Bridge River Water Use Plan

Effectiveness of Cayoosh Flow Dilution, Dam Operation, and Fishway Passage on Delay and Survival of Upstream Migration of Salmon in the Seton-Anderson Watershed

Implementation Year 3

Reference: BRGMON#14

Study Period: 2014 Annual Data Report

University of British Columbia
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March 2015

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BRGMON-14

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Annual Report - 2014 - FINAL

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Cover photo: Lillooet, BC. GSE screening an adult sockeye salmon. Photos © Matthew Casselman, University of British Columbia.

EXECUTIVE SUMMARY

Adult salmon migration in the Seton-Anderson watershed was studied for a third year as part of the BRGMON-14 monitoring program. The key objective of this five year program is to determine the effectiveness of BC Hydro's current mitigation measures for ensuring the successful migration of salmon past the Seton Generating Station and upstream of Seton Dam to spawning grounds. Current mitigation measures include dilution ratio targets during the Gates Creek and Portage Creek sockeye salmon migration periods and managing Seton Dam discharge for fish passage.

A second year of behavioural water preference experiments confirmed that Gates Creek and Portage Creek sockeye salmon display a preference for Seton River water when dilution ratios exceed present target values. Maintaining the target dilution ratios for Gates Creek (20%) and Portage Creek (10%) sockeye salmon could be expected to prevent migration delay at the Seton Generating Station. However, elevated study area water temperatures in 2013, and limited occurrence of above-target dilution ratios in 2014, has not allowed in-river migration behaviour to be adequately studied with telemetry to confirm water preference results.

An estimated 27,192 Gates Creek sockeye salmon passed Seton Dam in 2014. Attraction and passage efficiency were 98% for acoustic and radio-tagged fish and overall passage success was 97%. Migration benefitted from moderate water temperatures throughout the migration period. For PIT-tagged Gates Creek sockeye salmon released in the Seton River, passage success increased from 89% to 98% under an alternative flow scenario that reduced water velocities surrounding the fishway entrance. The alternative flow scenario was also associated with decreased post-passage delay and increased survival to spawning grounds.

Portage Creek sockeye salmon migration past Seton Dam was an estimated 38,812 fish in 2014. High abundance of Portage Creek sockeye salmon allowed for improved tagging efforts over 2013. Passage success at Seton Dam was high, with an estimated 98% attraction efficiency and 99% passage efficiency for radio-tagged fish. A small number of Portage Creek sockeye salmon tagged with acoustic transmitters showed that swimming speeds during passage were similar to those previously observed for Gates Creek sockeye salmon.

Challenges in 2014 included high turbidity during the Portage Creek sockeye salmon migration that prevented video validation of fish counter results and low natural variability in the Seton River dilution ratio. Given that 2015 is the final year of BRGMON-14 field studies, and dilution ratios can be expected to show little natural variation, it is recommended that Cayoosh Creek discharges are manipulated during the Gates Creek sockeye salmon migration period to temporarily increase the dilution ratio. This would allow fish behaviour at the Seton Generating Station to be studied using radio telemetry.

BRGMON-14 STATUS of OBJECTIVES, MANAGEMENT QUESTIONS and HYPOTHESES after Year 3

Objectives	Management Questions	Management Hypotheses	Year 3 (2014) Status
To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds. *And* To evaluate the sensitivity of the salmon populations to variations in the level of Cayoosh Creek dilution in the Seton River.	Are the Cayoosh flow dilution requirements for Seton River derived by the IPSFC effective for mitigating delays in migrations of Gates and Portage Creek sockeye salmon populations? *And* How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?	H_{O1}: Gates Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution exceeds 20%.	Gates Creek sockeye displayed a preference for Seton River water at a dilution ratios above 20%, suggesting upstream migration could be delayed if dilution ratios exceed 20%. In-river migration data at elevated dilution ratios is required to confirm that fish delay. Hypothesis cannot be rejected at this time. Methods: 2.4, 2.5. Results: 3.5, 3.6, 3.9. Discussion: 4.1.1.
		H_{O2}: Portage Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution exceeds 10%.	Portage Creek sockeye displayed a preference for Seton River water at a dilution ratios above 10%, suggesting upstream migration could be delayed if dilution ratios exceed 10%. In-river migration data at elevated dilution ratios is required to confirm that fish delay. Hypothesis cannot be rejected at this time. Methods: 2.4, 2.5. Results: 3.5, 3.6, 3.9. Discussion: 4.1.1.
		H_{O3}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Gates Creek sockeye.	Gates Creek sockeye migration was studied across a range of dilution ratios in Year 2 but high water temperatures may have confounded results. In Year 3, elevated dilution ratios did not occur during the Gates Creek sockeye migration. Additional telemetry data during elevated dilution ratios are required. Hypothesis cannot be rejected at this time. Methods: 2.4. Results: 3.5. Discussion: 4.1.1, 4.2.1.
		H_{O4}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Portage Creek sockeye.	Portage Creek sockeye migration has been studied at dilution ratios below the target ratio for this population but data are needed at elevated dilution ratios. Hypothesis cannot be rejected at this time. Methods: 2.4. Results: 3.5. Discussion: 4.1.1, 4.2.1.

Objectives	Management Questions	Management Hypotheses	Year 3 (2014) Status
To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds. *And* To evaluate the sensitivity of the salmon populations to variations in the level of Cayoosh Creek dilution in the Seton River.	What are the effects of Seton powerhouse operation on the upstream migration of other salmon populations (pink, Chinook, coho) migrating to the Seton-Anderson watershed?	H_{O5}: There is significant delay of pink salmon at the Seton Powerhouse under the normal operating procedure.	Pink salmon did not show a preference for Seton River water. Migration data suggests pink salmon did not delay but further data analysis is required. Hypothesis cannot be rejected at this time. Methods: 2.4, 2.5. Results: 3.9.
		H_{O6}: There is significant delay of Chinook salmon at the Seton Powerhouse under the normal operating procedure.	Hypothesis could not be tested in Year 2 or Year 3 because no Chinook salmon were collected for study. Methods: 2.4. Discussion: 4.2.3.
		H_{O7}: There is significant delay of coho salmon at the Seton Powerhouse under the normal operating procedure.	Coho were captured in limited numbers in Year 2 and Year 3. Low abundance of this species in the Seton River may prevent hypothesis from being properly tested. Methods: 2.3, 2.4. Results: 3.3, 3.4, 3.5, 3.6. Discussion: 4.2.3.
To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds.	Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam? *And* What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?	H_{O8}: Operation of Seton Dam and fishway does not affect attraction to the fishway.	Attraction efficiency varies with discharge, environmental conditions, and conveyance structure use. High temperatures reduced attraction efficiency in Year 2. Alternative conveyance structure use improved attraction efficiency in Year 3. Additional analyses and data are required. Hypothesis cannot be rejected at this time. Methods: 2.2, 2.3, 2.4. Results: 3.2, 3.3, 3.4, 3.6, 3.7. Discussion: 4.1.2.
		H_{O9}: Operation of the Seton Dam and fishway does not affect passage efficiency at the fishway.	Passage efficiency of Gates Creek sockeye was 89% in Year 1 and 98% in Year 2. Portage Creek sockeye passage efficiency was 94% in Year 2 and 99% in Year 3. The fishway does not appear to affect the passage efficiency of sockeye salmon. Methods: 2.2, 2.4. Results: 3.3, 3.4, 3.6, 3.7. Discussion: 4.1.2.

Keywords: Pacific salmon, *Oncorhynchus* spp., Seton River, Seton Dam, migration, fish passage, olfaction, telemetry.

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1.0 INTRODUCTION

The Bridge River Power Development Water Use Plan (WUP) was developed for BC Hydro's operations in the Bridge River Basin and includes the Seton Dam and associated infrastructure in the Seton-Anderson watershed (BC Hydro 2011). Five Pacific salmon (*Oncorhynchus* spp.) species migrate through the Seton-Anderson watershed including two genetically-distinct populations of sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), Chinook salmon (*O. tshawytscha*), pink salmon (*O. gorbuscha*), and steelhead trout (*O. mykiss*) (BC Hydro 2000). The primary spawning grounds for salmon, with the exception of pink salmon, are upstream of Seton Dam. To access spawning areas, adult salmon migrating up the Fraser River must pass the Seton Generating Station tailrace, enter the Seton River, negotiate the Seton Dam tailrace, and locate and ascend the Seton Dam fishway. Recommendations within the WUP by the Consultative Committee included the implementation of an adult fish passage monitoring program in the Seton-Anderson watershed to identify factors impeding the successful upstream migration of salmon through this migration route. Specifically, the Consultative Committee recommended the monitoring program address uncertainties in the effects of current Seton Dam and fishway operations on salmon passage and uncertainties in the effects of Seton River dilution by Cayoosh Creek on salmon migration.

Sockeye salmon passage through the Seton Dam fishway was recently examined in 2005 (Pon et al. 2006; Pon et al. 2009a, Pon et al. 2009b). A follow-up investigation in 2007 also monitored sockeye fishway passage as well as migration from the Seton Generating Station tailrace to spawning grounds above Seton Dam (Roscoe and Hinch 2008; Roscoe et al. 2010; Roscoe et al. 2011). Several impediments to salmon migration were identified in these studies including high discharge in the Seton River that hindered upstream migration and complex flow fields in the Seton Dam tailrace that delayed migration and reduced fishway attraction efficiency. These impediments resulted in the majority of observed sockeye salmon migration failure downstream of Seton Dam (Roscoe and Hinch 2008). Upstream migratory failure was also observed as post-passage mortality in Seton Lake and Anderson Lake with physiological indicators in failed migrants suggestive of increased stress. Post-passage mortality was also significantly higher for females than males. Fishway passage efficiency was high in both study years.

Absent from previous investigations was a comprehensive analysis of the influence of discharge and tailrace flow fields on salmon passage success at Seton Dam. Although a fish counter has historically been operated at the exit of the Seton Dam fishway, the low efficiency of the counter has not allowed Seton Dam operating conditions to be correlated with fish passage success. The studies in 2005 and 2007 provided some insight, but salmon passage could only be examined under five operating conditions and detailed information on Seton Dam water release patterns and associated flow conditions was not collected. In addition, the 2005 and 2007 investigations also primarily focused on sockeye salmon. Needed is a multi-year investigation of Seton River and Seton Dam fish passage to capture a range of discharge and flow conditions associated with Seton Dam operations. In addition, fish counter enumeration efficiency must be improved and a thorough assessment of how discharge and flow fields at Seton Dam influence delay and fishway attraction for all salmon species is required. Operating conditions at Seton Dam can then be correlated with migration success, post-passage survival, and environmental variables to identify factors impeding salmon migration and formulate mitigation measures.

Target dilution ratios for Cayoosh Creek discharge to total Seton River discharge are a component of the current WUP. Current targets were adopted from findings of the International Pacific Salmon Fisheries Commission (IPSFC) on population-specific water preference behaviour exhibited by Gates Creek and Portage Creek sockeye salmon (Fretwell 1989). Dilution targets for the Seton River are <20% Cayoosh Creek flow from 20 July to 31 August for Gates Creek sockeye salmon and <10% Cayoosh Creek flow from 28 September to 15 November for Portage Creek sockeye salmon (BC Hydro 2011). Maintaining target dilutions during sockeye migration periods are intended to reduce sockeye delay in the Seton Generating Station tailrace and encourage upstream migration to the Seton River-Fraser River confluence. The target dilution ratios and the apparent reduction in migratory delay are based on behavioural experiments and telemetry performed in the early 1980's. Neither the water preference behaviour of sockeye salmon nor the effectiveness of current dilution targets have been fully evaluated since the adoption and implementation of the target ratios. Recent studies have shown a high level of sockeye migration failure can still occur at target dilution levels (Hinch and Roscoe 2008). Further, it is not fully known how target dilution ratios influence the behaviour of other salmon species, although pink salmon appear less sensitive to changes in the dilution ratio (Fretwell 1989). The target dilution ratios and their effect on salmon migration will be assessed in this monitoring program.

The current BRGMON-14 monitoring program is a 5-year investigation that will provide a comprehensive assessment of how Seton River dilution, Seton Dam operations, and environmental variables interact with the behaviour and physiology of salmon to affect upstream migration in the Seton-Anderson watershed. Data collected in this program will build upon previous studies while incorporating new technologies to enhance monitoring. The University of British Columbia (UBC) will carry out physical parameter monitoring, use telemetry to assess fish migration, conduct behavioural experiments, and collaborate with the University of Alberta to measure Seton Dam tailrace flow fields. Instream Fisheries Research Inc. will conduct fish passage enumeration at the Seton Dam fishway using an electronic fish counter and video monitoring. Ultimately, this program will make recommendations to St'át'imc Government Services and BC Hydro on operational modifications to the hydroelectric facilities within the Seton-Anderson watershed to improve salmon passage. This report summarizes Year 3 of the BRGMON-14 monitoring program that continued the telemetry program and water preference experiments started in Year 1 and Year 2.

1.1 Scope and Objectives

The objectives of the BRGMON-14 monitoring program are:

1. To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds.
2. To evaluate the sensitivity of the salmon populations to variations in the level of Cayoosh dilution in Seton River.
3. To identify operating strategies that will mitigate delays in upstream migration without conflicting with other water use goals for environmental protection, flood risk, and power production in the Bridge Seton generating system.

1.2 Management Questions

The management questions of this monitoring program will achieve the program objectives by addressing specific uncertainties in the current operational requirements at Seton Dam and how these operations impact all salmon species migrating in the Seton-Anderson watershed. Uncertainty within the WUP operational requirements exist because Seton River dilution ratios were derived from studies that were limited to sockeye salmon and have not been re-evaluated. Further, fish passage at Seton Dam requires more detailed investigation. Therefore, the management questions of this monitoring program are:

1.1 Are the Cayoosh flow dilution requirements for Seton River derived by the IPSFC effective for mitigating delays in migrations of Gates and Portage Creek sockeye salmon populations?

1.2 How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?

2.1 What are the effects of Seton powerhouse operation on the upstream migration of other salmon populations (pink, Chinook, coho) migrating to the Seton-Anderson watershed?

3.1 Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam?

3.2 What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?

1.3 Management Hypotheses

Although previous investigations indicate that the target dilution ratios are necessary to mitigate delay of upstream migrating Gates Creek and Portage Creek sockeye salmon populations, confirming this operation requirement is central to the BRGMON-14 monitoring program and will address Management Question 1.1. The null (no effect) hypotheses to be tested for the effect of Cayoosh Creek dilution on the two sockeye salmon populations are:

H_{O1}: Gates Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution rate exceeds 20%.

H_{O2}: Portage Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution rate exceeds 10%.

Testing these hypotheses will require monitoring sockeye salmon migration at different dilution ratios. Operating conditions during the 5-year monitoring program period should provide sufficient variation in dilution levels to accept or reject these hypotheses.

Variations in the dilution ratio necessitate a secondary set of hypotheses to test the sensitivity of Gates Creek and Portage Creek sockeye migration behaviour and address Management Question 1.2. The null hypotheses are:

H_{O3}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Gates Creek sockeye.

H_{O4}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Portage Creek sockeye.

To date, investigations have focused on sockeye salmon because of their abundance in the Seton-Anderson watershed and high cultural and economic value. It has not been determined if discharge at the Seton Generating Station delay pink, Chinook, or coho salmon migrating to the Seton River. Management Question 2.1 will be addressed by testing the following hypotheses:

H_{O5}: There is significant delay of pink salmon at the Seton Powerhouse under the normal operating procedure.

H_{O6}: There is significant delay of Chinook salmon at the Seton Powerhouse under the normal operating procedure.

H_{O7}: There is significant delay of coho salmon at the Seton Powerhouse under the normal operating procedure.

The following hypotheses are related to Seton Dam and fishway operations and will address Management Questions 3.1 and 3.2:

H_{O8}: Operation of Seton Dam and fishway does not affect attraction to the fishway.

H_{O9}: Operation of the Seton Dam and fishway does not affect passage efficiency at the fishway.

Year 3 of the BRGMON-14 monitoring program investigated each of the management hypotheses.

1.4 Study Area

The study area for Year 3 (2014) of the BRGMON-14 monitoring program encompassed the entire salmon migration route within the Seton-Anderson watershed from downstream of the Seton Generating Station on the Fraser River to Gates Creek and the Gates Creek spawning channel upstream of Anderson Lake (Figure 1-1). Detailed study of salmon migration was carried out in the Seton River study area that included the Seton Generating Station, Fraser River, Seton River, Cayoosh Creek, and Seton Dam (Figure 1-2). In addition, the migratory success of salmon to spawning grounds at Gates Creek and Portage Creek was quantified.

Detailed examination of migration was also carried out at Seton Dam located 4.4 km upstream from the Fraser River (Figure 1-3). Seton Dam is a 76.5 m long by 13.7 m high concrete structure consisting of a radial gate, five siphons, a fish water release gate (FWRG), and fishway. In order to access Seton Lake and spawning grounds, migrating salmon must navigate the radial gate spillway and entrance area (together the Seton Dam tailrace), locate the fishway entrance adjacent to the FWRG, and ascend the fishway. The fishway has a total length of 107 m, contains 32 pools separated by vertical baffles, and has an overall grade of 6.9%. The Seton Dam fish counter is located at the upstream end of the fishway at the exit to Seton Lake. Migrating salmon must pass through the fish counter to exit the fishway.

Figure 1-1: Overview of the Seton-Anderson watershed and study area for the BRGMON-14 monitoring program

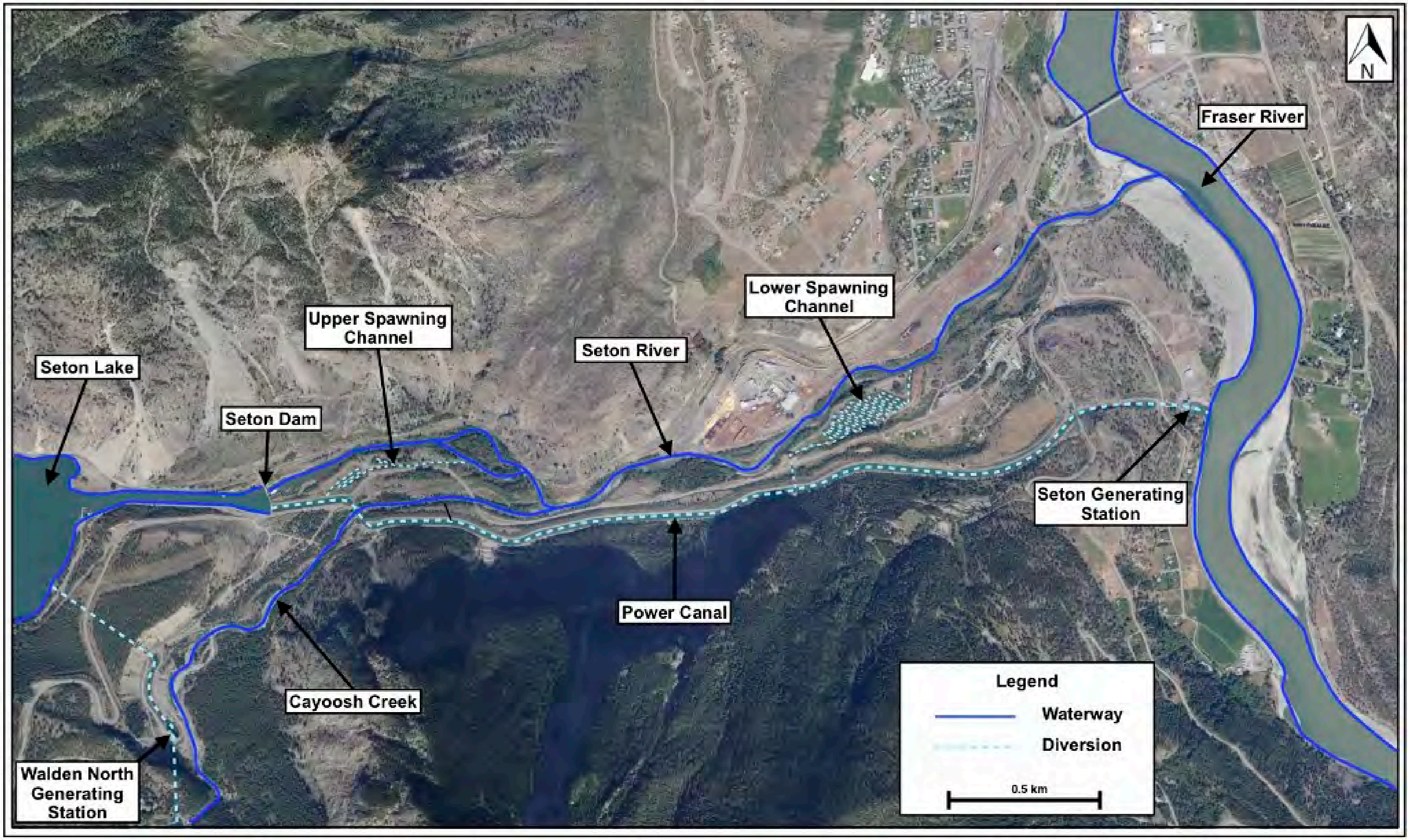

Figure 1-2: Waterways and diversion infrastructure within the Seton River study area

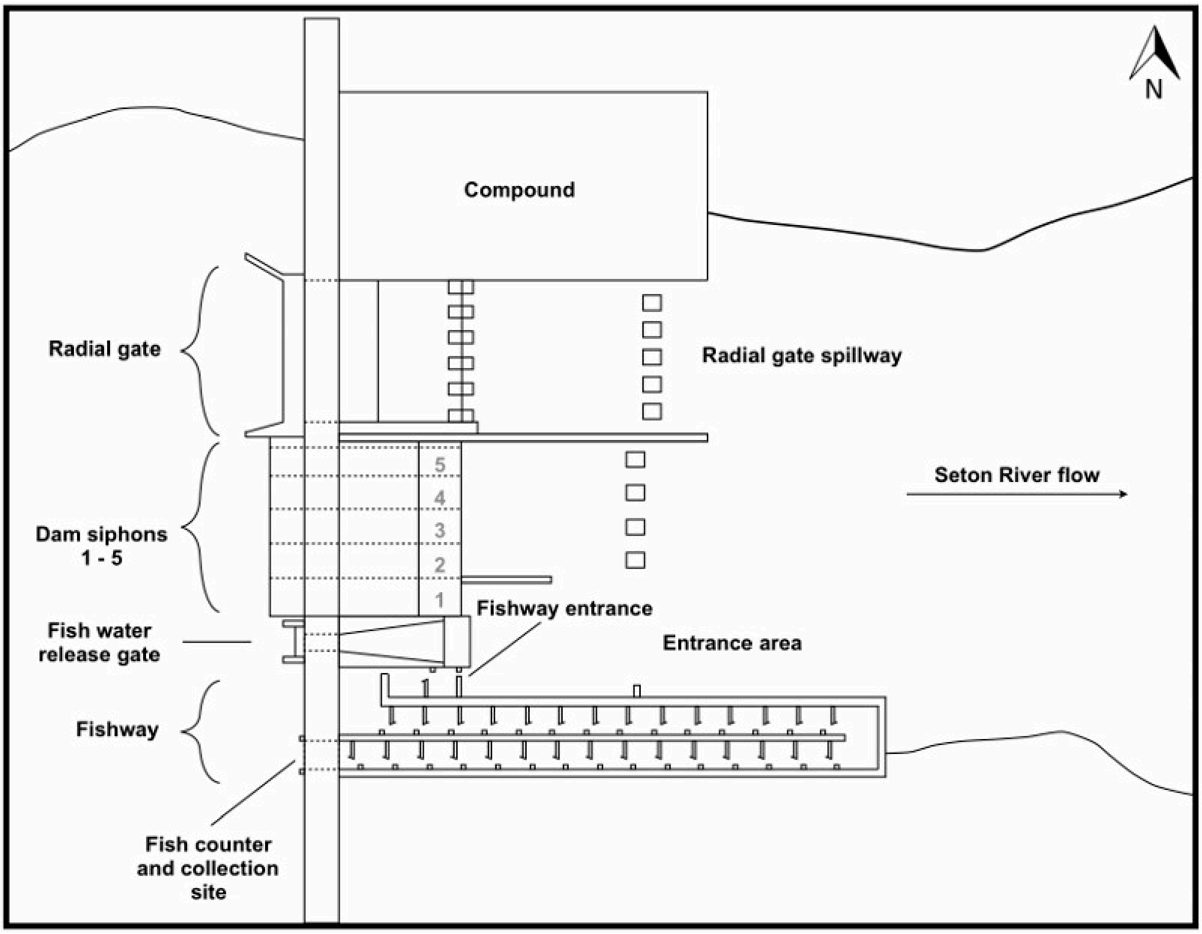

Figure 1-3: Schematic of Seton Dam showing water conveyance structures (left), fishway entrance are (bottom), and the radial gate spillway (top)

2.0 METHODS

2.1 Physical Parameter Monitoring

Monitoring of physical parameters important to salmon migration in the Seton-Anderson watershed began in 2012 and continued throughout the 2014 study period.

2.1.1 Discharge and Dilution Ratio

Discharge data for the Seton River, Cayoosh Creek, Seton Dam, and Seton Generating Station were obtained from BC Hydro Power Records. Daily discharge data were based on the average daily discharges recorded by Water Survey of Canada (WSC) gauging stations on Cayoosh Creek (No. 08ME002) and Seton River above Cayoosh Creek (No. 08ME003) (Figure 2-1). Hourly discharge data were obtained for each conveyance structure at Seton Dam and spawning channels.

The daily dilution ratio for the Seton River was obtained from BC Hydro Power Records. Dilution was calculated by BC Hydro using the daily average discharge of each location in the following equation:

$$\text{Dilution Ratio (\%)} = \frac{\text{Cayoosh Creek}}{(\text{Cayoosh Creek} + \text{Seton River} + \text{Spawning Channels})}$$

2.1.2 Water Temperature

Water temperature data were collected at the water quality sites established in 2012 (Figure 2-1; Table 2-1). In 2014, a new water quality site was established in lower Gates Creek (W13-GCK). No manual measurements of water temperature were taken from the Fraser River (W02-UFR) in 2014. TidbiT v2 water temperature loggers (± 0.2°C accuracy) (Onset Computer Corporation Inc., Bourne, MA, USA) recorded hourly water temperature at all sites except at W07-SFW and W13-GCK where temperature was set to record at 15 min intervals starting in 2014. Duplicate temperature loggers were installed at select sites to ensure data security.

Table 2-1: Geographic locations of water quality sites and serial numbers for installed temperature loggers

Site	Description	UTM Coordinates	Serial #1	Serial #2
W01-LFR	Seton Generating Station	10 U 0576019 5613952	10206555	10170913
W02-UFR	Upper Fraser River	10 U 0575582 5615178	NA	NA
W03-LSR	Lower Seton River	10 U 0574397 5613831	10170909	10219612
W04-LCC	Lower Cayoosh Creek	10 U 0573069 5613554	10206558	10206556
W05-USR	Upper Seton River	10 U 0572419 5613636	10219610	10170912
W07-SFW	Seton Dam Fishway	10 U 0572246 5613558	10206557	NA
W10-LPC	Lower Portage Creek	10 U 0550573 5617636	10219613	NA
W12-GSC	Gates Creek Channel	10 U 0536685 5599754	10219609	NA
W13-GCK*	Lower Gates Creek	10 U 0537162 5599963	10219608	NA

*Installed 18 June 2014

Additional water temperature data were obtained for the Fraser River to estimate the thermal experience of salmon prior to entering the Seton River. Water temperature data were obtained from Fisheries and Oceans Canada from the monitoring station at Qualark Creek (UTM 10 U 613935 5488072) and from the WSC station No. 08MF040 Fraser River above Texas Creek (Environment Canada – Water Survey Canada, 2014). The Qualark Creek monitoring station was used because it is located approximately equal distance from the mouth of the Fraser River and Seton River. Temperature at Qualark Creek was judged to be representative of the average thermal regime encountered by sockeye salmon during their upstream migration. Entry dates and run duration for Gates Creek and Portage Creek sockeye salmon were determined using migration data from Hague and Patterson (2009). Temperature data from the Fraser River above Texas Creek was used in place of a temperature logger in the Fraser River.

2.1.3 Water Chemistry

Specific conductivity measurements were collected for a third year to compare the water chemistry of the Seton River and Cayoosh Creek watersheds.

In 2014, monitoring was carried out at three sites: the lower Seton River (W03-LSR), lower Cayoosh Creek (W04-LCC), and the upper Seton River (W05-USR) above the Seton River-Cayoosh Creek confluence (Figure 2-1). Specific conductivity ($\mu S \cdot cm^{-1}$) measurements were taken from 21 July to 17 October using a hand-held YSI Pro30 conductivity meter (YSI Inc., Yellow Springs, OH, USA). Measurements were taken daily so long as personnel were available.

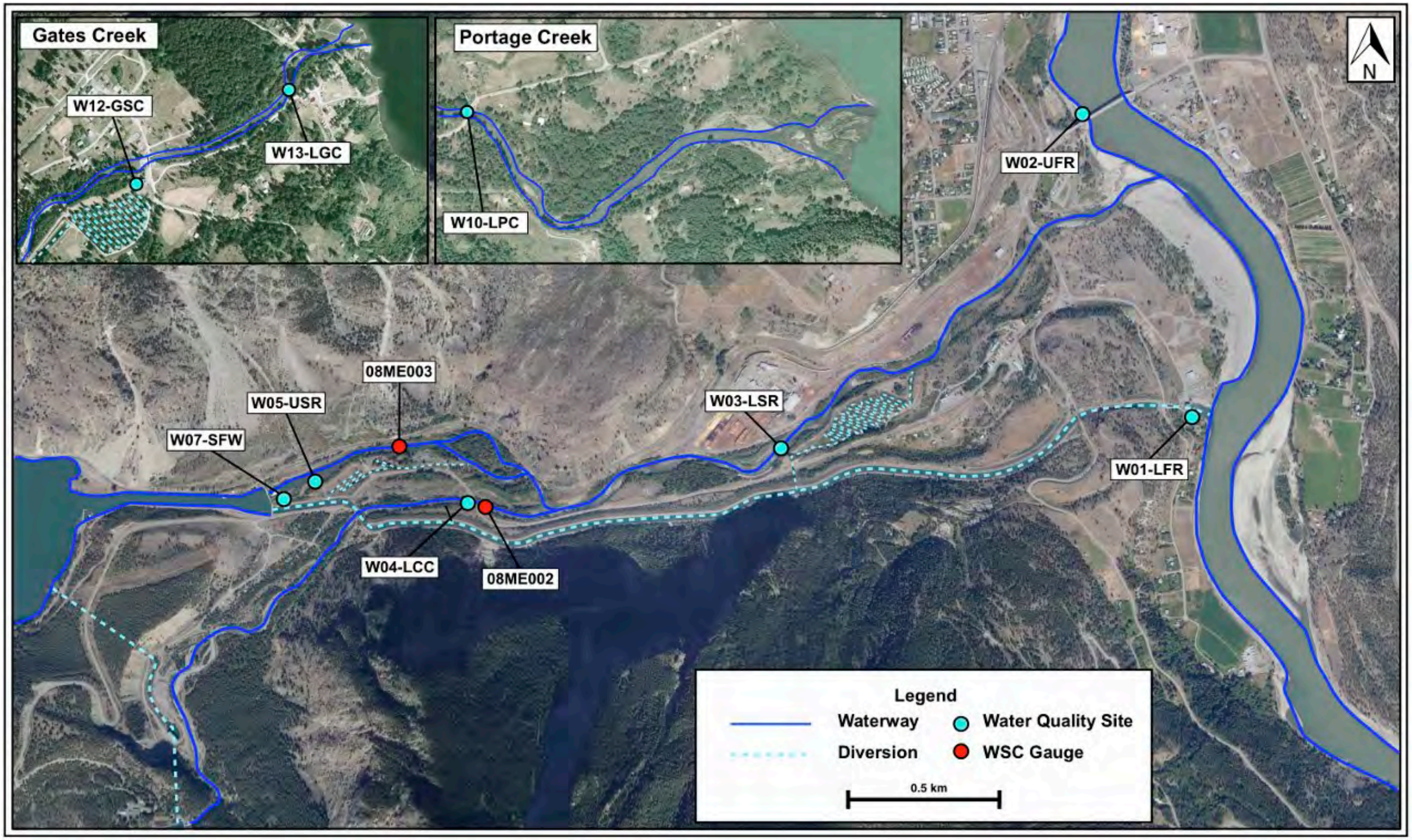

Figure 2-1: **Water quality sites in the Seton River (main map), Gates Creek spawning channel (insert, left), and Portage Creek (insert, right)**

2.2 Seton Dam Tailrace Flow Fields

Flow fields in the Seton Dam tailrace were investigated because of their potential to cause migration delay and failure of sockeye salmon (Pon et al. 2006; Roscoe and Hinch 2008). In 2014, an alternative flow scenario was tested to determine if using different conveyance structures to discharge water at Seton Dam could reduce water velocities surrounding the fishway entrance and improve salmon passage. The University of Alberta was contracted to measure flow velocities and direction in the tailrace during routine BC Hydro operations and the alternate flow scenario. In addition, river bathymetry was surveyed to develop computational fluid dynamic models in the future. Tagged fish were released during all flow scenarios.

2.2.1 Alternative Flow Scenario Changes

The alternative water flow scenario was implemented at Seton Dam between 08 and 19 August 2014. Prior to 08 August, BC Hydro operated Seton Dam according to routine operating procedures. On 08 August, discharge from the FWRG was reduced from 7.6 $m^3 \cdot s^{-1}$ to 1.9 $m^3 \cdot s^{-1}$ and discharge from the siphons changed from SSV1 to SSV4. On 19 August, BC Hydro returned Seton Dam to routine operating conditions during a scheduled ramp-down with FWRG flows increased to 2.5 $m^3 \cdot s^{-1}$ and siphon flows changed from SSV4 to SSV1.

2.2.2 Water Flow and Bathymetry Measurements

A 2-dimensional ChannelMaster H-ADCP (Teledyne RD Instruments, Poway, CA, USA) was used to measure water velocity across 43 transects in the Seton Dam tailrace (Figure 2-2). The ADCP was either manually positioned from the river bank (S1 to S35) or lowered into the tailrace from the dam compound (S36 to S38) or fishway wall (X1 to X5) using a custom-built frame. Transects S1 to S38 were taken at a depth of 0.5 m, while transects X1 to X5 were taken every 0.5 m from 0.5 m below the water surface to 0.5 m above the river bed. Each transect was approximately 20 m long with water velocity measurements taken at 0.20 m to 0.25 m segments along the transect. Water velocity measurements were taken for a minimum of 5 min with a 5.5 s sampling interval. Additional details on measurements can be found in Appendix II. Particle tracking was used to estimate water velocities where the ADCP measurements were attenuated by highly turbulent and aerated water. Movements of foam and wood particles of known dimensions were recorded by digital video cameras recording at 120 frames per second and video analysis was used to calculate surface water velocities.

River bathymetry was measured in October with a downward-facing 3.0 MHz RiverCat-ADP (SonTek, San Diego, CA, USA) mounted to aluminum hulls and towed across the tailrace. A total of 40 bathymetry transects were completed. The origin of each ADCP and bathymetry transect was measured using a RTK-GPS system (Trimble Navigation Limited, Sunnyvale, CA ,USA).

2.2.3 Data Analysis

ADCP and bathymetry data were post-processed using the software packages supplied by the ADCP manufacturers and imported to Microsoft Excel and Matlab for further analysis. See Appendix II for further information.

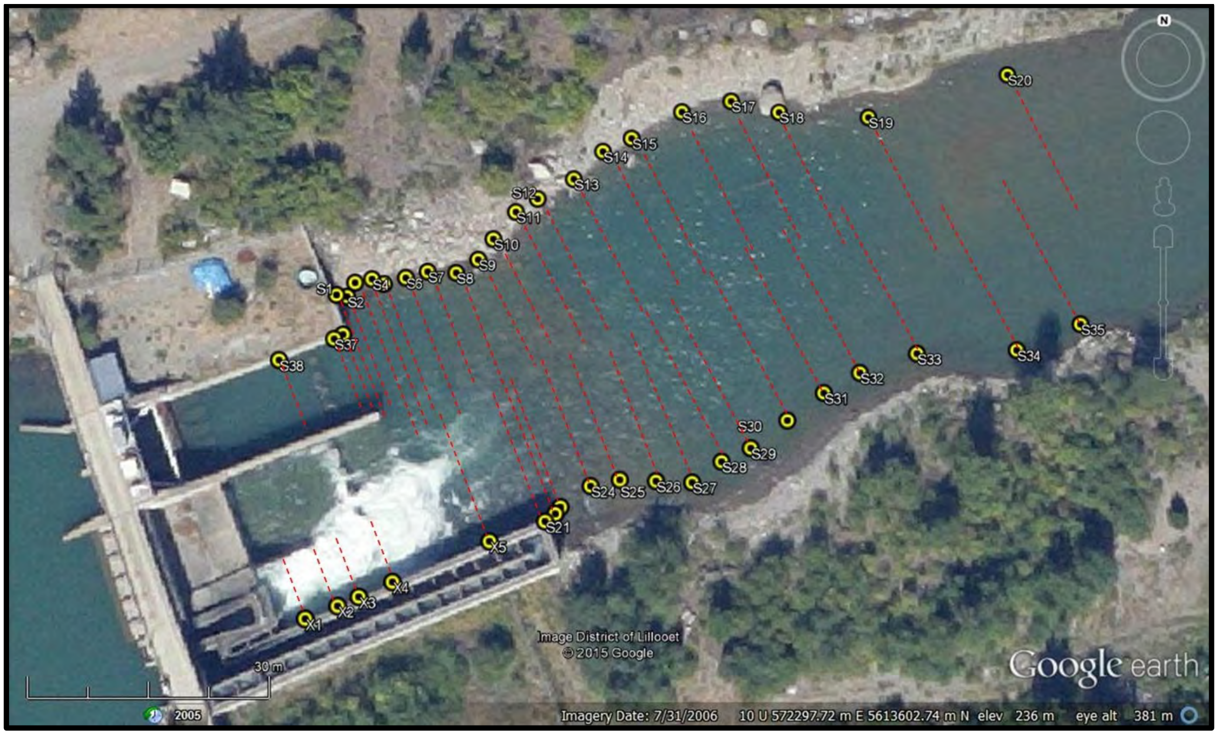

Figure 2-2: Acoustic Doppler Current Profiler measurement transects in the Seton Dam tailrace (S1-S38) and at the fishway entrance (X1-X5) in 2014

2.3 Fish Passage Enumeration

Population-specific fish passage abundances past Seton Dam were estimated using a resistivity fish counter installed at the exit of the Seton Dam fishway. Data from the counter was also used to estimate the migration timing of Gates Creek and Portage Creek sockeye salmon. Coho salmon abundance estimates could not be generated for 2014 due to overlap with the more abundant Portage Creek sockeye salmon migration and low water clarity, which impacted validation efforts. Observing Chinook salmon at night was problematic and Chinook salmon abundance could not be estimated in 2014.

2.3.1 Resistivity Counter

On 23 July, the Seton Dam fish counter was reinstalled at the top of the Seton Dam fishway (Figure 2-3). The sensor unit consisted of eight independent sensor tubes connected to two Logie 2100c resistivity electronic fish counter (Aquantic Ltd., Scotland, UK). Each sensor tube was monitored by a single counter channel.

Detailed fish counter operation is summarized in the Year 1 report. Briefly, the counter operates by detecting a change in electrical resistance when fish swim through a sensor tube (Figure 2-3; Figure 2-4). The change in resistance is measured by the counter and an algorithm is used to determine if a fish passed through the counter in the upstream or downstream direction or if the fish entered the sensor unit but failed to pass. For detections exceeding a minimum threshold, the date and time, conductivity, channel, direction (upstream or downstream), and peak signal size (PSS) are recorded. The PSS is a function of fish size, fish swimming distance from the sensors, electrode sensitivity, river conductivity, and bulk resistance (background resistance caused by flowing water). Minimum thresholds for detection were set (PSS of 40 out of 127) to eliminate resistance noise caused by air bubbles from the water surface or debris passing through the sensor tubes. Automatic re-calibrations of the sensor were programmed to occur every 30 min to compensate for changes in environmental conductivity. Detections were saved to one of eight channels on one of the two fish counters. Detection data was downloaded every 2-3 d during the study period.

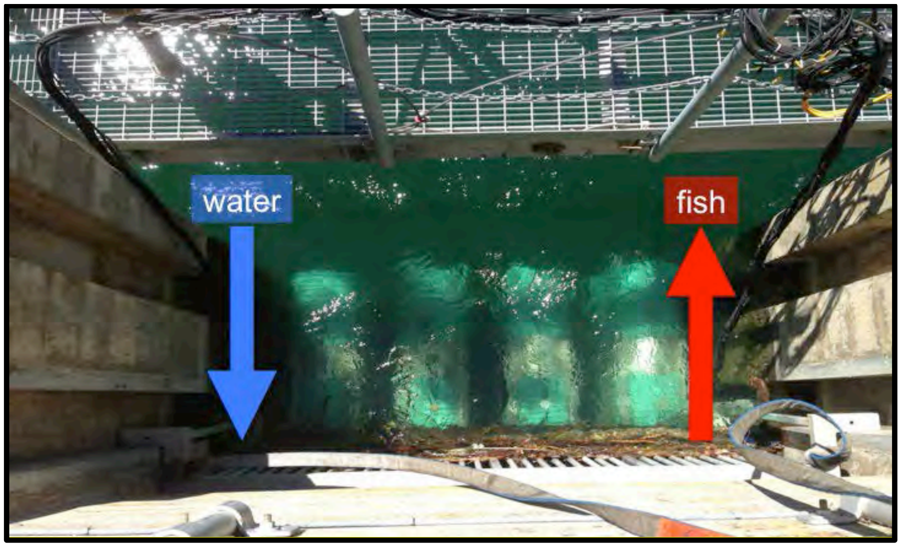

Figure 2-3: Overhead view of the resistivity counter sensor tubes installed at the exit of the Seton Dam fishway. Water flow and fish migration directions are indicated

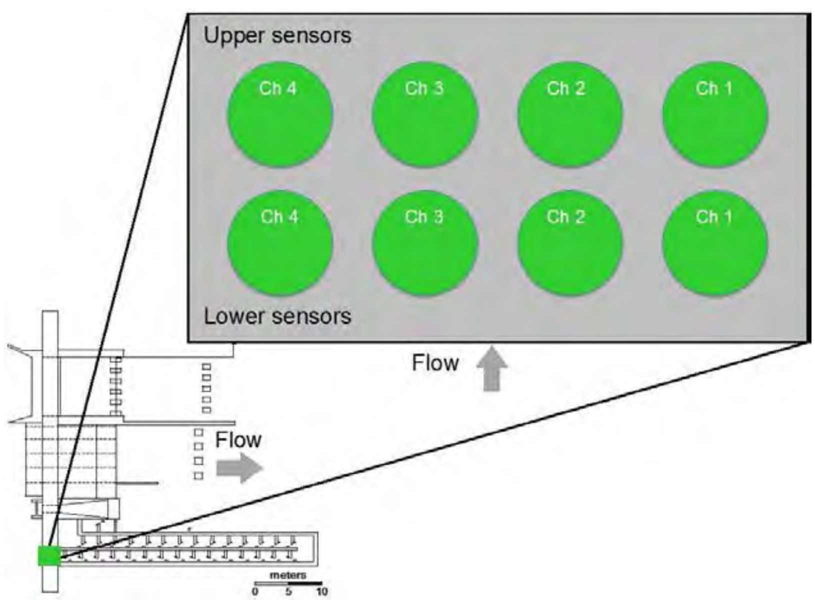

Figure 2-4: Schematic of the fish counter located at the exit of the Seton Dam fishway. The upper and lower sensors were monitored by two, four channel resistivity counters

2.3.2 Video Monitoring

Digital underwater video cameras were attached to camera mounts off the gantry upstream of the fish counter. The field of view of the cameras allowed for all eight tubes to be validated, an improvement from 2013 in which only four tubes were validated. However, the video image was susceptible to high turbidity events that occurred during a few days of the Gates Creek sockeye salmon migration and throughout most of the Portage Creek sockeye and coho salmon migration. Video was recorded from 13 August to 04 November and was saved to a digital-video recorder at 15 frames per second. An external infrared light was installed to aid nighttime viewing but was not powerful enough to illuminate at the depth of the tubes.

2.3.3 Data Analysis

For Gates Creek sockeye salmon, video recordings of fish passage were used to validate the counter detections and estimate the accuracy of each sensor tube. Recordings of fish passing through the counter were matched with the counter detections to determine the proportion of detections that were correctly recorded (accuracy). For each tube, six randomly–selected 20 min segments of video data were reviewed from every day between 13 and 24 August. The number of fish validated was in proportion to the number of fish passing through each tube. Validation data from 13 to 24 August was pooled for each sensor, resulting in a single accuracy for each sensor tube. This approach was reasonable as there was little daily variation in sensor tube accuracy with the exception of one tube (lower sensor tube 3) that showed substantial daily variation. To address this, video validation was supplemented with signal validation for that channel to produce robust daily accuracy estimates from 07 August to 10 September. The ratio of Gates Creek sockeye salmon to other species was also estimated using video validation and incorporated into abundance estimates using the average ratio of Gates Creek sockeye salmon to other species for each tube.

For Portage Creek sockeye salmon, video validation was not possible. Therefore, estimates of sensor tube accuracy during the Gates Creek sockeye migration were applied to abundance estimates. Signal validation for lower sensor tube 3 continued throughout the entire Portage Creek sockeye salmon run (11 September to 04 November). Unlike during the Gates Creek sockeye salmon migration, daily accuracy values for the lower sensor tube 3 were consistently high (90-100%). Thus, the validation data were pooled for the Portage Creek sockeye salmon migration period. The ratio of Gates Creek sockeye salmon to other species was applied to the estimate of Portage Creek sockeye salmon abundance. While these estimates characterize the ratio of sockeye salmon to resident species (primarily bull trout and rainbow trout), co-migrating coho salmon could not be differentiated from Portage Creek sockeye salmon. Therefore, estimates of Portage Creek include any coho salmon that may have passed through the counter.

Abundance estimates for Gates Creek and Portage Creek sockeye salmon, and coho salmon were calculated by expanding the raw counter counts using up count accuracies and species ratios. Uncertainty in sensor accuracy methods and species ratios were incorporated into estimates of abundance using Monte Carlo simulations.

Probability distributions for up count accuracy and species ratios were generated using a binomial beta distribution, which is a binomial distribution with a conjugate Beta prior:

$$\pi \sim \mathrm{B}(\alpha, \beta)$$

where π is the proportion of counts correctly classified, *B* is the binomial beta distribution, α and β are the alpha and beta parameters for the Beta distribution prior. Uniform priors were used in all simulations (i.e. the values of α and β were both 1).

The number of up counts for the target species was calculated as:

$$U_1^* = P_1^*(U - V_1) \qquad \text{equation 1}$$

where, U^* is the posterior distribution of the target species up count, and U is the up counts recorded by the counter for all species, P_1^* is the posterior distribution for the proportion of counts that are the target species, and V_1 is the number of target species up counts validated. Using the total up counts for the target species estimated in equation 1 the total abundance can be calculated by incorporating the uncertainty in sensor accuracy as follows:

$$S_1^* = \left[V_{U1} + \frac{U_1^*}{A_{U1}^*}\right] - \left[V_{D1} + \frac{U_1^*}{A_{D1}^*}\right] \qquad \text{equation 2}$$

where S_1^* is the posterior distribution for the abundance of the target species, V_{U1} and V_{D1} are the number of validated up and down counts for the target species, respectively. A_{U1}^* and A_{D1}^* are the posterior distributions for sensor accuracy for up and down counts for the target species, respectively. Downstream counts were ignored in abundance calculations because no sockeye salmon or coho salmon were observed moving downstream through the sensor tubes. For each Monte Carlo simulation 1,000 iterations were performed, which generated 1,000 abundance estimates. The mean abundance estimate 95% credible intervals are reported for Gates Creek and Portage Creek sockeye populations.

2.4 Telemetry

Salmon migration behaviour in the Seton-Anderson watershed was monitored in 2014 using acoustic, radio, and passive integrated transponder (PIT) telemetry. All fish were collected from a fish fence downstream of Seton Dam. Acoustic accelerometer transmitters were used for a third year to assess the swimming activity and behaviour of Gates Creek sockeye salmon during passage of Seton Dam. In addition, Portage Creek sockeye salmon were tagged for the first time with acoustic accelerometers. Radio transmitters were used with Gates Creek and Portage Creek sockeye salmon and coho salmon to monitor the migration of these species from the Fraser River to spawning grounds. All acoustic and radio-tagged fish received a PIT tag with additional Gates Creek and Portage Creek sockeye salmon and coho salmon receiving only PIT tags. All methods involving animals were approved by the University of British Columbia Animal Care Committee.

2.4.1 Fish Collection

Fish were collected using a full-span fish fence installed in the Seton River approximately 200 m downstream of Seton Dam (Figure 2-5). The installation location for the fence was the same as 2013. Fence installation was completed on 28 July and the fence was removed on 20 October. The Seton Dam fishway was not used as a site to collect fish for telemetry studies in 2014.

Fence operation varied according to fish abundance and migrating timing. During the majority of the Gates Creek and Portage Creek sockeye salmon migration, the fence was closed (i.e. actively fishing) at approximately 0600 h for five to eight daylight hours each tagging day. Since sockeye are known to primarily migrate at night, daytime closures minimized the likelihood of fence operations altering the behaviour of tagged salmon migrating through the system. However, from 04 to 06 August the fence was closed in the evening (2200 h to 0200 h) due to low abundance of Gates Creek sockeye salmon. Overall, limited recapture of tagged sockeye salmon occurred in 2014. When the fence was not operating, sections were removed to allow salmon migration to continue unimpeded.

Figure 2-5: Full-spanning fish fence in the Seton River in 2014

2.4.2 Tagging and Sampling Protocol

All fish were tagged and sampled using standardized protocols. Fish received either an acoustic, radio, or PIT tag as a primary tag. All tagging was performed at the Seton River fence site.

Fish were transferred from holding pens to a V-shaped trough supplied with fresh water and manually restrained. An estimate of somatic lipid concentration was made using a fish Fatmeter (Distell, West Lothian, Scotland, UK) (Crossin and Hinch 2005). Based on 2013 and 2014 results, sockeye salmon collected during the Gates Creek migration period with an average Fatmeter reading greater than 2.7% were identified as strays and received only a PIT tag. This screening procedure was not applied during the Portage Creek sockeye salmon migration. Fork length was then measured to the nearest 0.5 cm and sex estimated.

For acoustic- and radio-tagged fish, a 3 mL blood sample was withdrawn into Vacutainers using a caudal puncture with a 22G needle (Houston 1990). Samples were then centrifuged and plasma withdrawn and frozen in liquid nitrogen for 1-3 weeks before transfer to a -80°C freezer for storage until laboratory analysis. Following blood sampling, V13A-1x acoustic transmitters (Vemco, Bedford, NS, Canada) and Pisces5 radio transmitters (Sigma Eight Inc., Newmarket, ON, Canada) were inserted into the stomach using a plastic plunger. For Gates Creek sockeye salmon, an iButton DS1921Z or DS1922L temperature logger (Maxim Integrated, San Jose, CA, USA) was secured to each radio tag to record the thermal experience of fish during migration.

All fish received a 32 mm HDX PIT tag (Oregon RFID, Portland, OR, USA) implanted in the dorsal musculature and a 12” spaghetti tag (Floy Tag & Mfg. Inc., Seattle, WA, USA) tied behind the dorsal fin. A DNA sample was taken from the adipose fin using a hole punch and stored in 95% ethanol. Fish condition was then assessed and a photograph taken of the tagged fish. The average time to tag each acoustic- and radio-tagged fish was 4 min while the average time to tag PIT-tagged fish was 2 min.

Injury monitoring protocol used in 2014 was updated from the protocol used in 2013. As in 2013, overall fish condition was scored according to the presence of external injuries. Fish were scored as either being uninjured or were assessed as having minimal (would not be expected to impair migration), moderate (could be expected to impair migration), or severe injuries (expected to impair migration). The origin of the injury was also estimated. Radio-tagged fish received a more-detailed injury monitoring assessment (Table 2-2).

Table 2-2: Injury monitoring protocol performed on radio-tagged fish in 2014

Injured?	Severity	Injuries Assessed	Injury Origin
Yes / No	Minor Moderate Severe	Scale Loss (%), Skin Loss (%), Fungus Cover (%), Injured Eyes (0/1/2), Fins Injured (0-7), Worst Fin (Min/Mod/Sev), Vent (Normal/Inflamed), Old Wound (Presence/Absence) Wound Depth (1: Scales missing, skin visible; 2:Skin missing, muscle visible; 3: Missing muscle; 4: Organs, bones, cartilage visible) Gill Condition (0: Good condition; 1: Slightly pale gills, pale tips; 2: Pale gills, damage or fungus <25%; 3: Gills damaged >25%, necrotic tissue)	Gillnet Sea Lice Hook Wound Predator Unknown Other

2.4.3 Fish Releases

The four release sites established in 2013 were reduced to two sites in 2014 (Table 2-3; Figure 2-6). Analysis of 2013 telemetry data showed no effect of release site on the survival to or passage of Seton Dam by radio-tagged Gates Creek sockeye salmon (Appendix I). Therefore, only the Fraser River West site was used in 2014 due to its closer proximity to the collection site. The Lower Seton River site was not used as migration in the Seton River was examined with fish released in the Fraser River.

Table 2-3: Release sites for acoustic, radio, and PIT tagged salmon in 2013 and 2014

Release Site	UTM Coordinates	Tags Types Released	Year
Fraser River West	10 U 0576422 5612849	Radio, PIT	2013, 2014
Fraser River East	10 U 0576781 5612685	Radio	2013
Lower Seton River	10 U 0575385 5614966	Acoustic, Radio, PIT	2013
Upper Seton River	10 U 0572423 5613637	Acoustic, PIT	2013, 2014

The type of tags deployed at each release site depended upon the suitability of each tag type for monitoring the upstream migration of fish. In 2014, radio- and PIT-tagged fish were released at the Fraser River West site and acoustic- and PIT-tagged fish were released at the Upper Seton River site. Releases are summarized in Table 2-4. A total of 1,682 salmon were tagged in 2014.

Fish were transported to the Fraser River West site in a 1,000 L aerated transport tank. Maximum loading densities were 12 fish per trip in August and 20 fish per trip in late-September and October. Loading densities did not exceed 50% of the recommended maximum for adult salmon (Shepard and Bérézay 1987). Transport times ranged from 20 to 30 min. Releases at the Upper Seton River release site occurred immediately after tagging without the need for transport. However, a sub-set of Gates Creek sockeye salmon (n=71) were PIT-tagged, transported for 30 min, and released at this site between 25 and 29 August to study the effect of transport on migration success.

Table 2-4: Summary of 2013 and 2014 releases of tagged fish

Population	Tag Type	2013		2014	
		Fraser River West / East	Lower / Upper Seton River	Fraser River West	Upper Seton River
Gates Creek sockeye	Radio	81 / 87	37 / 0	166	-
	Acoustic	-	30 / 30	-	45
	PIT	-	24 / 300	191	565
Pink	Radio	30 / 28	-	-	-
	PIT	-	280	-	-
Portage Creek sockeye	Acoustic	-	-	-	10
	Radio	12 /12	-	191	-
	PIT	-	14	193	241
Coho	Radio	-	-	7	-
	PIT	-	30	-	2
Chinook	PIT	-	1	-	-

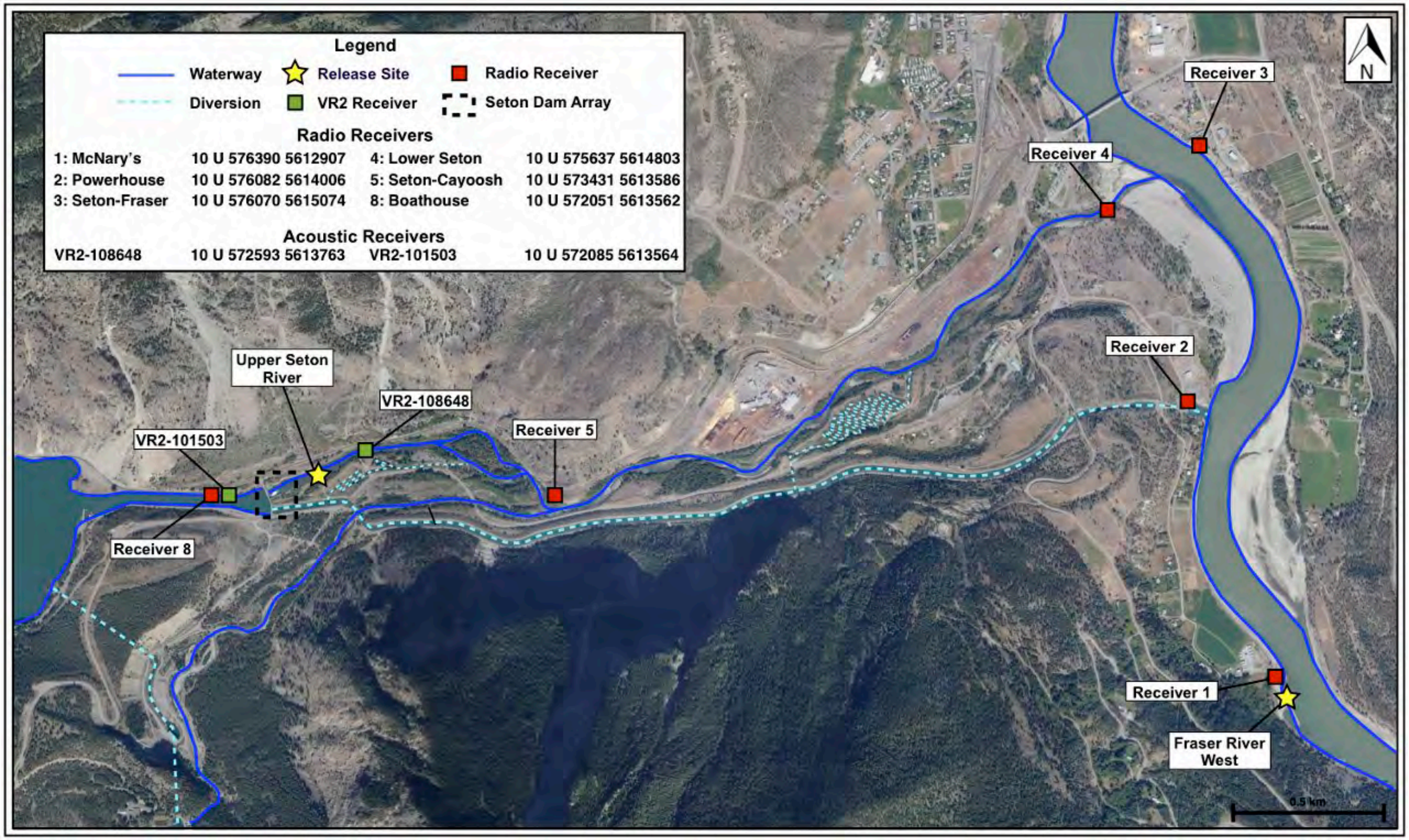

Figure 2-6: **Release sites, acoustic receiver installations, and radio receiver installations in the Fraser River, lower Seton River, Gates Creek, and Portage Creek in 2014**

2.4.4 Telemetry Arrays

Radio receivers were installed in the same locations on the Fraser River, Seton River, and Seton Dam tailrace as in 2013 (Figure 2-6; Figure 2-7). For 2014, additional radio receivers were installed in the lower Seton River, at the Seton Dam fishway entrance, and upstream of Seton Dam. In addition, the radio receiver at Portage Creek was operated throughout the 2014 season. Switching antennas were used in multiple locations to provide directional information on fish migration. Each receiver station consisted of either an Orion (Sigma Eight Inc.) or SRX-400 (Lotek Wireless Inc., Newmarket, ON, Canada) receiver connected to a Yagi 3- or 5-element antenna and powered by deep cycle batteries. Data on the radio receivers were downloaded approximately every two weeks and batteries changed as required.

Acoustic VR2W receivers (Vemco, Bedford, NS, Canada) were installed in the Seton Dam tailrace in the same areas as 2013 (Figure 2-7). Receivers were secured to concrete bases, lowered into the tailrace, and secured to the dam or river bank with rope. A total of 19 acoustic receivers were installed at Seton Dam, with three receivers installed along the north bank, 11 installed along the fishway wall, and five receivers installed in the fishway. In addition, one receiver was installed in the Seton Dam forebay to monitor successful dam passage by acoustic-tagged sockeye salmon (Figure 2-6). A receiver was also installed approximately 0.4 km downstream of Seton Dam to detect fish that fell back downstream. At spawning grounds, receivers were installed at the entrance to Portage Creek and Gates Creek as well as at the entrance to the Gates Creek spawning channel (Figure 2-8).

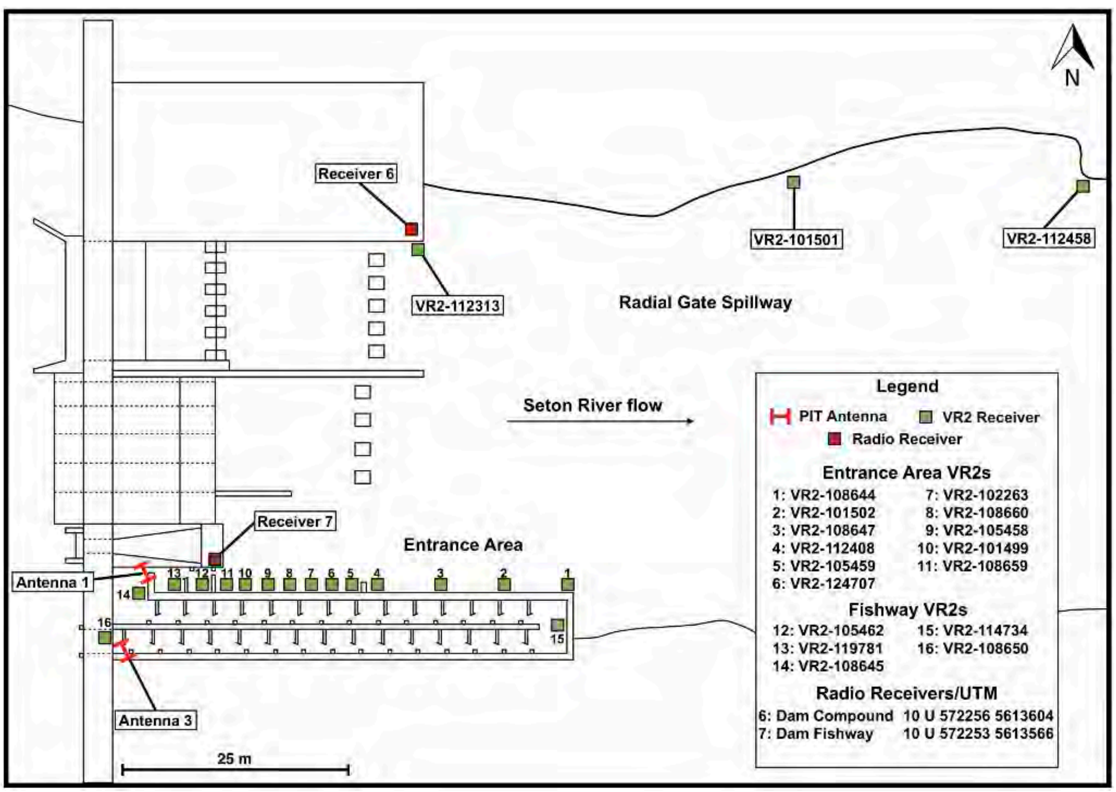

Figure 2-7: Location of acoustic receivers, radio receivers, and PIT antennas in the Seton Dam tailrace and fishway in 2014. The detection range of radio Receiver 6 extended to the right-most edge of the figure

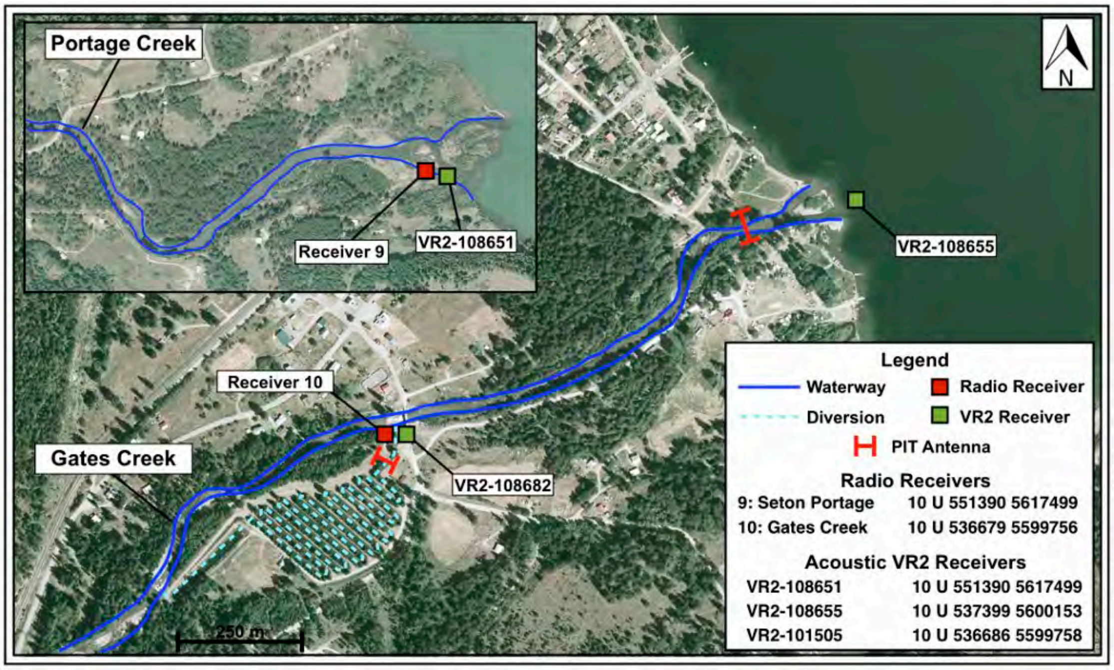

Figure 2-8: Location of acoustic receivers, radio receivers, and PIT antennas in Portage Creek, Gates Creek and the Gates Creek spawning channel in 2014

Migration of PIT-tagged fish was recorded by pass-through PIT antennas located in the entrance and exit basins of the Seton Dam fishway (Figure 2-7), in lower Gates Creek (Figure 2-8), and at the Gates Creek spawning channel (Figure 2-8). PIT antennas at Seton Dam were constructed out of 1.5” polyvinyl chloride (PVC) pipe with 12-gauge stranded electrical wire and positioned on the upstream side of the vertical slot baffles in the fishway entrance and exit basins. Each antenna was connected to a remote tuner box (Oregon RFID, Portland, OR, USA) and a multi-antenna HDX reader (Oregon RFID). Seton Dam antennas were tested daily to ensure optimal read range (0.5 m) and performance. In Gates Creek, a 20 m wide full-span PIT antenna was installed 120 m upstream of Anderson Lake. Stranded electrical wire was fed through a garden hose held on the creek bed with sandbags and a loop returned across the stream to complete the pass-through antenna. A three-antenna PIT array was installed at the Gates Creek spawning diversion with a PVC-framed antenna downstream of the channel entrance and loop antennas at both the spawning channel entrance and the diversion to Gates Creek. A PIT array could not be installed in Portage Creek due to high water flows.

2.4.5 Tag Recoveries

Tags were recovered to obtain the iButtons on radio-tags, assess the spawning success of tagged fish, or estimate the cause of migration failure. Tag recovery efforts focused primarily on Gates Creek sockeye salmon that spawned at the Gates Creek spawning channel and in Gates Creek. Deceased tagged fish were identified by either the external spaghetti tag or, for radio-tagged fish, located using a portable SRX-400 receiver. Where possible, fish sex was reassessed along with the spawning percent (0/50/100%) and fish condition. Mobile radio tracking was performed on the Seton River and Fraser River to locate tags from fish that did not migrate past Seton Dam. Radio transmitters that were repeatedly tracked to the same location but could not be recovered were classified as mortalities.

2.4.6 Data Analysis

All data were subject to a quality assurance-quality control process. Raw field notes and digitally entered data were reviewed to ensure the data were complete and accurate. All radio, acoustic and PIT telemetry data were filtered to remove detection errors and consolidated to confirm continuity.

Potential stray fish during the Gates Creek sockeye migration (average fat probe readings greater than 2.7%) were removed from all the analyses. No Portage Creek sockeye salmon were removed from analyses as the relationship between Gross Somatic Energy (GSE) estimates and stock identification has not been confirmed for this population. Estimates of GSE were carried out using the methods outlined in Year 1.

Migration success of Gates Creek and Portage Creek sockeye salmon was determined using detection data from the acoustic, radio, and PIT arrays. Survival was calculated as proportion of released fish that were subsequently detected at Seton Dam, passed Seton Dam, or reached spawning grounds. Survival was compared using Monte Carlo simulation methods to draw 1,000 samples from a binomial beta distribution, which generated posterior distributions for each survival estimate. Survival estimates were considered different if the 95% credible intervals for each estimate did not overlap.

Acoustic, radio, and PIT telemetry data were used to examine passage success at Seton Dam. As in previous years, multiple acoustic receivers within the Seton Dam tailrace were pooled because of the low detection range of individual receivers. The following passage parameters were calculated according to the definitions outlined in Year 1: entrance delay (h), attraction efficiency (%), passage efficiency (%), and overall success (%). Swimming speeds in body lengths per second ($BL\ s^{-1}$) were calculated according to the methods in Year 1. For swimming speed calculations, optimal swimming speed was 1 $BL \cdot s^{-1}$ and critical swimming speed was 2.10 $BL \cdot s^{-1}$. Seton Dam passage success and survival to spawning grounds was also calculated for PIT-tagged fish released at the Upper Seton River site.

Telemetry data management and analysis was carried out in Excel. Fish passage metrics were compared amongst tagging groups and discharges using the statistical methods stated in text. Statistical analyses were considered significant at $p<0.05$ and were performed using SigmaPlot 11 (San Jose, California, USA) and R Version 3.0.2 (R Core Team 2013). Data are presented as mean ± S.D. unless otherwise noted.

2.5 Water Preference Experiments

Water preference experiments in 2014 continued to examine the behavioural response of Gates Creek sockeye salmon to various dilutions ratios of Seton River to Cayoosh Creek. Portage Creek sockeye salmon were tested for the first time. Experiments were carried out to determine the dilution ratio threshold above which migrating Gates Creek and Portage Creek sockeye salmon display a preference for Seton River water versus Seton River water diluted with Cayoosh Creek.

2.5.1 Fish Collection and Holding

Gates Creek (*n*=164) and Portage Creek sockeye salmon (*n*=108) were collected from 01 to 29 August and 29 September to 09 October, respectively. All Gates Creek sockeye salmon were individually captured via dip net from the exit basin of the Seton Dam fishway while all Portage Creek sockeye salmon were collected from the Seton River fish fence (see Section 2.4). Upon collection, Gates Creek sockeye salmon were screened using the Fatmeter to identify and remove potential strays. Portage Creek sockeye salmon were not screened with the Fatmeter. Groups of up to 12 fish per day were transported in a 1,000 L oxygenated transport tank to a holding tank at the Seton Dam compound. Fish were held in the holding tank in individual flow-through isolation chambers made from PVC pipe measuring 8" in diameter and 28" in length. Fish were held in the isolation chambers for one to eight hours prior to experiments.

2.5.2 Test Apparatus

Water preference experiments were carried out at the Seton Dam compound in a custom-built Y-Maze apparatus (Figure 2-9; Figure 2-10). Water supply for the Y-Maze was supplied by two 11,365 L polyethylene supply tanks (Premier Plastics Inc., Delta, BC, Canada) One supply tank was used exclusively for Seton River water while the other contained the test mixture of Seton River water diluted with Cayoosh Creek water. Seton River water was pumped directly into the supply tanks using a submersible pump installed on the upstream side of Seton Dam. Cayoosh Creek water was trucked from Cayoosh Creek to the supply tanks using a 2,000 L transport tank. Prior to water transport, the transport tank was disinfected with Ovadine (Syndel Laboratories, Qualicum Beach, BC, Canada) to eliminate any residual odours. Each supply tank was filled with fresh water at the start of each day and the test mixture dilution ratio was pre-mixed in the supply tank. Tanks were refilled during the day as required and drained at the end of each experiment day. Water from the tanks was gravity-fed to two 1,135 L mixing tanks before draining into the Y-Maze.

The Y-Maze was a custom-built plywood test chamber (Figure 2-10) sealed with fiberglass and an odorless waterproof gel-coat. During dilution ratio experiments, water from each mixing tank gravity-fed into one of two test arms at a rate of $40\ L \cdot min^{-1}$. For experiments with conspecifics, flow was increased to $80\ L \cdot min^{-1}$. Dye-testing was used to confirm that water flow was unidirectional and there was no exchange of water between the two arms. Water depth in the Y-Maze was 0.6 m. For all trials, the test mixture was alternated daily between arms to control for any bias. During experiments, the test chamber was covered to prevent external visual cues from altering salmon behaviour. Behaviour of salmon was monitored remotely using a video camera installed at the rear of the test chamber.

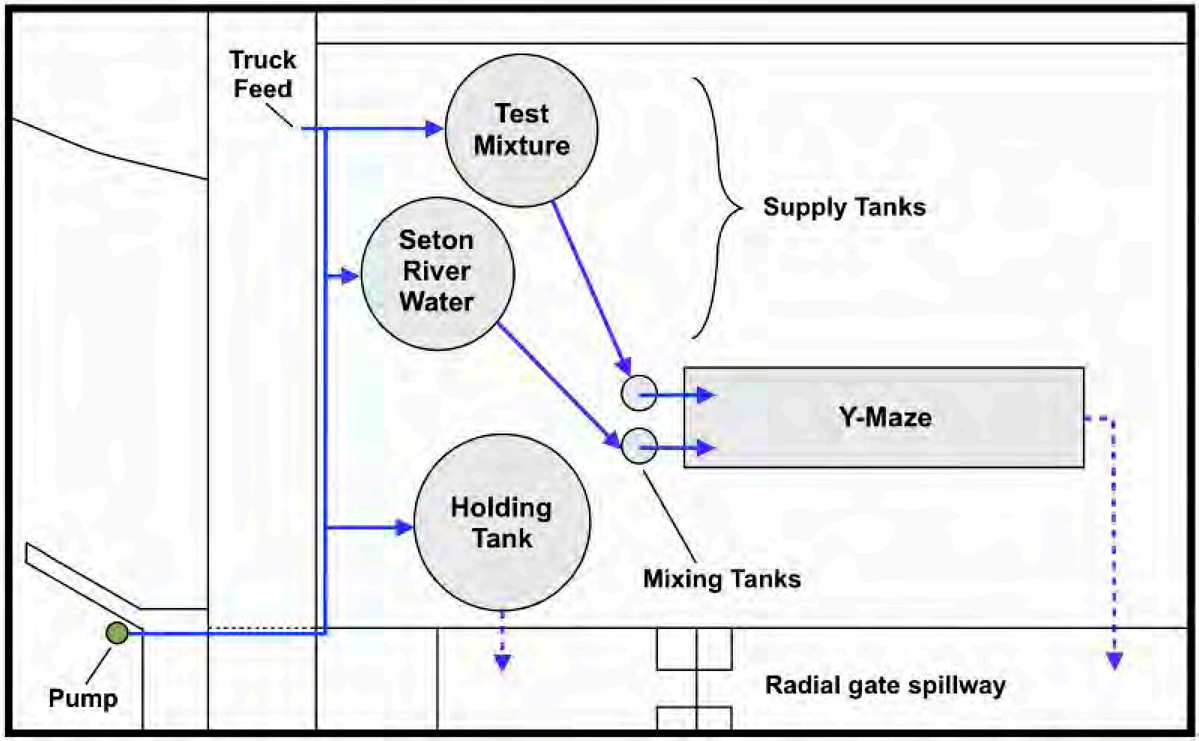

Figure 2-9: **Overview of the Y-Maze test apparatus installed at the Seton Dam compound. Supply tanks were filled with water pumped from the Seton River or truck-transported from Cayoosh Creek and drained into supply tanks (truck feed)**

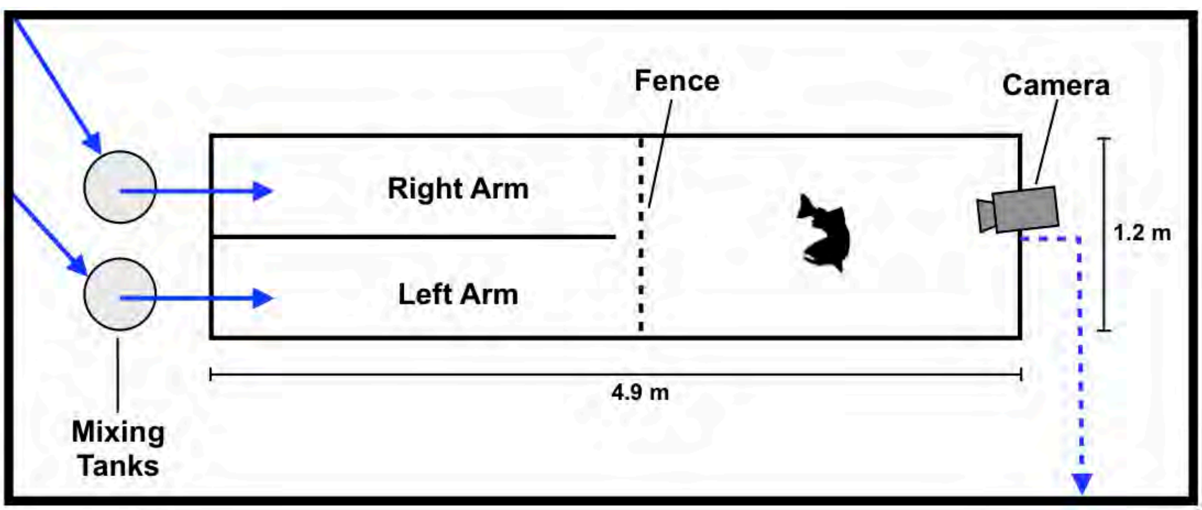

Figure 2-10: **Detailed view of the Y-Maze used for water preference experiments**

2.5.3 Experimental Protocol

Test fish were transferred from the isolation chambers to the Y-Maze and released. Each fish was allowed 10 min to acclimate to the Y-Maze prior to experiments. During the acclimation period, a temporary mesh fence was placed at the entrance to the Y-Maze arms to prevent fish from accessing the arms but still allowed water to flow from each arm into the rear section of the Y-Maze. At the end of the acclimation period, the fence was removed and behaviour of the fish observed for 20 min. All trials were viewed saved using a digital video recorder and real-time measurements of fish behaviour were recorded during the experiments. The behaviour of a fish was only tested once.

In 2014, Gates Creek sockeye salmon water preference experiments were carried out at a dilution ratio of 30% Cayoosh Creek to Seton River water versus pure Seton River water. Together with 2013 trails, Gates Creek sockeye salmon water preference was tested at 0%, 5%, 20%, 30% and 50% dilution ratios. Portage Creek sockeye salmon water preference was tested in 2014 at dilution ratios of 10% and 20% Cayoosh Creek to Seton River water. The need to test Portage Creek sockeye salmon at a dilution ratio of 0% was eliminated by alternating the test mixture between Y-Maze arms.

2.5.4 Fish Sampling

Fish were sampled at the end of the water preference experiment using the same protocol as tagged fish (see Section 2.4.2). All fish were sampled for fork length, sex, blood, and DNA for stock identification. Fat content was only measured for Gates Creek sockeye salmon.

2.5.5 Data Analysis

Fish behaviour during water preference experiments was analyzed to determine the number of times a fish entered each arm of the Y-Maze, the amount of time spent in each arm, and the proportion of time spent in each arm. The time in each arm for all individuals within a treatment group was tested for normality using the Shapiro-Wilk normality test. If normally distributed, a student's t-test was used to compare the time spent in each arm. If not normally distributed, a Wilcox signed rank-test was used instead. Individuals that did not enter either arm of the Y-Maze were removed from analysis as were individuals that spent less than 5 min in the two arms combined. Stock identification DNA analysis identified a small number of stray sockeye that were removed from analysis in 2013 (n=10) and 2014 (n=10).

3.0 RESULTS

3.1 Physical Parameters

3.1.1 Discharge and Dilution Ratio

Total discharge in the lower Seton River ranged from 33.4 to 41.1 $m^3 \cdot s^{-1}$ during the Gates Creek sockeye salmon migration period (20 July to 31 August) (Figure 3-1). For all but 3 days during this period, Cayoosh Creek discharge was <6 $m^3 \cdot s^{-1}$ and the dilution ratio <20% (Figure 3-2). Elevated Cayoosh Creek flows increased the dilution ratio above target values from 24 to 26 July (21-28%). From 28 September to 15 November, the <10% target dilution ratio for Portage Creek sockeye salmon was exceeded for 20 days. A sustained dilution ratio increase occurred from 21 to 24 October (12-20%) with a second increase from 01 to 15 November (10-45%). However, for 6 days during the second period the target dilution ratio was exceeded by <1%.

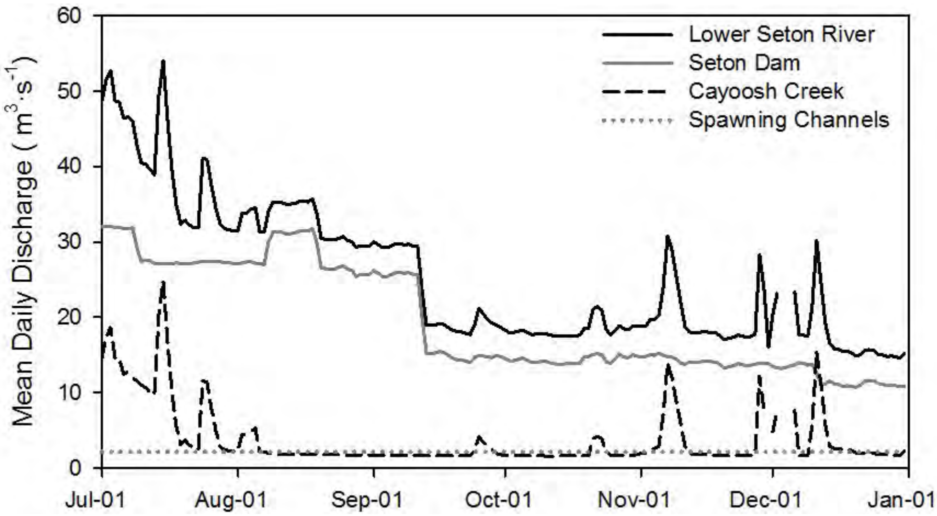

Figure 3-1: Discharge in 2014 for waterways used to calculate dilution ratios in the lower Seton River (BC Hydro data)

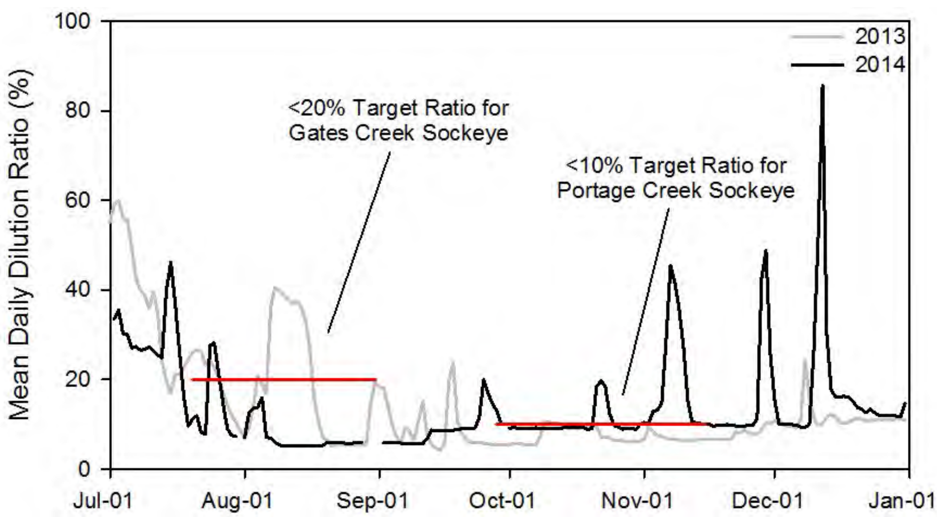

Figure 3-2: Daily dilution ratio of the Seton River in 2013 and 2014 (BC Hydro data). Target dilution ratios for sockeye salmon are shown in red (BC Hydro 2011)

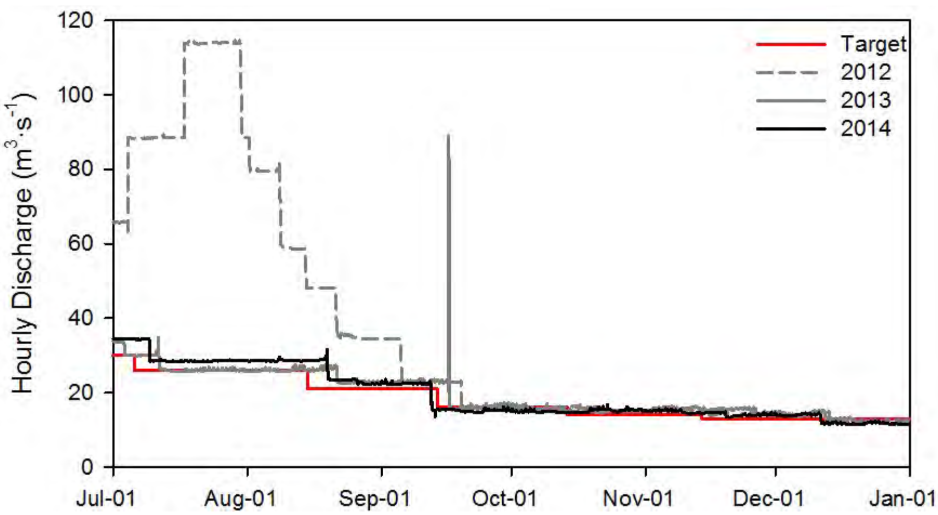

Figure 3-3: Total Seton Dam discharge in 2012, 2013 and 2014 (BC Hydro data)

Seton Dam discharge remained near the Water Use Plan target flow schedule throughout the study period (Figure 3-3). Discharge in 2014 was similar to 2013, with both years having considerably lower discharge prior to mid-September than in 2012.

In 2014, three Seton Dam flow scenarios occurred during the Gates Creek sockeye salmon migration period (Table 3-1). The first discharge scenario was established on 09 July with discharge released from SSV1 and the FWRG (flow scenario 1). The alternative flow scenario (flow scenario 2) began on 08 August with discharge from the FWRG reduced by 5.7 $m^3 \cdot s^{-1}$ and discharge from the siphons switched from SSV1 to SSV4. A scheduled ramp-down on 19 August was used to end the alternative flow scenario with FWRG flows increased by 0.6 $m^3 \cdot s^{-1}$ and siphon discharge returned to SSV1 (flow scenario 3). FWRG discharge was again reduced by 1.1 $m^3 \cdot s^{-1}$ on 26 August, however, these flows were considered part of flow scenario 3 since the overall change in discharge was minor.

One discharge scenario occurred during the Portage Creek sockeye salmon migration period (flow scenario 4). Flows were established 12 September, with the FWRG increased by 12.4 $m^3 \cdot s^{-1}$ and SSV1 closed. No further adjustments to discharge at Seton Dam were made until 18 November.

Table 3-1: Discharge from each conveyance structure during the 2014 alternative flow scenario and total Seton Dam discharge as estimated by BC Hydro (BCH) and Water Survey Canada (WSC)

Flow Scenario	Date	Discharge ($m^3 s^{-1}$)					
		Total (WSC)	Total (BCH)	Fishway	FWRG	SSV1	SSV4
1	09 July – 08 Aug	27.2	25.0*	1.1	7.6	16.3*	-
2	08 Aug – 19 Aug	31.3	28.6	1.1	1.9	-	25.6
3	19 Aug – 26 Aug	27.0	23.4	1.1	2.5	19.8	-
	26 Aug – 12 Sept	25.8	22.4	1.1	1.4	19.9	-
4	12 Sept – 18 Nov	15.0	15.0	1.2	13.8	-	-

*BC Hydro's estimated total Seton Dam and SSV1 discharge from 09 July to 08 August was reduced by 3.5 $m^3 s^{-1}$ to adjust for a known SSV1 blockage.

BC Hydro Power Records estimated that total Seton Dam discharge during flow scenario 2 was unchanged from the previous discharge. However, the WSC gauging station downstream of Seton Dam registered a 4.1 $m^3 \cdot s^{-1}$ increase in discharge. This discrepancy was likely a result of over-estimated pre-adjustment SSV1 flows stemming from a 20 June 2014 incident where total Seton Dam flows unexpectedly decreased by 3.5 $m^3 \cdot s^{-1}$, probably due to a partial blockage of SSV1 (D. Turner, personal communication). As Seton Dam flow rating curves had not been adjusted at the time of the alternative flow scenario, the change from SSV1 to SSV4 increased total Seton Dam discharge by an amount approximately equal to the prior decrease. Following the return of discharge to SSV1 on 19 August, the decrease in Seton River discharge, as estimated by BC Hydro, was approximately equal to the decrease at the WSC gauging station, suggesting the blockage in SSV1 was removed.

3.1.2 Water Temperature

The thermal experience of Gates Creek and Portage Creek sockeye salmon prior to entering the Seton-Anderson watershed was estimated using the temperature of the Fraser River at Qualark Creek (Figure 3-4). Run timing past Qualark Creek was estimated using the methods presented in Year 1, however, field observations in 2014 suggested a late run timing by both Gates Creek and Portage Creek sockeye salmon. Regardless, mean daily temperature of the Fraser River ranged from 16.7-20.7ºC during the Gates Creek sockeye salmon migration and 14.5-20.7°C during the Portage Creek sockeye salmon migration period. Maximum Fraser River temperatures in 2014 were 0.9ºC cooler than 2013 but exceeded 20ºC during the Gates Creek sockeye migration in mid-August. Given the 17.5ºC optimal temperature for this population (Lee et al. 2003), Gates Creek sockeye salmon may have experienced stressful thermal conditions within the Fraser River during their migration, although, conditions were likely less stressful than 2013. Elevated Fraser River temperatures occurred during the Portage Creek sockeye salmon migration in mid-August. However, the late run timing observed for Portage Creek sockeye salmon in 2014 suggests fish would not have encountered these warmer temperatures.

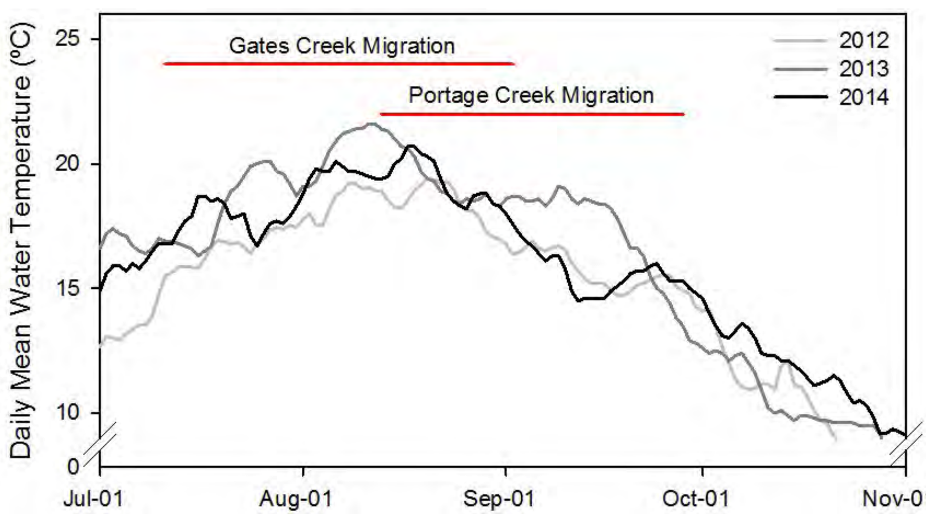

Figure 3-4: Temperature of the Fraser River at Qualark Creek in 2012-2014. The timing of Gates Creek and Portage Creek sockeye migration past Qualark Creek is shown in red (Hague and Patterson 2009)

Water temperatures within the Seton River study area in August 2014 were generally near the optimal temperature for Gates Creek sockeye salmon, although elevated temperatures occasionally occurred in the Fraser River and Seton Dam fishway (Figure 3-5). Mean daily temperatures in the Fraser River were >19ºC from 02 to 08 August and from 14 to 20 August, and were >20ºC from 16 to 20 August. In the Seton Dam fishway, the mean daily water temperature was >19ºC from 06 to 08 August, and on 27 August. The mean daily temperature in the fishway did not exceed 20ºC in 2014, however, hourly water temperatures exceeded 20ºC between 15 to 18 July, 05 to 07 August, and on 27 August. The maximum temperature in the Seton Dam fishway was 20.8ºC on 15 July. Overall, water temperatures during the 2014 Gates Creek sockeye salmon migration were cooler than in 2013. Slightly warmer temperatures were observed in 2014 than 2013 during the Portage Creek sockeye salmon migration, however, temperatures would not be expected to impair migration.

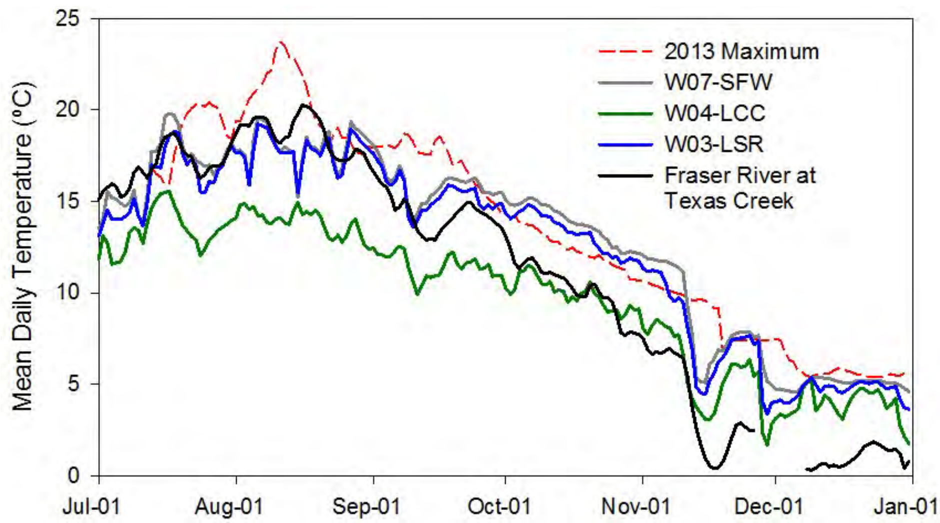

Figure 3-5: Mean daily temperature of the Fraser River, lower Seton River (LSR), Cayoosh Creek (LCC), and Seton Dam fishway (SFW) during the 2014 study period. The maximum study area temperature in 2013 (all sites) is shown for comparison

Cooler water temperatures in the Seton Generating Station tailrace and in Cayoosh Creek provided thermal refuge opportunities for Gates Creek sockeye salmon. The Seton Generating Station tailrace was up to 3.5ºC cooler than the Fraser River between 03 and 05 August, up to 5.3ºC cooler between 14 and 17 August, and up to 3.6ºC cooler on 20 August. For the remainder of the Gates Creek sockeye migration period, Seton Generating Station tailrace temperatures were typically within 1ºC of the Fraser River. Cayoosh Creek was colder than the Seton River throughout the study period. Use of thermal refuge by Gates Creek sockeye salmon will be examined using temperature data from iButtons.

Seton Generating Station shutdowns continued to influence temperatures in the Seton Dam fishway in 2014, but not to the extent observed in 2013 (Figure 3-6). In 2013, shutdowns of the Seton Generating Station were associated with rapid water temperature increases in the Seton Dam fishway. For example, during an overnight shutdown on 10 August 2013, water temperature in the fishway increased from 19.0ºC to 22.7ºC in 4 h. In August 2014, only three shut-downs occurred. Shut-downs on 07 and 19 August facilitated changes to conveyance structure use at Seton Dam and were not associated with increases in fishway temperature. However, a shut-down on 26 August was associated with increased fishway water temperatures, where 24 h after shut-down, fishway water temperature had increased by 1.7ºC. Incidentally, up to 30 sockeye salmon were observed holding in Cayoosh Creek the morning of 27 August, where none had previously been observed in 2014.

Rapid decreases in water temperature that do not appear to be associated with changes to Seton Generating Station flows occurred on 03 August, 14 August, and 20 August (Figure 3-6). For example, on 20 August water temperature decreased by 4.1ºC in 13 h. The cause of these temperature changes has yet to be determined but the Walden North diversion from Cayoosh Creek to Seton Lake may play a role.

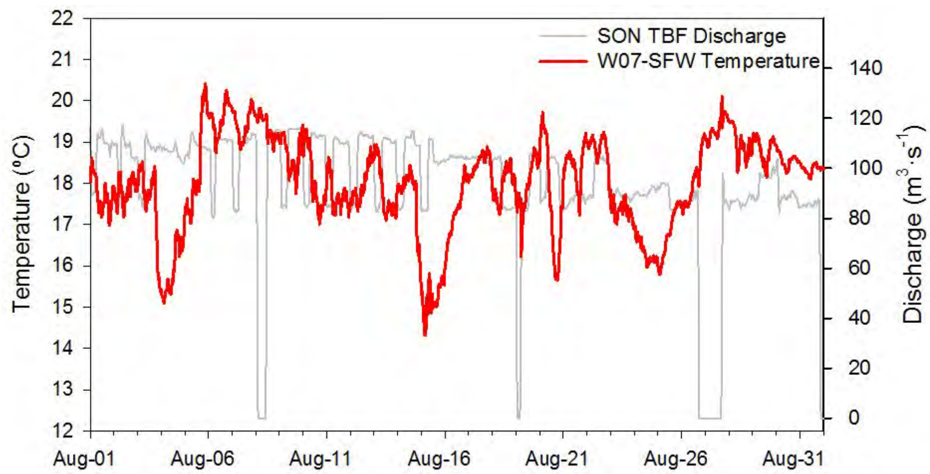

Figure 3-6: Seton Dam fishway (W07-SFW) temperature and Seton Generating Station turbine release flow (SON TBF) discharge from 01 to 31 August 2014

3.1.3 Water Chemistry

Specific conductivity measurements in 2014 were consistent with those measured in 2012 and 2013 (Figure 3-7). Specific conductivity in Cayoosh Creek gradually increased throughout the study period, whereas conductivity gradually decreased in the upper Seton River. As a result, the greatest differences in conductivity occurred during the Portage Creek sockeye migration period.

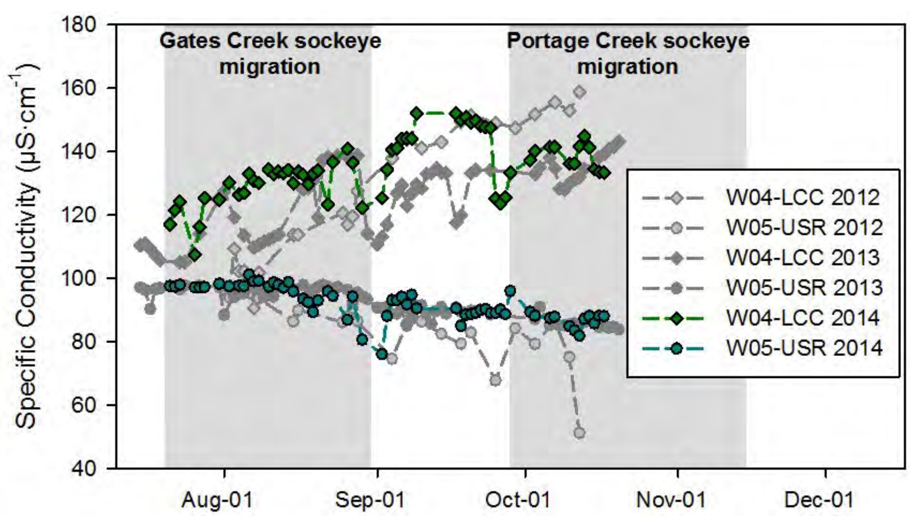

Figure 3-7: Specific conductivity readings from Cayoosh Creek (W04-LCC) and the upper Seton River (W05-USR) during the target dilution periods for Gates Creek and Portage Creek sockeye salmon in 2012, 2013 and 2014

3.2 Seton Dam Tailrace Flow Fields

ADCP units were used to measure flow velocities in the Seton Dam tailrace. Flow velocity measurements were compiled to describe tailrace flow fields under three scenarios: two routine BC Hydro flow scenarios (flow scenarios 1 and 3) where water was released from SSV1 and the FWRG; and an alternative flow scenario where water was released primarily through SSV4 (flow scenario 2). The alternative flow scenario was intended to reduce flow velocities surrounding the fishway entrance. Where the ADCP measurement range was attenuated by highly turbulent water, flow velocity measurements were supplemented by surface particle tracking. Detailed flow velocity results can be found in Appendix II.

3.2.1 Routine BC Hydro Operations

Flow velocities and flow fields in the tailrace under the two routine BC Hydro operations (flow scenario 1 and 3) were judged to be similar. Therefore, only flow velocities and flow fields during flow scenario 3 are presented for comparison with the alternative flow scenario.

Discharge from SSV1 and the FWRG created highly turbulent water in the fishway entrance area (Figure 3-8; Figure 3-9). Flow velocities immediately downstream of the fishway entrance were <2 $m \cdot s^{-1}$ as measured with ADCP transects. Flow velocity measurements at different depths showed both upstream and downstream flows near the fishway entrance, likely caused by flows from the FWRG and SSV1 interacting with the submerged baffle wall. Further downstream, highly turbulent and aerated water prevented ADCP measurements of flow velocities. However, particle tracking in the primary flows exiting SSV1 estimated surface flow velocities up to 4.2 $m \cdot s^{-1}$ downstream of SSV1. At the downstream end of the fishway, where ADCP measurements were possible, peak flow velocities ranged from 4.5-4.8 $m \cdot s^{-1}$ at a depth of 0.5 m. Fish migrating upstream would likely have to overcome these flows velocities to access the fishway entrance.

Tailrace flow fields produced by the SSV1 are show in Figure 3-9. Three vortices existed in the tailrace under flow scenario 3. Two large vortices were located on the northern bank of the Seton River and a third, smaller vortex was located on the southern bank downstream of the fishway. Flow velocities up to approximately 1 $m \cdot s^{-1}$ were measured in each vortex. The location, size, and flow velocities within the vortices were similar to those observed in 2013 during a similar flow scenario. Vortices on the northern bank were likely generated by the interaction of downstream flows with shallow gravel bars in the tailrace (see Appendix II for bathymetry).

3.2.2 Alternative Flow Scenario

Release of water from SSV4, rather than SSV1 and the FWRG, relocated the primary discharge from Seton Dam to approximately 10 m away from the fishway entrance area and into the centre of the tailrace (Figure 3-8; Figure 3-9). As a result, fish migrating upstream to the fishway entrance would not be required to overcome turbulent flows from SSV4, although this would not preclude fish from experiencing these flows. Peak flow velocities in the SSV4 discharge plume were up to 6.6 $m \cdot s^{-1}$ and extended 24 m downstream, just beyond the end of the radial gate wall. Flow velocities up to 4.3 $m \cdot s^{-1}$ extended 75 m downstream. However, downstream of the SSV4 discharge plume, flow velocities decreased to <2.5 $m \cdot s^{-1}$ and then to <1 $m \cdot s^{-1}$ as the tailrace widened into the Seton River.

Figure 3-8: Flow fields in the Seton Dam tailrace during routine BC Hydro operations of flow scenario 3 (top) and an alternative flow scenario (bottom)

Discharge from SSV4 into the centre of the Seton Dam tailrace produced two vortices on the northern bank of the Seton River and two vortices on the southern bank, one within the fishway entrance area (Figure 3-9). Vortices on the northern bank were similar in size and location to those observed under flow scenario 3, although the proximity of the SSV4 discharge plume to the northern bank reduced the size of both vortices while increasing flow velocities. On the southern bank, the vortex that was observed downstream of the fishway under flow scenario 3 increased in size under the alternative flow scenario and a fourth vortex, that was not observed under flow scenario 3, was created in the fishway entrance area adjacent to the fishway wall.

At the fishway entrance, downstream flows from the fishway and FWRG, and upstream flows from the vortex in the fishway entrance area, created a flow interface 8-10 m downstream of the fishway entrance. The velocity of downstream flows from the fishway and FWRG discharge were <0.5 m·s^{-1} whereas upstream flows from the vortex were 0.5-1.0 m·s^{-1}. Convergence of these two flows was drawn northward, around the SSV1 wall toward SSV4. As a result, attraction flows to the fishway entrance may have been limited under the alternative flow scenario, although direct comparison with flow scenario 3 is not possible since flows could not be measured near the fishway entrance. Regardless, flow velocities throughout the fishway entrance area were reduced under the alternative flow scenario and the prevailing direction of these flows reversed, from downstream to upstream.

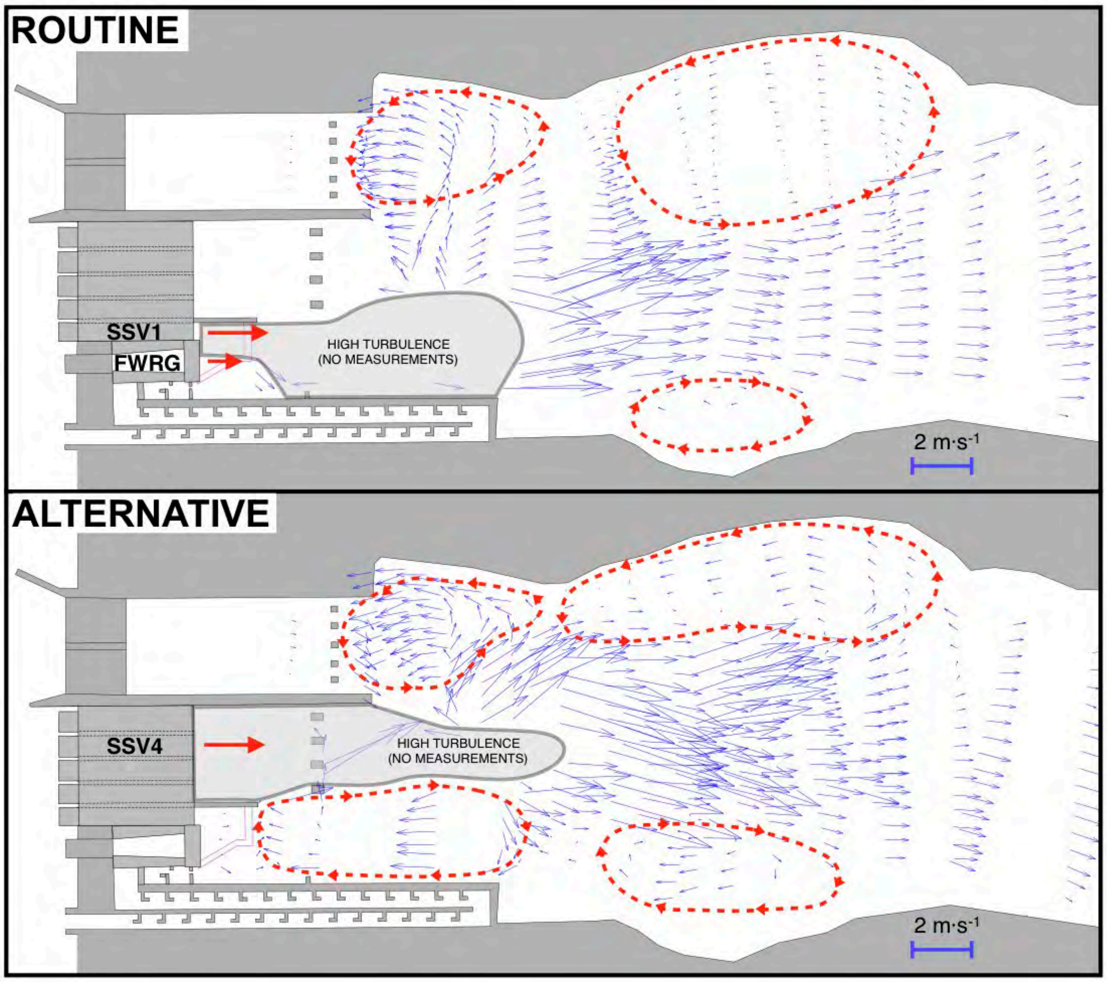

Figure 3-9: ADCP measurement transects and calculated flow velocities (blue arrows) and estimated flow fields (red arrows) in the Seton Dam tailrace under routine BC Hydro operations (top) and an alternative flow scenario (bottom)

3.3 Fish Passage Enumeration

Abundance and run timing estimates were generated for Gates Creek and Portage Creek sockeye salmon using an electronic fish counter at Seton Dam. Coho salmon abundance estimates could not be generated to 2014 due to overlap with Portage Creek sockeye salmon and low water clarity, which limited video validation efforts. Chinook salmon abundance could not be estimated in 2014.

3.3.1 Video and Signal Validation

Review of 24 h of video data between 13 and 24 August recorded 1,106 fish passing upstream through the counter sensor tubes of which 1,078 were Gates Creek sockeye salmon. Video validation confirmed the upstream detection accuracy for seven of the eight sensor tubes was 90-100%. Daily accuracies for the remaining sensor tube (lower sensor 3) were highly variable, ranging from 13-71%. Following review of 1,914 signal trace plots between 07 August and 10 September (minimum 50 traces per day), daily accuracies of lower sensor 3 were to 13-96%.

3.3.2 Gates Creek Sockeye Salmon

A mean estimate of 27,192 Gates Creek sockeye salmon passed through the Seton Dam between 25 July and 10 September (Figure 3-10). An exact date for the end of Gates Creek sockeye salmon migration could not be determined with the fish counter because the Gates Creek and Portage Creek populations cannot be visually discriminated. However, the daily migration numbers through Seton Dam decreased between 03 and 10 September, suggesting the Gates Creek sockeye salmon migration ended near this date.

The total abundance estimate for Gates Creek sockeye salmon is relatively insensitive to the selection of an end date for the Gates Creek run because of the low numbers of fish migrating in mid-September when the migration of Gates Creek and Portage Creek sockeye salmon overlaps. Lower and upper credible intervals around the mean estimate are 25,771 and 28,611, respectively. However, this uncertainty is an underestimate because the uncertainty in the counts from lower sensor tube 3 was not incorporated due to the different methods used in calculating the abundance.

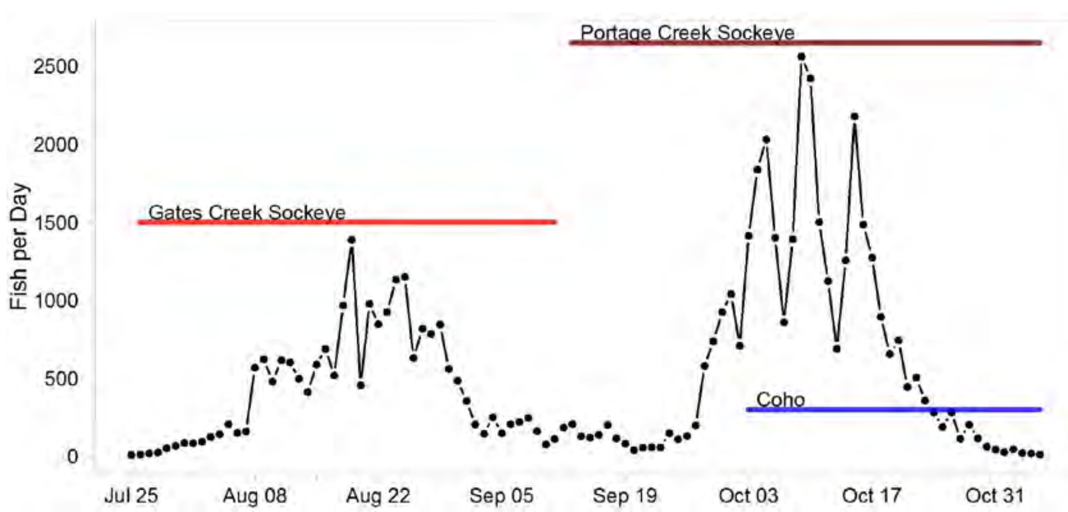

Figure 3-10: Daily abundance of fish migrating through the Seton Dam fishway between 25 July and 04 November 2014. Horizontal lines indicate migration timing

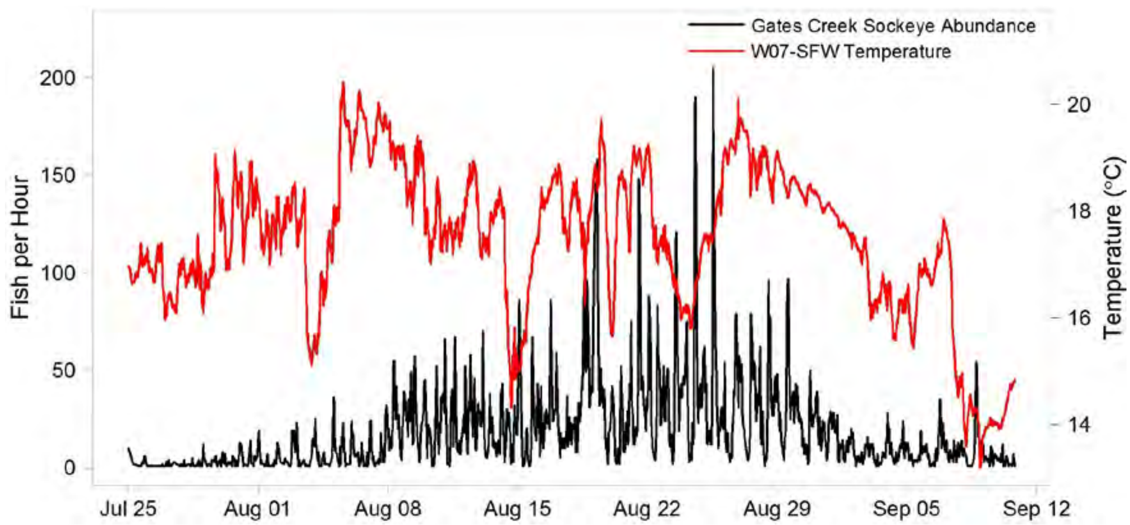

Figure 3-11: Hourly water temperature in the Seton Dam fishway and hourly abundance (up counts) of Gates Creek sockeye exiting the fishway

Gates Creek sockeye salmon migration peaked between 17 and 24 August (Figure 3-11). Daily peaks in migration were due to Gates Creek sockeye salmon primarily migrating during the early morning (05:00-07:00 h) and afternoon (16:00-18:00 h), with lower migration during the day (07:00-16:00 h) and night (20:00-05:00 h). Although temperature fluctuations occurred in the Seton Dam fishway in 2014, there was no clear effect on migration rates of Gates Creek sockeye salmon.

3.3.3 Portage Creek Sockeye Salmon

A mean estimate of 38,812 Portage Creek sockeye salmon passed through the Seton Dam between 11 September and 04 November (Figure 3-10). The start date for Portage Creek sockeye salmon was set as 11 September to correspond with the 10 September end date for Gates Creek sockeye salmon. Migration of Portage Creek sockeye salmon in 2014 continued for almost a month later than in 2013, likely due to higher abundance.

The peak in Portage Creek sockeye salmon migration was observed between 03 and 17 October, although there were large fluctuations in daily migration rates during this period (range of 700-2,500 fish per day). Daily peaks in migration of Portage Creek sockeye salmon occurred during the early morning (07:00-09:00) and late evening (15:00-18:00 h), with lower migration during the day (09:00-15:00 h) and night (18:00-6:00 h).

Although some overlap between Gates Creek and Portage Creek sockeye salmon may occur, the abundance estimate for Portage Creek sockeye salmon was relatively insensitive to the migration start date because of the low number of fish migrating in mid-September. Future stock identification DNA analysis will assist in determining a more precise start date for Portage Creek sockeye salmon.

The abundance of Portage Creek sockeye salmon in 2014 was probably over-estimated because co-migrating coho salmon could not be identified. Lower and upper credible intervals for the mean estimate are 32,392 and 45,231, respectively. In addition, the uncertainty is an underestimate because the uncertainty in the counts from lower sensor tube 3 was not incorporated due to the different methods used in calculating the abundance.

3.4 Fish Sampling

3.4.1 Gates Creek Sockeye Salmon

A total of 1,043 sockeye salmon were collected for tagging during the Gates Creek sockeye salmon migration period in 2014. Stock identification DNA analysis was not performed on fish tagged in 2014 because GSE screening was applied at the time of fish collection to identify stray sockeye salmon. Previously, GSE screening reduced the proportion of stray sockeye that were tagged from 37% in 2012 to 5% in 2013. In 2014, 89 sockeye salmon collected during the Gates Creek migration period were identified as potential strays (GSE density estimates >7.2 $MJ\cdot Kg^{-1}$). These fish received either a PIT (*n*=86) or radio tag (*n*=3), but were not included in migration analyses. It is possible that stray sockeye salmon with GSE density estimates <7.2 $MJ\cdot Kg^{-1}$ were tagged in 2014. However, sockeye salmon that were identified as potential strays comprised 8.5% of all fish collected and the GSE density range for all fish (3.5-9.0 $MJ\cdot Kg^{-1}$) was similar to that of DNA-identified Gates Creek sockeye salmon in 2013 (1.5-8.3 $MJ\cdot Kg^{-1}$). Therefore, following GSE screening and the identification of potential stray sockeye salmon, it is unlikely that a significant number of stray sockeye salmon are part of the 2014 analyses.

Females comprised 62% of the Gates Creek sockeye salmon tagged in 2014 (Table 3-2). This was a higher proportion of females than observed in 2013, when males and females were present in approximately equal proportions.

Table 3-2: Mean fork length and estimated gross somatic energy (GSE) density of Gates Creek sockeye salmon sampled in 2013 and 2014

Year / Sex		Number of Fish	Fork Length (cm)	GSE ($MJ\cdot kg^{-1}$)
2013	All*	437	58.1 ± 3.1	6.0 ± 1.4
	Male	161	59.4 ± 3.1	5.8 ± 1.4
	Female	154	56.8 ± 2.4	6.0 ± 1.5
2014	All*	944	59.7 ± 4.0	5.8 ± 0.6
	Male	381	61.0 ± 4.4	5.7 ± 0.6
	Female	582	58.7 ± 3.5	5.9 ± 0.6

All value are presented as mean ± S.D. *A sex estimate was not available for all fish in 2013 and 2014.

3.4.2 Other Salmon Species

Sampling results for Portage Creek sockeye salmon and coho salmon are presented in Table 3-3. As a relationship between GSE density and stock identification has yet to be established for Portage Creek sockeye salmon, no GSE screening occurred in 2014 and stock identification DNA analysis was not performed. Generally, there is a low likelihood of strays during the Portage Creek sockeye salmon migration period due to the late run timing of this population amongst Fraser River sockeye salmon. As a result, all fish tagged during the Portage Creek sockeye salmon migration period were included in sampling results and migration analyses.

Males made up 62% of the Portage Creek sockeye salmon collected in 2014. A small number of coho salmon were collected in 2014.

Table 3-3: Mean fork length and estimated gross somatic energy (GSE) of Portage Creek sockeye and coho salmon sampled in 2013 and 2014

Year / Sex		Number of Fish	Fork Length (cm)	GSE ($MJ·kg^{-1}$)
Portage Creek				
2013	All	24	56.9 ± 1.9	4.9 ± 1.8
	Male	9	57.8 ± 2.0	3.2 ± 2.0
	Female	15	56.3 ± 1.6	5.9 ± 0.7
2014	All	661	60.4 ± 3.0	5.6 ± 0.5
	Male	410	61.9 ± 2.4*	5.5 ± 0.4*
	Female	249	58.1 ± 2.2	5.7 ± 0.5
Coho salmon				
2013	All	30	60.8 ± 5.2	7.4 ± 1.5
	Male	24	61.1 ± 5.6	7.8 ± 0.7
	Female	6	59.3 ± 2.9	6.2 ± 2.9
2014	All	9	57.0 ± 4.8	7.4 ± 0.6
	Male	2	56.3 ± 1.1	7.6 ± 0.4
	Female	7	57.2 ± 5.4	7.4 ± 0.7

All value are presented as mean ± S.D.

3.4.3 Injury Monitoring

Gates Creek sockeye salmon had the highest prevalence of injuries amongst salmon species sampled in the Seton River in 2014 (Table 3-4). Of all Gates Creek sockeye sampled in 2014, 63% displayed some degree of injury. In comparison, 24% of Gates Creek sockeye were injured in 2013.

Increased injury prevalence in 2014 can likely be attributed to fisheries openings as no official fisheries openings occurred in the Fraser River in 2013. This is reinforced by the fact that 40% of injured fish that had identifiable gillnet or hook wound injuries (Table 3-5; Figure 3-12). Similarly, Portage Creek sockeye salmon had a higher prevalence of injuries in 2014 (27%) than 2013 (7%) although in most cases the cause of these injuries could not be identified.

Table 3-4: Prevalence of injuries and severity amongst salmon tagged in 2014

Species / Population	Injury Severity			
	Uninjured	Minor	Moderate	Severe
Gates Creek sockeye (*n*=944)	37% (*n*=349)	41% (*n*=388)	12% (*n*=114)	10% (*n*=93)
Portage Creek sockeye (*n*=667)	73% (*n*=489)	21% (*n*=137)	3% (*n*=21)	3% (*n*=20)
Coho (*n*=9)	100% (*n*=9)	-	-	-

Table 3-5: The proportion of injuries originating from different sources on Gates Creek and Portage Creek sockeye salmon in 2014

Species / Population	Injury Origin					
	Gillnet	Hook wound	Predator	Sea lice	Other	Unknown
Gates Creek sockeye (*n*=690)	30% (*n*=204)	10% (*n*=72)	4% (*n*=27)	22% (*n*=154)	3% (*n*=22)	31% (*n*=211)
Portage Creek sockeye (*n*=187)	8% (*n*=15)	10% (*n*=19)	4% (*n*=8)	6% (*n*=11)	9% (*n*=17)	63% (*n*=117)

Figure 3-12: Injured Gates Creek sockeye salmon. Top: Severe gillnet injury with dorso-ventral scarring and ventral abrasion indicating entanglement. Bottom: Recent head injury with lack of fungal growth

A limited number of head injuries on Gates Creek sockeye salmon were identified in 2014 (*n*=12). Post-season review of tagging photographs identified five individuals with injuries that may have originated from attempted migration at the Seton Generating Station. For example, a Gates Creek sockeye salmon collected on 10 August 2014 (Figure 3-12) had head injuries that were judged to be the result of abrasive contact and were also considered to have occurred recently. However, given the overall low number of head injuries, there is little evidence to suggest that operation of the Seton Generating Station caused injury to salmon in 2014.

3.5 Migration in the Fraser River and Seton River

3.5.1 Migration Conditions

Fraser River temperatures ranged from 14.3-20.5ºC and 10.3-16.7ºC during Gates Creek and Portage Creek sockeye salmon releases, respectively. Temperatures in the Seton Generating Station tailrace were generally within 1ºC of the Fraser River, although cooler temperatures in the tailrace did occur (see Section 3.1.2). Lower Seton River conditions during releases are summarized in Figure 3-13.

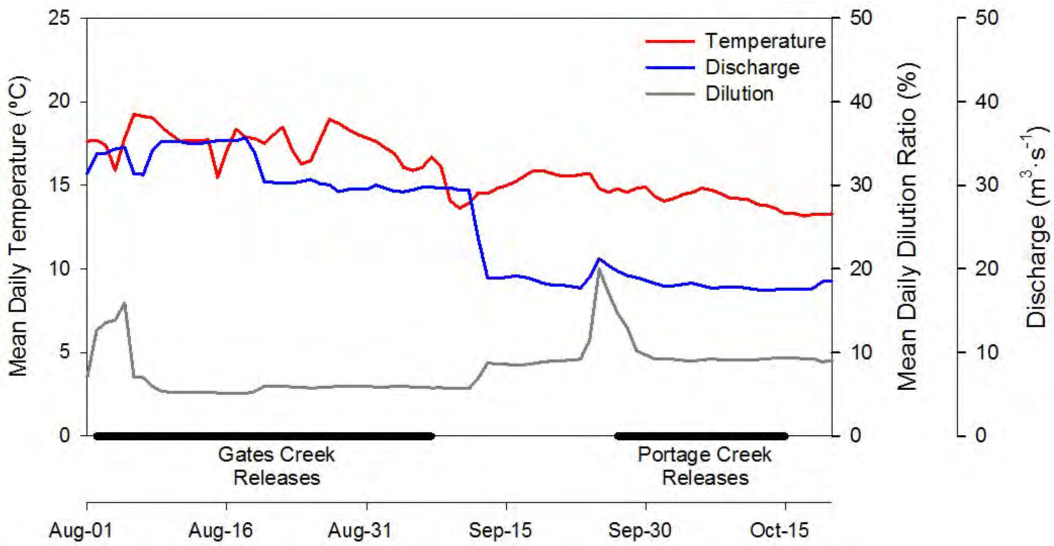

Figure 3-13: Lower Seton River discharge, dilution, and temperature conditions during releases of radio-tagged Gates Creek and Portage Creek sockeye salmon in 2014

During Gates Creek sockeye salmon releases, minor changes in discharge and dilution occurred between 08 and 19 August (see Section 3.1). All radio-tagged Gates Creek sockeye salmon were released at a dilution ratio < 20% in 2014 (Table 3-6). A total of 178 PIT-tagged Gates Creek sockeye were also released downstream with the dilution ratio at <10% during all releases. Cayoosh Creek flows temporarily increased Seton River discharge and the dilution ratio in late September during the Portage Creek sockeye migration. Both radio and PIT-tagged Portage Creek sockeye salmon were released during this increased dilution ratio, although, dilution was <1% above the target ratio for a single release of radio-tagged fish (*n*=20). A total of 194 PIT-tagged Portage Creek sockeye salmon were released in the Fraser River in 2014 with eight fish released at a dilution ratio >10%.

Table 3-6: Radio-tag fish releases in Fraser River in 2013-2014 by dilution ratio at release

Population	Year	Dilution Ratio				
		<10%	10-20%	20-30%	30-40%	>40%
Gates Creek sockeye salmon	2013	72	32	12	41	12
	2014	159	4	-	-	-
Pink salmon	2013	38	20	-	-	-
Portage Creek sockeye salmon	2013	19	5	-	-	-
	2014	137	52	-	-	-
Coho salmon	2014	7	-	-	-	-

3.5.2 Gates Creek Sockeye Salmon

Migration of radio- and PIT-tagged Gates Creek sockeye salmon was compared using migration time and successful arrival at the Seton Dam fishway from release at the Fraser River West site. Migration time to the fishway entrance was used because PIT-tagged fish could not be detected in the Seton Dam tailrace.

Migration success of Gates Creek sockeye salmon to the Seton Dam fishway was 89% (145/163) for radio-tagged fish and 88% (157/178) for PIT-tagged fish. The proportion of fish reaching Seton Dam was similar between sexes for both radio-tagged (males 88%: 63/72; females 90%: 82/91) and PIT-tagged fish (males 89%: 66/74; females 90%: 91/104). Failure of radio-tagged Gates Creek sockeye salmon to reach Seton Dam was, in part, due to fisheries captures (*n*=2). In addition, radio tags were recovered on the Bridge River (*n*=3) and lower Seton River (*n*=1). Future analyses will assess the relationship of downstream environmental factors (dilution, temperature, discharge) and migration success.

Gates Creek sockeye salmon that were radio-tagged took significantly longer than PIT-tagged fish to reach the Seton Dam fishway. Migration time (mean ± S.E.) to the Seton Dam fishway for radio-tagged fish was 38.3 ± 1.6 h, whereas PIT-tagged fish took 32.9 ± 1.4 h (Two-way ANOVA: d.f.=1, F=6.9, p=0.009). However, this difference was primarily driven by the longer migration time of female radio-tagged fish (Figure 3-14). Overall, female Gates Creek sockeye salmon took longer than males to reach the Seton Dam fishway (Two-way ANOVA: d.f.=1, F=8.4, p=0.004), however, differences between sexes were not observed for fish with the same tag type. Sex-specific differences in migration time to the Seton Dam fishway were likely due to downstream factors, as there was no difference in entrance delay at Seton Dam between radio-tagged male and female Gates Creek sockeye salmon.

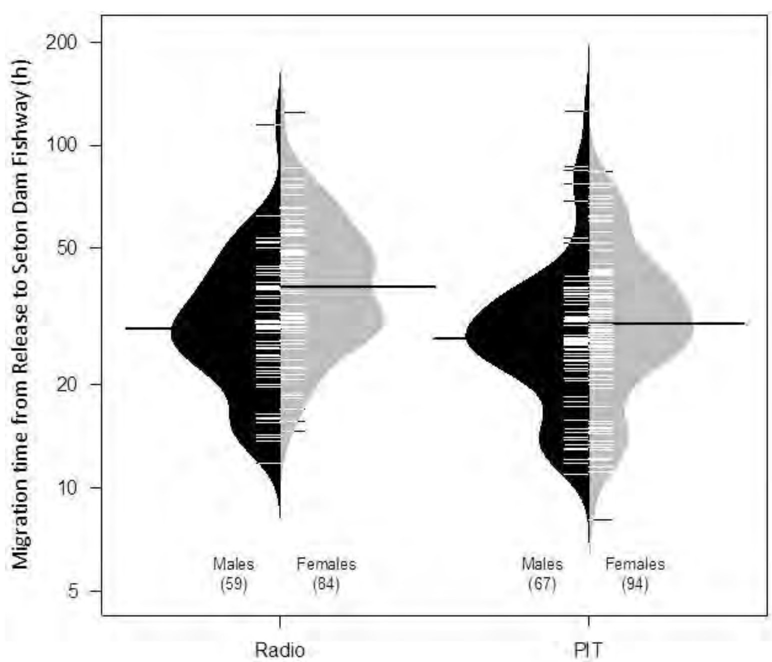

Figure 3-14: Gates Creek sockeye salmon migration time from release to the Seton Dam fishway entrance for males (black) and females (grey). Mean (black horizontal lines) and individual (white horizontal lines) values are shown

For radio-tagged Gates Creek sockeye salmon, migration rates to first detection at Seton Dam were similar to 2013, while success in reaching Seton Dam was greater in 2014. Migration rate of radio-tagged males (7.5 ± 0.4 km·d^{-1}) was significantly higher than females (5.7 ± 0.3 km·d^{-1}) (mean ± S.E.; Wilcoxon unpaired t-test: W=1,152, p<0.001). In comparison, migration rates of male and females in 2013 were 6.2 ± 2.6 km·d^{-1} and 4.6 ± 1.8 km·d^{-1}, respectively, and were also significantly different (Mann-Whitney rank sum test: T=2337, p<0.001). Migration success to Seton Dam in 2014 was greater than in 2013 and was 77% (65/84) for males and 64% (54/83) for females. Numerous factors downstream of Seton Dam likely contributed to the observed differences in success and migration rates between years. These factors will be examined in future analyses.

Delay of Gates Creek sockeye salmon at the Seton Generating Station, or at the Seton River- Fraser River confluence, did not differ for fish that were successful or unsuccessful at reaching Seton Dam (Figure 3-15). Fish that successfully migrated to Seton Dam spent 5.1 ± 0.5 h (mean ± S.E.; range of 0.0-37.4 h) in the Seton Generating Station tailrace and 2.3 ± 0.3 h (range of 0.0-27.2 h) at the Seton River-Fraser River confluence. Future analyses will examine the relationship of time spent at the Seton Generating Station to environmental factors such as dilution ratio or the temperature difference between the Fraser River and Seton Generation Station tailrace.

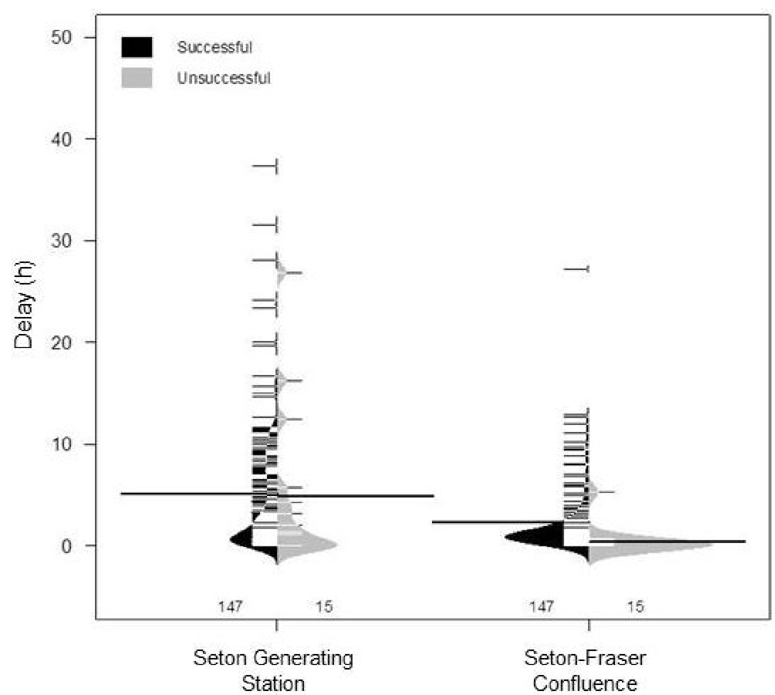

Figure 3-15: Delay of Gates Creek sockeye salmon at the Seton Generating Station and Seton River-Fraser River confluence for fish that were successful (black) or unsuccessful (grey) at reaching Seton Dam. Mean (black horizontal lines) and individual (white horizontal lines) values are shown

3.5.3 Portage Creek Sockeye Salmon

Migration of radio- and PIT-tagged Portage Creek sockeye salmon was compared using migration time and success to entrance at the Seton Dam fishway from release at the Fraser River West site.

Portage Creek sockeye salmon success to the Seton Dam fishway was 88% (167/189) for radio-tagged fish versus 73% (141/194) for PIT-tagged fish. Migration success of male radio-tagged fish was 93% (91/98) versus 84% (76/91) for females. In comparison, the migration success of male PIT-tagged fish was 81% (105/129) versus 57% (36/63) for females.

Migration time of Portage Creek sockeye salmon to Seton Dam did not differ between radio- and PIT-tagged fish. Mean migration times (mean ± S.E.) for radio- and PIT-tagged fish were 126.7 ± 6.2 h and 115.0 ± 7.3 h, respectively, and ranged from 11.9 h to 666.3 h for both tag types (Figure 3-16). However, significant differences in migration time were found between males and females (d.f.=2, F=5.7, p=0.004). Males had a shorter migration time to the Seton Dam fishway for both radio- and PIT-tagged Portage Creek sockeye salmon. Migration time of radio-tagged males was 113.7 ± 8.5 h, whereas the migration time of females was 140.7 ± 8.8 h. Similar trends were observed with PIT-tagged fish, with males reaching the Seton Dam fishway in 103.8 ± 6.5 h whereas females took 145.8 ± 20.1 h. Likewise, the migration rate of male radio-tagged fish from release to Seton Dam was also faster than females, 2.6 ± 0.2 $km \cdot d^{-1}$ (*n*=89) versus 1.7 ± 0.1 $km \cdot d^{-1}$ (*n*=69) for females (Wilcoxon unpaired t-test: W=1,152, p<0.001).

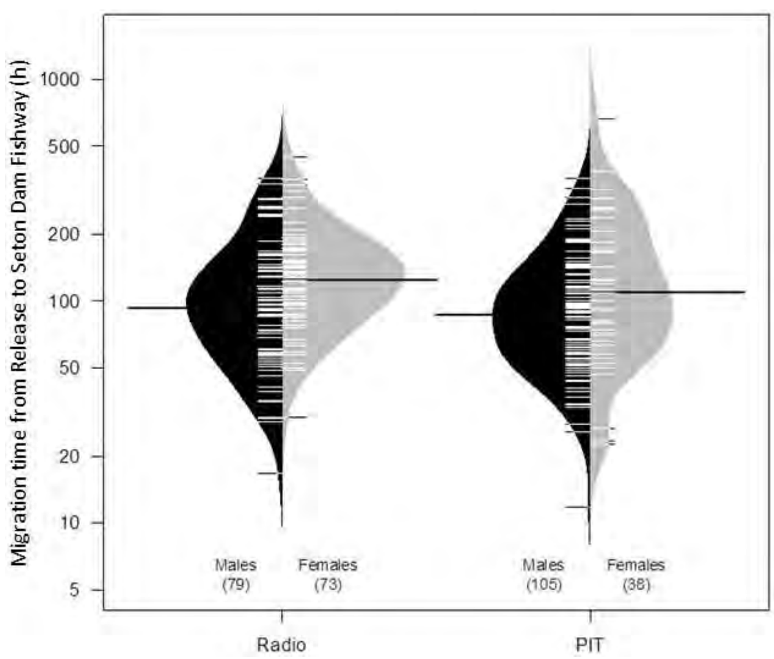

Figure 3-16: Portage Creek sockeye salmon migration time from release to the Seton Dam fishway entrance for males (black) and females (grey). Mean (black horizontal lines) and individual (white horizontal lines) values are shown

Delay (mean ± S.E.) at the Seton Generating Station was found to be significantly greater for Portage Creek sockeye salmon that did not successfully migrate to Seton Dam (Figure 3-17). Fish that successfully migrated to Seton Dam spent 22.8 ± 2.4 h at the Seton Generating Station whereas fish that were unsuccessful at reaching Seton Dam spent 33.8 ± 8.6 h (Mann-Whitney *U*-test: W=1314, p=0.03).

Overall, Portage Creek sockeye salmon spent considerably longer downstream than Gates Creek sockeye salmon. Cooler water temperatures during the migration period for Portage Creek sockeye salmon may be a factor. Further analyses will investigate the relationship between the delay of Portage Creek sockeye salmon and environmental variables and dilution ration?.

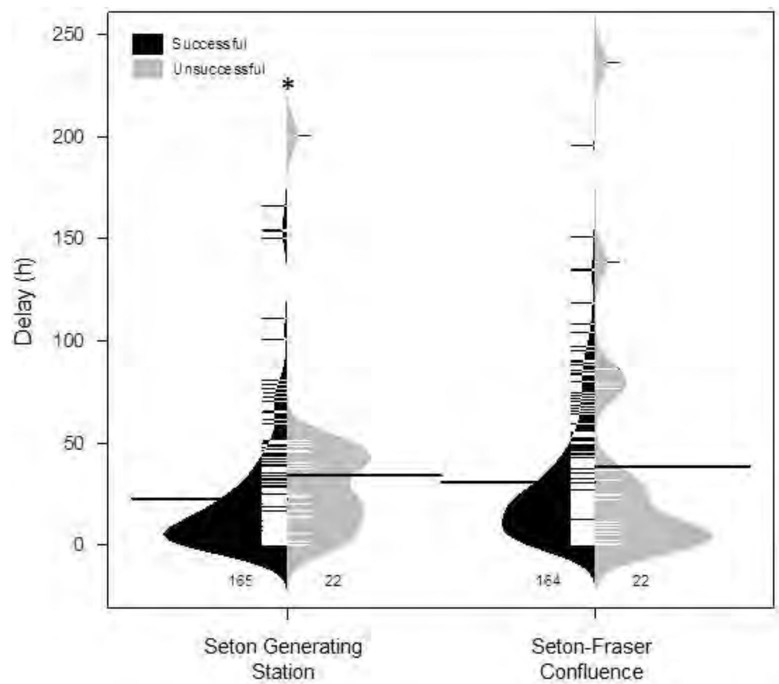

Figure 3-17: Delay of Portage Creek sockeye salmon at the Seton Generating Station and Seton River-Fraser River confluence for fish that were successful (black) or unsuccessful (grey) at reaching Seton Dam. Mean (black horizontal lines) and individual (white horizontal lines) values are shown

3.5.4 Coho Salmon

Estimating the migration success of radio-tagged coho salmon from release to Seton Dam, or spawning grounds downstream of Seton Dam, was complicated by a low sample size (n=7). Regardless, four coho salmon released in the Fraser River successfully migrated to Seton Dam. Migration time for these fish ranged from 27.6-82.3 h. Coho salmon that successfully migrated to Seton Dam spent 1.1-1.9 h (n=4) in the Seton Generating Station tailrace whereas unsuccessful coho salmon spent 0-2.7 h (n=3). At the Seton River-Fraser River confluence, coho salmon that successfully reached Seton Dam were detected for 0.6-7.9 h whereas unsuccessful coho salmon spent 0-43.4 h at the confluence.

3.6 Passage at Seton Dam

Gates Creek sockeye salmon passage at Seton Dam was examined for a third year using acoustic accelerometers. Passage success of acoustic-tagged fish in 2014 was compared with PIT-tagged fish co-released at the Upper Seton River site and radio- and PIT-tagged fish released at the Fraser River West site. Passage during an alternative flow scenario was also assessed to determine if using alternate conveyance structures to discharge water could improve passage success and post-passage survival of Gates Creek sockeye salmon. Portage Creek sockeye salmon passage success was examined with acoustic, radio, and PIT-tagged fish.

3.6.1 Acoustic and PIT Array Detection Efficiency

Detection efficiency of the Seton Dam acoustic array (Table 3-7) and PIT array was considered to be high in 2014. All acoustic-tagged Gates Creek sockeye salmon that were released were detected in the Seton Dam tailrace, although one fish that passed Seton Dam was not detected in the radial gate spillway. Three fish were not detected in the fishway entrance area, although reduced detection efficiency in the entrance area was likely due to the known decrease in detection range of acoustic receivers in the highly turbulent flows from SSV1 and the FWRG. The PIT array at the entrance and exit of the fishway detected 99% (579/587) of fence-released Gates Creek sockeye salmon that migrated through Seton Dam.

Table 3-7: Seton Dam acoustic array detection efficiency based on Gates Creek sockeye salmon detections

Seton Dam Area	Detection Efficiency
Radial Gate Spillway	100% (44 of 44 fish detected)
Entrance Area	93% (42 of 45 fish detected)
Fishway	100% (44 of 44 fish detected)
Seton Dam Forebay	100% (43 of 43 fish detected)

3.6.2 Migration Conditions

Gates Creek sockeye salmon were released at the Upper Seton River site from 02 August to 07 September. Water temperature in the Seton Dam tailrace ranged from 13.2-20.4ºC during this period. Preliminary analysis indicated temperature was not a significant factor in the passage success of Gates Creek sockeye salmon in 2014 and was not included in further analyses. The alternative flow scenario tested during the Gates Creek sockeye migration occurred from 08 to 19 August with discharge switched from the FRWG and SSV1 to SSV4 (see Section 3.2). Total Seton Dam discharge during alternative flow scenario was 31.3 $m^3 s^{-1}$. Discharge prior-to and after the alternative flow scenario differed by less than 1 $m^3 s^{-1}$ and produced similar tailrace flow fields, therefore, these scenarios were pooled for fish passage analysis.

Tagged Portage Creek sockeye salmon experienced one flow scenario in 2014. Acoustic- and PIT-tagged Portage Creek sockeye salmon were released at the Upper Seton River site between 16 September and 15 October. Water temperature in the tailrace was 13.9-16.6ºC during this period. All acoustic-tagged fish were released on 03 October and experienced the same migration conditions. Radio- and PIT-tagged Portage Creek sockeye salmon were released between 16 September and 15 October at the Fraser River West site during which time Fraser River and Seton River temperatures ranged from 10.3-15.1ºC and 13.1-16.4ºC, respectively.

3.6.3 Gates Creek Sockeye Salmon

Passage success of acoustic-tagged Gates Creek sockeye salmon released at the Upper Seton River was used to compare 2012-2014 results with the findings of previous studies as the methodologies were most similar. Attraction efficiency of acoustic-tagged Gates Creek sockeye in 2014 was the highest yet observed, with all but one fish successfully locating the fishway entrance (Table 3-8). Mean entrance delay in 2014 was similar to 2013 and was lower than all estimates in years prior. Passage efficiency remained high. In comparison, overall success of PIT-tagged fish also released at the Upper Seton River was 92% (543/592) in 2014.

Table 3-8: Passage success of Gates Creek sockeye salmon at Seton Dam in 2005 (radio tags), 2007 (acoustic tags), and 2012 to 2014 (acoustic tags)

Variable	2005[a]	2007[b]	2012	2013	2014
Attraction Efficiency	77% (23/30)	86% (44/51)	69% (18/26)	83% (45/54)	98% (44/45)
Entrance Delay (Range)	18.0 ± 4.7 h	16.3 ± 3.1 h (0.5–92.6 h)	18.8 ± 6.8 h (0.5–114.7 h)	10.8 ± 1.4 h (0.1–58.4 h)	12.9 ± 1.6 h (0.7-50.9 h)
Passage Efficiency	100% (23/23)	93% (41/44)	89% (16/18)	98% (44/45)	98% (43/44)
Overall Success	77% (23/30)	80% (41/51)	62% (16/26)	81% (44/54)	96% (43/45)

Entrance delay is mean ± S.E. Data from [a]Pon et al. (2006) and [b]Roscoe and Hinch (2008). Assessed discharges ($m^3 \cdot s^{-1}$) were: 15.8, 12.7, 11.0 (2005); 60.0, 35.0 (2007); 48.0, 35.0, radial gate opening (2012); 26.1, 22.8 (2013); 27.0, 27.2, 31.3 (2014).

Radio- and PIT-tagged Gates Creek sockeye salmon released at the Fraser River West site also had higher passage success than previous years. For all radio-tagged fish released downstream, including those not detected in the tailrace, passage success was 88% (143/163). Dam arrival could not be confirmed for PIT-tagged fish released downstream, however, passage success for this group was 88% (157/178).

Acoustic- and radio-tagged Gates Creek sockeye salmon detected in the Seton Dam tailrace had comparable attraction and passage efficiency within each of the 2013 and 2014 study years (Table 3-9). Delay of acoustic-tagged fish was greater than radio-tagged fish in both study years, possibly because the proximity of the Upper Seton River release site to the Seton Dam tailrace allowed acoustic-tagged fish to recover in the tailrace post-tagging. Overall, passage success in 2014 was 91% (886/978) for all tagged Gates Creek sockeye salmon and 97% (186/191) for acoustic- and radio-tagged fish known to have successfully migrated to Seton Dam.

Table 3-9: Passage success of acoustic- and radio-tagged Gates Creek sockeye salmon at Seton Dam in 2013 and 2014

Variable	2013		2014	
	Acoustic	Radio	Acoustic	Radio
Attraction Efficiency	83% (45/54)	74% (114/155)	98% (44/45)	98% (143/146)
Entrance Delay* (Range)	10.8 ± 1.4 h (0.1-58.4 h)	8.8 ± 1.3 h (0.1-80.3 h)	12.9 ± 1.6 h (0.7-50.9 h)	8.3 ± 1.3 h (0.0-95.9 h)
Passage Efficiency	98% (44/45)	95% (108/114)	98% (43/44)	100% (143/146)
Overall Success	81% (44/54)	70% (108/155)	96% (43/45)	98% (143/146)

*Entrance delay is mean ± S.E. Sample sizes for entrance delay of radio-tagged sizes were n=99 (2013) and n=117 (2014).

3.6.4 Passage Success during the Alternative Flow Scenario

Passage success of Gates Creek sockeye salmon under routine BC Hydro operating conditions (flow scenarios 1 and 3) was compared with passage success during an alternative flow scenario (flow scenario 2) that reduced flow velocities around the fishway entrance (see Section 3.2). Passage success during each flow scenario was assessed using acoustic-, radio-, and PIT-tagged fish while swimming activity and behaviour was examined using acoustic-tagged fish.

Monte Carlo simulations found differences in the passage success of PIT-tagged Gates Creek sockeye salmon during each flow scenario, with passage success 9% greater under the alternative flow scenario (98%; 199/204) than routine BC Hydro operations (89%; 344/388). Dam passage success during the alternative flow scenario was also 7% higher for acoustic-tagged Gates Creek sockeye salmon (Table 3-13). However, these differences were not significant, likely due to the small sample size of acoustic-tagged fish.

No differences in passage success were found for radio-tagged fish that successfully migrated to Seton Dam from the Fraser River West release site (Table 3-10). However, a portion of radio-tagged fish released downstream failed to migrate to Seton Dam (See Section 3.5). The loss of these fish downstream, rather than in the Seton Dam tailrace, may account for the lack of difference in passage success of radio-tagged fish at each flow scenario. No sex-specific differences in passage success were apparent for either radio- or PIT-tagged fish during either flow scenario.

Table 3-10: Radio-tagged Gates Creek sockeye salmon passage at Seton Dam during routine BC Hydro operations and an alternative flow scenario in 2014

Variable	Flow Scenario	
	Routine	Alternative
Attraction Efficiency	98% (102/104)	98% (41/42)
Entrance Delay (Range)	6.7 ± 1.7 h[a] (0.0-95.9 h)	11.1 ± 2.0 h[b]* (0.1-54.2 h)
Passage Efficiency	100% (102/102)	100% (41/41)
Overall Success	98% (102/104)	98% (41/42)

Entrance delay is mean ± S.E. A (*) indicates a significant difference.
[a]n=74. [b]n=41.

Fish behaviour in the Seton Dam tailrace differed between the two flow scenarios. Acoustic-tagged fish that experienced the alternative flow scenario delayed significantly longer below the dam (Mann-Whitney *U*-test: W=133, p=0.022) and made significantly more tailrace crossings from the fishway entrance area to the radial gate spillway (Mann-Whitney *U*-test: W=95, p=0.001) (Table 3-11). Radio-tagged fish also delayed significantly longer under the alternative flow scenario (Mann-Whitney *U*-test: W=1,025, p=0.003) (Table 3-12). Fish also appeared to prefer delaying in the entrance area over the radial gate spillway during the alternative flow scenario, although this difference was not significant (Mann-Whitney *U*-test: W=158, p=0.252).

Table 3-11: Acoustic-tagged Gates Creek sockeye salmon passage at Seton Dam during routine BC Hydro operations and an alternative flow scenario in 2014

Variable	Flow Scenario	
	Routine	Alternative
Attraction Efficiency	97% (29/30)	100% (15/15)
Entrance Delay (Range)	10.0 ± 1.3 h (0.7-25.9 h)	18.8 ± 3.5 h* (1.6-50.9 h)
Passage Efficiency	97% (28/29)	100% (15/15)
Overall Success	93% (28/30)	100% (15/15)
Tailrace Crossing (Range)	2.0 ± 0.2 (1-4)	4.5 ± 0.8* (1-12)
Entrance area: radial gate delay ratio (Range)	1.6 ± 0.2 (0.2-4.9)	5.4 ± 1.8 (0.3-20.4)
Anaerobic Recruitment	6.9 ± 1.6%	8.2 ± 2.1%
Forebay Delay	1.1 ± 0.3 h*	0.6 ± 0.3 h

All values are presented as mean ± S.E. A (*) indicates a significant difference.

Swimming speeds of Gates Creek sockeye salmon during each of the flow scenarios did not differ in any of the areas of the tailrace (Figure 3-18). The proportion of time fish would have recruited anaerobic muscle during dam passage, an indicator of passage difficulty, also did not differ between flow scenarios, although these measurements may have been limited by the detection range of the acoustic receivers. Delay in the dam forebay, however, was significantly greater during the routine flow scenario (Mann-Whitney *U*-test: W=336, p=0.001) suggesting fish required additional time to recover post-passage, possibly due to increased swimming effort during passage that was not detected on the acoustic array.

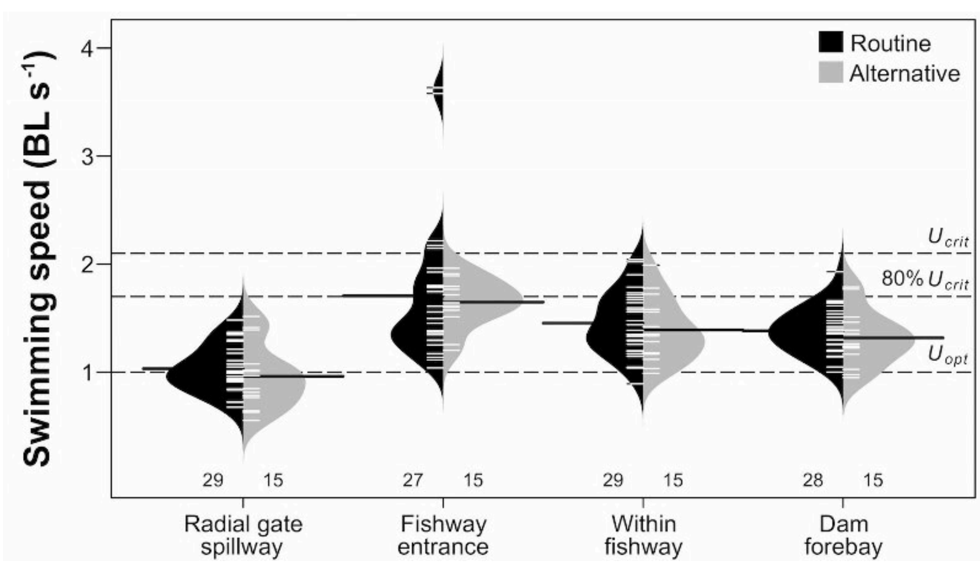

Figure 3-18: Swimming speeds of Gates Creek sockeye salmon during the routine flow scenario (black) and alternative flow scenario (grey) in different areas of the Seton Dam tailrace in 2014. Mean (black horizontal lines) and individual (white horizontal lines) values are shown. Dashed horizontal lines indicate the optimal (U_{opt}), 80% critical (80% U_{crit}), and critical (U_{crit}) swimming speeds for Gates Creek sockeye salmon

3.6.5 Alternative Flow Scenario and Post-Passage Survival

Survival to spawning grounds was examined following Gates Creek sockeye salmon passage through Seton Dam during either routine BC Hydro operations or the alternative flow scenario.

All acoustic-tagged fish that passed Seton Dam during the alternative scenario survived to spawning grounds (Table 3-12). In comparison, less than half the fish that passed the dam during routine BC Hydro operations survived to spawning grounds. Together with differences in dam passage success, the cumulative survival of acoustic-tagged Gates Creek sockeye salmon from release to spawning grounds was 55% greater under the alternative flow scenario. Post-passage survival of PIT-tagged Gates Creek sockeye salmon mirrored the survival trends of acoustic-tagged fish, with PIT-tagged fish that passed Seton Dam under the alternative flow scenario having 7% greater survival from the dam to spawning grounds and 14% greater cumulative survival from release to spawning grounds. Monte Carlo simulations found differences in the cumulative survival of PIT-tagged fish between flow scenarios.

Table 3-12: Seton Dam passage success and survival to spawning grounds for PIT and radio-tagged Gates Creek sockeye salmon during routine BC Hydro operations and an alternative flow scenario in 2014

Tag Type / Variable	Flow Scenario	
	Routine	Alternative
Acoustic-tag releases (Upper Seton River)		
Dam Passage	93% (28/30)	100% (15/15)
Post-Passage Survival	48% (13/27)	100% (15/15)
Cumulative Survival	45% (13/29)	100% (15/15)
PIT-tag releases (Upper Seton River)		
Dam Passage	89% (344/388)	98%* (199/204)
Post-Passage Survival	81% (279/344)	88% (176/199)
Cumulative Survival	72% (279/388)	86%* (176/204)
Radio-tag releases (Fraser River West)		
Dam Passage	98% (102/104)	98% (41/42)
Post-Passage Survival	76% (78/102)	80% (33/41)
Cumulative Survival	75% (78/104)	79% (33/42)

A (*) indicates non-overlapping 95% credible intervals.

Radio-tagged fish released at the Fraser River West site also had increased survival to spawning grounds under the alternative flow scenario, however, the increase in cumulative survival was not significant. The effects of transporting fish to the release site and downstream environmental variables may have reduced the ability to detect an effect of the alternative flow scenario on the survival of radio-tagged fish to spawning grounds. Regardless, all tag types showed increased post-passage survival of Gates Creek sockeye to spawning grounds under the alternative flow scenario, suggesting that alternative flows mitigate delayed effects of dam passage on fish.

3.6.6 Portage Creek Sockeye Salmon

In 2014, passage success of Portage Creek sockeye salmon varied with tag type and release location. Overall passage success a small group of acoustic-tagged fish released at the Upper Seton River site was 27% lower than radio-tagged fish that migrated to the dam from the Fraser River West site (Table 3-13). Passage success of PIT-tagged fish released at the Upper Seton River site was 80% (192/241), 17% lower than radio-tagged fish. As with Gates Creek sockeye salmon, a portion (12%) of radio-tagged Portage Creek sockeye salmon released downstream failed to migrate to Seton Dam (see Section 3.5). The loss of these fish downstream, rather than in the Seton Dam tailrace, may account for the higher observed passage success of radio-tagged fish. Delay of acoustic-tagged fish was also greater than radio-tagged fish, likely a result of the low sample size for acoustic-tagged fish (n=10). Fish condition, which was not included in preliminary passage analyses, may also explain differences in passage success between tag types.

Table 3-13: Radio and acoustic-tagged Portage Creek sockeye salmon passage at Seton Dam in 2013 and 2014

Variable	2013	2014	
	Radio	Radio	Acoustic
Attraction Efficiency	95% (21/22)	98% (163/167)	70% (7/10)
Entrance Delay (Range)	12.6 ± 2.9 h (0.2-42.8 h)	14.9 ± 2.2 h (0.1-74.0 h)	78.3 ± 33.6 h (4.6-289.4 h)
Passage Efficiency	95% (20/21)	99% (162/163)	100% (7/7)
Overall Success	91% (20/22)	97% (162/167)	70% (7/10)

*Entrance delay is mean ± S.E. Discharge was 15.0 $m^3 \cdot s^{-1}$ (2013) and 14.5 $m^3 \cdot s^{-1}$ (2014).

For all radio-tagged fish released downstream, including those not detected in the tailrace, passage success was 86% (162/189). Dam arrival could not be confirmed for PIT-tagged fish released downstream, however, passage success for this group was 72% (139/194). Radio-tagged Portage Creek sockeye salmon passage success in 2014 was similar to passage success in 2013 (Table 3-14). Overall passage success for all Portage Creek sockeye salmon released in 2014 was 82% (500/612).

Swimming speeds (mean ± S.E.) of Portage Creek sockeye salmon within the fishway entrance area (1.72 ± 0.07 $BL \cdot s^{-1}$) and the fishway (1.66 ± 0.12 $BL \cdot s^{-1}$) were significantly greater than swimming speeds in the radial gate spillway (1.02 ± 0.07 $BL \cdot s^{-1}$) or Seton Dam forebay (1.35 ± 0.07 $BL \cdot s^{-1}$) (One-way ANOVA: F=15.48, d.f.=3, p<0.001). Although critical swimming speeds are unknown for Portage Creek sockeye salmon, swimming speeds in the fishway entrance exceeded 80% of the critical swimming speed for Gates Creek sockeye salmon. Overall, swimming speeds approximated those observed for Gates Creek sockeye salmon in 2013 and 2014.

3.6.7 Coho Salmon Passage Success

Of the seven radio-tagged coho salmon released at the Fraser River West site, four were detected in the Seton Dam tailrace. All four coho salmon successfully located and ascended the fishway (100% attraction efficiency, 100% passage efficiency). Delay was 8.0 ± 3.9 h (mean ± S.E.).

3.7 Migration to Spawning Grounds

Survival to spawning grounds was determined for acoustic-, radio-, and PIT-tagged Gates Creek and Portage Creek sockeye salmon in 2014. Survival to spawning grounds was assessed following passage of Seton Dam as well as from release. For Gates Creek sockeye, tags were recovered to obtain iButtons and, when possible, female spawning success was assessed. Survival to spawning grounds has not yet been determined for coho salmon.

3.7.1 Survival of Gates Creek Sockeye Salmon

Gates Creek sockeye salmon survival to spawning grounds following passage of Seton Dam ranged from 67-84%, depending on tag type and release site, and was highest for PIT-tagged fish released at the Upper Seton River site (Table 3-14). Differences in male and female survival were observed for both radio- and PIT-tagged fish released at the Fraser River West site, however, radio-tagged males had greater survival whereas PIT-tagged females had greater survival. Overall, the post-passage survival of acoustic-, radio-, and PIT-tagged Gates Creek sockeye from Seton Dam to spawning grounds was 80% (705/885) in 2014.

Cumulative survival of all tagged Gates Creek sockeye salmon from release to spawning grounds was 72% (28% mortality) in 2014 (705/977). Given that 91% of fish that were released successfully passed Seton Dam (9% mortality), these results indicate that mortality of Gates Creek sockeye salmon primarily occurred upstream of Seton Dam in Seton Lake and Anderson Lake. In comparison, mortality of tagged fish in 2013 was approximately equal upstream (28%) and downstream (31%) of Seton Dam. Within the lakes, data from radio-tagged fish suggests that female mortality primarily occurred in Anderson Lake in 2014 whereas male mortality was equal in both lakes.

Table 3-14: Survival of Gates Creek sockeye salmon following passage of Seton Dam in 2014

Release Site / Tag Type	Post-Passage Survival		
	Male	Female	Combined
Fraser River West			
Radio-tagged	87% (54/62)	70% (57/81)	78% (111/143)
PIT-tagged	62% (41/66)	77% (70/91)	70% (111/157)
Upper Seton River			
PIT-tagged	81% (179/220)	85% (276/323)	84% (455/543)
Acoustic-tagged	68% (13/19)	65% (15/23)	67% (28/42)

The relationship between survival to spawning grounds and lower Seton River migration conditions, capture location, delay at Seton Dam and other factors will be considered in future analyses. Survival estimates using telemetry data can also be compared with a population-level survival estimate derived from comparison of fish passage at Seton Dam (via the fish counter) and escapement estimates at Gates Creek (via data from Fisheries and Ocean Canada stock assessment).

3.7.2 Lake Thermal Experience of Gates Creek Sockeye Salmon

Thermal profiles of Gates Creek sockeye salmon migration from release to arrival at spawning grounds were recorded using gastrically-implanted iButton loggers. Loggers (*n*=90) were recovered from decreased radio-tagged sockeye at spawning grounds. The thermal profiles were correlated with telemetry data to determine the temperatures fish encountered in different segments of their upstream migration.

Gates Creek sockeye salmon displayed individual variation in thermal profiles during migration to spawning grounds. For example, two female Gates Creek sockeye salmon co-released at the Fraser River West site on 18 August 2014 displayed different thermoregulatory behaviour in Seton Lake and Anderson Lake (Figure 3-19). One fish spent 8.8 d in the lakes with a median in-lake temperature of 8.8ºC, whereas another spent 12.8 d in the lake with a median in-lake temperature of 12.9ºC. At spawning grounds, the fish with a lower median lake temperature did not successfully spawn whereas the fish with a higher median lake temperature was successful.

Numerous factors both within and outside of the Seton River study area likely contributed to the behaviour and spawning success of Gates Creek sockeye salmon. Future analyses will assess the correlation between temperatures experienced during migration and migration rate, passage success at Seton Dam, and spawning success.

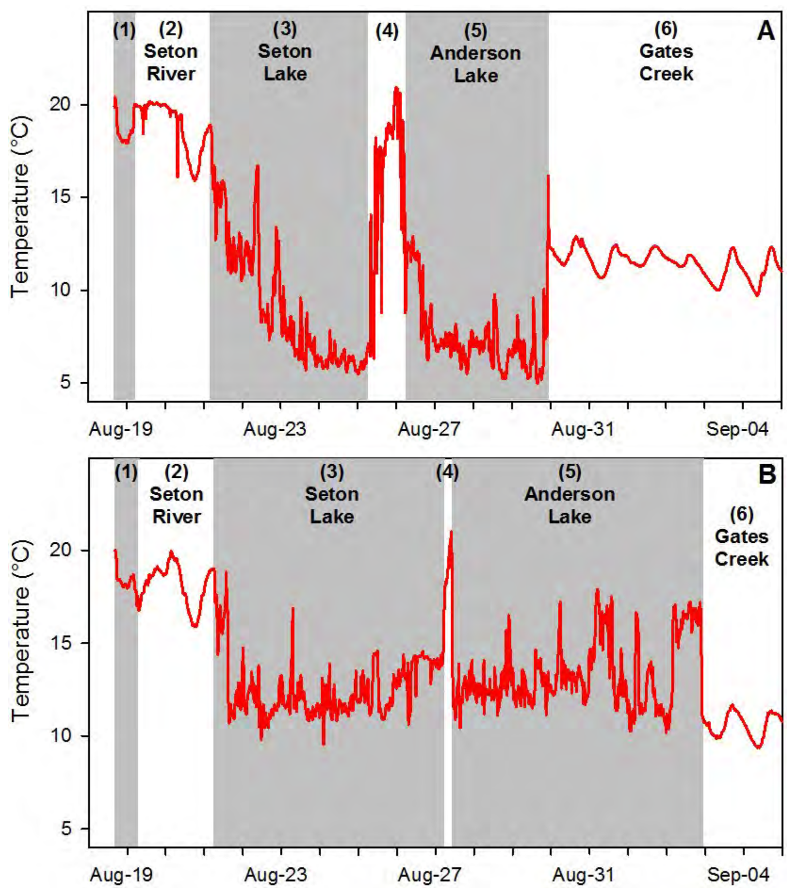

Figure 3-19: Temperature experience of Gates Creek sockeye salmon migrating from release through the Seton River study area to spawning grounds at Gates Creek. Profiles are for two female sockeye that either unsuccessfully (A) or successfully (B) spawned at Gates Creek. Labels not shown are (1) Fraser River and (4) Portage Creek

3.7.3 Spawning Success of Gates Creek Sockeye Salmon

Carcass recoveries were used to estimate the spawning success of female sockeye salmon that migrated to Gates Creek. A total of 405 radio- and PIT-tagged fish were recovered on spawning grounds in 2014. Of these recovered fish, 265 were female sockeye salmon that could be assessed for spawning. Fully-spawned females accounted for 68% (180/265) of the tagged females recovered at Gates Creek. Partially-spawned (50% spawn) or unspawned (0%) females accounted for 9% (24/265) and 23% (61/265) of females, respectively. Compared to 2013, where fully-spawned females accounted for only 22% of females recovered, spawning success of tagged females was higher in 2014.

Future analyses will determine if female spawning success is related to the conditions fish experienced during their upstream migration.

3.7.4 Survival of Portage Creek Sockeye Salmon

Survival to spawning grounds could only be determined for acoustic- and radio-tagged Portage Creek sockeye salmon as a PIT antenna could not be installed in Portage Creek. Temperature loggers were not implanted into Portage Creek sockeye, therefore, tag recoveries and spawning success assessments were not performed for Portage Creek sockeye salmon.

Post-passage survival of Portage Creek sockeye in 2014 (Table 3-15) was double that observed in 2013. In 2013, survival to spawning grounds from Seton Dam for radio-tagged fish was 35%, although the low sample size in 2013 (n=24) may have been a factor in this result. Low post-passage survival of acoustic-tagged fish in 2014 may also be due to a low sample size and likely accounts for the discrepancy between the survival of acoustic- and radio-tagged Portage Creek sockeye salmon following Seton Dam passage. Post-passage survival was equal for males and females.

Cumulative survival of radio-tagged Portage Creek sockeye salmon from release to spawning grounds was 61% (116/189) (39% mortality) in 2014. Mortality primarily occurred in Seton Lake with 14% of radio-tagged fish failing to migrate past Seton Dam and a subsequent 25% failing to migrate to spawning grounds. Similar patterns were seen with Gates Creek sockeye salmon in 2014.

Table 3-15: Survival of Portage Creek sockeye salmon following Seton Dam passage in 2014

Release Site / Tag Type	Post-Passage Survival		
	Male	Female	Combined
Fraser River West			
Radio-tagged	72% (63/87)	71% (53/75)	72% (116/162)
Upper Seton River			
Acoustic-tagged	40% (2/5)	50% (1/2)	43% (3/7)

3.8 Effect of Transport on Migration and Survival

The effect of transport on the ability of fish to migrate past Seton Dam and reach spawning grounds was investigated by comparing the migration success of PIT-tagged Gates Creek sockeye salmon collected and released at the Upper Seton River release site without transport (control group) to fish collected at the Upper Seton River site, transported, and released at Upper Seton River site (transport group). For added comparison, dam passage and survival to spawning grounds was determined for fish transported and released at the downstream Fraser River West site on the same days (downstream group). All tagging and releases occurred from 25 to 29 August and discharges at Seton Dam and Cayoosh Creek were unchanged throughout this time period. Temperature increased in the Seton Dam fishway, Cayoosh Creek and the Seton River from 27 to 29 August, however, all release groups on each day would have experienced the same temperature regimes.

Passage success at Seton Dam was high (>90%) for all groups (Table 3-16). High passage success for all groups indicate that, under the conditions experienced in 2014, there were limited short-term effects of transporting fish downstream. Therefore, releases at the Fraser River West site can be used to assess migration success to and passage success at Seton Dam without taking into account reduced survival due to transport. Transport groups showed 24-26% reductions in post-dam passage survival to spawning grounds compared to the survival of the control group (Table 3-16). Reductions in survival were similar for both sexes, although there was a non-significant trend of lower male survival compared to females (Table 3-17).

Although transported fish displayed reductions in post-dam passage survival, there are several caveats to consider in terms of applying these results more broadly to the tagging studies. Specifically, the transport effects were only examined over a very narrow window (5 days) at the end of the Gates Creek sockeye salmon migration period. Fish migrating in the latter portion of the migration can be expected to be different physiologically, possibly more mature, than fish during the early or peak portions of the run. Further analysis is needed that incorporates blood plasma samples from acoustic- and radio-tagged fish to determine how handling and transport may differentially affect fish based on run timing.

Table 3-16: Seton Dam passage success and survival to spawning grounds of Gates Creek sockeye salmon PIT-tagged and released at the Upper Seton River site (control) or transported and released at the Upper Seton River site (transport) or Fraser River West site (downstream) from 25 to 29 August 2014

Endpoint	Treatment		
	Control Group	Transport Group	Downstream Group
Seton Dam Passage Success	95% [88-98%] (88/93)	98% [92-100%] (62/63)	94% [84-98%] (50/53)
Survival to Spawning Grounds	94% [88-97%] (83/88)	68%* [55-78%] (42/62)	70%* [56-81%] (35/50)
Overall Survival	89% [81-94%] (83/93)	67%* [53-77%] (42/63)	66%* [53-78%] (35/53)

95% credible intervals are shown in square brackets. Sample sizes (successful/total) are shown in round brackets. A (*) indicates non-overlapping credible intervals.

Table 3-17: Seton Dam passage success and survival to spawning grounds of male and female Gates Creek sockeye salmon PIT-tagged and released at the Upper Seton River site (control) or transported and released at the Upper Seton River site (transport) or Fraser River West site (downstream) from 25 to 29 August 2014

Endpoint	Treatment					
	Control Group		Transport Group		Downstream Group	
	Male	Female	Male	Female	Male	Female
Seton Dam Passage Success	97% [85-99%] (32/33)	93% [84-97%] (56/60)	100% [87-100%] (25/25)	97% [87-99%] (37/38)	96% [81-99%] (25/26)	93% [77-98%] (25/27)
Survival to Spawning Grounds	88% [70-95%] (28/32)	98% [91-100%] (55/56)	64% [45-80%] (16/25)	72% [53-85%] (26/37)	68% [50-82%] (17/25)	72% [53-85%] (18/25)
Overall Survival	85% [69-93%] (28/33)	92% [83-96%] (55/60)	64% [45-79%] (16/25)	68% [46-80%] (26/38)	65% [46-80%] (17/26)	67% [47-82%) (18/27)

95% credible intervals are shown in square brackets. Sample size (successful/total) is shown in round brackets.

3.9 Water Preference Experiments

Behavioural water preference experiments over a range of dilution ratios were completed for Gates Creek and Portage Creek sockeye salmon in 2014 and dilution thresholds estimated for both populations. Results of pink salmon behavioural trials from 2013 are also presented.

3.9.1 Gates Creek Sockeye Salmon

Gates Creek sockeye salmon displayed no water preference during control tests (100% Seton River water in both arms) indicating that no arm bias was present in the Y-Maze. No significant differences were found in the amount of time fish spent in each arm (Wilcoxon signed rank test: n=19, V=66, p=0.25) (Figure 3-20), the proportion of time spent in each arm (Wilcoxon signed rank one sample test: μ=0.5, V=121, p=0.31) (Figure 3-21) or in the number of entrances into each arm (Student's t-test: t=-1.1019, p=0.29) (Figure 3-22).

Increasing the dilution ratio of the test mixture to 5% or 20% did not result in a water preference by Gates Creek sockeye salmon. At both 5% and 20%, no significant difference was found in either the amount of time spent in each arm (5%: Student's t-test: n=9, t=1.9189, p=0.09; 20%: Student's t-test: n=26, t=-0.5836, p=0.57) (Figure 3-20), the proportion of time spent in each arm (5%: One-sample t-test: μ=0.5, t=-2.1116, p=0.068; 20%: One-sample t-test: μ=0.5, t=0.6204, p=0.54) (Figure 3-21), or the number of entrances (5%: Student's t-test: t=1.6013, p=0.15; 20%: Student's t-test: t=0.9605, p=0.35) (Figure 3-22).

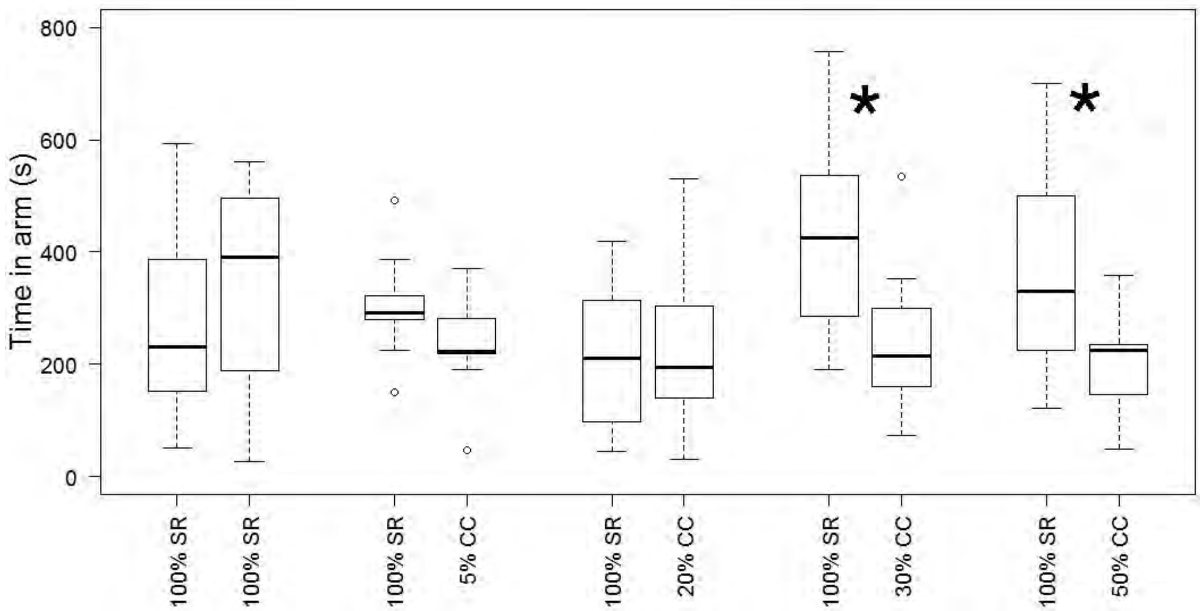

Figure 3-20: **Time spent by Gates Creek sockeye salmon in each arm of the Y-Maze during water preference tests. 100% Seton River (SR) water was tested with control (100% SR) and 5, 20, 30 and 50% Cayoosh Creek (CC) dilution ratios. Upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers. A (*) indicates a significant difference**

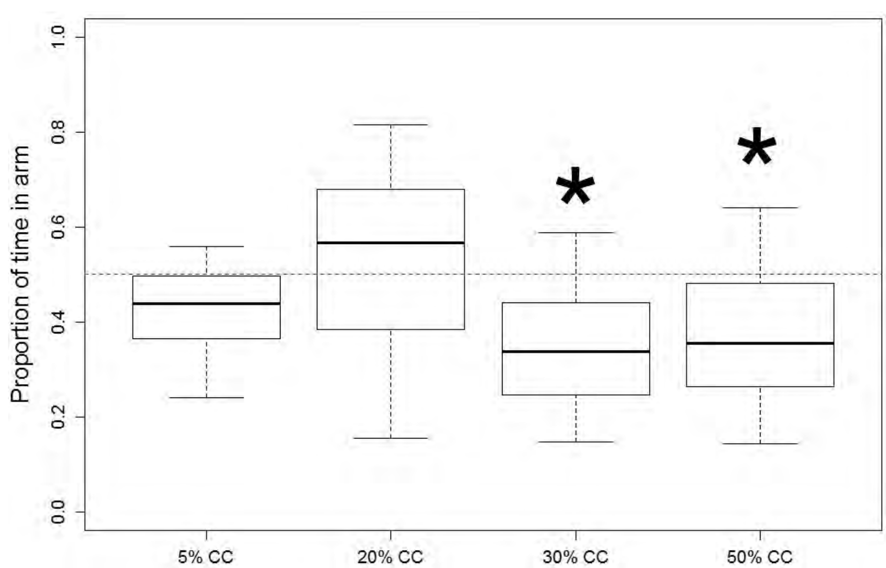

Figure 3-21: **The proportion of time spent by Gates Creek sockeye salmon in the dilution mixture arm of the Y-Maze during water preference tests. Dilution ratios of 5, 20, 30 and 50% Cayoosh Creek (CC) were tested against pure Seton River water. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicated a significant difference**

Gates Creek sockeye salmon showed a preference for Seton River water over Cayoosh Creek water when the dilution ratio was increased to 30%. At a 30% dilution ratio, fish spent significantly more time in the arm containing 100% Seton River water (Student's t-test: *n*=30, t=5.6389, p<0.01) (Figure 3-20) as well as a significantly greater proportion of time in this arm (One sample t-test: μ=0.5, t=-6.2444, p<0.01) (Figure 3-21). There was no significant difference, however, in the number of entrances to each arm (Wilcoxon signed rank test: n=30, V=247, p=0.17) (Figure 3-22). At a 50% dilution ratio, fish spent significantly more time in the arm containing 100% Seton River water (Student's t-test: *n*=26, t=4.3252, p<0.01) (Figure 3-20), spent a greater proportion of time in this arm (One-sample t-test: μ=0.5, t=-4.3206, p<0.01) (Figure 3-21), and also entered the arm more frequently (Student's t-test: *n*=26, t=2.1425, p=0.04) (Figure 3-22).

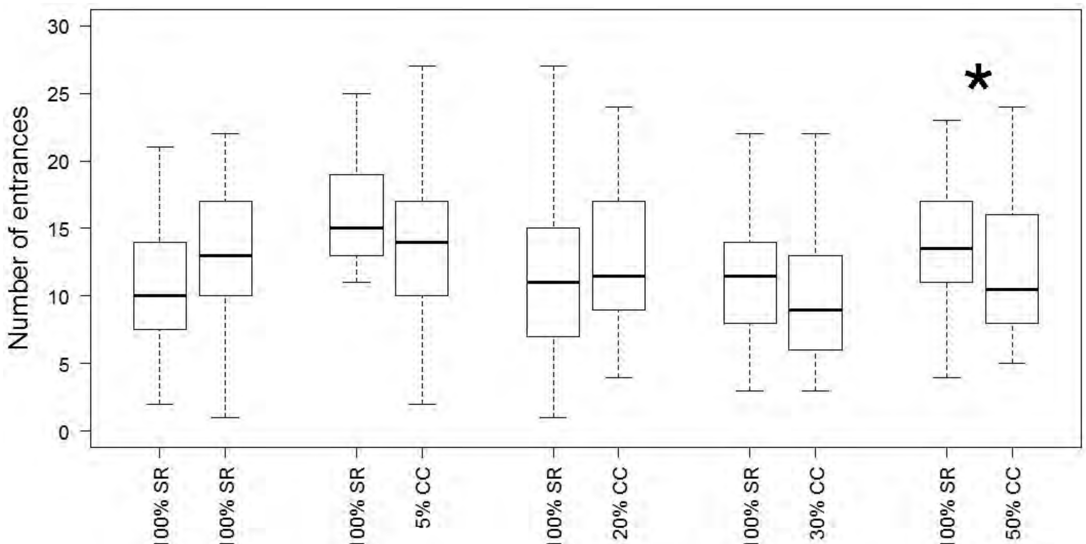

Figure 3-22: The number of entrances into each arm on the Y-Maze by Gates Creek sockeye salmon in each arm of the during water preference tests. 100% Seton River (SR) water was tested with control (100% SR) and 5, 20, 30 and 50% Cayoosh Creek (CC) dilution ratios. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicates a significant difference

3.9.2 Pink Salmon

In 2013, pink salmon were tested at a dilution ratio of 50% and showed a preference for the dilution mixture over 100% Seton River water. Pink salmon spent a significantly longer amount of time in the arm containing the 50% dilution ratio (Wilcoxon signed rank test: *n*=41, V=160, p<0.01) (Figure 3-23), and a significantly greater proportion of time (One sample t-test: μ=0.5, t=4.3369, p<0.01) (Figure 3-24). There was no difference in the number of entrances into each arm (Wilcoxon signed rank test: *n*=41, V=271.5, p=0.10) (Figure 3-25).

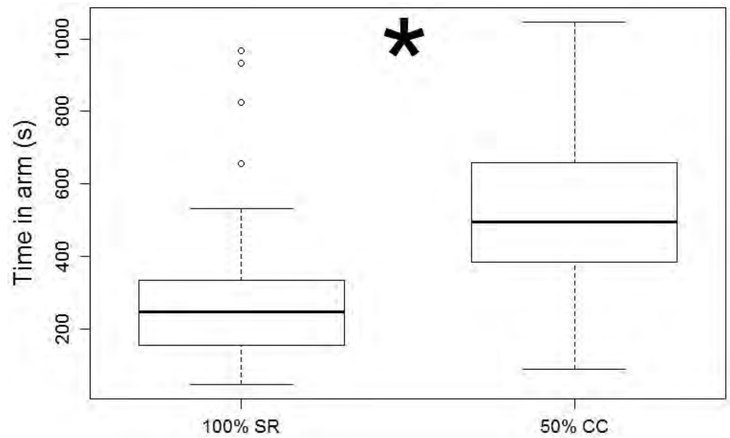

Figure 3-23: Time spent by pink salmon in each arm of the Y-Maze during water preference tests. 100% Seton River (SR) water was compared with a 50% Cayoosh Creek (CC) dilution ratio. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers. A (*) indicated a significant difference

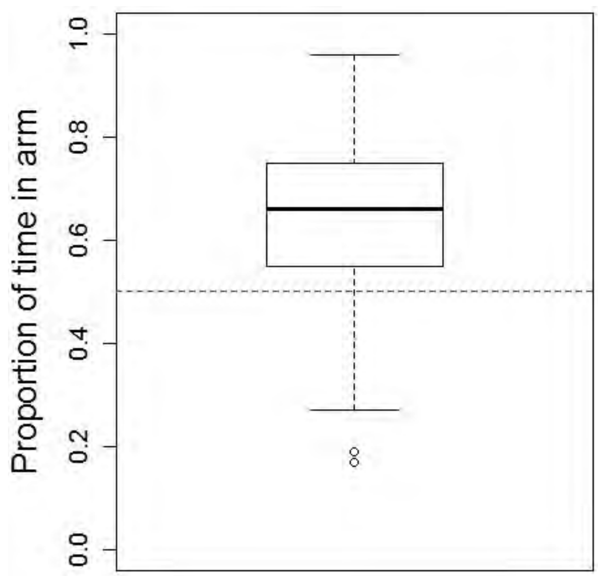

Figure 3-24: The proportion of time spent by pink salmon in the dilution mixture arm of the Y-Maze during water preference tests. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers

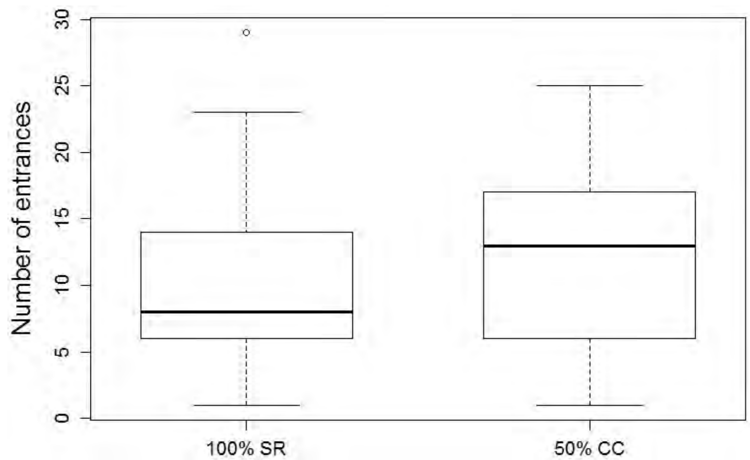

Figure 3-25: The number of entrances into each arm of the Y-Maze by pink salmon during water preference tests. 100% Seton River (SR) water was compared with a 50% Cayoosh Creek (CC) dilution ratio. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers. A (*) indicates a significant difference

3.9.3 Portage Creek Sockeye Salmon

Portage Creek sockeye did not exhibit a preference for Seton River water when tested at a dilution ratio of 10%. There was no difference in the time spent by fish in either the arm of the Y-maze (Wilcoxon signed rank test: n=35, V=337, p=0.73) (Figure 3-26) or the proportion of time spent in the arm containing the 10% dilution mixture (One-sample t-test: t=-0.6935, p=0.5) (Figure 3-27). In addition, fish did not enter either arm more frequently (Student's t-test: t=0.2253, p=0.82) (Figure 3-28).

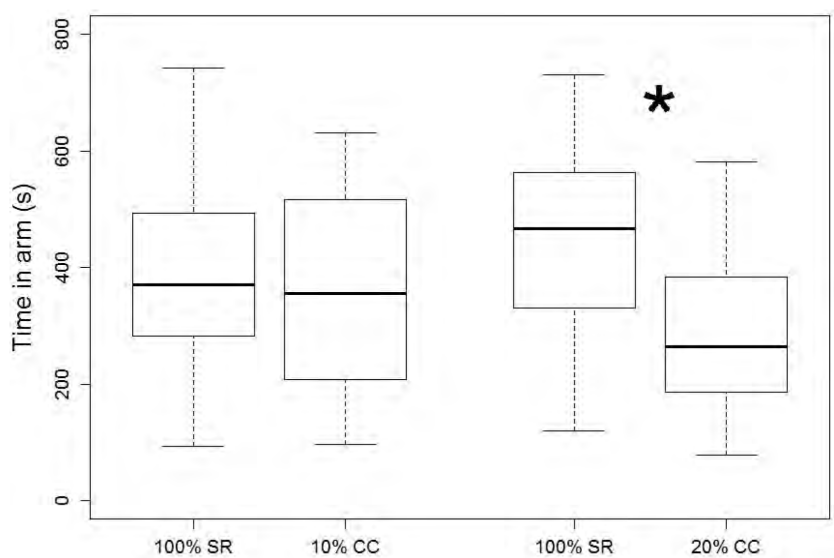

Figure 3-26: The time spent in each arm of the Y-Maze by Portage Creek sockeye salmon during water preference tests. 100% Seton River (SR) water was compared with a 10% and 20% Cayoosh Creek (CC) dilution ratio. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicates a significant difference

Portage Creek sockeye did exhibit a preference when tested with a dilution mixture of 20%, spending significantly more time in the arm with 100% Seton River water (Student's t-test: n=36, t=3.7966, p<0.01) (Figure 3-26) and a significant greater proportion of time in the arm containing pure Seton River water (One-sample t-test: μ=0.5, t=-3.4844, p=0.001) (Figure 3-27). However, there was no difference in the number of entrances into each arm (Student's t-test: t=0.8992, p=0.3747) (Figure 3-28).

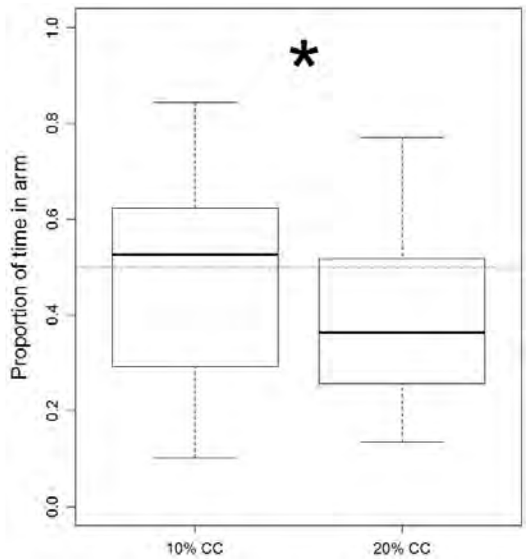

Figure 3-27: The proportion of spent in each arm of the Y-Maze by Portage Creek sockeye salmon during water preference tests. 100% Seton River (SR) water was compared with a 10% and 20% Cayoosh Creek (CC) dilution ratio. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicates a significant difference

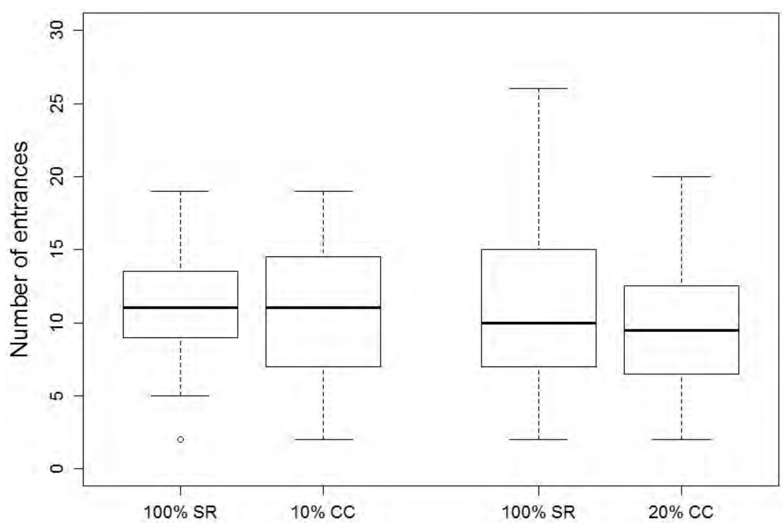

Figure 3-28: The number of entrances into each arm of the Y-Maze by Portage Creek sockeye salmon during water preference tests. 100% Seton River (SR) water was compared with a 10% and 20% Cayoosh Creek (CC) dilution ratio. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers

4.0 DISCUSSION

4.1 Key Findings

4.1.1 Dilution

In water preference experiments, Gates Creek and Portage Creek sockeye salmon demonstrated a preference for Seton River water when the Cayoosh Creek dilution ratio of the test water source was above the respective target ratios for each population. However, neither Gates Creek nor Portage Creek sockeye salmon demonstrated a preference for Seton River water when the dilution ratio was at or below the current target ratios. These results indicate that both populations continue to demonstrate a water preference and suggest that current target ratios of 20% for Gates Creek sockeye salmon and 10% for Portage Creek sockeye salmon could be effective at mitigating any potential delay during upstream migration.

Results of the present study differ slightly from that of Fretwell (1989), who found that Gates Creek sockeye salmon preferred Seton River water at a dilution ratio of 20% and that Portage Creek sockeye salmon displayed some preference for Seton River water at 10% and 15%. Methodological differences between the present study and that of Fretwell (1989) may explain the differences. Fretwell (1989) defined the water preference of an individual fish by which water source arm the fish was located in 1 h after the start of each trial. In the present study, fish behaviour was assessed more thoroughly, comparing the amount of time fish spent in each arm of the Y-Maze and the number of times fish entered each arm. Further, Fretwell (1989) tested multiple fish simultaneously, assuming that each individual was an independent sample and that its water preference was not influenced by the behaviour of other fish tested at the same time. However, since sockeye salmon exhibit schooling behaviour (Martin and Bateson 2003), fish that are tested in groups are likely to be biased towards an arm that contains other fish. The present study eliminated this potential bias by testing the water preference of individual sockeye salmon.

Seton River water temperatures are routinely warmer than Cayoosh Creek during the Gates Creek and Portage Creek sockeye salmon migrations. As the water used in the present experiments was drawn directly from each water source, water temperatures differences existed between each Y-maze arm. Sockeye salmon can exhibit water temperature preferences during migration (Goniea et al. 2006), however, Fretwell (1989) showed Gates Creek sockeye salmon did not exhibit a water preference during a control experiment when temperatures in one arm were reduced by 0.6-1.1ºC. In the present study, the water temperature in each arm of the Y-Maze also differed, typically by 0-1.3ºC. Although no control experiment was performed to assess the temperature preference behaviour of either Gates Creek or Portage Creek sockeye salmon, the temperature differences between the two water sources in the Y-maze reflected the natural migration conditions that fish would experience during their upstream migration in the Seton River.

In-river migration behaviour of Gates Creek and Portage Creek sockeye salmon at above-target dilution ratios has yet to be adequately studied. Although radio-tagged fish were released throughout the Gates Creek and Portage Creek sockeye salmon migration in 2014, elevated and prolonged in-river dilution ratios above the target ratios did not occur. While above-target dilution ratios did occur in 2013, these ratios coincided with elevated water temperatures, making it difficult to isolate the effect of elevated dilution ratios in analyses. If the in-river behaviour of sockeye salmon during high dilution ratios is to be properly studied in the final year of the BRGMON-14 program, manual increases in discharge on Cayoosh Creek via the Walden North Generating Station may be required.

4.1.2 Fish Passage at Seton Dam

Overall passage success of Gates Creek sockeye salmon at Seton Dam in 2014 was the highest observed when compared to all previous study years. Fish migration in 2014 benefitted from moderate water temperatures throughout the migration period and Seton Dam discharges that remained within the WUP target flow schedule. Passage success was similar across tag types and release locations, although acoustic-tagged fish released at the Upper Seton River site tended to have longer entrance delay than radio-tagged fish released at the Fraser River West site. All tagged fish must recover following tagging, and differences in entrance delay are likely attributable to radio-tagged fish recovering in the Fraser River whereas acoustic-tagged fish may have recovered in the Seton Dam tailrace. Lower entrance delay by radio-tagged fish suggest Fraser River West releases may provide better absolute estimates of entrance delay, although, Upper Seton River releases still allow for relative comparisons of entrance delay across conditions with increased probability of fish entering the Seton Dam tailrace.

An alternative flow scenario improved already high Gates Creek sockeye salmon passage success at Seton Dam while also increasing post-passage survival. Use of SSV4, rather than SSV1 and the FWRG, increased total Seton Dam discharge but reduced flow velocities in the fishway entrance area. The alternative flow scenario was associated with increased entrance delay, but this did not affect survival to spawning grounds. While entrance delay of Gates Creek sockeye salmon was lower during routine BC Hydro operations, post-passage delay in the Seton Dam forebay increased, possibly as a result of fish recovering after negotiation of higher flow velocities in the fishway entrance area. These results suggest the alternative flow scenario provided passage conditions in 2014 that were better suited than routine BC Hydro operations for ensuring Gates Creek sockeye salmon are successful in their upstream migration to spawning grounds.

4.2 Challenges

4.2.1 Dilution

While water preference experiments have been able to characterize the behavioural responses of Gates Creek and Portage Creek sockeye salmon at different dilution ratios in a controlled setting, opportunities to study the in-river migration behaviour of fish during high dilution ratios have been limited.

In 2013 and 2014, radio-tagged Gates Creek and Portage Creek sockeye salmon were released into the Fraser River to determine if fish delay at the Seton Generating Station during high Seton River dilution ratios. In 2013, however, high Seton River dilution ratios coincided with elevated water temperatures in the Fraser River and Seton River, confounding the study of migration behaviour. In 2014, Seton River dilution ratios did not exceed the target dilution ratios during the migration periods for Gates Creek or Portage Creek sockeye salmon. As a result, the majority of fish released into the Fraser River during the last two field seasons have experienced dilution ratios less than 10%.

Studies in 2015 would benefit from an experimental approach where Cayoosh Creek discharge is manipulated to create the elevated dilution ratios necessary to determine if Gates Creek and Portage Creek sockeye salmon continue to delay at the Seton Generating Station.

4.2.2 Seton Dam Fish Counter

Maintaining the accuracy of Gates Creek sockeye salmon passage abundance estimates required fish passage signal traces be individually reviewed to correct for a malfunctioning sensor tube. However, the sensor tube began to function correctly during the Portage Creek sockeye salmon migration. To avoid this issue in 2015, it is recommended that the sensor tubes on the Seton Dam fish counter are re-built prior to the next field season.

Video recordings of fish passage through the counter were not possible at night or during the Portage Creek sockeye salmon migration period. Night time video recordings were not possible due to the low depth penetration of an infrared light mounted above the fish counter. This prevented video validation of Chinook salmon migration, a species known to migrate primarily at night. Video recordings of Portage Creek sockeye salmon were limited by the increased turbidity of water during late-September and October. Relocating cameras to within each sensor tube and providing dedicated infrared lighting for each camera could improve video recordings. However, the addition of this equipment would have to be afforded with the current BRGMON-14 budget.

4.2.3 Coho Salmon and Chinook Salmon

Few coho and Chinook salmon have been captured for study under the BRGMON-14 program. In 2014, a total of nine coho salmon were captured at the Seton River fish fence and zero Chinook salmon. Other BRGMON programs have reported similar difficulties capturing coho and Chinook salmon in the Seton River. Moving forward, the importance of these species to the BRGMON-14 program should be reviewed.

4.3 Management Questions

4.3.1 Question 1

1.1 Are the Cayoosh flow dilution requirements for Seton River derived by the IPSFC effective for mitigating delays in migrations of Gates and Portage Creek sockeye salmon populations?

1.2 How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?

Water preference tests found that Gates Creek sockeye salmon displayed a preference for Seton River water above the current dilution target of 20%. However, no preference was observed at 20%. Similarly, Portage Creek sockeye salmon displayed a preference for Seton River water at a 20% dilution ratio, but no preference was observed at the current dilution target of 10%. Together, these data suggest the dilution requirements derived by the IPSFC should be effective for mitigating delays in the migration of Gates Creek and Portage Creek sockeye salmon. However, these data cannot be correlated with in-river migration behaviour as monitored with radio-tagged fish because too few fish have encountered elevated dilution ratios. If dilution ratios in 2015 do not exceed the target dilution ratios, it will be difficult to determine the effectiveness of the current IPSFC-derived targets for mitigating delays in the migration Gates Creek and Portage Creek sockeye salmon at the Seton Generation Station.

4.3.2 Question 2

2.1 What are the effects of Seton powerhouse operation on the upstream migration of other salmon populations (pink, Chinook, coho) migrating to the Seton-Anderson watershed?

Water preference tests in 2013 found that pink salmon did not display a preference for Seton River water and preferred a 50% dilution ratio. This result suggests that pink salmon migrating to the Seton-Anderson watershed would likely not delay at the Seton Generating Station due to high dilution. However, analysis of telemetry data from 2013 is required to determine if there are others impacts of Seton Generating Station operation on pink salmon. Pink salmon were not present on the Seton River in 2014.

Coho salmon were captured in limited numbers in 2013 and 2014. Effects of the Seton Generating Station on coho salmon migration cannot be determined due to the low number of fish tagged.

Chinook salmon migration to the Seton-Anderson watershed could not be studied in 2013 or 2014 due to the low abundance of this species.

4.3.3 Question 3

3.1 Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam?

3.2 What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?

Fish passage success at Seton Dam has varied across years, with total Seton Dam discharge, environmental conditions, and conveyance structure use all identified as important determining factors for fish passage. In 2014, moderate water temperatures and the maintenance of WUP target discharges resulted in high (>90%) overall passage success for Gates Creek and Portage Creek sockeye salmon. However, results from Gates Creek sockeye salmon acoustic accelerometer work in 2013 and an alternative flow scenario test in 2014, demonstrate that routine BC Hydro operations can impart delayed effects on fish that reduce survival to spawning grounds, even when passage success is high. Further, the alternative flow scenario tested in 2014 improved post-passage survival while also improving already high passage success. While further analysis is needed before recommendations can be made on how to mitigate fish passage issues at Seton Dam, current results suggest that fish passage at Seton Dam and survival to spawning grounds can be improved through the use of alternative conveyance structures.

4.4 Monitoring Program Schedule

A schedule of activities outlining the tasks completed in Year 3 and the revised schedule of tasks to be completed in Year 4 to Year 5 is presented in Table 4-1. All tasks proposed for Year 3 were completed as scheduled.

Table 4-1: Tasks completed in Year 1 and Year 2 of the BRGMON-14 monitoring program and the tasks proposed for Year 3 to Year 5

Task	Year 1 (2012)	Year 2 (2013)	Year 3 (2014)	Year 4 (2015)	Year 5 (2016)
1) Project Coordination	X	X	X	X	X
2) Physical Parameter Monitoring					
i. Discharge and Dilution Ratio	X	X	X	X	-
ii. Water Temperature	X	X	X	X	-
iii. Water Chemistry	X	X	X	X	-
3) Adult Salmon Telemetry					
i. Radio Transmitters	-	X	X	X	-
ii. PIT Tags	-	X	X	X	-
4) Adult Sockeye Telemetry					
i. Radio Transmitters	X	X	X	X	-
ii. Accelerometer Loggers	X	X	-	-	-
iii. Accelerometer Transmitters	X	X	X	-	-
iv. PIT Tags	-	X	X	X	-
5) Salmon Dilution Sensitivity					
i. Olfactory Sensitivity Trials	X	-	-	-	-
ii. Water Source Preference Tests	-	X	X	-	-
6) Physiology and Injury Monitoring	X	X	X	X	-
7) Fishway Fish Counter	X	X	X	X	X
8) Final Reporting	-	-	-	-	X

5.0 RECOMMENDATIONS

5.1 Status of Year 2 Recommendations

The majority of the recommendations made in Year 2 of the BRGMON-14 monitoring program were implemented in Year 3. Notable recommendations that were adopted included:

- BC Hydro implemented real-time water temperature monitoring in the Seton Dam forebay.
- An alternative flow scenario was tested at Seton Dam during the Gates Creek sockeye salmon migration period.

However, some Year 2 recommendations could not be completed:

- Additional cameras were installed at the Seton Dam fish counter, however, low visibility during the Portage Creek sockeye salmon migration prevented video observations of fish movements.
- Night time video validation at the Seton Dam fish counter was still not possible. Improved infrared lighting is required.
- A single telemetry receivers was installed at the downstream end of Portage Creek but a second upstream receiver was not installed due to budget limits.
- A second capture location study was not carried out. A transport effect study was performed instead.

5.2 Year 3 Recommendations

Based on findings in Year 1 to Year 3, the following recommendations are made for Year 4 of the BRGMON-14 monitoring program:

- Repeat the installation of a fish fence downstream of Seton Dam.
- Continue GSE screening all sockeye salmon to identify strays.
- Re-build Seton Dam fish counter sensor tubes and install additional cameras and infrared lighting to permit night time video recordings.
- Continue to release fish from the Fraser River West site, exclusively.
- Manipulate Cayoosh Creek discharge to increase Seton River dilution ratios while observing fish delay and behaviour at the Seton Generating Station.

6.0 REFERENCES

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APPENDIX I

2013 Release Site Analysis

AI.1 METHODS

AI.1.1 Release Site Analysis

Generalized linear models (GLM) were used to assess the effect of downstream release location (Fraser River West or Fraser River East) on survival to and passage of Seton Dam (family: binomial, link: logit) for radio-tagged Gates Creek sockeye salmon in 2013. Analyses were conducted to determine the validity of releasing radio-tagged fish only from the Fraser River West site in 2014, as this site was more easily accessed and allowed for greater numbers of fish to be released each day.

Three explanatory variables were included in each of the two models, including: (1) sex (male, female), (2) release location (Fraser River West, Fraser River East), and (3) release date and time. A total of 117 individuals (52 males, 65 females) were used in each of the models.

Analyses were conducted using the R (ver. 3.1.2; R Development Core Team 2012) package "MuMIn" (Barton 2012) and compared using an AIC_c approach. AIC_c weights (w_i) were used to describe the relative weights of each candidate model based on the amount of information lost by adding explanatory variables. Mean parameter estimates were calculated using the natural average method and 95% confidence interval set. Model fits were evaluated using adjusted-R^2 values.

AI.2 RESULTS

AI.2.1 Survival to Seton Dam

Release date and time was the only significant predictor of survival to Seton Dam (Table 1) explaining 23% of the variation in the data alone (Table 2). Probability of survival to Seton Dam increased with release date and time. This relationship was likely a result of a large water temperature effect observed in 2013 with temperatures decreasing steadily over the migration period. Only the third- and fourth-ranked models contained release location as factors in survival to Seton Dam (Table 2). Therefore, we concluded that release location was not a significant factor in survival to Seton Dam.

AI.2.2 Seton Dam Passage

None of the three explanatory variables were significant factors in predicting Seton Dam passage (Table 1) with the top-ranked model containing only the intercept (Table 2). Release location was a factor in the second-ranked model, however its relative weight was only 70% of the intercept model, and explained only 2% of the variation in the data.

AI.3 DISCUSSION

Release location was not a significant factor in predicting survival to or passage of Seton Dam for radio-tagged Gates Creek sockeye salmon released in 2013. Releasing radio-tagged fish from the Fraser River West in 2014 would be sufficient to study Gates Creek sockeye salmon migration and address management objectives.

Table AI-1: **Lower and upper 95% confidence intervals for variables explaining survival to and passage of Seton Dam. Explanatory variables with a significant effect are highlighted in bold (error bars do not cross zero)**

Explanatory Variable	Response Variable			
	Survival to Seton Dam		Seton Dam Passage	
	Lower CI	Upper CI	Lower CI	Upper CI
Sex	-0.8	2.6	-1.2	0.5
Release Location	-2.5	1.0	-1.3	0.3
Release Date/Time	**8.6×10^{-7}**	**4.0×10^{-6}**	-5.1×10^{-7}	1.1×10^{-6}

Table AI-1: **Model selection statistics for generalized linear models predicting A) Survival to Seton Dam and B) Seton Dam passage by radio-tagged Gates Creek sockeye salmon in 2013**

Response Variable and Model	Log Likelihood	AIC_c	ΔAIC_c	w_i	Adjusted R^2
A) Survival to Seton Dam					
Release date/time	-25.7	55.5	0.00	0.40	0.23
Release date/time + sex	-25.0	56.3	0.81	0.27	0.26
Release date/time + release location	-25.3	56.8	1.33	0.21	0.25
Release date/time + sex + release location	-24.8	57.9	2.45	0.12	0.27
B) Seton Dam Passage					
Intercept	-70.5	143.1	0.00	0.26	0.00
Intercept + release location	-69.8	143.8	0.71	0.18	0.02
Intercept + release date/time	-70.2	144.5	1.40	0.13	0.01
Intercept + sex	-70.2	144.5	1.47	0.13	0.01
Intercept + release location + sex	-69.3	144.8	1.71	0.11	0.03
Intercept + release date/time + release location	-69.6	145.5	2.40	0.08	0.02
Intercept + release date/time + sex	-69.9	146.0	2.98	0.06	0.01
Intercept + release date/time + release location + sex	-69.1	146.4	3.57	0.04	0.03

Note. ΔAIC_c represents the difference in AIC_c values between model *i* and the top-ranked candidate model. Models are ranked from lowest to highest ΔAIC_c

APPENDIX II

ADCP measurements downstream of Seton Dam
in the Seton River

ADCP Measurements Downstream of Seton Dam in the Seton River

March 2015

Report prepared for:

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EXECUTIVE SUMMARY

A field investigation was conducted in August and October 2014 to measure the flow fields and bathymetry downstream of Seton Dam. Three flow scenarios were examined: SSV1 was used for primary water release in Flow Scenarios 1 and 3, while SSV4 was used in Flow Scenario 2. Using a Teledyne H-ADCP, two-dimensional velocities (0.5 m below the water surface) were measured at 38 sections in the Seton River and at five sections (at various depths) in the dam tailrace. Particle tracking was also used to measure the velocity of water exiting SSV1 and SSV4. Topography of the riverbed and riverbanks were measured with a Trimble RTK GPS and a SonTek ADCP.

H-ADCP results showed that Flow Scenarios 1 and 3 have similar flow fields, in which the primary flow was closer to the southern bank. Two large eddies were detected near the northern bank, and a small eddy near the southern bank. Compared to Flow Scenario 1, velocity magnitudes under Flow Scenario 3 were smaller due to a reduced water discharge. Flow Scenario 2 had a very different flow field, in which the primary flow was near the middle of the river and eddies were smaller along the northern bank and larger along the southern bank. An additional eddy was detected in the dam tailrace near the fishway sidewall under Flow Scenario 2.

Water exiting SSV1 and SSV4 had an average velocity of 4.2 - 7.1 m s^{-1}. Under Flow Scenario 1, the average FWRG velocity was 2.2 m s^{-1} from its “boiling” location (3.4 m from the FWRG) to 3.25 m downstream. Outside these jet regions, the average water velocity was small in magnitude and disordered in direction, which was caused by areas of high turbulence. Water velocity in the radial gate spillway was close to zero. Based on fieldwork conducted in 2013 and 2014, it can be concluded that an ADCP has a limited measurement range in the dam tailrace due to the highly turbulent, air-water two-phase flow.

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ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

This field study is the second and final year investigating the flow fields downstream of Seton Dam (see Fig. 1 and 2). Results from the first year (2013) were summarized in Zhang *et al.* (2014). Two additional flow scenarios were examined in the second year (2014). In 2014, more measurements were taken in the dam tailrace, and bathymetry of the Seton River was surveyed.

The main objective of this study was to measure the flow fields in the dam tailrace and Seton River for three distinct operational scenarios using an Acoustic Doppler Current Profiler (ADCP). Ultimately, these measurements will be linked to fish telemetry data.

A secondary objective was to survey the bathymetry of the Seton River. River bathymetry, together with engineering drawings of the dam tailrace, will be inputted into a computational fluid dynamics (CFD) model to numerically investigate flow fields under a number of other operational scenarios. CFD models will supplement our understanding of flow scenarios that cannot be investigated in the field.

2.0 METHODS

Field measurements of flow fields and river bathymetry were conducted in August and October 2014, respectively. Flow fields were measured using a Teledyne RD Instrument ChannelMaster 1200 kHz H-ADCP (see Fig. 3). Zhang *et al.* (2014) describe the working mechanism of the H-ADCP. From the H-ADCP, two-dimensional (longitudinal and transverse) velocities can be simultaneously obtained along a horizontal straight line of a river section.

A total of three flow scenarios were investigated due to the change of dam operations (see Table 1). Under Flow Scenarios 1 and 3, SSV1 was open and all other siphons and radial gate were closed. SSV4 was open under Flow Scenario 2 (Fig. 4).

For each of the three flow scenarios, a total of 43 ADCP sections were measured (Fig. 5), which covered the dam tailrace and the Seton River approximately 110 m downstream of the tailrace. Sections 1-20 and 21-35 were at the northern and southern riverbanks respectively, where the H-ADCP was set at a depth of 0.5 m to both the water surface and the riverbed. Sections 36-38 were in the radial gate spillway where the H-ADCP was set at 0.5 m below the water surface.

Sections X1-X5 were in the dam tailrace downstream of the siphon spillway, where the H-ADCP was set at 0.5 - 1 m below the water surface and systematically lowered 0.5 m until the tailrace bed (or until the maximum depth of the ADCP frame). Compass bearings (relative to magnetic north) of the ADCP sections were recorded with a compass on an iPhone, and were later adjusted to be relative to true north (see Table 2).

For the river sections, the H-ADCP was mounted onto a “T”-shaped frame (Fig. 6). For the sections in the dam tailrace, a specially designed frame was built to mount the H-ADCP (Fig. 7). This frame consisted of a 40-ft extension ladder, parapet clamps for fixing the ladder to the concrete fishway sidewall, a rotatable steel plate for rotating the ladder, a steel plate at the bottom of the ladder for mounting the H-ADCP, and a pulley system for lifting and lowering the ladder.

ADCP acoustic beams cannot penetrate the “white” water region due to a high concentration of bubbles in the dam tailrace (Zhang *et al.* 2014). Because of this, we cannot use the ADCP unit to directly measure the flows released from SSV1 and SSV4. Instead, we used particle tracking to estimate the velocity of water exiting SSV1 and

SSV4 in 2014. Particles, made of foam or wood in known shapes and dimensions, were thrown into the jet region. Particle velocity was calculated using the known travel distance and time. Particle materials, sizes and shapes, and tracking results are listed in Table 3.

Bathymetry of the Seton River was measured by using Trimble R8 RTK GPS (Fig. 8) and SonTek 3.0 MHz ADCP (Fig. 9). We used a RTK GPS to provide coordinates (easting, northing and elevation) for the edge of the water, section locations for Teledyne H-ADCP, and the top and bottom of the riverbanks. To build a RTK base station, points with known coordinates are needed. At Seton Dam, only two Canada Geodetic Survey BM points (82C151 and 82C152) are available. Horizontal data (easting and northing) for these two points are not accurate, as they were scaled from the map (Canada Geodetic Survey). When the coordinates were input into Google Earth, the two points were over 100 m away from their actual positions. However, elevations were accurate according to the official website.

In this survey, the RTK GPS base station was set up in the dam compound along the northern bank (see Fig. 8a). Coordinates of the base control point were input into the GPS by using a static measurement mode. All of the recorded GPS horizontal data were adjusted based on comparison with over 10 points (e.g., corners of fishway walls) of the dam in Google Earth. Elevation data were adjusted by comparing the measured coordinates of 82C152 with its known elevation. Satellite signals were blocked at 82C151 as it was located too close to the dam. After adjustment, the GPS unit had an accuracy of < 1 m for the horizontal coordinates and a few centimeters for the elevation data. Accuracy of relative positions between measurement points is 1 cm for horizontal position and 2 cm for elevation.

A SonTek 3.0 MHz ADCP was mounted onto a RiverCat (yellow boat; see Fig. 9) and towed across the Seton River to measure bathymetry. During towing, the bottom-tracking function of the SonTek ADCP was used to measure riverbed topography at a total of 40 sections. Start and end points of all towing sections were recorded by RTK GPS. We ensured that the SonTek ADCP unit was in a straight line (see Fig. 9b).

3.0 RESULTS AND ANALYSIS

3.1 Integrated Water Velocity Field

ADCP measurements from all 43 sections are integrated in Fig. 10-12 for each of the three flow scenarios. Detailed measurements at each section for each flow scenario are provided in Appendix I.

Flow fields (on the horizontal plane at 0.5 m below the water surface) were similar under Flow Scenarios 1 and 3 (Figs. 10 & 12), and similar to the flow field measured in 2013 (Zhang *et al.* 2014). Overall, recirculation (eddies) of water was detected in three areas, agreeing with observations and particle tracking in the field. We detected two large eddies near the northern bank: one located between Sections 9 and 19, and a second located between Sections 37 and 8. A third eddy was detected between Sections 26 and 30 near the southern bank, and was significantly smaller than the other two eddies. A notable difference between Flow Scenario 1 and 3 was the velocity magnitude in Flow Scenario 1 was larger due to a higher FWRG discharge (see Table 1).

Unlike Flow Scenarios 1 and 3, SSV4 released the majority of water from the dam under Flow Scenario 2. This resulted in a drastically different flow field compared to the other two scenarios. Water exiting SSV4 was closer to the middle of Seton River, creating eddies of similar sizes near both banks (Fig. 11). Under Flow Scenario 2, eddies near the northern bank were compressed, while eddies along the southern bank were enlarged. Eddy locations near the northern bank were similar under Flow Scenarios 1 and 2, suggesting that river bathymetry (Fig. 23) was an important factor in determining eddy locations. We detected another eddy in the dam tailrace near the southern bank.

3.2 Water Velocity in the Dam Tailrace

ADCP results in the dam tailrace are presented in Figs. 13-22. Under Flow Scenario 1, the velocity magnitudes were small at Sections X1 and X3 (Figs. 13-14). Flows were so turbulent under this flow scenario that water released from SSV1 moved back and forth, resulting in small time-averaged values.

Under Flow Scenario 2, fewer bubbles were present in the dam tailrace near the fishway sidewall (Fig. 4), allowing the H-ADCP to measure a larger range (Figs. 15-19) than in Flow Scenario 1. Velocities were small in magnitude and organized in direction under this flow scenario. At Section X3, velocity direction at a depth of 2.6 m was reversed compared to those at other water depths (Fig. 17). A similar phenomenon occurs at Section X4 (Fig. 18). At Section X5, measurements were only taken at one water depth, as the total water depth was only 0.96 m.

Under Flow Scenario 3 (Figs. 20-22), measurements were taken at Sections X2, X4 and X5. We chose these sections because they were not measured under Flow Scenario 1 and the two flow scenarios were very similar to each other (Table 1). At Section X2, the direction of flow changed at different depths. At Sections X4 and X5, the measurement range was small due to the presence of bubbles in the water column.

Particle tracking results are listed in Table 3-5. Under Flow Scenario 1, the particles were released into the water exiting SSV1 approximately 1 m upstream of the jet impingement location. At this location, the maximum velocity of particles was 5.8 m s^{-1} (Table 3a). When the particles were released right at the exit of SSV1, the maximum velocity was 7.1 m s^{-1} for wood particles and 5.7 m s^{-1} for foam particles (Table 3b). Wood particles are heavier than foam particles, allowing them to enter closer to the center of water flow and possessing velocities closer to the actual velocity of water exiting SSV1. Average velocity of water exiting SSV1 was 7.1 m s^{-1} from the exit to 20 m downstream. Similarly, the average velocity of water exiting the FWRG boiling location (3.4 m from the FWRG) to 3.25 m downstream was 2.2 m s^{-1} (Table 3c).

Under Flow Scenario 2, the average velocity of water exiting SSV4 was 6.6 m s^{-1} from the exit to 24 m downstream (Table 4). Under Flow Scenario 3, the average velocity of water exiting SSV1 was 4.2 m s^{-1} from the exit to 13 m downstream (Table 5). Overall, the results from particle tracking indicate that velocities are not sensitive to particle materials, shapes and sizes.

3.3 River Bathymetry

A summary of the bathymetry results from T1 – T40 in the Seton River are presented in Fig. 23. Detailed results for all transects are presented in Appendix II.

4.0 CONCLUSIONS

In this field investigation, flow fields were examined downstream of Seton Dam in both the dam tailrace and in the Seton River. A total of three flow scenarios were studied: SSV1 was open under Flow Scenarios 1 and 3, while SSV4 was open under Flow Scenario 2. For each flow scenario, a Teledyne RD Instrument Channel Master 1200 kHz H-ADCP was used to measure two-dimensional velocity at the horizontal plane of 0.5 m water depth in the river, and at various depths in the dam tailrace. Particle tracking was used to measure the velocity of water exiting SSV1 and SSV4. Trimble R8 RTK GPS and SonTek 3.0 MHz ADCP were used to measure the topography of riverbed and riverbanks.

We have five main conclusions:

Overall, flow fields were similar under Flow Scenarios 1 and 3, in which the primary release of water was closer to the southern bank. Two large eddies and one smaller eddy were detected near the northern and southern banks, respectively.

Flow Scenario 2 had a drastically different flow field than the other two scenarios, in which the primary release of water in the middle of the river created eddies of similar sizes near the two banks. An additional eddy was detected in the dam tailrace near the fishway sidewall.

In the dam tailrace, the average velocity of water exiting SSV1 was 7.1 m s^{-1} from the exit of SSV1 to 20 m downstream under Flow Scenario 1, 6.6 m s^{-1} from SSV4 exit to 24 m downstream under Flow Scenario 2, and 4.2 m s^{-1} from SSV1 exit to 13 m downstream under Flow Scenario 3. Average velocity of water exiting the FWRG boiling location (3.4 m from the FWRG) to 3.25 m downstream was 2.2 m s^{-1} under Flow Scenario 1.

Time-averaged water velocities were typically small in the region away from SSV1 (or SSV4) and FWRG in the dam tailrace. In these areas, flow direction was disordered and reversed at some water depths, a phenomenon caused by the highly turbulent water (exiting SSV1 or SSV4) interacting with the baffle blocks in the tailrace.

Generally, an ADCP has a limited measurement range (as small as a few meters) in the dam tailrace in the presence of highly turbulent, air-water two-phase flow. Future studies using ADCP units to measure flow fields downstream of dams should focus on regions with fewer bubbles in the tailrace and in the river downstream.

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Table 1. Summary of the three flow scenarios under investigation.

Flow Scenario	Total discharge ($m^3 s^{-1}$)	Discharge components ($m^3 s^{-1}$)							
		Fishway	FWRG	SSV1	SSV2	SSV3	SSV4	SSV5	Radial gate spillway
1	28.5	1.1	7.6	19.8	-	-	-	-	-
2	28.5	1.1	1.9	-	-	-	25.5	-	-
3	23.4	1.1	2.5	19.8	-	-	-	-	-

Table 2. Detailed locations of ADCP sections.

Location	Section	Easting (m)	Northing (m)	Angle clockwise from true north to the section (°)		
				Flow Scenario 1	Flow Scenario 2	Flow Scenario 3
Northern bank of Seton River	S1	572257.78	5613612.38	149	147	148
	S2	572259.66	5613613.53	154	137	157
	S3	572261.43	5613613.92	154	149	157
	S4	572263.81	5613614.92	144	147	157
	S5	572265.15	5613615.52	154	147	162
	S6	572267.82	5613615.86	154	158	157
	S7	572270.99	5613616.84	154	155	174
	S8	572274.09	5613618.41	154	154	167
	S9	572276.91	5613619.53	144	157	161
	S10	572280.11	5613621.76	149	157	137
	S11	572282.67	5613625.23	134	152	149
	S12	572285.80	5613628.38	159	157	167
	S13	572289.75	5613631.75	144	149	147
	S14	572294.55	5613635.46	159	154	157
	S15	572299.00	5613638.76	159	140	147
	S16	572305.39	5613641.78	154	154	152
	S17	572311.90	5613644.72	159	159	152
	S18	572318.01	5613643.71	159	165	165
	S19	572331.80	5613646.40	159	170	152
	S20	572352.10	5613653.35	164	170	157
Southern bank of Seton River	S21	572291.58	5613578.08	329	337	342
	S22	572293.79	5613577.88	344	337	342
	S23	572294.04	5613578.70	332	337	335
	S24	572297.05	5613580.16	350	337	337
	S25	572301.12	5613581.54	350	330	327
	S26	572305.48	5613582.86	357	345	346
	S27	572311.39	5613582.50	345	347	340
	S28	572315.60	5613584.40	345	334	347
	S29	572318.68	5613586.87	350	338	344
	S30	572324.26	5613590.77	346	326	342
	S31	572328.79	5613595.64	345	325	343
	S32	572334.57	5613599.15	342	330	340
	S33	572341.45	5613602.24	350	336	340
	S34	572355.12	5613604.53	350	341	337
	S35	572364.67	5613609.41	345	341	343
Radial gate spillway	S36	572260.73	5613605.69			
	S37	572259.54	5613605.01		157	
	S38	572252.37	5613601.68			
Along fishway sidewall	X1	572258.86	5613567.19			
	X2	572262.86	5613568.91			
	X3	572265.53	5613570.17		337	
	X4	572269.81	5613572.23			
	X5	572282.6	5613578.08			

Table 3. Particle tracking setting and results for Flow Scenario 1.

(a) Particle released into the jet of SSV1, 1 m upstream of the jet impingement location.

Particle information					t (s)	Travel distance (m)	Velocity ($m\ s^{-1}$)
Material	No.	L (cm)	W (cm)	H (cm)			
Wood	1	13.5	13.5	3.5	2.75	16	5.8
	2	13.5	11.5		2.72	6	2.2
	3	13.5	13.5		-	-	-
	4	14	11		3.84	12	3.1
	5	13	13		3.44	15	4.4
	6	20	13		3.56	9	2.5
	7	20	13		2.28	7	3.1
	8	14.5	9		5.28	15	2.8

(b) Particle released into the jet of SSV1, right at the jet exit.

Particle information					t (s)	Travel distance (m)	Velocity ($m\ s^{-1}$)
Material	No.	L (cm)	W (cm)	H (cm)			
Wood	1	14.5	13.5	3.5	6.22	27.5	4.4
	2	20	13.5		4.66	16.5	3.5
	3	30	13.5		11.5	24	2.1
	4	40	13		3.47	14.6	4.2
	5	30	8.5		5.68	26	4.6
	6	30	13.5		-	-	-
	7	15	9		6.65	22	3.3
	8	14	9		9.81	20	2.0
	9	50	13.5		4.41	24	5.4
	10	43	13.5		2.82	20	7.1
Foam	1	Circular disk d = 14 cm H = 4 cm			2.47	14	5.7
	2				4.97	23	4.6
	3				4.79	20	4.2
	4				3	12	4.0
	5				3.28	14	4.3
	6				2.69	12	4.5
	7				5.19	21	4.0
	8				3.53	15	4.2
	9				-	-	-
	10				4.03	20	5.0
	11				4.22	19	4.5
	12				3.25	14	4.3
	13				4.12	17	4.1
	14				3.38	13	3.8
	15				3.28	12	3.7
	16				4.97	23	4.6

Table 3 continued

(c) Particle released downstream of FWRG boiling location (4.5 m north of fishway entrance).

Particle information					t (s)	Travel distance (m)	Velocity (m s^{-1})
Material	**No.**	**L (cm)**	**W (cm)**	**H (cm)**			
Wood	1	29	14	3.5	-	3.25	-
	2				1.51		2.2
	3				1.59		2.0
	4				1.65		2.0
	5				1.69		1.9
	6				-		-
Foam	1	Circular disk d = 14 cm H = 4 cm			1.62	3.25	2.0
	2				1.5		2.2
	3				-		-
	4				1.81		1.8
	5				1.41		2.3
	6				2.53		1.3
	7				1.84		1.8
	8				-		-

Table 4. Particle tracking setting and results for Flow Scenario 2.

(a) Particle released into the jet of SSV4, right at the jet exit.

Particle information					t (s)	Travel distance (m)	Velocity (m s^{-1})
Material	**No.**	**L (cm)**	**W (cm)**	**H (cm)**			
Wood	1	14	14	3.5	6.64	23	3.5
	2				7.64	24	3.1
	3				4.58	24	5.2
	4				4.53	23	5.1
	5				3.56	20	5.6
	6				6.56	25	3.8
	7				6.76	24	3.6
	8				6.79	24	3.5
	9				3.83	23	6.0
	10				3.65	24	6.6
	11				4	23	5.8
	12				4.93	22	4.5
	13				3.43	20	5.8
	14				-	-	-
	15				5.92	23	3.9
	16				5.15	23	4.5
Foam	1	Circular disk d = 14 cm H = 4 cm			3.89	20	5.1
	2				-	-	-
	3				4.06	24	5.9
	4				3.73	20	5.4
	5				8.34	22	2.6
	6				5.89	23	3.9
	7				4.19	20	4.8
	8				3.59	17	4.7
	9				5.16	20	3.9
	10				4.29	22	5.1
	11				-	-	-
	12				6.17	23	3.7
	13				3.22	21	6.5
	14				5.14	20	3.9
	15				/	/	/
	16				3.51	19	5.4
	17				6.64	22	3.3
	18				4.01	19	4.7
	19				3.89	20	5.1

Table 5. Particle tracking setting and results for Flow Scenario 3.

(a) Particle released into the jet of SSV1, right at the jet exit.

Particle information					t (s)	Travel distance (m)	Velocity (m s^{-1})
Material	**No.**	**L (cm)**	**W (cm)**	**H (cm)**			
Wood	1	14	14	4	-	-	-
	2				3.13	13	4.2
	3				5.34	21	3.9
	4				8.06	20	2.5
	5				-	-	-
	6				4.35	15	3.4
	7				-	-	-
	8				4.68	13	2.8
	9				7.6	18	2.4
	10				5.5	19	3.5
	11				-	-	-
	12				4.96	13	2.6
	13				5.75	18	3.1
	14	25	14	4	4.15	15	3.6
	15				5.59	21	3.8
	16				5.6	20	3.6
	17				5.07	15	3.0
	18				6.31	14	2.2
	19				5.29	19	3.6
Foam	1	Circular disk d = 14 cm H = 3.5 cm			-	-	-
	2				3.34	13	3.9
	3				3.22	12	3.7
	4				3.22	11	3.4
	5				3.06	10	3.3
	6				5.9	13	2.2
	7				3.43	11	3.2
	8				4.31	16	3.7
	9				3.82	13	3.4
	10				3.5	11	3.1
	11				3.04	10	3.3
	12				5.34	10	1.9
	13				3.5	14	4.0
	14				2.72	10	3.7
	15				3.81	11	2.9
	16				3.09	11	3.6

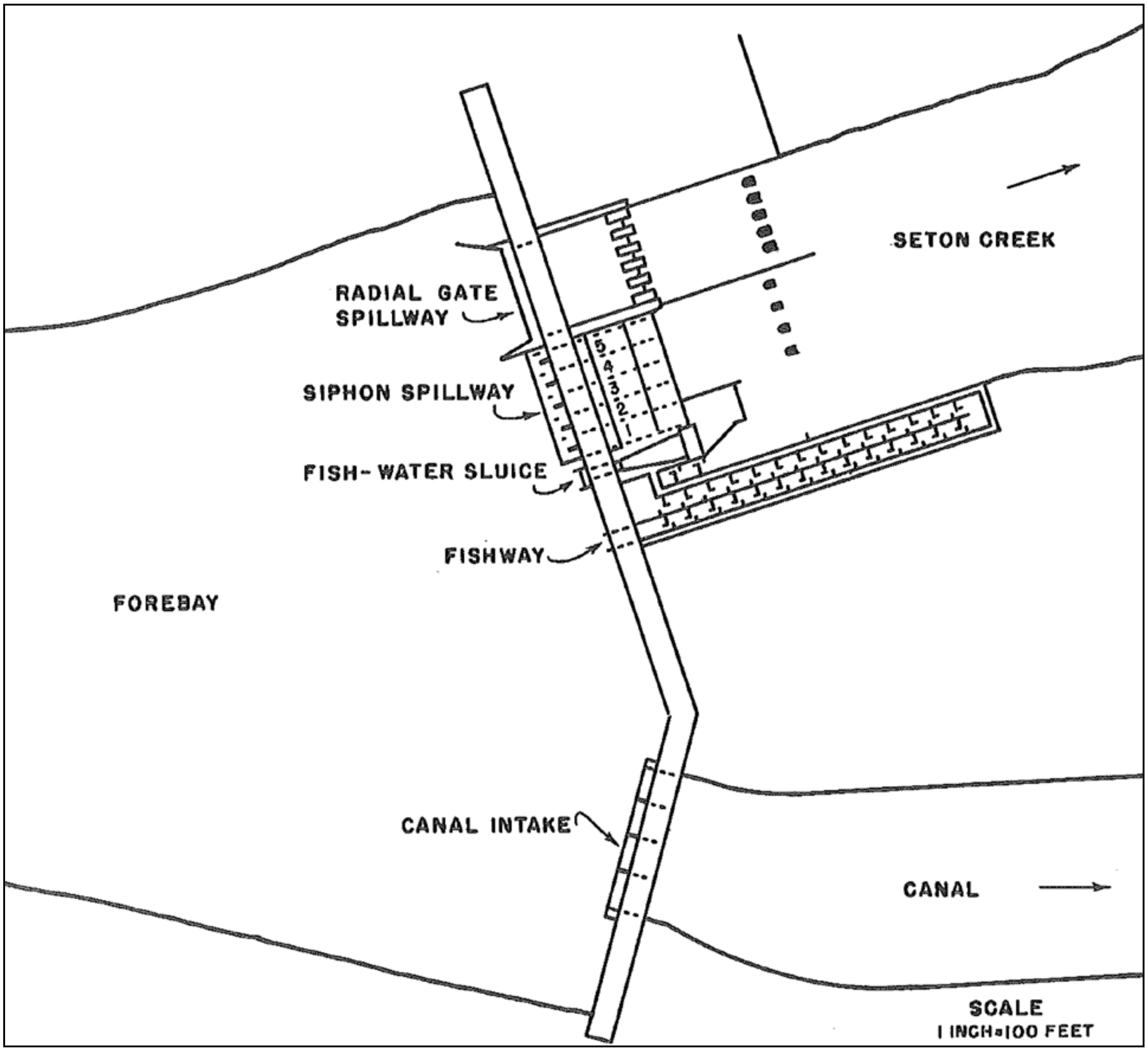


Figure 1. Plan view of Seton Dam (Andrew and Geen 1958).

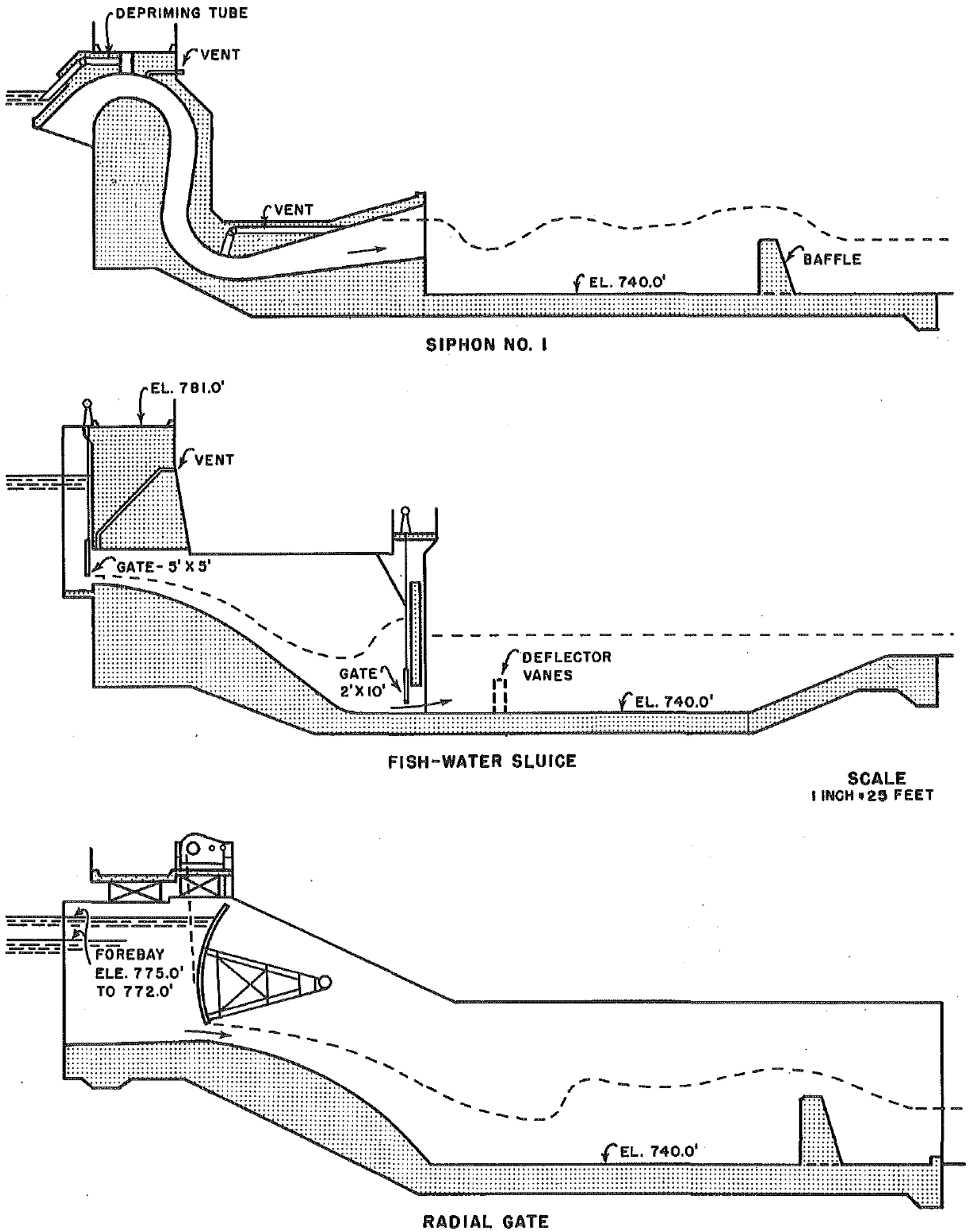


Figure 2. Side view of SSV1, FWRG and the radial gate spillway (Andrew and Geen 1958).

Figure 3. Teledyne RDI ChannelMaster H-ADCP 1200 kHz.

Figure 4. Photos of Flow Scenarios 1-3.

Figure 5. ADCP measurement sections in 2014.

Figure 6. (a) ADCP "T"-shaped frame for measurements in the Seton River. (b) H-ADCP during measurement.

Figure 7. ADCP frame for measurements in the dam tailrace.

Figure 8. (a) RTK base station. (b) RTK rover for bank topography, section location and edge of water.

Figure 9. Towing the Sontek ADCP across the river to measure bathymetry.

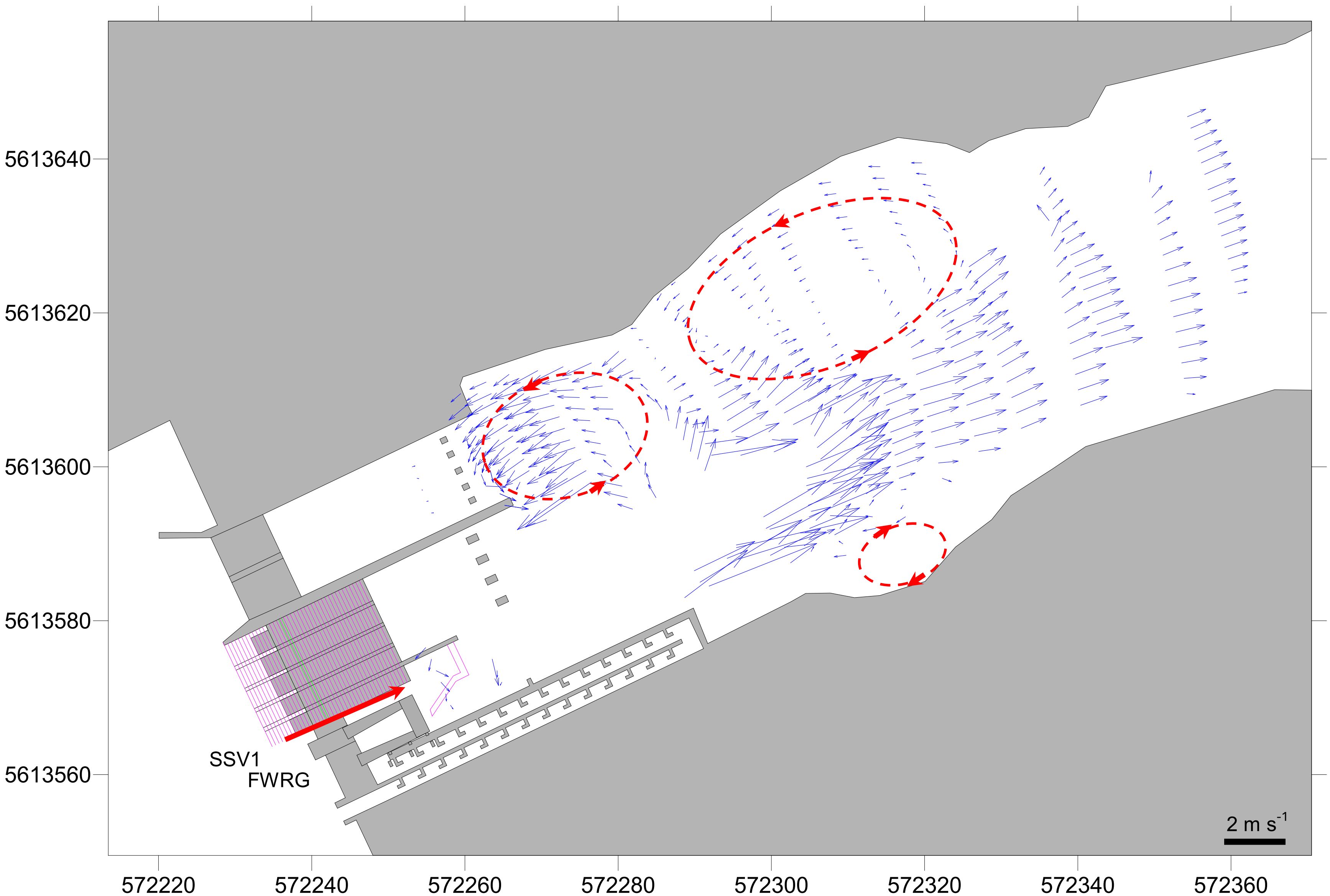


Figure 10. Flow Scenario 1 flow field measured by an ADCP at a water depth of 0.5 m. Note that the flow field is plotted at every eight measurement points..

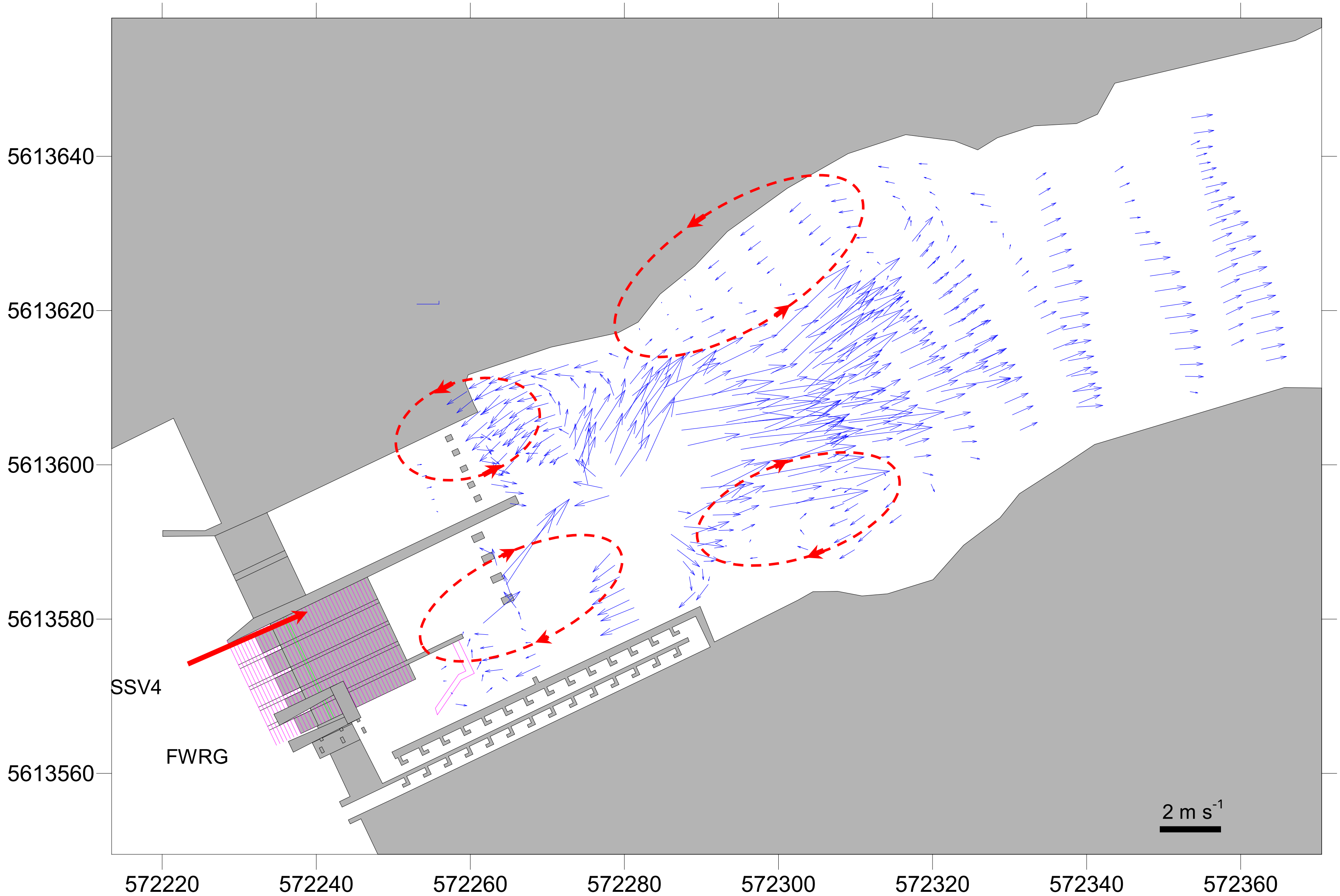


Figure 11. Flow Scenario 2 flow field measured by an ADCP at a water depth of 0.5 m. Note that the flow field is plotted at every eight measurement points.

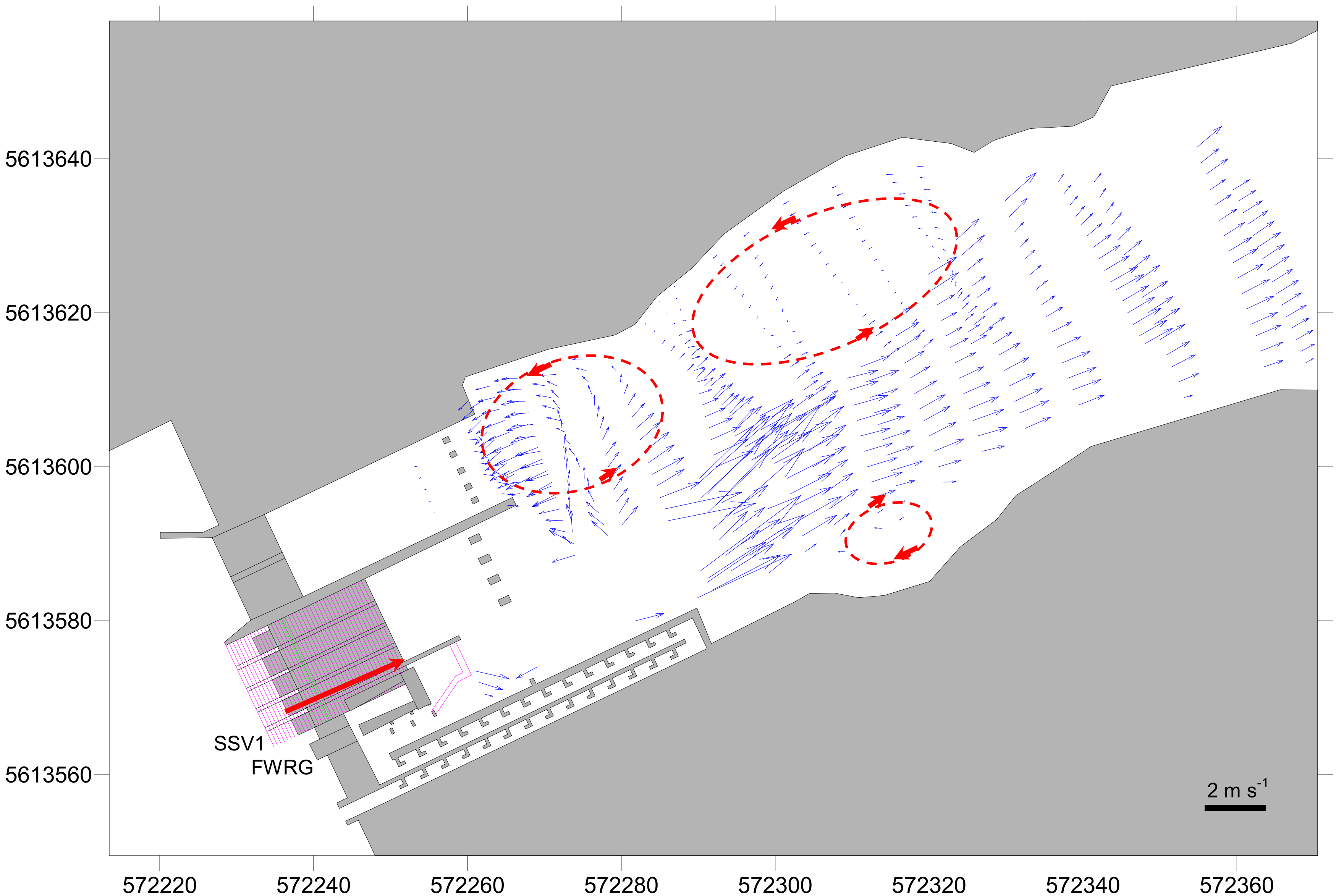
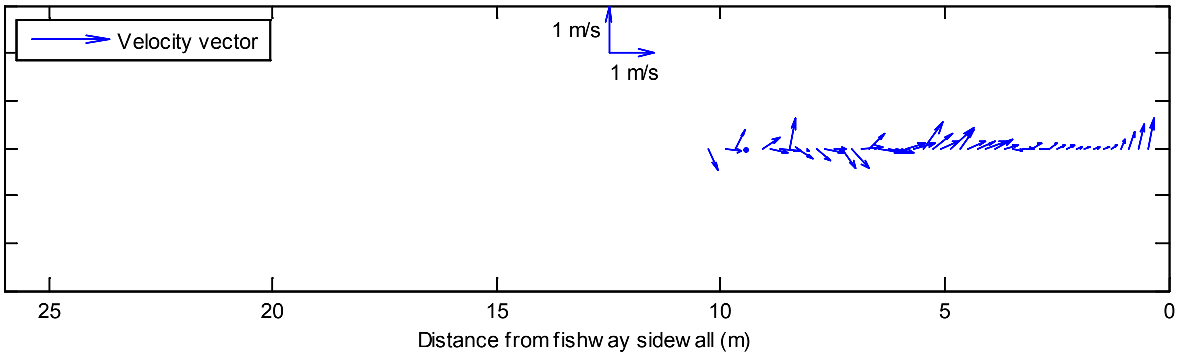


Figure 12. Flow Scenario 3 flow field measured by an ADCP at a water depth of 0.5 m. Note that the flow field is plotted at every eight measurement points.

Depth = 0.95 m



Depth = 1.52 m

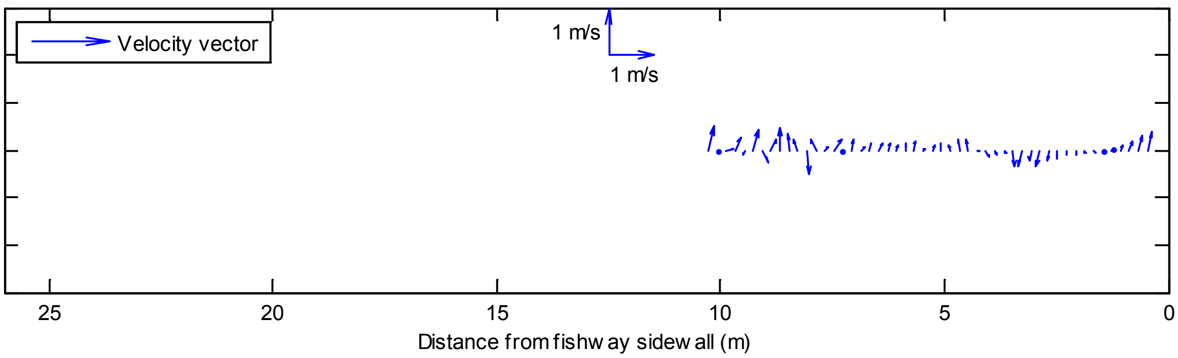


Figure 13. ADCP results at Section X1 for Flow Scenario 1.

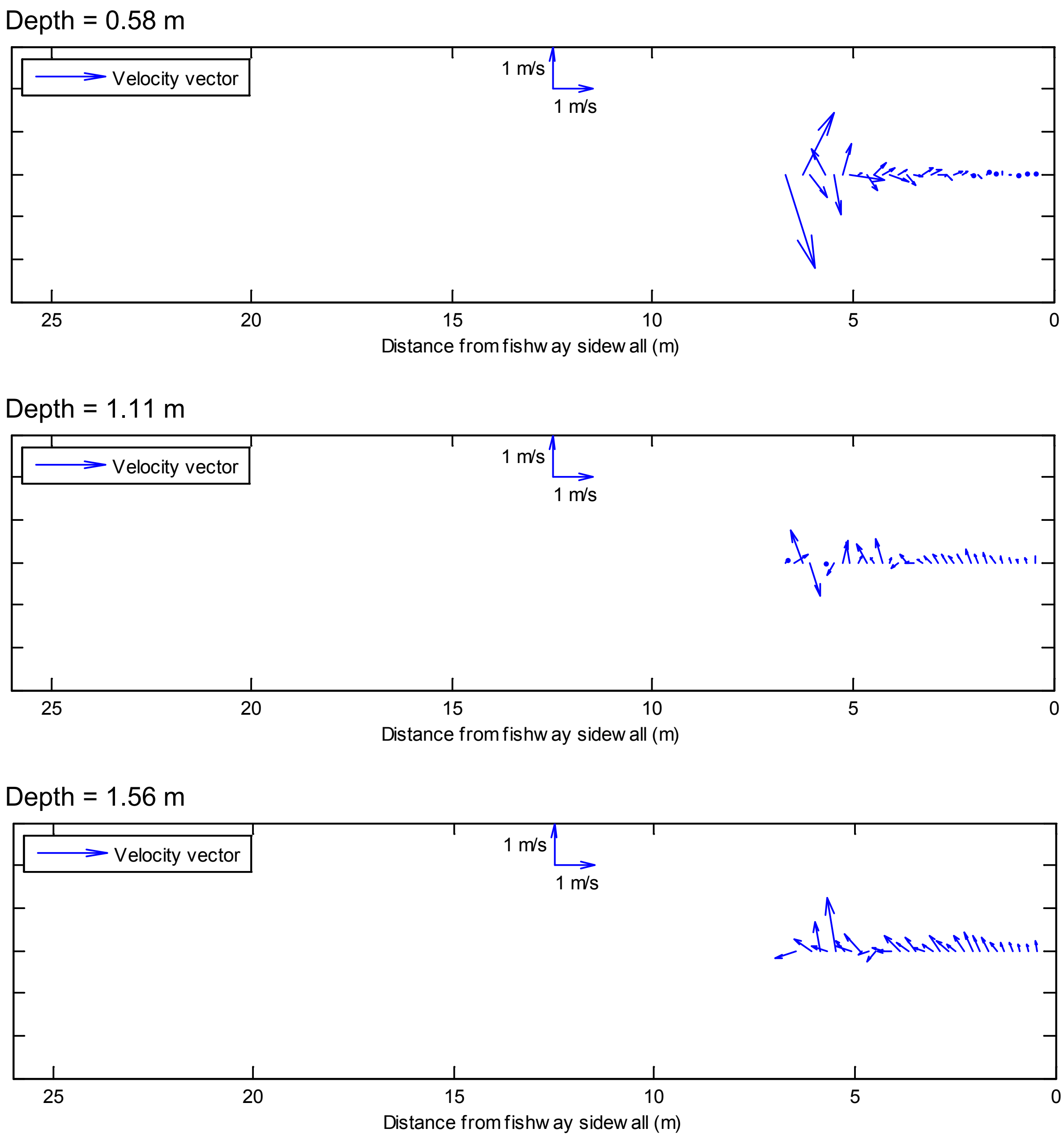


Figure 14. ADCP results at Section X3 for Flow Scenario 1.

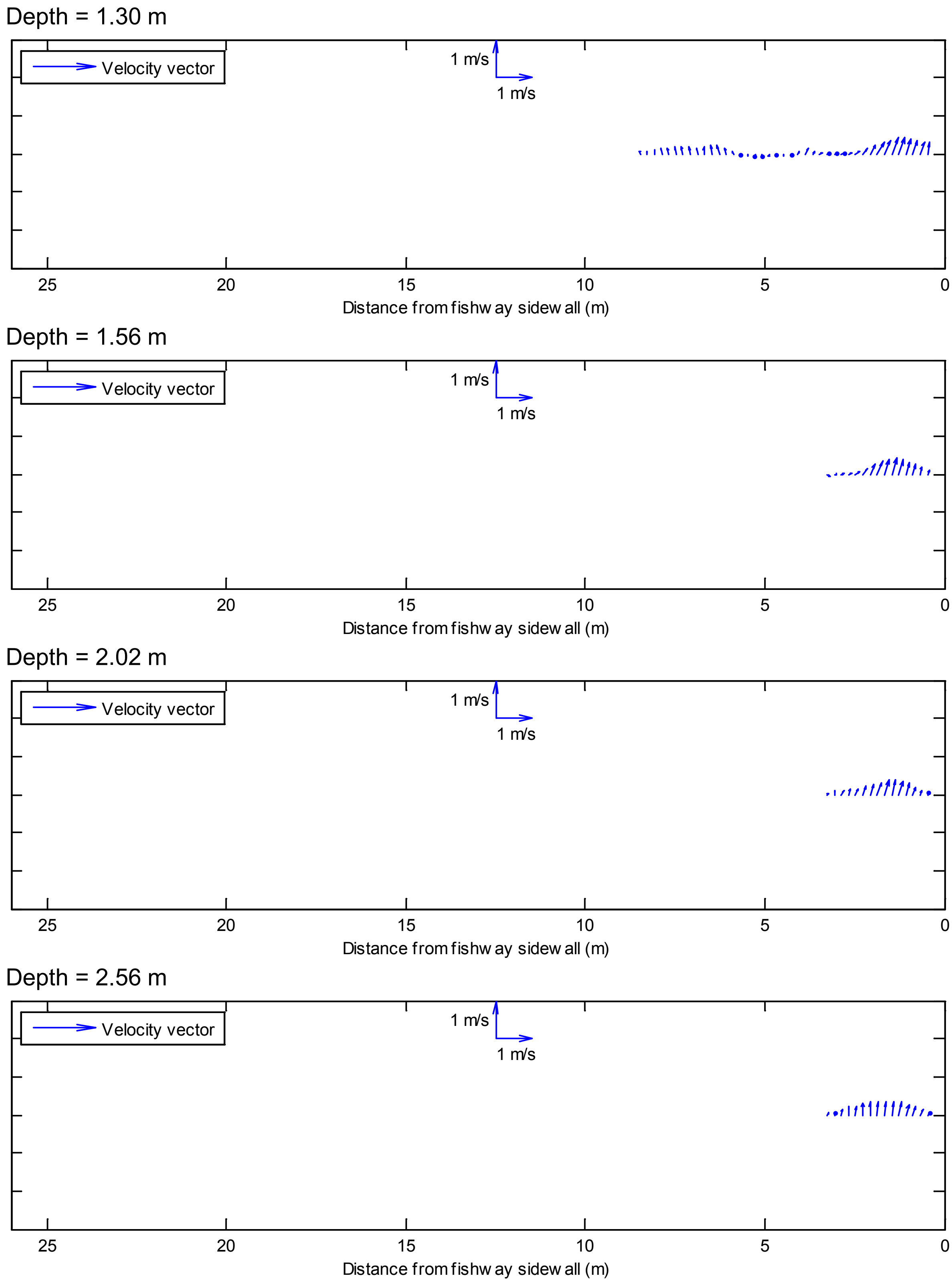


Figure 15. ADCP results at Section X1 for Flow Scenario 2.

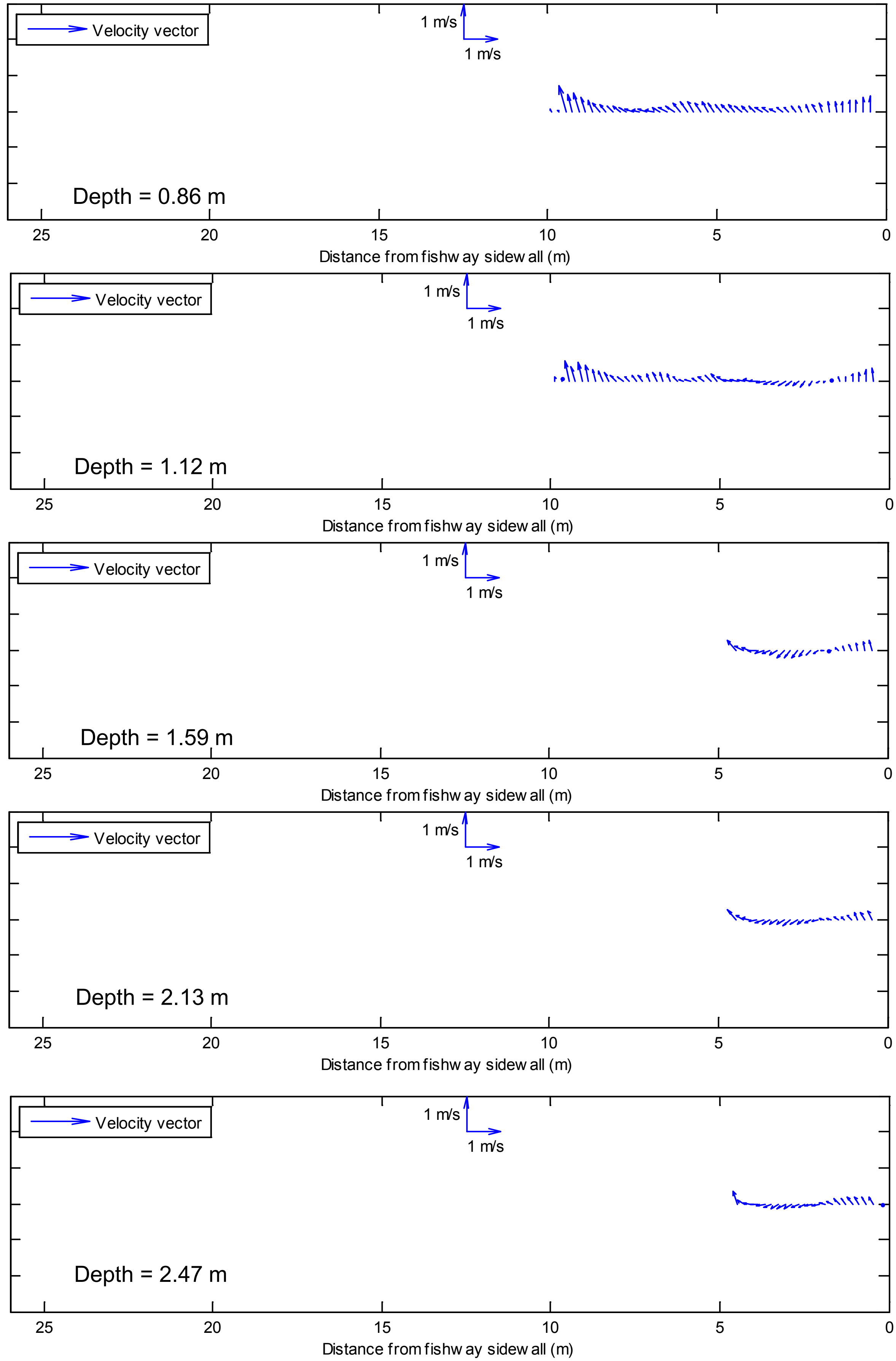


Figure 16. ADCP results at Section X2 for Flow Scenario 2.

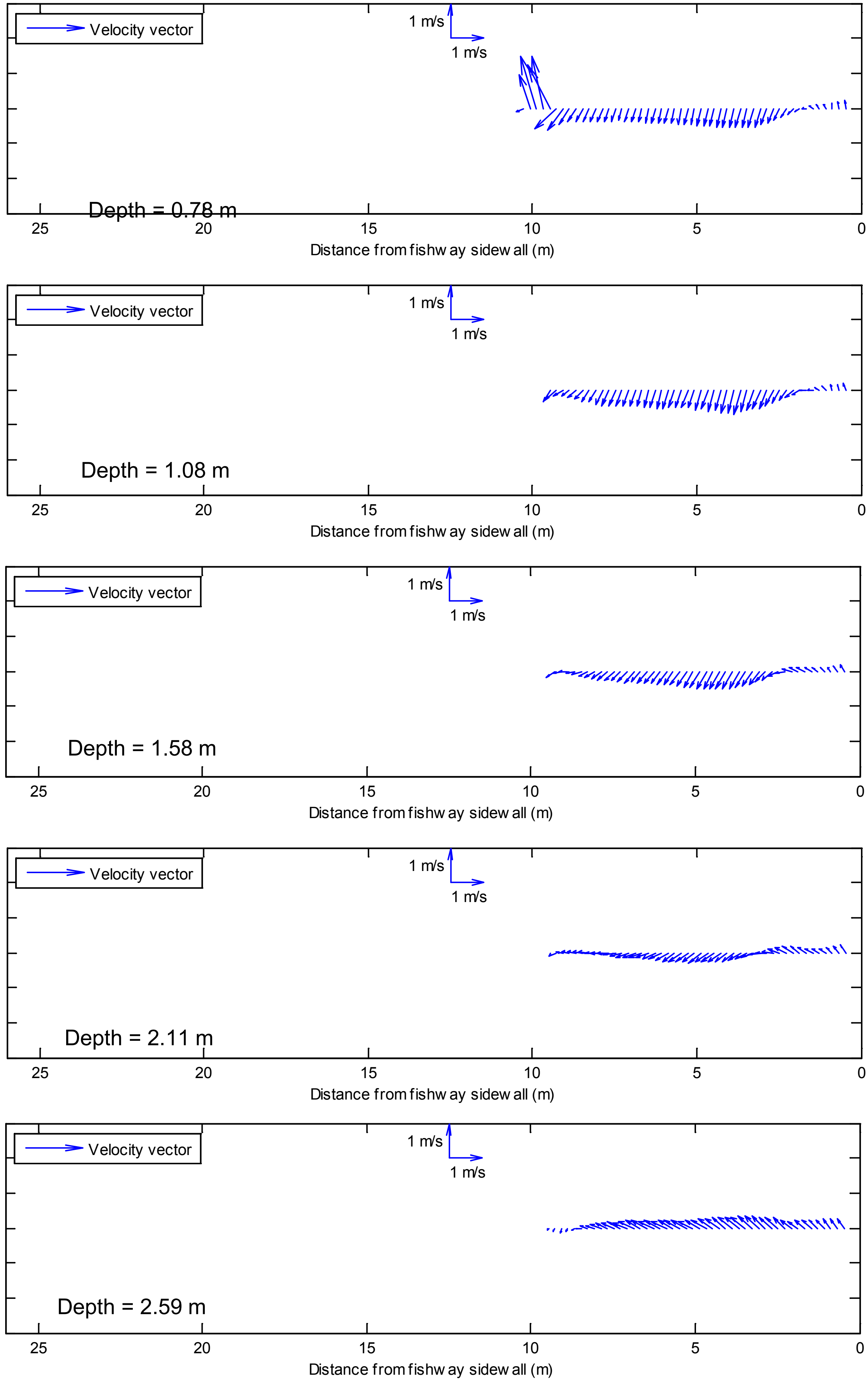


Figure 17. ADCP results at Section X3 for Flow Scenario 2.

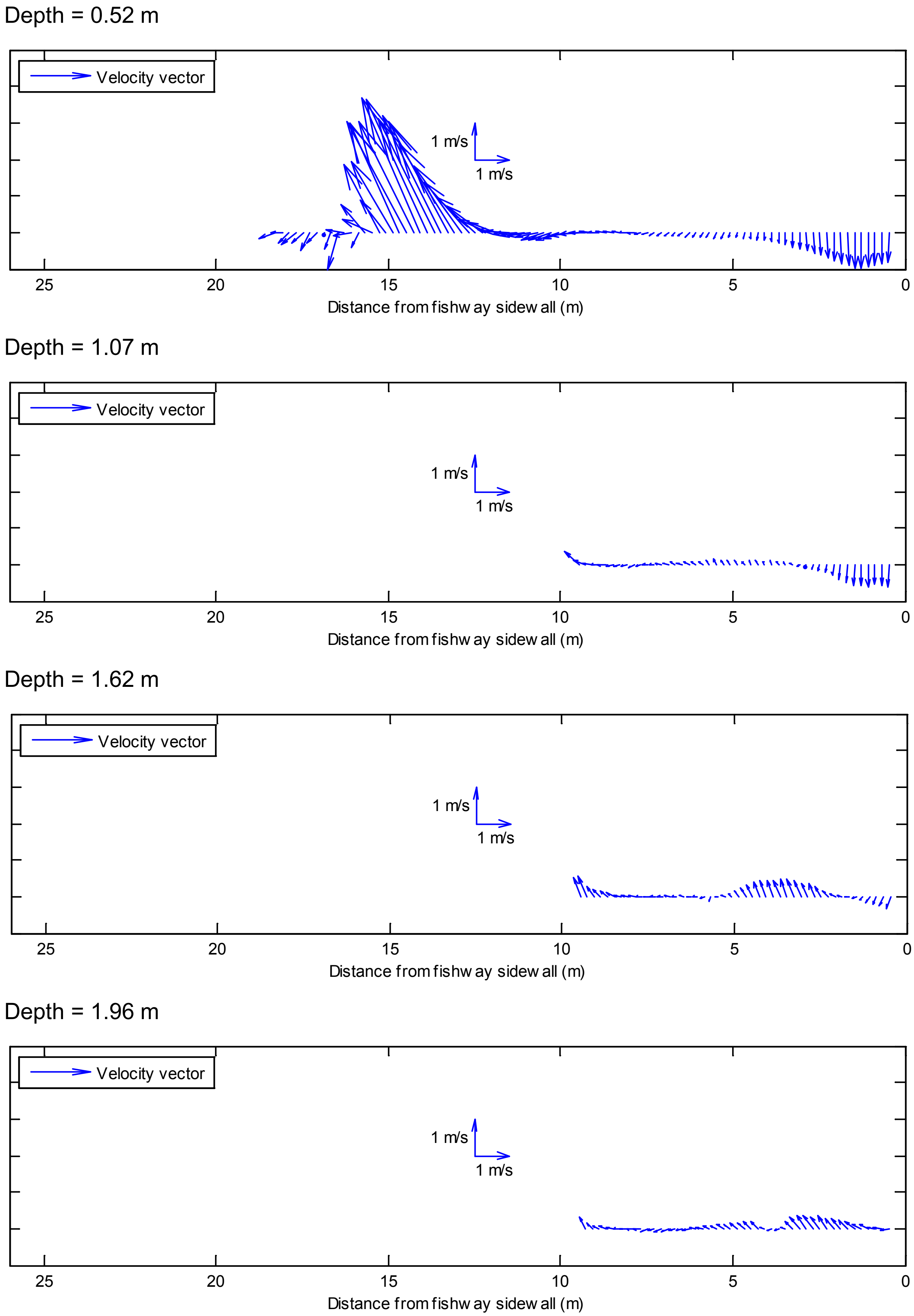


Figure 18. ADCP results at Section X4 for Flow Scenario 2.

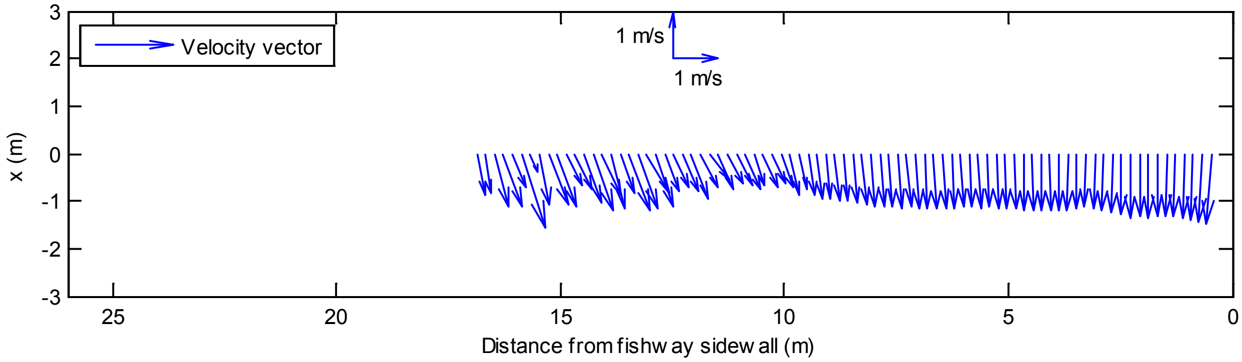


Figure 19. ADCP results at Section X5 for Flow Scenario 2.

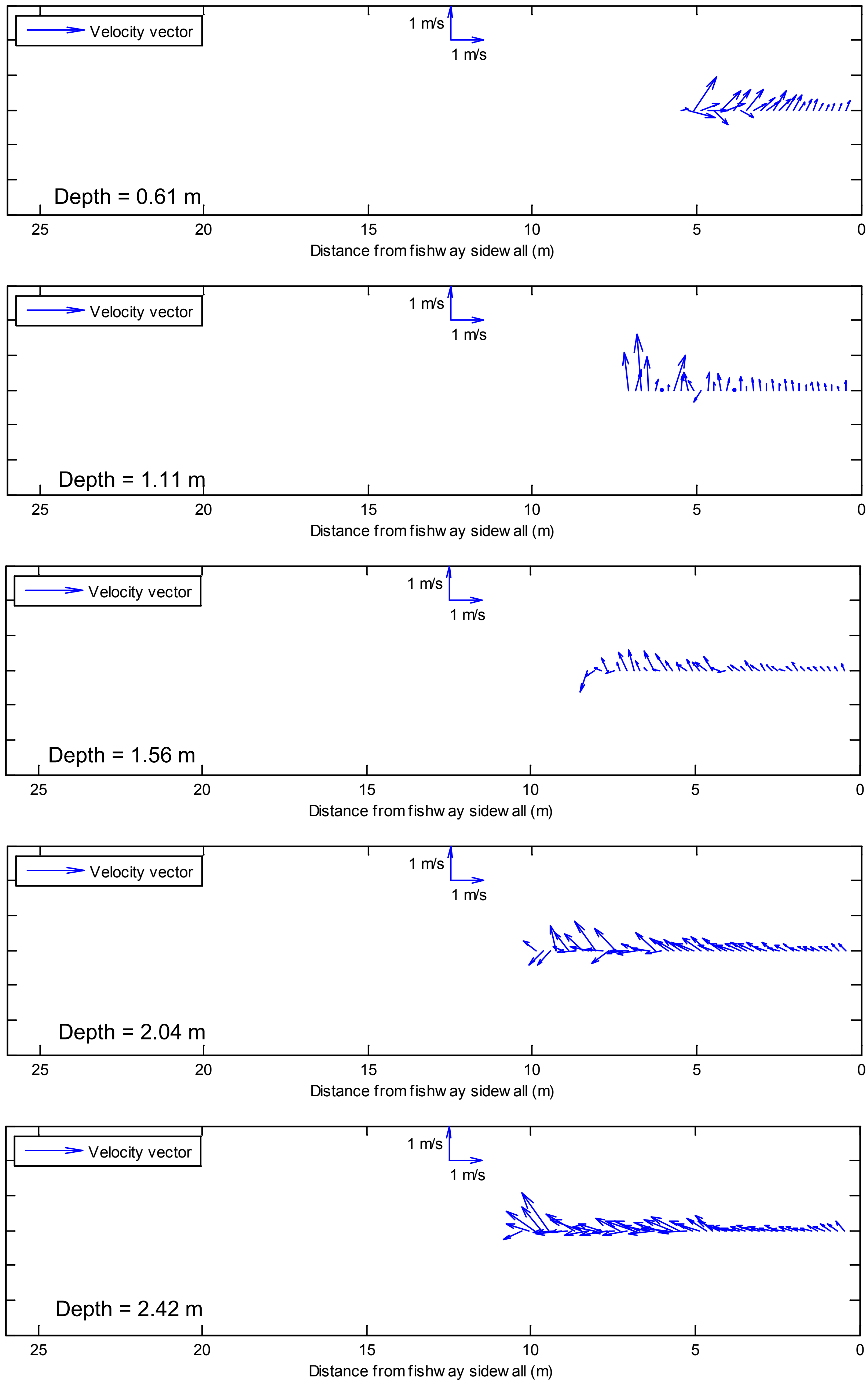


Figure 20. ADCP results at Section X2 for Flow Scenario 3.

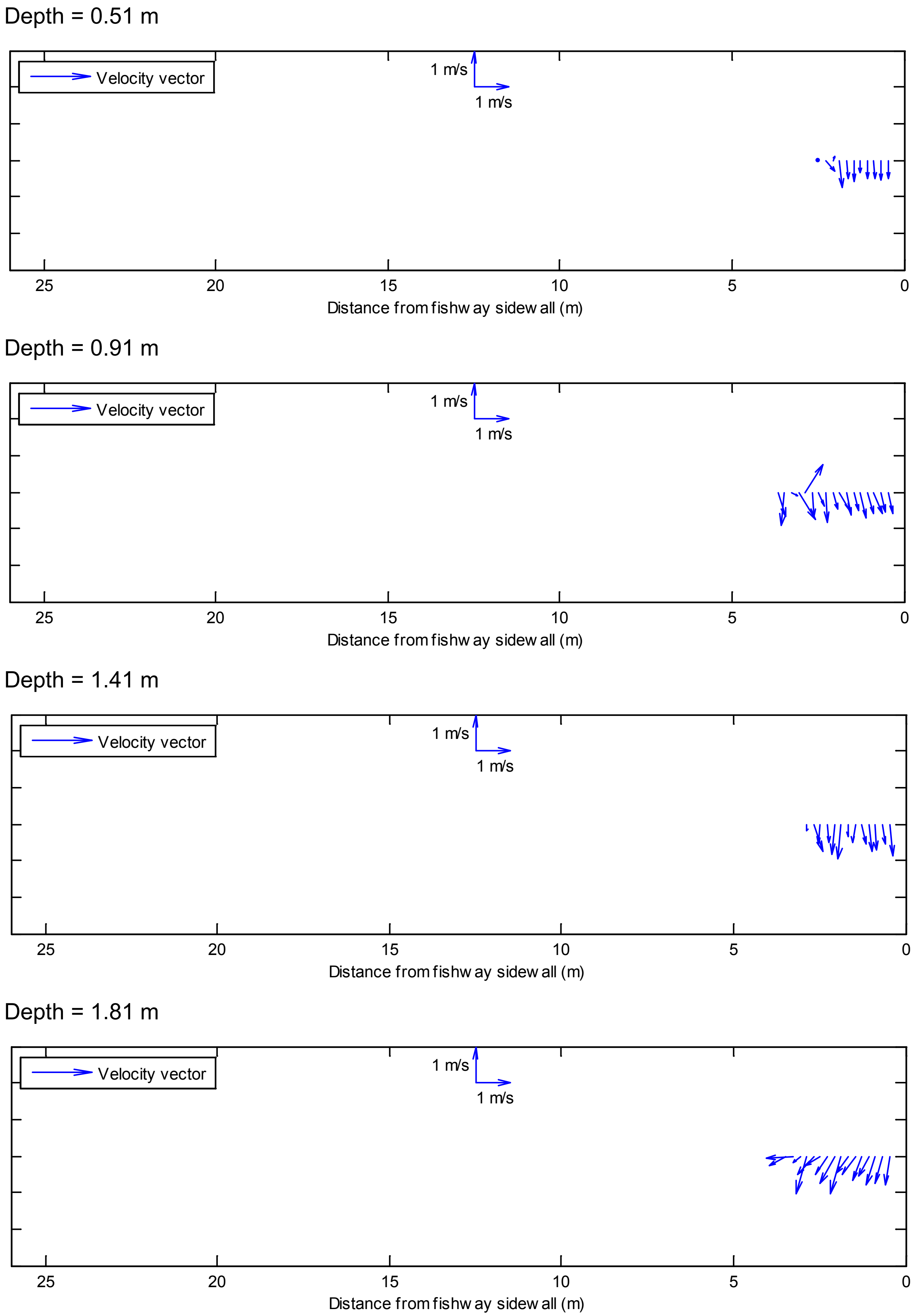


Figure 21. ADCP results at Section X4 for Flow Scenario 3.

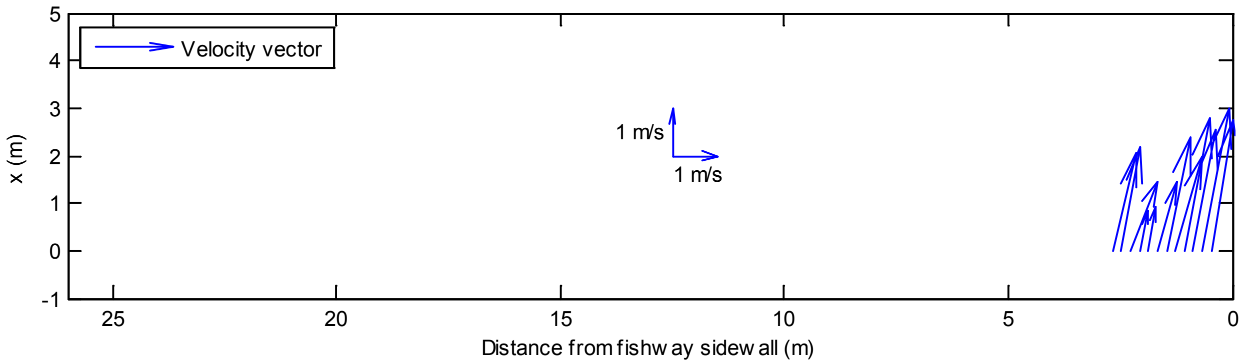


Figure 22. ADCP results at Section X5 for Flow Scenario 3.

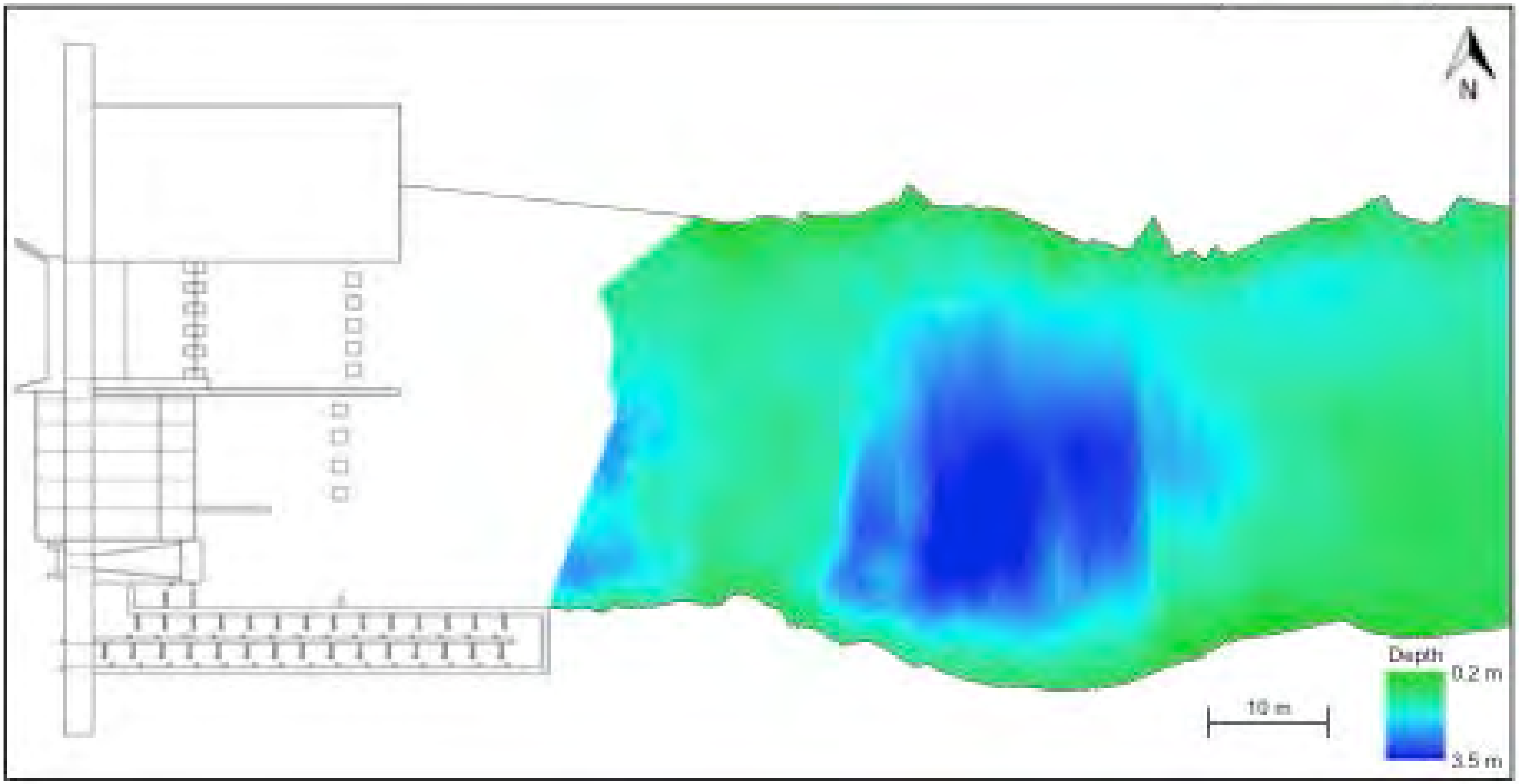


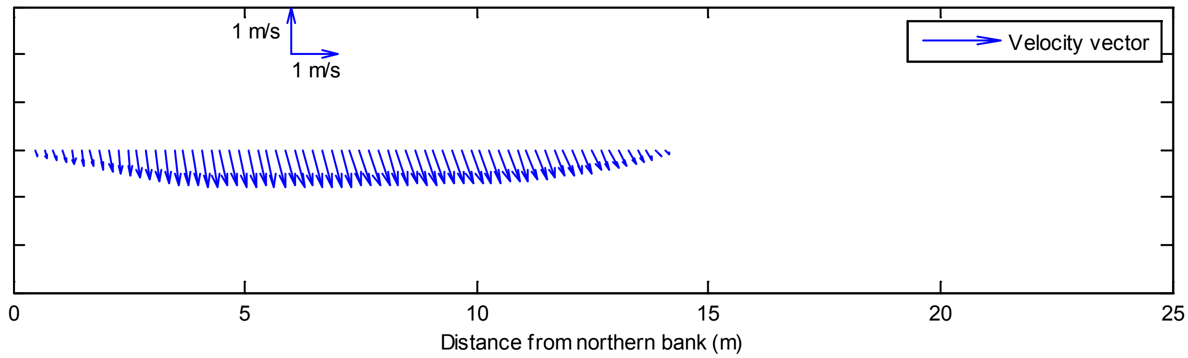
Figure 23. Summary of bathymetry results from T1-T40 in the Seton River.

APPENDIX I

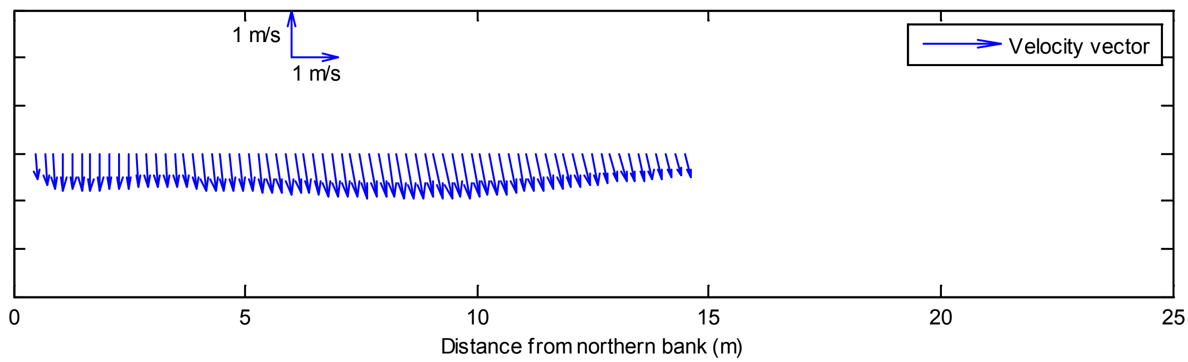
Detailed ADCP Results

River Section S1

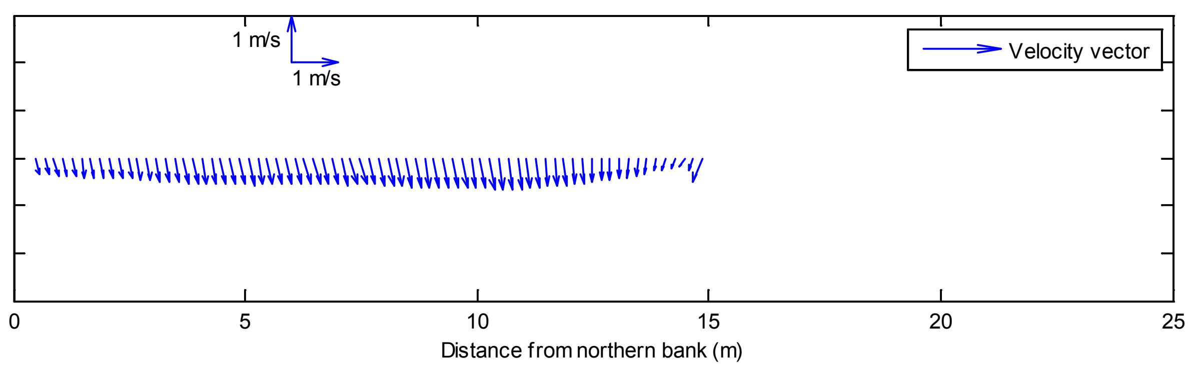
Flow Scenario 1



Flow Scenario 2

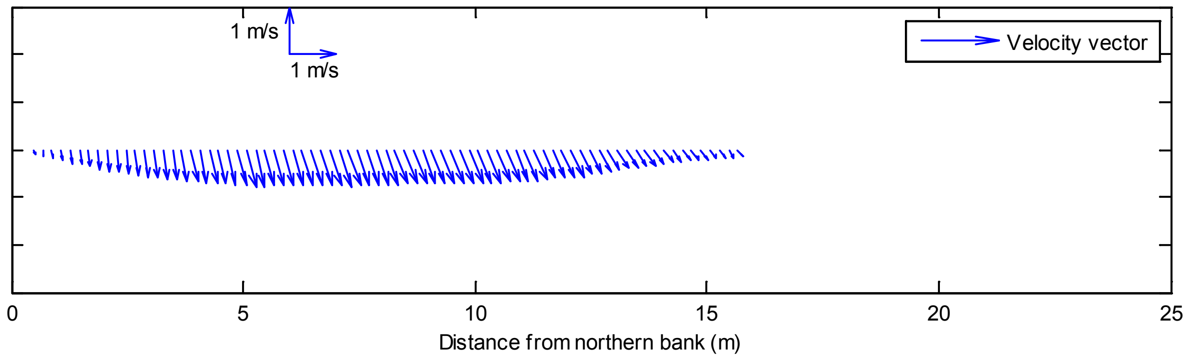


Flow Scenario 3

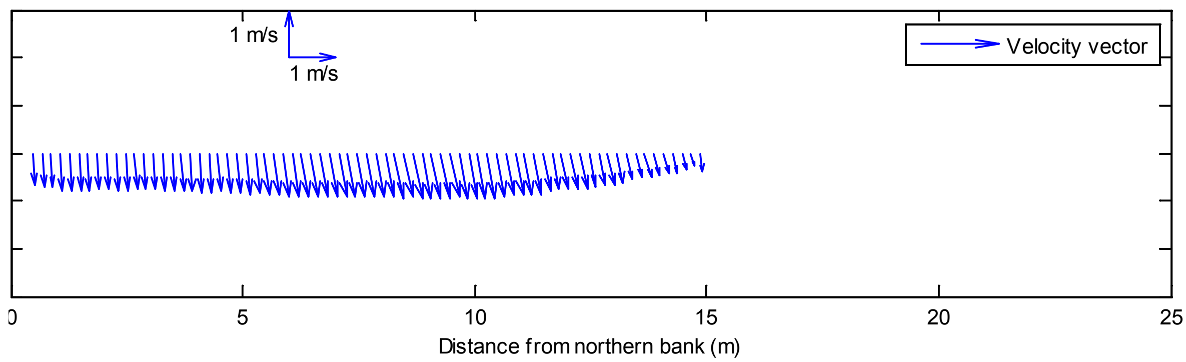


River Section S2

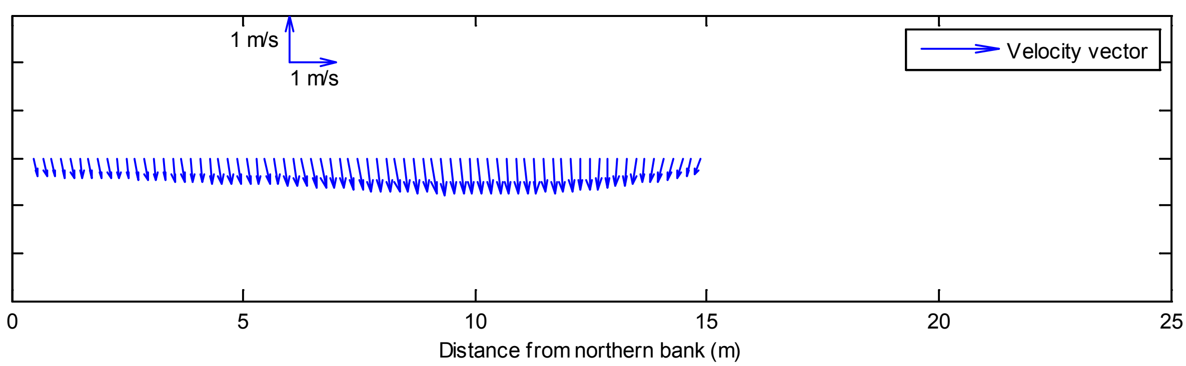
Flow Scenario 1



Flow Scenario 2

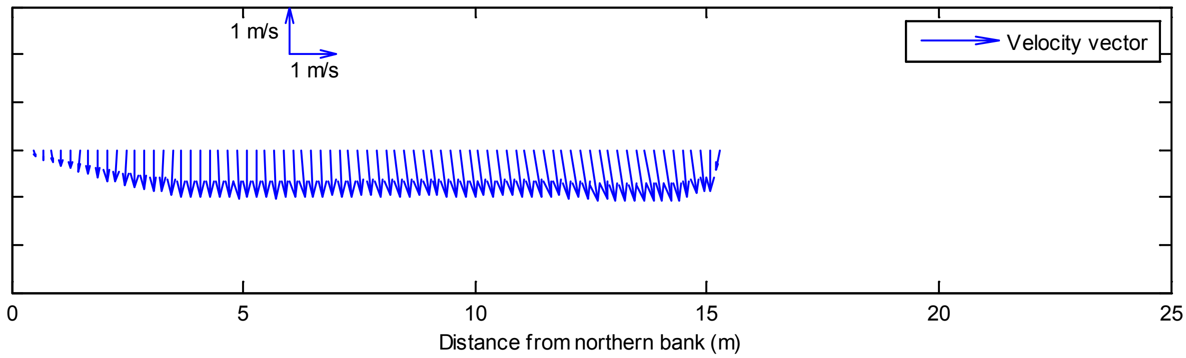


Flow Scenario 3

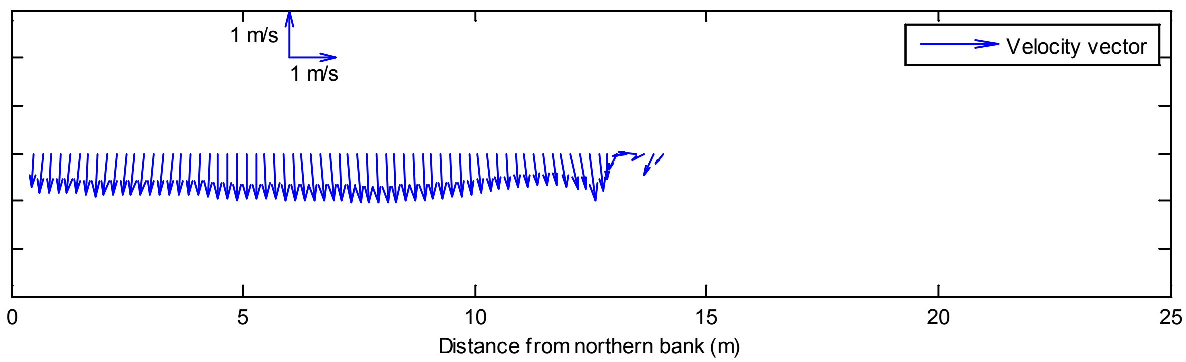


River Section S3

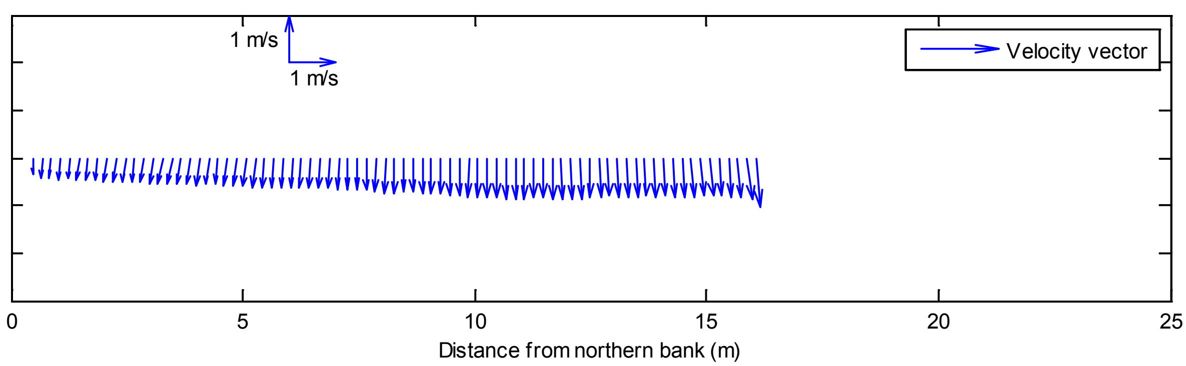
Flow Scenario 1



Flow Scenario 2

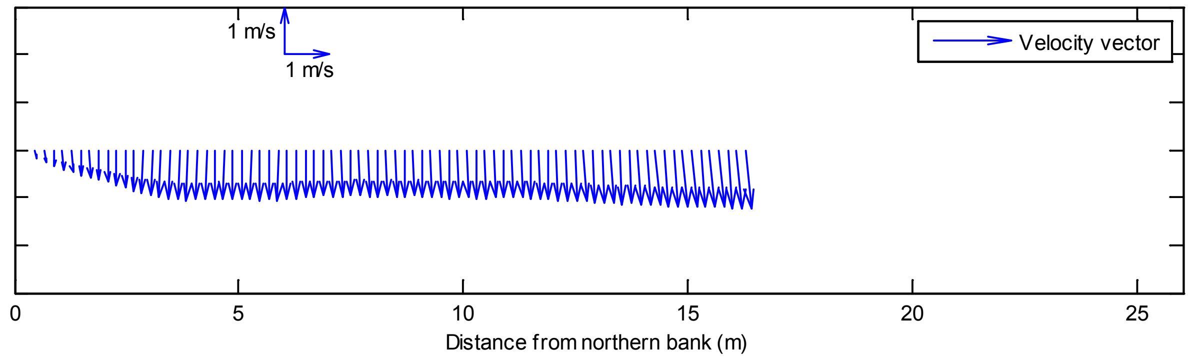


Flow Scenario 3

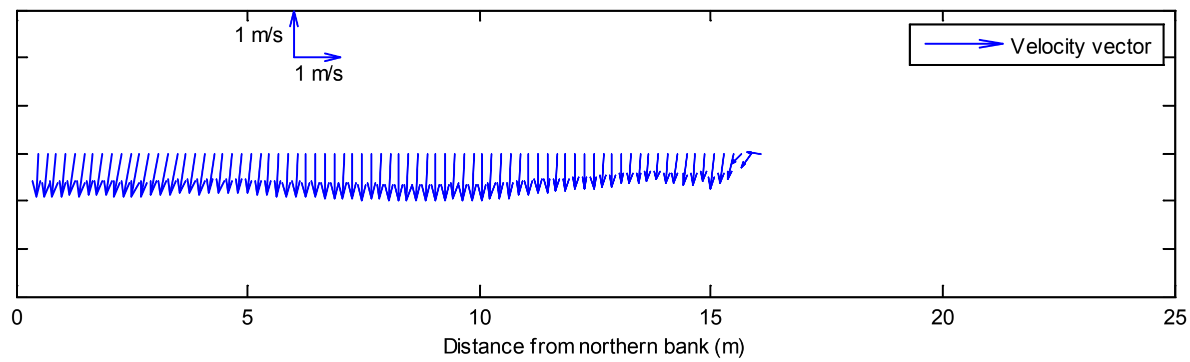


River Section S4

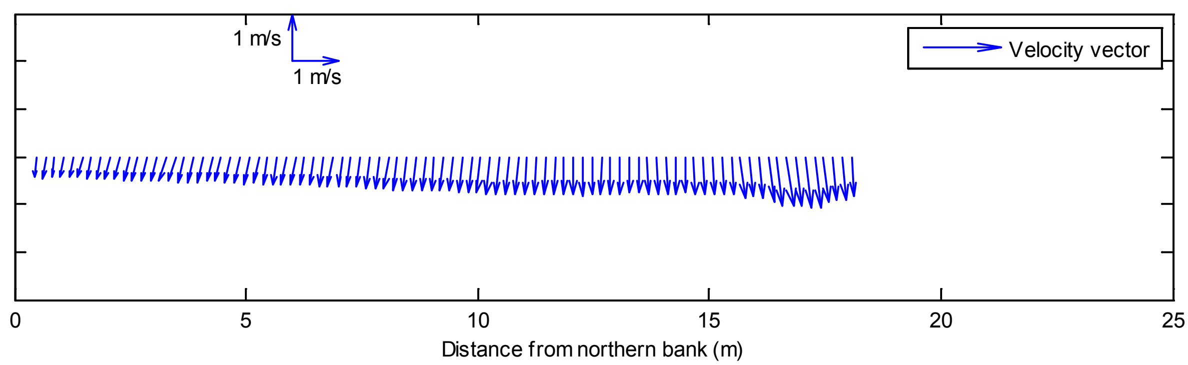
Flow Scenario 1



Flow Scenario 2

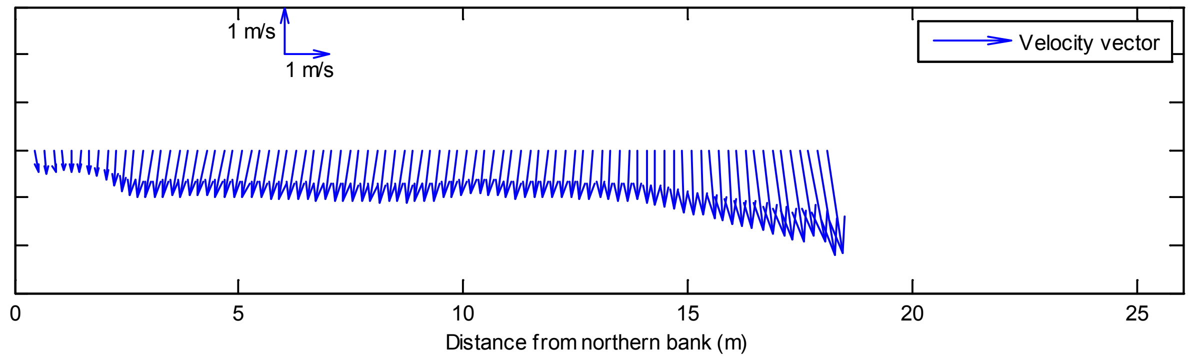


Flow Scenario 3

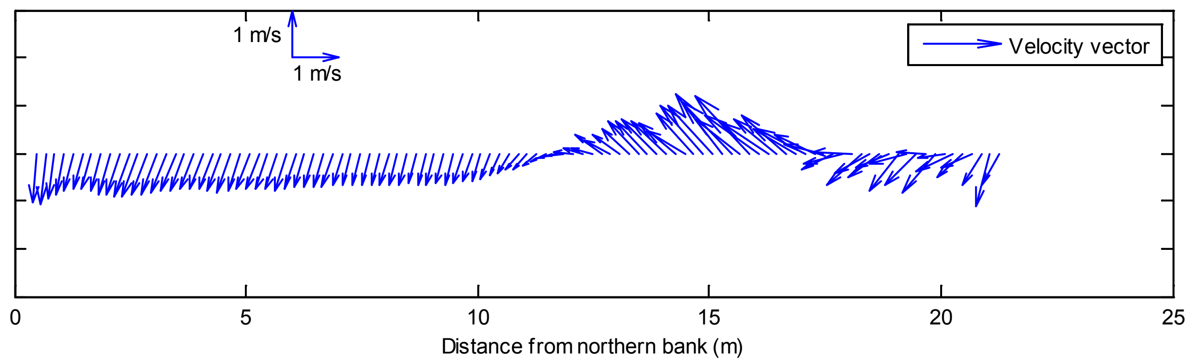


River Section S5

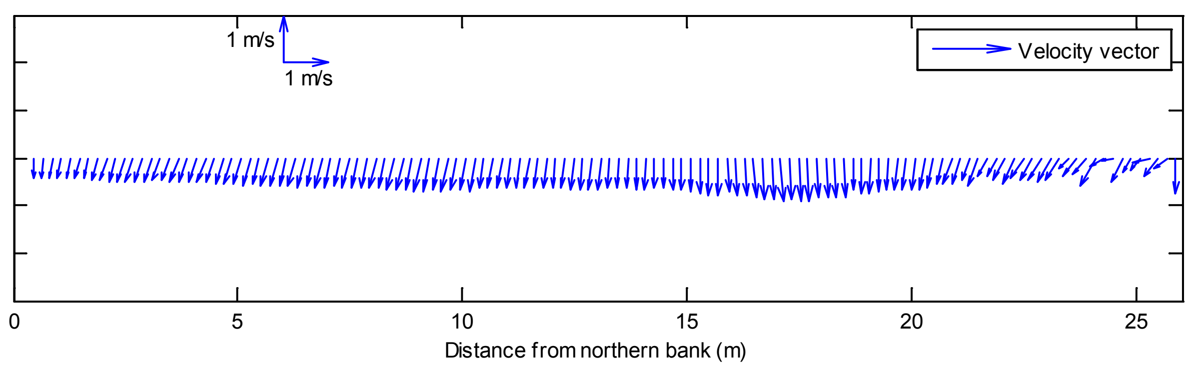
Flow Scenario 1



Flow Scenario 2

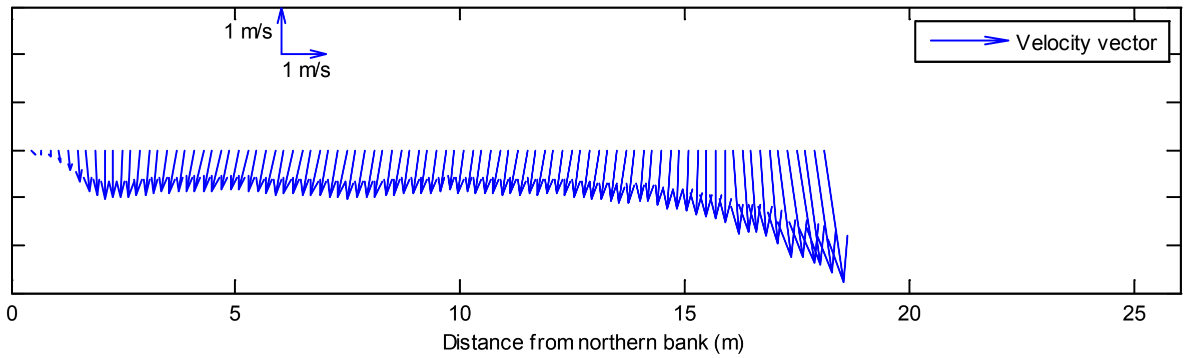


Flow Scenario 3

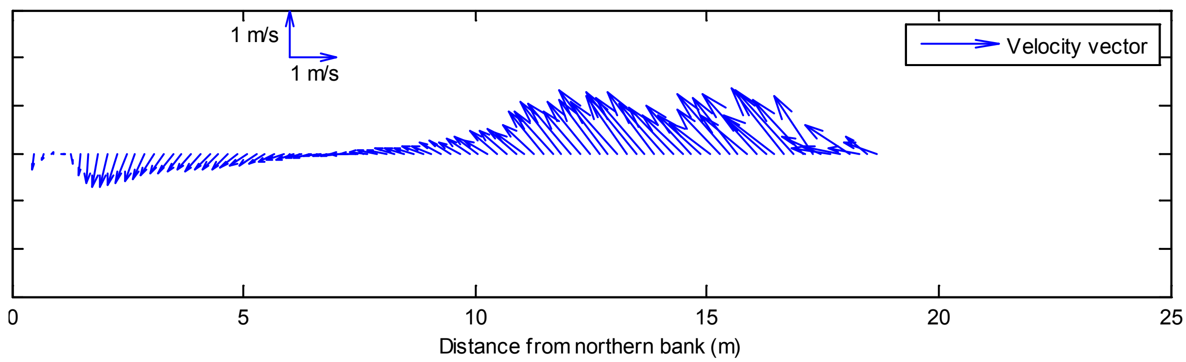


River Section S6

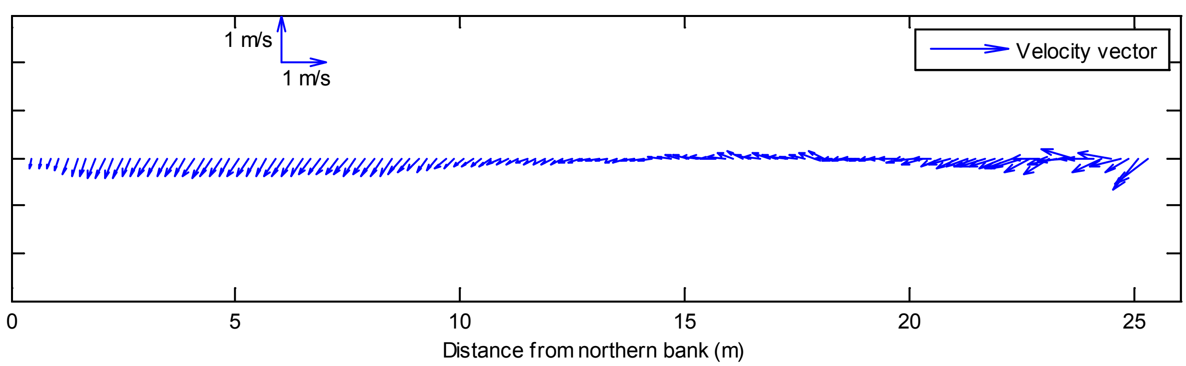
Flow Scenario 1



Flow Scenario 2

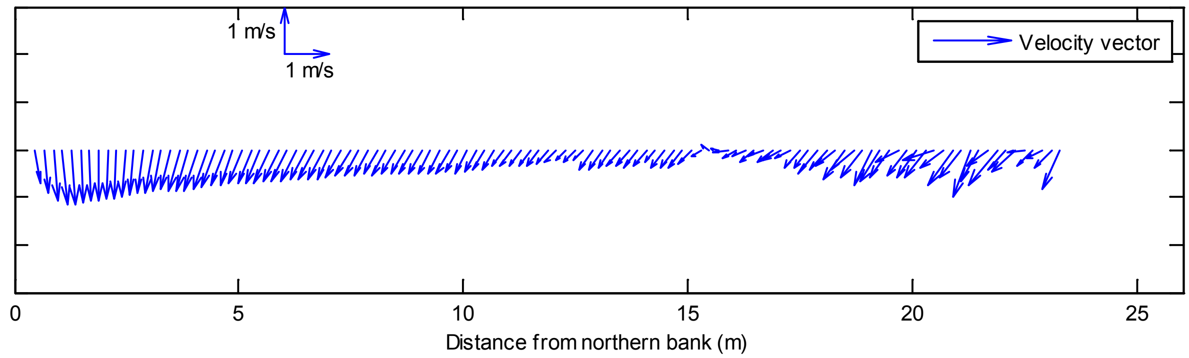


Flow Scenario 3

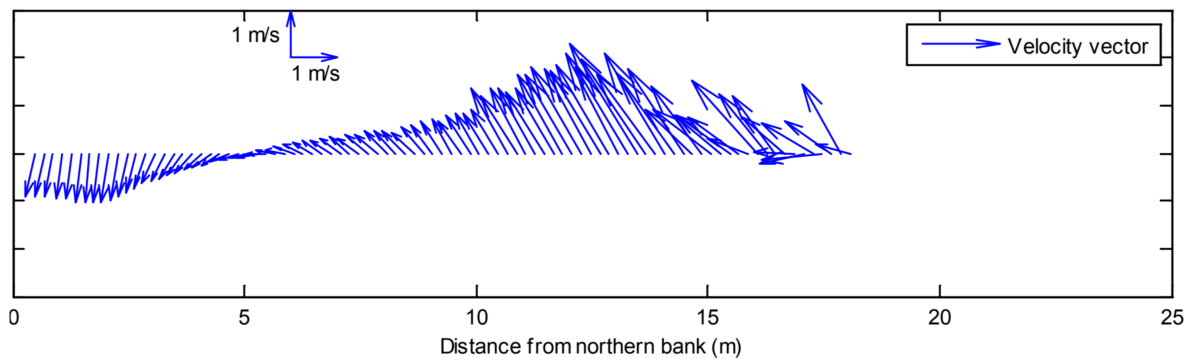


River Section S7

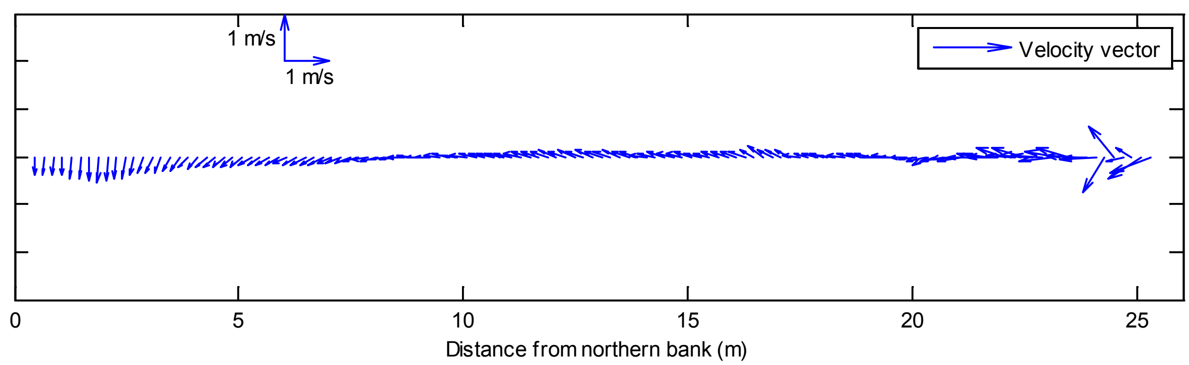
Flow Scenario 1



Flow Scenario 2

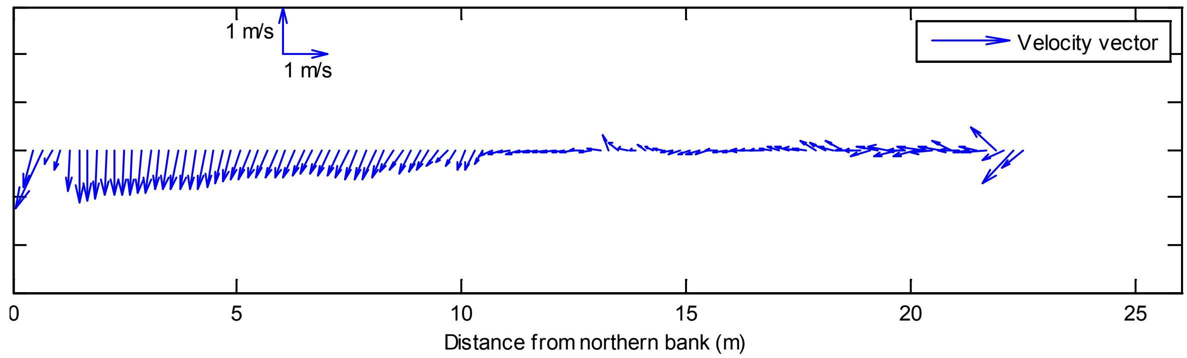


Flow Scenario 3

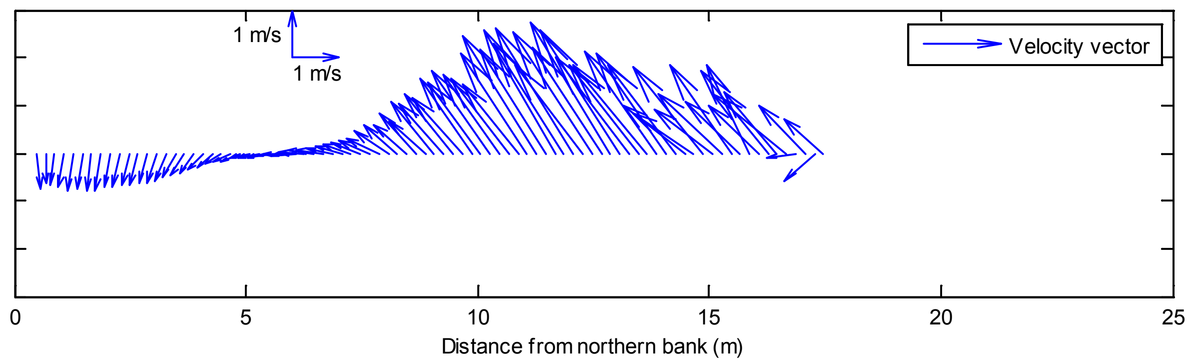


River Section S8

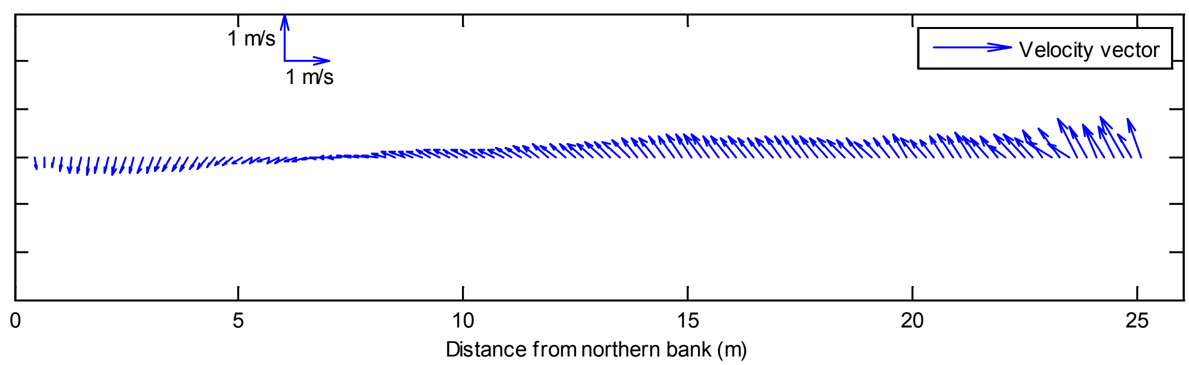
Flow Scenario 1



Flow Scenario 2

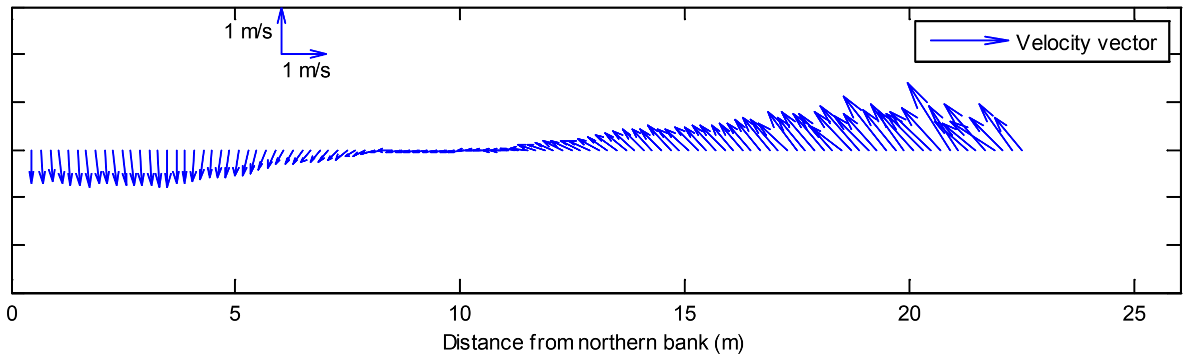


Flow Scenario 3

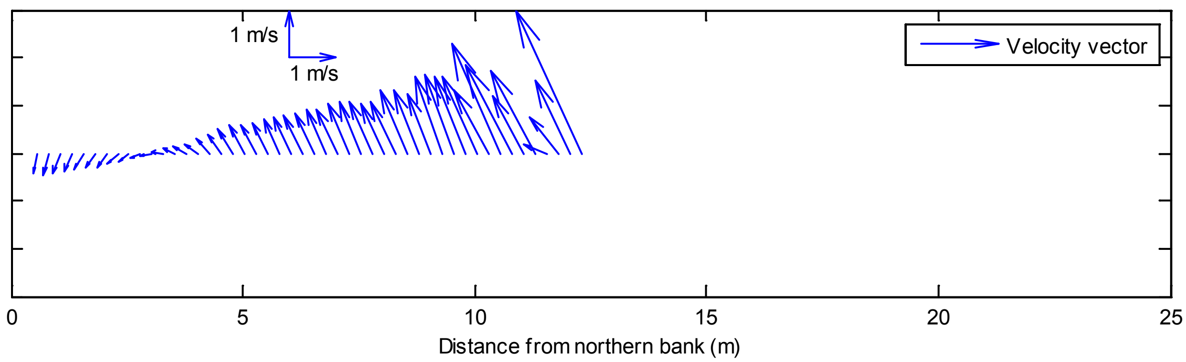


River Section S9

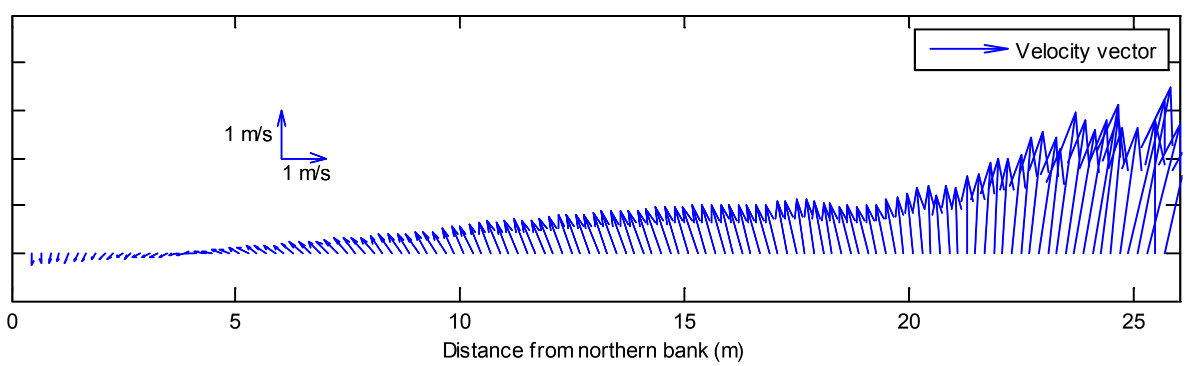
Flow Scenario 1



Flow Scenario 2

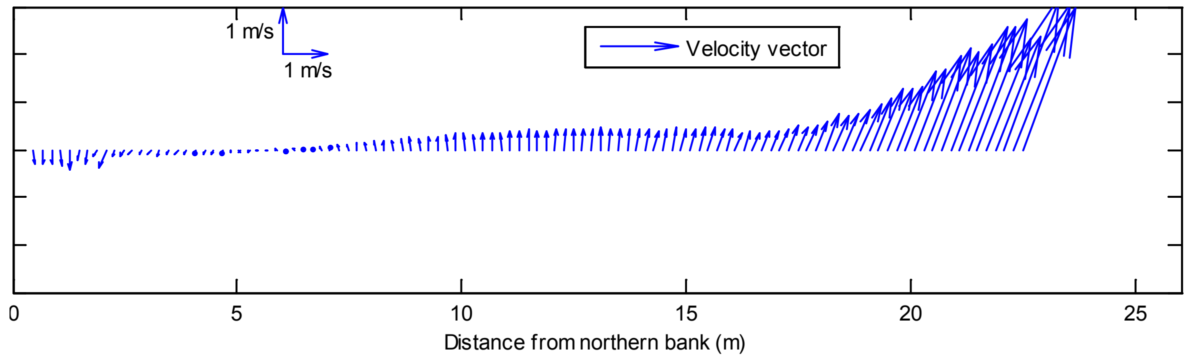


Flow Scenario 3

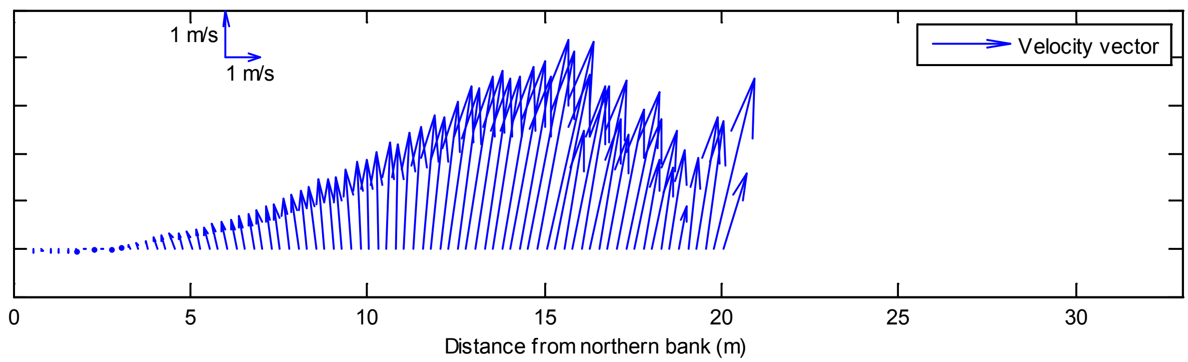


River Section S10

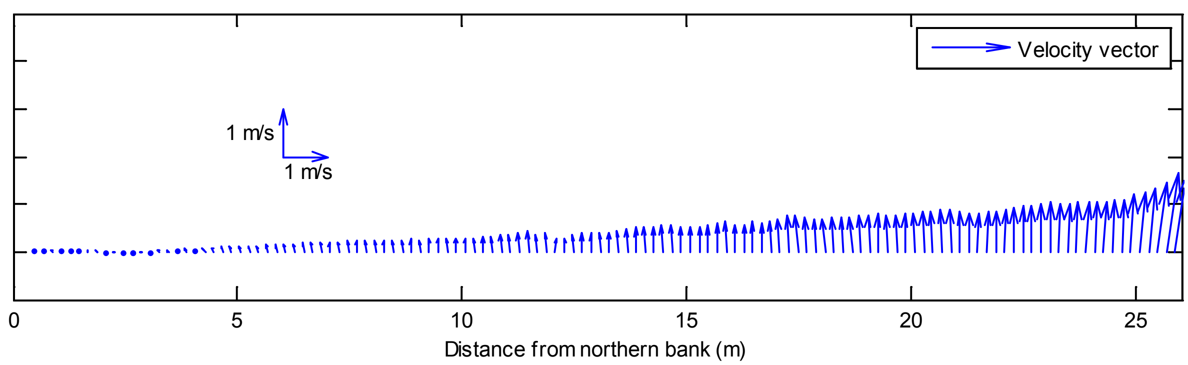
Flow Scenario 1



Flow Scenario 2

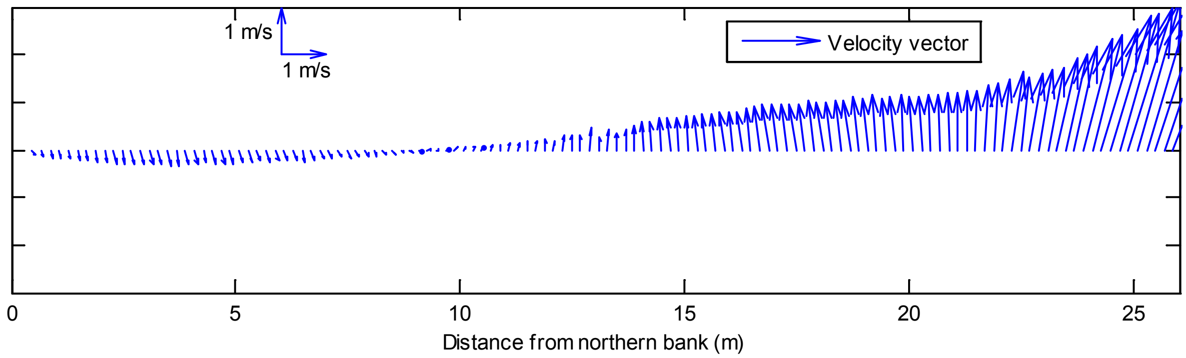


Flow Scenario 3

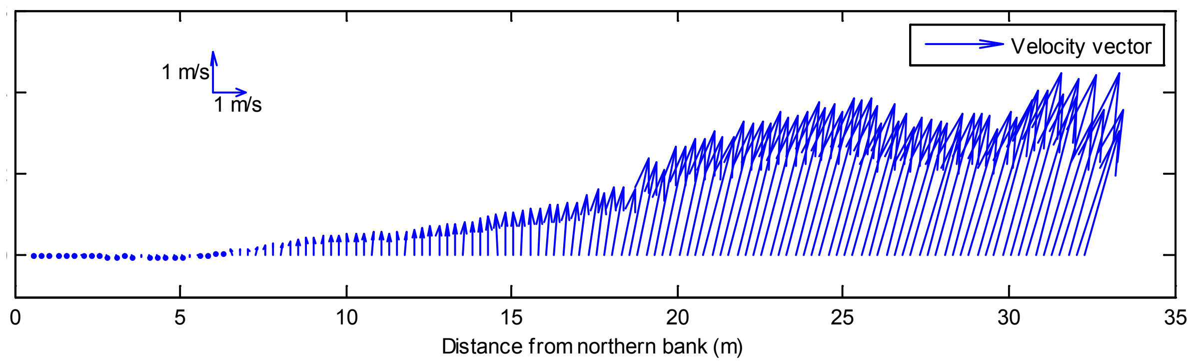


River Section S11

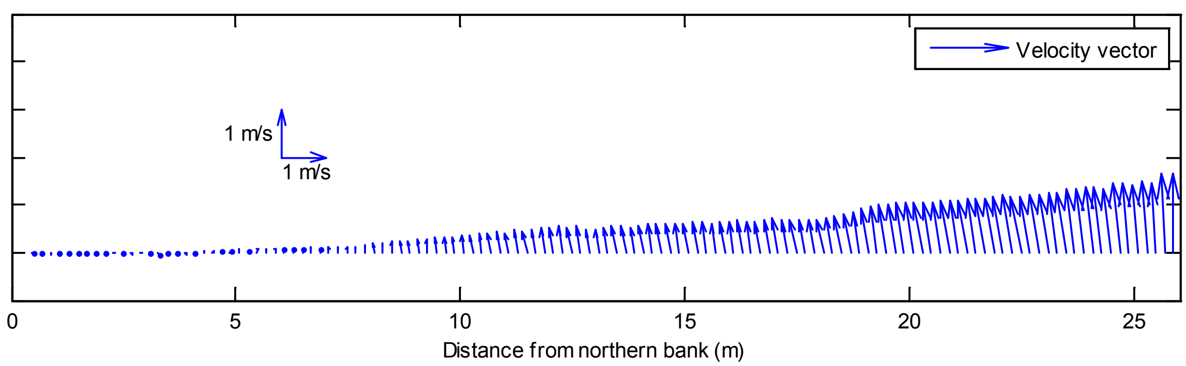
Flow Scenario 1



Flow Scenario 2

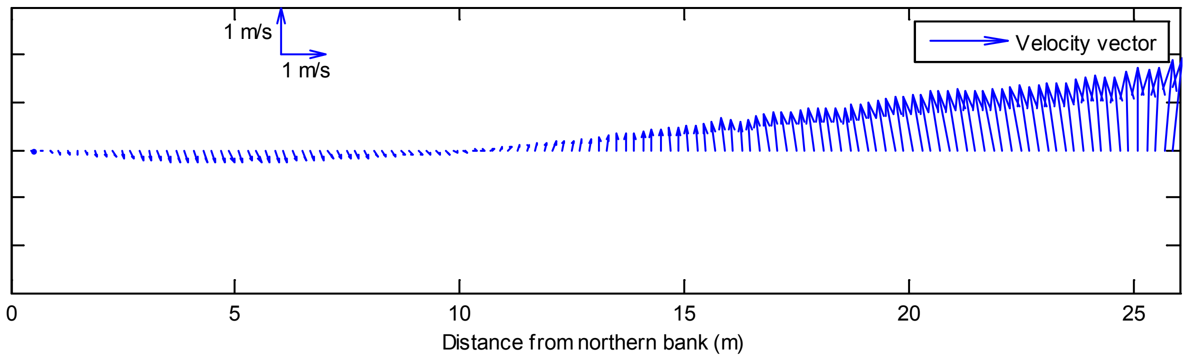


Flow Scenario 3

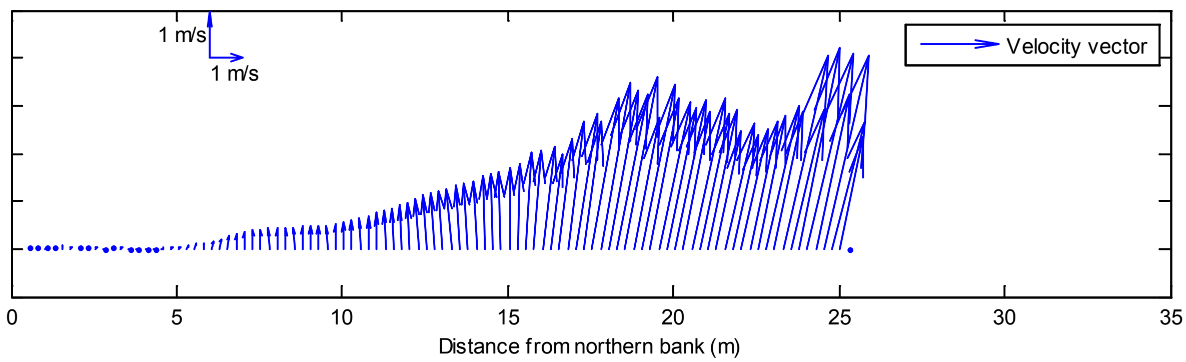


River Section S12

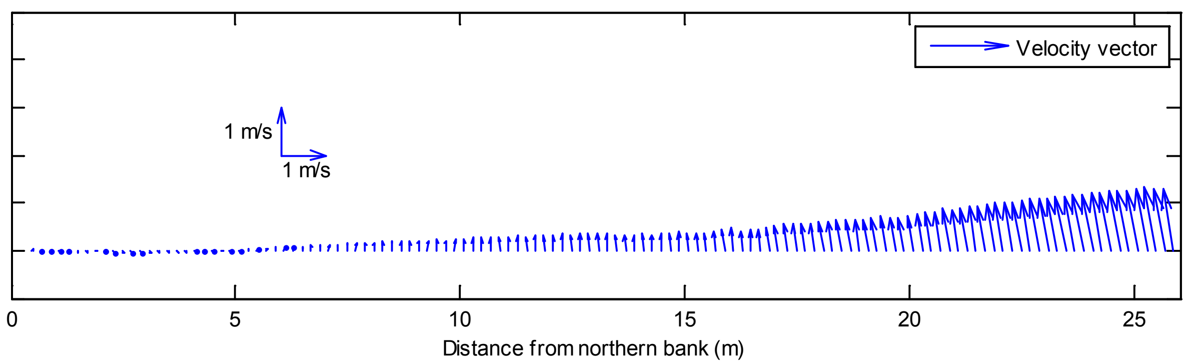
Flow Scenario 1



Flow Scenario 2

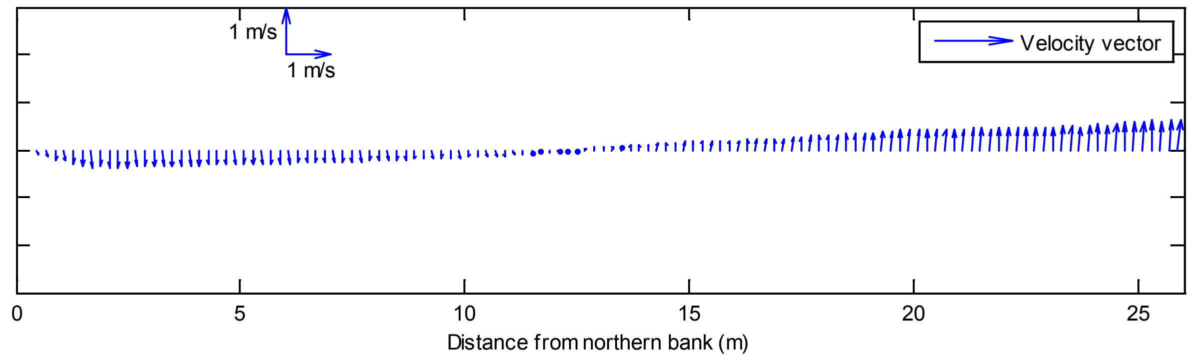


Flow Scenario 3

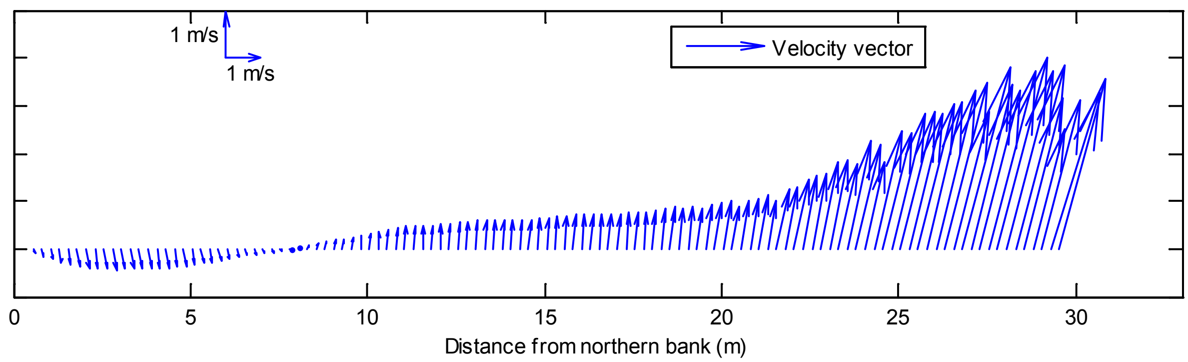


River Section S13

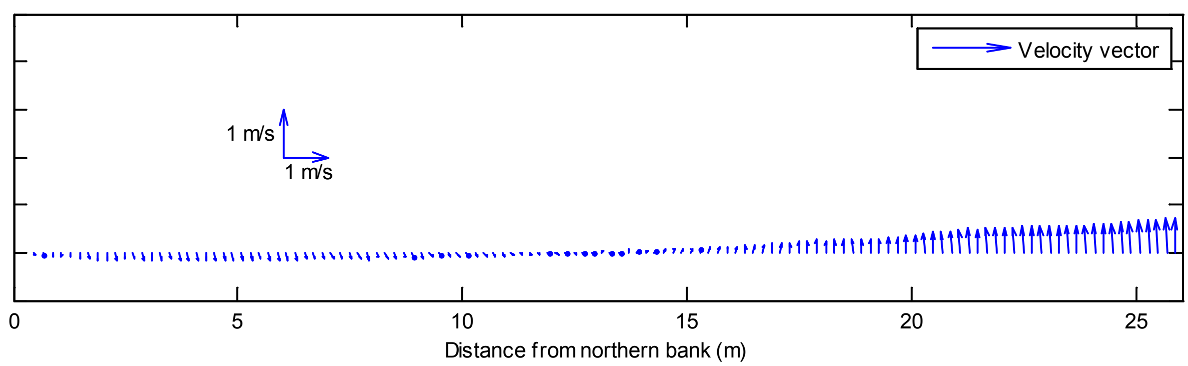
Flow Scenario 1



Flow Scenario 2

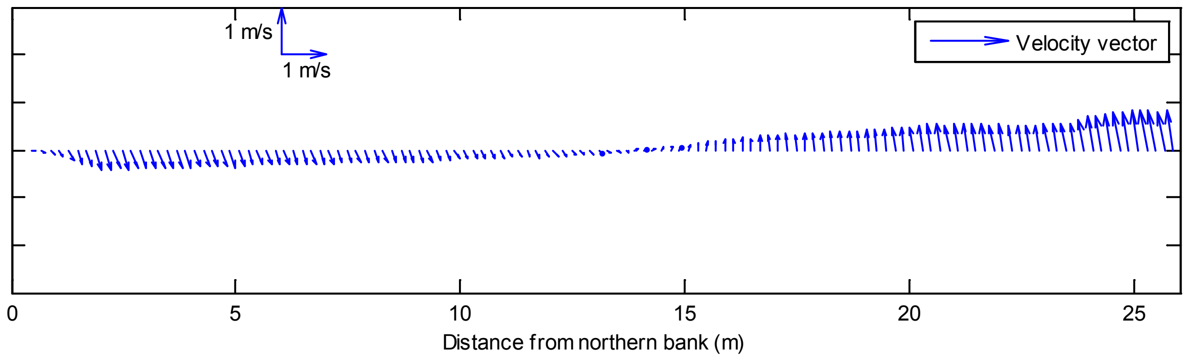


Flow Scenario 3

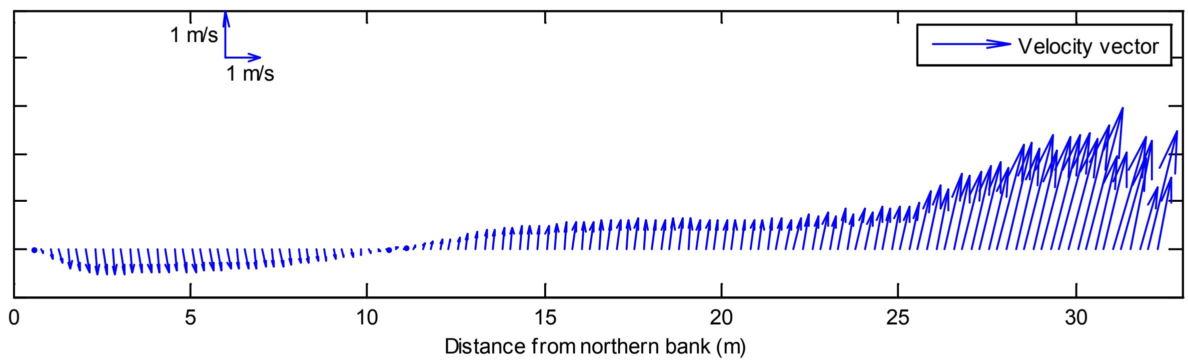


River Section S14

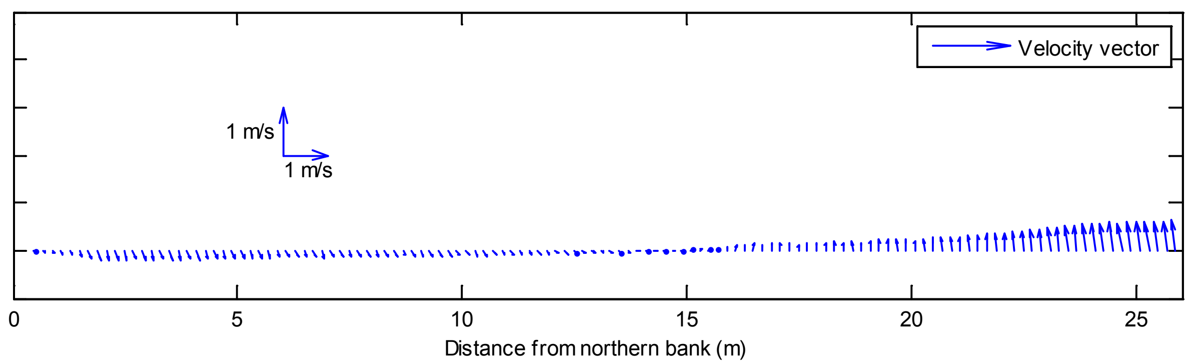
Flow Scenario 1



Flow Scenario 2

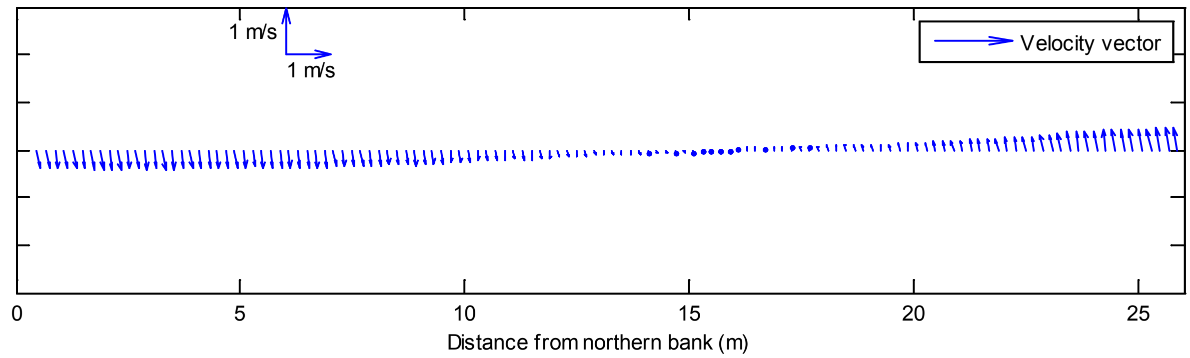


Flow Scenario 3

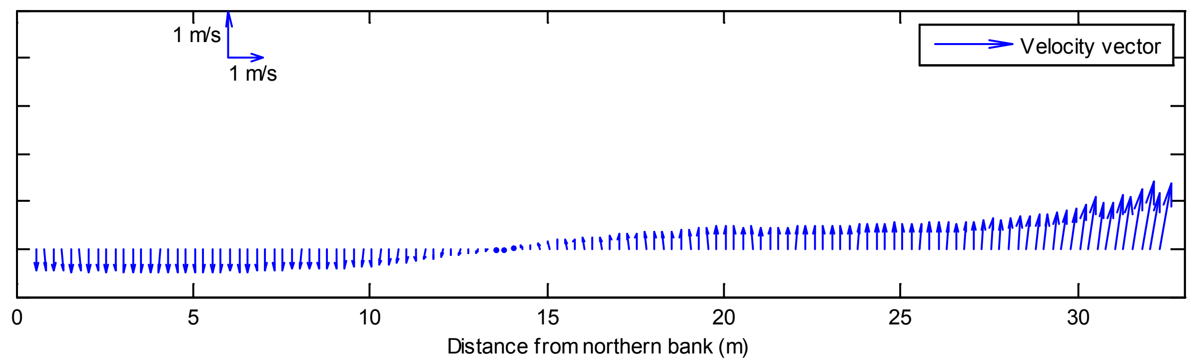


River Section S15

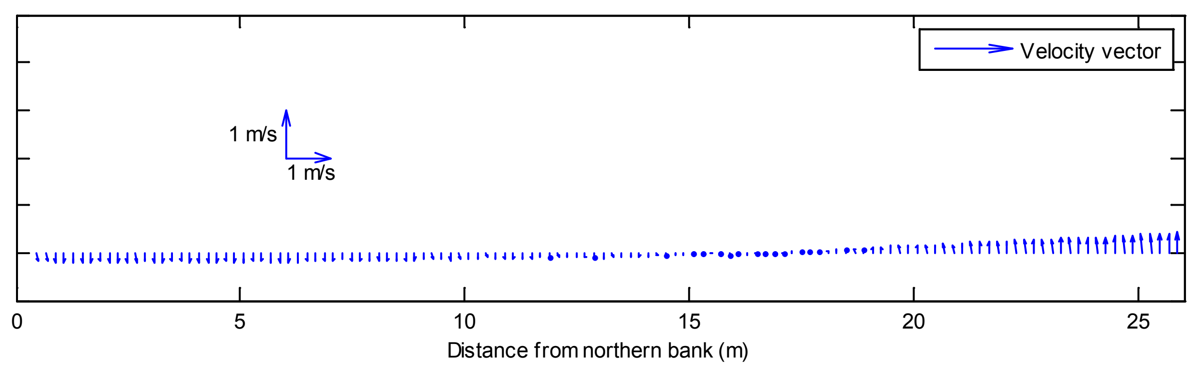
Flow Scenario 1



Flow Scenario 2

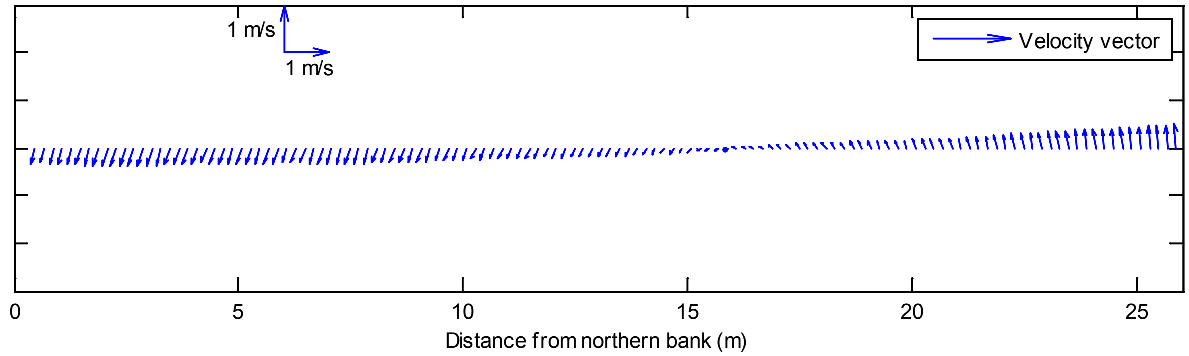


Flow Scenario 3

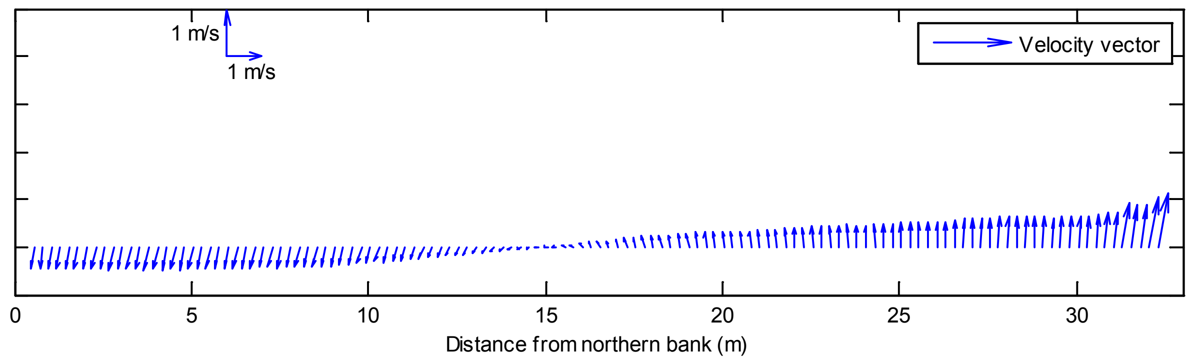


River Section S16

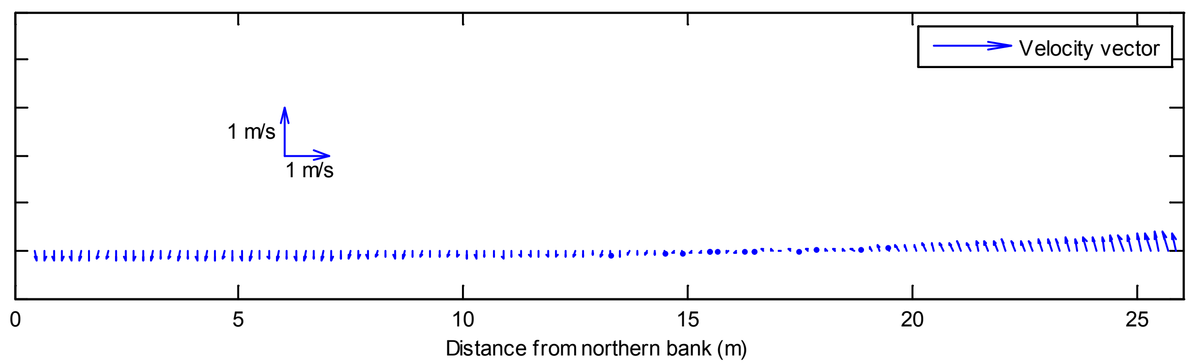
Flow Scenario 1



Flow Scenario 2

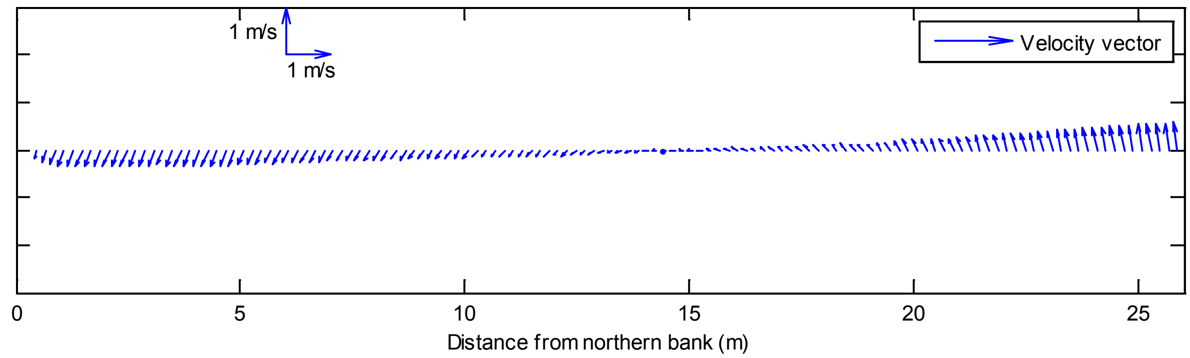


Flow Scenario 3

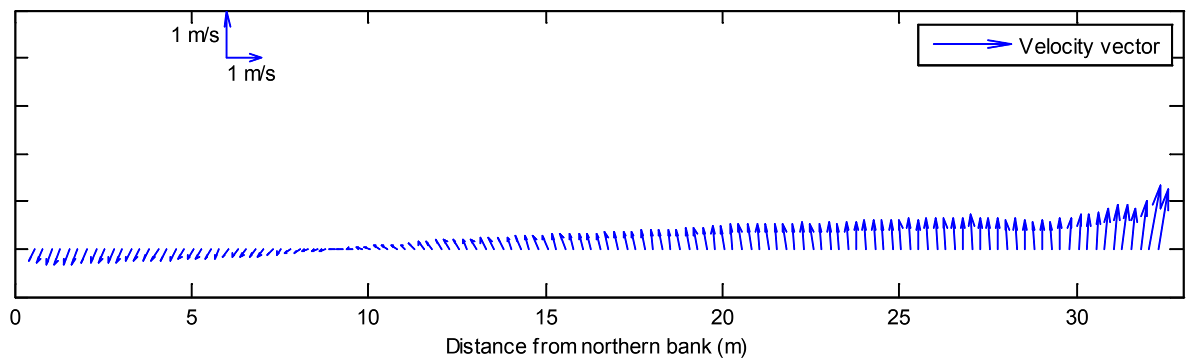


River Section S17

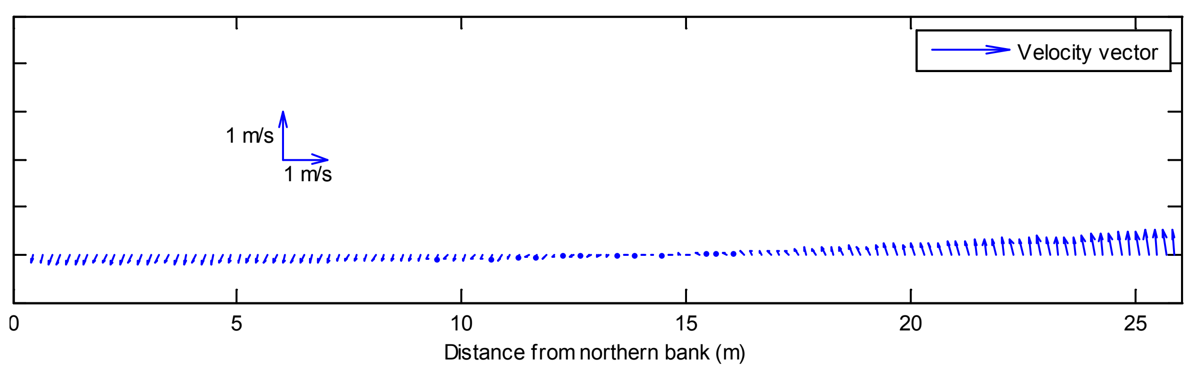
Flow Scenario 1



Flow Scenario 2

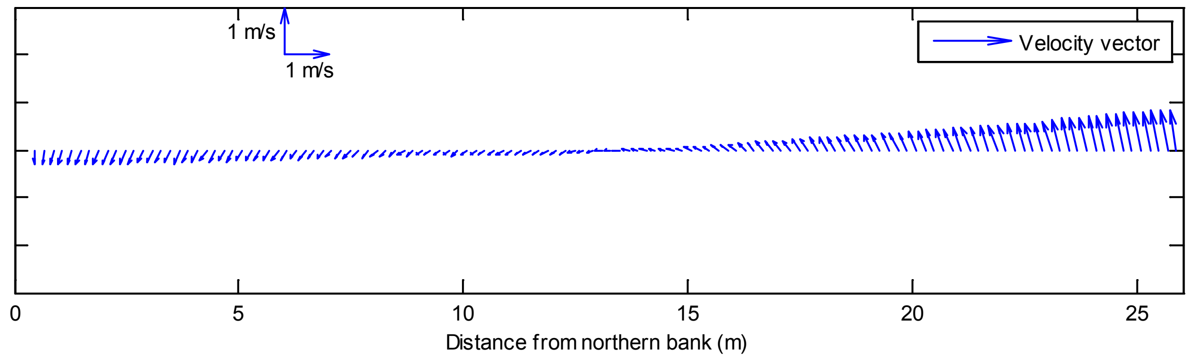


Flow Scenario 3

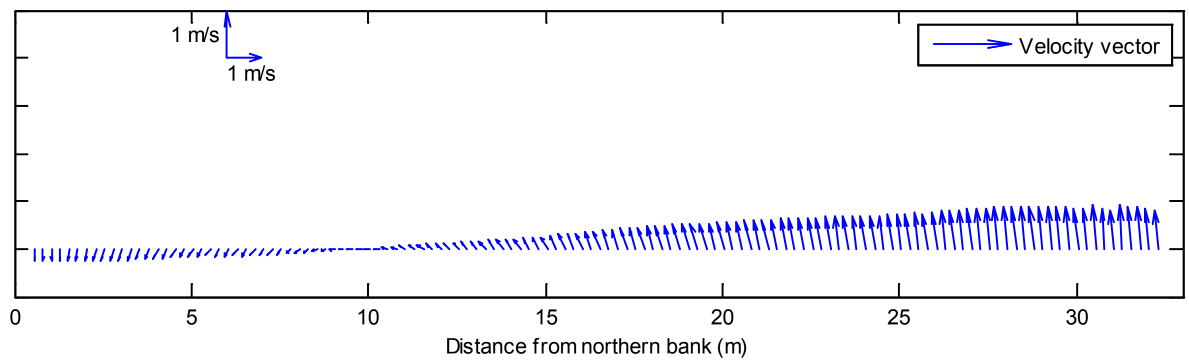


River Section S18

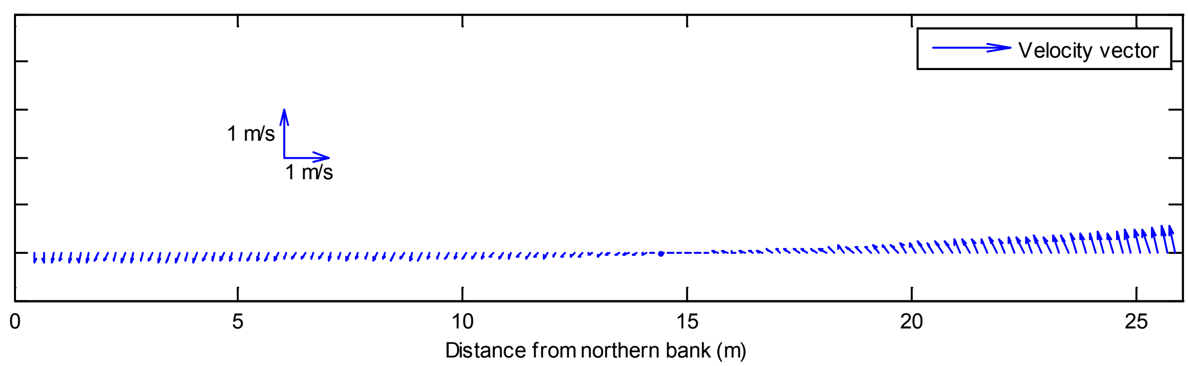
Flow Scenario 1



Flow Scenario 2

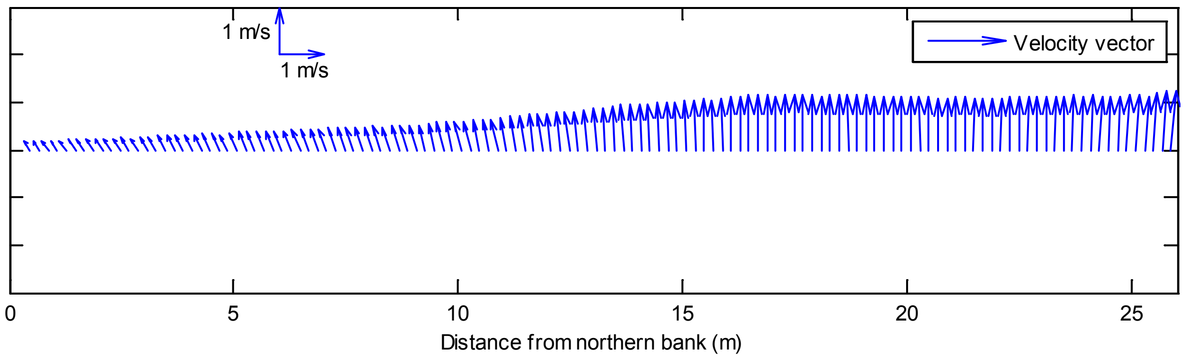


Flow Scenario 3

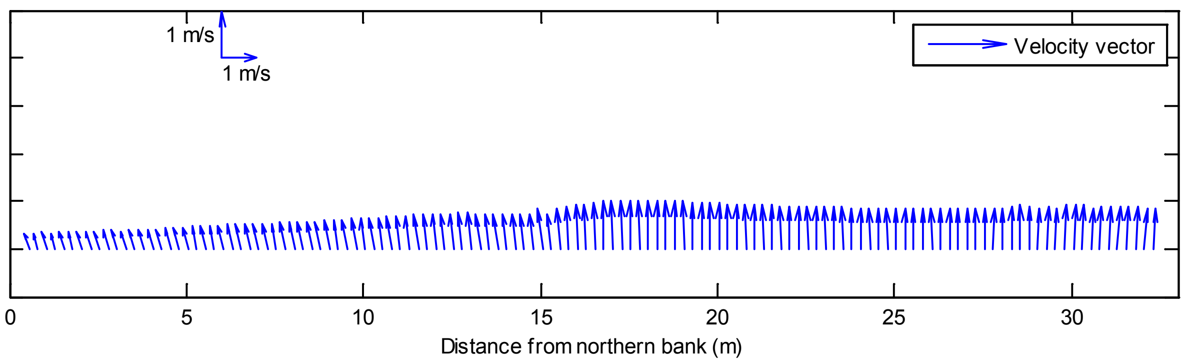


River Section S19

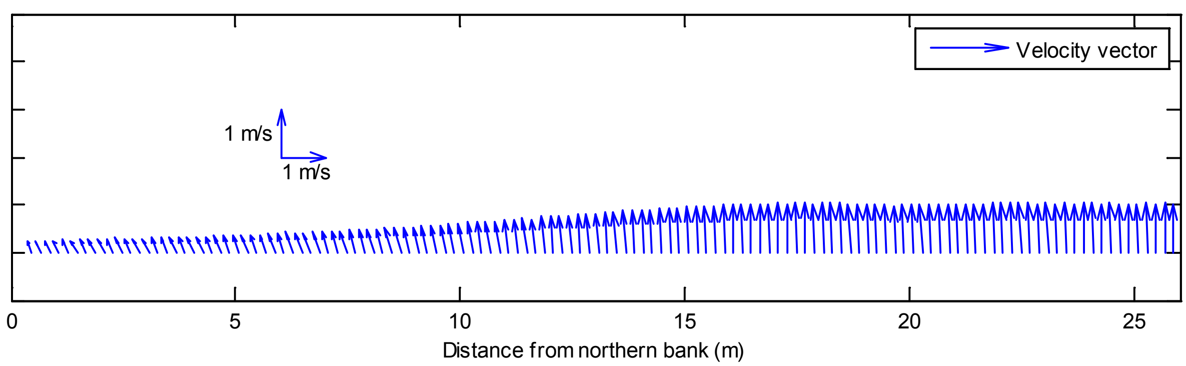
Flow Scenario 1



Flow Scenario 2

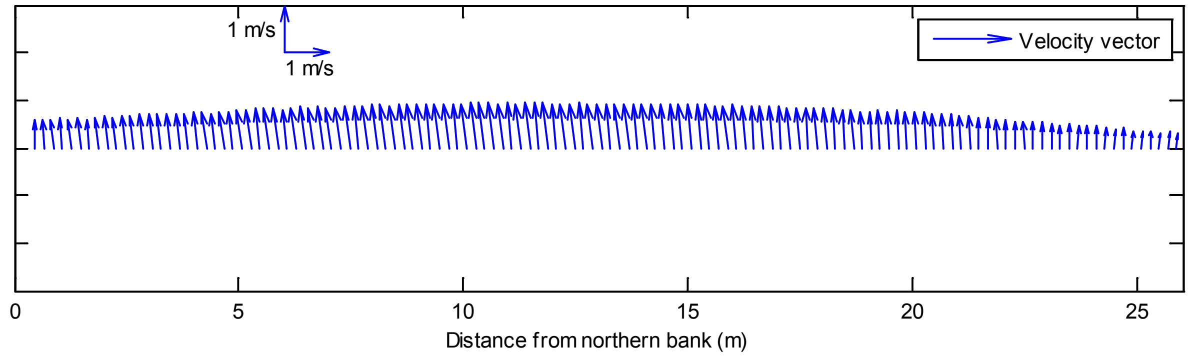


Flow Scenario 3

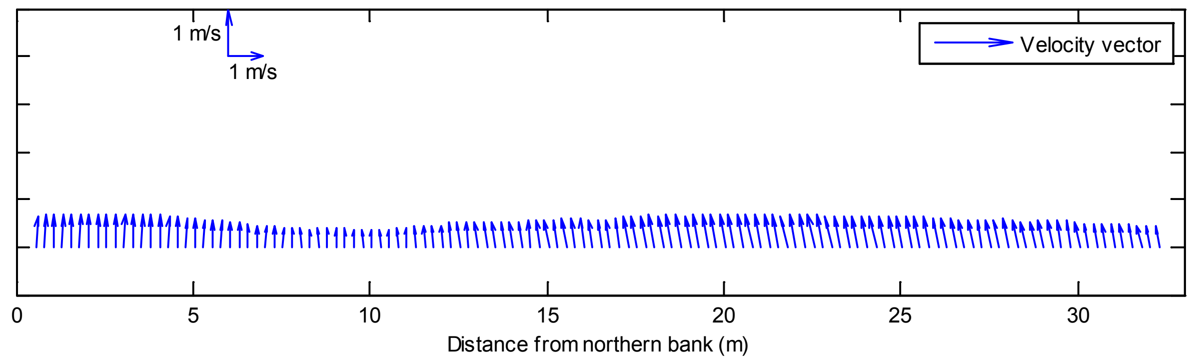


River Section S20

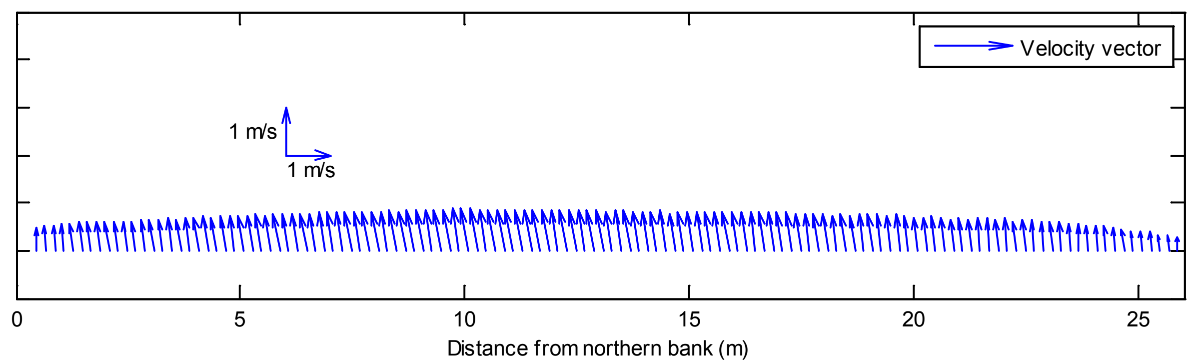
Flow Scenario 1



Flow Scenario 2

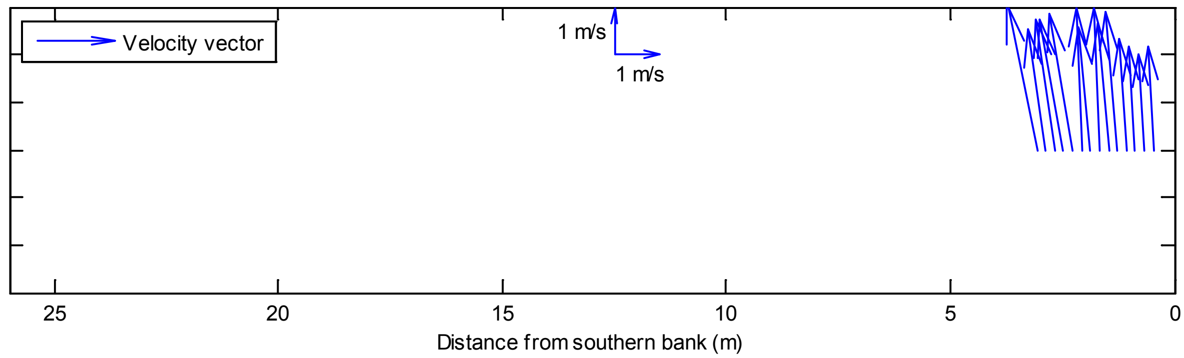


Flow Scenario 3

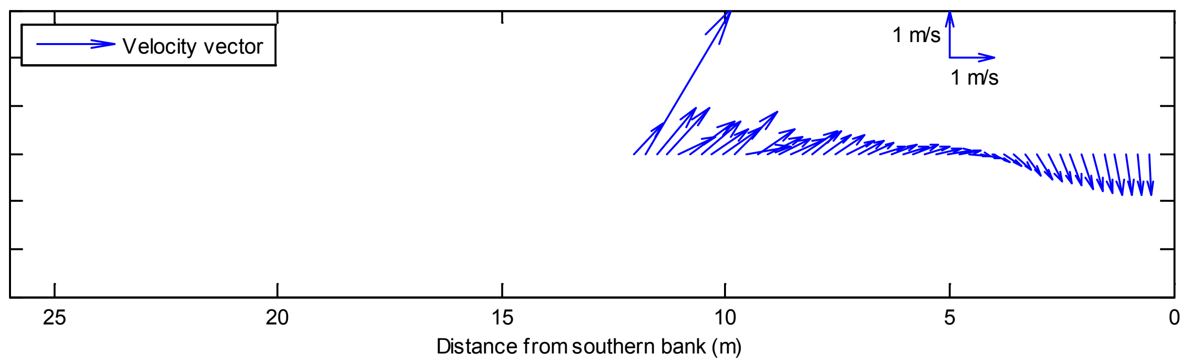


River Section S21

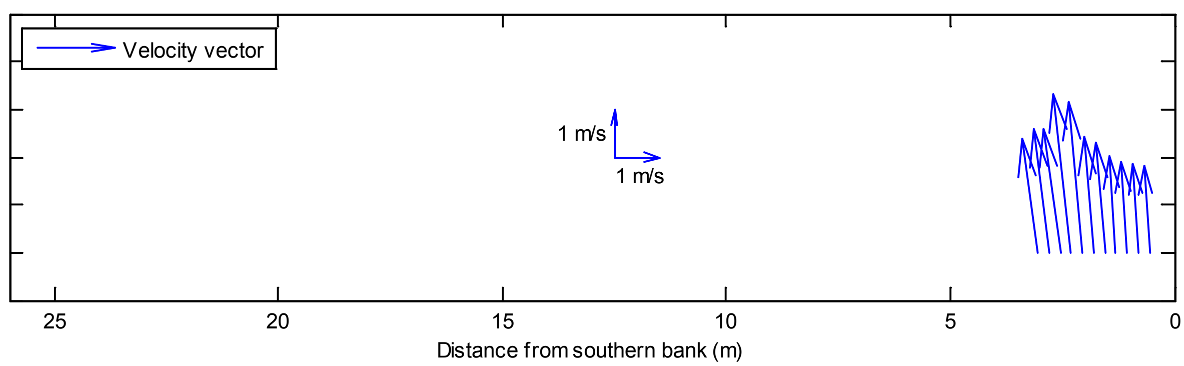
Flow Scenario 1



Flow Scenario 2

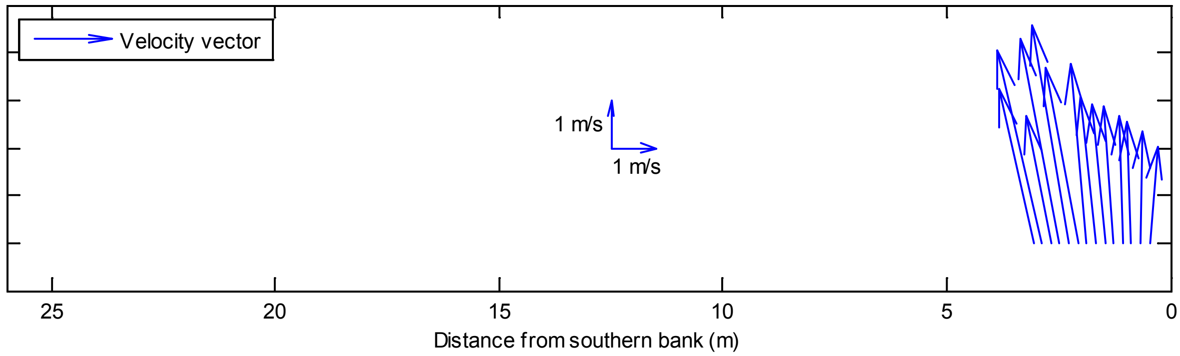


Flow Scenario 3

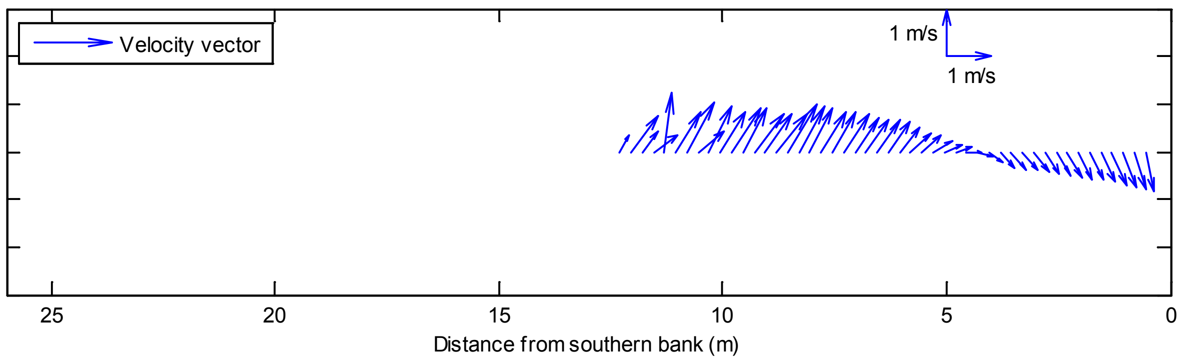


River Section S22

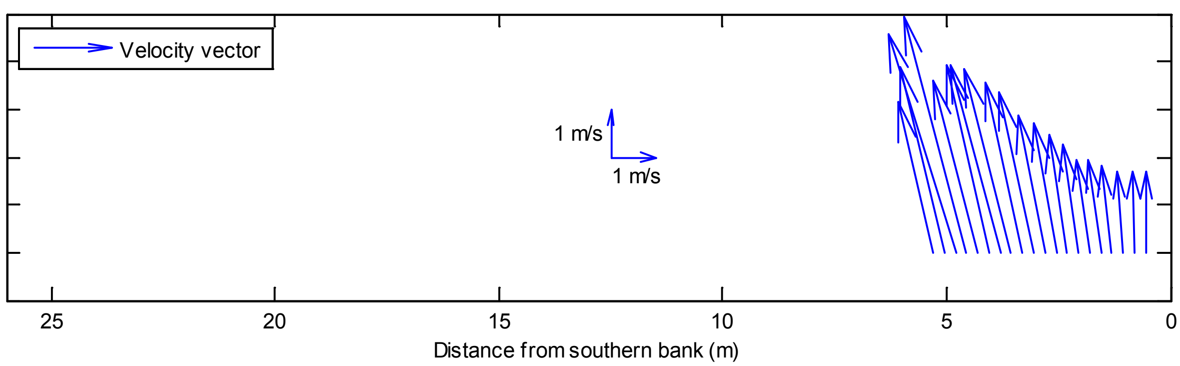
Flow Scenario 1



Flow Scenario 2

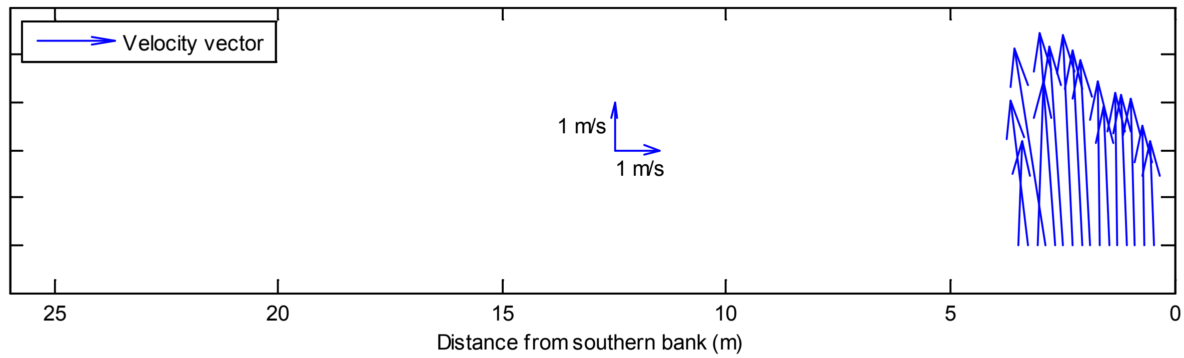


Flow Scenario 3

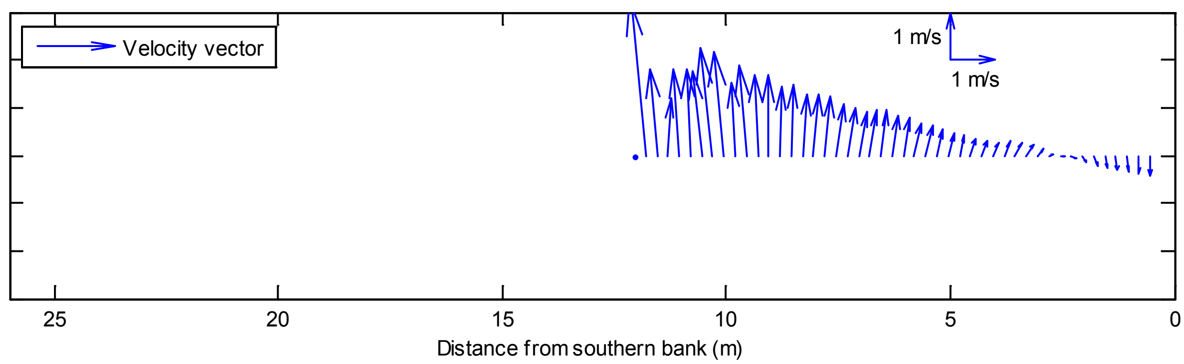


River Section S23

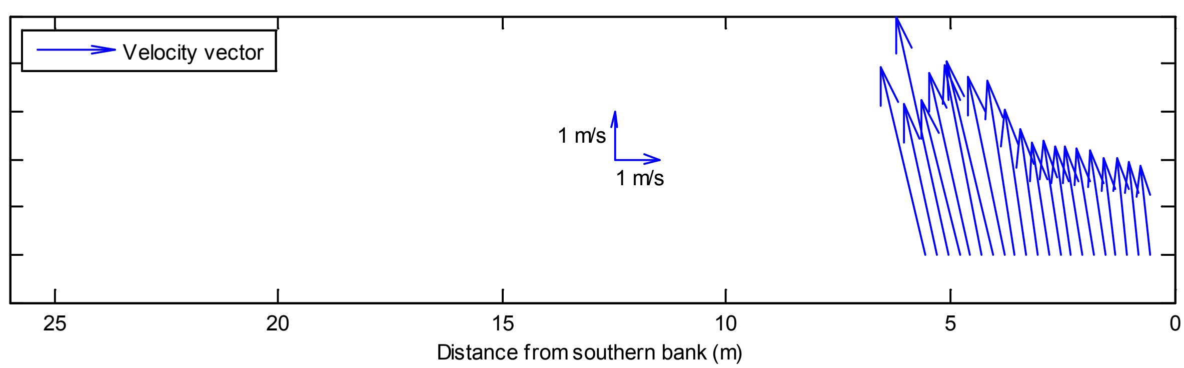
Flow Scenario 1



Flow Scenario 2

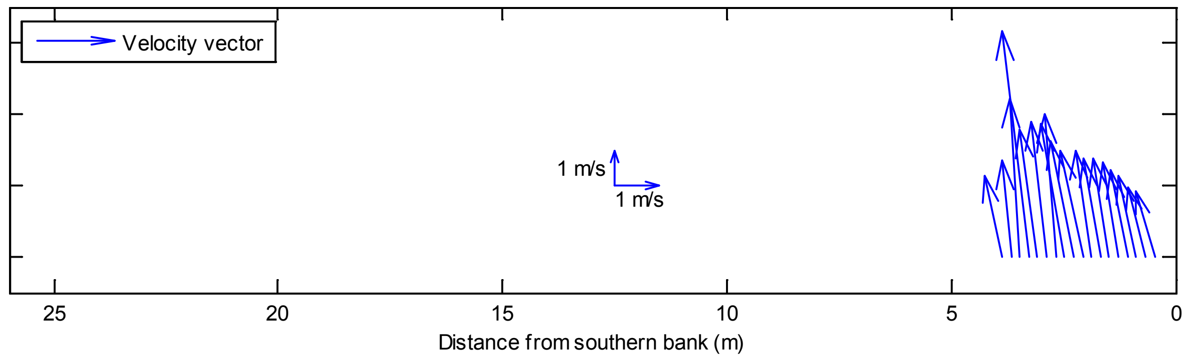


Flow Scenario 3

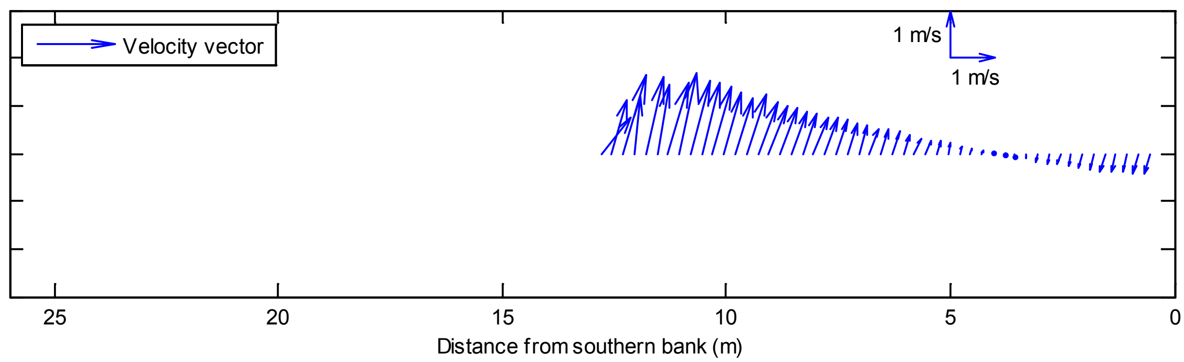


River Section S24

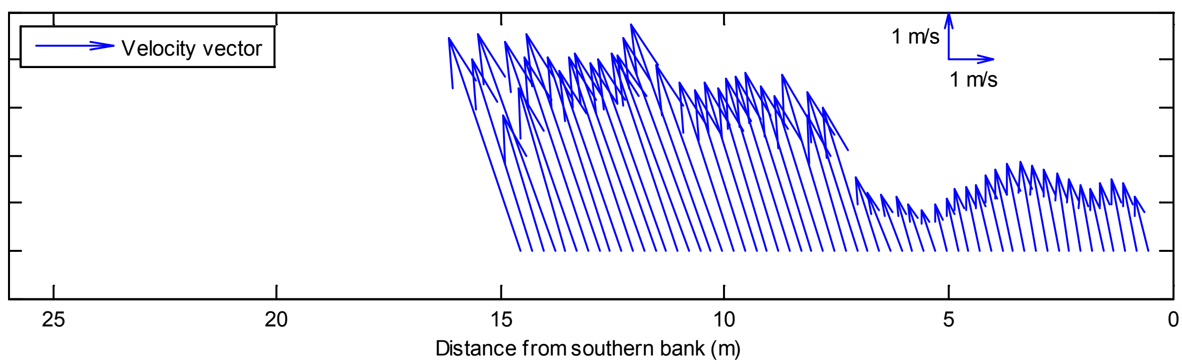
Flow Scenario 1



Flow Scenario 2

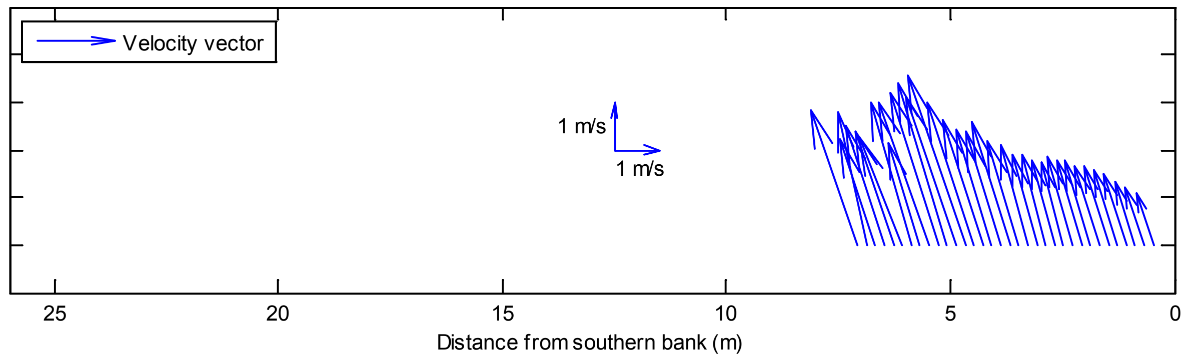


Flow Scenario 3

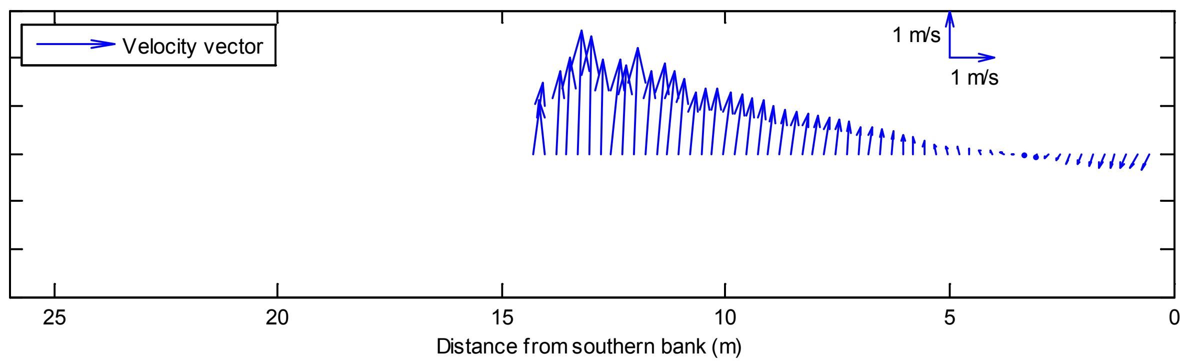


River Section S25

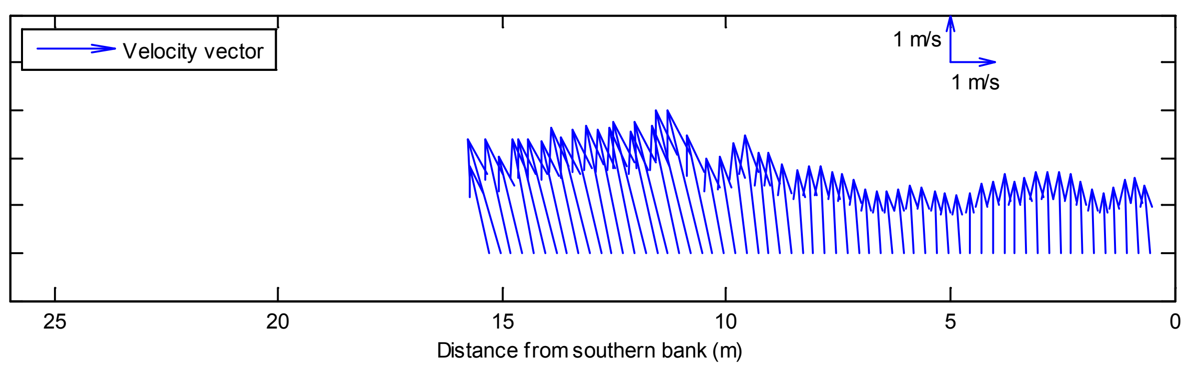
Flow Scenario 1



Flow Scenario 2

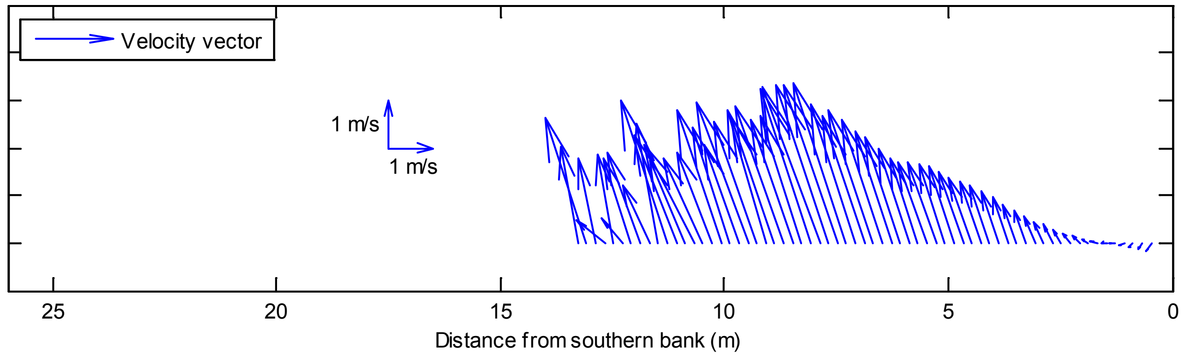


Flow Scenario 3

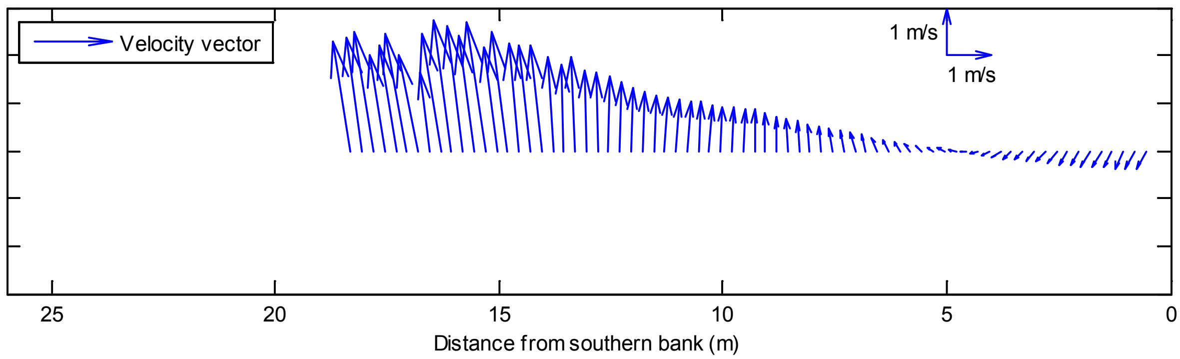


River Section S26

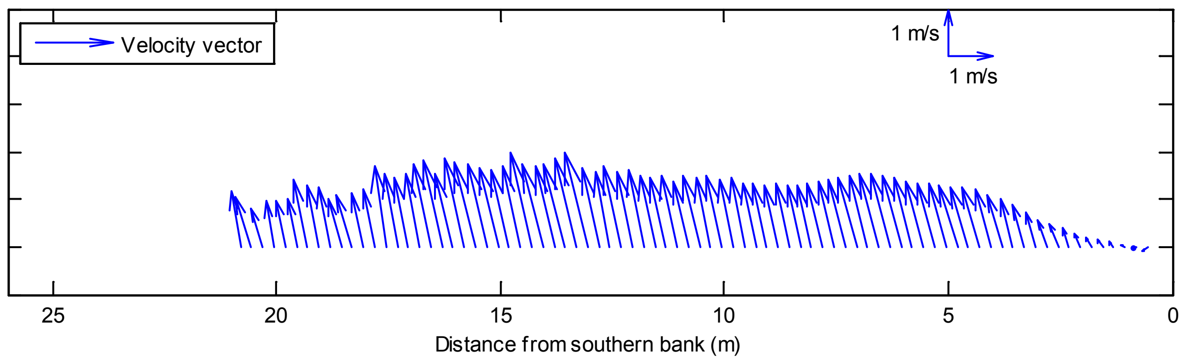
Flow Scenario 1



Flow Scenario 2

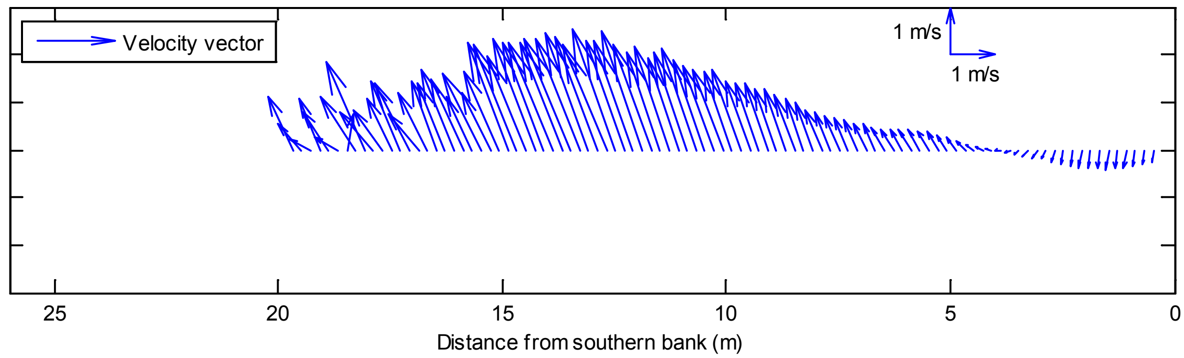


Flow Scenario 3

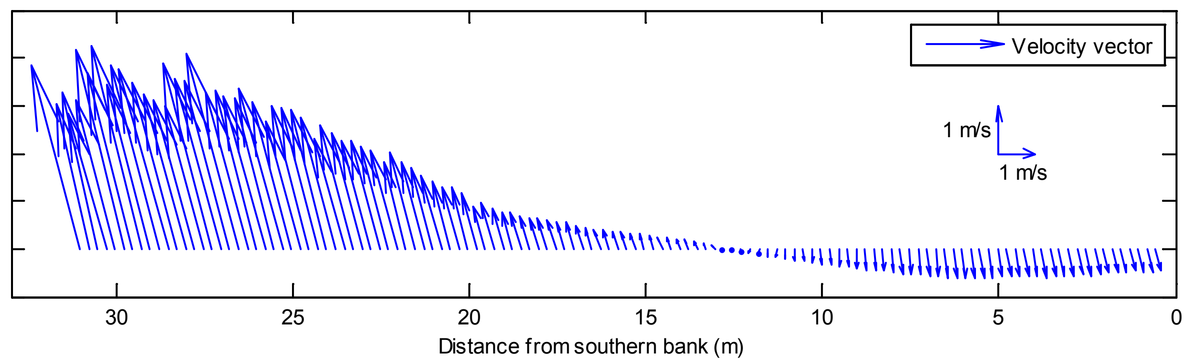


River Section S27

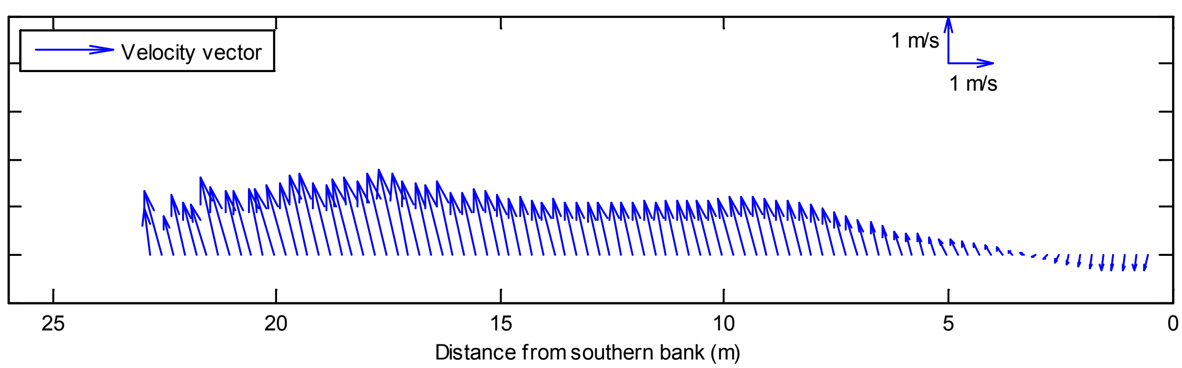
Flow Scenario 1



Flow Scenario 2

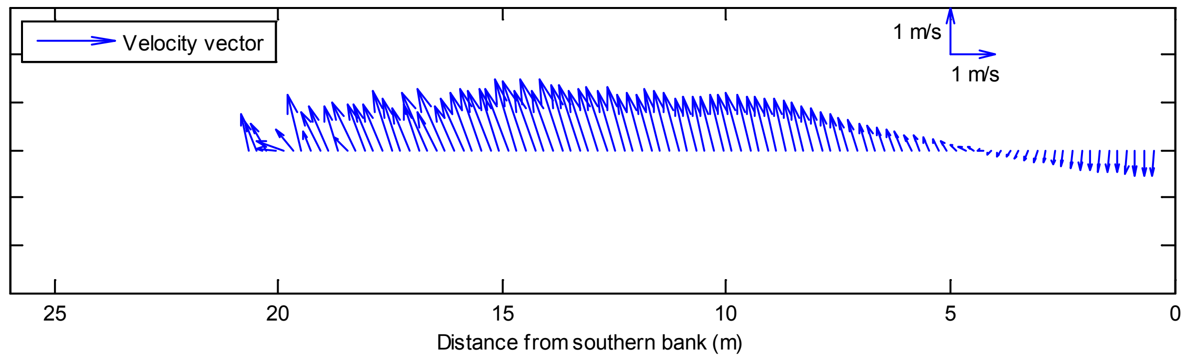


Flow Scenario 3

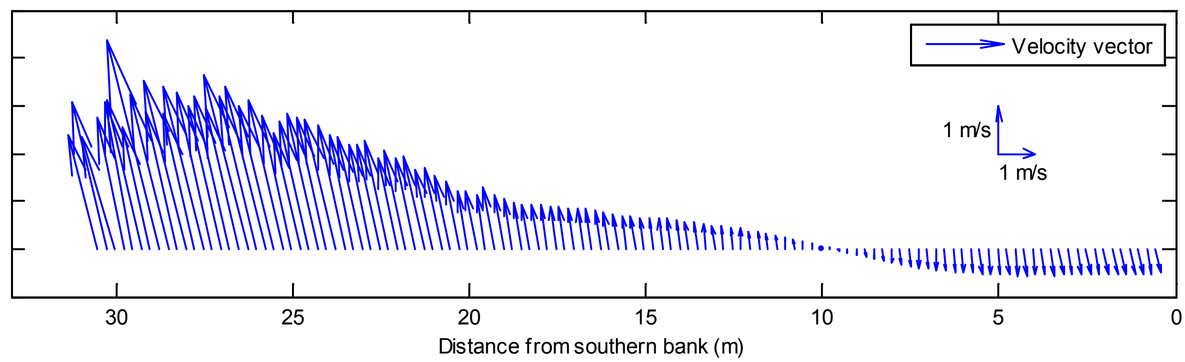


River Section S28

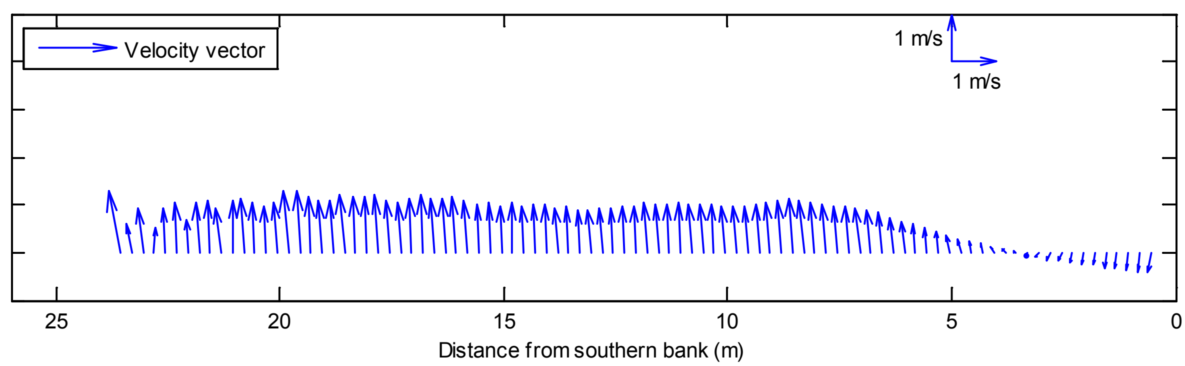
Flow Scenario 1



Flow Scenario 2

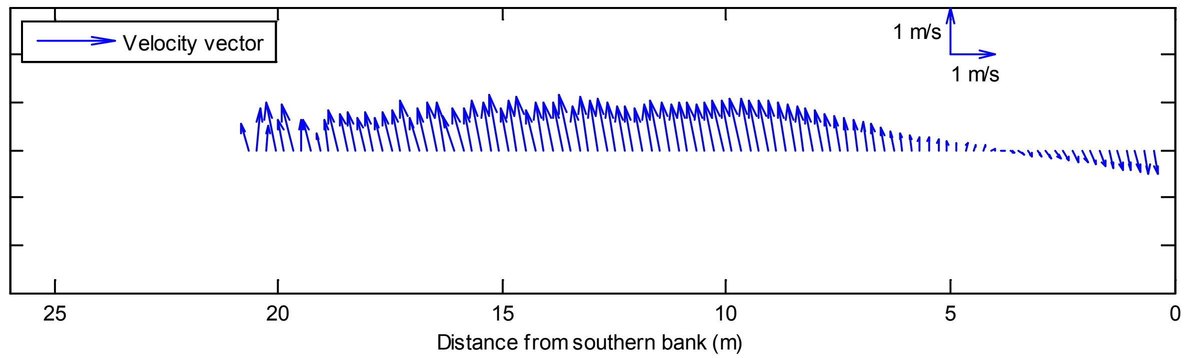


Flow Scenario 3

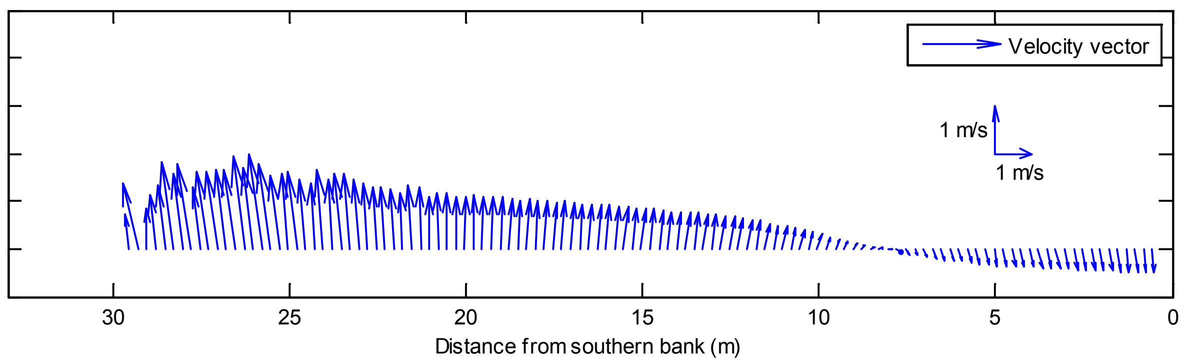


River Section S29

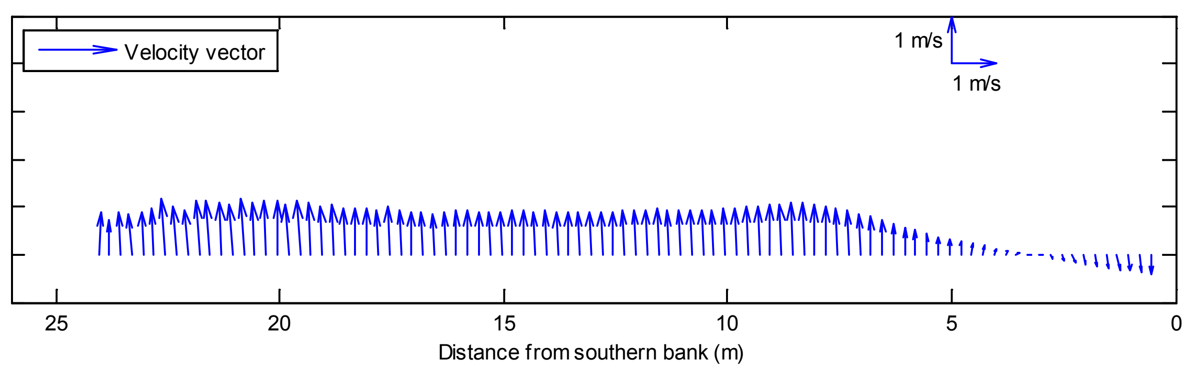
Flow Scenario 1



Flow Scenario 2

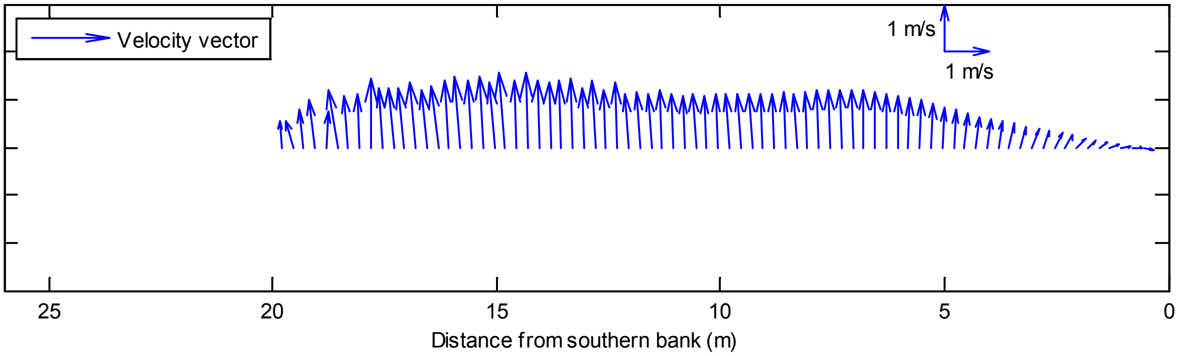


Flow Scenario 3

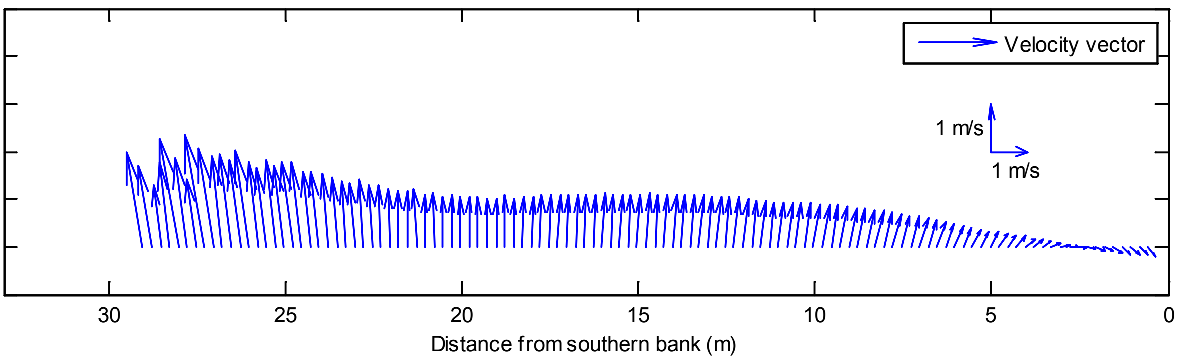


River Section S30

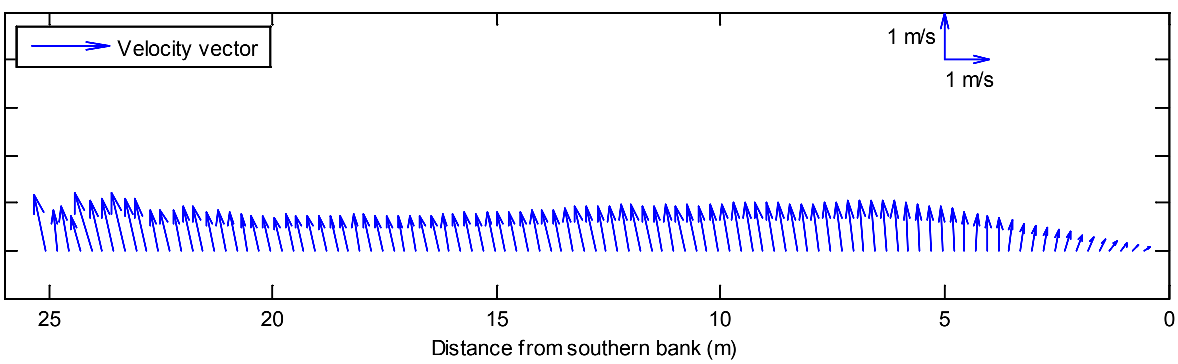
Flow Scenario 1



Flow Scenario 2

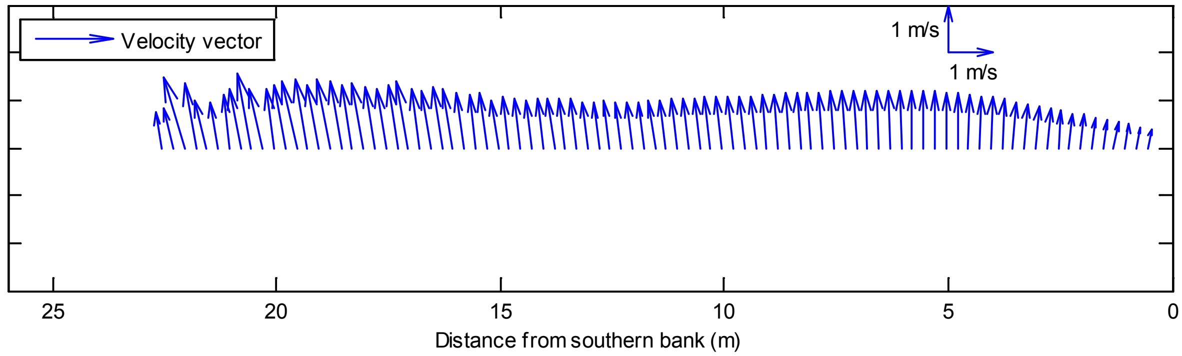


Flow Scenario 3

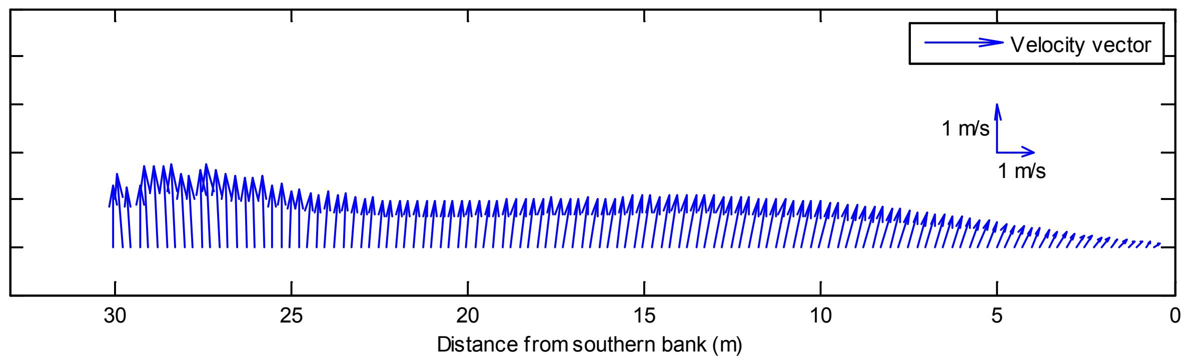


River Section S31

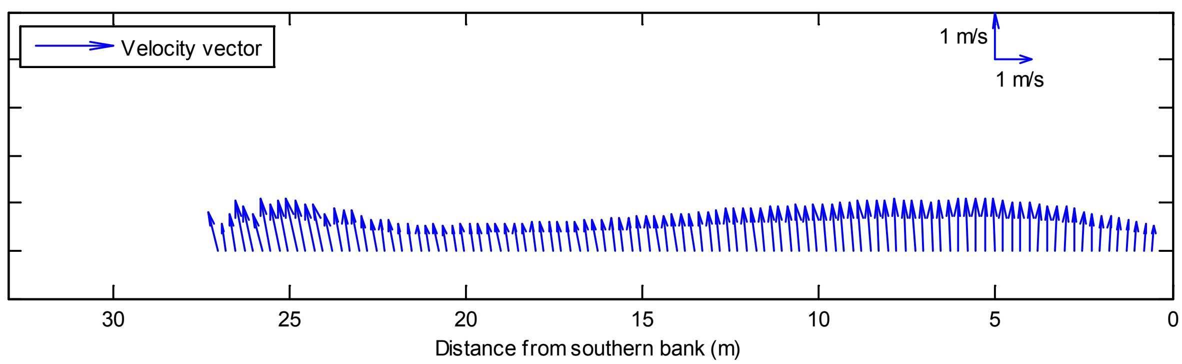
Flow Scenario 1



Flow Scenario 2

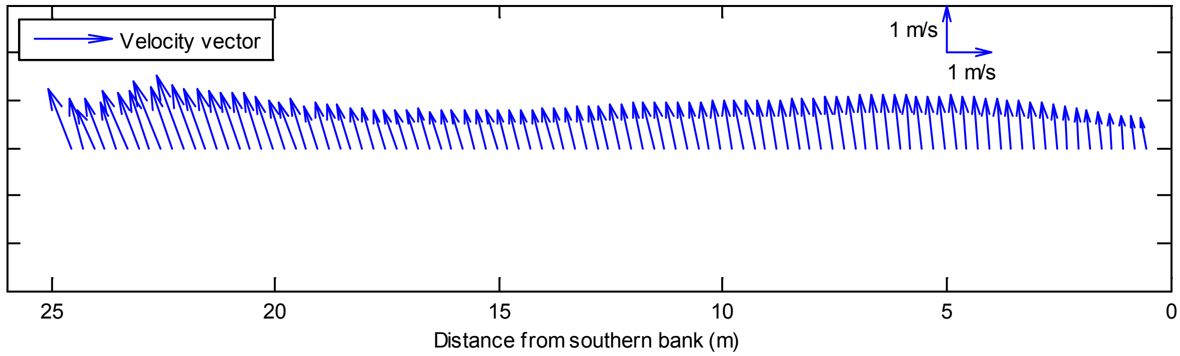


Flow Scenario 3

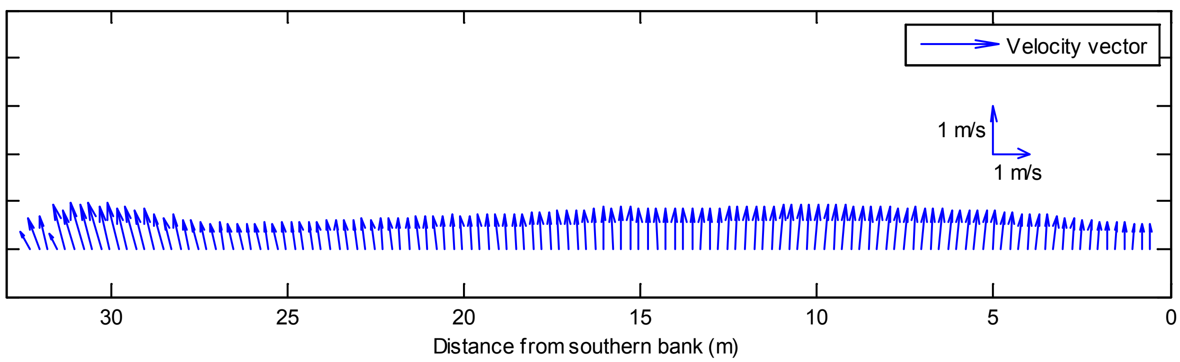


River Section S32

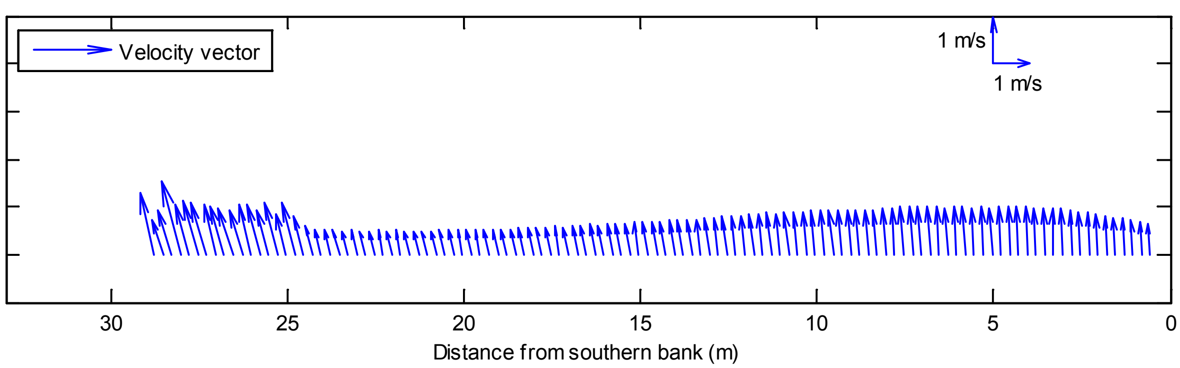
Flow Scenario 1



Flow Scenario 2

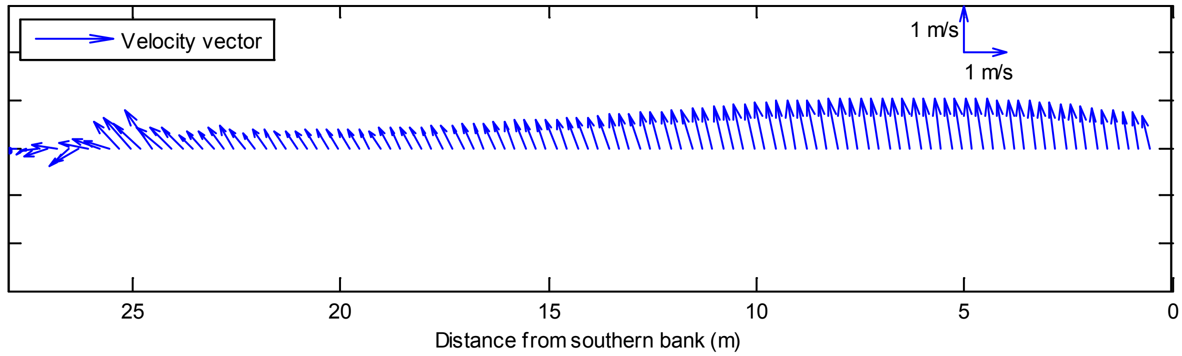


Flow Scenario 3

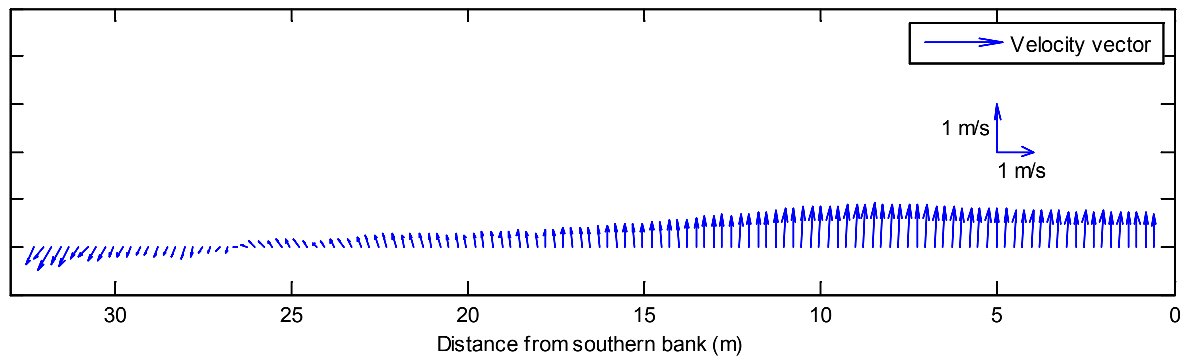


River Section S33

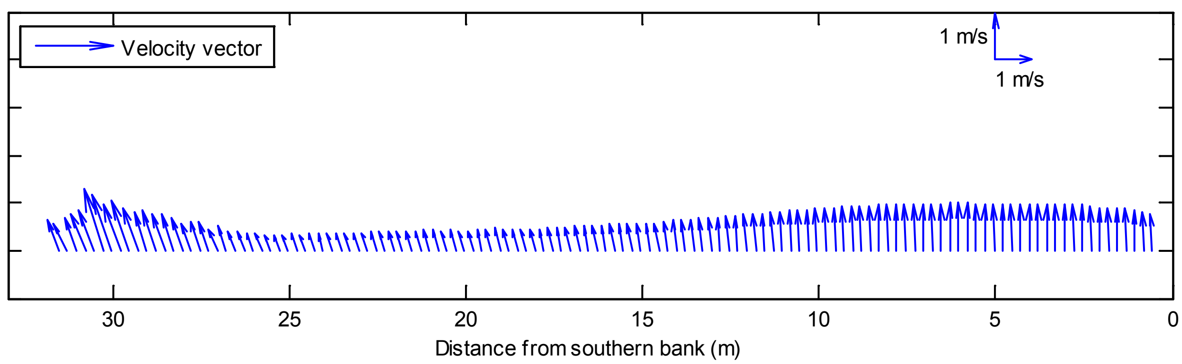
Flow Scenario 1



Flow Scenario 2

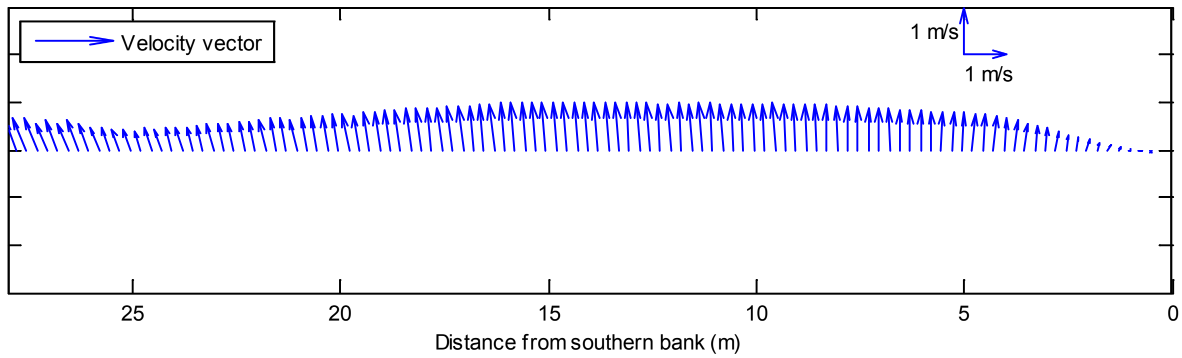


Flow Scenario 3

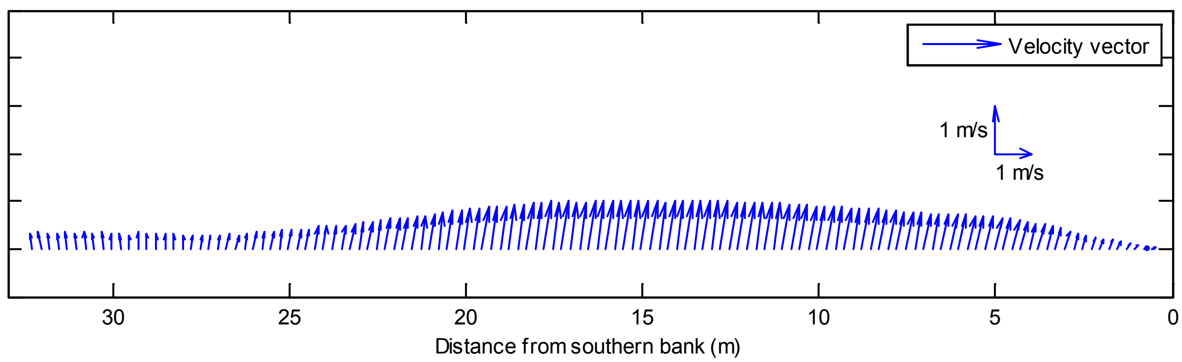


River Section S34

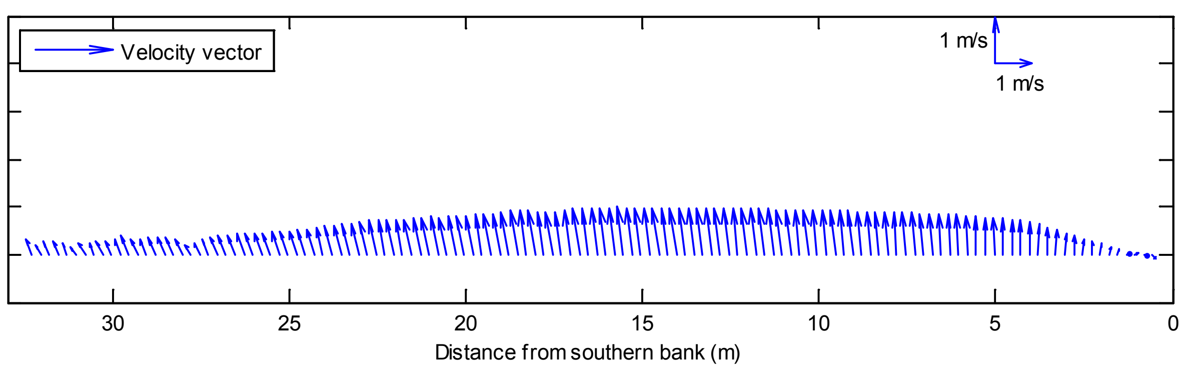
Flow Scenario 1



Flow Scenario 2

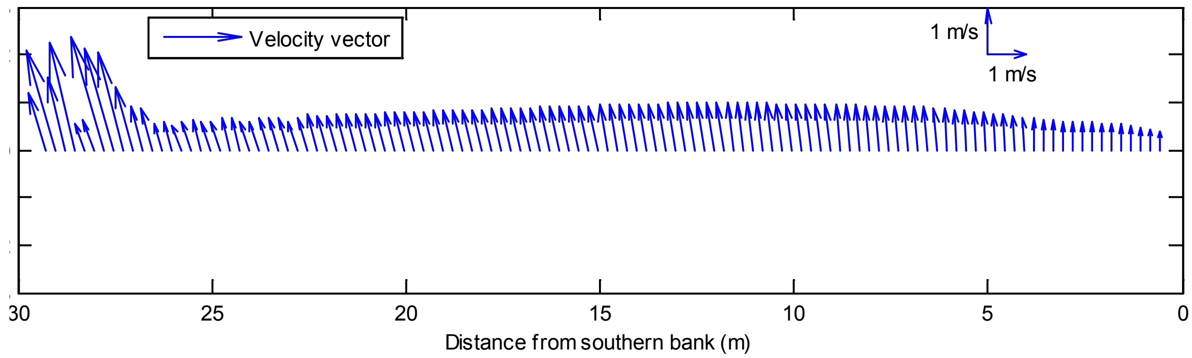


Flow Scenario 3

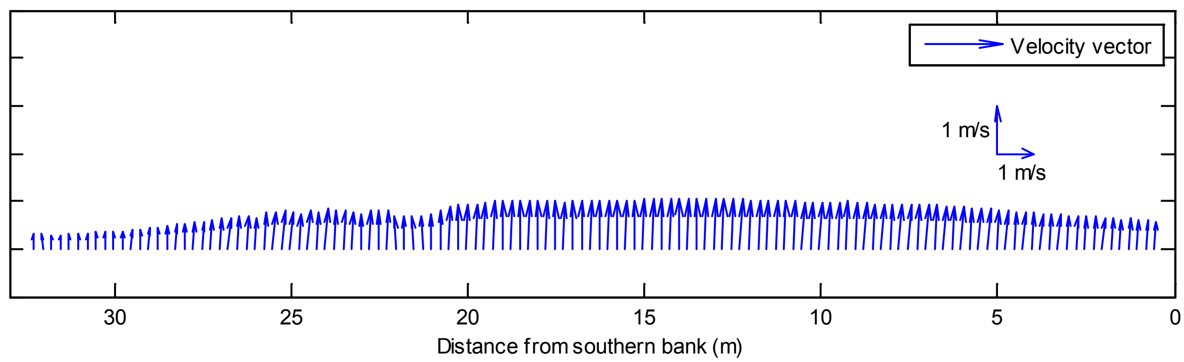


River Section S35

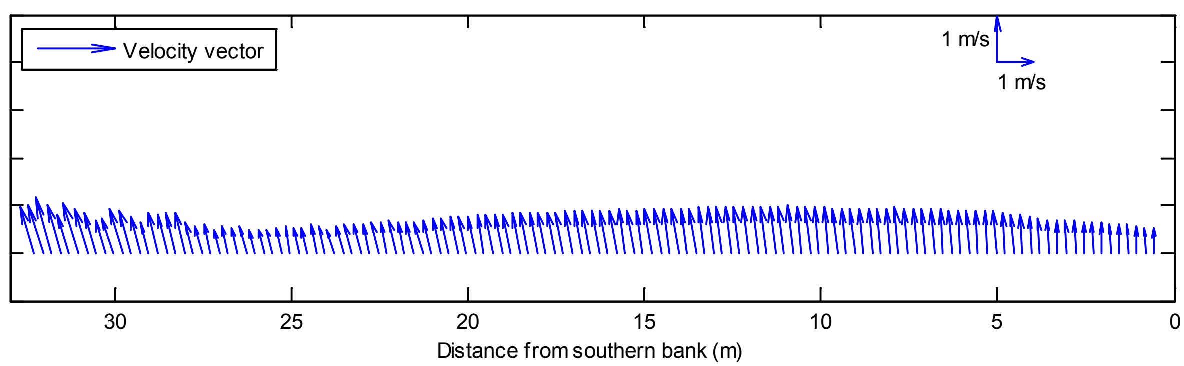
Flow Scenario 1



Flow Scenario 2

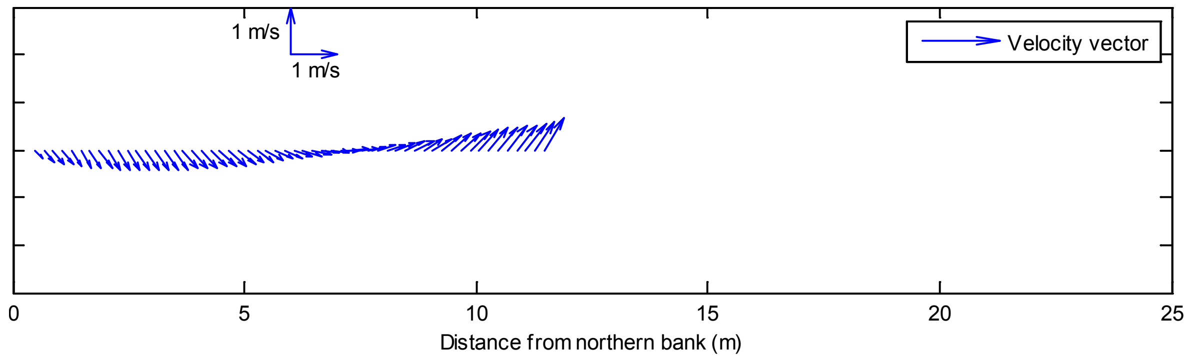


Flow Scenario 3

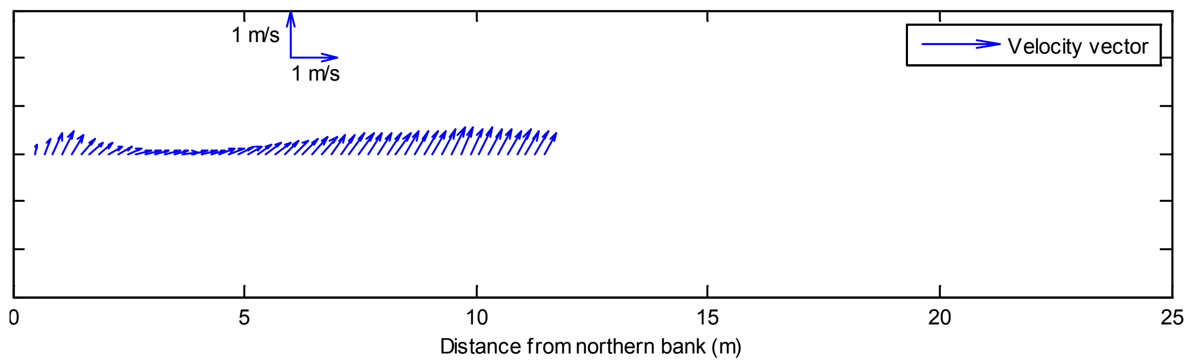


Radial Gate Section S36

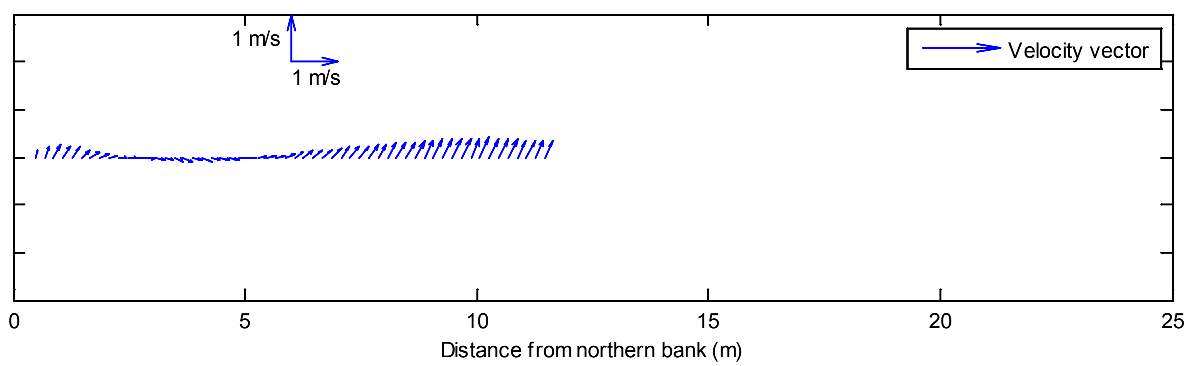
Flow Scenario 1



Flow Scenario 2

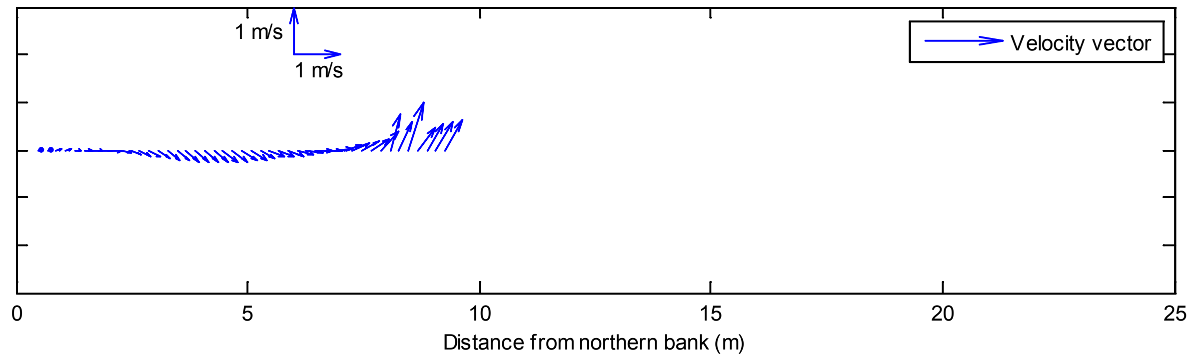


Flow Scenario 3

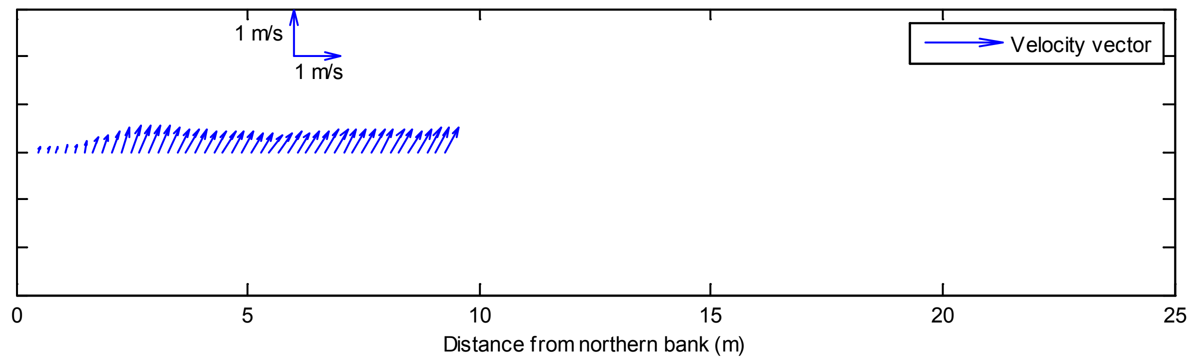


Radial Gate Section S37

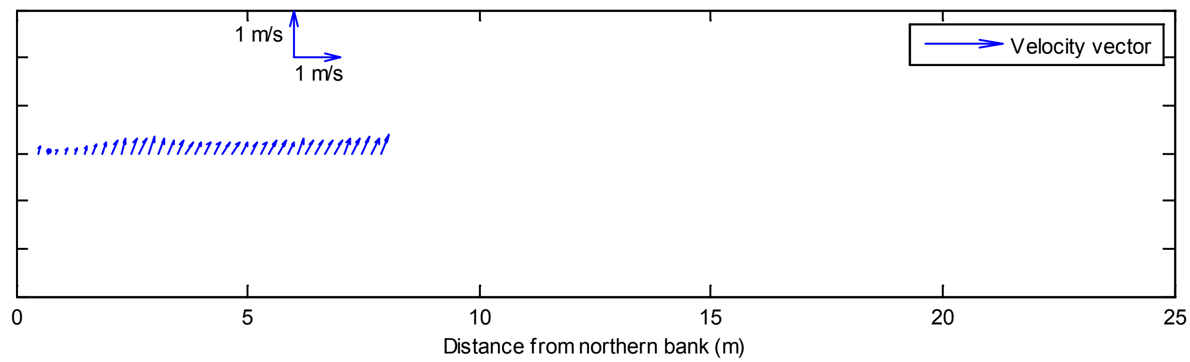
Flow Scenario 1



Flow Scenario 2

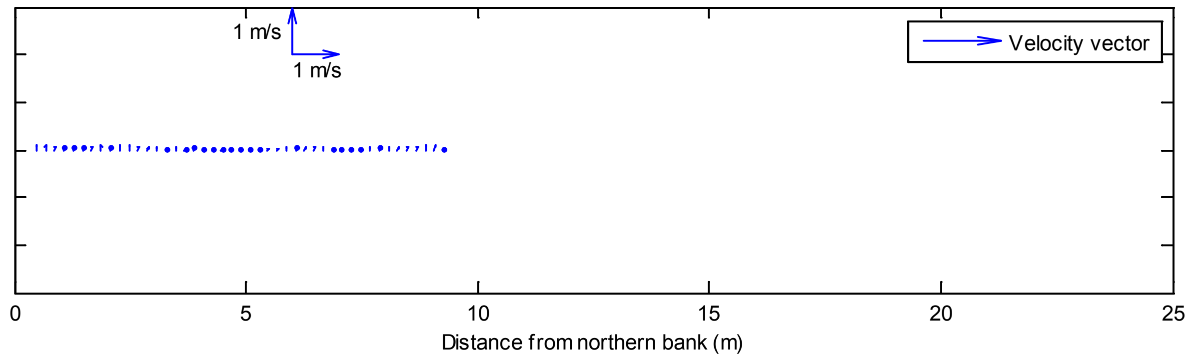


Flow Scenario 3

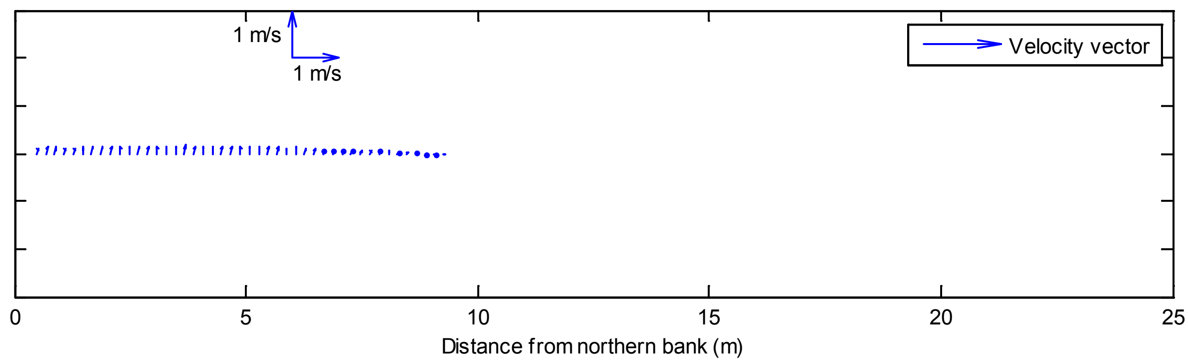


Radial Gate Section S38

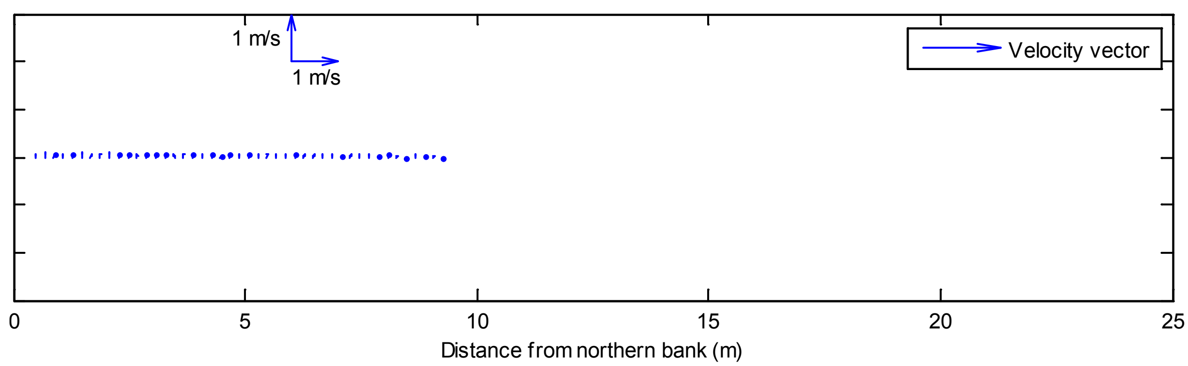
Flow Scenario 1



Flow Scenario 2



Flow Scenario 3

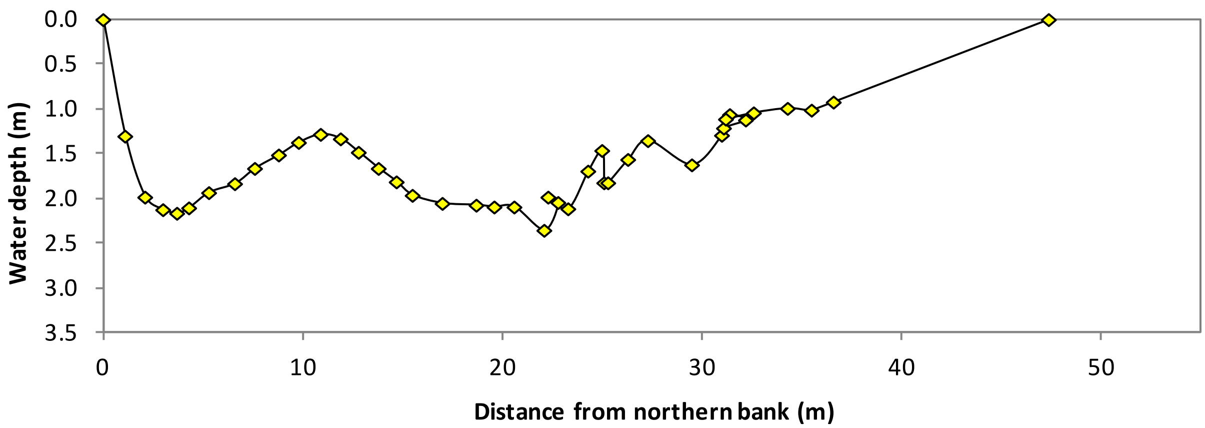


APPENDIX II

Detailed River Bathymetry Results

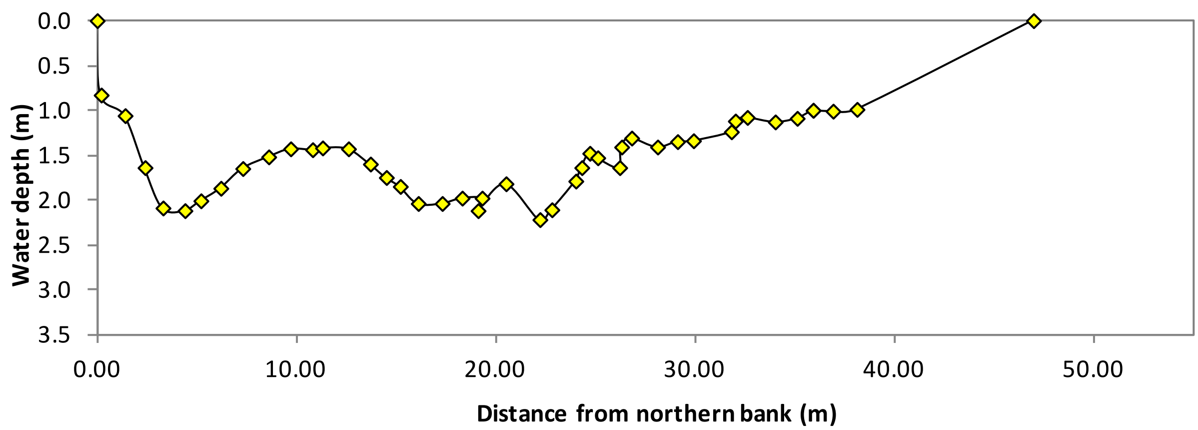
Bathymetry Transect T1

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572261.236	5613611.707	228.721
Southern bank	572291.580	5613578.080	228.653



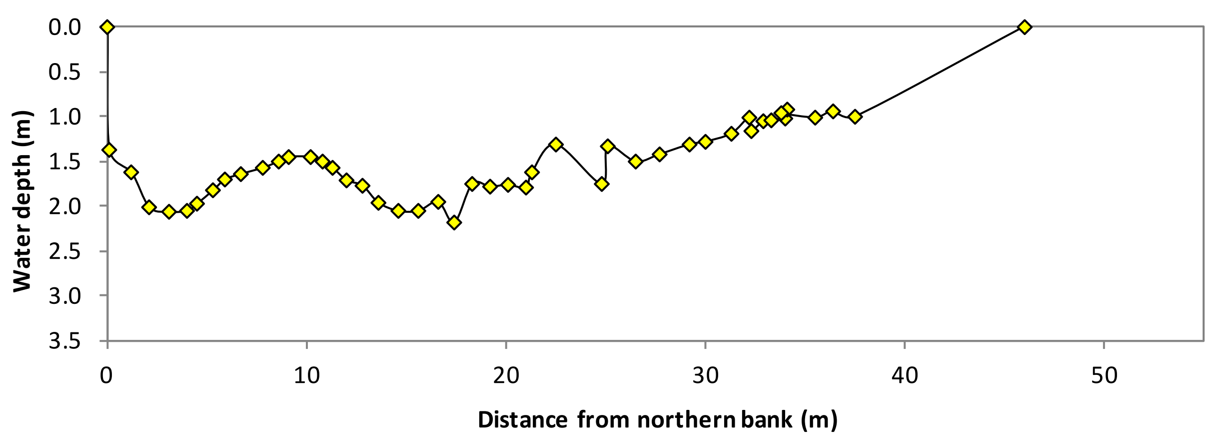
Bathymetry Transect T2

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572263.034	5613612.831	228.647
Southern bank	572291.580	5613578.080	228.653



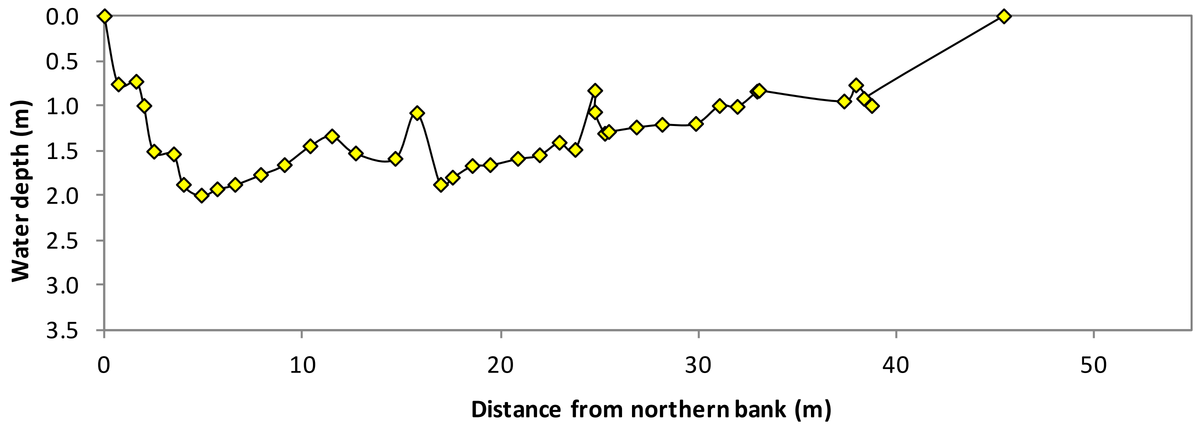
Bathymetry Transect T3

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572264.942	5613613.250	228.659
Southern bank	572291.580	5613578.080	228.653



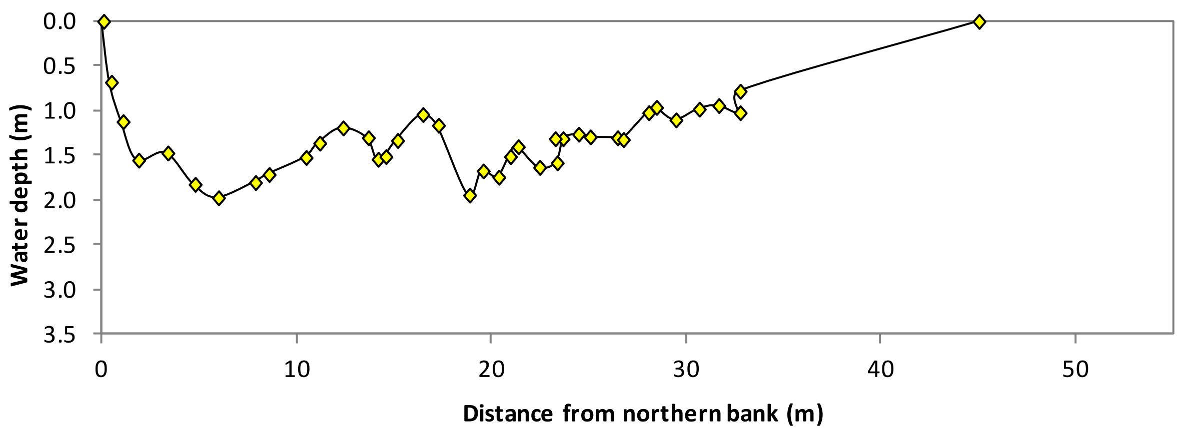
Bathymetry Transect T4

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572267.097	5613614.306	228.706
Southern bank	572291.580	5613578.080	228.653



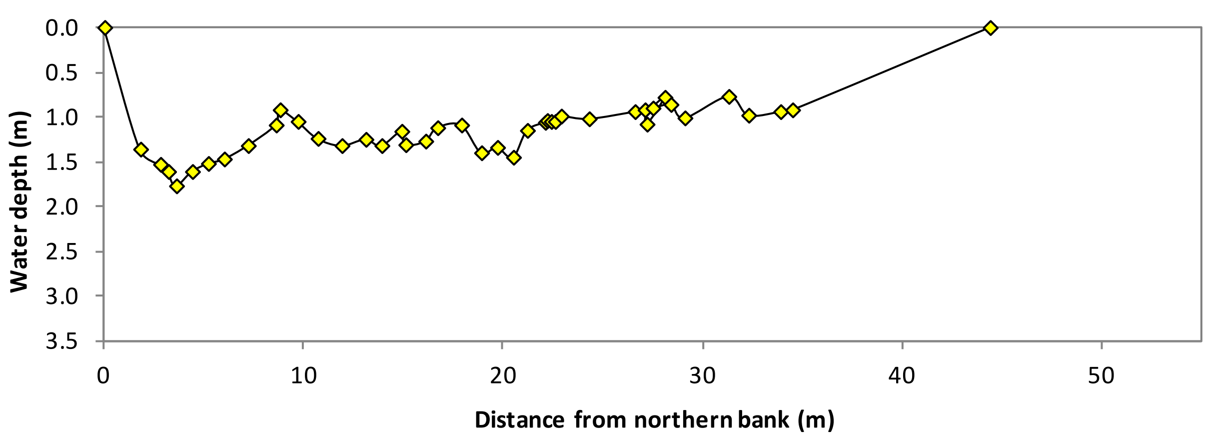
Bathymetry Transect T5

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572268.404	5613614.642	228.701
Southern bank	572291.580	5613578.080	228.653



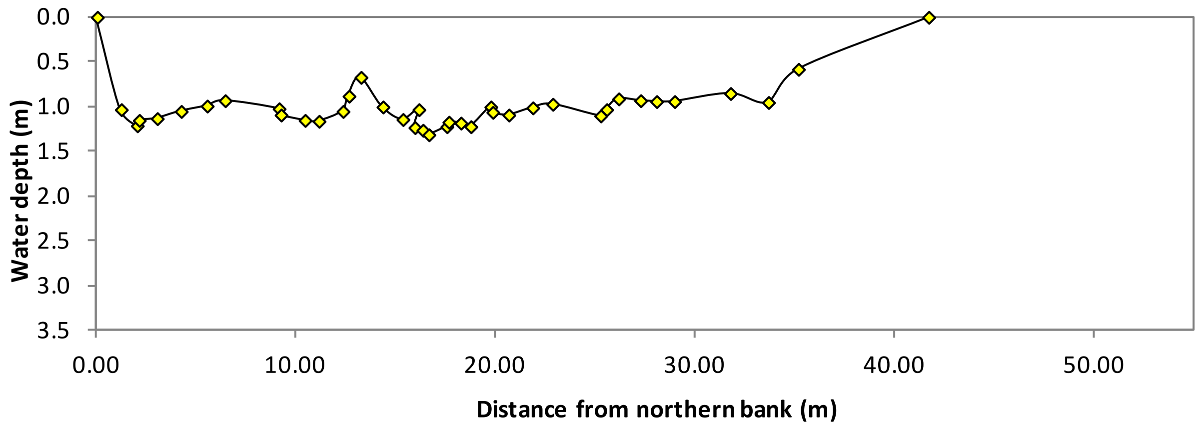
Bathymetry Transect T6

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572270.877	5613615.641	228.655
Southern bank	572291.580	5613578.080	228.653



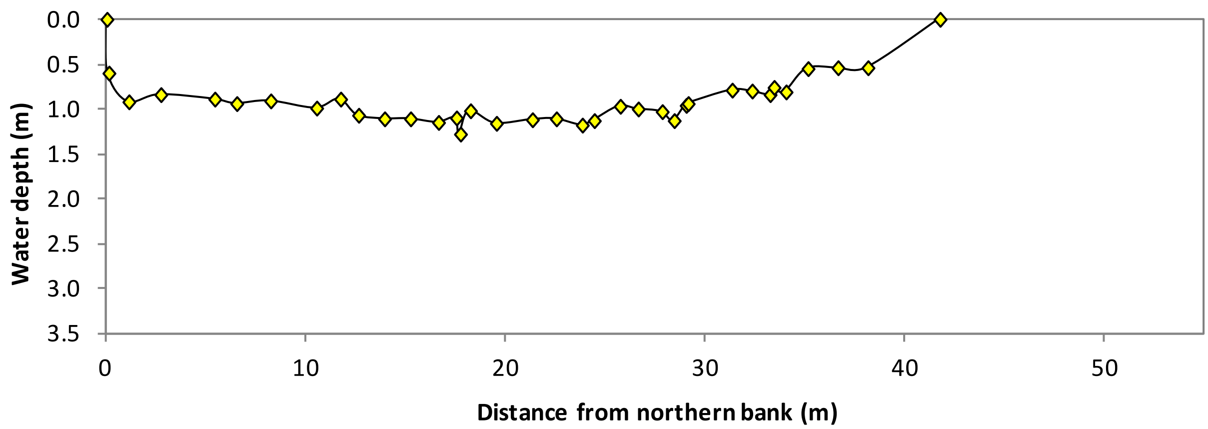
Bathymetry Transect T7

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572274.109	5613616.346	228.599
Southern bank	572292.333	5613578.925	228.653



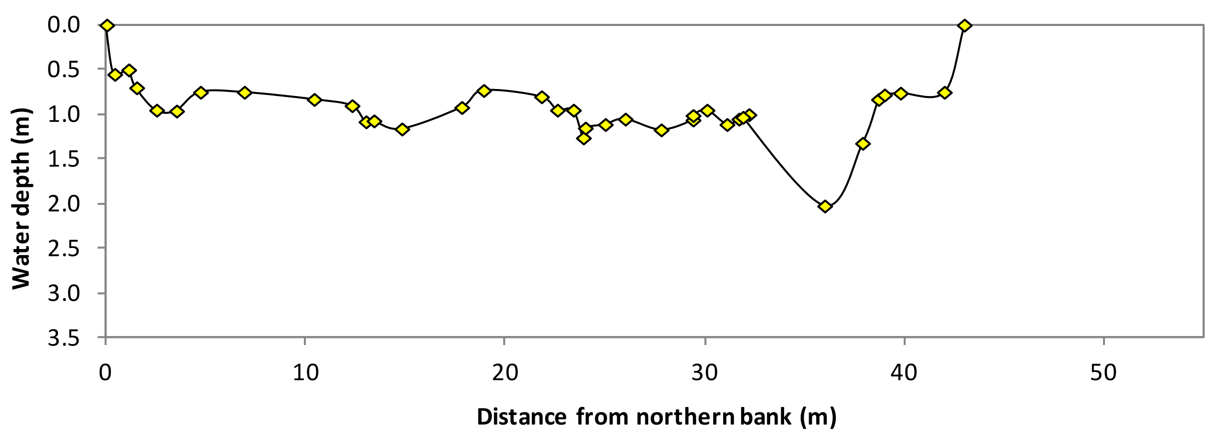
Bathymetry Transect T8

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572277.262	5613618.003	228.64
Southern bank	572294.408	5613579.981	228.707



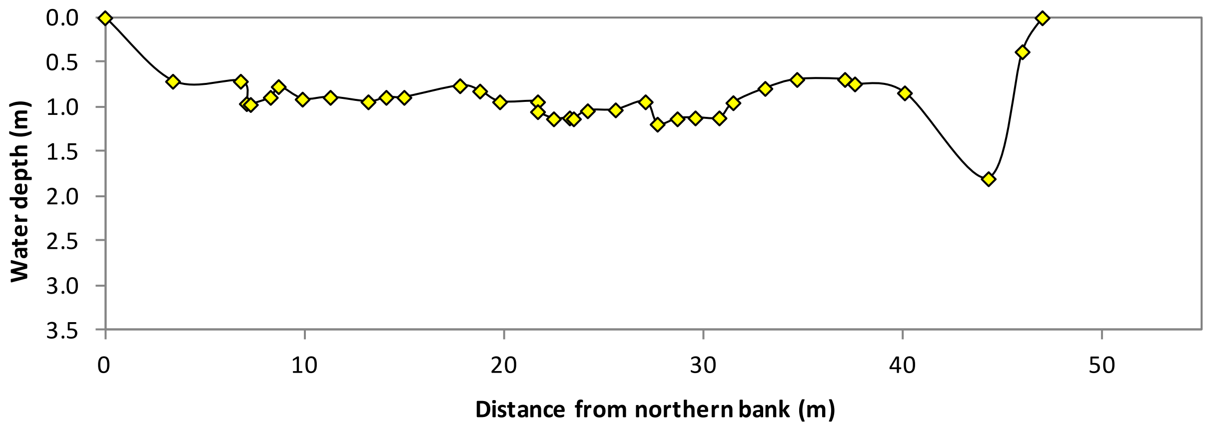
Bathymetry Transect T9

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572280.647	5613617.867	228.628
Southern bank	572296.312	5613580.914	228.67



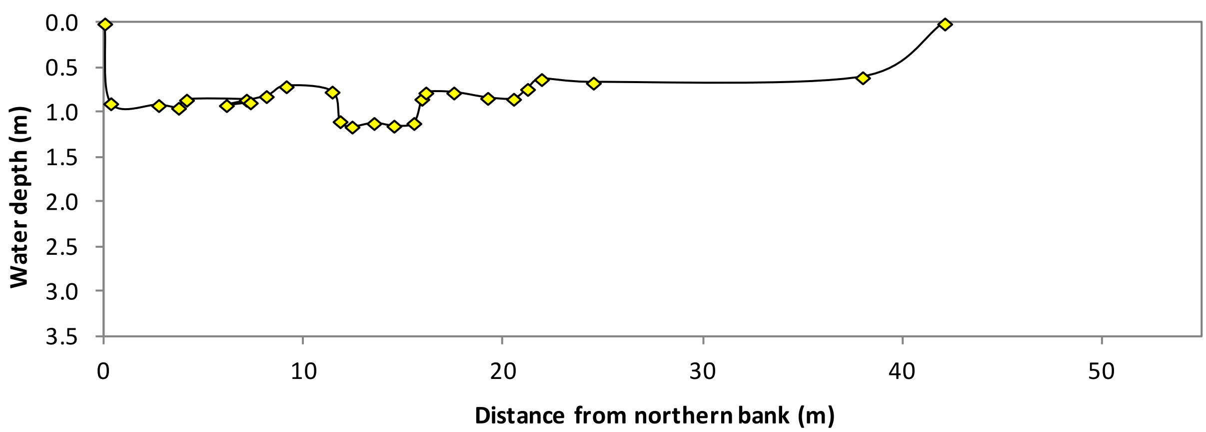
Bathymetry Transect T10

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572282.462	5613618.078	228.703
Southern bank	572298.151	5613580.833	228.696



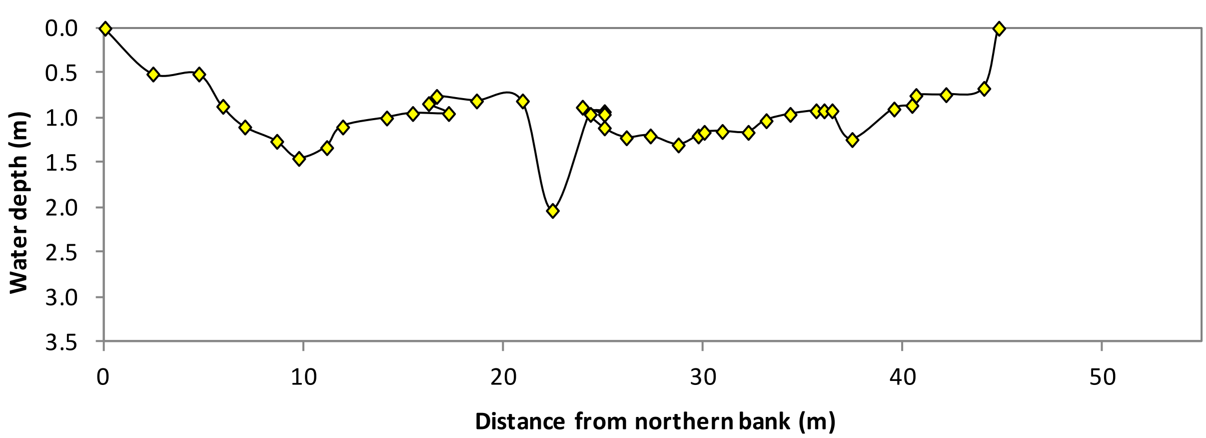
Bathymetry Transect T11

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572284.096	5613620.675	228.691
Southern bank	572299.799	5613581.593	228.739



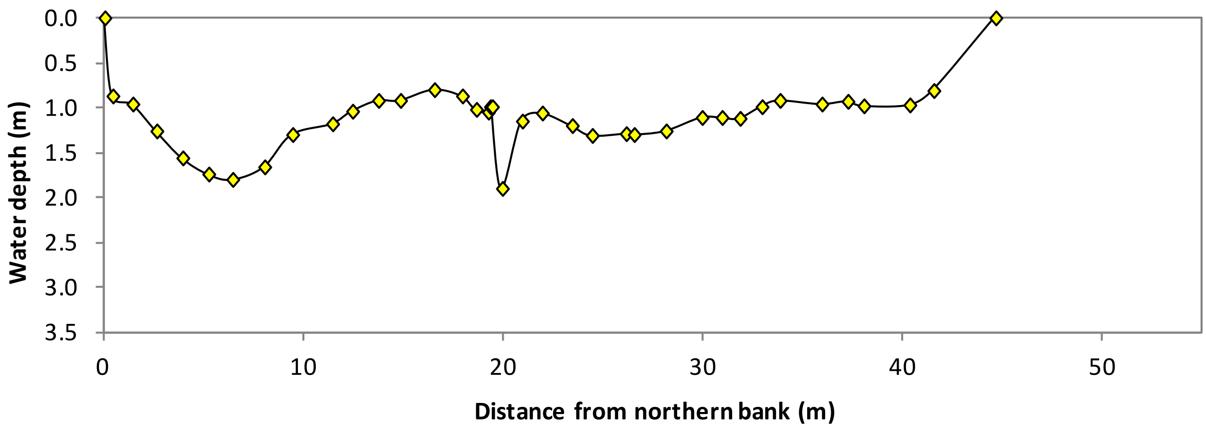
Bathymetry Transect T12

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572284.839	5613623.297	228.713
Southern bank	572302.369	5613582.127	228.676



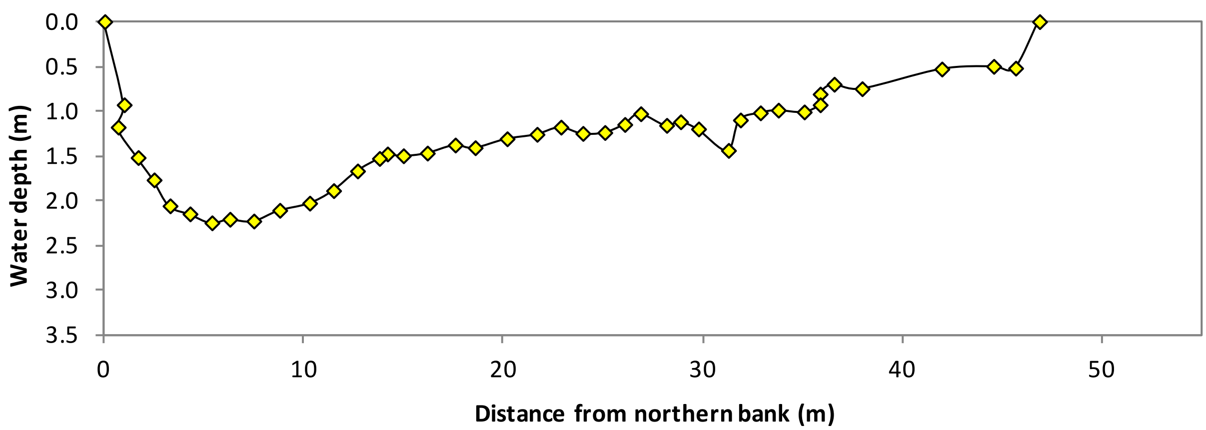
Bathymetry Transect T13

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572286.795	5613624.213	228.653
Southern bank	572303.702	5613582.938	228.711



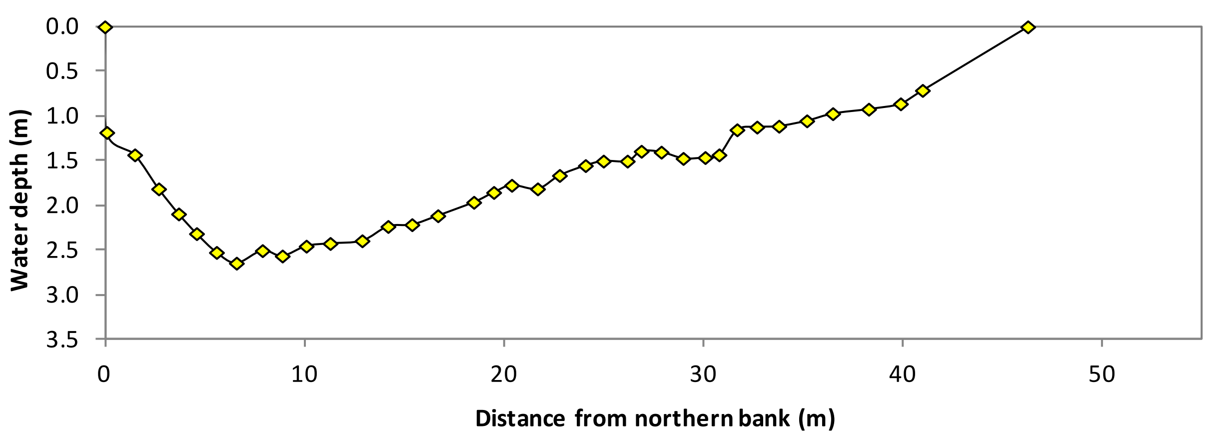
Bathymetry Transect T14

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572289.416	5613627.555	228.649
Southern bank	572306.203	5613583.790	228.634



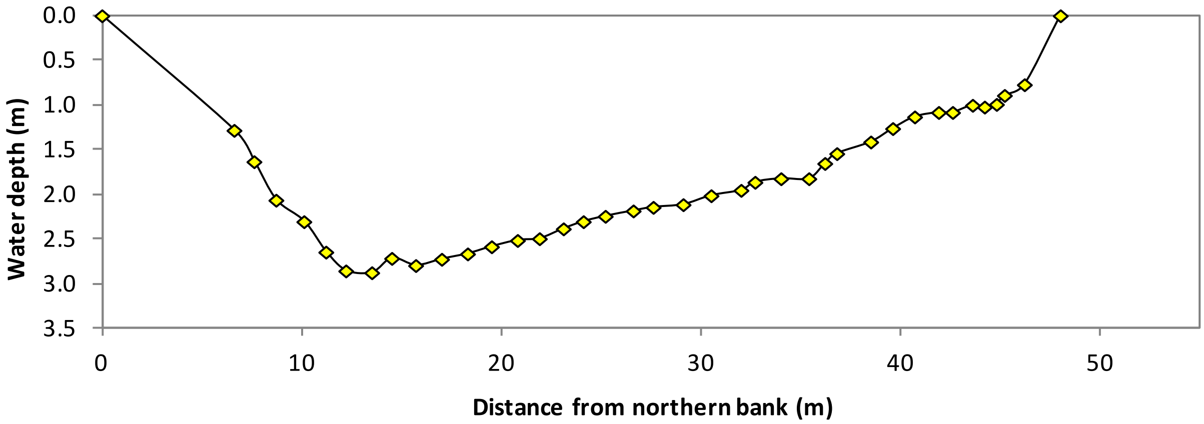
Bathymetry Transect T15

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572291.885	5613627.78	228.686
Southern bank	572308.586	5613584.617	228.698



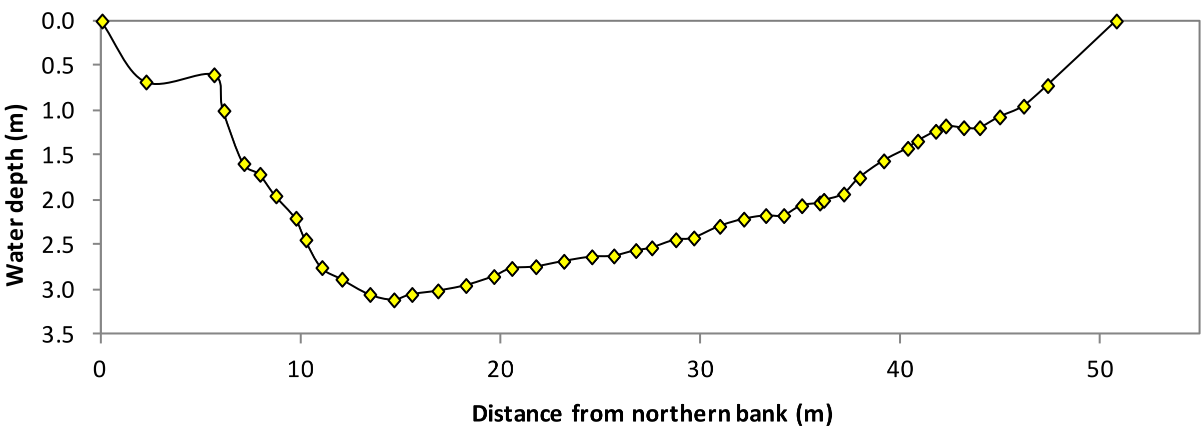
Bathymetry Transect T16

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572293.165	5613629.032	228.693
Southern bank	572311.441	5613584.625	228.723



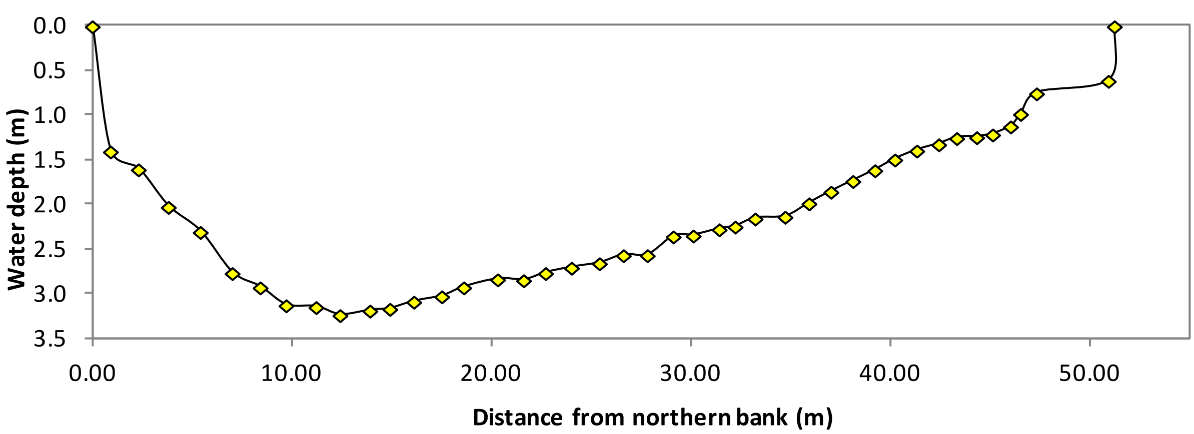
Bathymetry Transect T17

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572295.642	5613632.474	228.713
Southern bank	572313.229	5613584.881	228.723



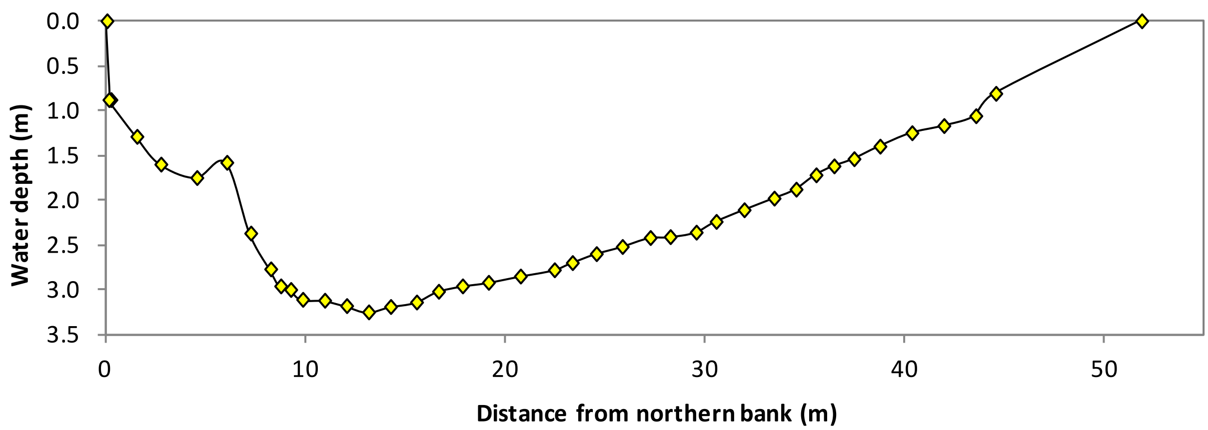
Bathymetry Transect T18

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572298.096	5613633.88	228.683
Southern bank	572315.570	5613585.745	228.731



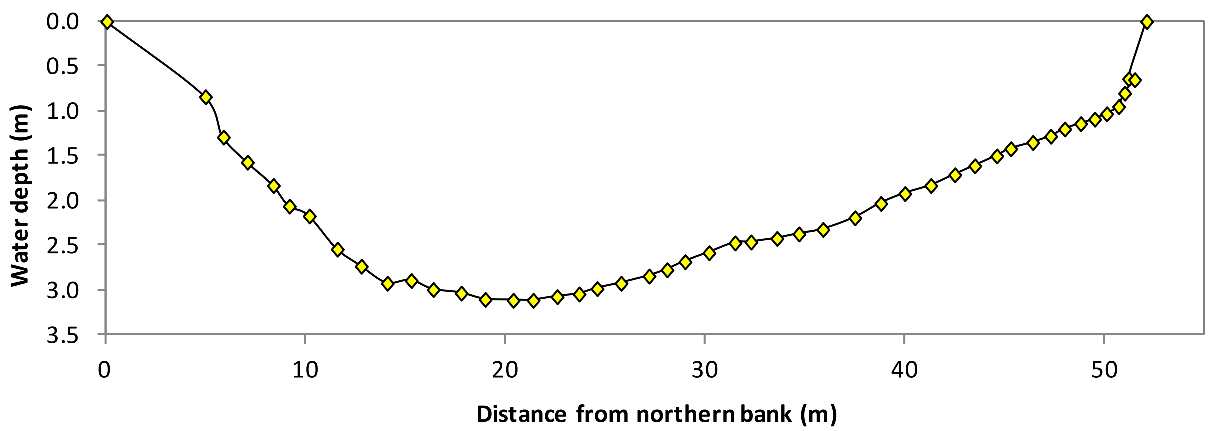
Bathymetry Transect T19

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572300.411	5613635.672	228.651
Southern bank	572316.954	5613586.581	228.676



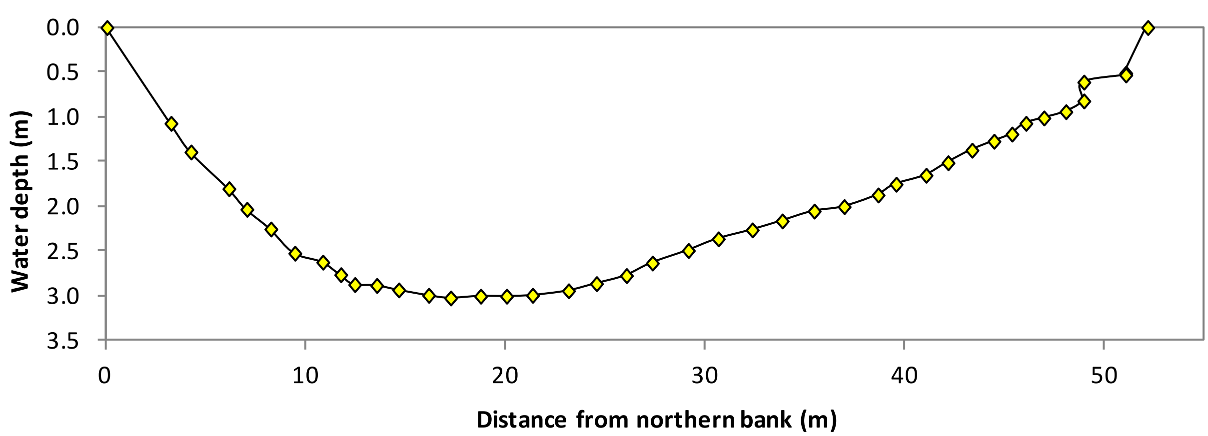
Bathymetry Transect T20

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572302.935	5613637.624	228.703
Southern bank	572318.889	5613588.092	228.684



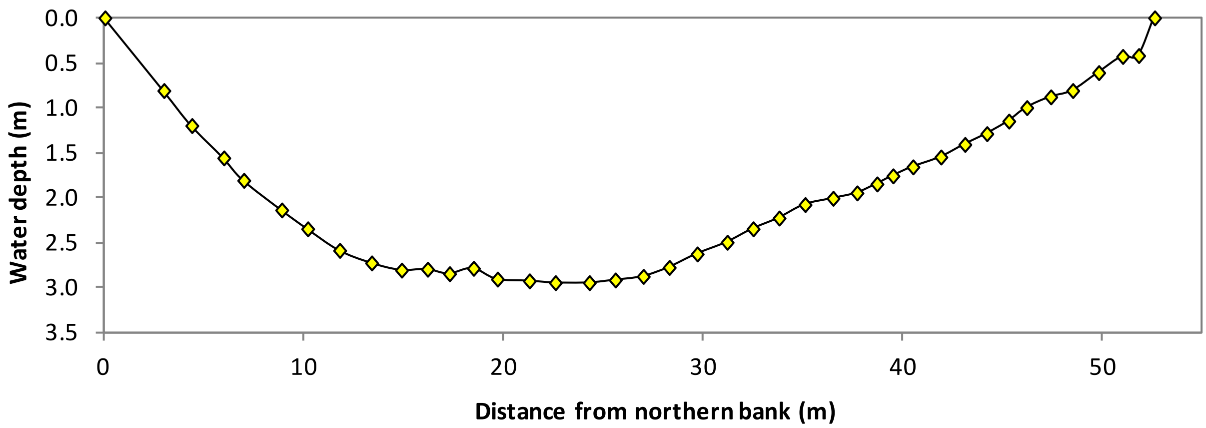
Bathymetry Transect T21

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572306.265	5613639.102	228.711
Southern bank	572320.436	5613588.959	228.685



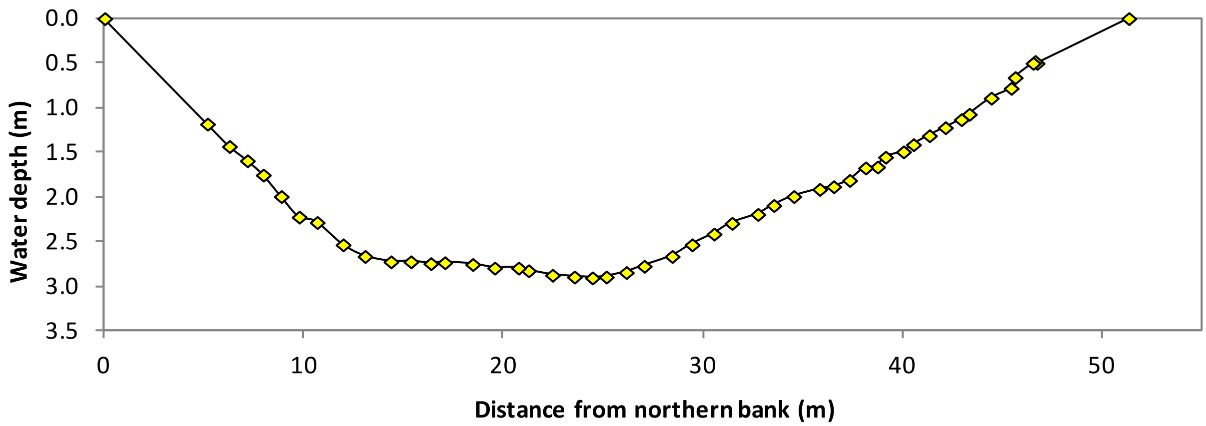
Bathymetry Transect T22

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572309.266	5613640.819	228.665
Southern bank	572323.128	5613590.13	228.736



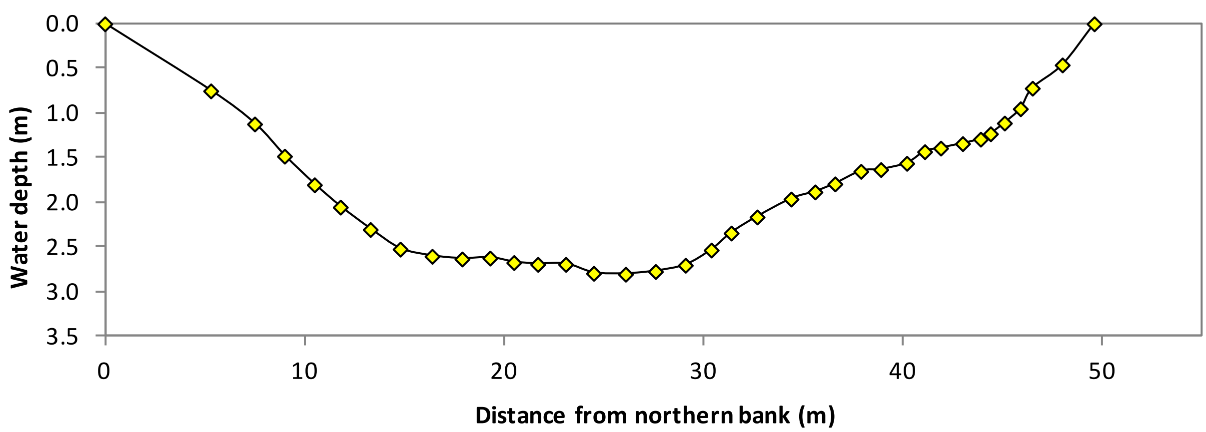
Bathymetry Transect T23

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572309.266	5613640.819	228.665
Southern bank	572325.337	5613592.046	228.723



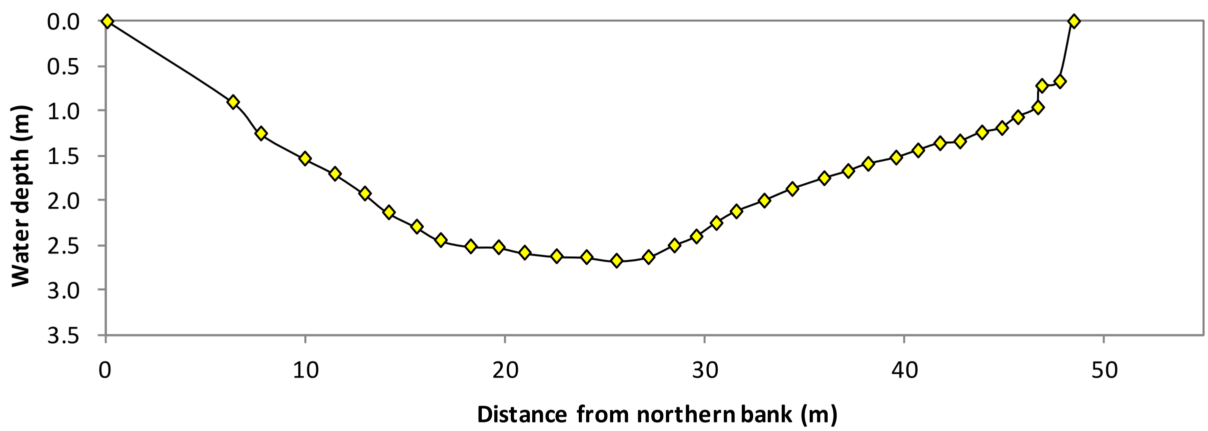
Bathymetry Transect T24

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572312.365	5613641.83	228.676
Southern bank	572328.008	5613594.75	228.738



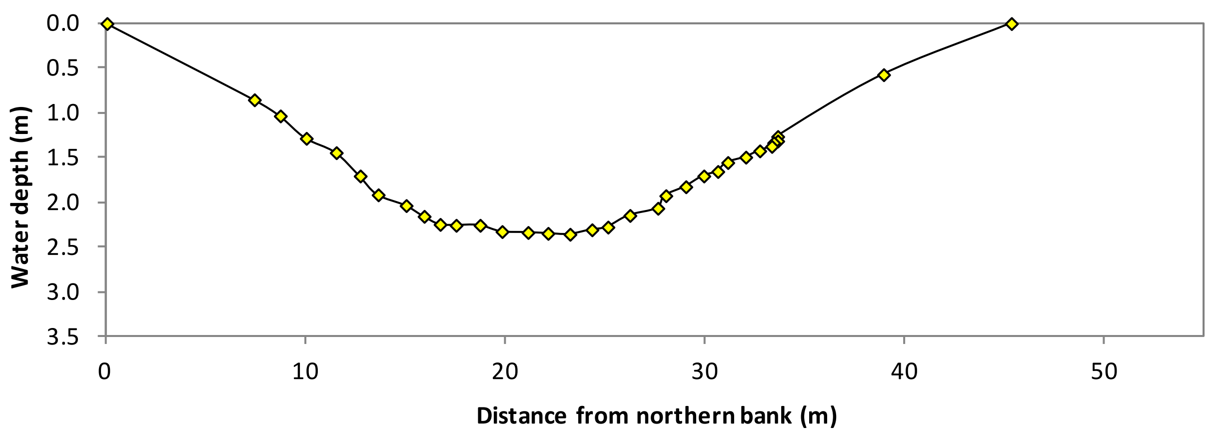
Bathymetry Transect T25

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572315.536	5613642.648	228.696
Southern bank	572330.766	5613596.711	228.696



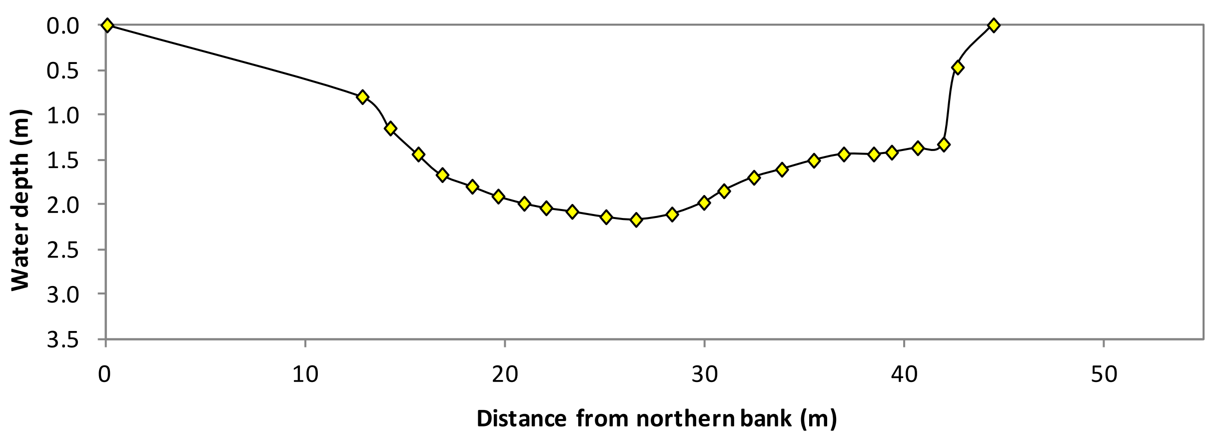
Bathymetry Transect T26

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572321.530	5613642.727	228.648
Southern bank	572334.206	5613599.258	228.681



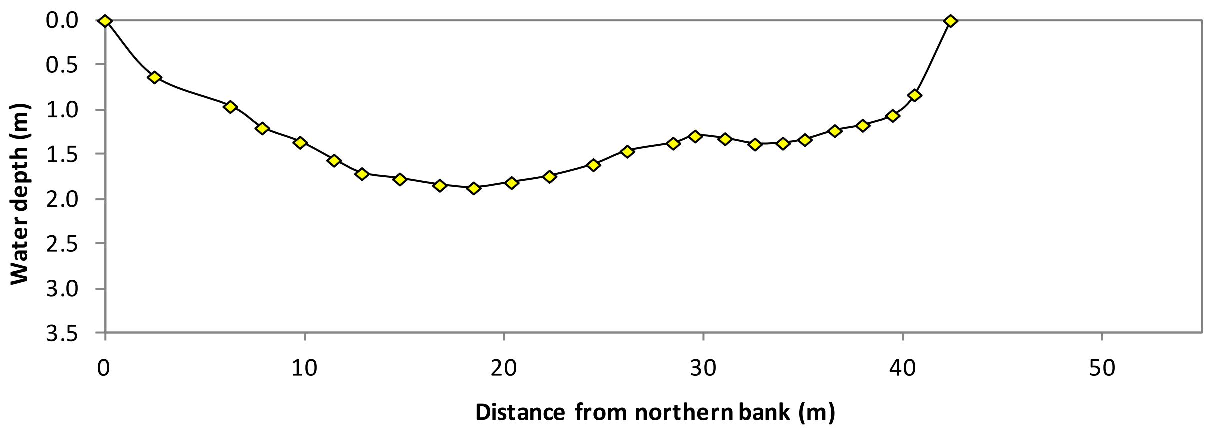
Bathymetry Transect T27

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572324.655	5613643.109	228.692
Southern bank	572336.406	5613600.315	228.667



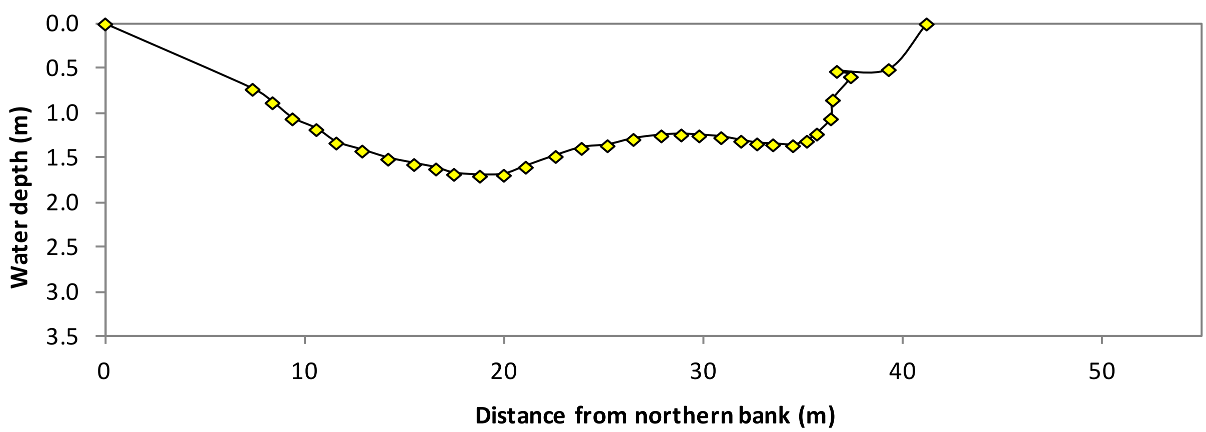
Bathymetry Transect T28

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572327.885	5613642.599	228.675
Southern bank	572338.548	5613601.579	228.684



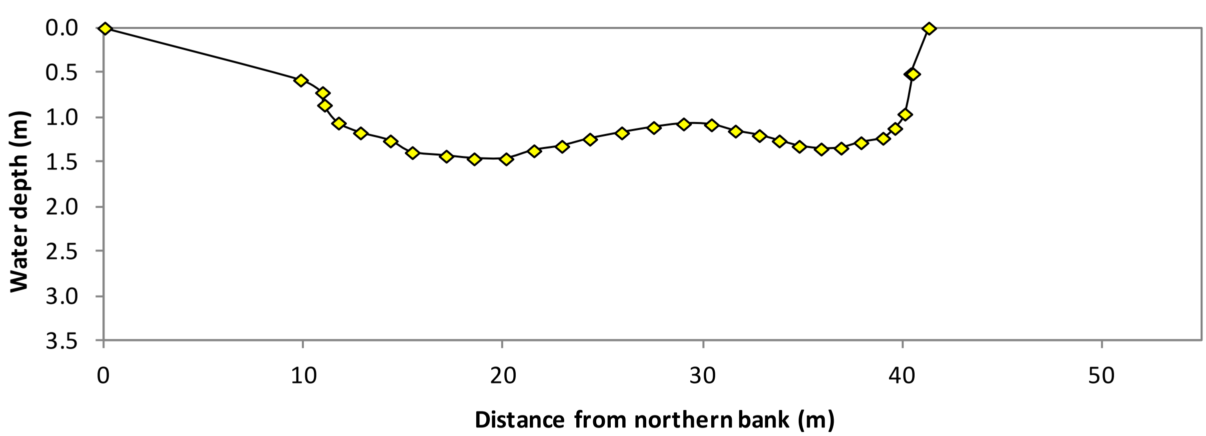
Bathymetry Transect T29

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572330.708	5613643.064	228.679
Southern bank	572341.452	5613603.300	228.678



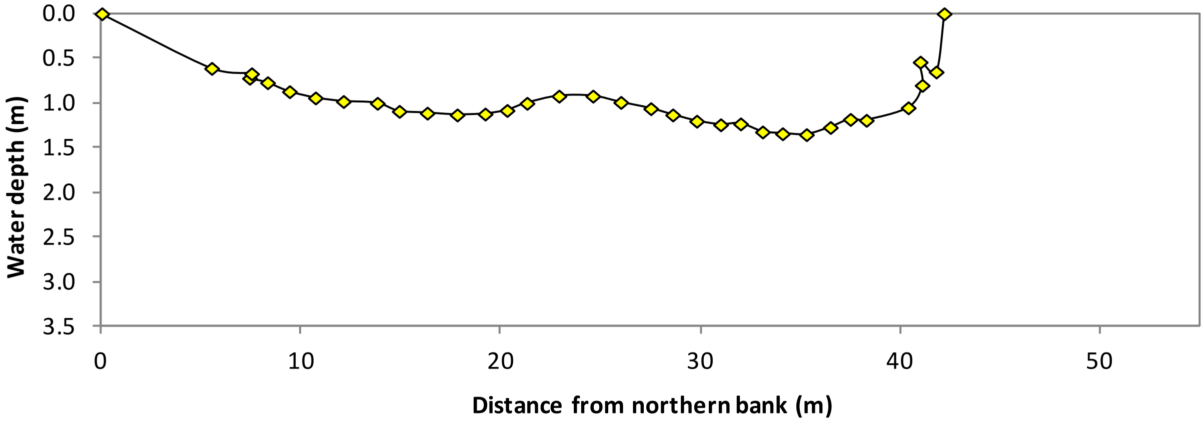
Bathymetry Transect T30

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572332.963	5613643.651	228.62
Southern bank	572343.972	5613603.826	228.719



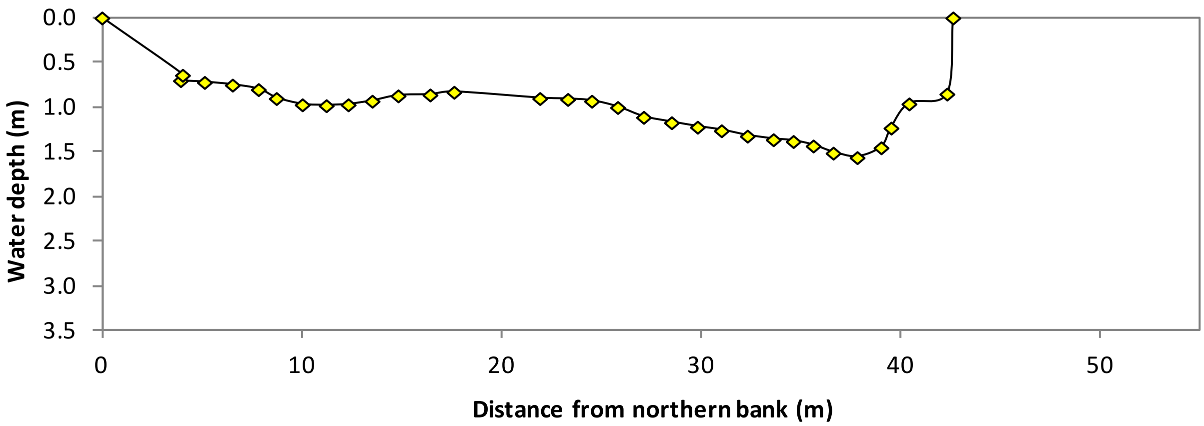
Bathymetry Transect T31

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572335.843	5613644.251	228.662
Southern bank	572347.459	5613603.68	228.698



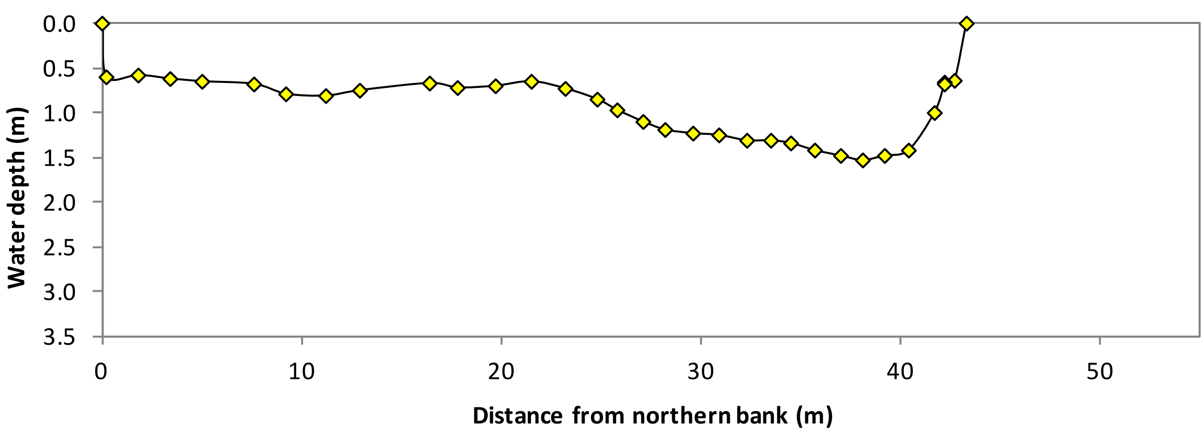
Bathymetry Transect T32

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572337.980	5613644.476	228.675
Southern bank	572350.320	5613603.661	228.678



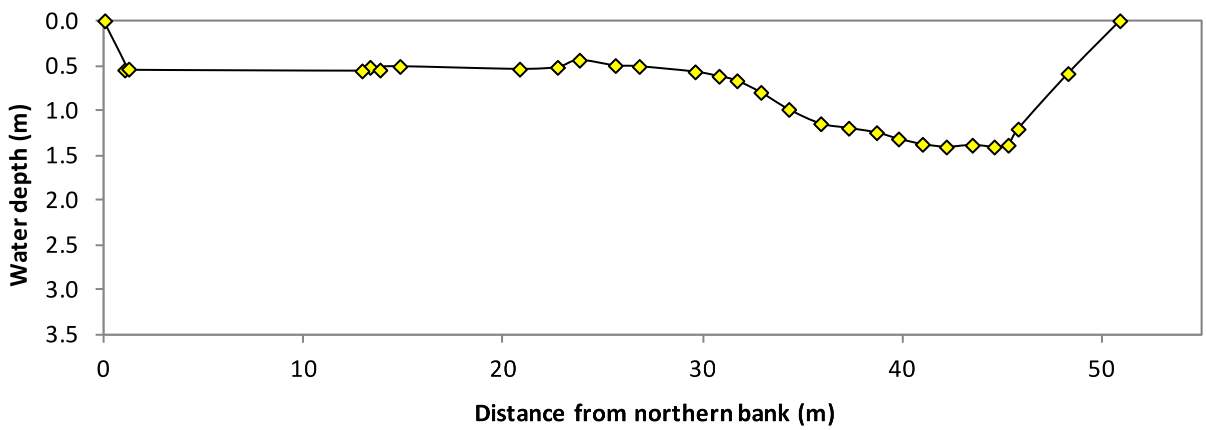
Bathymetry Transect T33

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572340.748	5613645.024	228.643
Southern bank	572353.451	5613603.62	228.679



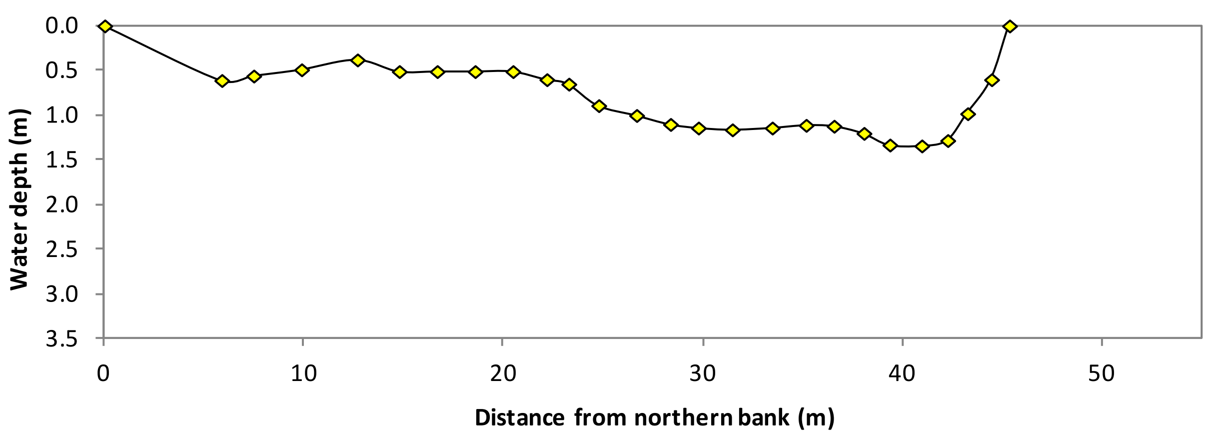
Bathymetry Transect T34

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572343.001	5613647.382	228.64
Southern bank	572355.919	5613604.461	228.679



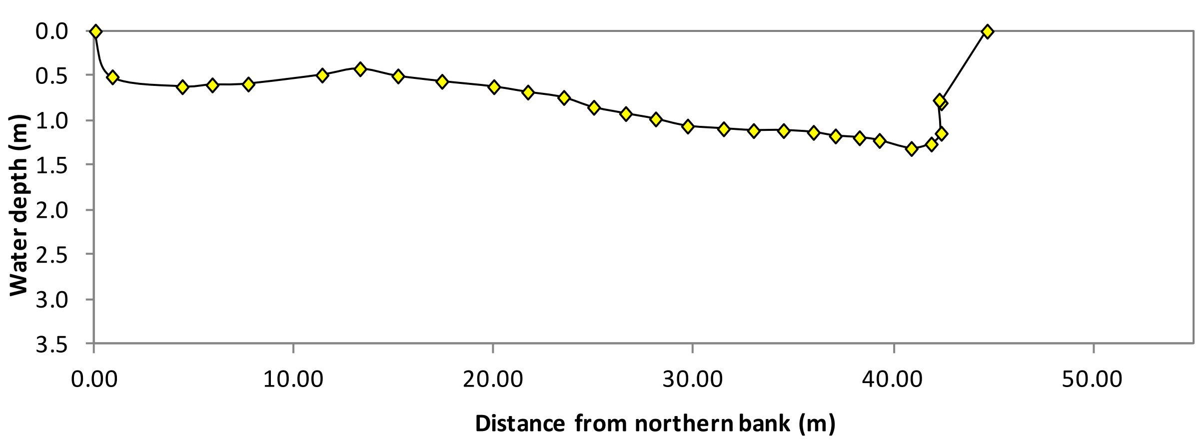
Bathymetry Transect T35

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572346.135	5613649.28	228.637
Southern bank	572357.541	5613605.367	228.678



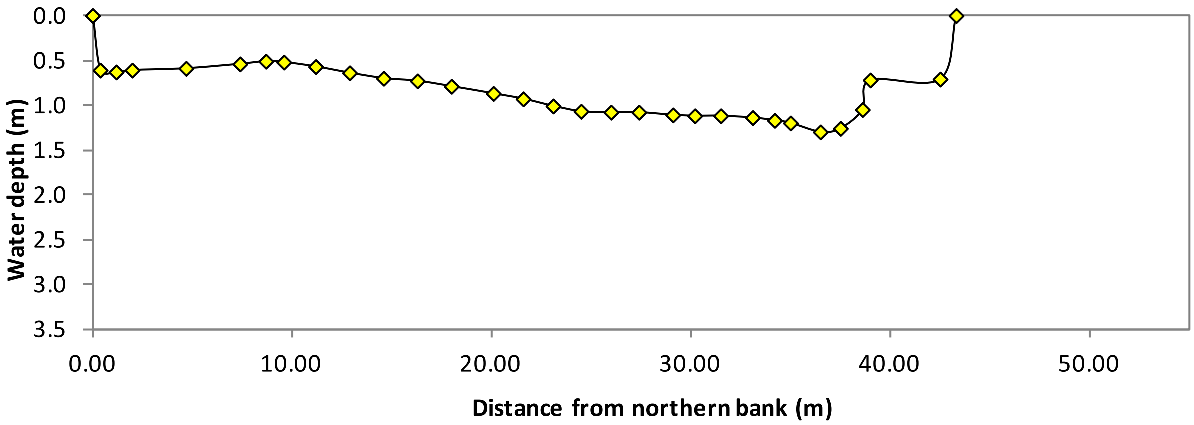
Bathymetry Transect T36

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572349.232	5613650.459	228.674
Southern bank	572360.482	5613607.254	228.73



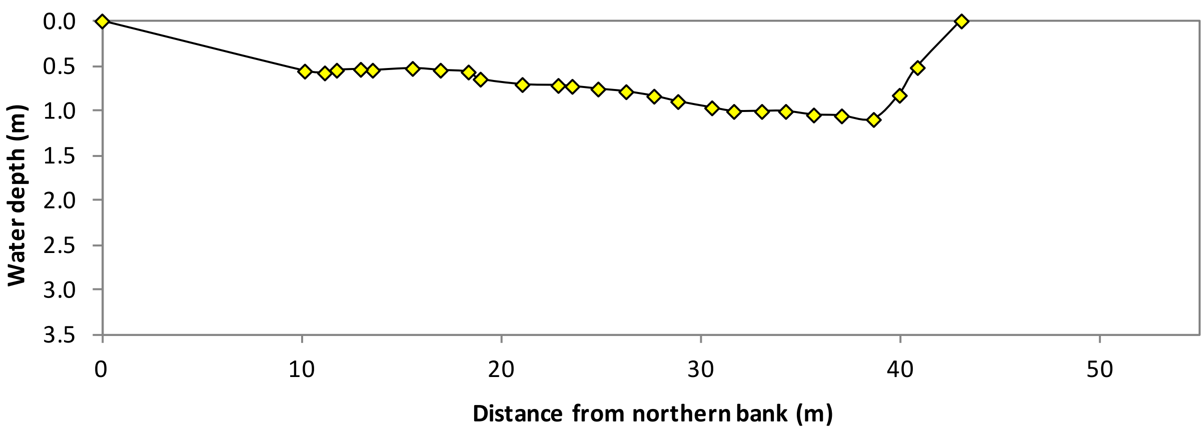
Bathymetry Transect T37

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572352.079	5613651.161	228.636
Southern bank	572363.504	5613609.411	228.692



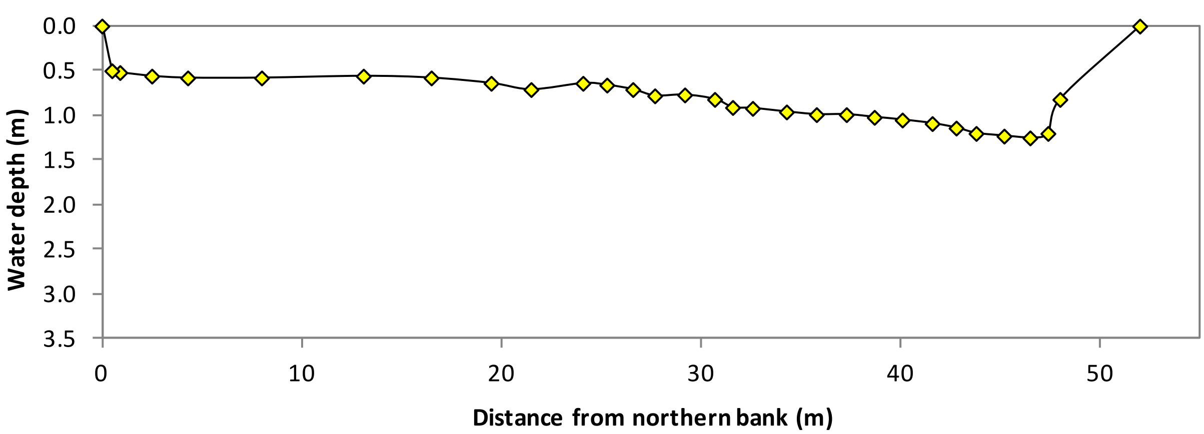
Bathymetry Transect T38

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572355.993	5613652.241	228.688
Southern bank	572367.315	5613610.701	228.707



Bathymetry Transect T39

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572357.688	5613652.259	228.646
Southern bank	572369.650	5613610.865	228.686



Bathymetry Transect T40

Edge of water	Easting (m)	Northing (m)	Elevation (m)
Northern bank	572361.912	5613653.007	228.64
Southern bank	572374.387	5613610.473	228.67