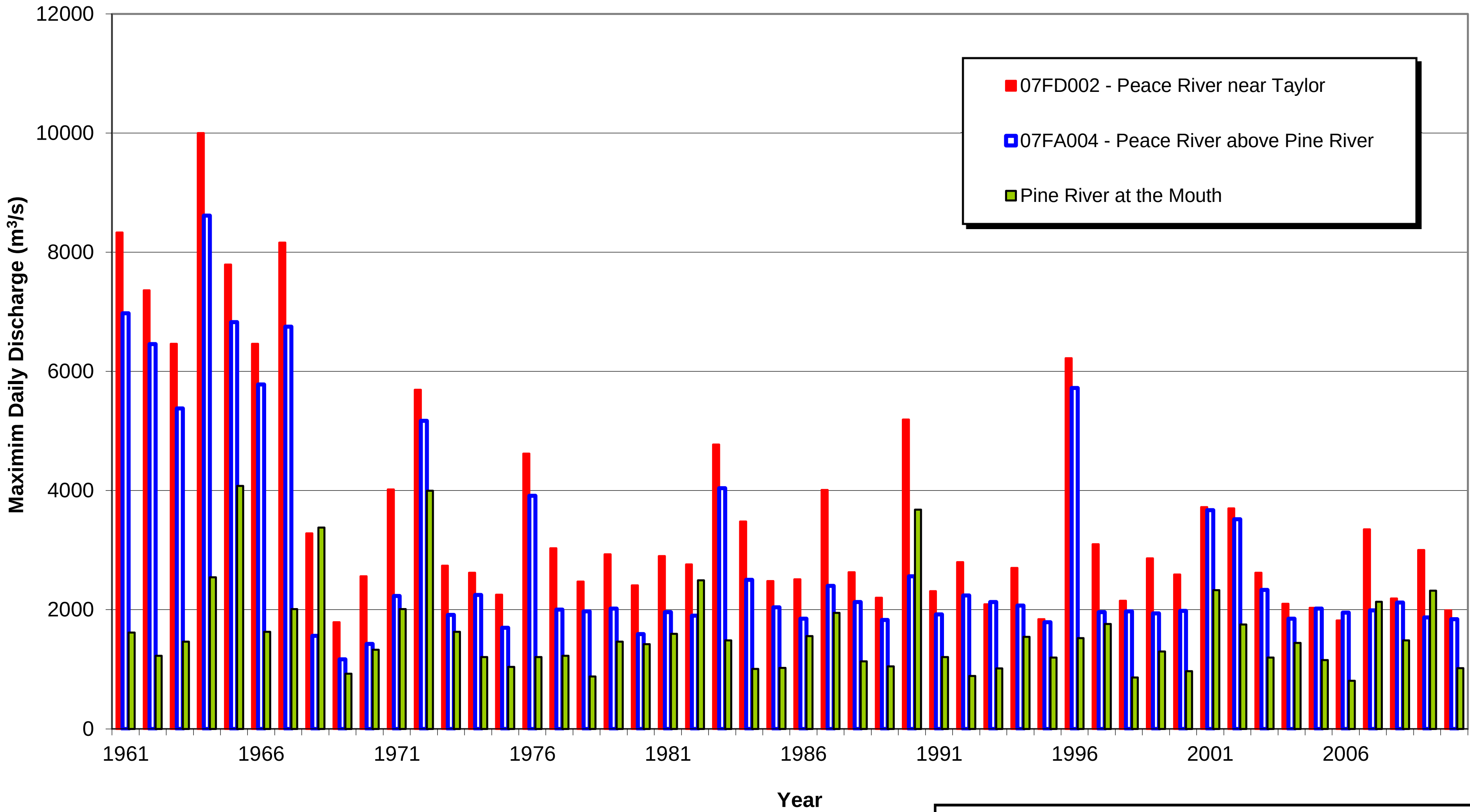
MEAN MONTHLY DISCHARGE
PEACE AND PINE RIVERS (1980-2010)

Knight Piésold CONSULTING

P/A NO. VA103-14/30 | REF. NO. 1

FIGURE 5.3 | REV 0

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	20FEB'12	ISSUED WITH REPORT	AA	VM	JPH



NOTES:
1. PEACE RIVER ABOVE PINE RIVER (07FA004): FLOWS PRIOR TO 1979 ESTIMATED BY SUBTRACTION OF ADJUSTED PINE RIVER FLOWS (07FB001) FROM PEACE RIVER FLOWS AT TAYLOR (07FD002).
2. PINE RIVER AT THE MOUTH: FLOWS ESTIMATED BY ADJUSTMENT OF THE PINE RIVER FLOWS AT EAST PINE (07FB001).

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	20FEB'12	ISSUED WITH REPORT	AA	VM	JPH

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

ANNUAL MAXIMUM DAILY DISCHARGE PEACE AND PINE RIVERS (1961-2010)

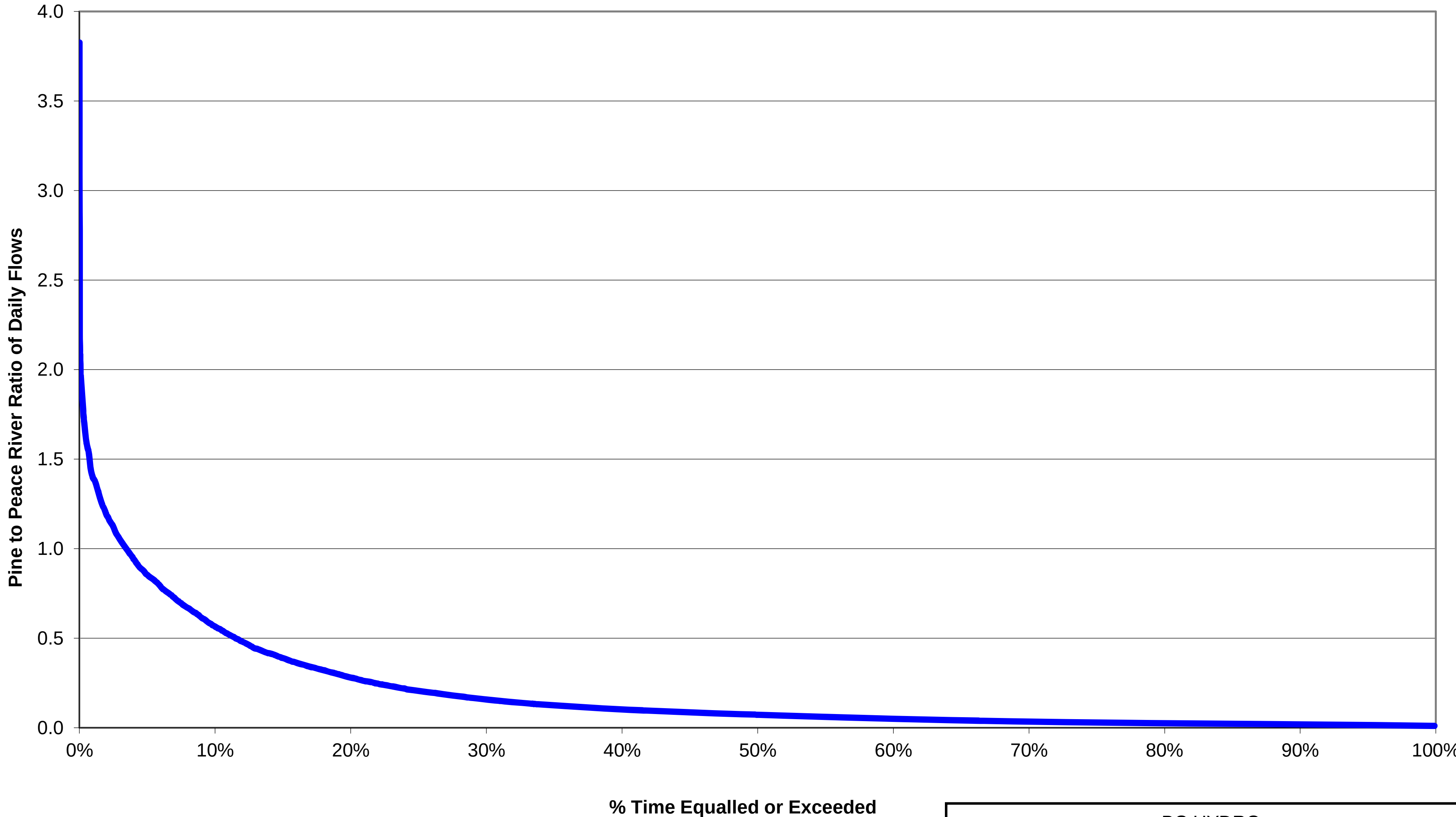
Knight Piésold CONSULTING

P/A NO. VA103-14/30

REF. NO. 1

FIGURE 5.4

REV 0



NOTES:

1. EXCEEDENCE CURVE BASED ON THE PERIOD OF RECORD FROM 1980 TO 2010.
2. DISCHARGE AT THE PINE RIVER MOUTH COMPUTED BY ADJUSTING THE FLOWS MEASURED AT WSC GAUGE 07FB001 BY 3%.
3. DISCHARGE FOR PEACE RIVER MEASURED AT WSC GAUGE 07FA004.
4. DISCHARGE DATA FOR 1986 WERE EXCLUDED FROM THE ANALYSIS AT BOTH STATIONS BECAUSE THE RECORD AT 07FA004 WAS INCOMPLETE.

0	10FEB'12	ISSUED WITH REPORT	VM	CJN	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

EXCEEDANCE CURVE
PINE TO PEACE RIVER FLOW RATIO (1980-2010)

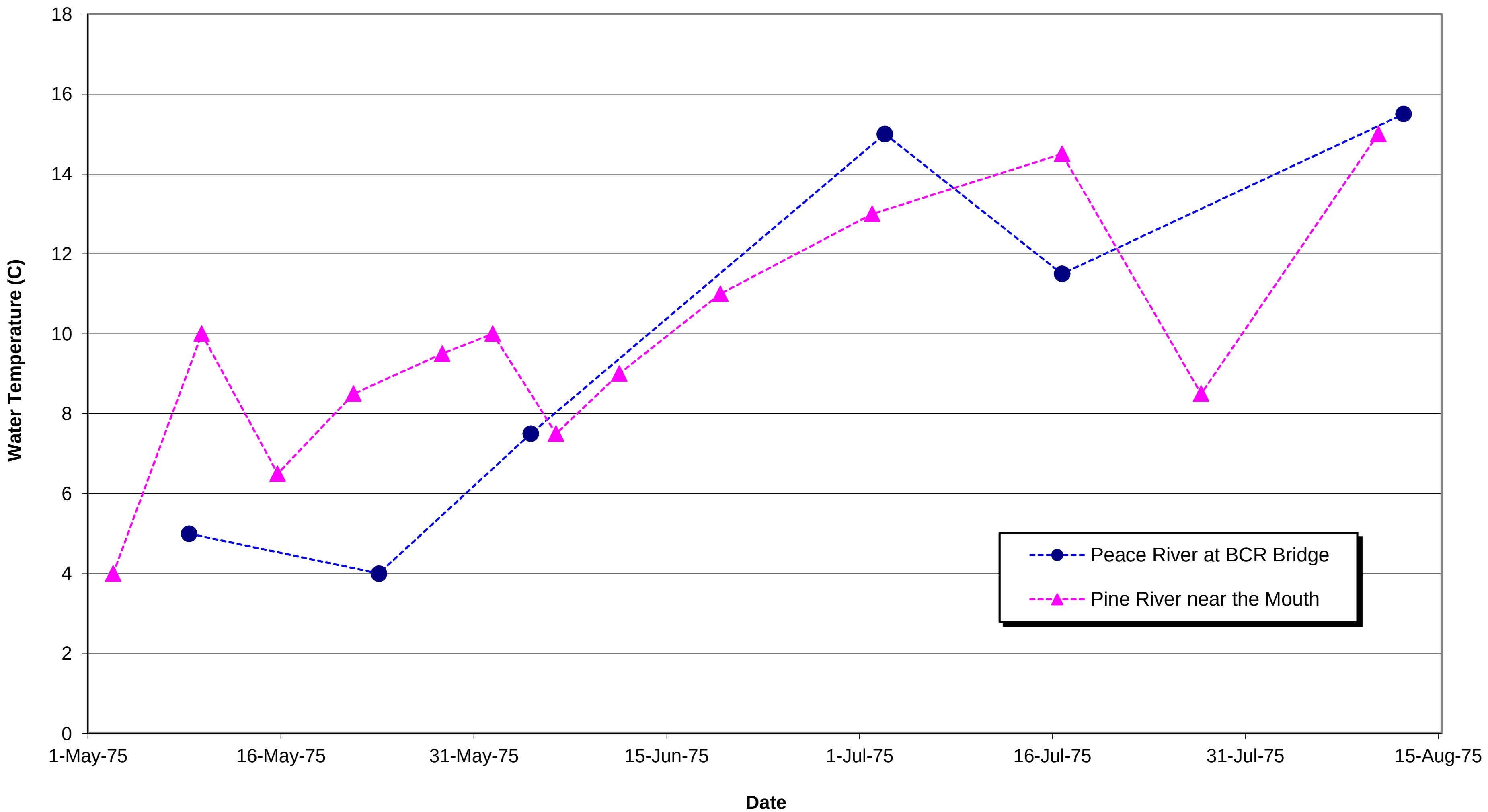
Knight Piésold CONSULTING

P/A NO. VA103-14/30

REF. NO. 1

FIGURE 5.5

REV 0



NOTES:
1. DATA SOURCE: BC HYDRO (1976).
2. THE BC RAIL BRIDGE IS LOCATED UPSTREAM OF THE PINE RIVER CONFLUENCE.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

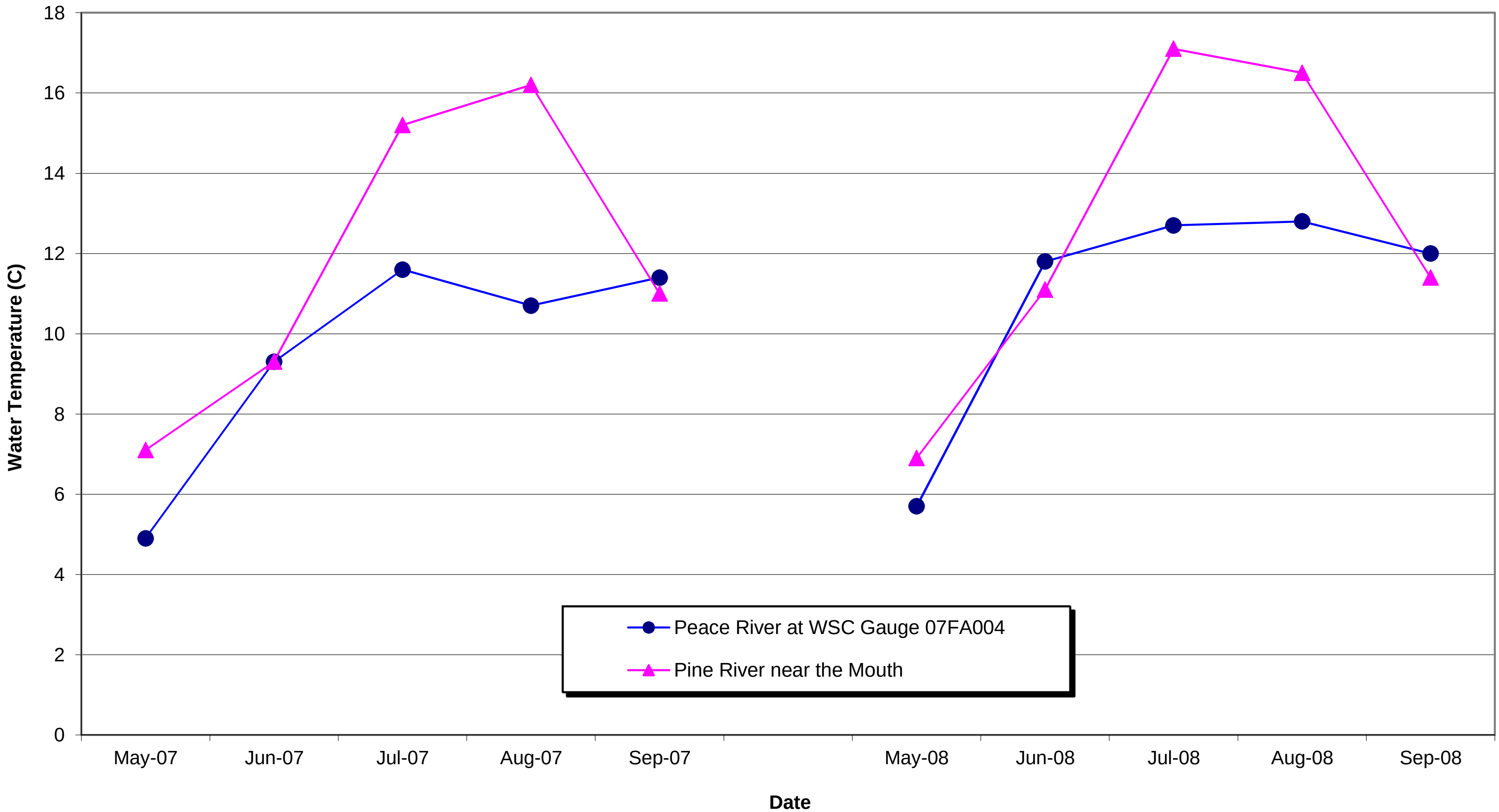
WATER TEMPERATURE SPOT MEASUREMENTS PEACE AND PINE RIVERS (1975)

Knight Piésold CONSULTING

P/A NO.	REF. NO.
VA103-14/30	1

FIGURE 5.6 REV 0

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	21FEB'12	ISSUED WITH REPORT	MH	CN	JPH



NOTES:

1. DATA SOURCE: GOLDER (2009a,b); TEMPERATURE MONITORING SITES "PEACE 4" AND "PINE 16".
2. WSC GAUGE 07FA004 IS LOCATED UPSTREAM OF THE PINE RIVER CONFLUENCE.
3. THE AVERAGE VALUES FOR SOME MONTHS ARE BASED ON INCOMPLETE RECORDS. THE ONLY MONTH WITH CONCURRENT COMPLETE RECORDS AT BOTH STATIONS IS JULY 2007.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

MONTHLY AVERAGE WATER TEMPERATURE PEACE AND PINE RIVERS (2007-2008)

Knight Piésold CONSULTING

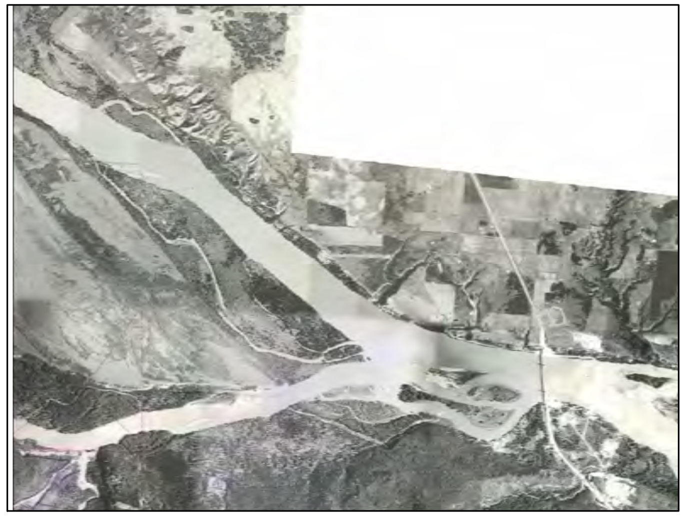
P/A NO. VA103-14/30

REF. NO. 1

FIGURE 5.7

REV 0

0	21FEB'12	ISSUED WITH REPORT	CN	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

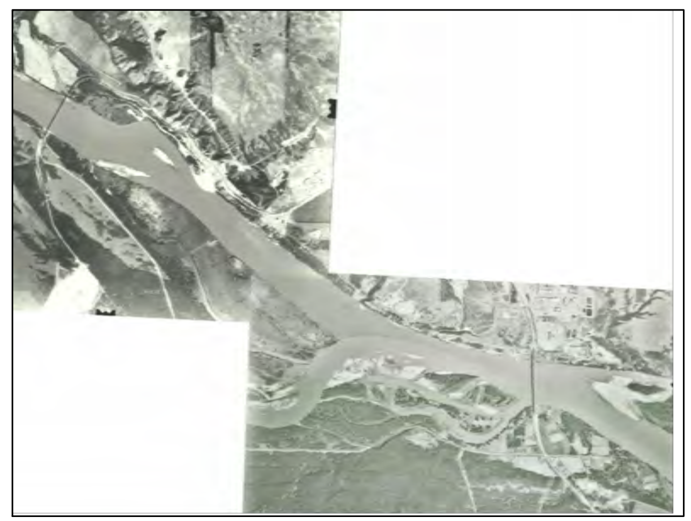


1945 (PINE/PEACE = N/A)

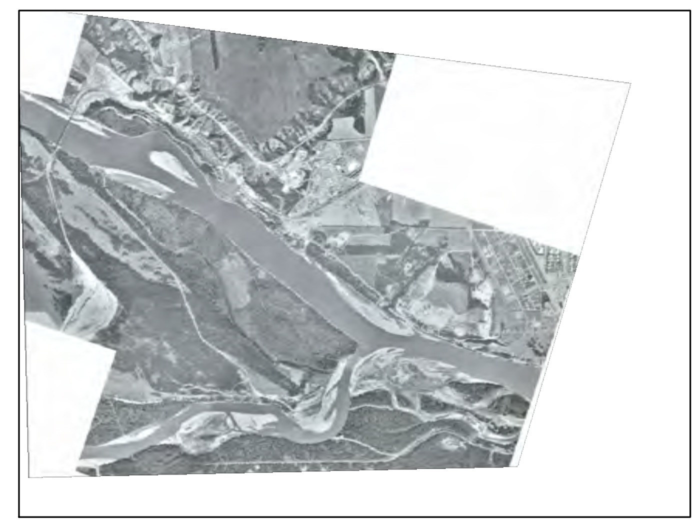
1956 (PINE/PEACE = N/A)

1967 (PINE/PEACE = 0.11)

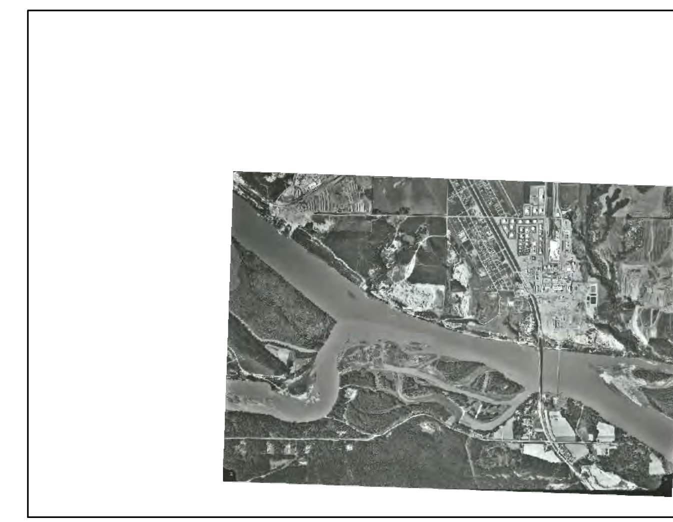
1970 (PINE/PEACE = 0.33)



1976 (PINE/PEACE = 0.75)



1981 (PINE/PEACE = 0.24)



1987 (PINE/PEACE = 0.58)

1996 (PINE/PEACE = 0.07)

1997 (PINE/PEACE = 0.34)

2005 (PINE/PEACE = 0.12)

NOTES:

1. PINE REFERS TO PINE RIVER FLOW AT THE MOUTH CALCULATED BY ADJUSTING THE MEASURED FLOWS AT WSC GAUGE 07FB001.

2. PEACE REFERS TO PEACE RIVER ABOVE PINE RIVER FLOW. THE FLOWS AFTER 1980 OBTAINED FROM WSC GAUGE 07FA004. THE FLOWS PRIOR TO 1980 OBTAINED BY SUBTRACTING THE ADJUSTED PINE RIVER FLOW AT THE MOUTH FROM WSC GAUGE 07FD002 (PEACE RIVER NEAR TAYLOR).

APPROX. SCALE A 500 0 1000 2000 3000 4000 m

BC HYDRO

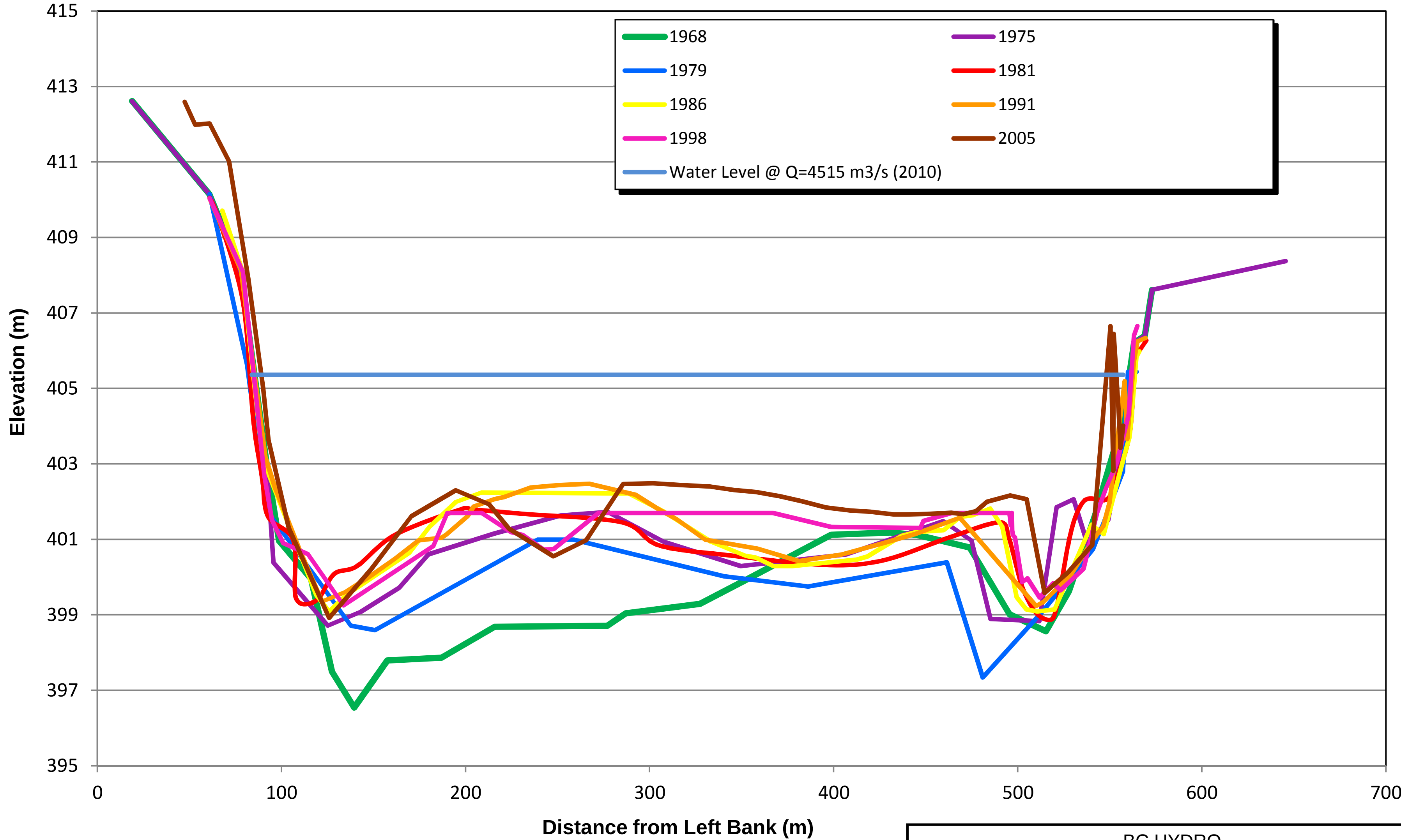
GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

HISTORICAL AIR PHOTO SEQUENCE
PEACE / PINE RIVER CONFLUENCE

Knight Piésold CONSULTING

P/A NO.	REF NO.
VA103-14/30	1
FIGURE 6.1	REV 0

0	22FEB'12	ISSUED WITH REPORT	MH	WAL	CN	KJB
REV	DATE	DESCRIPTION	DESIGNED	DRAWN	CHK'D	APP'D



NOTE:

1. WATER LEVEL CALCULATED FOR A DISCHARGE RATE OF 4515 m³/s USING THE 2010-02-25 RATING TABLE FOR WSC GAUGE 07FD002.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

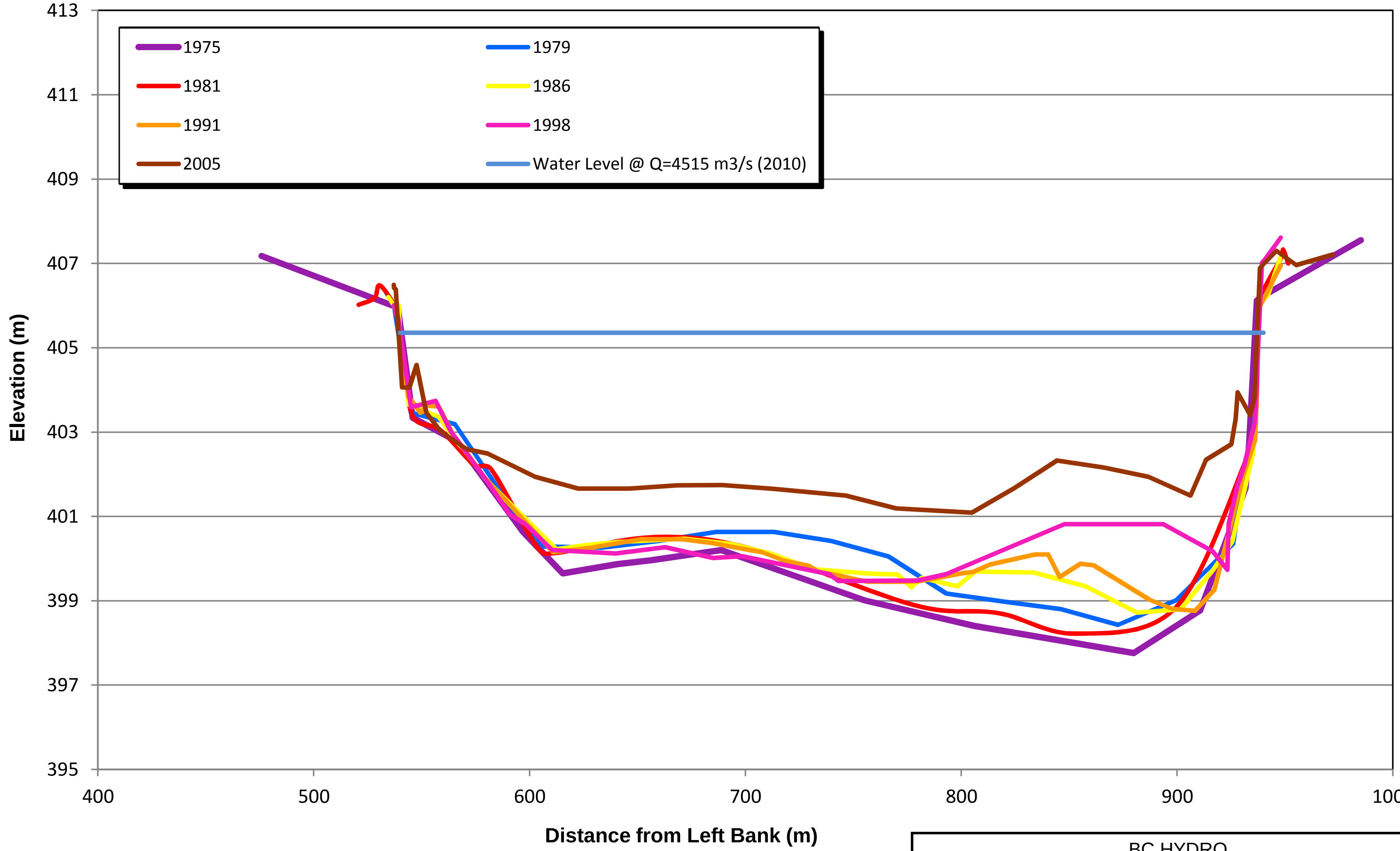
HISTORICAL CROSS SECTION ANALYSIS SECTION S10

Knight Piésold CONSULTING

P/A NO.	REF. NO.
VA103-14/30	1

FIGURE 6.2 REV 0

0	23FEB'12	ISSUED WITH REPORT	AD	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D



NOTE:

1. WATER LEVEL CALCULATED FOR A DISCHARGE RATE OF 4515 m³/s USING THE 2010-02-25 RATING TABLE FOR WSC GAUGE 07FD002.

0	23FEB'12	ISSUED WITH REPORT	AD	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

HISTORICAL CROSS SECTION ANALYSIS
SECTION 125

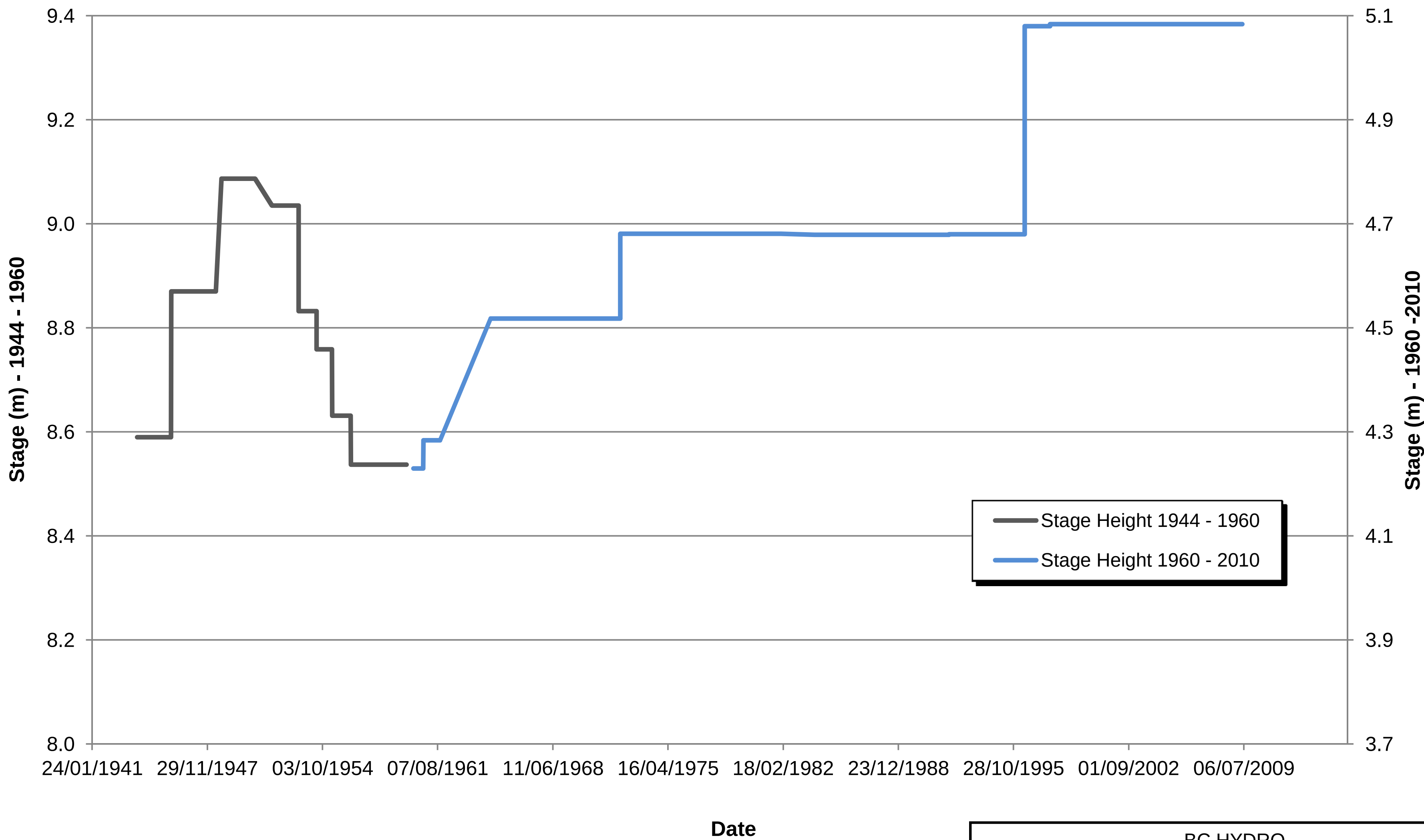
Knight Piésold CONSULTING

P/A NO. VA103-14/30

REF. NO. 1

FIGURE 6.3

REV 0



NOTES:

1. STAGE VALUES ASSOCIATED WITH A DISCHARGE OF 4515 m³, BASED ON WSC STAGE - DISCHARGE RATING TABLES, ARE PLOTTED AGAINST THE TIME PERIOD OF RATING TABLE APPLICATION.
2. A NEW GAUGE DATUM WAS ADOPTED IN 1960.

0	23FEB'12	ISSUED WITH REPORT	MDH	CN	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

SPECIFIC GAUGE ANALYSIS
WSC GAUGE 07FD002 PEACE RIVER NEAR TAYLOR

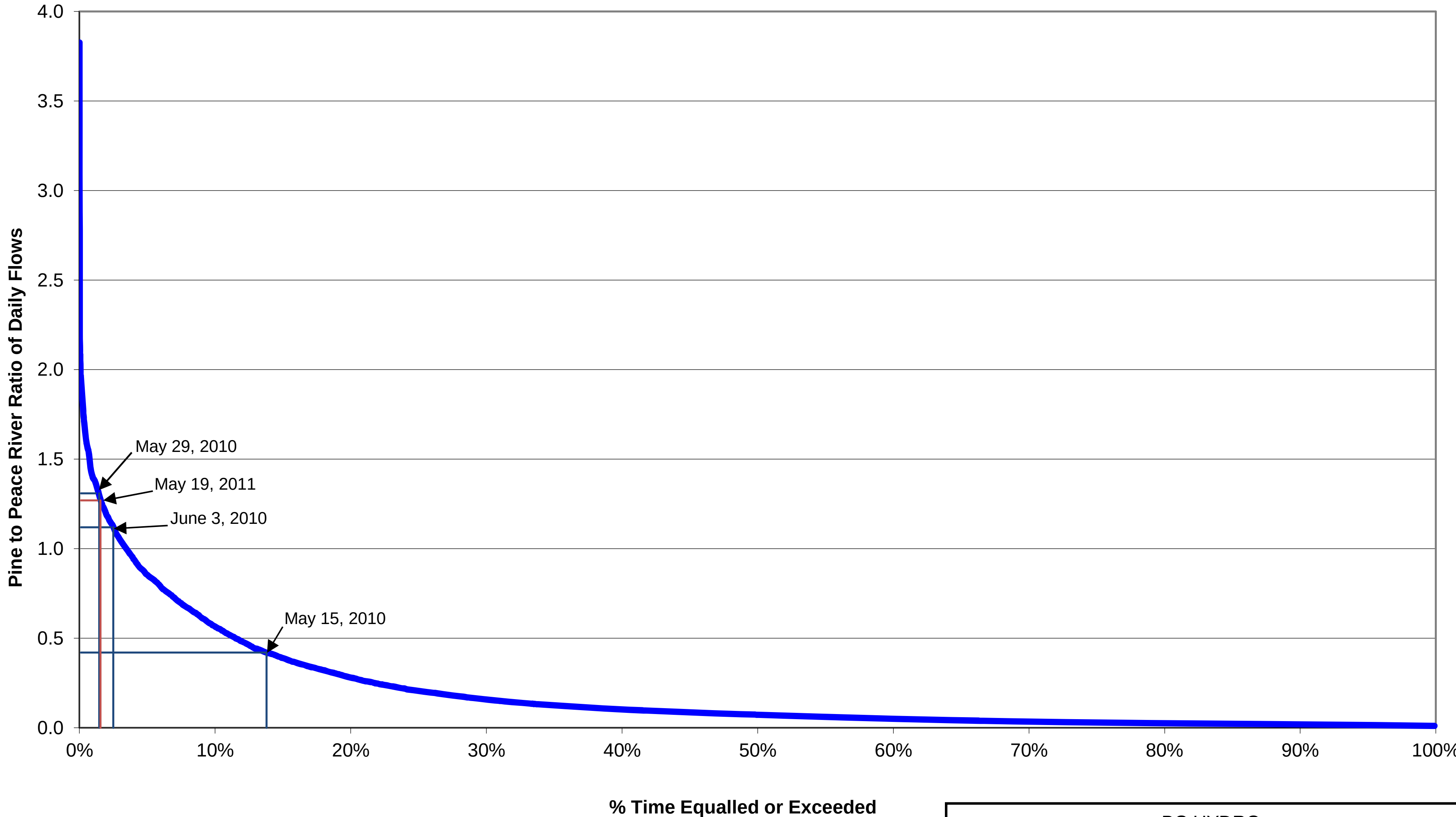
Knight Piésold CONSULTING

P/A NO. VA103-14/30

REF. NO. 1

FIGURE 6.4

REV 0



NOTES:

1. EXCEEDENCE CURVE BASED ON THE PERIOD OF RECORD FROM 1980 TO 2010.
2. DISCHARGE AT THE PINE RIVER MOUTH COMPUTED BY ADJUSTING THE FLOWS MEASURED AT WSC GAUGE 07FB001 BY 3%.
3. DISCHARGE FOR PEACE RIVER MEASURED AT WSC GAUGE 07FA004.
4. DISCHARGE DATA FOR 1986 WERE EXCLUDED FROM THE ANALYSIS AT BOTH STATIONS BECAUSE THE RECORD AT 07FA004 WAS INCOMPLETE.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

PINE TO PEACE FLOW RIVER RATIO DURING 2010 AND 2011 TRANSECT MEASUREMENTS

Knight Piésold CONSULTING

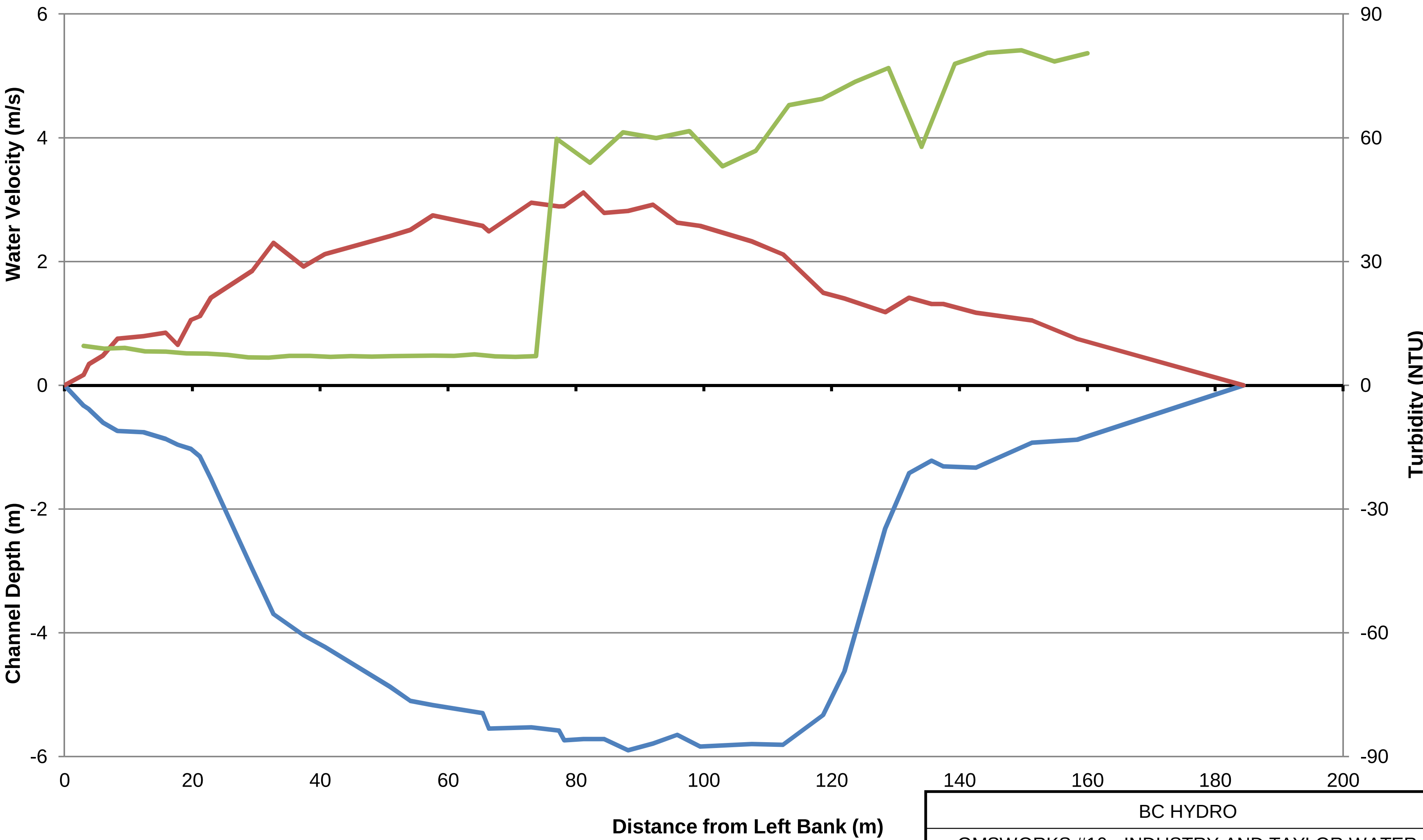
P/A NO. VA103-14/30

REF. NO. 1

FIGURE 7.1

REV 0

0	10FEB'12	ISSUED WITH REPORT	VM	CJN	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D



NOTES:

1. TRANSECT VIEWED LOOKING DOWNSTREAM.
2. TRANSECT LOCATED ON THE PEACE RIVER 0.1 km DOWNSTREAM FROM CONFLUENCE WITH THE PINE RIVER.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

TURBIDITY TRANSECT PROFILE
DISTRICT OF TAYLOR PUMPHOUSE
15 MAY 2010

Knight Piésold CONSULTING

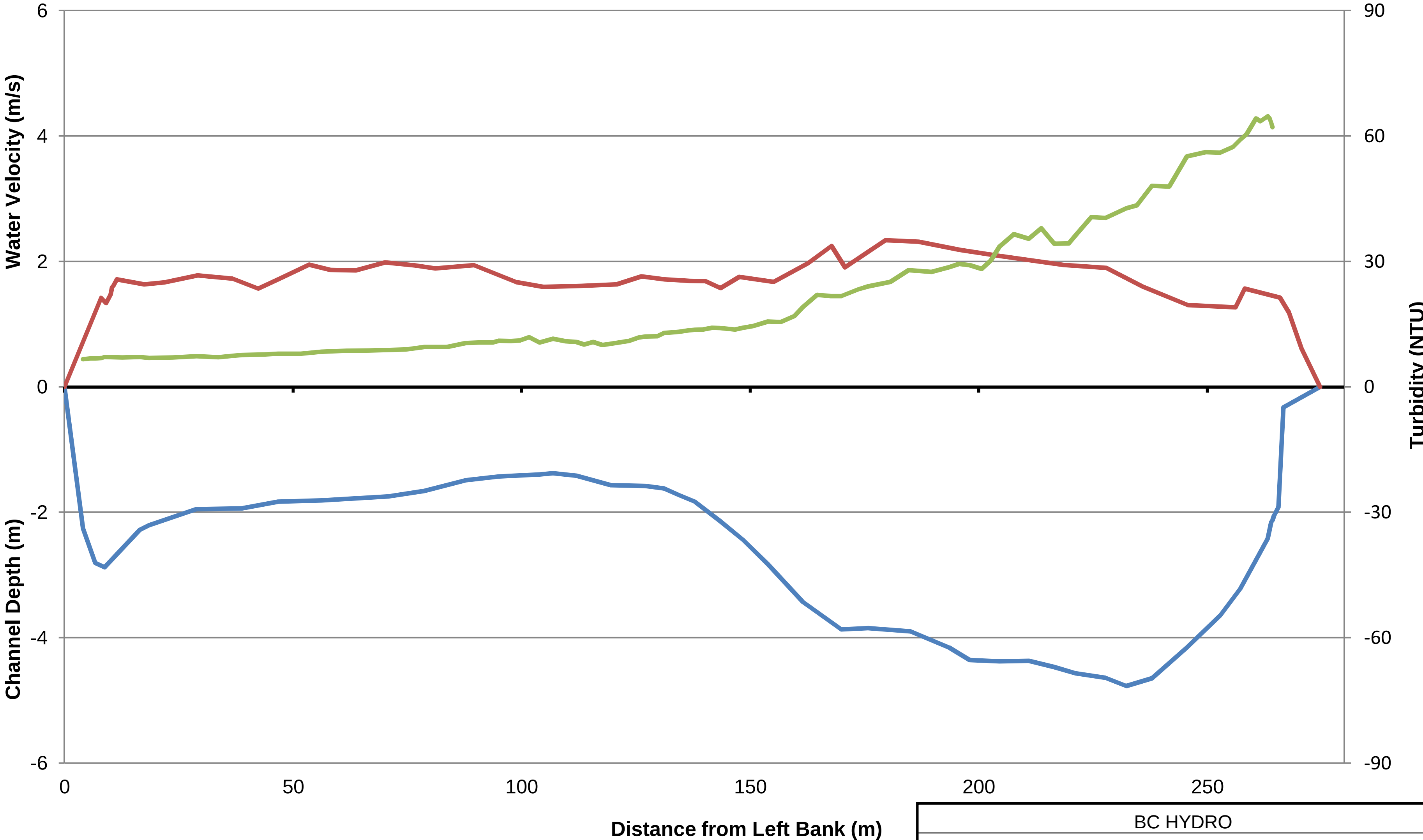
P/A NO. VA103-14/30-1

REF. NO. 1

FIGURE 7.2

REV 0

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	31JAN'12	ISSUED WITH REPORT	KT	CN	KPH



NOTES:

1. TRANSECT VIEWED LOOKING DOWNSTREAM.
2. TRANSECT LOCATED ON THE PEACE RIVER 1.3 km DOWNSTREAM OF CONFLUENCE WITH THE PINE RIVER.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

TURBIDITY TRANSECT PROFILE
POWERLINE CROSSING
15 MAY 2010

Knight Piésold CONSULTING

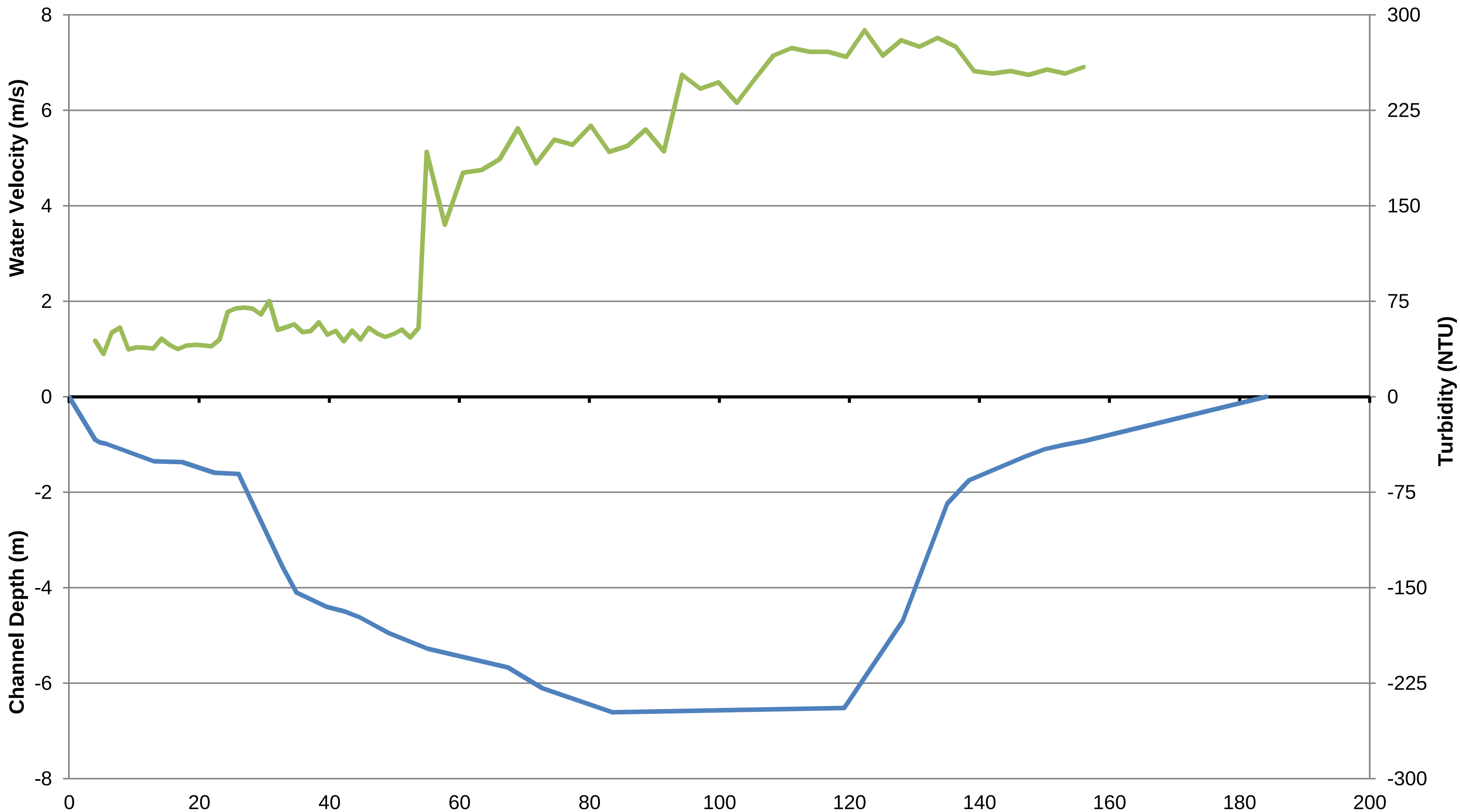
P/A NO. VA103-14/30

REF. NO. 1

FIGURE 7.3

REV 0

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	31JAN'12	ISSUED WITH REPORT	KT	CN	JPH



NOTES:

1. TRANSECT VIEWED LOOKING DOWNSTREAM.
2. TRANSECT LOCATED ON THE PEACE RIVER 0.1 km DOWNSTREAM FROM CONFLUENCE WITH THE PINE RIVER.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

TURBIDITY TRANSECT PROFILE
DISTRICT OF TAYLOR PUMPHOUSE
29 MAY 2010

Knight Piésold CONSULTING

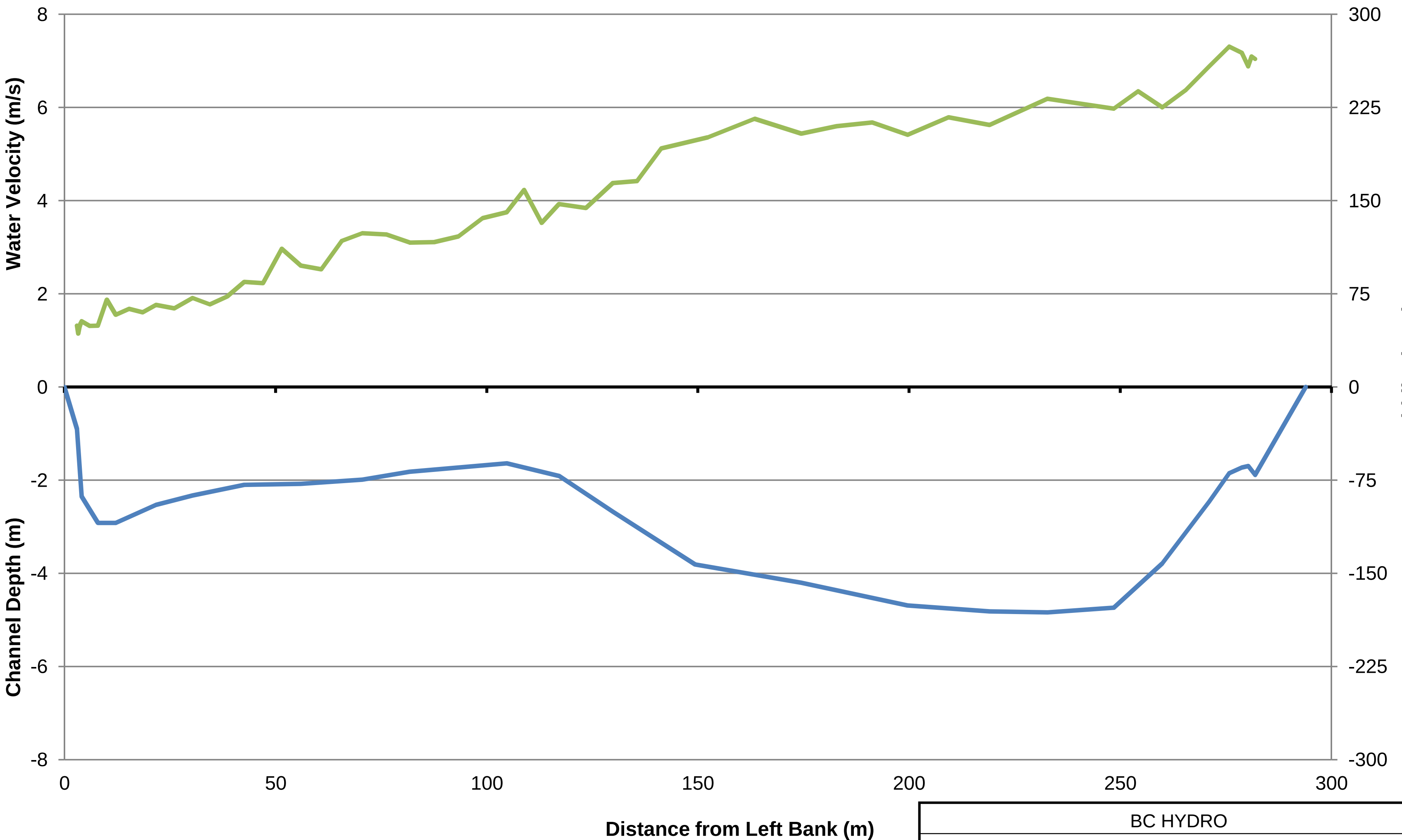
P/A NO. VA103-14/30

REF. NO. 1

FIGURE 7.4

REV 0

0	27FEB'12	ISSUED WITH REPORT	AA	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D



NOTES:

1. TRANSECT VIEWED LOOKING DOWNSTREAM.
2. TRANSECT LOCATED ON THE PEACE RIVER 1.3 km DOWNSTREAM OF CONFLUENCE WITH THE PINE RIVER.

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	27FEB'12	ISSUED WITH REPORT	AA	VM	JPH

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

TURBIDITY TRANSECT PROFILE
POWERLINE CROSSING
29 MAY 2010

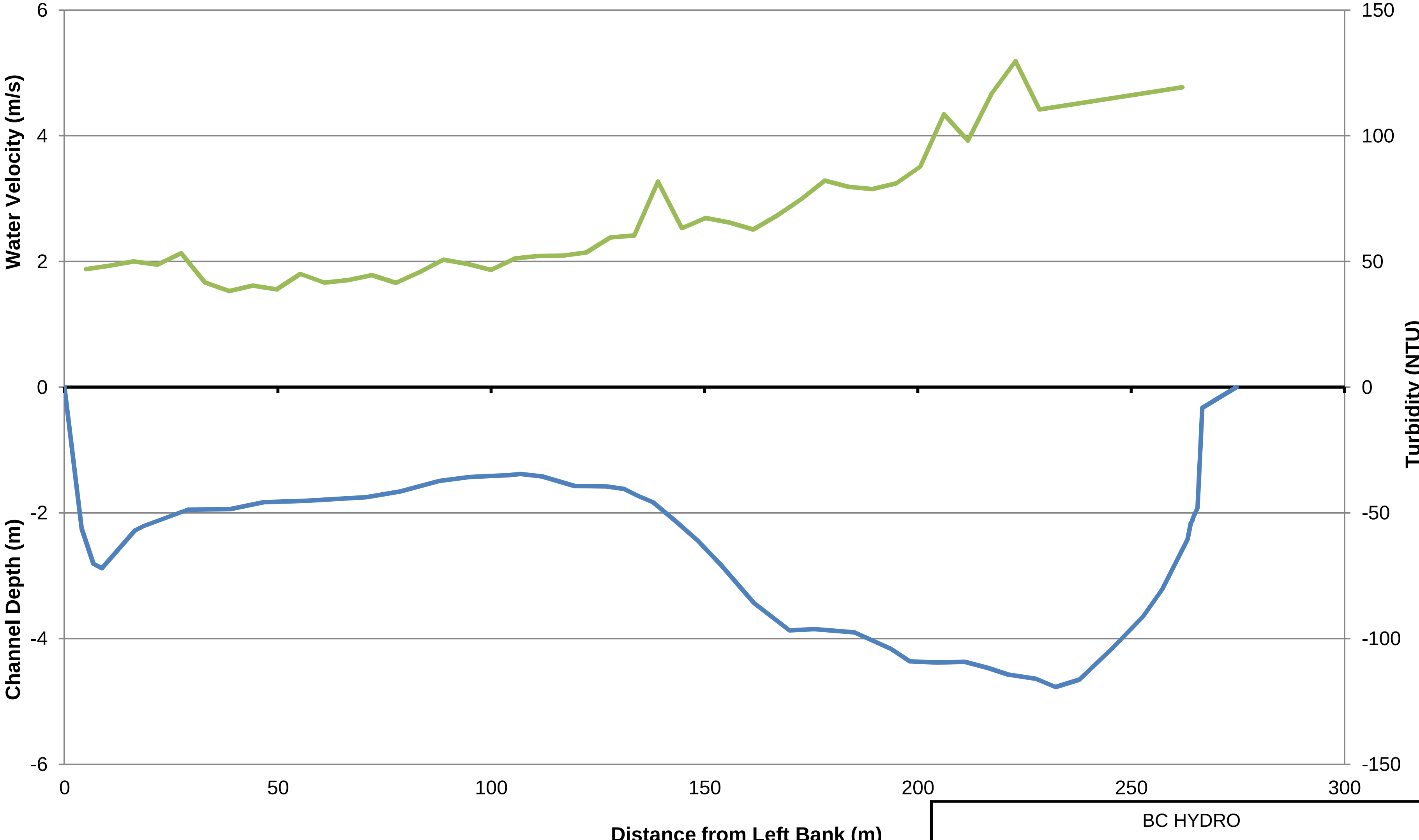
Knight Piésold CONSULTING

P/A NO. VA103-14/30

REF. NO. 1

FIGURE 7.5

REV 0



NOTES:

1. TRANSECT VIEWED LOOKING DOWNSTREAM.
2. TRANSECT LOCATED ON THE PEACE RIVER 1.3 km DOWNSTREAM OF CONFLUENCE WITH THE PINE RIVER.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

TURBIDITY TRANSECT PROFILE
POWERLINE CROSSING
3 JUNE 2010

Knight Piésold CONSULTING

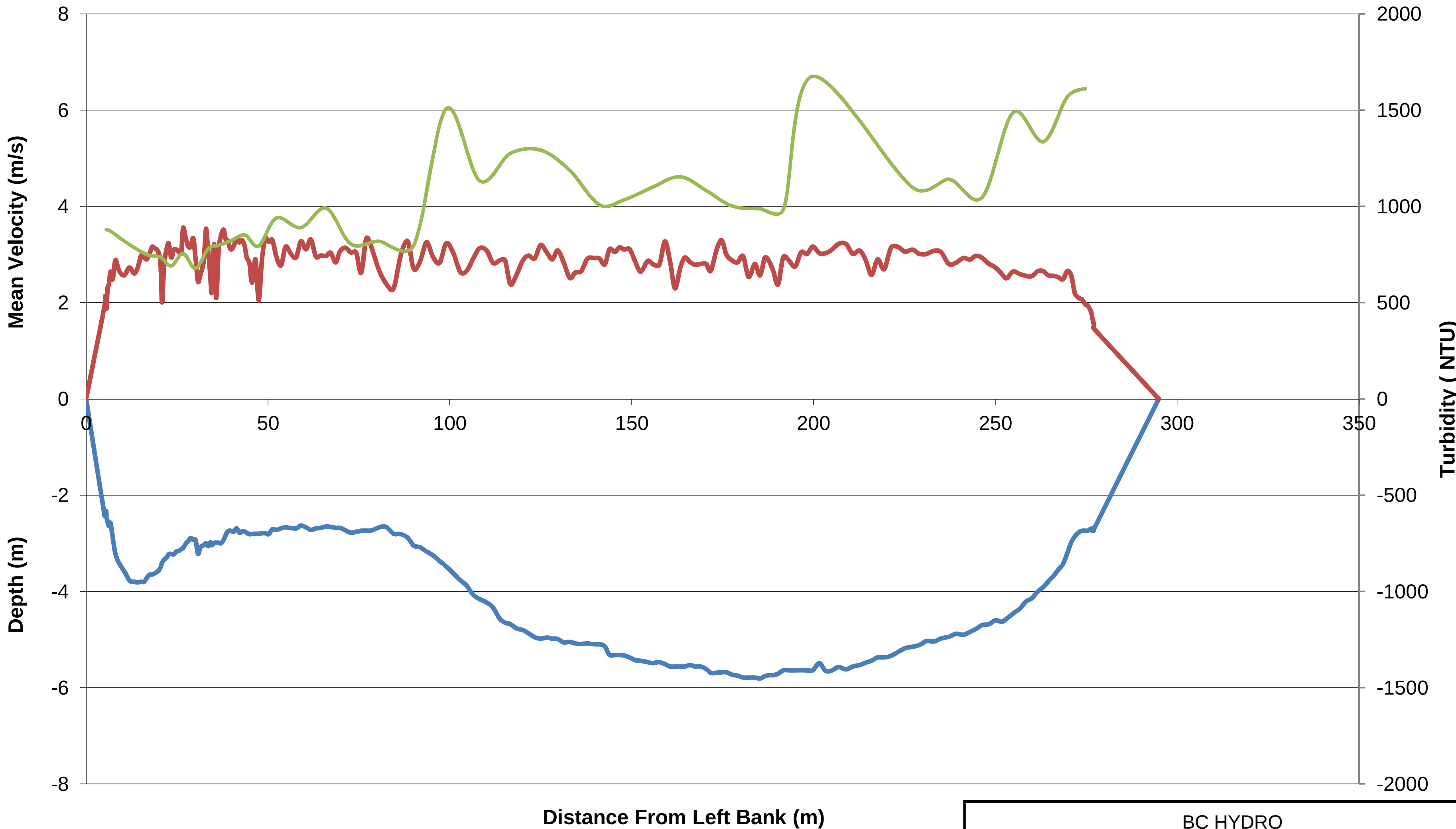
P/A NO. VA103-14/30

REF. NO. 1

FIGURE 7.6

REV 0

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	27FEB'12	ISSUED WITH REPORT	AA	VM	JPH



NOTES:

1. TRANSECT VIEWED LOOKING DOWNSTREAM.
2. TRANSECT LOCATED ON THE PEACE RIVER 1.3 km DOWNSTREAM FROM CONFLUENCE WITH THE PINE RIVER.
3. DATA COLLECTED DURING THE 2011 KPL SUSPENDED SEDIMENT SAMPLING PROGRAM.

River Profile
Mean Velocity, Q = 3025 cms
Turbidity

0	27FEB'12	ISSUED WITH REPORT	AA	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

TURBIDITY TRANSECT PROFILE
POWERLINE CROSSING
19 MAY 2011

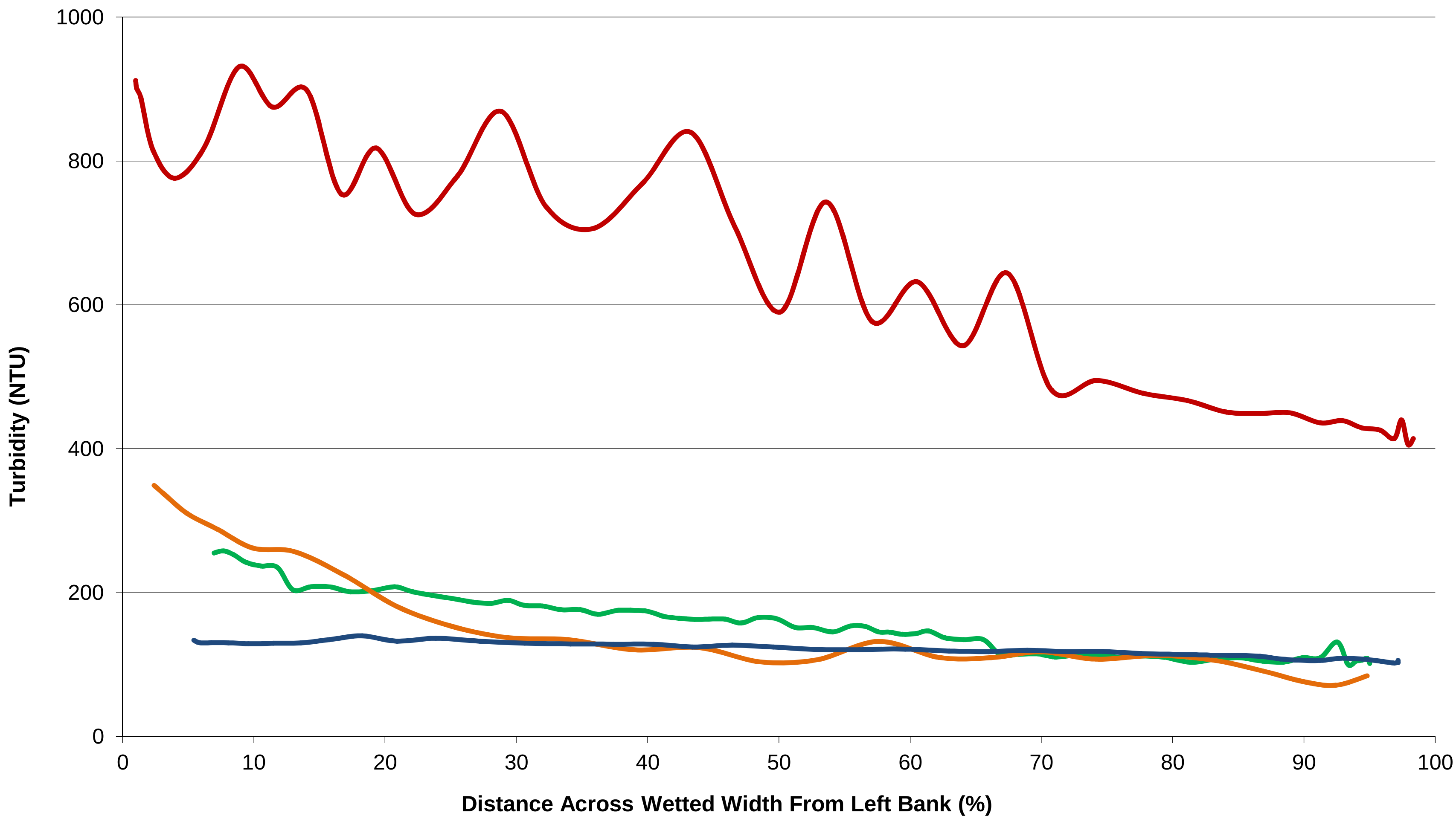
Knight Piésold CONSULTING

P/A NO. VA103-14/30

REF. NO. 1

FIGURE 7.7

REV 0



NOTES:
1. WETTED CHANNEL WIDTH VARIED WITH FLOW; HORIZONTAL DISTANCES ACROSS THE CHANNEL ARE EXPRESSED AS PERCENTAGES OF WETTED CHANNEL WIDTH ON EACH DATE.
2. TRANSECTS ARE VIEWED LOOKING DOWNSTREAM.
3. DATA COLLECTED DURING THE 2011 KPL SUSPENDED SEDIMENT SAMPLING PROGRAM.

0	27FEB'12	ISSUED WITH REPORT	AA	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

TURBIDITY TRANSECT PROFILES
PEACE ABOVE PINE

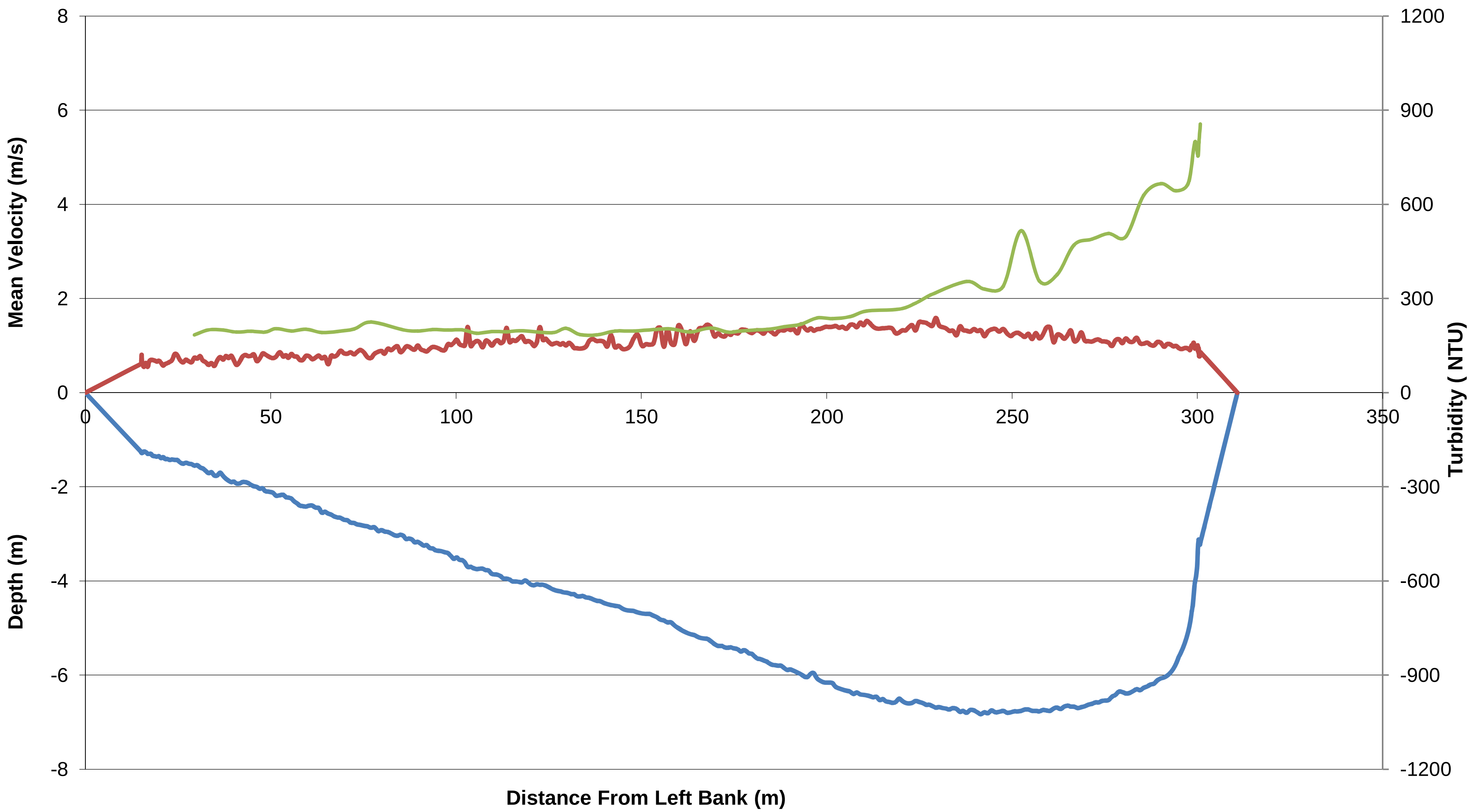
Knight Piésold CONSULTING

P/A NO. VA103-14/30 | REF. NO. 1

FIGURE 7.8 | REV 0

M:\1\03\00014\30\A\Data\Spectra Intake\turbidity transect\01-05-2011 Turbidity PAB FIG

Print 01/03/2012 3:31 PM



NOTES:

1. TRANSECT VIEWED LOOKING DOWNSTREAM.
2. TRANSECT LOCATED ON THE PEACE RIVER 1.1 km UPSTREAM OF CONFLUENCE WITH THE BEATTON RIVER.
3. DATA COLLECTED DURING THE 2011 KPL SUSPENDED SEDIMENT SAMPLING PROGRAM.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

TURBIDITY TRANSECT PROFILE
PEACE ABOVE BEATTON
1 MAY 2011

Knight Piésold CONSULTING

P/A NO.	REF. NO.
VA103-14/30	1

FIGURE 7.9 REV 0

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	27FEB'12	ISSUED WITH REPORT	AA	VM	JPH

NOTES:

1. A - INNER FOREBAY TRANSECT
2. B - MID FOREBAY TRANSECT
3. C - LOG BOOM TRANSECT
4. RM - ELEVATION REFERENCE MARK (TOP CORNER OF CONCRETE AT END OF UPSTREAM WING WALL)

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	27FEB'12	ISSUED WITH REPORT	VM	CJN	JPH

BC HYDRO

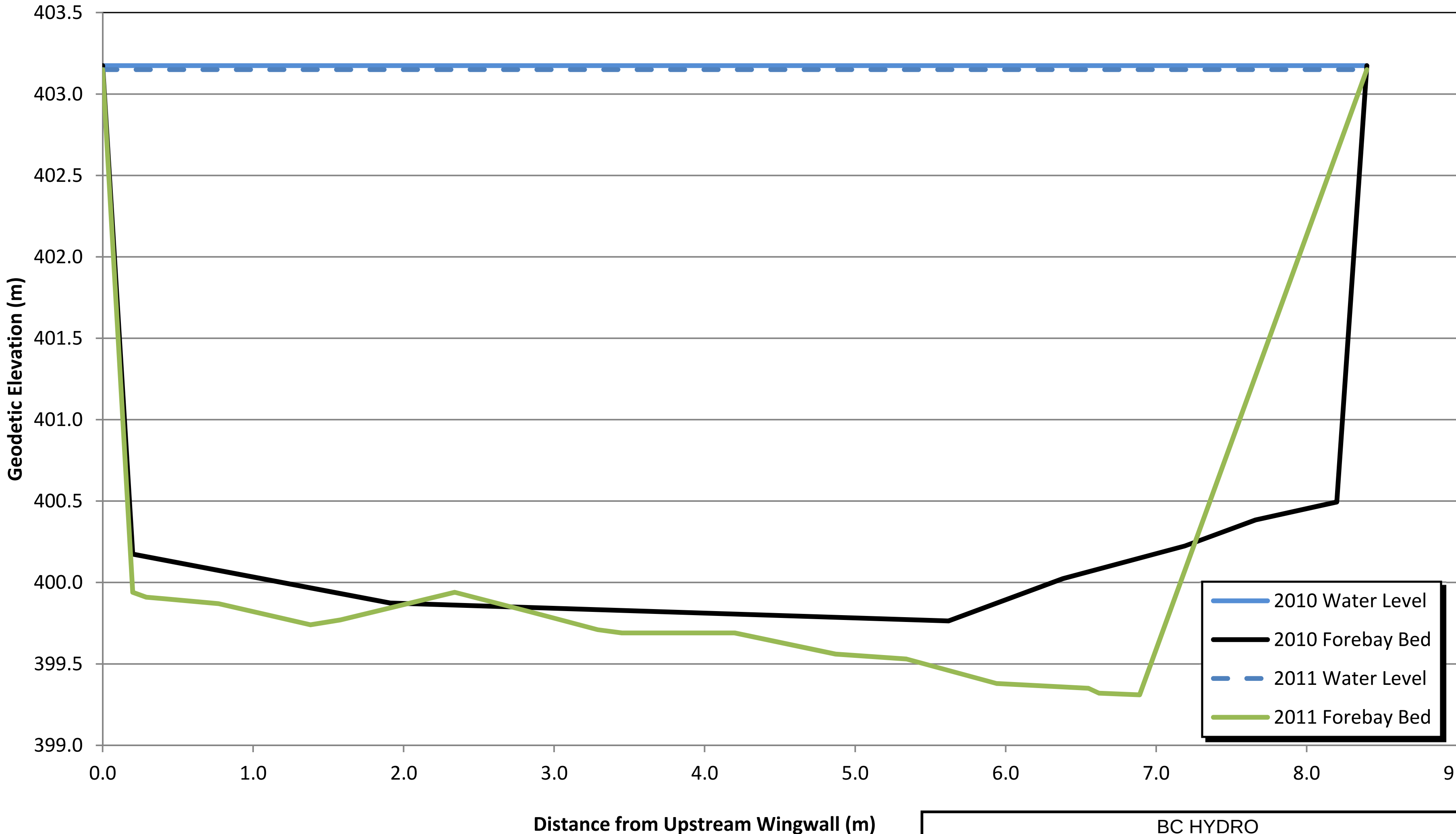
GMSWORKS #10 - - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

SPECTRA INTAKE BATHYMETRY SURVEY TRANSECT LOCATIONS

Knight Piésold CONSULTING

P/A NO.	REF. NO.
VA103-14/30	1

FIGURE 8.1 REV 0



NOTES:

1. THE INNER FOREBAY TRANSECT WAS SURVEYED ON JUNE 1, 2010 AT 14:30 MST AND ON MAY 3, 2011 AT 9:40 MST.
2. THE TRANSECT LOCATION IS DEPICTED IN THE PHOTOS SHOWN ON FIGURE 8.1.

0	8FEB'12	ISSUED WITH REPORT	AA	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

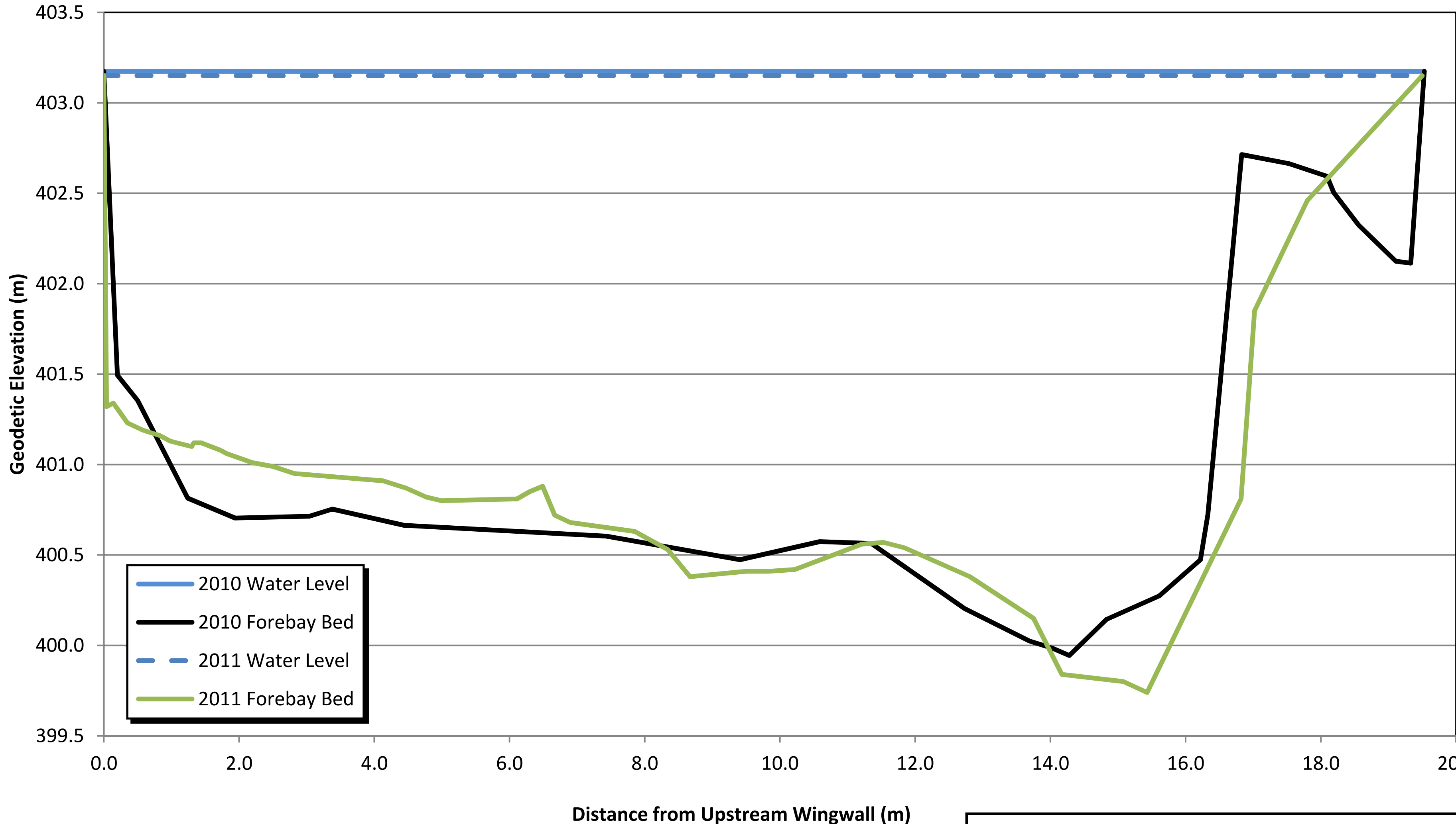
BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

SPECTRA INTAKE BATHYMETRY
INNER FOREBAY TRANSECT

Knight Piésold
CONSULTING

P/A NO. VA103-14/30	REF. NO. 1
FIGURE 8.2	REV 0



NOTES:
1. THE MID FOREBAY TRANSECT WAS SURVEYED ON JUNE 1, 2010 AT 14:30 MST AND ON MAY 3, 2011 AT 9:40 MST.
2. THE TRANSECT LOCATION IS DEPICTED IN THE PHOTOS SHOWN ON FIGURE 8.1.

0	8FEB'12	ISSUED WITH REPORT	AA	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

BC HYDRO
GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

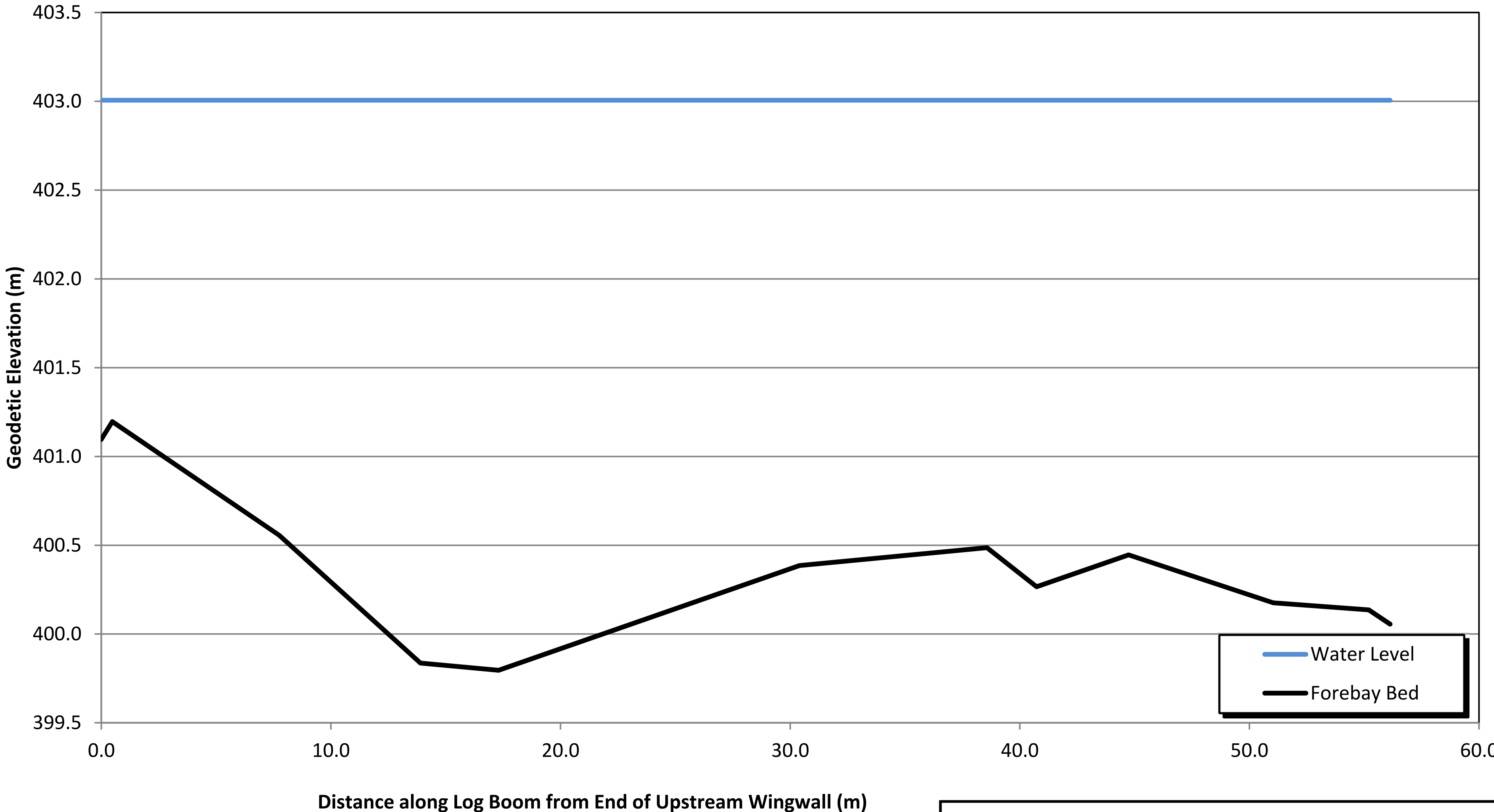
SPECTRA INTAKE BATHYMETRY
MID FOREBAY TRANSECT

Knight Piésold CONSULTING

P/A NO. VA103-14/30
REF NO. 1

FIGURE 8.3

REV 0



NOTES:

1. THE LOG BOOM TRANSECT WAS SURVEYED ON JUNE 3, 2010 AT 16:40 MST. THE SURVEY WAS NOT REPEATED IN 2011.
2. THE TRANSECT LOCATION IS DEPICTED ON THE PHOTOS SHOWN IN FIGURE 8.1.

0	07JAN'11	ISSUED WITH REPORT	MDH	CN	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

BC HYDRO

GMSWORKS # 10 - - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

SPECTRA INTAKE BATHYMETRY LOG BOOM TRANSECT

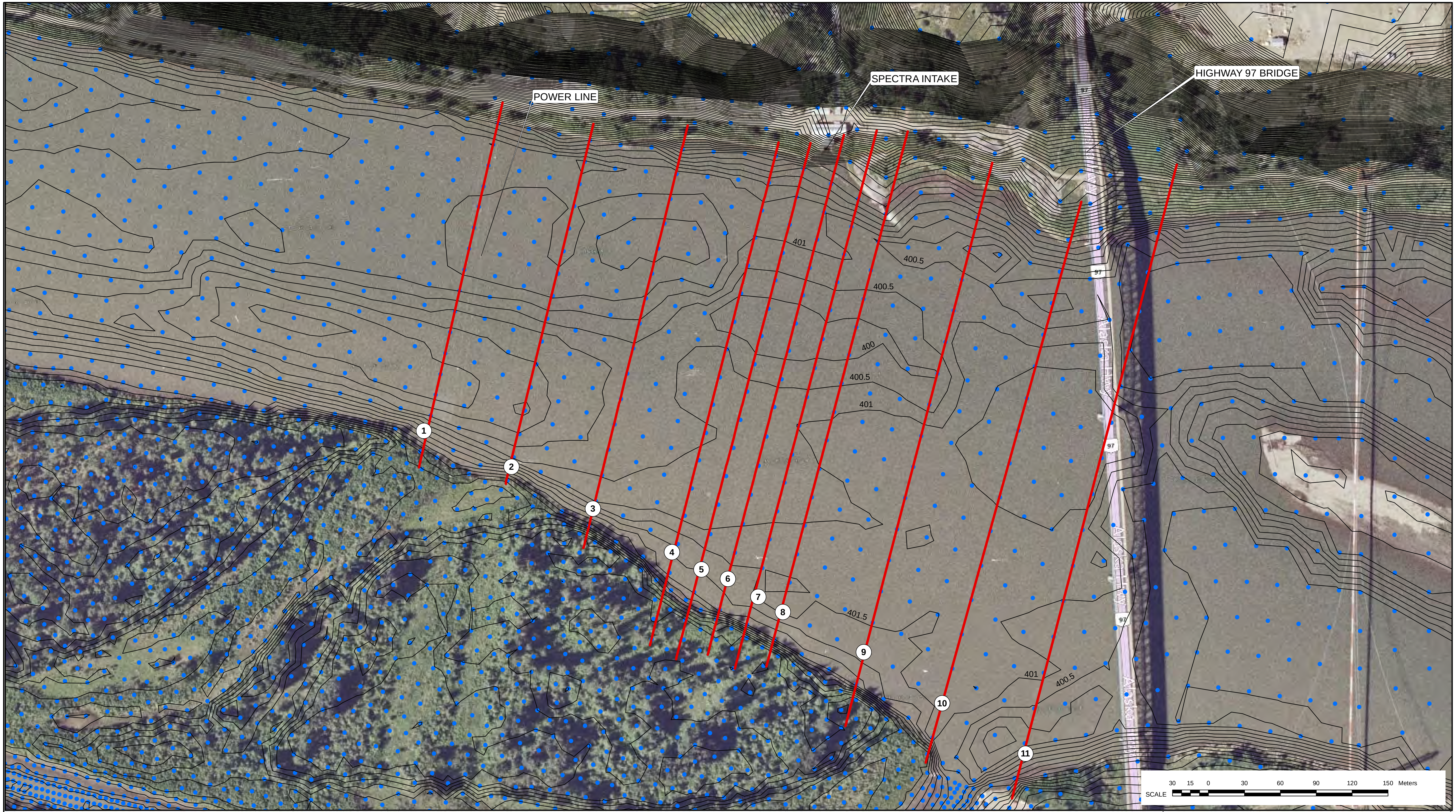
Knight Piésold CONSULTING

P/A NO. VA103-14/30

REF. NO. 1

FIGURE 8.4

REV 0



LEGEND:

GENERAL

- BATHYMETRIC OR TERRAIN POINT
- BATHYMETRIC OR TERRAIN CONTOUR
- BATHYMETRIC TRANSECT

NOTES:

1. BASE MAP: (C) MICROSOFT BING MAPS.
2. COORDINATE GRID IS IN METRES.
COORDINATE SYSTEM: NAD 1983 UTM ZONE 10N.
3. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:3,000 FOR 11X17 (TABLOID) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.
4. BOAT-BASED BATHYMETRY SURVEYED BY CAPELLA GEOMATICS INC. IN JUNE 2010.
5. TERRAIN ELEVATIONS BASED ON LIDAR.

REV	DATE	DESCRIPTION	DESIGNED	DRAWN	CHK'D	APP'D
0	20FEB'12	ISSUED WITH REPORT	VM	AMD	CJN	JPH

KP FIGURE SAVED: M:\1\03\00014\30\A\GIS\Figs\PeaceR_Bathymetry.mxd; Mar 29, 2012 9:09:21 AM adinca

BC HYDRO

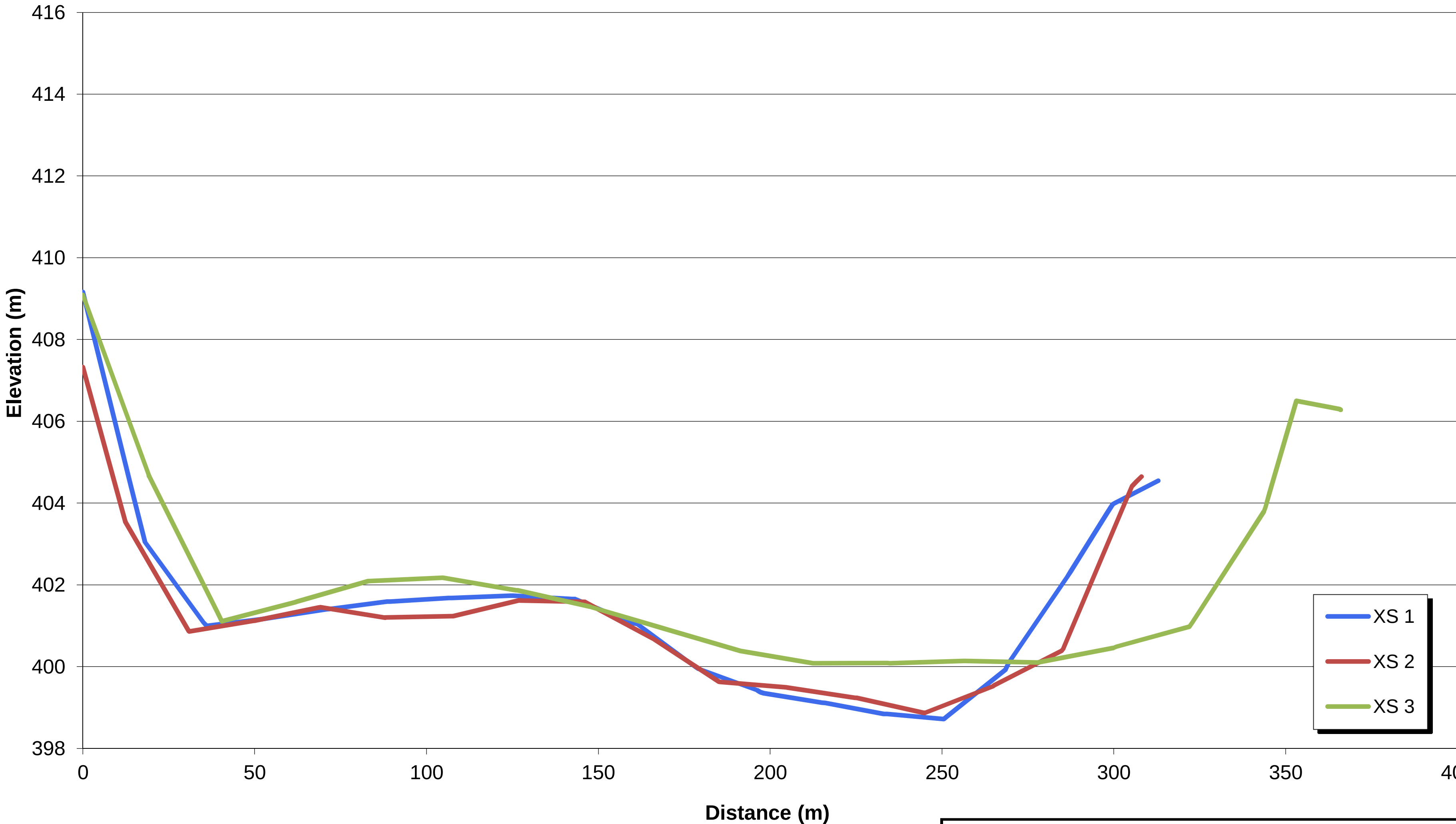
GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

PEACE RIVER BATHYMETRIC AND TERRAIN MAP AND CROSS-SECTION LOCATIONS

Knight Piésold CONSULTING

P/A NO. VA103-14/30 | REF NO. 1

FIGURE 8.5 | REV 0



NOTE:
1. BOAT-BASED BATHYMETRY SURVEYED BY CAPELLA GEOMATICS INC. IN JUNE 2010.

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	21FEB'12	ISSUED WITH REPORT	AA	VM	JPH

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

PEACE RIVER BATHYMETRY CROSS-SECTIONS BETWEEN THE POWERLINE AND SPECTRA FOREBAY

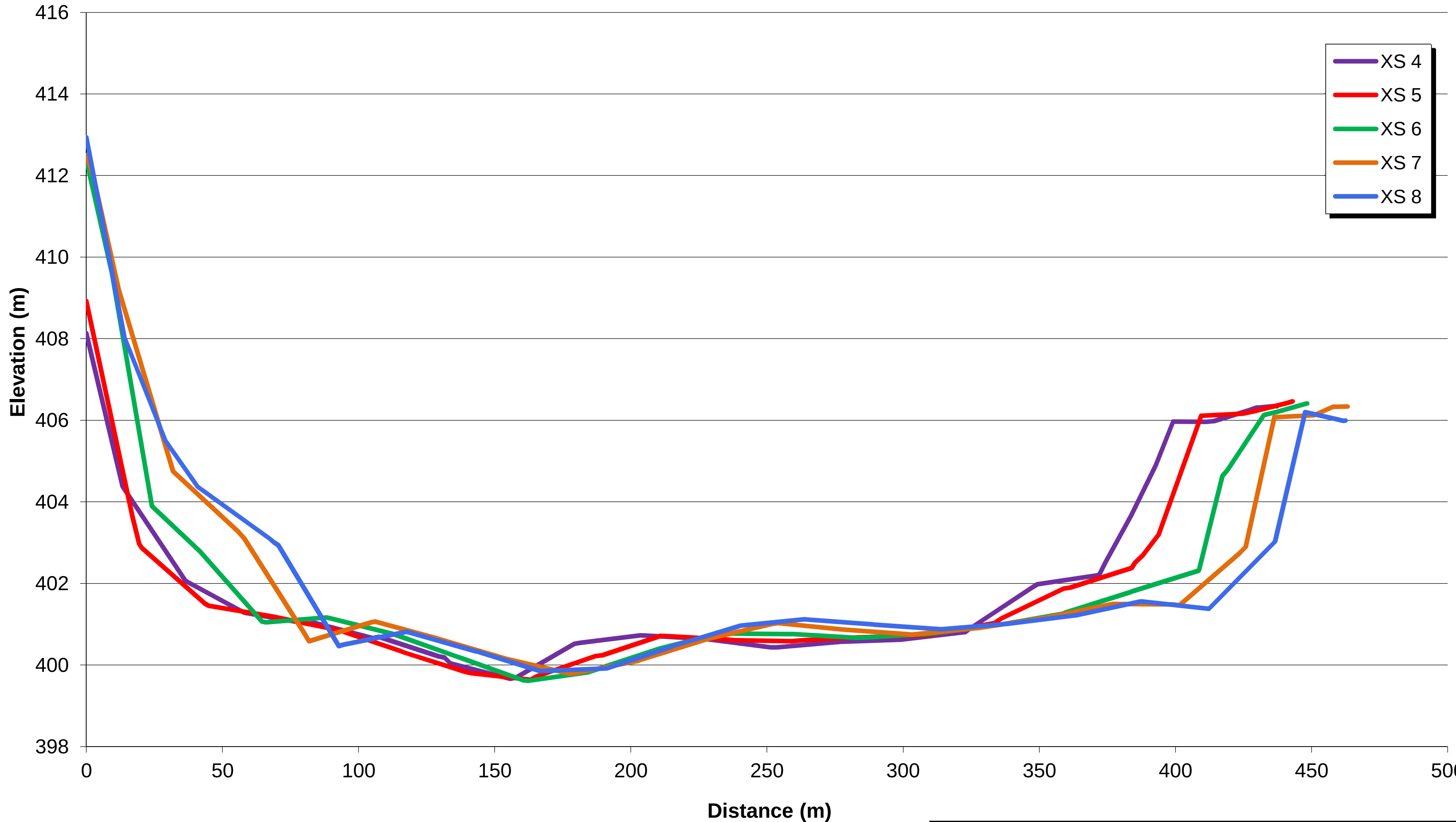
Knight Piésold CONSULTING

P/A NO. VA103-14/30

REF. NO. 1

FIGURE 8.6

REV 0



NOTE:
1. BOAT-BASED BATHYMETRY SURVEYED BY CAPELLA GEOMATICS INC. IN JUNE 2010.

0	21FEB'12	ISSUED WITH REPORT	AA	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

PEACE RIVER BATHYMETRY
CROSS-SECTIONS AT THE SPECTRA FOREBAY

Knight Piésold CONSULTING

P/A NO. VA103-14/30

REF. NO. 1

FIGURE 8.7

REV 0

M:\1\03\00014\30\A\Data\Peace Bathymetry\[Profiles_new.xls]Figure 8.8

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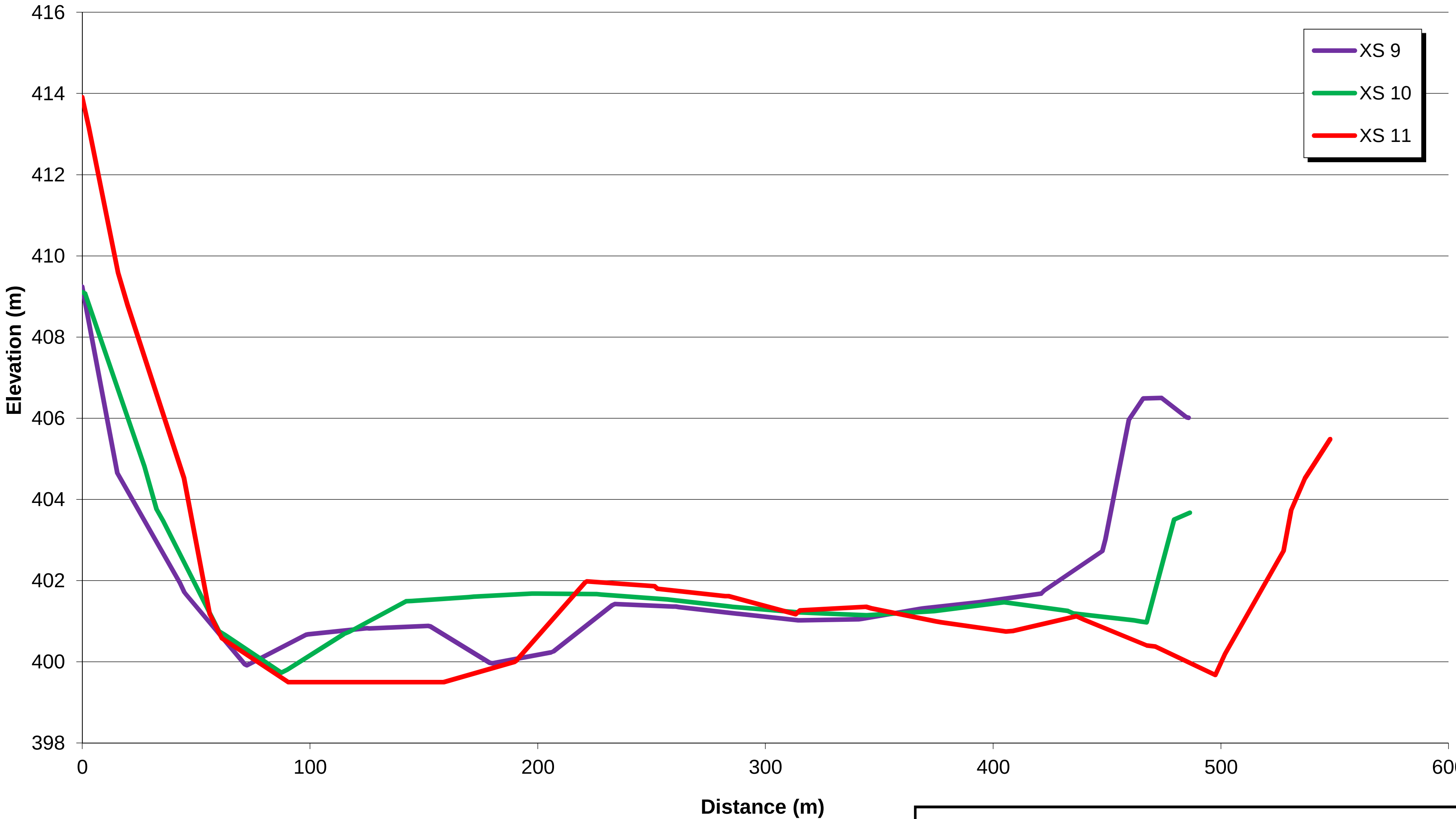


NOTE:

1. BOAT-BASED BATHYMETRY SURVEYED BY CAPELLA GEOMATICS INC. IN JUNE 2010.

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

PEACE RIVER BATHYMETRY
CROSS-SECTIONS BETWEEN THE SPECTRA FOREBAY AND HIGHWAY 97 BRIDGE

Knight Piésold CONSULTING

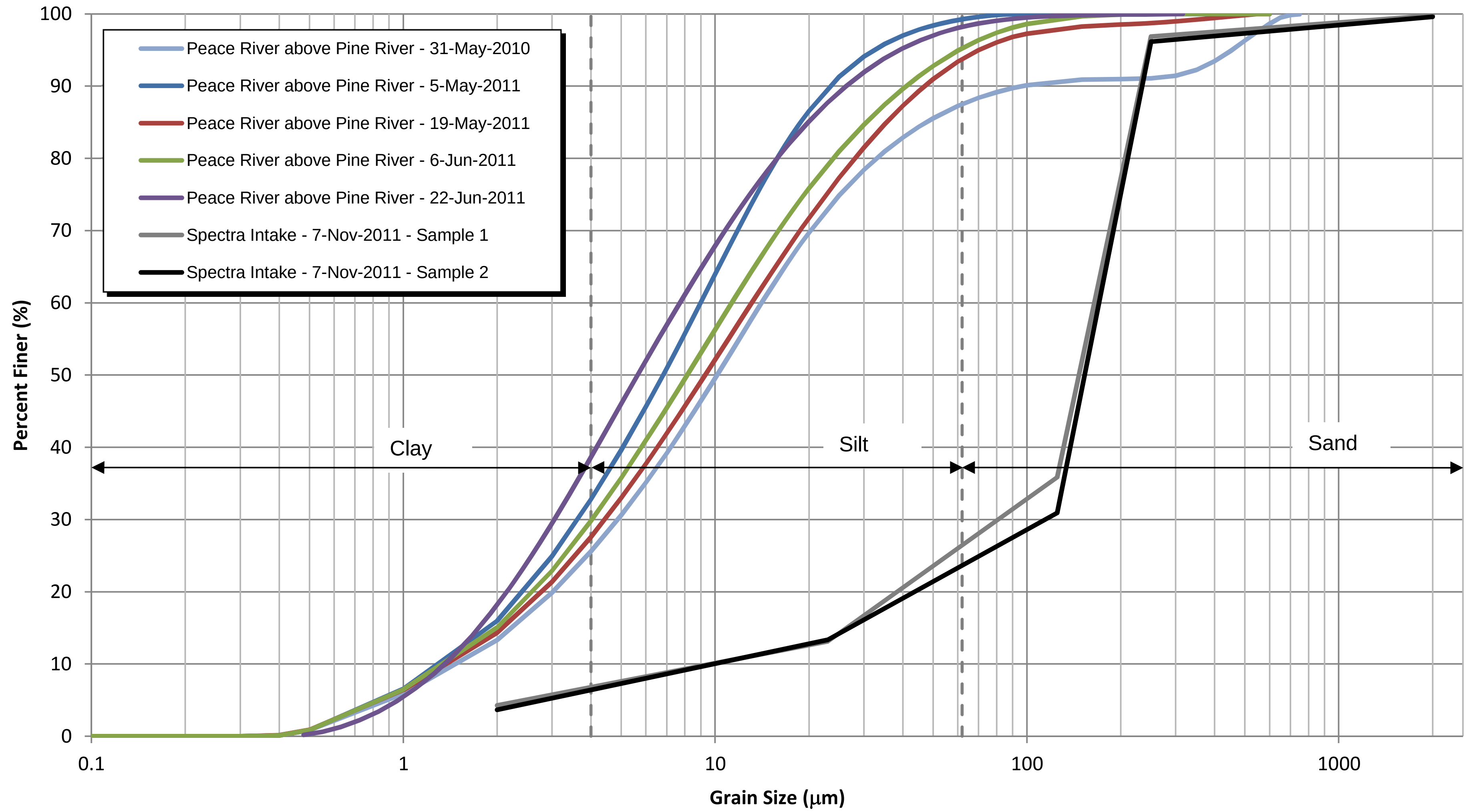
P/A NO. VA103-14/30

REF. NO. 1

FIGURE 8.8

REV 0

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
0	21FEB'12	ISSUED WITH REPORT	AA	VM	JPH



NOTES:

1. BOTH SPECTRA INTAKE SAMPLES TAKEN FROM THE ACCESS HOLE ON THE WEST END OF THE DREDGED MATERIAL CONTAINER.
2. PEACE ABOVE PINE RIVER SUSPENDED SEDIMENT SAMPLES TAKEN MID-CHANNEL DURING VARIOUS FLOW CONDITIONS.
3. GRAINSIZE DISTRIBUTIONS PERFORMED BY MAXXAM ANALYTICS.

1	27MAR'12	ISSUED WITH REPORT	AA	VM	JPH
REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D

BC HYDRO

GMSWORKS #10 - INDUSTRY AND TAYLOR WATER QUALITY ASSESSMENT

GRAIN SIZE DISTRIBUTION OF DREDGED MATERIAL AT SPECTRA INTAKE AND SUSPENDED SEDIMENT IN PEACE RIVER ABOVE PINE RIVER.

Knight Piésold CONSULTING

P/A NO.	REF. NO.
VA103-14/30	1

FIGURE 8.9 REV 1

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PHOTO 1 – Peace River above the Pine River confluence – typical sidewall landslide deposit.

PHOTO 2 – Peace River above the Pine River confluence – typical eroding shale sidewall.

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PHOTO 3 – Peace River above the Pine River confluence – typical vegetated gravel bar.

PHOTO 4 – Peace / Pine River confluence – looking downstream across gravel bar.

PHOTO 5 – Peace / Pine River confluence – looking upstream.

PHOTO 6 – Lower Pine River – typical site of active bank erosion.

PHOTO 7 – Lower Pine River – typical alluvial bank materials.

PHOTO 8 – Lower Pine River – typical glacio-fluvial bank materials.

PHOTO 9 – Lower Pine River – typical gravel bar.

PHOTO 10 – Sontek RiverSurveyor S5 Acoustic Doppler Current Profiler attached to a boom and held off the bow of the jet boat.

PHOTO 11 – Analite NEP 160 turbidity sensor attached to a 1 m rod and held 20 cm below the water surface from the side of the jet boat.

PHOTO 12 – Spectra Energy intake facility.

PHOTO 13 – Spectra Energy intake forebay.

PHOTO 14 – Spectra Energy intake – typical bed material in mid-channel gravel shoal.

PHOTO 15 – Aggregate mine settling ponds – looking upstream along the Peace River bank.

PHOTO 16 – Container of dredged material from Spectra Intake - looking downstream.

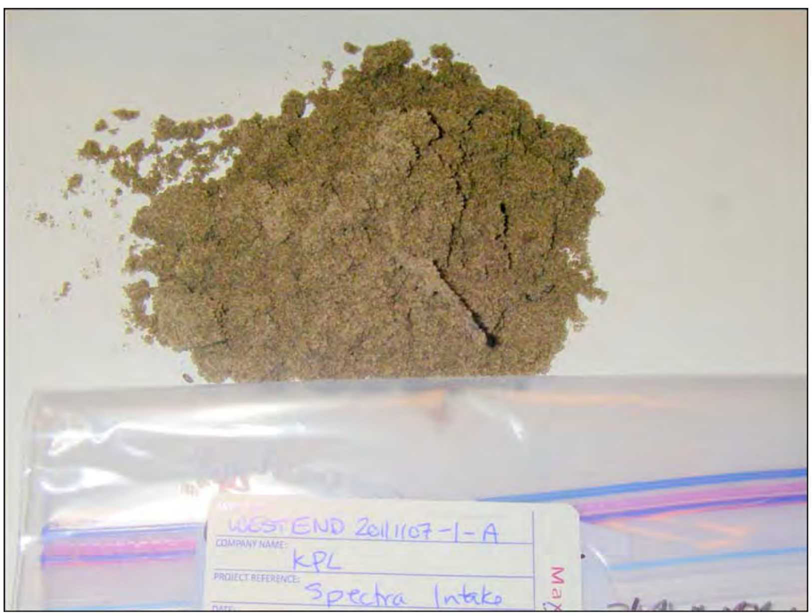

PHOTO 17 – Sample of material dredged from Spectra Intake.

PHOTO 18 – District of Taylor intake site – looking upstream at the two test wells.

PHOTO 19 – District of Taylor intake site – looking downstream along the island shoreline.