SITE C CLEAN ENERGY PROJECT

VOLUME 2 APPENDIX D SURFACE WATER REGIME TECHNICAL MEMO, PART 1

SITE C OPERATIONS STUDY

FINAL REPORT

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Abbreviations and Acronyms

GOM .... Generalized Optimization Model

HYSIM .... Hydro Simulation Model

WUP .... Water Use Plan

Glossary

Water Year	A water year is a term commonly used in hydrology to describe a time period of 12 months between October 1st of one year and September 30th of the next. The water year is designated by the calendar year in which it ends.
Heavy Load Hours	Heavy load hours in a month are those between 6:00 AM and 10:00 PM Monday through Saturday excluding holidays.
Light Load Hours	Light Load Hours in a month are those between 10:00 PM and 6:00 AM, all day Sunday and holidays.
Electricity Self-Sufficiency	As prescribed under the Clean Energy Act, amended Electricity Self-Sufficiency Regulation and amended Special Direction #10.
Duration Graph	A duration graph is a graphical summary of data which shows the per cent of time that the data values would equal or exceed the corresponding value indicated on the graph axis.
Freshet	Freshet is the runoff resulting from melting of winter snow and ice during the spring and early summer.

1 OBJECTIVE AND SCOPE

This report summarizes the studies carried out by BC Hydro Generation Resource Management in support of the environmental assessment for the Site C Clean Energy Project (the Project). The objective of these studies was to characterize the reservoir releases to the Peace River under two different future operating scenarios: i) the first scenario characterizes the releases from the Dinosaur Reservoir in a future which does not include the Project and ii) the second scenario characterizes releases from the Site C reservoir in a future which includes the Project. The characterization of reservoir releases was achieved through the simulation of possible future operations based on a 60-year period of historical inflows from 1 October 1940 to 30 September 2000 (i.e., Water Years[1] 1941 to 2000). In addition, the estimated frequency and range of water levels for the Site C reservoir were supplemented by a scenario analysis to assess the sensitivity of reservoir operation to a future system load/resource balance which is more generation resource constrained than that assumed in the 60-year simulation period.

The hydraulic routing of reservoir releases from each of the above operating scenarios to points further downstream on the Peace River and the description of the hydrologic regime during the construction phase of the Project are discussed in Volume 2 Section 11.4 Surface Water.

2 NORMAL RESERVOIR OPERATING CONSTRAINTS

The operation of a hydroelectric facility must adhere to the facility-specific physical and regulatory constraints including reservoir level ranges, maximum turbine releases, and minimum flow requirements. The ranges of normal reservoir levels and release constraints assumed in simulating the future operation of BC Hydro's existing facilities on the Peace River and, if it proceeds, the Project are provided in Table 1.

[1] A water year is a term commonly used in hydrology to describe a time period of 12 months between October 1st of one year and September 30th of the next. The water year is designated by the calendar year in which it ends.

Table 1 Assumed Normal Reservoir Operating Constraints

	Normal Reservoir Levels (m)		Normal Flow Releases (m^3/s)	
	Maximum	**Minimum**	**Maximum (turbine)**	**Minimum (turbine or spill)**
Williston Reservoir	672.08	654.41[(a)]	1,968	0
Dinosaur Reservoir	502.92	500.00	1,982	283[(c)]
Site C Reservoir	461.80	460.00	2,520[(b)]	390[(d)]

Notes:
(a) Williston Reservoir minimum level is variable based on a formula under the Peace Water Use Plan (WUP) which permits a lower minimum reservoir level under certain system water supply conditions and with Water Comptroller approval. The WUP anticipates that this normal minimum level may be reduced to 652.3 m once certain conditions have been met.
(b) Depending on final design, the Site C maximum turbine discharge capability is expected to be within +/- five per cent of that assumed in this study.
(c) Minimum flow requirement as measured in the vicinity of the Water Survey of Canada Station 07EF001, Peace River at Hudson Hope.
(d) Minimum flow for the Project is discussed in Volume 2 Section 11.4 Surface Water.

3 OPERATION MODEL DESCRIPTION

BC Hydro operates its generation system to maximize the long-term expected net revenue from operations and to manage risks associated with serving the BC domestic load by optimizing the use of generation resources with available market opportunities while adhering to operating requirements. While the operation of all generation resources are coordinated to meet this overall objective, the large size (in both energy and capacity) of the existing facilities on the Peace and Columbia basin relative to total system demand dictates a much higher level of coordination between these two basins. The addition of a major resource such as the Site C generating station on the Peace River could influence how each facility on the Peace and Columbia systems are coordinated. To characterize the future operation of the Peace River facilities with or without the Project, it is therefore necessary to use models that can account for this inter-basin coordination.

BC Hydro has extensive experience in the use of the Hydro Simulation Model (HYSIM) and the Generalized Optimization Model (GOM) for planning purposes. These proprietary models were used to predict operational influence on reservoir releases of Revelstoke Unit 5 and Mica Units 5 and 6 projects in support of their respective environmental effects assessments. They were also used to evaluate operating alternatives in support of BC Hydro's Columbia and Peace River Water Use Plans.

For this study, the HYSIM and GOM models were used to simulate a range of possible future reservoir releases to the Peace River under two different operating scenarios: one with the Project and the other without the Project. HYSIM was used first to simulate the monthly operation of BC Hydro's generation system over the 60-year study period. GOM was subsequently used to optimize the hourly operation of the hydropower system, guided by the month-end storage targets produced by HYSIM for the Williston and Kinbasket reservoirs (the two major storage reservoirs of the integrated hydroelectric generation system). GOM results provide the basis for expected reservoir levels and the expected reservoir releases, with and without the Project, across different historical inflow sequences.

3.1 Hydro Simulation Model (HYSIM)

The HYSIM model is a monthly simulation model of the integrated BC Hydro electric generation system with limited foresight. The model simulates the system sequentially at a one month time-step given inputs of inflow, electricity load and prices during that month. It includes detailed hydraulic simulation of the hydro system as well as operating rules derived under the Columbia River Treaty operating plans to guide operations of the Columbia River facilities. For a given load and resource portfolio, the model determines the most economic dispatch of the generating system subject to fixed operating constraints (i.e. dam safety, physical capability, flood and ice control, regulatory requirements) across a historical sequence of inflows and subject to external market opportunities. The external markets are represented by heavy and light load hour[2] energy prices and limited by the capacity ratings of transmission lines connecting the BC Hydro system to neighboring systems in the United States and Alberta.

As a monthly time-step model, HYSIM can only be used to address constraints on a monthly time resolution. The outputs from the model include: end-of-month reservoir elevations and reservoir storage contents, monthly average energy production, powerhouse and spill discharges, and electricity trade. The results do not reflect any variability within the month beyond splitting electricity trade activities into heavy and light load periods.

3.2 Generalized Optimization Model (GOM)

GOM is a system optimization model which uses deterministic linear programming modelling techniques to solve for the optimal operating conditions, subject to physical and

[2] Heavy load hours in a month are those between 6:00 AM and 10:00 PM Monday through Saturday excluding holidays. Light load hours are the rest of the hours in that month. This split is important because electricity trades are typically made in heavy and light load hour blocks and the electricity prices are typically different.

operating constraints. The model can operate with a variable time-step down to one hour increments. The GOM model optimizes the operation of the hydropower system to meet BC Hydro electrical system loads while seeking to maximize the operational value of the generating resources subject to dam safety requirements, physical capability, flood and ice control, regulatory requirements and Columbia River Treaty operational requirements. The optimal operating conditions are further subject to transmission line limits on electricity trade with the United States and Alberta markets.

GOM assumes perfect foresight of parameters such as loads, market prices, and inflows for the time period being modelled. In order to limit the influence of perfect foresight, GOM must adhere to the year-end storage targets for the Williston and Kinbasket reservoirs as modelled by HYSIM, while the month-end storages for these reservoirs are allowed to deviate only slightly (0.46 m for Williston Reservoir and 1.65 m for Kinbasket Reservoir) from HYSIM targets for the optimization of within-month operation.

For this study, GOM was run with a one hour time-step, one water year at a time, to capture the variability in inflows, loads and prices within months and days. Inputs included the domestic load and available generating resources for each time step in the studied year (2028-2029 as shown in Table 2) along with their operating characteristics, such as operating and flow constraints, unit efficiency curves and storage and tailrace characteristics. The market price of electricity was used to determine whether it is more economical to store water or to draw down the BC Hydro system reservoirs to meet load requirements, and to engage in electricity market trade.

GOM determines optimal reservoir elevations and plant discharges and provides a proxy for hourly hydro system operations. The GOM model is not influenced by subjective bias in that it determines optimal reservoir releases based solely on the given inputs and system configuration. This characteristic, along with the capability to run in an hourly time-step resolution, makes GOM well suited to assess operational changes resulting from two or more operating scenarios. Comparison of GOM results from different operating scenarios can indicate the expected changes in reservoir releases between scenarios, which was the primary objective of this study.

By simulating operations over historical inflow sequences, GOM output provides a range of possible future operations under different scenarios. The model output is not intended to represent a chronological forecast of actual operations. Consequently, comparisons between the GOM model results for different scenarios should not be conducted on an hour-to-hour or daily basis because the time series are intended to represent a range of possibilities rather than a representation of an occurrence at a fixed point in time. It is appropriate, however, to compare scenarios using duration/frequency curves or other statistical metrics.

4 MODEL INPUTS AND ASSUMPTIONS

The key parameters and assumptions associated with the HYSIM and GOM models used to simulate and optimize, respectively, the operations of the BC Hydro coordinated generation system for scenarios with and without the Project is presented in Table 2.

Table 2 Summary of Model Parameters and Assumptions

	HYSIM	GOM
Model type	Simulation	Linear programming optimization
Time step	Monthly	Hourly
Foresight	Limited foresight (one month)	Perfect foresight within one water year (Oct to Sep) but guided by month-end storage targets from HYSIM
Study year (electrical load/ resource Portfolio)	2028/2029	2028/2029
Load forecast and shape	Corporate forecast (Monthly)	Corporate forecast (Monthly), shaped hourly based on historical load shape
Market price and shape	Corporate forecast (Monthly for High Load Hours and Low Load Hours)	Corporate forecast with hourly variability based on typical weekly price patterns
Resources	Electricity self-sufficiency[3] (under average water conditions, no insurance energy)	Electricity self-sufficiency (under average water conditions, no insurance energy)
Planned outages	Averaged availability for each month	Daily, based on average annual maintenance needs
Constraints	Physical, operational, dam safety, regulatory, Columbia River Treaty (monthly resolution)	Physical, operational, dam safety, regulatory, Columbia River Treaty (hourly or longer resolution)
Optimized reservoir storage	Williston Reservoir, Treaty, Non-Treaty Storage in Kinbasket Reservoir, and flex between Kinbasket Reservoir and Arrow Lakes Reservoir	Williston Reservoir, Dinosaur Reservoir, Site C Reservoir, Kinbasket Reservoir, Revelstoke Reservoir and Arrow Lakes Reservoir
Intended use	End of month reservoir storage contents and Columbia River Treaty discharge to the United States for each water year for GOM optimizations	Energy and shaping impacts, hourly reservoir elevations, plant generation, and discharges

[3] As prescribed under the Clean Energy Act, the amended Electricity Self-Sufficiency Regulation and amended Special Direction #10.

For the operating scenario without the Project, the system load was reduced by the amount of firm energy that the Project would have produced. This avoids the need to select a specific alternate resource in place of the Project so that the remaining resource balance could match the operating scenario that included the Project. This approach eliminates, to the extent possible, the operational changes that could have otherwise resulted from the selection of different alternative resources in place of the Project.

For the operating scenario with the Project, downstream ice control flow constraints were assumed to be transferred from Peace Canyon to the Site C generating station. Details on ice control flow objectives and constraints on the Peace River are presented in Volume 2 Appendix G Downstream Ice Regime Technical Data Report.

4.1 Streamflow Records

Prior to undertaking the HYSIM/GOM operation studies, a review of the availability and quality of streamflow records on the Peace River upstream of the Site C dam site was completed, as this is an important input to the models. The review considered both gauged streamflow records as well as those resulting from past data extension efforts. Based on this review, best available series of continuous streamflow data were compiled. The periods of continuous streamflow record for the Peace River at each location compiled through this data review are shown in Table 3.

Table 3 Streamflow Records Periods

Drainage	Monthly Data Years	Daily Data Years
Williston Reservoir	1928 to 2010	1957 to 2010
Dinosaur Reservoir (local)	1928 to 2010	1964 to 2010
Site C Reservoir (local)	1928 to 2010	1964 to 2010

System wide studies using HYSIM and GOM require a consistent set of inflows as well as Columbia River Treaty operations for the modelling period. Currently, the Columbia River Treaty planning studies are only performed using historical streamflow from water years 1941 to 2000. This range is the extent of the inflow and flood control data that have been approved by the Columbia River Treaty Operating Committee of both the United States and Canada at the time the HYSIM and GOM studies for the Project were conducted. Accordingly, these studies were performed using this 60-year historical inflow sequence. This period of streamflow provides a representative sample of system inflow conditions ranging from 80 per cent of average during the 1944 water year to 122 per cent of average during the 1976 water year.

For periods where the available streamflow time resolution is limited to monthly data, daily values were assumed to equal the monthly value without further adjustments. No within-day variations in streamflows were applied, i.e., hourly streamflows were assumed to equal daily values for all periods.

5 SUMMARY OF RESULTS

The GOM output provides simulated hourly reservoir releases to the Peace River for the two operating scenarios, with and without the Project, over a 60-year inflow sequence. These results were provided as the basis for further analyses (e.g. hydraulic routing) of downstream changes, the results of which are described in Section 11.4 of the Environmental Impact Statement and Volume 2 Appendix D Surface Water Regime Technical Memos, Part 2 Downstream Flow Modelling (1D). A summary of predicted Site C reservoir releases and reservoir levels are provided below.

5.1 Site C Operations

5.1.1 Site C Reservoir Releases

The operation of the Site C generating station would be coordinated with the operation of existing facilities upstream on the Peace River as well as other available system resources to meet provincial demand for electricity in a safe, reliable, and efficient manner. Accordingly, Site C reservoir releases follow the same general pattern as the provincial demand for electricity. Generally the pattern is higher during the winter and lower during the summer on a seasonal basis, higher during weekdays and lower during weekends on a weekly basis, and higher during daylight hours and lower during late night hours on a daily basis.

A duration graph[4] of the Site C reservoir releases on an annual and seasonal (winter, spring freshet[5] and summer) basis, over the 60-year simulation period is provided in Figure 1. The seasons are defined as follows:

Winter: November 15 to February 15

Freshet: May 1 to July 15

Summer: July 16 to September 30

[4] A duration graph is a graphical summary of data which shows the per cent of time that the data values would equal or exceed the corresponding value indicated on the graph axis.
[5] Freshet is the runoff resulting from melting of winter snow and ice during the spring and early summer.

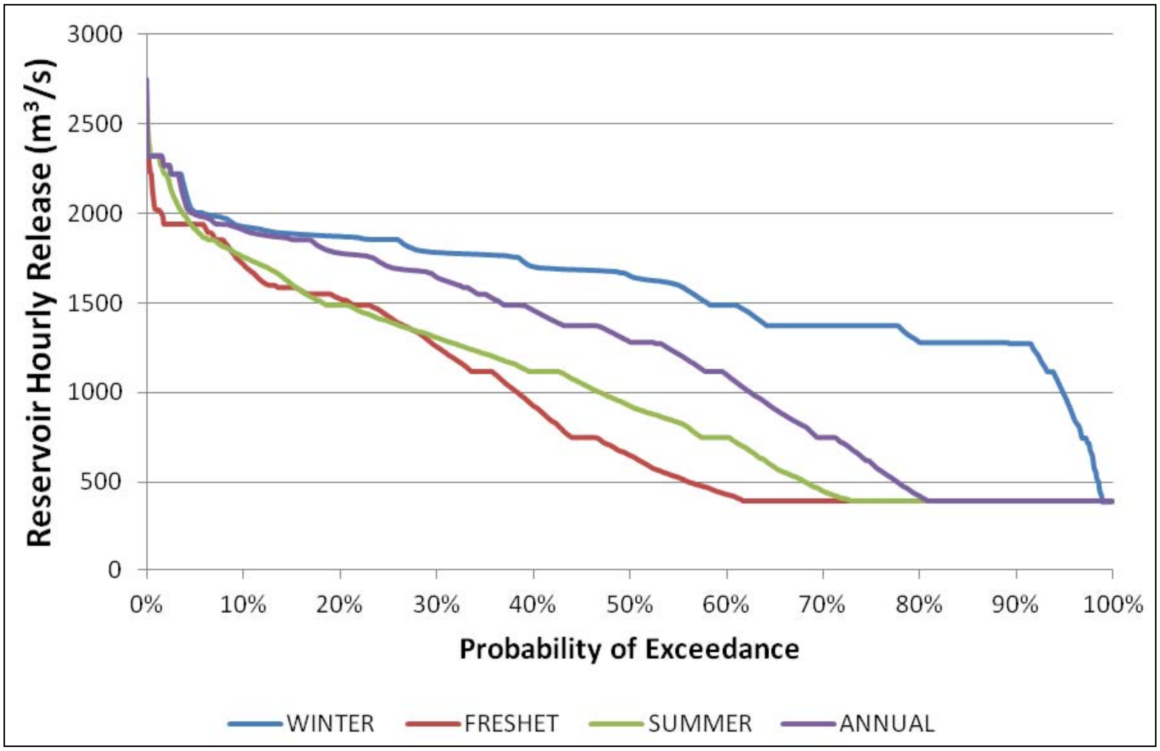

Figure 1 Annual and Seasonal Site C Reservoir Release Duration Curve (60-year GOM Model Results)

The volume of reservoir releases from the Site C reservoir would typically be highest during the winter months when increased generation is needed to meet high system loads. In addition, there would be limited opportunity to decrease releases during light load hours over the winter due to ice control flow requirements. The volume of reservoir releases is typically lowest during the spring freshet due to low demand and because generation during this period has the lowest financial value due to high generation from non-dispatchable resources such as run-of-river hydro. On an annual basis, Site C reservoir releases would be expected to be at the normal minimum flow (see Table 1) for approximately 20 per cent of the time. The maximum reservoir release over the 60-year simulation period reached 2,750 m^3/s which includes both turbine and spill releases.

The normal ranges of reservoir releases to the Peace River under a future operating scenario with the Project are well characterized by the GOM model over the 60-year simulation period. However, because the GOM model assumes perfect foresight of inflows, spills which occur infrequently are likely under-represented by the modelled results. A discussion on alternate approaches to quantify the frequency and magnitude of spills from the Project is provided in Section 5.1.3 of this report.

5.1.2 Site C Reservoir Levels

The simulated operation of the Project shows that the Site C reservoir would be operated within the top 0.6 m, between elevations 461.8 and 461.2 m, over 99 per cent of the time. Similarly, daily reservoir level fluctuations would be less than 0.6 m over 99 per cent of the time. The use of the full 1.8 m normal reservoir operating range, between elevations 461.8 and 460.0 m, would still be required, but the duration of time the reservoir is drafted to the lower levels would be less than 1 per cent of the time. For example, the Site C reservoir would be drawn down in order concentrate generation into heavy load hours to maximize the value of generation. Also, the reservoir would be drawn down if high local inflows are forecasted in order to avoid spill or to maintain ice control flow or minimum flow requirements when it is uneconomic to release additional flows from Peace Canyon.

The GOM model results described above simulate how the Site C reservoir would be operated assuming future generation resource development, including the Project, kept pace with load growth. However, if a more generation constrained load/resource balance develops, the frequency with which the Site C reservoir would need to be drafted could increase. Such a scenario could materialize if future generation resource development is delayed, load growth exceeded forecast, or transmission capacity to external markets is expanded.

A discussion on an approach to analyse the sensitivity of Site C reservoir levels to a more generation constrained future is provided in Section 5.1.2.1 of this report.

5.1.2.1 Reservoir Level Scenario Analysis

A scenario analysis, independent of the GOM study, was used to evaluate the sensitivity of Site C reservoir levels in an alternate future where generation resources would be more constrained such that the Project would be heavily relied upon to meet system load requirements. This scenario analysis assumed the Peace system would be operated under the following conditions:

- System resources are constrained such that the optimal system operation would make full use of the Project generation flexibility during heavy load hours.
- Operational foresight related to markets and inflows is limited to one week.

Under this scenario, it is during the winter period that the operation of the Site C reservoir could deviate from that simulated by the GOM model. The scenario analysis indicates that, in winter, under a generation constrained load/resource balance, the duration that the Site C reservoir would be operated within the top 0.6 m (between elevations 461.8 and 461.2 m) could decrease from 99 per cent of time to about 83 per cent of time. The duration that the reservoir would be operated within the mid 0.6 m of the normal range (between elevations 461.2 and 460.6 m) and bottom 0.6 m of the normal range (between elevations 460.6 and 460.0 m) could increase from less than one percent to about 11 per cent of time and 6 per cent of time, respectively. The duration that daily reservoir level fluctuations would be less than 0.6 m would decrease from over 99 per cent of time to about 60 per cent. It is estimated that the daily fluctuation of the reservoir would exceed 1.0 m for about 25% of the time.

The above sensitivity analysis confirms that even if a generation constrained future develops, the Site C reservoir would continue to operate at relatively high levels (within the top 0.6 m, about 83 per cent of time) in order to maximize the value of power production.

5.1.3 Expected Frequency of Site C Spillway Discharges

The Site C spillway facilities are designed to safely pass a design flood that is orders of magnitude greater than what the hydroelectric facility would normally be expected to discharge on a day to day or year to year basis. The design flood and spillway capacity are described in the Environmental Impact Statement Volume 1 Section 4 Project Description. At the other end of the spectrum, lower magnitude spills, though infrequent, are expected under normal operations and could occur at any time. These events are driven by normal operating requirements including uncertainties associated with inflows, unit outage, transmission restrictions, electricity market prices and system energy needs.

The combined hydraulic capacity of the proposed Site C generating station (six generating units) would be roughly twenty five per cent greater than the hydraulic capacity at G.M. Shrum or Peace Canyon. The turbine discharge characteristics, along with a normal storage volume range that is roughly six times greater than Dinosaur Reservoir would provide the Project with operating flexibility to reduce the occurrence of spills.

As indicated in Section 5.1.1 of this report, because the GOM model assumes perfect foresight of inflows, the model would tend to draw down the Site C reservoir ahead of any high inflows that could cause spills. However, because in reality inflow forecasts are never perfect, spills are likely under-represented by GOM. To address this potential spill under-representation, a partial re-operation of the GOM model was undertaken to limit the inflow foresight of the model to one month. For each of the years for which the monthly HYSIM model resulted in either spills at the Project or surplus energy in the system, the GOM model was re-operated while limiting inflow foresight to one month. This re-operation resulted in spills at the Site C dam in five years over the 60-year inflow sequence. The magnitude and duration of these spills are shown in Figure 2.

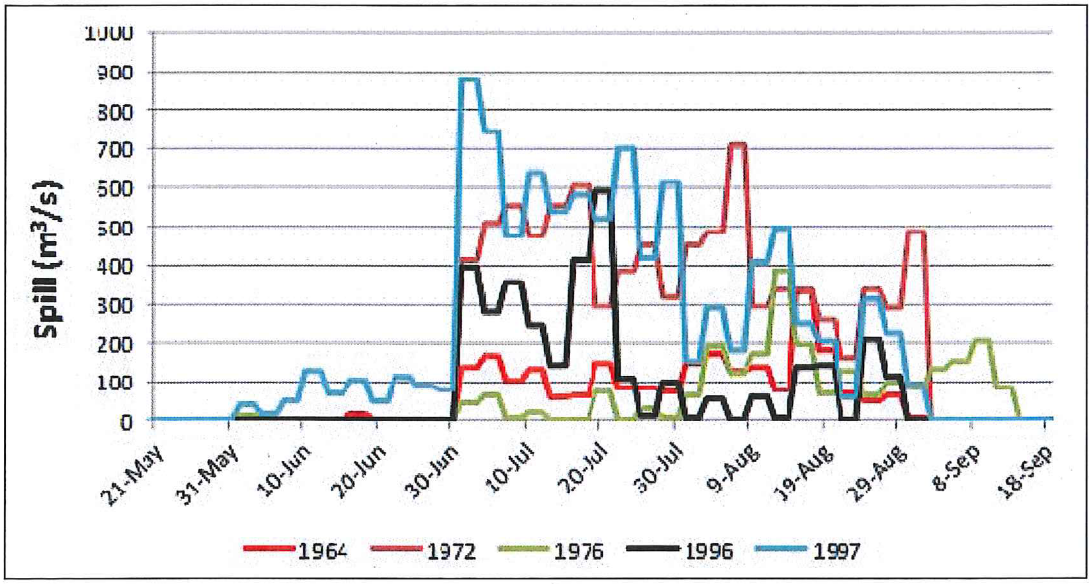

Figure 2 Site C Spills Modelled Using GOM (Re-operated to limit inflow foresight to one month)

While limiting the inflow foresight to one month enabled GOM to better predict occasional spills at the Site C dam, this foresight limitation was not applied for predicting normal reservoir releases because the shaping of reservoir releases between months, which would be facilitated by the forecast of seasonal inflow patterns spanning several months, is an important determinant in the actual operation of the Williston Reservoir.

6 CLOSURE

This report was prepared and reviewed by the undersigned.

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Inter-office memo

To:	Site C Clean Energy Project Team	Date:	4 December 2012
From:	Faheem Sadeque	File:	STC12MIS YM80003-3281

Subject: **Site C Clean Energy Project - Downstream Flow Modelling (1D)**

1. Introduction

An analysis of the influence of the Site C Clean Energy Project (the Project) operations on downstream Peace River flows and water levels was conducted using a one-dimensional numerical hydraulic model (MIKE11). Two scenarios were considered in this study: "Without the Project" and "With the Project". These two scenarios are termed Case A and Case B, respectively, for the purpose of this memo. The Case A model extends from the outlet of the Peace Canyon Dam to Peace Point, Alberta (a distance of approximately 1,115 km). The Case B model extends from the outlet of the Site C dam to the same downstream location (a distance of approximately 1,030 km). The hourly flows that were input to the hydraulic model for each scenario were obtained from the results of the operational modelling that is described in Volume 2 Appendix D Surface Water Regime Technical Memos, Part 1 Operations Study.

2. Hydraulic Model

2.1 Bathymetry

The hydraulic model was developed using available measured cross-sections as well as some interpolated and synthetic sections. Approximately 180 measured cross-sections were available to represent the geometry of the reach between Peace Canyon Dam and Fort Vermilion, Alberta. An additional 54 cross-sections were surveyed in the B.C. portion of the river in 2009. The measured cross-section interval for the 148 km reach of the Peace River between Peace Canyon Dam and the B.C. / Alberta border is about 0.9 km. Downstream of the border, measured cross-sections are spaced approximately 7 km apart in the 229 km reach downstream to the Town of Peace River. Twenty six measured sections and several interpolated sections were used to represent the 450 km reach between the Town of Peace River and Fort Vermilion, Alberta. Synthetic cross-sections were used for the reach between Fort Vermilion and Peace Point due to a lack of surveyed data. Synthetic sections were also added for more than 100 km downstream of Peace Point to allow a constant downstream water level boundary condition to be specified in the MIKE 11 model that does not affect the model results at Peace Point.

Measured flows for all gauged tributaries to the Peace River were included as input to the MIKE 11 model. A list of the Water Survey of Canada gauged tributaries of the Peace River upstream of Peace Point are provided in Table 1.

Table 1. Water Survey of Canada Gauged Tributaries of the Peace River Upstream of Peace Point, Alberta

Tributary	Station Number	Period of Record	Drainage Area above gauge (km^2)	Distance of Confluence from W.A.C. Bennett Dam (km)	Mean Annual Flow (m^3/s)
Halfway River	07FA006	1981-2010	9,330	66	73
Moberly River	07FB008	1980-2010	1,520	105	11
Pine River	07FB001	1961-2010	12,100	121	189
Beatton River	07FC001	1961-2010	15,600	143	53
Kiskatinaw River	07FD001	1944-2010	3,640	156	10
Pouce Coupe River	07FD007	1971-2010	2,850	175	6
Clear River	07FD009	1971-2010	2,879	189	8
Smoky River	07GJ001	1915-2010	50,300	389	339
Heart River	07HA003	1963-2010	1,968	395	3
Whitemud River	07HA005	1971-2010	2,010	454	5
Notikewin River	07HC001	1961-2010	4,680	565	13
Keg River	07HF002	1971-2010	667	677	3
Ponton River	07JF003	1962-2010	2,440	847	15
Boyer River	07JF002	1962-2010	6,660	847	5
Jackpine River	07JD003	1971-2010	582	886	2
Wabasca River	07JD002	1970-2010	35,800	886	83

Notes:

1. The Ponton and Jackpine Rivers are tributaries of the Boyer and Wabasca Rivers, respectively. Flows from these rivers were included in the modelling because the hydrometric stations on the Boyer and Wabasca Rivers are upstream of the confluence with these rivers.
2. Mean Annual Flow is presented based on the period of record of each station, where data are available.

2.2 Calibration

MIKE 11 model calibration is described in Appendix A of this memo. In general, the model is well calibrated at the Water Survey of Canada stations along the Peace River. Graphs comparing model results to Water Survey of Canada rating curves and flow routing tests are included in Appendix A. Maximum water level differences are generally within 0.2 m to 0.3 m. Modelled flows at downstream Water Survey of Canada stations were found to follow the observed flow patterns both in magnitude and timing.

The Manning's roughness coefficient (n), specified at each cross-section in the model was the primary calibration parameter. This coefficient describes the roughness of the channel bottom and sides, which influences the relationship between flow and water level. The calibrated Manning's roughness coefficients for the main portions of the river channel were between 0.024 to 0.04 from Peace Canyon Dam to the Town of Peace River and between 0.017 to 0.025 from the Town of Peace River to Peace Point.

The predicted flows and water levels from this MIKE 11 model are reliable for comparing different operational scenarios (such as the comparison between "With the Project" and "Without the Project") as far downstream as Fort Vermilion, and at Peace Point for discharges up to 2,000 m^3/s. At higher discharges, modelled flows at Peace Point could be converted to water levels using the Water Survey of Canada rating curve if absolute water levels are required. For the purpose of relative comparisons of operational scenarios, modelled results of discharge and water levels at Peace Point are considered adequate.

3. Model Inputs

Operations modelling (described in Volume 2 Appendix D Surface Water Regime Technical Memos, Part 1 Operations Study) was conducted for a 60-year period from 1 October 1940 to 30 September 2000 (i.e. water years 1941 to 2000). For the current downstream flow modelling study, a subset of 10 representative water years, 1965 to 1974, was identified on the basis of Peace River flows during this 60-year period. Water years 1965 to 1974 include years that are between 86% and 130% of the 60-year average in terms of annual Peace River inflows (including reservoir inflows) upstream of the Site C dam site. The 10-year average flow is 105% of the 60-year average flow. The 10-year period contains one of the three peak daily inflows above 2,000 m^3/s in the 1964-2000 period for which daily flows are available. The selection of representative years was also verified on the basis of total BC Hydro system inflows. The 10-year period contains system inflows ranging from 85% to 119% of the 60-year average, which is only slightly less than the entire 60-year period range of 80% to 122%. A qualitative comparison of 10-year hourly and daily system inflows to the Williston, Dinosaur, and Site C reservoirs with 60-year inflows also validated the selection of 1965 to 1974 as representative water years[1].

Hourly outflows from Peace Canyon Dam (case A) and Site C dam (case B) for the 10 representative water years were used for the flow routing study. Total local inflows to the Site C reservoir were estimated for the same period, and they were divided between the Halfway and Moberly Rivers based on the ratio of mean annual discharges at Water Survey of Canada gauges 07FA006 (Halfway River at Farrell Creek) and 07FB008 (Moberly River below Moberly Lake). This division was estimated to be 90% Halfway River and 10% Moberly River. The water year 1969-70 represents the average discharge year in terms of total annual flow volumes at Peace Canyon Dam, based on the 10-year period.

For case B, hourly outflows from the Site C dam were used as the upstream boundary condition while hourly outflows from Peace Canyon Dam were used as the upstream boundary condition for case A. For each scenario, a constant water level more than 100 km downstream of Peace Point was used as the downstream boundary condition. Model testing confirmed that the assumed water level at the downstream boundary does not affect simulated results at Peace Point.

For case A, the Halfway and Moberly flows used in the MIKE 11 model were the same as those used in the operations modelling. Daily flows from all gauged tributaries between the Site C dam

[1] Woo, A. (2012). Personal communication with Allan Woo on September 18, 2012.

site and Peace Point were input to the hydraulic model as hourly values (i.e. same value entered for each hour in a day) to minimize model interpolation errors.

Since the available tributary discharge data were discontinuous for the 1964-1974 period, especially for smaller rivers during the winter, data infilling was required. For tributaries with data gaps in winter months during low flow periods, infilling was performed using the average daily flow for other years for which data existed for that same tributary. However, when the data gaps were longer and extended into high flow periods, gaps were infilled using regional methods with other available Peace River tributary flows. Daily average unit discharge hydrographs were produced for each tributary for the 10-year period and compared to find similarities. Reference rivers were selected for the estimation of daily flows where substantial data gaps existed. Daily discharge hydrographs for each tributary from 1964 to 1974 are included in Appendix B, showing the measured and estimated flow data. Although there is uncertainty in these estimates of tributary flows, the same assumptions were used for both cases (i.e., with and without the Project) and therefore the relative comparison of flows and water levels between the two scenarios is considered reliable.

4. Model Results and Discussion

Table 2 shows a list of figures used for presentation of the flow routing results. Note that all MIKE 11 simulations were performed without considering the effects of ice. A separate study was conducted to assess ice conditions and associated water levels with and without the Project. This study is described in the Volume 2 Appendix G Downstream Ice Regime Technical Data Report.

Comparisons of model results for case A and B are discussed below for each model output format.

Table 2: Summary of Model Output Formats

Output Format	Description	Key Locations
Hourly/ Daily Flow and Water Level Time Series (Appendix C of this memo)	Hourly flow time series (Oct. 1969 to Sep. 1970)	Site C tailrace, Taylor, Alces, Town of Peace River and Peace Point
	Hourly water level time series (Oct. 1969 to Sep. 1970)	Site C tailrace, Taylor, Alces, Town of Peace River and Peace Point
	Daily flow time series (Oct. 1969 to Sep. 1970)	Site C tailrace
	Daily water level time series (Oct. 1969 to Sep. 1970)	Site C tailrace
Hourly Water Level and Flow Duration Curves (Appendix D of this memo)	Hourly flow and water level duration curves (annual and seasonal, Oct. 1964 to Sept. 1974)	Site C tailrace, Taylor, Alces, Dunvegan, Town of Peace River, Fort Vermilion and Peace Point
Hourly Water Level Change Duration Curves (Appendix E of this memo)	Hourly duration curves (Oct. 1964 to Sept. 1974)	Site C tailrace, Taylor, Alces, Dunvegan, Town of Peace River, Fort Vermilion and Peace Point
Daily Water Level Range (Table 3 of this memo)	Tabular comparison of average daily water level range (annual and seasonal, Oct. 1964 to Sept. 1974).	Site C tailrace, Taylor, Alces, Town of Peace River and Peace Point
Hourly Wetted Width Duration Curves (Appendix F of this memo)	Hourly duration curves for wetted width (Oct. 1964 to Sept. 1974)	Site C tailrace, Taylor, Alces, Town of Peace River and Peace Point
Hourly Average Cross-Sectional Velocity Duration Curves (Appendix G of this memo)	Hourly duration curves for average cross-sectional velocity (Oct. 1964 to Sept. 1974)	Site C tailrace, Taylor, Alces, Town of Peace River and Peace Point

4.1 Time Series Hydrographs

Hydraulic model results were compiled as hourly time series plots of discharge and water level in Appendix C of this memo. Daily average discharge and water level time series at Site C tailrace (outlet of the generating station) are also presented in Appendix C. Results are presented for the average water year 1969-70 with the minimum and maximum hourly values for the 1964-1974 period shown to illustrate the range of discharge and water level simulated over the ten year period. To improve clarity of the plots at the Site C tailrace and at Taylor, minimum and maximum hourly values over each day (i.e. daily time series) are drawn instead of the hourly time series.

Observations from the time series hydrographs presented in Appendix C are listed below.

- With Site C reservoir in place, generation at the Site C generating station would follow the daily load fluctuation and therefore have a similar timing pattern as that of Peace Canyon Dam.
- The proposed Site C dam is located 85 km downstream of Peace Canyon Dam. Regular operational flows from Peace Canyon take between 5 and 15 hours to reach the location of the Site C dam, depending on the flow scenario, with an average of 10 to 12 hours. Therefore, operational changes would be noticed at downstream locations on average 10-12 hours earlier with the Project.
- In general, flow oscillations are greater in magnitude in case B compared to case A, especially near Site C tailrace. This is because of flow attenuation effects between Peace Canyon Dam and the Site C dam site for case A. It is also due to the increased operational flow range in Case B compared to Case A. In general, results suggest that conditions at the outlet of the Site C dam would be more similar to the conditions experienced today near the outlet of Peace Canyon Dam. Flow attenuation is dampened with distance downstream for both case A and B.
- Modelled results for the 1964-1974 period indicate that the overall range of annual water levels at Site C tailrace are higher by up to 0.5 m for case B compared to A, except in the spring freshet period (in particular during the Halfway River peak) when the range is reduced for case B compared to case A. The difference in the range reduces to 0.3 m at Taylor. The range of hourly water levels is similar between case A and B at the Town of Peace River and Peace Point.
- For both case A and B, Peace Canyon Dam and Site C dam discharges are generally higher and vary over a relatively smaller range in December and January compared to the rest of the year. Due to low tributary inflows in winter, discharges at downstream stations are similar.

4.2 Flow and Water Level Duration Curves

Water level duration curves are presented for the 1964-1974 period in Appendix D. These duration curves show the exceedance probability (percentage of time a certain water level is equaled or exceeded based on hourly results); corresponding discharge estimates are shown using a secondary vertical axis based on the Water Survey of Canada stage-discharge relationship at each station, with the exception of Site C tailrace discharges which are based on modelled results.

Duration curves are presented for annual and seasonal periods including: typical winter operations period (Nov. 15 to Feb. 15), typical freshet operations period (May 1 to Jul. 15) and typical summer operations period (Jul. 16 to Sept. 30).

Observations from the duration curves presented in Appendix D are listed below.

- Flow duration curves for case A and B show differences at Site C tailrace near the maximum and minimum powerhouse discharges. The maximum powerhouse discharge from the Site C generating station (2,540 m^3/s) is 558 m^3/s higher than the Peace Canyon Dam maximum powerhouse discharge (1,982 m^3/s). This results in more frequent discharges above 2,000 m^3/s in case B compared to case A for the 10-year period.
- There is a greater occurrence of low flows/ water levels at Site C tailrace for case B. This is because of flow attenuation effects between Peace Canyon Dam and the Site C dam site for case A which dampen the oscillations in Peace Canyon outflows; it is also due to the difference between the minimum powerhouse discharge from the Site C generating station and the combination of the Peace Canyon minimum powerhouse discharge with the inflows from the local drainage area between Peace Canyon and the Site C dam site.
- The differences between the duration curves diminish at downstream stations due to flow attenuation and tributary inflows. For stations downstream of Alces the water level duration curves show little difference between case A and B for the 10-year period.
- During the typical winter operations period (Nov. 15 to Feb. 15), duration curves at Town of Peace River and Peace Point are similar for case A and B except for 5% of the time during low flows/ water levels due to a shift in upstream plant release patterns with the Project.
- Both high and low water levels at Site C tailrace during the typical freshet period (May 1 to Jul. 15) are more frequent in case B compared to A. For example, water levels at Site C tailrace are above 411 m for about 15% of the time in case A, but 25% of the time in case B. Water levels are predicted to be less than 410 m about 20% of the time in case A and 45% of the time in case B. These differences diminish by Alces due to relatively high tributary discharges at this time of year.
- Similar to the freshet period, both high and low flows and water levels at Site C tailrace during the typical summer operations period (Jul. 16 to Sept. 30) are more frequent for case B compared to A. For example, water levels at Site C tailrace are above 411 m about 16% of the time in case A and 24% of the time in case B. Water levels are predicted to be less than 410 m about 20% of the time in case A and 28% of the time in case B. These differences diminish more gradually at downstream stations compared to other periods of the year due to relatively low tributary discharges at this time of year.

4.3 Hourly Change in Water Levels

Observations about hourly change in water level based on the time series hydrographs presented in Appendix C are as follows.

- Hourly water level fluctuations at the Site C tailrace are higher for case B compared to case Adue to flow attenuation over the distance from Peace Canyon Dam to the Site C tailrace in case A, and due to the higher range of operational discharges in case B.
- Hourly water level fluctuations are less pronounced in winter months in both case A and B.
- The hourly water level fluctuations are attenuated to less than 0.1 m at the Town of Peace River for both case A and B.

Duration curves for increasing and decreasing hourly changes in water level during 1964-1974 are presented in Appendix E. An hourly change in modelled water level less than 0.001 m has been considered as no change in water level for the purposes of this analysis. If 0.01 m had been considered as no change in modelled water level instead of 0.001 m, the tabulated exceedance probabilities shown on these plots for increasing, decreasing or no change in hourly water level change would be different, but the curves would be similar. The following conclusions can be made based on the duration curves shown in Appendix E.

- The maximum hourly change in water level at Site C tailrace in case B is about ±1.5 m during the 1964-1974 period. However, the positive and negative hourly change in water level exceed 0.5 m only 3% and 4% of the time, respectively.
- In general, model results show that water levels at the Site C tailrace remain steady in two consecutive hours more frequently in case B than case A.
- A positive hourly change in water level at Alces of 0.1 m is exceeded about 5% of the time in case A and 15% of the time in case B. Similarly, a negative hourly change in water level at Alces of 0.1 m is exceeded about 5% of the time in case A and 15% of the time in case B.
- The difference between the hourly water level change duration curves for case A and B downstream of Dunvegan is negligible.

4.4 Daily Water Level Range

The average daily range of water level (i.e. average difference between the maximum and minimum water level over each day) in the 10-year period (1964-1974) is summarized in Table 3. Estimates are shown for both annual and seasonal periods for cases A and B. The average daily range of water level is higher in case B than case A by approximately 0.5 m at Site C tailrace, and by approximately 0.05 m at the Town of Peace River. Results suggest no difference at Peace Point.

Table 3: Daily Range of Water Levels (1964-1974)

Period	Average Daily Range of Water Level (m)									
	Site C Tailrace		Taylor		Alces		Town of Peace River		Peace Point	
	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
Full Year	0.48	1.01	0.43	0.76	0.50	0.85	0.16	0.20	0.07	0.07
Typical Winter Operations Period	0.36	0.68	0.33	0.54	0.39	0.60	0.12	0.14	0.02	0.02
Typical Freshet Operations Period	0.40	1.22	0.35	0.77	0.41	0.82	0.19	0.24	0.14	0.14
Typical Summer Operations Period	0.58	1.09	0.51	0.90	0.59	1.06	0.17	0.22	0.07	0.07

4.5 Hourly Wetted Width

Duration curves of hourly wetted width at five key locations are plotted in Appendix F based on the 10-year period (1964-1974). The wetted width is defined as the horizontal distance across the wetted portion of a cross-section. The relationship between flow and wetted width is fixed for each cross-section of the model based on the channel geometry, roughness, and slope; hence the differences in wetted width between cases A and B follow similar patterns as the differences noted above for flows and/or water levels.

Results indicate that the frequency of larger wetted widths in case A and B at all key locations are similar. However, smaller wetted widths would be expected to occur more frequently in case B than case A. For example, the hourly wetted width of the river at Site C tailrace is less than 400 m for about 8% of the time in case A and 20% of the time in case B. These differences diminish at downstream stations. The duration curves for wetted widths at Alces, Town of Peace River and Peace Point are very similar in case A and B. Some of the differences in durations for lower wetted widths, are mainly due to the shape of the cross-sections chosen for comparison. For example, at Town of Peace River there is almost no difference in wetted width for any duration. However, at Peace Point, for about 10% of the time, the wetted width for case B is in the order of 5 m less than case A.

4.6 Hourly Average Cross-Sectional Velocity

Duration curves of hourly average cross-sectional velocity in the Peace River at five key locations are provided in Appendix G based on the 10-year period (1964-1974). These velocities are derived from the one-dimensional hydraulic model results and represent spatially-averaged velocities across the selected cross-sections. In reality, velocities will vary locally within each cross-section. The relationship between flow and average cross-sectional velocity is fixed for each cross section of the model; hence the differences in wetted width between cases A and B follow similar patterns as the difference noted above for flows and/or water levels.

Duration curves for hourly average cross-sectional velocity at Site C tailrace show that velocity would be less than 1 m/s for about 20% of the time for case A and 25% of the time in case B. Differences in average cross-sectional velocities in case A and B are negligible at other downstream stations.

5. Conclusions

A one-dimensional hydraulic model was developed and calibrated to simulate flows and water levels on the Peace River between Peace Canyon Dam and Peace Point, Alberta. Two cases were simulated based on the results of the operations modelling described in Volume 2 Appendix D Surface Water Regime Technical Memos, Part 1 Operations Study. Case A represents possible future operations without the Project and case B represents possible future operations with the Project.

Differences in modelled water levels between cases A and B are reduced along the Peace River due to flow attenuation effects and tributary inflows. In general, modelled water level differences between case A and B are diminished after Dunvegan, approximately 190 km downstream of the Site C dam site.

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Dr. M. A. F. SADEQUE
34358

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Prepared by: ______________________
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Reviewed by: ______________________
Faizal Yusuf, P.Eng.

Attachments
Appendix A MIKE 11 Model Calibration
Appendix B Daily Flow Hydrographs (Tributaries)
Appendix C Hourly/Daily Flow and Water Level Time Series (Case A and B)
Appendix D Hourly Water Level and Flow Duration Curves (Case A and B)
Appendix E Hourly Water Level Change Duration Curves (Case A and B)
Appendix F Hourly Wetted Width Duration Curves (Case A and B)
Appendix G Hourly Average Cross-Sectional Velocity Duration Curves (Case A and B)

APPENDIX – A

MIKE 11 Model Calibration

APPENDIX A

MIKE 11 Model Calibration

The MIKE 11 model was calibrated and checked by:

- matching the Water Survey of Canada (WSC) rating curves at eight stations between Hudson's Hope and Peace Point;
- matching Northwest Hydraulic Consultants (NHC) rating curves at five stations between Hudson's Hope and Old Fort;
- running the model with hourly discharges recorded at Hudson's Hope and tributary flows and comparing simulated results with flows measured at downstream WSC gauges for the following periods -
  - April 2001
  - April 2009
  - October 2009

The locations of the WSC and NHC gauges are shown in Figure A1. The NHC gauges were established in 2009 based on work for BC Hydro Environment.

The WSC rating curves from Hudson's Hope to Alces extend to between 6,000 m^3/s and 10,000 m^3/s while the rating curves at gauges below Alces extend beyond 12,000 m^3/s to 20,000 m^3/s. The NHC rating curves extend to about 2,000 m^3/s. Model calibration was performed for the full range of discharges for the WSC and NHC rating curves up to Fort Vermilion. However, MIKE 11 model testing for discharges above 2,000 m^3/s was not considered at Peace Point for this operational flow routing study due to the synthetic representation of the Peace River geometry below Fort Vermilion. The comparison of model results with the eight WSC and five NHC rating curves are shown in Figures A2 to A14. Maximum water level differences are generally within 0.2 m to 0.3 m.

The results of flow routing tests are shown in Figures A15 to A32. Flow routing tests were conducted for low tributary flow periods in April 19-26, 2001, April 18-30, 2009 and October 15-30, 2009. Modelled flows at downstream WSC stations were found to follow the observed flow patterns reasonably well.

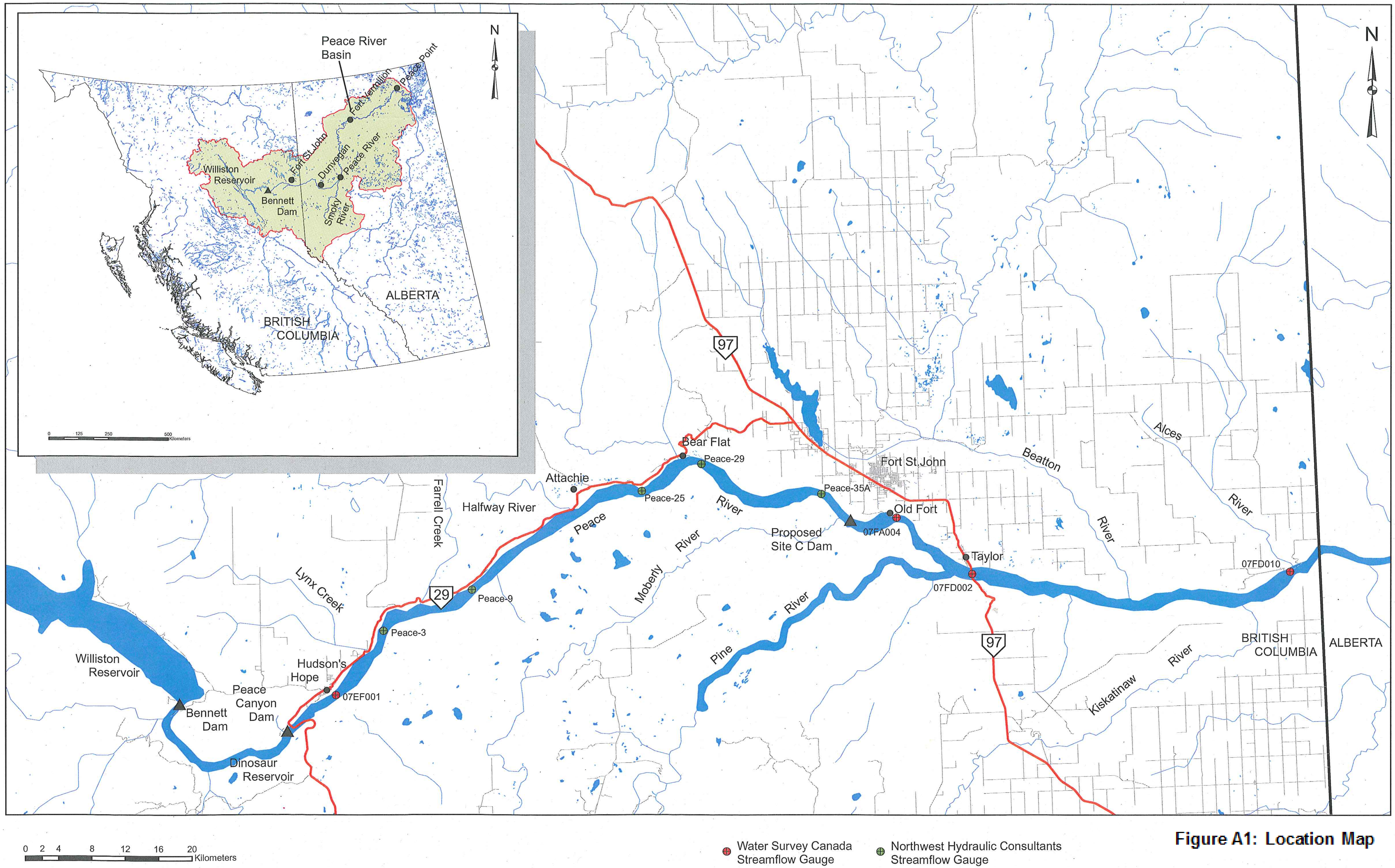


Figure A1: Location Map

Figure A2-A5: WSC Rating Curves Calibration

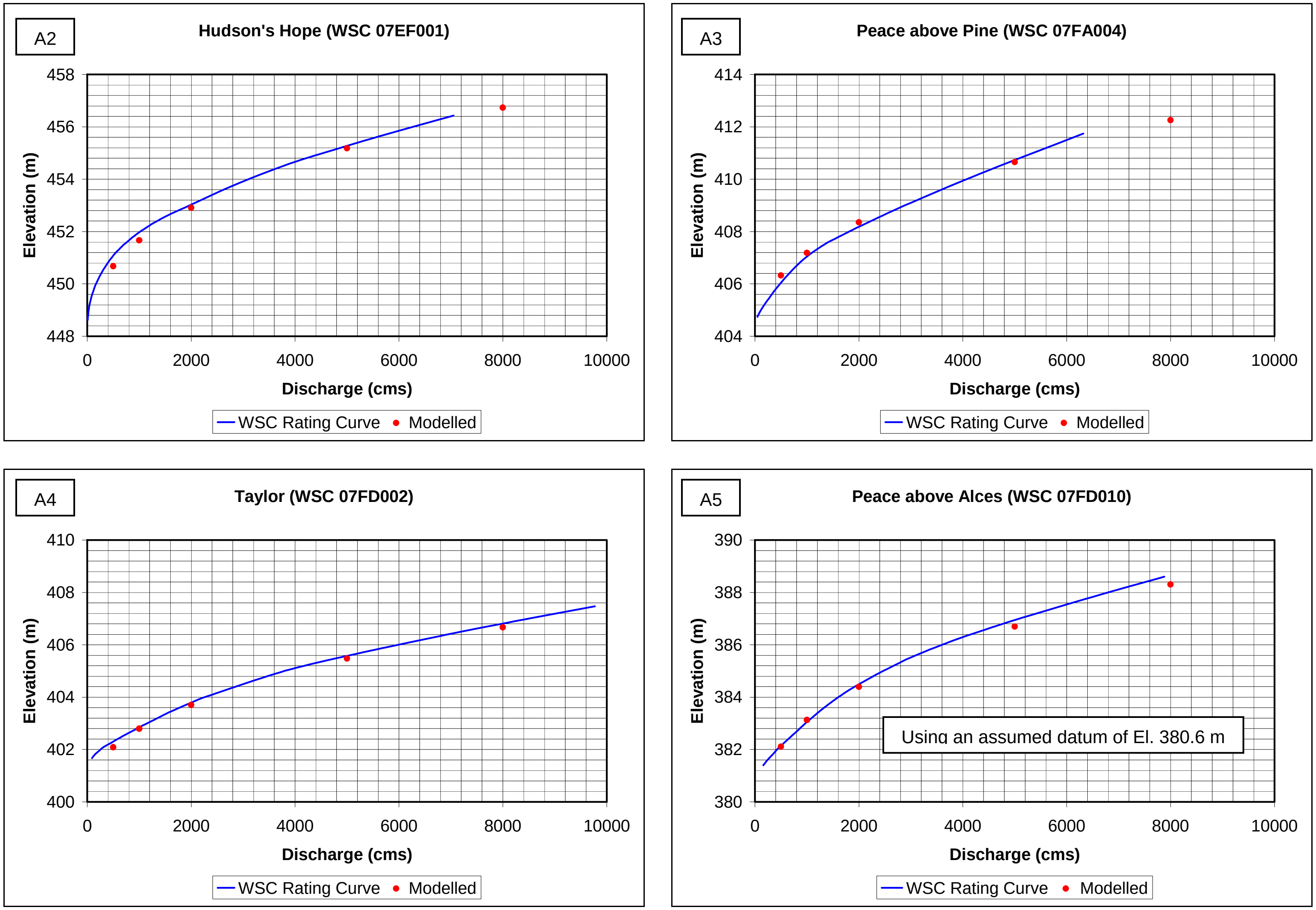
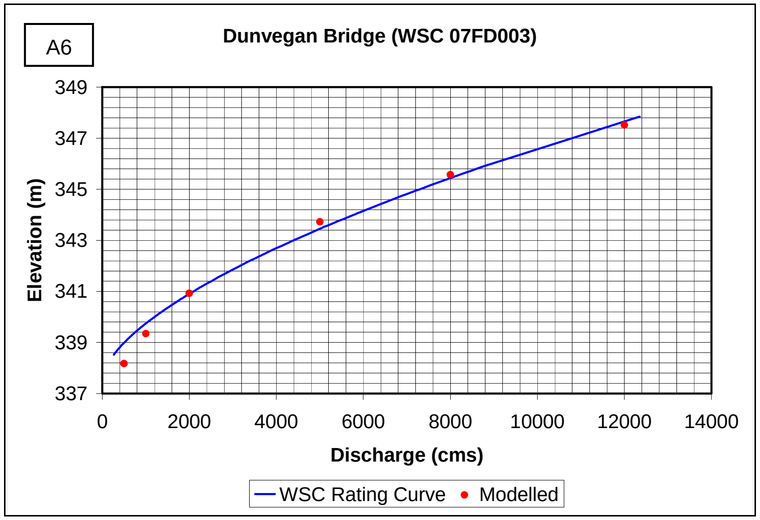
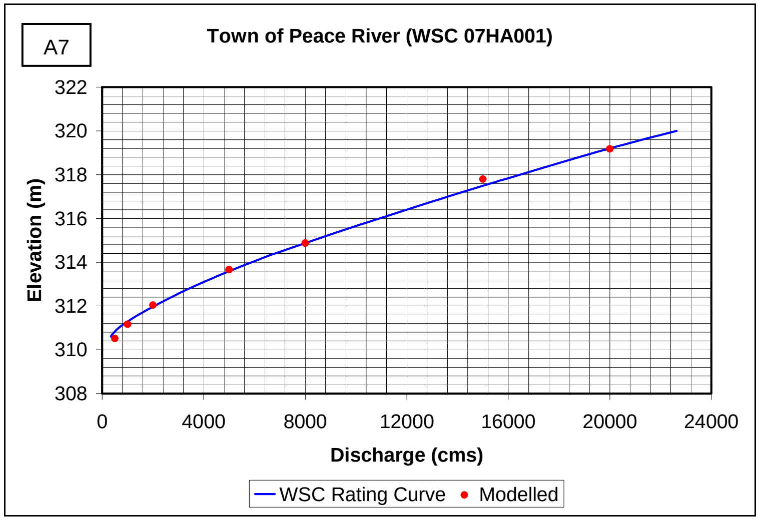
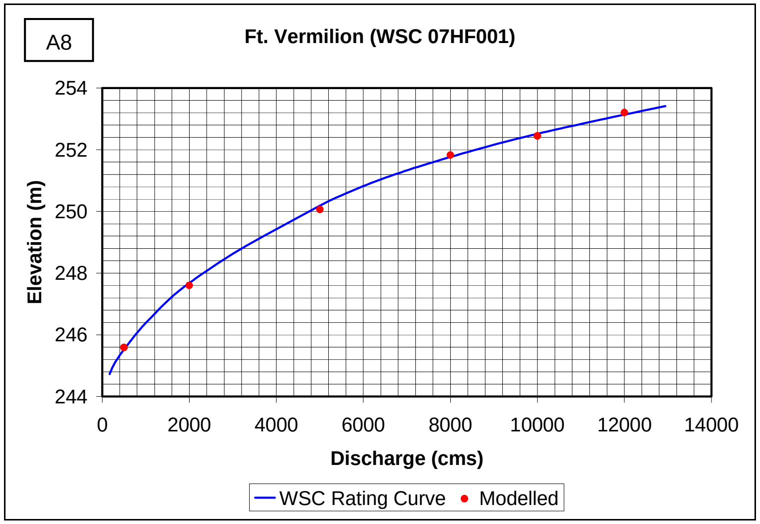


Figure A6-A9: WSC Rating Curves Calibration







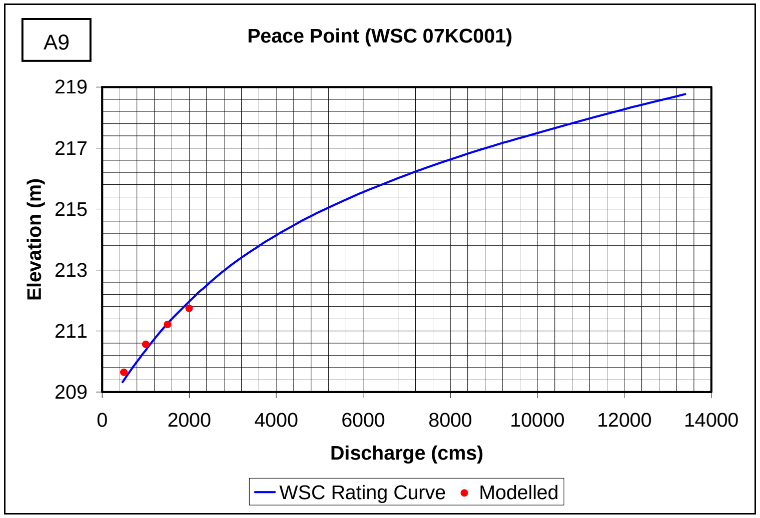


Figure A10-A13: NHC Rating Curves Calibration

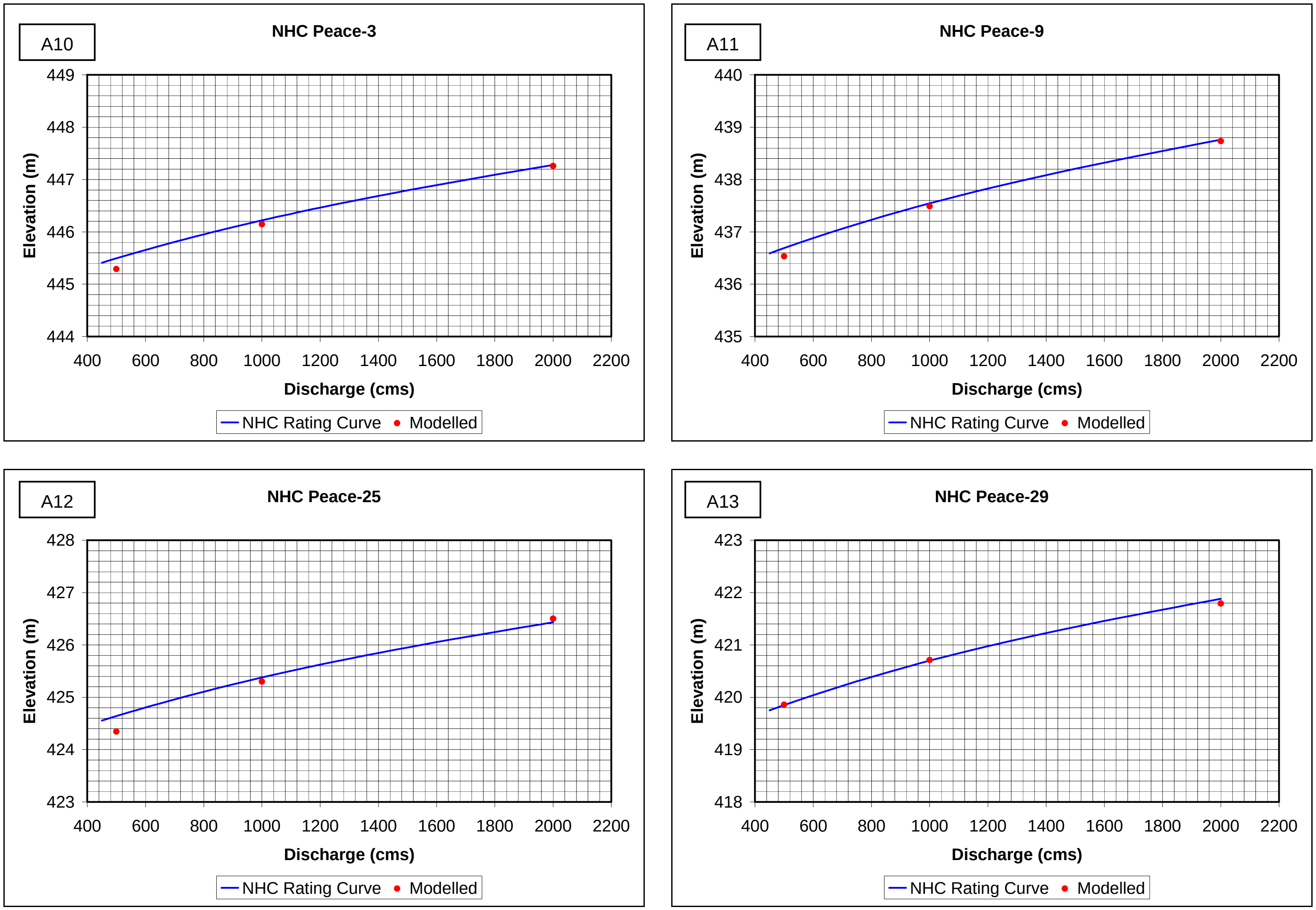


Figure A14: NHC Rating Curves Calibration

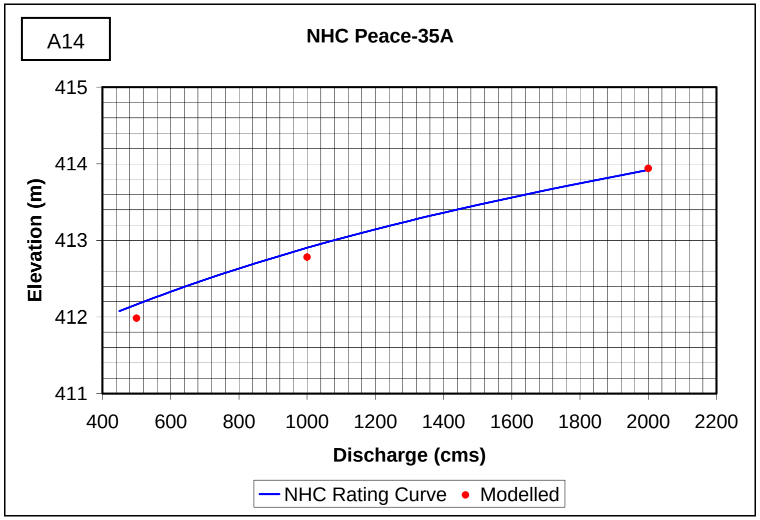
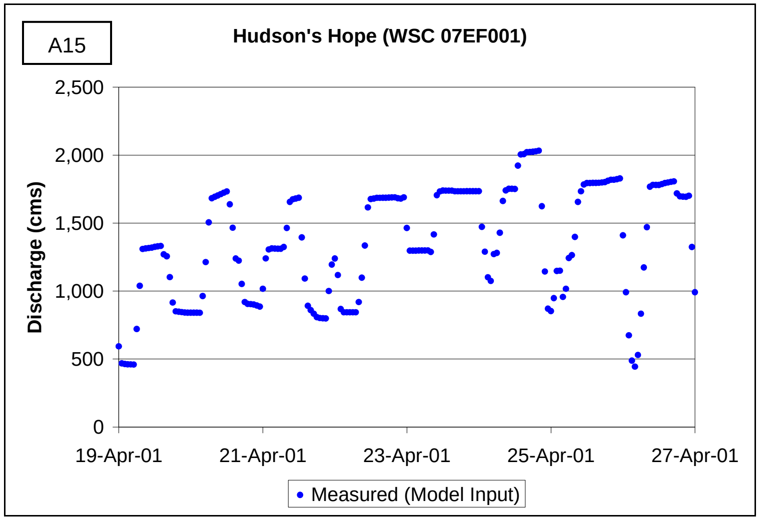
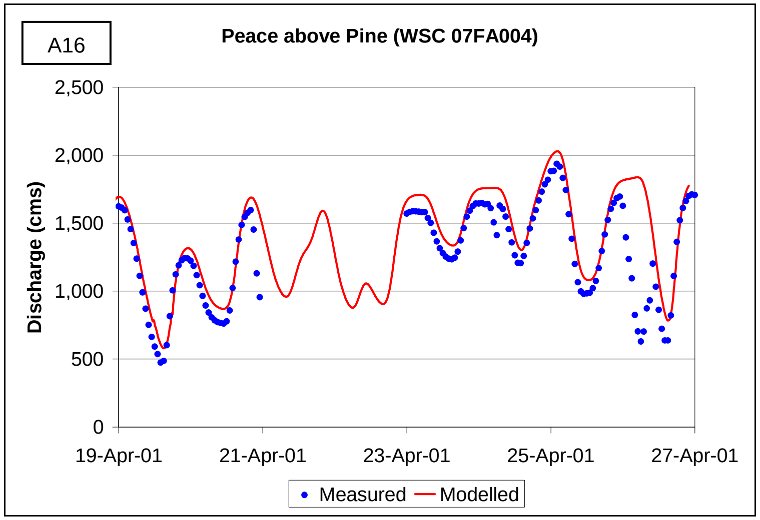
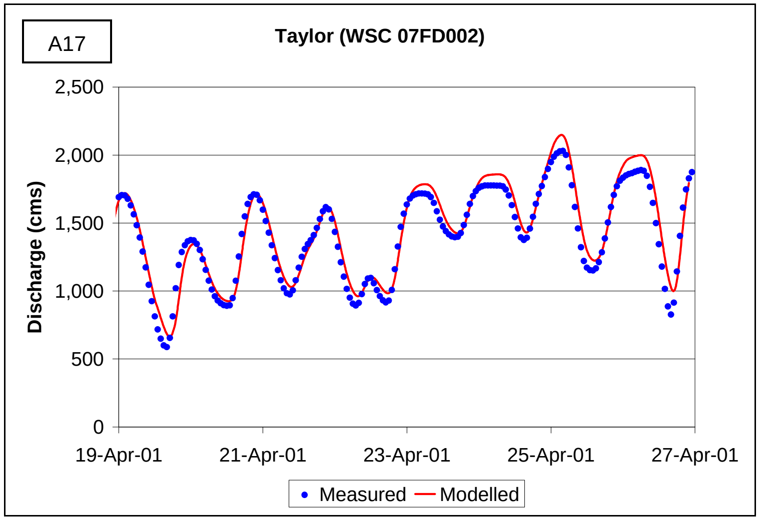


Figure A15-A18: April 2001 Flow Routing Calibration







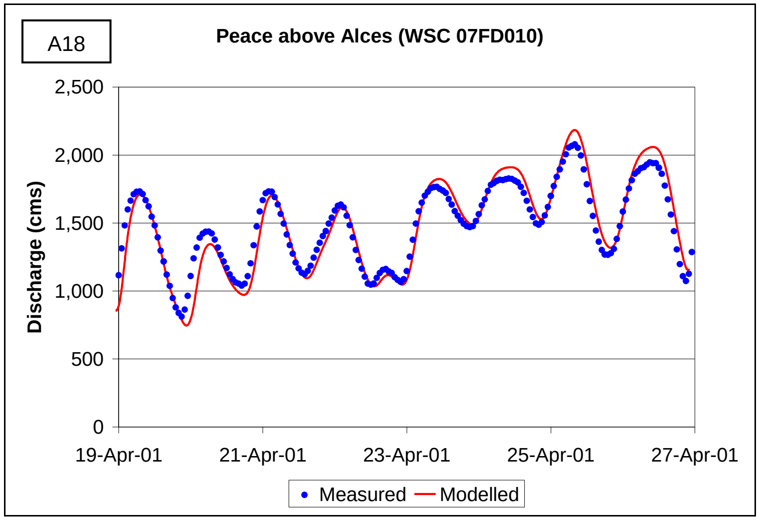
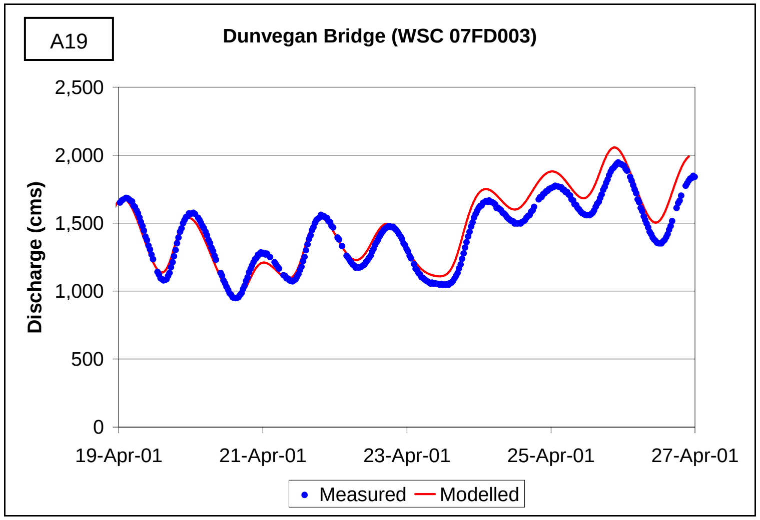
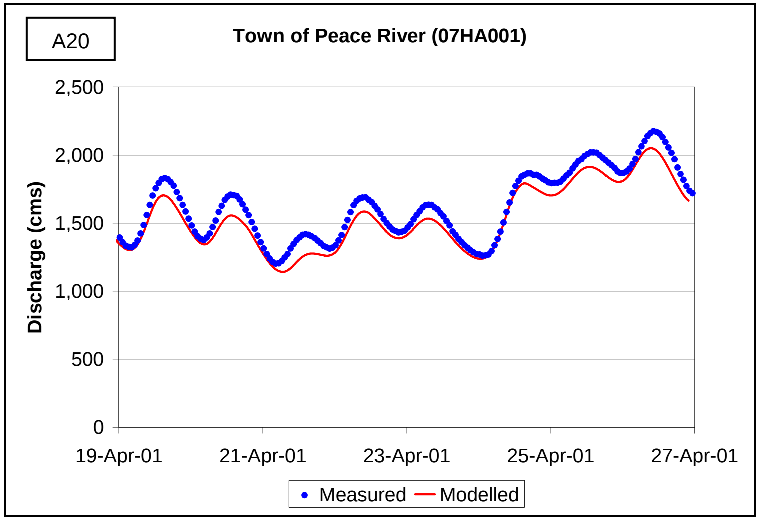


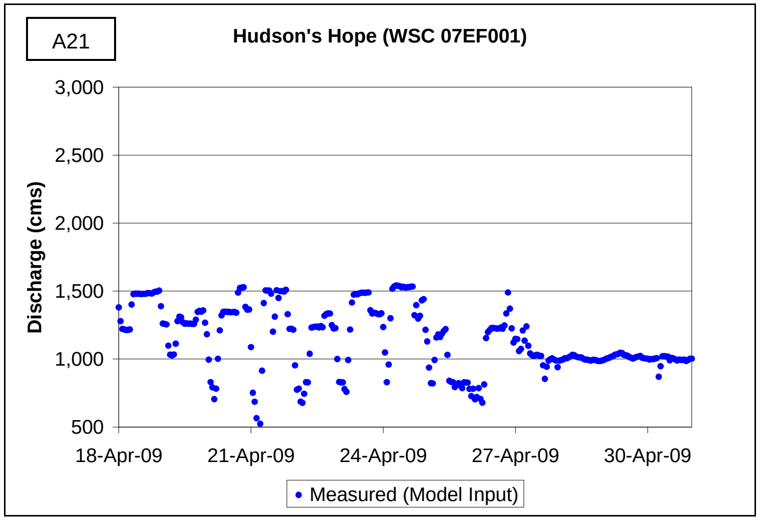
Figure A19-A20: April 2001 Flow Routing Calibration

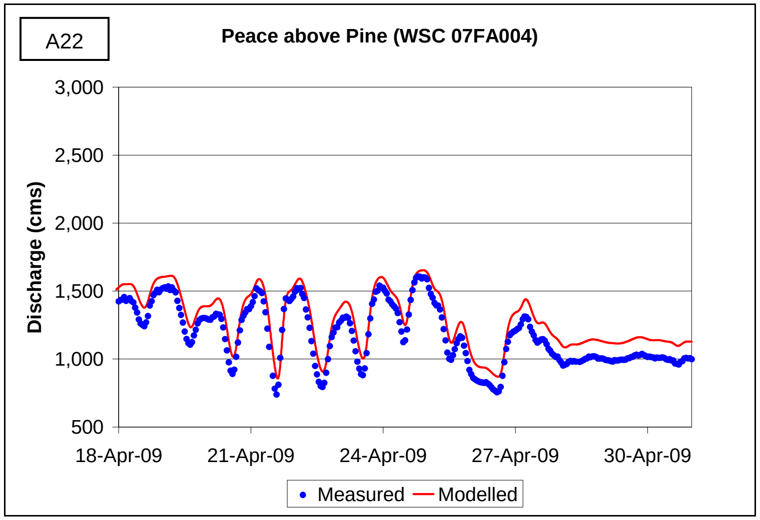


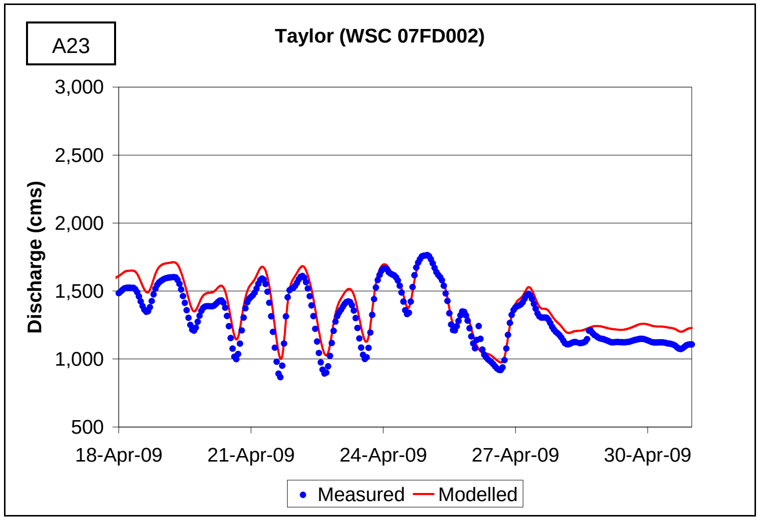


Note:
In April 2001, WSC flow records were unavailable at Fort vermilion (07HF001) and ice affected at Peace Point (07KC001).

Figure A21-A24: April 2009 Flow Routing Calibration







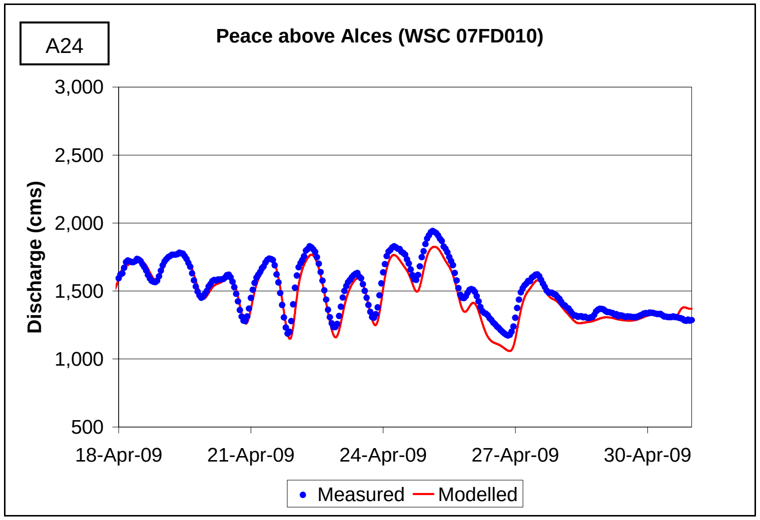
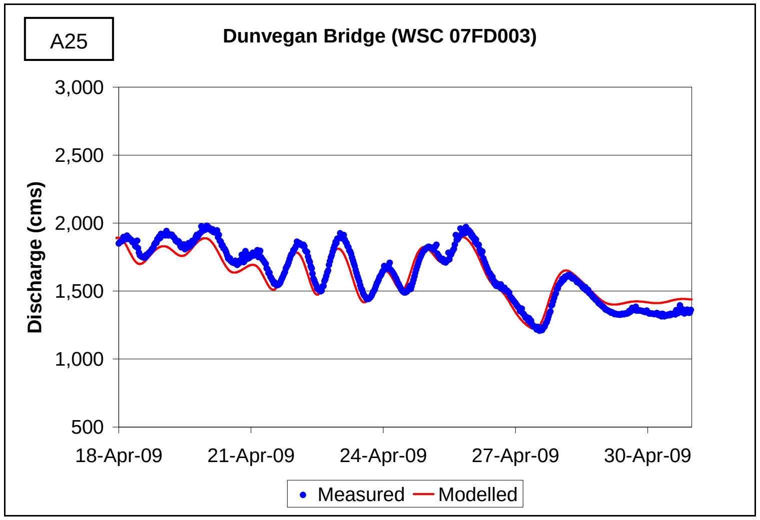
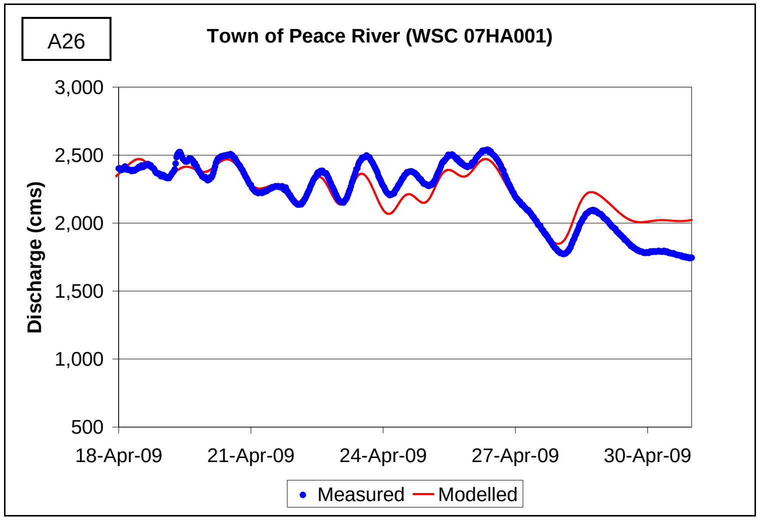


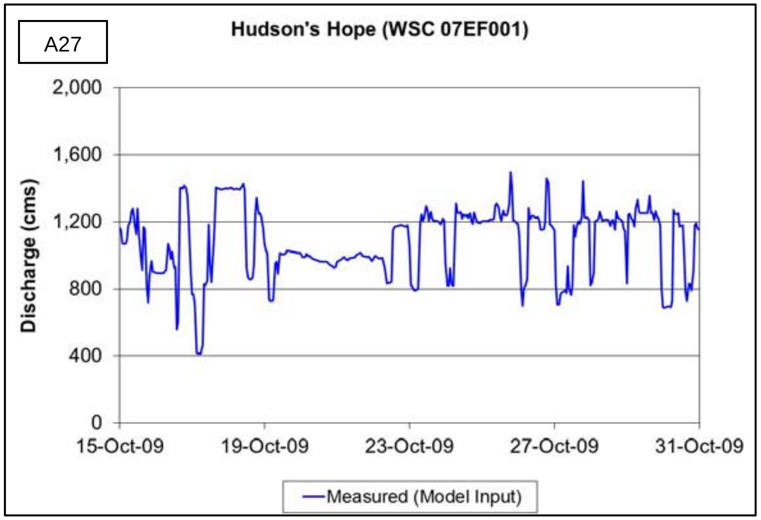
Figure A25-A26: April 2009 Flow Routing Calibration

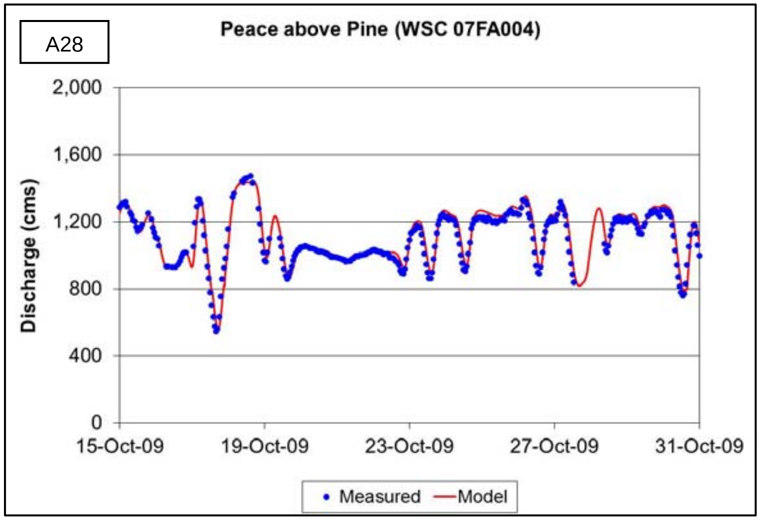


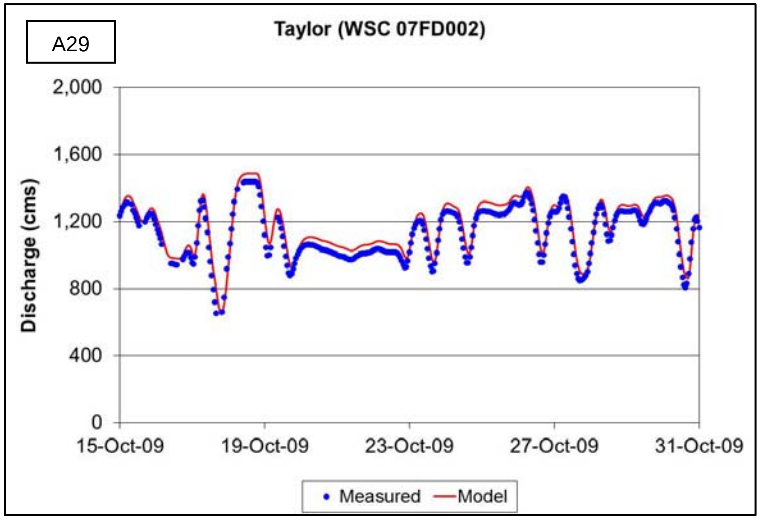


Note:
In April 2009, WSC flow records were ice affected at Fort vermilion (07HF001) and Peace Point (07KC001).

Figure A27-A30: October 2009 Flow Routing Calibration







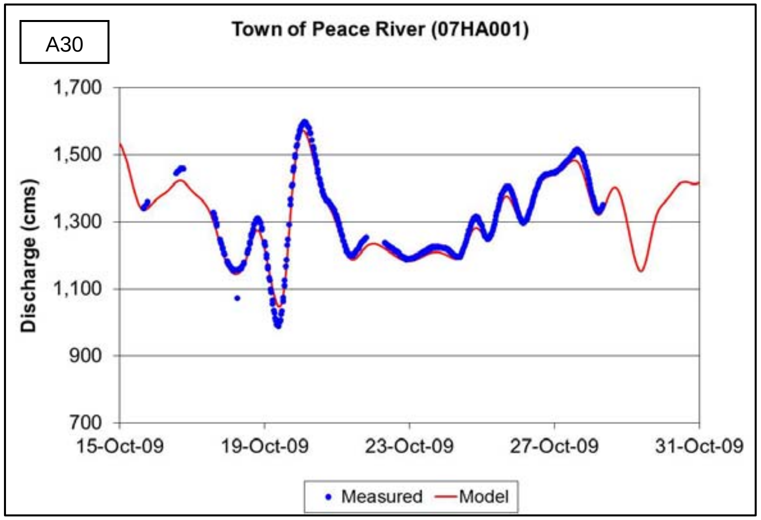
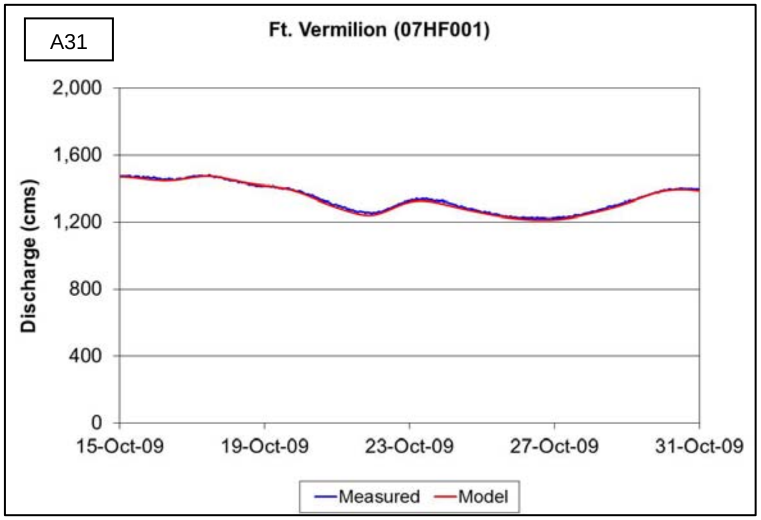
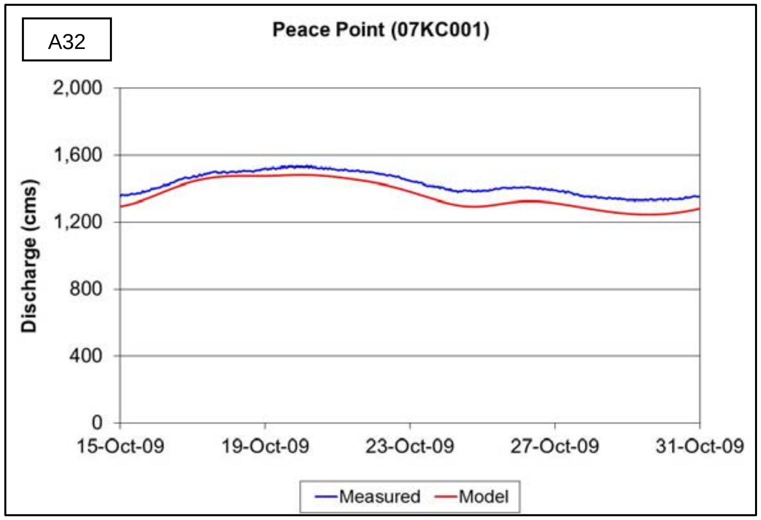


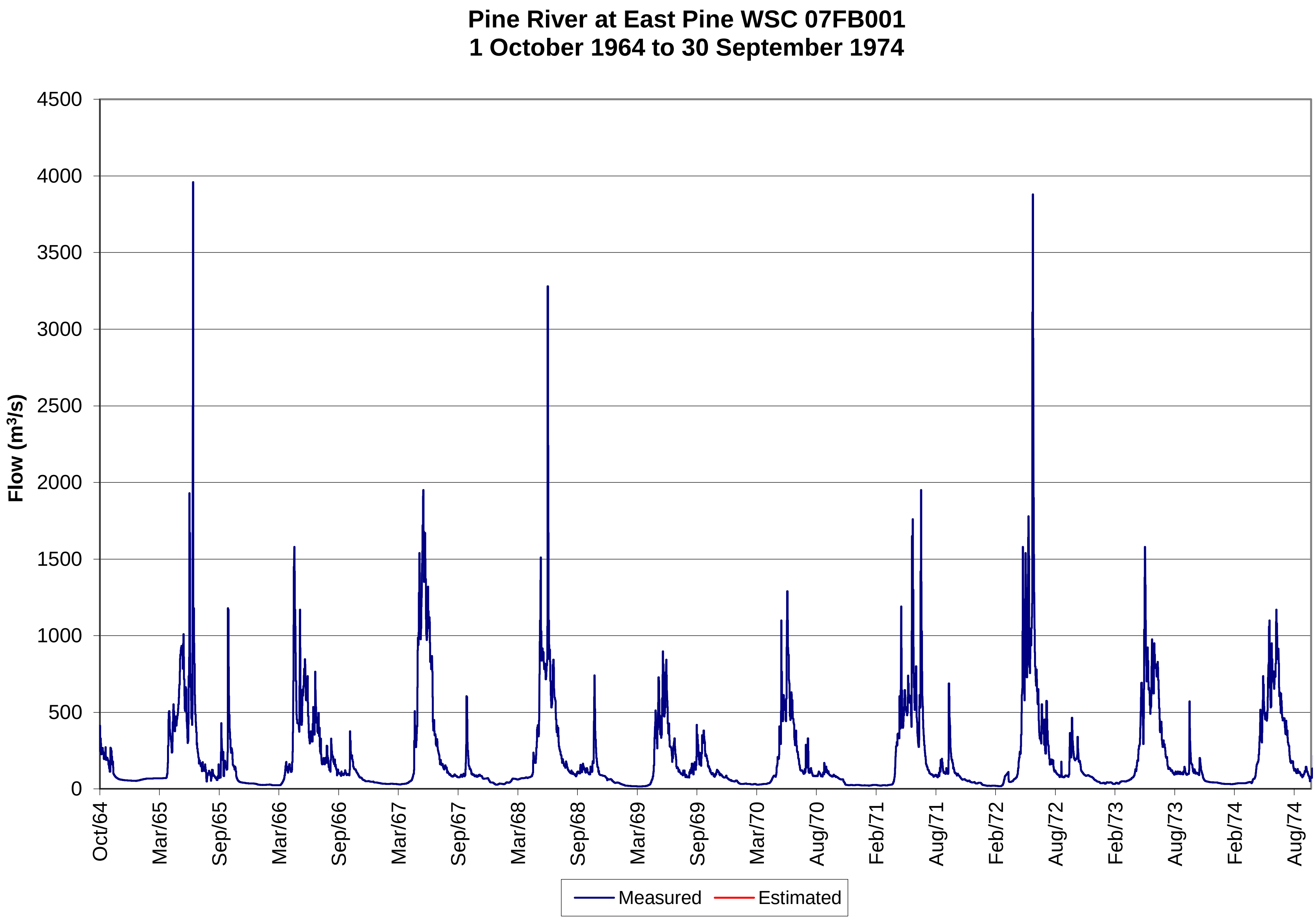
Figure A31-A32: October 2009 Flow Routing Calibration



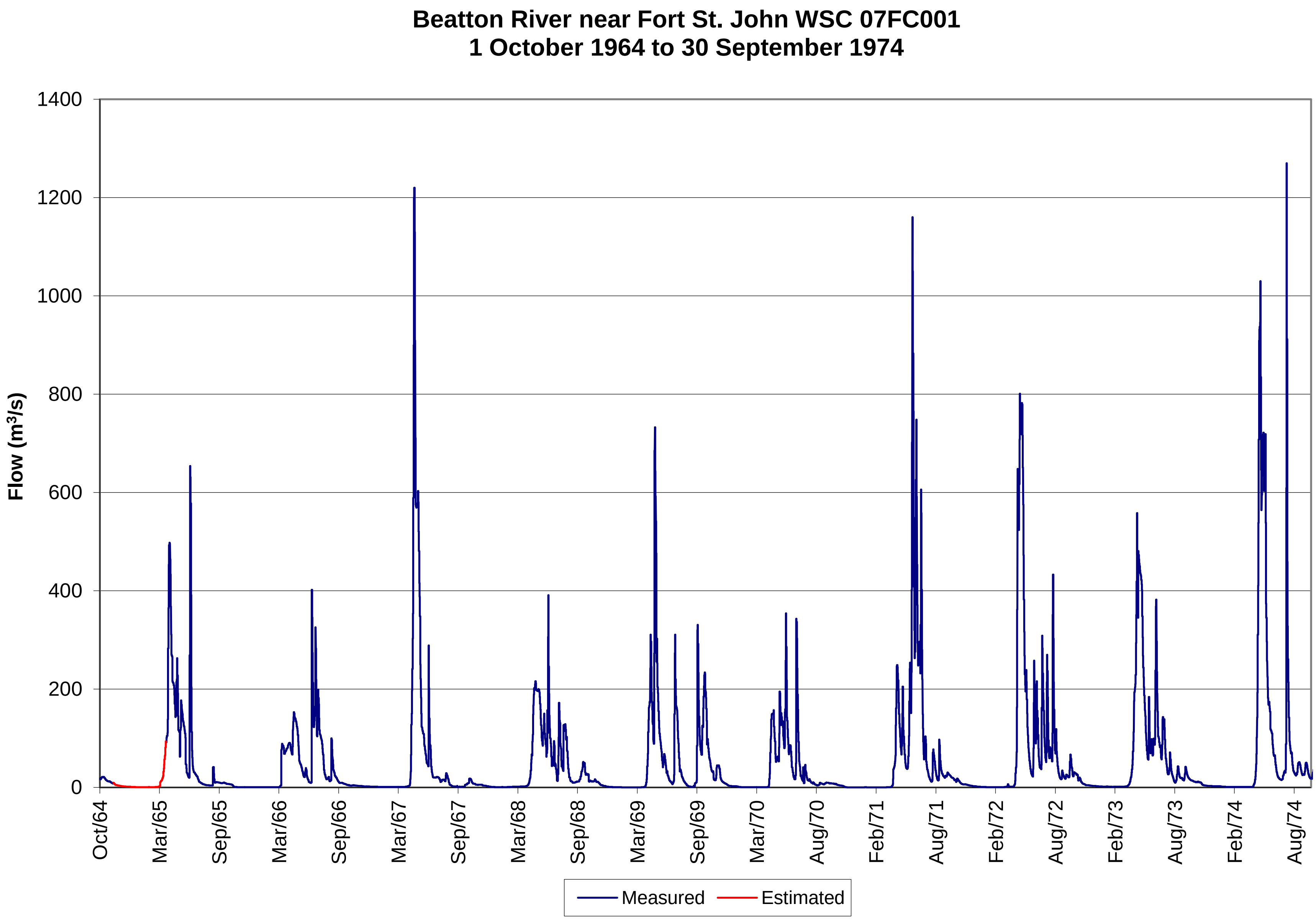


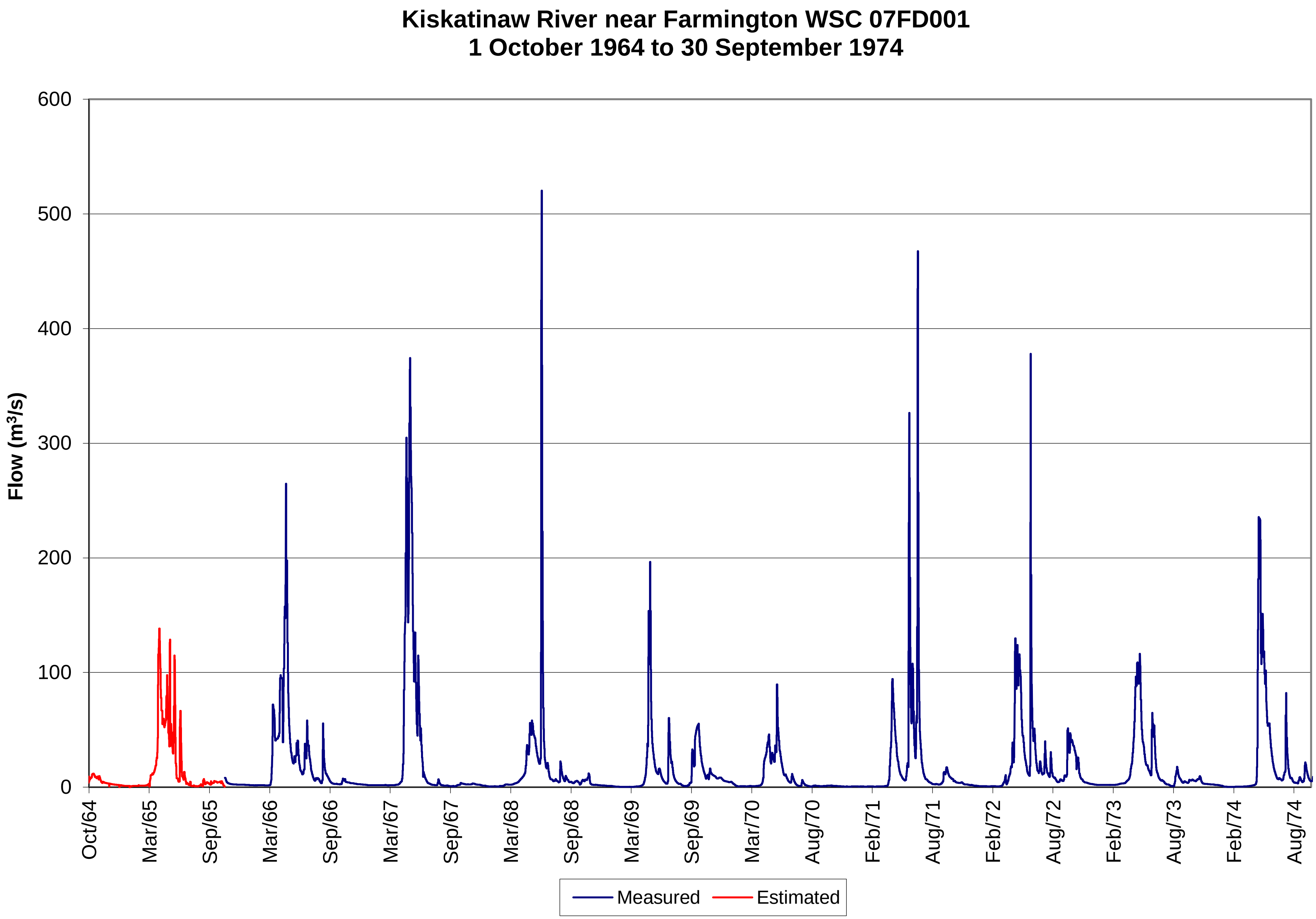
APPENDIX – B

Daily Flow Hydrographs (Tributaries)

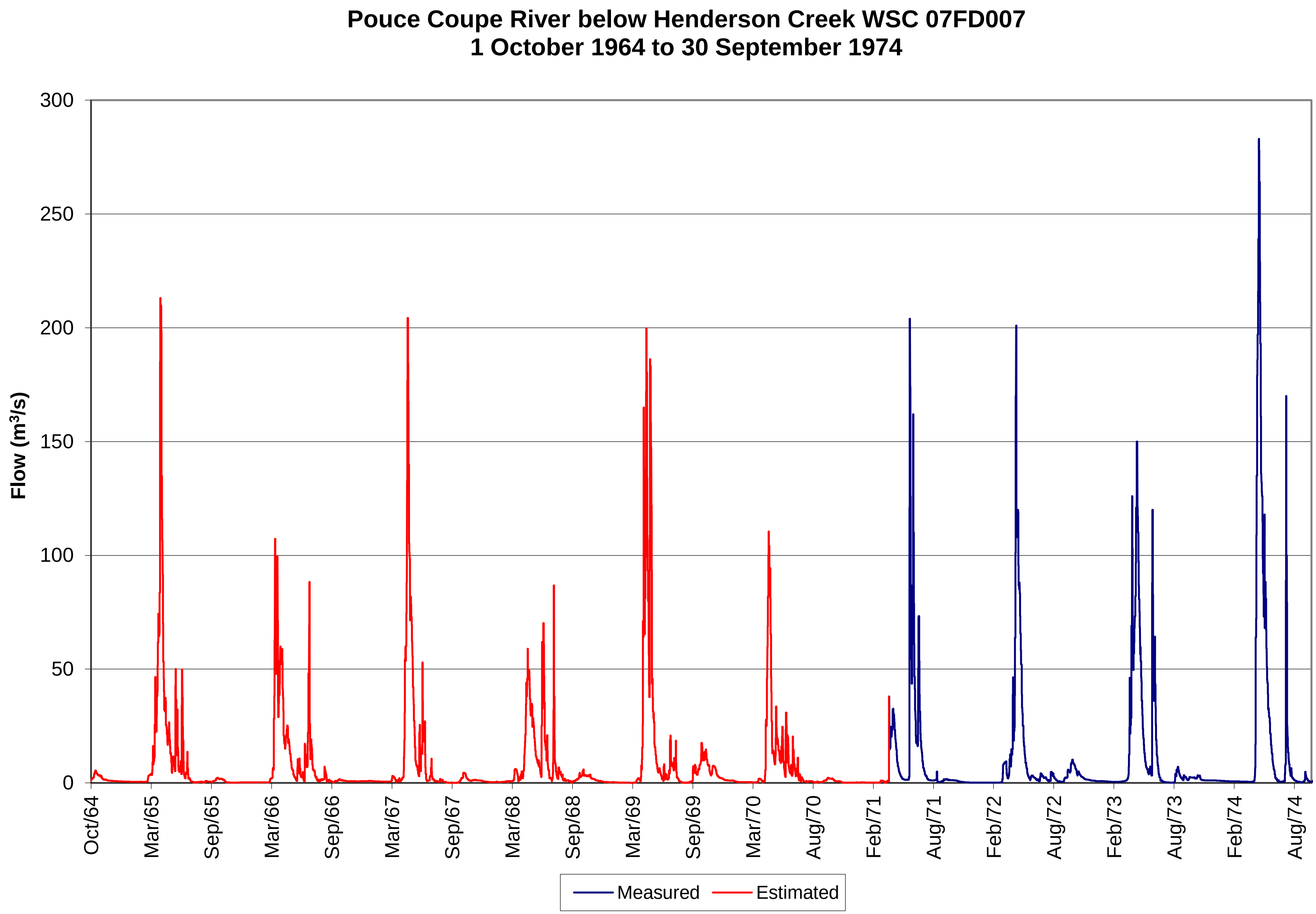


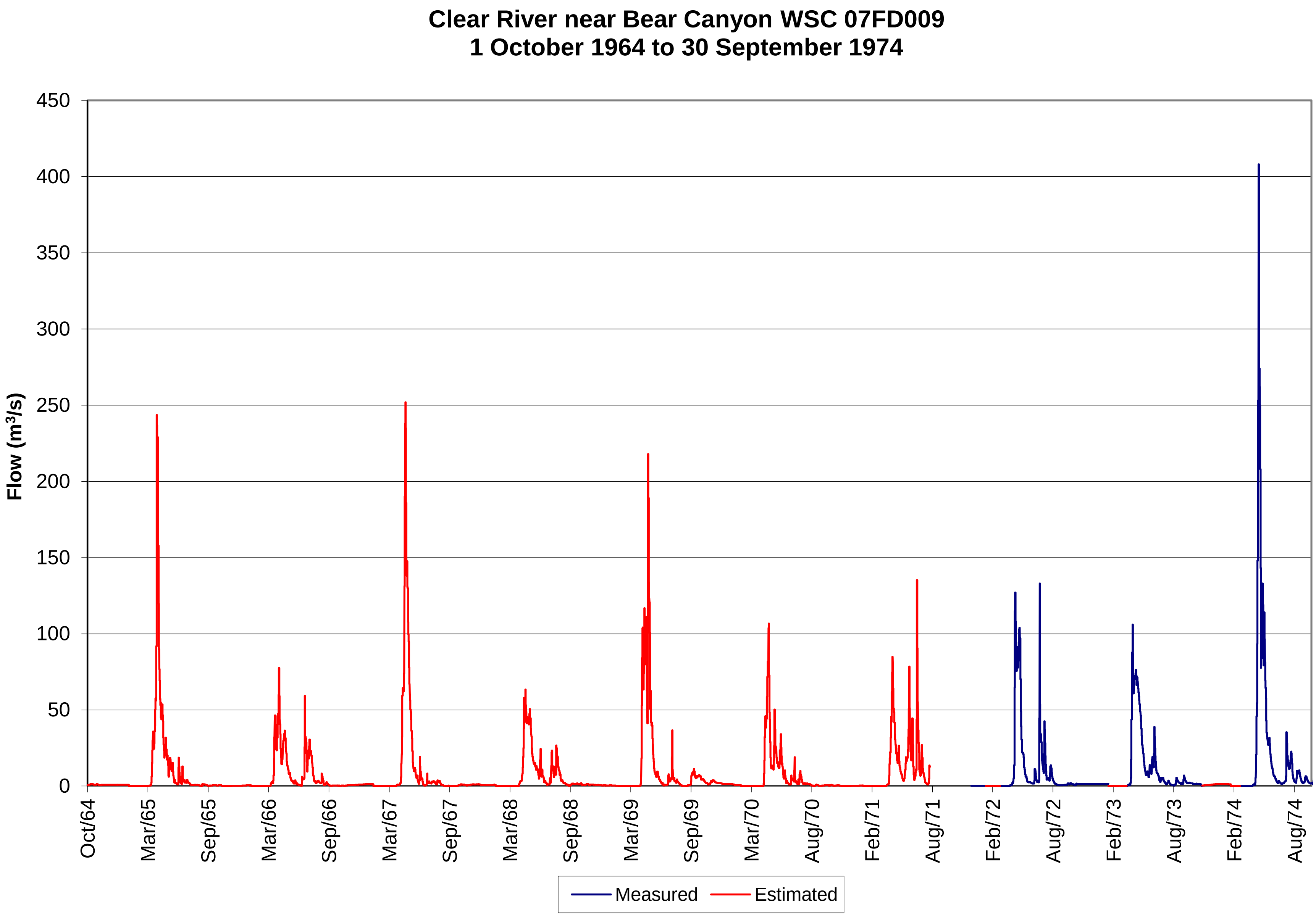
Pine River at East Pine WSC 07FB001
1 October 1964 to 30 September 1974
Flow (m³/s)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated


Beatton River near Fort St. John WSC 07FC001
1 October 1964 to 30 September 1974
Flow (m³/s)
1400
1200
1000
800
600
400
200
0
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated

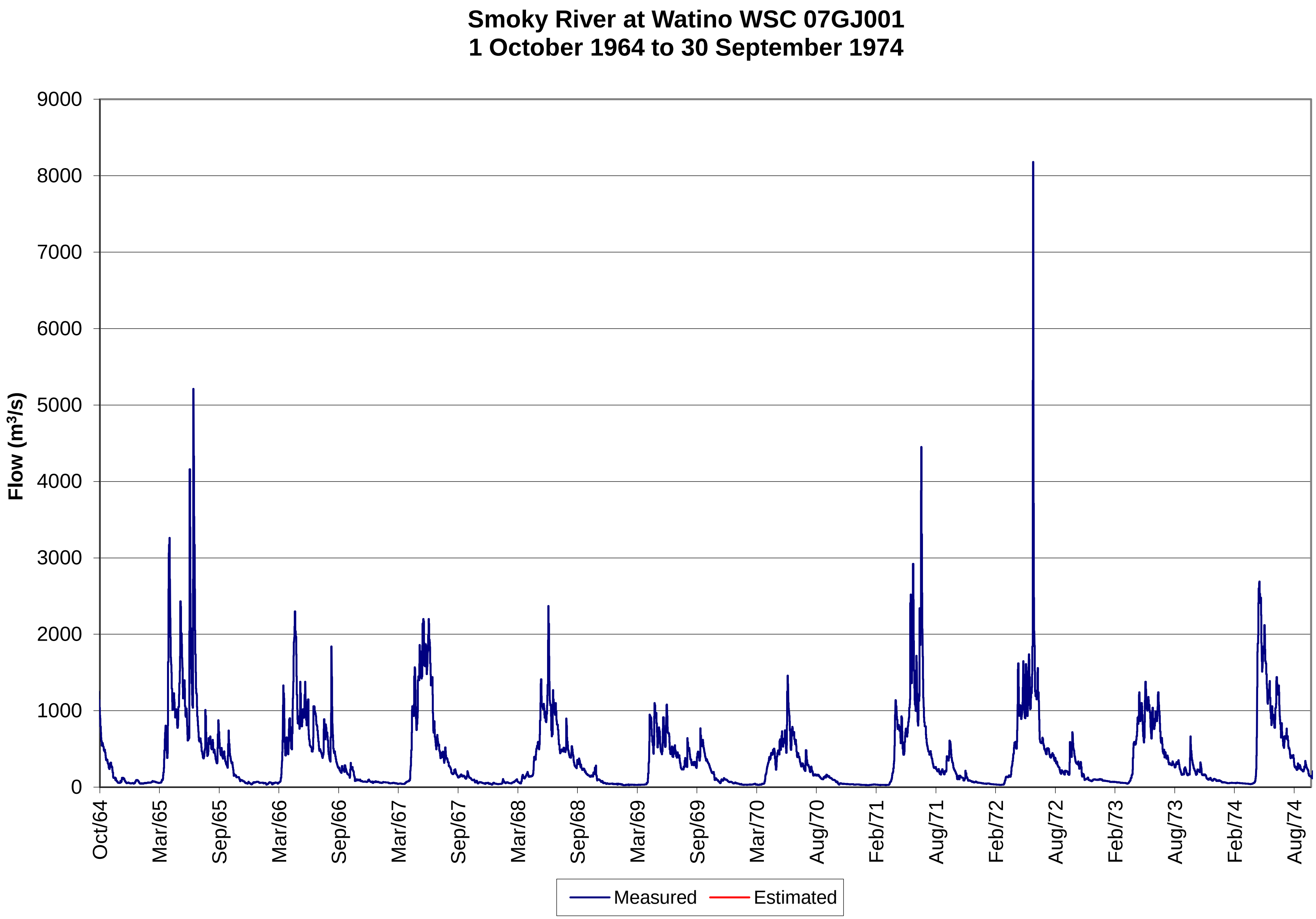


Kiskatinaw River near Farmington WSC 07FD001
1 October 1964 to 30 September 1974
Flow (m³/s)
600
500
400
300
200
100
0
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated

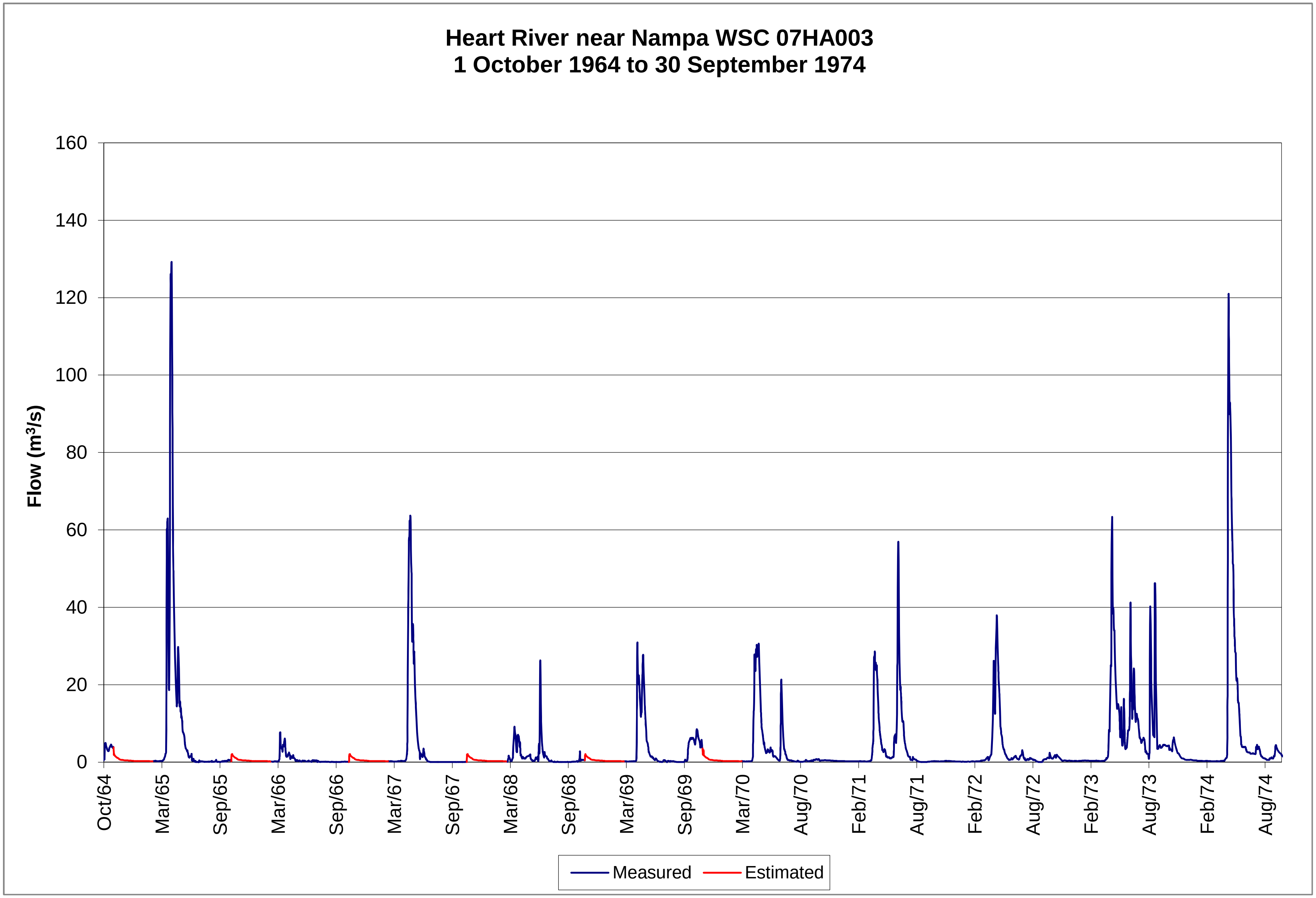

Pouce Coupe River below Henderson Creek WSC 07FD007
1 October 1964 to 30 September 1974
Flow (m³/s)
300
250
200
150
100
50
0
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated



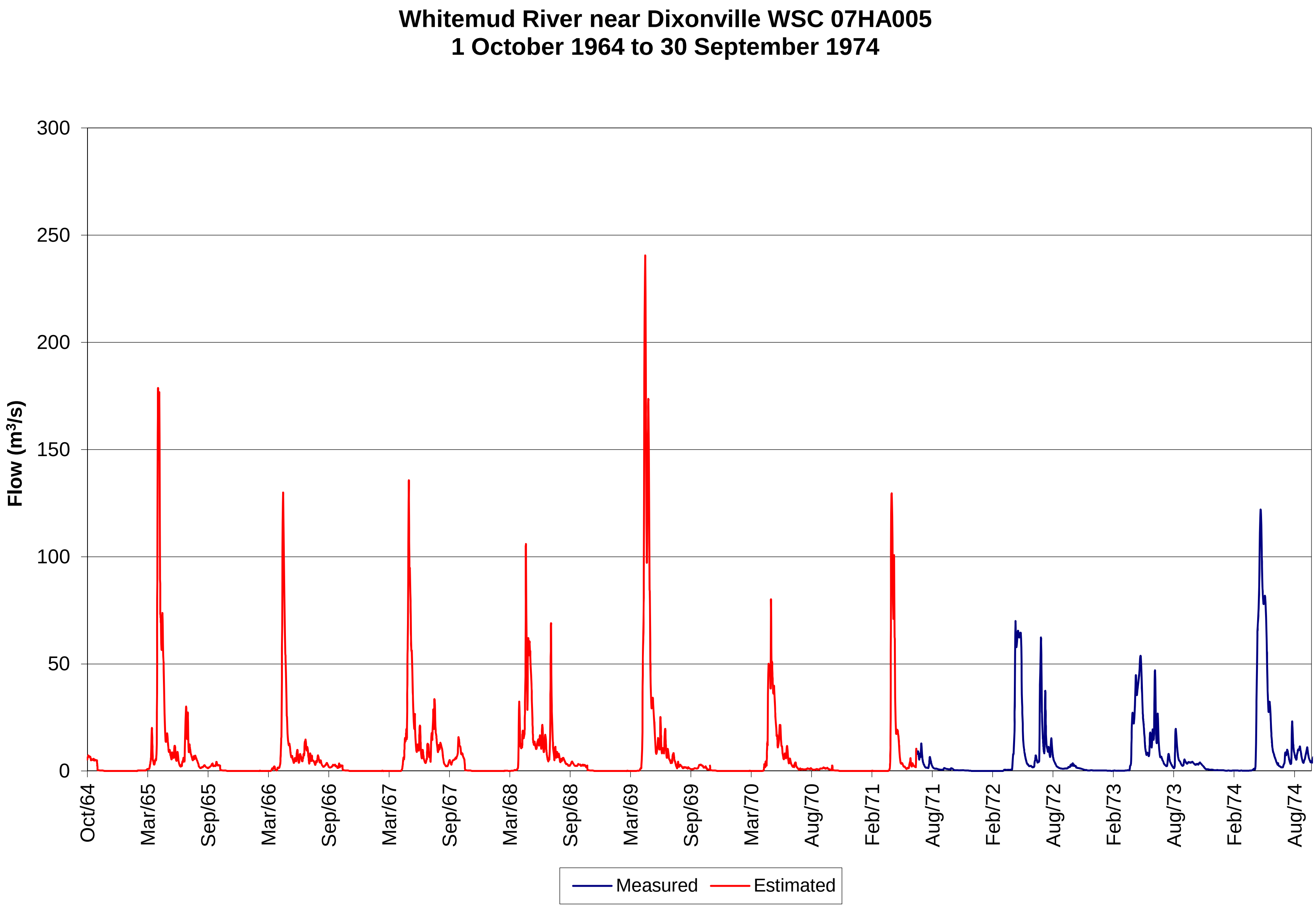
Clear River near Bear Canyon WSC 07FD009
1 October 1964 to 30 September 1974
Flow (m³/s)
450
400
350
300
250
200
150
100
50
0
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated



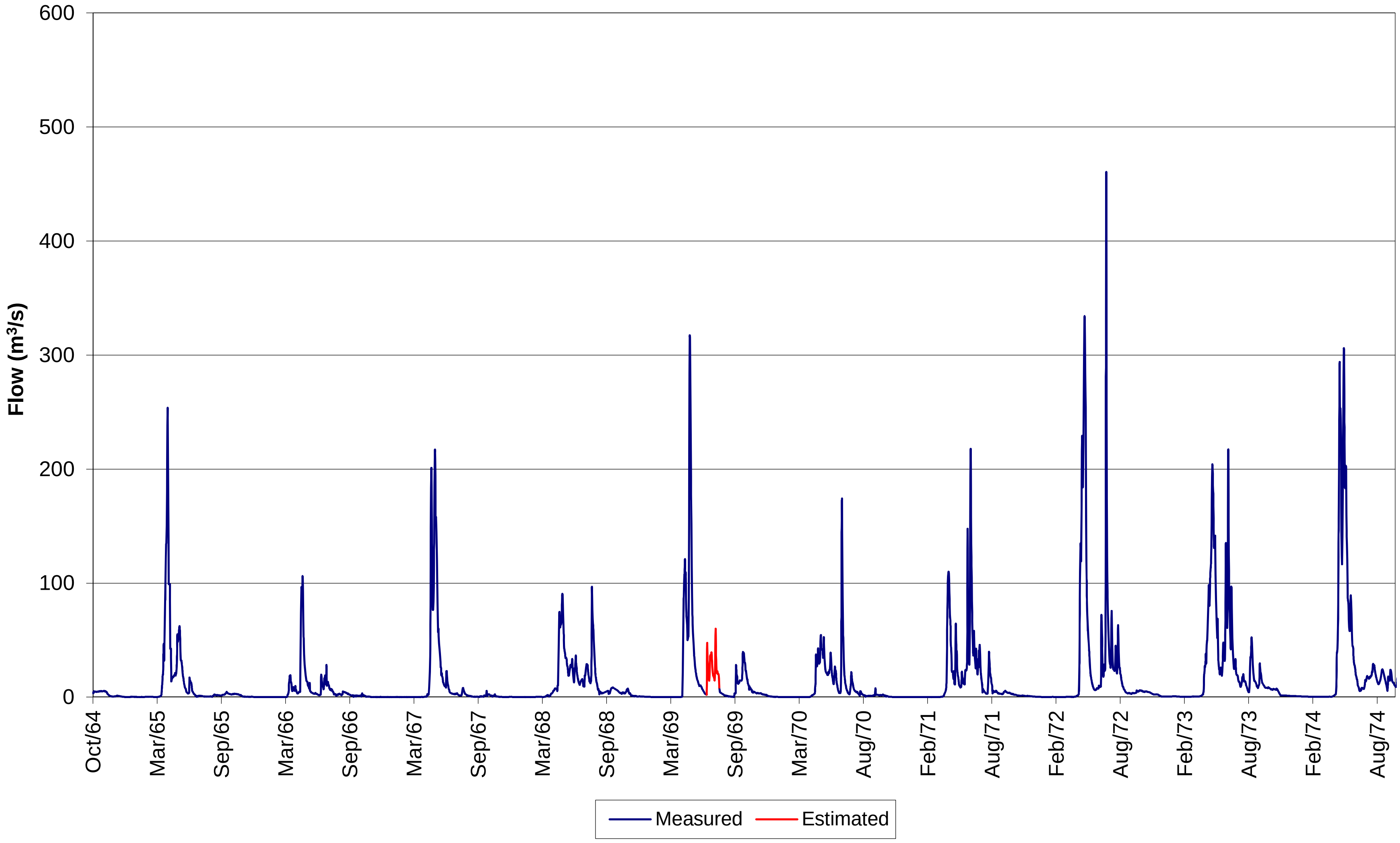
Smoky River at Watino WSC 07GJ001
1 October 1964 to 30 September 1974
Flow (m³/s)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated



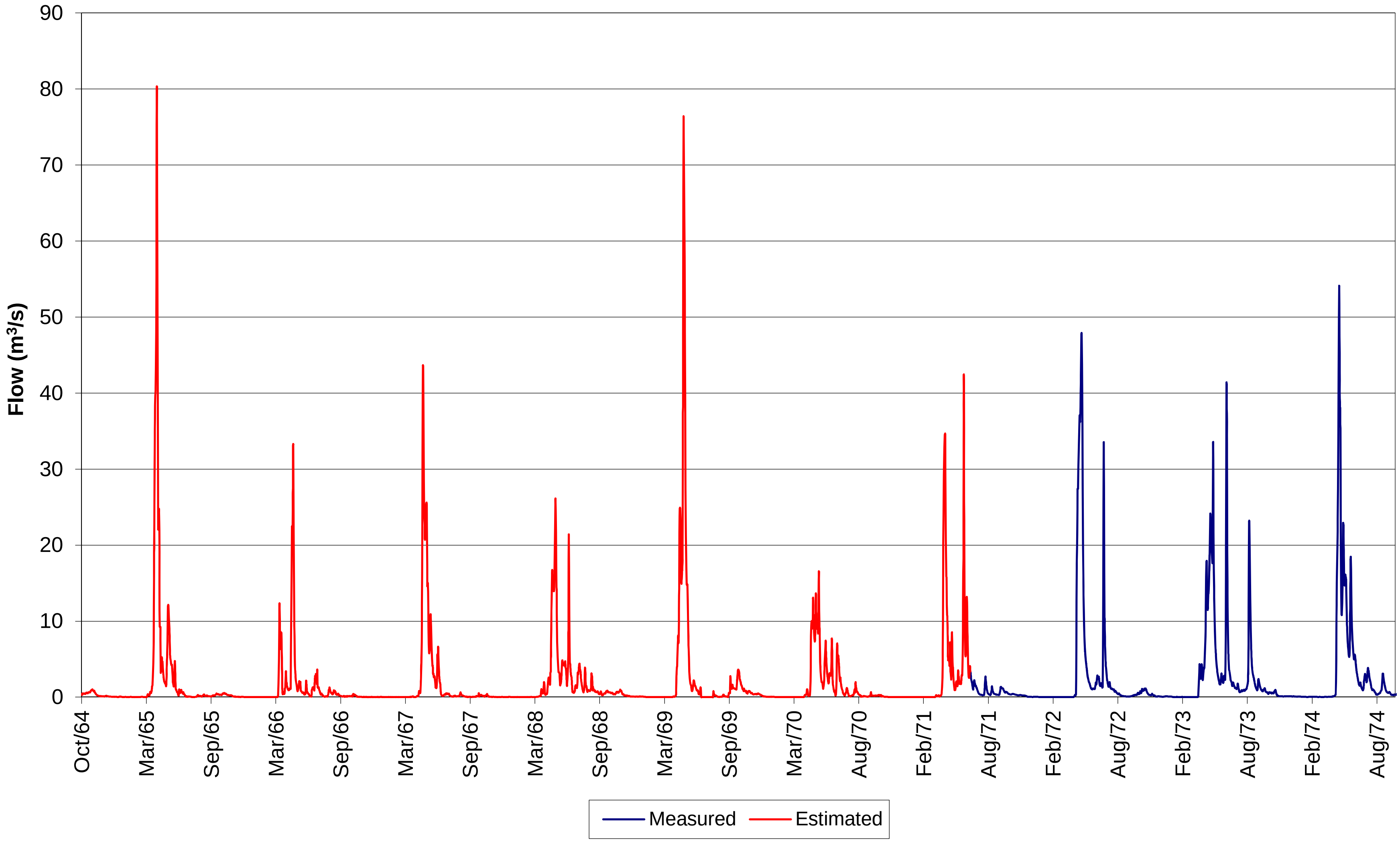
Heart River near Nampa WSC 07HA003
1 October 1964 to 30 September 1974
Flow (m³/s)
160
140
120
100
80
60
40
20
0
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated

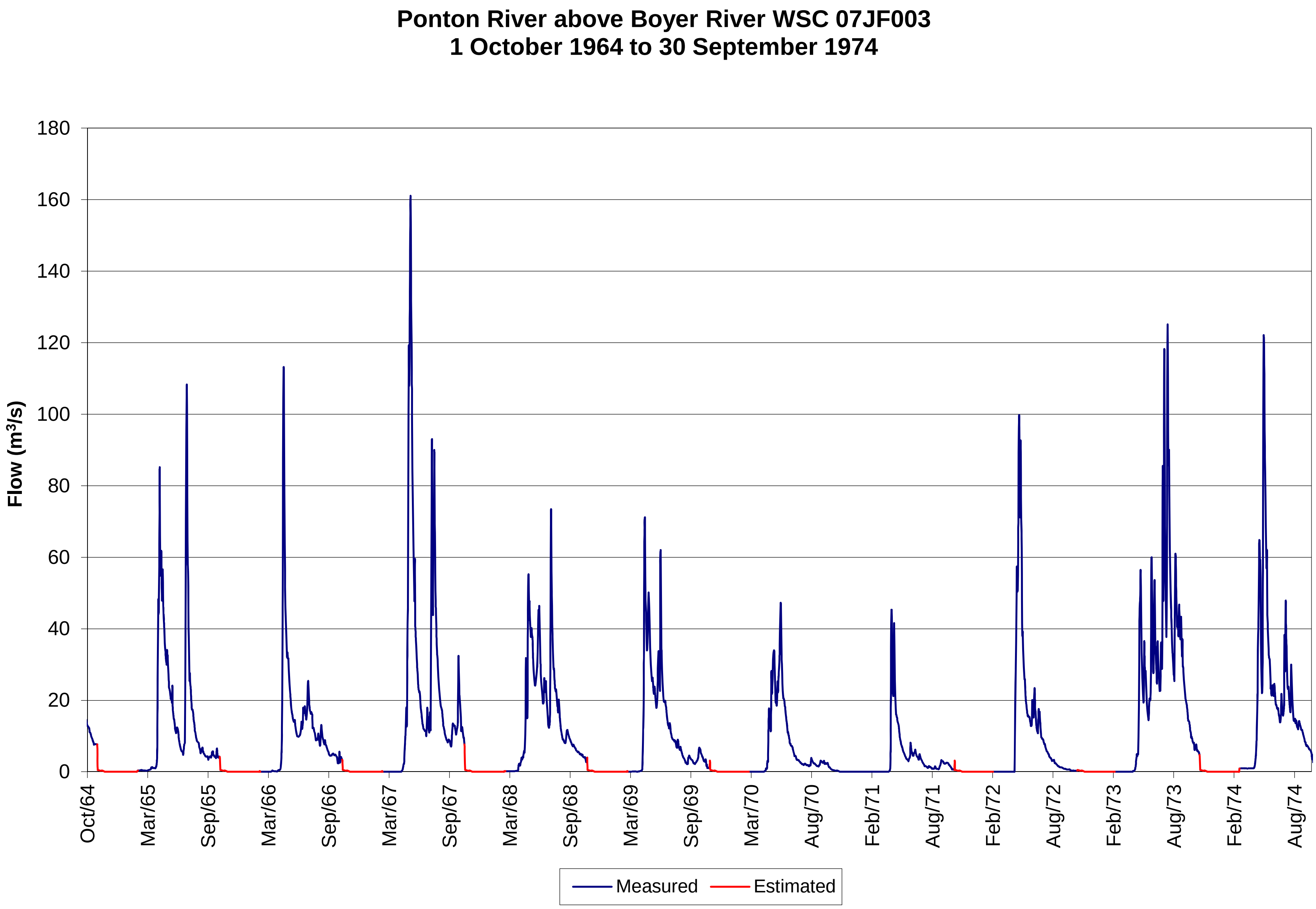

Whitemud River near Dixonville WSC 07HA005
1 October 1964 to 30 September 1974
Flow (m³/s)
300
250
200
150
100
50
0
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated

Notikewin River at Manning WSC 07HC001
1 October 1964 to 30 September 1974

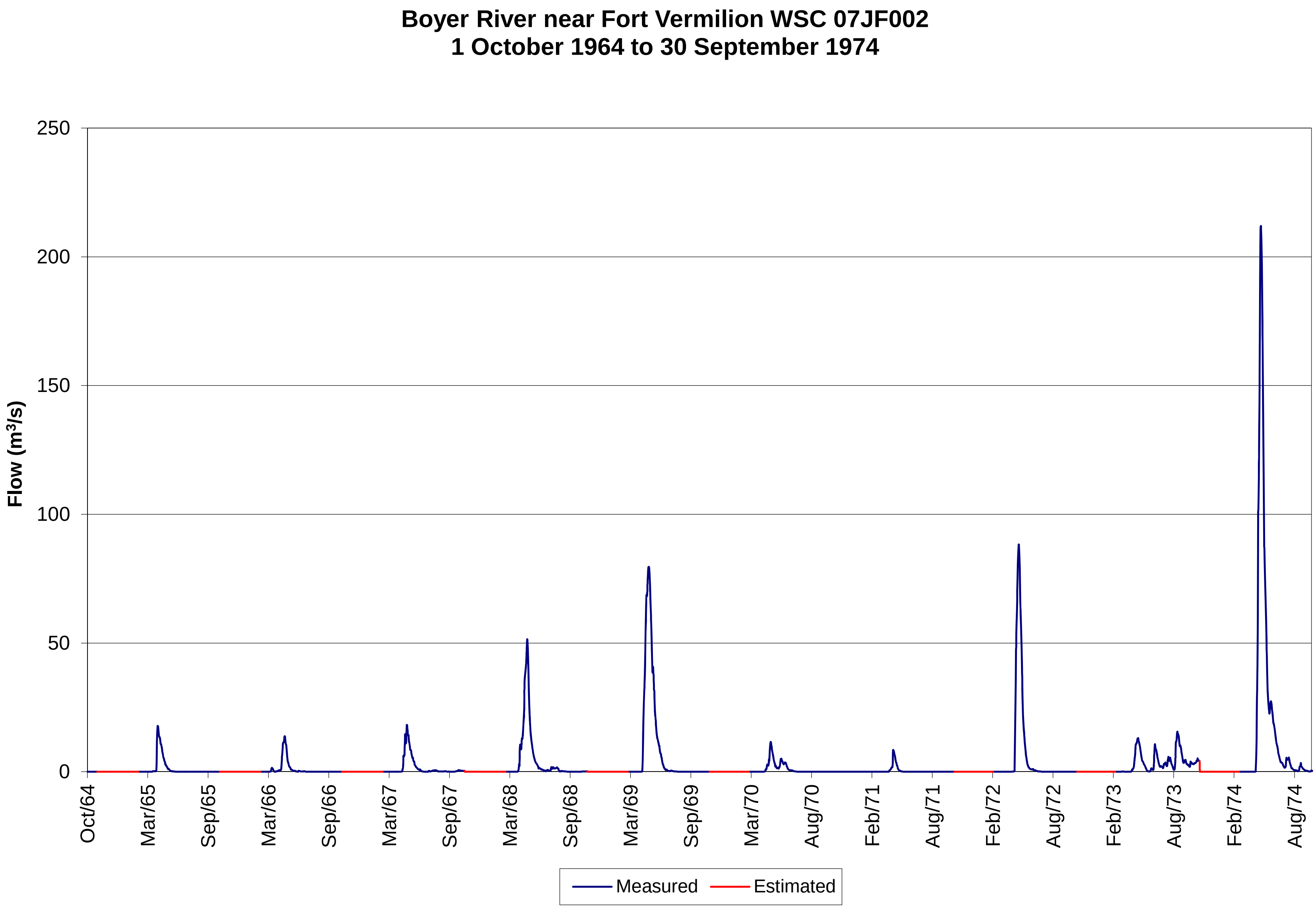


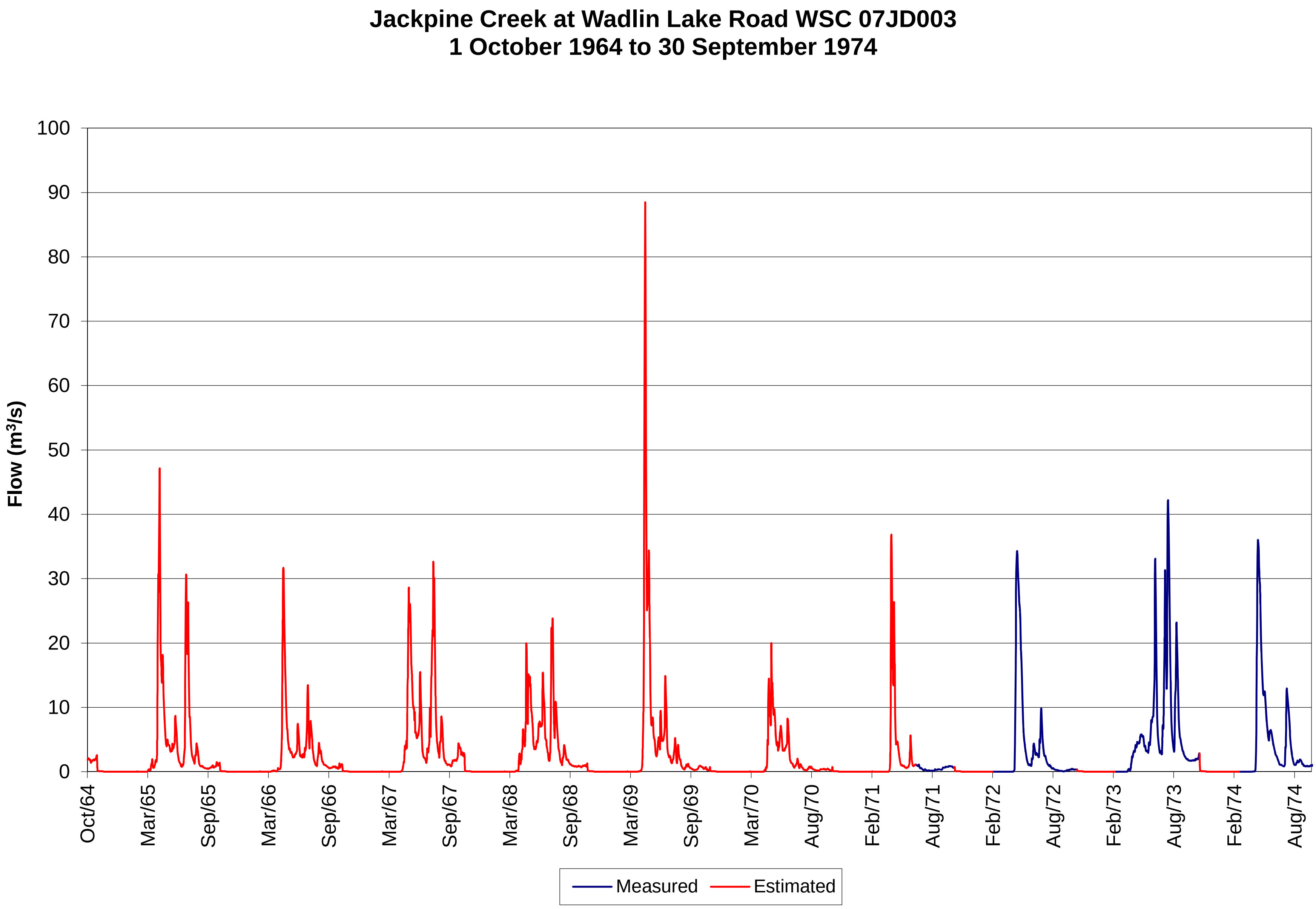
Keg River at Highway No. 35 WSC 07HF002
1 October 1964 to 30 September 1974



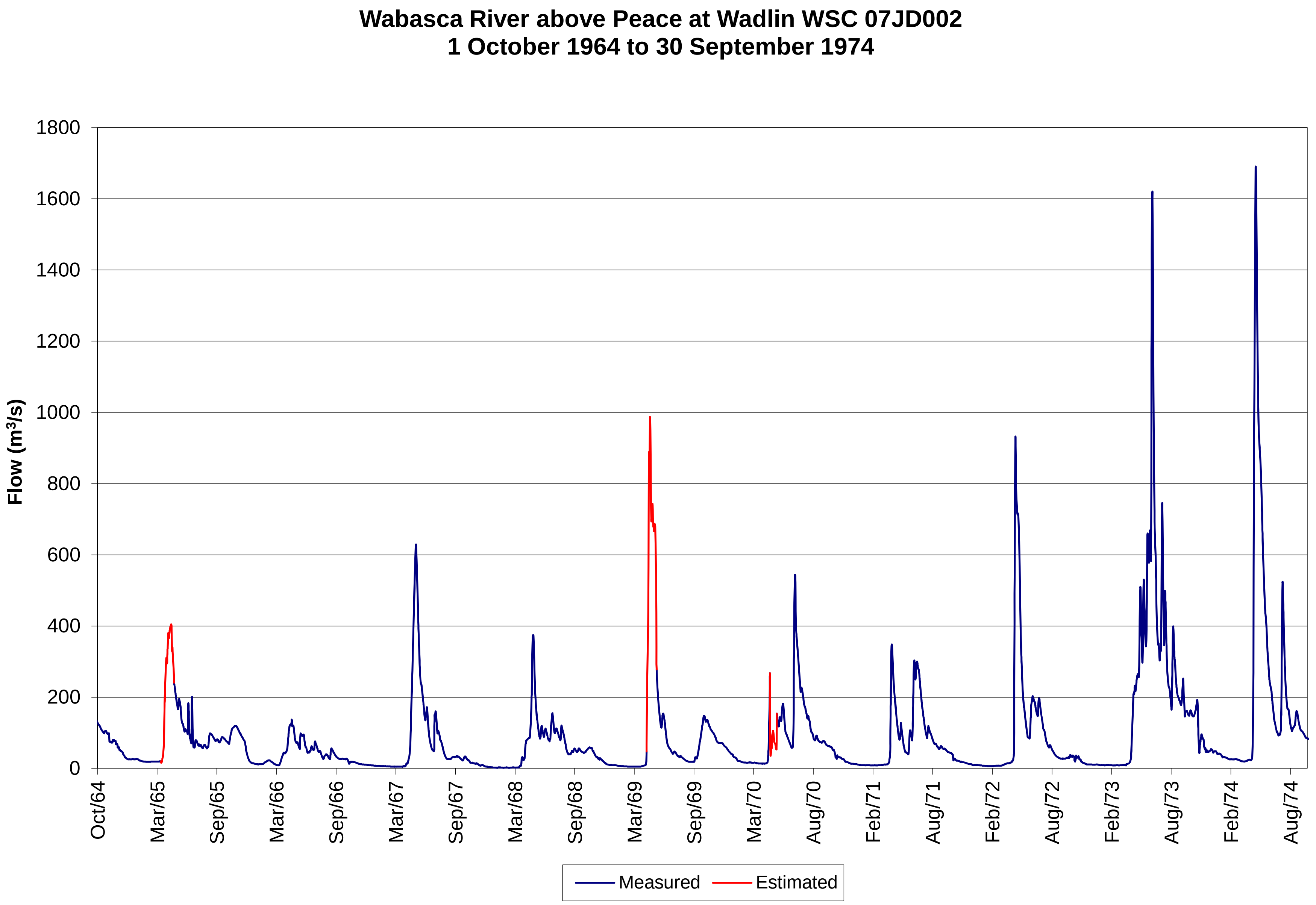


Ponton River above Boyer River WSC 07JF003
1 October 1964 to 30 September 1974
Flow (m³/s)
0
20
40
60
80
100
120
140
160
180
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated


Boyer River near Fort Vermilion WSC 07JF002
1 October 1964 to 30 September 1974
Flow (m³/s)
250
200
150
100
50
0
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated

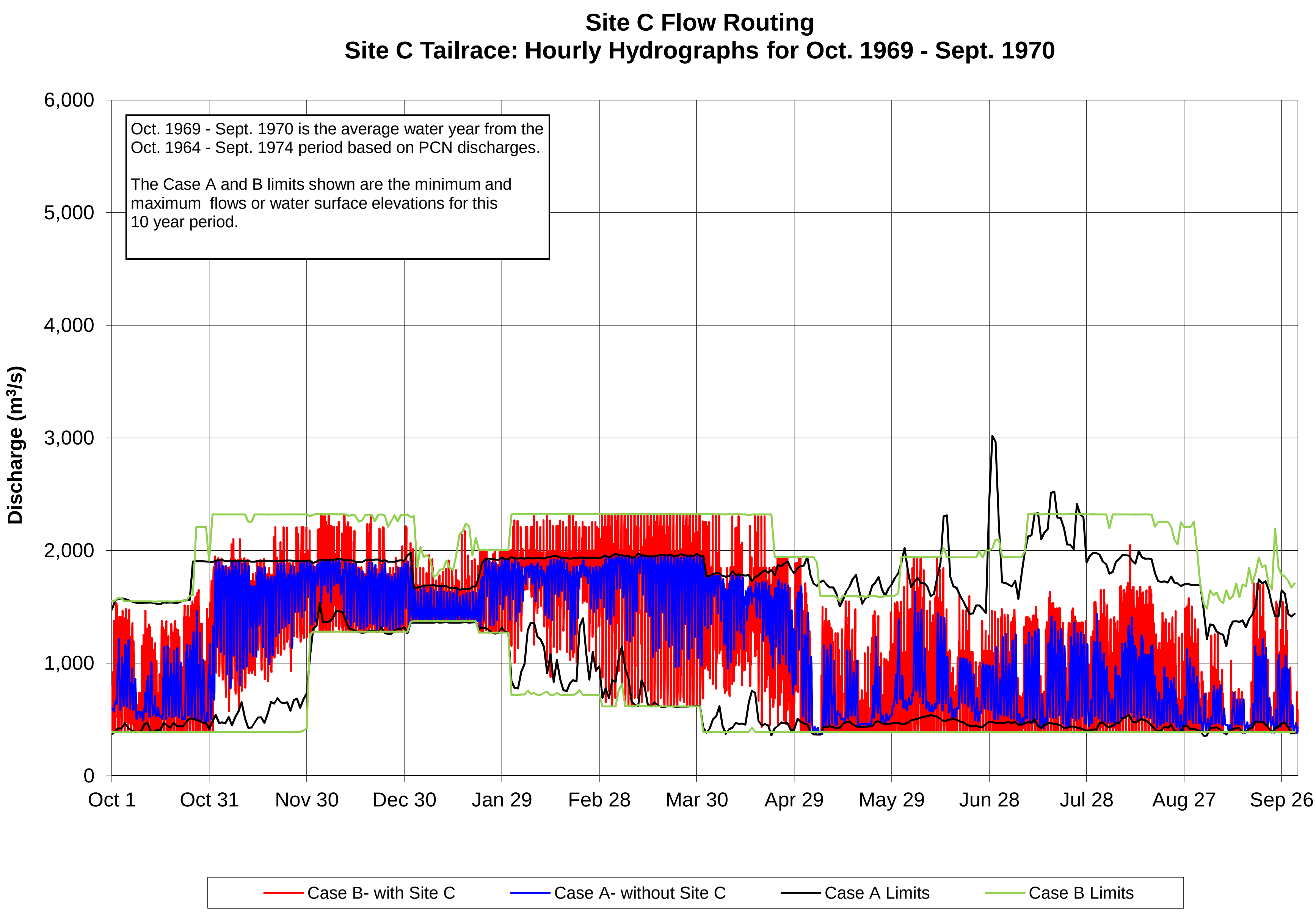


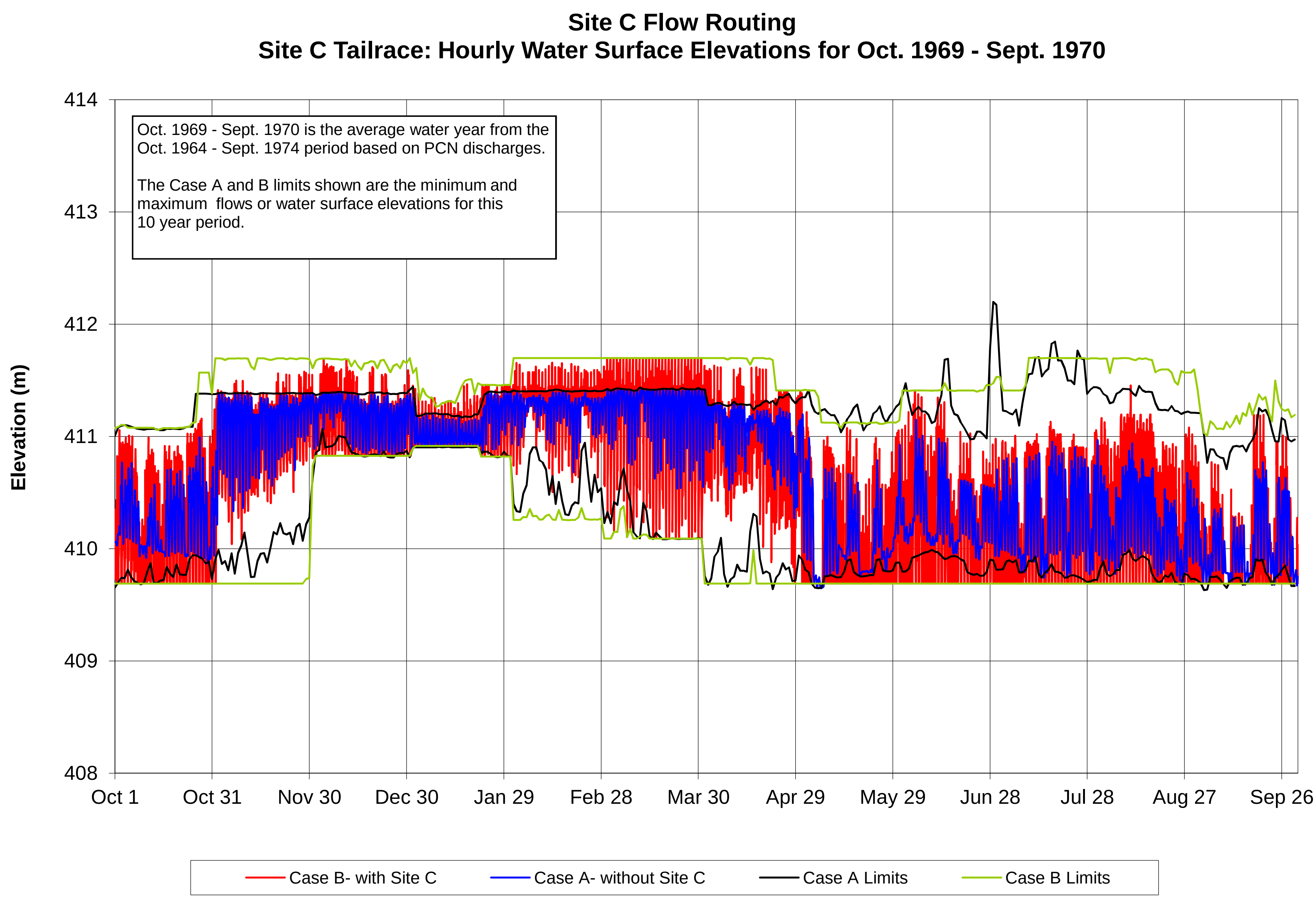
Jackpine Creek at Wadlin Lake Road WSC 07JD003
1 October 1964 to 30 September 1974
Flow (m³/s)
100
90
80
70
60
50
40
30
20
10
0
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated

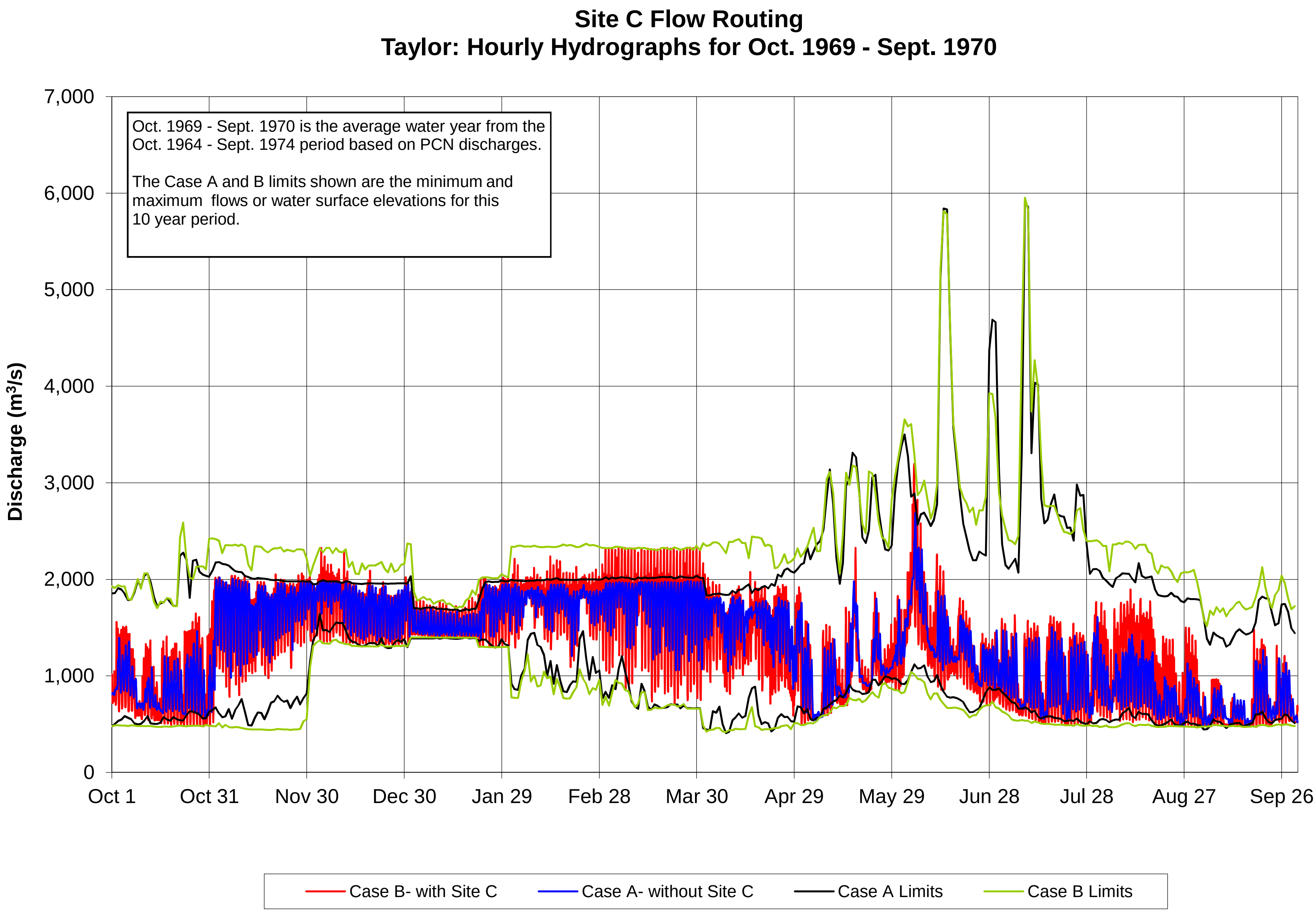

Wabasca River above Peace at Wadlin WSC 07JD002
1 October 1964 to 30 September 1974
Flow (m³/s)
1800
1600
1400
1200
1000
800
600
400
200
0
Oct/64
Mar/65
Sep/65
Mar/66
Sep/66
Mar/67
Sep/67
Mar/68
Sep/68
Mar/69
Sep/69
Mar/70
Aug/70
Feb/71
Aug/71
Feb/72
Aug/72
Feb/73
Aug/73
Feb/74
Aug/74
Measured
Estimated

APPENDIX – C

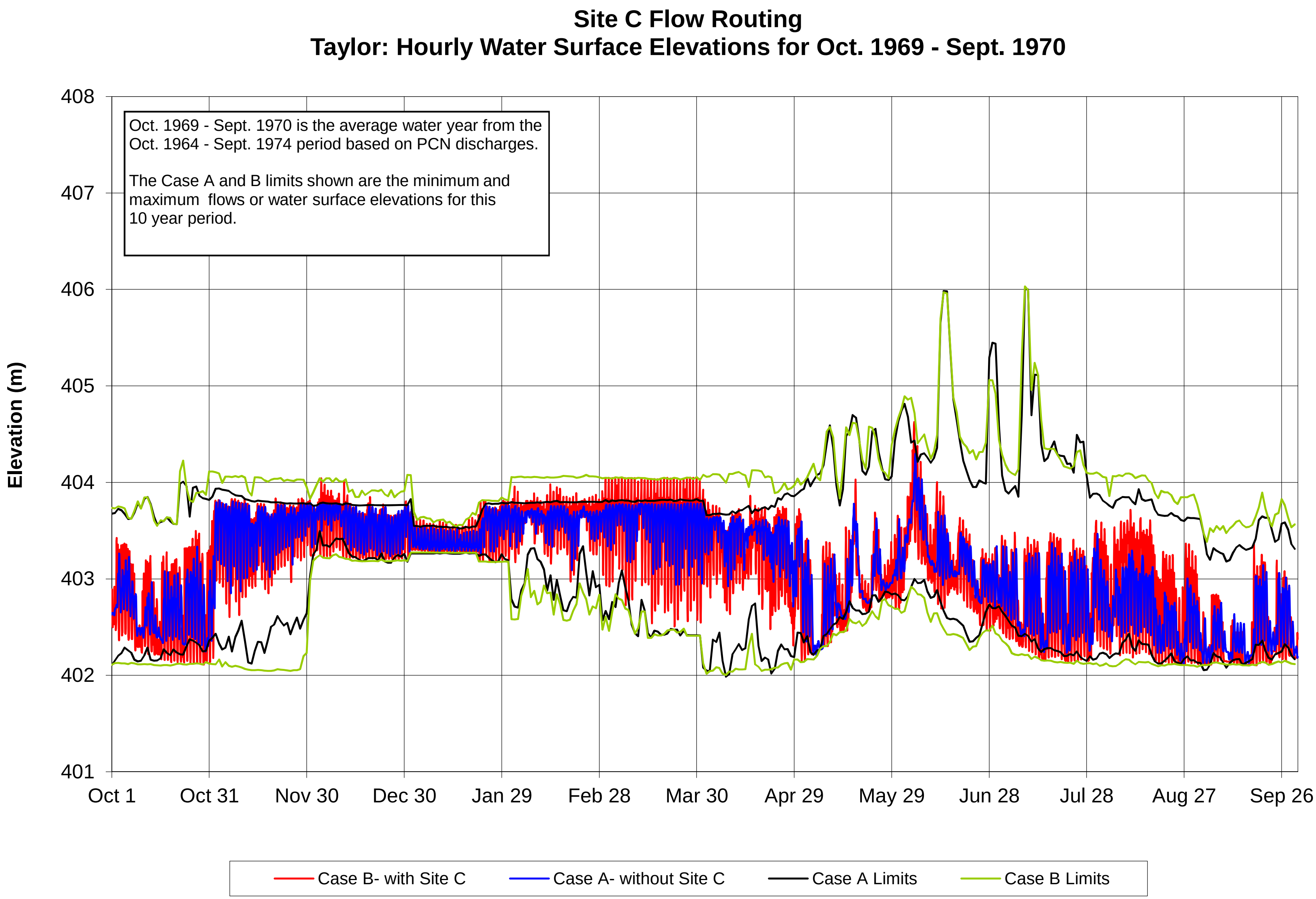
Hourly/Daily Flow and Water Level Time Series
(Case A and B)


Site C Flow Routing
Site C Tailrace: Hourly Hydrographs for Oct. 1969 - Sept. 1970
Oct. 1969 - Sept. 1970 is the average water year from the Oct. 1964 - Sept. 1974 period based on PCN discharges.
The Case A and B limits shown are the minimum and maximum flows or water surface elevations for this 10 year period.
Discharge (m³/s)
6,000
5,000
4,000
3,000
2,000
1,000
0
Oct 1
Oct 31
Nov 30
Dec 30
Jan 29
Feb 28
Mar 30
Apr 29
May 29
Jun 28
Jul 28
Aug 27
Sep 26
Case B- with Site C
Case A- without Site C
Case A Limits
Case B Limits

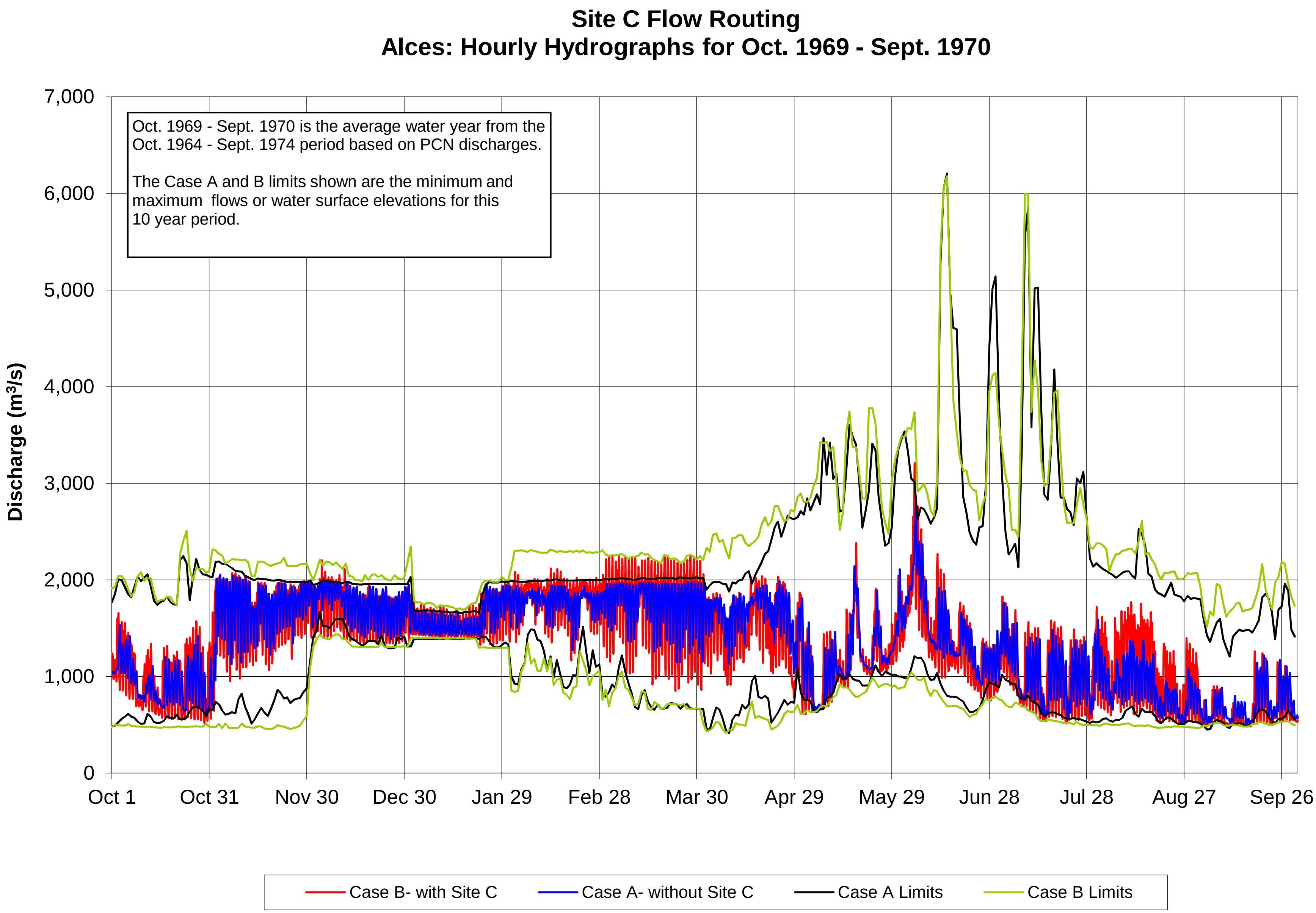

Site C Flow Routing
Site C Tailrace: Hourly Water Surface Elevations for Oct. 1969 - Sept. 1970
Oct. 1969 - Sept. 1970 is the average water year from the Oct. 1964 - Sept. 1974 period based on PCN discharges.
The Case A and B limits shown are the minimum and maximum flows or water surface elevations for this 10 year period.
Elevation (m)
414
413
412
411
410
409
408
Oct 1
Oct 31
Nov 30
Dec 30
Jan 29
Feb 28
Mar 30
Apr 29
May 29
Jun 28
Jul 28
Aug 27
Sep 26
Case B- with Site C
Case A- without Site C
Case A Limits
Case B Limits



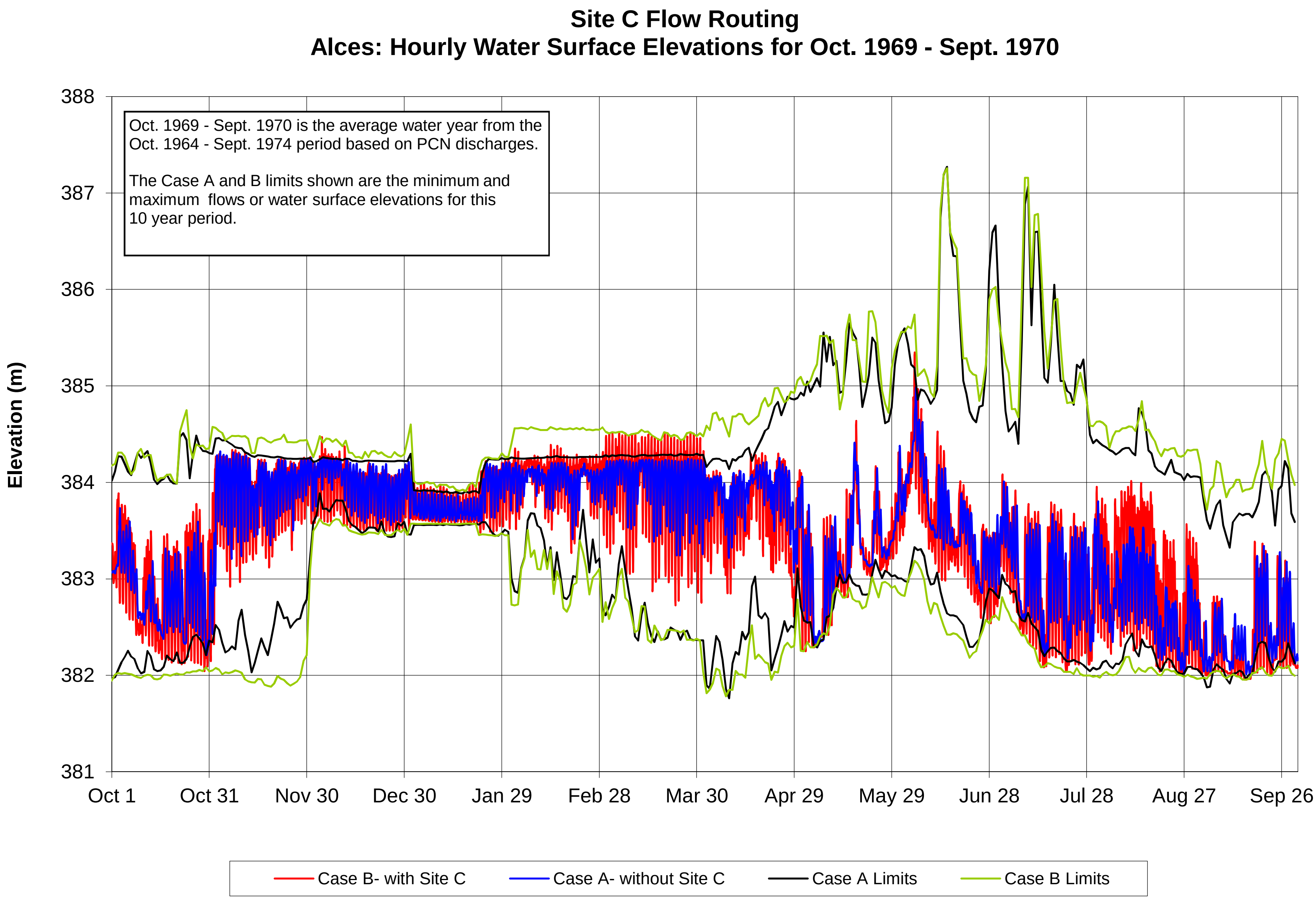
Site C Flow Routing
Taylor: Hourly Hydrographs for Oct. 1969 - Sept. 1970
Oct. 1969 - Sept. 1970 is the average water year from the Oct. 1964 - Sept. 1974 period based on PCN discharges.
The Case A and B limits shown are the minimum and maximum flows or water surface elevations for this 10 year period.
Discharge (m³/s)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Oct 1
Oct 31
Nov 30
Dec 30
Jan 29
Feb 28
Mar 30
Apr 29
May 29
Jun 28
Jul 28
Aug 27
Sep 26
Case B- with Site C
Case A- without Site C
Case A Limits
Case B Limits

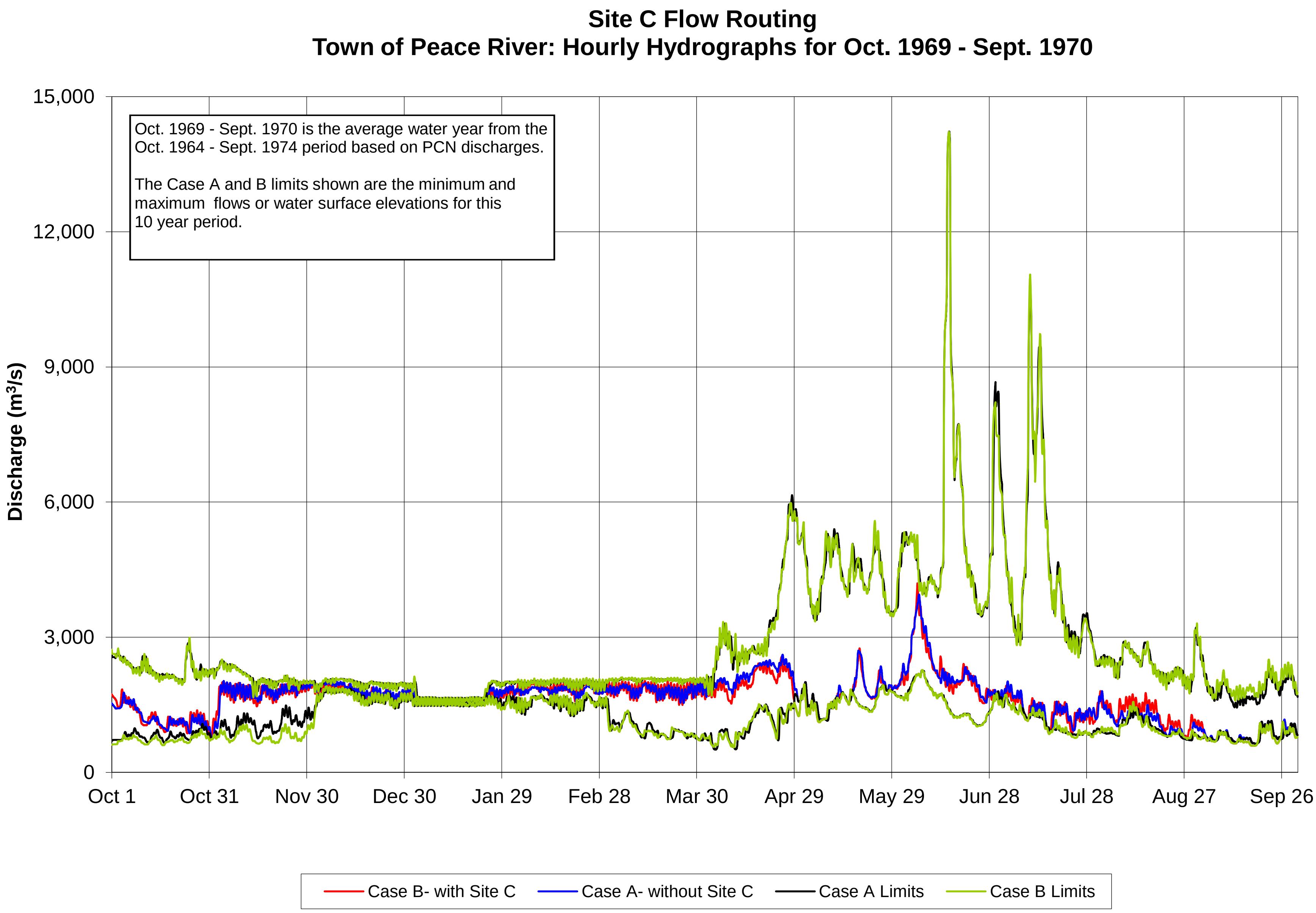


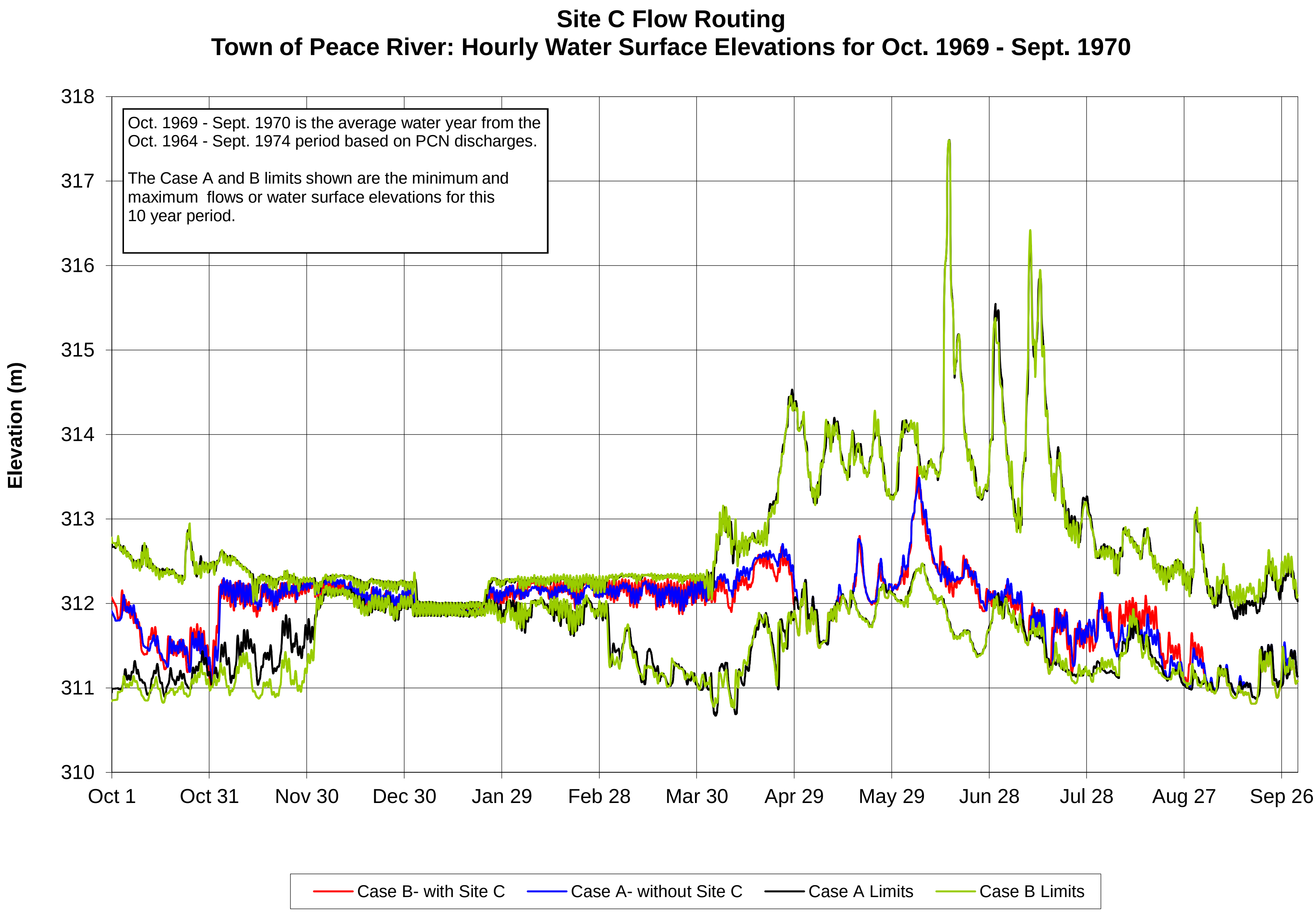
Site C Flow Routing
Taylor: Hourly Water Surface Elevations for Oct. 1969 - Sept. 1970
Oct. 1969 - Sept. 1970 is the average water year from the Oct. 1964 - Sept. 1974 period based on PCN discharges.
The Case A and B limits shown are the minimum and maximum flows or water surface elevations for this 10 year period.
Elevation (m)
408
407
406
405
404
403
402
401
Oct 1
Oct 31
Nov 30
Dec 30
Jan 29
Feb 28
Mar 30
Apr 29
May 29
Jun 28
Jul 28
Aug 27
Sep 26
Case B- with Site C
Case A- without Site C
Case A Limits
Case B Limits

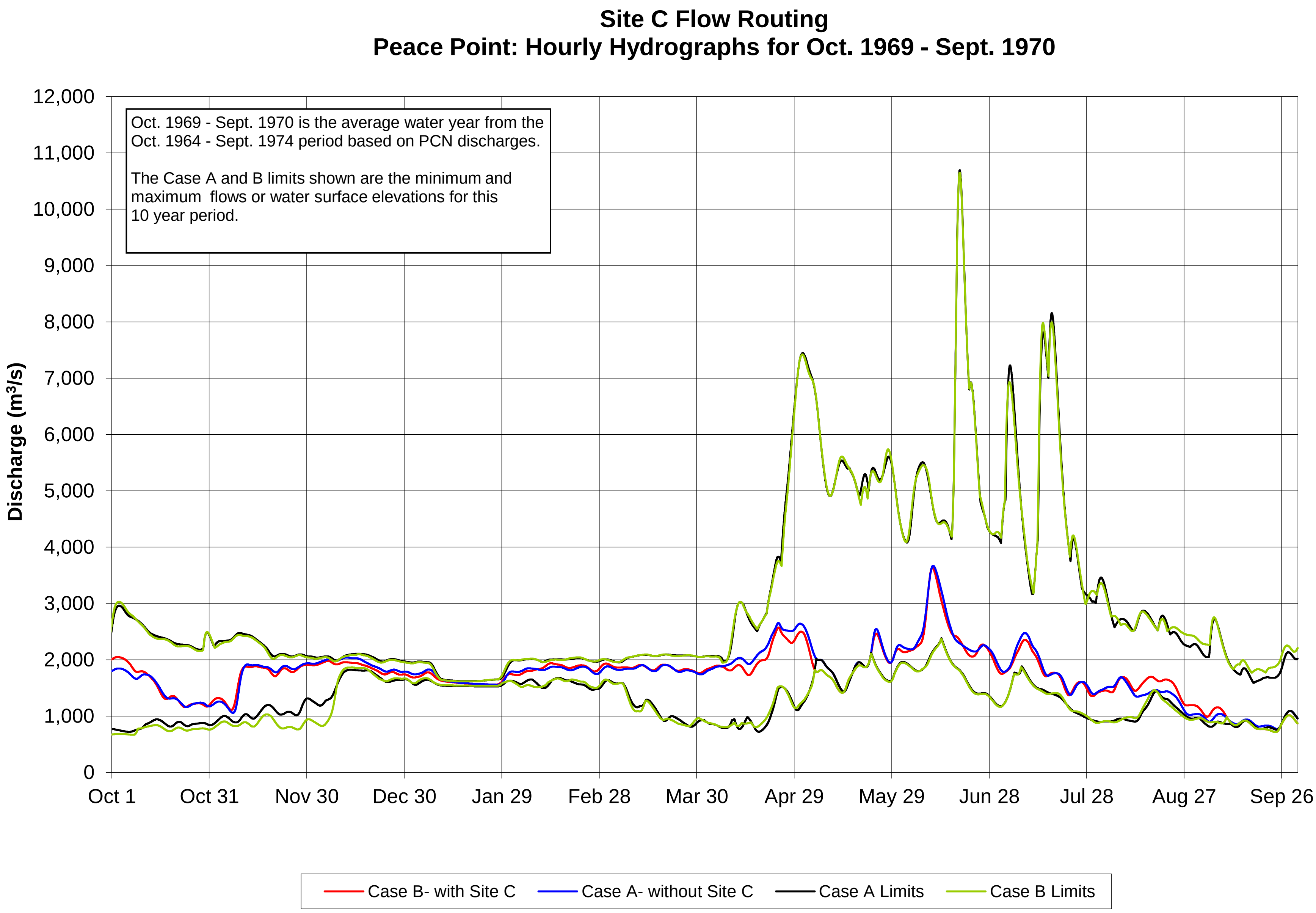


Site C Flow Routing
Alces: Hourly Hydrographs for Oct. 1969 - Sept. 1970
Oct. 1969 - Sept. 1970 is the average water year from the Oct. 1964 - Sept. 1974 period based on PCN discharges.
The Case A and B limits shown are the minimum and maximum flows or water surface elevations for this 10 year period.
Discharge (m³/s)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Oct 1
Oct 31
Nov 30
Dec 30
Jan 29
Feb 28
Mar 30
Apr 29
May 29
Jun 28
Jul 28
Aug 27
Sep 26
Case B- with Site C
Case A- without Site C
Case A Limits
Case B Limits

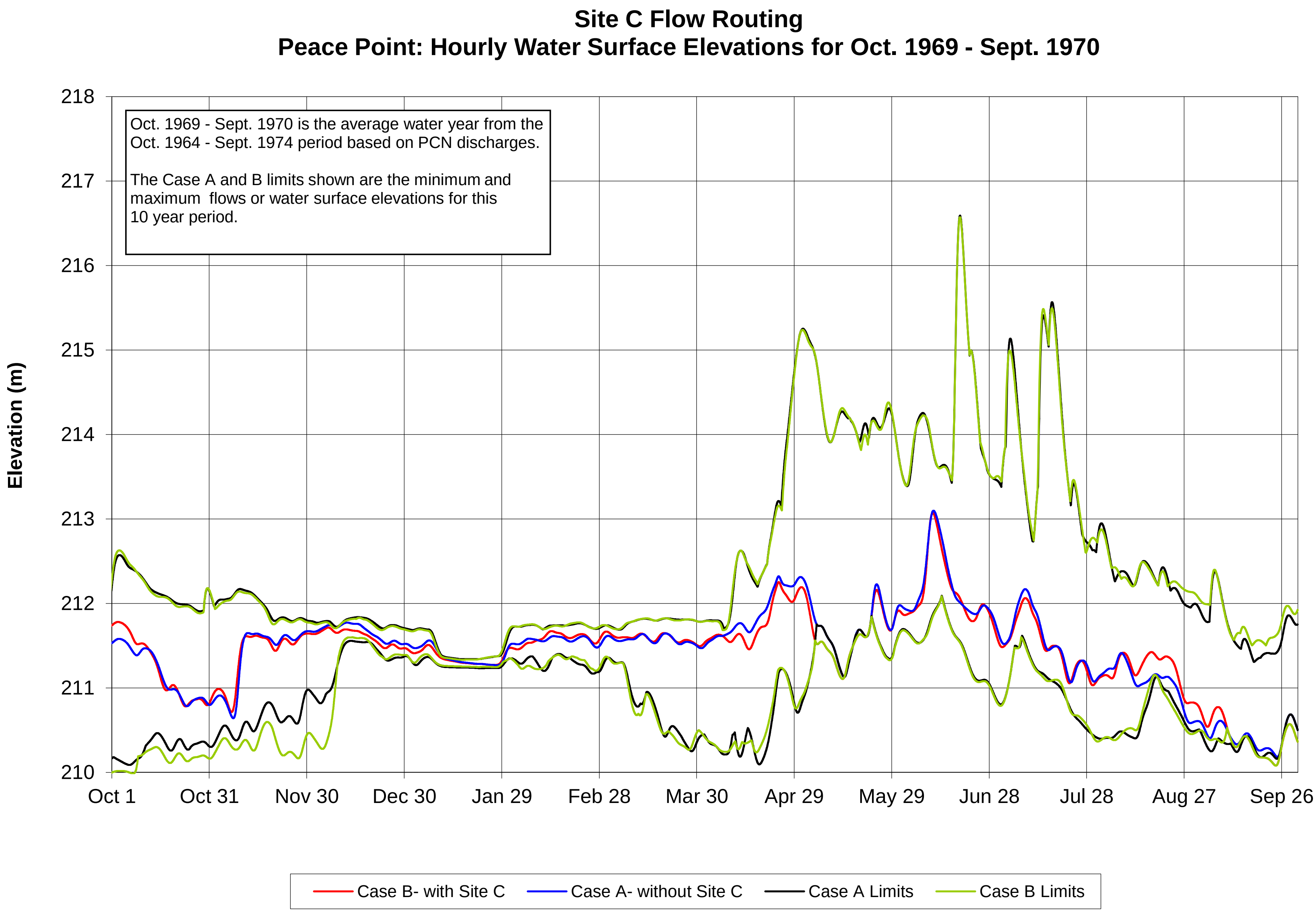

Site C Flow Routing
Alces: Hourly Water Surface Elevations for Oct. 1969 - Sept. 1970
Oct. 1969 - Sept. 1970 is the average water year from the Oct. 1964 - Sept. 1974 period based on PCN discharges.
The Case A and B limits shown are the minimum and maximum flows or water surface elevations for this 10 year period.
Elevation (m)
388
387
386
385
384
383
382
381
Oct 1
Oct 31
Nov 30
Dec 30
Jan 29
Feb 28
Mar 30
Apr 29
May 29
Jun 28
Jul 28
Aug 27
Sep 26
Case B- with Site C
Case A- without Site C
Case A Limits
Case B Limits


Site C Flow Routing
Town of Peace River: Hourly Hydrographs for Oct. 1969 - Sept. 1970
Oct. 1969 - Sept. 1970 is the average water year from the Oct. 1964 - Sept. 1974 period based on PCN discharges.
The Case A and B limits shown are the minimum and maximum flows or water surface elevations for this 10 year period.
Discharge (m³/s)
15,000
12,000
9,000
6,000
3,000
0
Oct 1
Oct 31
Nov 30
Dec 30
Jan 29
Feb 28
Mar 30
Apr 29
May 29
Jun 28
Jul 28
Aug 27
Sep 26
Case B- with Site C
Case A- without Site C
Case A Limits
Case B Limits


Site C Flow Routing
Town of Peace River: Hourly Water Surface Elevations for Oct. 1969 - Sept. 1970
Oct. 1969 - Sept. 1970 is the average water year from the Oct. 1964 - Sept. 1974 period based on PCN discharges.
The Case A and B limits shown are the minimum and maximum flows or water surface elevations for this 10 year period.
Elevation (m)
318
317
316
315
314
313
312
311
310
Oct 1
Oct 31
Nov 30
Dec 30
Jan 29
Feb 28
Mar 30
Apr 29
May 29
Jun 28
Jul 28
Aug 27
Sep 26
Case B- with Site C
Case A- without Site C
Case A Limits
Case B Limits

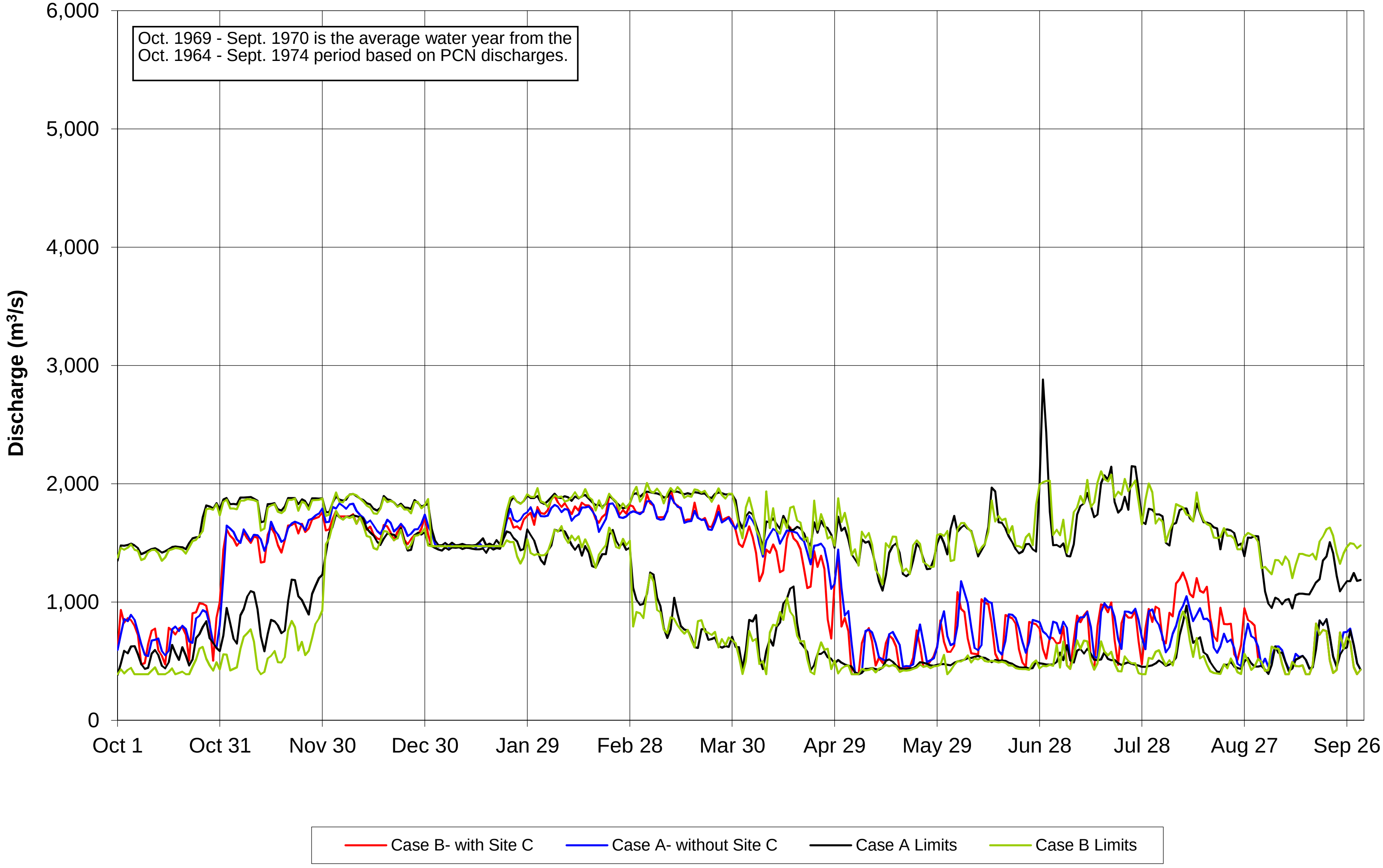


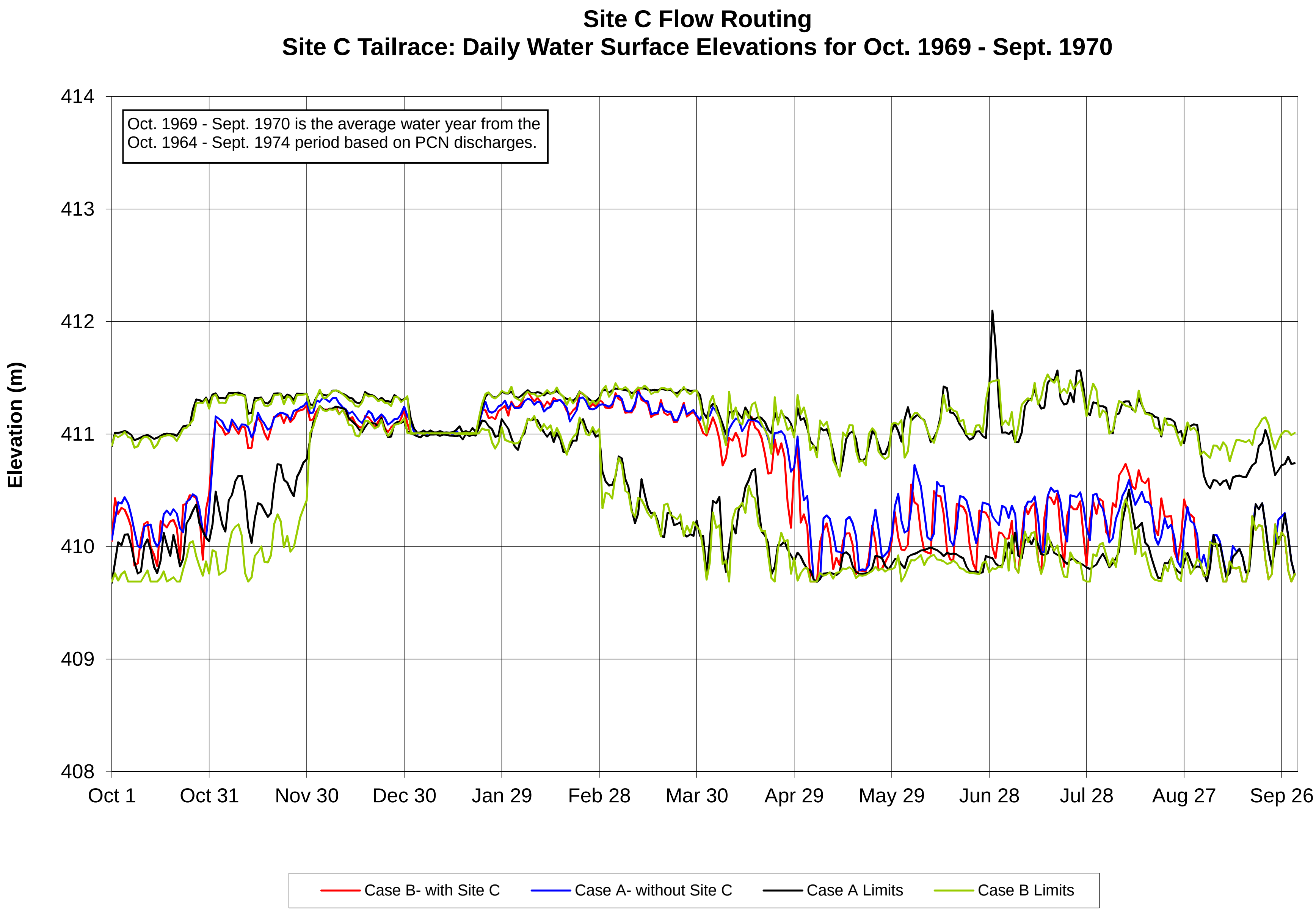
Site C Flow Routing
Peace Point: Hourly Hydrographs for Oct. 1969 - Sept. 1970
Oct. 1969 - Sept. 1970 is the average water year from the Oct. 1964 - Sept. 1974 period based on PCN discharges.
The Case A and B limits shown are the minimum and maximum flows or water surface elevations for this 10 year period.
Discharge (m³/s)
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
12,000
Oct 1
Oct 31
Nov 30
Dec 30
Jan 29
Feb 28
Mar 30
Apr 29
May 29
Jun 28
Jul 28
Aug 27
Sep 26
Case B- with Site C
Case A- without Site C
Case A Limits
Case B Limits



Site C Flow Routing
Peace Point: Hourly Water Surface Elevations for Oct. 1969 - Sept. 1970
Oct. 1969 - Sept. 1970 is the average water year from the Oct. 1964 - Sept. 1974 period based on PCN discharges.
The Case A and B limits shown are the minimum and maximum flows or water surface elevations for this 10 year period.
Elevation (m)
218
217
216
215
214
213
212
211
210
Oct 1
Oct 31
Nov 30
Dec 30
Jan 29
Feb 28
Mar 30
Apr 29
May 29
Jun 28
Jul 28
Aug 27
Sep 26
Case B- with Site C
Case A- without Site C
Case A Limits
Case B Limits

Site C Flow Routing
Site C Tailrace: Daily Hydrographs for Oct. 1969 - Sept. 1970

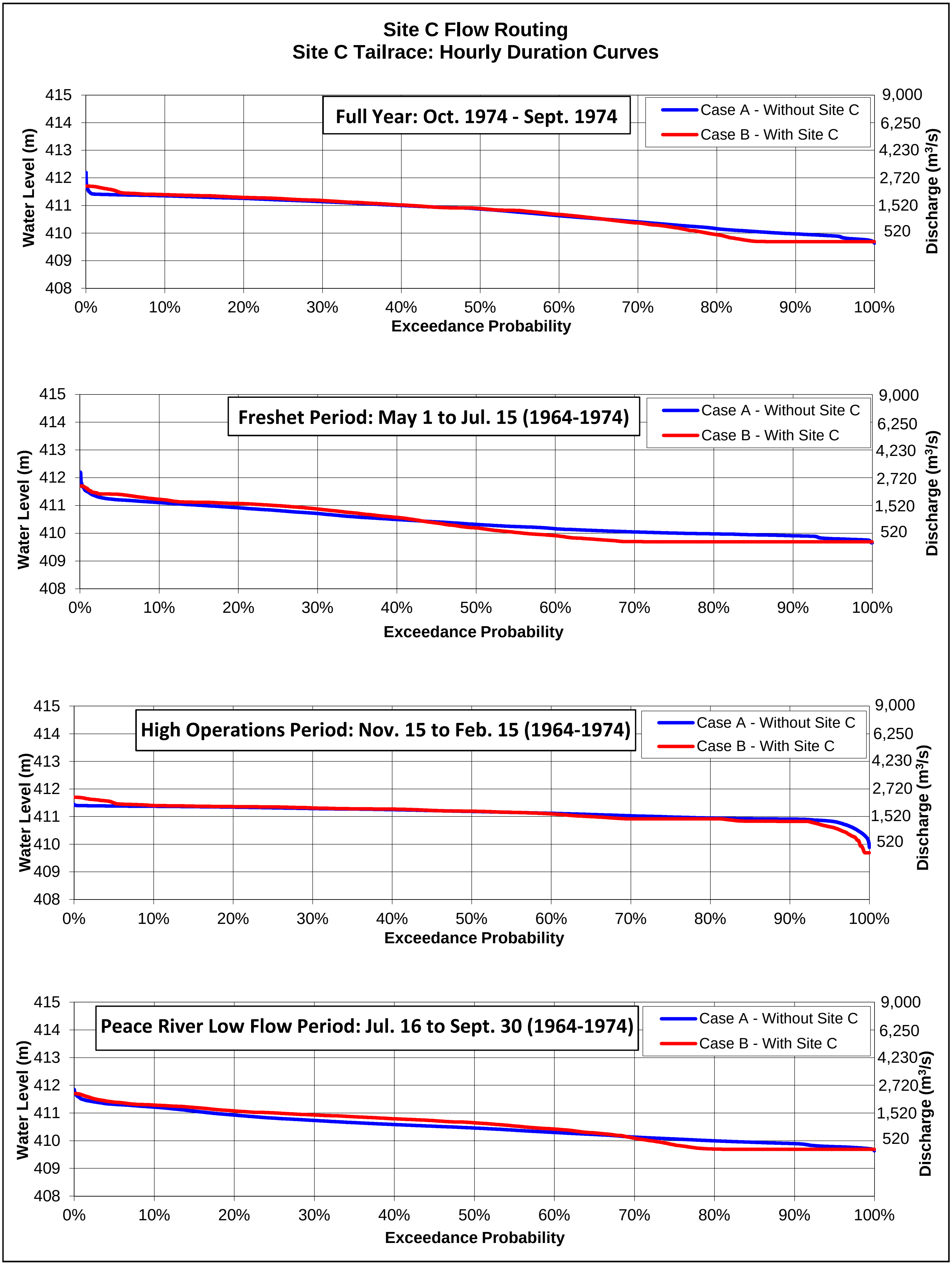




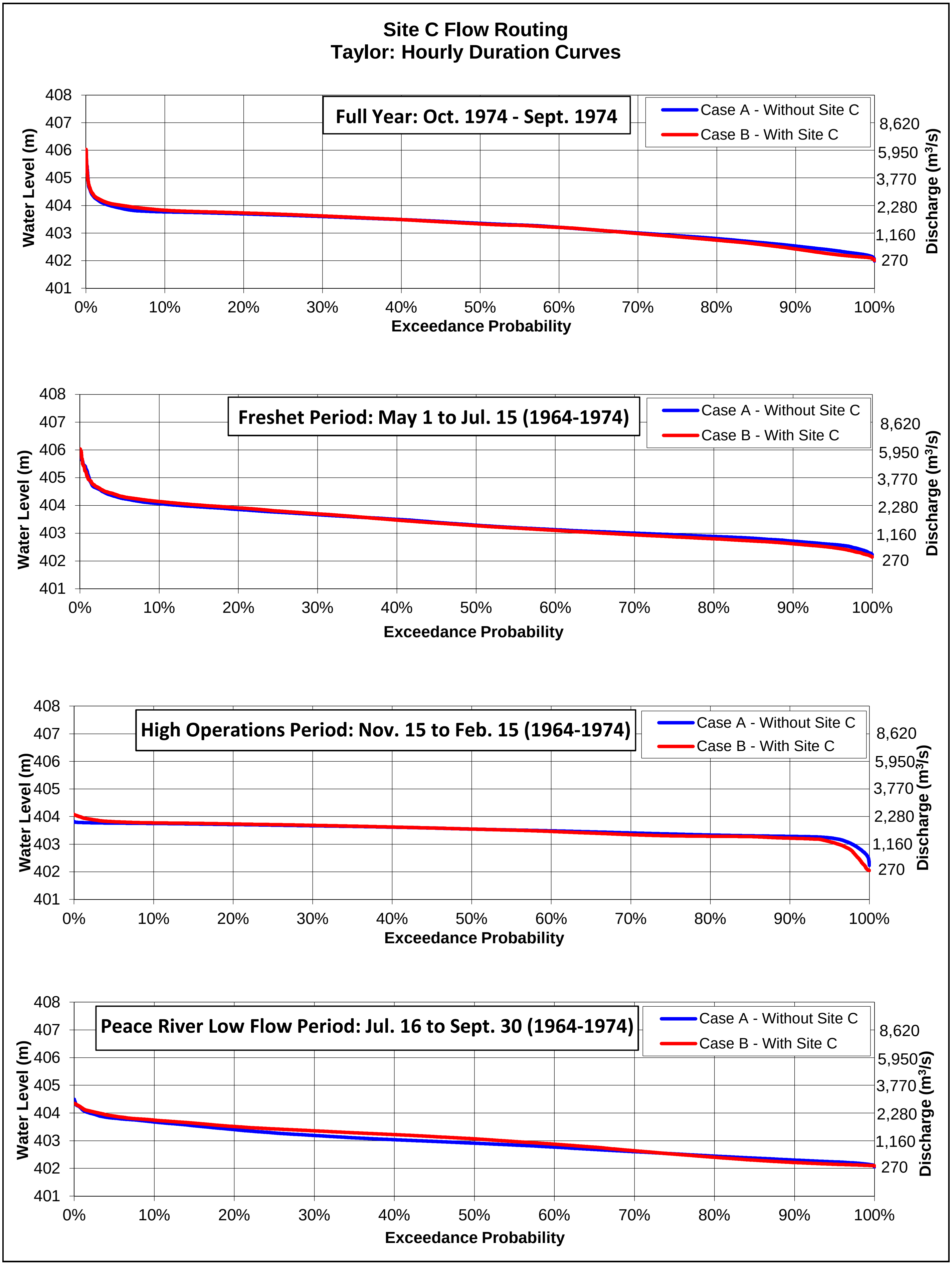
Site C Flow Routing
Site C Tailrace: Daily Water Surface Elevations for Oct. 1969 - Sept. 1970
Oct. 1969 - Sept. 1970 is the average water year from the Oct. 1964 - Sept. 1974 period based on PCN discharges.
Elevation (m)
414
413
412
411
410
409
408
Oct 1
Oct 31
Nov 30
Dec 30
Jan 29
Feb 28
Mar 30
Apr 29
May 29
Jun 28
Jul 28
Aug 27
Sep 26
Case B- with Site C
Case A- without Site C
Case A Limits
Case B Limits

APPENDIX – D

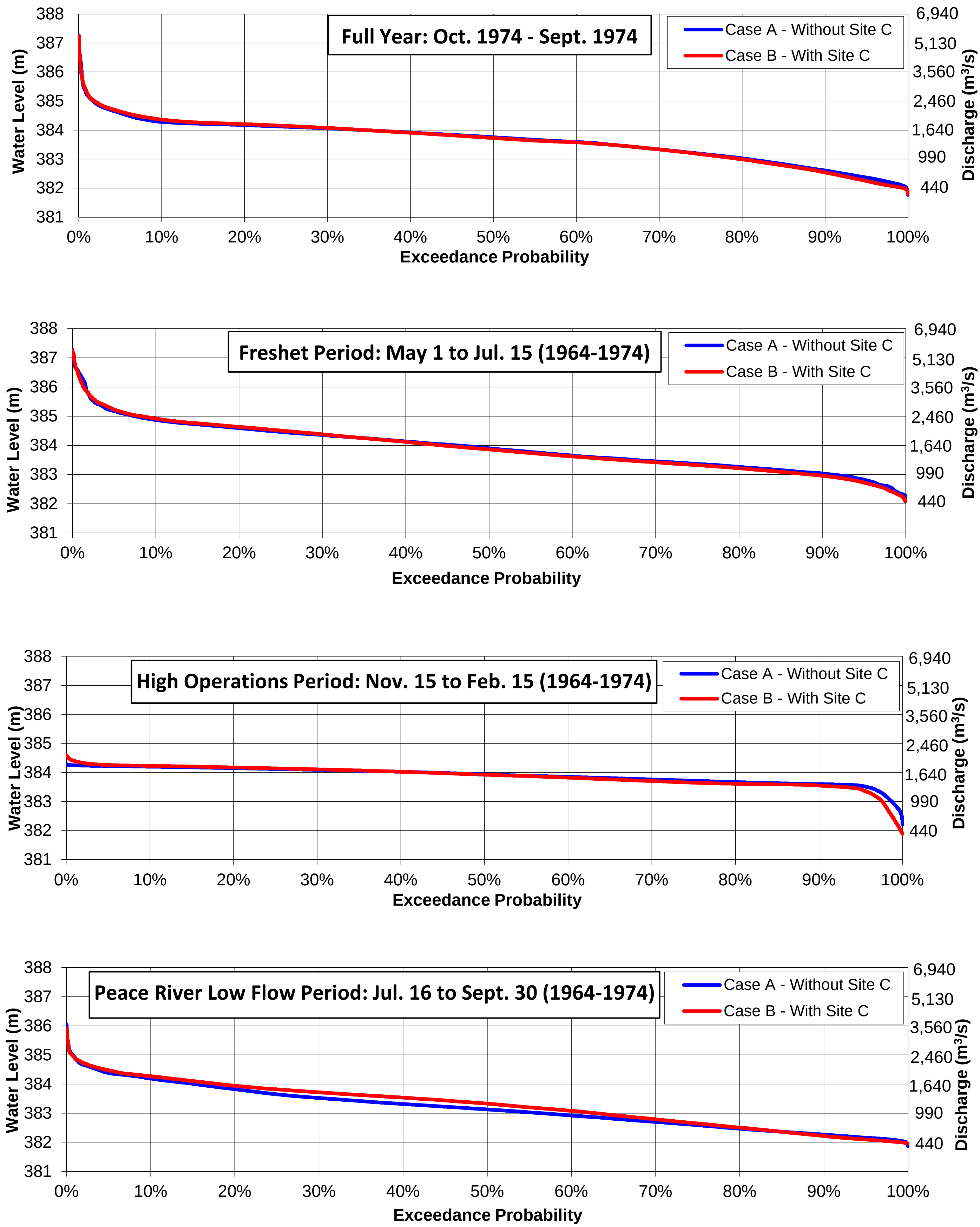
Hourly Water Level and Flow Duration Curves
(Case A and B)

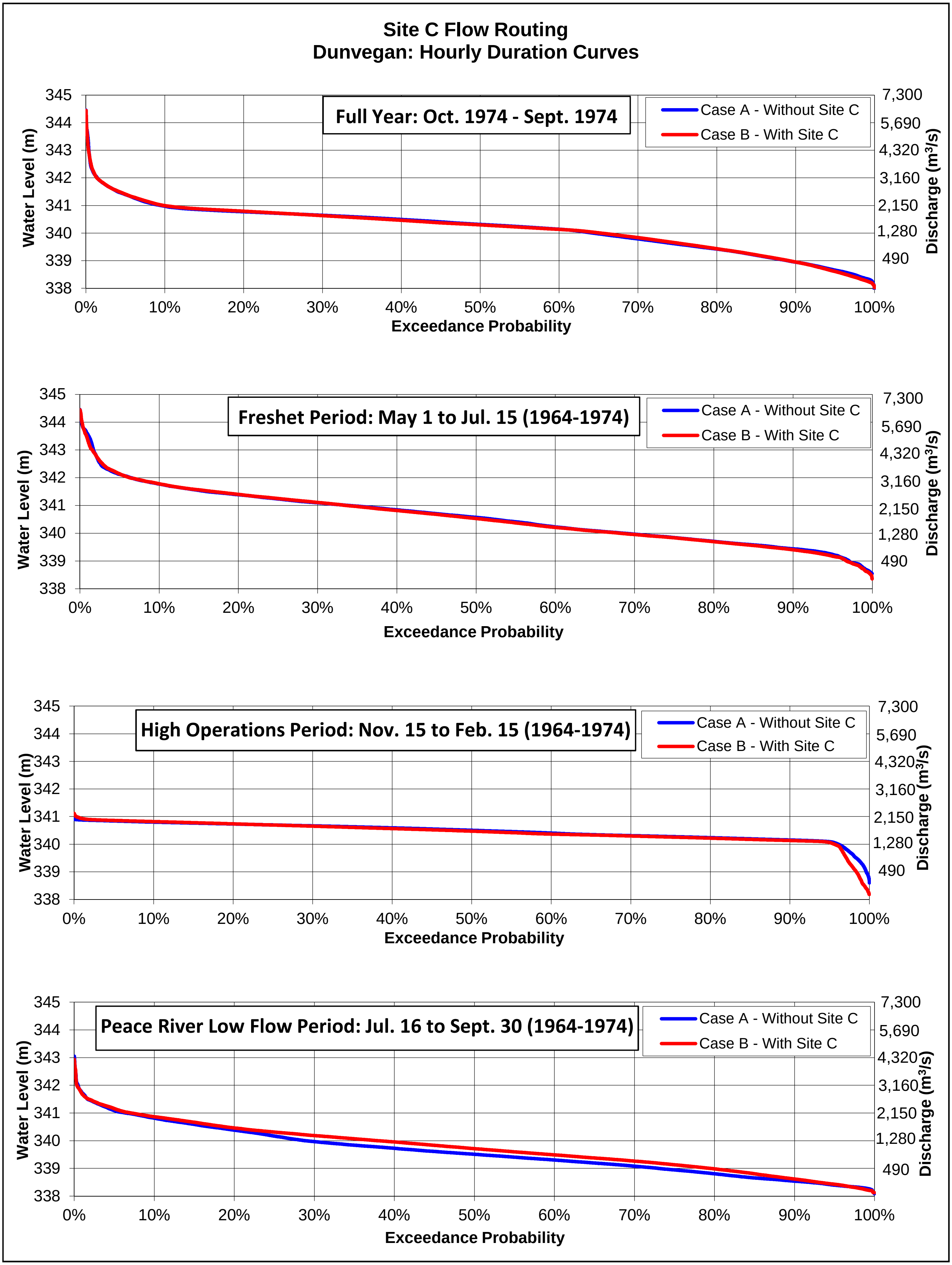


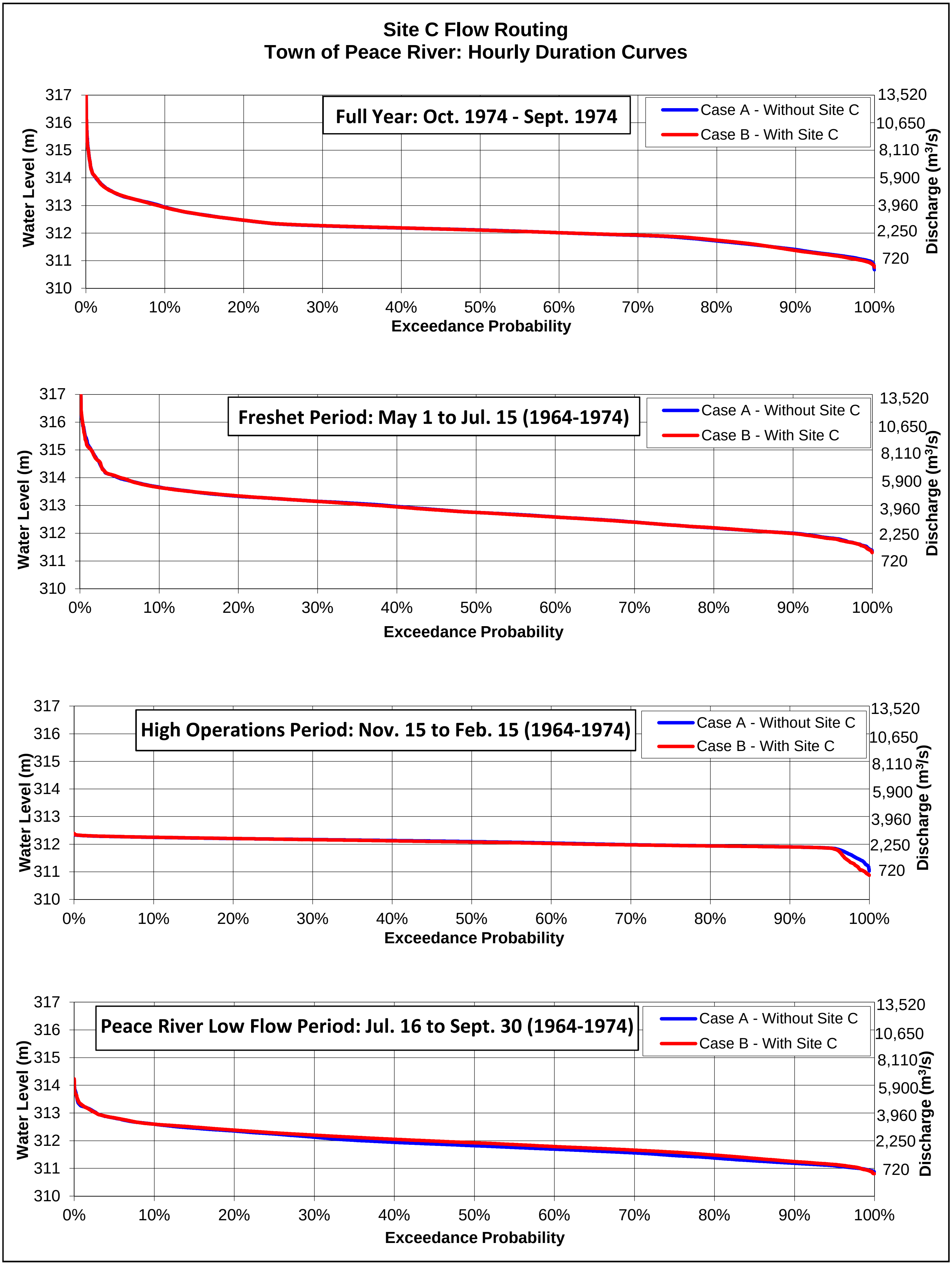
Site C Flow Routing
Site C Tailrace: Hourly Duration Curves
Full Year: Oct. 1974 - Sept. 1974
Freshet Period: May 1 to Jul. 15 (1964-1974)
High Operations Period: Nov. 15 to Feb. 15 (1964-1974)
Peace River Low Flow Period: Jul. 16 to Sept. 30 (1964-1974)
Case A - Without Site C
Case B - With Site C
Water Level (m)
Discharge (m³/s)
Exceedance Probability
408
409
410
411
412
413
414
415
520
1,520
2,720
4,230
6,250
9,000
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

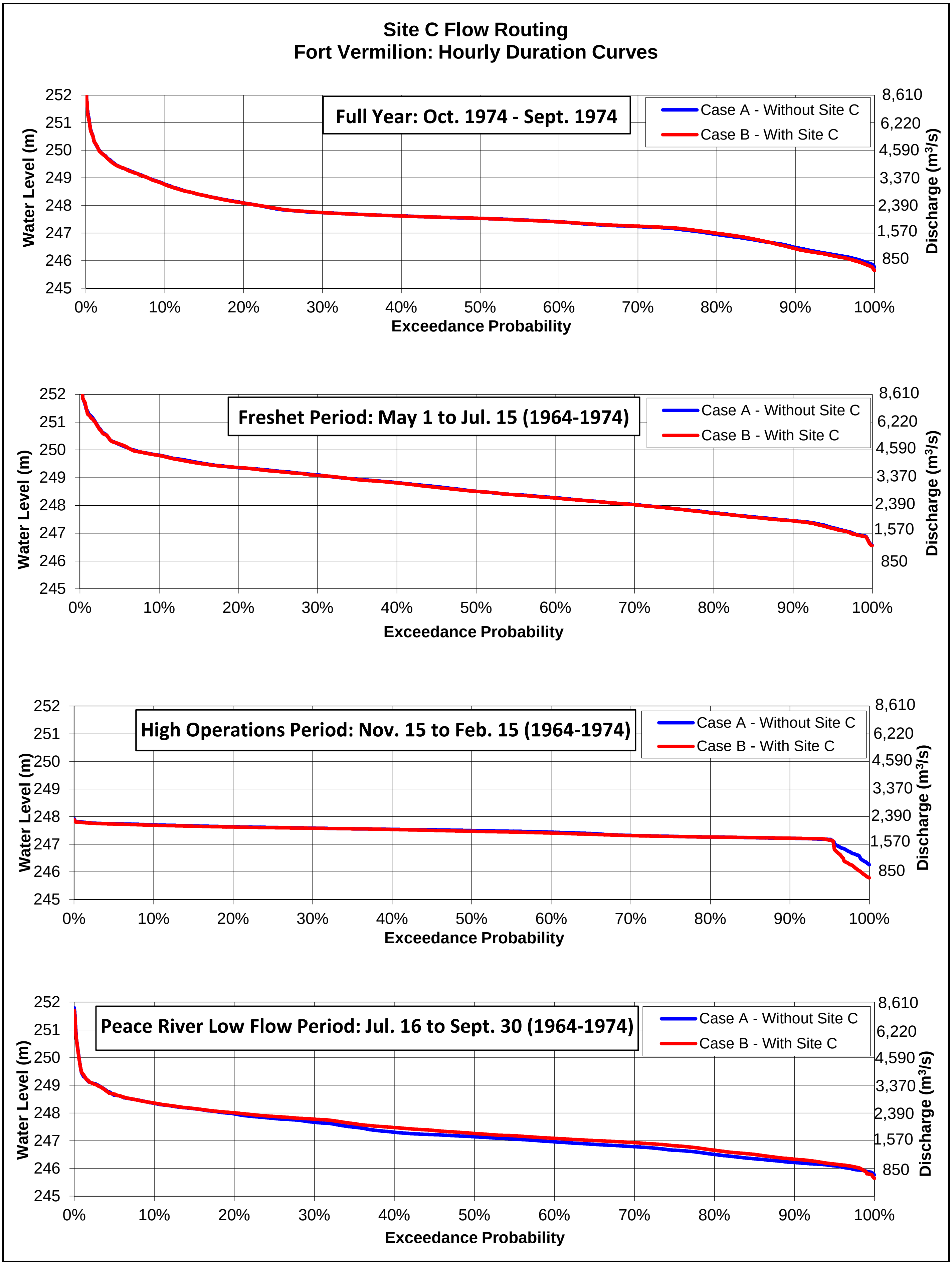

Site C Flow Routing
Taylor: Hourly Duration Curves
Full Year: Oct. 1974 - Sept. 1974
Freshet Period: May 1 to Jul. 15 (1964-1974)
High Operations Period: Nov. 15 to Feb. 15 (1964-1974)
Peace River Low Flow Period: Jul. 16 to Sept. 30 (1964-1974)
Case A - Without Site C
Case B - With Site C
Water Level (m)
Discharge (m³/s)
Exceedance Probability
408
407
406
405
404
403
402
401
8,620
5,950
3,770
2,280
1,160
270
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

Site C Flow Routing
Alces: Hourly Duration Curves

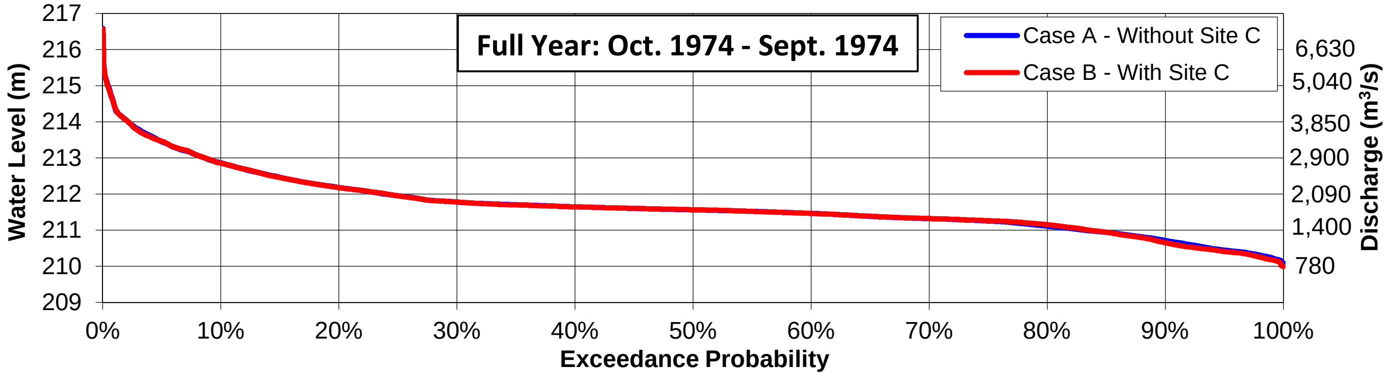


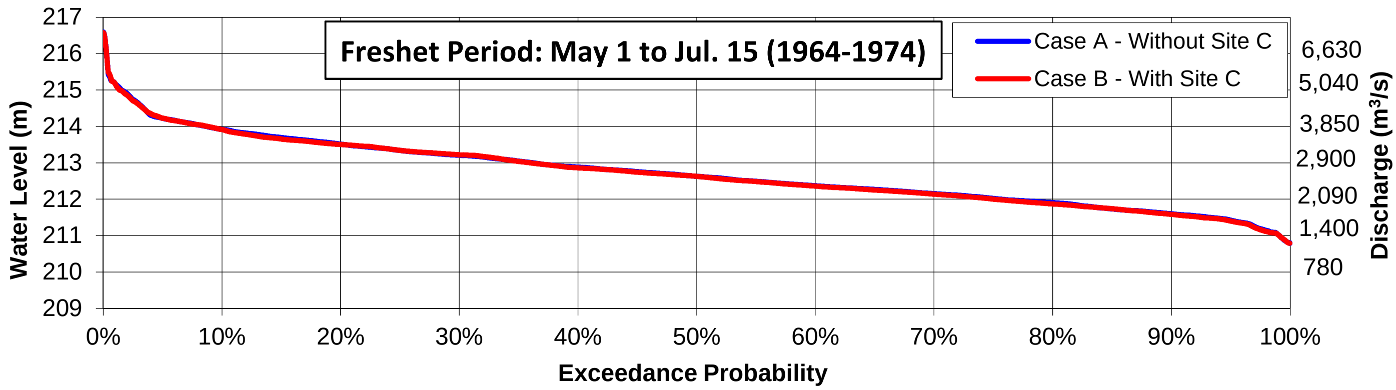

Site C Flow Routing
Dunvegan: Hourly Duration Curves
Full Year: Oct. 1974 - Sept. 1974
Case A - Without Site C
Case B - With Site C
Water Level (m)
Discharge (m³/s)
Exceedance Probability
345
344
343
342
341
340
339
338
7,300
5,690
4,320
3,160
2,150
1,280
490
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Freshet Period: May 1 to Jul. 15 (1964-1974)
Case A - Without Site C
Case B - With Site C
Water Level (m)
Discharge (m³/s)
Exceedance Probability
High Operations Period: Nov. 15 to Feb. 15 (1964-1974)
Case A - Without Site C
Case B - With Site C
Water Level (m)
Discharge (m³/s)
Exceedance Probability
Peace River Low Flow Period: Jul. 16 to Sept. 30 (1964-1974)
Case A - Without Site C
Case B - With Site C
Water Level (m)
Discharge (m³/s)
Exceedance Probability

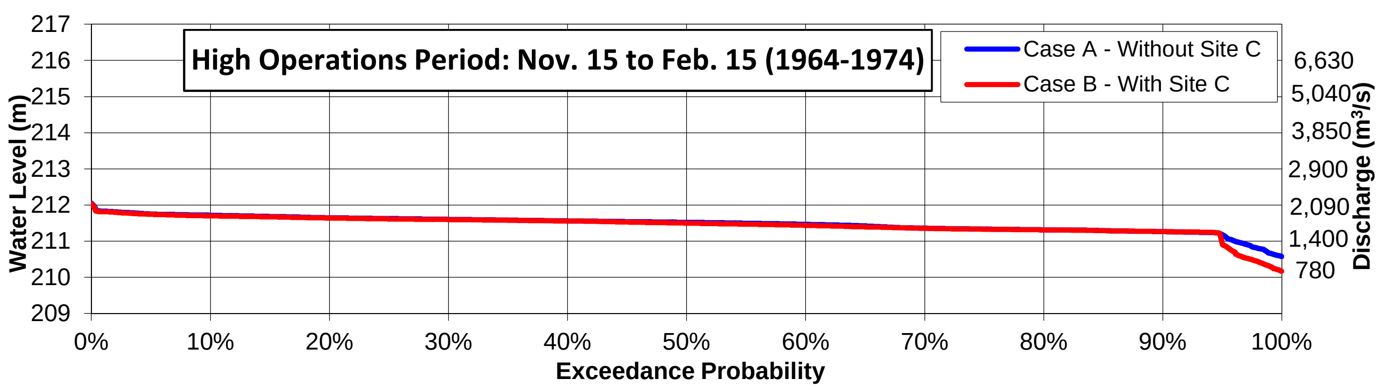

Site C Flow Routing
Town of Peace River: Hourly Duration Curves
Full Year: Oct. 1974 - Sept. 1974
Freshet Period: May 1 to Jul. 15 (1964-1974)
High Operations Period: Nov. 15 to Feb. 15 (1964-1974)
Peace River Low Flow Period: Jul. 16 to Sept. 30 (1964-1974)
Case A - Without Site C
Case B - With Site C
Water Level (m)
Discharge (m³/s)
Exceedance Probability
317
316
315
314
313
312
311
310
13,520
10,650
8,110
5,900
3,960
2,250
720
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

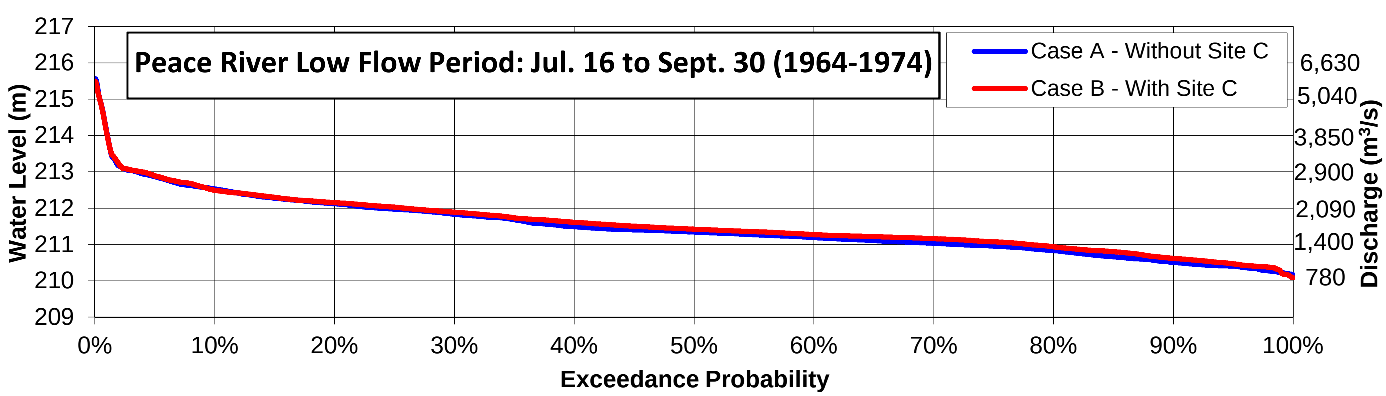

Site C Flow Routing
Fort Vermilion: Hourly Duration Curves
Full Year: Oct. 1974 - Sept. 1974
Freshet Period: May 1 to Jul. 15 (1964-1974)
High Operations Period: Nov. 15 to Feb. 15 (1964-1974)
Peace River Low Flow Period: Jul. 16 to Sept. 30 (1964-1974)
Case A - Without Site C
Case B - With Site C
Water Level (m)
Discharge (m³/s)
Exceedance Probability
252
251
250
249
248
247
246
245
8,610
6,220
4,590
3,370
2,390
1,570
850
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

Site C Flow Routing
Peace Point: Hourly Duration Curves





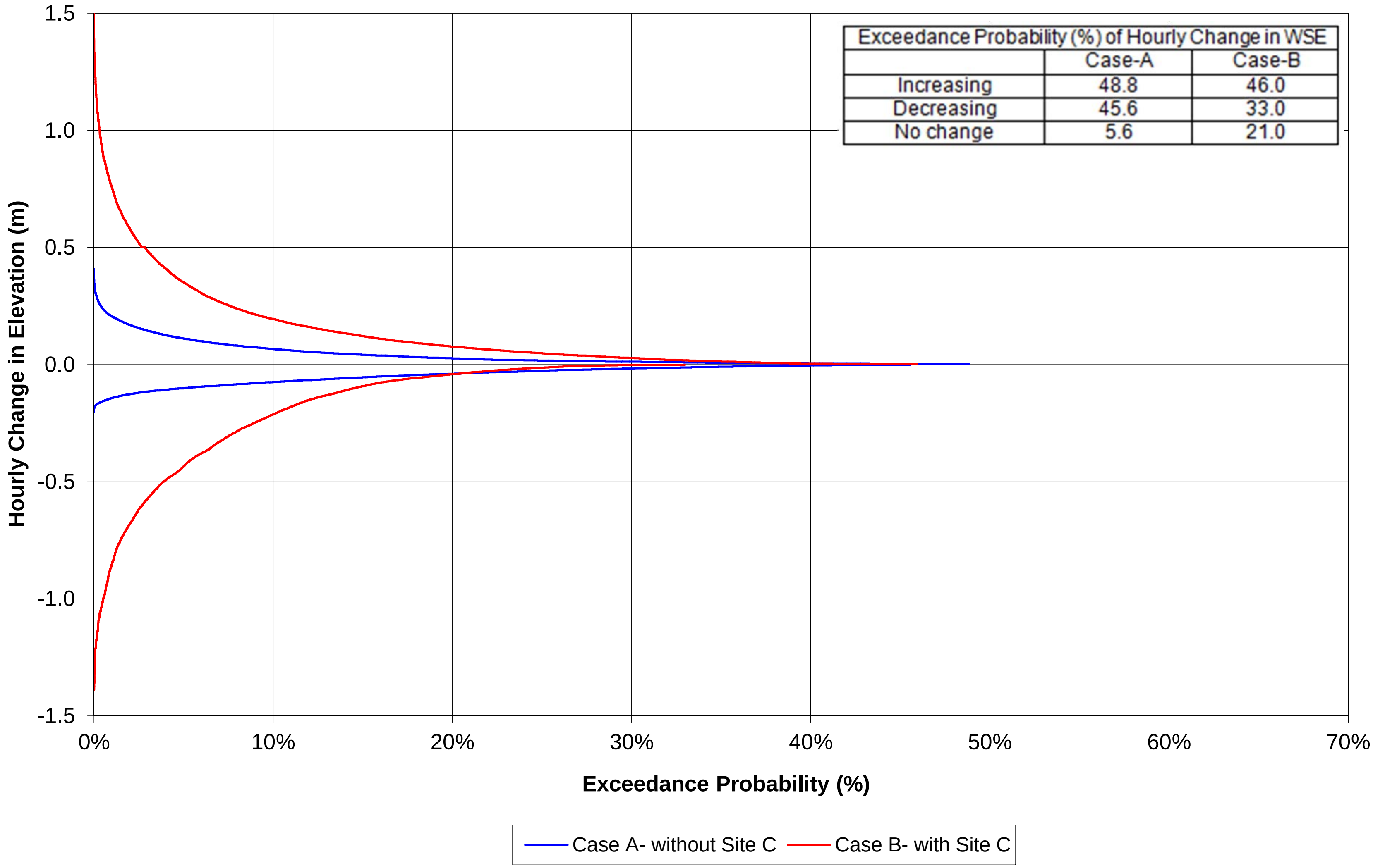




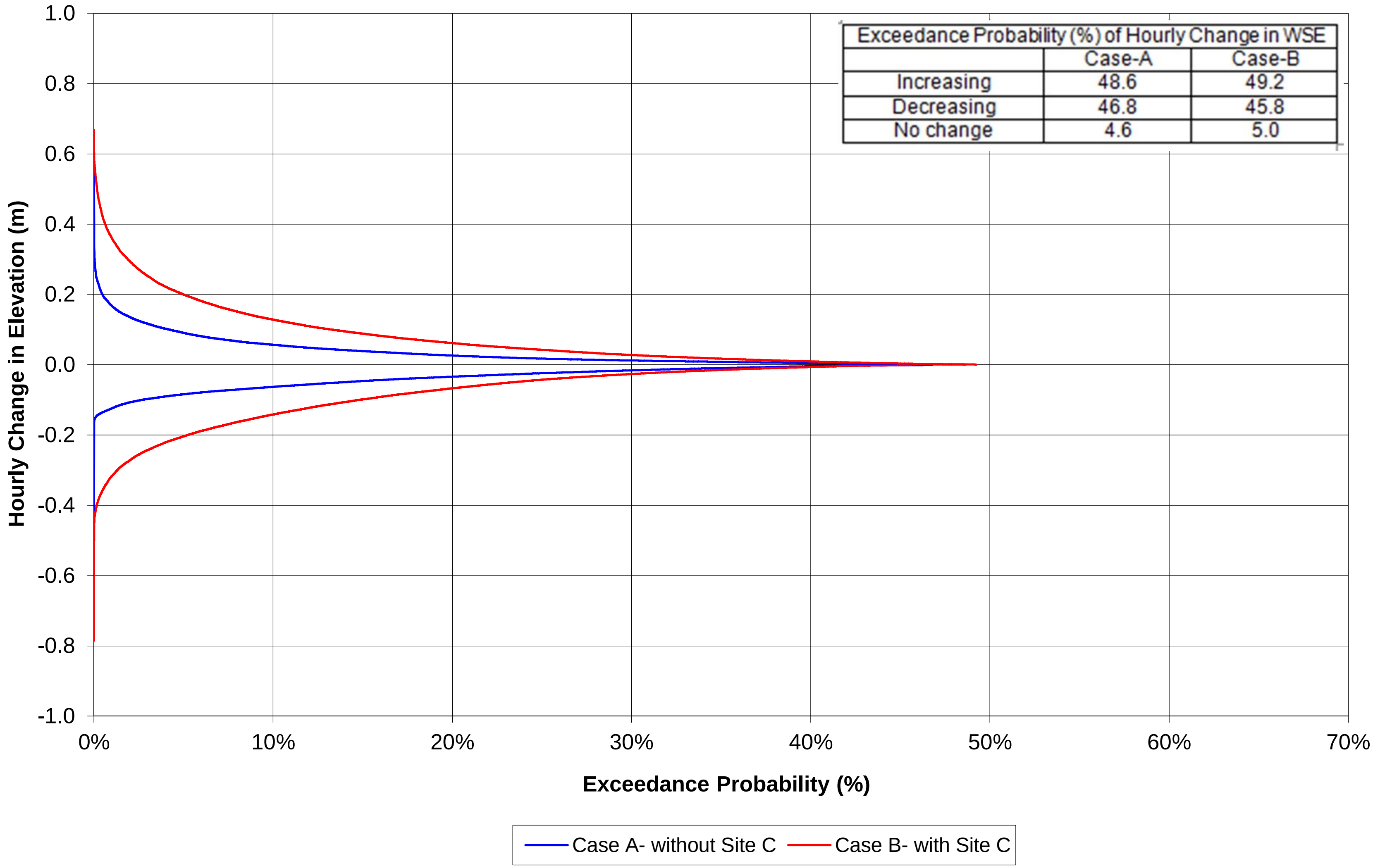
APPENDIX – E

Hourly Water Level Change Duration Curves (Case A and B)

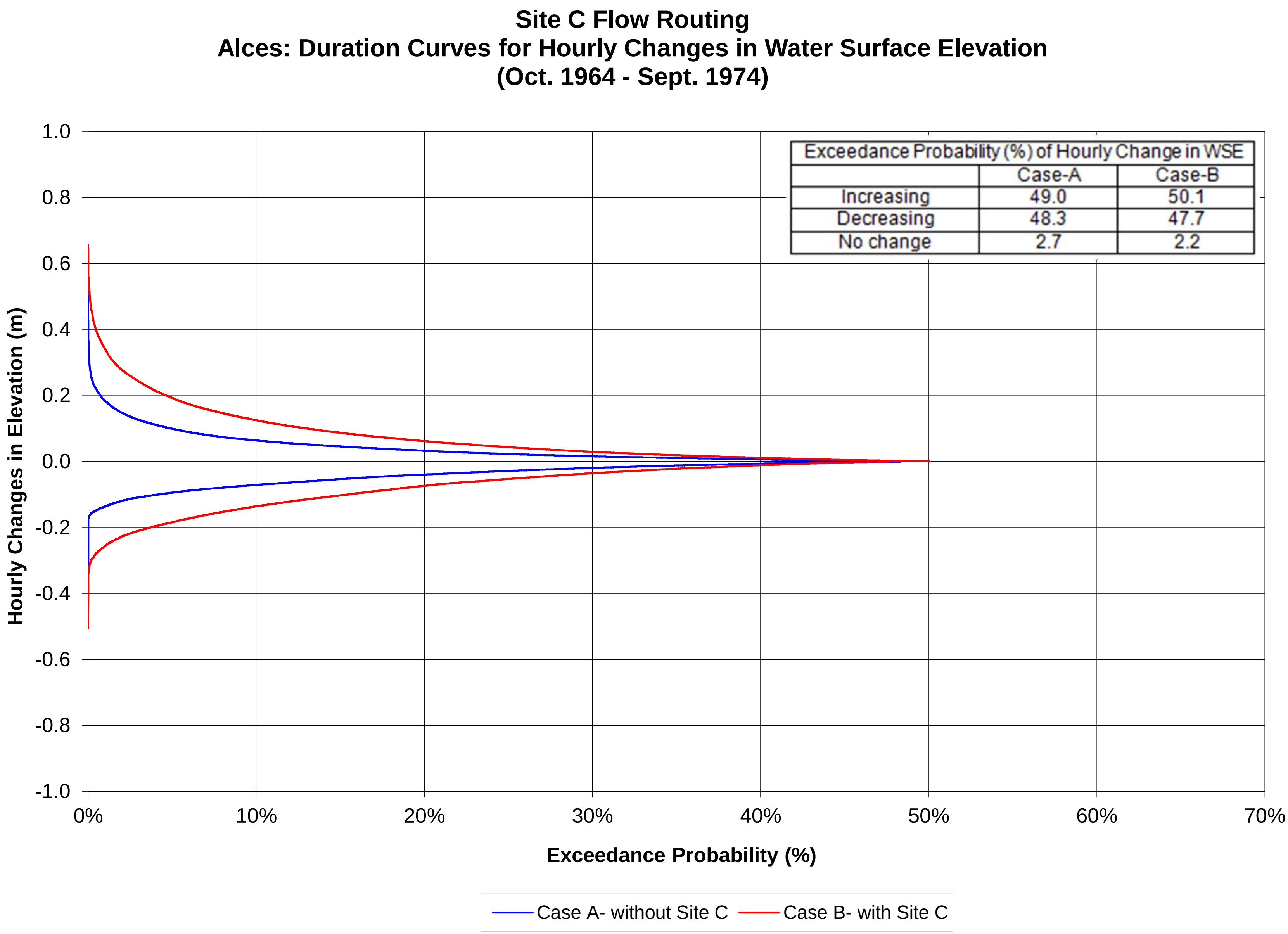
Site C Flow Routing
Site C Tailrace: Duration Curves for Hourly Change in Water Surface Elevation (WSE)
(Oct. 1964 - Sept. 1974)



Site C Flow Routing
Taylor: Duration Curves for Hourly Change in Water Surface Elevation (WSE)
(Oct. 1964 - Sept. 1974)

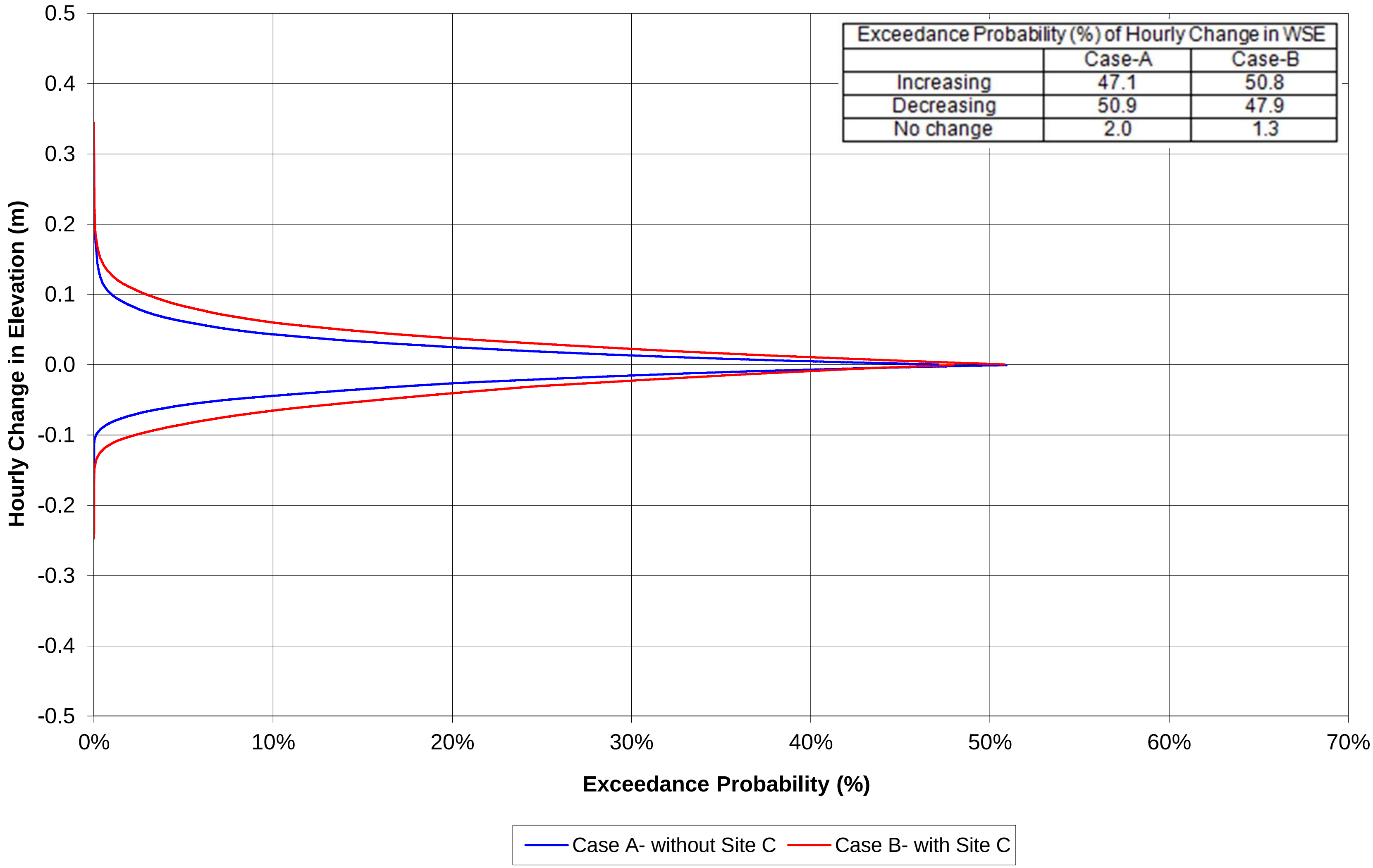


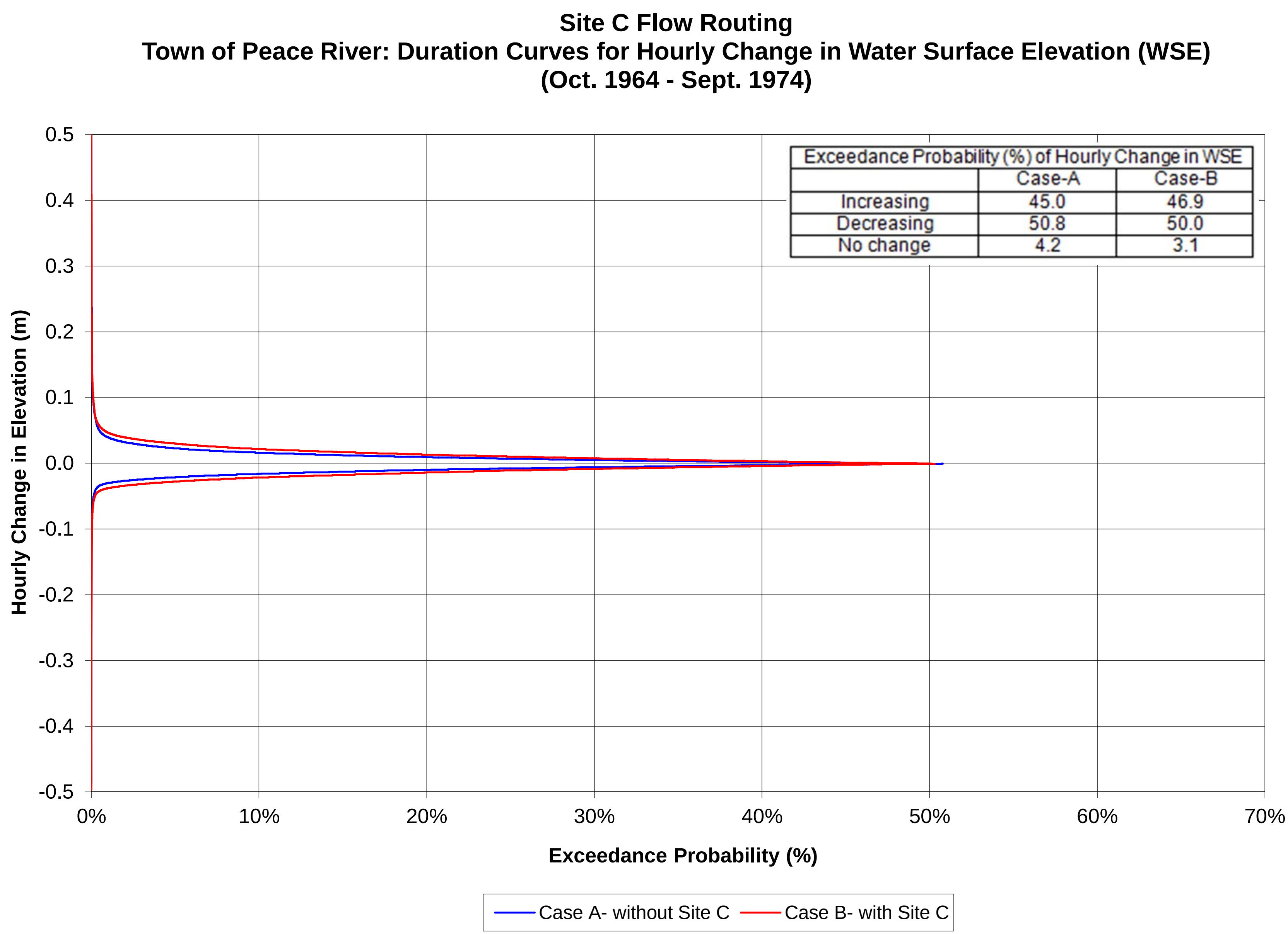
Exceedance Probability (%) of Hourly Change in WSE		
	Case-A	Case-B
Increasing	48.6	49.2
Decreasing	46.8	45.8
No change	4.6	5.0



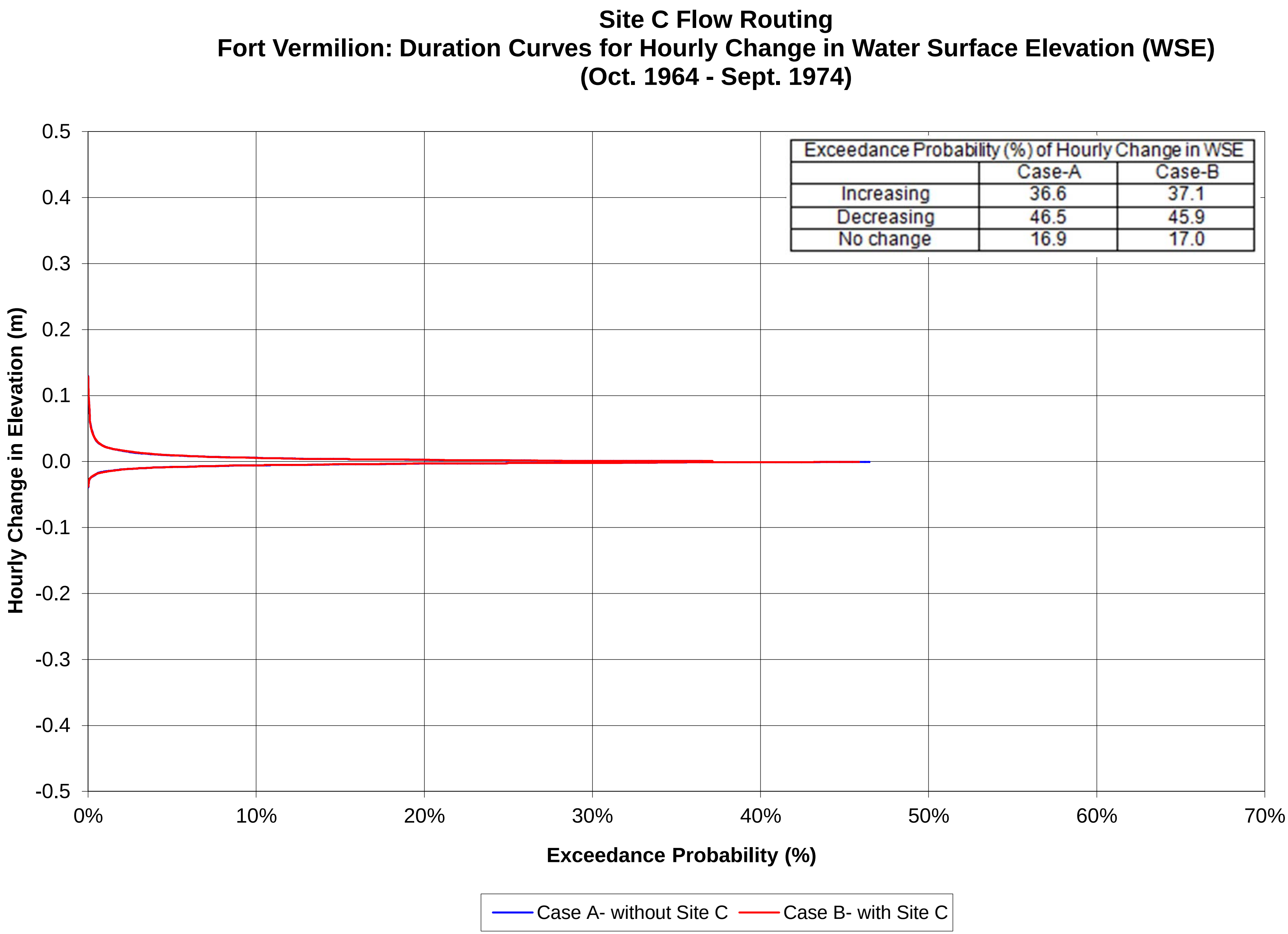
Site C Flow Routing
Alces: Duration Curves for Hourly Changes in Water Surface Elevation
(Oct. 1964 - Sept. 1974)
Exceedance Probability (%) of Hourly Change in WSE
Case-A
Case-B
Increasing
49.0
50.1
Decreasing
48.3
47.7
No change
2.7
2.2
Hourly Changes in Elevation (m)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0%
10%
20%
30%
40%
50%
60%
70%
Exceedance Probability (%)
Case A- without Site C
Case B- with Site C

Site C Flow Routing
Dunvegan: Duration Curves for Hourly Change in Water Surface Elevation (WSE)
(Oct. 1964 - Sept. 1974)

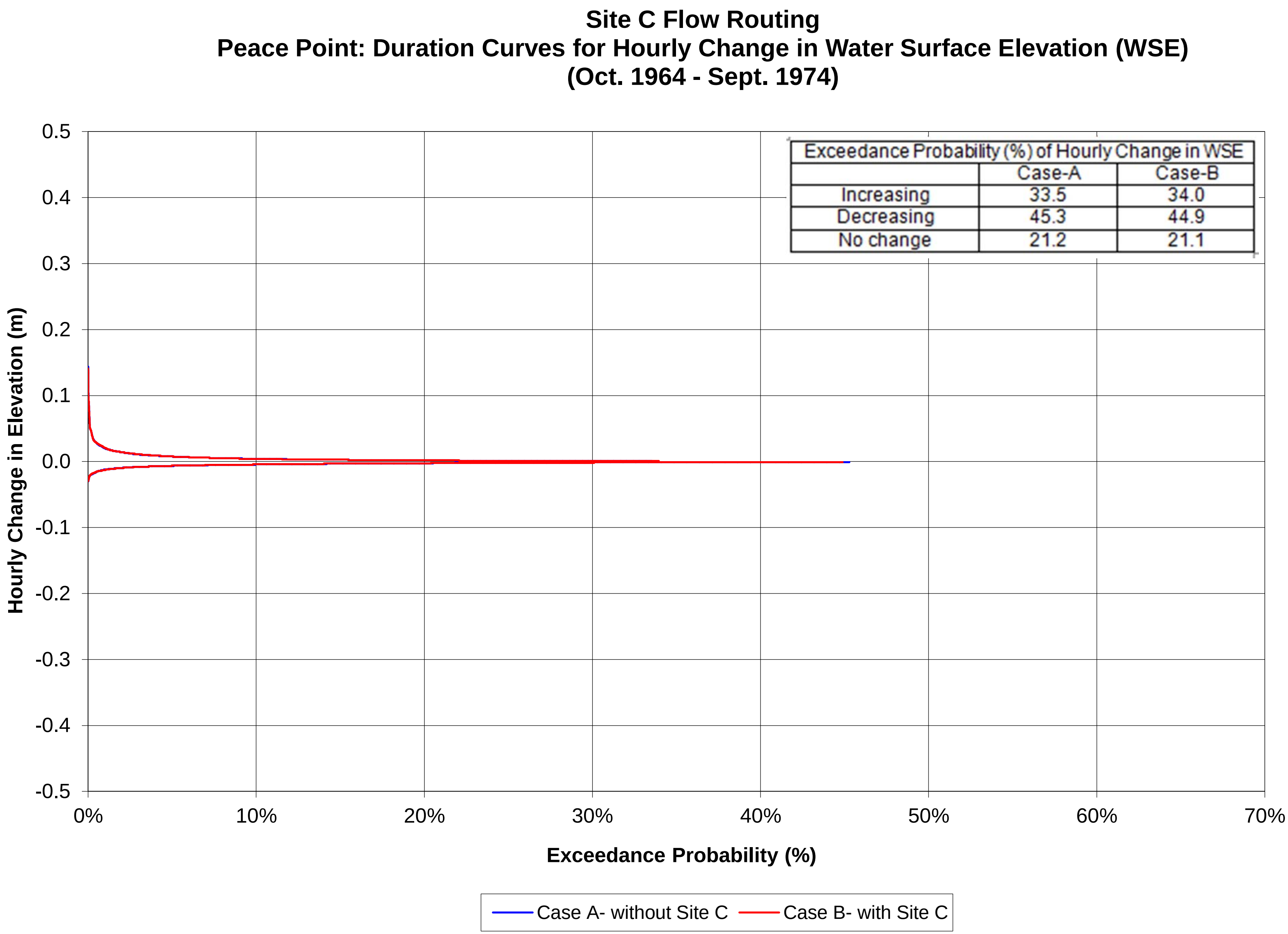




Site C Flow Routing
Town of Peace River: Duration Curves for Hourly Change in Water Surface Elevation (WSE)
(Oct. 1964 - Sept. 1974)
Exceedance Probability (%) of Hourly Change in WSE
Case-A
Case-B
Increasing 45.0 46.9
Decreasing 50.8 50.0
No change 4.2 3.1
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
Hourly Change in Elevation (m)
0%
10%
20%
30%
40%
50%
60%
70%
Exceedance Probability (%)
Case A- without Site C
Case B- with Site C



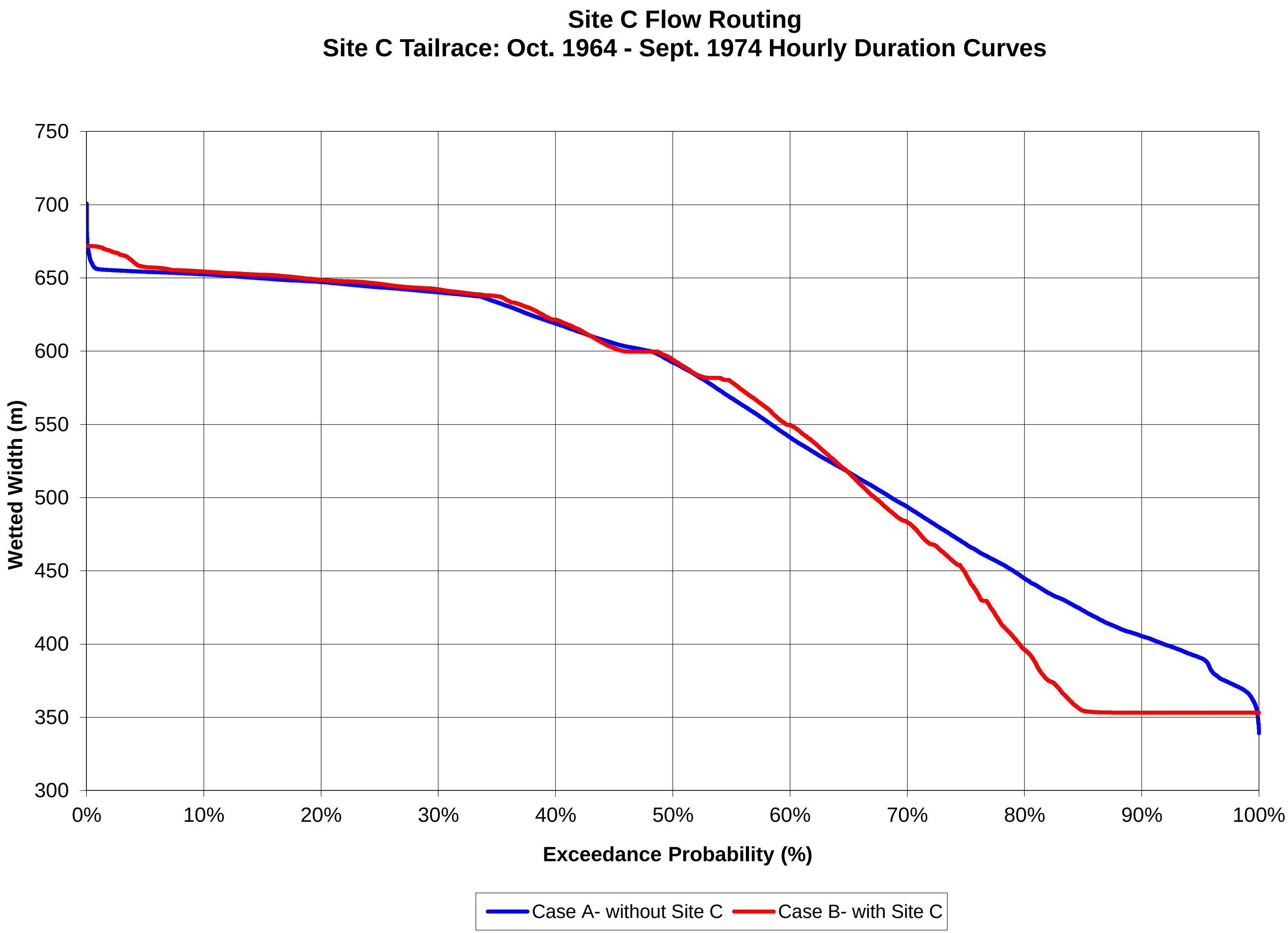
Exceedance Probability (%) of Hourly Change in WSE		
	Case-A	Case-B
Increasing	36.6	37.1
Decreasing	46.5	45.9
No change	16.9	17.0



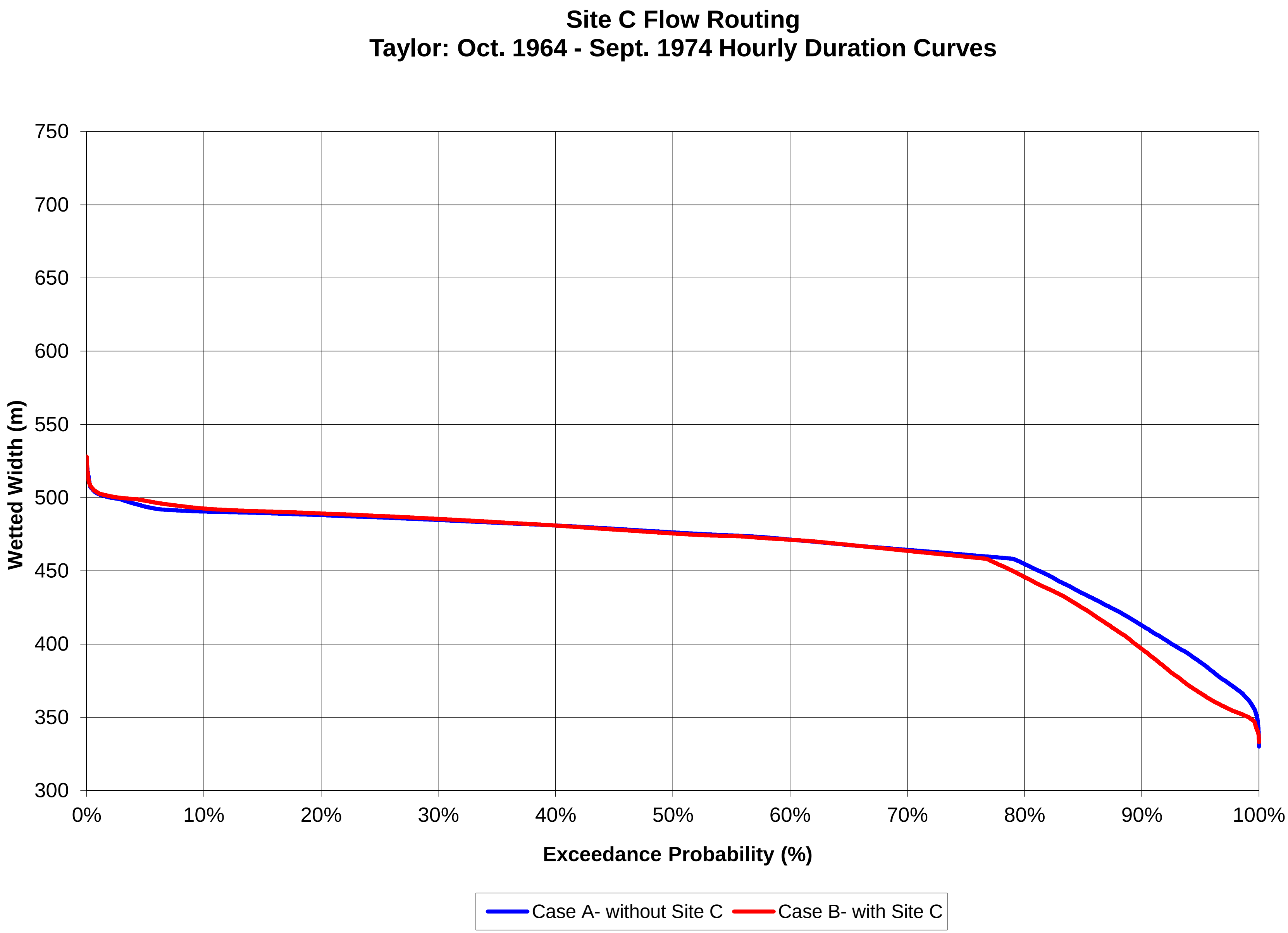
Exceedance Probability (%) of Hourly Change in WSE		
	Case-A	Case-B
Increasing	33.5	34.0
Decreasing	45.3	44.9
No change	21.2	21.1

APPENDIX – F

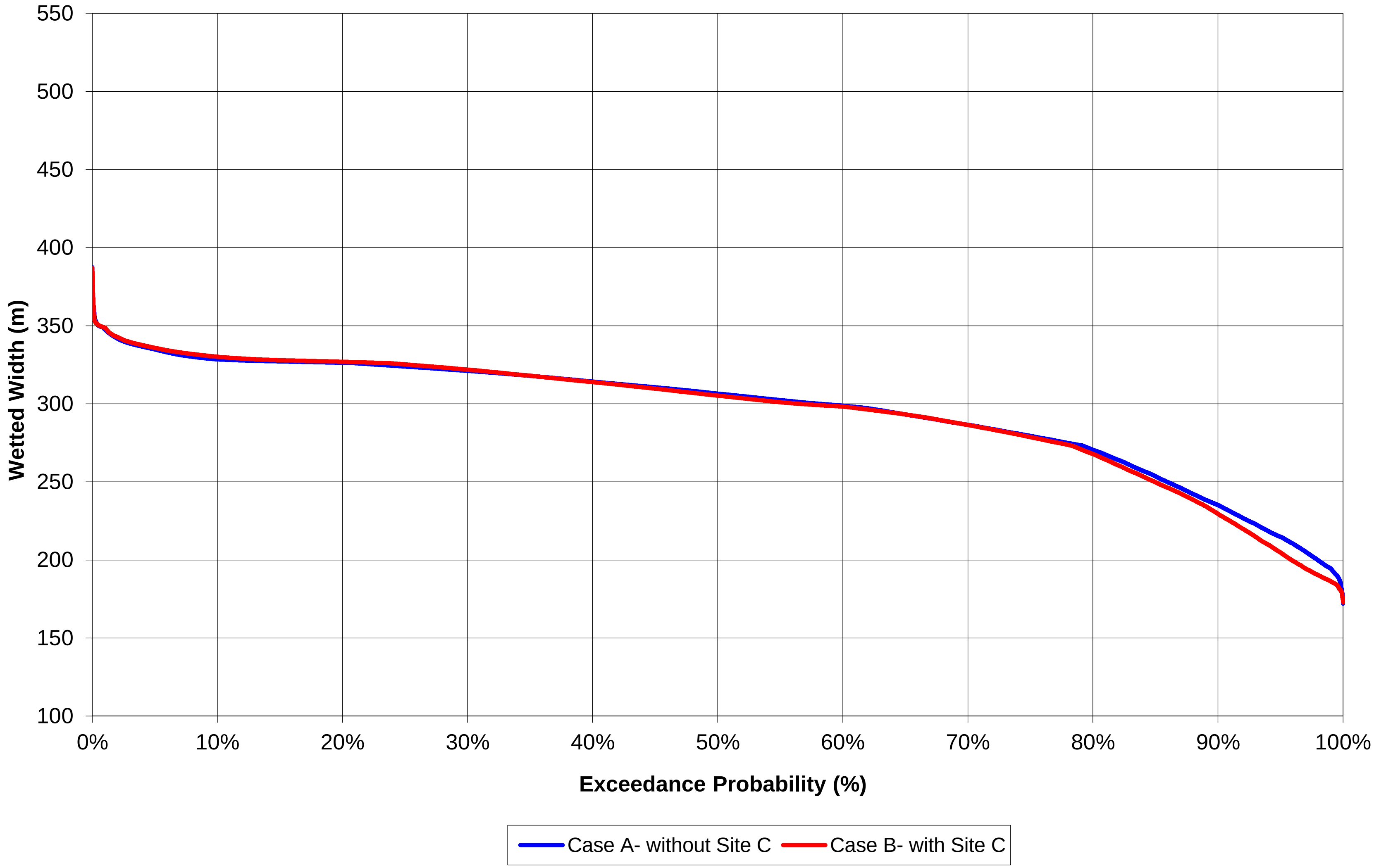
Hourly Wetted Width Duration Curves
(Case A and B)

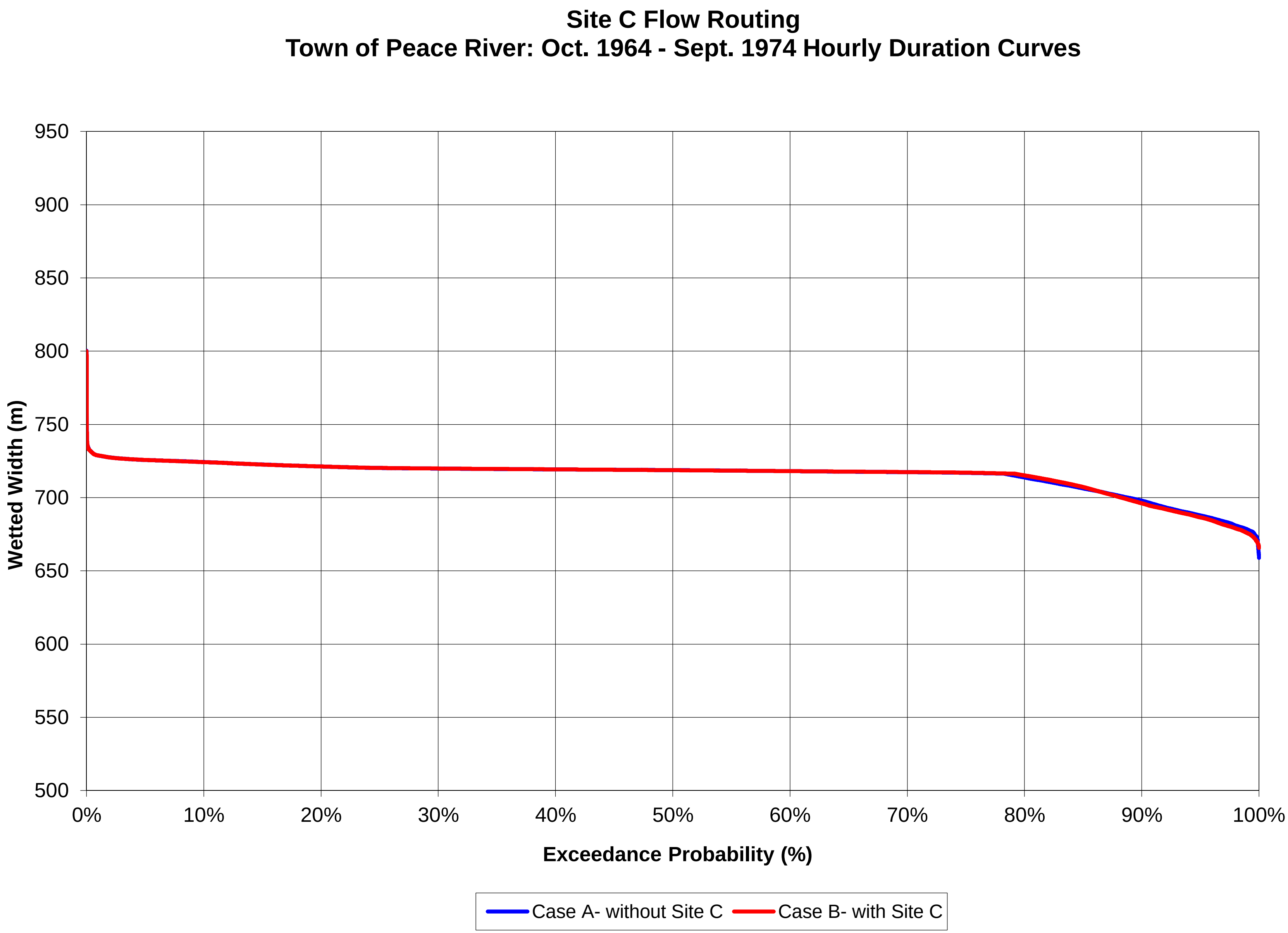


Site C Flow Routing
Site C Tailrace: Oct. 1964 - Sept. 1974 Hourly Duration Curves
Wetted Width (m)
750
700
650
600
550
500
450
400
350
300
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Exceedance Probability (%)
Case A- without Site C
Case B- with Site C


Site C Flow Routing
Taylor: Oct. 1964 - Sept. 1974 Hourly Duration Curves
Wetted Width (m)
750
700
650
600
550
500
450
400
350
300
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Exceedance Probability (%)
Case A- without Site C
Case B- with Site C

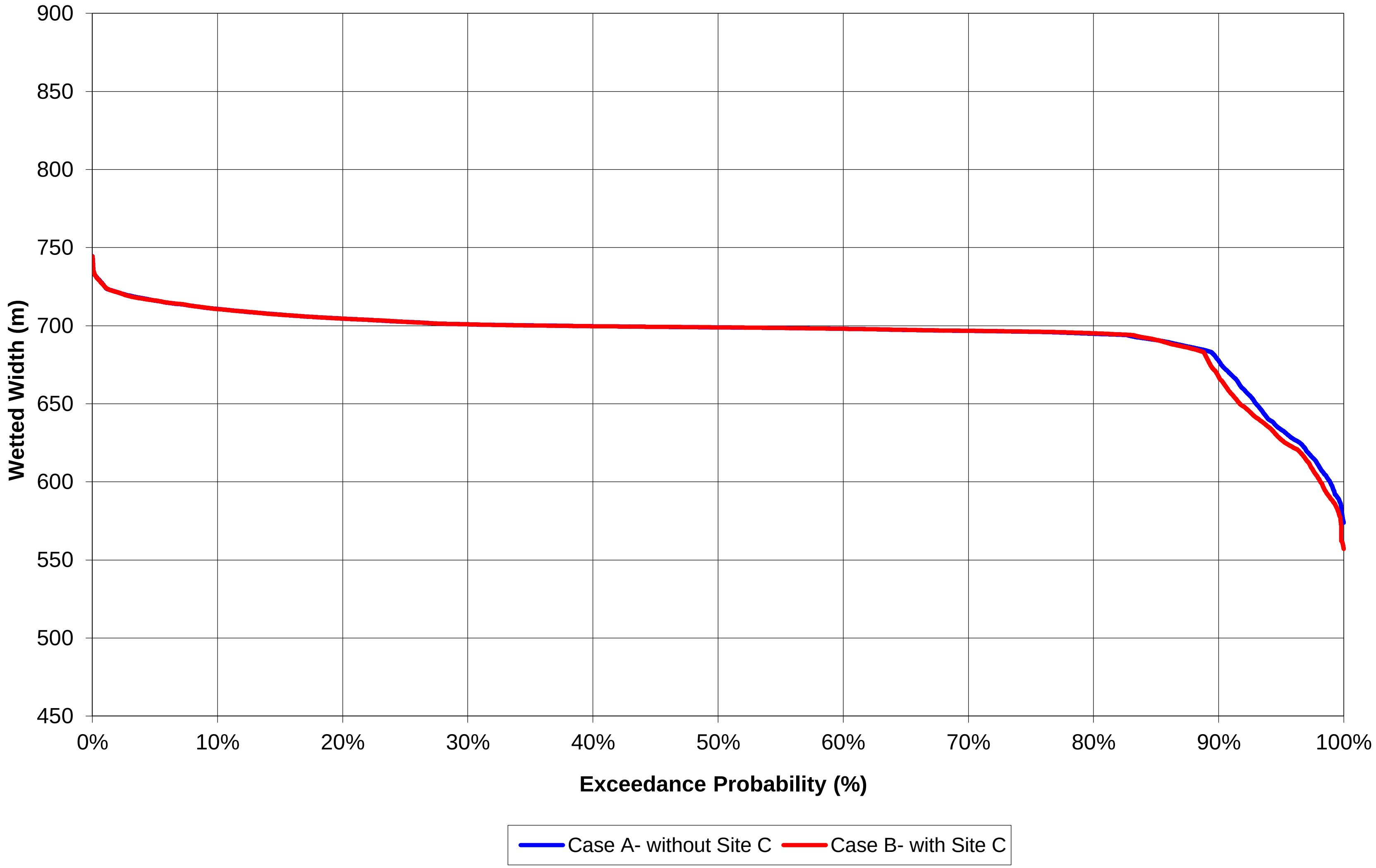
Site C Flow Routing
Alces: Oct. 1964 - Sept. 1974 Hourly Duration Curves





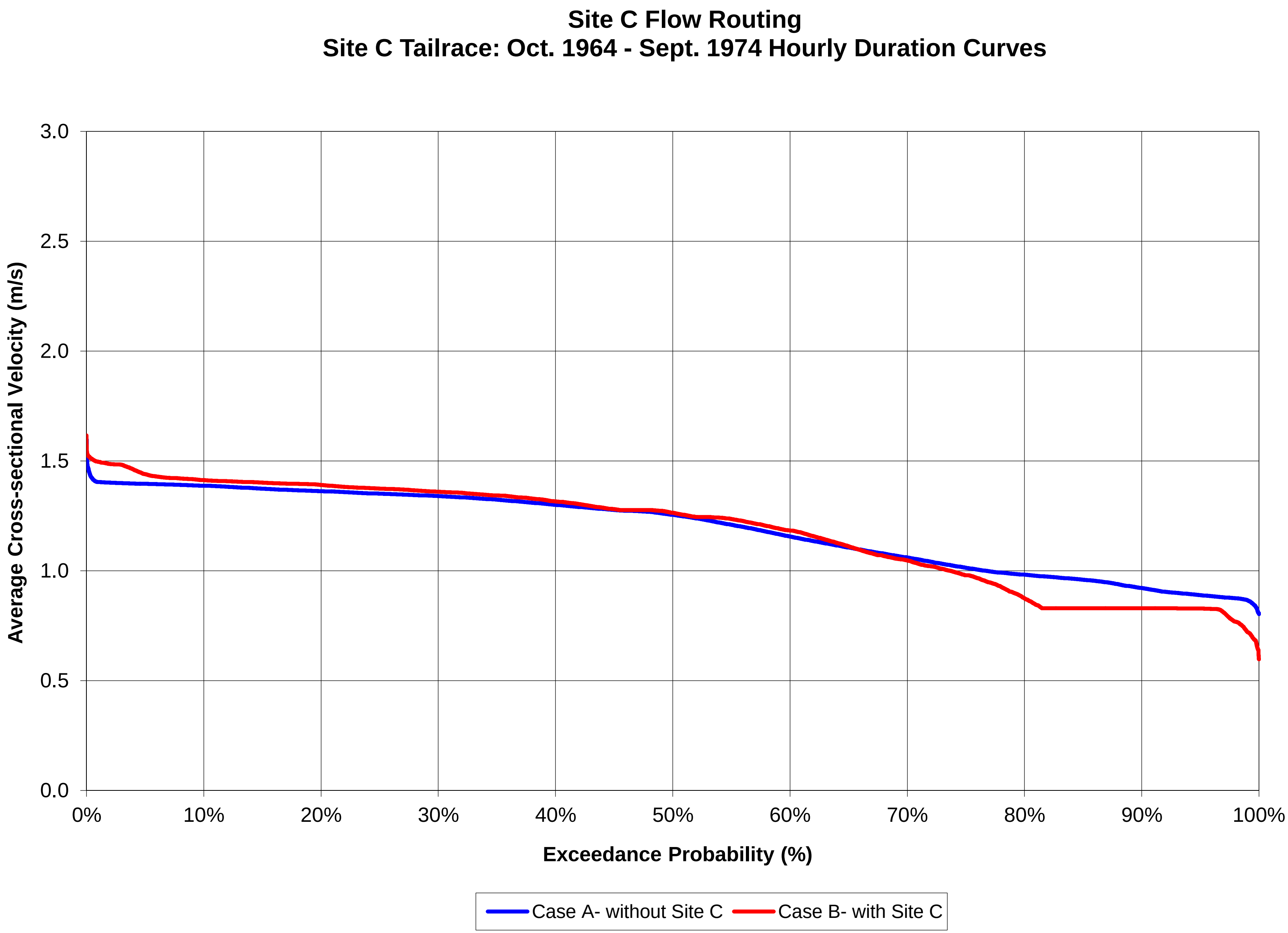
Site C Flow Routing
Town of Peace River: Oct. 1964 - Sept. 1974 Hourly Duration Curves
Wetted Width (m)
950
900
850
800
750
700
650
600
550
500
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Exceedance Probability (%)
Case A- without Site C
Case B- with Site C

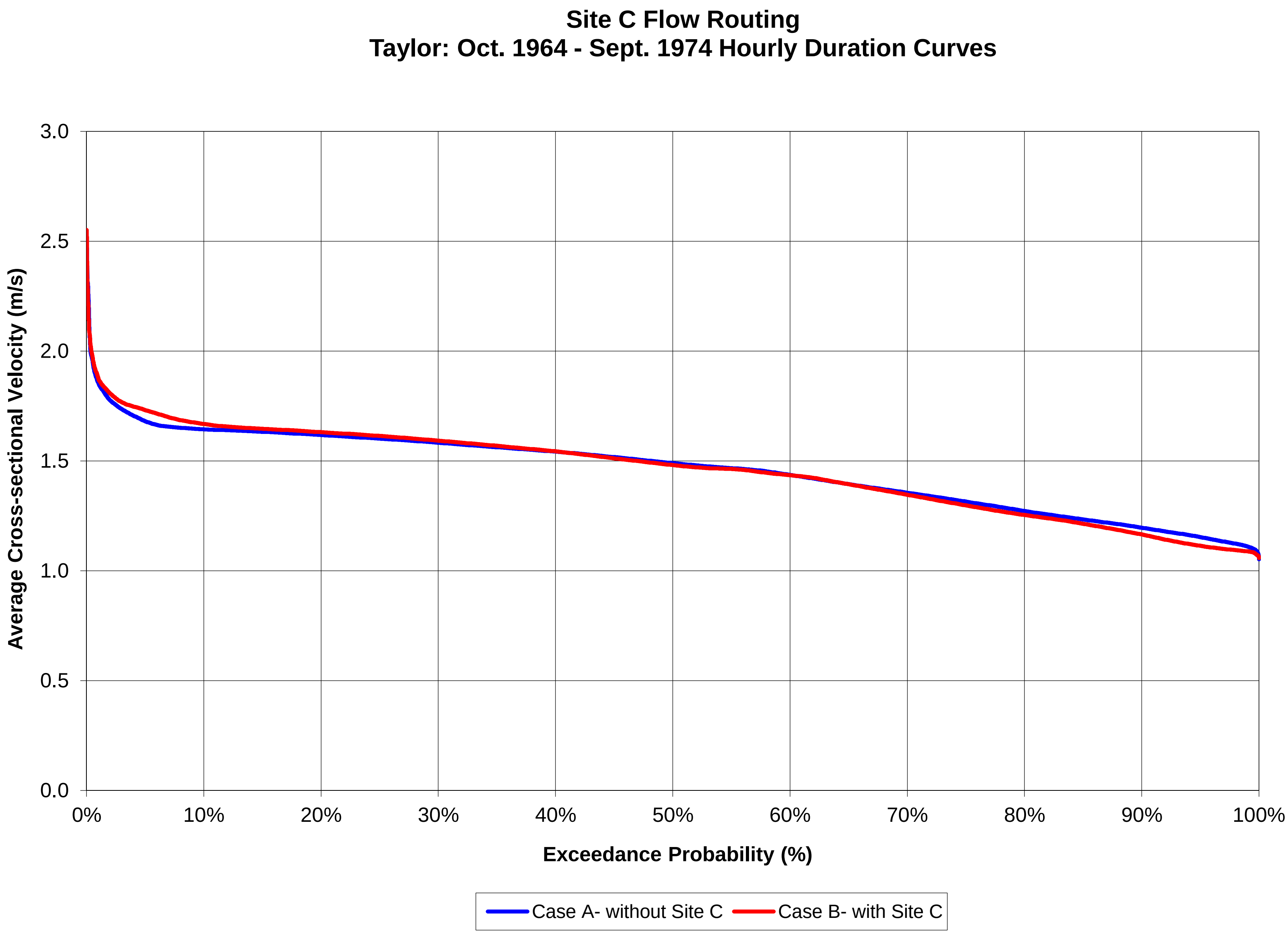
Site C Flow Routing
Peace Point: Oct. 1964 - Sept. 1974 Hourly Duration Curves



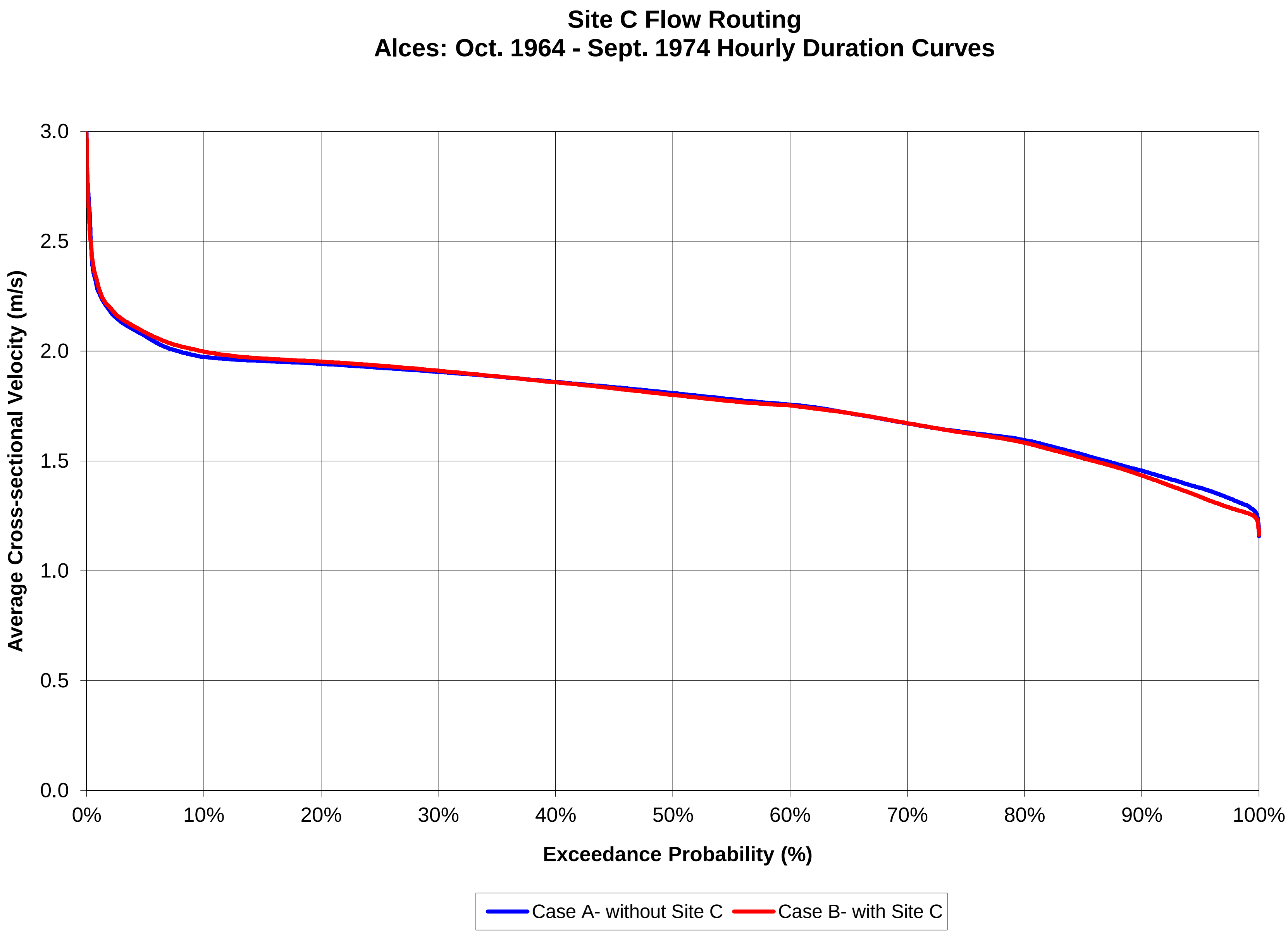
APPENDIX – G

Hourly Average Cross-Sectional Velocity Duration Curves (Case A and B)

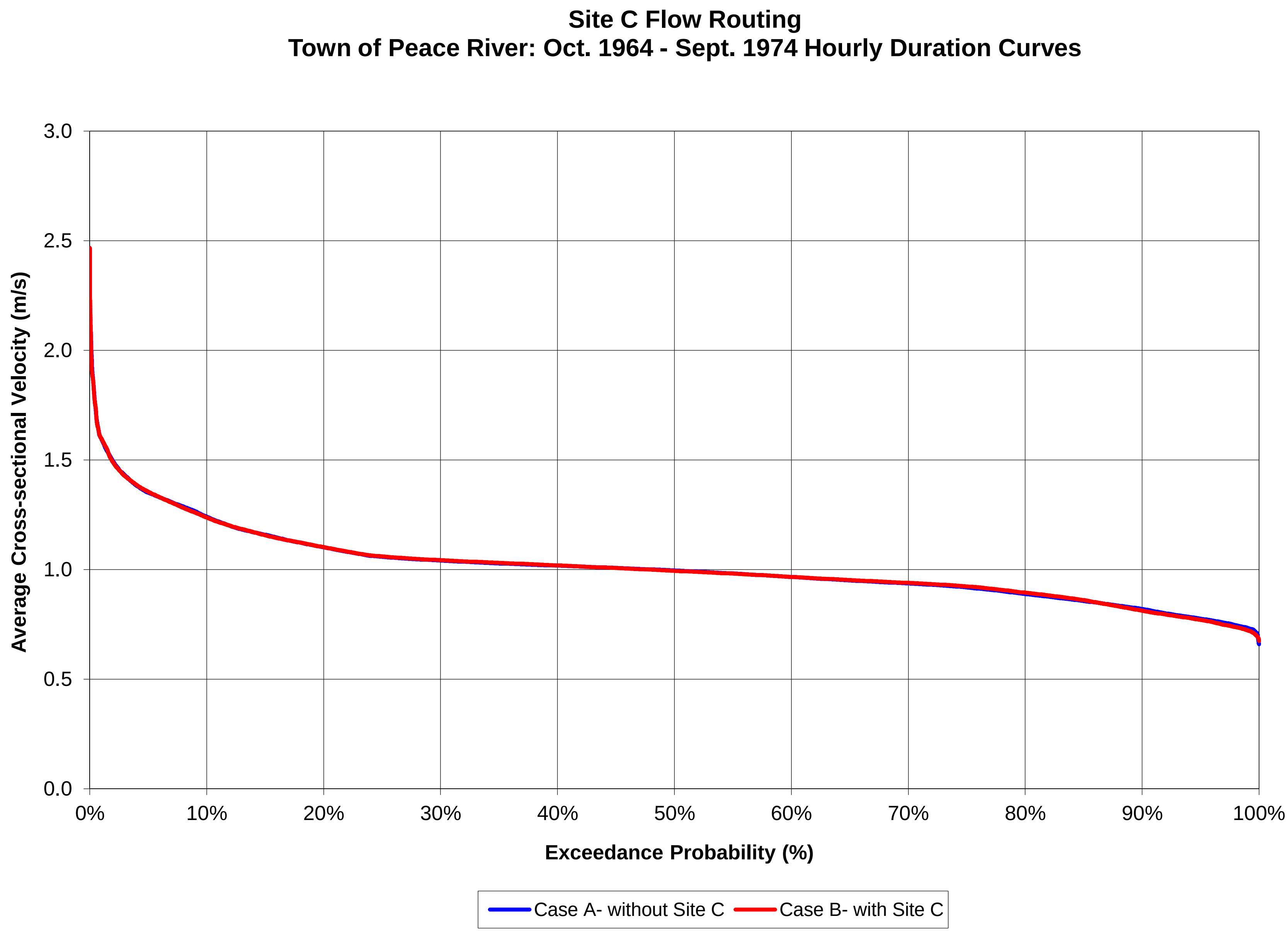

Site C Flow Routing
Site C Tailrace: Oct. 1964 - Sept. 1974 Hourly Duration Curves
Average Cross-sectional Velocity (m/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Exceedance Probability (%)
Case A- without Site C
Case B- with Site C



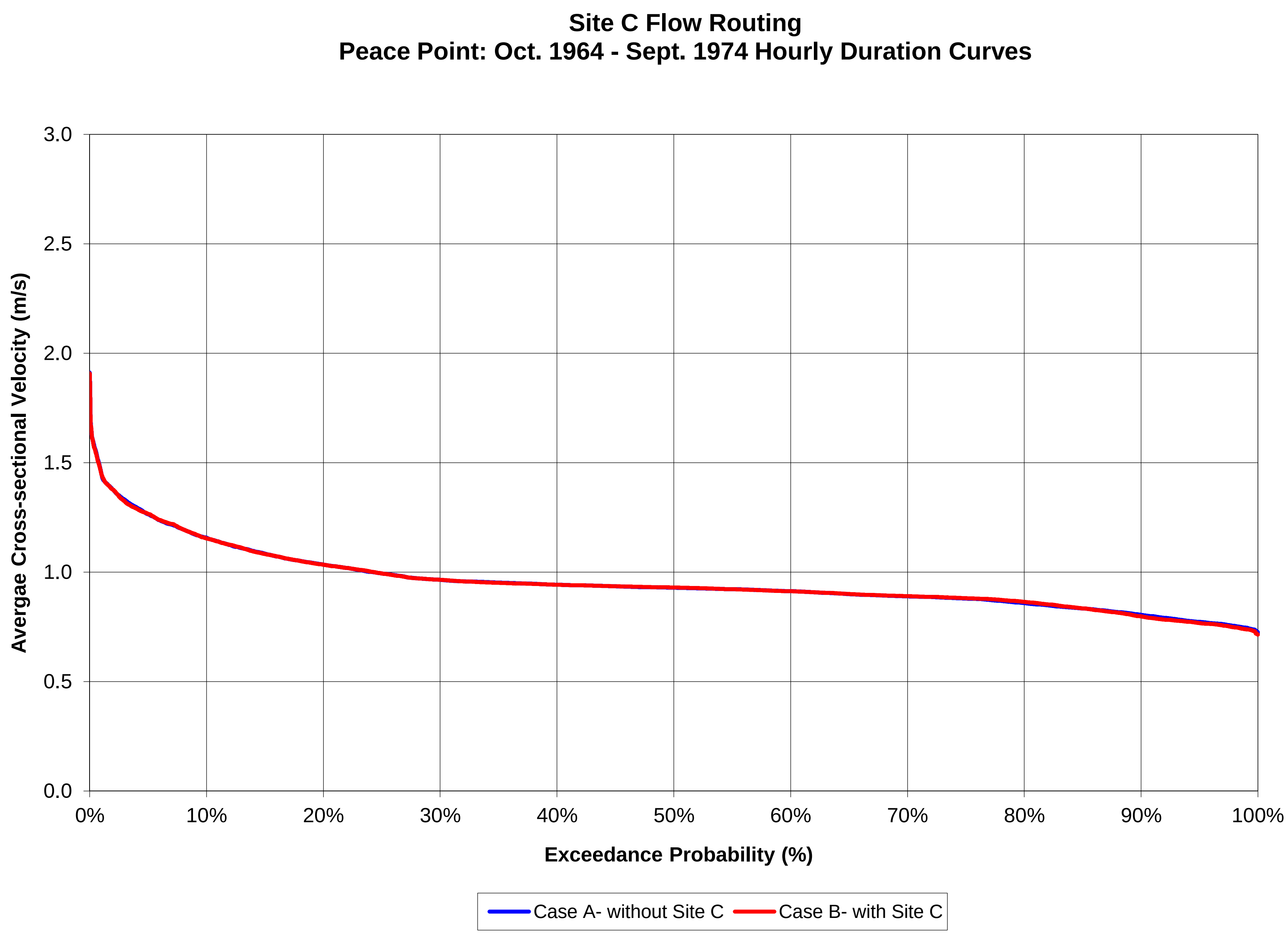
Site C Flow Routing
Taylor: Oct. 1964 - Sept. 1974 Hourly Duration Curves
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Average Cross-sectional Velocity (m/s)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Exceedance Probability (%)
Case A- without Site C
Case B- with Site C



Site C Flow Routing
Alces: Oct. 1964 - Sept. 1974 Hourly Duration Curves
Average Cross-sectional Velocity (m/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Exceedance Probability (%)
Case A- without Site C
Case B- with Site C



Site C Flow Routing
Town of Peace River: Oct. 1964 - Sept. 1974 Hourly Duration Curves
Average Cross-sectional Velocity (m/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Exceedance Probability (%)
Case A- without Site C
Case B- with Site C


Site C Flow Routing
Peace Point: Oct. 1964 - Sept. 1974 Hourly Duration Curves
Avergae Cross-sectional Velocity (m/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Exceedance Probability (%)
Case A- without Site C
Case B- with Site C

BC hydro
FOR GENERATIONS

Inter-office memo

To:	Site C Clean Energy Project Team	Date:	12 December 2012
From:	Faheem Sadeque and Morgan Garrett	File:	STC12MIS YM80003-3281

Subject: **Site C Clean Energy Project - Downstream Flow Modelling (2D)**

1.0 Introduction

Two-dimensional (2D) modelling of four reaches of the Peace River downstream of the proposed Site C dam has been carried out for the purpose of analyzing the influence of the Project on water levels and wetted areas within four specific side-channel areas thought to provide valuable fish habitat. The four areas include an 18 km reach between the Site C dam location and the Highway 97 bridge at Taylor as well as 7 to 13 km long reaches at Pallings Flat, Raspberry Island, and Many Islands in Alberta. The four study reaches are shown together in Appendix A on Figure A-1, and in more detail on Figures A-2 through A-5.

Some of the large islands in these reaches are never submerged during normal operation of the upstream dams on the Peace River. There are also a number of gravel bars that are exposed during low flow periods and submerged during higher flow periods creating wetting and drying of numerous side channels in these river reaches.

To assess water levels and wetted areas in these reaches, two-dimensional modelling is required due to the complex flow patterns within the numerous side channels. The modelling provides a better understanding of the wetting and drying patterns as the flow in the Peace River rises and falls.

2.0 Data Collection

Bathymetric and hydraulic data were collected to support the hydrodynamic modelling of the Peace River. Bathymetric data were primarily collected in July 2010 with additional data collection in June 2011. Table 2.1 summarizes the flow in the Peace River during hydraulic data collection at each of the four reaches. Hydraulic data collected included water surface profiles along various channels as well as flow and velocity data across several transects.

Table 2.1 Peace River Flow (m^3/s) during Hydraulic Data Collection

Reach	October 2010	June 2011
Site C dam to Taylor	500	850
Pallings Flat	800	2,050
Raspberry Island	1,025	1,920
Many Islands	-	2,650

3.0 Model Description

The modelling was carried out using the two-dimensional Telemac2D modelling software. Telemac2D uses an unstructured flexible mesh composed of triangular elements where the vertices of each triangle represent the computational points for the model. Figures A-6 to A-9 illustrate the computational mesh and bathymetry for each modelled reach.

The model mesh of the study area encompasses the main river channel, numerous side channels and gravel bars, large central islands, and a portion of the steep banks on either side of the river. Smaller channels in the study area are modelled with a finer mesh while larger river sections and overbank areas are represented with a coarser mesh. At each node of the mesh, the model calculates the water depth and two horizontal, depth-averaged velocity components for each time step in the simulation. By varying the mesh density in the models, the number of nodes is kept to a minimum resulting in a computationally efficient model that is suitable for simulation of the complex hydraulics within the reach.

The upstream boundary condition for each model is an inflow boundary where the Peace River flow for each scenario is entered into the model. The downstream boundary condition for each model is a steady state water level corresponding to the flow based on a rating curve of a Water Survey of Canada hydrometric gauge (e.g. 07FD002 Peace River near Taylor) or developed from the one-dimensional MIKE 11 model (described in Volume 2 Appendix D Surface Water Regime Technical Memos, Part 2 Downstream Flow Modelling (1D)). Tributary flows are added as input to the model as required (e.g. the Pine River flows were input to the Site C dam to Taylor model).

3.1 Site C Dam to Taylor

The Site C dam to Taylor modelled reach is approximately 18 km long, extending from the proposed Site C dam to the Highway 97 bridge at Taylor. The Peace River flows approximately 7 km from the proposed Site C dam location to Old Fort. Downstream of Old Fort, the river turns southeast and continues for another 11 km to the Highway 97 bridge at Taylor. The model mesh contains nearly 71,000 nodes with node spacing ranging from 1.6 m to 93 m.

3.2 Pallings Flat

The Pallings Flat study reach is almost 7 km long and is located about 13 km downstream of Taylor and about 31 km downstream of the proposed Site C dam. The model mesh contains about 25,500 nodes with the smallest spacing between nodes at about 4.5 m.

3.3 Raspberry Island

The Raspberry Island study reach is almost 13 km long and is located about 11 km downstream of the Pallings Flat study reach. The Raspberry Island model mesh contains about 27,000 nodes with the smallest spacing between nodes at almost 4.0 m. The confluence of the Kiskatinaw River (mean annual flow = 11 m^3/s) and the Peace River was represented in the 2D model mesh using available data.

3.4 Many Islands

The Many Islands study reach is about 7 km long and is located in Alberta almost 50 km downstream of the B.C. / Alberta border. The model mesh contains about 39,000 nodes with the smallest spacing between nodes at about 4.0 m.

4.0 Model Calibration

4.1 Site C Dam to Taylor

The Site C dam to Taylor model was calibrated and verified as follows.

- Modelled water surface extents were matched to water surface extents shown on aerial photography. The date of photographs and the corresponding flows in the Peace and Pine Rivers are listed in Table 4.1.

Table 4.1 Dates of Aerial Photographs used for Model Calibration and Corresponding Flows (Site C Dam to Taylor Reach)

Date of Aerial Photograph	Peace River Flow at Site C Dam (m^3/s)	Pine River Flow (m^3/s)
October 25-26, 2008	1,010	85
September 13, 2009	400	100
September 20, 2009	645	70
August 25, 2011	1,975	295
August 26, 2011	1,550	295
July 9, 2012	3,100	440

- The model was calibrated using hydraulic survey data collected on October 22 and 23, 2010, when the Peace River flow was between approximately 450 m^3/s and 550 m^3/s near Old Fort. The concurrent Pine River flow was approximately 180 m^3/s. The model was calibrated based on the following:
  - water surface profiles along four branches;
  - flow through six branches; and
  - velocity profiles along six transects.

- The model was calibrated using hydraulic survey data collected on June 4, 2011, when the Peace River flow was around 850 m^3/s near Old Fort and the Pine River flow was around 1,100 m^3/s. The model was calibrated as follows:
  - water surface profiles along three branches;
  - flow through ten branches ;
  - velocity profiles along ten transects.

The calibration results based on the aerial photos are shown in Appendix B on Figures B-1 to B-6; these figures indicate a very similar modelled water surface extent including the numerous gravel bars that are exposed at low flow in the Site C dam to Taylor reach.

Figure B-7 shows the location of the 2010 and 2011 surveyed water surface profiles and flow/ velocity transect locations used to calibrate the model. Figures B-8 to B-11 compare the surveyed and modelled water surface profiles from October 2010. Figures B-12 to B-17 compare the surveyed and modelled velocity profiles at the six locations surveyed in 2010. Table 4.2 summarizes the surveyed and modelled flow at the same six locations.

Table 4.2 Transect Flow (m^3/s) – October 2010

Transect	Surveyed	Modelled
OF1	445 - 460	479
OF2	488 - 499	471
OF3	0.6 - 1.1	1.4
OF4	18 – 21	13
T1	565 - 573	551
T2	324 - 330	313

As shown on the figures, the modelled water levels along the profiles are generally within 0.1 m of the recorded levels except some local differences in the range of 0.15 m to 0.2 m. The six velocity transects show a good match between simulated and recorded values. As listed in Table 4.2, the model was also able to replicate the splitting of the flow amongst the various side channels.

Figures B-18 to B-20 compare the modelled and surveyed water surface profiles from June 2011. Figures B-21 to B-30 compare the modelled and surveyed velocity profiles at the ten locations. Table 4.3 summarizes the surveyed and modelled flow at the same ten locations.

Table 4.3 Transect Flow (m^3/s) – June 2011

Transect	Surveyed	Modelled
SC1	717 - 720	714
SC2	126 - 127	126
SC3	843 - 916	848
OF1	843 - 861	852
OF2	778 - 841	823
OF3	15	22
OF4	71	113
OF5	763 - 776	734
TA1	32 – 34	27
TA2	2,024 – 2,046	1,962

As shown on the figures, the modelled water levels along the profiles are generally within 0.1 m of the recorded levels and the ten velocity transects show good agreement between simulated and recorded values. The discrepancies of the velocity magnitude are generally limited to within about 0.2 m/s. The model was also able to replicate the splitting of the flow amongst the various side channels as listed in Table 4.3. A discussion of uncertainties is presented in Section 7.0.

4.2 Pallings Flat

The Pallings Flat model was calibrated and verified as follows.

- Modelled water surface extents were matched to water surface extents shown on aerial photography. The dates of photographs and the corresponding flows in the Peace River are listed in Table 4.4.

Table 4.4 Dates of Aerial Photographs used for Model Calibration and Corresponding Flows (Pallings Flat Reach)

Date of Aerial Photograph	Peace River Flow at Pallings Flat (m^3/s)
September 22, 2010	400
August 25, 2011	2,270
August 26, 2011	1,840
July 9, 2012	3,535

- The model was calibrated using hydraulic survey data collected on October 23, 2010, when the Peace River flow in this reach was approximately 800 m^3/s. The model was calibrated based on the following:
  - water surface profiles along four branches;
  - flow through six branches; and,
  - velocity profiles along six transects.

- The model was calibrated using hydraulic survey data collected on June 3, 2011, when the Peace River flow in this reach was approximately 2,050 m^3/s. The model was calibrated based on the following:
  - water surface profiles along four branches;
  - flow through eight branches; and,
  - velocity profiles along eight transects.

The calibration results based on aerial photos are shown in Appendix C on Figures C-1 to C-4; these figures indicate a very similar modelled water surface extent including the numerous gravel bars that are exposed at low flow and side channels that are flooded during high flows.

Figure C-5 shows the locations of the 2010 and 2011 surveyed water surface profiles and flow/ velocity transect locations used to calibrate the model. Figures C-6 to C-9 compare the surveyed and modelled water surface profiles from October 2010. Figures C-10 to C-15 compare the surveyed and modelled velocity profiles at the six locations surveyed in 2010. Table 4.5 summarizes the surveyed and modelled flow at the same six locations.

Table 4.5 Transect Flow (m^3/s) – October 2010

Transect	Surveyed	Modelled
1	599 - 607	603
2	186 - 195	204
3	753 - 777	766
4	35 – 39	38
5	432 - 436	429
6	377 - 387	369

As shown on the figures, the modelled water levels along the profiles are generally within 0.1 m of the recorded levels except for a dip in the recorded data in Profile 3 (Figure C-8). The six velocity transects show a good match between simulated and recorded values. As listed in Table 4.5, the model was also able to replicate the splitting of the flow amongst the various side channels.

Figures C-16 to C-19 compare the modelled and surveyed water surface profiles from June 2011. Figures C-20 to C-27 compare the modelled and surveyed velocity profiles at the eight locations. Table 4.6 summarizes the surveyed and modelled flows at the same eight locations.

Table 4.6 Transect Flow (m^3/s) – June 2011

Transect	Surveyed	Modelled
1	1,115 – 1,200	1,161
2	872 - 898	894
3	1,396 – 1,809	1,681
4	269 - 270	300
5	989 – 1,421	1,311
6	623 - 691	743
7	1,498 – 2,194	2,053
8	144 - 173	153

As shown on the figures, the modelled water levels along the profiles are generally within 0.1 m of the recorded levels and the eight velocity transects show good agreement between simulated and recorded values. At transect 7 (Figure C-26), there is a discrepancy in the velocities between the two transect measurements. Additional measurements were not made to establish a consistent result. The model matched closely to the Recorded 'B' transect. The model was also able to replicate the splitting of the flow amongst the various side channels as listed in Table 4.6. A discussion of uncertainties is discussed in Section 7.0.

4.3 Raspberry Island

The Raspberry Island model was calibrated and verified as follows.

- Modelled water surface extents were matched to water surface extents shown on aerial photography. The date of photographs and the corresponding flows in the Peace River are listed in Table 4.7.

Table 4.7 Dates of Aerial Photographs used for Model Calibration and Corresponding Flows (Raspberry Island Reach)

Date of Aerial Photograph	Peace River Flow at Raspberry Island (m^3/s)
September 22, 2010	400
August 25, 2011	2,290
August 26, 2011	1,865
July 9, 2012	3,580

- The model was calibrated using hydraulic data collected on October 22, 2010, when the Peace River flow in this reach was approximately 1,025 m^3/s. The model was calibrated based on the following:
  - water surface profiles along two branches;
  - flow through six branches; and,
  - velocity profiles along six transects.

- The model was calibrated using hydraulic data collected on June 5, 2011, when the Peace River flow in this reach was approximately 1,920 m^3/s. The model was calibrated based on the following:
  - o water surface profiles along four branches;
  - o flow through eight branches; and,
  - o velocity profiles along eight transects.

The calibration results based on the aerial photos are shown in Appendix D on Figures D-1 to D-4; these figures indicate a very similar modelled water surface extent including the numerous gravel bars that are exposed at low flow and side channels that are flooded during high flows.

Figure D-5 shows the location of the 2010 and 2011 surveyed water surface profiles and flow/ velocity transect locations used to calibrate the model. Figures D-6 and D-7 compare the surveyed and modelled water surface profiles from October 2010. Figures D-8 to D-13 compare the surveyed and modelled velocity profiles at the six locations surveyed in October 2010. Table 4.8 summarizes the surveyed and modelled flow at the same six locations.

Table 4.8 Transect Flow (m^3/s) – October 2010

Transect	Surveyed	Modelled
1	27 - 28	28
2	970 - 996	985
3	850 - 855	850
4	145 - 152	140
5	47 - 50	45
6	102 - 104	95

As shown on the figures, the modelled water levels along the profiles are generally within 0.1 m of the recorded levels with the six velocity transects showing a good match between the simulated and recorded values. The model was also able to replicate the splitting of the flow amongst the various side channels as shown in Table 4.8.

Figures D-14 to D-17 compare the surveyed and modelled water surface profiles from June 2011. Figures D-18 to D-25 compare the surveyed and modelled velocity profiles at the eight locations. There was no survey carried out at the location of Transect 3 for the 2011 survey. Table 4.9 summarizes the surveyed and modelled flow at the same eight locations.

Table 4.9 Transect Flow (m^3/s) – June 2011

Transect	Surveyed	Modelled
1	111 - 115	108
2	1,824 – 1,840	1,825
4	467 - 476	477
5	191 - 193	191
6	273 - 285	300
7	1,387 – 1,487	1,421
8	89 - 93	91
9	194 - 205	210

As shown on the figures, the modelled water levels along the profiles are generally within 0.1 m of the recorded levels. The eight velocity transects show good agreement between the simulated and recorded values, although there are differences of up to 0.2 m/s to 0.4 m/s across transect 6 (Figure D-22). The modelled flow for this transect is within about 20 m^3/s of the recorded average value of 280 m^3/s (Table 4.9). As shown in Table 4.9, the model was also able to replicate the splitting of the flow amongst the various side channels. A discussion of uncertainties is discussed in Section 7.0.

4.4 Many Islands

The Many Islands model was calibrated and verified as follows.

- Modelled water surface extents were matched to water surface extents shown on aerial photography. The date of photographs and the corresponding flows in the Peace River are listed in Table 4.10.

Table 4.10 Dates of Aerial Photographs used for Model Calibration and Corresponding Flows (Many Islands Reach)

Date of Aerial Photograph	Peace River Flow at Many Islands (m^3/s)
August 26, 2011	2,200
July 9, 2012	3,590

- The model was calibrated using hydraulic data collected on June 2, 2011, when the Peace River flow in this reach was approximately 2,650 m^3/s. The model was calibrated based on the following:
  - water surface profiles along three branches;
  - flow through ten branches; and,
  - velocity profiles along ten transects.

The calibration results based on the aerial photos are shown in Appendix E on Figures E-1 and E-2; these figures indicate a very similar modelled water surface extent including the numerous side channels between the numerous islands.

Figure E-3 shows the location of the three surveyed water surface profiles and the ten flow and velocity transect locations surveyed in June 2011. Figures E-4 to E-6 compare the surveyed and modelled water surface profiles. Figures E-7 to E-16 compare the surveyed and modelled velocity transects at the ten locations. Table 4.11 summarizes the surveyed and modelled flow at the same ten locations.

Table 4.11 Transect Flow (m^3/s) – June 2011

Transect	Surveyed	Modelled
1	2,668 – 2,747	2,644
2	2,619 – 2,718	2,638
3	1,237 – 1,342	1,400
4	516 - 547	580
5	243 - 255	236
6	143 - 145	163
7	42 - 43	48
8	199 - 200	185
9	182 - 196	236
10	2,382 – 2,436	2,423

As shown on the figures, the modelled water levels along the profiles are generally within 0.1 m of the recorded levels except for the lower reach of Profile 3 (Figure E-6) where the difference is about 0.2 m through the several islands. The ten velocity transects show good agreement between the simulated and recorded values. In general, the model was also able to replicate the splitting of the flow amongst the various side channels. As discussed in Section 7.0, there is uncertainty in the flow measurements, particularly for relatively shallow side channels.

5.0 Simulation of Minimum and Maximum Turbine Flows

Inundation mapping was carried out for the four reaches using the two-dimensional model developed for this study. Steady-state (constant with time) minimum and maximum turbine flow scenarios from both Peace Canyon Dam and Site C dam were simulated. Minimum and maximum licensed turbine flows from Peace Canyon Dam are 283 m^3/s and 1,982 m^3/s, respectively. Minimum and maximum Site C turbine flows were assumed to be 390 m^3/s and 2,540 m^3/s, respectively.

In order to compare scenarios with and without the Project, estimates of gauged tributary inflows between the Peace Canyon Dam and the Site C dam (i.e. Halfway and Moberly Rivers) were added to Peace Canyon turbine flows for the case without the Project. In addition, flow estimates for gauged tributaries downstream of the Site C dam were considered in the model as a lateral inflow for both scenarios. To understand the near maximum possible difference in the Peace River flow regime with and without the Project, the minimum turbine flows from Peace Canyon were combined with high tributary flows (90th percentile) and the maximum turbine flows from Peace Canyon were combined with low tributary flows (10th percentile). The maximum difference between Peace Canyon and Site C minimum turbine flow scenarios would typically occur during the annual freshet when some of the Halfway and Moberly River flows could be captured in Site C reservoir. The largest difference between Peace Canyon and Site C maximum turbine flows scenarios would be expected to occur during periods of low tributary flow highlighting the difference in generation capacity of the Peace Canyon and Site C generating stations.

The flow scenarios for the inundation mapping are summarized in Table 5.1. Constant flows were used as input for these 2D model simulations. In reality, operational flows fluctuate according to the daily load pattern. The daily rise and fall of Peace River operational flows results in dynamic wetting and drying of channel areas. Therefore, the inundation maps presented in this memo are conservative (i.e. they illustrate the near maximum possible change due to the Project).

Table 5.1 Peace River Flows* for Inundation Mapping Scenarios

Reach	Without the Project (m^3/s)		With the Project (m^3/s)	
	Min[a]	Max[b]	Min	Max
Site C Dam to Taylor[c]	511	1,993	390	2,540
Pallings Flat	1,052	2,021	931	2,568
Raspberry Island[d]	1,211	2,022	1,090	2,569
Many Islands	1,268	2,022	1,147	2,569

* - Peace River flows are calculated at the upstream end of the reach.

a - Minimum Peace Canyon turbine flow is combined with 90th percentile flow from tributaries between the Peace Canyon Dam and the Site C dam.

b – Maximum Peace Canyon turbine flow is combined with 10th percentile flow from tributaries between the Peace Canyon Dam and the Site C dam.

c – Pine River flows are considered as lateral inflows.

d – Kiskatinaw River flows are considered as lateral inflows.

Inundation maps comparing the water surface extent for the minimum and maximum turbine flow scenarios with and without the Project are shown in Appendix F, Figures F-1 to F-5.

For the Site C dam to Taylor reach, the main difference in water surface extent between the minimum flow scenarios with and without the Project is in the side channels near Old Fort which are partially dry in the case with the Project. The water surface extents for the maximum flow scenarios with and without the Project are similar except for a few side channels that are inundated near Old Fort and below the Pine River confluence for case with the Project.

For the three downstream reaches, there is very little difference in water surface extent between the minimum flow scenarios with and without the Project other than small areas of some gravel bars that are exposed for the case with the Project. There is almost no difference in water surface extent between the maximum flow scenarios with and without the Project other than a couple of small side channels that are wetted in the Many Islands reach for the case with the Project. The flow scenarios presented in this memo extend beyond the lower range of available data and imagery used for model development and calibration at Many Islands.

6.0 Relationship between Peace River Flow and Wetted Area in the Site C Dam to Taylor Reach

Peace River flows were modelled for the Site C dam to Taylor reach to develop a relationship between the Peace River flow and wetted area. Forty six scenarios were simulated with 50 m^3/s increments of Peace River flow from 300 m^3/s to 2,540 m^3/s. An additional four scenarios were simulated between 283 m^3/s to 425 m^3/s for a more precise relationship at lower flows. The concurrent Pine River flow was assumed to be at the annual average flow of 200 m^3/s. Shapefiles for the water surface extent were extracted from 2D model steady-state simulation results to calculate wetted area for each flow.

Average Peace River flow is roughly 1,000 m^3/s near Old Fort. Therefore, initial conditions for simulating the above flow scenarios in the model were developed with a flow of 1,000 m^3/s. Modelled flows were held constant for 24 hours to obtain steady-state conditions. Flows less than 1,000 m^3/s resulted in draining of some of the side channels, while flows above 1,000 m^3/s inundated additional areas. Some side channels show ponded areas (i.e. inundated regions that are disconnected from the main river) for low flows at the end of the 24-hour simulation. Connected inundated areas were calculated for each flow scenario. The modelled ponded areas, which are sensitive to assumed initial conditions and the duration of the steady-state simulations, were calculated separately.

Figure G-1 in Appendix G shows the relationship between Peace River flow and wetted area for the Site C dam to Taylor reach, with and without modelled ponded areas for flows in the range of 283 m^3/s to 2,540 m^3/s. The relationship is generally smooth with some inflection points where additional side channels and/or shoreline areas become inundated.

In addition, a separate flow vs. wetted area relationship was developed for the Old Fort side channels. Figure G-2 shows the region considered to develop this relationship. The Peace River flow vs. wetted area curve at Old Fort shown in Figure G-3 indicates abrupt changes in slope around 500 m^3/s and 1,900 m^3/s. Figures G-4, G-5, and G-6 show the wetting conditions in the Old Fort Side channel area for Peace River flows around 400 m^3/s, 500 m^3/s and 1,900 m^3/s, respectively. Side channels 1, 2, 3 and 4 were found to connect to the main river at Peace River flows of about 400 m^3/s, 450 m^3/s, 800 m^3/s and 2,500 m^3/s, respectively.

7.0 Uncertainties

Although the 2D models presented in this memo are well calibrated based on available data, there are several sources of error that result in uncertainties with the modelling results. The error sources include the following:

- The largest source of uncertainty is the dynamic nature of the river as the bed level in the side channels and along the banks of the main channel can change from year to year due to large flows and the sediment input from the tributaries. For example, the bed elevations of one particular side channel in the Palling's Flat reach changed substantially between 2009 and 2011 as shown by available photos. Also, vegetation growth in the side channel can vary from year to year affecting the depth and magnitude of flow. Since the model was calibrated based on imagery and data available at the time of the study, the models may not be representative of local conditions in some areas in future years.

- The model of the Site C dam to Taylor reach was calibrated based on data at various flows in the range of approximately 400 m^3/s to 3,100 m^3/s. Modelling flows outside the range of calibration information may introduce errors in the results.

- The models of the Pallings Flat and Raspberry Island reaches were calibrated based on substantially more calibration data at various flows than the Many Islands reach. As a result, the confidence in the model calibration of Pallings Flat and Raspberry Island is higher for a wider range of flows compared to Many Islands. Modelling flows outside the range of calibration information may introduce potential errors in the results.

- To get reliable results when measuring the channel velocities and flows with Acoustic Doppler Current Profiler (ADCP), at least two transects are made. If the velocity profiles and flow estimates differ, additional passes are generally made. For some of the transects in the study reaches, additional field measurements would have improved the confidence in surveyed results. For most surveyed transects, there is agreement between the two sets of measurements that were made.

- Some side channels in the study reaches did not have detailed bathymetry data taken during the field surveys thereby reducing the accuracy of the model in these areas. In many side channels, including channels with survey data, the bathymetry was refined using imagery taken during low flow.

- The near shore topography was partially derived from LiDAR data which typically has a vertical accuracy of about +/- 0.2 m in clear, open ground. However, the accuracy diminishes with the level of vegetation.

- Water Survey of Canada flow estimates could be in error by +/-5% or more which could affect the aerial photo calibration results.

As stated above, the 2D models are well calibrated based on available data. The 2D models are generally reliable for relative comparisons of minimum and maximum turbine flow scenarios with and without the Project.

8.0 Conclusions

1. The 2D models developed and calibrated in this study can be used to aid in aquatic habitat assessment of operational scenarios with and without the Project.

2. The simulation of minimum and maximum turbine flows and corresponding maps illustrating the surface water extent suggest the following:
   a. In the Site C dam to Taylor reach, the main difference in water surface extent between the minimum flow scenarios with and without the Project is in the side channels near Old Fort which are partially dry for the case with the Project. The water surface extents for the maximum turbine flow scenario are similar with and without the Project except for a few side channels that are inundated near Old Fort and below the Pine River confluence for the case with the Project but not for the case without the Project.
   b. In the three downstream reaches there is very little difference in water surface extent between the minimum turbine flow scenarios with and without the Project other than relatively small areas of some gravel bars that are exposed for the scenario with the Project. For the maximum turbine flow scenario, there is almost no difference with and without the Project with the exception of a couple of small side channels that are inundated for the scenario with the Project in the Many Islands reach.

3. A relationship between Peace River flow and wetted area for the Site C dam to Taylor reach was developed using the model results for flows in the range of 283 m^3/s to 2,540 m^3/s. The relationship is generally smooth with some inflection

points where additional side channels and/or shoreline areas become inundated. An additional curve was developed to show the relation between Peace River flow and Old Fort side channel wetted area.

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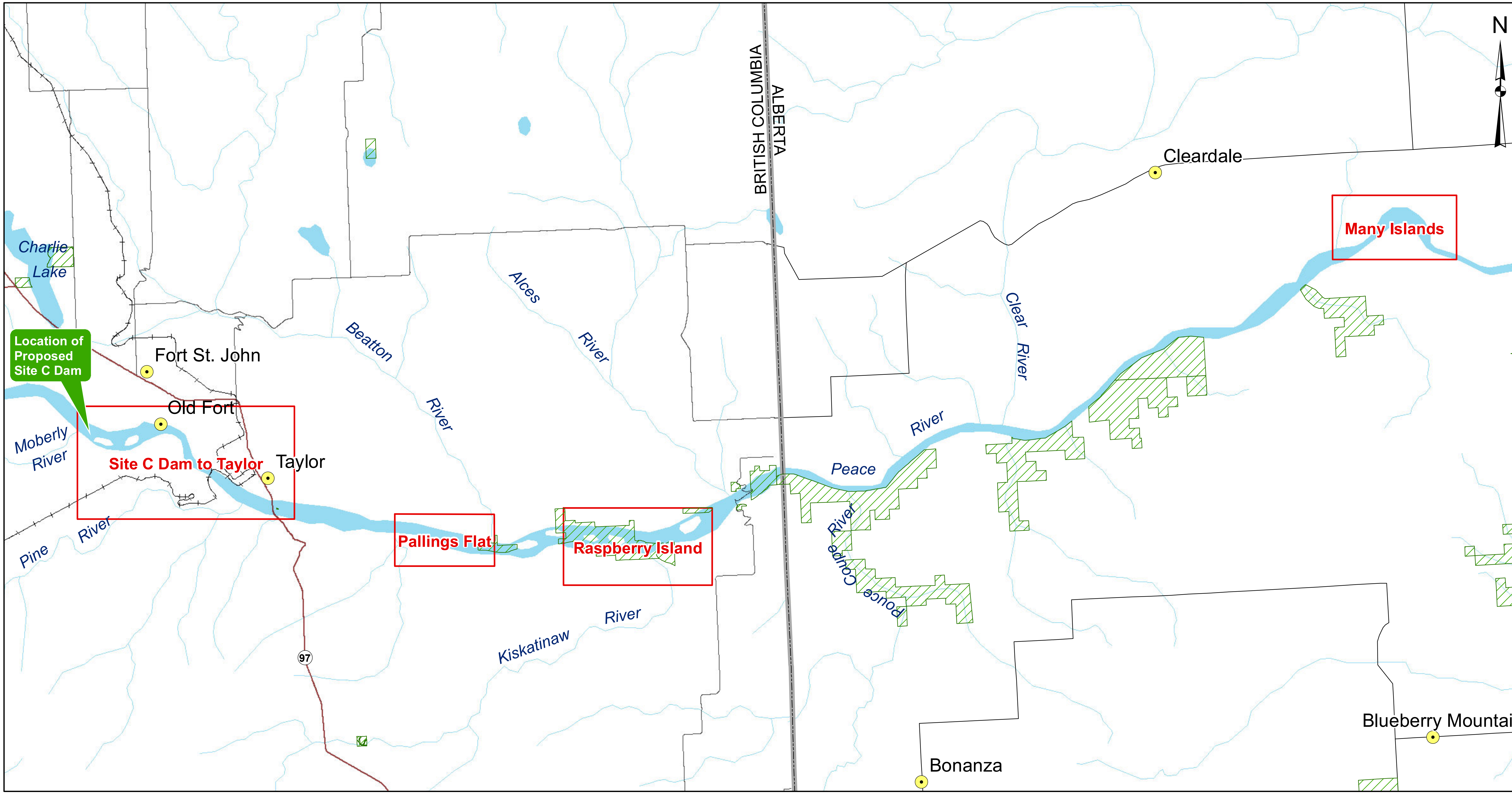
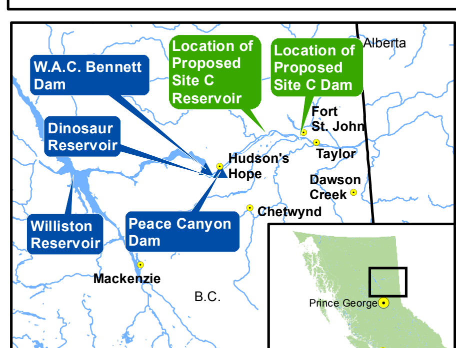
Attachments
Appendix A Maps of 2D Modelling Study Reaches
Appendix B Site C Dam to Taylor Reach – Calibration Figures
Appendix C Pallings Flat Reach – Calibration Figures
Appendix D Raspberry Island Reach – Calibration Figures
Appendix E Many Islands Reach – Calibration Figures
Appendix F Maps Comparing Water Surface Extents for Minimum and Maximum Turbine Flows
Appendix G Site C Dam to Taylor Reach – Flow-Wetted Area Relationship

Appendix A

Maps of 2D Modelling Study Reaches





Map Notes:
1. Datum: NAD83
2. Projection: UTM Zone 10N
3. Base Data: Province of B.C.

Legend

- Reach Map Extent
- Existing Road
- Existing Highway
- Existing Railway
- City/District Municipality
- Protected Areas, Provincial Parks, Regional Parks, and Ecological Reserves
- Provincial/Territory Boundary

1:310,000

0 — 10 km

BC hydro

SITE C CLEAN ENERGY PROJECT

Figure 1: Selected Peace River Reaches for 2D Modelling for Side Channel Habitat Assessment

Date	Dec. 13, 2012	DWG NO	1016-C14-B6126	R 0

Construction of the Site C Clean Energy Project is subject to required regulatory approvals including environmental certification

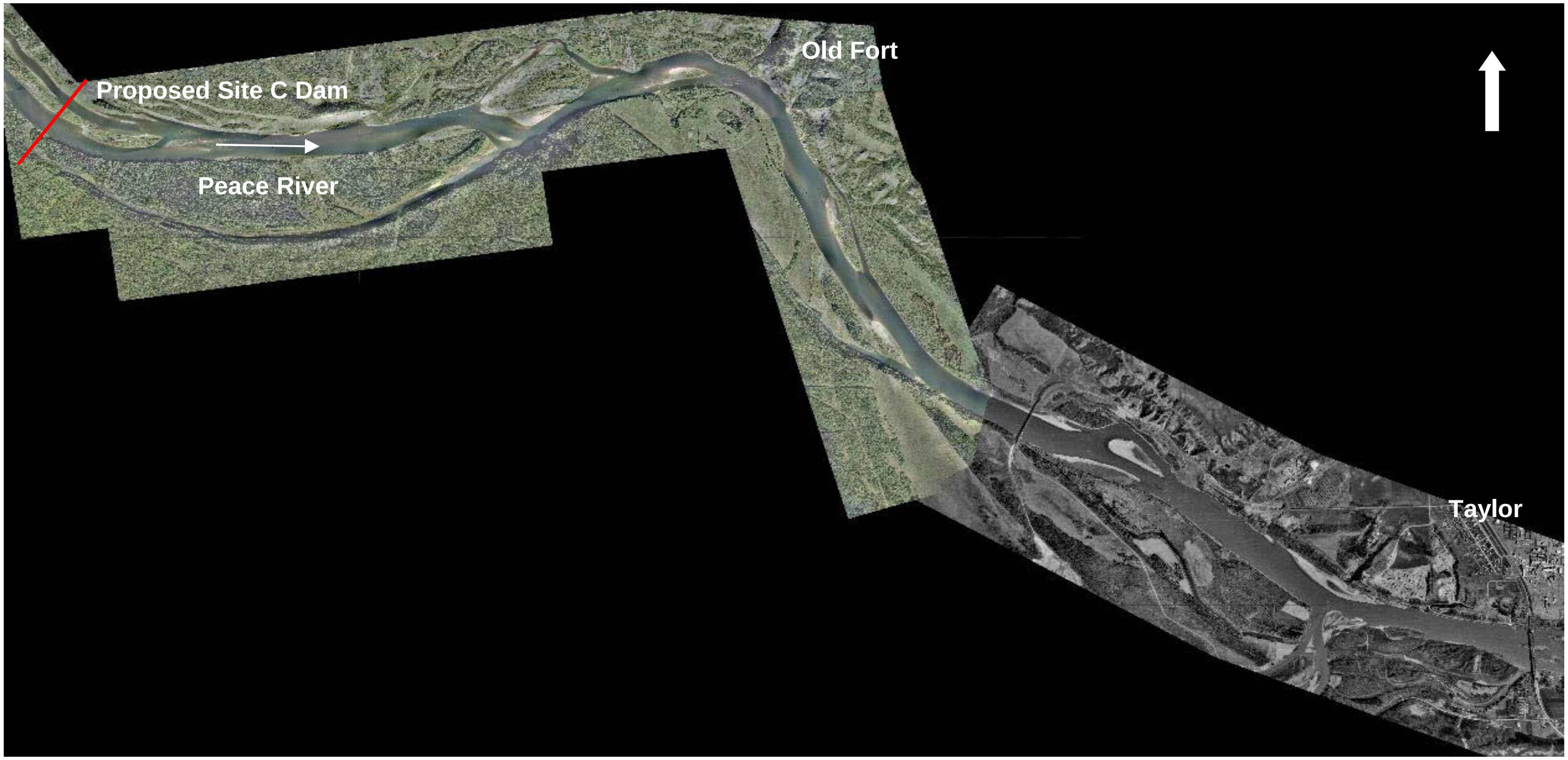


Figure A-2 - Site C Dam to Taylor Study Area

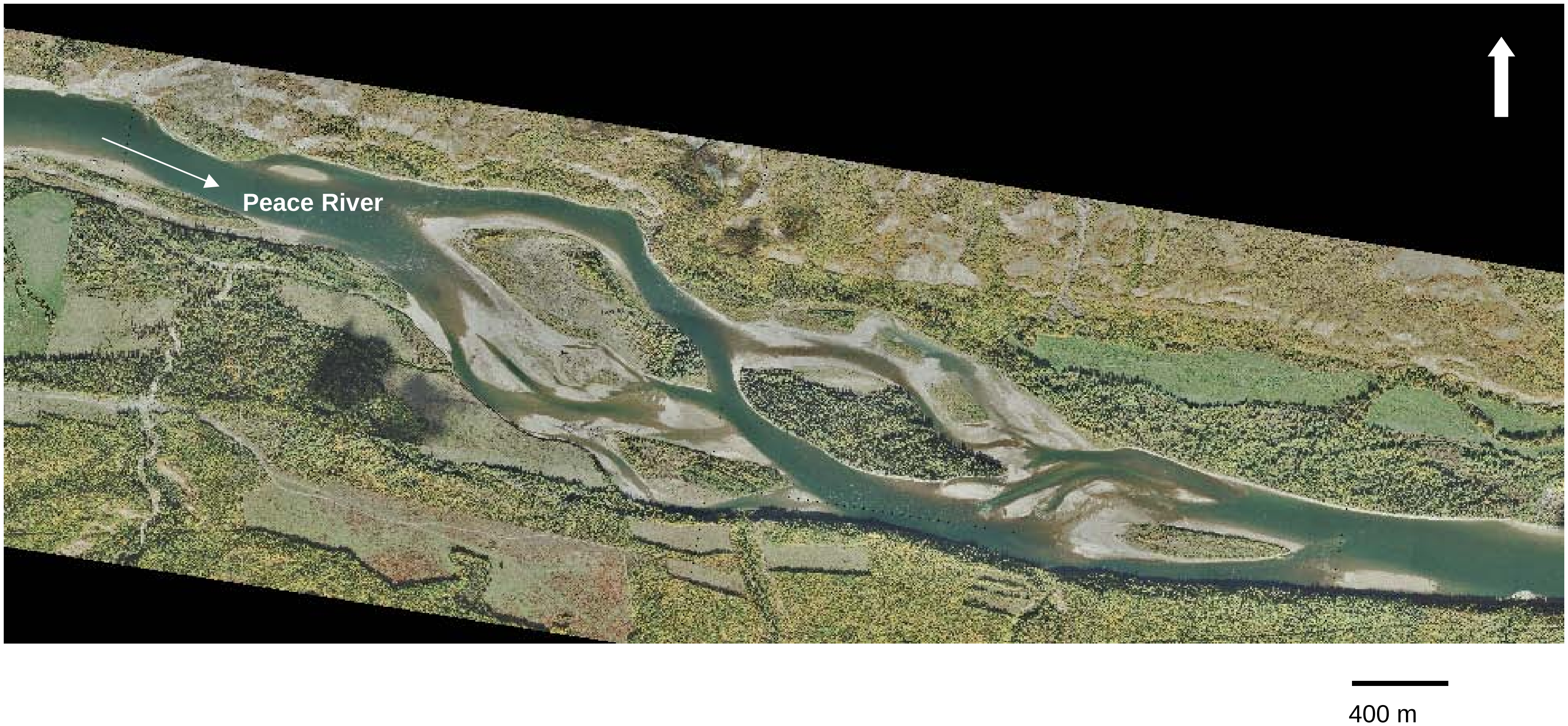


Figure A-3 - Pallings Flat Study Area

Figure A-4 - Raspberry Island Study Area

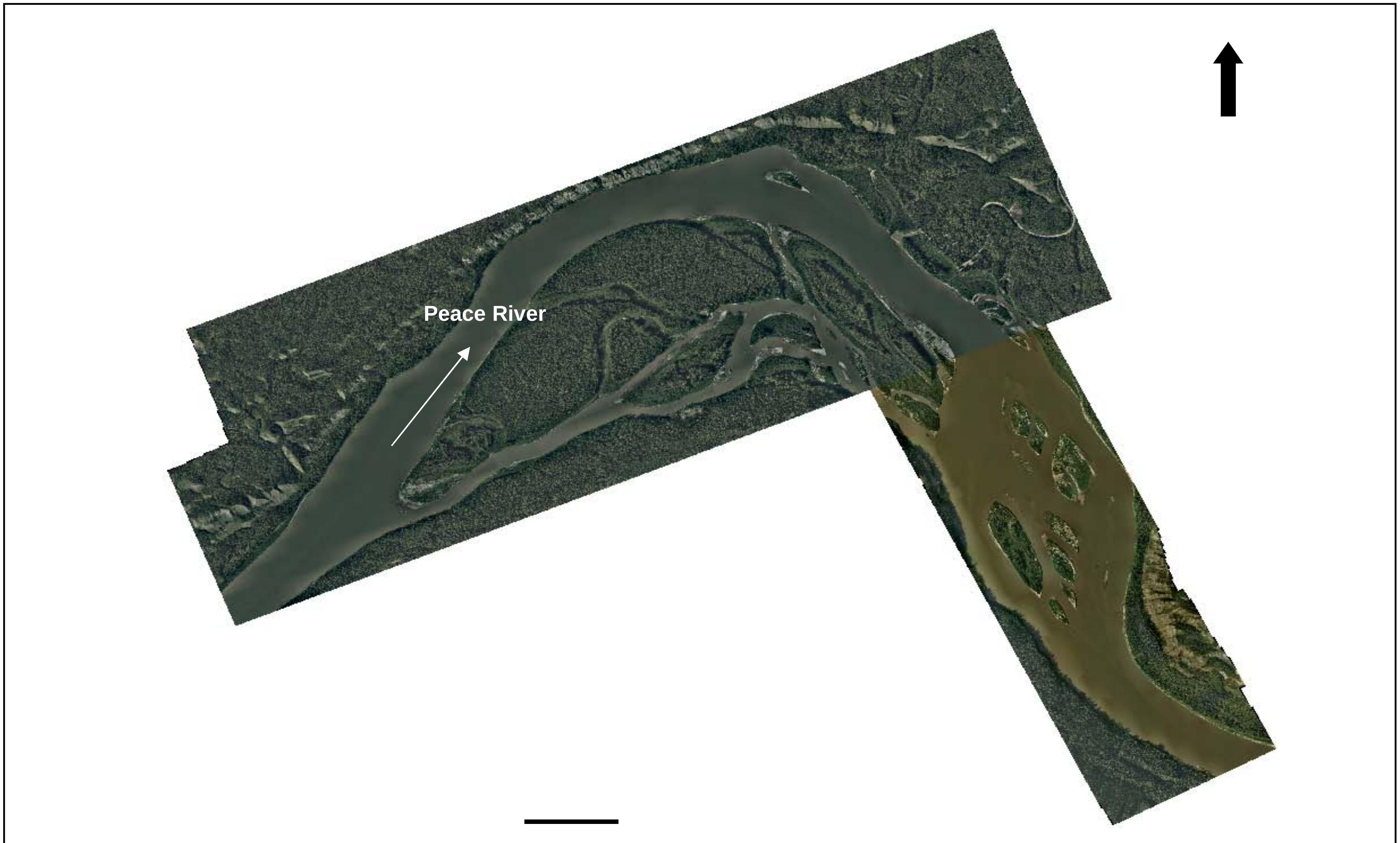


Figure A-5 - Many Islands Study Area

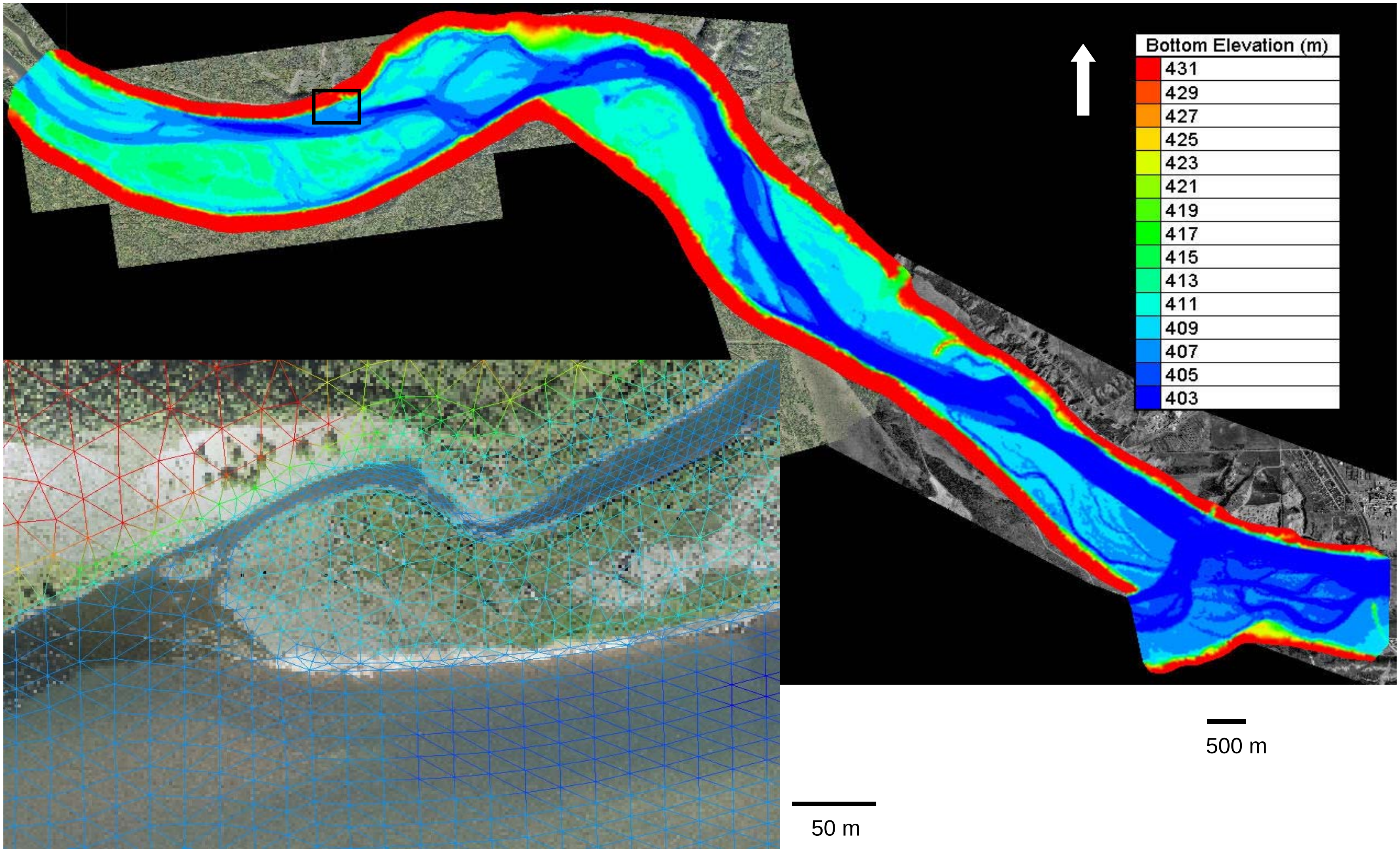


Figure A-6 - Telemac2D Model Mesh and Bathymetry - Site C Dam to Taylor

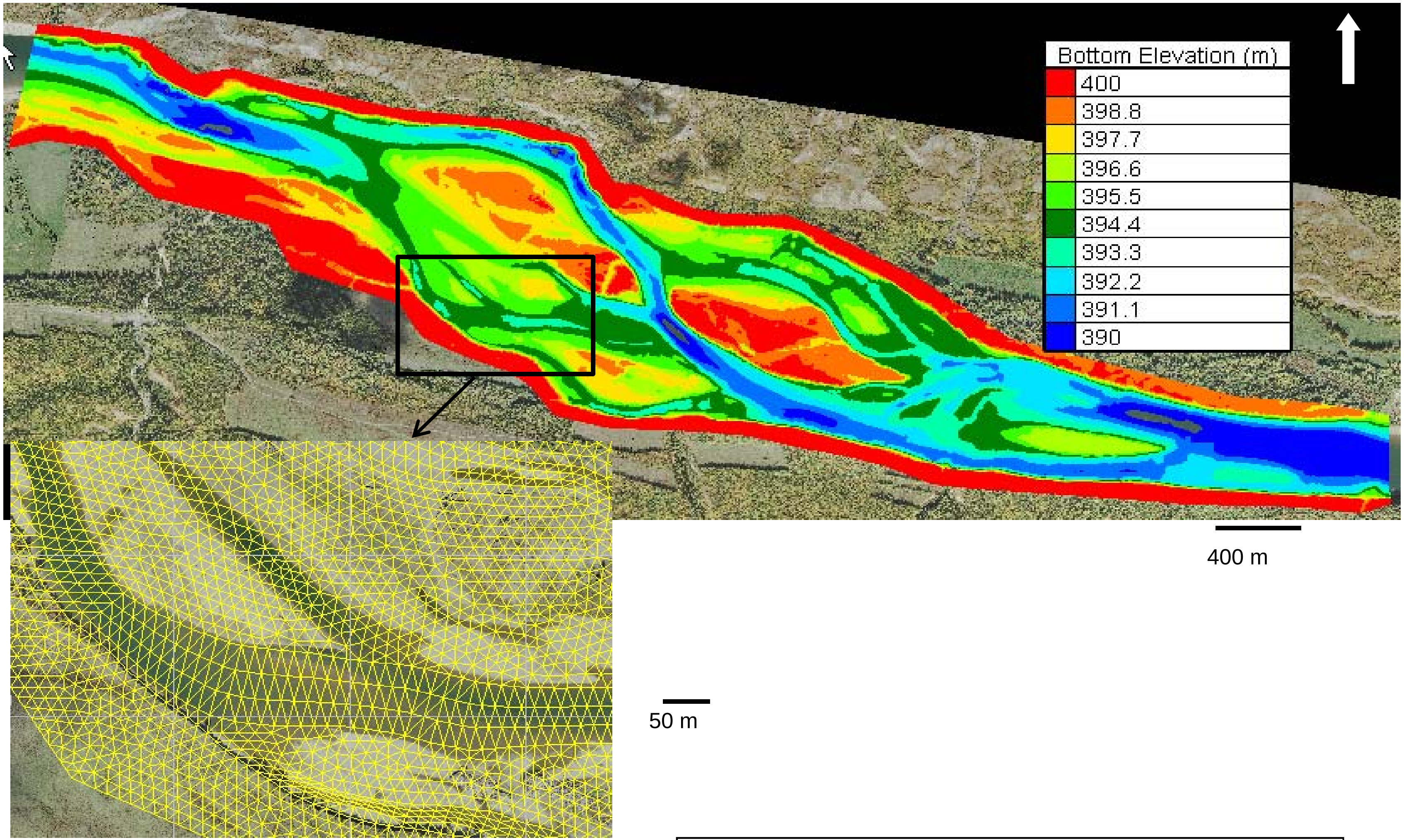


Figure A-7 - Telemac2D Model Mesh and Bathymetry - Pallings Flat

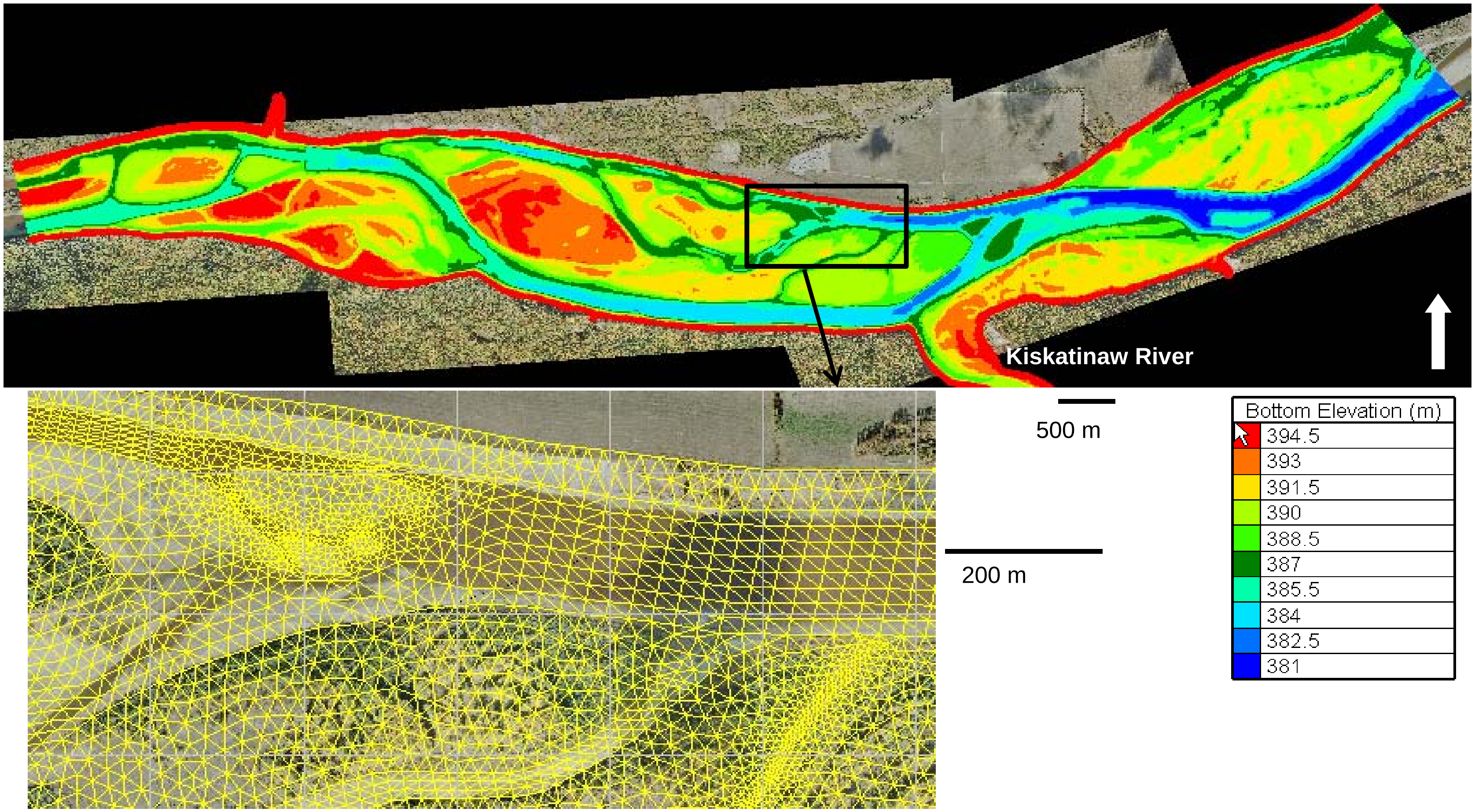


Figure A-8 - Telemac2D Model Mesh and Bathymetry - Raspberry Island

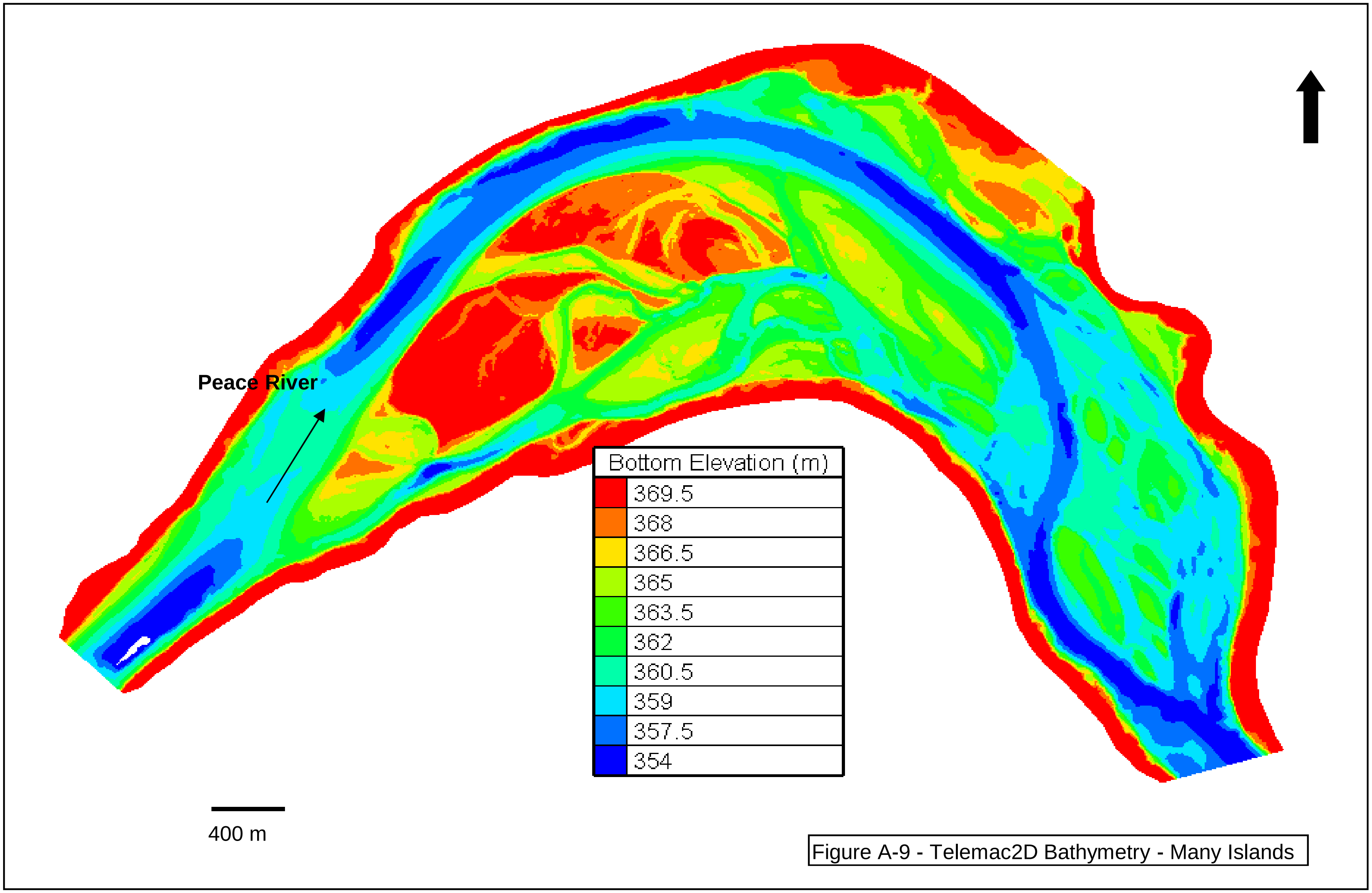


Figure A-9 - Telemac2D Bathymetry - Many Islands

Appendix B

Site C Dam to Taylor Reach Calibration Figures

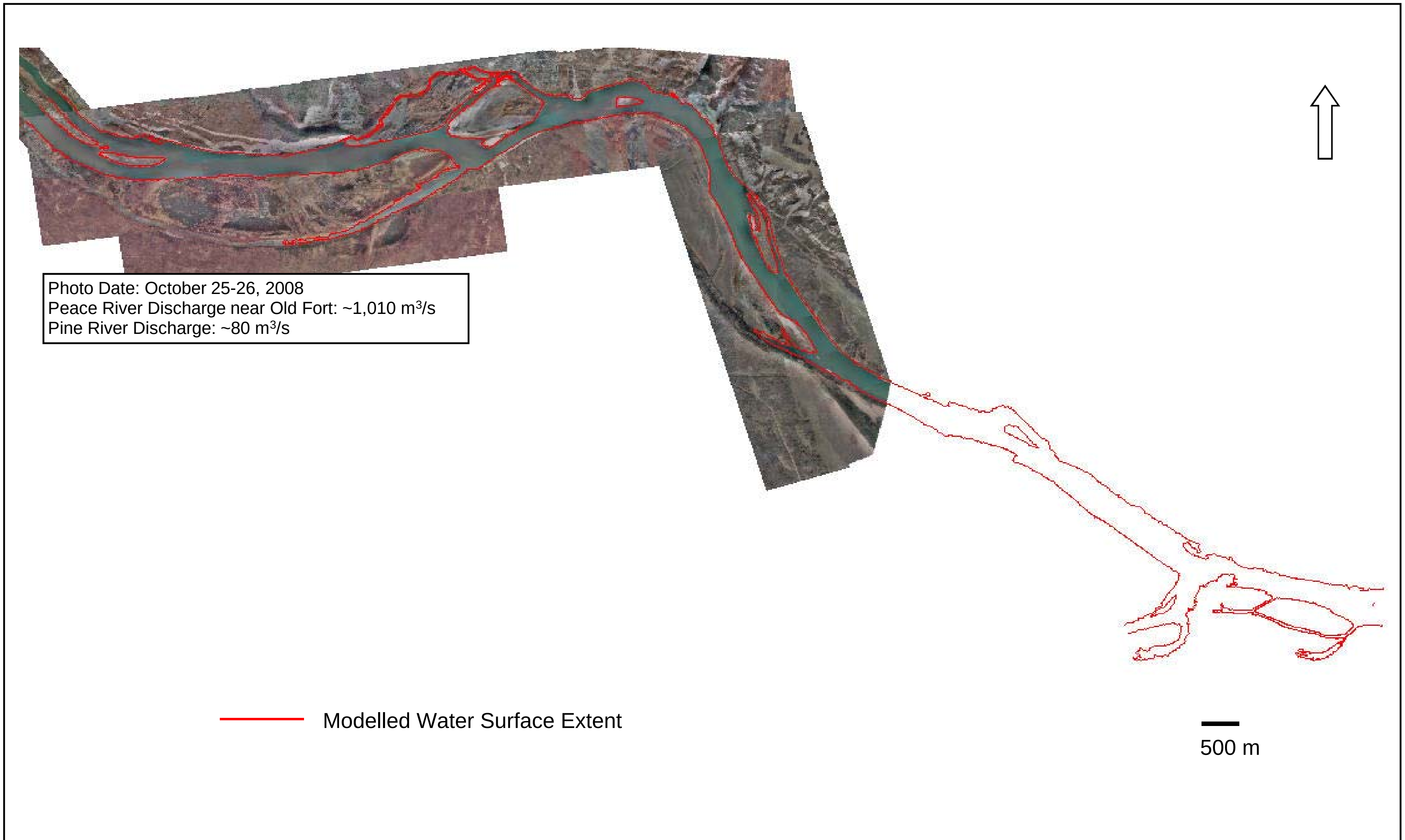


Figure B-1 - Aerial Photo Calibration (Site C Dam to Taylor, Flow = 1,010 m^3/s)

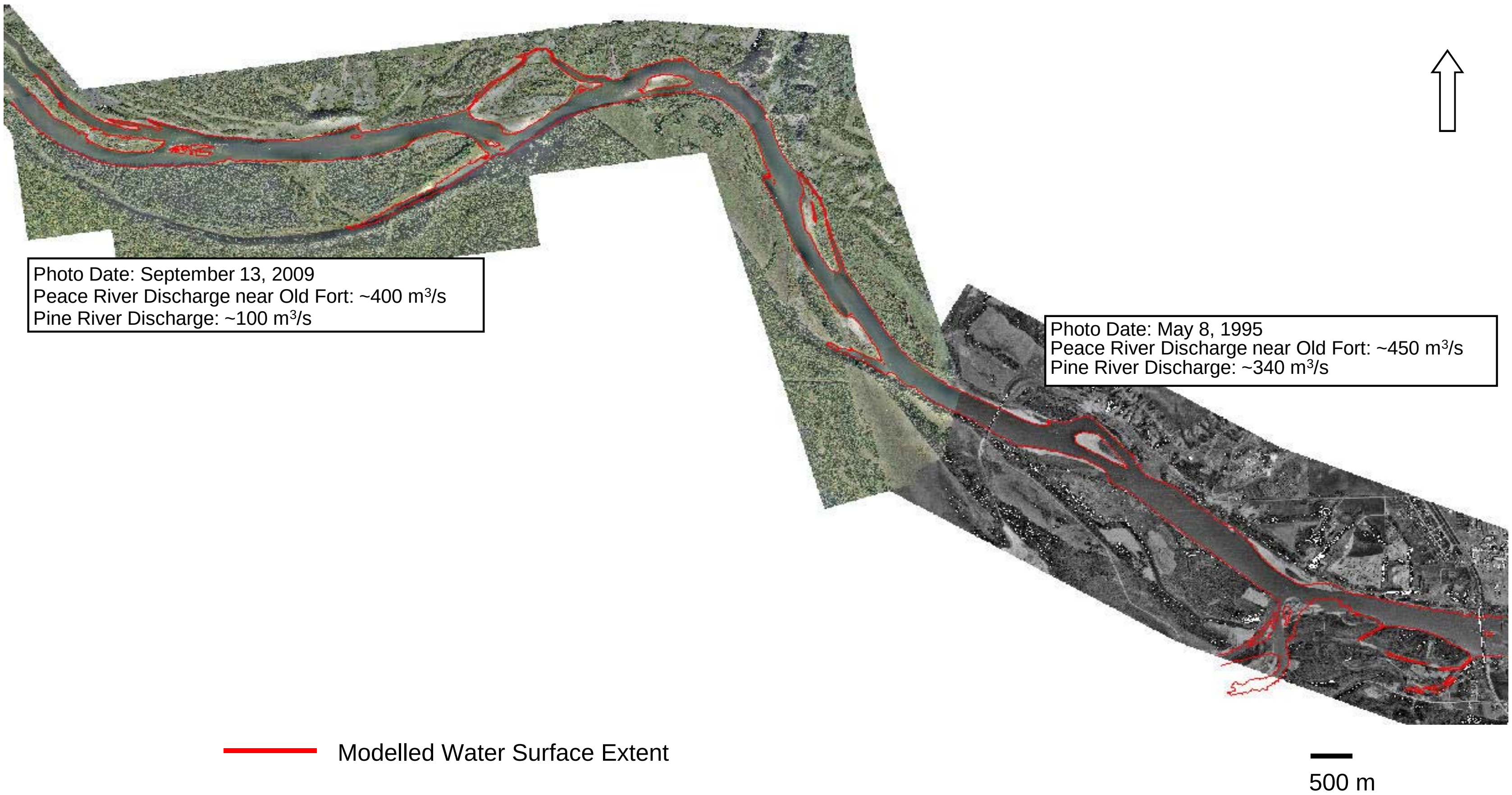


Figure B-2 - Aerial Photo Calibration (Site C Dam to Taylor, Flow = 400 m^3/s)

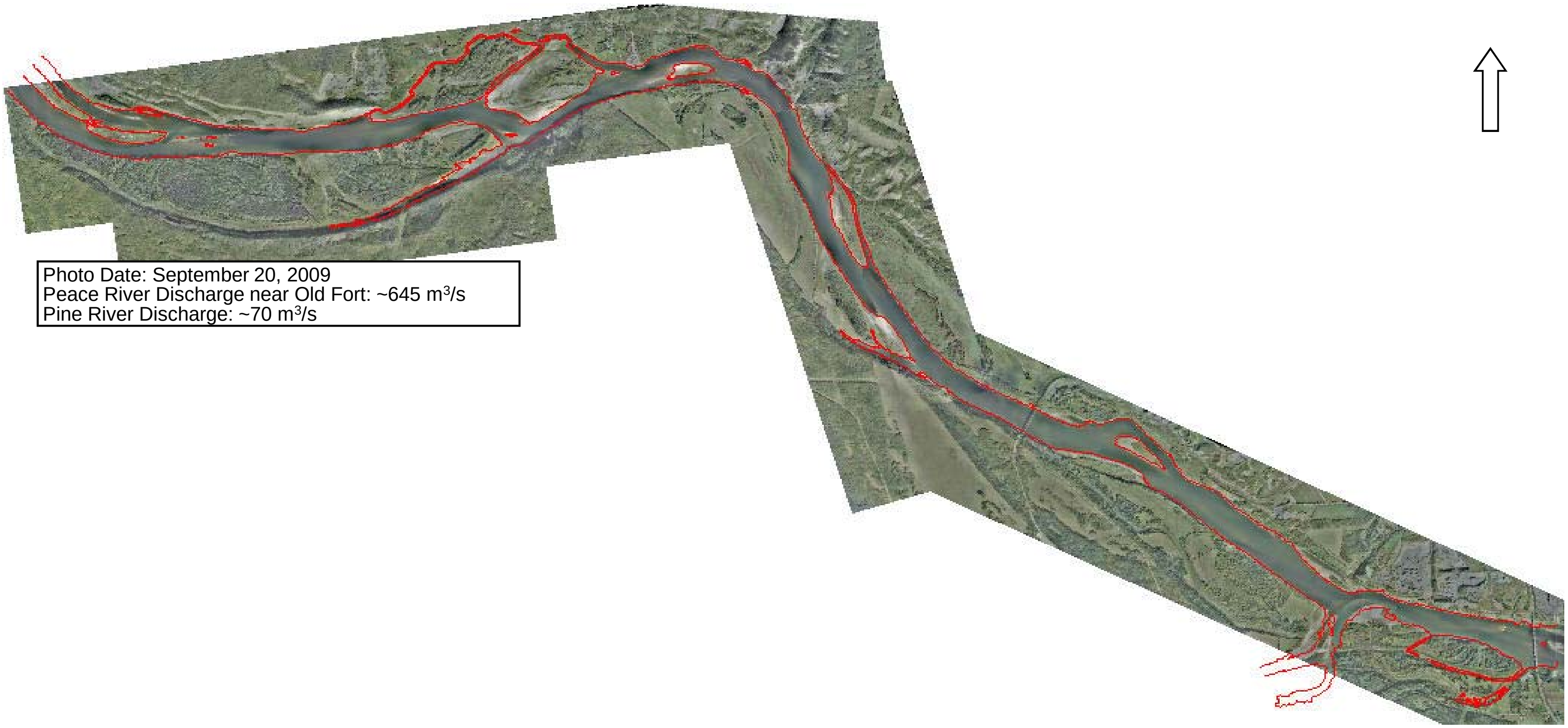


Photo Date: September 20, 2009
Peace River Discharge near Old Fort: ~645 m^3/s
Pine River Discharge: ~70 m^3/s

Modelled Water Surface Extent

500 m

Figure B-3 - Aerial Photo Calibration (Site C Dam to Taylor, Flow = 645 m^3/s)

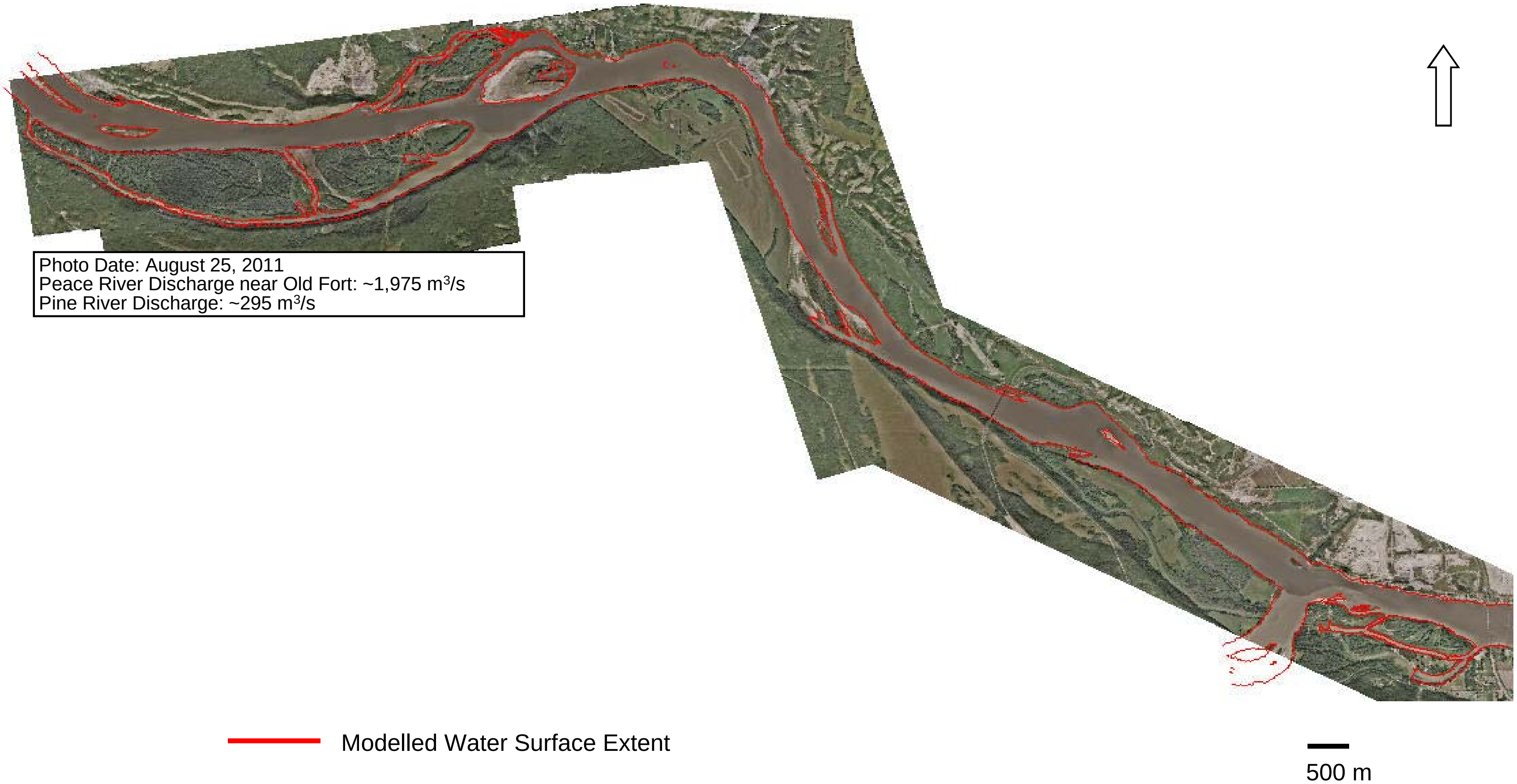


Figure B-4 - Aerial Photo Calibration (Site C Dam to Taylor, Flow = 1,975 m^3/s)

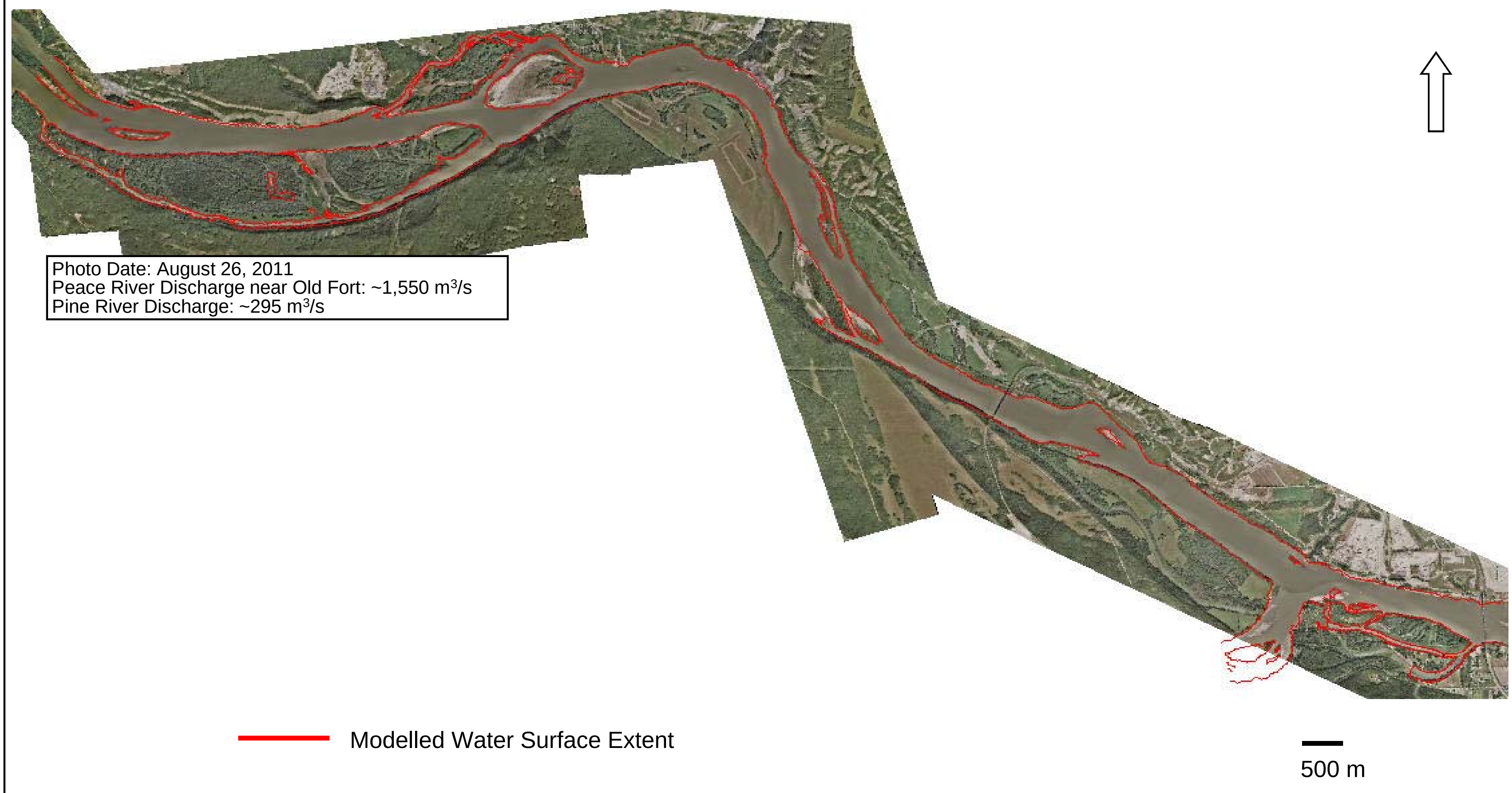


Figure B-5 - Aerial Photo Calibration (Site C Dam to Taylor, Flow = 1,550 m^3/s)

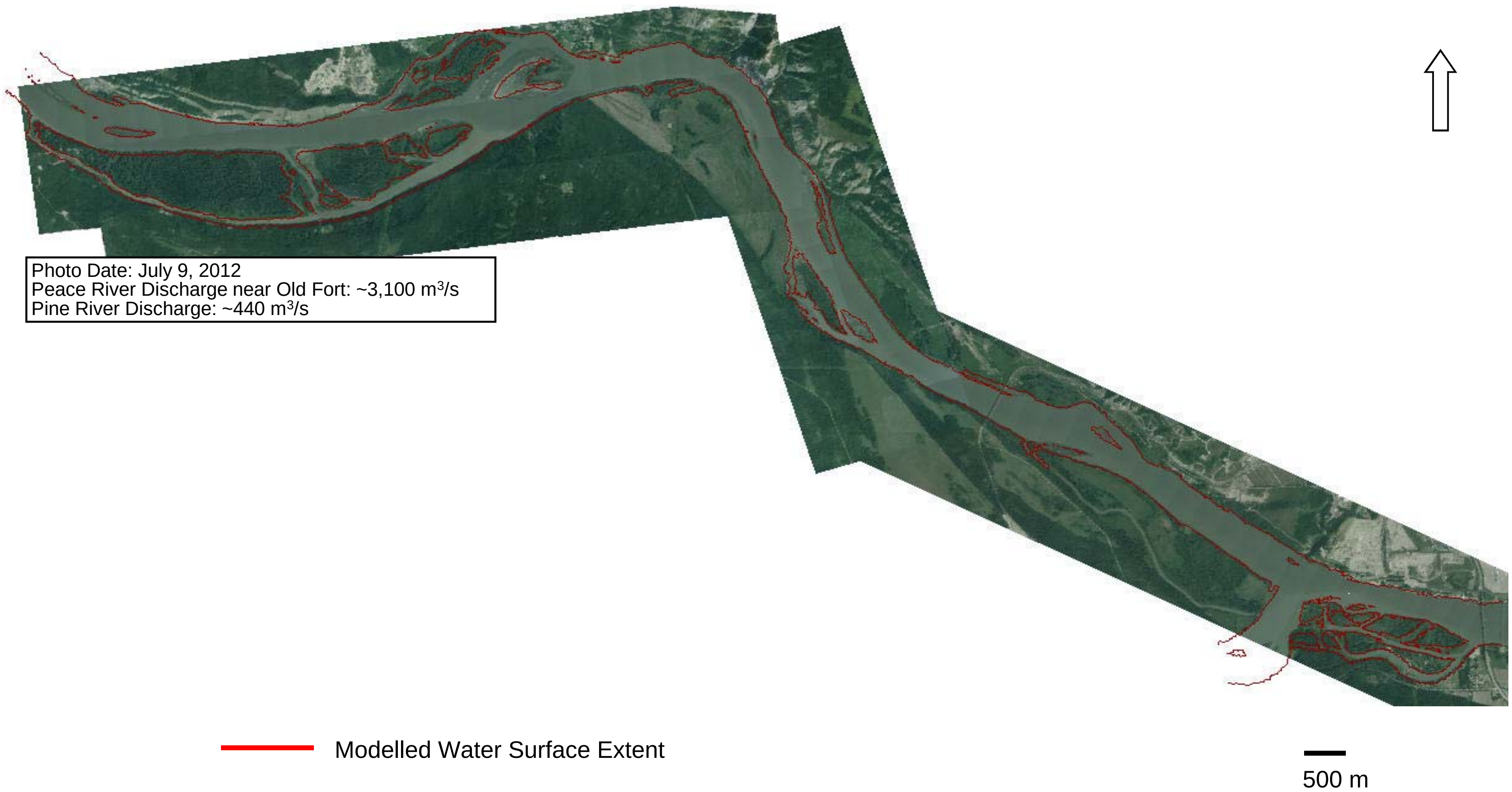
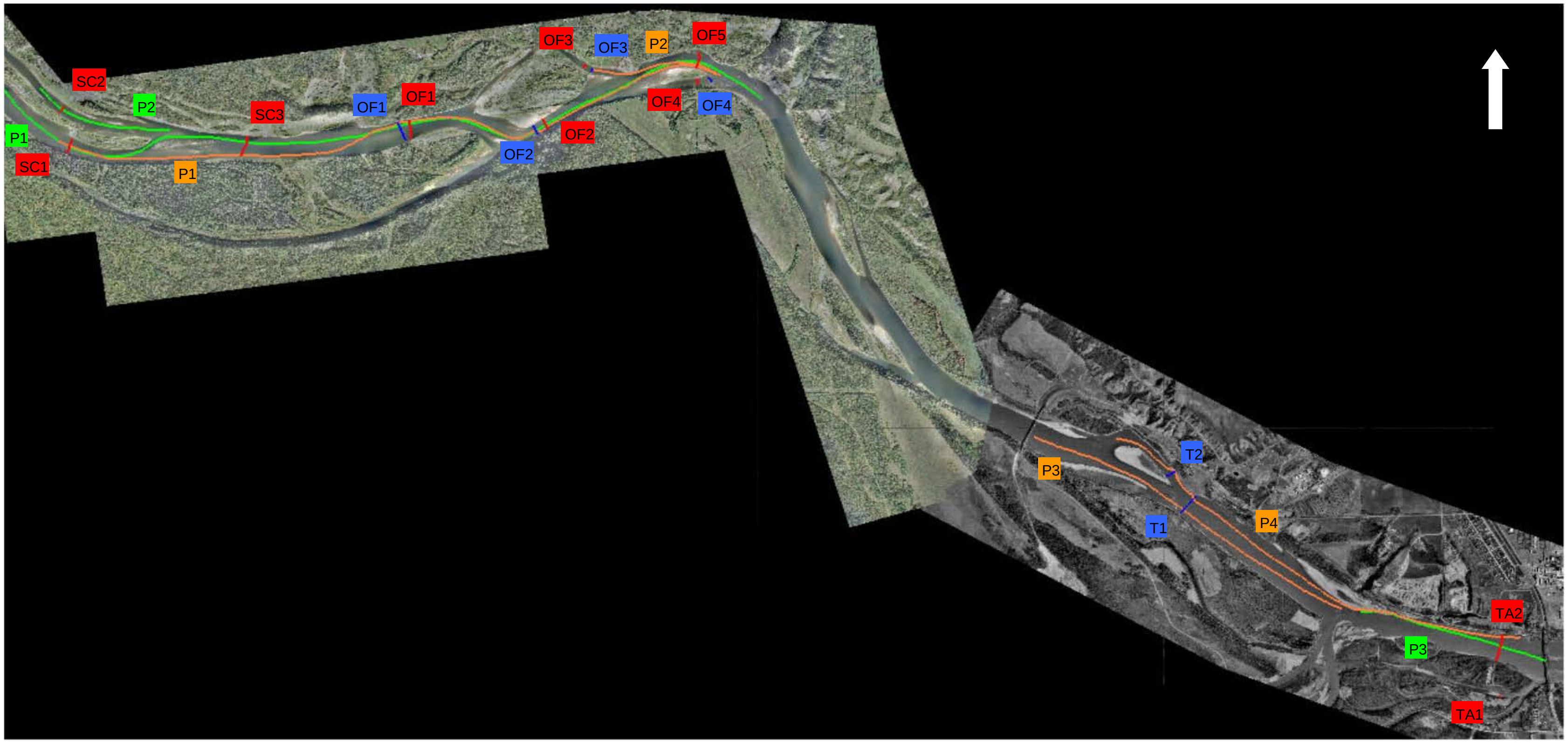


Figure B-6 - Aerial Photo Calibration (Site C Dam to Taylor, Flow = 3,100 m^3/s)



October 2010 Water Surface Profiles

June 2011 Water Surface Profiles

Transect Location (October 2010)

Transect Location (June 2011)

500 m

Figure B-7 - Hydraulic Survey Locations (Site C Dam to Taylor)

Figure B-8 - Water Surface Profile Comparison
(Site C Dam to Taylor, October 2010 Line P1)

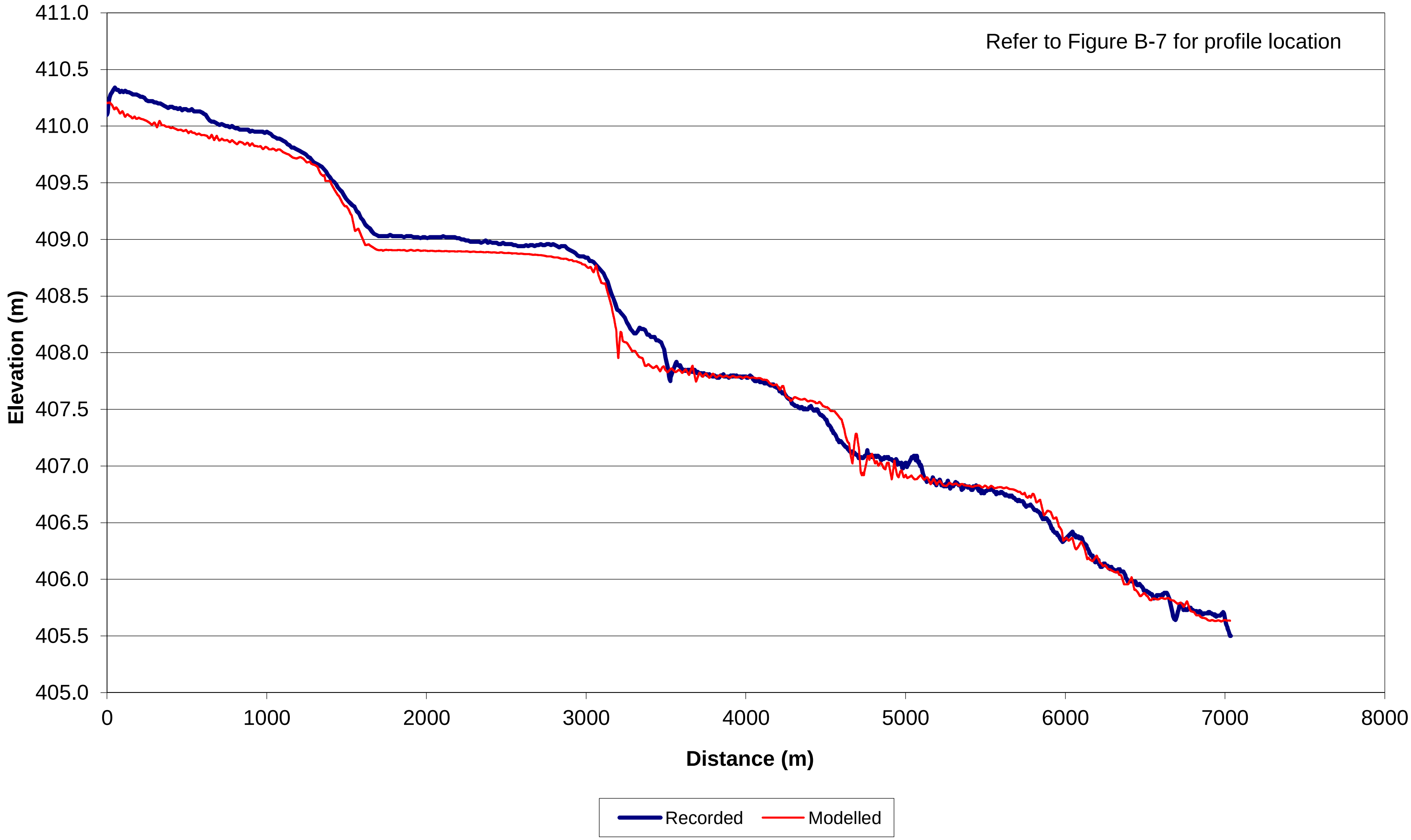


Figure B-9 - Water Surface Profile Comparison
(Site C Dam to Taylor, October 2010 Line P2)

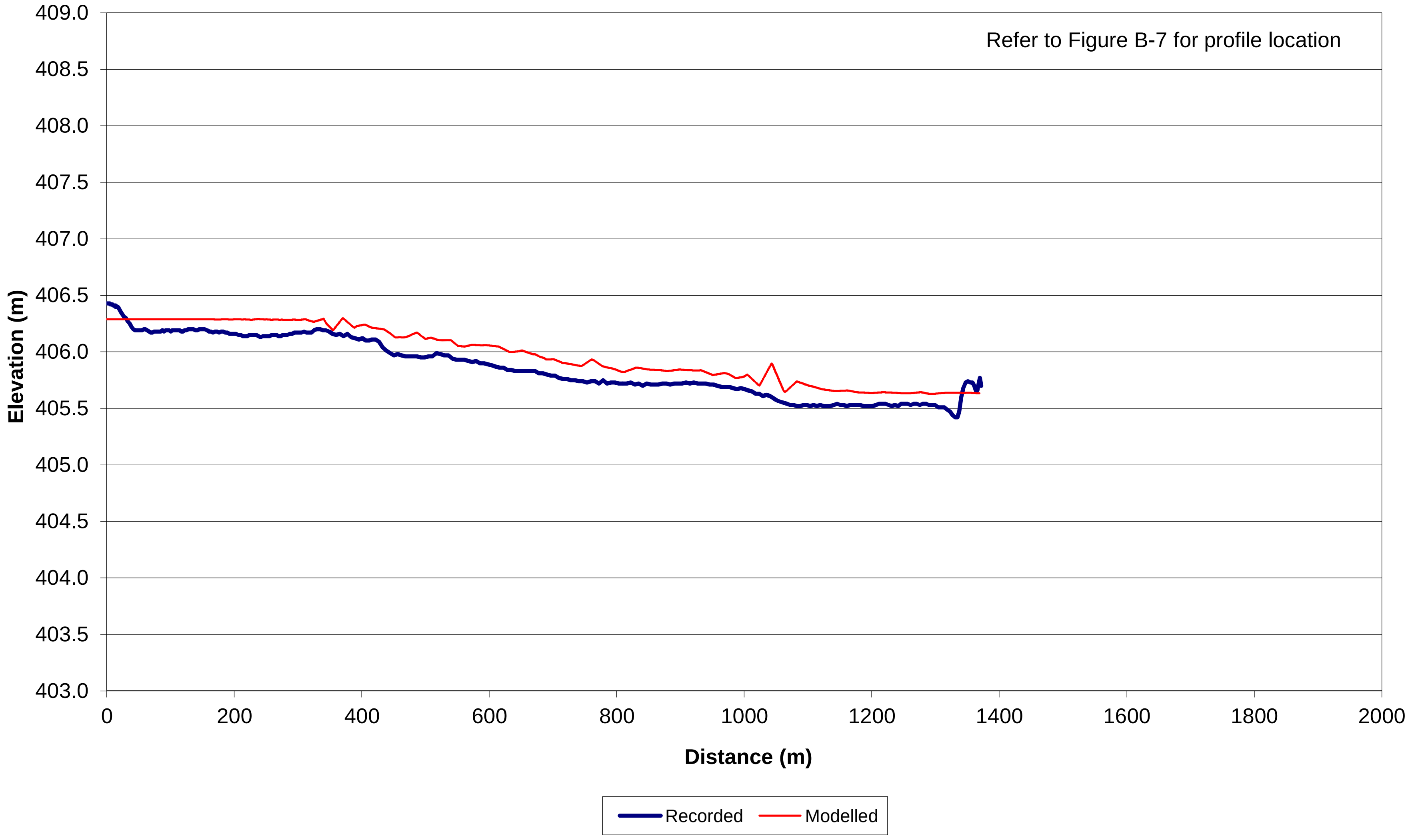


Figure B-10 - Water Surface Profile Comparison
(Site C Dam to Taylor, October 2010 Line P3)

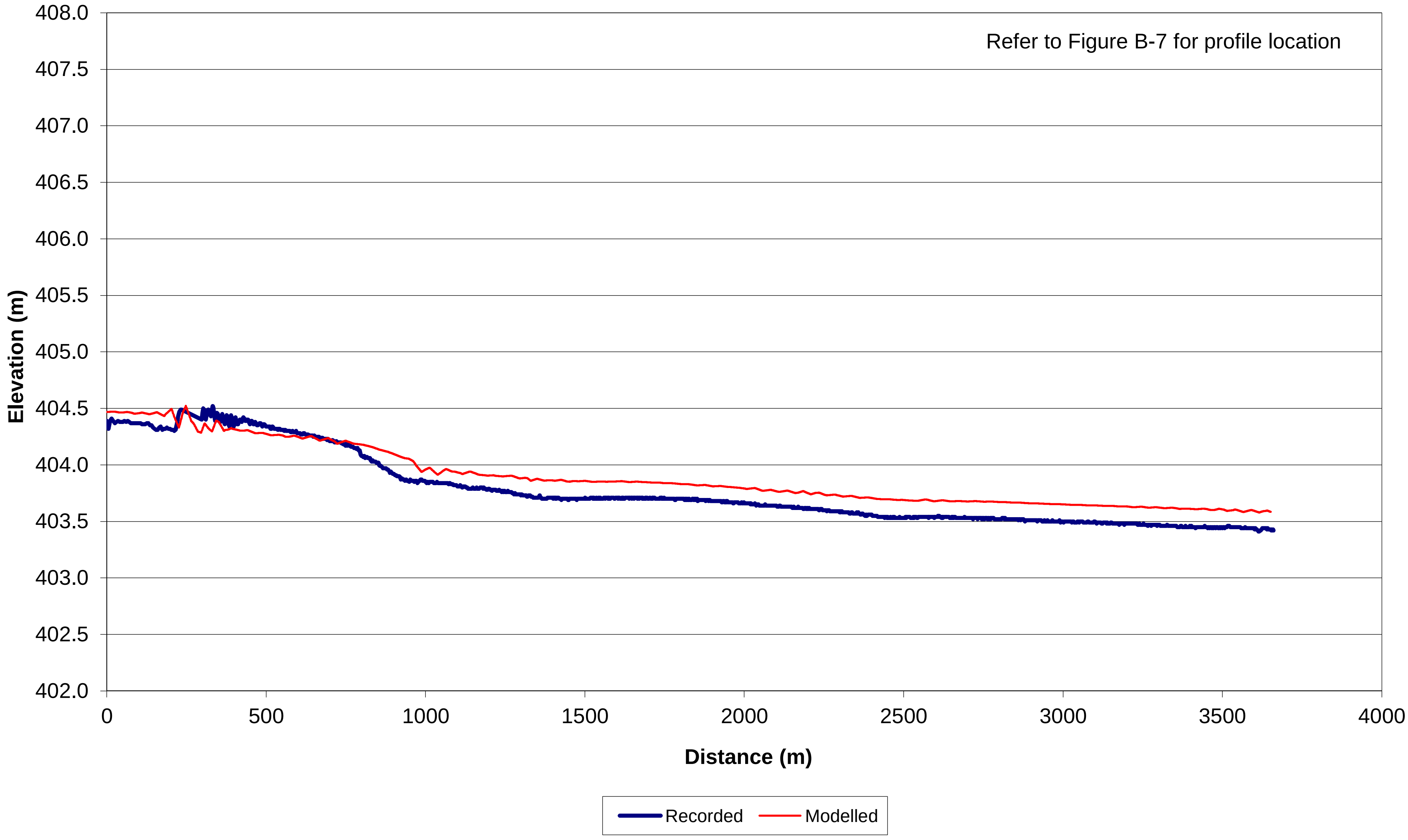
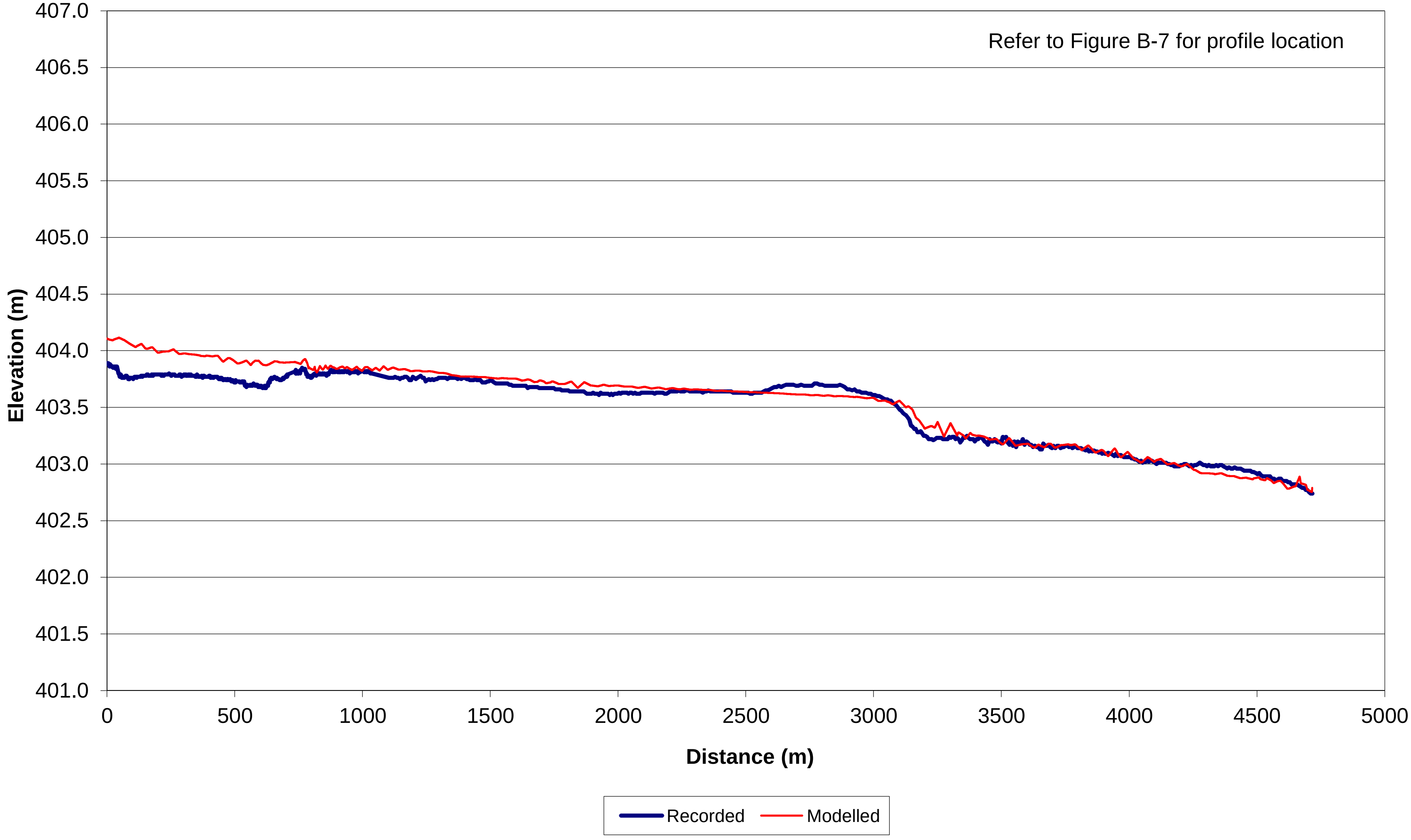
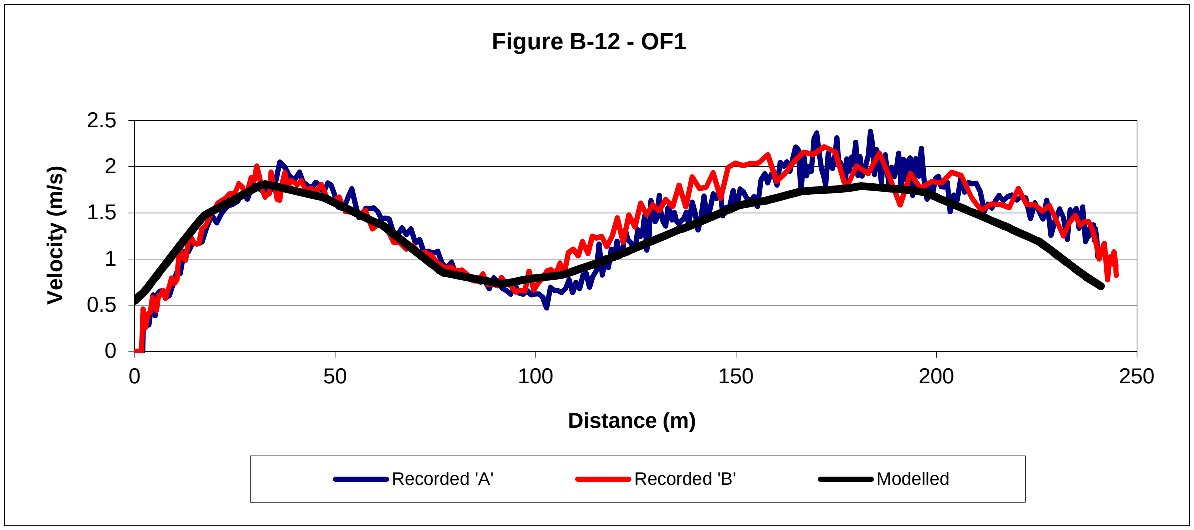
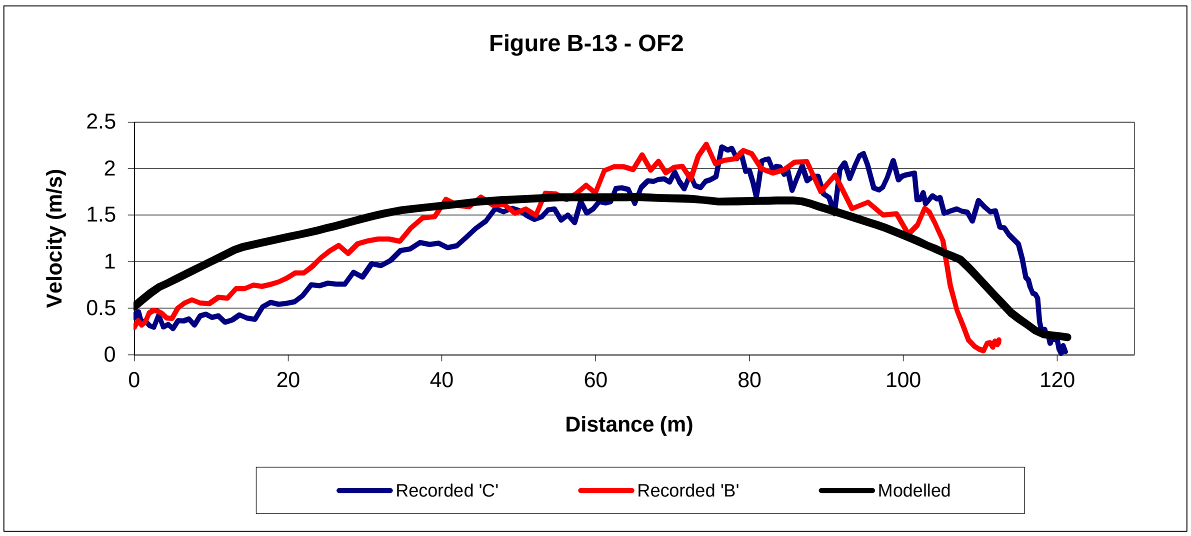


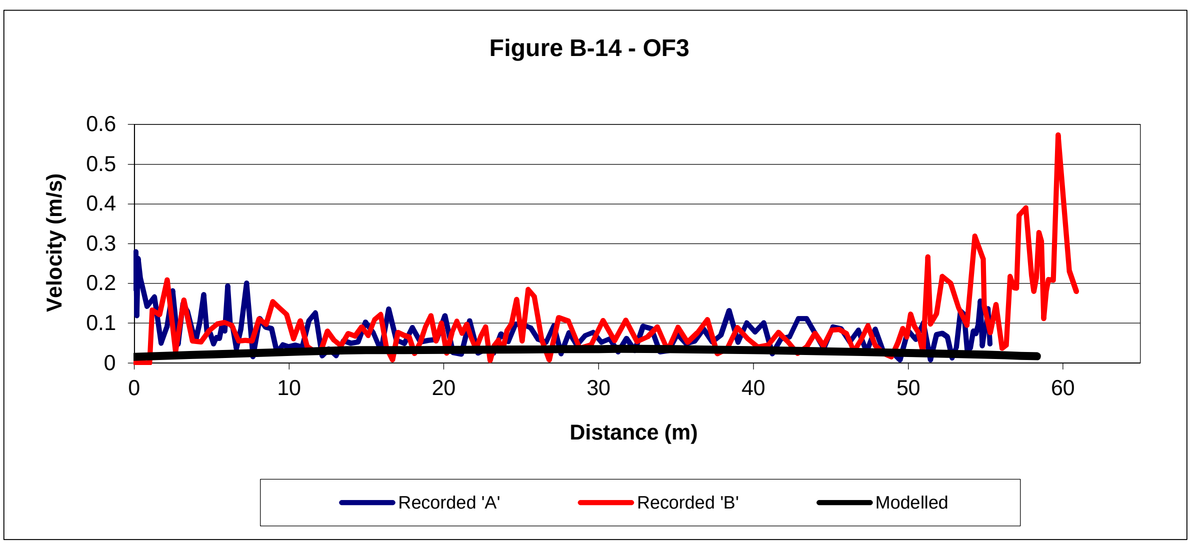
Figure B-11 - Water Surface Profile Comparison (Site C Dam to Taylor, October 2010 Line P4)



Old Fort to Taylor Reach Transect Velocity Comparision
October 2010

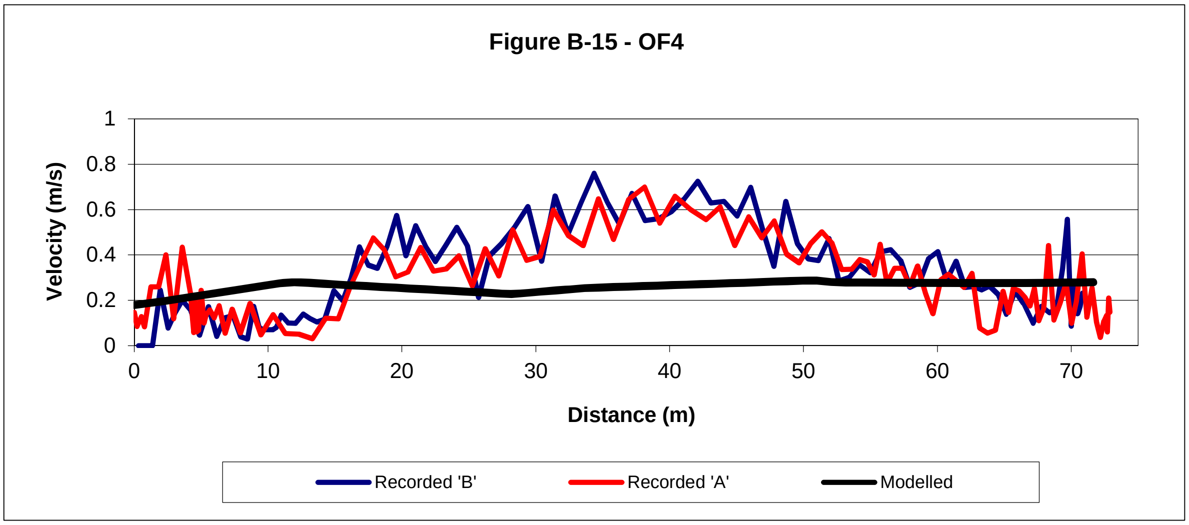


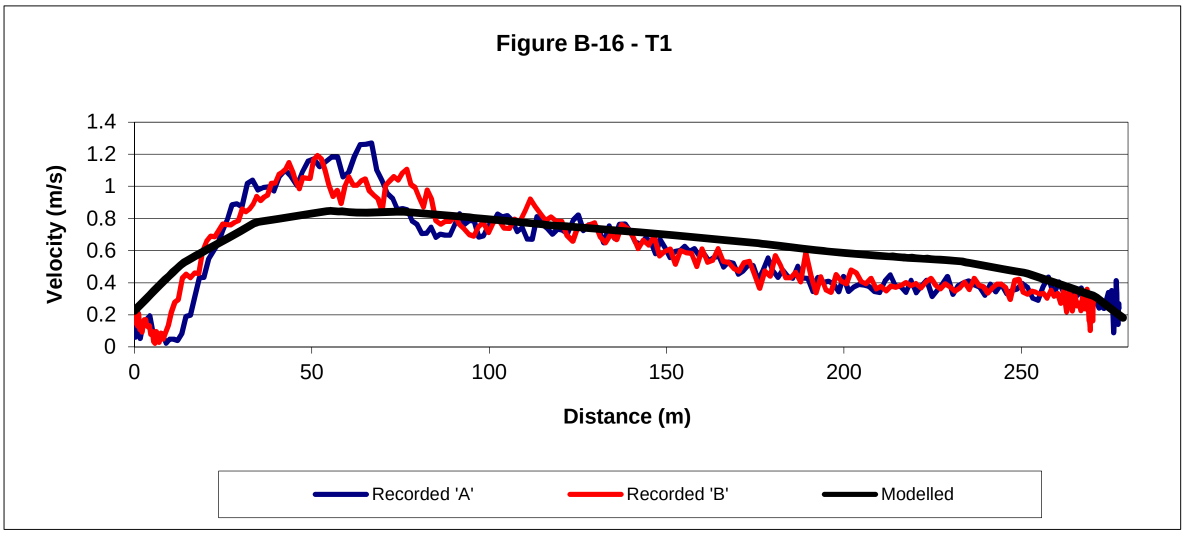


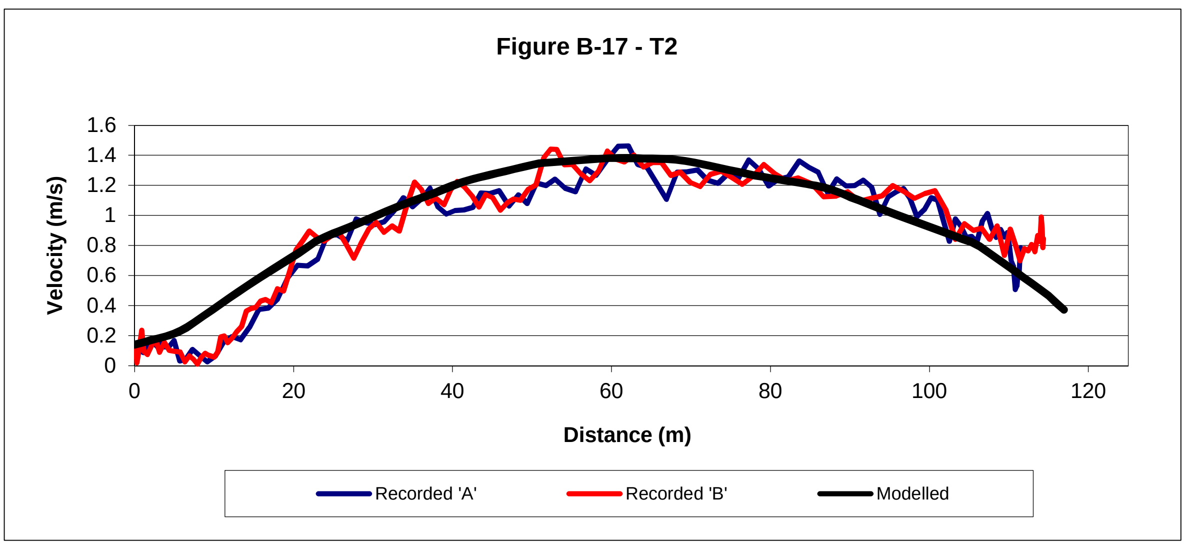


Refer to Figure B-7 for transect location

Old Fort to Taylor Reach Transect Velocity Comparision
October 2010







Refer to Figure B-7 for transect location

Figure B-18 - Water Surface Profile Comparison
(Site C Dam to Taylor, June 2011 Line P1)

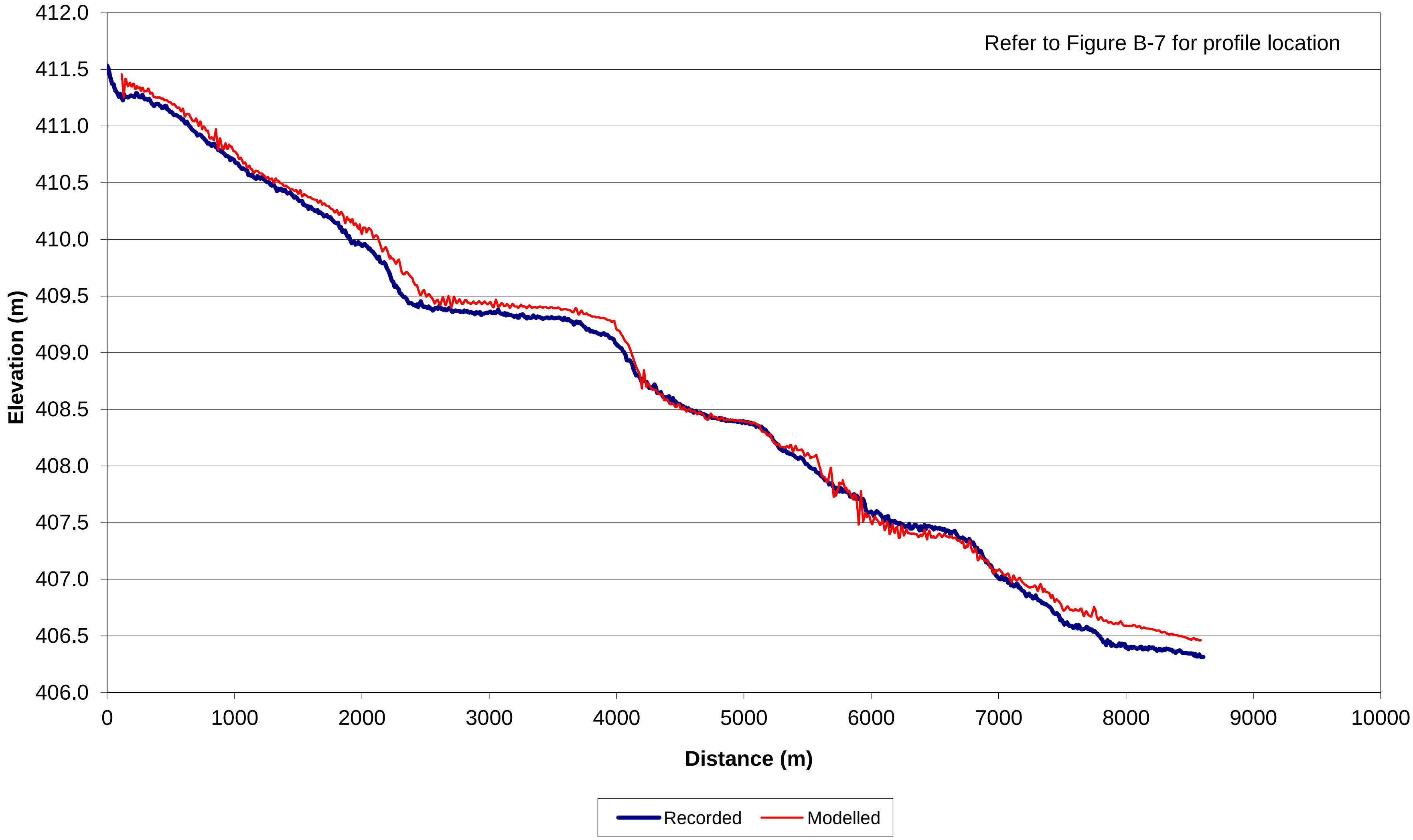
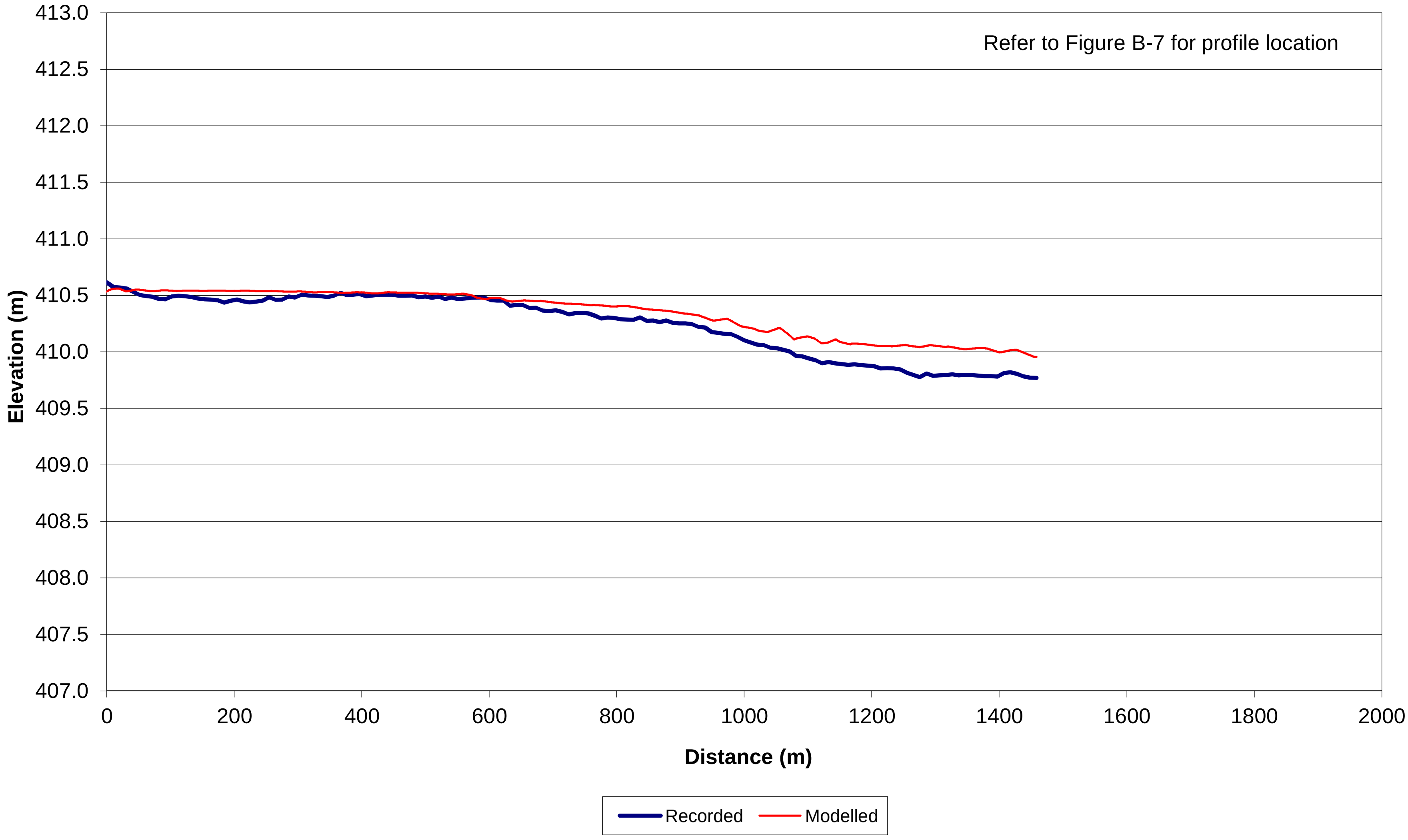


Figure B-19 - Water Surface Profile Comparison (Site C Dam to Taylor, June 2011 Line P2)



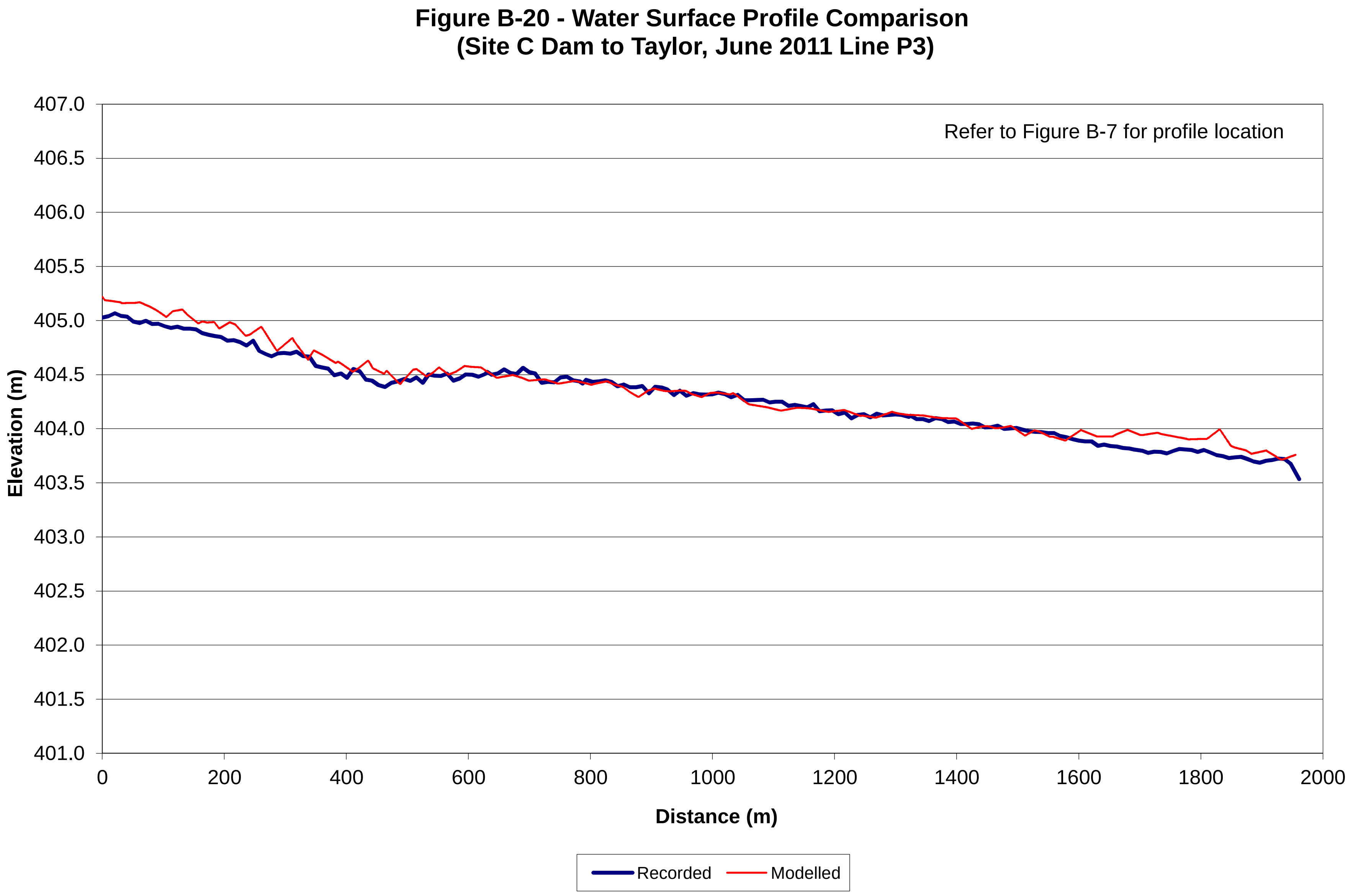
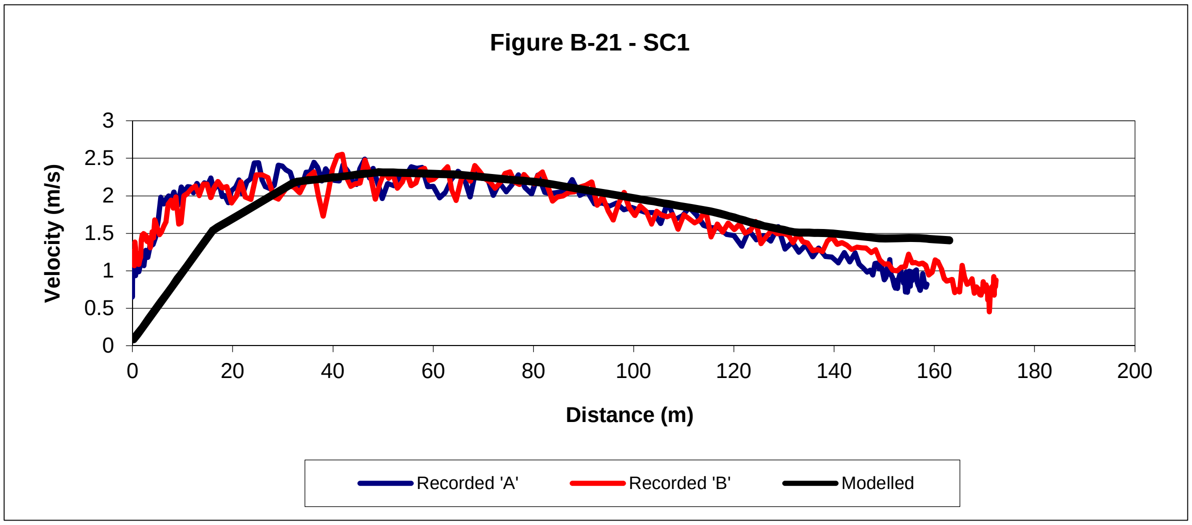
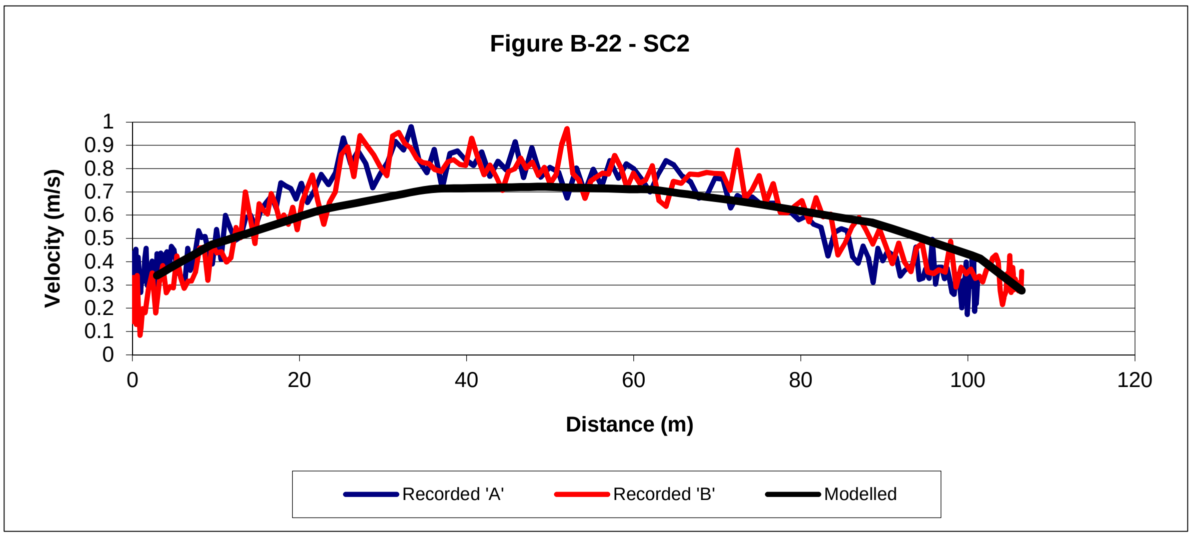
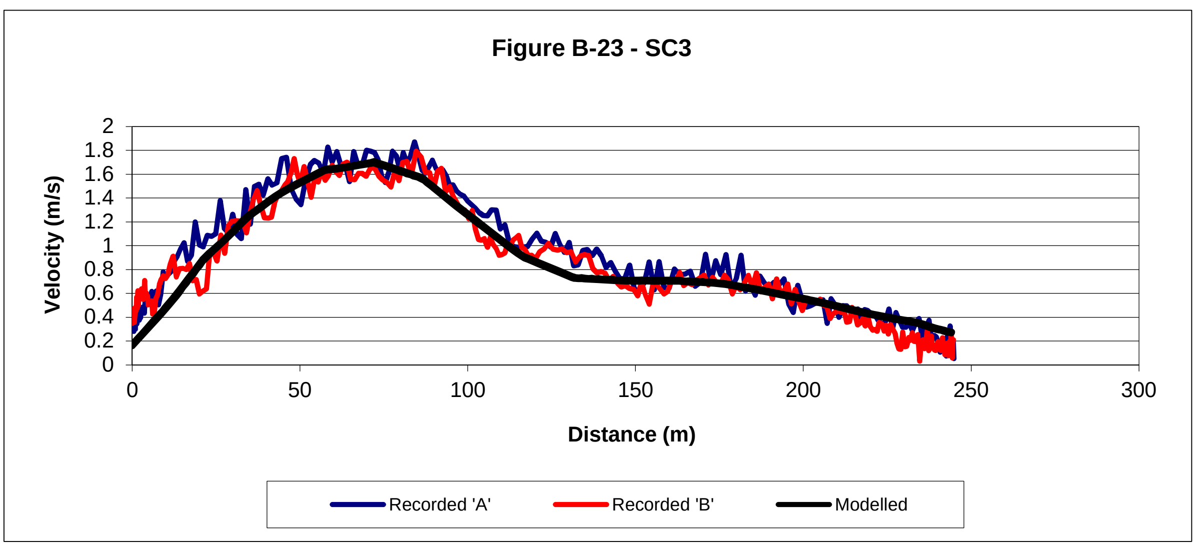


Figure B-20 - Water Surface Profile Comparison
(Site C Dam to Taylor, June 2011 Line P3)
Refer to Figure B-7 for profile location
Elevation (m)
407.0
406.5
406.0
405.5
405.0
404.5
404.0
403.5
403.0
402.5
402.0
401.5
401.0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Distance (m)
Recorded
Modelled

Site C Dam to Taylor Reach Transect Velocity Comparision
June 2011

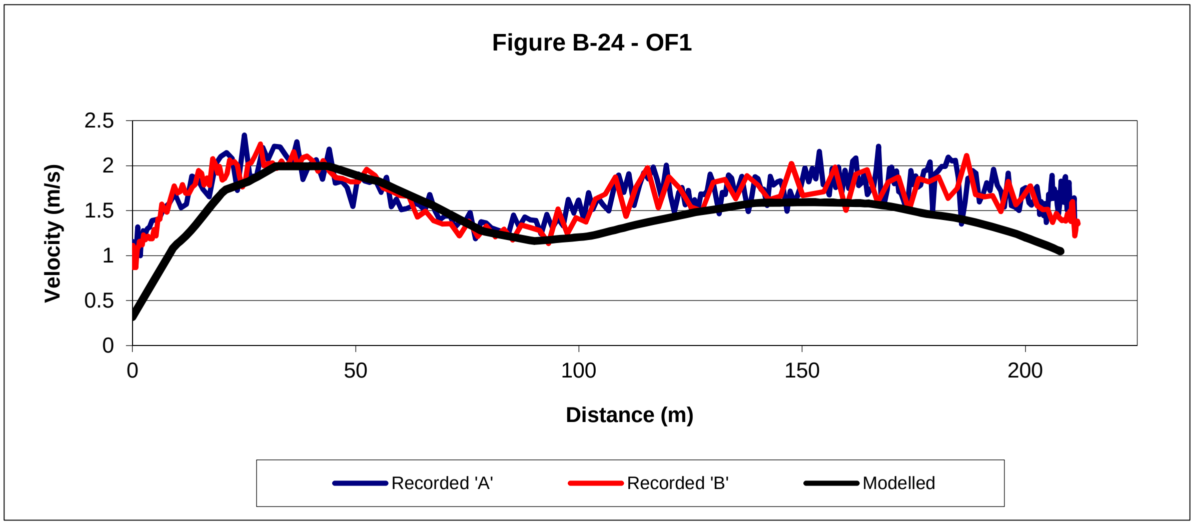


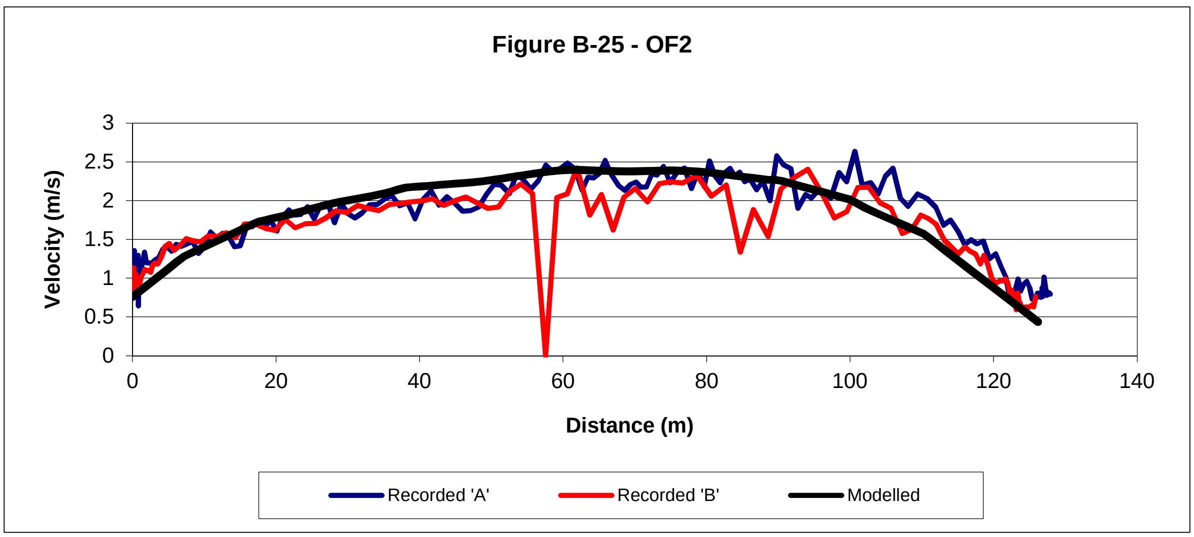


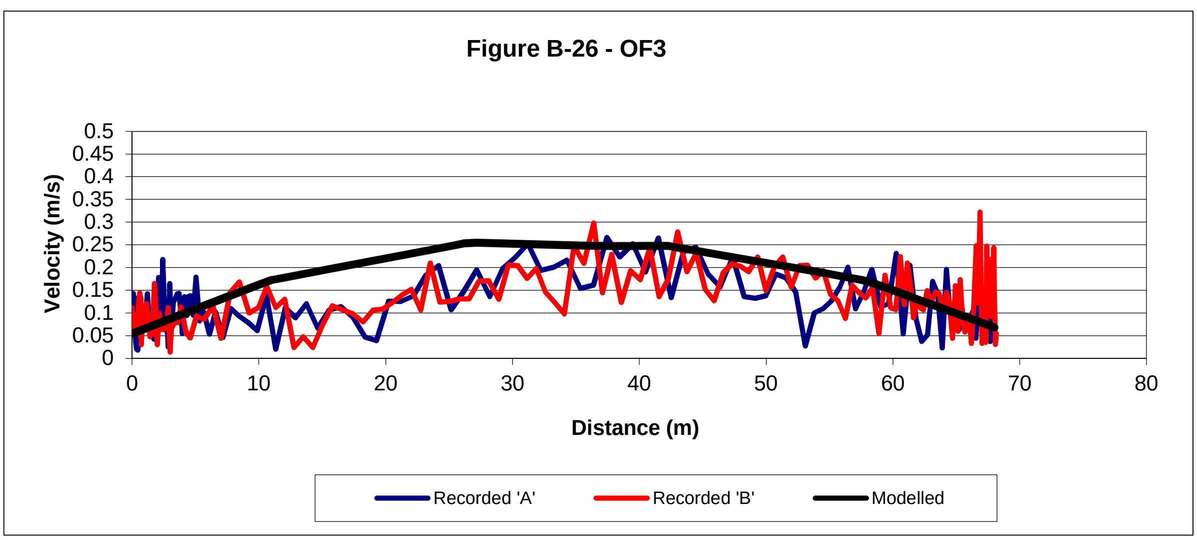


Refer to Figure B-7 for transect location

Site C Dam to Taylor Reach Transect Velocity Comparision
June 2011

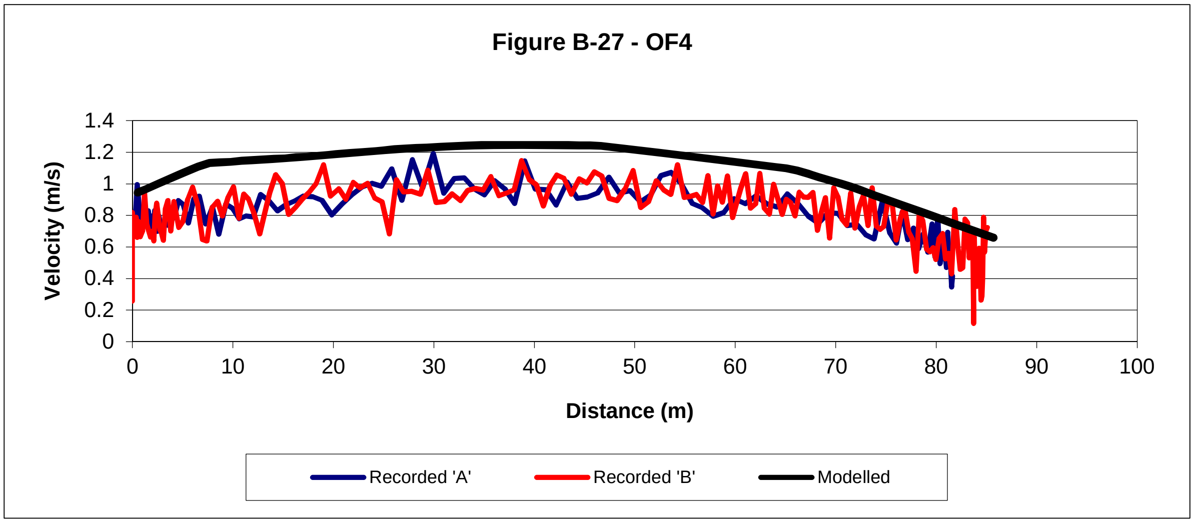


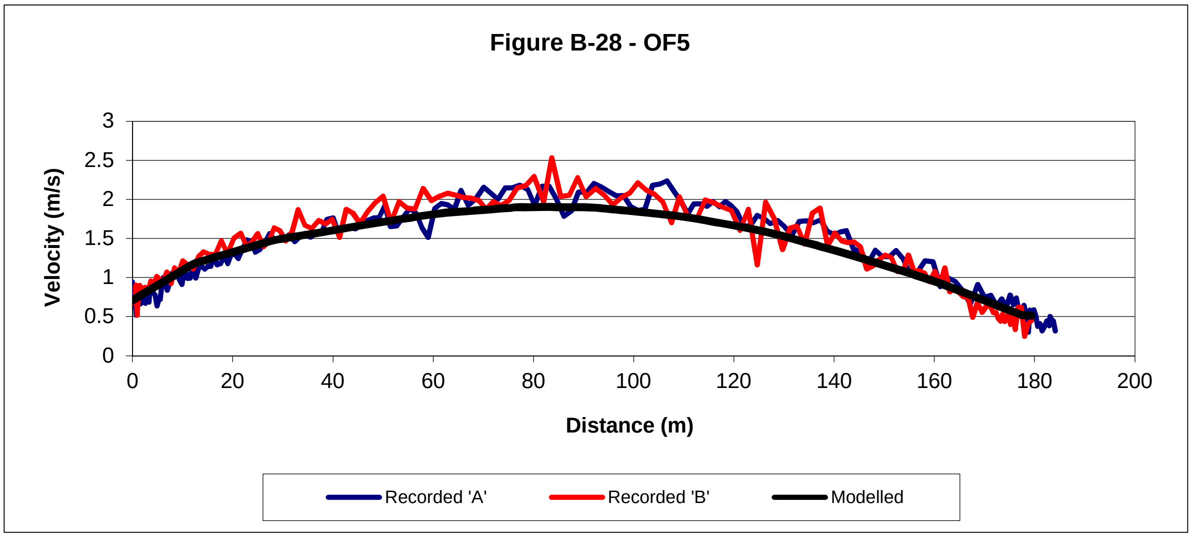


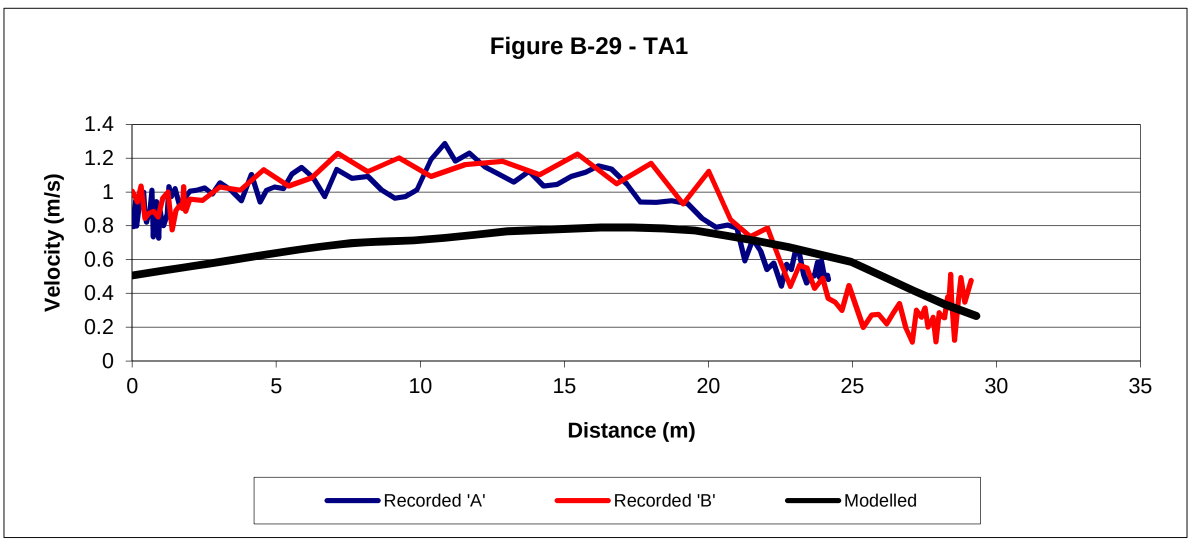


Refer to Figure B-7 for transect location

Site C Dam to Taylor Reach Transect Velocity Comparision
June 2011

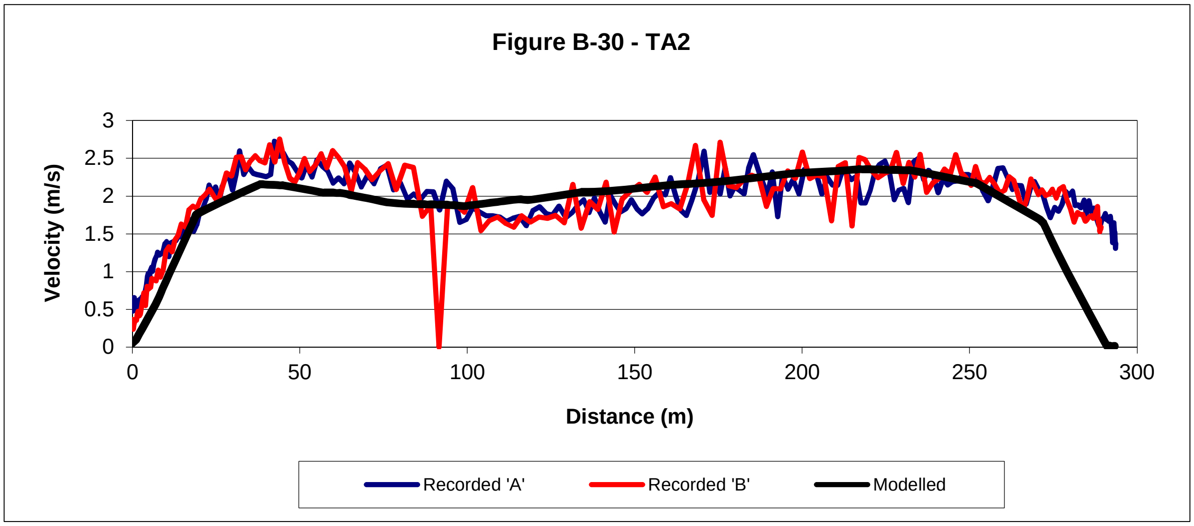






Refer to Figure B-7 for transect location

Site C Dam to Taylor Reach Transect Velocity Comparision
June 2011



Refer to Figure B-7 for transect location

Appendix C

Palling Flat Reach
Calibration Figures

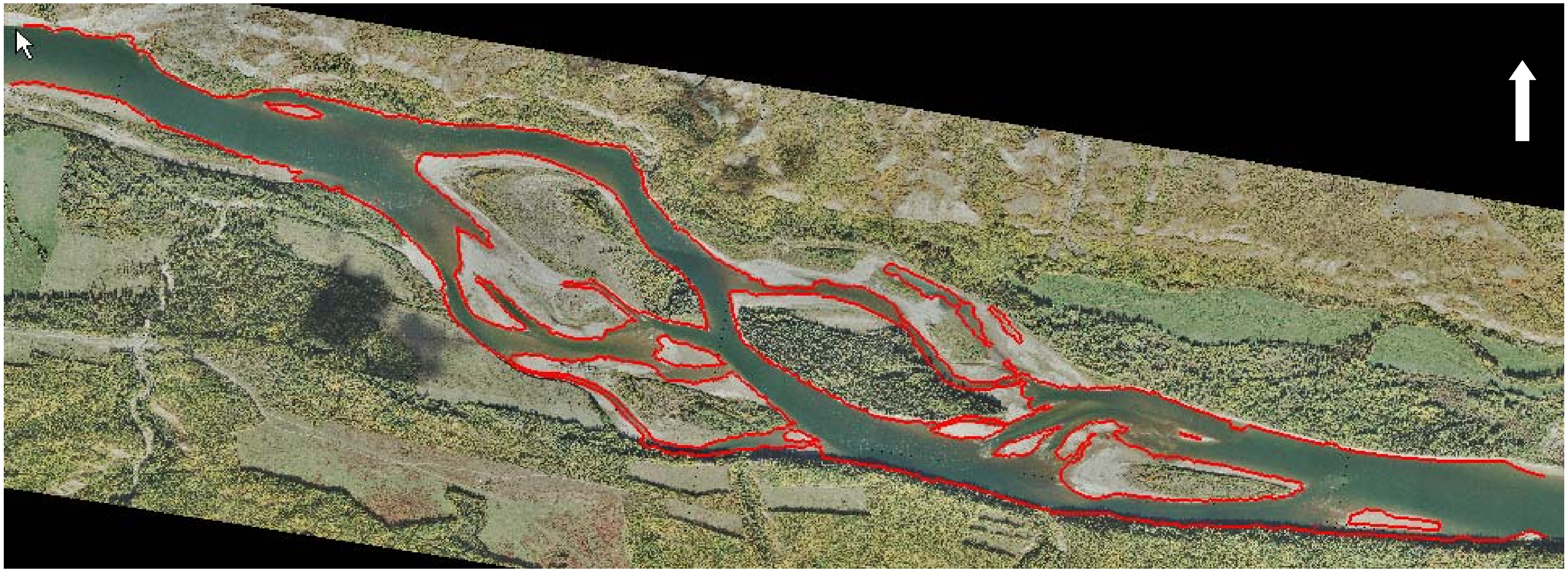


Photo Date: Sep. 22, 2010

Discharge: 400 m3/s

Modelled Water Surface Extent

400 m

Figure C-1 - Aerial Photo Calibration (Palling s Flat, Flow = 400 m^3/s)

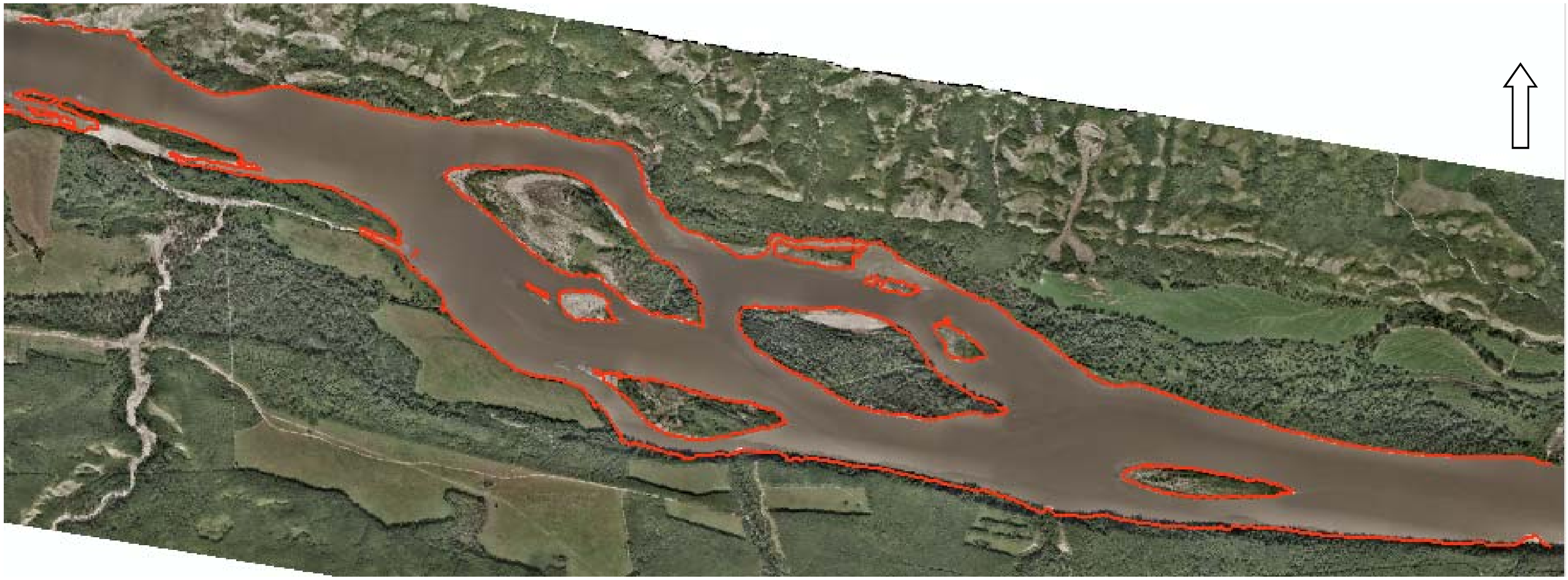


Photo Date: Aug. 25, 2011
Discharge: 2,270 m3/s

Modelled Water Surface Extent

400 m

Figure C-2 - Aerial Photo Calibration (Pallings Flat, Flow = 2,270 m^3/s)

Photo Date: Aug. 26, 2011
Discharge: 1,840 m3/s

Modelled Water Surface Extent

400 m

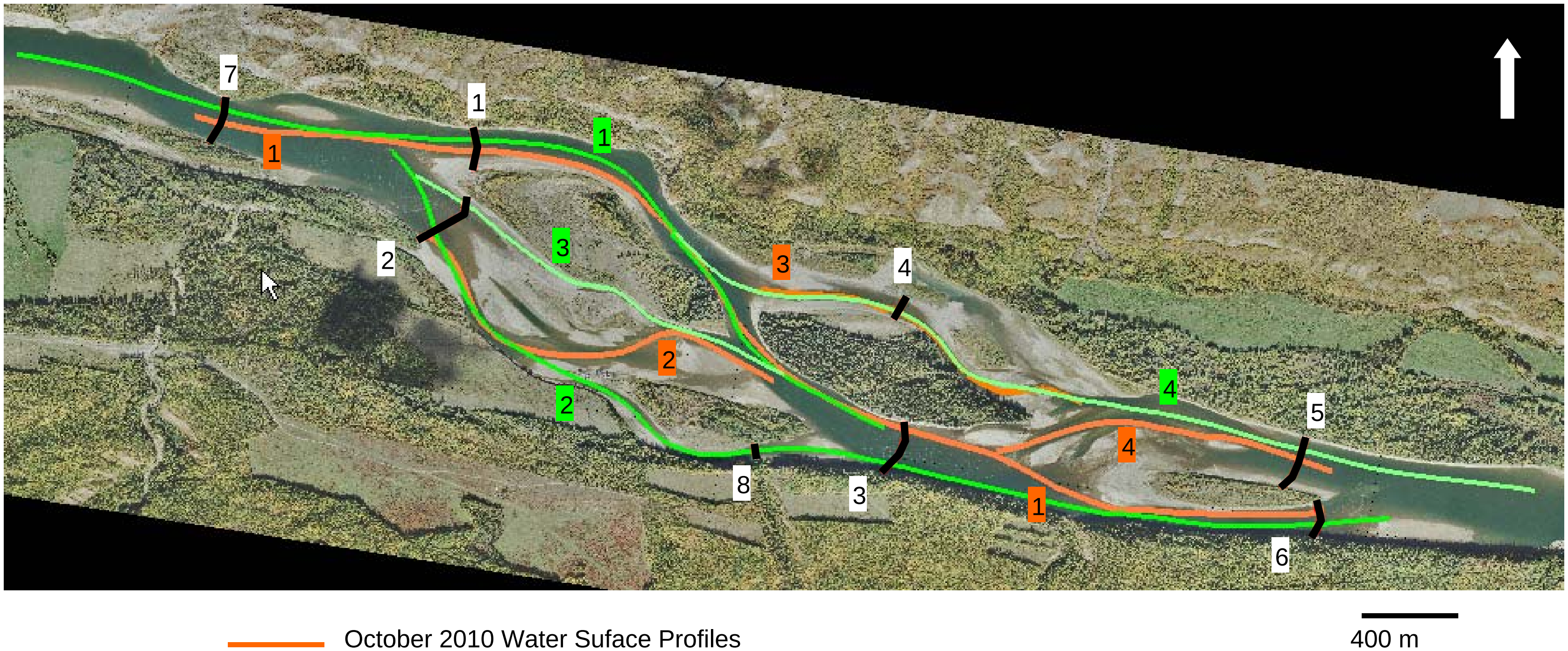
Figure C-3 - Aerial Photo Calibration (Pallings Flat, Flow = 1,840 m^3/s)

Photo Date: July 9, 2012
Discharge: 3,535 m^3/s

400 m

Modelled Water Surface Extent

Figure C-4 - Aerial Photo Calibration (Pallings Flat, Flow = 3,535 m^3/s)



October 2010 Water Suface Profiles

June 2011 Water Surface Profiles

Transect Location

Figure C-5 - Hydraulic Survey Locations (Pallings Flat)

Figure C-6 - Water Surface Profile Comparison (Pallings Flat, October 2010 Line P1)

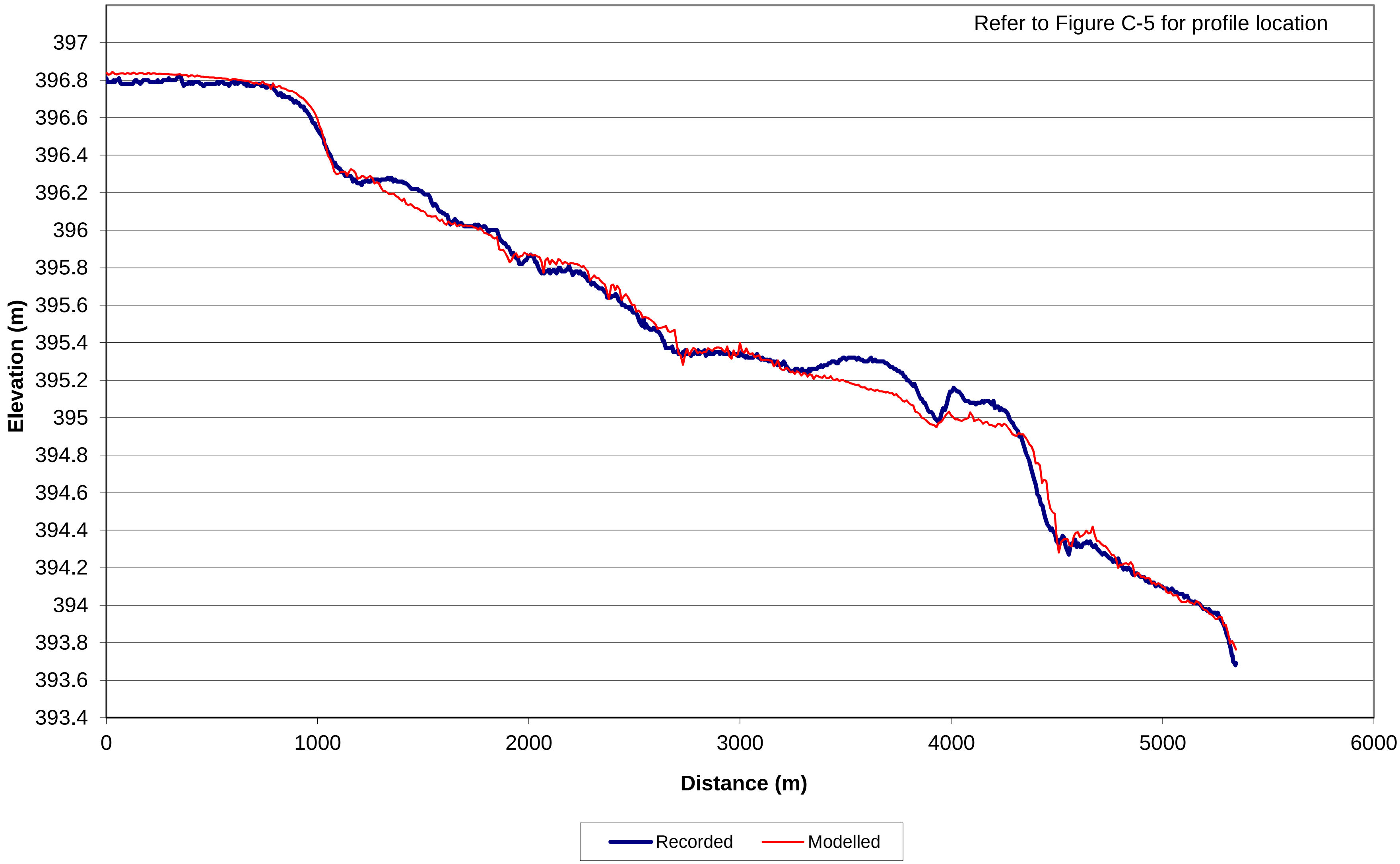


Figure C-7 - Water Surface Profile Comparison
(Pallings Flat, October 2010 Line P2)

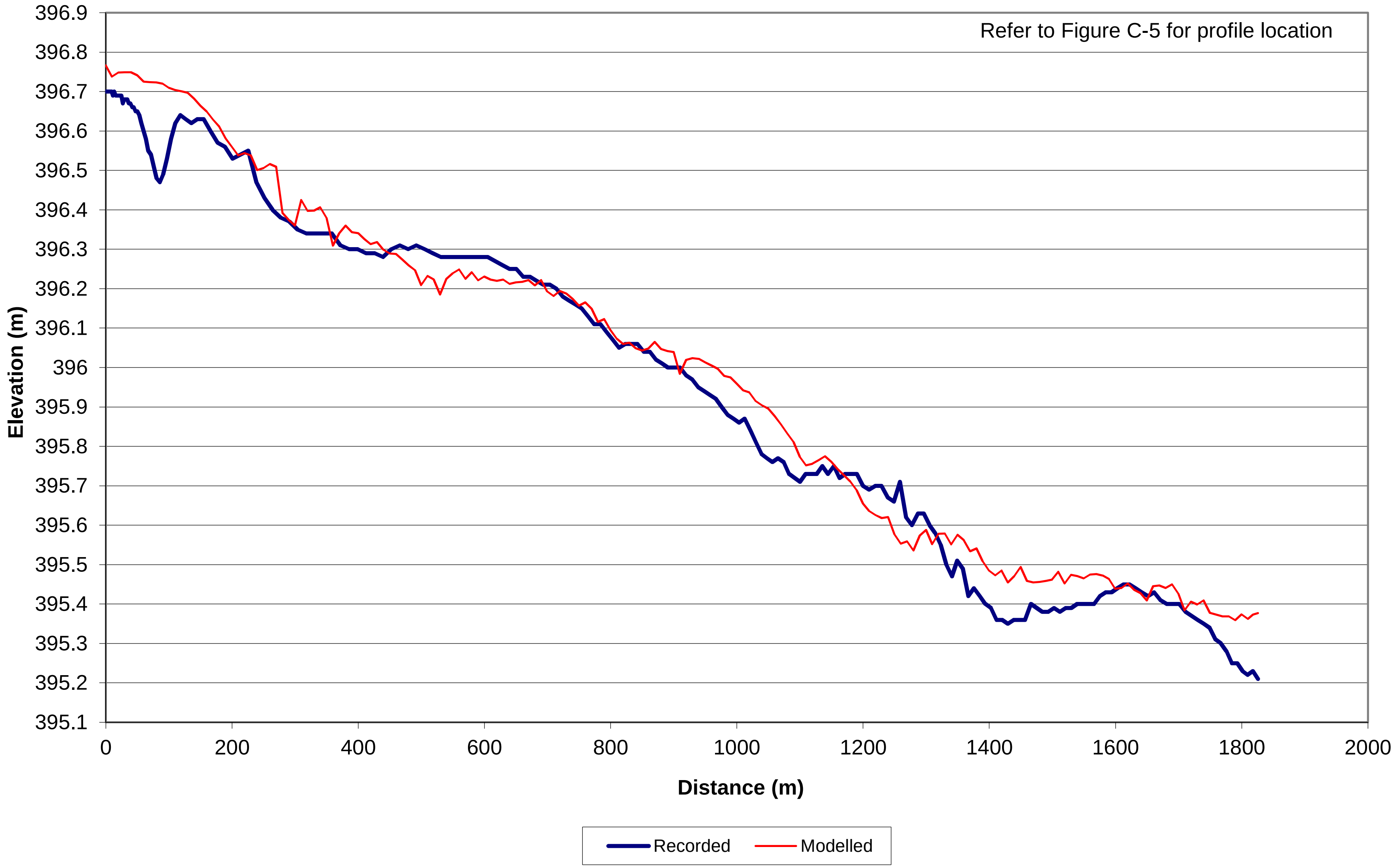


Figure C-8 - Water Surface Profile Comparison
(Pallings Flat, October 2010 Line P3)

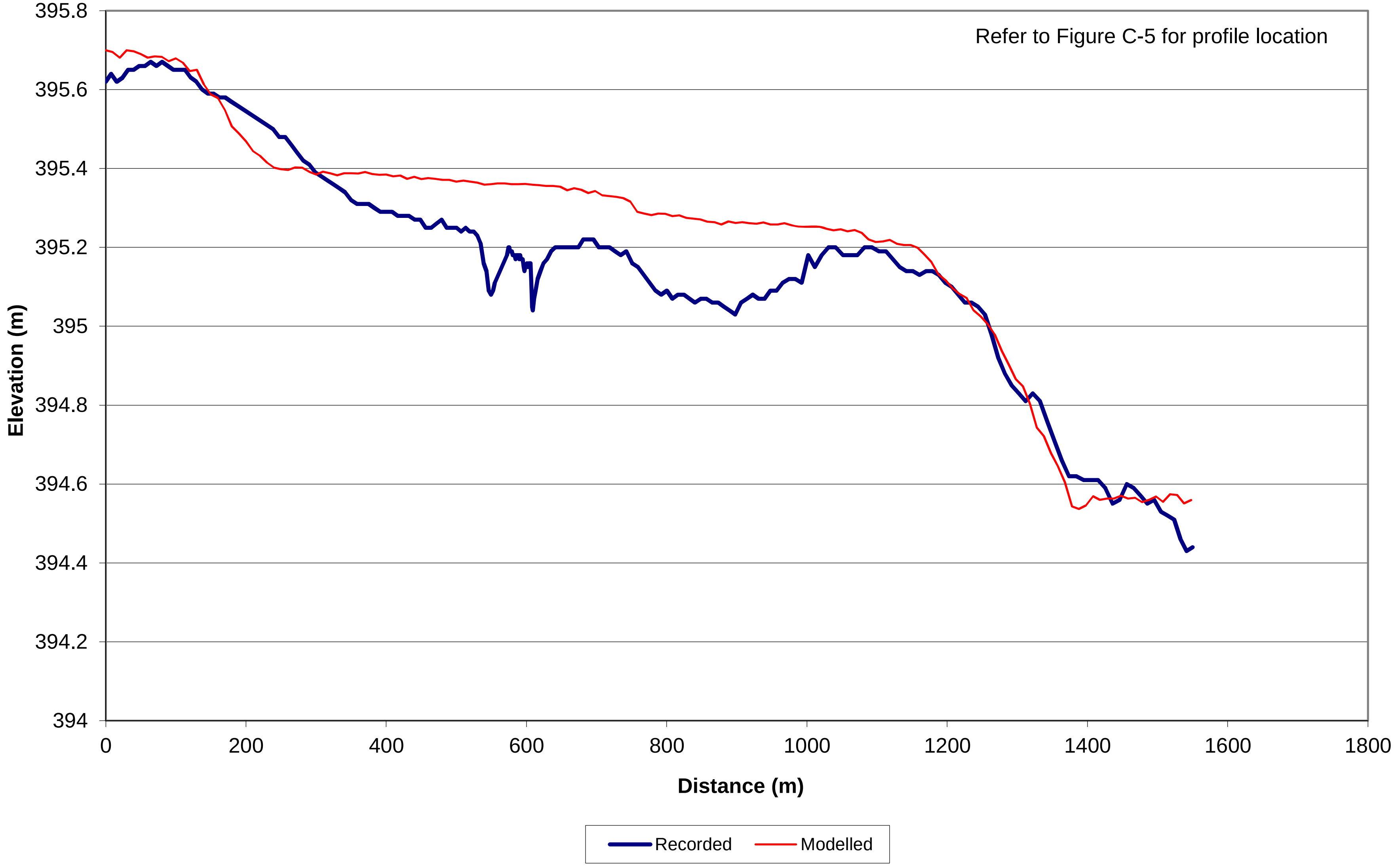
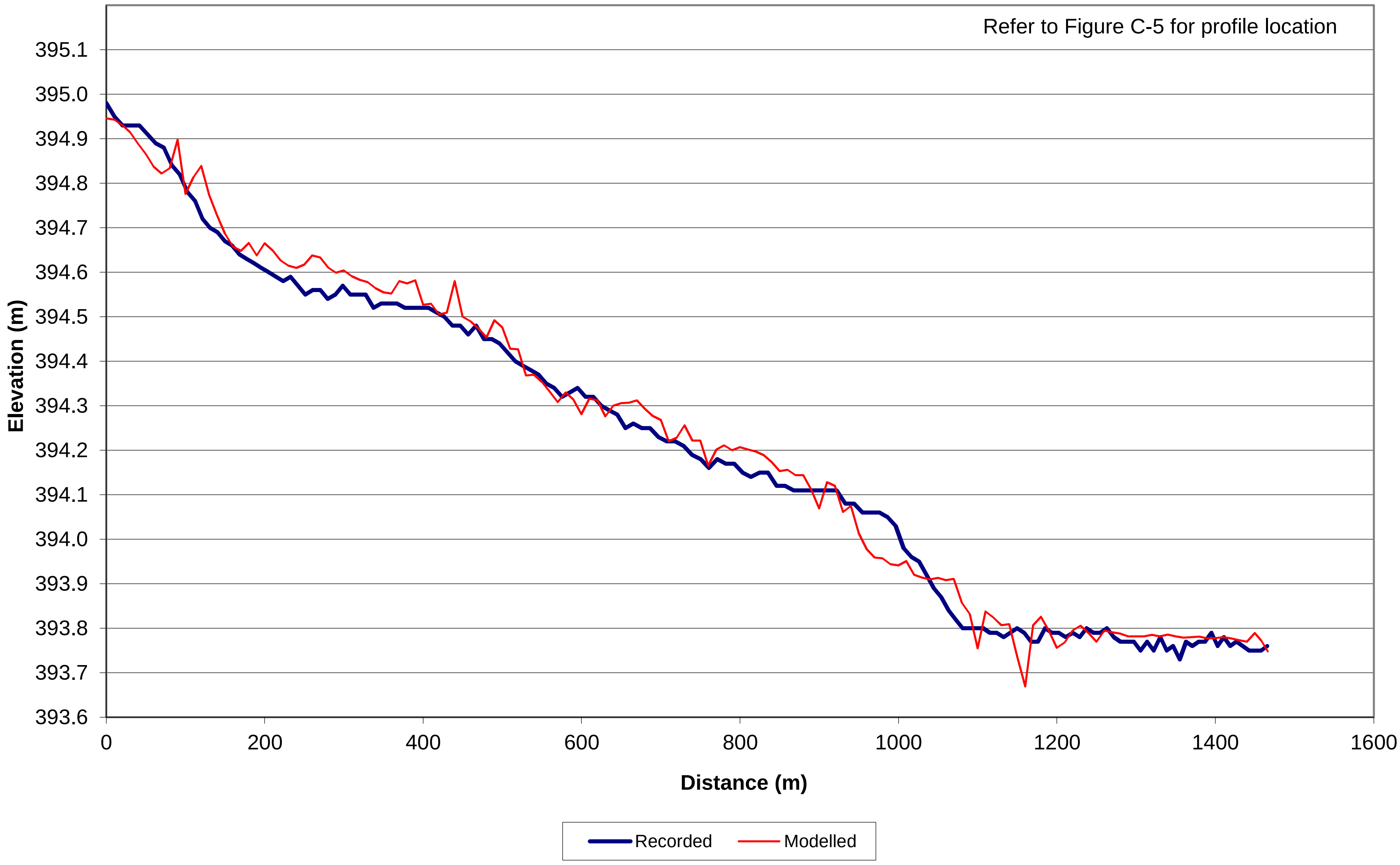
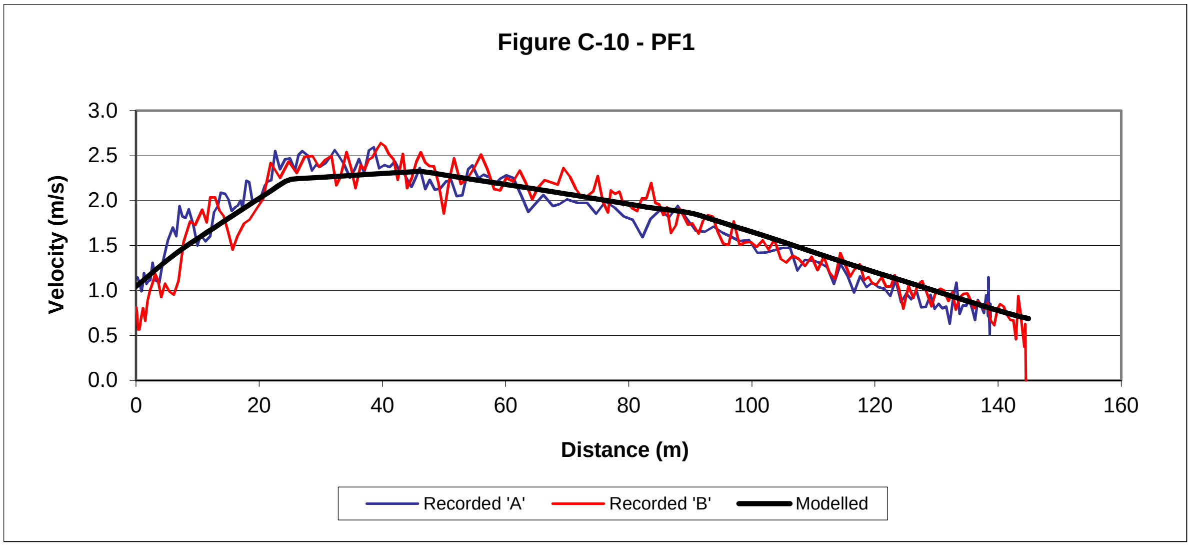
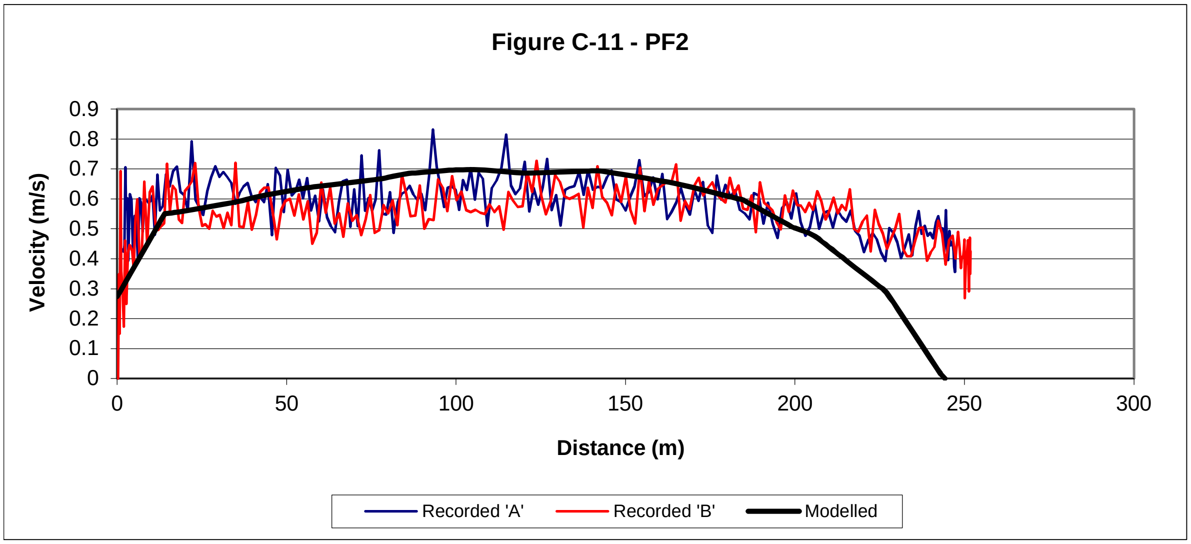


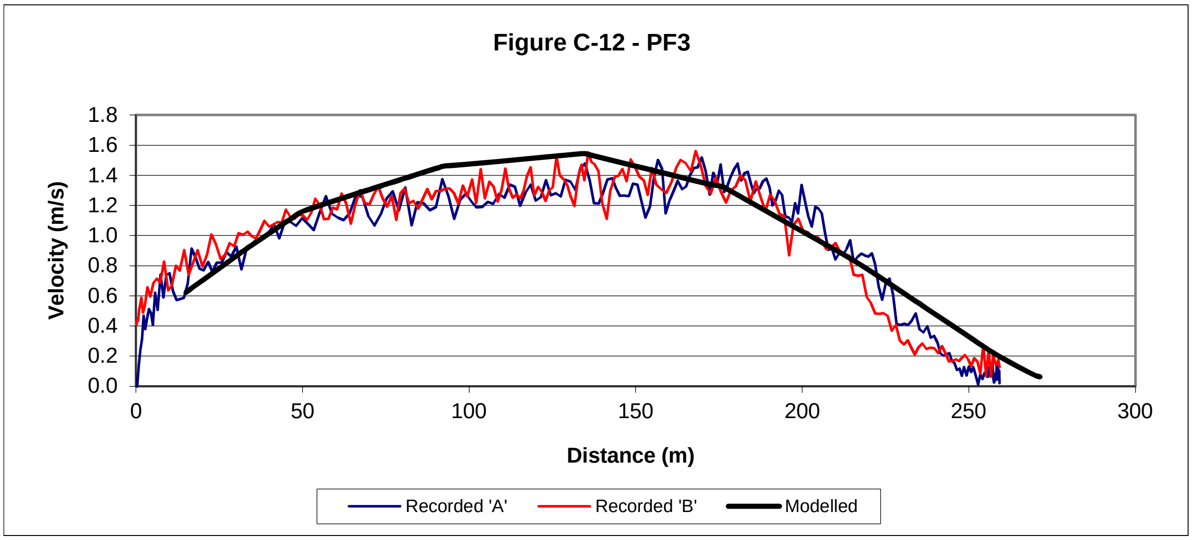
Figure C-9 - Water Surface Profile Comparison
(Pallings Flat, October 2010 Line P4)



Pallings Flat Reach Transect Velocity Comparision
October 2010

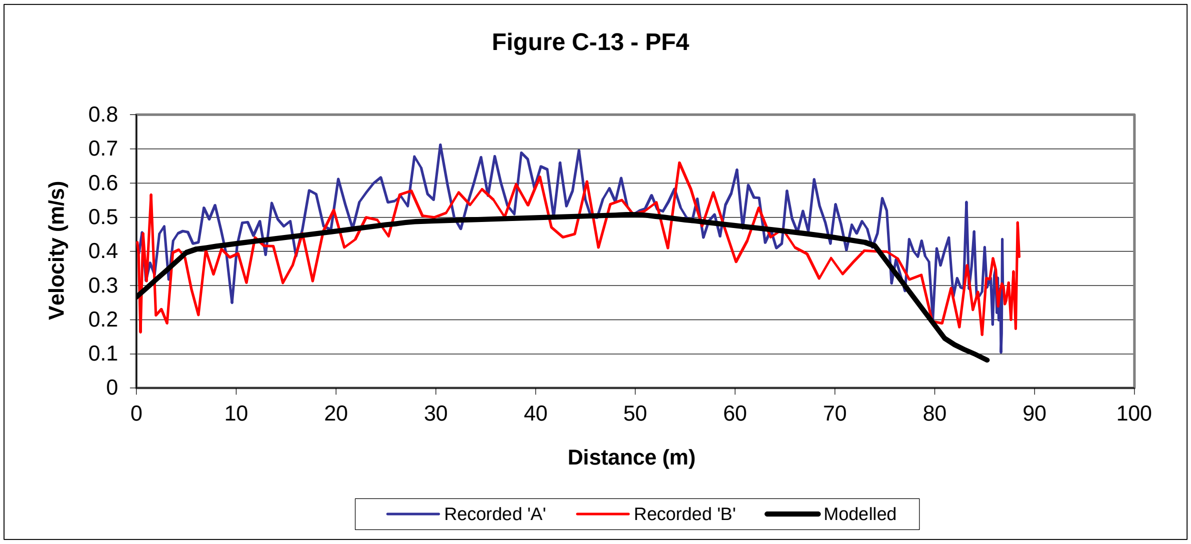


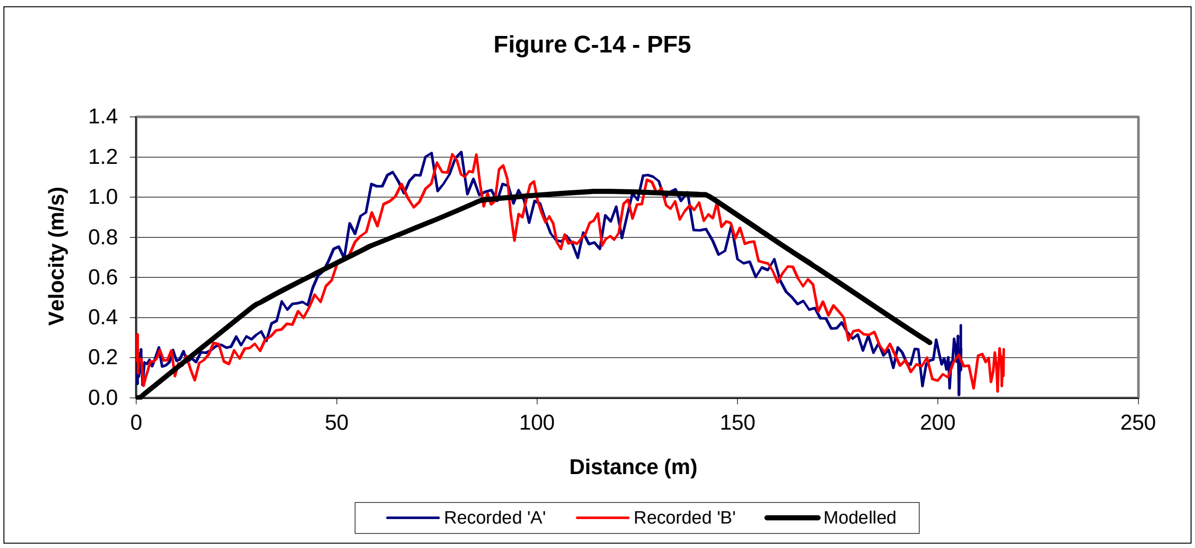


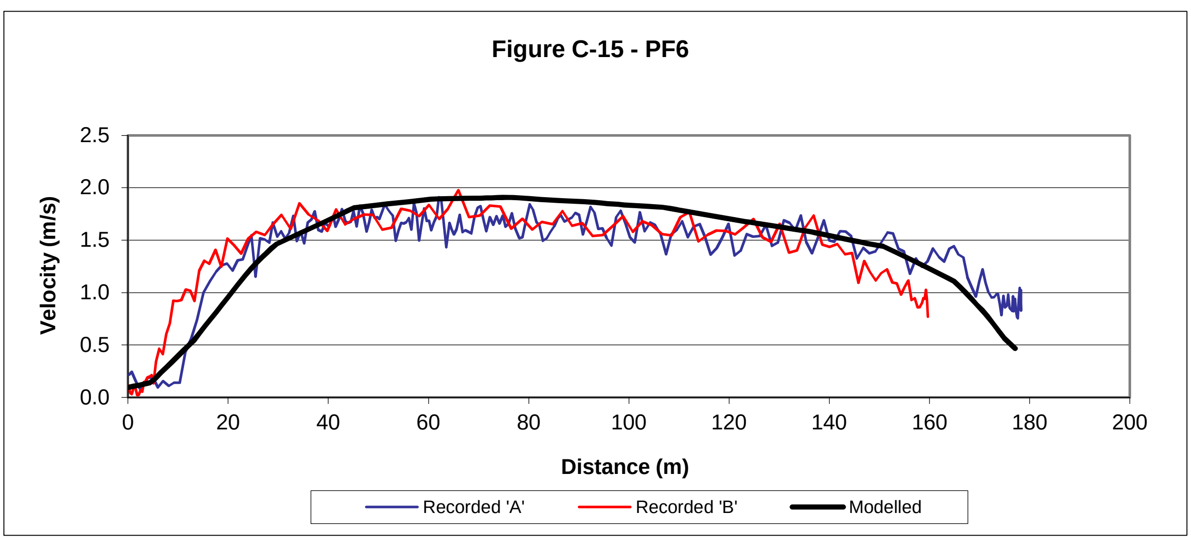


Refer to Figure C-5 for transect location

Pallings Flat Reach Transect Velocity Comparision October 2010







Refer to Figure C-5 for transect location

Figure C-16 - Water Surface Profile Comparison
(Pallings Flat, June 2011 Line P1)

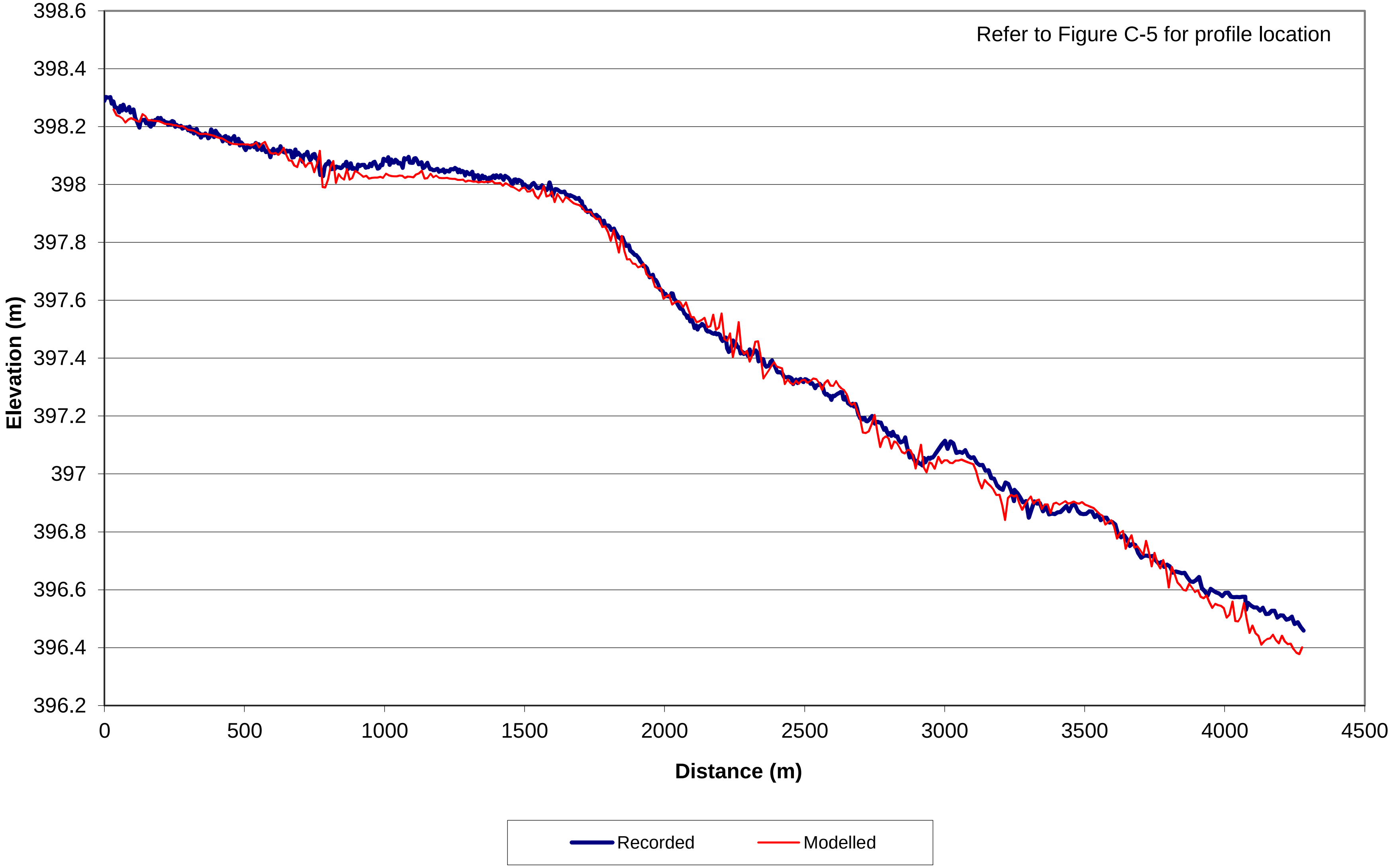


Figure C-17 - Water Surface Profile Comparison (Pallings Flat, June 2011 Line P2)

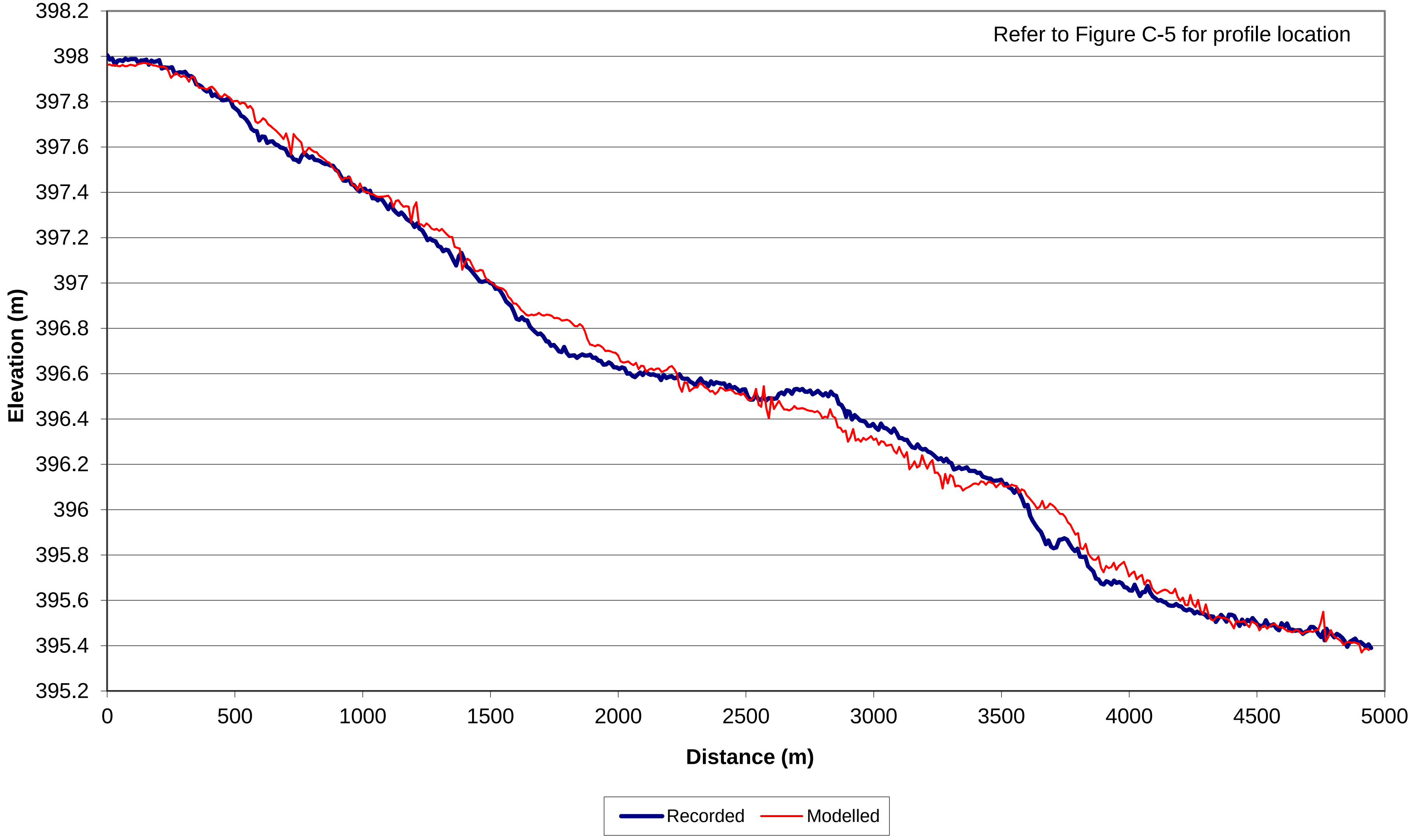


Figure C-18 - Water Surface Profile Comparison
(Pallings Flat, June 2011 Line P3)

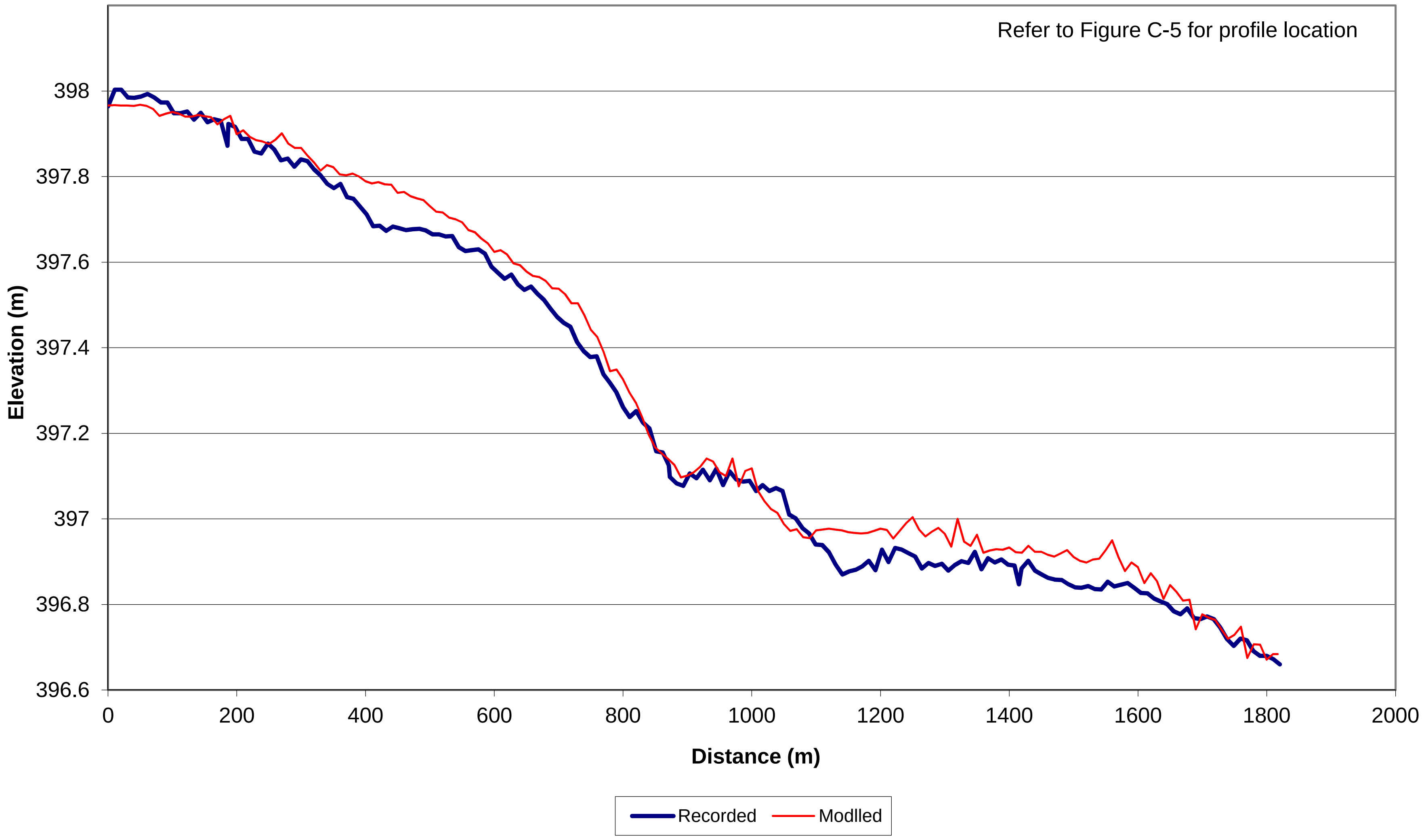
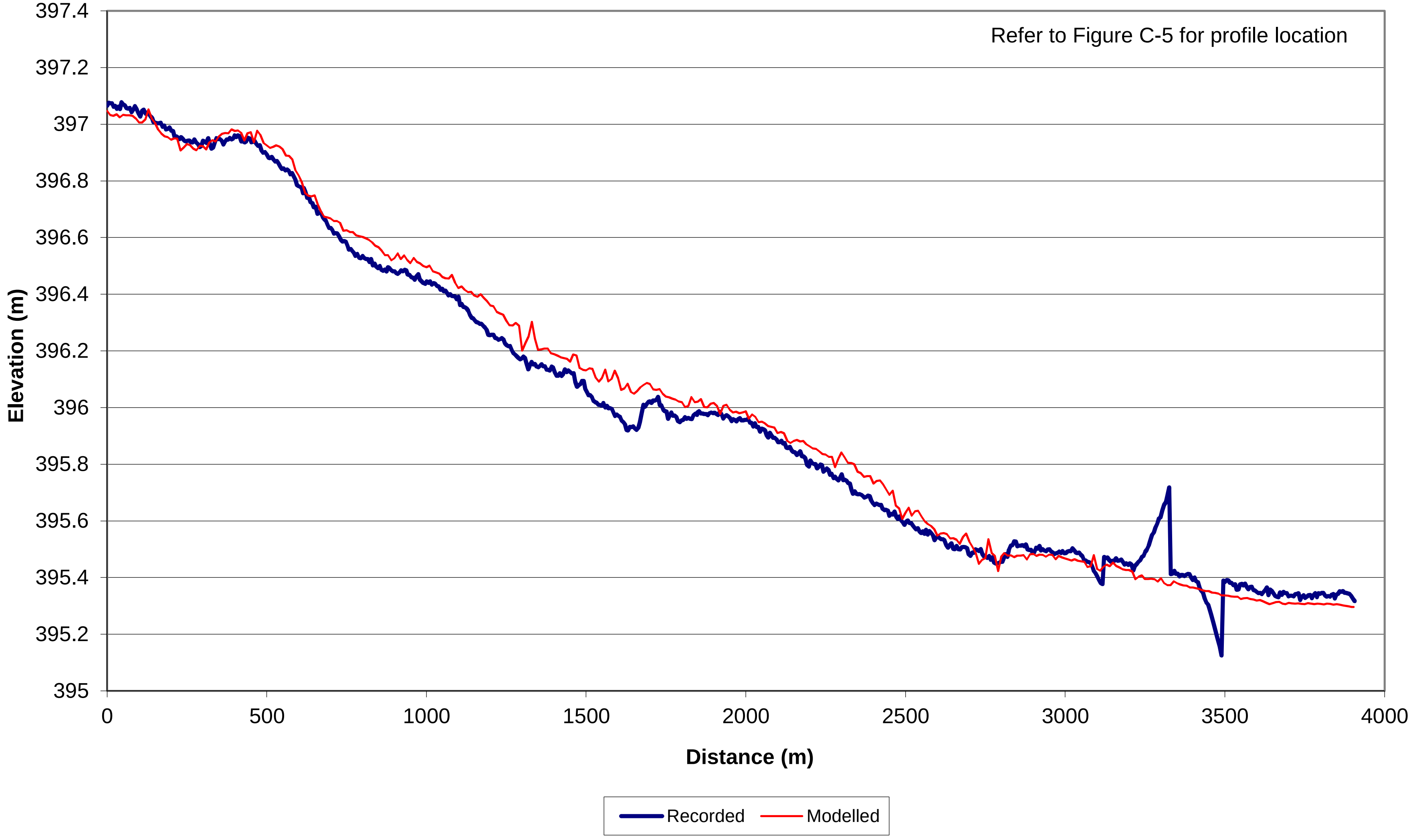


Figure C-19 - Water Surface Profile Comparison (Pallings Flat, June 2011 Line P4)



Pallings Flat Reach Transect Velocity Comparision
June 2011

Figure C-20 - PF1

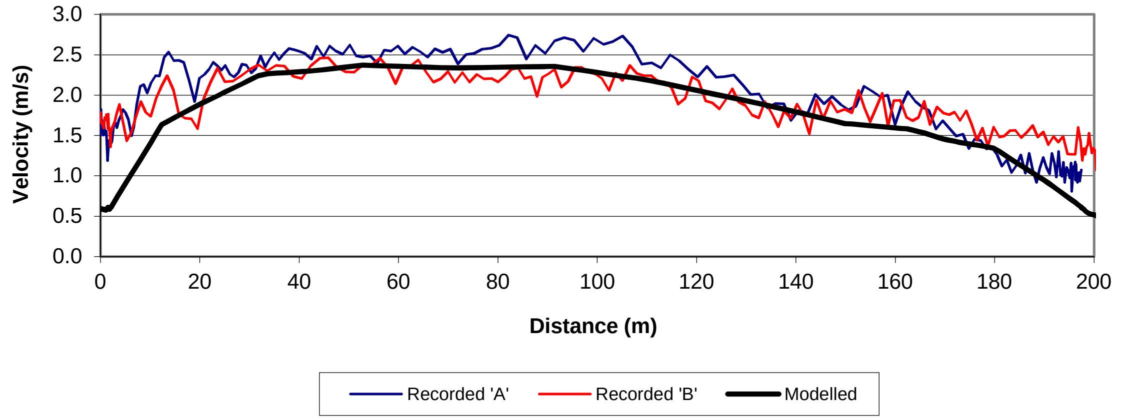


Figure C-21 - PF2

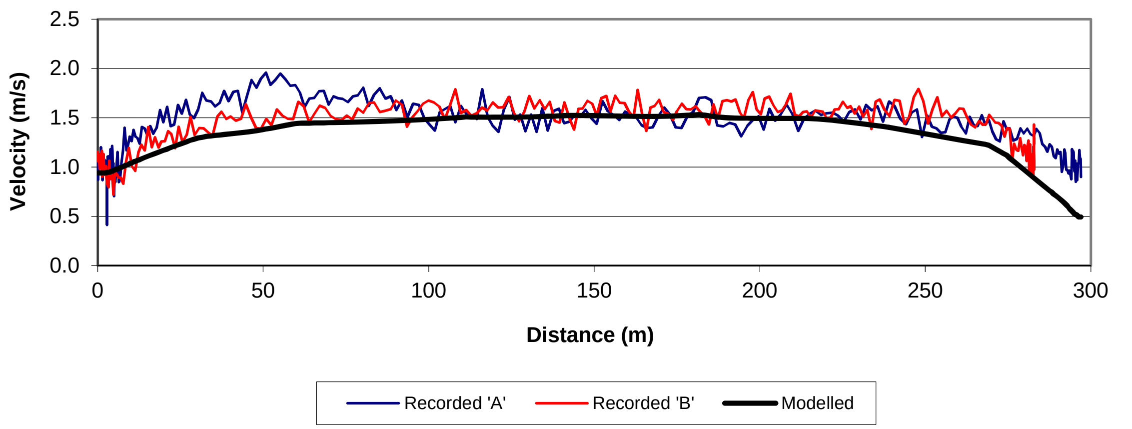
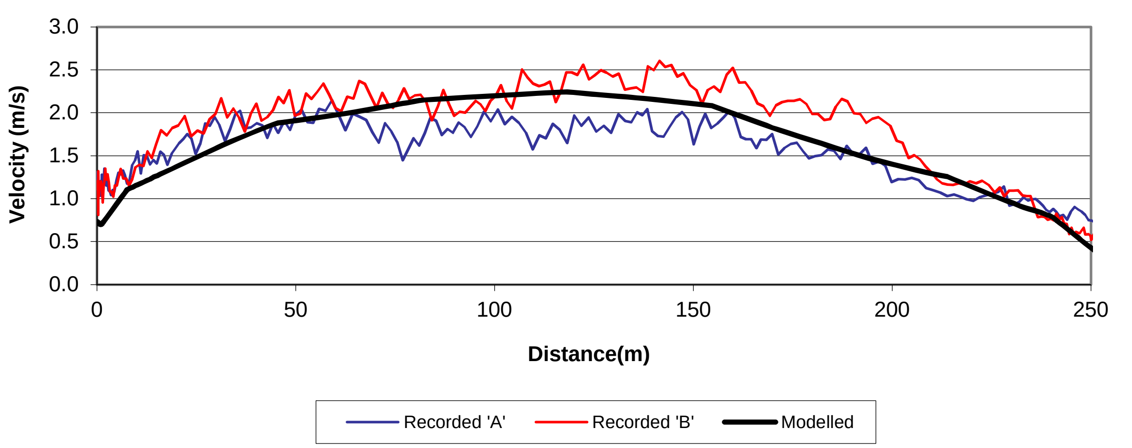
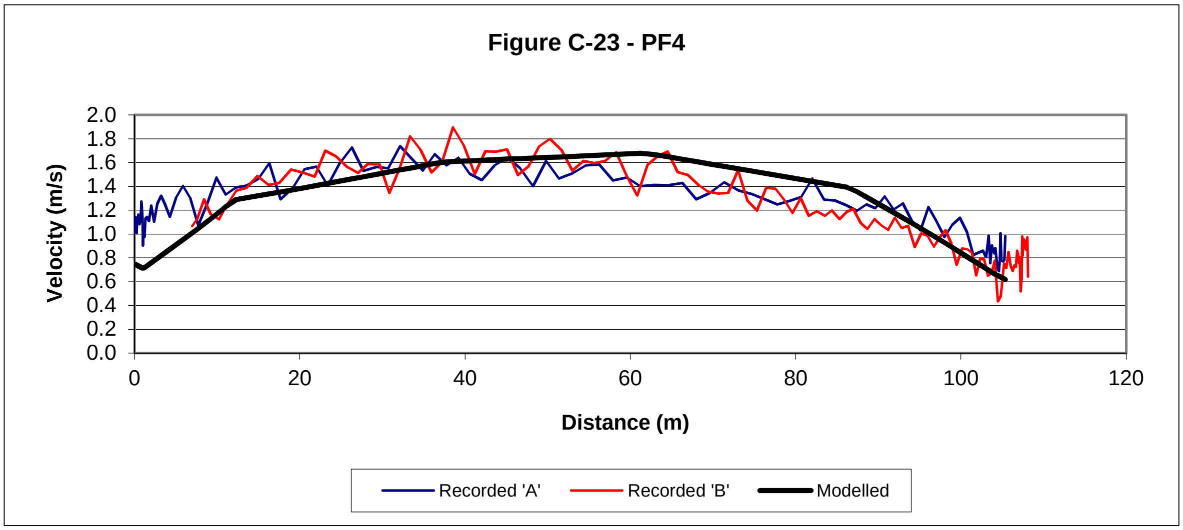


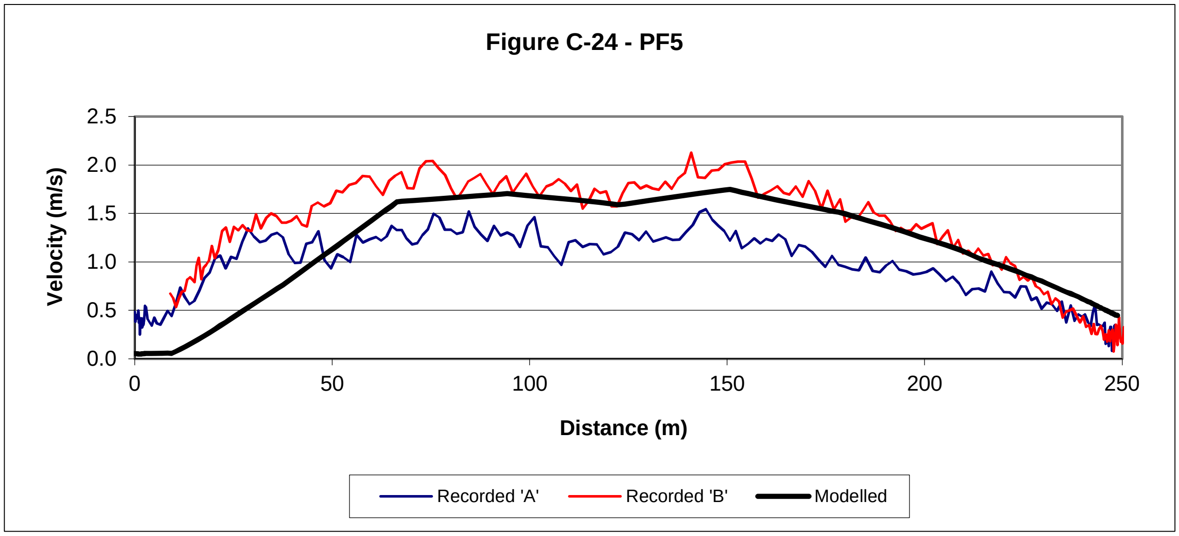
Figure C-22 - PF3

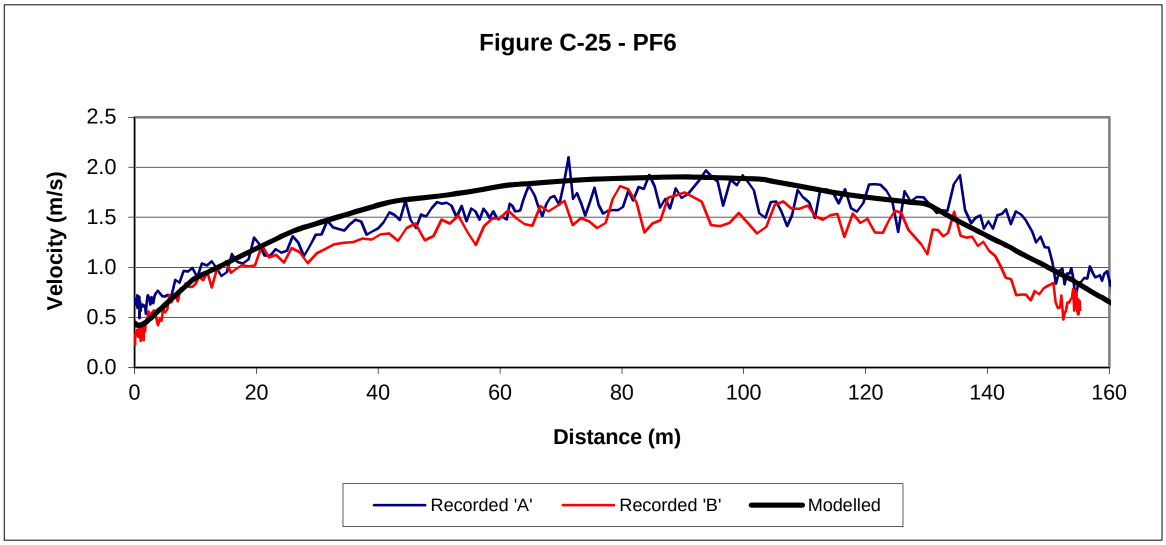


Refer to Figure C-5 for transect location

Pallings Flat Reach Transect Velocity Comparision
June 2011

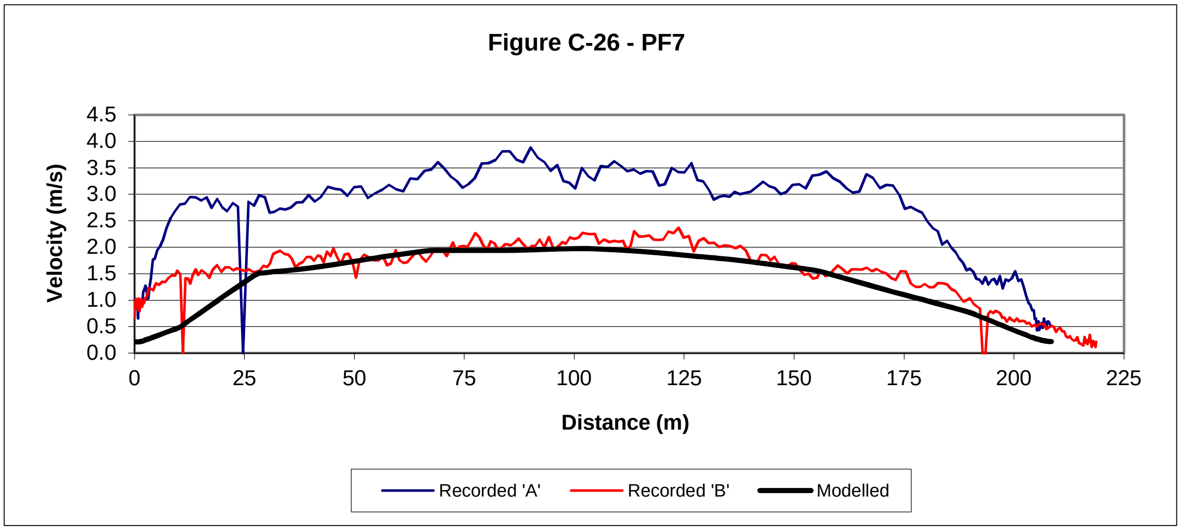


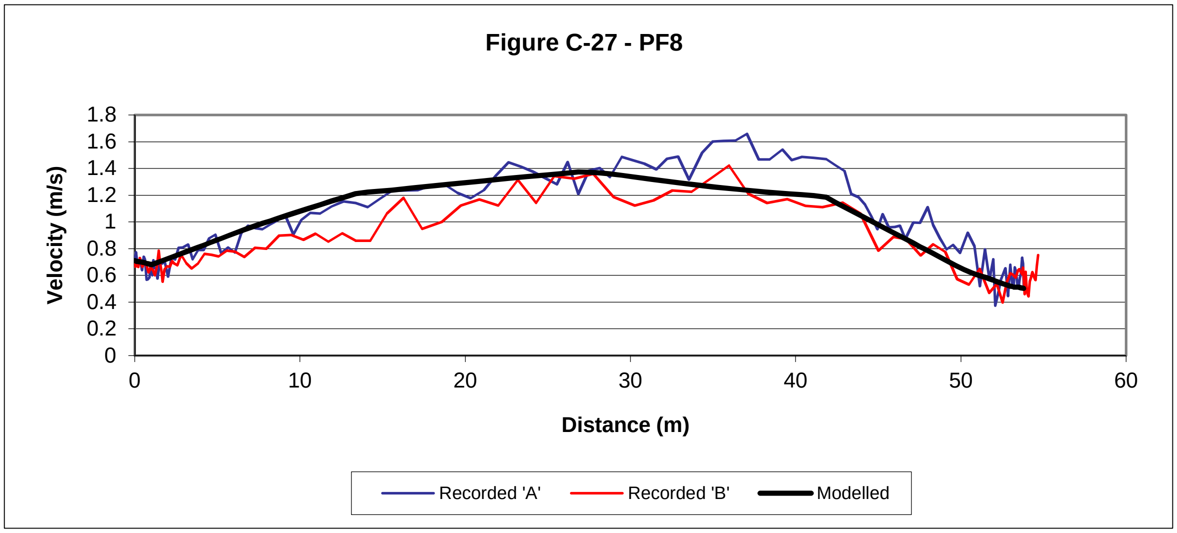




Refer to Figure C-5 for transect location

Pallings Flat Reach Transect Velocity Comparision
June 2011





Refer to Figure C-5 for transect location

Appendix D

Raspberry Island Reach
Calibration Figures

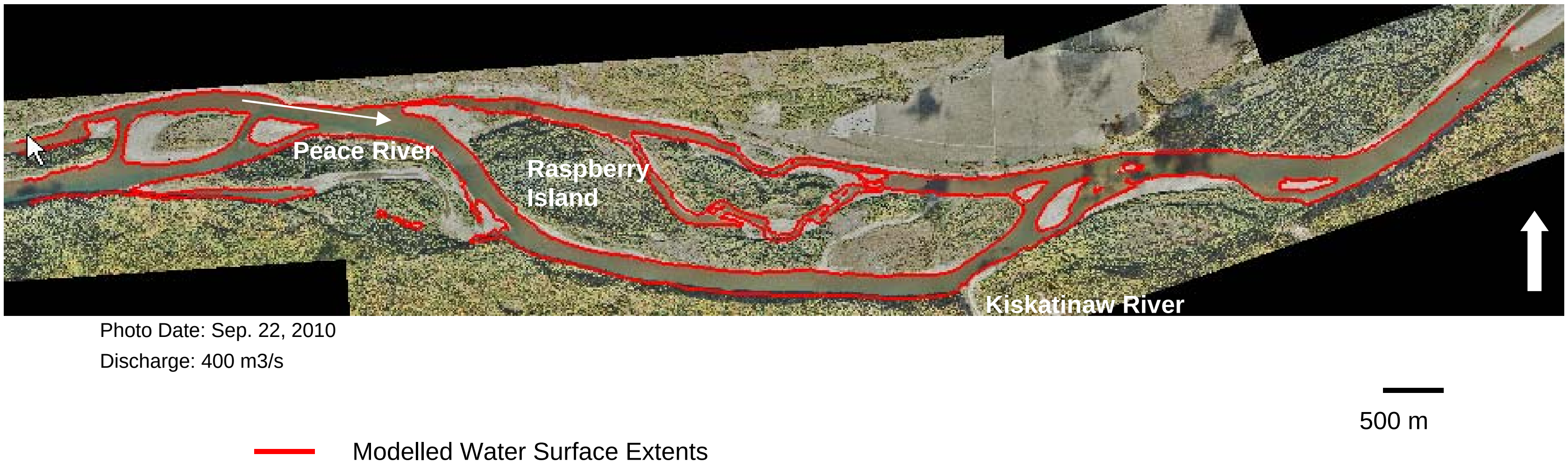


Photo Date: Sep. 22, 2010
Discharge: 400 m3/s

Figure D-1 - Aerial Photo Calibration (Raspberry Island, Flow = 400 m^3/s)

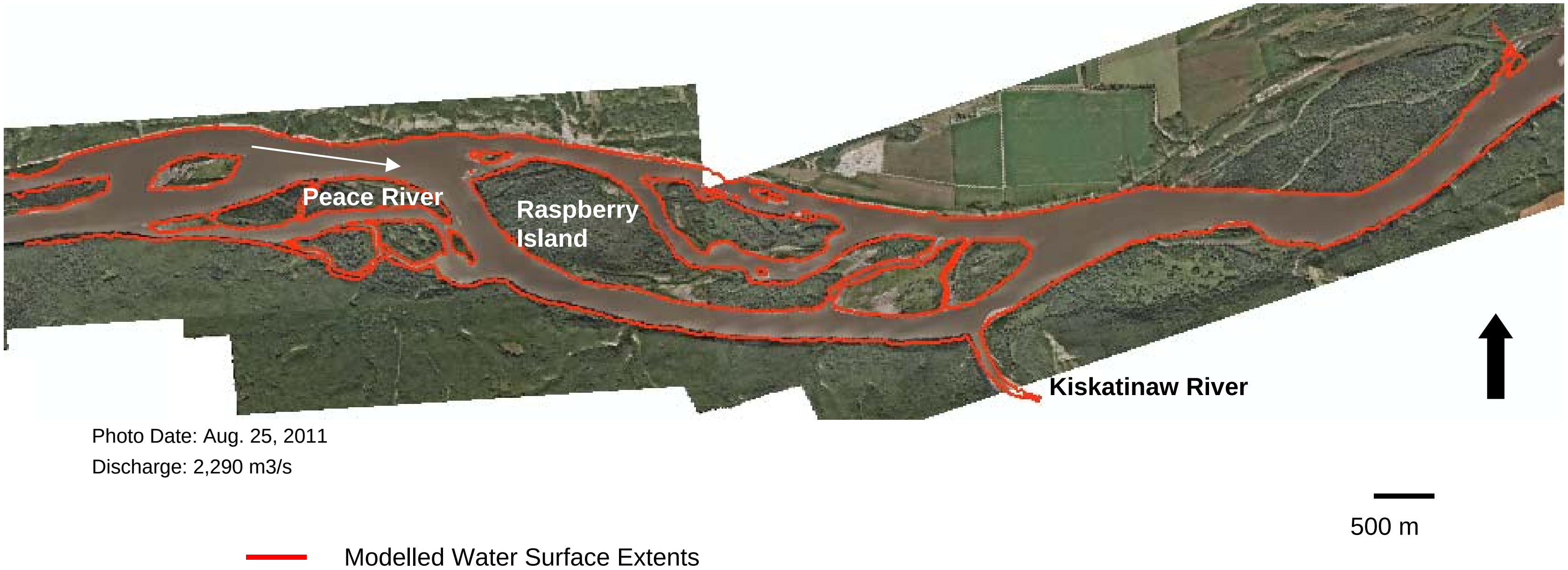


Figure D-2 - Aerial Photo Calibration (Raspberry Island, Flow = 2,290 m^3/s)

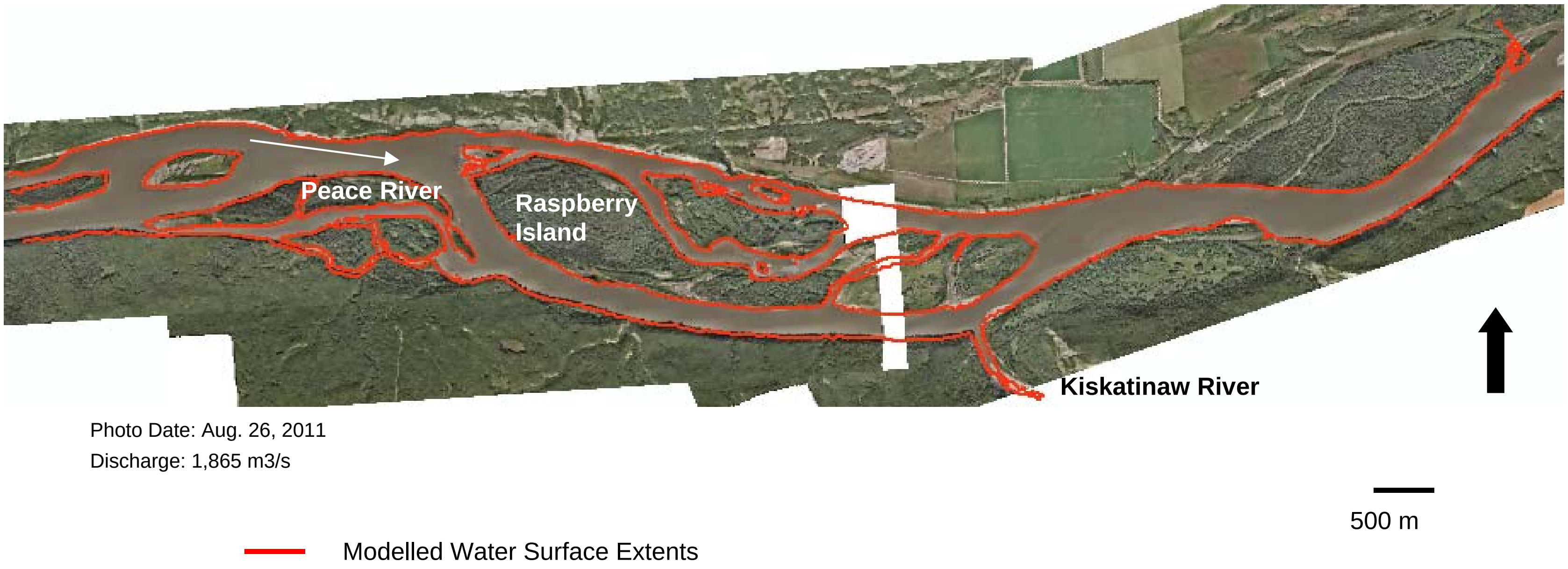


Figure D-3 - Aerial Photo Calibration (Raspberry Island, Flow = 1,865 m^3/s)

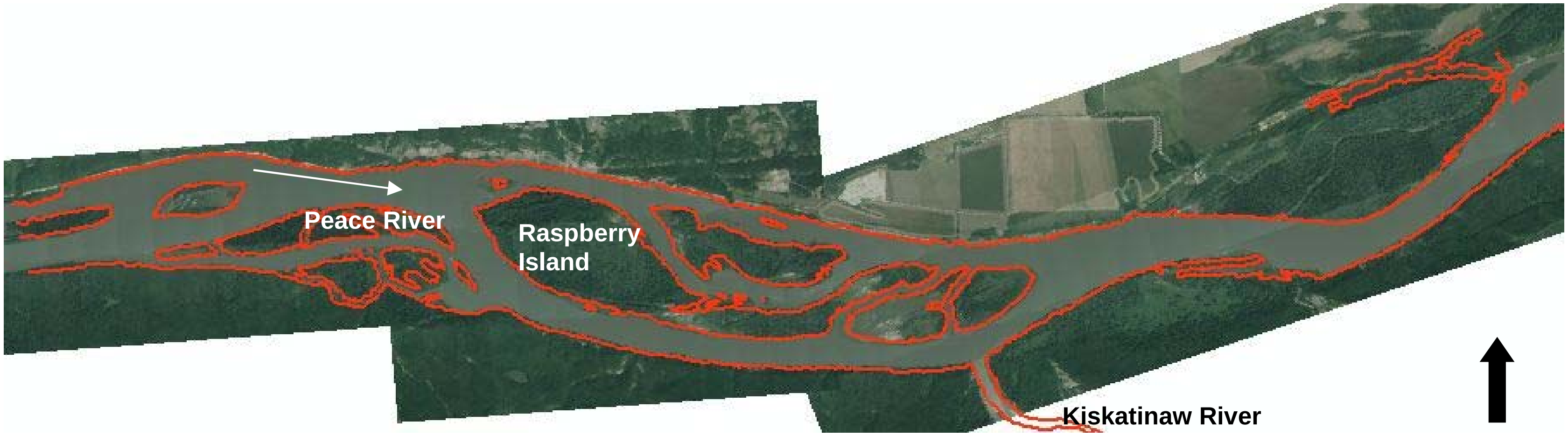


Photo Date: July 9, 2012

Discharge: 3,580 m3/s

500 m

Modelled Water Surface Extents

Figure D-4 - Aerial Photo Calibration (Raspberry Island, Flow = 3,580 m^3/s)

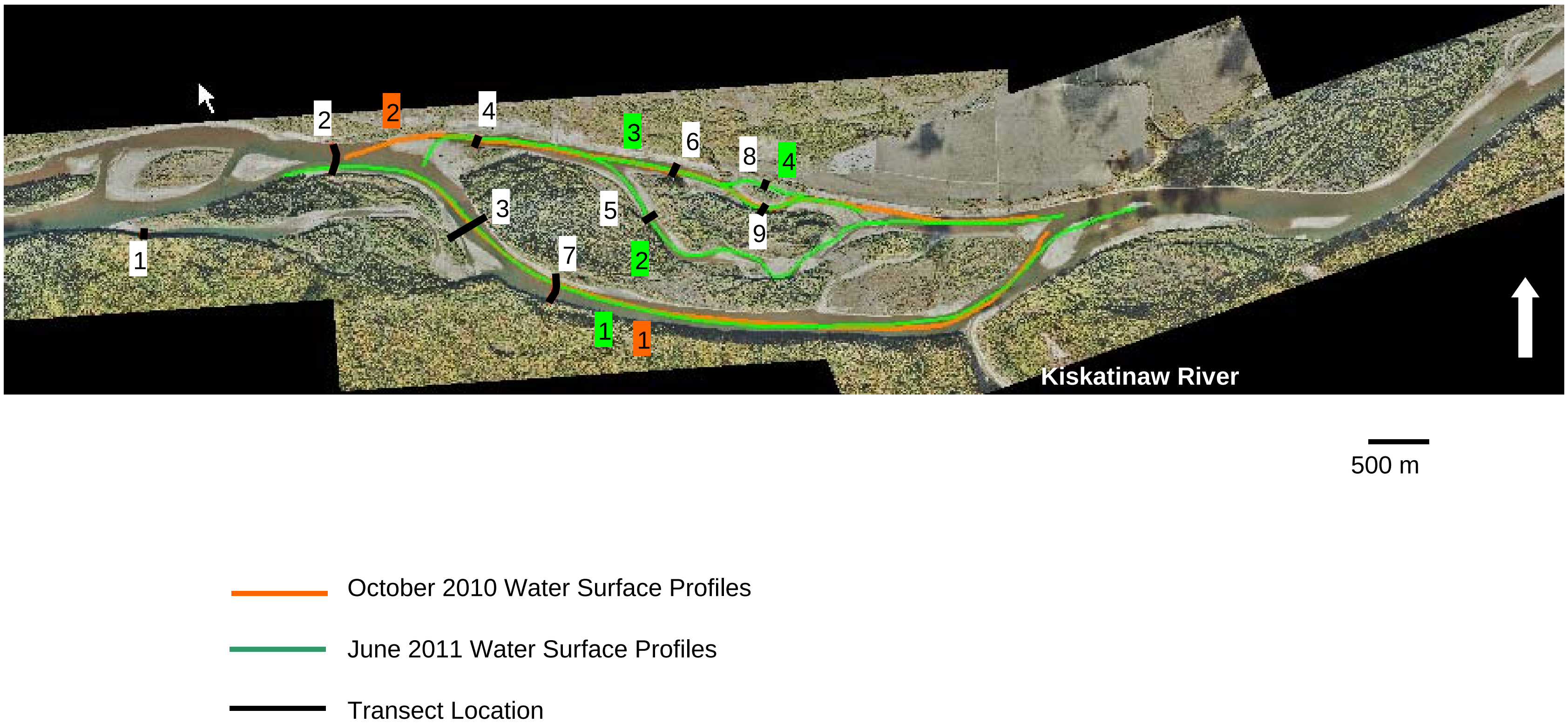


Figure D-5 - Hydraulic Survey Locations (Raspberry Island)

Figure D-6 - Water Surface Profile Comparison
(Raspberry Island, October 2010 Line P1)

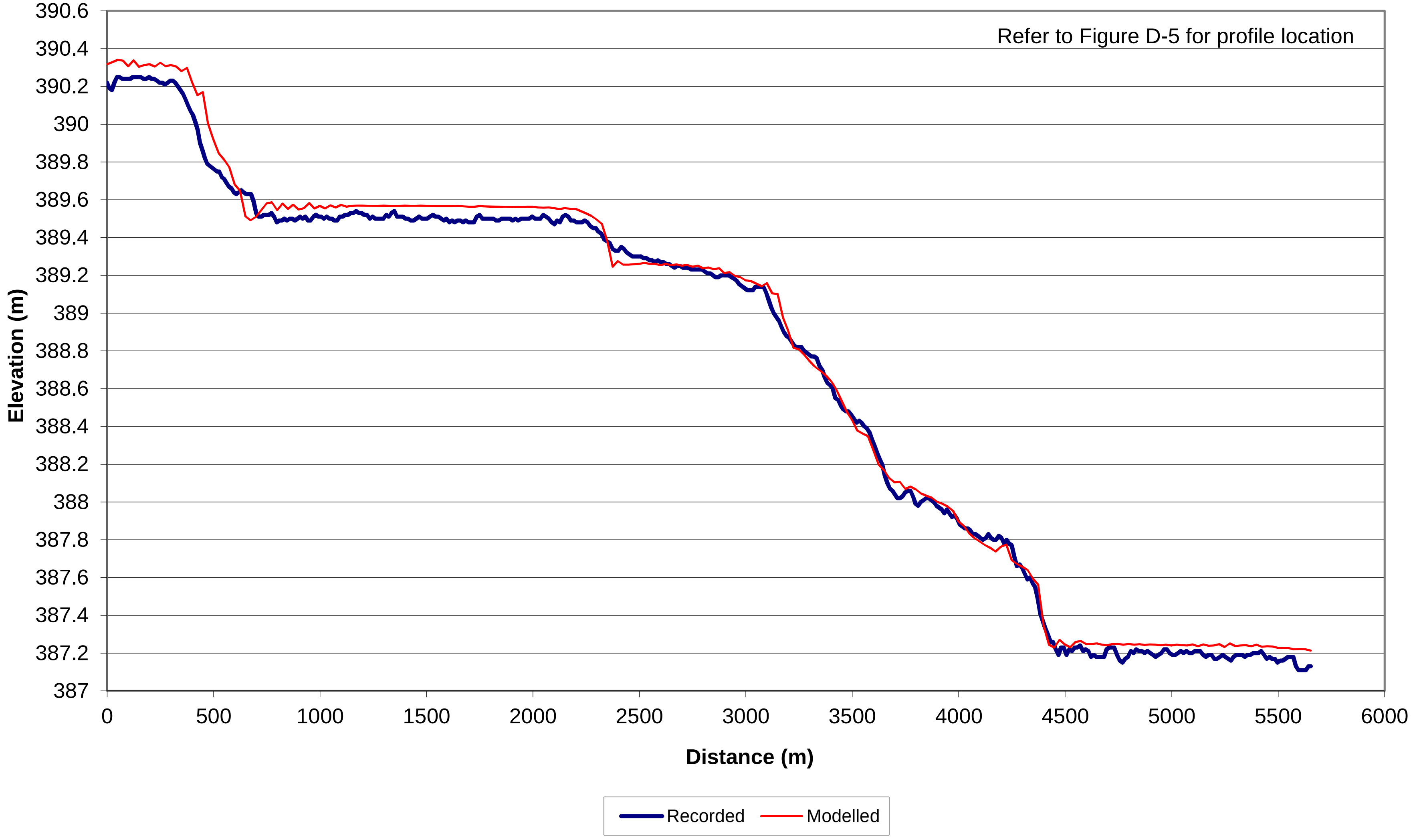
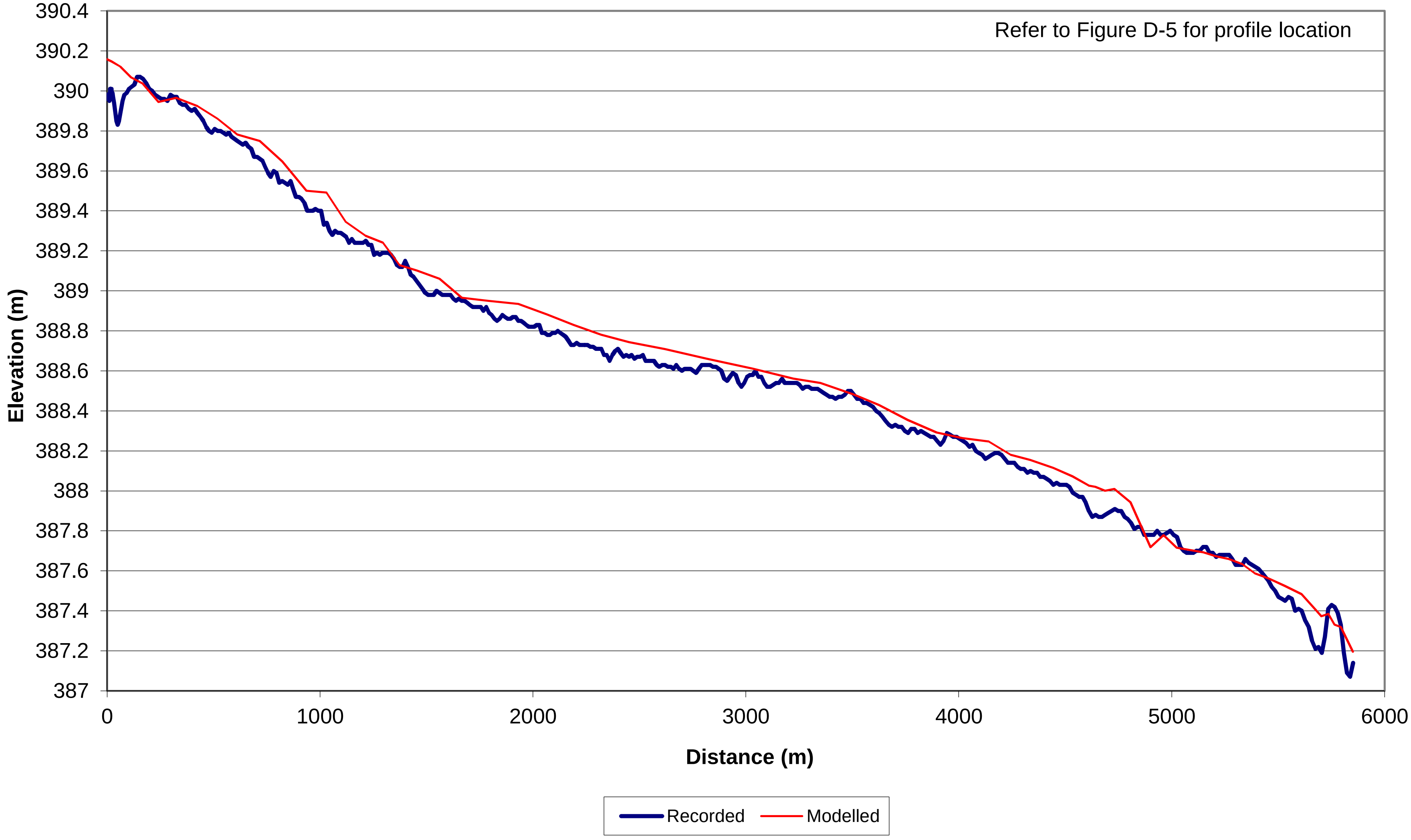
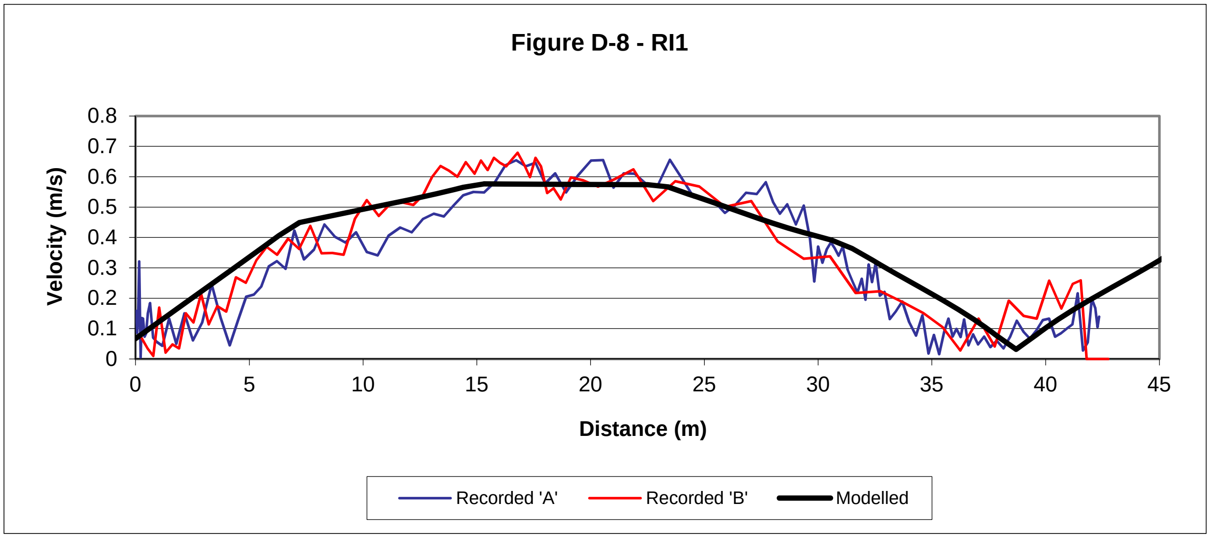
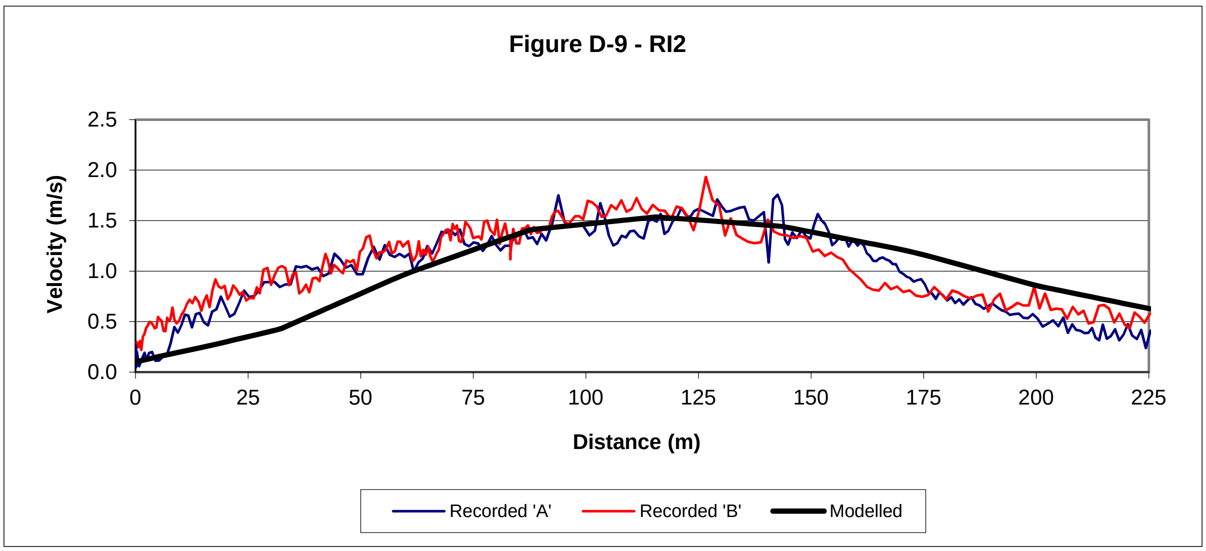


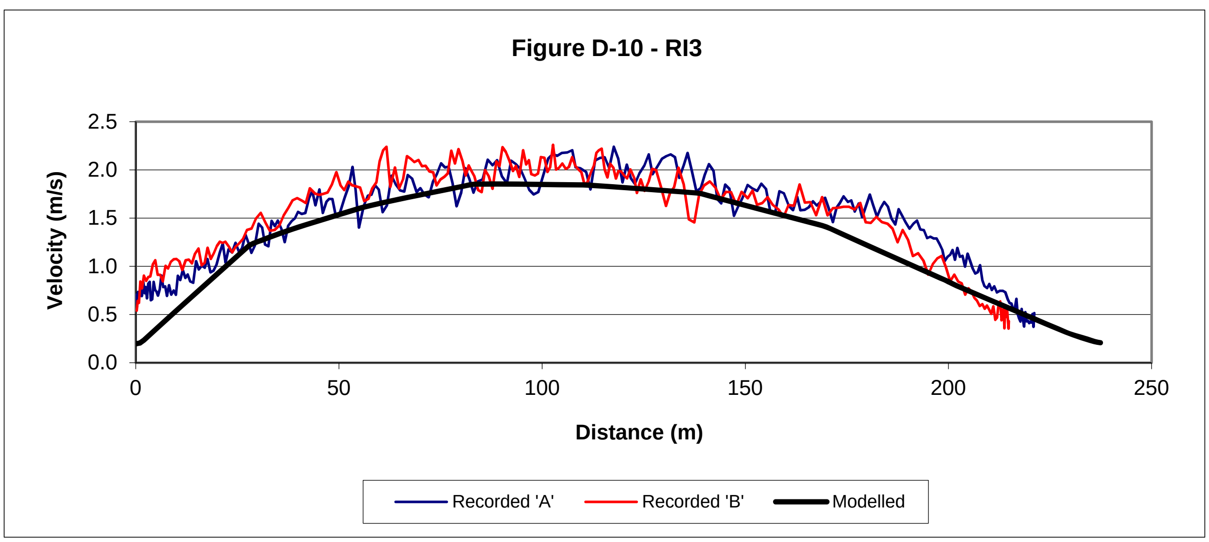
Figure D-7 - Water Surface Profile Comparison (Raspberry Island, October 2010 Line P2)



Raspberry Island Reach Transect Velocity Comparision
October 2010

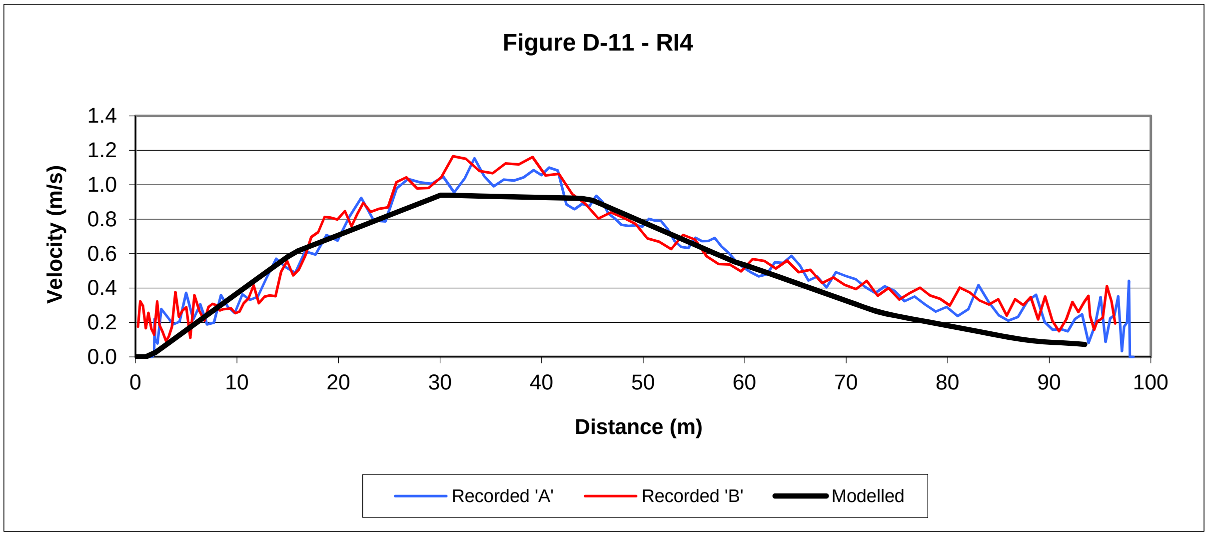


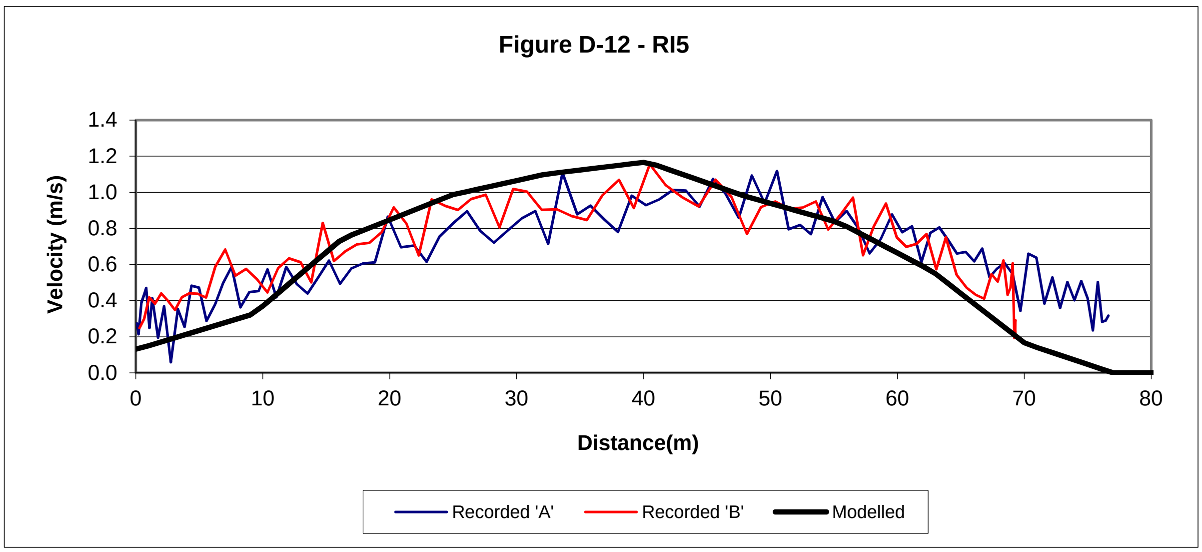


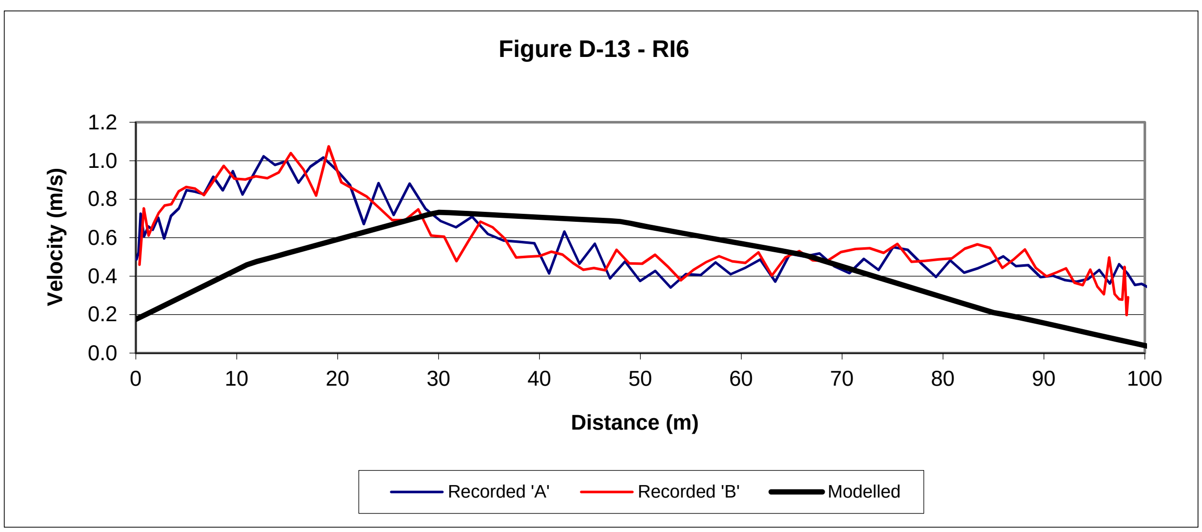


Refer to Figure D-5 for transect location

Raspberry Island Reach Transect Velocity Comparision
October 2010







Refer to Figure D-5 for transect location

Figure D-14 - Water Surface Profile Comparison
(Raspberry Island, June 2011 Line P1)

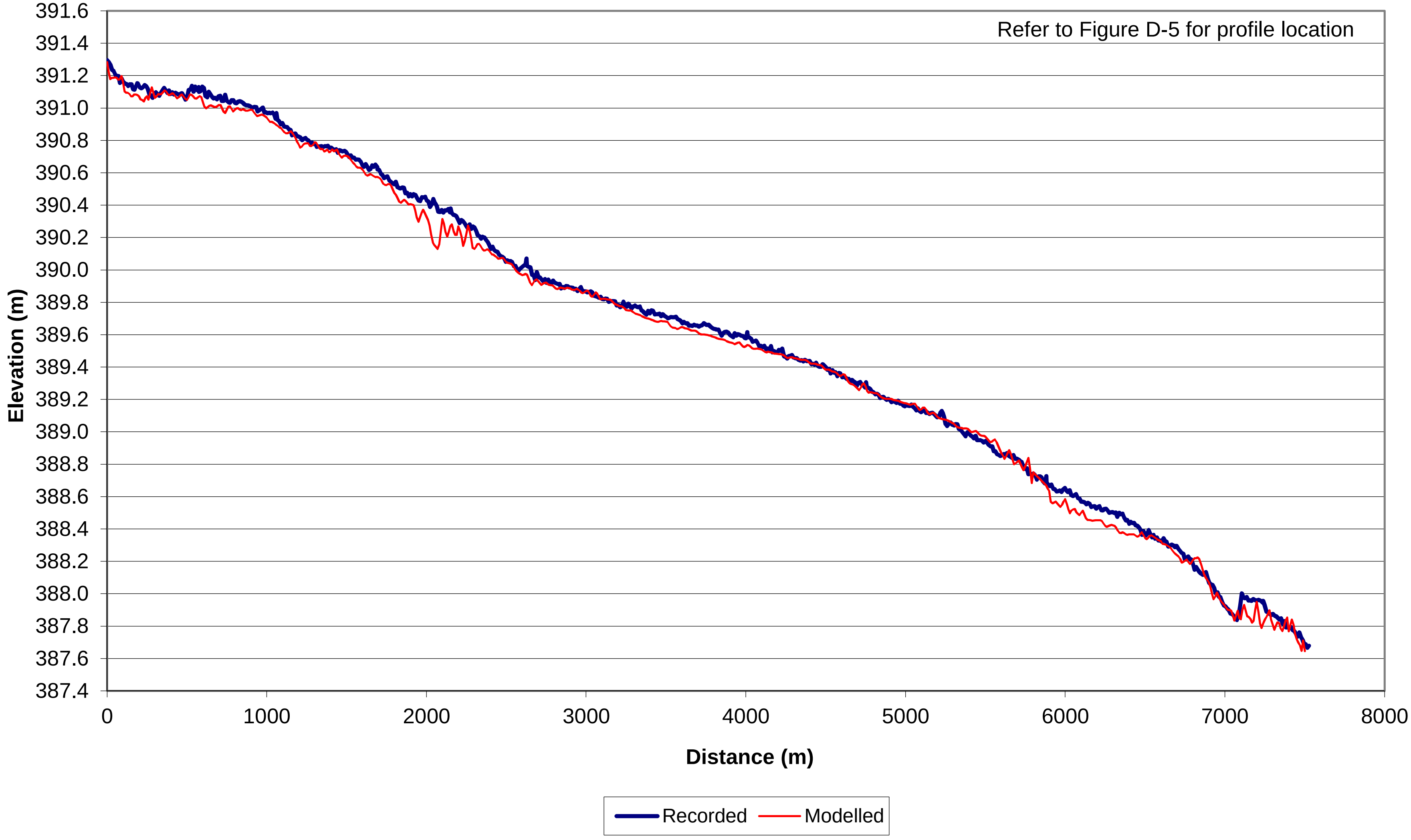


Figure D-15 - Water Surface Profile Comparison
(Raspberry Island, June 2011 Line P2)

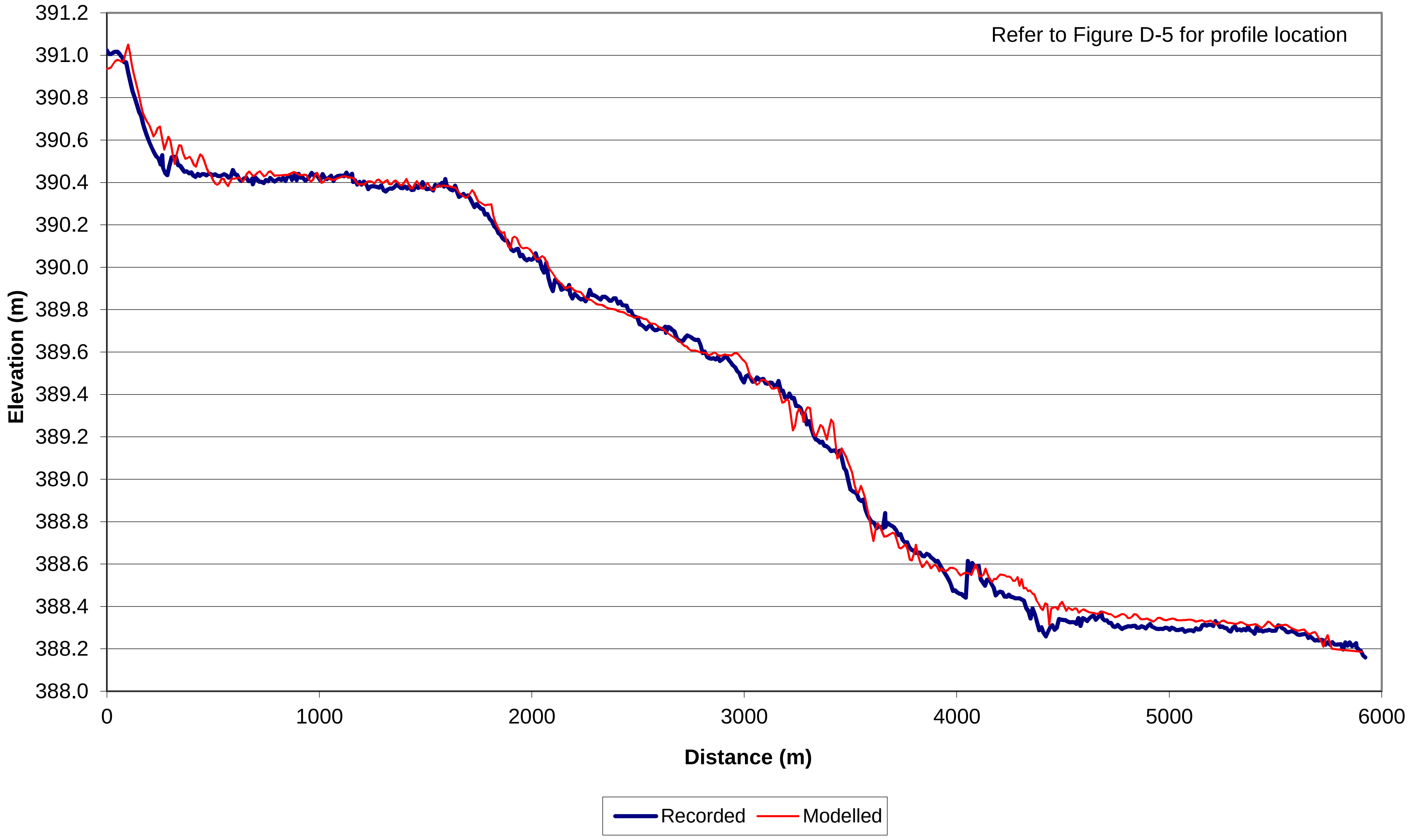


Figure D-16 - Water Surface Profile Comparison
(Raspberry Island, June 2011 Line P3)

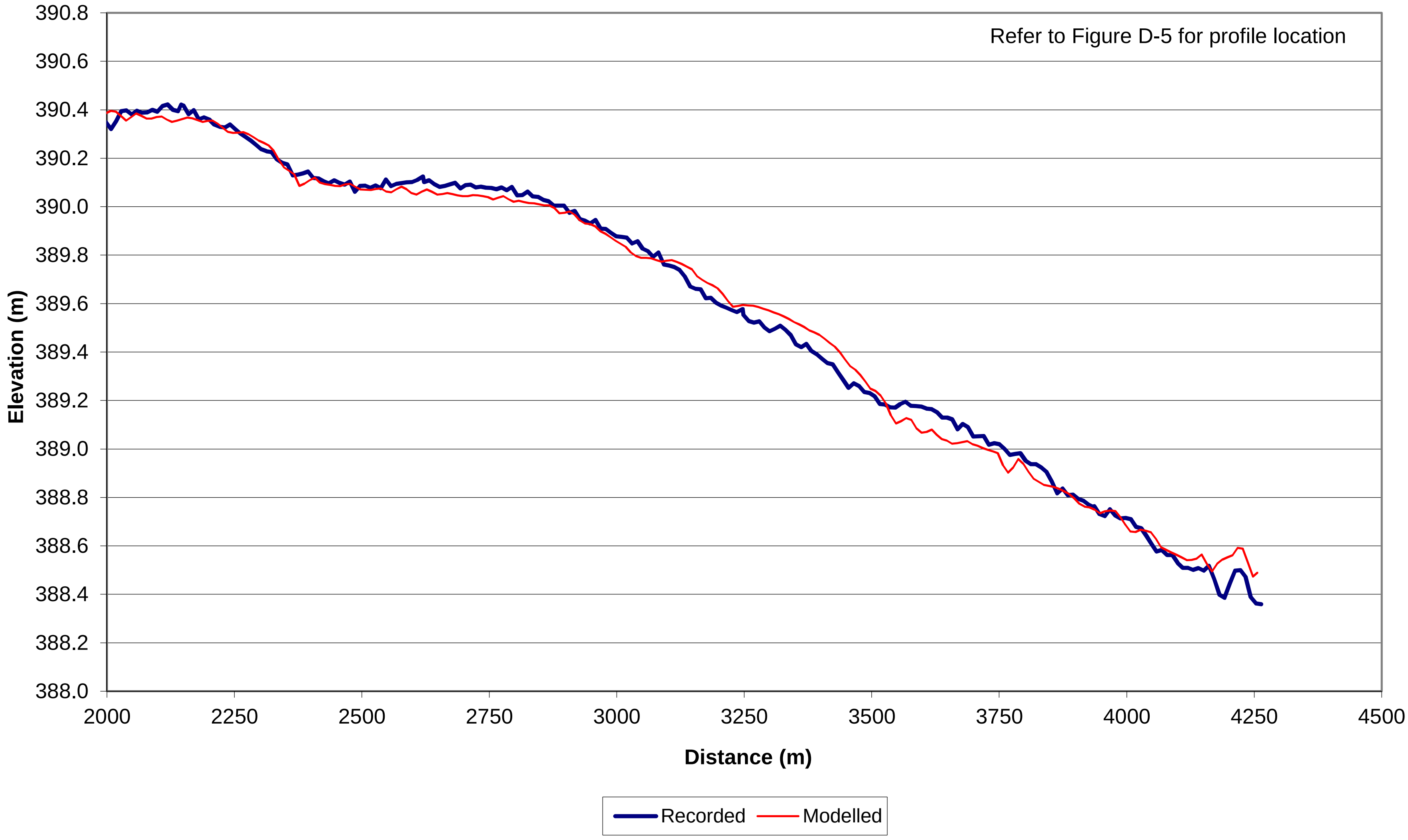
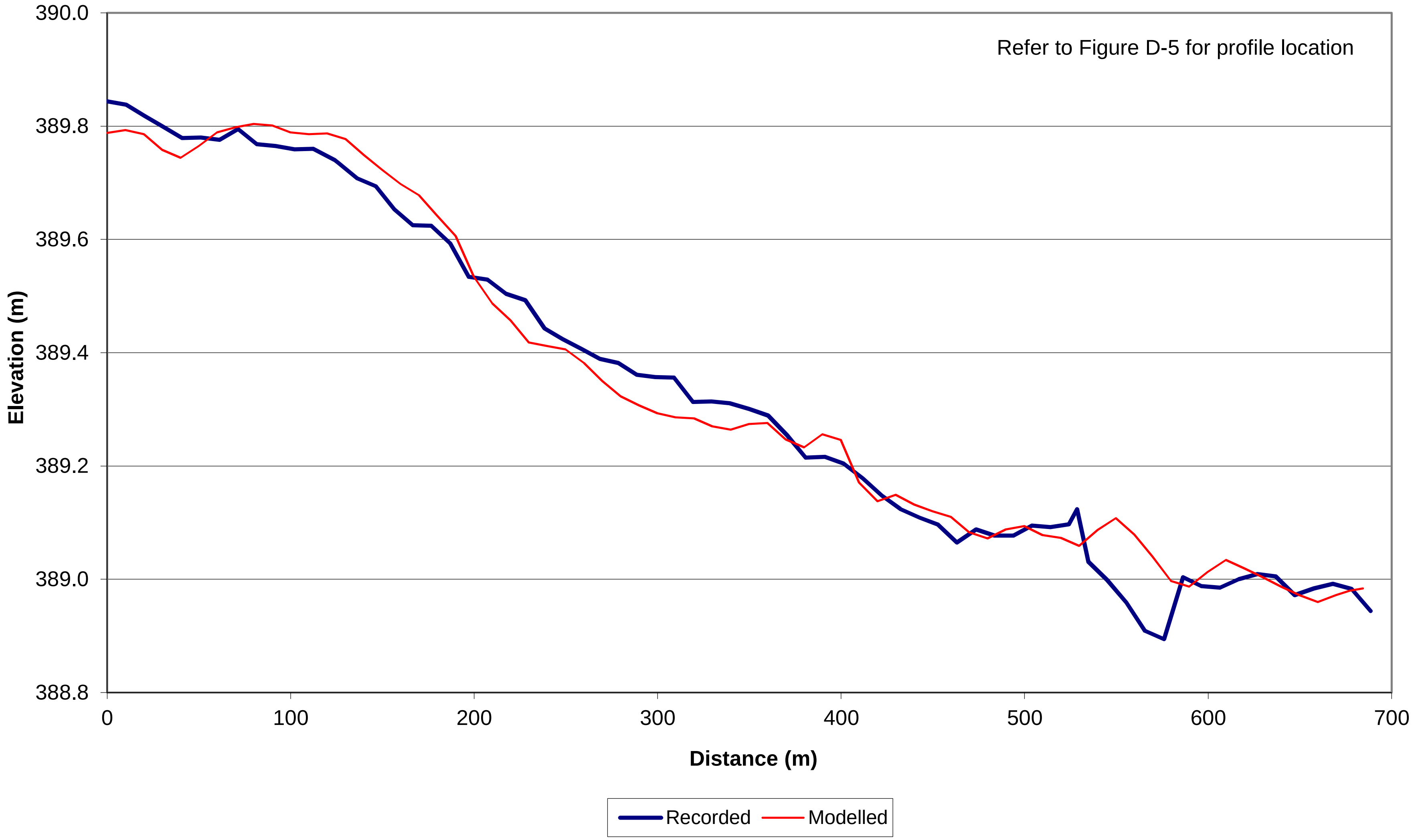
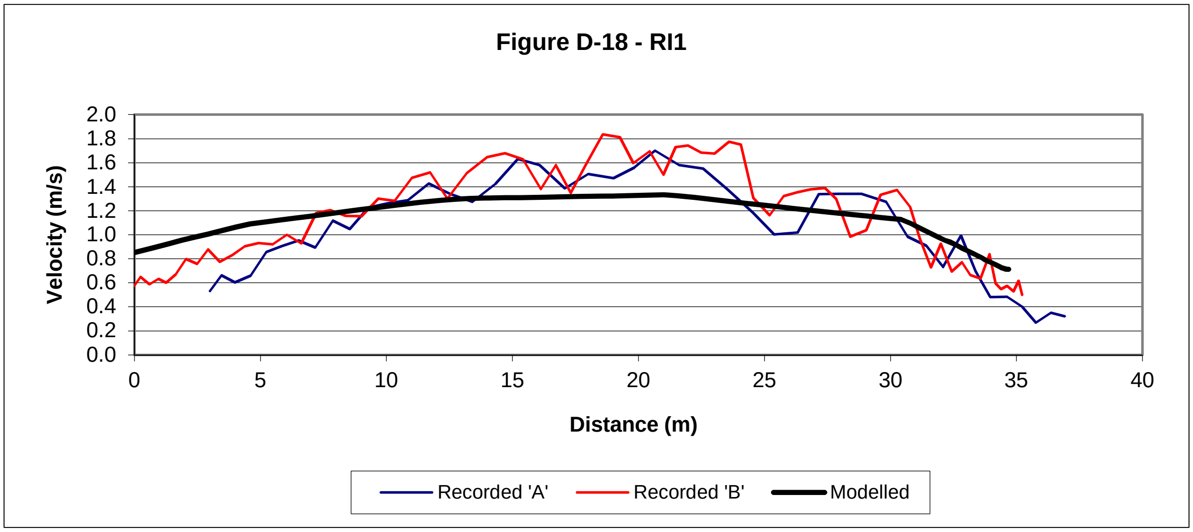
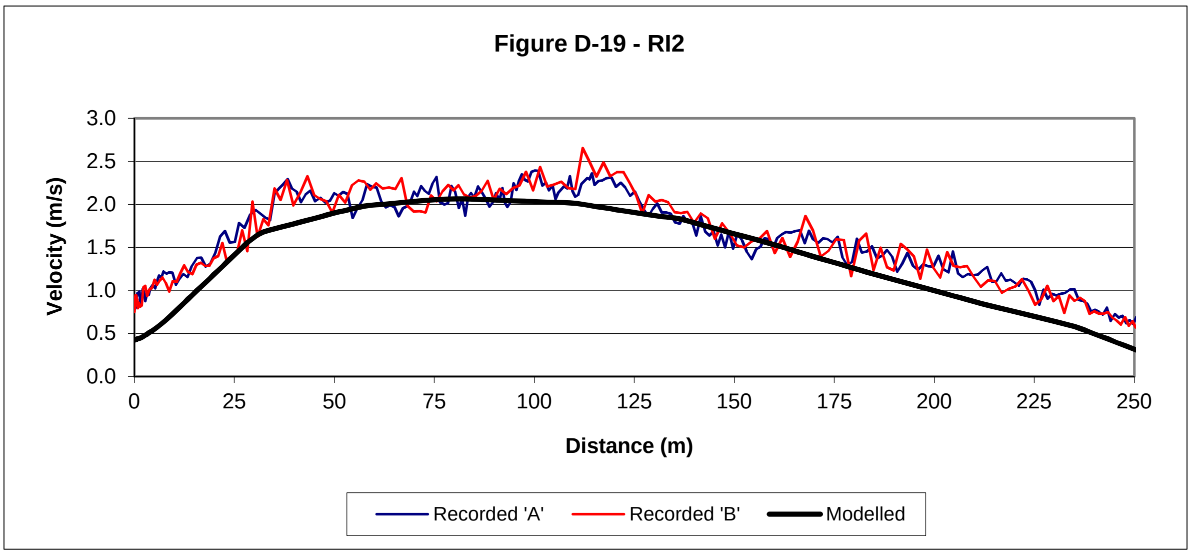


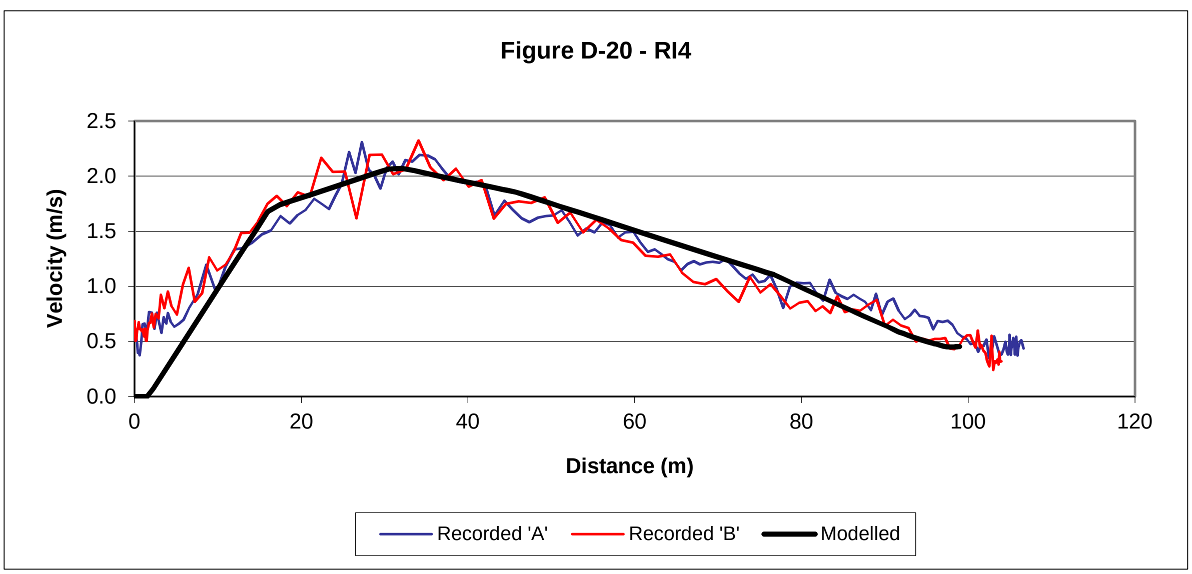
Figure D-17 - Water Surface Profile Comparison
(Raspberry Island, June 2011 Line P4)



Raspberry Island Reach Transect Velocity Comparision
June 2011

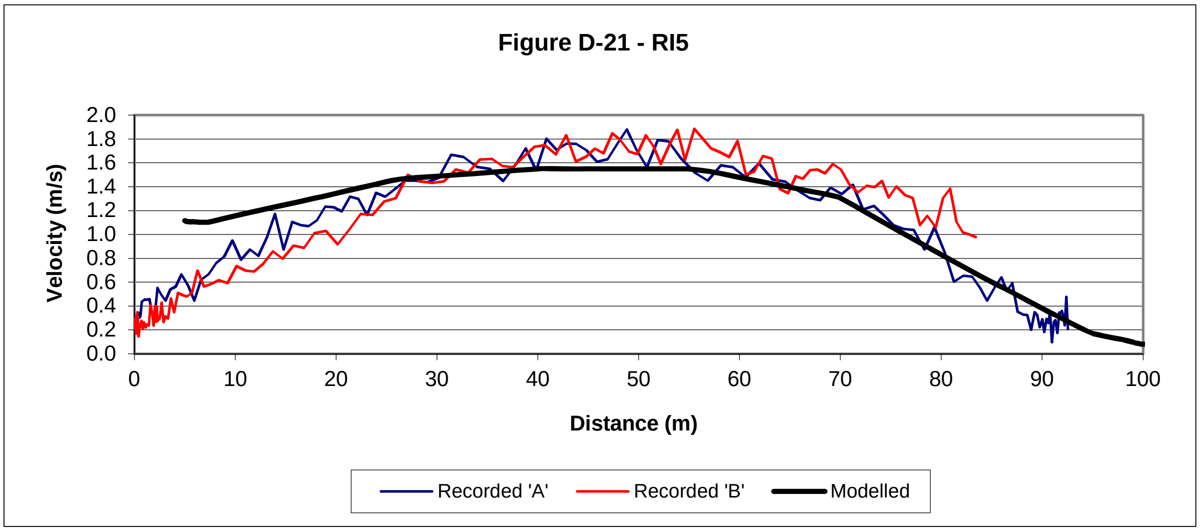


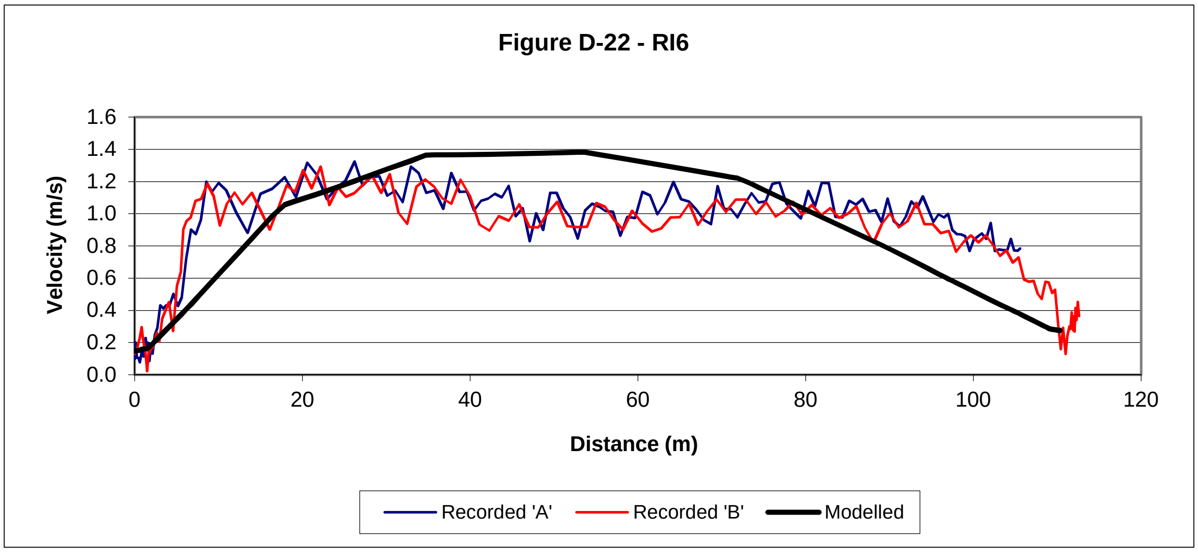


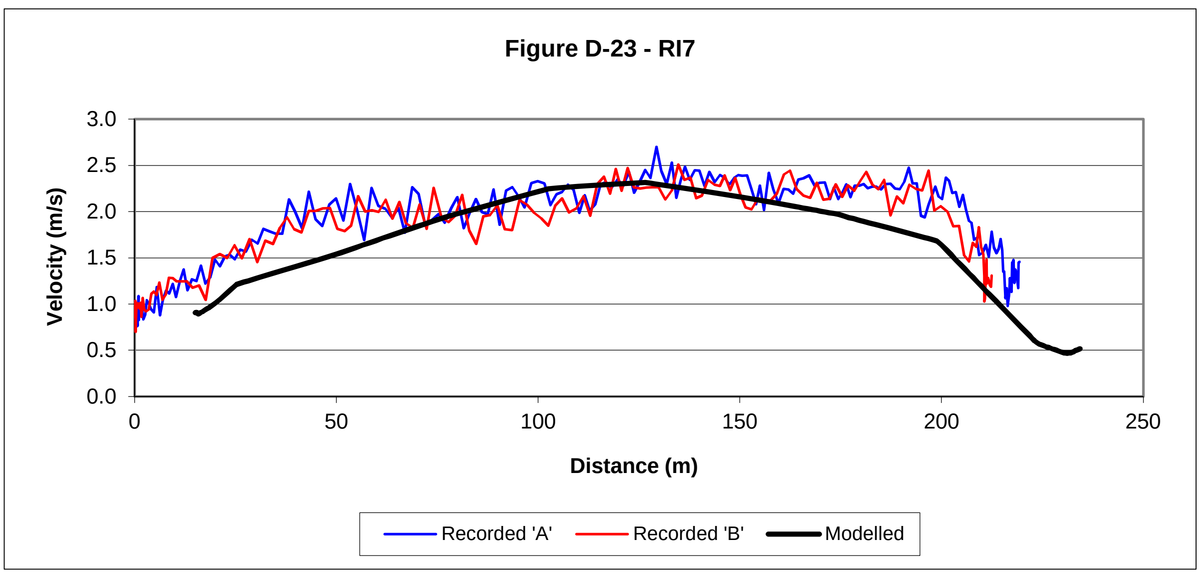


Refer to Figure D-5 for transect location

Raspberry Island Reach Transect Velocity Comparision
June 2011

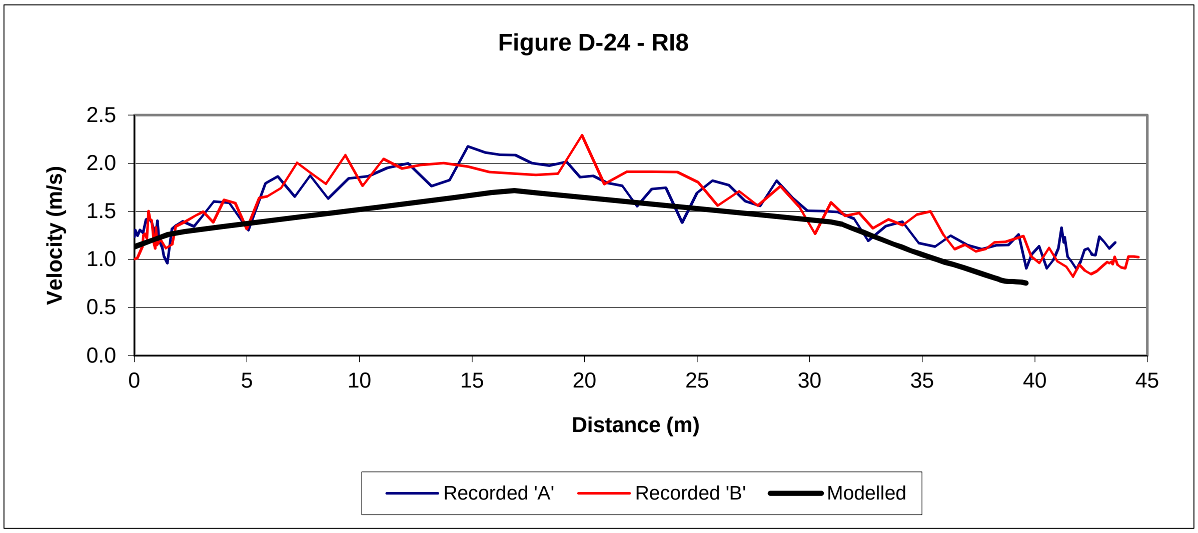


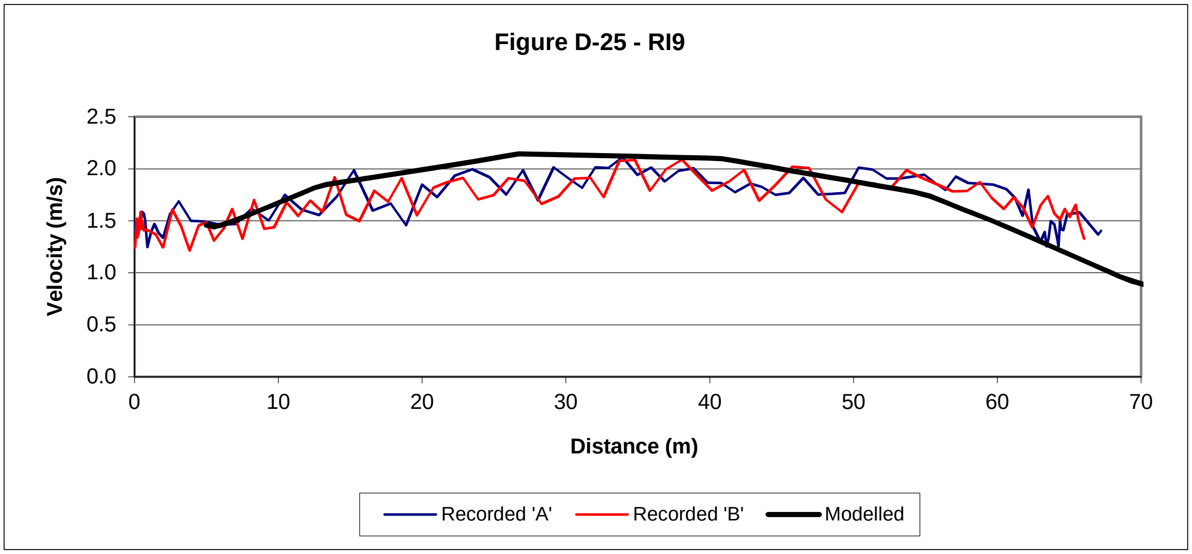




Refer to Figure D-5 for transect location

Raspberry Island Reach Transect Velocity Comparision
June 2011





Refer to Figure D-5 for transect location

Appendix E

Many Islands Reach
Calibration Figures

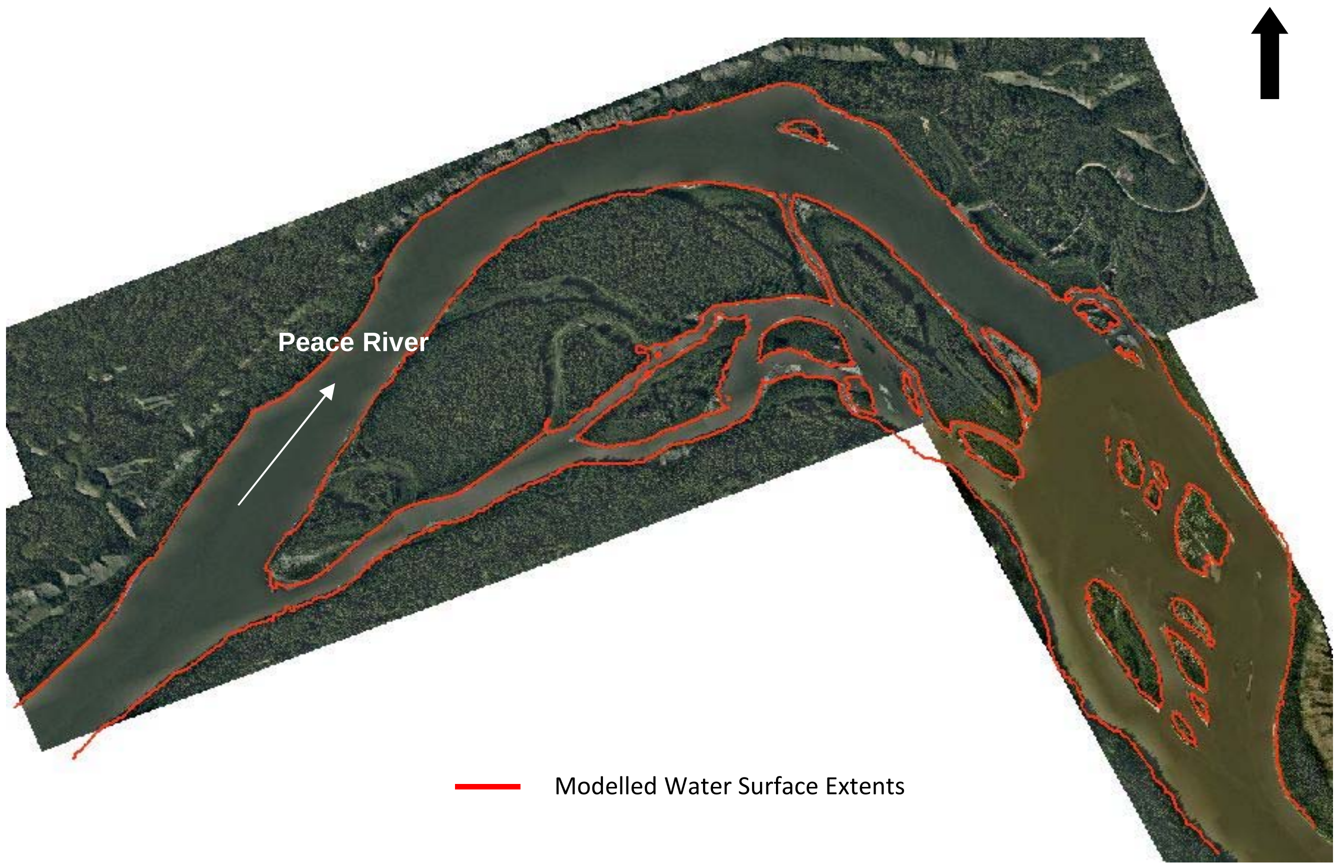


Photo Date: Aug. 26, 2011
Discharge: 2,200 m3/s

500 m

Figure E-1 - Aerial Photo Calibration (Many Islands, Flow = 2,200 m^3/s)

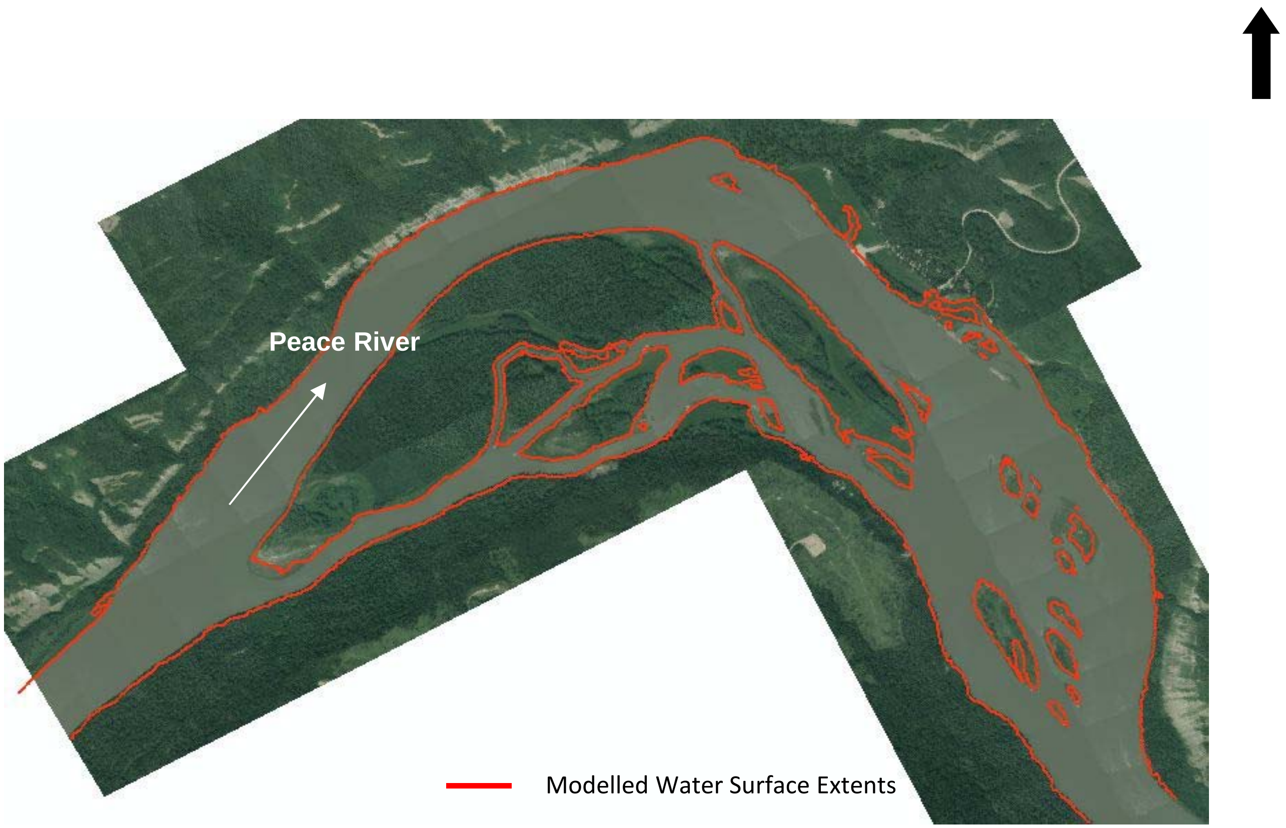


Photo Date: July 9, 2012
Discharge: 3,590 m3/s

500 m

Figure E-2 - Aerial Photo Calibration (Many Islands, Flow = 3,590 m^3/s)

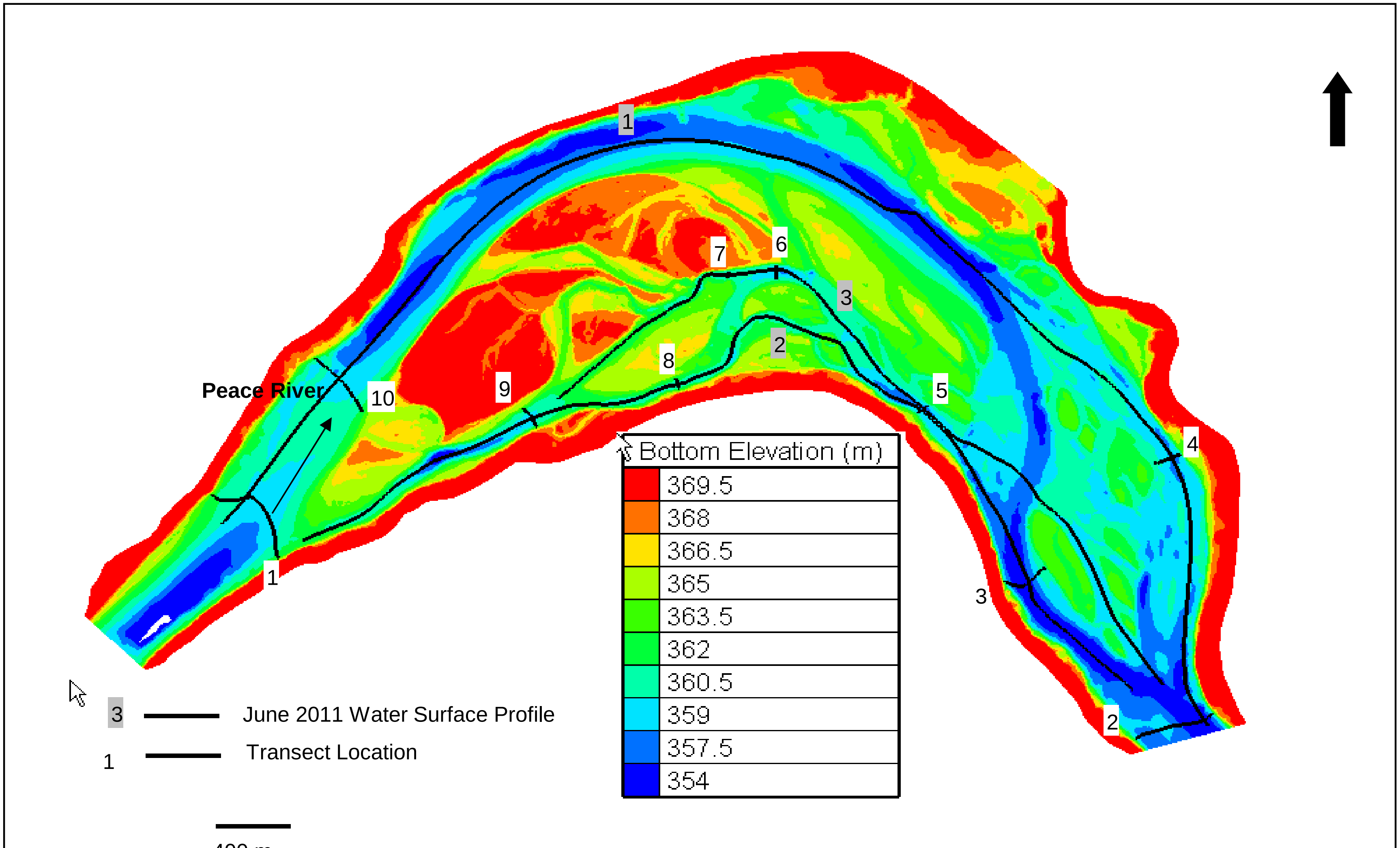


Figure E-3 - Hydraulic Survey Locations (Many Islands)

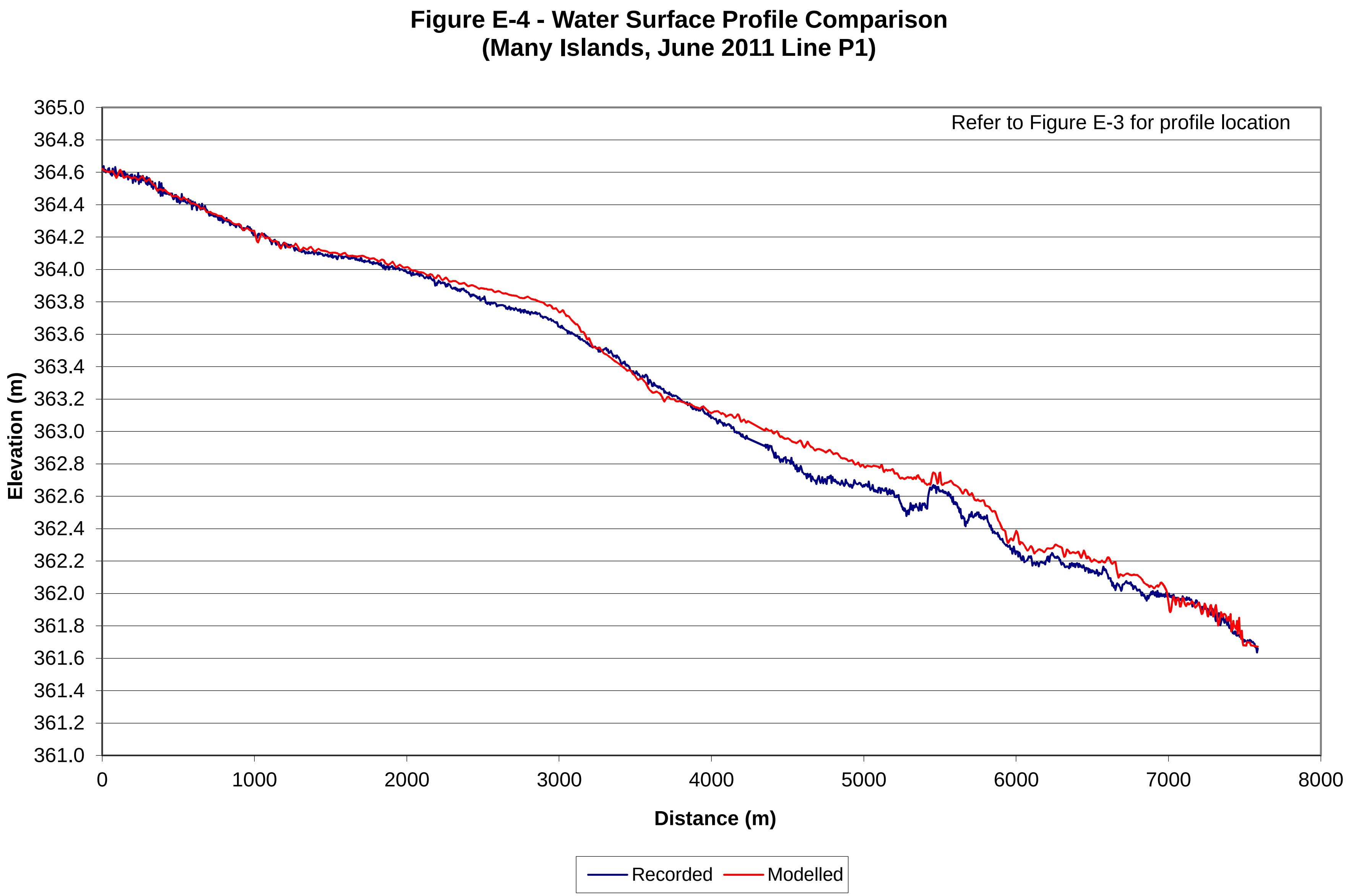


Figure E-4 - Water Surface Profile Comparison
(Many Islands, June 2011 Line P1)
Refer to Figure E-3 for profile location
Elevation (m)
365.0
364.8
364.6
364.4
364.2
364.0
363.8
363.6
363.4
363.2
363.0
362.8
362.6
362.4
362.2
362.0
361.8
361.6
361.4
361.2
361.0
0
1000
2000
3000
4000
5000
6000
7000
8000
Distance (m)
Recorded
Modelled

Figure E-5 - Water Surface Profile Comparison
(Many Islands, June 2011 Line P2)

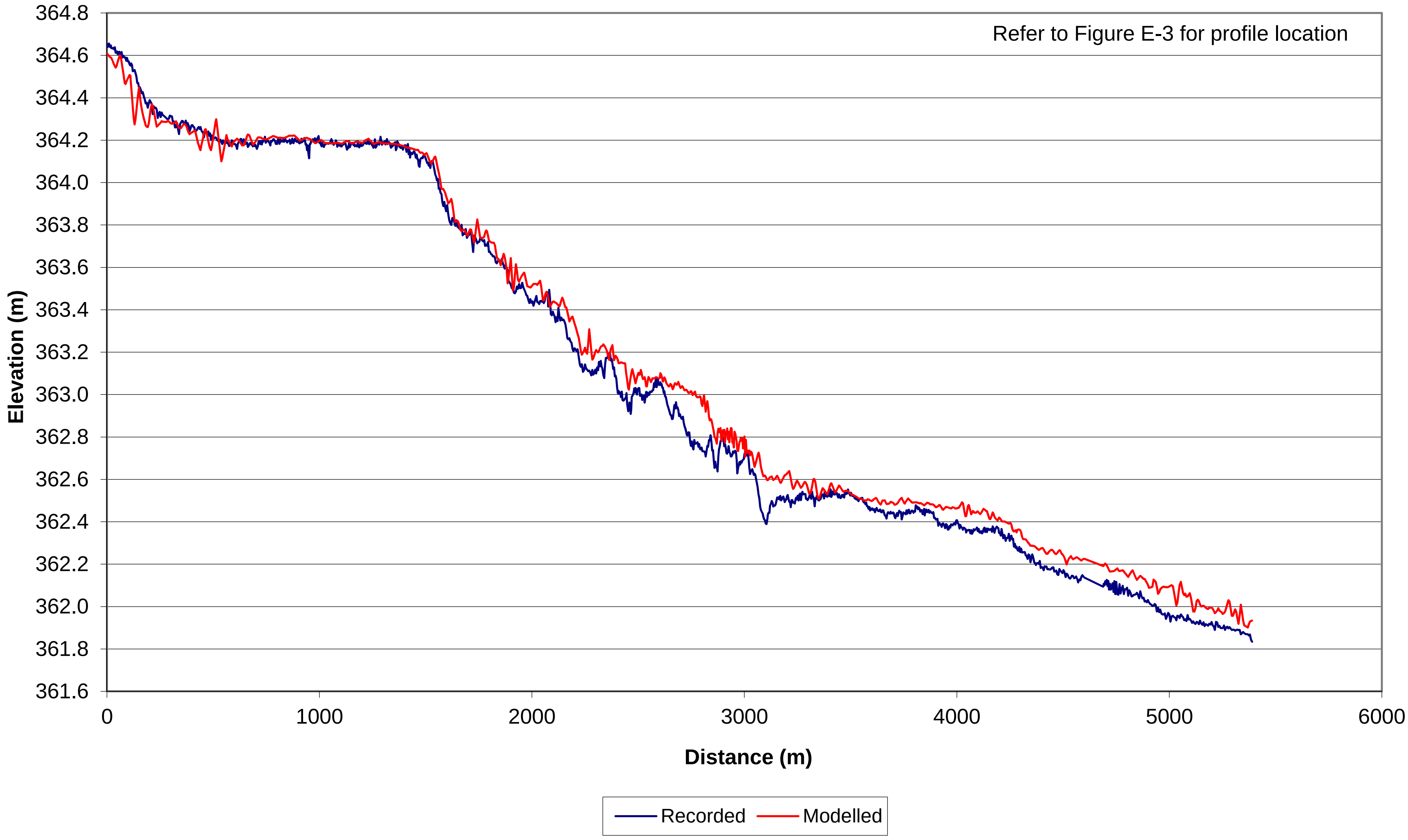
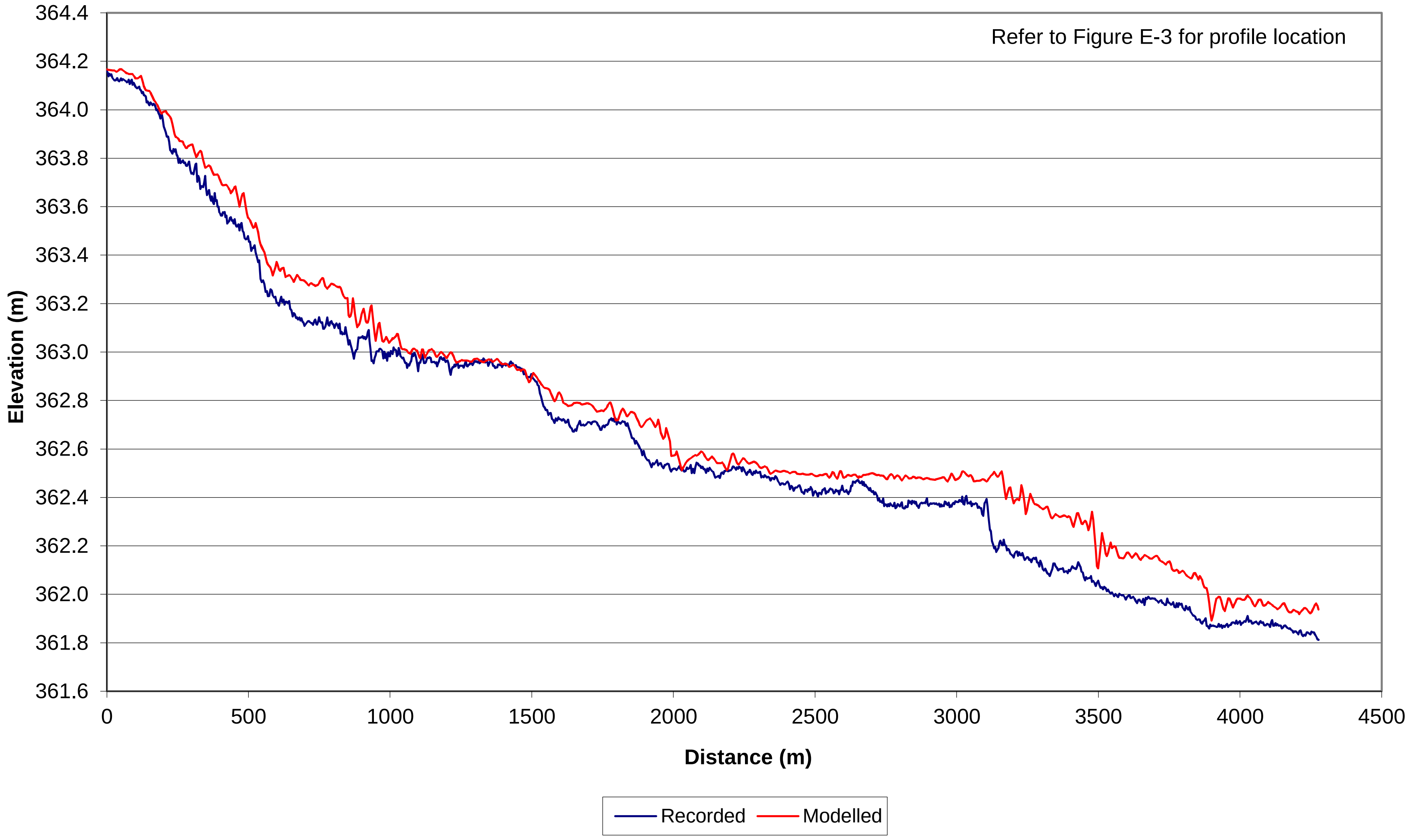


Figure E-6 - Water Surface Profile Comparison
(Many Islands, June 2011 Line P3)



Many Islands Reach Transect Velocity Comparision
June 2011

Figure E-7 - MI1

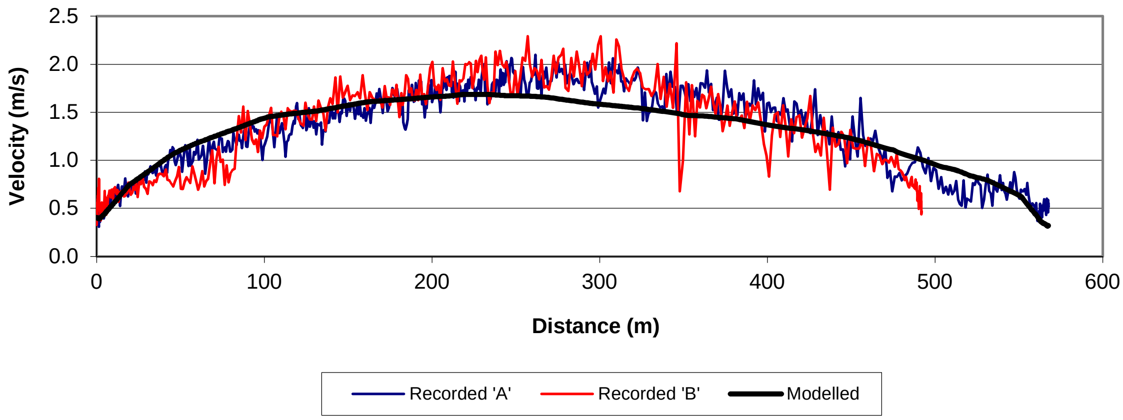


Figure E-8 - MI2

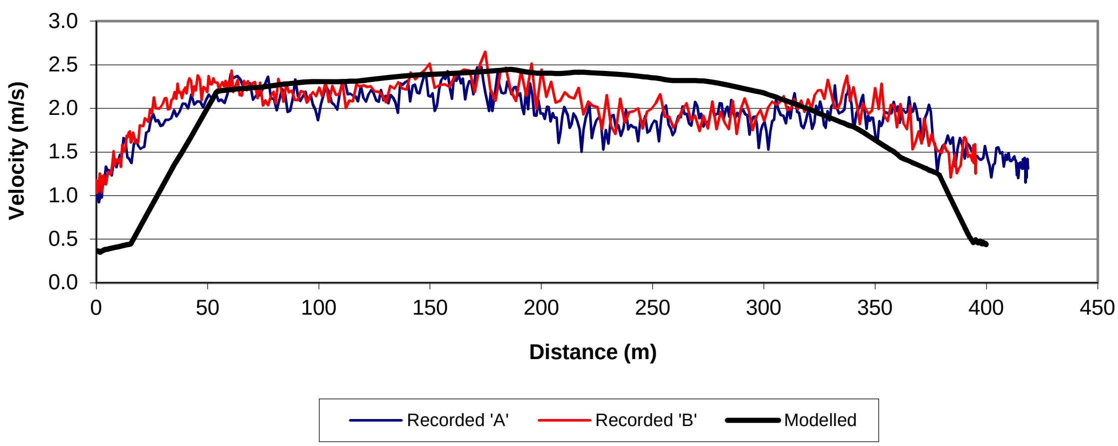
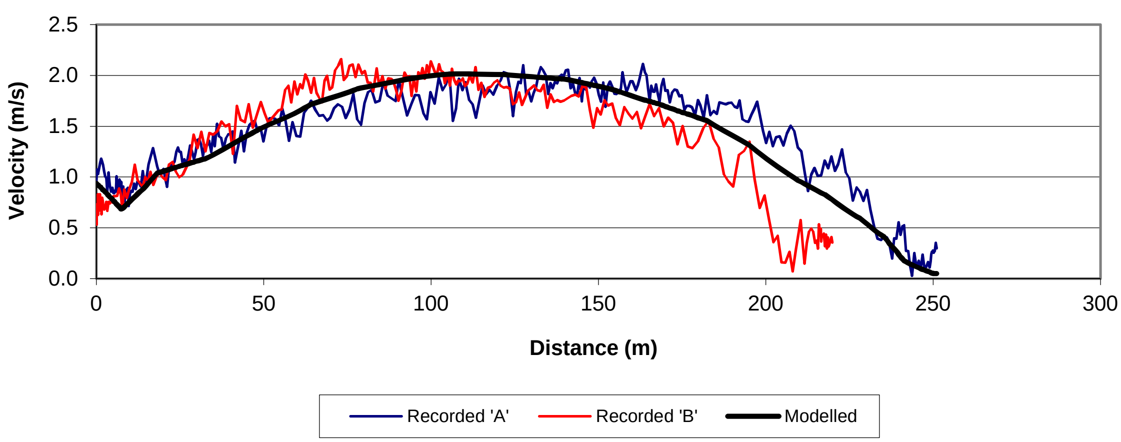
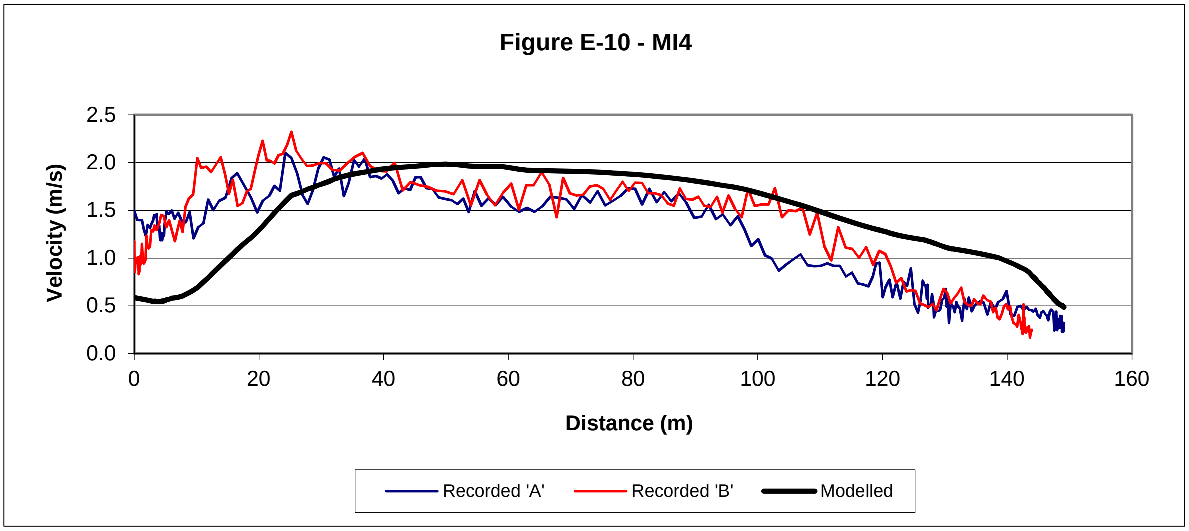


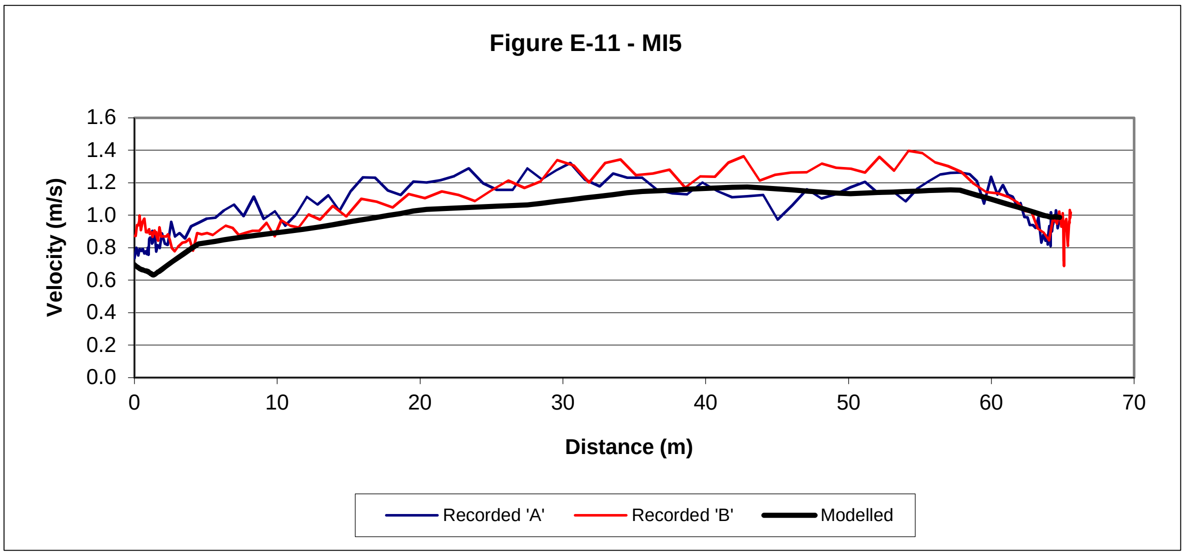
Figure E-9 - MI3

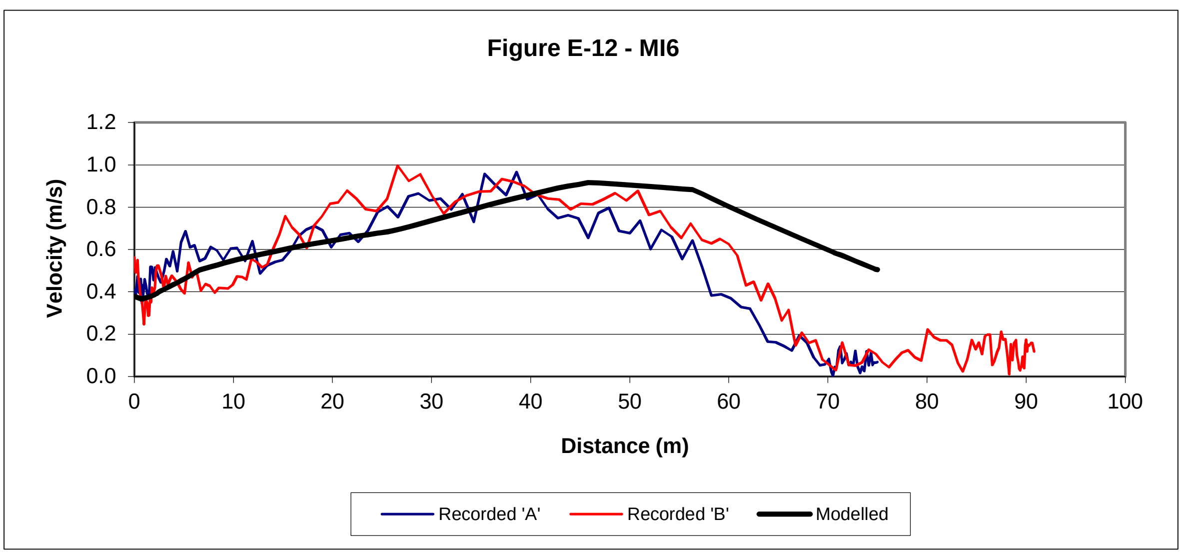


Refer to Figure E-3 for transect location

Many Islands Reach Transect Velocity Comparision
June 2011

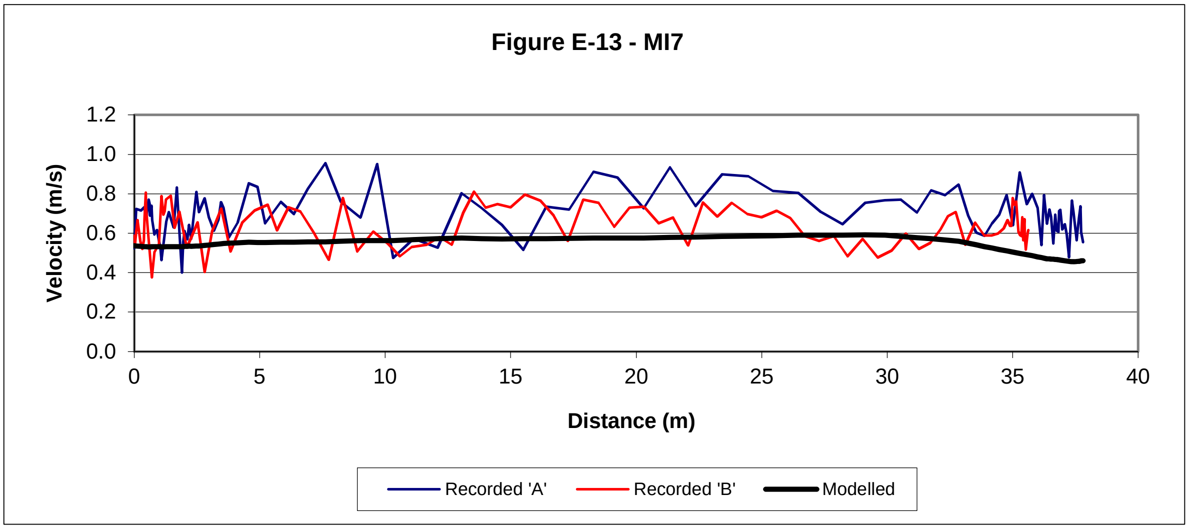


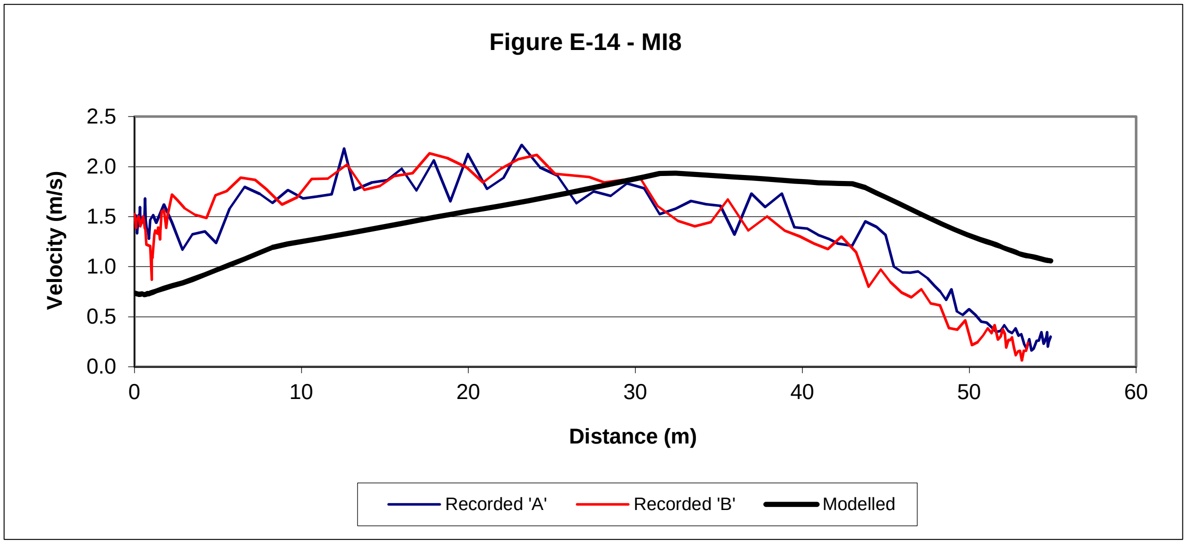


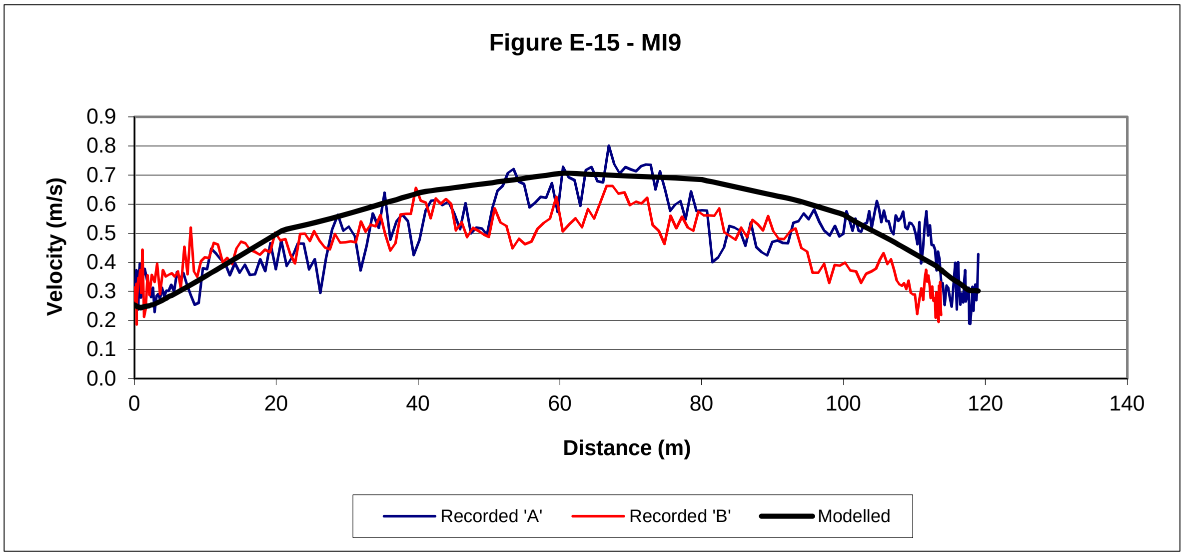


Refer to Figure E-3 for transect location

Many Islands Reach Transect Velocity Comparision
June 2011

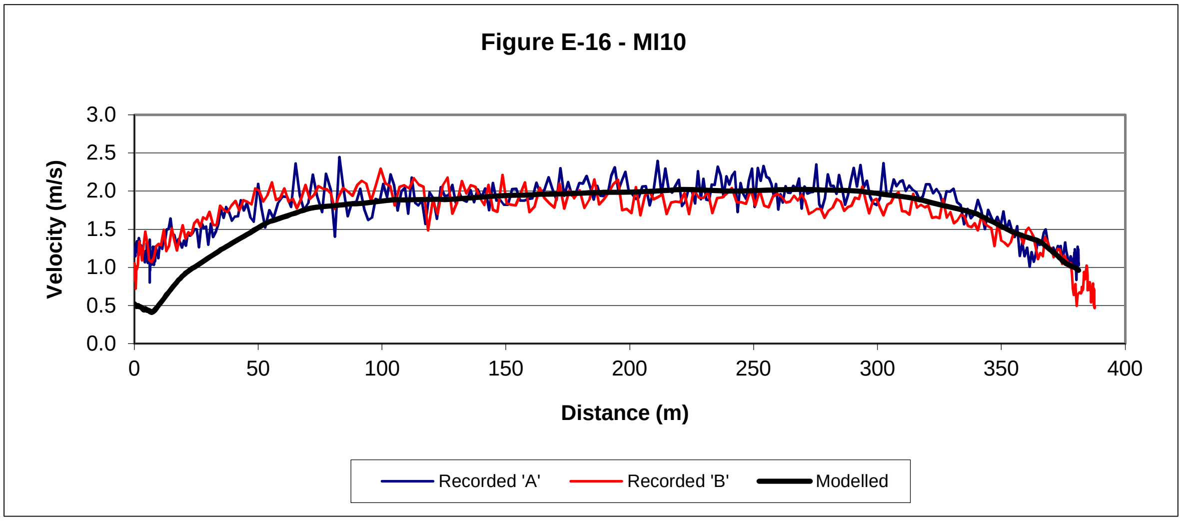






Refer to Figure E-3 for transect location

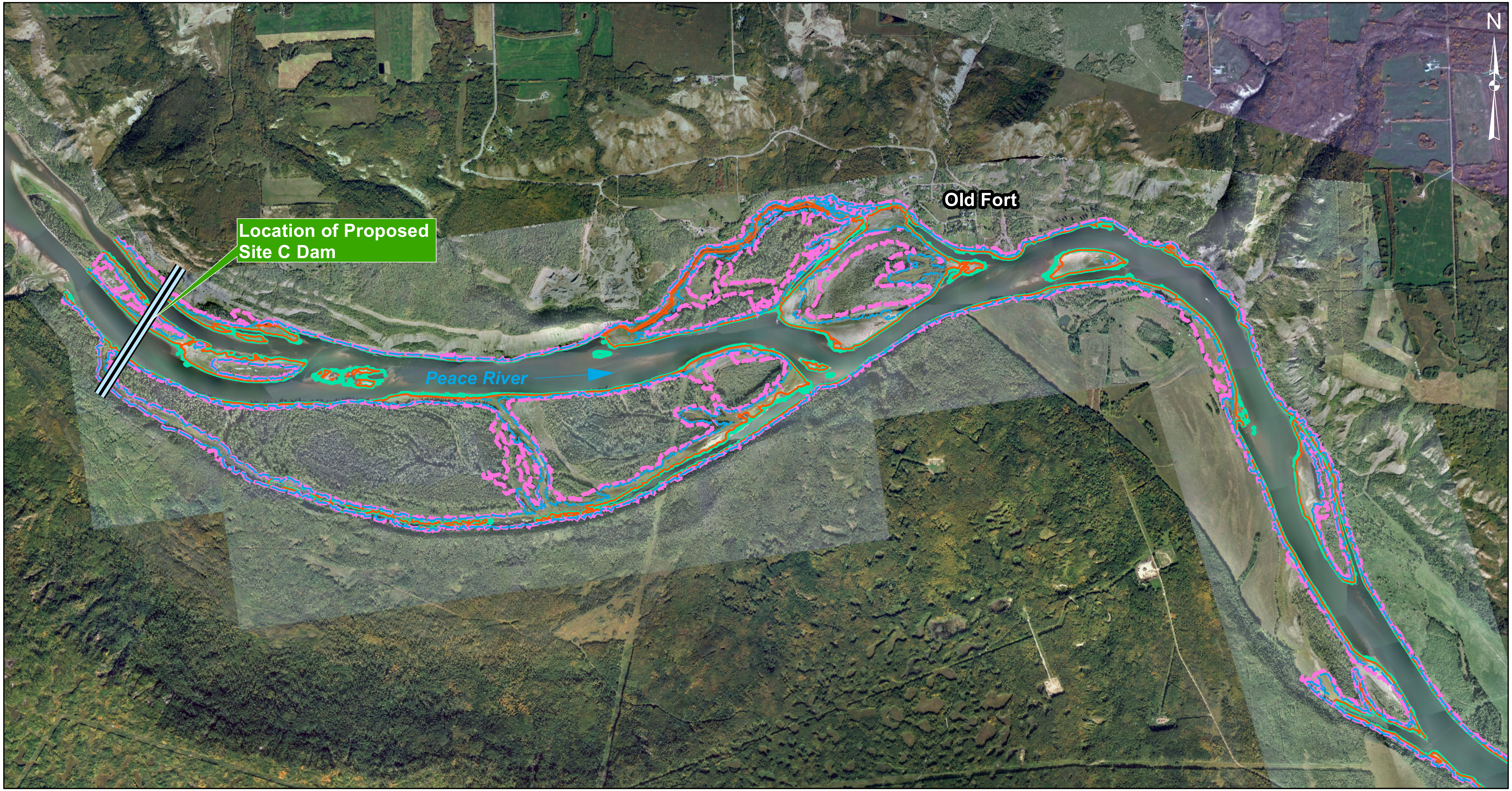
Many Islands Reach Transect Velocity Comparision
June 2011

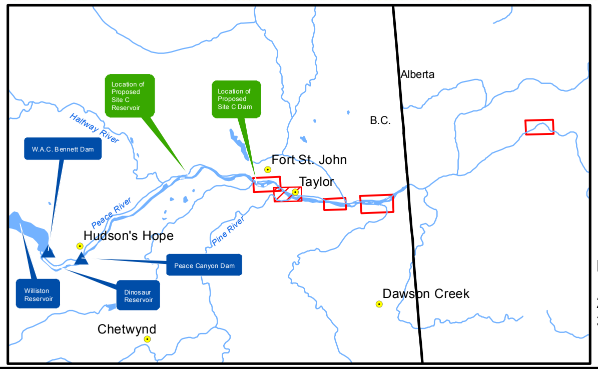


Refer to Figure E-3 for transect location

Appendix F

Maps Comparing Water Surface Extents for Minimum and Maximum Turbine Flows





Legend

Scenario	Dam Discharge (m^3/s)	Tributary Discharge (m^3/s) [a]	Total Discharge (m^3/s)
Peace Canyon minimum flow	283	228	511
Site C minimum flow	390	0	390
Peace Canyon maximum flow	1,982	11	1,993
Site C maximum flow	2,540	0	2,540

a - Minimum dam discharges have been combined with 90th %ile tributary discharges. Maximum dam discharges have been combined with 10th %ile tributary discharges. These flow combinations provide near maximum differences in inundation between Peace Canyon Dam and Site C Dam operational scenarios.

Map Notes:
1. Datum/Projection: NAD83/UTM Zone 10N
2. Data Source: TRIM data from B.C. Government.
3. Orthophotos created from 1:40,000 photos taken Sept.10th 2007; 1:5,000 photos taken September 13, 2009; TRIM; Bing Maps Aerial. Peace River above Pine (WSC 07FA004) discharge = 390 m^3/s (near Old Fort).

1:25,000

0 0.25 0.5 1 km

BC hydro

SITE C CLEAN ENERGY PROJECT

Peace River Inundation Map Site C Dam to Taylor 1 of 2 Minimum and Maximum Powerhouse Discharges for Peace Canyon Dam and Site C Dam

DATE	Dec. 13, 2012	DWG NO	1016-C14-B4788	R 0

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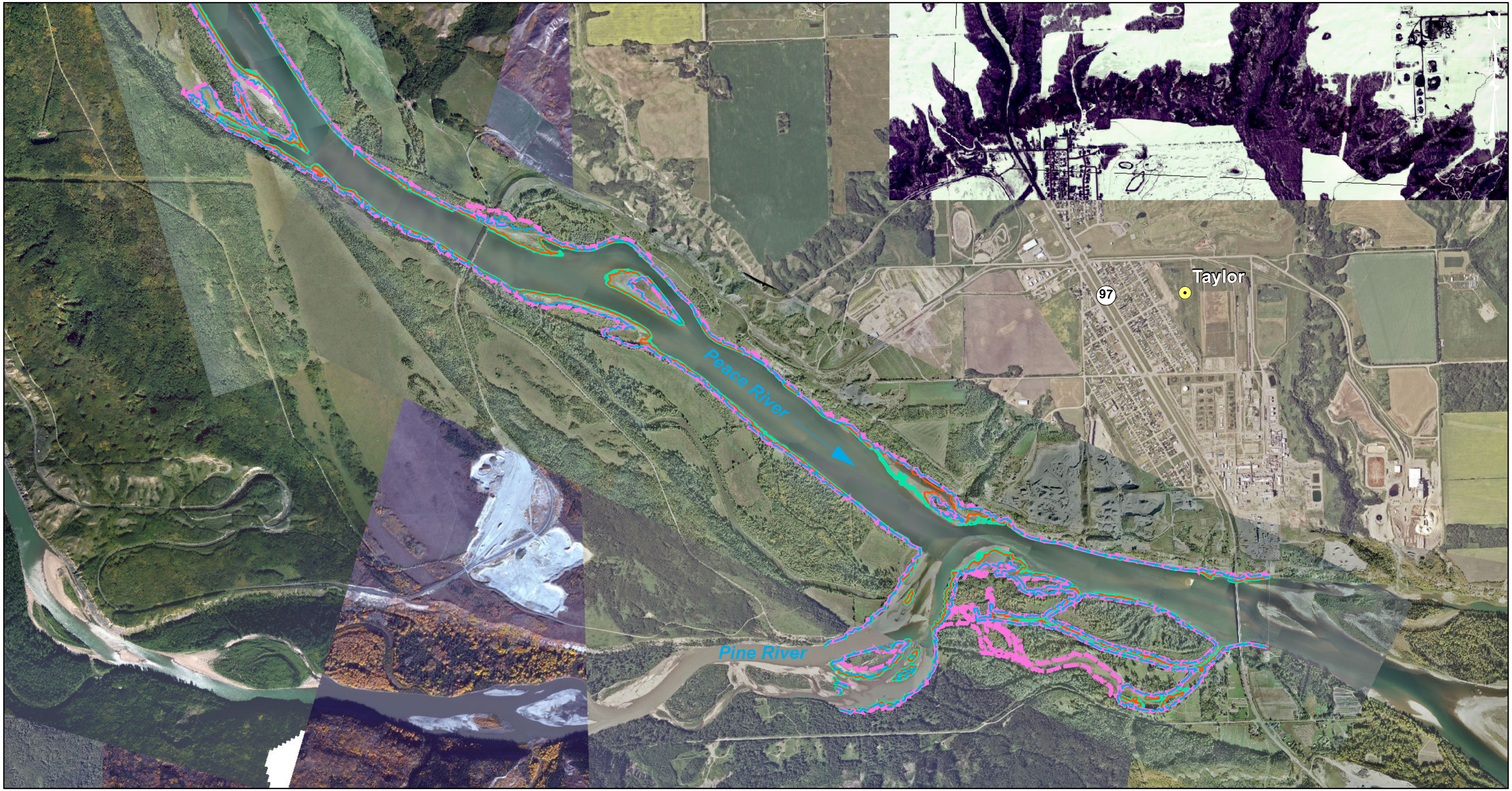
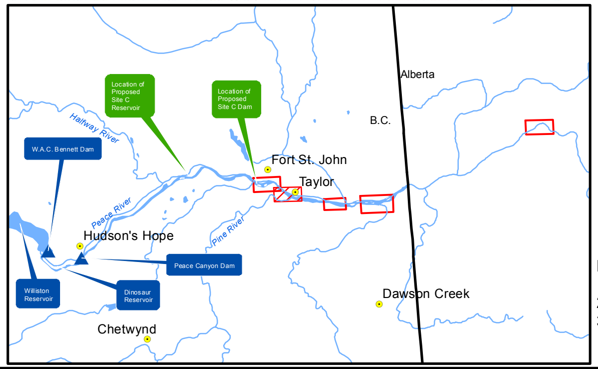




Legend

Scenario	Dam Discharge (m^3/s)	Tributary Discharge (m^3/s) [a]	Total Discharge (m^3/s)
Peace Canyon minimum flow	283	228	511
Site C minimum flow	390	0	390
Peace Canyon maximum flow	1,982	11	1,993
Site C maximum flow	2,540	0	2,540

a - Minimum dam discharges have been combined with 90[th] %ile tributary discharges. Maximum dam discharges have been combined with 10[th] %ile tributary discharges. These flow combinations provide near maximum differences in inundation between Peace Canyon Dam and Site C Dam operational scenarios.

Map Notes:
1. Datum/Projection: NAD83/UTM Zone 10N
2. Data Source: TRIM data from B.C. Government.
3. Orthophotos created from 1:40,000 photos taken Sept.10th 2007; 1:5,000 photos taken September 13, 2009; TRIM; Bing Maps Aerial. Peace River above Pine (WSC 07FA004) discharge = 390 m^3/s (near Old Fort).

1:25,000

0 0.25 0.5 1 km

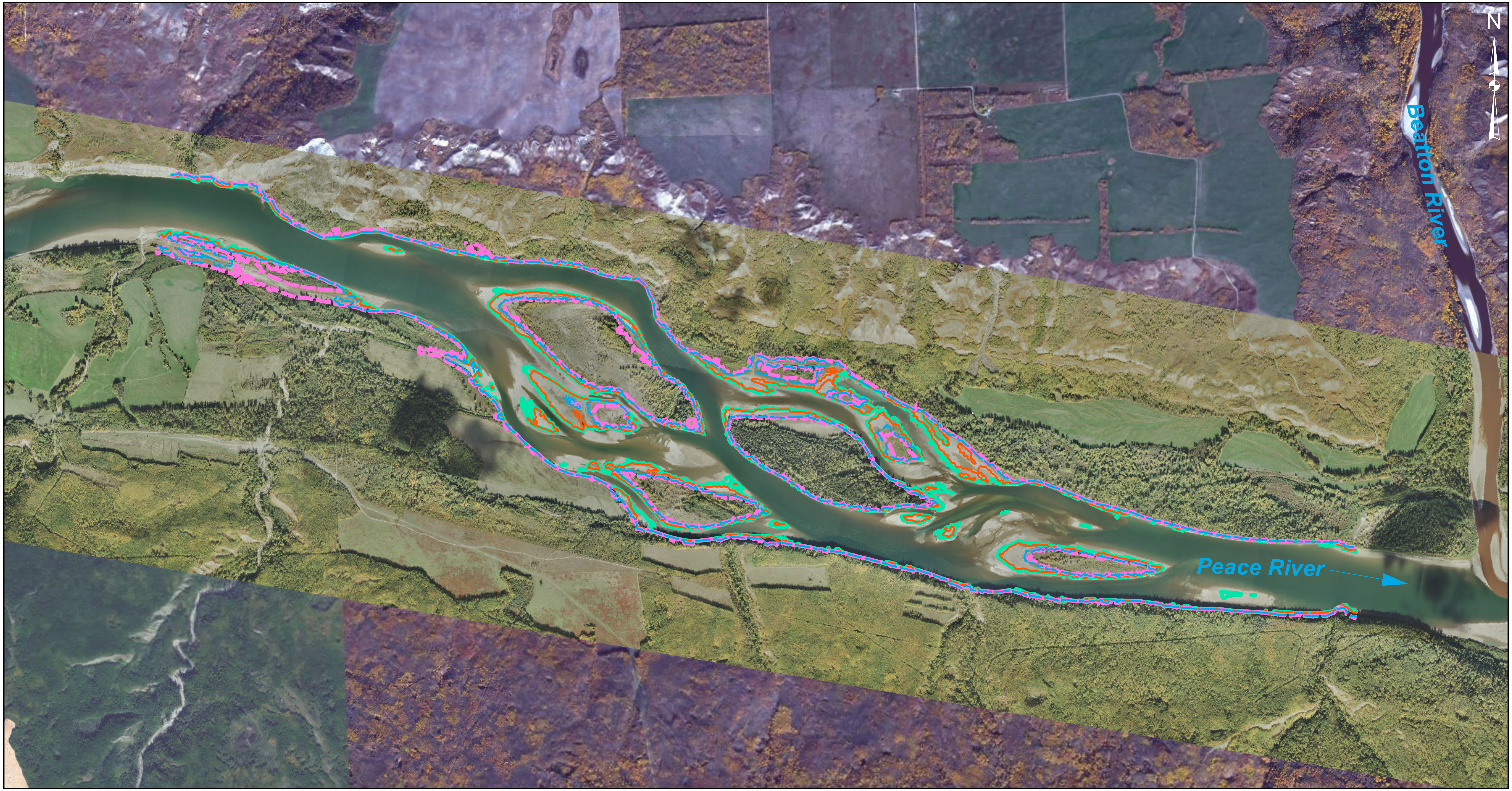
SITE C CLEAN ENERGY PROJECT

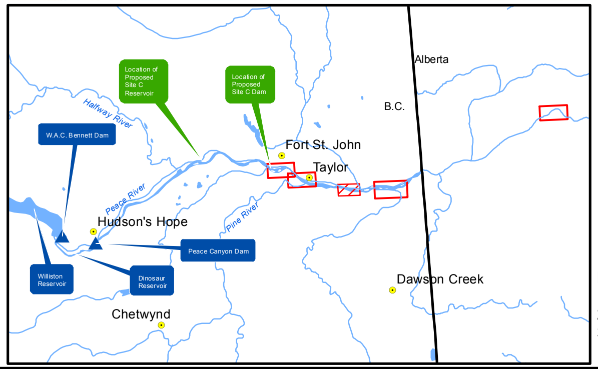
BC hydro

Peace River Inundation Map
Site C Dam to Taylor 2 of 2
Minimum and Maximum
Powerhouse Discharges for
Peace Canyon Dam and Site C Dam

DATE	Dec. 13, 2012	DWG NO	1016-C14-B4788	R 0

Construction of the Site C Clean Energy Project is subject to required regulatory approvals including environmental certification





Legend

Scenario		Dam Discharge (m^3/s)	Tributary Discharge (m^3/s) [a]	Total Discharge (m^3/s)
(orange solid line)	Peace Canyon minimum flow	283	769	1,052
(green solid line)	Site C minimum flow	390	541	931
(blue dashed line)	Peace Canyon maximum flow	1,982	39	2,021
(pink dashed line)	Site C maximum flow	2,540	28	2,568

a - Minimum dam discharges have been combined with 90th %ile tributary discharges. Maximum dam discharges have been combined with 10th %ile tributary discharges.
These flow combinations provide near maximum differences in inundation between Peace Canyon Dam and Site C Dam operational scenarios.

Map Notes:
1. Datum/Projection: NAD83/UTM Zone 10N
2. Data Source: TRIM data from B.C. Government.
3. Orthophotos created from 1:5,000 photos taken September 22, 2010; Bing Maps Aerial.
Peace River near Taylor (WSC 07FD002) discharge = 371 m^3/s (below Pine River confluence).

1:20,000

0 0.25 0.5 1 km

SITE C CLEAN ENERGY PROJECT

BC hydro

Peace River Inundation Map
Pallings Flat
Minimum and Maximum Powerhouse Discharges for Peace Canyon Dam and Site C Dam

DATE	Dec. 13, 2012	DWG NO	1016-C14-B4788	R 0

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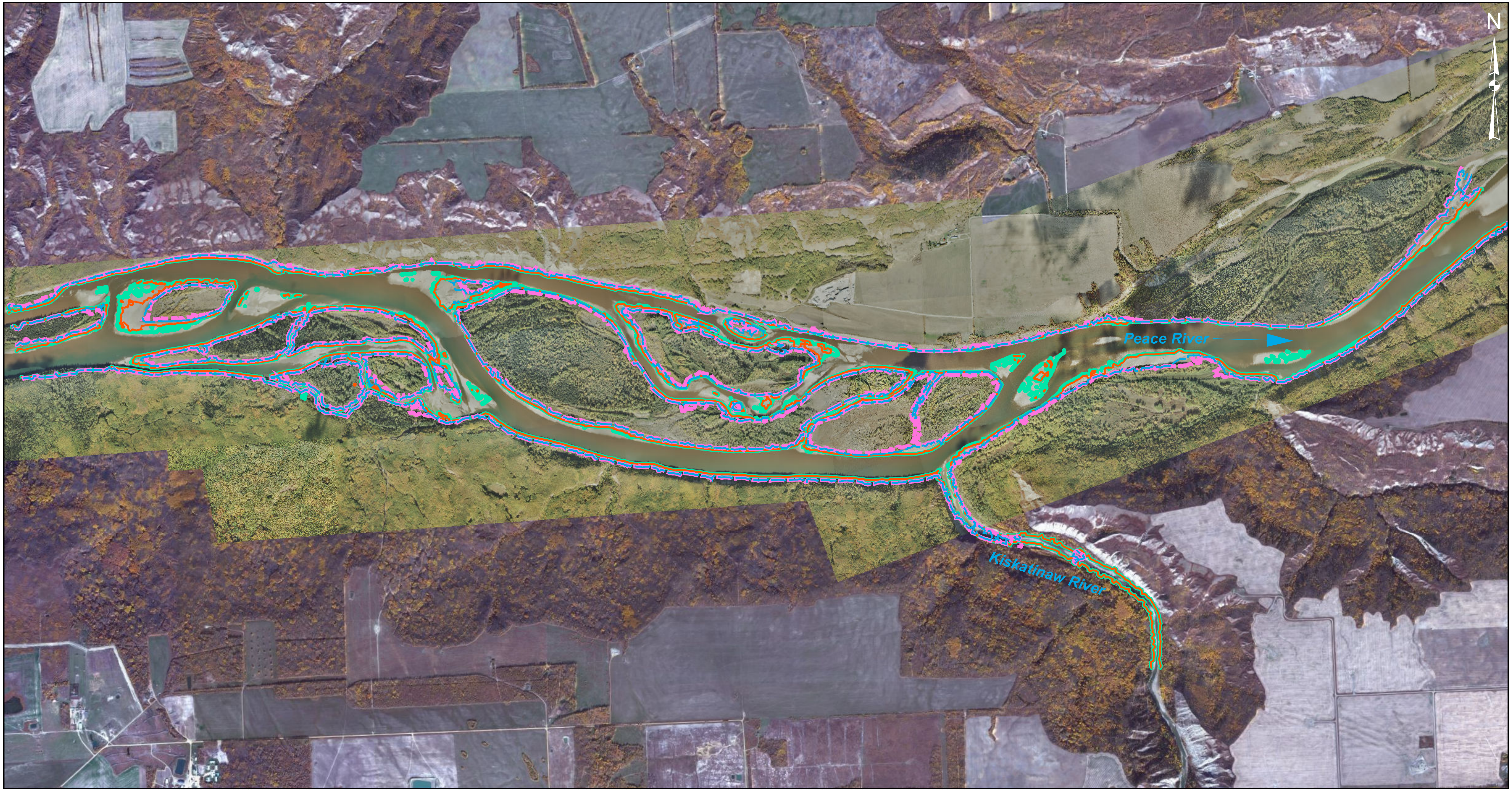
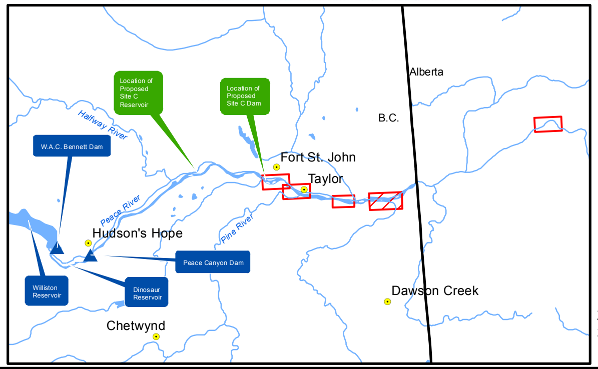




Legend

Scenario	Dam Discharge (m^3/s)	Tributary Discharge (m^3/s) [a]	Total Discharge (m^3/s)
Peace Canyon minimum flow	283	928	1,211
Site C minimum flow	390	700	1,090
Peace Canyon maximum flow	1,982	40	2,022
Site C maximum flow	2,540	29	2,569

a - Minimum dam discharges have been combined with 90th %ile tributary discharges. Maximum dam discharges have been combined with 10th %ile tributary discharges. These flow combinations provide near maximum differences in inundation between Peace Canyon Dam and Site C Dam operational scenarios.

Map Notes:
1. Datum/Projection: NAD83/UTM Zone 10N
2. Data Source: TRIM data from B.C. Government.
3. Orthophotos created from 1:5,000 photos taken September 22, 2010; Bing Maps Aerial.
Peace River near Taylor (WSC 07FD002) discharge = 371 m^3/s (below Pine River confluence).

1:30,000 — 0 0.5 1 2 km

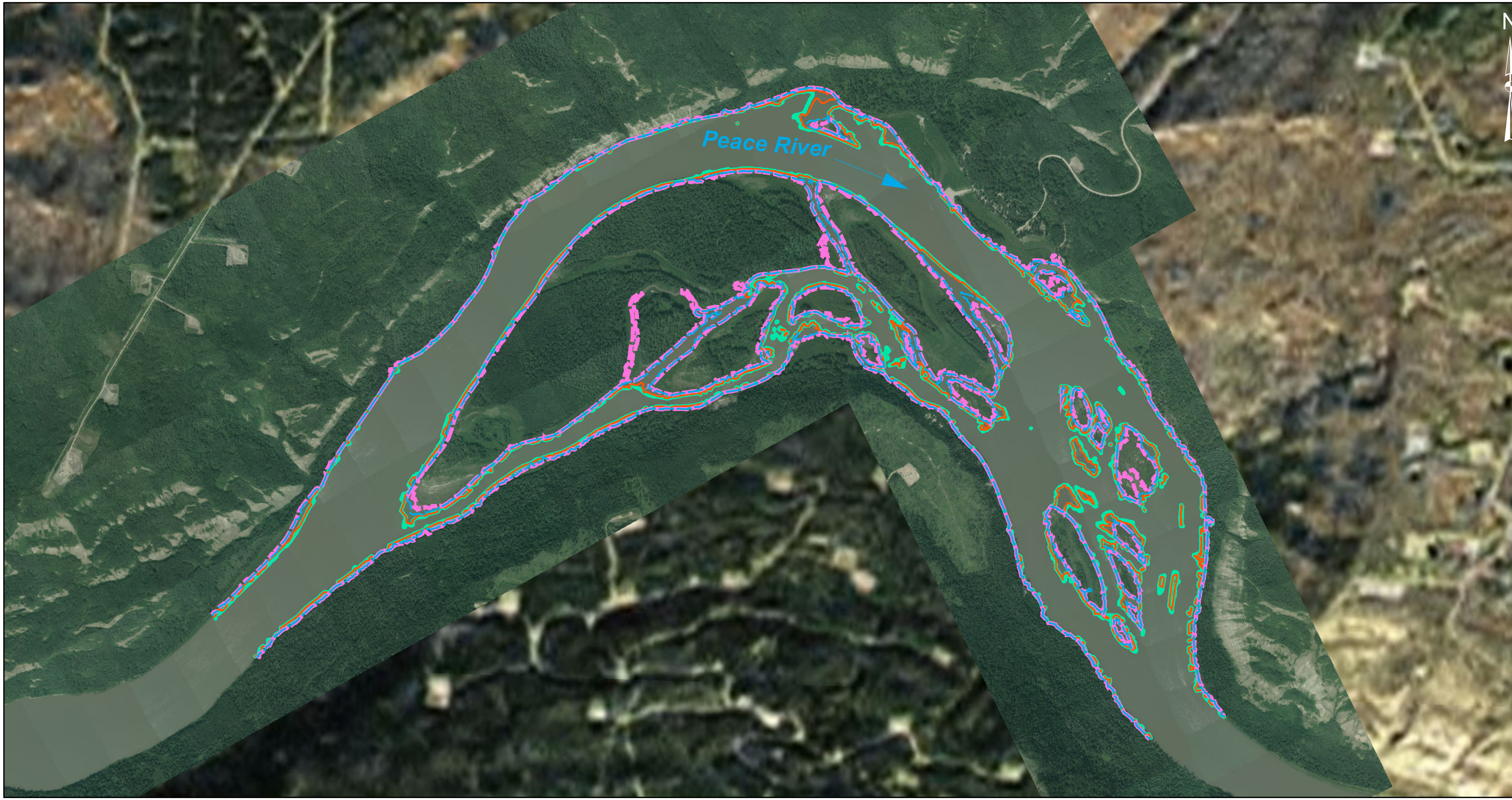
SITE C CLEAN ENERGY PROJECT

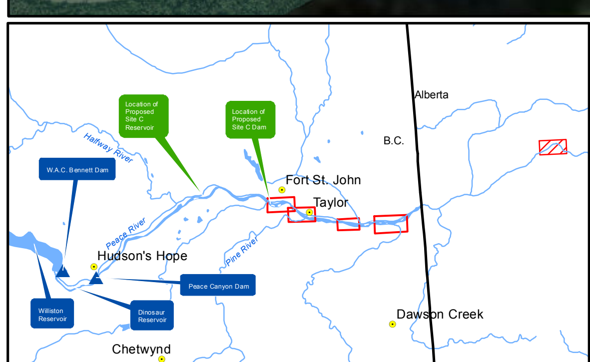
BC hydro

Peace River Inundation Map
Raspberry Island
Minimum and Maximum Powerhouse Discharges for Peace Canyon Dam and Site C Dam

DATE	Dec. 13, 2012	DWG NO	1016-C14-B4788	R 0

Construction of the Site C Clean Energy Project is subject to required regulatory approvals including environmental certification





Legend

Scenario		Dam Discharge (m^3/s)	Tributary Discharge (m^3/s) [a]	Total Discharge (m^3/s)
(orange solid line)	Peace Canyon minimum flow	283	985	1,268
(green solid line)	Site C minimum flow	390	757	1,147
(blue dashed line)	Peace Canyon maximum flow	1,982	40	2,022
(pink dashed line)	Site C maximum flow	2,540	29	2,569

a - Minimum dam discharges have been combined with 90th %ile tributary discharges. Maximum dam discharges have been combined with 10th %ile tributary discharges. These flow combinations provide near maximum differences in inundation between Peace Canyon Dam and Site C Dam operational scenarios.

Map Notes:
1. Datum/Projection: NAD83/UTM Zone 11N
2. Data Source: TRIM data from B.C. Government.
3. Imagery Source: Orthophotos created from 1:5,000 photos taken July 9th, 2012; Bing Maps Aerial.
Peace River above Alces (WSC 07FD010) discharge = ~3550 m^3/s

1:20,000

0 0.25 0.5 1 km

BC hydro

SITE C CLEAN ENERGY PROJECT

Peace River Inundation Map
Many Islands
Minimum and Maximum
Powerhouse Discharges for
Peace Canyon Dam and Site C Dam

DATE	Dec. 13, 2012	DWG NO	1016-C14-B4788	R 0

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Appendix G

Site C Dam to Taylor Reach
Flow-Wetted Area Relationship

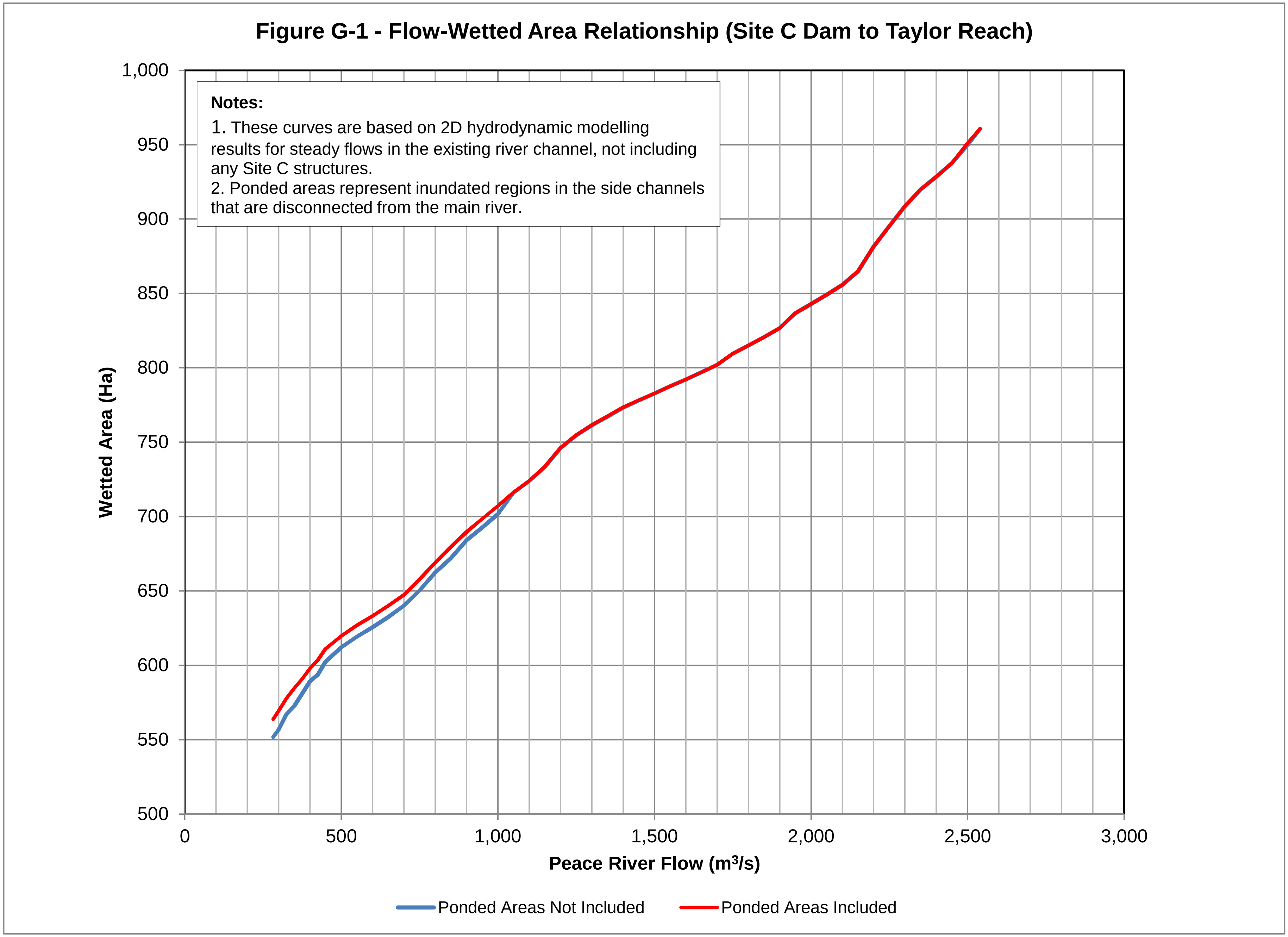


Figure G-1 - Flow-Wetted Area Relationship (Site C Dam to Taylor Reach)
Notes:
1. These curves are based on 2D hydrodynamic modelling results for steady flows in the existing river channel, not including any Site C structures.
2. Ponded areas represent inundated regions in the side channels that are disconnected from the main river.
Wetted Area (Ha)
1,000
950
900
850
800
750
700
650
600
550
500
0
500
1,000
1,500
2,000
2,500
3,000
Peace River Flow (m³/s)
Ponded Areas Not Included
Ponded Areas Included

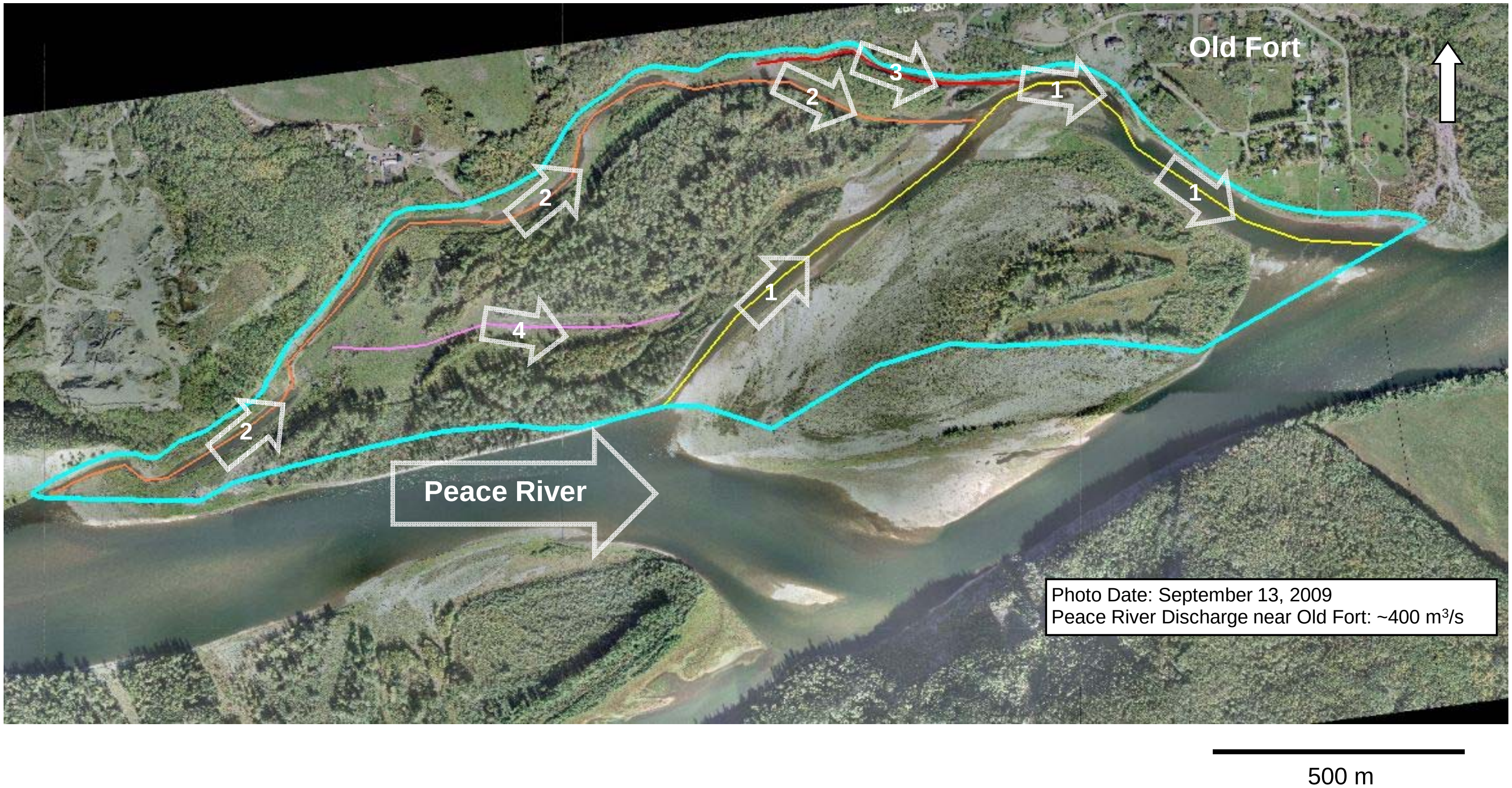
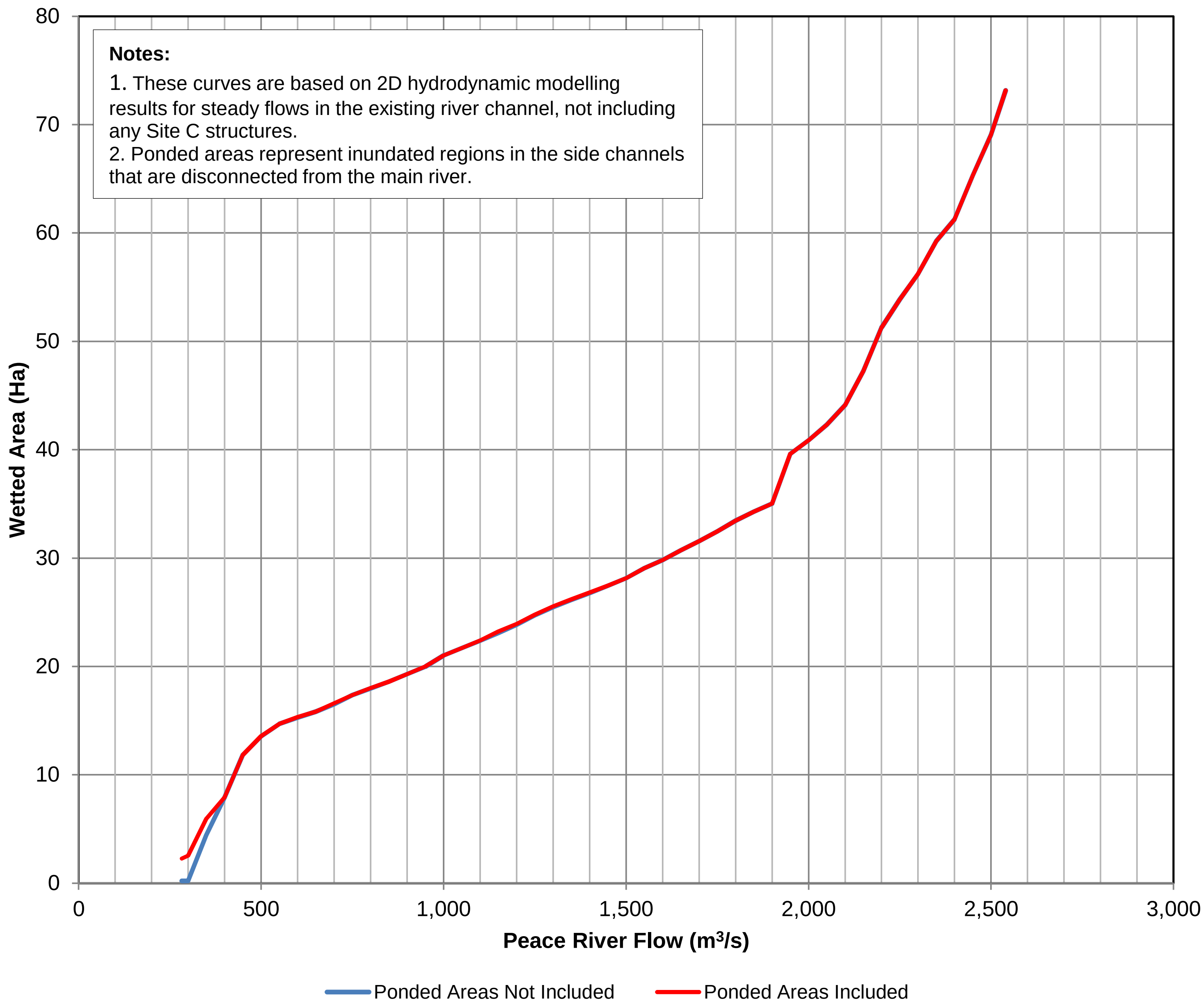
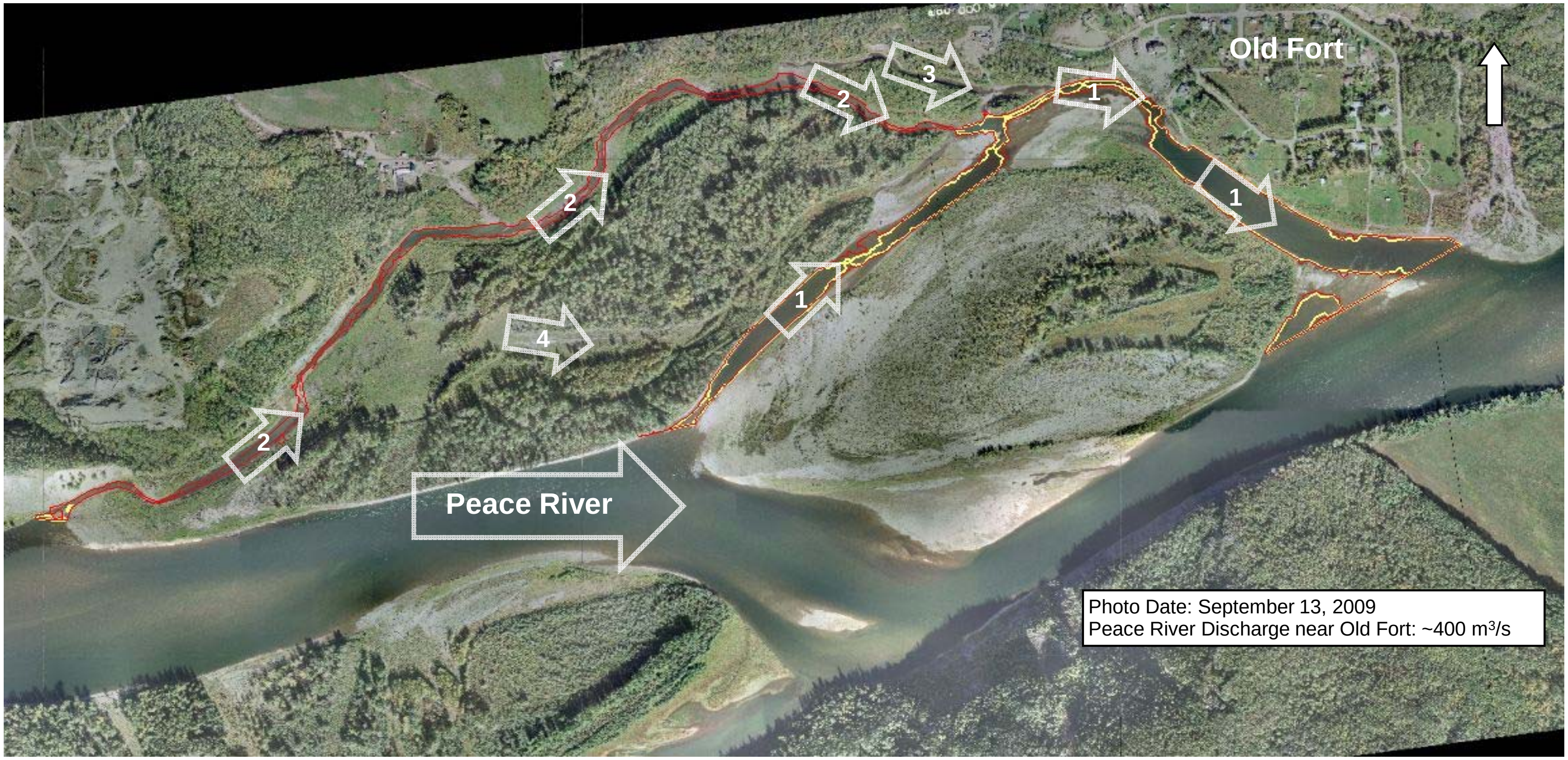


Figure G-2 - Flow-Wetted Area Relationship - Map of Old Fort Side Channel Region Considered

Figure G-3 - Flow-Wetted Area Relationship (Old Fort Side Channels)





Peace River Discharge = 400 m^3/s

Peace River Discharge = 450 m^3/s

500 m

Figure G-4 - Old Fort Side Channel Wetted Area for Flow of 400 m^3/s and 450 m^3/s

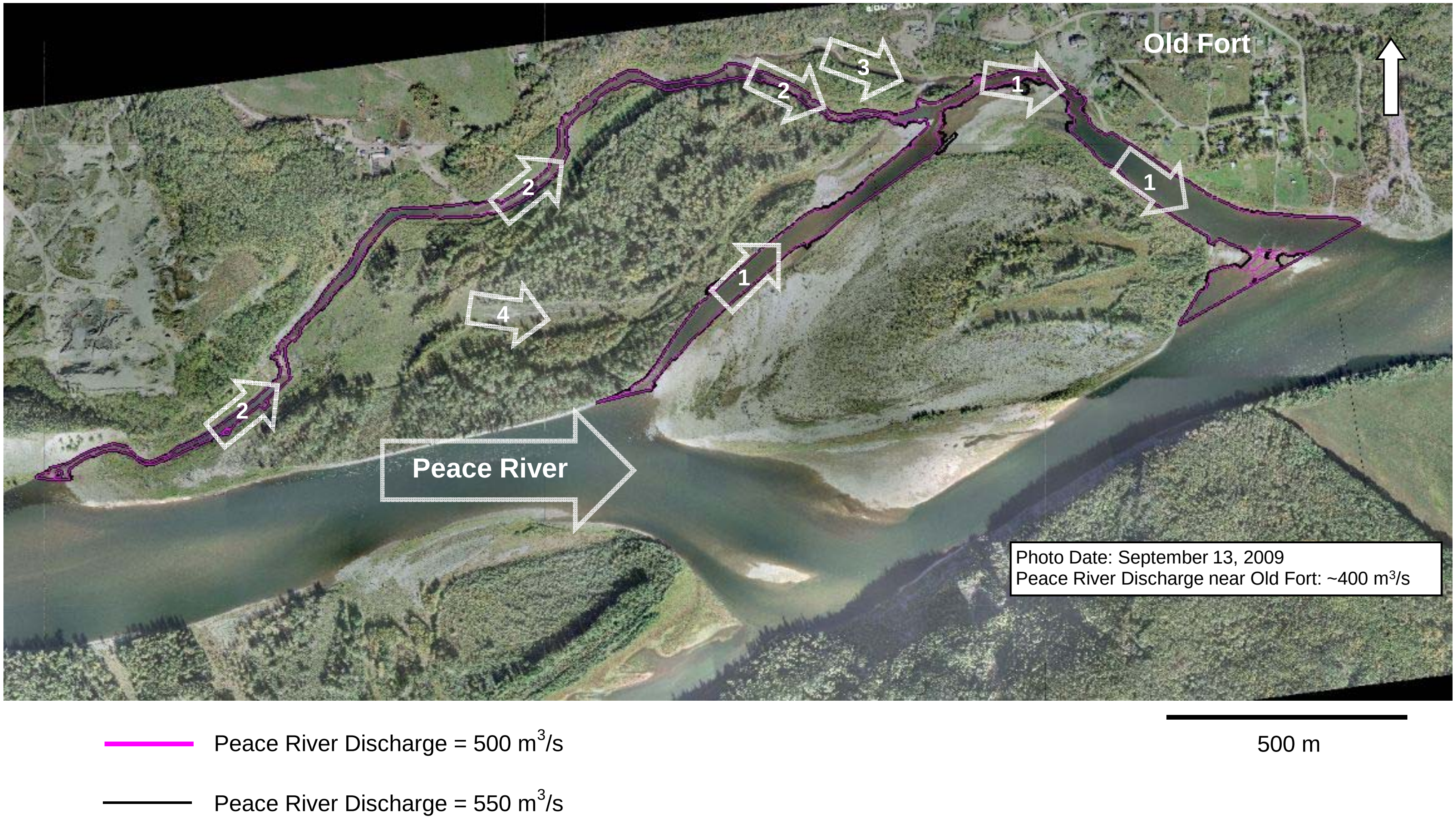
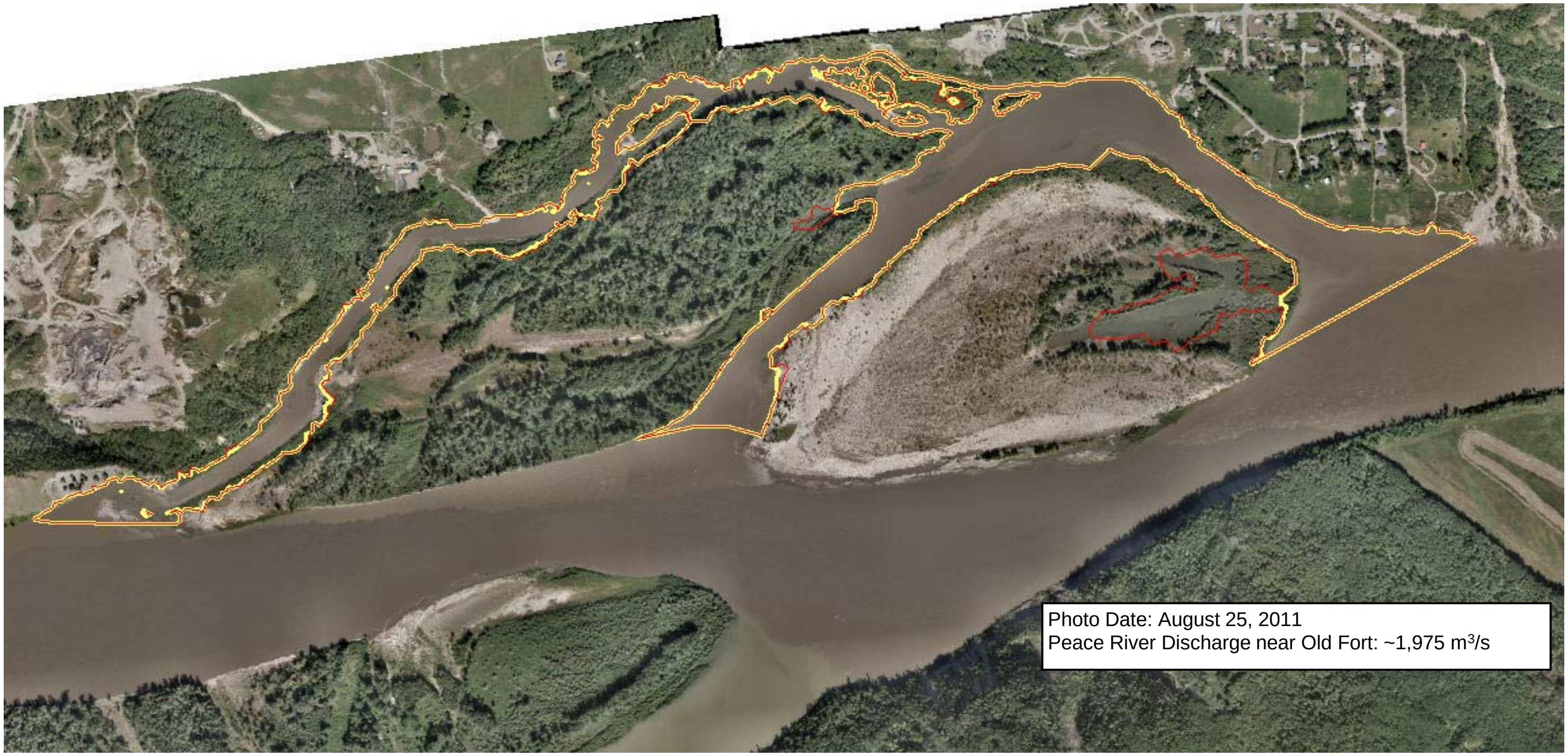


Figure G-5 - Old Fort Side Channel Wetted Area for Flow of 500 m^3/s and 550 m^3/s



Peace River Discharge = 1,900 m^3/s

Peace River Discharge = 1,950 m^3/s

500 m

Figure G-6 - Old Fort Side Channel Wetted Area for Flow of Approximately 1,900 m^3/s