Peace River Water Use Plan

Monitoring Program

Implementation Year 5

Reference: GMSMON-9

Peace River Spill Hydrology

Study Period: January 01, 2012 to December 31, 2012

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May 15, 2014

PEACE RIVER SPILL HYDROLOGY
GMSMON-9

2014 May 21

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Final Pre-Spill Report submitted: March 7th, 2012
Report updated following 2012 spill: May 15th, 2014
35229

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EXECUTIVE SUMMARY

Following a spill on the Peace Project in 2002, discussions between BC Hydro and Fisheries and Oceans Canada (DFO) led to the recommendation that a protocol be established for the Peace River (PCR) projects, which reflects DFO concern for fisheries resources in the Peace River. The protocol would address issues relating to the operational use of water and the environmental consequences (positive and negative) of spill events. The Peace Spill Protocol (PSP) was established by the Peace Water Use Plan (WUP) Committee to formalize agency notification and to identify monitoring programs that quantify the environmental effects of a spill. There was insufficient time and data during the Water Use Planning process to fully scope and investigate the influence of spill events on the environment of the Peace River. The alternative was a plan to manage and monitor spill events at the Peace Canyon (PCN) and Williston (GMS) Projects to collect the information necessary to refine operational procedures for spilling. If a spill occurred within the 10 year scope of the PSP monitoring programs (initiated in August 2007), then the information gained from these studies would assist future decisions related to spill risk strategies and environmental audit procedures.

A proper understanding of the data requirements of the various monitoring programs under PSP was necessary in order to develop a widely useful spill hydrology program and deliver a spill event analysis with which other programs could work. In support of PSP and the impact hypotheses that it hopes to address, the GMSMON-9 PCR Spill Hydrology Project ensures that the appropriate hydrologic data is being collected and analyzed. The Peace River Spill Hydrology GMSMON-9 Pre-Spill Report (NHC, 2012) assessed the data that are being collected and determined additional data requirements. A data collection and distribution framework was constructed to identify what data is to be collected, how the data should be reported, and the end use of that data. This allowed all necessary data collection protocols and platforms to be in place prior to the start of any spill event.

A spill event occurred in June/July 2012 that triggered spill event initiation criteria for PSP Conditional Monitoring Components (Table 1). Dates of 1 June to 1 August 2012 were set to encompass an appropriate pre-spill, spill, and post-spill period. The June/July 2012 spill conditions triggered the initiation of all conditional monitoring programs. The following GMS and PCN spill flow conditions were met during the 1 June to 1 August 2012 period:

- GMS spill discharge was above 205 m^3/s for at least 2 days (total of 14.8 days).
- PCN project discharge was above 2000 m^3/s for at least 2 days (total of 14.3 days).
- PCN project discharge was above 2500 m^3/s for at least 2 days (total of 11.9 days).

Water Survey of Canada (WSC) discharge and water level data for the 1 June to 1 August 2012 period have not yet been approved. Preliminary unverified WSC data were used for the post-spill hydrology analysis and are subject to change following review by WSC.

An assessment of the BC Hydro and WSC data from 1 June to 1 August 2012 was completed and a database was prepared. The database includes:

- Discharge and river stage at all BC Hydro hydrometric stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River (BCH Peace 3, BCH Peace 9, BCH Peace 25, BCH Peace 29 and BCH Peace 35A), provided at hourly and daily time steps.
- Peak discharge and river stage at the five BC Hydro hydrometric stations, provided at hourly and daily time steps.
- 10-day, 20-day, and 30-day rolling average discharges for the five BC Hydro hydrometric stations.
- Preliminary and unverified discharge and river stage at all WSC stations between PCN Dam and the confluence of PCR with the Pine River (WSC 07EF001, WSC 07FA004, WSC 07FD002, 07FA006, 07FB008), at hourly and daily time steps.
- PCN and GMS project, spillway and turbine discharge at hourly and daily time steps.

CREDITS AND ACKNOWLEDGEMENTS

The authors would like to thank BC Hydro for initiating this study, and for assistance from the following BC Hydro personnel:

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1 INTRODUCTION

1.1 BACKGROUND

The Peace Project Water Use Plan (WUP) Committee provided consensus recommendations on the operation of BC Hydro's Peace River (PCR) hydroelectric facilities in the Peace WUP, which was accepted by the Comptroller of Water Rights and subsequently implemented in August 2007 (BC Hydro, 2007). The operating conditions set in the Peace WUP will change prior operations on the Peace Project and are expected to positively affect fisheries and wildlife habitat, shoreline conditions, flood control, and recreation interests, but are also expected to decrease power generation revenues. The Peace Project includes the Williston Project (GMS) and the Peace Canyon (PCN) Project. GMS consists of the Williston Reservoir, W.A.C. Bennett Dam, and the G.M. Shrum Generating Station, while PCN consists of Dinosaur Reservoir, Peace Canyon Dam, and the Peace Canyon Generating Station.

Following a spill on the Peace Project in 2002 (BC Hydro, 2008j), discussions between BC Hydro and the Department of Fisheries and Oceans Canada (DFO) led to the recommendation that a protocol be established for the PCR projects, which reflects DFO concern for fisheries resources in the Peace River. The protocol would address issues relating to the operational use of water and the environmental consequences (both positive and negative) of spill events.

The Peace Spill Protocol (PSP) was established by the Peace WUP Committee to formalize agency notification and to identify monitoring programs that quantify the environmental effects of a spill. There was insufficient time and data during the Water Use Planning process to properly scope and investigate the influence of spill events on the environment of the Peace River. The alternative, recommended by the WUP Committee, was a plan to manage and monitor spill events at PCN and GMS to develop the information necessary to develop more refined operational procedures for spilling. If a spill occurred within the 10 year scope of the PSP monitoring programs (initiated in August 2007), then the information gained from these studies would assist in future decision-making related to spill risk strategies and environmental audit procedures (BC Hydro, 2003, 2007).

PSP addresses the following ecological hypotheses (listed in order of significance with the highest emboldened and the lowest italicized, from BC Hydro, 2008j):

1. Spill releases at GMS cause acute fisheries mortality from entrainment and may contribute to Total Gas Pressure (TGP) impacts downstream of GMS and PCN.

2. Spill down-ramping may strand fish in areas above 2000 m^3/s between PCN and the Pine River.

3. Spill up-ramping may isolate wildlife on river bars and islands above 2000 m^3/s between PCN and the Pine River.

4. The seasonal timing of spill events eliminates edge habitat for birds and mammals above 2000 m^3/s between PCN and the Pine River.

5. Significant spills scour the river bed and improve mainstem and side channel fishery habitat between PCN and the Pine River.

6. Significant spills inundate riparian areas and maintain floodplain vegetation between PCN and the Pine River.

PSP is integral to the Peace Flood Pulse Plan (PFPP), which was developed by the WUP Committee to improve fisheries productivity and riparian habitat for flora and fauna by investigating the feasibility of periodic flood pulse events to maintain side channel and riparian habitat downstream of Peace Canyon Dam. Monitoring programs under both of these management plans were to be conducted opportunistically as there were no planned spill releases. PSP monitoring programs may identify adverse effects related to uncontrolled spills that conflict with the objectives of the periodic flood pulse events considered under PFPP. It was critical to monitor the effects of spill events and acknowledge differences in timing, magnitude, and duration.

Within the BC Hydro system there are two classes of spills; system spills and project spills. System spills are required when power generation from projected inflows exceed the capacity of the entire BC Hydro system because the system may be operating at reduced capacity due to maintenance or demand. Spilling in such case is necessary, but the spills can be transferred between projects and the transfer almost always targets the project where the cost of the spill, in economic, environmental and infrastructure terms, is minimized. Project spills, on the other hand, are project-specific and cannot be transferred. They arise when inflows to the project exceed the ability of the project to store and/or discharge the inflow through normal operations. Project spills may also arise in order to test spillway or emergency discharge infrastructure. Some projects within the system spill on an annual basis due largely to an inability to store inflows related to substantial precipitation or freshet.

Williston Reservoir has a very large storage capacity and substantially reduces the likelihood of project spills on the Peace Project. Spill events on the Peace Project (exceeding a generation capacity of 2000 m^3/s) are rare with only eight spills occurring since the completion of the W.A.C. Bennett Dam (1967). Based on historical operations (1967-2003), the average yearly spill risk for the Peace Project is estimated to be 15% ± 5%, or a 65-89% chance of occurring within 10 years (BC Hydro, 2007).

1.2 STUDY AREA

The headwaters of Peace River, a tributary of the Mackenzie River, are located in north-eastern British Columbia (BC) (Figure 1 and Figure 2). The Peace River is formed by the confluence of the Finlay and Parsnip Rivers which flow in opposite directions in the Rocky Mountain Trench. At the confluence of these rivers, the Peace River flows east and is the only river to cut through the Rocky Mountains. Once out of the Peace Canyon the river maintains an easterly direction, crossing the BC-Alberta border. The Peace drains into Great Slave Lake and joins the Mackenzie River before it enters the Arctic Ocean.

The existing works comprising the Peace Project include:

W.A.C. Bennett Dam

This earth-fill dam, commissioned in 1967, is located at the head of the Peace Canyon forming Williston Reservoir. Williston Reservoir covers approximately 1,773 km^2 at full pool and has an active storage of 393 million m^3. The spillway has three radial gates and nine sluice gates. The maximum discharge is 9,200 m^3/s using the radial and sluice gates.

G.M. Shrum Generating Station

The underground G.M. Shrum Generating Station has 10 units (G1 through to G10) with a total installed capacity of 2,730 MW. Once through the turbines, the water is discharged through two manifolds, one for units G1 to G5 and one for G6 to G10, into the upper end of Dinosaur Reservoir.

Peace Canyon Dam

This dam is located at the foot of the Peace Canyon forming Dinosaur Reservoir. The Peace Canyon Dam consists of a concrete gravity dam and earth-fill saddle dam on the right abutment. The spillway has six radial gates, with a maximum discharge of 10,280 m^3/s. Dinosaur Reservoir covers approximately 9 km^2 at full pool and has limited active storage.

Peace Canyon Generating Station

The Peace Canyon Generating Station has four units with a total installed capacity of 700 MW. The water is discharged into the lower Peace River.

1.3 SCOPE OF WORK

1.3.1 RATIONALE AND PURPOSE

The environmental effects of a spill are generally a function of the magnitude and duration of the spill, maximum discharge into the river, the rate of discharge change, tributary flow into the river, and seasonal timing of the spill event. Spill monitoring programs within PSP may require some or all of these data but vary in the degree of data resolution that is required to evaluate the impacts of the spill event. A proper understanding of the data requirements of the various monitoring programs under PSP is necessary in order to develop a widely useful Spill Hydrology Program and deliver a spill event analysis with which other programs can work.

In support of PSP and the impact hypotheses that it hopes to address, the GMSMON-9 PCR Spill Hydrology Project (BC Hydro, 2008j) was developed to ensure that the appropriate hydrologic data was collected and analyzed. The first stage in the PCR Spill Hydrology project was to assess the kinds of data that were being collected and to determine additional data requirements. Gaps between needs and availability were identified and an assessment was made on whether or not there was value in closing that gap. Based on the assessment the second stage was to recommend the augmentation of existing data with additional data collection or by updating existing data collection efforts. A data collection and distribution framework was constructed to show the kinds of data to be collected, how the data were to be reported, and the end use of that data. All data collection protocols and platforms needed to be in place prior to the start of any spill event. The entire cycle of the spill event (pre-spill, spill, and post-spill) had to be captured for the analysis to be complete.

A spill event occurred in June/July 2012 that triggered spill event initiation criteria for PSP Conditional Monitoring Components outlined in Table 1. Not all recommendations for the augmentation of existing data outlined in the pre-spill assessment were initiated prior to or during the June/July 2012 spill event. Following the June/July 2012 event all available data were analyzed and reported. The analysis included a review of the data, a discussion of its relevance, and additional data needs such that analysis of a future spill event can be refined.

1.3.2 PRE-SPILL TASKS

- Review related spill data, PSP monitoring program Terms of Reference (ToR), and protocols to summarize data that will be collected during pre-spill, spill, and post-spill periods.
- Identify data gaps within monitoring programs or protocols and provide recommendations and scope for any additional monitoring necessary to address identified gaps.
- Identify additional data collection platforms or efforts necessary to improve the coverage of a spill event.

- Develop a comprehensive Data Collection and Distribution Framework to ensure adequate collection and distribution of PCR mainstem hydrometric data (stage and discharge) during pre-spill, spill, and post-spill periods.

1.3.3 POST-SPILL TASKS

- Conduct a hydrologic analysis utilizing PCR mainstem hydrometric data that will encompass the pre-spill, spill, and post-spill periods.

1.3.4 POST-SPILL DELIVERABLES

- A database for each spill event of PCR mainstem hydrometric data (stage and discharge) including pre-spill, spill, and post-spill data for both GMS and PCN.

- A detailed report on the hydrology of each spill event with a focus on presenting the data from the database above in formats relevant to other spill protocol monitoring projects.

1.4 PEACE SPILL PROTOCOL PROJECTS

The GMSMON-9 PCR Spill Hydrology ToR (BC Hydro, 2008j) specifies that the following PSP projects be included in this assessment:

- GMSMON-3 PCR Fish Stranding (BC Hydro, 2008e): A conditional monitoring program to be implemented immediately following a spill event that will assess the magnitude of fish stranding in the PCR, and focuses on the negative impact of fish loss through stranding. GMSMON-3 addresses two management plans: the Peace Spill Protocol and the PCR Flood Pulse Plan.

- GMSMON-4 W.A.C. Bennett Dam Entrainment Study (BC Hydro, 2008f): A conditional monitoring program to be implemented for a spill event that will estimate the number of fish entrained through W.A.C. Bennett Dam spillway and the rate of mortality experienced by fish entrained through the spillway.

- GMSMON-6 PCR Riparian Flooding (BC Hydro, 2008g): A conditional 2-year monitoring program to be implemented in Years 9 and 10 of the Peace Project Water Use Plan should a spill event occur during the 10-period.

- GMSMON-8 PCR Side Channel Response (BC Hydro, 2008i): A conditional monitoring program to assess the response of side channels to spill events in terms of flow, fish use, and substrate.

- GMSMON-9 PCR Spill Hydrology (BC Hydro, 2008j): This conditional program will ensure the adequate collection and reporting of hydrologic data associated with a spill event.

- GMSMON-10 PCR Spill Photos (BC Hydro, 2008a): A conditional monitoring program that captures the PCR at five different flows during a spill event and post spill (captured 28 April 2013 during a Peace River flow of roughly 430 m^3/s)

- GMSMON-11 PCR Spill TGP/Temp (BC Hydro, 2008b): A conditional monitoring program that monitors PCR TGP and temperature levels during a spill and two weeks following.

- GMSMON-12 PCR Wildlife Survey (BC Hydro, 2008c): A conditional monitoring program that assesses the impact of a spill event on ungulates, beavers, riparian birds, and toads.

- GMSMON-13 Williston Fish Index (BC Hydro, 2008d): A study that will estimate the abundance of fish in the pelagic area of the Peace Arm of the Williston Reservoir to assist in assessing the impact of entrainment on fish populations during a spill.

The following projects may also benefit from a data and needs assessment and have been included in our review:

- GMSWORKS-2 PCR Baseline TGP/Temp (BC Hydro, 2008l): This required works program involves the continuous measurement of water temperatures over a 10 year study period at designated study sites. This program involves the purchase of TGP equipment to be transferred to the GMSMON-11 PCR Spill TGP/Temp (BC Hydro, 2008b) conditional monitoring program in the event of a spill. The TGP equipment will not be installed unless there is a spill event.

- GMSWORKS-3 PCR Trial Side Channels (BC Hydro, 2008m): This required works program identifies side channels that are isolated at low discharges. A selection of side channels will be made to demonstrate different techniques in reactivating and restoring these key habitat features.

- GMSWORKS-4 PCR Hydraulic Habitat (BC Hydro, 2008n): This required monitoring program involves the classification of hydraulic habitat types and the creation of maps delimitating these areas as a function of PCR discharge.

- GMSWORKS-5 PCR Hydraulic Model (BC Hydro, 2008o): This required works project involves the development of a PCR hydraulic model to provide measures of mainstem and side channel inundation for various discharge regimes.

- GMSWORKS-6 PCR Mainstem Stage Discharge (BC Hydro, 2008p): This required works project involves the development of discharge relations at five locations along PCR mainstem from downstream of PCN to the Pine River confluence.

- GMSWORKS-7 PCR Riparian Habitat Assessment (BC Hydro, 2008q): This required works program provides an assessment of riparian habitat to establish a baseline dataset of the PCR vegetation community.

2 DATA ASSESSMENT

2.1 AVAILABLE HYDROLOGIC DATA SOURCES

Much of the hydrology data that may be useful for analyzing a spill event is already collected by BC Hydro and Water Survey of Canada (WSC):

1. Williston Reservoir volume (modelled by BC Hydro) and water levels (measured by BC Hydro),
2. GMS and PCN spill and turbine discharge (measured by BC Hydro),
3. PCR hydrometric stage and discharge (measured by BC Hydro and WSC), and
4. GMS and PCN tributary inflows (modelled by BC Hydro).

NHC reviewed the parameters above during the pre-spill data assessment for prior Peace Project spill events and found that all measured parameters were adequate for future spill analyses, while modelled values should only be used for estimation purposes. Consideration was given to the frequency with which this data has been collected. Time series for each of the parameters above are available at an hourly time step, but tributary inflows should only be used at a daily time step since the daily average provides a better estimate for this parameter.

Peace Project hydrometric data sources are discussed in more detail in Section 2.2.1 below.

Other projects within the Peace WUP such as GMSWORKS-6 PCR Mainstem Stage Discharge (BC Hydro, 2008p) or GMSWORKS-5 PCR Hydraulic Model (BC Hydro, 2008o), may provide important spill hydrology data for some of the PSP monitoring programs (e.g. cross sections, water surface elevations along PCR for a particular discharge, and stage and discharge time series). However, objectives of data collection for these other projects are not always aligned with PSP; as such discharge measurements for the GMSWORKS-6 hydrometric stations do not go beyond normal operating flows (or much beyond for some of the WSC gauges) and requires extrapolation of the stage-discharge rating curves.

2.2 DATA SOURCES FOR SPILL ANALYSES

2.2.1 HYDROMETRIC DATA

Under GMSWORKS-6 five hydrometric stations were installed all BC Hydro hydrometric stations between PCN Dam and the confluence of Peace River with the Pine River (BCH Peace 3, BCH Peace 9, BCH Peace 25, BCH Peace 29 and BCH Peace 35A) (NHC, 2010b). In addition WSC maintains three

Peace River gauges and two tributary gauges (Halfway River and Moberly River) between PCN Dam and the town of Taylor. All local available BC Hydro and WSC data for the study period have been reviewed and hydrometric stations that have been determined to be useful for analyzing a spill event have been listed in Table 5. Note that the nomenclature for the BC Hydro hydrometric stations is based on Peace River cross-section surveys established by BC Hydro (BC Hydro, 2008o; NHC, 2010a). The selected stations provide stage and discharge information for the PCR mainstem lying between PCN and below the Pine River confluence (Figure 2), and the spatial distribution of this information has been found to be sufficient.

All stage and discharge data for these stations is available at an hourly time step and will be adequate for future spill analyses once additional data is collected for stations identified in Section 2.3. While the raw stage data from the selected hydrometric stations can be obtained near real-time with discharge calculated from recent rating curves, it is recommended that quality assured (published) data be utilized for final spill analyses. Published WSC data are not yet available for the 1 June to 1 August 2012 period and may take up to an additional year to release. Preliminary and unverified WSC stage data and calculated discharge have been included in this report.

A summary of data sources, significant flow inputs (tributaries), and features for the PCR mainstem lying between GMS and below the Pine River confluence are summarized in Table 6. The table provides details on the relative location of significant tributaries and how these and lateral inflow contributions entering the Peace River between data sources may be estimated between PCR mainstem Data Collection Platforms (DCP).

2.2.2 TGP DATA

Initiation of TGP monitoring was conditional on the occurrence of a spill event (BC Hydro, 2008b, 2008l). This report provides the TGP needs and gap assessment for relevant PSP monitoring programs (Section 3) assessed in the Peace River Spill Hydrology GMSMON-9 Pre-Spill Report (NHC, 2012), but the GMSMON-9 PCR Spill Hydrology project was not involved in the collection and distribution of TGP data as this task was assigned to GMSMON-11 PCR Spill TGP/Temp (BC Hydro, 2008b).

Six TGP monitors were purchased under GMSWORKS-2 PCR Baseline TGP/Temp (Diversified Environmental Services, 2010) and were maintained until the June/July 2012 spill event, at which time the equipment was transferred to the project coordinator of GMSMON-11 PCR Spill TGP/Temp who is now responsible for the installation of the TGP equipment (BC Hydro, 2008b).

2.2.3 WATER TEMPERATURE DATA

Temperature loggers have been installed at 18 locations in the PCR mainstem from the forebay of W.A.C. Bennett Dam to downstream of the Pine River confluence between September 6, 2008 and November 30, 2009 (locations provided in Figure 1 of Diversified Environmental Services, 2010).

Loggers were positioned strategically to provide information on the temperature regime of PCR in relation to dam and reservoir operations and inflow from major tributaries (Diversified Environmental Services, 2010). The loggers initially recorded water temperature at a 6 hour interval beginning in 2009, and currently record at an hourly interval since 2010. Water temperature is planned to be monitored at these locations for a total of 10 years under GMSWORKS-2 PCR Baseline TGP/Temp (BC Hydro, 2008l).

All five BC Hydro hydrometric stations are equipped with pressure transducers that are capable of monitoring water temperature (KPSI Series 500 SDI-12 Transducer, ±0.5°C accuracy and ±0.001°C resolution, www.pressuresystems.com). Collection of this parameter was initiated in May 2012.

This report provides the water temperature needs and gap assessment for relevant PSP monitoring programs (Section 3) assessed in the Peace River Spill Hydrology GMSMON-9 Pre-Spill Report (NHC, 2012) but the GMSMON-9 PCR Spill Hydrology project will not be involved in the collection and distribution of water temperature data as this task has been assigned to the GMSWORKS-2 PCR Baseline TGP/Temp and GMSMON-11 PCR Spill TGP/Temp monitoring programs (BC Hydro, 2008b, 2008l).

2.3 PREVIOUSLY RECOMMENDED ADDITIONAL DATA COLLECTION

The GMSMON-9 pre-spill report recommended the following additional data collection (NHC, 2012):

2.3.1 FLOW MEASUREMENT DURING A SPILL

Although there are a number of hydrometric stations, both WSC and BC Hydro operated, on the Peace River from Hudson's Hope to Taylor, the quality of the relationship or rating curve to calculate discharge from the stage record is limited by a lack of flow measurements during spill flows for the majority of stations. The WSC gauges rating curves are defined up to 5,600 to 6,200 m^3/s and the BC Hydro gauges are defined up to 2,000 m^3/s; high flows have been as high as 7,800 to 9,800 m^3/s. The status of each hydrometric station rating curve with upper limits of measured ($Meas_{Max}$) and observed (Upper Q_{EST}) flow is presented in Table 5.

Discharge measurements during spill flows are recommended to further refine and define the rating curves of gauges that are to be used during spill flow. Under the current work program this is limited to the WSC gauges, however there may be interest to expand this to the BC Hydro gauges if the BC Hydro gauges are to be maintained for future use. The WSC hydrometric stations 07FA006 *Halfway River near Farrell Creek* and 07FD002 *Peace River near Taylor* are the two WSC gauges most in need of further rating curve development, because $Meas_{Max}$ for these stations are significantly below the estimated upper observed discharge (Upper Q_{EST}).

2.3.2 TEMPERATURE DATA

As part of GMSWORKS-2 TDCP/temperature monitoring, Peace River water temperature has been continuously monitored since 2008 at 1 hour sample intervals, manually downloaded every 3 months. Sensors are installed at 18 discrete locations from the WAC Bennett Dam forebay to 6.5 km downstream of the Pine River confluence (Diversified Environmental Services, 2013). Temperature sensor locations concentrate at the Peace River canyon, the Halfway River confluence, the Moberly River confluence, and the Pine River confluence.

As part of GMSWORKS-6, five BC Hydro hydrometric stations equipped with pressure transducers capable of monitoring water temperature are located between PCN and the Pine River confluence (17.7, 30.3, 55.7, 64.4, and 80.9 km downstream from PCN). However, this parameter was not previously being recorded. Since the pre-spill report the loggers have been reprogrammed to record temperature data and provide a supplementary data source for water temperature, available in real-time through the GOES network.

3 MONITORING AND DATA REQUIREMENTS

This section provides an assessment of needs for all PSP projects to be considered under GMSMON-9 PCR Spill Hydrology, including any additional projects that may benefit from such an assessment (identified in Section 1.4). This information was previously provided in the GMSMON-9 Pre-Spill Report (NHC, 2012). The hydrologic information to be provided under the GMSMON-9 Data Collection and Distribution Framework has been identified for each project, with an outline of the framework for the pre-spill, spill, and post-spill periods in Section 4.

While the definition of the pre-spill and post-spill periods depends on the ability to forecast spills (pre-spill period) and the duration of spill effects (post-spill period), it is assumed that the scope of the GMSMON-9 Data Collection and Distribution Framework will involve a time frame of one (1) month for the pre-spill and post-spill periods.

3.1 WUP MONITORING PLAN

The Peace Spill Protocol (BC Hydro, 2007) has both conditional (Table 1) and required (Table 2) monitoring criteria.

3.2 SPILL HYDROLOGY MONITORING PROGRAM NEEDS

This section assesses the needs of PSP projects that are to be included in the GMSMON-9 PCR Spill Hydrology ToR assessment (BC Hydro, 2008j).

3.2.1 GMSMON-3 PCR FISH STRANDING

The PCR study area for this conditional monitoring program is from PCN Dam to the confluence of the Pine River. Fish stranding impacts are expected to occur following each spill event where PCN discharge (PCN Q_{OUT}) is > 2000 m^3/s for 2 days or longer (Table 1).

Study planning, including study design and site selection, will be completed prior to the completion of a spill meeting this criterion allowing for immediate commencement of a ground survey when PCN Q_{OUT} has returned to normal operating conditions (≤ 2000 m^3/s). A review of prior studies, aerial surveys, and maps will be required to plan the study design and coordination of aerial surveys may be possible with other spill monitoring programs such as GMSWORKS-1 PCR Aerial Photos and GMSMON-10 PCR Spill Photos (BC Hydro, 2008a, 2008k).

Fish stranding will be assessed at pre-selected index sites. At least three index sites will be selected within each stratum, with three stratification schemes proposed in the ToR from a prior study. Survey sites will only include areas above the PCR water surface elevation at PCN Q_{OUT} = 2000 m^3/s, which may be defined by a combination of: the edge of terrestrial vegetation, flow maps (developed

for the 1996 spill), aerial photos (BC Hydro, 2008a, 2008k), or using more recent PCR water surface elevation information from GMSWORKS-5 PCR Hydraulic Model (NHC, 2010a).

A ground survey will occur immediately after a qualifying spill (PCN Q_{OUT} > 2000 m^3/s) within 2 days of PCN Q_{OUT} having returned to the normal operating levels (≤ 2000 m^3/s). The ground survey must be completed within 1 day.

This monitoring program requires the following hydrologic information for the purposes of field survey documentation and reporting:

- Operating conditions (discharge, ramp down schedule, and river stage) for the spill and post-spill periods.

The following hydrologic information will be provided under the GMSMON-9 Data Collection and Distribution Framework (Section 4) for the **spill** and **post-spill** periods:

- Discharge and river stage at all WSC and BC Hydro hydrometric stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River.

The discharge and river stage data will be provided at **hourly** and **daily** time steps.

3.2.2 GMSMON-4 W.A.C. Bennett Dam Entrainment Study

The PCR study area for this conditional monitoring program is from the spillway of the W.A.C. Bennett Dam (GMS spillway) to Dinosaur Reservoir, upstream of PCN Dam. This monitoring program will be implemented for a spill event meeting the criterion of GMS spill discharge (GMS Q_{SDI}) > 205 m^3/s for 2 days or longer (Table 1), and will be implemented for each spill event that meets this criterion.

Fish entrainment will be monitored at the GMS spillway during the entire period of the spill or some statistically representative period. The magnitude and assumed rate of fish mortality will be estimated using a pilot study in the first spill event and, based on the initial results, the pilot study may be expanded in the case of a second spill within the 10 year study period.

This monitoring program will estimate the number of fish entrained through the GMS spillway and the mortality rate of entrained fish. Coordination with GMSMON-13 Williston Fish Index (BC Hydro, 2008d) will be necessary to determine the relative impact of entrained fish to populations in the Peace Arm of the Williston Reservoir. Hydroacoustic equipment that will be used to monitor fish in the spillway will be installed as close as possible to the start of the spill and maintained throughout the spill.

A boat survey will be conducted in Dinosaur Reservoir over 2 days and 2 nights to assess fish species that suffered injury or mortality as a result of the spill. The pilot study that will attempt to assess the mortality rate of entrained fish will occur over a 2-3 day period, and will be of limited scope until the initial results establish that the proposed technology is successful in estimating the mortality rate (BC Hydro, 2008f).

This monitoring program requires the GMS spillway discharge rate during a spill for the following purposes:

- To determine the correlation between GMS spillway discharge and spillway fish entrainment, and
- To directly estimate the mortality rate and possibly the total mortality at a given GMS spillway discharge for each fish species considered.

The following hydrologic information will be provided under the GMSMON-9 Data Collection and Distribution Framework (Section 4) for the **spill** period:

- GMS spillway discharge rate.

The discharge data will be provided at **hourly** and **daily** time steps.

3.2.3 GMSMON-6 PCR Riparian Flooding

The study area for this conditional monitoring program is the PCR riparian area from PCN Dam to the confluence of the Pine River. The implementation of this monitoring program is conditional on a spill event where PCN Q_{OUT} > 2500 m^3/s for 2 days or longer (Table 1).

This monitoring program is a riparian habitat assessment that will examine the impact of a spill event on large scale temporal and spatial trends of the vegetative community along PCR. River bars and islands have been identified as areas of key concern and will be the focus of this program.

Vegetation inventory maps are to be developed based on GMSWORKS-1 PCR Aerial Photos (BC Hydro, 2008k) in Year 10 and ground surveys re-assessing the same study sites surveyed as part of the GMSWORKS-7 PCR Riparian Habitat Assessment will be conducted in Years 9 and 10 (BC Hydro, 2008q). The results of this monitoring program will be compared in a before-after analysis to data in GMSWORKS-7 PCR Riparian Habitat Assessment (MacInnis et. al, 2013). Assessment of effects of spill flows on riparian vegetation need to be done within the context of the ongoing changes in PCR riparian vegetation in response to regulation and any lasting effects from previous spills

The vegetation inventory maps are to be created for the PCR riparian area between normal operating flows (PCN $Q_{OUT} \leq 2000$ m^3/s) and the PCR water surface elevation at PCN Q_{OUT} =

3400 m^3/s. Discharge and stage records, along with flow maps (developed for the 1996 spill), aerial photos (BC Hydro, 2008a), and PCR water surface elevations from information developed in GMSWORKS-5 PCR Hydraulic Model (NHC, 2010a) will need to be examined to establish the spatial extent of the spill and to infer potential linkages to changes from the spill event.

The following hydrologic information will be provided under the GMSMON-9 Data Collection and Distribution Framework (Section 4) for the **spill** event:

- Discharge and river stage at all WSC and BC Hydro hydrometric stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River.

The discharge and river stage data will be provided at **hourly** and **daily** time steps.

3.2.4 GMSMON-7 PCR Side Channel Fisheries

The PCR study area for this required monitoring program is from PCN Dam to the confluence of the Pine River. The monitoring program will provide baseline information on PCR side channels to determine the effects of habitat manipulation on the side channels. The study sites will include at least 2 trial side channels created under the GMSWORKS-3 PCR Trial Side Channels (BC Hydro, 2008m), and 2 control side channels. Monitoring will commence in Year 1 and continue throughout the 10-year study period. In the event of a spill, monitoring will be carried out in accordance with GMSMON-8 PCR Side Channel Response (BC Hydro, 2008i). Data transfer between GMSMON-8 PCR Side Channel Response and this program will be required as part of project coordination.

Individual components of this monitoring program will be carried out throughout the 10-year study period as detailed in Table 7.1 of the GMSMON-7 PCR Side Channel Fisheries ToR (BC Hydro, 2008h). These components will include cross-section surveys to determine aggradation/degradation, and bed surface and subsurface texture sampling to determine armouring or infilling with fine material. Integrated stage/temperature data loggers will be installed at each site at stable cross sections and rating curves will be developed for each side channel during Year 1.

Installation may require coordination with GMSWORKS-3 PCR Trial Side Channels to ensure placement does not interfere with physical works. The third component of the monitoring program will be a fish survey to determine the abundance and distribution of small fish within the side channels. An index survey will occur in Year 1 and subsequent surveys will occur every other year, beginning in Year 2, for the duration of the 10-year study program.

In the event of a spill, monitoring of these study sites will be conducted under GMSMON-8 PCR Side Channel Response; therefore, the spill related hydrologic information necessary for this project will be provided to GMSMON-8 PCR Side Channel Response (Section 3.2.5) under the GMSMON-9 Data Collection and Distribution Framework (Section 4).

3.2.5 GMSMON-8 PCR Side Channel Response

The PCR study area for this conditional monitoring program is from PCN Dam to the confluence of the Pine River. This study will be implemented for any spill event where PCN Q_{OUT} > 2500 m³/s for two or more days (Table 1), and monitoring is to be completed within one month of a spill event. The monitoring program is to be implemented after each spill in the 10-year study period that meets the spill criterion.

This monitoring program will characterize the morphology of side channels and the presence and distribution of fish in side channels following a spill event. The changes in the PCR flow regime due to regulation have reduced peak flows along PCR below the PCN Dam leading to changes in the channel morphology and degradation of fish habitat in side channels. This program will assess how spill events may affect these habitat areas through scouring of new channels and alteration of riverbanks by comparing post-spill conditions to pre-spill baseline conditions documented under GMSMON-7 PCR Side Channel Fisheries (BC Hydro, 2008h).

Coordination between this conditional monitoring program and GMSMON-7 PCR Side Channel Fisheries is essential to ensure that the same field and office methodologies are used to allow for meaningful comparison. Study sites selected by GMSMON-7 PCR Side Channel Fisheries will be used to assess changes in channel morphology and the bed texture of side channels. The abundance, distribution, and life stage of fish species will also be determined for comparison to pre-spill conditions. Discharge and stage records, along with flow maps (developed for the 1996 spill), aerial photos (BC Hydro, 2008a), and PCR water surface elevations from information developed in GMSWORKS-5 PCR Hydraulic Model (NHC, 2010a) may be need to be examined to establish the spatial extent of the spill and to infer potential linkages to the changes from the spill event.

This monitoring program requires the following hydrologic information for the purposes of determining whether field sampling is occurring during rising or falling PCR stages:

- PCN_{OUT} and PCR stage and discharge for the time of field sampling.

The following hydrologic information will be provided under the GMSMON-9 Data Collection and Distribution Framework (Section 4) for the **spill** and **potentially post-spill** periods:

- Discharge at PCN and stage and discharge at all WSC and BC Hydro hydrometric stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River.

The stage and discharge data will be provided at **hourly** and **daily**, time steps for the spill period and also for the post-spill period if field sampling occurs during this time. Discharge data will also be provided for the spill period at the **hourly peak flow**, and **10-day**, **20-day** and **30-day metrics**. The additional discharge metrics are recommended to characterize the magnitude of long duration high flow events that can have a significant effect on channel morphology and fish communities.

3.2.6 GMSMON-9 PCR Spill Hydrology

This conditional program will ensure the adequate collection and reporting of hydrologic data associated with a spill event for the following programs: GMSMON-3, GMSMON-4, GMSMON-6, GMSMON-7, GMSMON-8, GMSMON-10, GMSMON-11, GMSMON-12, GMSMON-13 (see Section 1.4). The study area for this conditional monitoring program is from Williston Reservoir to below the PCR confluence with the Pine River. This study will be implemented for any spill event with criteria outlined in Table 1, which is essentially for any event that initiates any of the conditional monitoring programs listed above. Details on the rationale and purpose, tasks, and deliverables for the GMSMON-9 PCR Spill Hydrology program are provided in Section 1.3 with further details in BC Hydro (2008j).

This monitoring program requires the following **pre-spill**, **spill**, and **post-spill** hydrologic information for the purposes of analysis and processing, and subsequent distribution to the monitoring programs listed in Section 4:

- Williston Reservoir water level,
- GMS and PCN spill and turbine discharge,
- Discharge and river stage at all WSC and BC Hydro hydrometric stations situated on PCR between PCN Dam and below the confluence of PCR with the Pine River, and
- Tributary discharge and stage data (WSC 07FA006 and WSC 07FB008, Figure 2).

The data above will be obtained directly from BC Hydro at an **hourly** time step upon confirmation of a spill event meeting any of the conditional monitoring program's initiation criteria (Table 1). Tributary discharge may or may not be distributed to the various programs depending on need, but may be required for flow balance analyses under this program.

3.2.7 GMSMON-10 PCR Spill Photos

The PCR study area of this conditional monitoring program is from PCN Dam to the confluence of the Pine River. This program will be implemented for each spill that occurs where PCN Q_{OUT} > 2000 m^3/s for at least 2 days (Table 1).

This monitoring program will provide a plan view of PCR at different flow levels during a spill event to support various projects and monitoring programs within all of the PCR management plans (BC Hydro, 2008a). Aerial photograph surveys of PCR will be completed at a scale of 1:5000 at three different discharge levels that are in 283 m^3/s intervals above 2000 m^3/s. Photos will also be captured immediately following the spill event once PCN Q_{OUT} < 2000 m^3/s.

This monitoring program requires the following hydrologic information for the purposes of coordinating flights at the various spill discharges:

- PCN Q_{OUT} for the duration of a spill event.

The following hydrologic information will be provided under the GMSMON-9 Data Collection and Distribution Framework (Section 4) for the duration of a **spill** event:

- PCN Q_{OUT} for the duration of the spill period.

Note that PCN discharge will be by provided by the GMSMON-9 Data Collection and Distribution Framework at **hourly** and **daily** time steps for documentation and reporting purposes only. It will not be possible to provide this information in the time frame that necessary for coordination of the aerial photography flights, and the project coordinator for GMSMON-10 PCR Spill Photos will need to coordinate with BC Hydro directly to obtain this scheduling information in the timely manner required.

3.2.8 GMSMON-11 PCR SPILL TGP/TEMP

The study area for this conditional monitoring program is from the forebay of GMS to immediately downstream of the PCR confluence with the Pine River. The implementation of this monitoring program is conditional on a spill event where any of the following conditions are met (Table 1):

- GMS Q_{SDI} daily average >205 m^3/s for 2 days or more,
- PCN Q_{SDI} daily average > 500 m^3/s for 7 days or more,
- PCN Q_{SDI} daily average > 1500 m^3/s for 2 days or more, and
- PCN Q_{OUT} > 2000 m^3/s for 2 days or more.

This monitoring program will quantify the effect of a spill on TGP levels and the potential implications for fish populations. Supersaturation of dissolved gases during a spill may occur as water plunges from a dam into receiving waters and in the process entrains air into the flow. This results in partial pressures of atmospheric gases in solution that are greater than in the atmosphere, which can have a detrimental effect on fish health. The impacts to fish will be assessed in terms of acute mortality and chronic responses to TGP levels (BC Hydro, 2008b).

TGP data loggers will be installed 2 weeks prior to the spill and data will be collected continuously for the duration of the spill as well as two weeks after the spill.

The necessary TGP equipment acquired under GMSWORKS-2 PCR Baseline TGP/Temp (BC Hydro, 2008l; Diversified Environmental Services, 2010) will be transferred to the project coordinator of the

GMSMON-11 PCR Spill TGP/Temp monitoring program (BC Hydro, 2008b) who will then be responsible for the installation of the TGP equipment. Water temperature data will be collected from data loggers installed as part of GMSWORKS-2 PCR Baseline TGP/Temp. Two weeks after the completion of the spill event, TGP equipment will be removed and temperature data will be downloaded as part of GMSMON-11 PCR Spill TGP/Temp, and temperature data will be shared with GMSWORKS-2 PCR Baseline TGP/Temp.

As previously mentioned (Section 2.2.3), it is recommended that temperature monitoring be initiated at all five BC Hydro hydrometric stations established under GMSWORKS-6 to be included as part of the GMSMON-11 PCR Spill TGP/Temp monitoring program.
The TGP data loggers will be installed at the following 6 locations:

1. GMS forebay,
2. GMS tailrace,
3. PCN Dam forebay,
4. PCR at Hudson Hope pump house station,
5. PCR downstream of the Halfway River, and
6. PCR downstream of the Pine River.

Spot measurements will be taken over the course of the monitoring period to determine the TGP production of a specific facility or tributary. Portable meters will be used to investigate mixing assumptions and for cross-checking continuous monitoring stations as a quality control measure. Quality control will ensure proper functioning of the 6 continuous monitoring stations. In addition to cross-checking the continuous monitoring stations, spot measurements (minimum of 2 repeated measurements per visit) will be taken at the following locations:

- Dinosaur Reservoir near Johnson Creek (both banks and the middle of reservoir),
- PCN Dam tailrace (both banks),
- Immediately upstream of and within the Halfway River,
- Immediately upstream of and within the Pine River, and
- Cross channel TGP profiles of the latter two locations.

This monitoring program requires the following spill and post-spill (2 weeks after) hydrologic information for the purposes of identifying conditions that cause TGP levels to reach lethal and sub-lethal levels for fish and the potential duration of exposure to fish:

- PCR TGP and water temperature,
- GMS Q_{SDI} and Q_{OUT},
- PCN Q_{SDI} and Q_{OUT}, and
- PCR mainstem discharge from PCN Dam to below the Pine River confluence.

The following hydrologic information will be provided under the GMSMON-9 Data Collection and Distribution Framework (Section 4) for the **spill** and **post-spill** (2 weeks after) periods:

- GMS Q_{SDI} and Q_{OUT},
- PCN Q_{SDI} and Q_{OUT}, and
- Discharge at all WSC and BC Hydro hydrometric stations situated on PCR between PCN Dam and below the confluence of PCR with the Pine River.

The discharge data will be provided at an **hourly** time step. The GMSMON-9 PCR Spill Hydrology project will not be involved in the collection and distribution of TGP or temperature data as this task has been assigned to the GMSWORKS-2 PCR Baseline TGP/Temp and GMSMON-11 PCR Spill TGP/Temp monitoring programs (BC Hydro, 2008b, 2008l).

3.2.9 GMSMON-12 PCR Wildlife Survey

The study area for this conditional monitoring program is the PCR floodplain from PCN Dam to the confluence of the Pine River. The implementation of this monitoring program is conditional on a spill event where PCN_{OUT} > 2000 m^3/s for two days or longer (Table 1).

This monitoring program will assess the negative impacts of a spill event on wildlife in terms of mortality and habitat loss. Study sites will be selected based on existing terrestrial ecosystem mapping and flow mapping. Surveys will be conducted to assess the morality/habitat loss of ungulate, beaver, riparian bird and western toad populations.

Aerial surveys will be used over the course of the spill to estimate the number of ungulates on islands, swimming or in the water. Surveys will occur at the start and conclusion of the spill as well as at the peak if the spill is large enough in magnitude so that it could inundate islands potentially forcing ungulates into the water. The survey count does not provide a direct estimate of mortality

so the impact to the population will be assessed by assuming a range of mortality rates to the count for each species.

A minimum of two beaver surveys will be conducted, scheduled to coincide with other wildlife surveys. Aerial/boat surveys will be used to collect information on beaver populations as well as beaver structures. For the riparian bird and western toad surveys, several study sites will be selected to act as index sites for the larger study area. Two surveys will occur: the first prior to the spill and the second immediately following the completion of the spill at the same index sites. Incidental wildlife observations in addition to the target species will be recorded.

This monitoring program requires the following information for the purposes of determining habitat areas that will be impacted by the spill event:

- Flows maps (developed for the 1996 spill), aerial photos (BC Hydro, 2008a, 2008k), or using more recent PCR water surface elevation information from GMSWORKS-5 PCR Hydraulic Model (NHC, 2010a),

This monitoring program requires the following hydrologic information for the purposes of reporting and documentation for the pre-spill, spill and post-spill periods:

- Discharge and river stage along PCR mainstem from PCN Dam to the confluence of the Pine River for, and

- PCN Q_{SDI} and Q_{OUT}.

The following hydrologic information will be provided under the GMSMON-9 Data Collection and Distribution Framework (Section 4) for the **pre-spill, spill** and **post-spill** periods:

- Discharge and river stage at all WSC and BC Hydro hydrometric stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River, and

- PCN Q_{SDI} and Q_{OUT}.

The discharge and river stage data will be provided at **hourly** and **daily** time steps.

3.2.10 GMSMON-13 Williston Fish Index

The study area for this monitoring project is limited to the Peace Arm of the Williston Reservoir as the populations in this area are expected to incur the greatest impact from a spill. The objective of the study is to collect data on the composition, abundance, and spatial distribution of fish species in this zone. The survey is limited to the pelagic zone of the Peace Arm where pelagic is defined as

open waters where water is ≥ 20 meters deep at the time of survey. Near-shore habitat, which is <20 meters deep will be excluded from the study (BC Hydro, 2008d).

Originally, this study was conditional on the occurrence of a spill such that the fish survey would commence following a spill. The study design was changed, however, and the focus of this study has been modified to collect one year of baseline information on fish populations only under normal operating conditions at GMS dam. It was thought that a baseline survey conducted at an optimal period for sampling will provide a best estimate of the total number of reservoir fish and their spatial and size distribution under normal operating conditions. Under this assumption, the impact of the spill to reservoir fish would then be assessed based on the results of this study in combination with the GMSMON-4 W.A.C. Bennett Dam Entrainment Study (BC Hydro, 2008f) which estimates the number of fish entrained through the spillway.

As this survey is a one-time event, the major assumption is that interannual variability of these estimates is not extremely large (BC Hydro, 2008d). After completion of the study (Sebastian et al. 2009), however, it was found that the annual population levels and species composition can change drastically. Since this index survey is to be used in conjunction with GMSMON-4 W.A.C. Bennett Dam Entrainment Study (BC Hydro, 2008f) to evaluate the effects of a spill on fish populations in Williston Reservoir, the timing of the survey must be similar to the timing of the spill event in order to provide adequate information. Recommendations to reinstate this program as conditional to a spill event have been provided in Section 1.

If this program is reinstated as a conditional monitoring program under PSP, it will require the following hydrologic information during a spill for the purposes of determining location of survey transects:

- Williston Reservoir levels

In its current state, no data will be provided under the GMSMON-9 Data Collection and Distribution Framework (Section 4) unless this program is reinstated as a conditional monitoring program under PSP.

3.3 ADDITIONAL MONITORING PROGRAM NEEDS

This section assesses the needs of any additional projects identified in Section 1.4, which may benefit from a similar assessment to PSP projects included in the GMSMON-9 PCR Spill Hydrology ToR (BC Hydro, 2008j).

3.3.1 GMSWORKS-2 PCR Baseline TGP/Temp

GMSWORKS-2 PCR Baseline TGP/Temp does not appear to require any hydrologic information in addition to what will already be provided to GMSMON-11 PCR Spill TGP/Temp (Section 3.2.8), and this information could be shared between the two projects if required. As identified in Section 2.2.3, initiating temperature monitoring at the five existing BC Hydro hydrometric station would also benefit this program.

3.3.2 GMSWORKS-3 PCR Trial Side Channels

This required works program covers a study area extending from the PCN Dam to the confluence of the Pine River along PCR. A preliminary survey of the area (BC Hydro, 2008m) identified side channels that became isolated when Peace Canyon discharges declined to 141.6 m^3/s, as well as a number of side channels that remained cut-off from the main stem with PCN discharges of 283 m^3/s. These areas consisted of significantly sized isolated pools that often harboured stranded fish. This works project involves the selection of two or more side channel complexes for demonstrating different techniques of reactivating moribund side channels isolated due to regulated flows. The selection process should be aided by the results GMSWORKS-5 PCR Hydraulic Model (BC Hydro, 2008o).

The completion of this work was projected to be finished by October 2010 (BC Hydro, 2008m); however, the project has only been approved through Year 1. GMSWORKS-3 PCR Trial Side Channels will not require any spill related data under GMSMON-9 PCR Spill Hydrology.

3.3.3 GMSWORKS-4 PCR Hydraulic Habitat

This required monitoring program covers a study area extending from the PCN Dam to the confluence of the Pine River along the PCR. Analysis will be completed for five distinct flows between 283 m^3/s and 2000 m^3/s. This work is dependent on the completion of GMSWORKS-1 Aerial Photos (BC Hydro, 2008k), as the analysis requires aerial photography of an appropriate scale captured over a range of flows.

The analysis will consist of the development of a classification scheme and set rules for each habitat type, which should include areas of uncertain flow conditions that may provide habitat for amphibians. Once the list of habitat types has been developed the interpretation of aerial photographs can proceed as the photo sets become available. Habitat typing will be digitized and rendered as layers on a Peace River base map along with metadata for each photo set and habitat polygon (BC Hydro, 2008n). The last stage of the project requires the development of a hydraulic habitat model for the PCR between the PCN and Pine River as a function of flow. This will require a record of the discharge and river stage along the study area, specifically during the times that the aerial photography occurred.

This monitoring program requires the following hydrologic information for the purposes of determining hydraulic habitat as a function of flow:

- Discharge and river stage at all WSC and BC Hydro hydrometric stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River.

- Mainstem and side channel inundation for various discharge regimes from GMSWORKS-5

It is recommended that the scope of GMSWORKS-4 PCR Hydraulic Habitat be expanded to include spill flows so that an adequate hydraulic habitat model encompassing the full range of PCR flows can be developed. In such case, the following hydrologic information would be provided under the GMSMON-9 Data Collection and Distribution Framework (Section 4) for the **pre-spill**, **spill** and **post-spill** periods:

- Discharge and river stage at all WSC and BC Hydro hydrometric stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River.

The discharge and river stage data will be provided at **hourly** and **daily** time steps.

3.3.4 GMSWORKS-5 PCR HYDRAULIC MODEL

This required works project covers a study area along PCR extending from PCN Dam to the confluence of the Pine River. The purpose of this project is to produce a working PCR hydraulic model that will provide measures of mainstem and side channel inundation for various discharge regimes (BC Hydro, 2008o). Modeling of river flows and stages will also help to define what restoration opportunities are available at specific side channels along the river that have been cut-off from the PCR mainstem under the existing flow regime. This project involves collaboration with GMSWORKS-3 PCR Trial Side Channels, GMSWORKS-4 PCR Hydraulic Habitat, and GMSWORKS-6 PCR Mainstem Stage Discharge.

A 1D hydraulic model has been developed and has been shown to adequately represent the study reach (NHC, 2010a). The model was developed with the assumption that flow is primarily within the channel banks or shallow overbank, so the use of the model for extreme flood flows such as probable maximum flood or dam break scenarios would require further adjustment and calibration. It was also recommended that future aerial data collection and bathymetric surveys be conducted in proximity to key habitat study areas to improve the precision and accuracy of the model at these sites (NHC, 2010a).

The model was validated using data from November 1-10, 2009 involving a range of flows (600 to 1400 m^3/s). As the model is used to predict stages and river flows of up 6000 m^3/s, it would be beneficial to have stage and discharge data from spill events for calibration from all seven (7) hydrometric stations in the study reach (Table 5 and Figure 2). This data was not available at the

time of model development and would be useful for future model validation of high discharge events.

It is recommended that the scope of GMSWORKS-5 PCR Hydraulic Model be expanded to include spill flows so that an adequate hydraulic model encompassing the full range of PCR flows can be developed. In such case, the following hydrologic information would be provided under the GMSMON-9 Data Collection and Distribution Framework (Section 4) for the **pre-spill**, **spill** and **post-spill** periods:

- Discharge and river stage at all WSC and BC Hydro hydrometric stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River.

The discharge and river stage data will be provided at **hourly** and **daily** time steps.

3.3.5 GMSWORKS-6 PCR MAINSTEM STAGE DISCHARGE

This required works project covers a study area along PCR extending from PCN Dam to the confluence of the Pine River. The objective of this project is to establish stage (river water level)-discharge relations at strategic points along PCR such that side channel inundation can be inferred from mainstem discharges. This project will allow a more accurate calculation of flow attenuation and gross changes in flow during required spill events (BC Hydro, 2008p). This ability will be of particular utility when the operation is ramping discharges down, a time when fish can become stranded in side channels. Fine tuning of ramping sequences will reduce fish stranding and consequently stress and mortality tolls on fish.

As discussed in Section 2, five BC Hydro hydrometric stations (Peace 3, Peace 9, Peace 25, Peace 29, and Peace 35A; Table 5 and Figure 2) have been established under GMSWORKS-6, with rating curves defined within the normal range of PCN operating conditions (PCN discharge = 283 to 2000 m^3/s) as required in the project ToR (NHC, 2014). It has been found that further rating curve development will be essential for these stations to ensure that adequate hydrometric data be collected during the pre-spill, spill and post-spill periods, which will require additional flow measurements and rating curve development for any size spill event (PCN discharge ≥ 2000 m^3/s).

While WSC hydrometric information is available at three PCR sites (two within this project study area; Table 5 and Figure 2), this data is insufficient for determining the within day stage fluctuation of flow at critical river cross sections such as those that include side channels (BC Hydro, 2008p).

Expansion of the GMSWORKS-6 PCR Mainstem Stage Discharge scope to include spill flows has been found to be essential for six (6) PSP projects requiring hydrologic information under GMSMON-9 PCR Spill Hydrology:

1. GMSMON-3 PCR Fish Stranding

2. GMSMON-6 PCR Riparian Flooding
3. GMSMON-8 PCR Side Channel Response
4. GMSMON-9 PCR Spill Hydrology
5. GMSMON-11 PCR Spill TGP/Temp
6. GMSMON-12 PCR Wildlife Survey.

and for four (4) additional projects that have been identified in this pre-spill assessment:

1. GMSWORKS-2 PCR Baseline TGP/Temp
2. GMSWORKS-4 PCR Hydraulic Habitat
3. GMSWORKS-5 PCR Hydraulic Model
4. GMSWORKS-7 PCR Riparian Habitat Assessment (described below).

3.3.6 GMSWORKS-7 PCR RIPARIAN HABITAT ASSESSMENT

The study area for this required monitoring program includes the riparian area of PCR extending from PCN Dam to the Pine River confluence. The riparian assessment will occur over Years 1 and 2. This works program is a riparian habitat assessment that will establish a baseline dataset of the vegetative community along PCR on a large spatial scale. This data will be used for future monitoring studies such as GMSMON-6 PCR Riparian Flooding (BC Hydro, 2008g). River bars and islands have been identified as areas of key concern and will be the focus of this program.

Vegetation inventory maps are to be created for the PCR riparian area between normal operating flows (PCN $Q_{OUT} \leq 2000$ m^3/s) and the PCR water surface elevation at PCN $Q_{OUT} = 3400$ m^3/s. Discharge and stage records, along with flow maps (developed for the 1996 spill) and PCR water surface elevations from information developed in GMSWORKS-5 PCR Hydraulic Model (NHC, 2010a) will need to be examined to establish the spatial extent of potential spills and to select appropriate study sites. Aerial photos from GMSWORKS-1 PCR Aerial Photos (BC Hydro, 2008k) will be used to delineate polygons of similar vegetation cover. Ground-truthing will be conducted through Year 1 and 2 to ensure the accuracy of air photo interpretation. Six sample sites will also be selected for detailed vegetation inventories as detailed in GMSWORKS-7 (BC Hydro, 2008q).

This works program requires the following hydrologic information for the purposes of sampling site selection:

- River channel elevations for flows = 2000 m^3/s and 3400 m^3/s from GMSWORKS-5.

- Discharge and river stage at all WSC and BC Hydro hydrometric stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River.

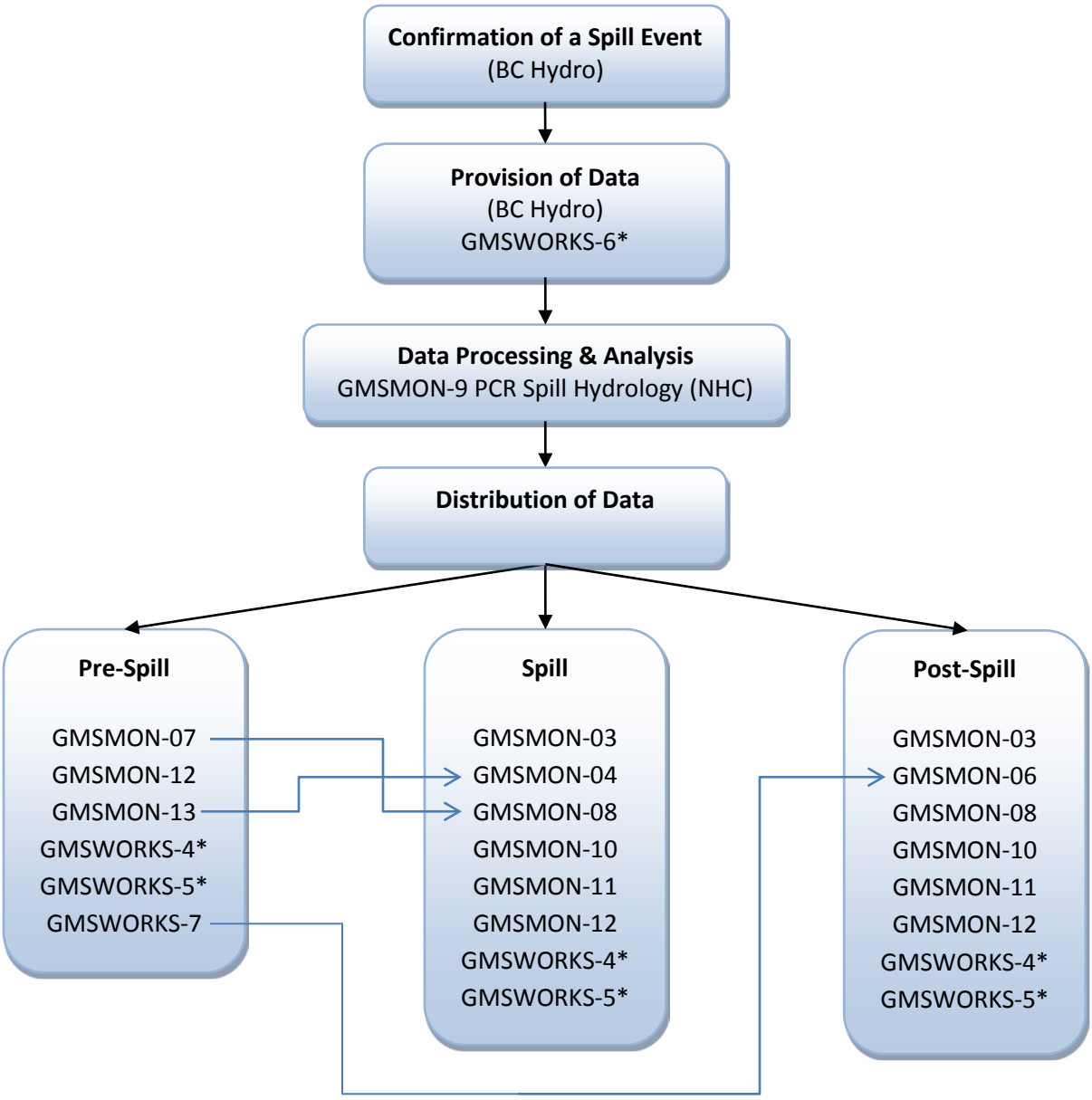
The following information will be provided under the GMSMON-9 Data Collection Framework (Section 4) for the assessment of **pre-spill**, **spill,** and **post-spill** periods:

- Discharge and river stage at all WSC and BC Hydro hydrometric stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River.

The discharge and river stage data will be provided at **hourly** and **daily** time steps.

4 DATA COLLECTION AND DISTRIBUTION FRAMEWORK

The flow chart below illustrates the framework used for hydrologic data collection and subsequent distribution to PSP monitoring programs for the June/July 2012 spill event. Programs with an asterisk (*) were only included if scopes for these programs were expanded (refer to relevant section and Section 1).



The initiation criteria for each of the monitoring programs are summarized in Table 1, with details on the necessary data formats and end use in Section 3. The scope of the GMSMON-9 Data Collection and Distribution Framework was set to 1 June to 1 August 2012 by BC Hydro. This involves a time frame of approximately one (1) month for the pre-spill and post-spill periods.

5 2012 SPILL

5.1 OVERVIEW

A spill event occurred in June/July 2012 that triggered spill event initiation criteria for PSP Conditional Monitoring Components as outlined in Table 1 (Figure 5). Dates of 1 June to 1 August 2012 were set to encompass an appropriate pre-spill, spill, and post-spill period. The 2012 spill conditions triggered the initiation of all conditional monitoring programs. The following GMS and PCN spill flow conditions were met during the 1 June to 1 August 2012 period:

- GMS spill discharge was above 205 m^3/s for at least 2 days (total of 14.8 days).
- PCN project discharge was above 2000 m^3/s for at least 2 days (total of 14.3 days).
- PCN project discharge was above 2500 m^3/s for at least 2 days (total of 11.9 days).

WSC has not yet approved discharge and water level data for 2012. Preliminary unverified WSC data were used for the post-spill hydrology analysis and are subject to change following review by WSC. This section details the hydrometric data available from BC Hydro and WSC for the 1 June to 1 August 2012 period, and outlines the quality assurance and quality control (QA/QC) procedures for the BC Hydro hydrometric stations as well as the data analyses.

5.2 SPILL HYDROLOGY ANALYSES

BC Hydro discharge and river stage data extents and percent data coverage for the 1 June to 1 August 2012 period are outlined in Table 1. Complete discharge and river stage records are available for BCH Peace 3 and BCH Peace 35A, while discharge and river stage records for BCH Peace 9, BCH Peace 25, and BCH Peace 29 contain periods of missing data:

- The Keller Series 500 SDI-12 pressure transducer originally installed at BCH Peace 9 was damaged on 15 August 2011. A temporary water level datalogger-sensor, consisting of a paired Solinst Levelogger and Barologger was installed at BCH Peace 9 on 25 June 2012; however, higher flow conditions prevented installation at a river depth that would allow for monitoring of the full range of flows in PCR. As a result, during the 1 June to 1 August 2012 period, BCH Peace 9 discharge and river stage records were not monitored for water levels lower than a 435.580 m elevation resulting in 729 hours of missing data over 42 days (not consecutive).
- The Keller Series 500 SDI-12 pressure transducer and battery originally installed at BCH Peace 25 failed on 3 July 2012. A replacement OTT pressure transducer, battery, and solar

panel were installed on 12 August 2013. In total, 684 hours or 29 days of data is missing within the 1 June to 1 August 2012 period.

- The battery at BCH Peace 29 failed on 21 May 2012 and was replaced on 21 May 2013, resulting in no data collection at this site during the 1 June to 1 August 2012 period.

The QA/QC of BC Hydro hydrometric data is detailed in the Peace Project Water Use Plan GMSWORKS-6 2013 Study (NHC, 2014). In brief, QA/QC procedures included gauge level checks with physical water level measurements, checking the level of agreement between additional measured and calculated discharge values to verify the continued suitability of stage-discharge rating curves, and a comparison of discharge records between stations using the AQUARIUS software and database (Aquatics Informatics Inc.). Comparison of the data from sequential BC Hydro hydrometric stations was also used to develop a system wide flow balance as an additional tool for QA/QC. Sequential discharge series were found to be within 10% of each other suggesting an acceptable level of uncertainty, within less than or equal to 5%, for BCH Peace 3, BCH Peace 9, BCH Peace 25, BCH Peace 29 and BCH Peace 35A. Observed errors between gauges were upwards of 20.3% for short durations. Large negative daily inflows were infrequent and of short duration, and attributed to variations in lag time and flow attenuation between gauges. The BCH Peace 35A discharge series exhibits a higher level of uncertainty than the other series but is still within the acceptable error. Although preliminary WSC data were initially compared with the BC Hydro hydrometric station data to identify gross anomalies, these data were not considered for assessing data quality due to the high level of uncertainty associated with preliminary and unverified data.

Mean and maximum hourly and daily discharge and river stage series were computed for all of the BC Hydro hydrometric stations between 1 June and 1 August 2012. Maximum values represent the peak high frequency (15 minute) value over the calculation period. The required data coverage for a calculation period was set to 100 % (hourly and daily discharge and river stage values were not calculated for BCH Peace 9 when water levels were below a 435.580 m elevation within the calculation period). Time stamps represent the beginning of the period of aggregation. Additionally, 10-day, 20-day, and 30-day rolling average flows were calculated for data within the 1 June to 1 August 2012 period.

GMS spillway as well as GMS and PCN project discharge data were provided by BC Hydro in the form of preceding average hourly values. Date time stamps for hourly GMS and PCN spillway discharge data were adjusted to represent the beginning of the period of aggregation for consistency with all other data provided. Mean daily GMS and PCN project discharge was computed for the period 1 June to 1 August 2012. The required data coverage for a calculation period was again set to 100 % and time stamps represent the beginning of the aggregation period.

Preliminary hourly and daily discharge and river stage series were obtained from WSC for stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River for the 1 June to 1 August 2012 period.

The 2012 spill event is shown in Figure 1, and a visual comparison to the 1996 and 2002 spill events is given in Figure 2. A summary of the available data series is provided in Table 3 and Table 4 with full data records provided in the attached database (Appendix A). The database includes:

- Discharge and river stage at the five BC Hydro hydrometric stations, provided at hourly and daily time steps.
- Peak discharge and river stage at the five BC Hydro hydrometric stations, provided at hourly and daily time steps.
- 10-day, 20-day, and 30-day rolling average discharges for the BC Hydro hydrometric stations situated on PCR between PCN Dam and the confluence of PCR with the Pine River
- Preliminary discharge and river stage at all PCR and PCR tributary WSC stations between PCN Dam and the confluence of PCR with the Pine River (WSC 07EF001, WSC 07FA004, WSC 07FD002, 07FA006, and 07FB008) at hourly and daily time steps
- PCN and GMS project, spillway and turbine discharge at hourly and daily time steps.

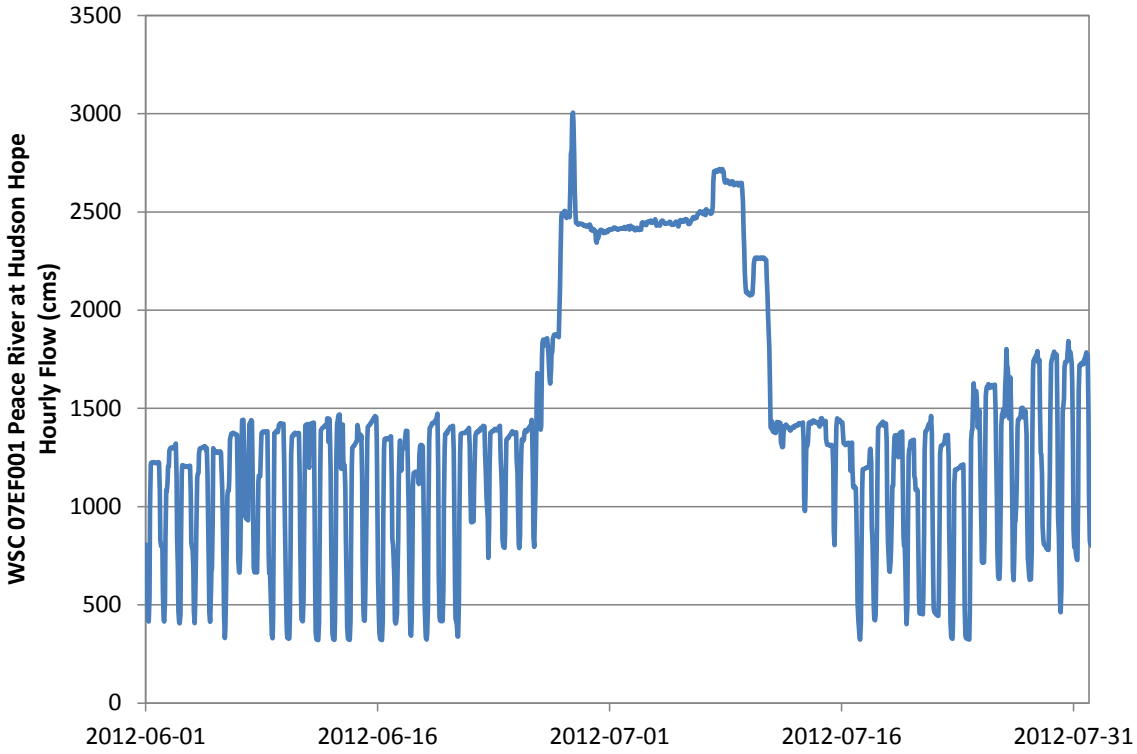


Figure 1. **WSC 07EF001 Peace River at Hudson Hope hourly flow before, during, and after the 2012 spill event. GMS spill discharge was above 205 m^3/s for a total of 14.8 days, PCN project discharge was above 2000 m^3/s for a total of 14.3 days and PCN project discharge was above 2500 m^3/s for a total of 11.9 days in June/July 2012.**

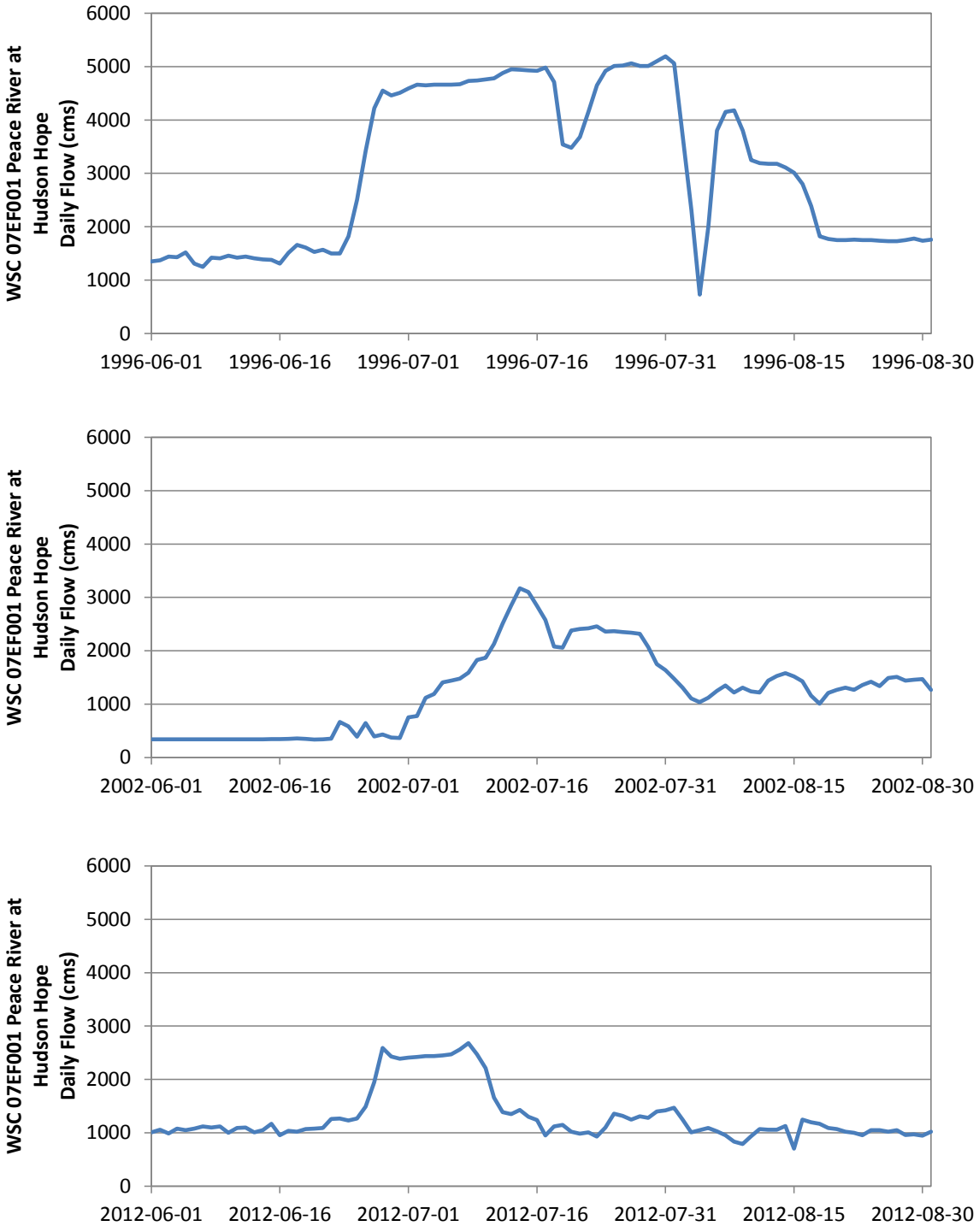


Figure 2. Comparison of WSC 07EF001 Peace River at Hudson Hope daily flows during the 1996, 2002, and 2012 spill events (i.e. PCN project discharge above 2000 m^3/s).

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TABLES

Table 1. PSP Conditional Monitoring Components with spill event initiation criteria for each program.

Monitoring Program	PCN Q_{OUT}		GMS Q_{SDI}	Q_{SDI} PCN	
	> 2500 (2d)	> 2000 (2d)	> 205 (2d)	> 1500(2d) > 500(7d)	> 2000 (2d) > 500 (7d)
GMSMON-3		X			
GMSMON-4			X		
GMSMON-6	X				
GMSMON-8	X				
GMSMON-9	X	X	X		X
GMSMON-10		X			
GMSMON-11		X	X	X	
GMSMON-12		X			
GMSMON-13				Note [A]	

[A] GMSMON-13 was originally a conditional PSP monitoring program (BC Hydro, 2007) with the initiation criteria above, but was modified to be a one-time study (BC Hydro, 2008d).

Total project discharge (QOUT) and spill discharge (QSDI) are listed in m3/s with the minimum required duration in days (BC Hydro, 2007 with updated criteria from each monitoring program's TOR).

Table 2. PSP Required Monitoring Components (BC Hydro, 2007).

Required Monitoring Programs
GMSWORKS-1 (BC Hydro, 2008k) [A]
GMSWORKS-2
GMSWORKS-4
GMSWORKS-6
GMSWORKS-7
GMSMON-7

[A] GMSWORKS-1 was not included in the needs assessment as the program identifies and maps areas of flood plain and side channel inundation at PCN Q_{OUT} < 2000 m^3/s. GMSMON-10 (BC Hydro, 2008a) addresses aerial photo documentation for spill discharge (Table 1).

Table 3. Summary of 1 June to 1 August 2012 PCR, GMS, and PCN hydrology. BCH Peace 29 data do not exist for the period of 1 June to 1 August 2012.

		BCH Peace 3	BCH Peace 9*	BCH Peace 25	BCH Peace 35A	GMS	PCN
Data extents**		1 Jun to 1 Aug	27 Jun to 16 Jul	1 Jun to 2 Jul	1 Jun to 1 Aug	1 Jun to 1 Aug	1 Jun to 30 Jul
Data coverage	(%)	100	31	52	100	100	98
Peak 15 min flow	(m^3/s)	3184.4	3299.4	3557.6	3528.6	N/A	N/A
	(Date)	28 Jun 16:00	28 Jun 17:00	28 Jun 19:30	28 Jun 22:15	N/A	N/A
Peak hourly flow	(m^3/s)	3174.8	3274.1	3554.9	3520.4	4167.3	3289.2
	(Date)	28 Jun 15:00	28 Jun 16:00	28 Jun 19:00	28 Jun 22:00	28 Jun 15:00	28 Jun 16:00
Peak daily flow	(m^3/s)	2819	2935	3171	3198	2956	2921
	(Date)	8 Jul	8 Jul	28 Jun	8 Jul	8 Jul	8 Jul
Peak 10 day flow	(m^3/s)	2633	2708	2979	3015	N/A	N/A
Peak 20 day flow	(m^3/s)	2262	N/A	1955	2613	N/A	N/A
Peak 30 day flow	(m^3/s)	1919	N/A	1958	2264	N/A	N/A

* hourly and daily values were not calculated for BCH Peace 9 when water levels were below a 435.580 m elevation within the calculation period
** based on daily records

Table 4. Summary of preliminary 1 June to 1 August 2012 WSC hydrology. These data are preliminary and unverified, and are subject to change following review by WSC.

		07EF001 Peace River at Hudson Hope	07FA004 Peace River above Pine River	07FD002 Peace River near Taylor	07FA006 Halfway River near Farrell Creek	07FB008 Moberly River near Fort St John
Data extents*		1 Jun to 1 Aug	1 Jun to 1 Aug	1 Jun to 1 Aug	1 Jun to 1 Aug	1 Jun to 1 Aug
Data coverage	(%)	100	100	100	100	100
Peak hourly flow	(m^3/s)	3005	3985	4974	2040	69
	(Date)	28 Jun 15:00	28 Jun 23:00	8 Jun 6:00	8 Jun 2:00	10 Jun 18:00
Peak daily flow	(m^3/s)	2680	3540	4580	1860	68
	(Date)	8 Jul	8 Jun	8 Jun	8 Jun	22 Jun

** based on daily records

Table 5. Peace Project hydrometric stations selected for analyzing a spill event.

Station	Name	Data Manager	Rating Curve Status		
			$Meas_{Max}$ (m^3/s)	Upper Q_{Est} (m^3/s)	Recommendations for further flow measurements
07EF001	Peace Rr at Hudson Hope	WSC	6260	7810	Required to define for Q ≥ 6260 m^3/s and to refine for Q > 2000 m^3/s
Peace 3	-	BC Hydro	1971	2010	Required to define for Q ≥ 2000 m^3/s if to be used for spill flows
Peace 9	-	BC Hydro	1969	1971	Required to define for Q ≥ 2000 m^3/s if to be used for spill flows
07FA006	Halfway Rr near Farrell Ck	WSC	1389	3200	Required to define for Q ≥ 1389 m^3/s
Peace 25	-	BC Hydro	1982	1979	Required to define for Q ≥ 2000 m^3/s if to be used for spill flows
Peace 29	-	BC Hydro	1971	1986	Required to define for Q ≥ 2000 m^3/s if to be used for spill flows
Peace 35A	-	BC Hydro	2020	2119	Required to define for Q ≥ 2000 m^3/s if to be used for spill flows
07FB008	Moberly Rr near FSJ	WSC	139	159	Required to define for Q > 139 m^3/s
07FA004	Peace Rr above Pine Rr	WSC	5638	6320	Required to define for Q ≥ 5638 m^3/s and to refine for Q > 2000 m^3/s
07FD002	Peace Rr near Taylor	WSC	6180	9770	Required to define for Q ≥ 6180 m^3/s and to refine for Q > 2000 m^3/s

The stations have been listed from upstream to downstream for the PCR area lying between PCN and below the Pine River confluence (refer to Figure 2 for locations). The rating curve status describes the following for each station: maximum discharge measured to date (MeasMax); the level to which discharge estimates have been extrapolated above MeasMax for the period of record (Upper QEst); and based on these parameters, whether further rating curve development is necessary for a spill event.

Table 6. Peace Project discharge data sources for analyzing a spill event with details on flow sources between PCR data source.

Feature	Flow Source	Type	Discharge	**Detail** how inflows may be estimated
BCH Dam	GMS turbine & spill flow	PCR Mainstem	Data	BCH Data: GMS turbine & spill flow
2 Tributaries	Gething & Johnson Cks [B]	Tributary	Interpolated	PCN & GMS turbine & spill flow [A]
BCH Dam	PCN turbine & spill flow	PCR Mainstem	Data	BCH Data: PCN turbine & spill flow
Tributary	Maurice Ck [B]	Tributary	Interpolated	WSC 07EF001 & PCN turbine & spill flow [A]
WSC Hydrometric	Peace Rr at Hudson Hope	PCR Mainstem	Data	WSC 07EF001
Tributary	Lynx Ck [B]	Tributary	Interpolated	BCH Peace 3 & WSC 07EF001 [A]
BCH Hydrometric	Peace 3	PCR Mainstem	Data	Coincident with cross-section (NHC, 2010a)
Tributary	Farrell Creek [B]	Tributary	Interpolated	BCH Peace 9 & BCH Peace 3 [A]
BCH Hydrometric	Peace 9	PCR Mainstem	Data	Coincident with cross-section (NHC, 2010a)
WSC Hydrometric	Halfway Rr near Farrell Ck	Tributary	Data	WSC 07FA006 [B]; BCH Peace 25 & BCH Peace 9 [A]
BCH Hydrometric	Peace 25	PCR Mainstem	Data	Coincident with cross-section (NHC, 2010a)
Tributary	Cache Ck [B]	Tributary	Interpolated	BCH Peace 29 & BCH Peace 25 [A]
BCH Hydrometric	Peace 29	PCR Mainstem	Data	Coincident with cross-section (NHC, 2010a)
2 Tributaries	Wilder & Tea Cks [B]	Tributary	Interpolated	BCH Peace 35A & BCH Peace 29 [A]
BCH Hydrometric	Peace 35A	PCR Mainstem	Data	Coincident with cross-section (NHC, 2010a)
WSC Hydrometric	Moberly Rr near Fort St. John [B]	Tributary	Data	WSC 07FB008 [C]
Tributary & Lateral Inflow		Tributary	Interpolated	WSC 07FA004 & BCH Peace 35A
WSC Hydrometric	Peace Rr above Pine Rr	PCR Mainstem	Data	WSC 07FA004
Major Tributary	Pine Rr	Tributary	Interpolated	WSC 07FD002 & WSC 07FA004 [A]
WSC Hydrometric	Peace Rr near Taylor	PCR Mainstem	Data	WSC 07FD002

[A] Tributary and lateral inflow contributions may be estimated between upstream and downstream PCR mainstem DCPs.
[B] Flow input to PCR from a significant tributary or tributaries.
[C] This station is a considerable distance upstream of PCR confluence, but a gauge exists on PCR just downstream of confluence (WSC 07FA004).

Features have been listed from upstream to downstream for the PCR area lying between GMS and the Pine River confluence (refer to Figure 2 for feature locations).

FIGURES
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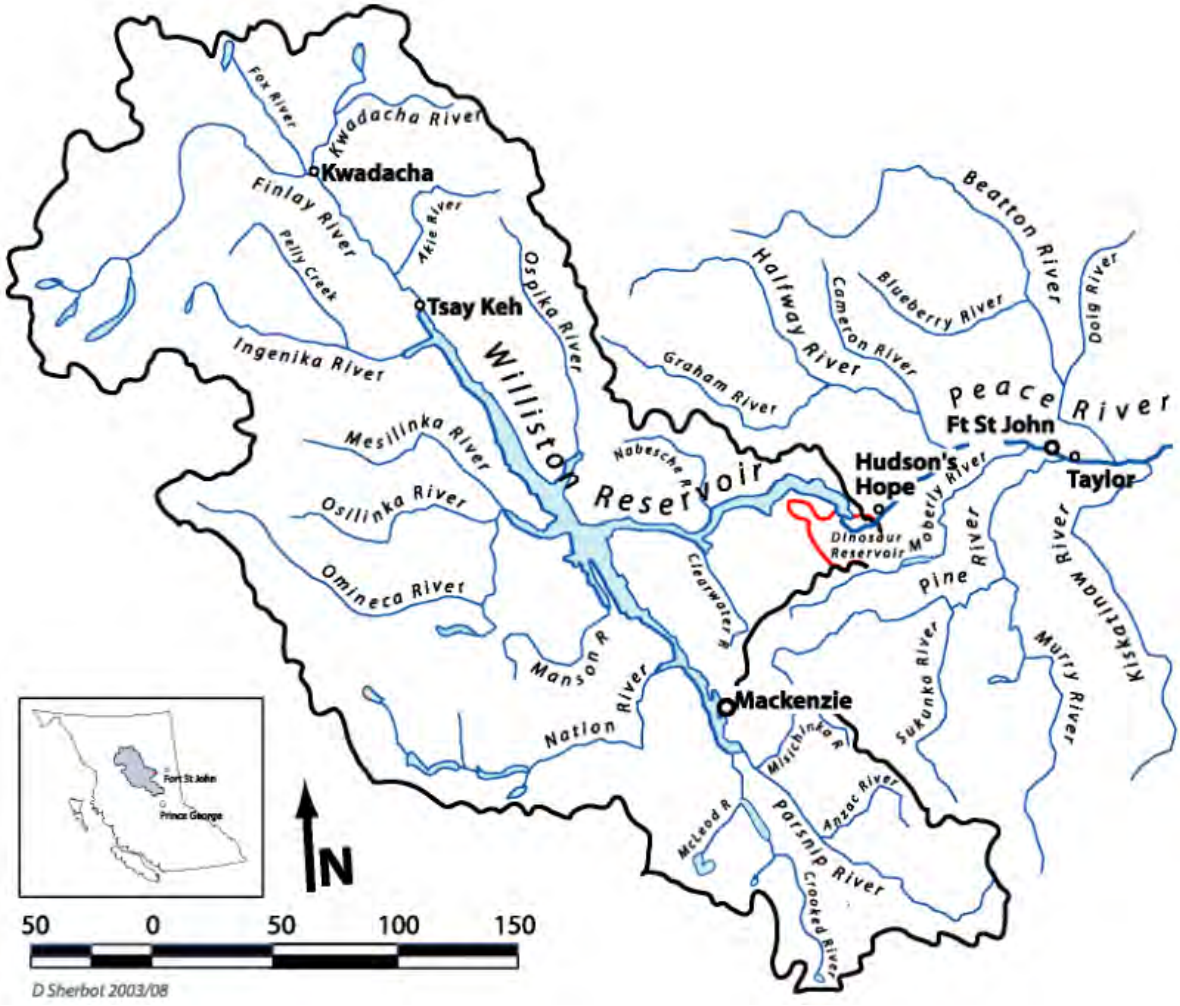

Figure 3. Peace Project location and place names (excerpt from BC Hydro, 2008j)

Legend

Gauges

- BC Hydro Hydrometric Stations
- WSC Hydrometric Stations
- Community
- Stream Network
- Dam

HALFWAY RIVER
FARRELL CREEK
CACHE CREEK
WILDER CREEK
TEA CREEK
LYNX CREEK
PEACE RIVER
MOBERLY RIVER
PINE RIVER
GETHING CREEK
JOHNSON CREEK
MAURICE CREEK

07FA006
Peace 29
Peace 25
Peace 35A
07FA004
07FD002
Peace 9
Peace 3
07FB008
07EF001

Fort St. John
Taylor
Hudson's Hope

W.A.C. BENNET DAM
PEACE CANYON DAM

450000 123°20'0"W 500000 122°30'0"W 550000 121°40'0"W 600000 120°50'0"W 650000
6250000
6200000
55°5'0"N

N

Base Data Sources:
- Background, Bing Maps - Aerial.
- Streams from BC Corporate Watershed Base.

Scale 1:500,000

0 11,000 22,000 44,000 Meters
0 36,500 73,000 146,000 Feet

Coordinate System: UTM Zone 10 Metres, NAD 83

DSGN	PKK
IND CHKD	
DFTG	JXD
DFTG CHKD	PKK
INSPD	
REV	
ACPT	

nhc

BC hydro

GMSMON-9 Peace River Spill Hydrology

Peace Mainstem Hydrometric Station Map

DATE 05 NOV 2010

DWG NO. CAD Mapsheet 1 of 1

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Figure 4

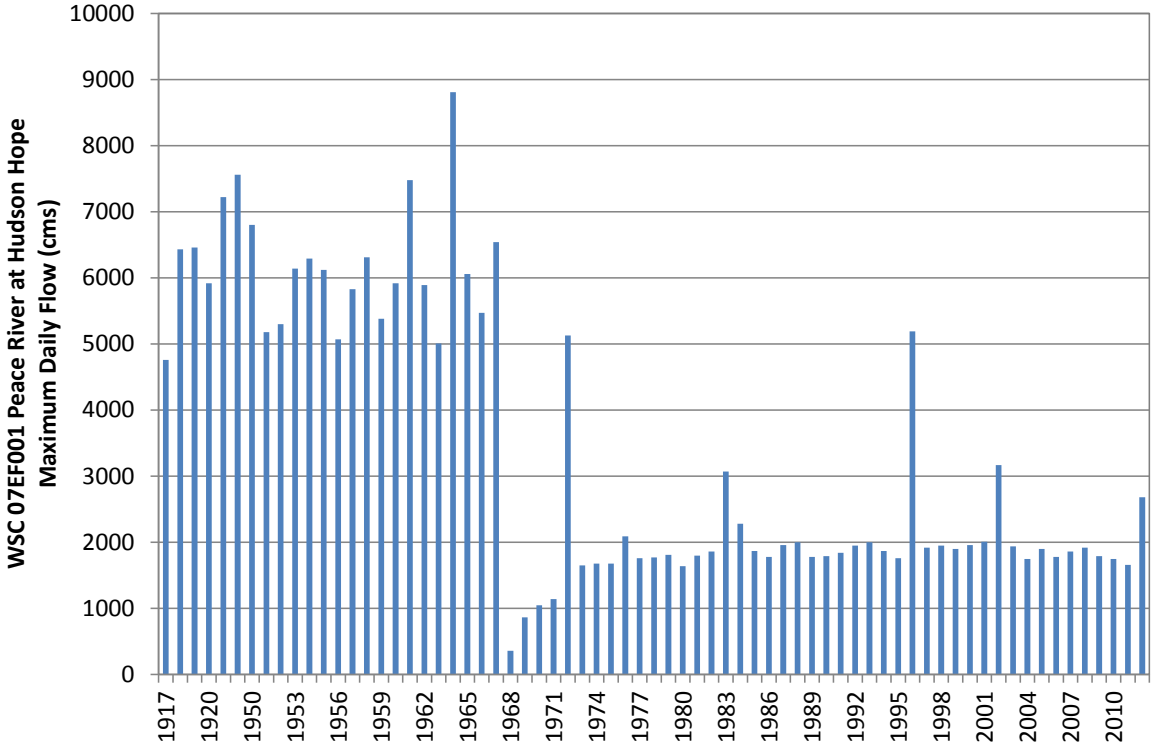

Figure 5. WSC 07EF001 Peace River at Hudson Hope maximum daily flows by year with the 1972, 1983, 1996, 2002, and 2012 spill events visible.

nhc
northwest hydraulic consultants

APPENDIX A
HYDROMETRIC DATA 2012 SPILL EVENT