Subject Matter Expert Report
RAMPING AND STRANDING
Evaluation of Cause – Decline in Upper Fording River Westslope Cutthroat Trout Population




Prepared for:

Teck Coal Limited
421 Pine Avenue
Sparwood, BC, V0B 2G0

April 19, 2021

Prepared by:

Ecofish Research Ltd.

Published by Ecofish Research Ltd., 600 Comox Rd., Courtenay, B.C., V9N 3P6

For inquiries contact: Technical Lead documentcontrol@ecofishresearch.com 250-334-3042

Citation:

Faulkner, S., M. Sparling, S. Nicholl, J. Carter, and T. Hatfield. 2021. Subject Matter Expert Report: Ramping and Stranding. Evaluation of Cause – Decline in Upper Fording River Westslope Cutthroat Trout Population. Report prepared for Teck Coal Limited by Ecofish Research Ltd, 2021.

Certification: *stamped version on file.*

Senior Reviewer:

Todd Hatfield, Ph.D., R.P.Bio. No. 927

Director, Senior Environmental Scientist

Technical Lead:

Sean Faulkner, M.Sc., R.P.Bio. No. 2242

Fisheries Biologist/Project Manager

Disclaimer:

EXECUTIVE SUMMARY

Abundances of both juvenile and adult life stages of Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) (WCT) in the upper Fording River (UFR) were substantively lower in 2019 than 2017, indicating a large decline during that two-year period (the Westslope Cutthroat Trout Population Decline Window, also referred to as the Decline Window). Teck Coal Limited (Teck Coal) initiated the "Evaluation of Cause" (EoC) to determine whether and to what extent various stressors and conditions played a role in the decline. One of several potential stressors that has been identified is ramping within the UFR, which could cause stranding and potential mortality of fish. This report investigates if, and to what extent, ramping, due to natural factors or water withdrawal, contributed to the WCT decline. Ramping could potentially cause, or contribute to, reduced WCT abundance if stranding increased mortality during the Decline Window.

The impact hypothesis evaluated was:

- Did ramping within the UFR cause or contribute to the observed WCT population decline?

To investigate the potential role of ramping in the WCT decline, we used available short-interval hydrometric (stage) data from hydrometric stations for the mainstem UFR from September 2017 to December 2019 to calculate ramping rates. We then identified potential ramping events that exceeded Fisheries and Oceans Canada (DFO) life-stage specific ramping rate criteria (i.e., -2.5 cm/h and -5.0 cm/hr for the fry-present and fry not-present periods; Lewis *et al.* 2013) and classified these potential exceedance events based on cause (either due to gauge error/maintenance or unknown cause). All potential exceedance events of unknown cause were then classified for fish stranding risk (low, medium, or high) based on potential exceedance event characteristics (duration of stage decline and exceedance, maximum stage ramping rate, total stage change, wetted history, discharge, and season) and professional judgement. Hydrometric data were obtained as part of an expanded analysis for the Fording River Operations (FRO) Operational Environmental Monitoring Plan (OEMP) which included data from hydrometric stations at Measuring Points A, B and C and from temporary water level loggers (level loggers) that were installed in August 2018 and June 2019 at transects established for an instream flow study (IFS) and at stranding sensitive sites (SSMSs) for a ramping assessment related to operation of the proposed FRO Active Water Treatment Facility – North (AWTF-N) (ramping assessments to date indicate that exceedance events have not been associated with operational water withdrawal). Data from level loggers were used to verify the 2019 hydrometric ramping results, as well as evaluate whether potential exceedance events occurring downstream of Measuring Point B could be attenuated by the southern drying reach, and therefore not detected at Measuring Point C. Further, all short interval hydrometric data (i.e., <1 hour) from tributaries to the UFR were evaluated to assess whether potential exceedance events occurring in tributaries may have contributed to the WCT decline; available data were limited to Clode Creek (i.e., FR_CC1 gauge) and Line Creek Operation (LCO) Dry Creek (i.e., LC_DC1 gauge). We evaluated requisite conditions (conditions that would need to be true if ramping was responsible for some or all of the observed

WCT decline) by evaluating Spatial Extent, Duration, Location, Timing, and Intensity of potential ramping exceedance events that could not be attributed to gauge error/maintenance.

In total, 110 and 33 potential ramping exceedance events were identified in 2018 at Measuring Point A and Measuring Point B, respectively (no potential exceedance events were identified at Measuring Point C, or in 2017 or 2019). Of these, only eight events were identified to have been of unknown cause (cause could not be attributed to gauge error or gauge maintenance activities) and could therefore have reflected real stage change. However, all eight potential exceedance events were assessed to pose a low stranding risk for fish, and none were detected at IFS or SSMS level loggers. An additional 15 potential exceedance events were detected within data from level loggers downstream of Measuring Point B, but not detected at Measuring Point C. Of these 15 events, eight events were assessed as posing a low stranding risk, five events were assessed as posing a moderate stranding risk, and two were assessed as posing a high stranding risk. Within the tributary data, no potential exceedance events were detected in Clode Creek, while 40 potential exceedance events were detected in Dry Creek. Of these 40 events, 31 events were assessed as posing a low stranding risk, six events were assessed as posing a moderate stranding risk, and three were assessed as posing a high stranding risk.

The potential exceedance events occurred during the Decline Window in both the fry present and fry-not present periods, in locations where habitat is sensitive to stranding and fish may be present, and were of sufficient duration to have caused fish mortality; thus, the Timing, Location, and Duration requisite conditions were satisfied. However, the potential exceedance events were relatively local in occurrence, occurred infrequently, and were of a magnitude most likely to affect fry and juvenile fish. Thus, the Spatial Extent and Intensity requisite conditions were not satisfied. Given these results, ramping is unlikely to have caused the decline, although ramping could have contributed (some potential exceedance events were identified) the small number of potential exceedance events and their limited spatial extent indicate that it is unlikely that it was a substantive contributing factor to the documented WCT population decline. Based on frequency of events, their limited spatial extent, and their intensity, the ramping events identified may result in localized mortality of juvenile fish; however, it is unlikely that ramping would act in combination with other stressors, except as a contribution to cumulative mortality.

Few uncertainties were identified in relation to this assessment. Conclusions of the assessment rely on the correct classification of the majority of potential exceedance event as being caused by gauge error/maintenance; however, comparison to supplemental data recorded by level loggers in representative stranding sensitive habitat in 2019 provided support that the identified events were due to gauging issues and were not true ramping events. Further, several large gaps existed in the tributary data provided from Teck at LC_DC1 and FR_CC1, and the LC_DC1 data were not evaluated to determine which events were attributable to known gauge error. There is also some uncertainty associated with the application of the ramping rate criteria to the UFR without having site-specific ramping response information, and with the categorization of fish stranding risk based on quantitative and qualitative considerations; however, uncertainty was assessed to be low.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

LIST OF APPENDICES

SIGNATORY PAGE

Certification: *stamped version on file.*

Senior Reviewer:

Todd Hatfield, Ph.D., R.P.Bio. No. 927

Director, Senior Environmental Scientist

Technical Lead:

Sean Faulkner, M.Sc., R.P.Bio. No. 2242

Fisheries Biologist/Project Manager

ACRONYMNS AND ABBREVIATIONS

AWTF-N – Active Water Treatment Facility North

DFO – Fisheries and Oceans Canada

EoC – Evaluation of Cause

FRO – Fording River Operations

HDPE – High Density Polyethylene

IFS – Instream Flow Study

KWL – Kerr Wood Leidel

OEMP – Operational Environmental Monitoring Plan

POD – Point of Diversion

SME – Subject Matter Expert

SSMS – Stranding Sensitive Monitoring Site

UFR – Upper Fording River

WCT – Westslope Cutthroat Trout

READER'S NOTE

What is the Evaluation of Cause and what is its purpose?

The Evaluation of Cause is the process used to investigate, evaluate and report on the reasons the Westslope Cutthroat Trout population declined in the upper Fording River between fall 2017 and fall 2019.

Background

The Elk Valley is located in the southeast corner of British Columbia (BC), Canada. It contains the main stem of the Elk River (220 km long) and many tributaries, including the Fording River (70 km long). This report focuses on the upper Fording River, which starts 20 km upstream from its confluence with the Elk River at Josephine Falls. The Ktunaxa First Nation has occupied lands in the region for more than 10,000 years. Rivers and streams of the region provide culturally important sources of fish and plants.

The upper Fording River watershed is at a high elevation and is occupied by only one fish species, a genetically pure population of Westslope Cutthroat Trout *(Oncorhynchus clarkii lewisi)* — an iconic fish species that is highly valued in the area. This population is physically isolated because Josephine Falls is a natural barrier to fish movement. The species is protected under the federal Fisheries Act and the Species at Risk Act. In BC, the Conservation Data Center categorized Westslope Cutthroat Trout as "*imperiled or of special concern, vulnerable to extirpation or extinction.*" Finally, it has been identified as a priority sport fish species by the Province of BC.

The upper Fording River watershed is influenced by various human-caused disturbances including roads, a railway, a natural gas pipeline, forest harvesting and coal mining. Teck Coal Limited (Teck Coal) operates the three surface coal mines within the upper Fording River

Evaluation of Cause

Following identification of the decline in the Westslope Cutthroat Trout population, Teck Coal initiated an Evaluation of Cause process. The overall results of this process are reported in a separate document (Evaluation of Cause Team, 2021) and are supported by a series of Subject Matter Expert reports.

The report that follows this Reader's Note is one of those Subject Matter Expert Reports.

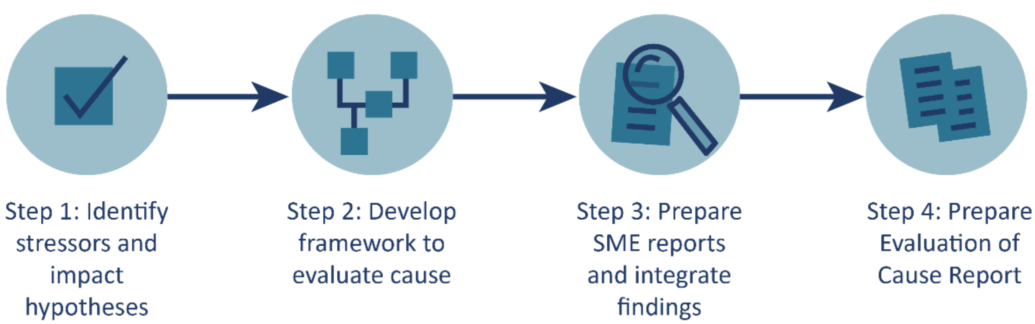
watershed, upstream of Josephine Falls: Fording River Operations, Greenhills Operations and Line Creek Operations.

Monitoring conducted for Teck Coal in the fall of 2019 found that the abundance of Westslope Cutthroat Trout adults and sub-adults in the upper Fording River had declined significantly since previous sampling in fall 2017. In addition, there was evidence that juvenile fish density had decreased. Teck Coal initiated an *Evaluation of Cause* process. The overall results of this process are reported separately (Evaluation of Cause Team, 2021) and are supported by a series of Subject Matter Expert reports such as this one. The full list of SME reports follows at the end of this Reader's Note.

Building on and in addition to the Evaluation of Cause, there are ongoing efforts to support fish population recovery and implement environmental improvements in the upper Fording River.

How the Evaluation of Cause was approached

When the fish decline was identified, Teck Coal established an *Evaluation of Cause Team* (the Team), composed of *Subject Matter Experts* and coordinated by an Evaluation of Cause *Team Lead.* Further details about the Team are provided in the Evaluation of Cause report. The Team developed a systematic and objective approach (see figure below) that included developing a Framework for Subject Matter Experts to apply in their specific work. All work was subjected to rigorous peer review.



Conceptual approach to the Evaluation of Cause for the decline in the upper Fording River Westslope Cutthroat Trout population.

With input from representatives of various regulatory agencies and the Ktunaxa Nation Council, the Team initially identified potential stressors and impact hypotheses that might explain the cause(s) of the population decline. Two overarching hypotheses (essentially, questions for the Team to evaluate) were used:

- Overarching Hypothesis #1: The significant decline in the upper Fording River Westslope Cutthroat Trout population was a result of a single acute stressor[1] or a single chronic stressor[2.]
- Overarching Hypothesis #2: The significant decline in the upper Fording River Westslope Cutthroat Trout population was a result of a combination of acute and/or chronic stressors, which individually may not account for reduced fish numbers, but cumulatively caused the decline.

The Evaluation of Cause examined numerous stressors in the UFR to determine if and to what extent those stressors and various conditions played a role in the Westslope Cutthroat Trout's decline. Given that the purpose was to evaluate the cause of the decline in abundance from 2017 to 2019[3], it was important to identify stressors or conditions that changed or were different during that period. It was equally important to identify the potential stressors or conditions that did not change during the decline window but may, nevertheless, have been important constraints on the population with respect to their ability to respond to or recover from the stressors. Finally, interactions between stressors and conditions had to be considered in an integrated fashion. Where an *impact hypothesis* depended on or may have been exacerbated by interactions among stressors or conditions, the interaction mechanisms were also considered.

The Evaluation of Cause process produced two types of deliverables:

1. **Individual Subject Matter Expert (SME) reports** (such as the one that follows this Note): These reports mostly focus on impact hypotheses under Overarching Hypothesis #1 (see list, following). A Framework was used to align SME work for all the potential stressors, and, for consistency, most SME reports have the same overall format. The format covers: (1) rationale for impact hypotheses, (2) methods, (3) analysis and (4) findings, particularly

---

[1] Implies September 2017 to September 2019.

[2] Implies a chronic, slow change in the stressor (using 2012–2019 timeframe, data dependent).

[3] Abundance estimates for adults/sub-adults are based on surveys in September of each year, while estimates for juveniles are based on surveys in August.

whether the requisite conditions4 were met for the stressor(s) to be the sole cause of the fish population decline, or a contributor to it. In addition to the report, each SME provided a summary table of findings, generated according to the Framework. These summaries were used to integrate information for the Evaluation of Cause report. Note that some SME reports did not investigate specific stressors; instead, they evaluated other information considered potentially useful for supporting SME reports and the overall Evaluation of Cause, or added context (such as in the SME report that describes climate (Wright et al., 2021).

2. **The Evaluation of Cause report** (prepared by a subset of the Team, with input from SMEs): This overall report summarizes the findings of the SME reports and further considers interactions between stressors (Overarching Hypothesis #2). It describes the reasons that most likely account for the decline in the Westslope Cutthroat Trout population in the upper Fording River.

Participation, Engagement & Transparency

To support transparency, the Team engaged frequently throughout the Evaluation of Cause process. Participants in the Evaluation of Cause process, through various committees, included:

Ktunaxa Nation Council

BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development

BC Ministry Environment & Climate Change Strategy

Ministry of Energy, Mines and Low Carbon Innovation

Environmental Assessment Office

[4] These are the conditions that would need to have occurred for the impact hypothesis to have resulted in the observed decline of Westslope Cutthroat Trout population in the upper Fording River.

Citation for the Evaluation of Cause Report

When citing the Evaluation of Cause Report use:

Evaluation of Cause Team, (2021). *Evaluation of Cause — Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Evaluation of Cause Team.

Citations for Subject Matter Expert Reports

Focus	Citation for Subject Matter Expert Reports
Climate, temperature, and streamflow	Wright, N., Greenacre, D., & Hatfield, T. (2021). *Subject Matter Expert Report: Climate, Water Temperature, Streamflow and Water Use Trends. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Ice	Hatfield, T., & Whelan, C. (2021). *Subject Matter Expert Report: Ice. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. Report Prepared by Ecofish Research Ltd.
Habitat availability (instream flow)	Healey, K., Little, P., & Hatfield, T. (2021). *Subject Matter Expert Report: Habitat availability. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Ecofish Research Ltd.
Stranding – ramping	Faulkner, S., Carter, J., Sparling, M., Hatfield, T., & Nicholl, S. (2021). *Subject Matter Expert Report: Ramping and stranding. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Ecofish Research Ltd.

Focus	Citation for Subject Matter Expert Reports
Stranding – channel dewatering	Hatfield, T., Ammerlaan, J., Regehr, H., Carter, J., & Faulkner, S. (2021). *Subject Matter Expert Report: Channel dewatering. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Ecofish Research Ltd.
Stranding – mainstem dewatering	Hocking M., Ammerlaan, J., Healey, K., Akaoka, K., & Hatfield T. (2021). *Subject Matter Expert Report: Mainstem dewatering. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd. and Lotic Environmental Ltd. Zathey, N., & Robinson, M.D. (2021). *Summary of ephemeral conditions in the upper Fording River Watershed. In Hocking et al. (2021). Subject Matter Expert Report: Mainstem dewatering. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd. and Lotic Environmental Ltd.
Calcite	Hocking, M., Tamminga, A., Arnett, T., Robinson M., Larratt, H., & Hatfield, T. (2021). *Subject Matter Expert Report: Calcite. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd., Lotic Environmental Ltd., and Larratt Aquatic Consulting Ltd.
Total suspended solids	Durston, D., Greenacre, D., Ganshorn, K & Hatfield, T. (2021). *Subject Matter Expert Report: Total suspended solids. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Fish passage (habitat connectivity)	Harwood, A., Suzanne, C., Whelan, C., & Hatfield, T. (2021). *Subject Matter Expert Report: Fish passage. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd. Akaoka, K., & Hatfield, T. (2021). Telemetry Movement Analysis. In Harwood et al. (2021). *Subject Matter Expert Report: Fish passage. Evaluation of Cause – Decline in upper*

Focus	Citation for Subject Matter Expert Reports
	Fording River Westslope Cutthroat Trout population. Report prepared for Teck Coal Ltd. by Ecofish Research Ltd.
Cyanobacteria Algae / macrophytes	Larratt, H., & Self, J. (2021). *Subject Matter Expert Report: Cyanobacteria, periphyton and aquatic macrophytes. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Larratt Aquatic Consulting Ltd.
Water quality (all parameters except water temperature and TSS [Ecofish])	Costa, EJ., & de Bruyn, A. (2021). *Subject Matter Expert Report: Water quality. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd. Healey, K., & Hatfield, T. (2021). *Calculator to assess Potential for cryoconcentration in upper Fording River.* In Costa, EJ., & de Bruyn, A. (2021). *Subject Matter Expert Report: Water quality. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd.
Industrial chemicals, spills and unauthorized releases	Van Geest, J., Hart, V., Costa, EJ., & de Bruyn, A. (2021). *Subject Matter Expert Report: Industrial chemicals, spills and unauthorized releases. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd. Branton, M., & Power, B. (2021). *Stressor Evaluation – Sewage.* In Van Geest et al. (2021). *Industrial chemicals, spills and unauthorized releases. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd.
Wildlife predators	Dean, D. (2021). *Subject Matter Expert Report: Wildlife predation. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by VAST Resource Solutions Inc.

Focus	Citation for Subject Matter Expert Reports
Poaching	Dean, D. (2021). *Subject Matter Expert Report: Poaching. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by VAST Resource Solutions Inc.
Food availability	Orr, P., & Ings, J. (2021). *Subject Matter Expert Report: Food availability. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Minnow Environmental Inc.
Fish handling	Cope, S. (2020). *Subject Matter Expert Report: Fish handling. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Westslope Fisheries Ltd.
	Korman, J., & Branton, M. (2021). *Effects of capture and handling on Westslope Cutthroat Trout in the upper Fording River: A brief review of Cope (2020) and additional calculations.* Report prepared for Teck Coal Limited. Prepared by Ecometric Research and Azimuth Consulting Group.
Infectious disease	Bollinger, T. (2021). *Subject Matter Expert Report: Infectious disease. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by TKB Ecosystem Health Services Ltd.
Pathophysiology	Bollinger, T. (2021). *Subject Matter Expert Report: Pathophysiology of stressors on fish. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by TKB Ecosystem Health Services Ltd.
Coal dust and sediment quality	DiMauro, M., Branton, M., & Franz, E. (2021). *Subject Matter Expert Report: Coal dust and sediment quality. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Azimuth Consulting Group Inc.

Focus	Citation for Subject Matter Expert Reports
Groundwater quality and quantity	Henry, C., & Humphries, S. (2021). *Subject Matter Expert Report: Hydrogeological stressors. Evaluation of Cause - Decline in upper Fording River Westslope Cutthroat Trout population.* Report Prepared for Teck Coal Limited. Prepared by SNC-Lavalin Inc.

1. INTRODUCTION

Abundances of adult and juvenile life stages of Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) (WCT) in the upper Fording River (UFR) have been estimated since 2012 through high-effort snorkel and electrofishing surveys, supported by radio-telemetry and redd surveys (Cope *et al*. 2016). Annual snorkel and electrofishing surveys were conducted in the autumns of 2012-2014, 2017, and 2019. Abundances of both juvenile and adult life stages were substantively lower in 2019 than 2017, indicating a large decline during the two-year period between September 2017 to September 2019 (Westslope Cutthroat Trout Population Decline Window; hereafter referred to as Decline Window; Cope 2020). The magnitude of the decline as well as refinements in the timing of decline are reviewed in detail by Cope (2020) and Korman (2021).

Teck Coal Limited (Teck Coal) initiated the "Evaluation of Cause" (EoC) to assess factors responsible for the population decline. The EoC evaluates numerous impact hypotheses to determine whether and to what extent various stressors and conditions played a role in the decline of WCT. Given that the primary objective is to evaluate the cause of the sudden decline over a short time period (from 2017 to 2019), it is important to identify stressors or conditions that changed or were different from during the Decline Window. However, it is equally important to identify all potential stressors or conditions that did not change during the Decline Window but nevertheless may be important constraints on the population. Finally, interactions among stressors are also considered in the EoC. Where an impact hypothesis depends on interactions among stressors or conditions, or where the impact may be exacerbated by particular interactions, the mechanisms of interaction are considered as part of the evaluation of specific impact hypotheses.

A project team is evaluating the cause of WCT decline in abundance and is investigating two "over-arching" hypotheses:

- Over-arching Hypothesis #1: The significant decline in the UFR WCT population was a result of a single acute stressor[5] or a single chronic stressor[6].
- Over-arching Hypothesis #2: The significant decline in the UFR WCT population was a result of a combination of acute and/or chronic stressors, which individually may not account for reduced WCT numbers, but cumulatively caused the decline.

Ecofish Research Ltd. (Ecofish) was asked to provide support as Subject Matter Expert (SME) for an evaluation of various stressors. Fish stranding in the UFR was identified as a stressor that may have caused or contributed to the observed WCT decline. Stranding occurs when changes in water level result in fish becoming isolated in residual pools or become stranded in the interstices of exposed gravel or cobble substrate. This report evaluates the potential for stranding from rapid changes in

[5] Implies the single acute stressor acted between September 2017 and September 2019.

[6] Implies a chronic slow change in the stressor (using 2011-2019 timeframe, data dependent).

water level (i.e., ramping). Stranding caused by dewatering in tributaries is evaluated in the Channel Dewatering SME report (Faulkner e*t al.* 2021) and stranding caused by dewatering in the mainstem is evaluated in the Mainstem Dewatering SME report (Hocking *et al.* 2021).

1.1. Background

1.1.1. Overall Background

This document is one of a series of SME reports that supports the overall EoC of the UFR WCT population decline (Evaluation of Cause Team 2021). For general information, see the preceding Reader's Note.

1.1.2. Report-Specific Background

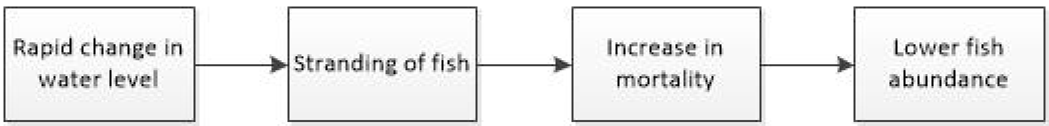
Rapid changes in water level or flow in streams (ramping) can result in stranding and mortality of fish. When flows drop quickly fish may become isolated in pools or become stranded in the interstices of exposed gravel or cobble substrate (Irvine *et al.* 2009, Irvine *et al.* 2014). This can lead to mortality from suffocation, desiccation, freezing, or predation. The likelihood of fish stranding during ramping events is dependent on fish life stage (i.e., younger life stages are more vulnerable), species, wetted history of the habitat, rate of stage change (i.e., ramping rate), magnitude of stage change, substrate characteristics, bank slope, channel morphology, water temperature, time of day, and other biotic and abiotic factors (Nagrodski *et al.* 2012, Irvine *et al.* 2014). Fisheries and Oceans Canada (DFO) have specified ramping rate criteria that are typically protective of fish (Lewis *et al.* 2013). These rates were adapted from earlier DFO guidance (Cathcart 2005) and are specific to life stages present: -2.5 cm/hr when fry are present and -5.0 cm/hr when fry are not present.

Ramping can result from natural factors (e.g., changes to inflows) or water withdrawal for mining or other water uses. Ramping has been identified as an issue for large scale water uses such as hydropower, but there is uncertainty regarding ramping in the UFR caused by Teck Coal's operations. Many of the points of diversion (PODs) for Teck's water withdrawals in the UFR watershed are located on settling ponds and flooded mine excavations, and water withdrawal therefore may not cause rapid stage changes in the mainstem UFR. A small effect is expected due to the buffering capacity of the settling ponds and because some of the utilized PODs do not directly connect to the UFR (note that we do not have data to quantify the attenuation). Although substantial ramping effects on the UFR downstream from the PODs may be unlikely, there is uncertainty in actual ramping rates and the potential ramping effects from cumulative water withdrawal. An examination of the potential for ramping was therefore included as part of the Fording River Operations (FRO) Operational Environmental Monitoring Plan (OEMP; Wright *et al.* 2020), which requires that ramping is monitored at three existing hydrometric stations (Measuring Points A, B, and C). Ramping assessments to date indicate that exceedance events have not been associated with operational water withdrawal (Johnson *et al.* 2019, Wright *et al.* 2020). Ramping rate criteria for the UFR are specified in accordance with a fry-present period defined as August 1 to October 31, which extends from emergence to the overwintering period. The fry not-present period in the UFR includes all other times of the year since juveniles and adults are present year-round (Cope *et al.* 2016).

For the EoC, the ramping analysis for the FRO OEMP has been revisited and expanded. As part of the additional analyses, further data were examined from temporary water level loggers (level loggers) that were installed at transects established in June 2019 in the UFR as part of an instream flow study (IFS) for the OEMP, and at stranding sensitive monitoring sites (SSMSs) identified for a ramping study assessing stranding risk to fish posed by operation of the proposed AWTF-N.

Figure 1 provides a pathway of effect conceptual model for the cause-effect linkages between ramping (due to natural or operational causes) and reduced fish abundance.

Figure 1. Pathway of effect relevant to potential effects to fish from ramping in the UFR.



1.1.3. Author Qualifications

Todd Hatfield, Ph.D., R.P.Bio.

This project is being led by Todd Hatfield, Ph.D., a registered Professional Biologist and Principal at Ecofish Research Ltd. Todd has been a practising biological consultant since 1996 and he has focused his professional career on three core areas: environmental impact assessment of aquatic resources, environmental assessment of flow regime changes in regulated rivers, and conservation biology of freshwater fishes. Since 2012, Todd has provided expertise to a wide array of projects for Teck Coal: third party review of reports and studies, instream flow studies, environmental flow needs assessments, aquatic technical input to structured decision making processes and other decision support, environmental impact assessments, water licensing support, fish community baseline studies, calcite effects studies, habitat offsetting review and prioritizations, aquatic habitat management plans, streamflow ramping assessments, development of effectiveness and biological response monitoring programs, population modelling, and environmental incident investigations.

Todd has facilitated technical committees as part of multi-stakeholder structured decision making processes for water allocation in the Lower Athabasca, Campbell, Quinsam, Salmon, Peace, Capilano, Seymour and Fording rivers; he has been involved in detailed studies and evaluation of environmental flows needs and effects of river regulation for Lois River, China Creek, Tamihi Creek, Fording River, Duck Creek, Chemainus River, Sooke River, Nicola valley streams, Okanagan valley streams, and Teck Coal's Line Creek Operations (LCO) Dry Creek. Todd was the lead author or co-author on guidelines related to water diversion and allocation for the BC provincial government and industry, particularly as related to the determination of instream flow for the protection of valued ecosystem components in BC. He has worked on numerous projects related to water management, fisheries conservation, and impact assessments, and developed management plans and guidelines for industry and government related to many different development types. Todd is currently in his third 4-year term with

COSEWIC (Committee on the Status of Endangered Wildlife in Canada) on the Freshwater Fishes Subcommittee.

Sean Faulkner, M.Sc., R.P.Bio., Fisheries Biologist

Sean Faulkner is a fisheries biologist who obtained his Master of Science in Environmental Biology and Ecology at the University of Alberta. He has over twelve years of experience conducting fisheries and aquatic assessments in British Columbia and has worked at Ecofish since 2007, where he has designed and led numerous studies assessing the effects of ramping rates of fish and defining protective ramping rates for hydroelectric facilities.

Mr. Faulkner's experience as a consultant to Teck Coal, specifically in the Upper Fording river watershed, includes leading instream flow assessment and habitat studies on LCO Dry Creek, developing and conducting ramping assessment for the Fording River as part of the operational environmental monitoring program (OEMP), and assessments of potential ramping effects to support development of active water treatment facilities and saturated rock fill treatment locations.

Sean has also developed, implemented, and reported on several unique fish salvage and ramping assessments throughout a number of BC streams to support regulatory requirements (e.g., Fisheries Act Authorizations and Conditional Water Licences). Sean has also led ramping workshops and training sessions for ramping assessments for Fisheries and Oceans Canada and other environmental consultants.

1.2. Objective

The objective of this report is to review available hydrometric data for the mainstem UFR from September 2017 to December 2019 and assess potential effects to fish abundance from rapid changes of water levels (ramping) in the UFR. The potential impacts to fish from ramping are stranding or isolation, which can lead to death, and which can in turn lead to population decline if a large proportion of the population is impacted.

Thus, the specific impact hypothesis evaluated was:

- Did ramping within the UFR cause or contribute to the observed WCT population decline?

1.3. Approach

All ramping monitoring data for the September 2017 to December 2019 period was assessed for this report to determine whether rapid declines in stage occurred in the mainstem UFR and whether they led to substantial stranding of fish. The approach taken was to first identify potential ramping events that exceeded life-stage specific ramping rate criteria (referred to as ramping exceedance events or exceedance events) and then to assess stranding risk to fish from these events. Identification of potential exceedance events involved calculating ramping rates from stage data measured at hydrometric stations Measuring Points A, B, and C for 2017, 2018, and 2019 (Section 2.1) and comparing these rates to ramping rate criteria for the fry-present and fry not-present periods

(Section 2.4). Stage data from level loggers recorded in 2018 and 2019 were used to verify the 2018 and 2019 ramping results (Section 2.2). In addition to the Fording River mainstem gauge locations, two additional tributaries were assessed for ramping events: Clode Creek and LCO Dry Creek. These were the only tributaries identified with continuous high frequency data (<1 hour data interval) available for the ramping rate assessment. Stranding risk was then assessed for each potential exceedance event by characterizing duration of stage decline and exceedance, maximum stage ramping rate, total stage change, wetted history, discharge, and season (Section 2.5).

Once stranding risk was determined, we evaluated whether stranding within the UFR could be responsible for the observed WCT decline (Section 2.6). Specifically, we identified requisite conditions that would have to be met for ramping to cause or contribute to the observed WCT decline.

2. METHODS

2.1. Primary Data: Hydrometric Stations

Data were recorded by hydrometric gauges at three hydrometric stations (located at Measuring Point A, B and C[7]; Map 1) between September 2017 and December 2019. Measuring Point A is located in Henretta Creek, Measuring Point B is located approximately 7 km downstream of Measuring Point A, and Measuring Point C is located approximately 13 km downstream of Measuring Point B (Map 1). All hydrometric gauges are located within pool mesohabitat.

2.1.1. Data Collection

All finalized stage and flow data were provided by Kerr Wood Leidel (KWL), Teck's consultant that runs the primary hydrometric program. Data were recorded at 15-minute intervals from 2017 to December 18, 2019, with the exception of Measuring Point C in 2019, where data were recorded at two-minute intervals and were averaged to 15-minute values. After December 18, 2019, data at all hydrometric stations were recorded at 2-minute intervals and averaged to 15-minute values. This change was implemented in accordance with recommendations from Year 1 of the FRO OEMP (Johnson *et al.* 2019) due to the high variability in individual 15-minute values caused by turbulence (e.g., wave action); the implementation of 2-minute intervals averaged to 15-minute values was expected to reduce this variability.

[7] Hydrometric gauges are referred to as Measuring Points in the water license and that is why we have chosen to label them as Measuring Points A, B, and C here. The alternative name for each Measuring Point is: Measuring Point A – FR_HC1, Measuring Point B – FR_FRNTP, and Measuring Point C – FR_FRABCHF.

2.1.2. Period of Record

All available data from hydrometric gauges at Measuring Points A, B, and C were evaluated between September 2017 to December 2019. QA processes by KWL removed some data due to icing or gauge malfunctions. After QA, data were available from the following time periods:

- Measuring Point A:
    - September 1, 2017 to December 22, 2017;
    - January 8, 2018 to December 31, 2018; and
    - March 18, 2019 to December 9, 2019[8].
- Measuring Point B:
    - September 1, 2017 to December 31, 2017;
    - March 13, 2018 to November 7, 2018[8]; and
    - January 10, 2019 to December 20, 2019.
- Measuring Point C:
    - October 6, 2017 to December 23, 2017;
    - January 2, 2018 to December 31, 2018; and
    - January 1, 2019 to December 31, 2019.

2.2. Secondary Data: IFS and Ramping Gauges

Temporary water level loggers (Solinst Levelogger Edge, 0 to 5 m range and 2.5 mm accuracy) had been installed in protective metal housings on vertical rebar posts at SSMSs and at IFS transects as part of a stranding assessment and IFS, respectively, conducted in the UFR in 2019. The IFS was conducted as part of the OEMP to develop relationships between flow and fish habitat quantity (Wright *et al.* 2020) and level loggers were deployed at 34 transects. A total of 10 level loggers were also installed to evaluate the rates of flow change that would maintain the ramping rate criteria as measured at the SSMSs as part of a stranding assessment initiated on the UFR in 2019 to support a screening assessment of potential impacts to fish of the proposed AWTF-N outfall and intake locations and design; however, the analysis has yet to be completed (Ecofish unpublished data).

Stage data recorded by level loggers at selected IFS and ramping assessment locations near hydrometric stations were used to verify the 2019 hydrometric gauge ramping results. Hydrometric stations (i.e., Measuring Points A, B, and C) are not typically located in stranding sensitive habitat; rather, they tend to be located in hydraulically controlled areas with confined channels. As a result of relatively steep bankslope gradients (which do not typically pose a stranding risk to fish), such confined

[8] QA processes by KWL removed data due to icing or gauge malfunctions.

channels tend to have greater stage changes for a given flow change than do the wider, flatter, shallower areas represented by stranding sensitive habitats. This may therefore result in overestimation of stage change and ramping rates at stranding sensitive sites. In contrast, a portion of the IFS and SSMS level loggers were located in stranding sensitive habitat and can depict a clearer picture of stage change and ramping rates than the hydrometric gauges. Appendix A provides cross-sectional bed profiles and representative photographs to demonstrate this difference between the hydrometric stations and the IFS and SSMS logger locations.

2.2.1. Data Collection

2.2.1.1. Confirmation of Measuring Point Data

Level loggers at SSMSs ramping assessment sites and IFS transects were selected for this ramping assessment to represent stranding sensitive habitat in the vicinity of the hydrometric gauges. Seven level loggers (five at IFS transects and two at ramping assessment sites) were selected for comparison to Measuring Point stations data; data from one, four, and two level loggers were used to compare to ramping results at Measuring Points A, B, and C stations, respectively (Map 1). Selected level loggers were located within 2.9 km of each Measuring Point; all were in low gradient riffle habitat, with the exception of one located at Henretta Creek (FRD-LWTR09), which was in glide habitat (Table 1). Water level was recorded by the level loggers at 10-minute intervals at IFS transect sites and 5-minute intervals at SSMSs sites. Benchmarks and level loggers were surveyed at three different flows to ensure sensors did not shift over the course of the study.

Table 1. Locations of water level loggers at IFS transects and ramping sites (SSMSs) relative to associated hydrometric stations.

Hydrometric Gauge[1]	Associated Level Logger			
	Site Name	Type	Habitat Type	Distance from Measuring Point (km)
Measuring Point A	FRD-UPTR34	IFS	Glide	<0.1
Measuring Point B	FRD-SDLG03	Ramping	Riffle	0.4
	FRD-UPTR22	IFS	Riffle	0.8
	FRD-SDLG02	Ramping	Riffle	0.9
	FRD-UPTR23	IFS	Riffle	1.1
Measuring Point C	FRD-LWTR02	IFS	Riffle	0.1
	FRD-LWTR09	IFS	Glide	2.8

[1]Hydrometric gauges were all located in pool habitat

2.2.1.2. Southern Drying Reach Attenuation

To address concerns that potential exceedance events occurring downstream of Measuring Point B could be attenuated by the southern drying reach, and therefore not detected at Measuring Point C, four additional level loggers were selected for supplementary analysis. Three additional SSMS loggers (FRD-SD01, FRD-SD02 and FRD-SDLG01) and one additional IFS logger (FRD-LWTR16) were selected for analysis. All four level loggers were located downstream of Measuring Point B and upstream of Cataract Creek; except for FRD-SD01, which is located immediately downstream of Cataract Creek.

2.2.2. Period of Record

Available data from level loggers in 2019 were recorded between June and October. Although the aim of this assessment was to have a complete 2019 record, this time period encompasses most of the fry-present period and time periods when Measuring Point data document the potential exceedance events. Data were available for the following time periods to verify 2019 hydrometric gauge data:

- IFS level loggers: June 14, 2019 to November 8, 2019; and
- SMSSs level loggers: June 18, 2019 to October 10, 2019.

2.2.2.1. Southern Drying Reach Attenuation

The additional data from the four supplementary level loggers included the following periods:

- FRD-SD01 and FRD-SD02: August 30 to October 30, 2018;
- FRD-SDLG01: June 18 to October 10, 2019; and
- FRD-LWTR16: June 16 to November 7, 2019.

Data from each level logger were compensated using barometric pressure. Compensated stage data and air and water temperature data were visually inspected and ice-affected data were removed prior to analysis; accordingly, data from October 27 to November 8, 2019 were removed from the IFS stage data.

2.3. Tributary Data (Clode Creek and LCO Dry Creek)

Two tributaries were assessed for ramping events to supplement the ramping analysis conducted for the UFR mainstem. Clode Creek is a short channel fed by surface water decanting from Clode Settling Ponds (Smithson 2019), which flows into the UFR between Measuring Points A and B. Data from Clode Creek were recorded at the FR_CC1 hydrometric station, located in glide mesohabitat immediately downstream of the Clode Settling Pond outflow culverts. LCO Dry Creek is located downstream of Chauncey Creek and upstream of Greenhills Creek in the UFR. Fish from the UFR can access approximately one km of primarily riffle and glide mesohabitat, at which point a culvert under the highway exists that is presumed to prevent or restrict upstream access by fish. WCT are located upstream of the culvert but have not been considered in this assessment since they are not part of the continuously distributed UFR fish community being evaluated by the EoC. Surface water from active mining in the upper watershed is diverted through two sedimentation ponds approximately five km upstream of the confluence of the UFR. Data from LCO Dry Creek were recorded at LC_DC1 hydrometric station, located just upstream of the highway culvert in glide mesohabitat.

2.3.1. Data Collection

All finalized stage and flow data were provided by KWL. Data were recorded at 15-minute intervals from both FR_CC1 and LC_DC1.

2.3.2. Period of Record

All available data from hydrometric gauges at FR_CC1 and LC_DC1 were evaluated between 2017 and 2019. Final QA processes by KWL were not completed at the time of writing; however, data were available from the following time periods:

- FR_CC1: January 1, 2017 to December 31, 2019; however, there were 49 data gaps of greater than 1 hour (up to a maximum of approximately 6 months between February 6 and August 8, 2018).
- LC_DC1: April 25, 2017 to December 16, 2019; however, there were 43 data gaps of greater than 1 hour (up to a maximum of approximately 4 months between June 7 to October 6, 2017).

2.4. Ramping Analysis

Ramping rate for each data point was calculated as the difference between stage (cm) and the maximum stage in the previous hour (cm), using the following procedure:

1. The maximum stage observed over the past hour for each data point i was calculated as:

$$hmax(t_i) = \max\big(h(t_{i-k}), \ldots, h(t_{i-1})\big)$$

   where h is stage, k is the number of data points recorded per hour, and t is time.

2. The maximum stage decrease over the past hour relative to time $\mathrm{t_i}$, $\Delta\mathrm{hmax(t_i)}$, was calculated as:

$$\Delta hmax(t_i) = h(t_i) - hmax(t_i)$$

Ramping rates at all locations were then compared to ramping rate criteria (i.e., -2.5 cm/hr and -5.0 cm/hr, for the fry-present and fry not-present periods, respectively; Lewis *et al.* 2013) to identify exceedances. A potential ramping exceedance event was identified any time the ramping rate exceeded these criteria.

For the secondary data from the level loggers, potential ramping exceedance events were confirmed if the ramping rate at the corresponding level loggers exceeded the ramping criterion for a minimum of 10 minutes, which is consistent with provincial guidelines accepted as the standard for hydroelectric projects in BC (Lewis *et al.* 2011). This guideline is based on the rationale that fish and fish habitat may not become dewatered immediately because stranding sensitive habitats will not drain instantly, and fish will not immediately die when stranded.

Potential ramping exceedance events flagged by Ecofish at Measuring Points A, B, and C were evaluated by KWL to determine the potential cause for each exceedance. KWL classified potential ramping exceedance events that Ecofish flagged as either having been caused by gauge error or having an unknown cause:

- 'Noise': exceedance events caused by debris partially and briefly blocking the orifice creating a false increase in water level (gauge error).
- 'Turbulence': turbulent water causing noisy water level data; and were not actually caused by water level changes (gauge error).
- 'Bubbler purge': an auto cycle bubbler purge function of the gauge that was used to clear debris from the orifice line, which caused the sensors to falsely identify changes in water levels during the purge (Miller, pers. comm. 2019). These bubbler purge functions occur on a scheduled frequency but may not be consistent between gauges. (Gauge errors may occur from these gauge maintenance activities.)
- 'Unknown': could not be attributed to gauge error or gauge maintenance; could represent a real change in water level.

All 'noise' and 'turbulence' exceedance events were further evaluated graphically by Ecofish (Appendix A, Appendix B and Appendix C) to verify the classifications determined by KWL. For 2019, secondary data (gauges) were used to corroborate data from Measuring Points A, B, and C.

2.5. Fish Stranding Risk Assessment

We conducted a fish stranding risk assessment for all potential exceedance events of unknown cause (i.e., not classified as gauge error) for potential stranding risk to fish. This provided a conservative assessment (i.e., may include some exceedance events that were not real changes in water level but that had not been identified as false) and identified all exceedance events that may have caused fish stranding, regardless of the cause of the event (e.g., natural or operational).

Stranding risk was assessed for each potential exceedance event by first quantifying the following:

- Duration of stage decline and of exceedance: Typically, 10 minutes of continuous exceedance of the ramping criteria is considered the requirement for a ramping event to pose a stranding and potential mortality risk. This is based on the rationale that fish and fish habitat may not become dewatered immediately because stranding sensitive habitats will not drain instantly, and fish will not immediately die when stranded. However, this constraint is not applicable when 15-minute data are used.

- Maximum stage ramping rate: Higher magnitude exceedances may have greater potential for stranding; note that, in general, accuracy of most hydrometric gauges is typically +/- 2 mm; therefore, smaller magnitude ramping events may be within the margin of error for gauge accuracy.
- Total stage change: The total magnitude of an event must be large enough to dewater habitat that fish are occupying (i.e., fish will typically not inhabit very shallow habitats).
- Wetted history: Fish presence in stranding sensitive habitats may be affected by the duration the habitat has been continuously wetted. Wetted history was calculated for each ramping exceedance as the duration of time prior to the event that stage was greater than the minimum stage during the exceedance. The following categories help characterize wetted history:
    - Extensive: habitat wetted for >24 hours; habitats have been wetted for a full diurnal cycle which provides opportunity for fish to occupy them;
    - Moderate: habitat wetted 4 to 24 hours; habitats may not have been wetted long enough to have become occupied by fish; and
    - Short: habitat only briefly wetted (e.g., <4 hours). Habitats are unlikely to have been wetted long enough to have become occupied by fish.
- Discharge: Stranding sensitive habitats are more likely to be fully inundated with high flows and may be less likely to dewater to the extent of causing stranding if stage drops; thus, if a ramping event is not considered likely to dewater these habitats, risk may be considered low.

In addition, time of year, presence of life history stage (e.g., newly emerged fry presence), and fish behaviour were considered as they can affect the potential stranding risk. The differential sensitivity of fry to stranding is encompassed by the seasonally specific ramping rate criteria (i.e., -2.5 cm/hr vs -5.0 cm/hr for the fry-present and not-present periods, respectively); however, cold temperature can further decrease risk as fish may move to deeper overwintering habitats, show nocturnal behaviour, use deep interstitial spaces (which are particularly sensitive to stranding), and fish may be excluded from shallow stranding sensitive habitats due to ice formation.

A single overall stranding risk rating (low, medium, or high) was then assigned to each potential ramping exceedance event. This was based quantitative and qualitative information and professional experience with previous ramping assessments. The assigned risk categories provide an indication of potential risk of fish stranding and mortality. For example, the low risk classification is not meant to imply that no mortality of fish may have occurred, rather that low incidence may have occurred.

2.6. Evaluation of Requisite Conditions

Requisite conditions are defined as the circumstances that would need to be met for ramping in the UFR to potentially cause or contribute to the WCT population decline. The approach described above was used to evaluate stranding risk to fish due to ramping and to determine whether requisite conditions were met. Requisite conditions (Table 4) were based on spatial (extent and location) and temporal (timing and duration) aspects of potential ramping exceedance events and on the intensity (magnitude) of the events in relation to stranding risk for fish. The frequency, magnitude, wetted history, and distribution of potential ramping exceedance events were used to determine whether the requisite conditions for cause were met. The results of this analysis are meant to support evaluation of Hypothesis 1 (requisite condition to cause) and Hypothesis 2 (requisite condition to contribute) for the ramping stressor.

Table 2. Requisite conditions for ramping to cause or contribute to the WCT population decline.

Spatial extent	Ramping exceedance events occurred in a relatively large portion of the UFR (therefore assumed to affect a large portion of the population)
Duration	Ramping exceedance events were of a duration great enough to cause fish mortality
Location	Ramping exceedance events occurred within the UFR where habitat is sensitive to stranding and fish are present
Timing	Ramping exceedance events occurred during the Decline Window when fish are present (adults are present throughout the year; fry are present from August through October)
Intensity	Exceedances of ramping rate criteria were large enough to isolate or strand substantial numbers of fish or were frequent enough to cause substantial mortality over time

3. RESULTS

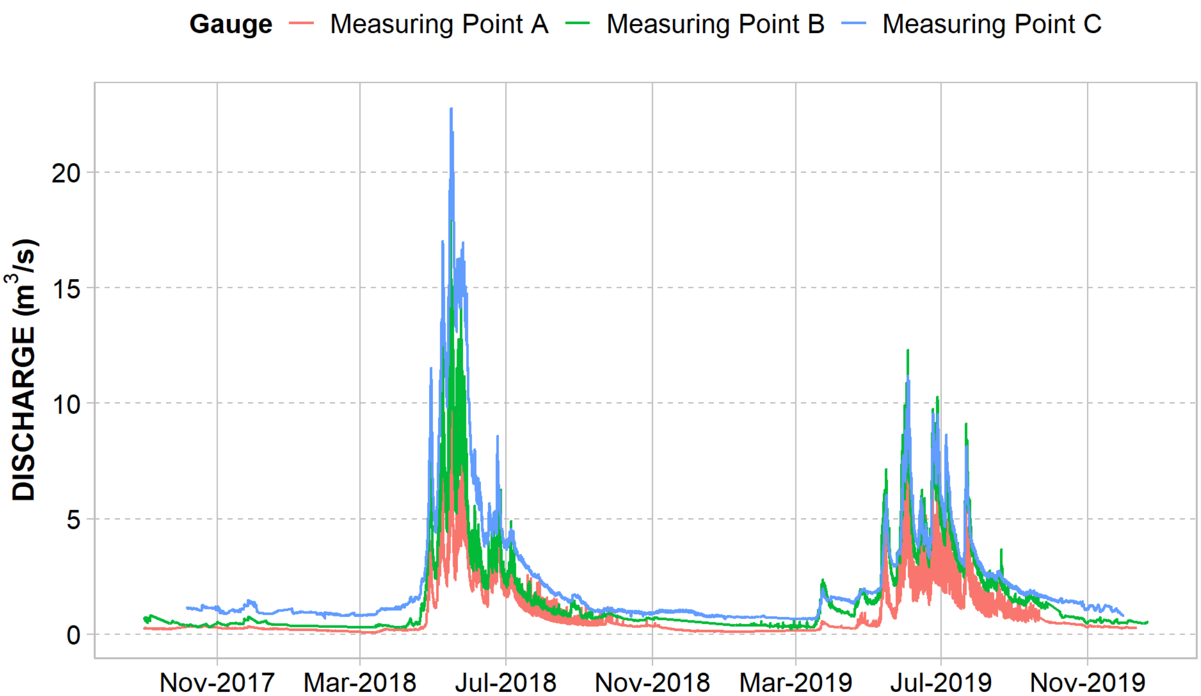
3.1. Ramping Analysis

3.1.1. Primary Data (Hydrometric Stations)

Discharges for the September 2017 to December 2019 period of record as recorded by hydrometric gauges at Measuring Points A, B, and C are presented in Figure 2. In general, discharge was lowest at Measuring Point A, intermediate at Measuring Point B, and greatest at Measuring Point C, as expected given their relative positions on the stream.

Results for September 2017 to December 2019 ramping monitoring at Measuring Points A, B, and C are presented by year in the sections below. Detailed descriptions of 2018 and 2019 ramping monitoring results can be found in Johnson *et al.* (2019) and Wright *et al.* (2020), respectively.

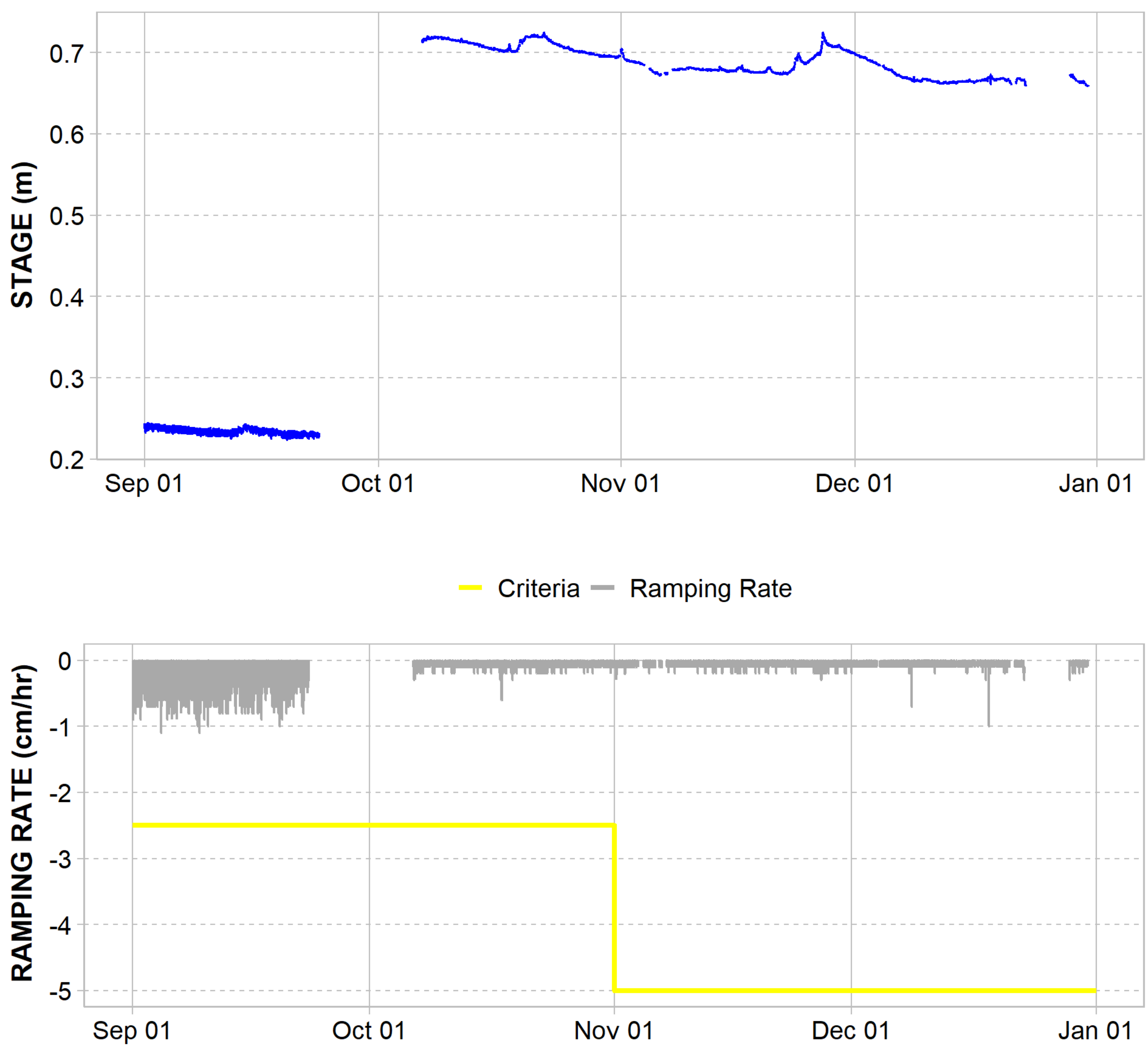
Figure 2. Discharge at Measuring Points A, B, and C in the UFR for the September 2017 to December 2019 period of record.



3.1.1.1. 2017 Ramping Monitoring

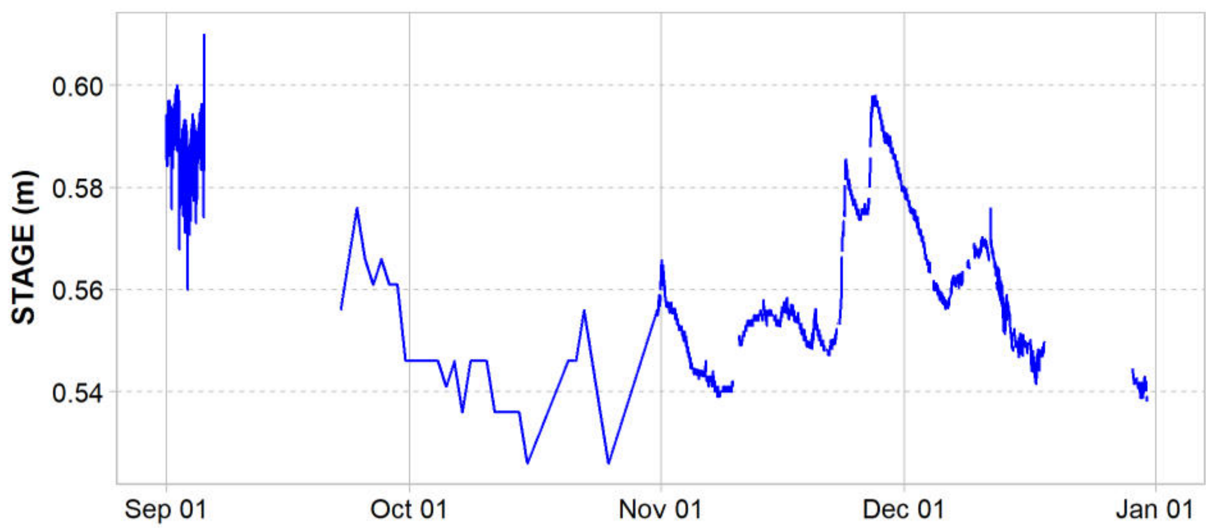
UFR stage and ramping rates for Measuring Points A, B, and C in 2017 are shown in Figure 3, Figure 4, and Figure 5, respectively. There were no potential ramping exceedance events at Measuring Points A or C in 2017 (Figure 3, Figure 5). At Measuring Point B, two potential events were identified that exceeded the ramping rate criteria (Table 3). These potential exceedance events occurred with stage ramping rates between -2.8 cm/hr and -2.9 cm/hr (Figure 4). However, they occurred at the same time each day and were attributed to an auto cycle bubbler purge that was used to clear debris from the gauge orifice line, and which caused the sensors to falsely identify changes in water levels that did not actually occur.

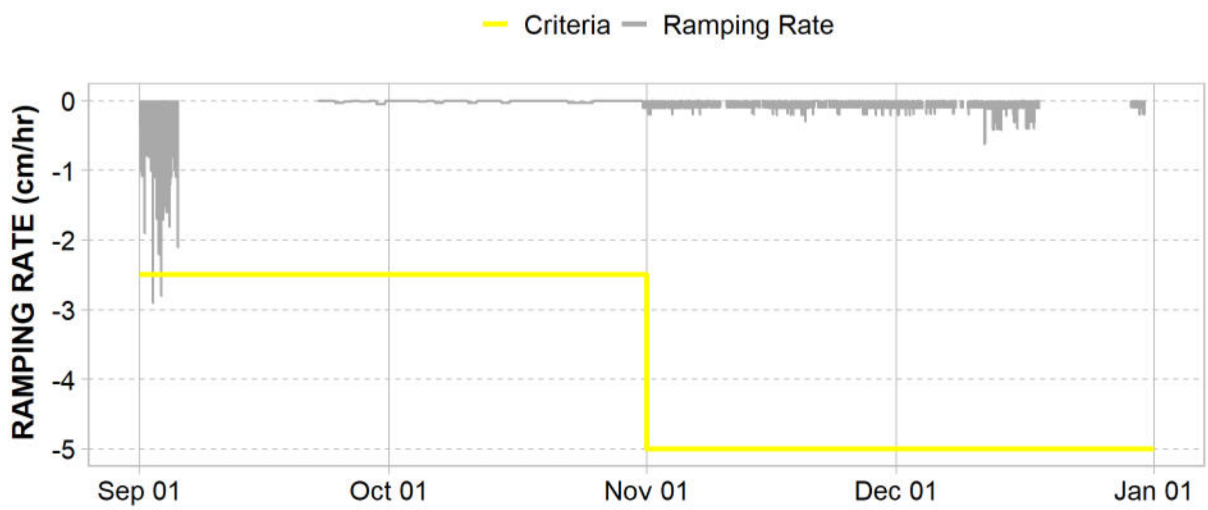
Figure 3. Stage (top panel) and ramping rate (bottom panel) for Measuring Point A during the 2017 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.



Note: Ramping rates are shown for all identified potential events prior to evaluation/filtering

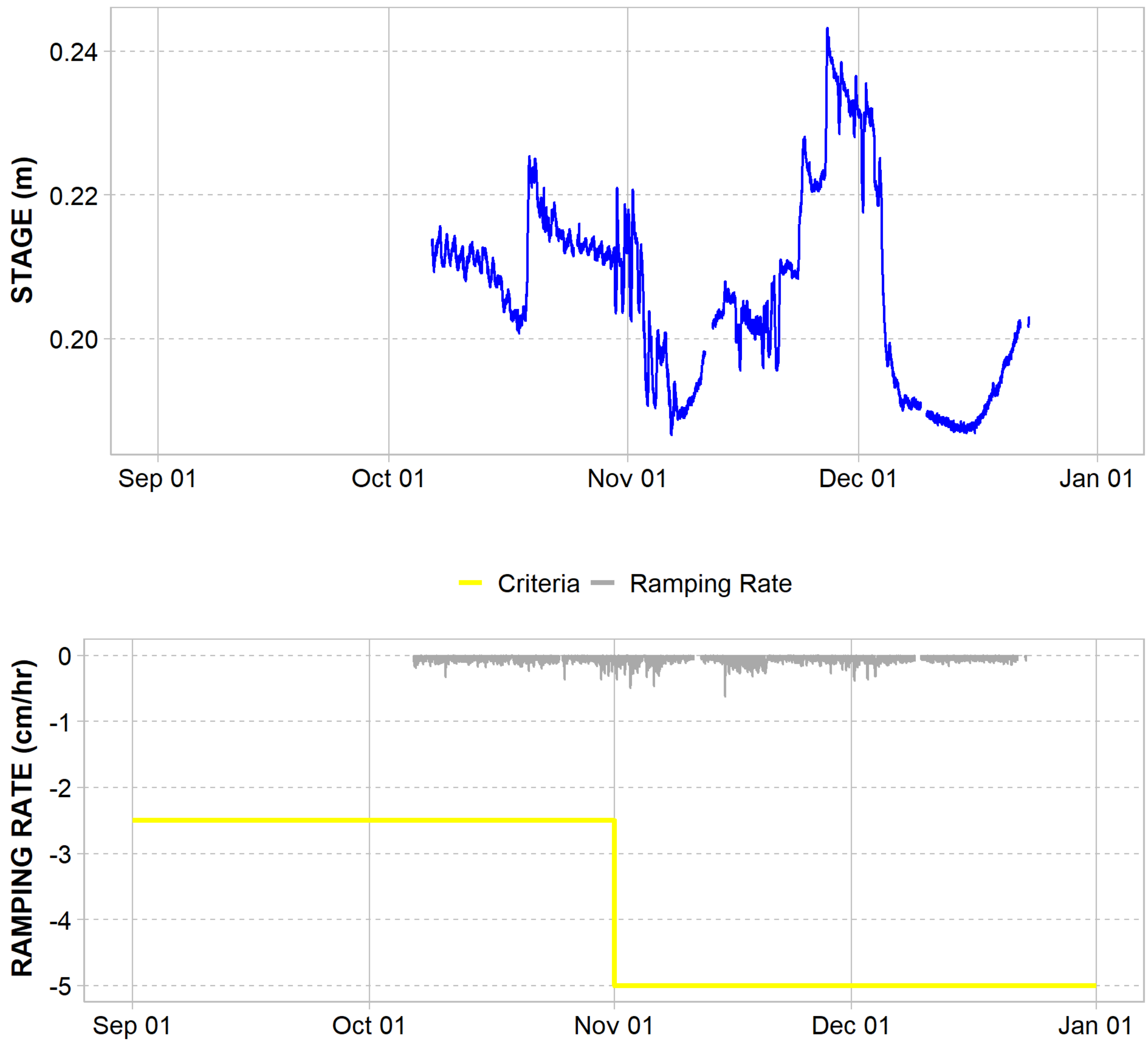
Figure 4. Stage and ramping rate for Measuring Point B during the 2017 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.





Note: Ramping rates are shown for all identified potential events prior to evaluation/filtering

Figure 5. Stage and ramping rate for Measuring Point C during the 2017 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.



Note: Ramping rates are shown for all identified potential events prior to evaluation/filtering

Table 3. Summary of potential ramping exceedance events identified at Measuring Point B for the 2017 period of record (September 1, 2017 to December 31, 2017).

Year	Month	Day	Start Time	Duration of Stage Decline	Criteria Used (cm/hr)	Maximum Stage Ramping Rate	Total Stage Change	Discharge (m^3/s) Start	Discharge (m^3/s) End	Discharge (m^3/s) Change	Event Cause
2017	9	2	14:30	0:15	-2.5	-2.9	-2.9	0.73	0.53	-0.20	Bubbler Purge
		3	14:00	0:45	-2.5	-2.8	-2.8	0.67	0.49	-0.18	Bubbler Purge

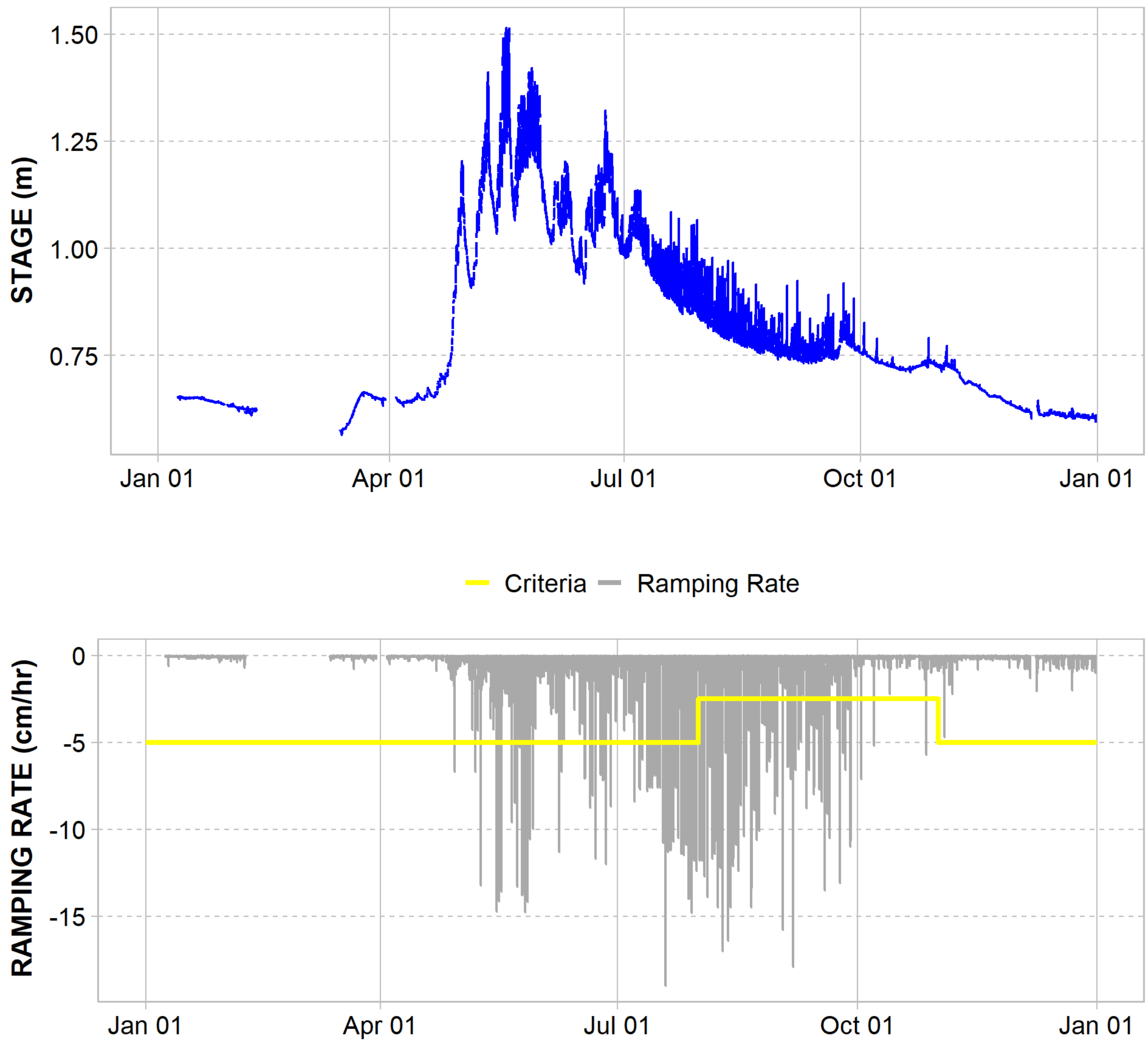
3.1.1.2. 2018 Ramping Monitoring

UFR stage and ramping rates for Measuring Points A, B, and C in 2018 are shown in Figure 6, Figure 7, and Figure 8, respectively. The analysis of Measuring Point A stage data identified 110 potential exceedance events. These occurred with stage ramping rates between -3.0 cm/hr and - 19.0 cm/hr (Figure 6). At Measuring Point B, 33 potential exceedance events were identified that occurred with stage ramping rates between -2.6 cm/hr and -13.6 cm/hr (Figure 7). No potential exceedance events were identified at Measuring Point C (Figure 8).

Of the 110 potential exceedance events identified at Measuring Point A, KWL determined that 103 were related to an auto cycle bubbler purge at the gauge that was used to clear debris from the gauge orifice line, which caused the sensors to identify changes in water levels that did not actually occur (Table 4). One potential exceedance event was determined to have been caused by noise in water level from partial blockage of the orifice, which was verified by Ecofish (Appendix A, Appendix B). All ‘turbulence’ events appeared to be indicative of pulses of turbulent water flowing over the sensor during high flow periods. All ‘noise’ events occurred at low flows and were characterized by a sudden jump or drop in water level, which is suggestive of debris build up and sudden release. Six potential events were classified as having an unknown cause at Measuring Point A in 2018, which were further evaluated for potential stranding risk to fish (Section 3.2).

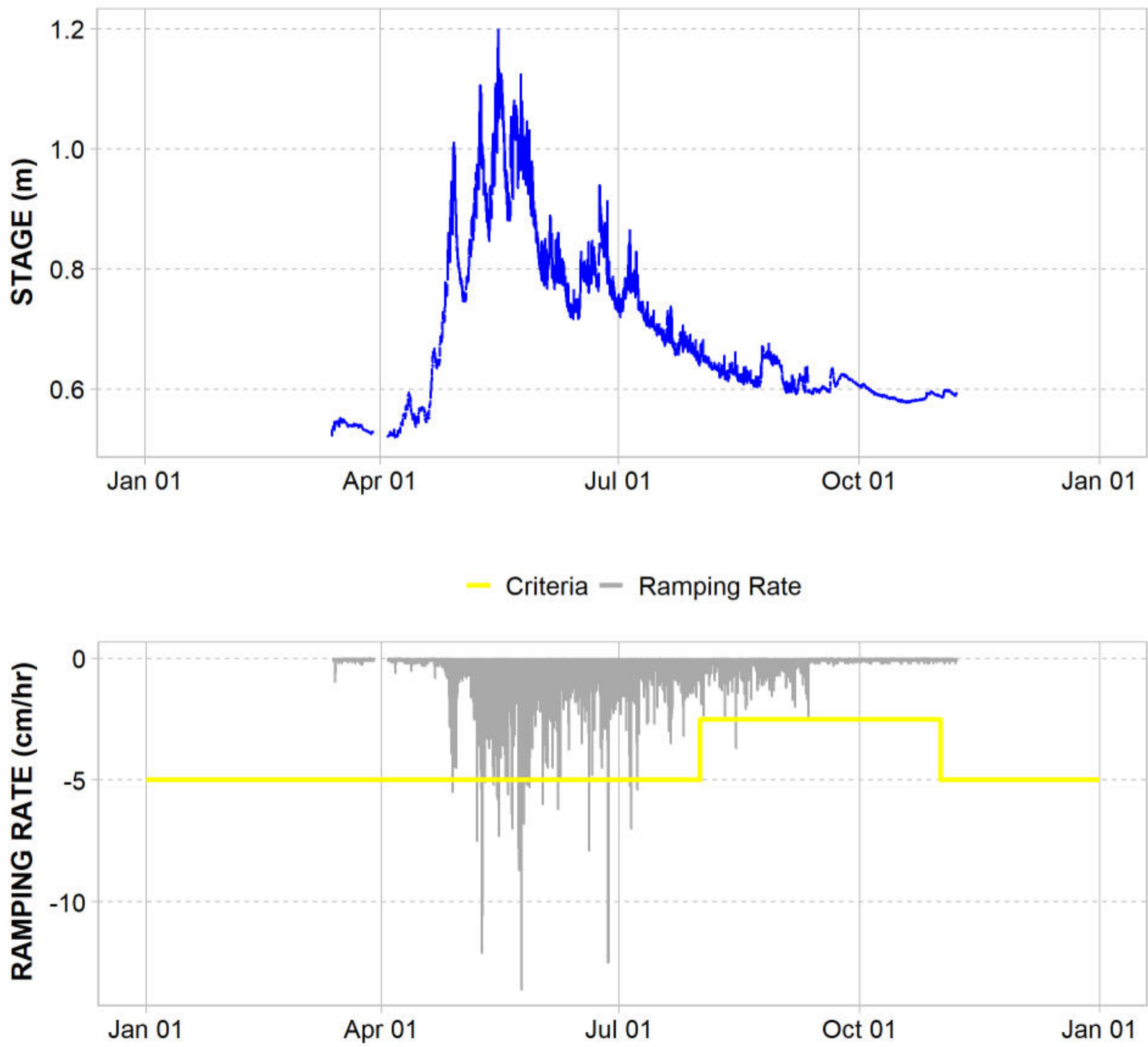
Of the 33 potential exceedance events identified at Measuring Point B, KWL determined that the majority were caused by gauge maintenance or noise in water levels (Table 5), which were verified by Ecofish (Appendix A, Appendix B). Six events were determined by KWL to be related to an auto cycle bubbler purge at the gauge. Two events were classified as having an unknown cause and were further evaluated for potential stranding risk to fish (Section 3.2).

Figure 6. Stage and ramping rate for Measuring Point A during the 2018 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.



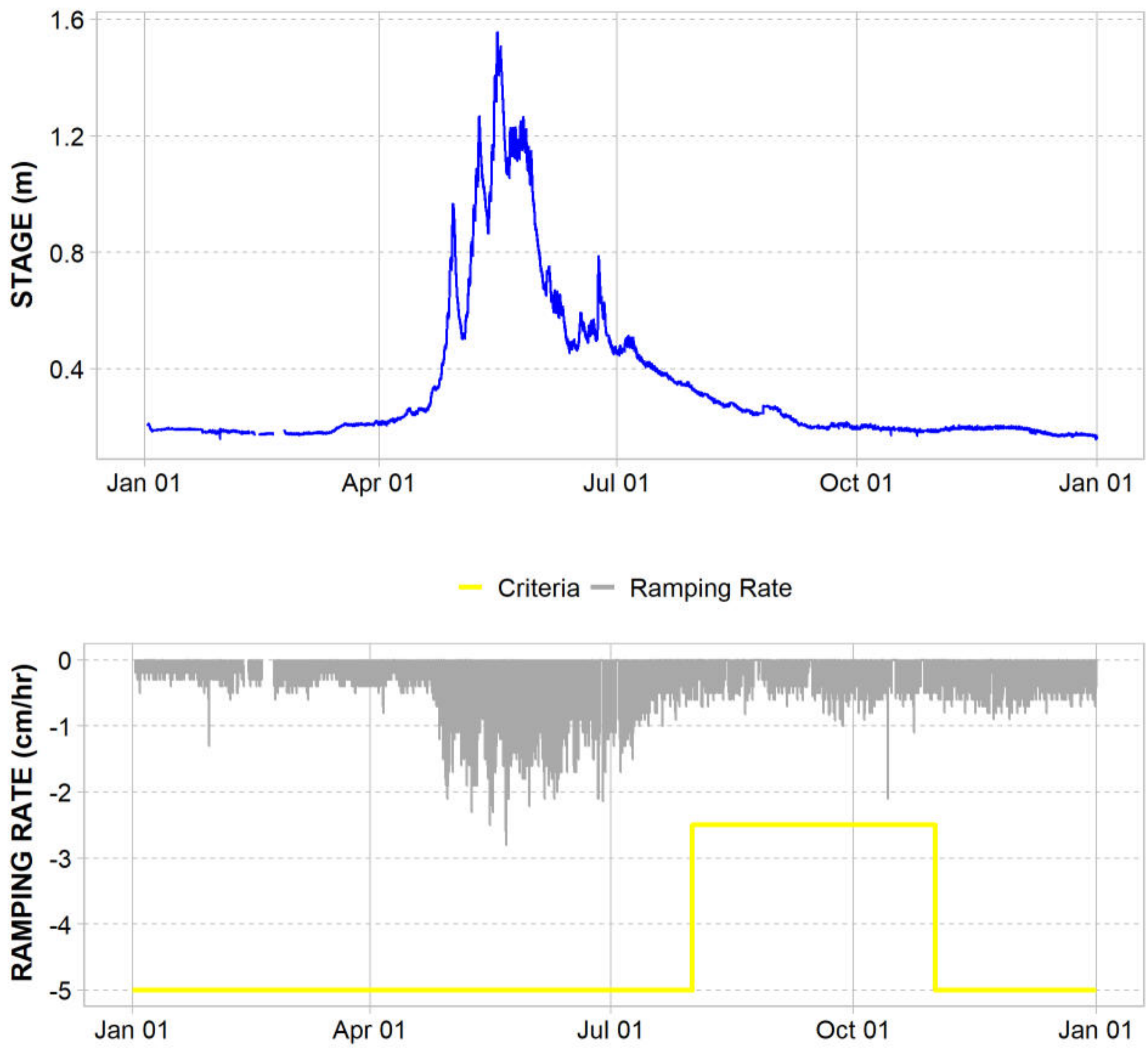
Note: Ramping rates are shown for all identified potential events prior to evaluation/filtering

Figure 7. Stage and ramping rate for Measuring Point B during the 2018 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.



Note: Ramping rates are shown for all identified potential events prior to evaluation/filtering

Figure 8. **Stage and ramping rate for Measuring Point C during the 2018 period of record. Ramping rate criteria for the fry-present (-2.55 cm/hr) and fry not-present (-5.0 cm/hr) periods are highlighted with horizontal yellow lines.**



Note: Ramping rates are shown for all identified potential events prior to evaluation/filtering

Table 4. Summary of potential ramping exceedance events identified at Measuring Point A for the 2018 period of record (January 8, 2018 to December 31, 2018).

Year	Month	Day	Start Time	Duration of Stage Decline (hh:mm)	Criteria Used (cm/hr)	Maximum Stage Ramping Rate (cm/hr)	Total Stage Change (cm)	Discharge (m^3/s)			Event Cause
								Start	End	Change	
2018	4	29	10:45	1:00	-5.0	-6.7	-6.8	3.88	3.01	-0.869	Bubbler Purge
	5	7	6:45	1:30	-5.0	-6.7	-8.2	4.54	3.39	-1.15	Unknown
		9	11:00	1:00	-5.0	-13.2	-13.3	6.54	4.23	-2.31	Bubbler Purge
		15	11:00	1:00	-5.0	-14.7	-14.7	7.02	4.37	-2.64	Bubbler Purge
		16	6:30	0:45	-5.0	-10.2	-10.2	10.4	7.86	-2.56	Debris
			10:45	1:15	-5.0	-14.1	-14.8	7.67	4.85	-2.82	Bubbler Purge
		17	10:45	0:45	-5.0	-13.6	-13.6	8.25	5.47	-2.78	Bubbler Purge
		21	10:45	0:45	-5.0	-9.6	-9.6	4.87	3.48	-1.40	Bubbler Purge
		22	10:45	1:15	-5.0	-8.5	-9.3	5.09	3.69	-1.40	Bubbler Purge
		23	10:45	0:45	-5.0	-13.3	-13.3	6.08	3.90	-2.18	Bubbler Purge
		24	10:45	1:00	-5.0	-5.3	-5.5	4.64	3.83	-0.808	Bubbler Purge
		25	11:15	0:15	-5.0	-13.8	-13.8	6.67	4.26	-2.41	Bubbler Purge
		26	9:45	0:45	-5.0	-5.1	-5.1	7.69	6.62	-1.08	Unknown
			11:15	0:45	-5.0	-14.8	-14.8	6.99	4.35	-2.64	Bubbler Purge
		27	11:00	0:30	-5.0	-14.2	-14.2	6.43	4.03	-2.40	Bubbler Purge
		28	10:45	0:45	-5.0	-10.6	-10.6	5.48	3.82	-1.66	Bubbler Purge
		29	10:45	0:45	-5.0	-10.0	-10.0	5.35	3.80	-1.55	Bubbler Purge
	6	8	11:15	0:15	-5.0	-11.3	-11.3	3.57	2.29	-1.28	Bubbler Purge
		9	10:45	0:45	-5.0	-6.7	-6.7	3.22	2.47	-0.751	Unknown
		18	11:15	0:45	-5.0	-7.1	-7.1	2.70	2.00	-0.694	Bubbler Purge
		20	10:45	0:45	-5.0	-8.8	-8.8	3.09	2.16	-0.927	Bubbler Purge
		21	10:45	1:00	-5.0	-8.1	-8.3	3.22	2.31	-0.906	Bubbler Purge
		22	11:15	0:15	-5.0	-11.7	-11.7	3.61	2.28	-1.33	Bubbler Purge
		24	10:45	1:15	-5.0	-6.9	-7.3	4.40	3.39	-1.01	Bubbler Purge
		25	11:00	0:45	-5.0	-7.2	-7.2	4.00	3.07	-0.933	Bubbler Purge
		26	10:45	0:45	-5.0	-12.0	-12.0	4.15	2.64	-1.51	Bubbler Purge
		28	11:15	0:15	-5.0	-8.7	-8.7	2.93	2.05	-0.887	Bubbler Purge
	7	7	11:00	0:30	-5.0	-8.4	-8.4	2.74	1.92	-0.819	Bubbler Purge
		9	11:15	1:00	-5.0	-7.7	-7.8	2.21	1.55	-0.656	Bubbler Purge
		10	11:15	0:15	-5.0	-6.0	-6.0	2.01	1.52	-0.484	Bubbler Purge
		12	8:30	1:00	-5.0	-7.8	-8.0	1.94	1.33	-0.611	Bubbler Purge
		13	8:30	1:00	-5.0	-7.6	-7.7	1.87	1.30	-0.575	Bubbler Purge
		14	8:15	0:30	-5.0	-7.6	-7.6	1.86	1.30	-0.567	Bubbler Purge
		15	8:30	1:00	-5.0	-6.9	-7.0	1.66	1.18	-0.485	Bubbler Purge
		16	8:00	1:30	-5.0	-7.6	-8.2	1.68	1.12	-0.560	Bubbler Purge
		17	8:30	0:30	-5.0	-7.6	-7.6	1.58	1.07	-0.501	Bubbler Purge
		18	8:00	1:30	-5.0	-10.8	-11.2	1.83	1.05	-0.776	Bubbler Purge
		19	8:15	0:45	-5.0	-19.0	-19.0	2.57	1.06	-1.51	Bubbler Purge
		20	8:15	0:30	-5.0	-11.3	-11.3	1.88	1.08	-0.799	Bubbler Purge
		21	8:00	0:45	-5.0	-11.2	-11.2	1.70	0.966	-0.736	Bubbler Purge

Table 4. Continued (2 of 3).

Year	Month	Day	Start Time	Duration of Stage Decline (hh:mm)	Criteria Used (cm/hr)	Maximum Stage Ramping Rate (cm/hr)	Total Stage Change (cm)	Discharge (m^3/s) Start	Discharge (m^3/s) End	Discharge (m^3/s) Change	Event Cause
2018	7	22	7:15	1:00	-5.0	-9.6	-9.6	2.43	1.59	-0.841	Unknown
			8:30	1:00	-5.0	-10.7	-10.7	1.61	0.928	-0.680	Bubbler Purge
		23	8:30	1:00	-5.0	-7.6	-7.7	1.28	0.842	-0.435	Bubbler Purge
		24	8:30	0:30	-5.0	-10.5	-10.5	1.59	0.927	-0.664	Bubbler Purge
		25	8:30	0:30	-5.0	-11.4	-11.4	1.63	0.906	-0.722	Bubbler Purge
		26	8:30	1:00	-5.0	-11.5	-11.5	1.54	0.845	-0.699	Bubbler Purge
		27	7:30	2:00	-5.0	-10.9	-19.3	2.25	0.874	-1.38	Bubbler Purge
		28	7:15	0:15	-5.0	-5.8	-5.8	2.28	1.77	-0.514	Unknown
			8:00	1:30	-5.0	-14.0	-14.1	1.85	0.909	-0.940	Bubbler Purge
		29	7:30	1:30	-5.0	-14.8	-21.5	2.38	0.828	-1.55	Bubbler Purge
		30	8:30	0:30	-5.0	-11.8	-11.8	1.52	0.814	-0.705	Bubbler Purge
		31	8:15	1:00	-5.0	-12.4	-12.5	1.50	0.771	-0.732	Bubbler Purge
	8	1	8:00	1:00	-2.5	-11.8	-11.8	1.44	0.766	-0.679	Bubbler Purge
		2	8:30	0:45	-2.5	-11.8	-11.8	1.40	0.738	-0.663	Bubbler Purge
		3	8:00	1:30	-2.5	-12.7	-12.9	1.46	0.724	-0.732	Bubbler Purge
		4	8:30	1:15	-2.5	-13.9	-14.3	1.61	0.755	-0.855	Bubbler Purge
		5	8:30	1:00	-2.5	-6.4	-6.5	0.960	0.655	-0.305	Bubbler Purge
		6	7:15	0:45	-2.5	-3.0	-3.0	1.43	1.23	-0.200	Unknown
			8:15	0:30	-2.5	-11.7	-11.7	1.26	0.651	-0.607	Bubbler Purge
		7	8:00	0:45	-2.5	-11.4	-11.4	1.22	0.638	-0.581	Bubbler Purge
		8	8:00	0:45	-2.5	-14.5	-14.5	1.46	0.658	-0.801	Bubbler Purge
		9	8:30	0:15	-2.5	-12.2	-12.2	1.24	0.617	-0.619	Bubbler Purge
		10	8:15	1:15	-2.5	-17.0	-17.0	1.56	0.613	-0.946	Bubbler Purge
		11	8:00	0:45	-2.5	-5.6	-5.6	0.834	0.593	-0.242	Bubbler Purge
		12	8:30	1:00	-2.5	-16.4	-16.5	1.53	0.615	-0.911	Bubbler Purge
		13	8:30	1:00	-2.5	-14.5	-14.7	1.35	0.588	-0.762	Bubbler Purge
		14	8:30	0:15	-2.5	-12.1	-12.1	1.13	0.554	-0.574	Bubbler Purge
		15	8:30	0:15	-2.5	-10.9	-10.9	1.05	0.550	-0.502	Bubbler Purge
		16	8:30	0:15	-2.5	-12.4	-12.4	1.12	0.538	-0.582	Bubbler Purge
		17	8:30	1:15	-2.5	-8.6	-9.0	0.915	0.527	-0.388	Bubbler Purge
		18	8:30	0:15	-2.5	-10.4	-10.4	0.994	0.530	-0.463	Bubbler Purge
		19	8:30	0:15	-2.5	-7.5	-7.5	0.829	0.519	-0.310	Bubbler Purge
		20	8:15	1:15	-2.5	-4.3	-4.5	0.688	0.515	-0.173	Bubbler Purge
		21	8:00	1:30	-2.5	-14.5	-14.5	1.18	0.501	-0.681	Bubbler Purge
		22	7:45	1:45	-2.5	-8.9	-10.8	0.922	0.471	-0.451	Bubbler Purge
		23	8:30	1:00	-2.5	-10.6	-10.6	0.911	0.470	-0.440	Bubbler Purge
		24	8:00	0:45	-2.5	-10.1	-10.1	0.880	0.467	-0.413	Bubbler Purge
		25	8:00	1:00	-2.5	-3.9	-3.9	0.673	0.523	-0.149	Bubbler Purge
		26	8:15	1:15	-2.5	-4.0	-4.4	0.644	0.482	-0.161	Bubbler Purge
		27	8:15	1:00	-2.5	-6.7	-6.8	0.795	0.519	-0.276	Bubbler Purge

Table 4. Continued (3 of 3).

Year	Month	Day	Start Time	Duration of Stage Decline (hh:mm)	Criteria Used (cm/hr)	Maximum Stage Ramping Rate (cm/hr)	Total Stage Change (cm)	Discharge (m^3/s) Start	End	Change	Event Cause
2018	8	28	8:00	0:45	-2.5	-6.1	-6.1	0.767	0.522	-0.245	Bubbler Purge
		29	8:30	0:30	-2.5	-4.4	-4.4	0.614	0.458	-0.156	Bubbler Purge
		30	8:15	1:15	-2.5	-9.1	-9.3	0.822	0.454	-0.367	Bubbler Purge
		31	8:00	1:30	-2.5	-8.1	-8.4	0.761	0.441	-0.319	Bubbler Purge
	9	2	8:30	1:00	-2.5	-15.8	-15.9	1.17	0.447	-0.719	Bubbler Purge
		4	8:00	0:45	-2.5	-6.4	-6.4	0.671	0.440	-0.232	Bubbler Purge
		5	8:00	1:15	-2.5	-7.1	-7.7	0.696	0.418	-0.278	Bubbler Purge
		6	8:00	1:30	-2.5	-17.9	-18.1	1.24	0.414	-0.823	Bubbler Purge
		7	7:45	1:45	-2.5	-6.6	-11.0	0.826	0.405	-0.421	Bubbler Purge
		8	8:30	1:00	-2.5	-5.4	-5.5	0.582	0.399	-0.183	Bubbler Purge
		9	8:30	0:15	-2.5	-4.9	-4.9	0.555	0.396	-0.160	Bubbler Purge
		11	8:00	1:30	-2.5	-8.8	-9.5	0.763	0.409	-0.353	Bubbler Purge
		12	8:15	0:45	-2.5	-6.6	-6.6	0.614	0.391	-0.223	Bubbler Purge
		13	8:30	0:15	-2.5	-4.0	-4.0	0.540	0.409	-0.130	Bubbler Purge
		14	8:15	0:30	-2.5	-8.0	-8.0	0.692	0.406	-0.286	Bubbler Purge
		15	8:00	1:15	-2.5	-4.2	-4.4	0.562	0.416	-0.146	Bubbler Purge
		16	8:15	0:30	-2.5	-7.7	-7.7	0.719	0.434	-0.285	Bubbler Purge
		17	8:00	1:15	-2.5	-8.4	-8.8	0.773	0.437	-0.336	Bubbler Purge
		18	8:00	1:30	-2.5	-13.5	-14.1	1.04	0.438	-0.606	Bubbler Purge
		19	8:30	0:15	-2.5	-9.1	-9.1	0.774	0.429	-0.345	Bubbler Purge
		20	8:30	0:15	-2.5	-10.5	-10.5	0.816	0.414	-0.402	Bubbler Purge
		23	8:15	1:15	-2.5	-4.2	-4.3	0.731	0.557	-0.173	Bubbler Purge
		24	8:30	0:15	-2.5	-13.1	-13.1	1.20	0.561	-0.640	Bubbler Purge
		25	8:30	0:15	-2.5	-5.6	-5.6	0.781	0.551	-0.230	Bubbler Purge
		26	8:30	0:15	-2.5	-6.6	-6.6	0.809	0.537	-0.273	Bubbler Purge
		27	8:30	0:15	-2.5	-3.1	-3.1	0.608	0.495	-0.112	Bubbler Purge
		28	8:30	0:15	-2.5	-11.0	-11.0	0.993	0.509	-0.484	Bubbler Purge
	10	2	8:00	0:45	-2.5	-7.1	-7.1	0.721	0.454	-0.267	Bubbler Purge
		7	8:30	0:15	-2.5	-5.2	-5.2	0.569	0.398	-0.172	Bubbler Purge
		27	8:30	0:30	-2.5	-5.7	-5.7	0.576	0.389	-0.187	Bubbler Purge

Table 5. Summary of potential ramping exceedance events identified at Measuring Point B for the 2018 period of record (March 13, 2018 to November 7, 2018).

Year	Month	Day	Start Time	Duration of Stage Decline (hh:mm)	Criteria Used (cm/hr)	Maximum Stage Ramping Rate (cm/hr)	Total Stage Change (cm)	Discharge (m^3/s) Start	Discharge (m^3/s) End	Discharge (m^3/s) Change	Event Cause
2018	4	28	5:15	1:00	-5.0	-5.5	-5.5	7.28	5.59	-1.69	Unknown
	5	7	14:30	0:15	-5.0	-7.5	-7.5	7.75	5.42	-2.33	Unknown
		9	6:15	0:45	-5.0	-5.4	-5.4	13.7	11.1	-2.57	Turbulence
			14:30	0:15	-5.0	-12.1	-12.1	13.4	8.16	-5.19	Bubbler Purge
		10	14:00	1:00	-5.0	-5.1	-5.6	8.47	6.56	-1.91	Bubbler Purge
		13	23:00	0:30	-5.0	-5.2	-5.2	9.90	7.91	-1.99	Turbulence
		15	8:30	0:45	-5.0	-5.7	-5.7	12.5	9.94	-2.54	Turbulence
			11:45	1:00	-5.0	-5.8	-8.3	13.4	9.61	-3.74	Turbulence
			13:30	1:00	-5.0	-5.3	-7.0	12.0	8.98	-2.97	Turbulence
			22:30	0:30	-5.0	-7.3	-7.3	17.6	13.5	-4.03	Turbulence
		16	1:30	0:30	-5.0	-5.5	-5.5	19.5	16.2	-3.33	Turbulence
		19	14:15	0:45	-5.0	-5.6	-5.6	7.22	5.51	-1.71	Turbulence
		20	21:00	0:15	-5.0	-5.2	-5.2	10.2	8.18	-2.03	Turbulence
			23:45	0:45	-5.0	-6.4	-6.4	10.7	8.15	-2.53	Turbulence
		21	0:45	1:00	-5.0	-7.0	-8.2	11.5	8.19	-3.34	Turbulence
			3:30	0:30	-5.0	-5.1	-5.1	9.85	7.90	-1.94	Turbulence
		23	14:15	1:00	-5.0	-8.7	-8.8	10.2	6.90	-3.25	Bubbler Purge
		24	14:45	1:00	-5.0	-13.6	-14.9	15.0	8.30	-6.71	Turbulence
		25	3:45	0:15	-5.0	-5.5	-5.5	12.6	10.1	-2.47	Turbulence
			4:30	1:00	-5.0	-6.6	-8.9	12.8	8.91	-3.85	Turbulence
			14:30	0:30	-5.0	-6.8	-6.8	9.99	7.44	-2.55	Bubbler Purge
		26	15:00	0:30	-5.0	-5.1	-5.1	8.86	7.06	-1.81	Turbulence
			20:00	0:15	-5.0	-5.2	-5.2	10.1	8.09	-2.01	Turbulence
		27	14:30	0:15	-5.0	-5.3	-5.3	8.40	6.59	-1.80	Turbulence
	6	1	18:00	0:45	-5.0	-6.0	-6.0	4.43	3.14	-1.29	Turbulence
		7	17:30	0:45	-5.0	-6.2	-6.2	4.49	3.15	-1.34	Turbulence
		19	14:30	1:00	-5.0	-7.9	-8.2	4.32	2.65	-1.66	Bubbler Purge
		26	20:30	0:45	-5.0	-12.5	-12.5	6.26	3.18	-3.07	Turbulence
	7	5	0:45	0:45	-5.0	-5.3	-5.3	4.26	3.14	-1.13	Turbulence
			14:30	0:15	-5.0	-7.0	-7.0	4.04	2.65	-1.39	Bubbler Purge
		7	20:15	1:00	-5.0	-5.4	-5.5	4.02	2.90	-1.12	Turbulence
	8	14	15:30	0:15	-2.5	-3.7	-3.7	1.30	0.94	-0.356	Turbulence
	9	11	10:00	0:30	-2.5	-2.6	-2.6	0.929	0.724	-0.205	Turbulence

3.1.1.3. 2019 Ramping Monitoring

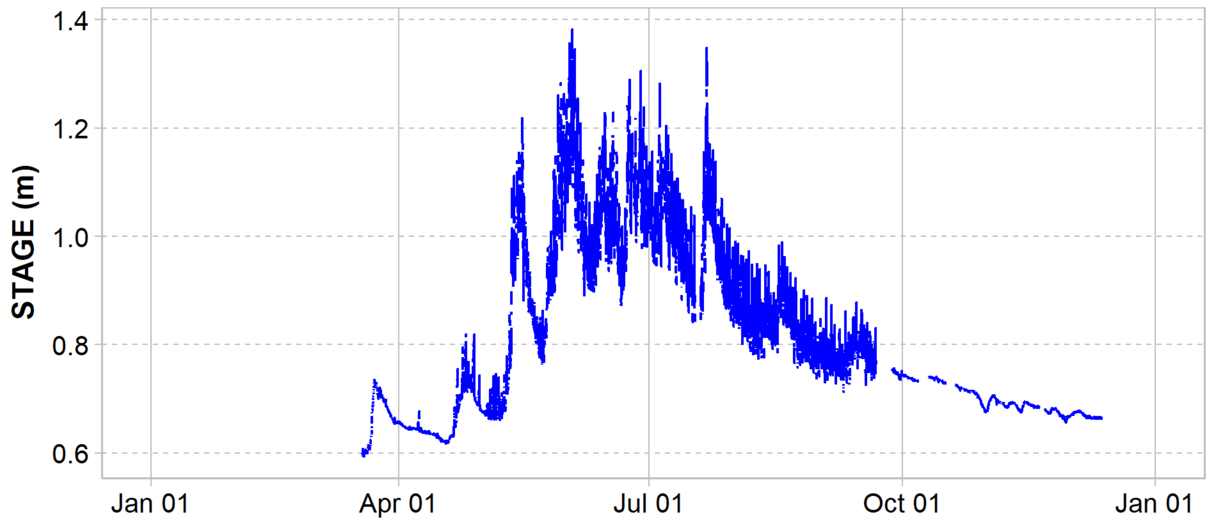
UFR stage and ramping rates for Measuring Points A, B, and C in 2019 are shown in Figure 9, Figure 10, and Figure 11, respectively. The analysis of Measuring Point A stage data identified 105 potential exceedance events that occurred with stage ramping rates between -2.5 cm/hr and -20.2 cm/hr (Figure 9). At Measuring Point B, 18 potential exceedance events were identified that occurred with stage ramping rates between -2.6 cm/hr and -8.5 cm/hr (Figure 10). No potential exceedance events were identified at Measuring Point C (Figure 11).

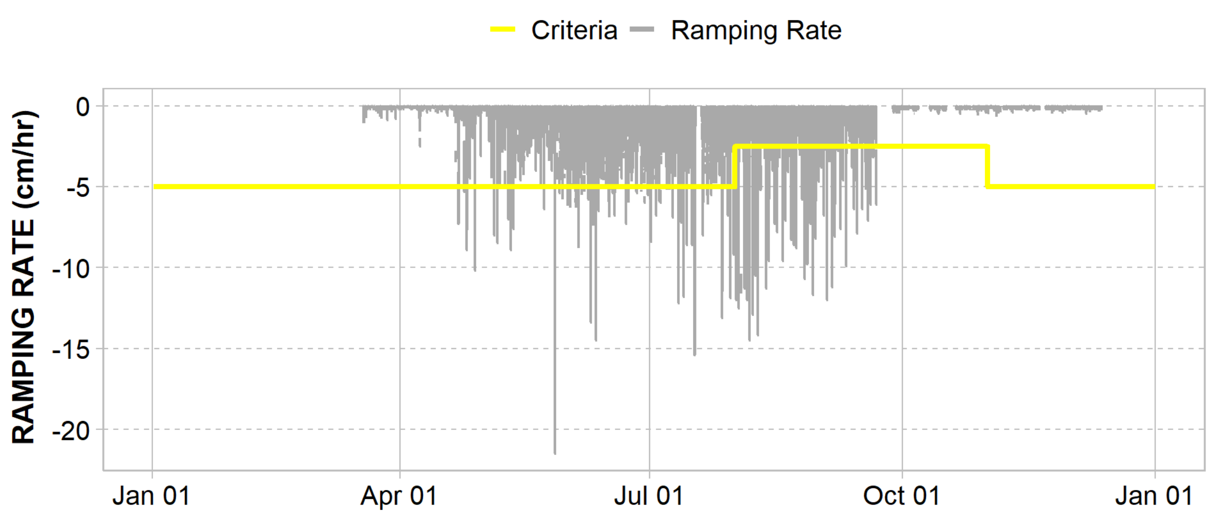
Of the 105 potential exceedance events that were identified at Measuring Point A, 80 were determined to be related to an auto cycle bubbler purge at the gauge that caused the sensors to falsely identify changes in water levels during the purge (Table 6). The remaining 25 were classified by KWL as either 'noise' or 'turbulence', which were verified by Ecofish (Appendix C). As described in Section 3.1.1.2, all 'turbulence' events were associated with turbulent water at high flows and all 'noise' events were associated with sudden increases or declines in flow during low flow periods, likely due to debris build-up and sudden release.

Measuring Point B stage data in 2019 included 18 potential exceedance events that were classified by KWL as due to either 'noise' or 'turbulence' (Table 7), and were verified by Ecofish (Appendix C).

Thus, all potential exceedance events at Measuring Points A and B in 2019 were determined to be caused by gauge error or gauge maintenance. Secondary data collected in 2019 were evaluated in the following sections to confirm these conclusions.

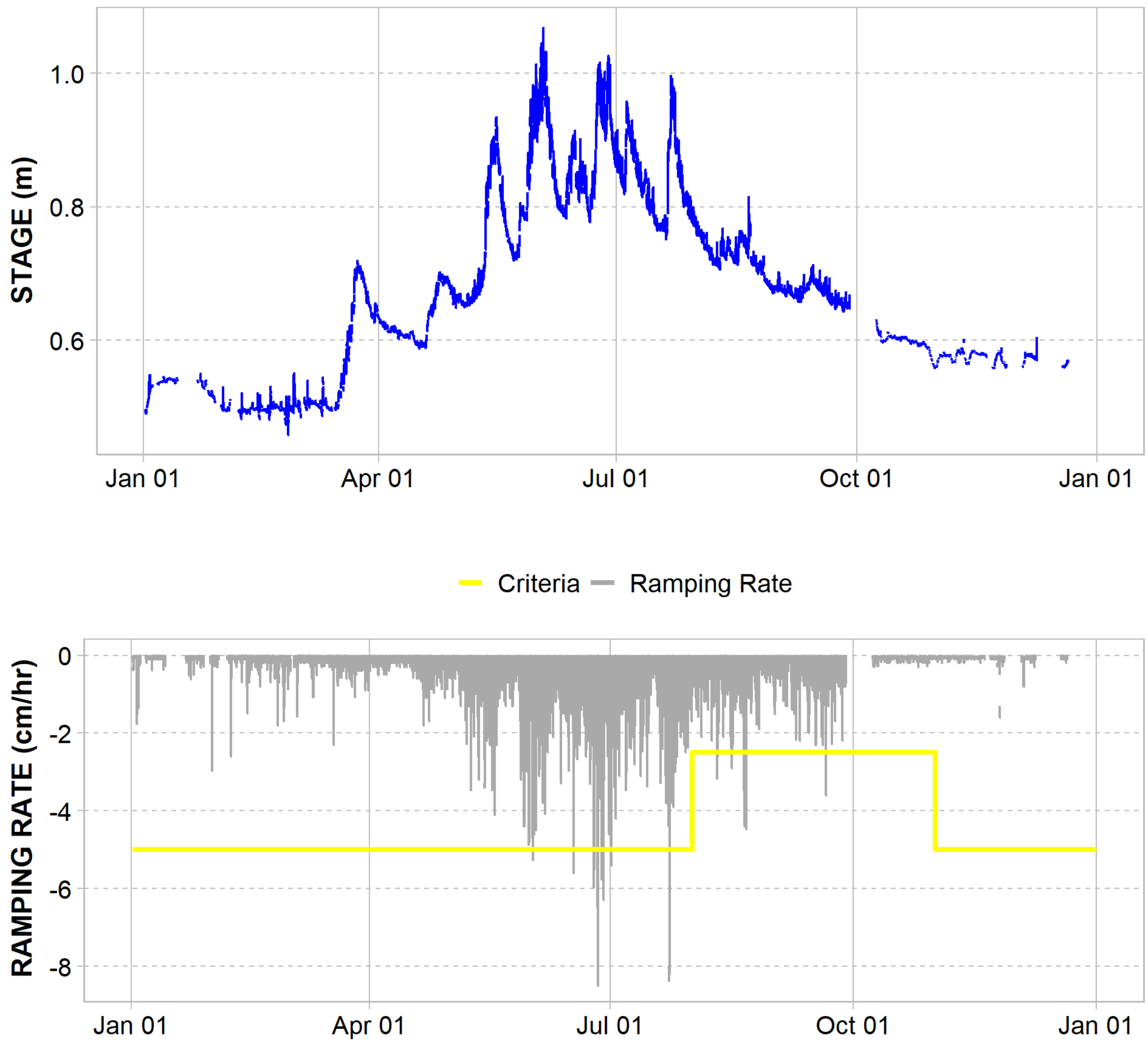
Figure 9. Stage and ramping rate for Measuring Point A during the 2019 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.





Note: Ramping rates are shown for all identified potential events prior to evaluation/filtering

Figure 10. Stage and ramping rate Measuring Point B during the 2019 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.



Note: Ramping rates are shown for all identified potential events prior to evaluation/filtering

Figure 11. Stage and ramping rate Measuring Point C during the 2019 period of record. Ramping rate criteria for the fry-present (-2.55 cm/hr) and fry not-present (-5.0 cm/hr) periods are highlighted with horizontal yellow lines.

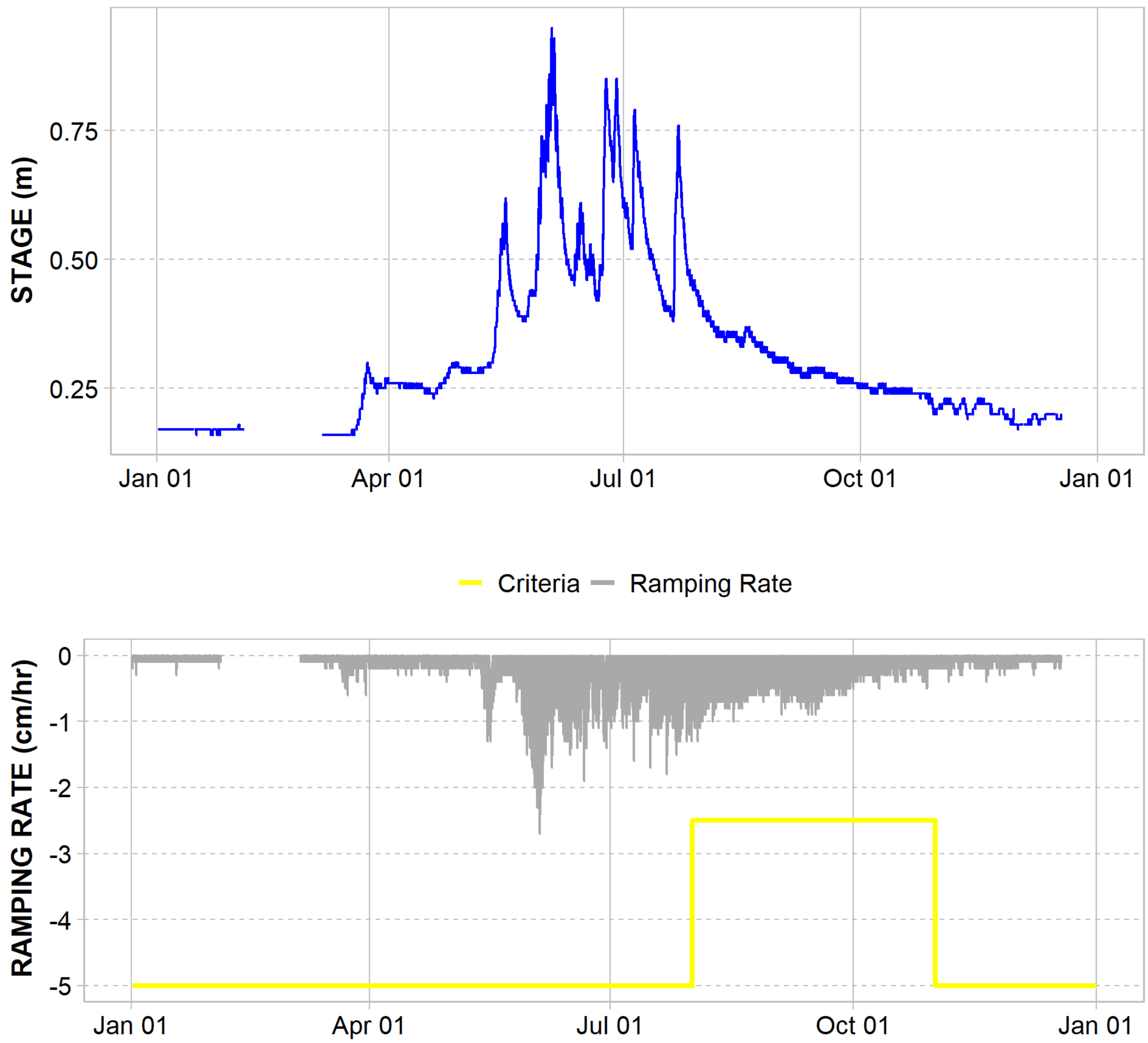


Table 6. Summary of potential ramping exceedance events identified at Measuring Point A for the 2019 period of record (March 18, 2019 to December 9, 2019).

Year	Month	Day	Start Time	Duration of Stage Decline (hh:mm)	Criteria Used (cm/hr)	Maximum Stage Ramping Rate (cm/hr)	Discharge (m^3/s) Start	End	Change	Event Cause
2019	4	25	8:00	0:45	-5.0	-8.8	0.88	0.51	-0.368	Bubbler Purge
		28	8:15	0:30	-5.0	-10.2	0.95	0.51	-0.442	Bubbler Purge
	5	5	8:00	1:30	-5.0	-7.9	0.60	0.34	-0.258	Bubbler Purge
		6	8:30	0:15	-5.0	-8.5	0.58	0.35	-0.232	Bubbler Purge
		7	6:45	0:45	-5.0	-5.1	0.59	0.42	-0.174	Bubbler Purge
		10	8:00	0:45	-5.0	-7.0	0.76	0.49	-0.274	Bubbler Purge
		11	8:00	0:45	-5.0	-8.0	1.04	0.65	-0.387	Bubbler Purge
		12	8:30	0:15	-5.0	-7.4	2.33	1.71	-0.628	Bubbler Purge
		23	8:30	0:15	-5.0	-6.0	1.11	0.80	-0.316	Bubbler Purge
		27	8:45	1:00	-5.0	-20.2	3.71	1.52	-2.198	Bubbler Purge
	6	4	23:30	1:00	-5.0	-5.7	5.64	4.20	-1.436	Turbulence
		8	14:00	0:45	-5.0	-5.8	2.09	1.60	-0.482	Turbulence
		9	8:30	0:15	-5.0	-13.4	2.94	1.69	-1.249	Bubbler Purge
		10	8:00	0:45	-5.0	-7.4	2.26	1.63	-0.637	Bubbler Purge
		11	8:30	0:15	-5.0	-14.5	2.89	1.61	-1.281	Bubbler Purge
		12	8:30	0:15	-5.0	-6.5	2.87	2.31	-0.557	Bubbler Purge
		17	22:45	1:00	-5.0	-5.2	5.16	4.27	-0.890	Turbulence
		18	8:45	0:45	-5.0	-5.2	2.93	2.38	-0.556	Bubbler Purge
		22	7:00	0:45	-5.0	-6.6	2.45	2.29	-0.159	Bubbler Purge
	7	1	7:30	0:15	-5.0	-8.4	3.53	3.53	0.000	Bubbler Purge
		3	7:30	0:15	-5.0	-6.8	2.77	2.77	0.000	Bubbler Purge
		4	7:00	0:45	-5.0	-5.1	2.76	2.54	-0.225	Turbulence
		9	4:30	1:00	-5.0	-5.9	3.72	2.98	-0.741	Bubbler Purge
			7:30	0:15	-5.0	-6.3	3.12	3.12	0.000	Bubbler Purge
		11	7:30	0:15	-5.0	-12.2	3.55	3.55	0.000	Bubbler Purge
		12	7:30	0:15	-5.0	-7.2	2.66	2.66	0.000	Bubbler Purge
		13	7:30	0:15	-5.0	-11.8	3.04	3.04	0.000	Bubbler Purge
		14	7:30	0:15	-5.0	-8.6	2.57	2.57	0.000	Bubbler Purge
		16	7:30	0:15	-5.0	-8.4	2.18	2.18	0.000	Bubbler Purge
		17	7:30	0:15	-5.0	-15.4	2.74	2.74	0.000	Bubbler Purge
		20	7:00	0:45	-5.0	-7.3	1.97	1.81	-0.170	Bubbler Purge
		27	7:30	0:15	-5.0	-13.1	3.10	3.10	0.000	Bubbler Purge
		29	7:30	0:15	-5.0	-5.1	1.91	1.91	0.000	Bubbler Purge
		30	7:30	0:15	-5.0	-11.9	2.48	2.48	0.000	Bubbler Purge
		31	7:30	0:15	-5.0	-9.2	2.14	2.14	0.000	Bubbler Purge

Table 6. Continued (2 of 3).

Year	Month	Day	Start Time	Duration of Stage Decline (hh:mm)	Criteria Used (cm/hr)	Maximum Stage Ramping Rate (cm/hr)	Discharge (m^3/s)			Event Cause
							Start	End	Change	
2019	8	1	7:30	0:15	-2.5	-12.0	2.26	2.26	0.000	Bubbler Purge
		2	7:30	0:15	-2.5	-12.5	2.21	2.21	0.000	Bubbler Purge
			9:00	1:00	-2.5	-2.6	1.42	1.25	-0.174	Bubbler Purge
		3	7:15	0:30	-2.5	-11.6	2.02	2.02	0.000	Bubbler Purge
		4	4:45	1:45	-2.5	-2.7	1.26	1.52	0.267	Bubbler Purge
			7:30	0:15	-2.5	-11.3	1.89	1.89	0.000	Bubbler Purge
			19:45	1:15	-2.5	-2.8	1.24	0.96	-0.286	Bubbler Purge
		5	7:30	0:15	-2.5	-12.0	1.95	1.95	0.000	Bubbler Purge
		6	7:30	0:15	-2.5	-14.5	2.09	2.09	0.000	Bubbler Purge
			8:45	1:15	-2.5	-3.1	1.28	1.08	-0.196	Bubbler Purge
		7	7:30	0:15	-2.5	-12.9	1.87	1.87	0.000	Bubbler Purge
		8	7:30	0:15	-2.5	-10.5	1.66	1.66	0.000	Bubbler Purge
		9	7:30	0:15	-2.5	-14.2	1.88	1.88	0.000	Bubbler Purge
		10	7:00	0:45	-2.5	-4.4	1.38	1.24	-0.138	Bubbler Purge
		11	17:45	1:00	-2.5	-2.6	0.99	0.83	-0.159	Noise
		12	7:00	0:45	-2.5	-11.3	1.19	1.79	0.607	Bubbler Purge
		13	7:30	0:15	-2.5	-9.6	1.76	1.76	0.000	Bubbler Purge
		14	7:30	0:15	-2.5	-3.4	1.30	1.30	0.000	Bubbler Purge
			12:30	0:45	-2.5	-4.0	1.10	0.88	-0.217	Noise
		15	7:30	0:15	-2.5	-7.3	1.46	1.46	0.000	Bubbler Purge
		16	7:30	0:15	-2.5	-7.8	1.37	1.37	0.000	Bubbler Purge
			11:00	0:45	-2.5	-2.8	1.05	0.90	-0.150	Noise
			13:30	1:00	-2.5	-3.2	1.05	0.88	-0.171	Noise
			9:00	0:30	-2.5	-2.6	1.58	1.39	-0.186	Noise
		18	7:30	0:15	-2.5	-9.6	2.22	2.22	0.000	Bubbler Purge
		19	7:30	0:15	-2.5	-7.1	1.94	1.94	0.000	Bubbler Purge
		20	4:00	1:00	-2.5	-2.7	1.34	1.55	0.204	Noise
			4:30	1:30	-2.5	-3.1	1.70	1.30	-0.397	Noise
			19:45	1:00	-2.5	-2.7	1.34	1.16	-0.178	Noise
		21	7:00	0:45	-2.5	-7.8	1.61	1.51	-0.097	Bubbler Purge
			9:45	0:45	-2.5	-3.4	1.26	1.06	-0.206	Noise
		22	7:30	0:15	-2.5	-8.6	1.55	1.55	0.000	Bubbler Purge
		23	7:00	0:45	-2.5	-8.4	1.55	1.45	-0.101	Bubbler Purge
		25	7:00	0:45	-2.5	-5.4	1.19	1.13	-0.061	Bubbler Purge
			10:00	0:45	-2.5	-3.3	1.01	0.89	-0.127	Noise
			13:30	1:00	-2.5	-2.8	1.03	0.88	-0.148	Noise
		26	7:30	0:15	-2.5	-10.7	1.51	1.51	0.000	Bubbler Purge
		27	7:30	0:15	-2.5	-9.8	1.43	1.43	0.000	Bubbler Purge
			8:45	0:45	-2.5	-2.6	0.92	0.80	-0.128	Noise
		28	7:30	0:15	-2.5	-7.3	1.20	1.20	0.000	Bubbler Purge
		29	7:00	0:45	-2.5	-11.2	1.39	1.31	-0.087	Bubbler Purge
			9:00	0:45	-2.5	-2.6	0.87	0.75	-0.123	Noise
		30	7:30	0:15	-2.5	-8.2	1.12	1.12	0.000	Bubbler Purge
		31	7:00	0:45	-2.5	-4.5	0.91	0.86	-0.050	Bubbler Purge

Table 6. Continued (3 of 3).

Year	Month	Day	Start Time	Duration of Stage Decline (hh:mm)	Criteria Used (cm/hr)	Maximum Stage Ramping Rate (cm/hr)	Discharge (m^3/s)			Event Cause
							Start	End	Change	
2019	9	1	7:30	0:15	-2.5	-3.8	0.94	0.94	0.000	Bubbler Purge
		2	7:30	0:15	-2.5	-6.8	1.06	1.06	0.000	Bubbler Purge
		3	0:00	0:45	-2.5	-2.7	0.82	0.70	-0.122	Noise
			7:30	0:15	-2.5	-12.0	1.41	1.41	0.000	Bubbler Purge
		4	7:30	0:15	-2.5	-3.5	0.92	0.92	0.000	Bubbler Purge
		5	7:30	0:15	-2.5	-11.2	1.32	1.32	0.000	Bubbler Purge
		6	7:30	0:15	-2.5	-8.1	1.09	1.09	0.000	Bubbler Purge
		7	7:30	0:15	-2.5	-2.8	0.82	0.82	0.000	Bubbler Purge
			8:45	0:45	-2.5	-2.6	0.78	0.67	-0.114	Noise
		8	7:30	0:15	-2.5	-7.6	1.05	1.05	0.000	Bubbler Purge
		9	7:00	0:45	-2.5	-4.4	0.85	0.80	-0.048	Bubbler Purge
		10	7:00	0:45	-2.5	-9.9	1.23	1.20	-0.031	Bubbler Purge
			13:00	1:00	-2.5	-2.7	0.85	0.71	-0.139	Noise
		12	9:30	1:00	-2.5	-3.4	0.99	0.80	-0.193	Noise
		13	7:00	0:45	-2.5	-6.1	1.16	1.11	-0.054	Bubbler Purge
			11:00	0:45	-2.5	-3.2	0.99	0.82	-0.163	Noise
			13:15	1:15	-2.5	-2.8	1.00	0.86	-0.140	Noise
		14	7:30	0:15	-2.5	-7.9	1.35	1.35	0.000	Bubbler Purge
		16	7:00	0:45	-2.5	-5.6	1.18	1.07	-0.107	Bubbler Purge
		17	7:30	0:15	-2.5	-3.5	0.95	0.95	0.000	Bubbler Purge
			13:45	1:00	-2.5	-4.7	0.93	0.67	-0.262	Noise
		18	7:00	0:45	-2.5	-7.0	1.12	1.08	-0.041	Bubbler Purge
			9:00	1:30	-2.5	-2.9	0.89	0.73	-0.165	Noise
		19	7:00	0:45	-2.5	-5.7	1.01	0.95	-0.054	Bubbler Purge
		20	7:30	0:15	-2.5	-3.2	0.83	0.83	0.000	Bubbler Purge
		21	7:00	0:45	-2.5	-5.4	0.94	0.84	-0.106	Bubbler Purge

Table 7. Summary of potential ramping exceedance events identified at Measuring Point B for the 2019 period of record (January 10, 2019 to December 20, 2019).

Year	Month	Day	Start Time	Duration of Stage Decline (hh:mm)	Criteria Used (cm/hr)	Maximum Stage Ramping Rate (cm/hr)	Discharge (m^3/s)			Total Change from Water Withdrawal (m^3/s)[1]	Event Cause
							Start	End	Change		
2019	6	1	18:30	0:30	-5.0	-5.3	9.68	7.69	-1.99	0.093	Turbulence
		17	4:30	0:45	-5.0	-5.6	5.91	4.42	-1.49	0.000	Turbulence
		24	18:45	0:45	-5.0	-6.0	9.40	7.22	-2.19	0.000	Turbulence
		25	0:00	0:45	-5.0	-5.5	9.16	7.18	-1.98	0.000	Turbulence
		26	5:15	0:45	-5.0	-6.5	8.44	6.26	-2.18	0.000	Turbulence
			10:00	0:30	-5.0	-8.5	9.16	6.23	-2.93	0.000	Turbulence
		27	18:15	0:45	-5.0	-5.8	9.72	7.55	-2.17	0.001	Turbulence
		28	11:45	0:45	-5.0	-6.3	9.72	7.38	-2.34	0.000	Turbulence
	7	1	9:15	0:45	-5.0	-5.4	6.29	4.79	-1.50	0.003	Turbulence
		23	10:00	0:30	-5.0	-8.4	8.19	5.51	-2.68	0.000	Turbulence
	8	10	13:00	0:30	-2.5	-3.2	2.76	2.23	-0.53	0.000	Noise
			14:00	0:45	-2.5	-2.6	2.78	2.34	-0.43	0.000	Noise
			18:15	0:45	-2.5	-2.6	2.49	2.09	-0.40	0.000	Noise
		16	2:30	0:30	-2.5	-2.9	2.38	1.94	-0.43	0.000	Noise
		20	17:00	0:15	-2.5	-3.5	3.15	2.52	-0.63	0.000	Noise
			17:45	1:00	-2.5	-4.1	3.69	2.83	-0.86	0.000	Noise
		21	9:45	0:45	-2.5	-4.5	2.80	2.07	-0.73	0.000	Noise
	9	20	15:45	1:00	-2.5	-3.1	1.65	1.24	-0.41	0.040	Noise

3.1.2. Secondary Data (IFS and Ramping Gauges)

3.1.2.1. Confirmation of Measuring Point Data

For the time period when data from hydrometric stations (at the Measuring Points) and level loggers (at IFS transect and SSMSs sites) exist (referred to as the period of overlap), secondary data collected at IFS and SSMS locations near Measuring Points A, B, and C in 2019 confirmed that potential exceedance events observed at Measuring Points A and B in 2019 were due to gauge error or gauge maintenance (i.e., 'noise', 'turbulence', or 'bubbler purge'). In total, overlapping secondary data existed for 90 of the 106 potential ramping exceedance events at Measuring Point A in 2019, and 16 of the exceedance events occurred outside of the period of overlap (between April 25 and June 12, 2019) (Table 6). Within the period of overlap, no potential exceedance events were identified at the IFS location associated with Measuring Point A (Figure 12). For Measuring Point B, there were overlapping secondary data for all potential exceedance events, with the exception of one on June 1, 2019 (Table 7). No potential exceedance events were identified at any of the four IFS and SSMS locations associated with Measuring Point B (Figure 13) or with the IFS location associated with Measuring Point C (Figure 14).

Data from Measuring Points A, B, and C are plotted with associated level logger data in Figure 12, Figure 13, and Figure 14, respectively, to investigate the cause of potential exceedances identified at the Measuring Points. Figure 12 and Figure 13 show a high variability in stage data at Measuring Points A and B, respectively, that is absent from the IFS or SSMS level logger data; the absence of high variability in the latter records supports KWL's assessment that the ramping rates at the hydrometric gauge are exaggerated by blockage of the orifice tube and not actually caused by water level changes. At Measuring Point C, where no potential exceedance events were documented, variability in stage data was low for both hydrometric gauge and level logger data (Figure 14).

Figure 12. Measuring Point A and associated IFS level logger data.

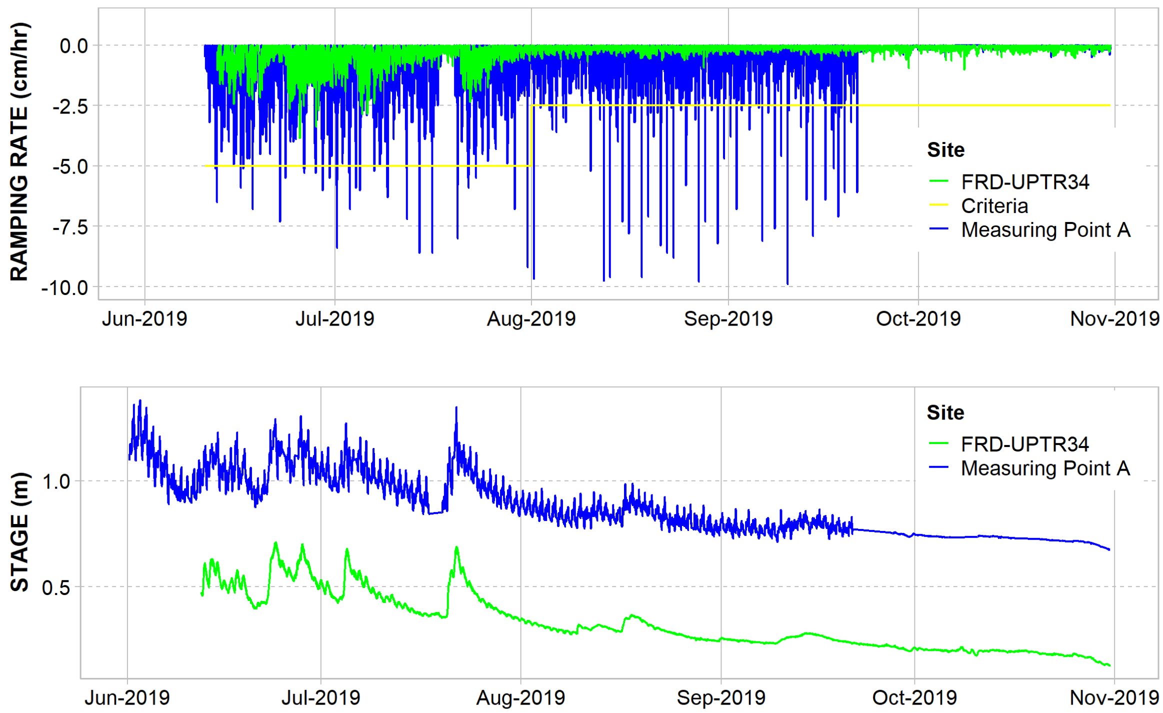


Figure 13. Measuring Point B and associated IFS and SSMS level logger data.

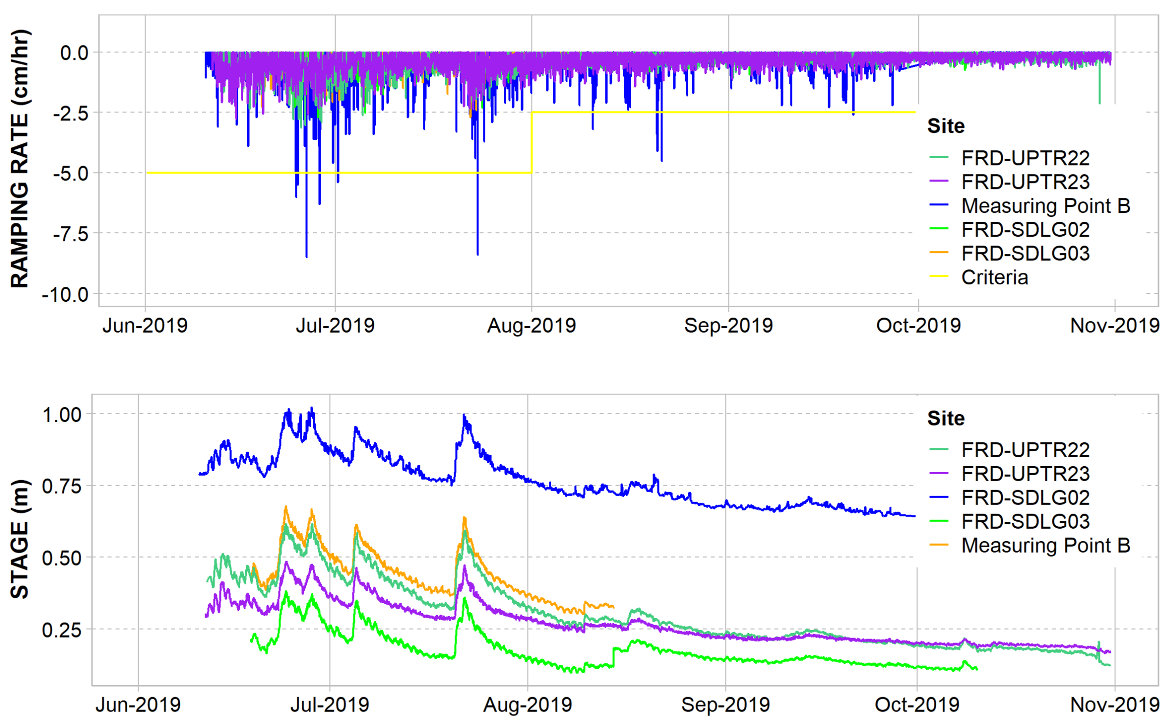
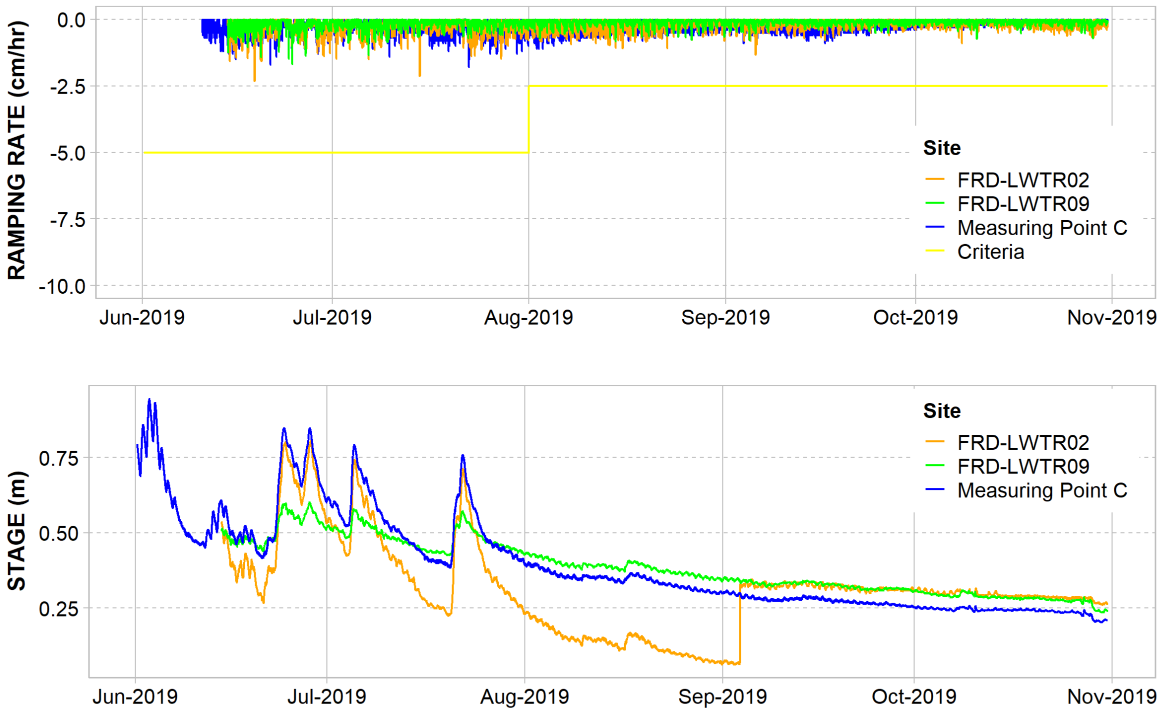


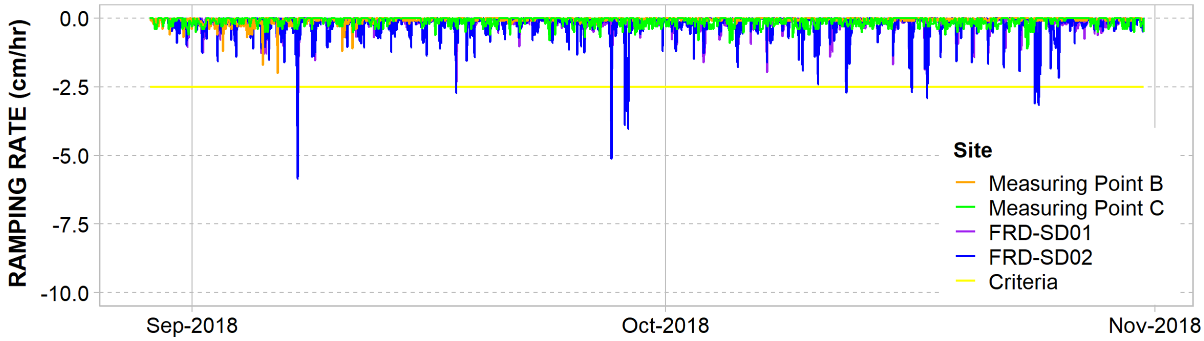
Figure 14. Measuring Point C and associated IFS level logger data. Note that the logger at FRD LWTR02 was moved to deeper habitats in September 2019, causing an apparent increase in stage.



3.1.2.2. Southern Drying Reach Attenuation

To investigate the potential for attenuation of ramping events through the southern drying reach, stage and ramping rates recorded at IFS and SSMS level loggers are shown in comparison to Measuring Points B and C for 2018 (Figure 15) and 2019 (Figure 16). Within the data from the four additional level loggers used for this supplementary analysis, there were 15 potential exceedance events recorded: one at FRD-LWTR16, one at FRD-SD01, and thirteen at FRD-SD02; no potential exceedance events were recorded at the FRD-SDLG01 level logger. All potential exceedance events were recorded in the fry-present season, except the one potential event at FRD-LWTR16; however, this potential exceedance event occurred at high flows, and appeared to be attributed to noise. However, none of these 15 potential exceedance events appeared to coincide with flow changes at Measuring Points B or C. These 15 events were classified as having an unknown cause and were further evaluated for potential stranding risk to fish (Section 3.2)

Figure 15. Measuring Points B and C, and SSMS level logger data from upstream of the southern drying reach in 2018.



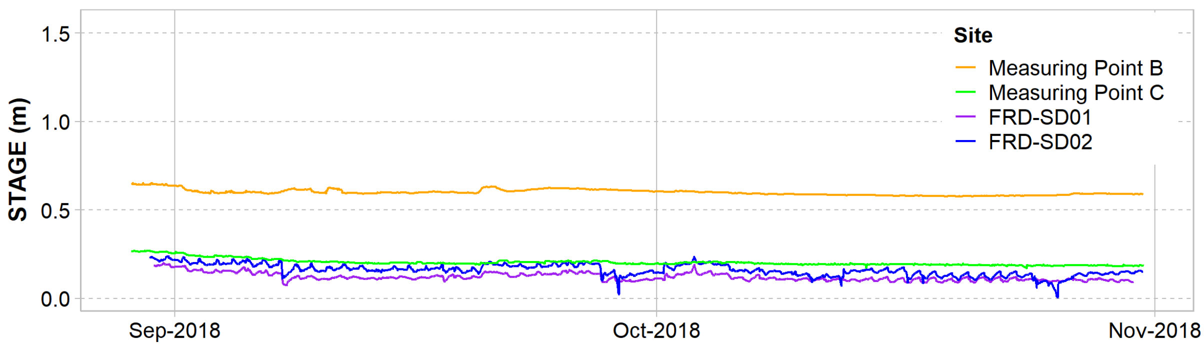
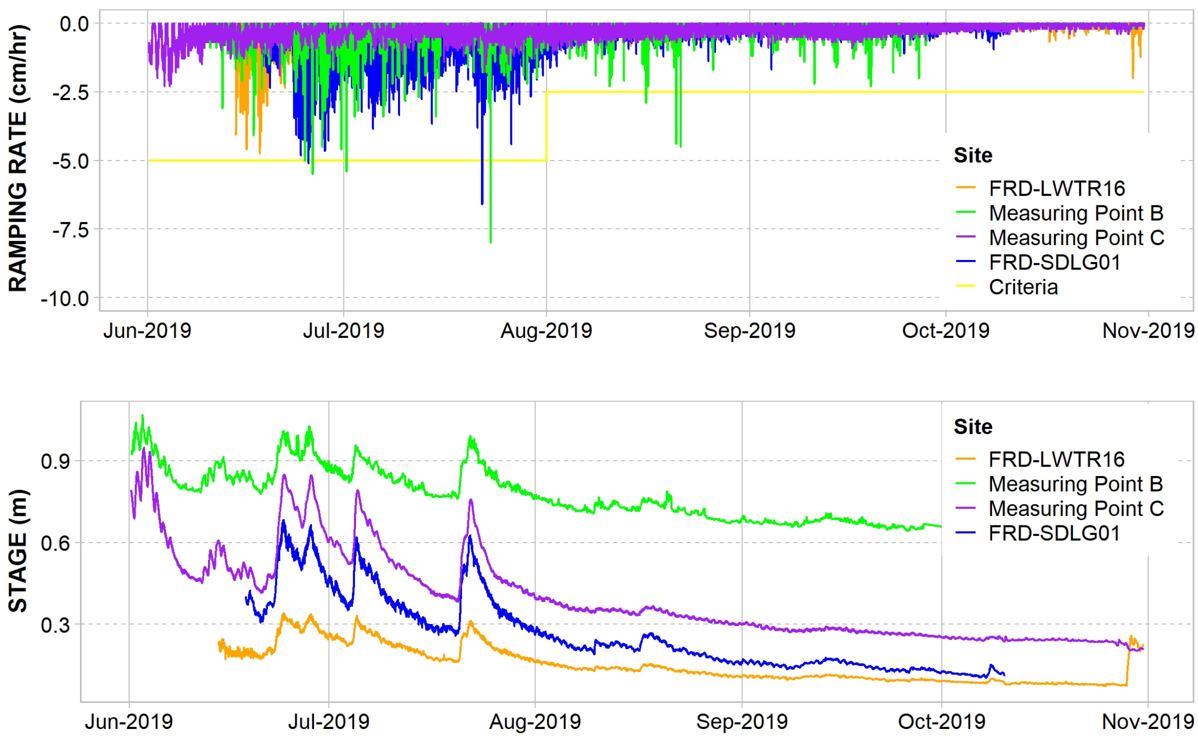


Figure 16. Measuring Points B and C, and IFS and SSMS level logger data from upstream of the southern drying reach in 2019. Note that potential exceedance events apparent at FRD-SDLG01 were of <10 minutes duration, therefore did not exceed criteria.



3.1.3. Tributary Data (Clode Creek and LCO Dry Creek)

3.1.3.1. Clode Creek FR_CC1

Clode Creek stage and ramping rates recorded at FR_CC1 in 2017, 2018 and 2019 are shown in Figure 17, Figure 18, and Figure 19, respectively. Within the period of available data (January 1, 2017 to December 31, 2019), no potential exceedance events were identified at the FR_CC1 hydrometric station.

Figure 17. Stage and ramping rate for FR_CC1 during the 2017 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.

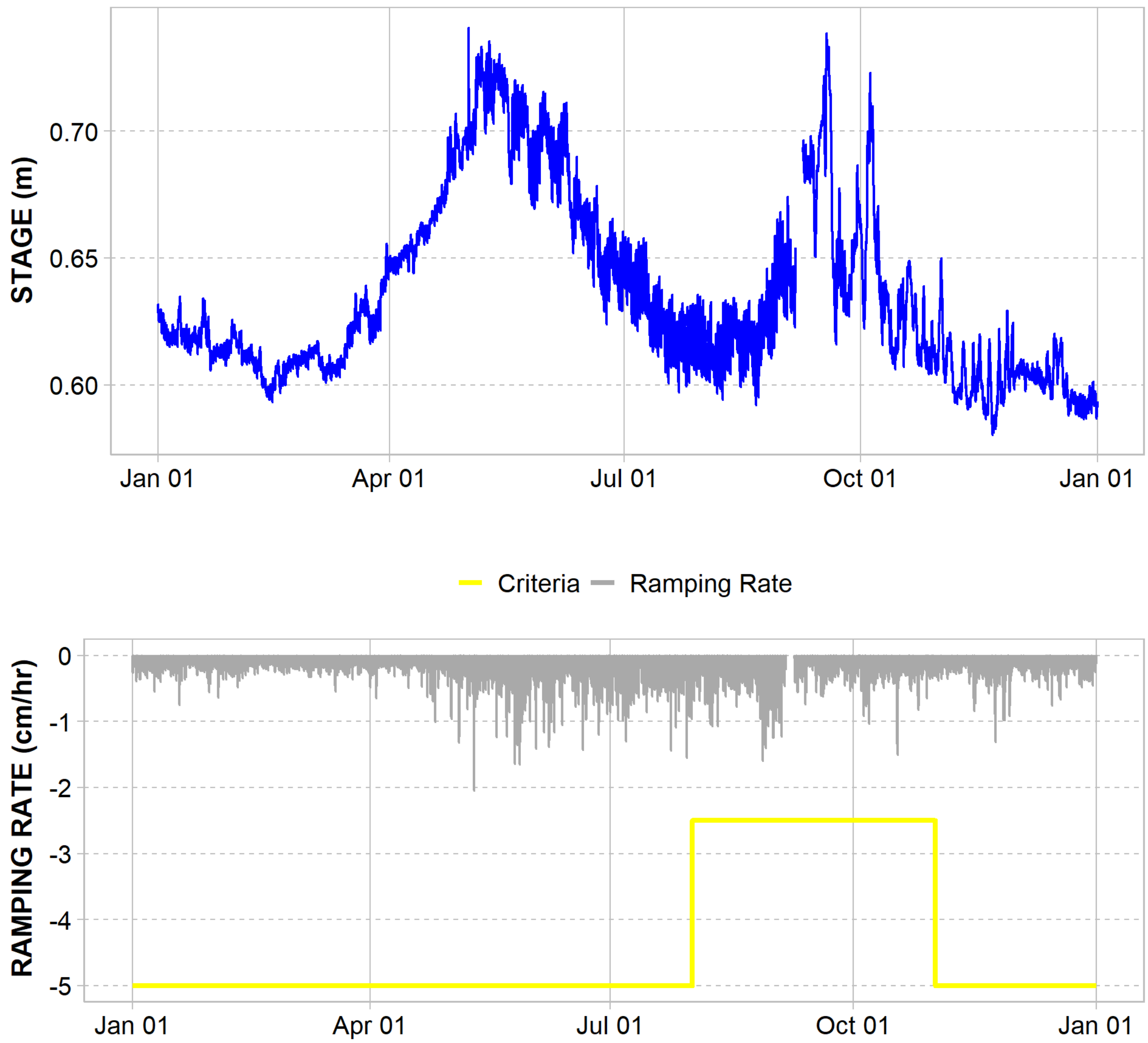


Figure 18. **Stage and ramping rate for FR_CC1 during the 2018 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.**

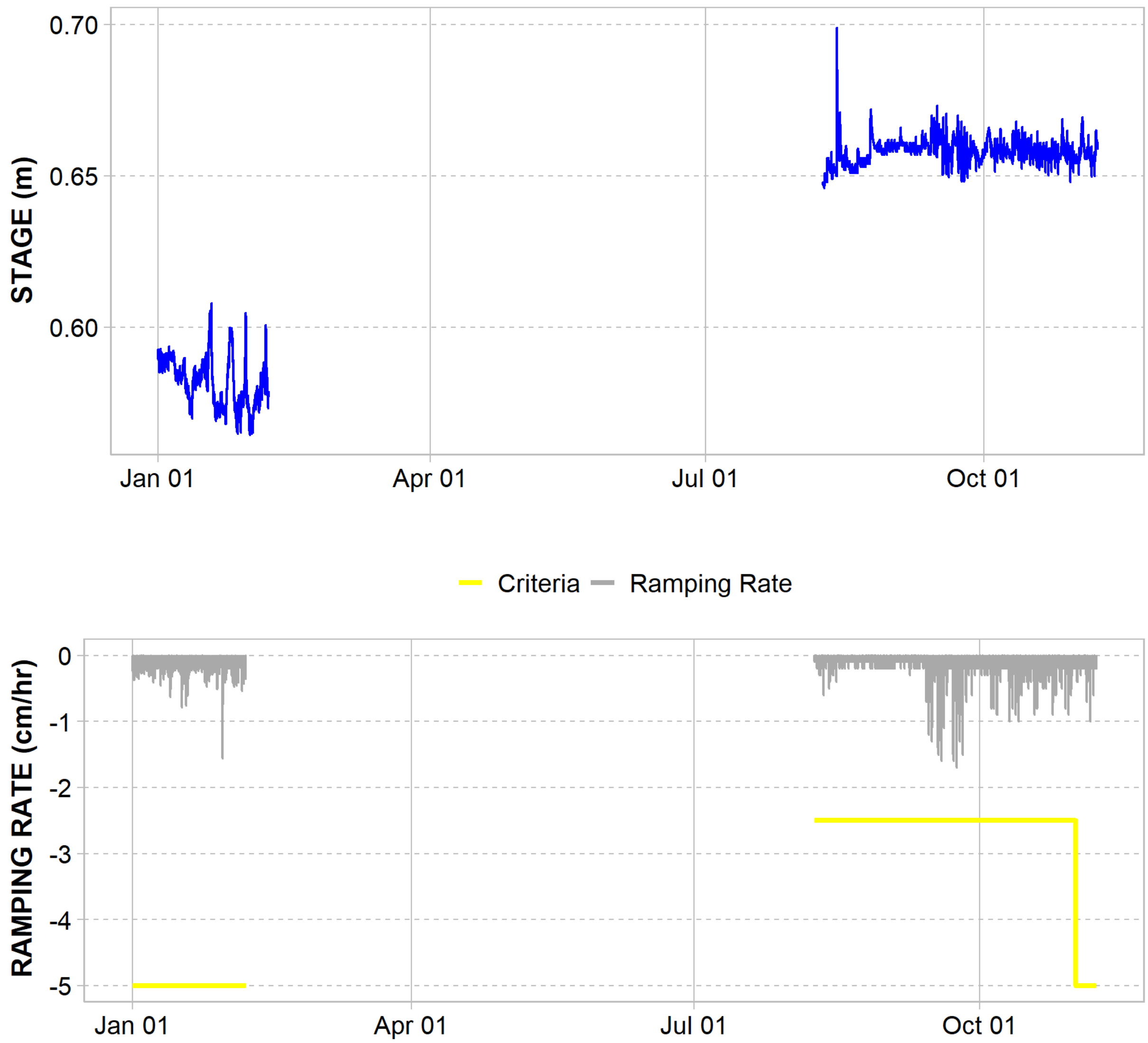


Figure 19. Stage and ramping rate for FR_CC1 during the 2019 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.

3.1.3.2. LCO Dry Creek LC_DC1

Gaps in the data record for LCO Dry Creek (LC_DC1) and Clode Creek (FR_CC1) precluded assessment during those periods. Potential exceedances in the LC_DC1 data could not be attributed confidently to gauge error or other technical causes (Chiarandini 2021, pers. comm.).

LCO Dry Creek stage and ramping rates recorded at LC_DC1 in 2017, 2018 and 2019 are shown in Figure 20, Figure 21, and Figure 22, respectively. Within the period of available data (April 25, 2017 to December 31, 2019), 40 potential exceedance events were identified at the LC_DC1 hydrometric station. Of these 40 potential exceedance events, one occurred in 2017, 39 occurred in 2018, and none occurred in 2019. Approximately half of all events (i.e., 19 occurred in during the sensitive fry-present season), and the remaining 21 potential exceedances occurred in the fry not-present season. Potential exceedances in the LC_DC1 data could not be attributed confidently to gauge error or other technical causes (Chiarandini 2021, pers. comm.). Although fluctuations in the dataset may not reflect real flow changes, as a precautionary approach, we have included these as potential exceedance events in our assessment. Accordingly, these 40 events were classified as having an unknown cause and were evaluated for potential stranding risk to fish (Section 3.2).

Figure 20. Stage and ramping rate for LC_DC1 during the 2017 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.

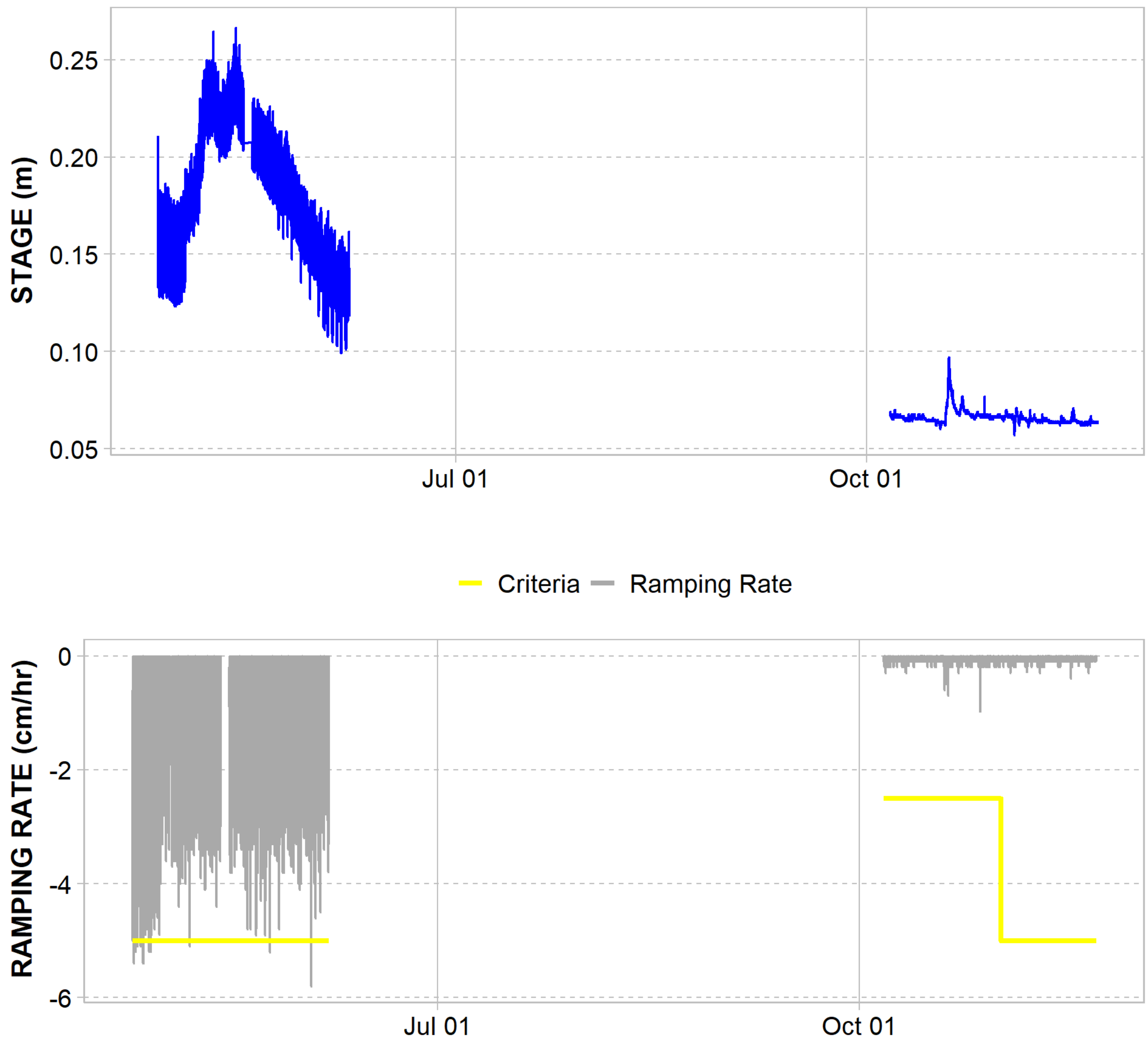


Figure 21. Stage and ramping rate for LC_DC1 during the 2018 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.

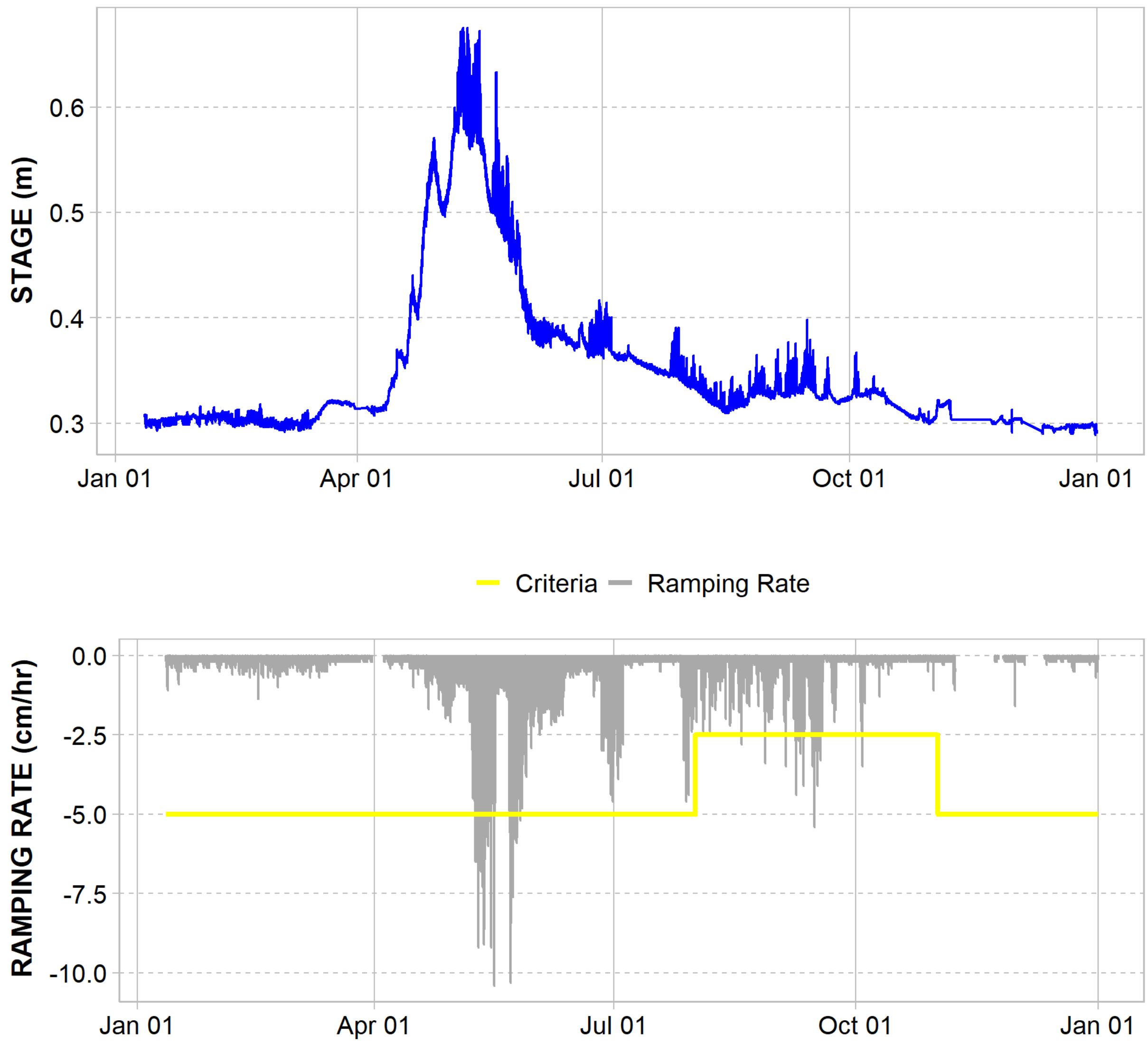
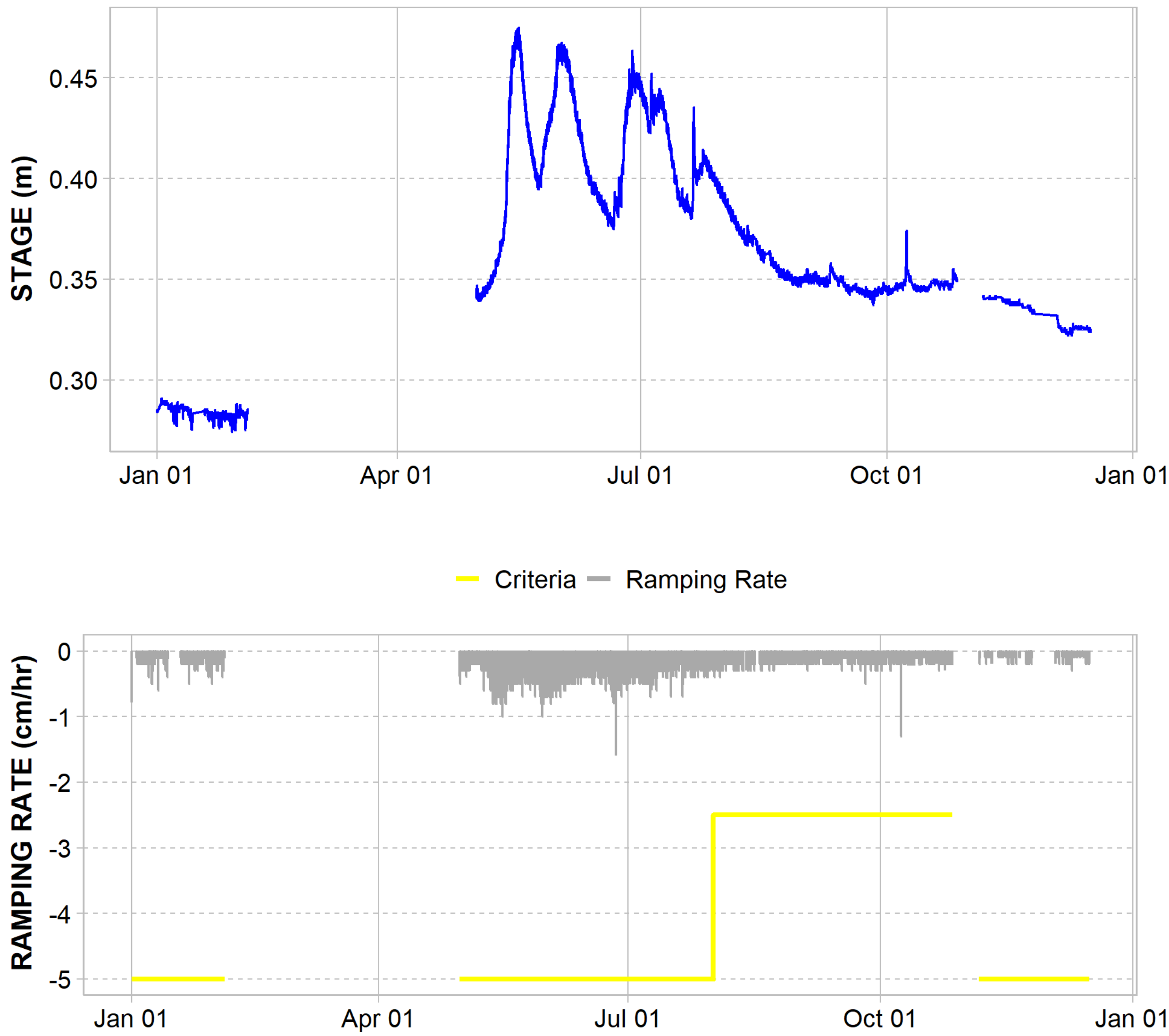


Figure 22. Stage and ramping rate for LC_DC1 during the 2019 period of record. Ramping rate criteria for the fry-present (-2.5 cm/hr) and fry not-present (-5.0 cm/hr) periods are indicated with horizontal yellow lines.



3.2. <u>Fish Stranding Risk Assessment</u>

3.2.1. Primary Data: Hydrometric Stations

The cause of eight potential ramping exceedance events at Measuring Points A and B in 2018 (six and two at Measuring Points A and B, respectively; none in 2017 and 2019) were classified as having an unknown cause and a fish stranding risk assessment was therefore conducted for each (summarized in Table 8). These events were also plotted and visually assessed to evaluate stranding risk (Appendix D).

All eight potential ramping exceedance events classified as having an unknown cause were determined to pose low stranding risk to fish. One of the events occurred during the fry-present period (August through October; ramping rate criteria of -2.5 cm/hr); however, it had a relatively minor ramping rate exceedance (-3.0 cm/hr relative to the -2.5 cm/hr criteria) that was associated with a short wetted history (i.e., fish would have had little time to occupy the habitat before it was dewatered). Of the remaining seven potential exceedance events that occurred during the fry-not present period, two had short wetted history (<4 hours). One potential exceedance event had a maximum wetted history of exactly 4 hours; while this length of time was considered to be moderate wetted history, the majority of the event was <4 hours wetted history, and therefore similarly considered low risk. The remaining potential exceedance events had moderate wetted history and either minor exceedances or occurred during high flows. Exceedances at high flows typically pose less risk for stranding because stranding sensitive habitats are more likely to be fully inundated at higher flows and therefore are less likely to dewater when stage drops. Furthermore, assessing ramping rate exceedances at the hydrometric stations is assumed to provide a conservative assessment of potential fish stranding because the channel shape is steeper at hydrometric stations than it is at sites that are sensitive to stranding (where the channel is wider and has lower gradient; see Appendix A); thus, for a given change in flow, stage changes tend to be greater at hydrometric station locations than at stranding sensitive habitats. Duration of all exceedance events except one were greater than the dewatering threshold of 10 minutes; as described in Section 2.4, this guideline is based on the rationale that fish and fish habitat may not become dewatered immediately because stranding sensitive habitats will not drain instantly, and fish will not immediately die when stranded. However, the exceedance event reported to be 15 minutes in duration is of unknown duration given that only one data point was recorded every 15 minutes.

Table 8. Summary of stranding risk assessment conducted for exceedances for the September 2017 to December 2019 period of record.

Location	Year	Month	Day	Start Time	Duration of Stage Decline (hh:mm)	Duration of Exceedance (hh:mm)	Criteria Used (cm/hr)	Maximum Stage Ramping Rate	Total Stage Change (cm)	Wetted History (hrs)	Discharge (m^3/s)			Stranding Risk
											Start	End	Change	
Measuring Point A	2018	5	7	6:45	1:30	0:45	-5.0	-6.7	-8.2	11.5	4.54	3.39	-1.15	Low
			26	9:45	0:45	0:15	-5.0	-5.1	-5.1	14.5	7.69	6.62	-1.08	Low
		6	9	10:45	0:45	0:30	-5.0	-6.7	-6.7	20.25	3.22	2.47	-0.751	Low
		7	22	7:15	1:00	0:45	-5.0	-9.6	-9.6	4	2.43	1.59	-0.841	Low
			28	7:15	0:15	0:30	-5.0	-5.8	-5.8	1.25	2.28	1.77	-0.514	Low
		8	6	7:15	0:45	0:30	-2.5	-3.0	-3.0	1.25	1.43	1.23	-0.200	Low
Measuring Point B	2018	4	28	5:15	1:00	0:30	-5.0	-5.5	-5.5	3.75	7.28	5.59	-1.69	Low
		5	7	14:30	0:15	0:30	-5.0	-7.5	-7.5	19.75	7.75	5.42	-2.33	Low

3.2.2. Secondary Data: IFS and Ramping Gauges

3.2.2.1. Confirmation of Measuring Point Data

Within the period of available data for the IFS level loggers (June 14, 2019 to October 27, 2019) and SMSSs level loggers (June 18, 2019 to October 10, 2019) selected to confirm the potential exceedance events at the Measuring Points, no potential exceedance events were identified. The results corroborate KWL's evaluation that the majority of the potential exceedance events identified at Measuring Points A and B were attributed to erroneous data. Further, the lack of potential exceedance events at locations selected to be representative of stranding sensitive fish habitat supports that the eight potential exceedance events of unknown cause in the primary data discussed in Section 3.2.1 support the assessment of low risk to fish in the Fording River.

3.2.2.2. Southern Drying Reach Attenuation

Within the period of available data for the IFS level loggers and SMSS level loggers selected to evaluate whether potential exceedance events occurred downstream of Measuring Point B and upstream of the southern drying reach, 15 potential exceedances were identified within the data from the four additional level loggers used for supplementary analysis. Of these 15 potential exceedance events, eight were assessed as posing a low stranding risk; these were typically characterized by relatively small magnitudes and/or short wetted histories for the majority of the potential exceedance event (however maximum wetted history reported in Table 9 may have been greater for a portion of the event). Five exceedances were associated with moderate wetted histories for the majority of the event, and/or represented moderate exceedances of the ramping rate criteria; accordingly, these were evaluated as posing a moderate stranding risk. Two events recorded at FRDSD02 had extensive wetted history and represented more substantial exceedances of the -2.5 cm/hr ramping rate criteria (i.e., more than double); accordingly, these were classified as posing a high stranding risk. Of these two high risk potential exceedance events, the stage change on September 7, 2018 was also recorded at FRD-SD01; although the magnitude of the potential exceedance events at the latter site was smaller and evaluated as posing a moderate stranding risk, detection of a potential exceedance event at two SSMSs support the determination that a real flow change had occurred that was not detected at either Measuring Points B or C. Although the cause of these 15 potential exceedance events remains unknown, the results confirm that flow changes originating downstream of Measuring Point B may be attenuated through the southern drying reach before reaching Measuring Point C.

Table 9. Summary of stranding risk assessment conducted for potential exceedance events for the September 2017 to December 2019 period of record.

Site	Year	Month	Day	Start Time	Duration of Stage Decline (hh:mm)	Criteria Used (cm/hr)	Maximum Stage Ramping Rate (cm/hr)	Start Stage (m)	Total Stage Change (cm)	Maximum Wetted History (hh:mm)	Observed at Measuring Point B	Stranding Risk
FRD-LWTR16	2019	6	18	3:50	0:40	-5.0	-5.9	9.41	-5.9	6:10	No	Low
FRD-SD01	2018	9	7	15:30	1:55	-2.5	-3.7	9.34	-5.3	>24:00	No	Moderate
FRD-SD02	2018	9	7	14:40	2:20	-2.5	-6.5	8.54	-9.9	>24:00	No	High
			17	15:50	1:10	-2.5	-4.0	8.52	-4.2	>24:00	No	Low
			27	11:35	2:20	-2.5	-5.2	8.51	-8.0	>24:00	No	High
			28	8:15	1:25	-2.5	-3.9	8.49	-4.0	17:30	No	Low
				11:10	2:00	-2.5	-3.6	8.45	-4.6	>24:00	No	Low
				13:20	2:00	-2.5	-4.0	8.41	-5.7	>24:00	No	Moderate
		10	12	9:25	1:25	-2.5	-2.7	8.45	-3.7	>24:00	No	Low
			16	12:30	1:10	-2.5	-3.8	8.48	-3.8	>24:00	No	Moderate
				13:55	0:50	-2.5	-3.6	8.45	-3.6	>24:00	No	Moderate
			17	12:05	1:35	-2.5	-3.3	8.46	-4.8	>24:00	No	Low
			24	8:20	1:15	-2.5	-3.1	8.47	-3.5	>24:00	No	Low
				12:05	1:10	-2.5	-2.9	8.45	-3.2	3:25	No	Low
				13:45	1:50	-2.5	-3.2	8.44	-5.3	>24:00	No	Moderate

3.2.3. Tributary Data (Clode Creek and LCO Dry Creek)

3.2.3.1. Clode Creek FR_CC1

Within the period of available data (January 1, 2017 to December 31, 2019), no potential exceedance events were identified at the FR_CC1 hydrometric station; stranding risk in Clode Creek was therefore assessed as low for this period.

3.2.3.2. LCO Dry Creek LC_DC1

Within the period of available data (April 25, 2017 to December 31, 2019), 40 potential exceedance events were identified at the LC_DC1 hydrometric station. Several events appeared to be caused by noise at the gauge or brief spikes in stage (i.e., short wetted history); although the validity of the classifications could not be confirmed by KWL, these events were evaluated as posing a low risk to fish. Other events appeared to represent more discrete stage changes unlikely to be attributable by noise; however, in consideration of relatively small magnitudes of the exceedances and/or short wetted history for a portion of the potential exceedance event, the majority of all potential exceedance events (i.e., 31 of the 40 potential exceedance events) were assessed as posing a low stranding risk. Of the remaining nine potential exceedance events, six were evaluated as posing a moderate risk of stranding. These six events were typically characterized as moderate exceedances of the ramping rate criteria and affected habitats with primarily moderate wetted histories. However, three of the 40 potential exceedance events were approximately double the applicable -5.0 cm/hr ramping rate criteria (i.e., -9.2 cm/hr, -9.1 cm/hr and -10.3 cm/hr, respectively), and were characterized by rapid drops in stage. Despite affecting habitats of primarily moderate wetted history (i.e., <24 hours), these potential exceedance events were of large enough magnitude and occurred rapidly enough to pose a potential stranding risk, and were therefore classified as posing a high stranding risk. There remains uncertainty as to whether any of these potential exceedance events were real, based on KWL's assessment that the LC_DC1 hydrometric station was affected by calcite or algae buildup at the orifice tip of the gauge, and distinguishing potential exceedance events from noise in the dataset would not be possible (Chiarandini 2021, pers. comm.).

Table 10. Summary of stranding risk assessment conducted for potential exceedance events recorded at LC_DC1 for the September 2017 to December 2019 period of record.

Year	Month	Day	Start Time	Duration of Stage Change (hh:mm)	Criteria Used (cm/hr)	Maximum Stage Ramping Rate (cm/hr)	Total Stage Change (cm)	Discharge (m^3/s)			Maximum Wetted history (hh:mm)	Stranding Risk
								Start	End	Change		
2017	6	3	8:00	1:00	-5.0	-5.8	-5.8	1.48	1.42	-0.055	>24:00	Low
2018	5	9	9:45	0:25	-5.0	-6.5	-6.5	3.25	2.24	-1.01	0:40	Low
			12:30	0:55	-5.0	-6.2	-6.2	3.16	2.21	-0.950	1:05	Low
		10	10:10	0:55	-5.0	-9.2	-9.2	3.24	1.88	-1.36	>24:00	High
		11	10:15	1:00	-5.0	-6.8	-6.8	2.77	1.82	-0.950	>24:00	Low
		12	4:10	0:55	-5.0	-7.3	-7.3	3.09	2.01	-1.08	7:35	Moderate
			10:25	1:10	-5.0	-9.1	-9.4	2.98	1.67	-1.32	>24:00	High
			17:20	0:50	-5.0	-7.4	-7.4	2.67	1.67	-1.00	>24:00	Moderate
			20:45	0:20	-5.0	-8.6	-8.6	2.88	1.69	-1.19	1:25	Low
			23:50	0:35	-5.0	-5.5	-5.5	2.57	1.82	-0.750	1:55	Low
		13	10:40	0:05	-5.0	-5.2	-5.2	2.39	1.71	-0.681	8:30	Low
			11:10	0:45	-5.0	-5.7	-5.7	2.45	1.69	-0.752	13:45	Low
		14	4:50	0:15	-5.0	-6.0	-6.0	2.75	1.90	-0.845	3:25	Low
		15	8:50	0:45	-5.0	-9.2	-9.2	3.07	1.75	-1.32	>24:00	Moderate
		16	10:50	0:30	-5.0	-10.4	-10.4	3.18	1.69	-1.49	>24:00	Moderate
		22	10:15	0:25	-5.0	-5.6	-5.6	1.70	1.11	-0.592	2:05	Low
			17:35	1:00	-5.0	-5.6	-5.6	2.54	1.78	-0.759	7:45	Low
			19:05	0:55	-5.0	-10.3	-10.3	2.10	0.972	-1.13	>24:00	High
		23	15:20	0:55	-5.0	-7.6	-7.6	1.67	0.913	-0.761	>24:00	Moderate
		24	10:30	0:50	-5.0	-5.9	-5.9	1.41	0.865	-0.541	>24:00	Low
		25	3:35	1:10	-5.0	-5.7	-5.7	1.42	0.883	-0.537	8:50	Low
	8	18	10:00	1:50	-2.5	-2.8	-2.9	0.139	0.070	-0.069	15:35	Moderate
		27	9:50	1:10	-2.5	-3.4	-3.4	0.205	0.104	-0.101	11:40	Low
	9	4	5:30	0:20	-2.5	-3.5	-3.5	0.223	0.114	-0.109	17:45	Low
			7:40	0:50	-2.5	-2.8	-2.8	0.198	0.115	-0.083	20:25	Low
			9:10	0:55	-2.5	-2.8	-2.8	0.192	0.110	-0.082	23:00	Low
		8	6:40	0:25	-2.5	-4.4	-4.4	0.247	0.107	-0.140	5:35	Low
		9	3:05	1:00	-2.5	-2.7	-2.7	0.187	0.109	-0.078	6:05	Low
			22:00	0:40	-2.5	-3.1	-3.1	0.195	0.105	-0.090	10:10	Low
		10	23:30	0:40	-2.5	-4.1	-4.1	0.245	0.113	-0.132	8:20	Low
		14	10:05	0:15	-2.5	-3.5	-3.5	0.220	0.112	-0.108	14:40	Low
			22:05	0:45	-2.5	-2.6	-2.6	0.226	0.140	-0.086	2:40	Low
		15	2:40	0:50	-2.5	-4.8	-4.8	0.307	0.134	-0.173	9:55	Low
			6:10	0:20	-2.5	-5.4	-5.4	0.343	0.140	-0.203	3:00	Low
			10:15	0:45	-2.5	-3.0	-3.0	0.206	0.115	-0.091	>24:00	Low
		16	8:05	0:45	-2.5	-4.1	-4.1	0.260	0.123	-0.137	3:45	Low
			17:10	0:35	-2.5	-3.0	-3.0	0.198	0.109	-0.089	6:00	Low
		17	8:55	0:35	-2.5	-3.3	-3.3	0.221	0.121	-0.100	4:30	Low
			10:10	0:45	-2.5	-3.3	-2.1	0.160	0.103	-0.057	>24:00	Low
	10	3	9:10	1:15	-2.5	-3.1	-4.1	0.214	0.094	-0.120	>24:00	Low

4. DISCUSSION

4.1. Evaluation of Requisite Conditions

Spatial Extent, Duration, Location, Timing, and Intensity of the potential ramping exceedance events classified as having an unknown cause were evaluated to determine if the requisite conditions are met (Table 2). The potential exceedance events occurred during the Decline Window in both the fry present and fry-not present periods, and were of sufficient duration (i.e., >10 minutes) to have caused fish mortality; thus, the Timing and Duration requisite conditions were satisfied. However, the majority of potential exceedance events were localized: in the primary data analysis, of the eight potential exceedance events detected at Measuring Point A or B, only one potential exceedance was detected at both Measuring Points A and B. For the remaining six potential exceedances, each occurred at either Measuring Point A or B, but not both. The location of potential exceedance events was also limited to the most upstream portion of the UFR as no events were observed at Measuring Point C. Further, none of these eight potential exceedance events in the primary data were detected at loggers installed at locations where habitat is sensitive to stranding (i.e., in the secondary data). Accordingly, the Spatial Extent requite condition was not satisfied.

Additional analyses were conducted to evaluate whether potential ramping events could have occurred downstream of Measuring Point B, but be indetectable at Measuring Point C (e.g., due to potential attenuation through the drying reach). Potential exceedance events were identified within additional IFS and ramping loggers located in stranding sensitive habitats where fish are expected to be present between Measuring Point B and Cataract Creek (i.e., near the upstream extent of the southern drying reach); accordingly, the Location requisite condition was met by this secondary analysis. Although the cause of these potential exceedance events remains unknown, three events were evaluated to pose a high stranding risk, and six events were evaluated to pose a moderate stranding risk. In the absence of stream-specific data on fish standing, mortality of fish could not be confirmed. Several potential exceedance events occurred under sensitive conditions, so we concluded that stranding of fry and juvenile fish was possible. However, based on our experience monitoring stranding on other similar streams in BC, the magnitude of these potential exceedance events was unlikely to pose a stranding risk to adult fish. Furthermore, potential exceedances posing a moderate or high stranding risk occurred infrequently. Overall, we conclude that the Intensity requisite condition was not satisfied. Furthermore, only one potential exceedance event was detected at more than one location, and none of the events were detected at Measuring Points B or C; accordingly, the Spatial Extent requisite condition was not met.

Similar results were obtained from analysis of tributary data from Clode Creek (FR_CC1) and LCO Dry Creek (LC_DC1). A small number of potential exceedance events were noted that posed a high stranding risk (n=3) or moderate stranding risk (n=6) in the LCO Dry Creek dataset spanning three years (2017-2019). These events of moderate or high risk occurred infrequently, and although these occurred under appropriately sensitive conditions, and the magnitude of exceedance was large enough to pose a potential stranding risk to juvenile fish, there is uncertainty whether substantial stranding mortality was likely. Furthermore, the magnitude of potential exceedance events was unlikely to pose a stranding risk to adult fish. Overall, we conclude that the Intensity requisite condition was not met. Furthermore, considering the small amount of habitat for WCT in LCO Dry Creek and Clode Creek in comparison to the rest of the UFR watershed the Spatial Extent requisite condition was not satisfied.

Overall, we have evaluated that the potential exceedance events detected in these analyses satisfy the Duration, Location, and Timing requisite conditions. Although the exceedances of the ramping criteria were large enough to pose a potential stranding mortality risk to fish, such exceedances occurred infrequently and were localized (i.e., the potential exceedance events did not occur throughout the UFR, and therefore are assumed to not be applicable to a large portion of the WCT population). Based on these observations, the Intensity and Spatial Extent requisite conditions were not met. Given these results, ramping is unlikely to have caused the decline, although ramping could have contributed (some potential exceedance events were identified) the small number of potential exceedance events and their limited spatial extent indicate that it is unlikely that it was a substantive contributing factor to the documented WCT population decline.

4.2. Uncertainty

There is uncertainty in our assessment because the potential exceedance events were classified as gauge error or gauge maintenance could not be fully validated. However, comparison to supplemental data recorded by water level loggers in representative stranding sensitive habitat in 2018 and 2019 supported interpretation of the identified events in the primary data as gauging issues rather than real ramping events. Furthermore, ramping events are expected to be detected in downstream sites, albeit at an attenuated rate. The absence of events identified at Measuring Point C provides further support for concluding an absence of large-magnitude ramping events at upstream sites.

Gaps in the data record for LCO Dry Creek (LC_DC1) and Clode Creek (FR_CC1) precluded assessment during those periods. Potential exceedances in the LC_DC1 data could not be attributed confidently to gauge error or other technical causes (Chiarandini 2021, pers. comm.).

There is uncertainty associated with the application of the ramping rate criteria to the UFR without having site-specific verification of ramping responses. Site-specific data to assess the response of WCT to ramping and the effectiveness of the ramping rate criteria in the UFR would increase confidence in this assessment. However, in our experience, the ramping rate criteria provide protection in other streams in BC.

Uncertainty was also identified with the categorization of fish stranding risk based on quantitative and qualitative considerations. The fish stranding risk assessment was based on the authors' experience of monitoring ramping effects on streams; thus, there is some uncertainty associated with professional judgment. However, the professional judgement applied in this assessment is based on extensive experience with ramping and fish stranding throughout BC (see Section 1.1.3). Further, quantitative characterization of potential exceedance events (Table 8, Table 9, and Table 10) also informed the classification of stranding risk for fish.

5. CONCLUSION

This assessment evaluated the potential for ramping to have caused or contributed to the documented WCT decline. Potential ramping rate exceedance events were identified, characterized, and assessed for potential to cause fish stranding. Stage changes were documented at three hydrometric stations in the Fording River (Measuring Point A, B and C), one hydrometric station in Clode Creek (FR_CC1), and one hydrometric station in LCO Dry Creek (LC_DC1) in 2017 through 2019. Further evaluations were completed with data from 11 temporary water level loggers located at SSMSs and IFS transects in 2018 or 2019.

Many exceedances were identified in the data from Measuring Points A (total of 110) and B (total of 33) in 2018; however, the great majority were attributed to gauge error or gauge maintenance procedures. Eight potential exceedance events were classified as having an unknown cause and could therefore have reflected real stage changes. Although none of these events were detected at loggers in stranding sensitive habitats, 15 unrelated potential exceedance events of unknown cause were detected in the secondary data from three of the 11 temporary water level loggers located at SSMSs and IFS transects. Potential exceedance events (total of 40) were also detected at LC_DC1; although many of these may be similarly related to gauge error, all were classified as having an unknown cause in the absence of detailed evaluation by KWL.

The potential exceedance events occurred during the Decline Window in both the fry present and fry-not present periods, in locations where habitat is sensitive to stranding and fish may be present, and were of sufficient duration to have caused fish mortality; thus, the Timing, Location, and Duration requisite conditions were satisfied. However, the potential exceedance events were relatively local in occurrence, occurred infrequently, and were of a magnitude most likely to affect fry and juvenile fish. Thus, the Spatial Extent and Intensity requisite conditions were not satisfied. Given these results, the requisite condition to cause was not met and, although the requisite condition to contribute was met (some potential exceedance events were identified), it is unlikely that ramping was a substantive contributing factor to the documented WCT population decline. Based on frequency of ramping exceedance events, their limited spatial extent, and their intensity, the ramping events identified may result in localized mortality of juvenile fish; however, it is unlikely that ramping would act in combination with other stressors, except as a contribution to cumulative mortality.

REFERENCES

Cathcart, J. 2005. Study of flow ramping rates for hydropower developments. Consultant's report prepared by Knight Piésold Ltd. (Ref. No. Va103-79/2-1) for the Department of Fisheries and Oceans Canada.

Cope, S., C.J. Schwarz, A. Prince and J. Bisset. 2016. Upper Fording River Westslope Cutthroat Trout Population Assessment and Telemetry Project: Final Report. Report Prepared for Teck Coal Limited, Sparwood, BC. Report Prepared by Westslope Fisheries Ltd., Cranbrook, BC. 259 p.

Cope, S. 2020. Upper Fording River Westslope Cutthroat Trout Population Monitoring Project: 2019. Report Prepared for Teck Coal Limited, Sparwood, BC. Report Prepared by Westslope Fisheries Ltd., Cranbrook, BC. 40 p + 1 app.

Evaluation of Cause Team, (2021). Evaluation of Cause — Decline in upper Fording River Westslope Cutthroat Trout population. Report prepared for Teck Coal Limited by Evaluation of Cause Team.

Faulkner, S., J. Ammerlaan., H. Regehr, J. Carter, and T. Hatfield. 2021. Subject Matter Expert Report: Channel dewatering. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population. Report prepared for Teck Coal Limited by Ecofish Research Ltd.

Hocking M., J. Ammerlaan, K. Healey, K. Akaoka, and T. Hatfield. 2021. Subject Matter Expert Report: Mainstem dewatering. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population. Report prepared for Teck Coal Ltd. by Ecofish Research Ltd. and Lotic Environmental Ltd.

Irvine, R.L., T. Oussoren, J.S. Baxter, and D.C. Schmidt. 2009. The Effects of flow reduction rates on fish stranding in British Columbia, Canada. River. Res. Applic. doi: 10.1002/rra.1172.

Irvine, R.L., L. Thorley, R. Wescott, D. Schmidt, and D. DeRosa. 2014. Why do fish strand? An analysis of ten years of flow reduction monitoring data from the Columbia and Kootenay Rivers, Canada. River Res. Appl., n/a-n/a. doi:10.1002/rra.2823.

Johnson, S., J. Krogh, E. Vogt, M. Sparling, A. Marriner, K. Akaoka, R. Day, D. Greenacre, N. Wright, S. Faulkner and T. Hatfield. 2019. Fording River Operational Environmental Monitoring Plan 2018. Draft V2. Consultant's report prepared for Teck Coal Limited Fording River Operations by Ecofish Research Ltd. July 31, 2019.

Korman, J. 2021. Effects of capture and handling on Westslope Cutthroat Trout in the upper Fording River: A brief review of Cope (2020) and additional calculations. Report prepared for Teck Coal Limited. Prepared by Ecometric Research.

Lewis, A., C. Zyla and P. Gibeau. 2011. Flow Ramping Guidelines for Hydroelectric Projects: Developing, Testing and Compliance Monitoring, Draft V1. Consultant's report prepared by Ecofish Research Ltd. for Clean Energy BC, Department of Fisheries and Oceans Canada, and the BC Ministry of Environment.

Lewis, F. J. A., A. J. Harwood, C. Zyla, K. D. Ganshorn, and T. Hatfield. 2013. Long term Aquatic Monitoring Protocols for New and Upgraded Hydroelectric Projects. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/166. ix + 88p.

Smithson, J., Robinson, M.D. and K. Baranowska. 2019. Teck Coal Ltd – Elk Valley 2018 Calcite Monitoring Program Annual Report and Program Assessment. Prepared for Teck Coal Ltd. by Lotic Environmental Ltd. 27 pp + appendices.

Nagrodski, A., G.D. Raby, C.T. Hasler, M.K. Taylor, and S.J. Cooke. 2012. Fish stranding in freshwater systems: sources, consequences, and mitigation. J. Envir. Man. 103, 133-141.

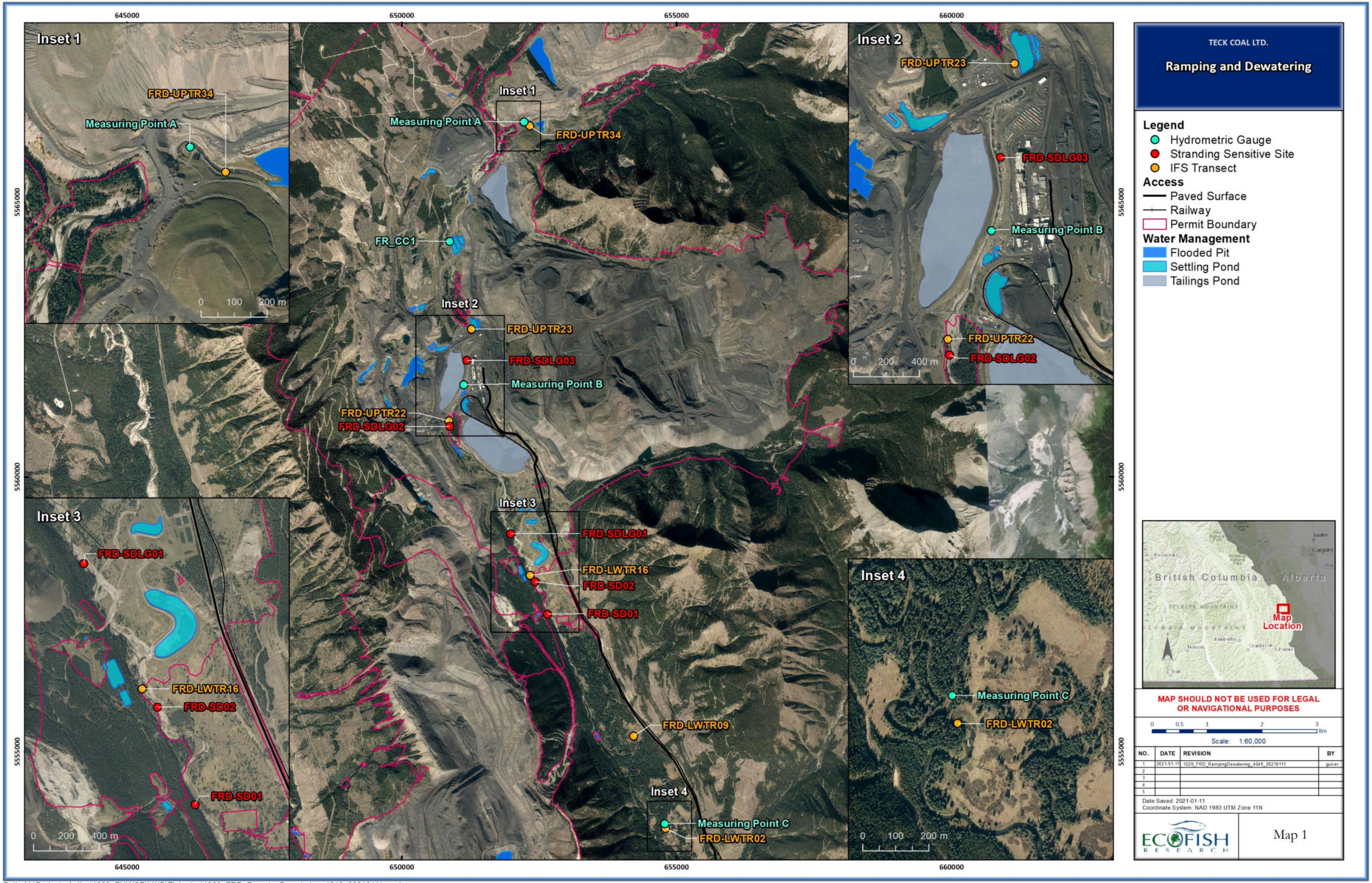
Wright, N., S. Faulkner, C. Suzanne, J. Carter, M. Sparling, D. Greenacre, J. Ammerlaan, and T. Hatfield. 2020. Fording River Operational Environmental Monitoring Plan 2019. Consultant's report prepared for Teck Coal Limited Fording River Operations by Ecofish Research Ltd. April 30, 2020.

Personal Communications

Chiarandini, M. 2021. Hydrometric Group Lead, Kerr Wood Leidal (KWL). Email with Jason Ammerlaan of Ecofish Research Ltd. on January 14, 2021.

Miller, J. 2019. Water Resources Engineer, Kerr Wood Leidal (KWL). Email with Lee Wilm of Teck Coal Limited on July 17, 2019., Teck Coal Limited. Email with Michael Moore of Teck Coal Limited on January 12, 2021.

PROJECT MAPS



Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_FRD_RampingDewatering_4049_20210111.mxd

APPENDICES

Appendix A. Upper Fording River Bed Profiles and Photographs

TABLE OF CONTENTS

LIST OF FIGURES

1. MEASURING POINT A

Figure 1. Representative depth profile at FR_HC1 (provided by KWL).

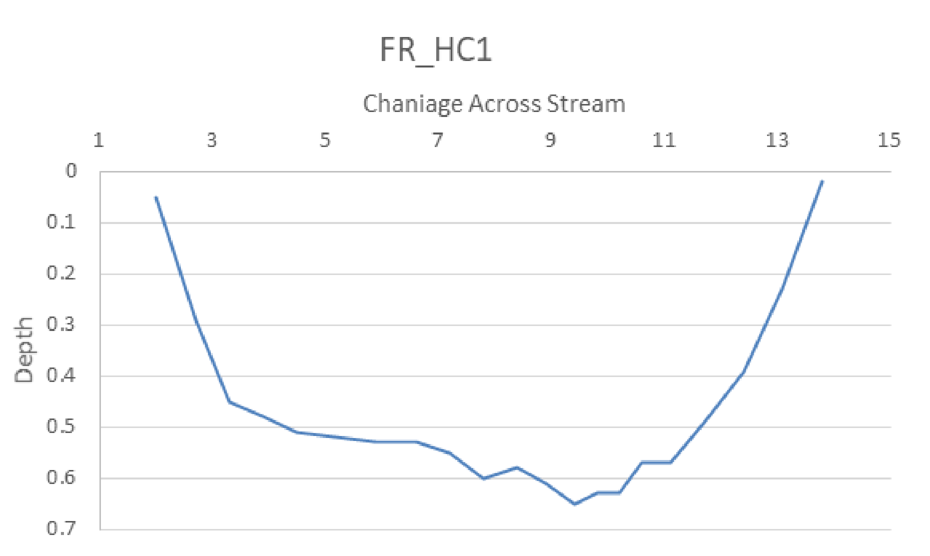
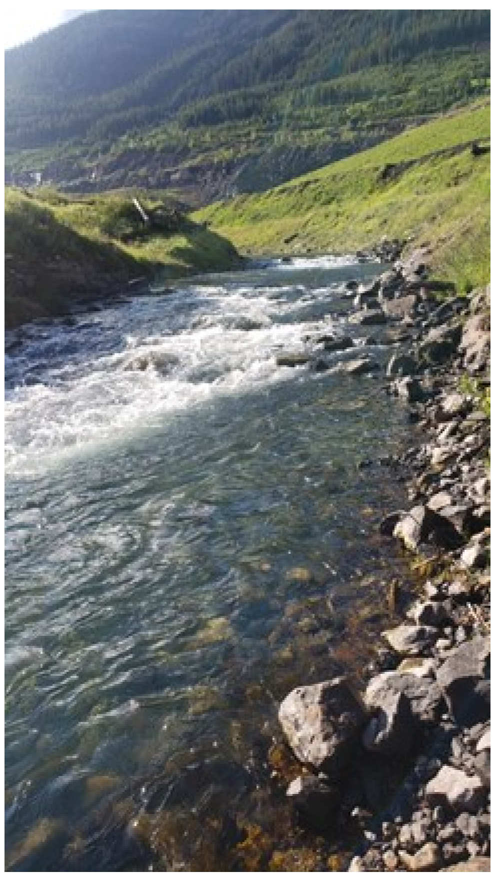


Figure 2. Looking upstream at FR_HC1 on July 13, 2020.



2. MEASURING POINT B

Figure 3. Representative depth profile at FR_FRNTP (provided by KWL).

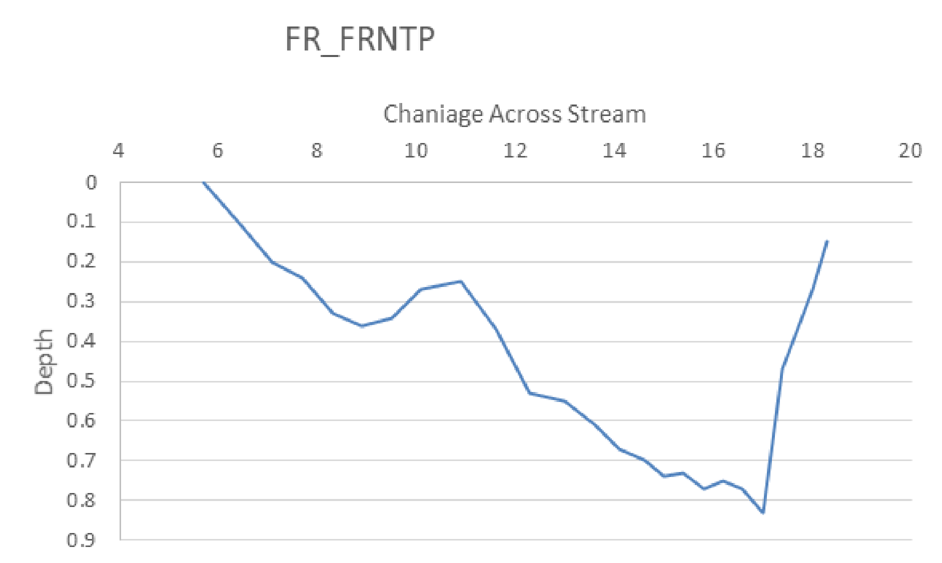


Figure 4. Looking downstream at FR_FRNTP n August 5, 2020.

3. MEASURING POINT C

Figure 5. Representative depth profile at FR_FRABCHF (provided by KWL).

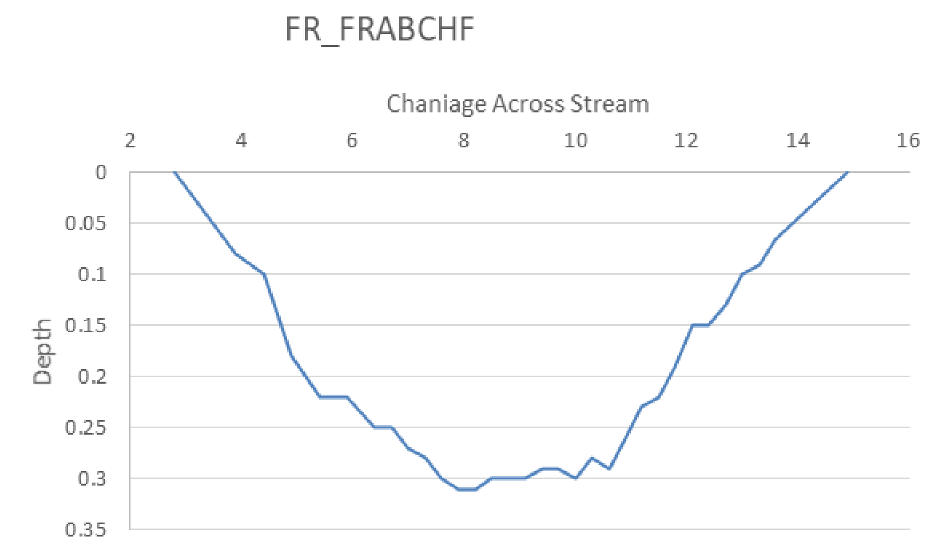


Figure 6. Looking upstream at FR_FRABCHF on August 5, 2020.

4. FRD-SD01

Figure 7. FRD-SD01 bed profile. Stranding habitat present from ~9.24 m to 9.64 m relative water surface elevation.

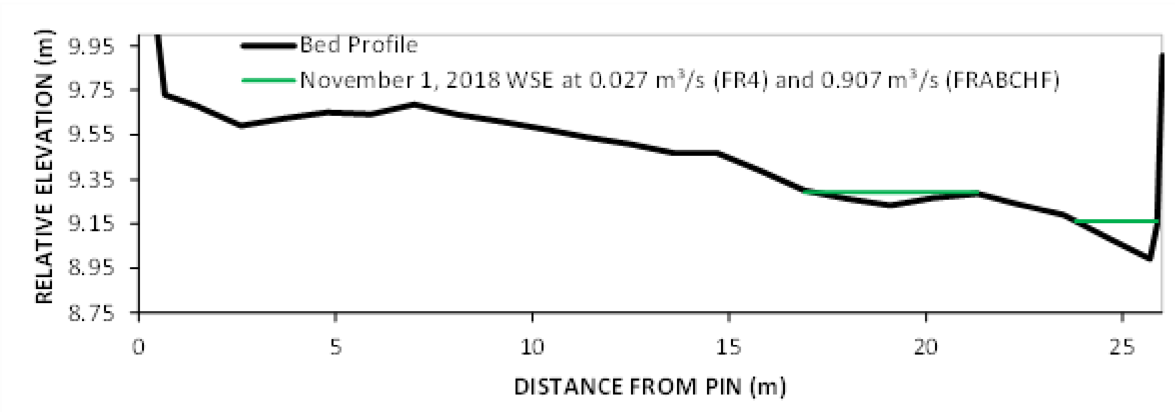


Figure 8. Looking upstream at FRD-SD01 logger on August 30, 2018.

5. FRD-SD02

Figure 9. FRD-SD02 bed profile. Stranding habitat present above 8.51 m relative water surface elevation.

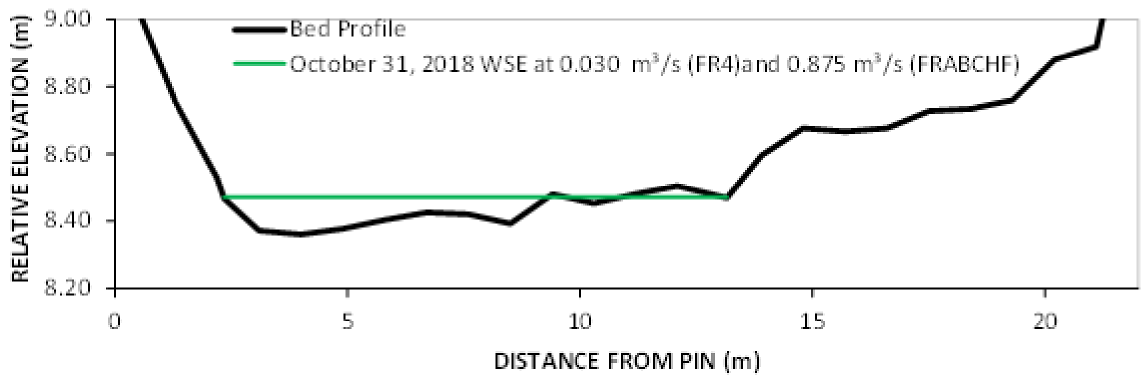


Figure 10. Looking upstream at FRD-SD02 logger on August 18, 2018.

6. FRD-LWTR02

Figure 11. FRD-LWTR02 bed profile.

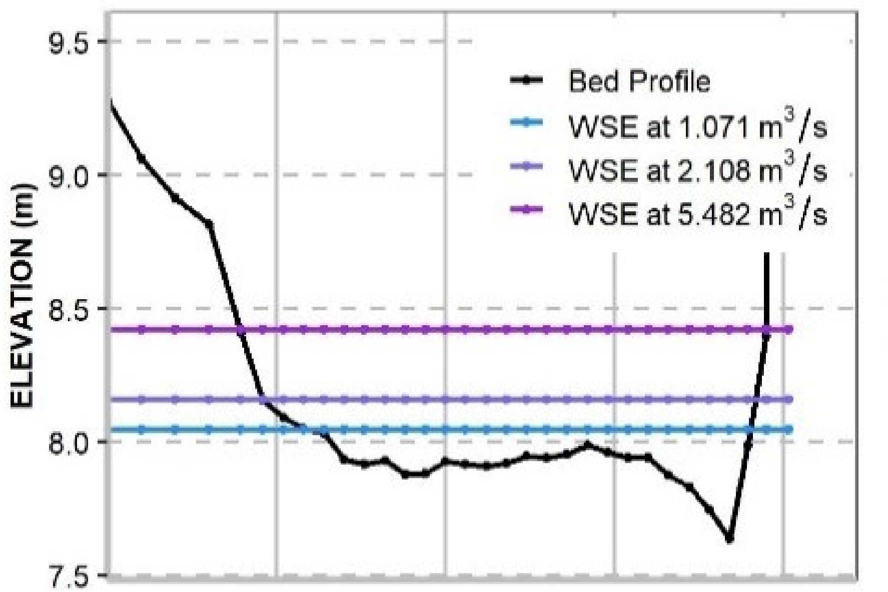


Figure 12. Looking upstream at transect FRD-LWTR02.

a) June 17, 2019

b) September 3, 2019

c) November 7, 2019

7. FRD-LWTR09

Figure 13. FRD-LWTR09 bed profile.

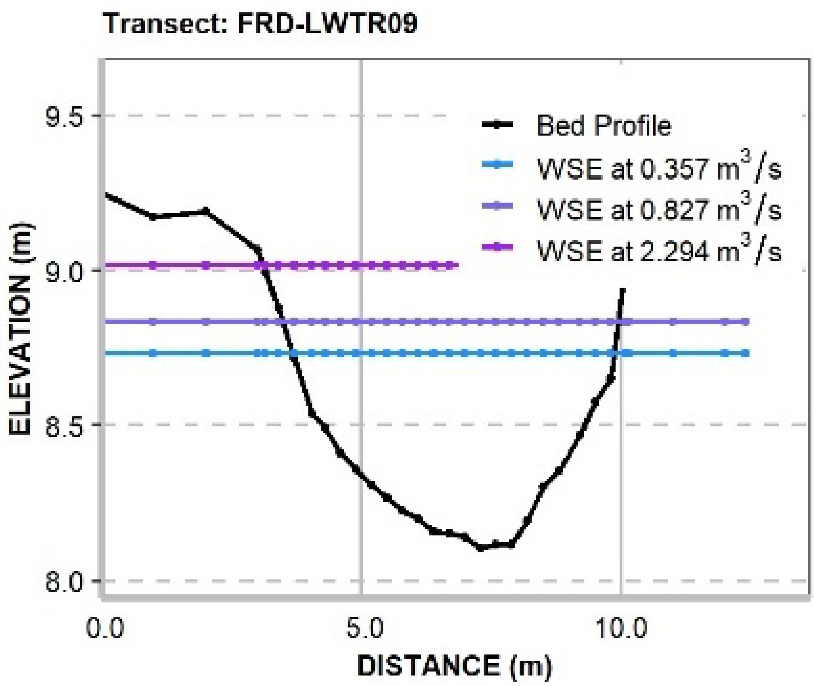


Figure 14. Looking upstream at transect FRD-LWTR09.

a) June 14, 2019

b) September 3, 2019

c) November 7, 2019

8. FRD-LWTR16

Figure 15. FRD-LWTR16 bed profile.

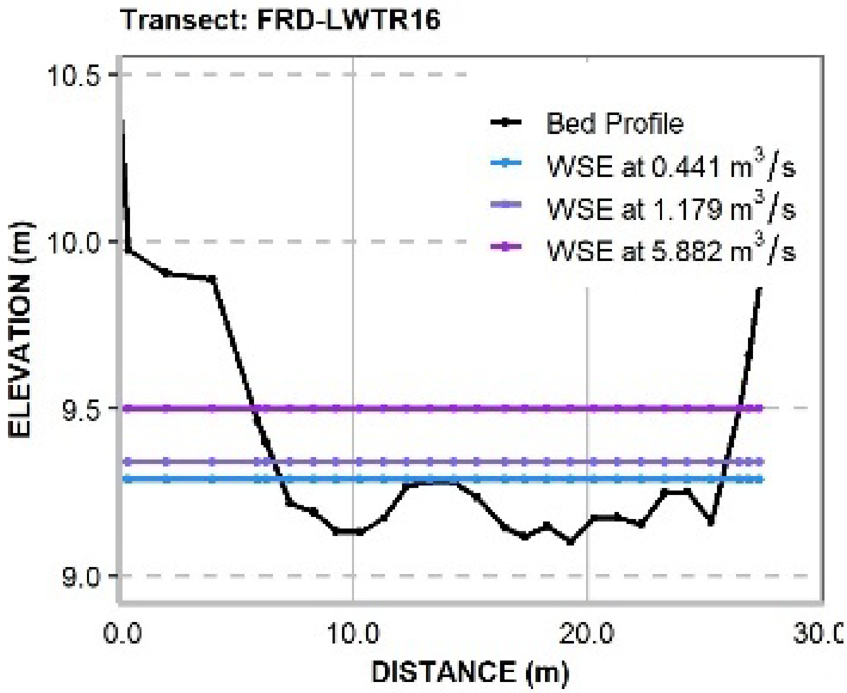


Figure 16. Looking upstream at transect FRD-LWTR16.

a) June 14, 2019

b) September 2, 2019

c) November 7, 2019

Appendix B. Potential Ramping Event Evaluation Plots (2018)

LIST OF FIGURES

Figure 1. **Flow and ramping rate for May 16, 2018 for Measuring Point A, classification "Turbulence".**

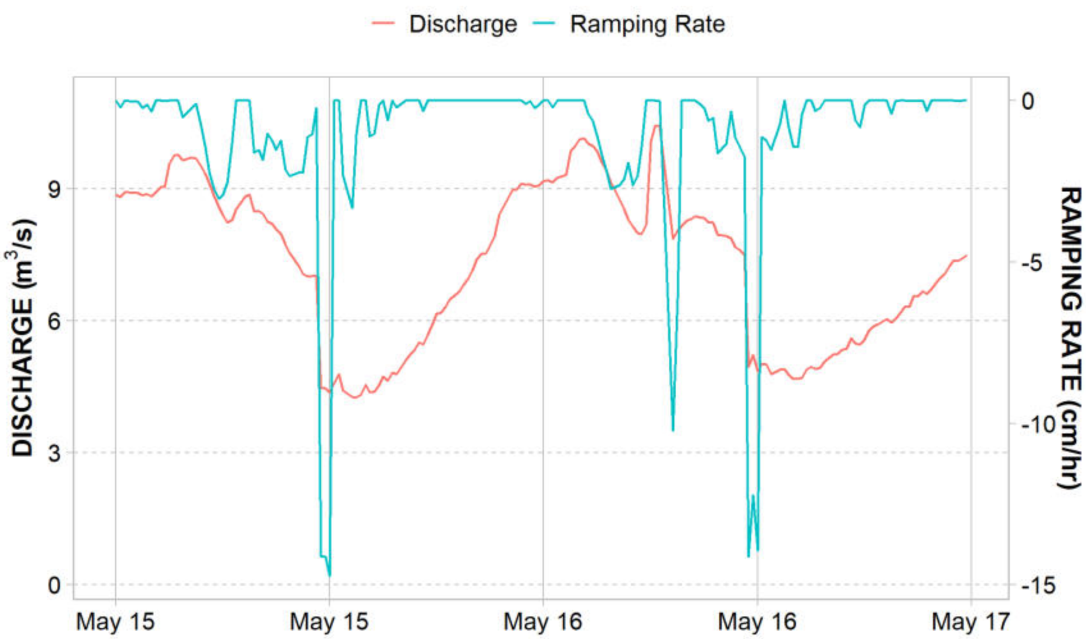


Figure 2. **Flow and ramping rate for May 9, 2018 for Measuring Point B, classification "Turbulence" and "Bubbler Purge".**

Figure 3. **Flow and ramping rate for May 13, 2018 for Measuring Point B, classification "Turbulence".**

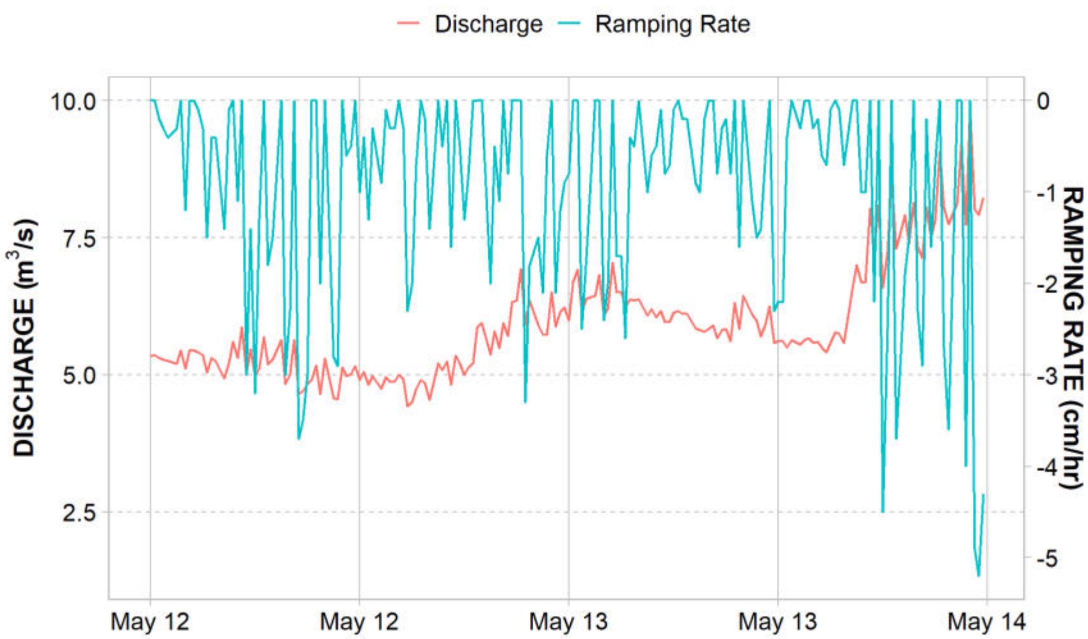


Figure 4. **Flow and ramping rate for May 15, 2018 for Measuring Point B, classification "Turbulence".**

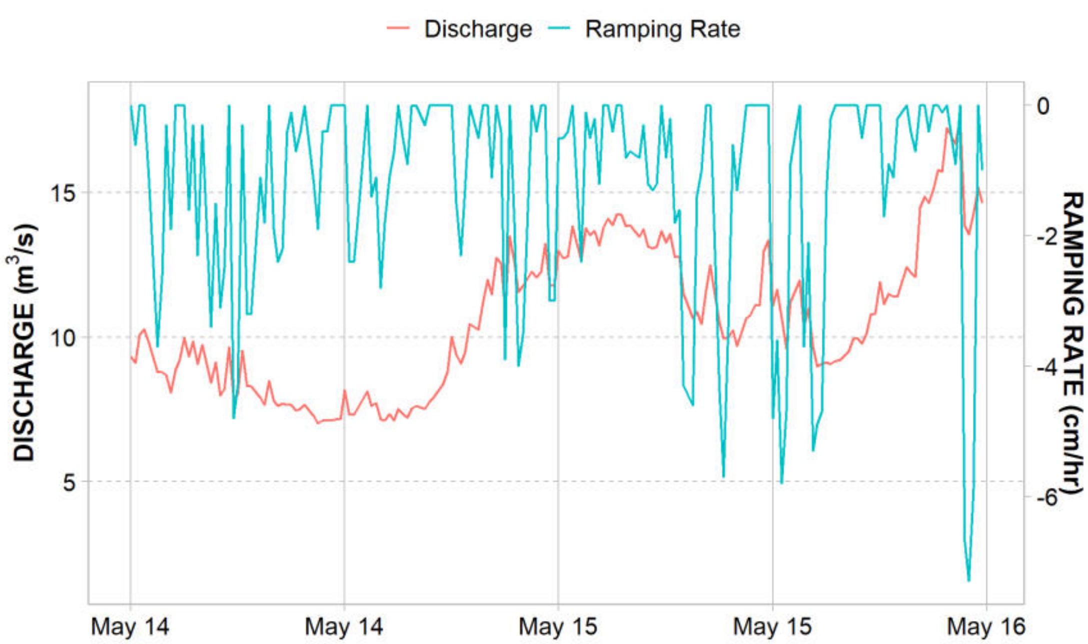


Figure 5. **Flow and ramping rate for May 16, 2018 for Measuring Point B, classification "Turbulence".**

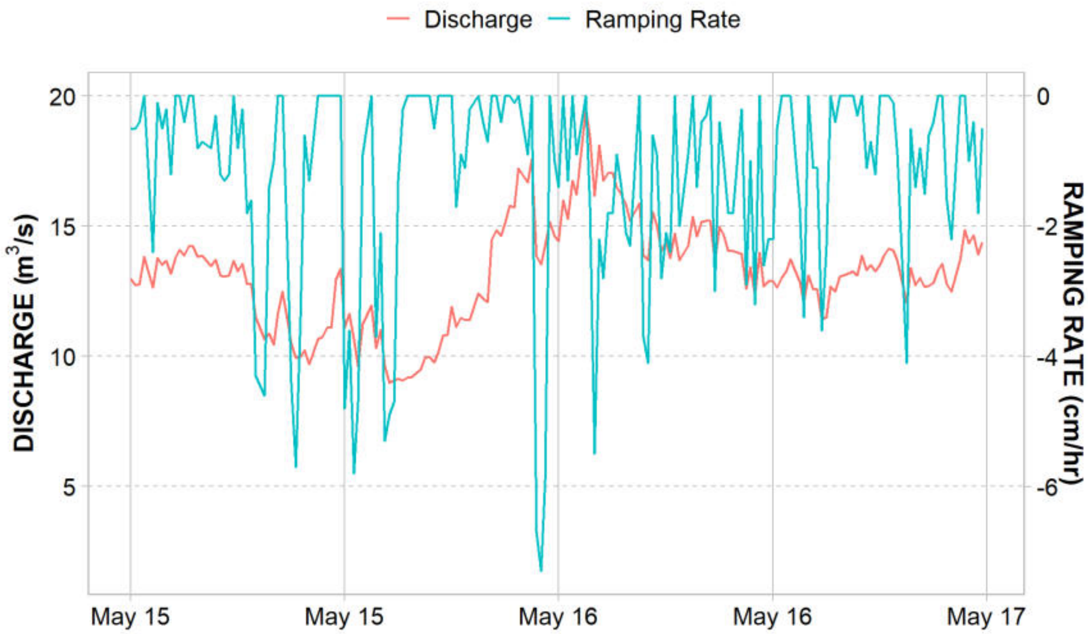


Figure 6. **Flow and ramping rate for May 19, 2018 for Measuring Point B, classification "Turbulence".**

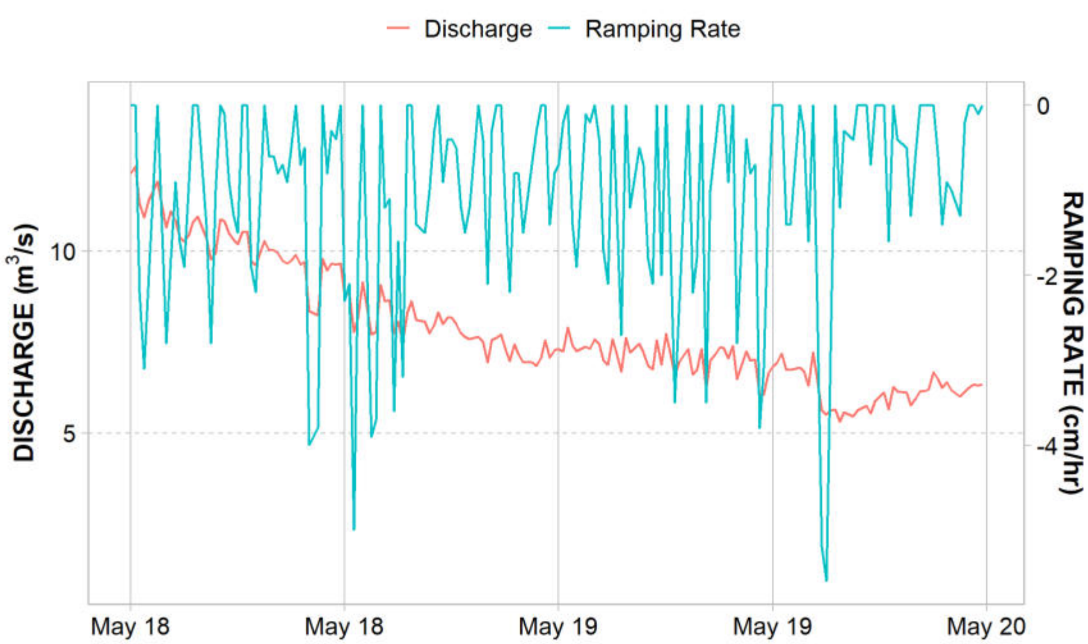


Figure 7. Flow and ramping rate for May 20, 2018 for Measuring Point B, classification "Turbulence".

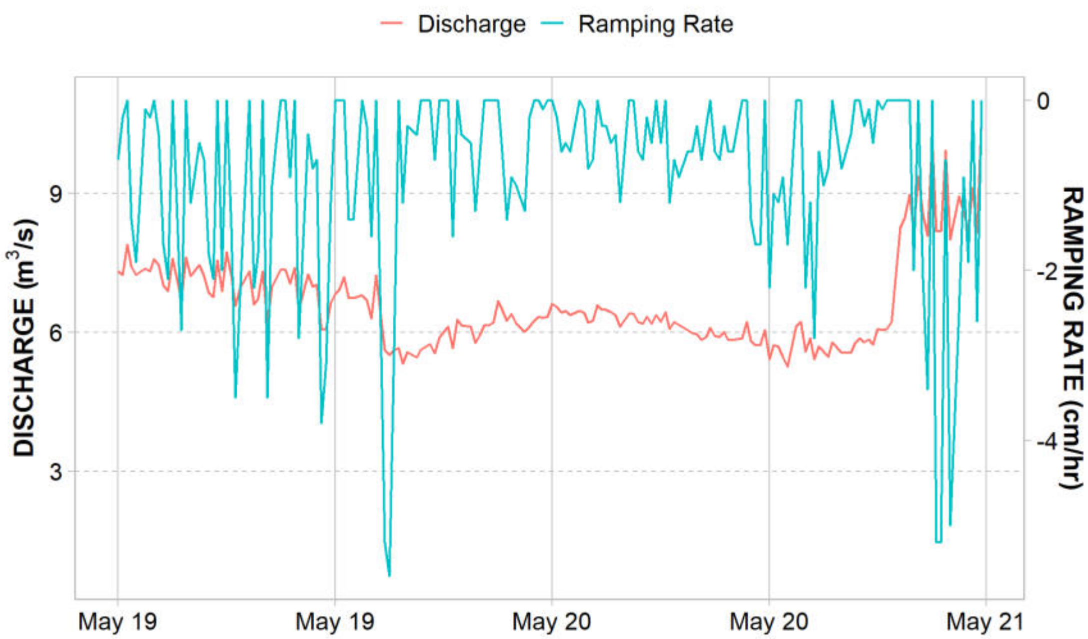


Figure 8. Flow and ramping rate for May 21, 2018 for Measuring Point B, classification "Turbulence".

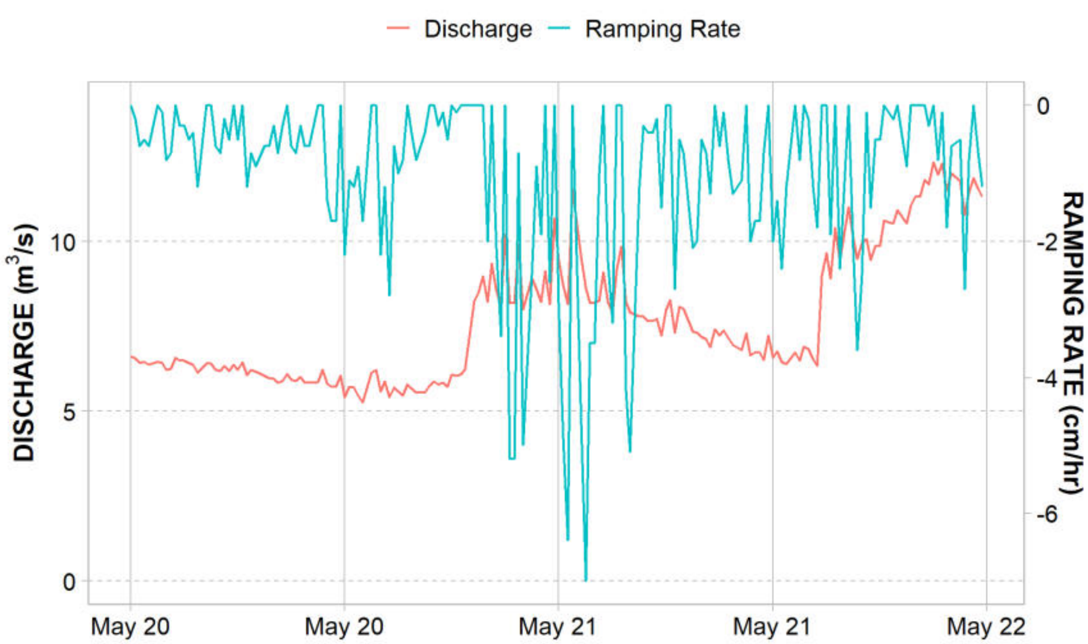


Figure 9. Flow and ramping rate for May 24, 2018 for Measuring Point B, classification "Turbulence".

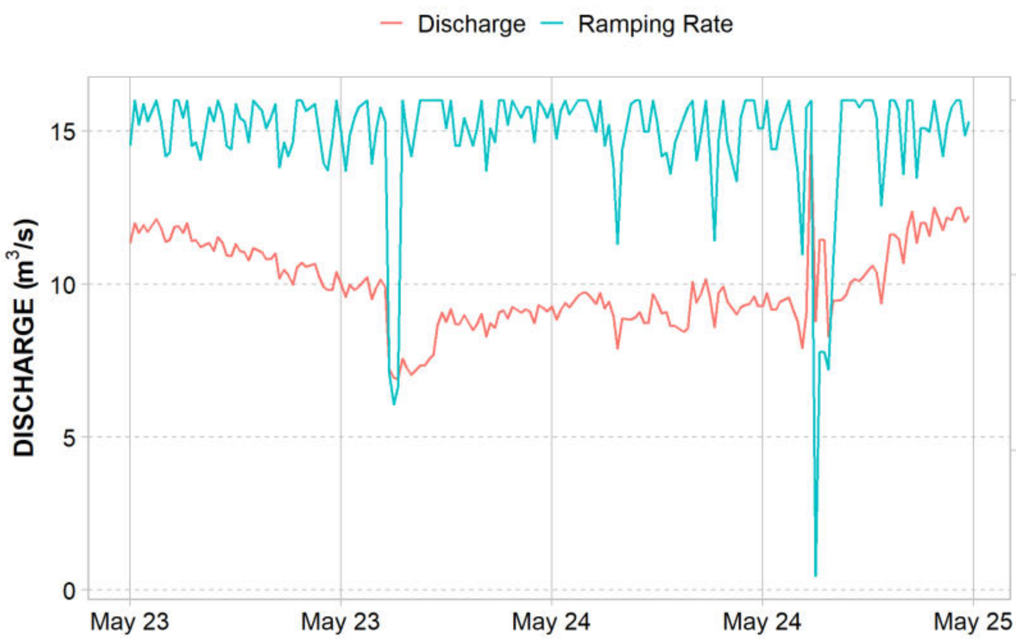


Figure 10. Flow and ramping rate for May 25, 2018 for Measuring Point B, classification "Turbulence" and "Bubbler Purge".

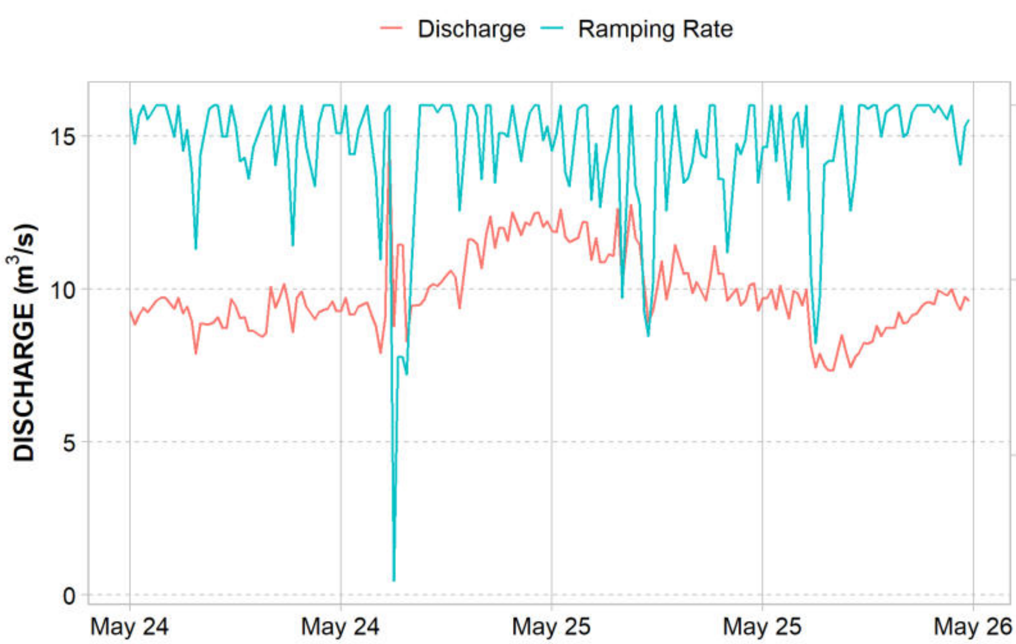


Figure 11. Flow and ramping rate for May 26, 2018 for Measuring Point B, classification "Turbulence".

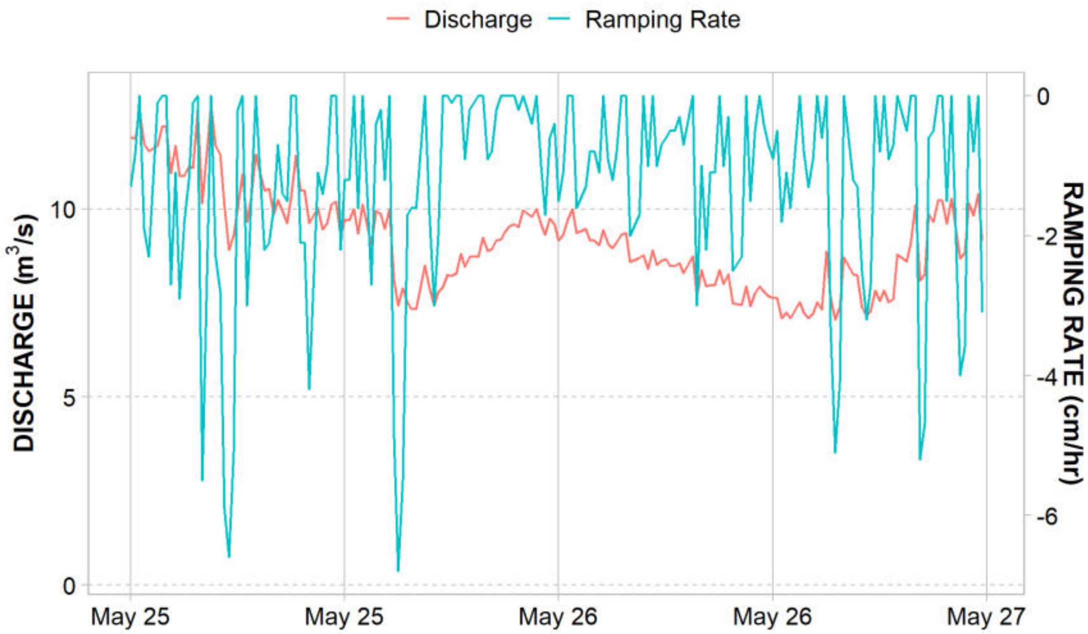


Figure 12. Flow and ramping rate for May 27, 2018 for Measuring Point B, classification "Turbulence".

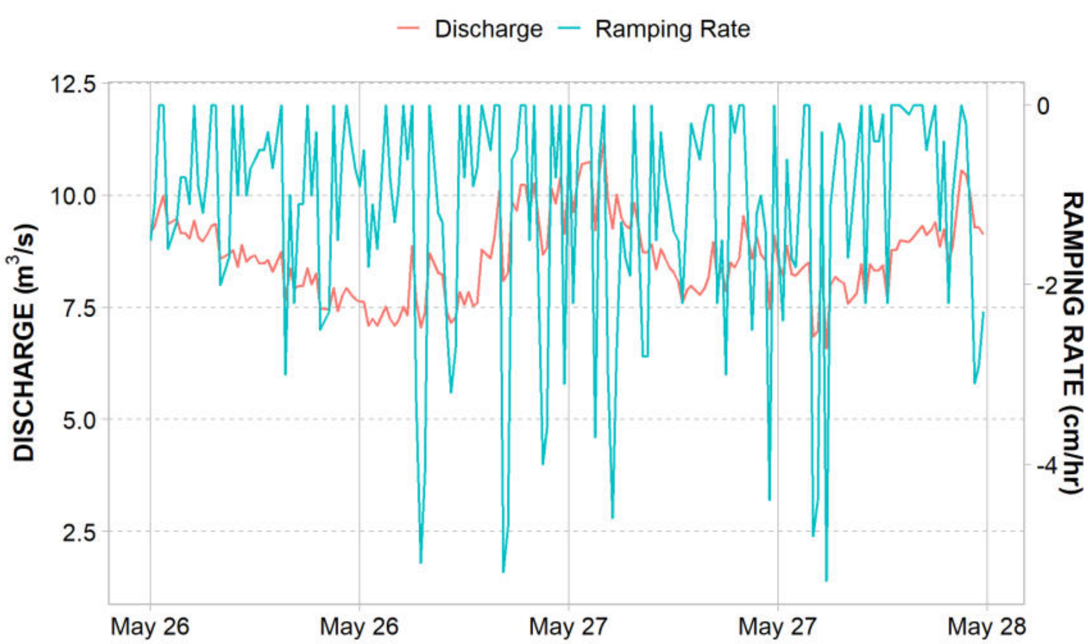


Figure 13. Flow and ramping rate for June 1, 2018 for Measuring Point B, classification "Turbulence".

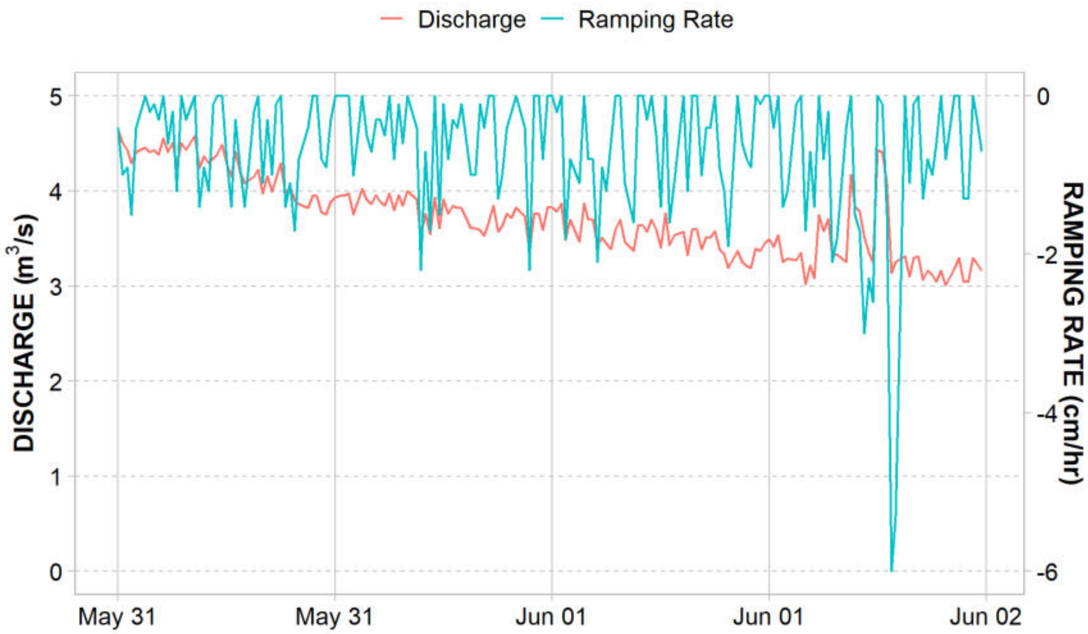


Figure 14. Flow and ramping rate for June 7, 2018 for Measuring Point B, classification "Turbulence".

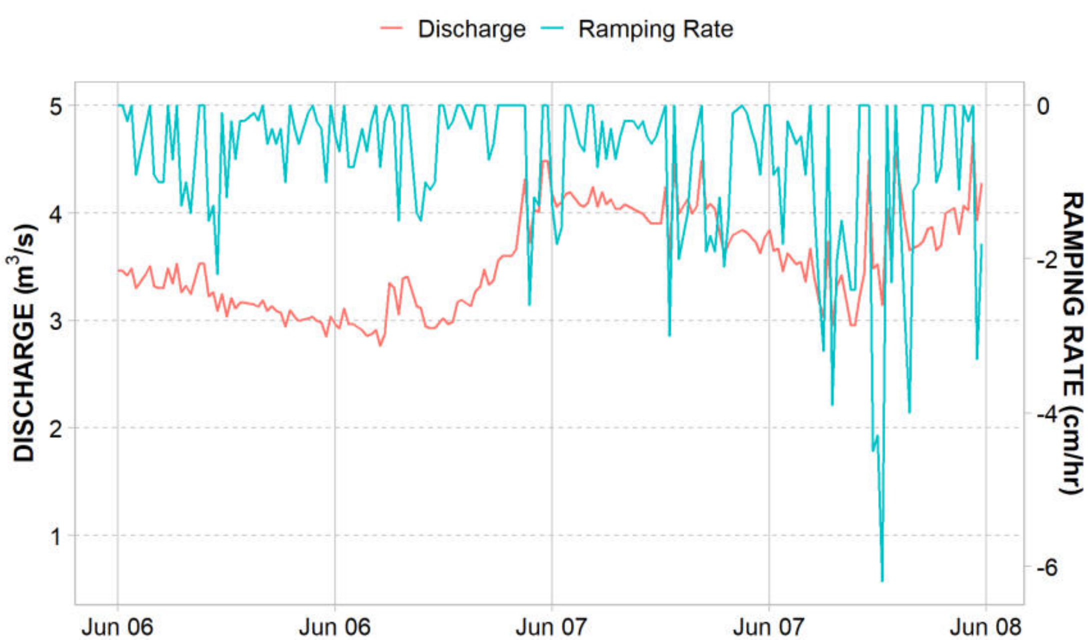


Figure 15. Flow and ramping rate for June 26, 2018 for Measuring Point B, classification "Turbulence".

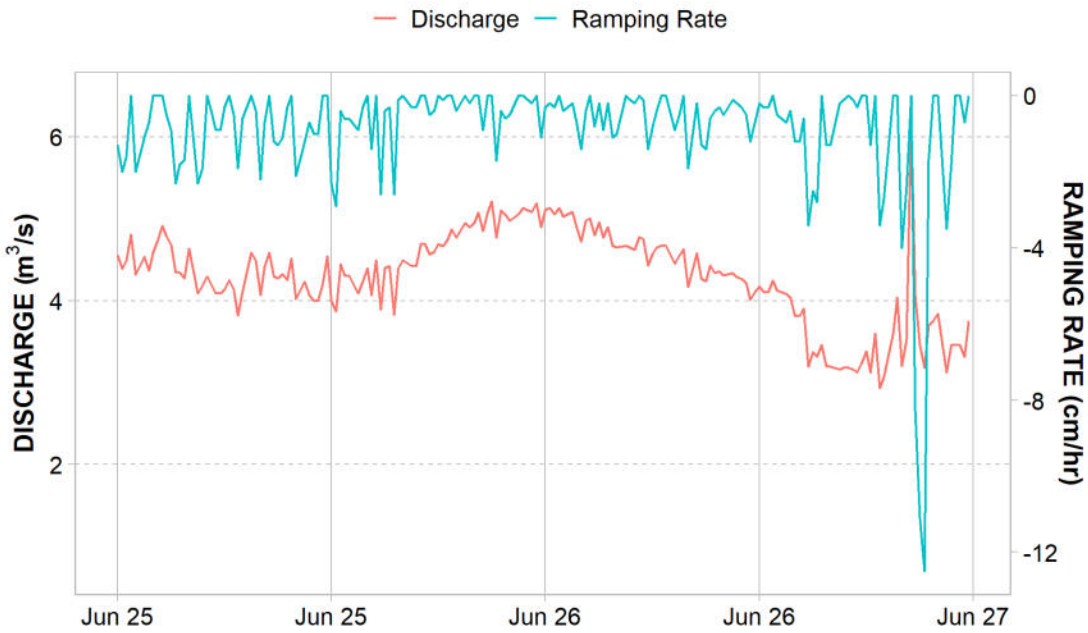


Figure 16. Flow and ramping rate for July 5, 2018 for Measuring Point B, classification "Turbulence" and "Bubbler Purge".

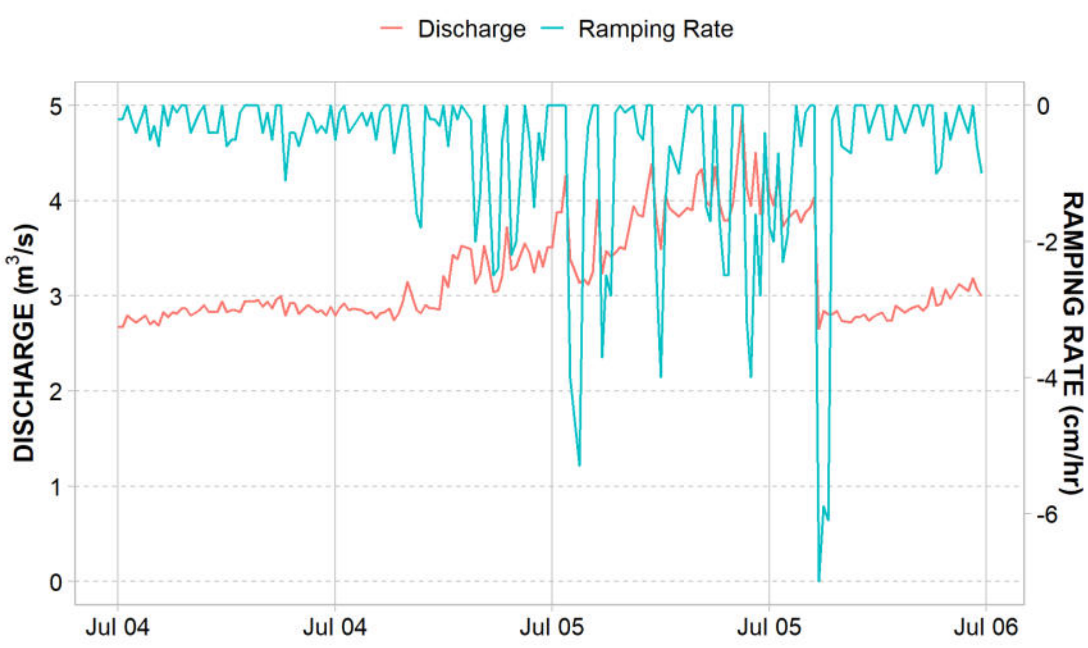


Figure 17. Flow and ramping rate for July 7, 2018 for Measuring Point B, classification "Turbulence".

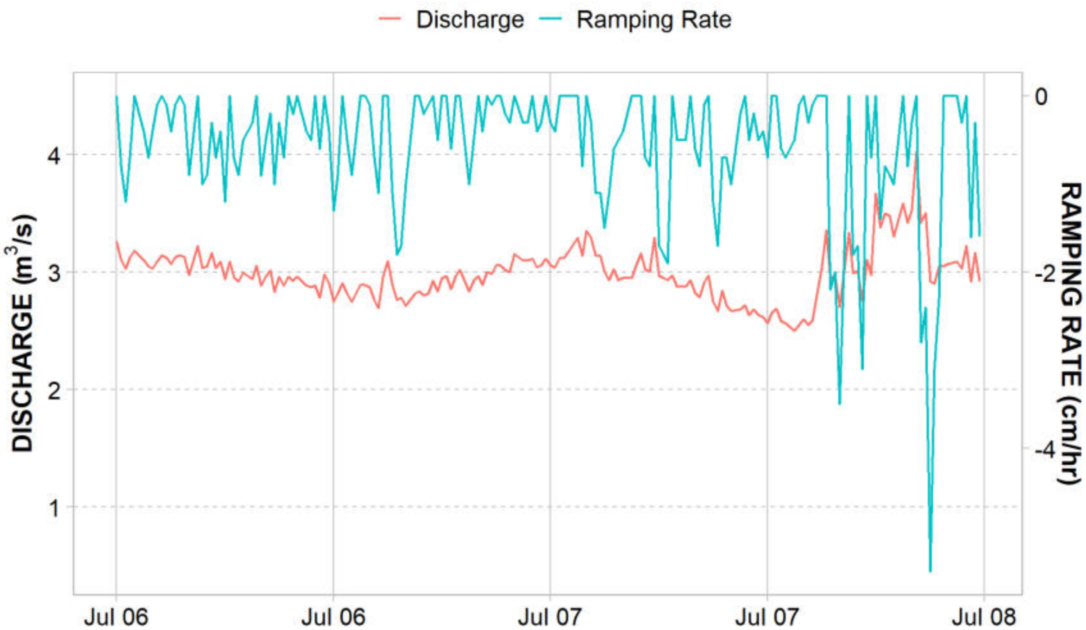


Figure 18. Flow and ramping rate for August 14, 2018 for Measuring Point B, classification "Turbulence".

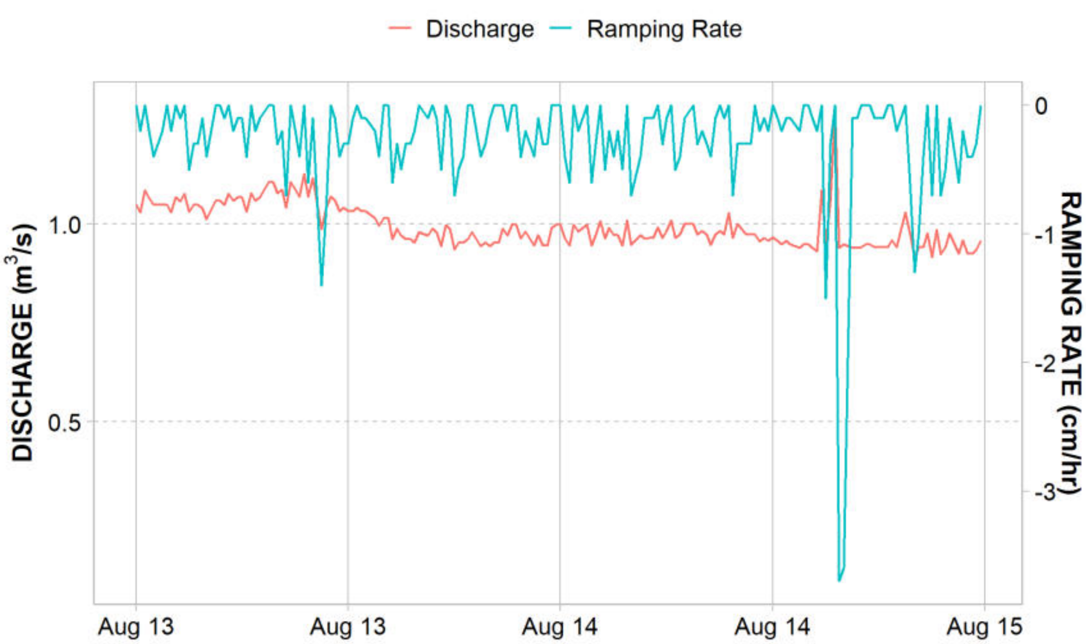
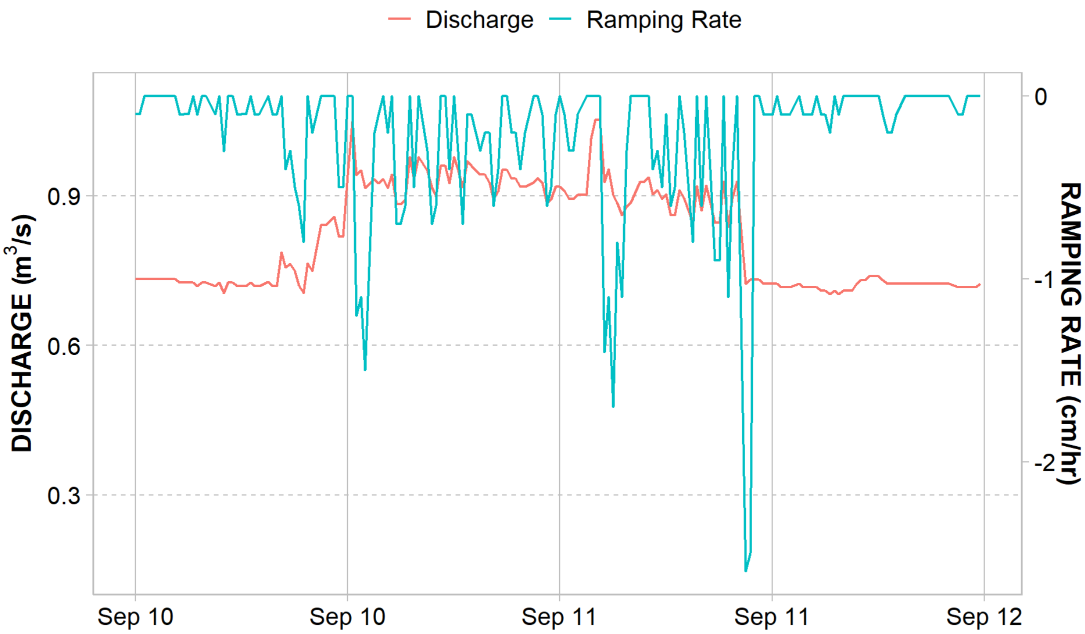


Figure 19. Flow and ramping rate for September 11, 2018 for Measuring Point B, classification "Turbulence".



Appendix C. Potential Ramping Event Evaluation Plots (2019)

LIST OF FIGURES

Figure 1. Flow and ramping rate for June 4, 2019 for Measuring Point A, classification "Turbulence".

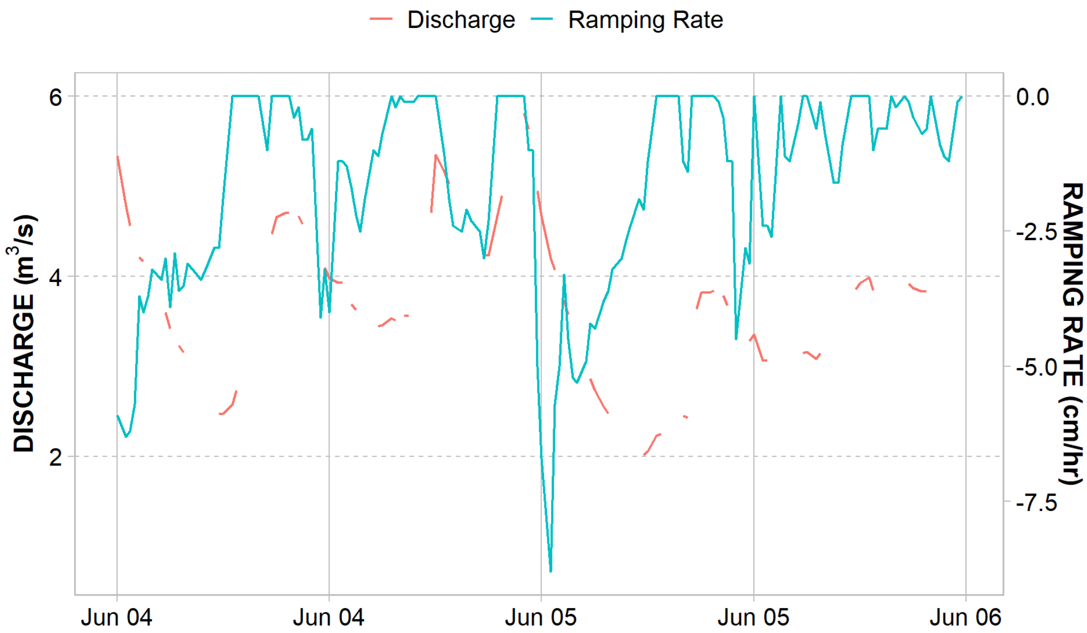


Figure 2. Flow and ramping rate for June 8, 2019 for Measuring Point A, classification "Turbulence".

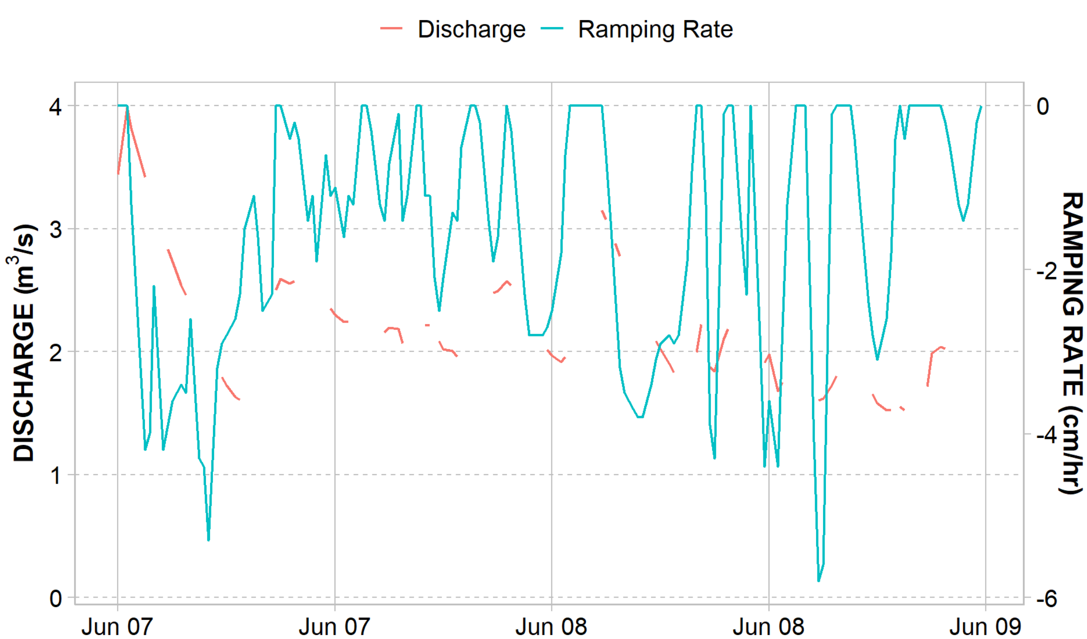


Figure 3. Flow and ramping rate for June 17, 2019 for Measuring Point A, classification "Turbulence".

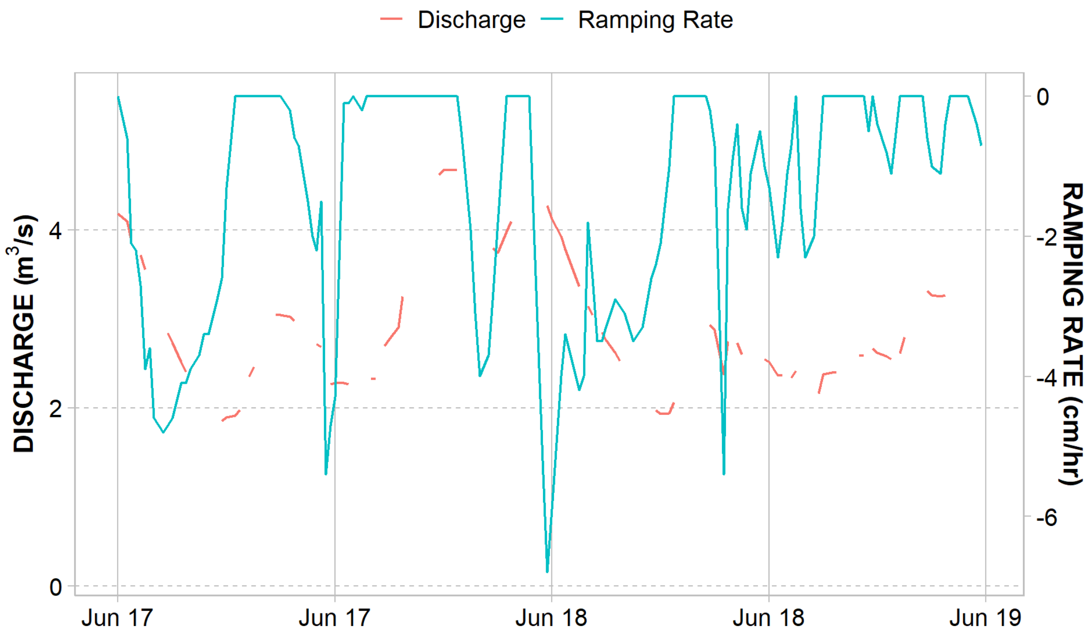


Figure 4. Flow and ramping rate for July 4, 2019 for Measuring Point A, classification "Turbulence".

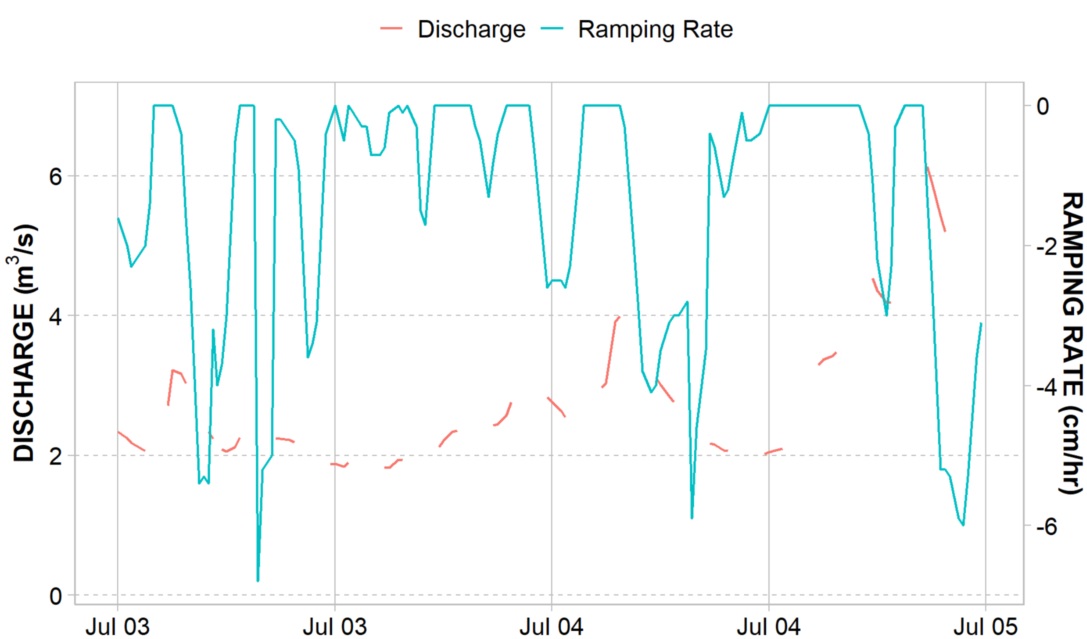


Figure 5. Flow and ramping rate for August 11, 2019 for Measuring Point A, classification "Noise".

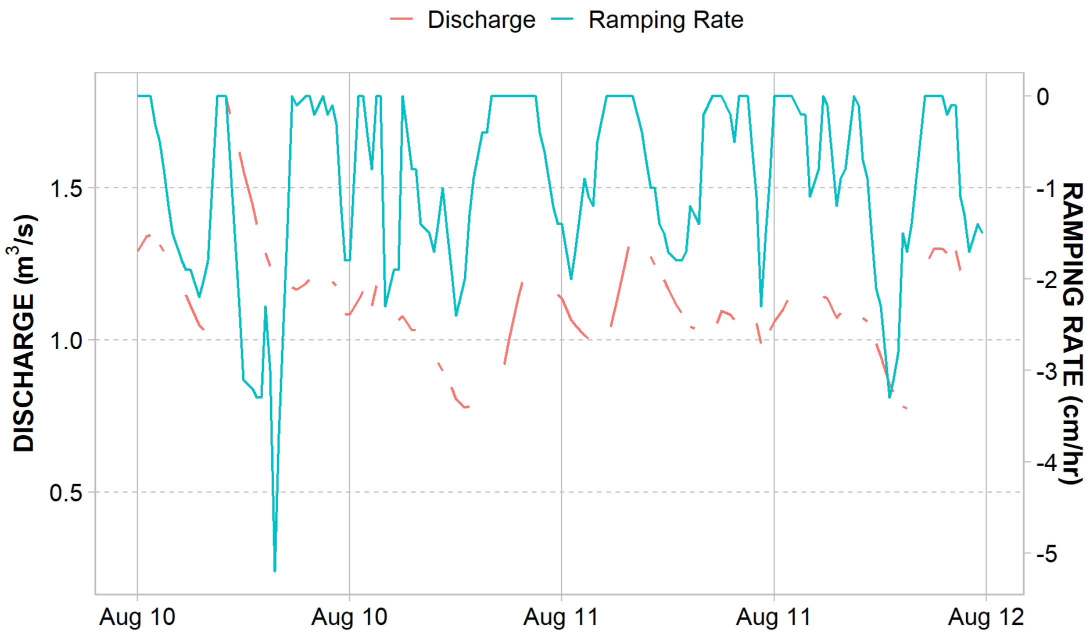


Figure 6. Flow and ramping rate for August 14, 2019 for Measuring Point A, classification "Noise".

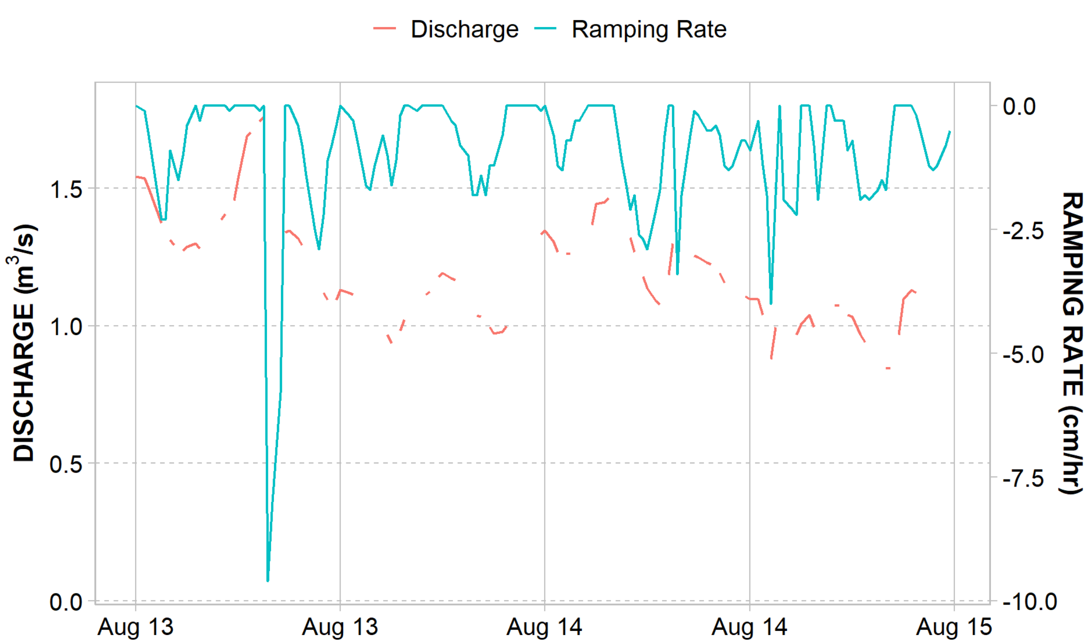


Figure 7. Flow and ramping rate for August 16, 2019 for Measuring Point A, classification "Noise".

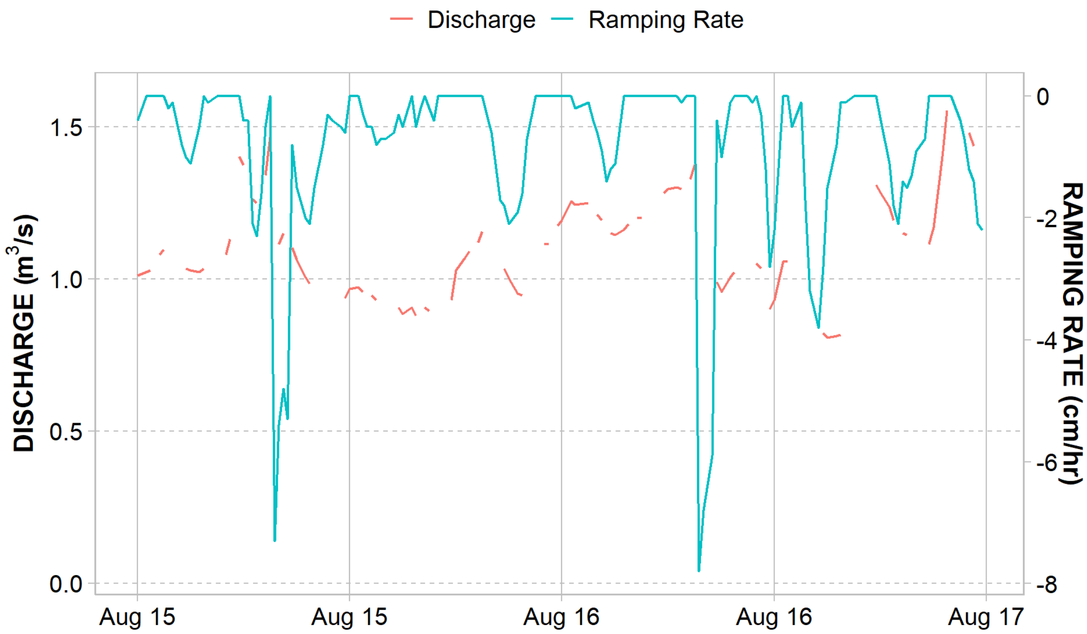


Figure 8. Flow and ramping rate for August 17, 2019 for Measuring Point A, classification "Noise".

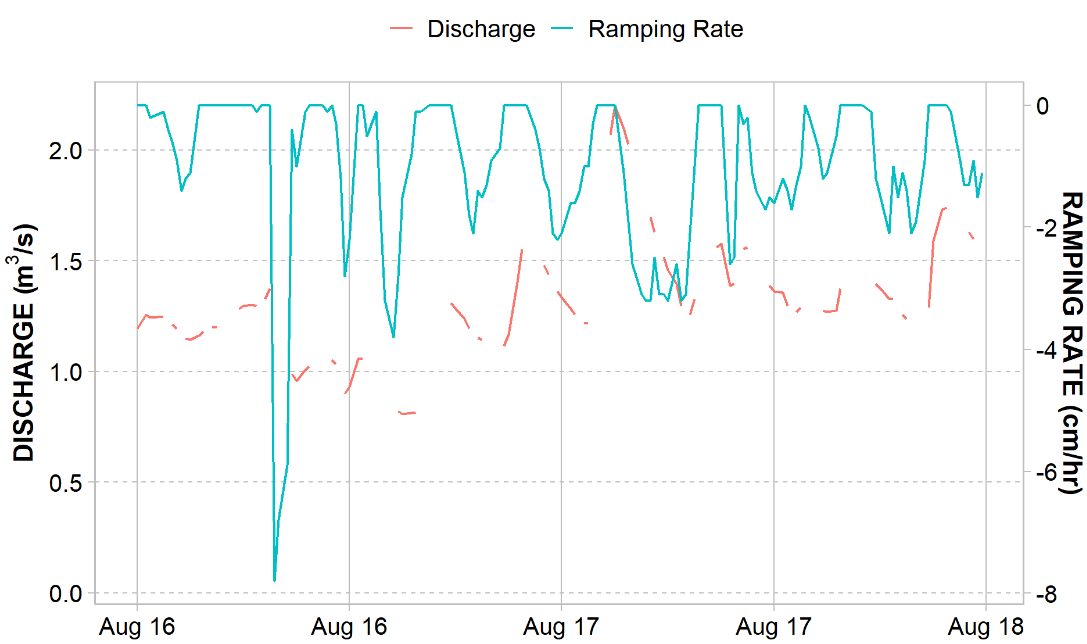


Figure 9. Flow and ramping rate for August 20, 2019 for Measuring Point A, classification "Noise".

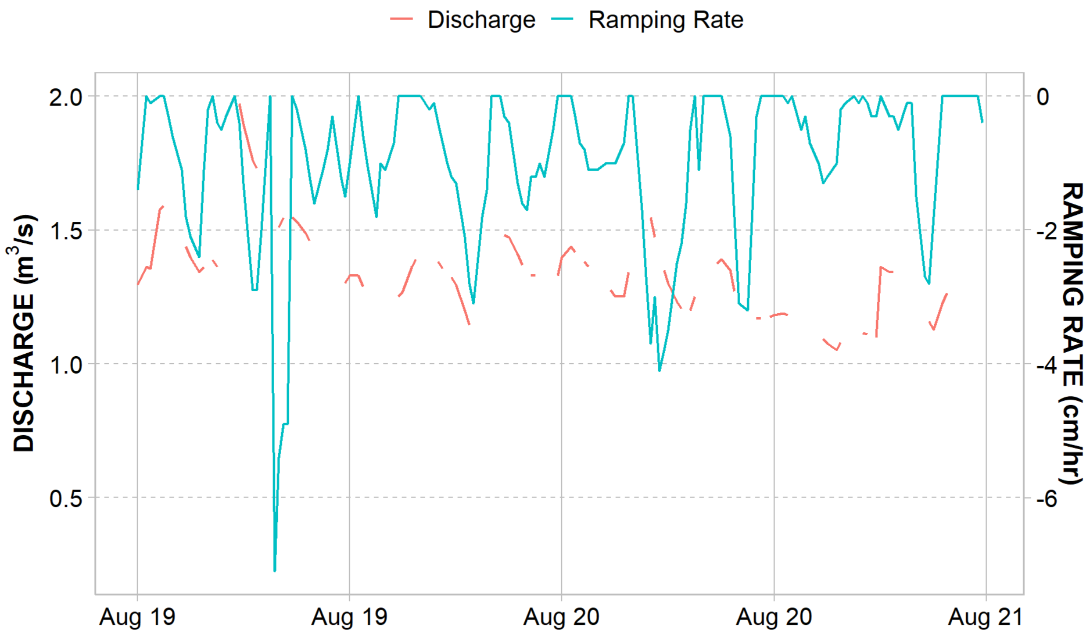


Figure 10. Flow and ramping rate for August 21, 2019 for Measuring Point A, classification "Noise".

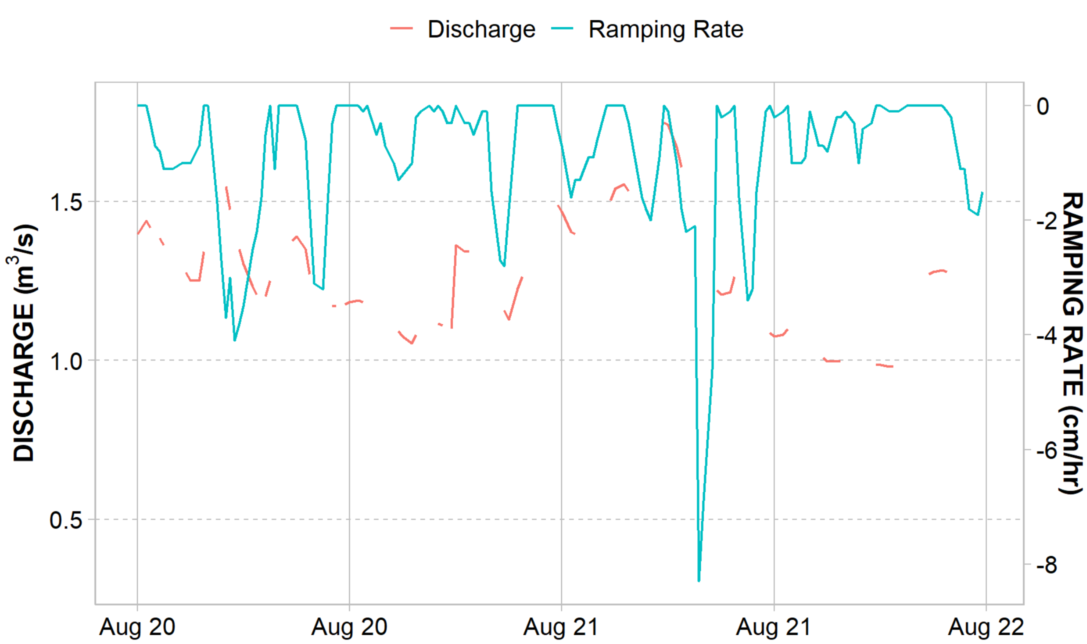


Figure 11. Flow and ramping rate for August 25, 2019 for Measuring Point A, classification "Noise".

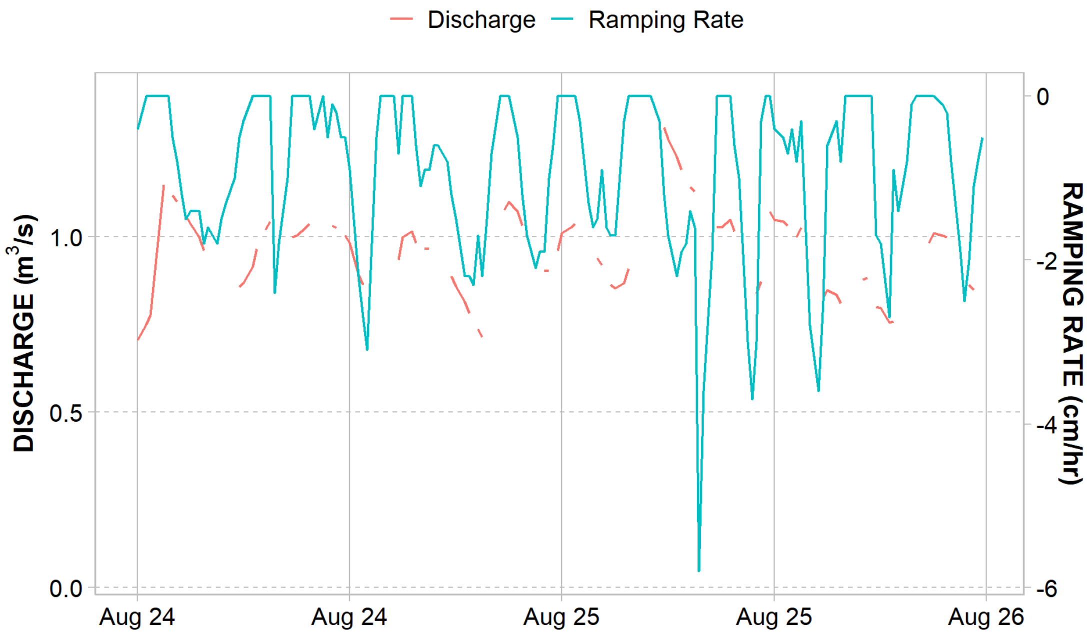


Figure 12. Flow and ramping rate for August 27, 2019 for Measuring Point A, classification "Noise".

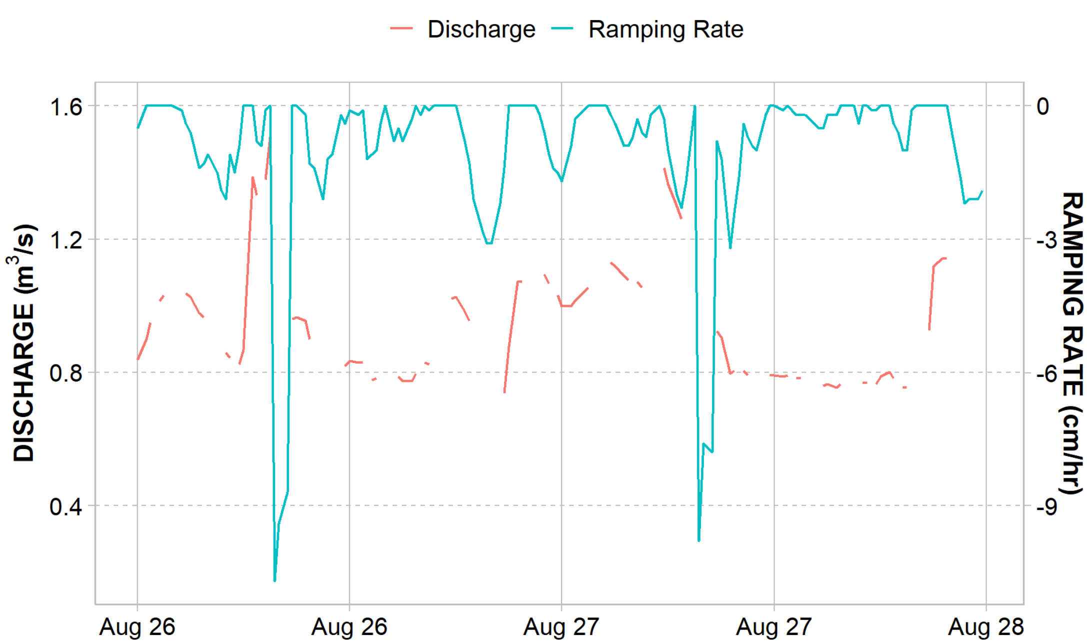


Figure 13. Flow and ramping rate for August 29, 2019 for Measuring Point A, classification "Noise".

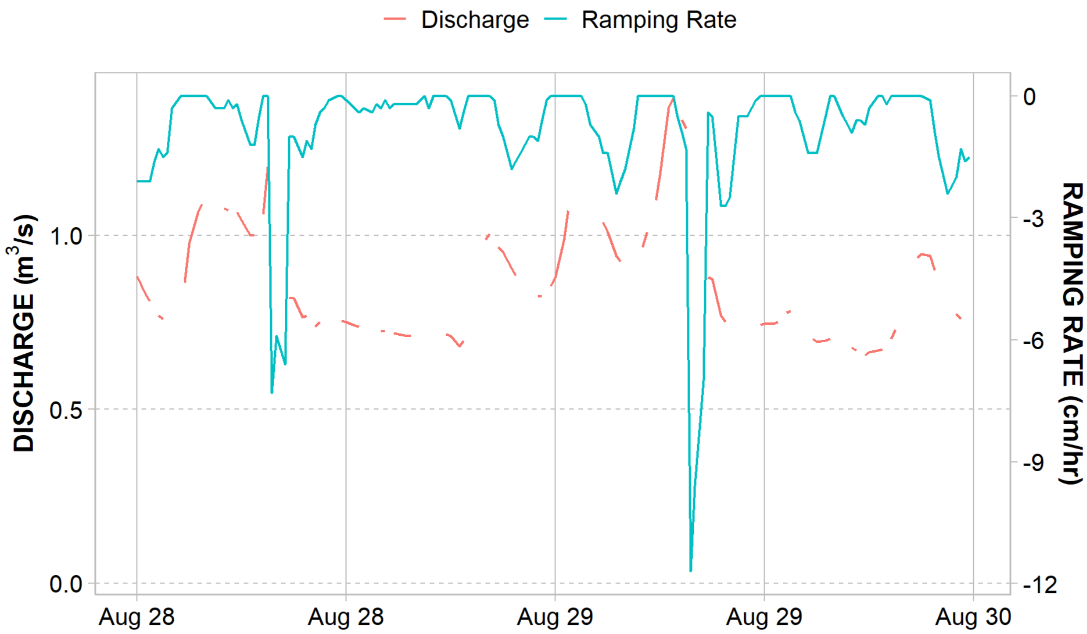


Figure 14. Flow and ramping rate for September 3, 2019 for Measuring Point A, classification "Noise".

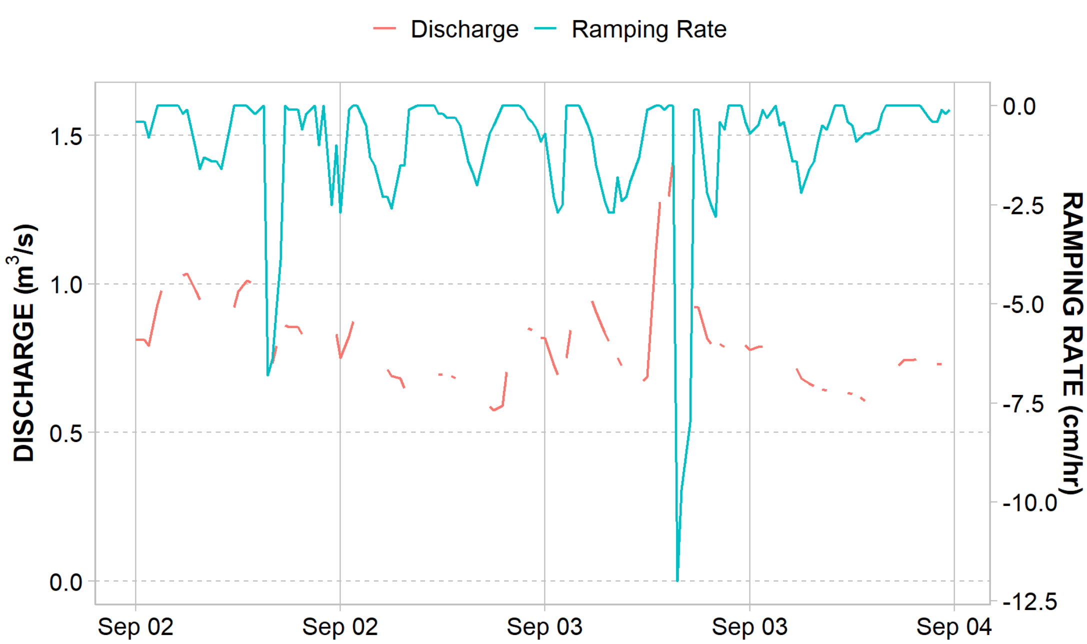


Figure 15. Flow and ramping rate for September 4, 2019 for Measuring Point A, classification "Noise".

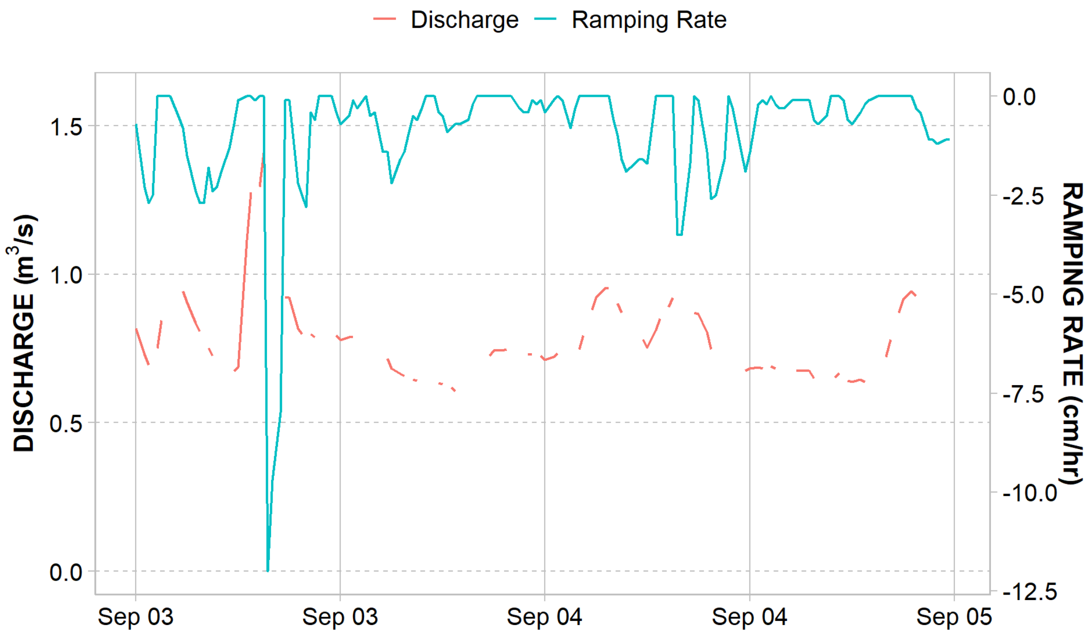


Figure 16. Flow and ramping rate for September 7, 2019 for Measuring Point A, classification "Noise".

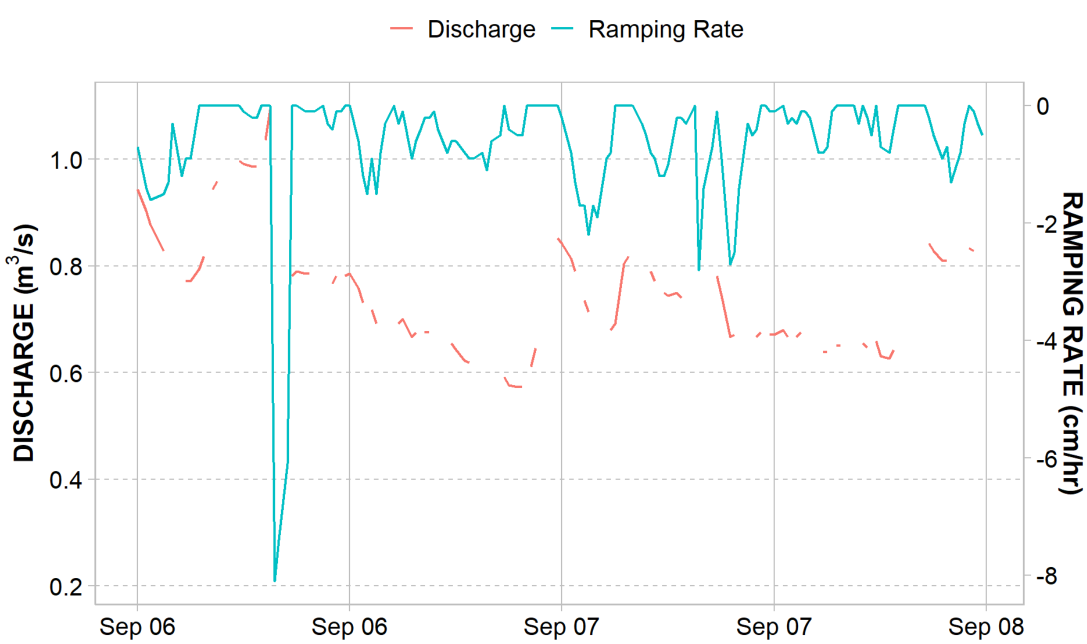


Figure 17. Flow and ramping rate for September 10, 2019 for Measuring Point A, classification "Noise".

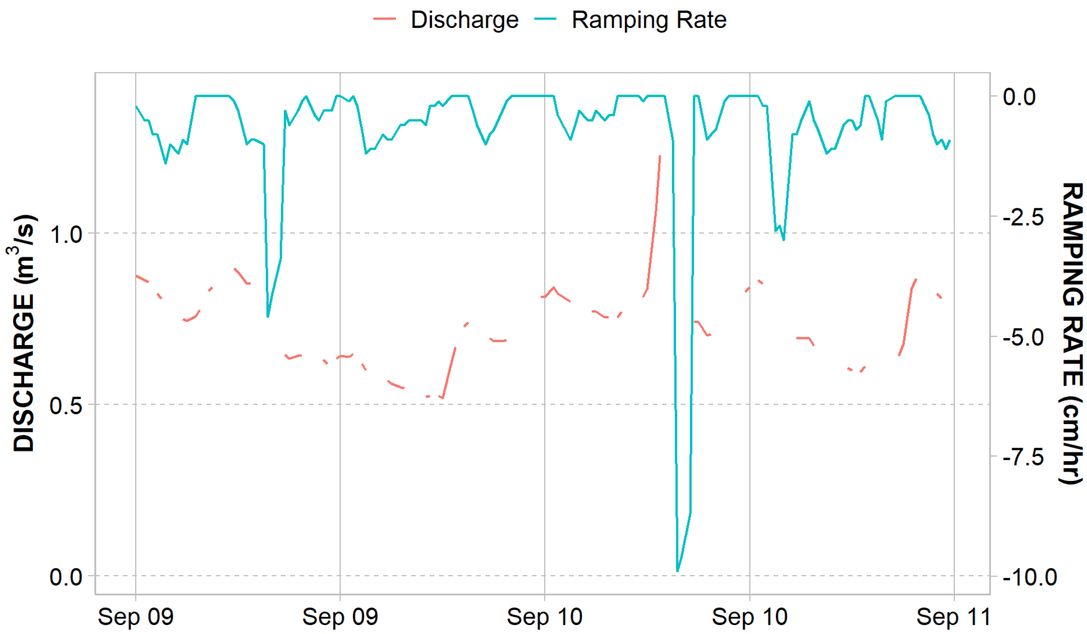


Figure 18. Flow and ramping rate for September 12, 2019 for Measuring Point A, classification "Noise".

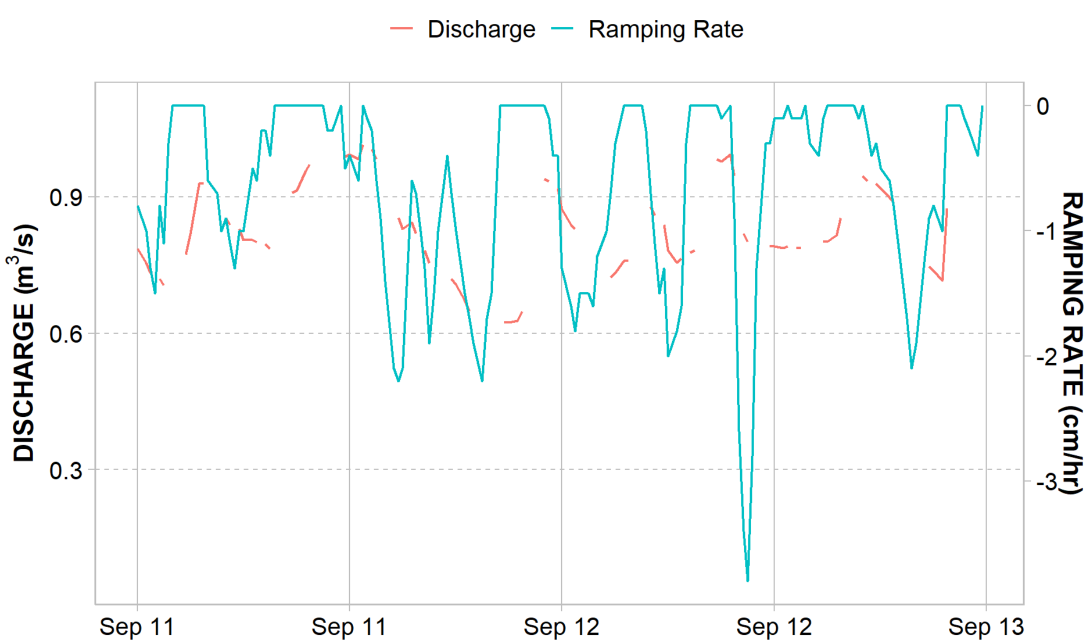


Figure 19. Flow and ramping rate for September 13, 2019 for Measuring Point A, classification "Noise".

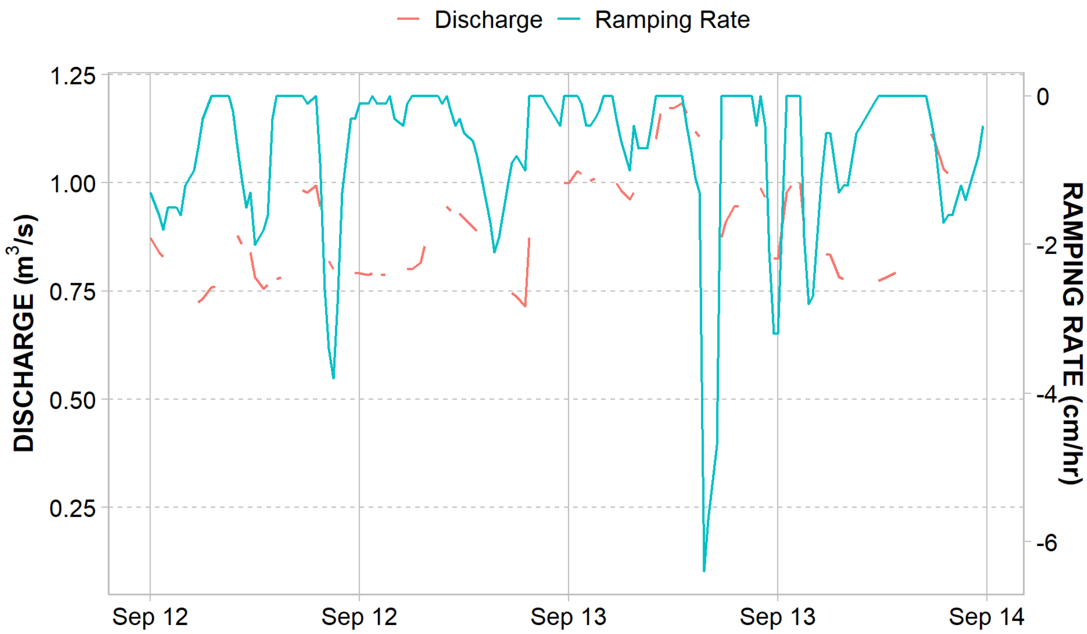


Figure 20. Flow and ramping rate for September 17, 2019 for Measuring Point A, classification "Noise".

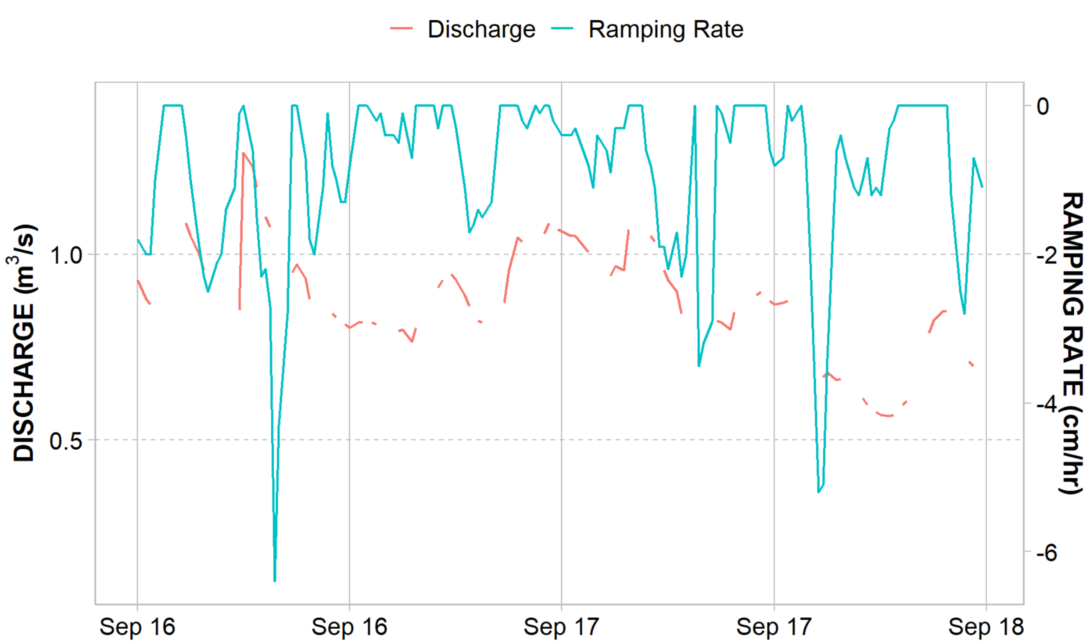


Figure 21. Flow and ramping rate for September 18, 2019 for Measuring Point A, classification "Noise".

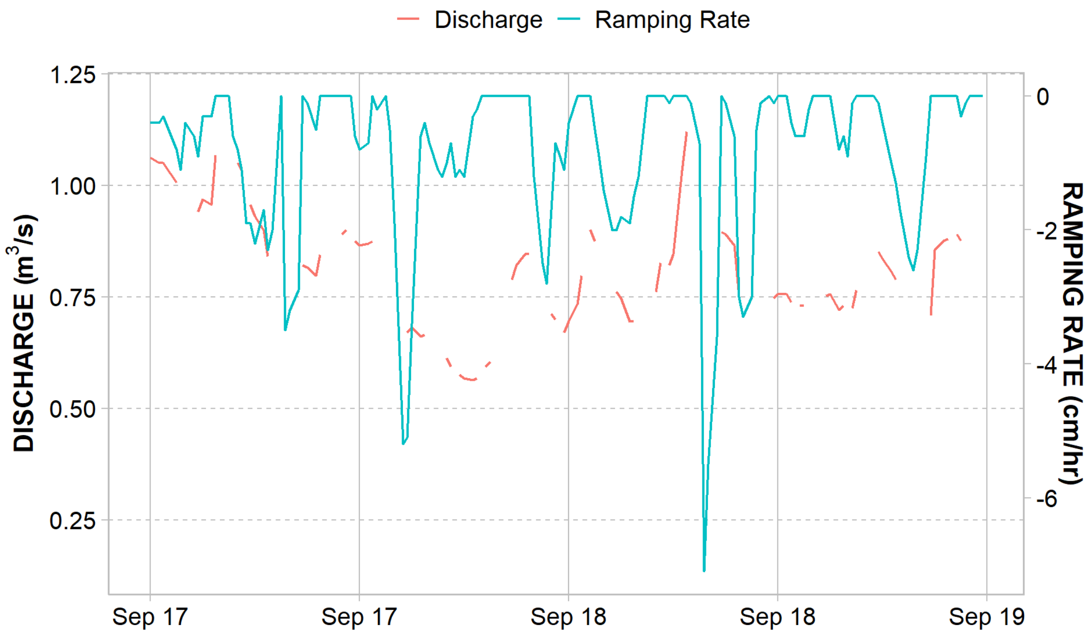
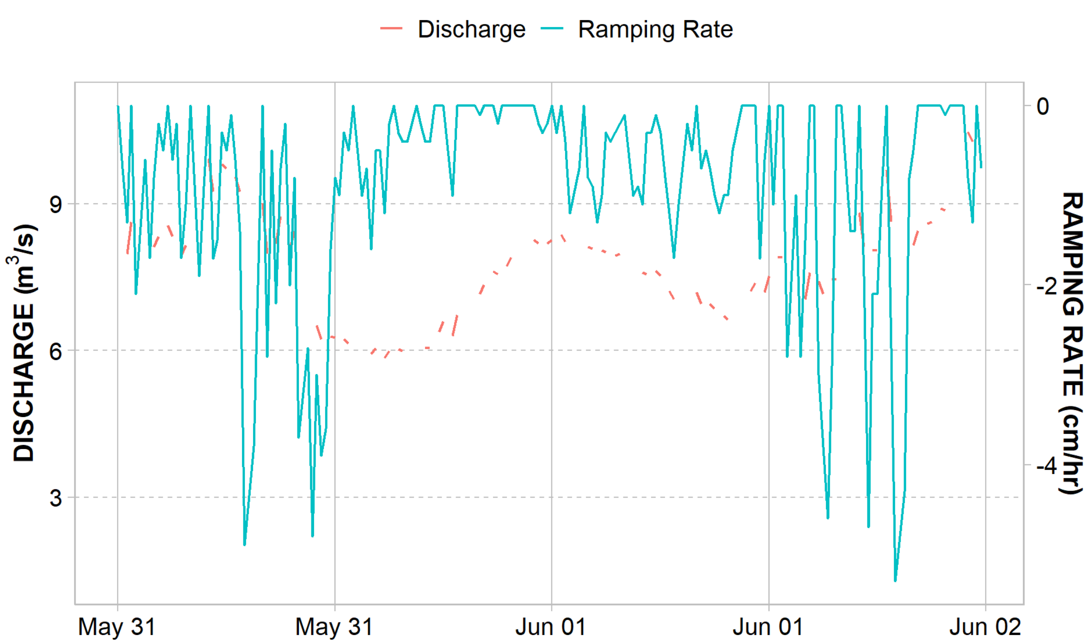


Figure 22. Flow and ramping rate for June 1, 2019 for Measuring Point B, classification "Turbulence".



ECOFISH RESEARCH

Figure 23. Flow and ramping rate for June 17, 2019 for Measuring Point B, classification "Turbulence".

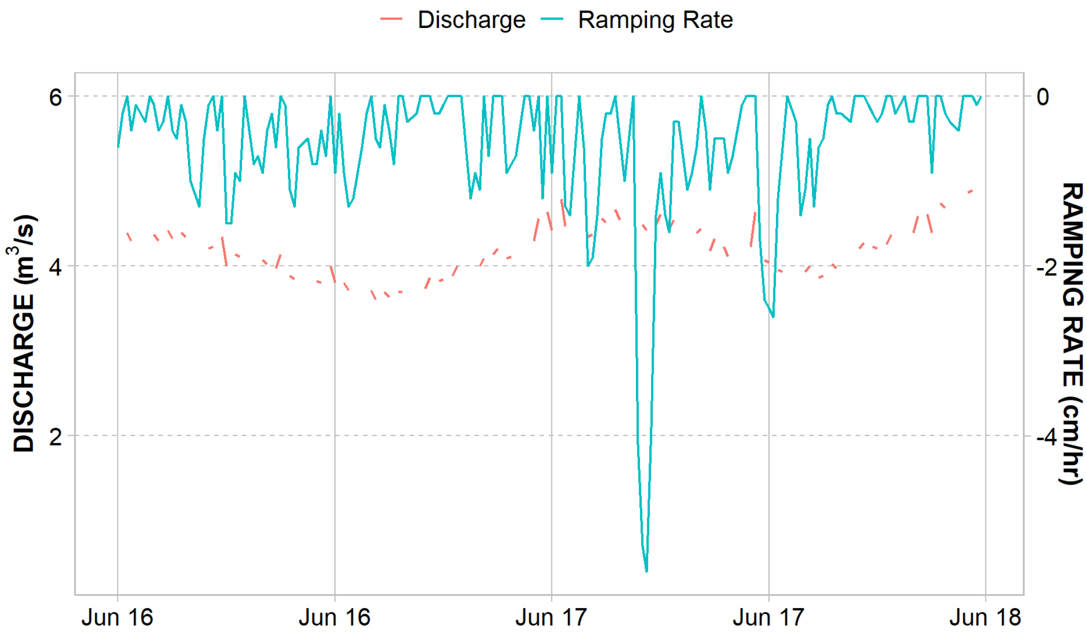


Figure 24. Flow and ramping rate for June 24, 2019 for Measuring Point B, classification "Turbulence".

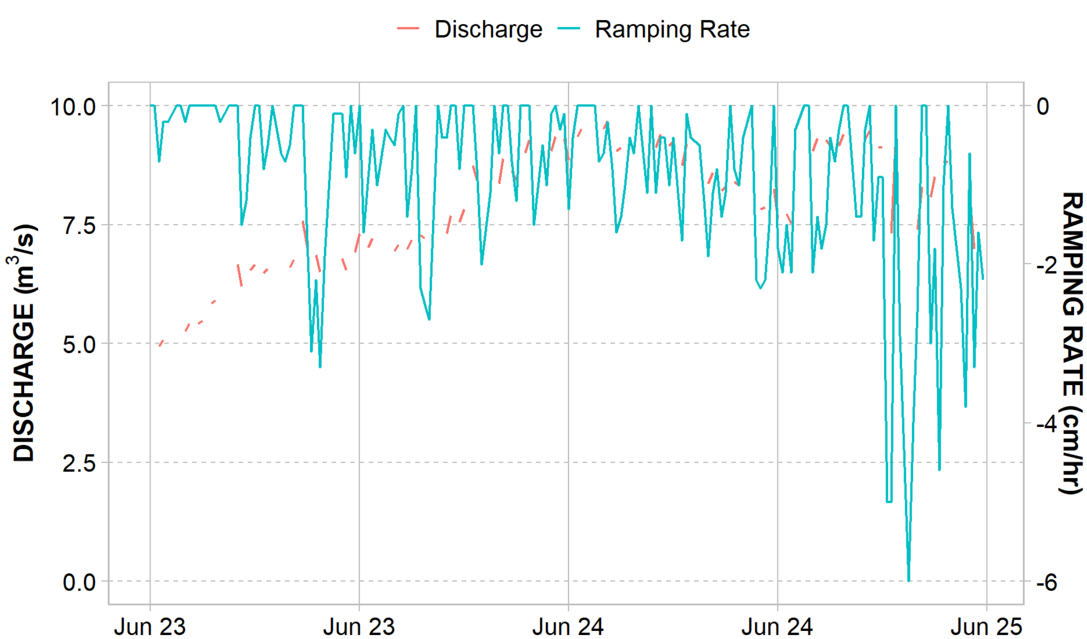


Figure 25. Flow and ramping rate for June 25, 2019 for Measuring Point B, classification "Turbulence".

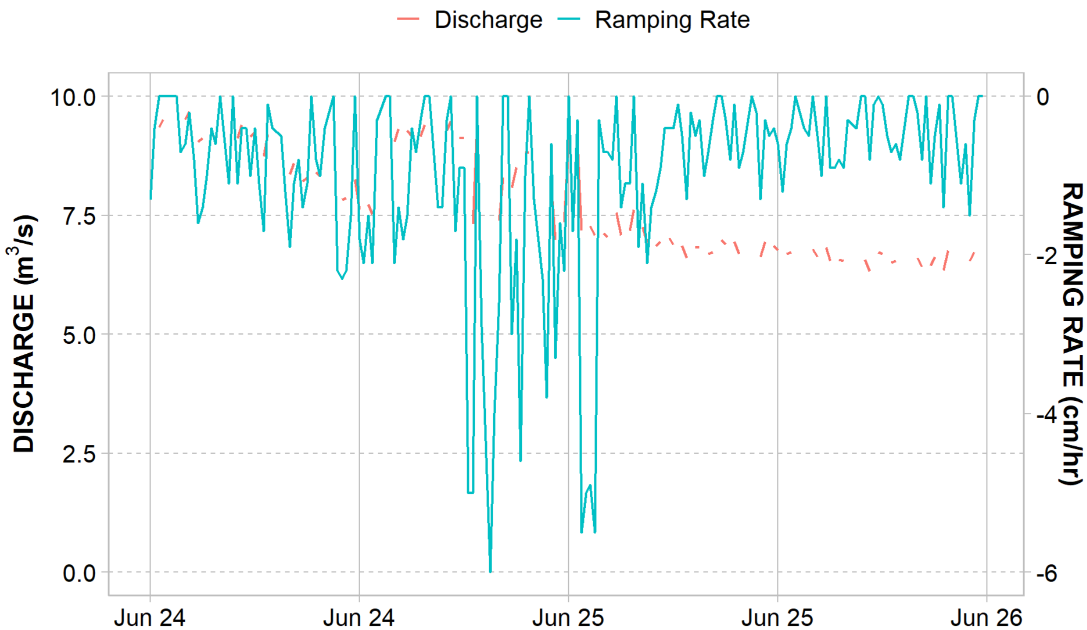


Figure 26. Flow and ramping rate for June 26, 2019 for Measuring Point B, classification "Turbulence".

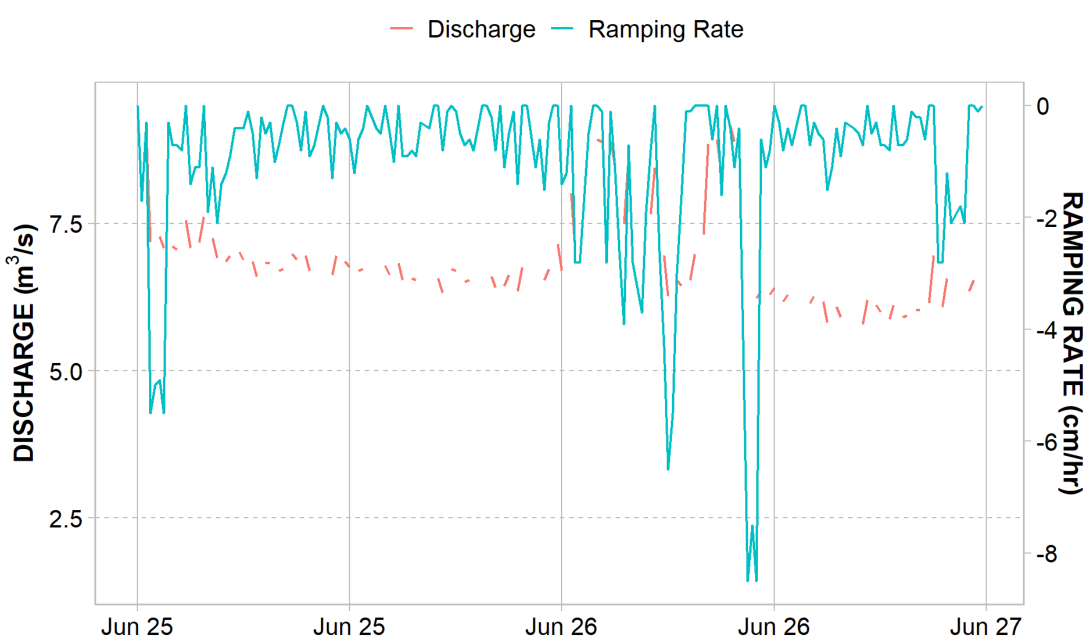


Figure 27. Flow and ramping rate for June 27, 2019 for Measuring Point B, classification "Turbulence".

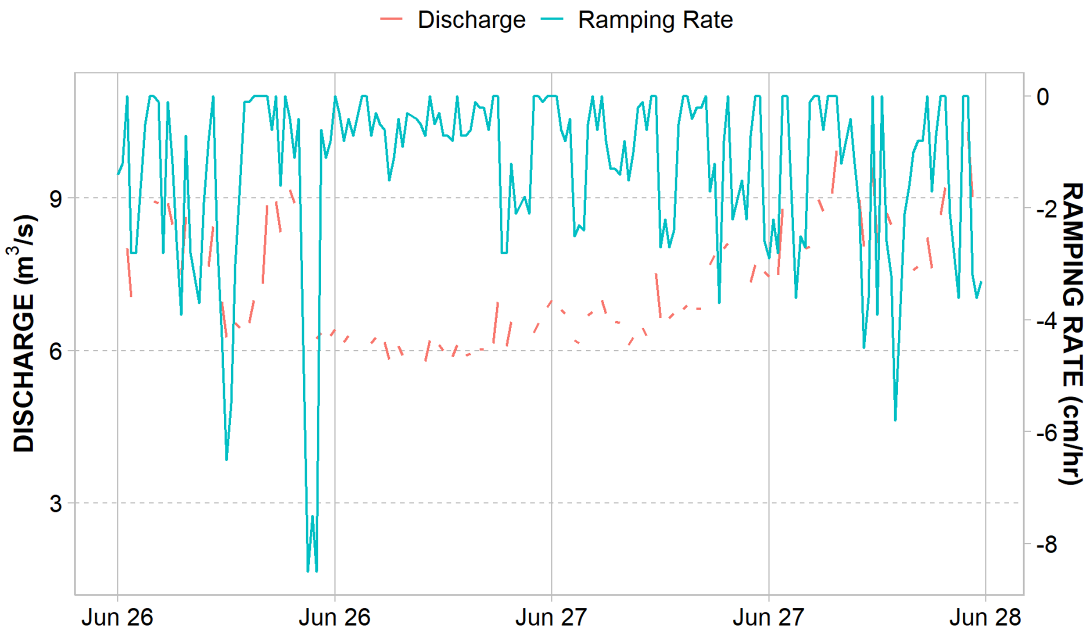


Figure 28. Flow and ramping rate for June 28, 2019 for Measuring Point B, classification "Turbulence".

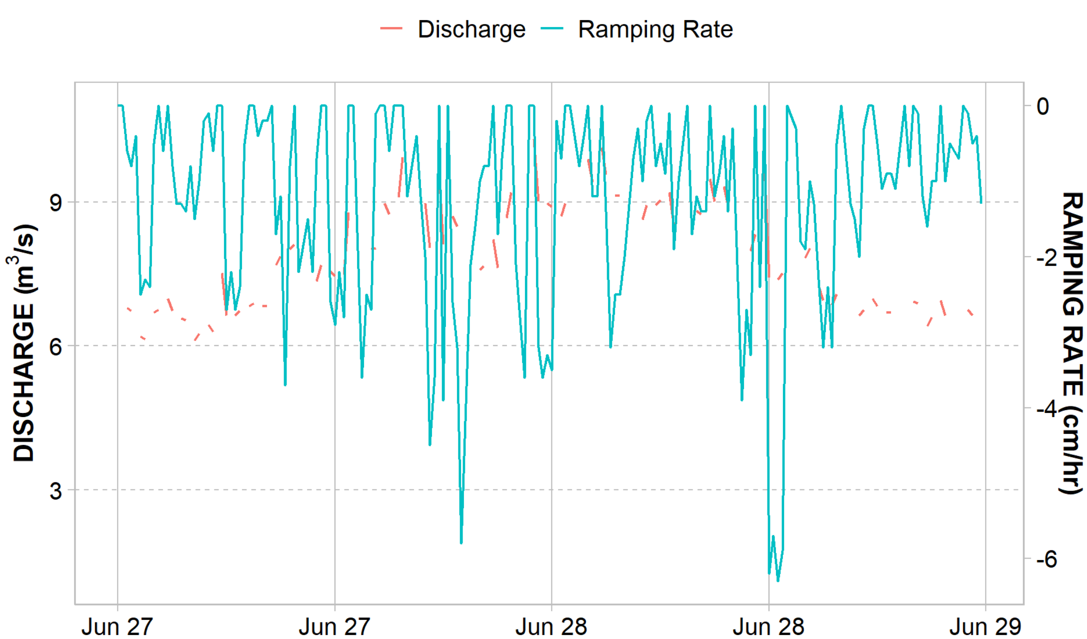


Figure 29. Flow and ramping rate for July 1, 2019 for Measuring Point B, classification "Turbulence".

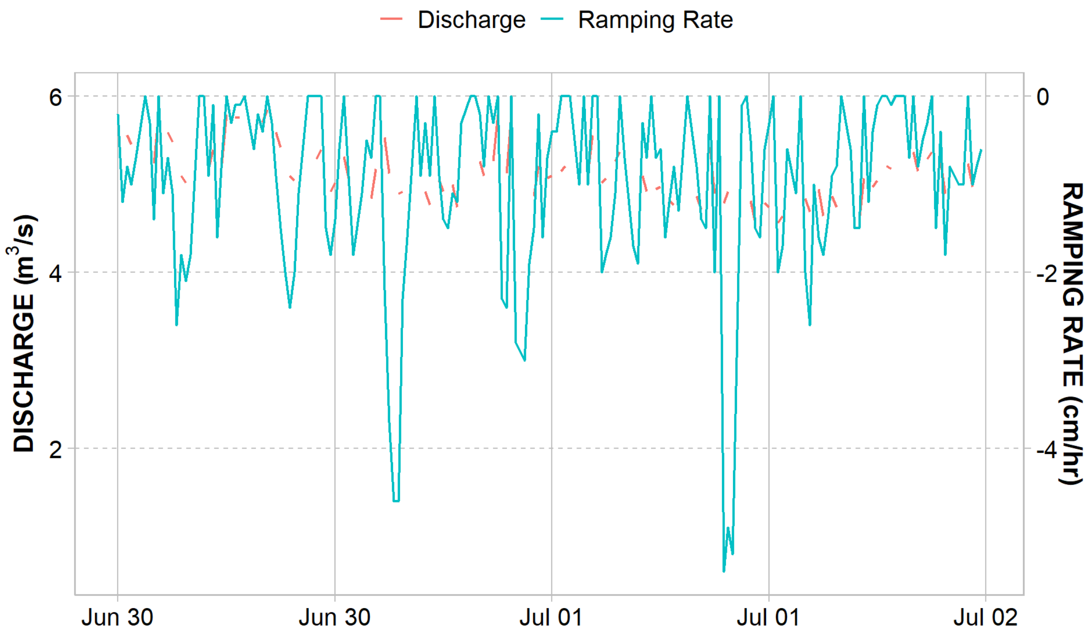


Figure 30. Flow and ramping rate for July 23, 2019 for Measuring Point B, classification "Turbulence".

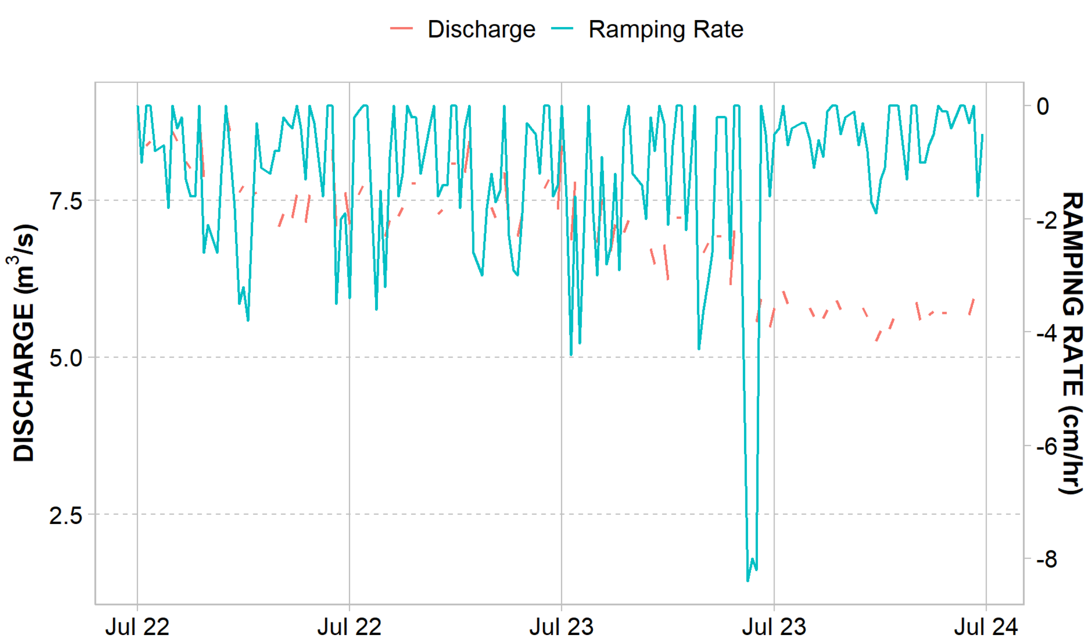


Figure 31. Flow and ramping rate for August 10, 2019 for Measuring Point B, classification "Noise".

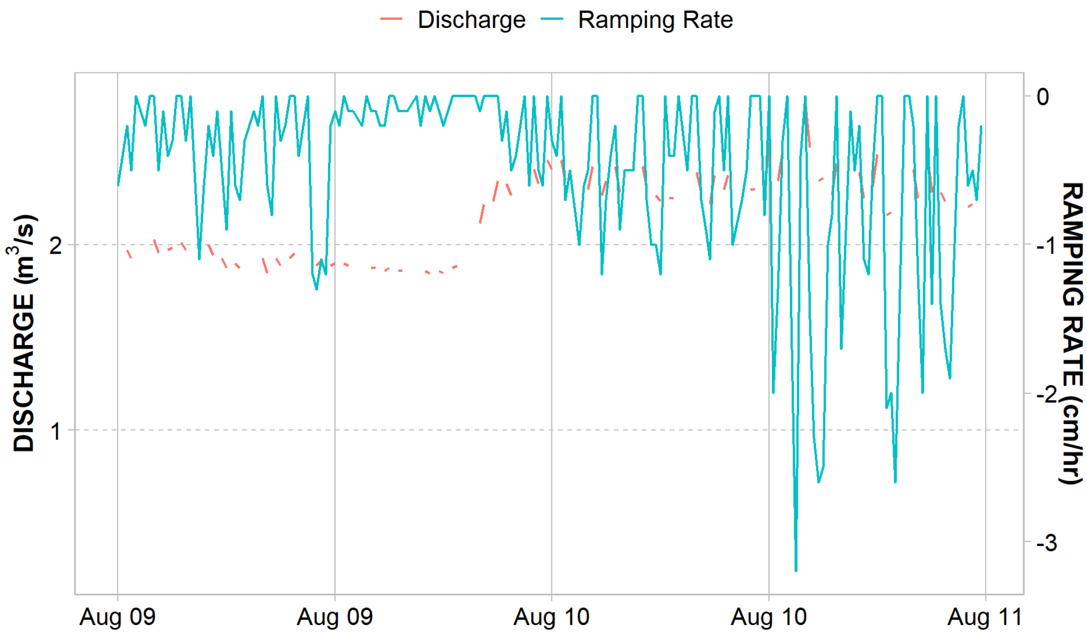


Figure 32. Flow and ramping rate for August 16, 2019 for Measuring Point B, classification "Noise".

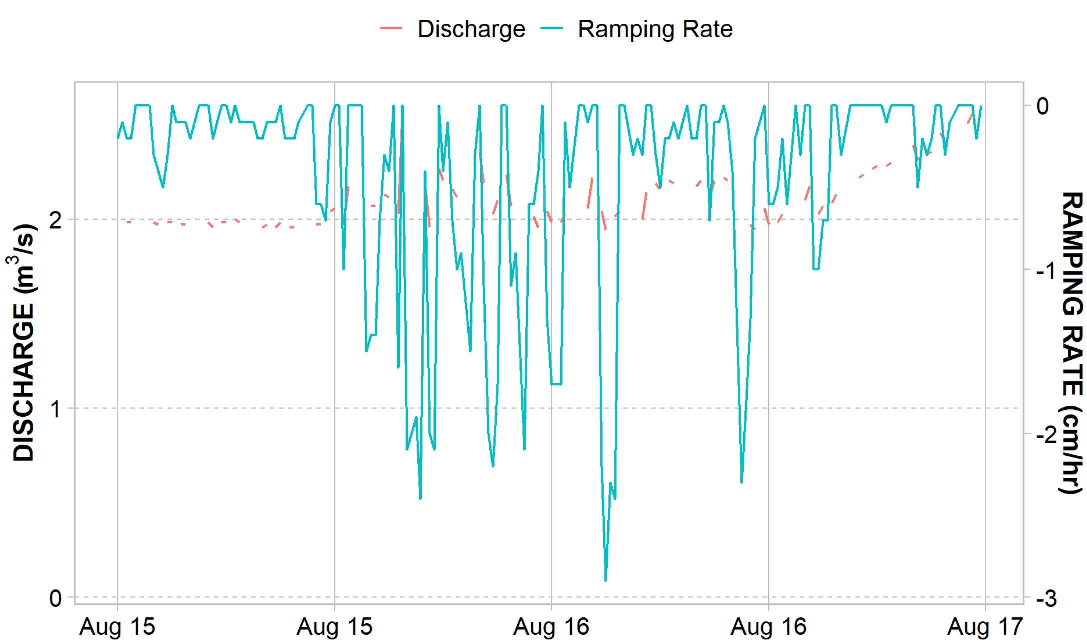


Figure 33. Flow and ramping rate for August 20, 2019 for Measuring Point B, classification "Noise".

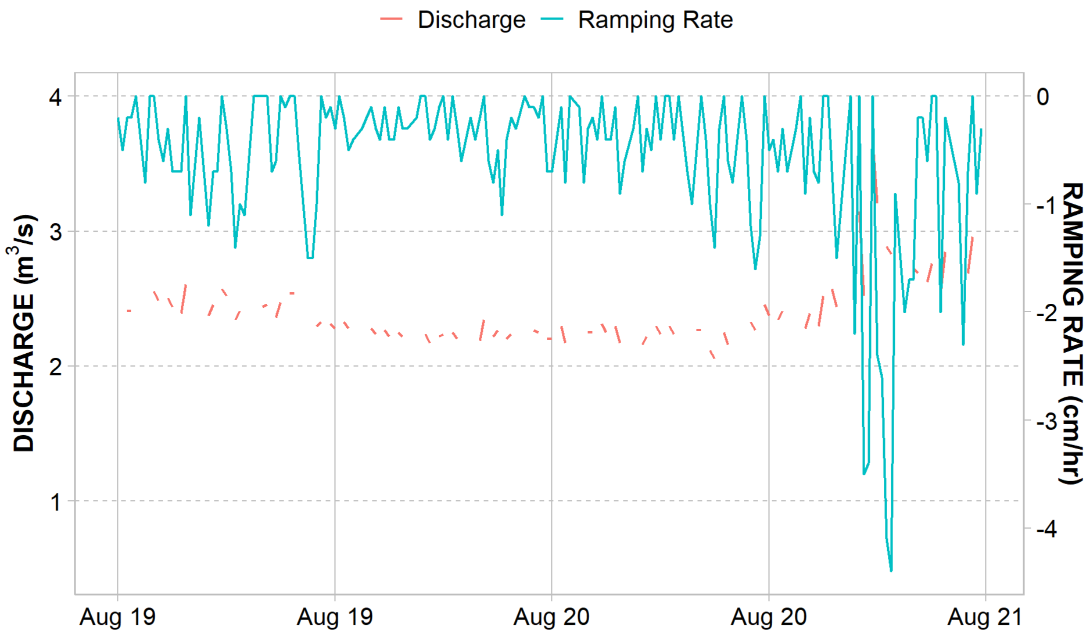


Figure 34. Flow and ramping rate for August 21, 2019 for Measuring Point B, classification "Noise".

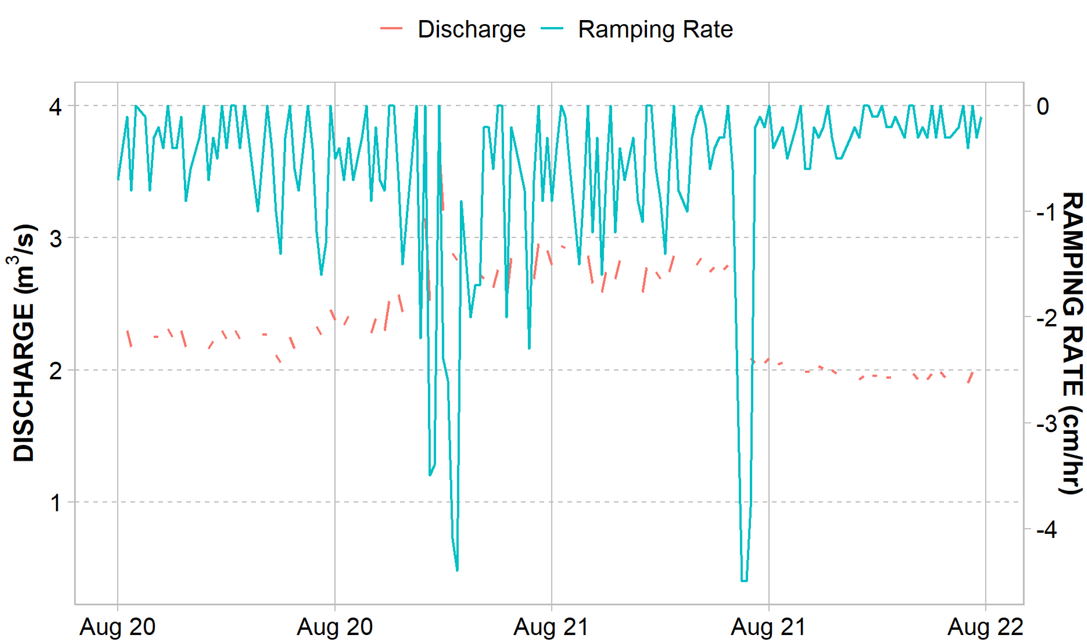
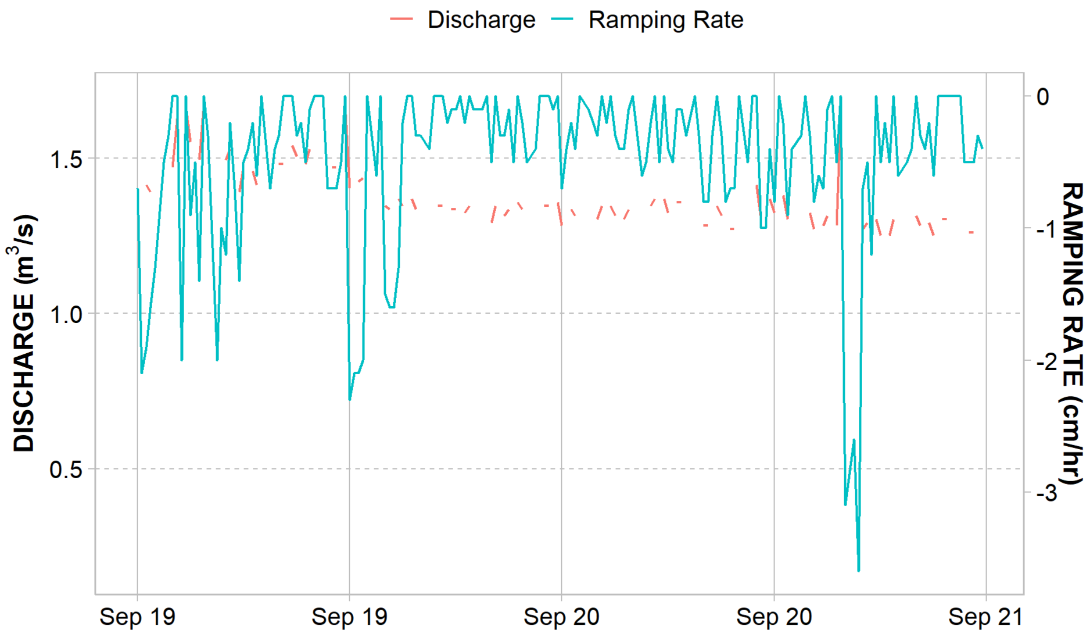


Figure 35. Flow and ramping rate for September 20, 2019 for Measuring Point B, classification "Noise".



Appendix D. Potential Ramping Event Plots of Unknown Cause (2017-2018)

LIST OF FIGURES

Figure 1. **Flow and ramping rate for May 7, 2018 for Measuring Point A.**

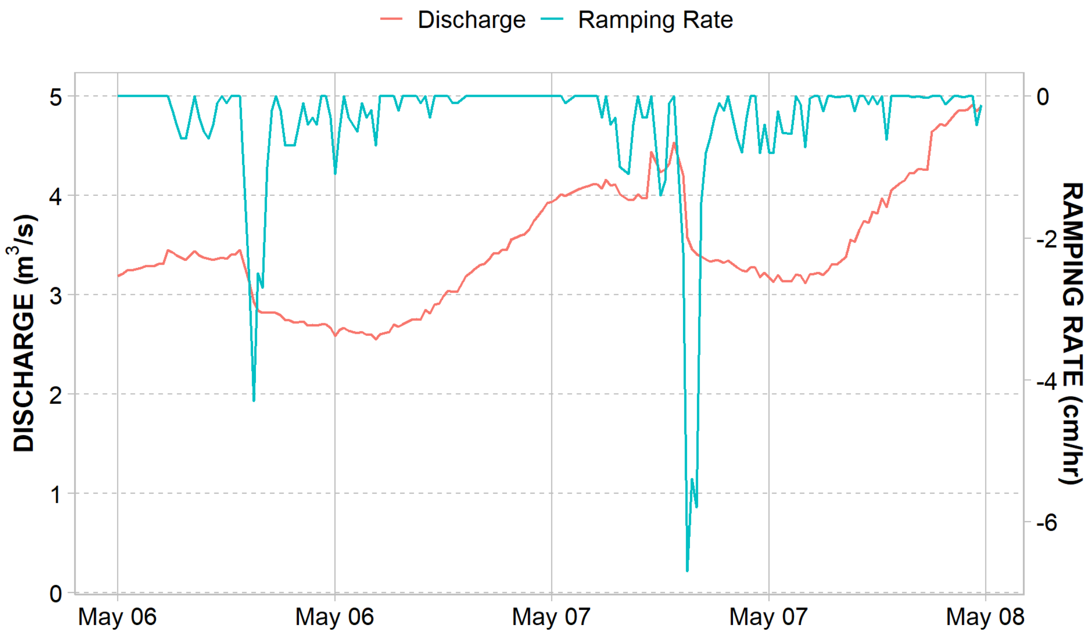


Figure 2. **Flow and ramping rate for May 26, 2018 for Measuring Point A.**

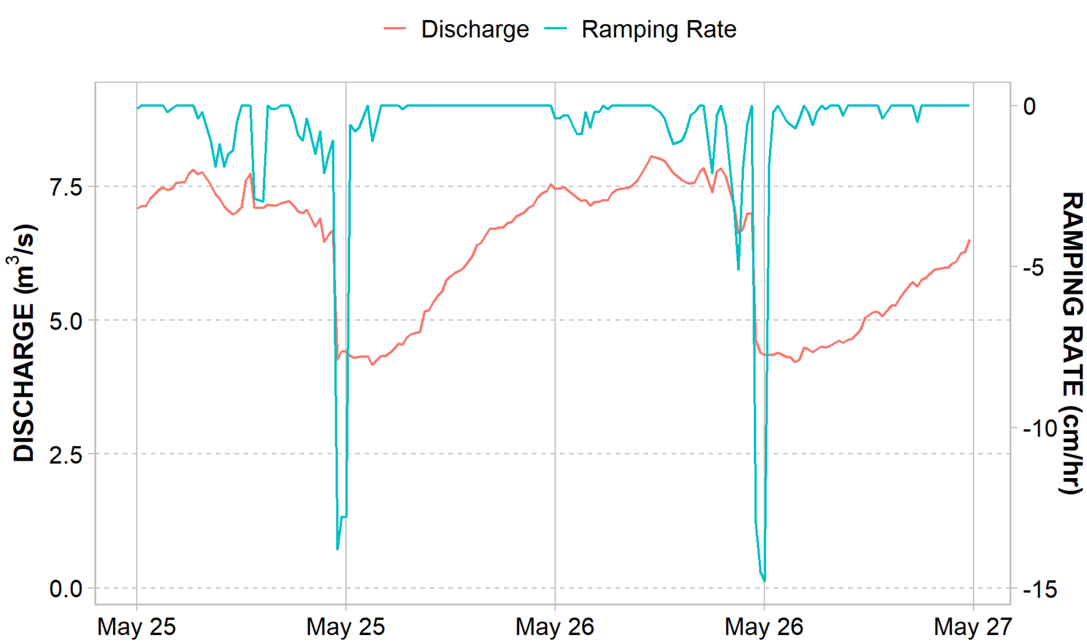


Figure 3. Flow and ramping rate for June 9, 2018 for Measuring Point A.

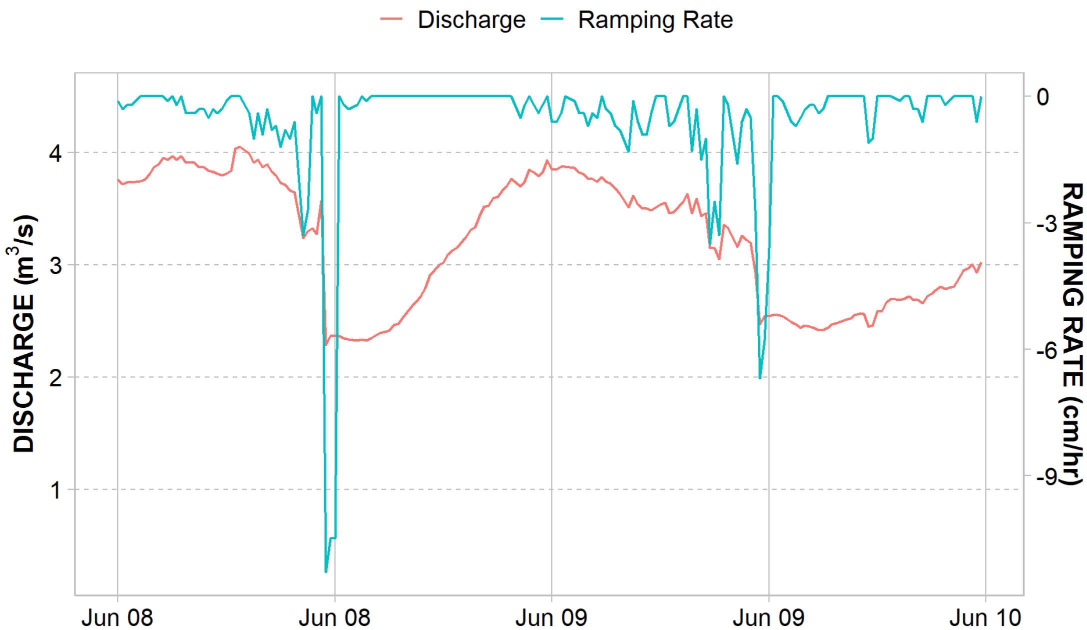


Figure 4. Flow and ramping rate for July 22, 2018 for Measuring Point A.

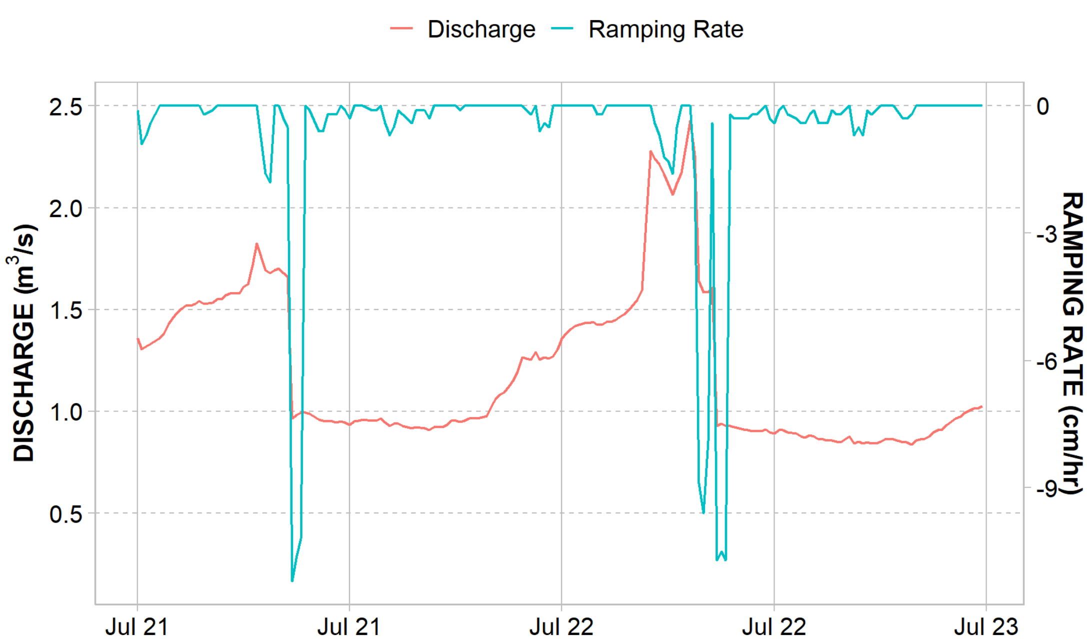


Figure 5. Flow and ramping rate for July 28, 2018 for Measuring Point A.

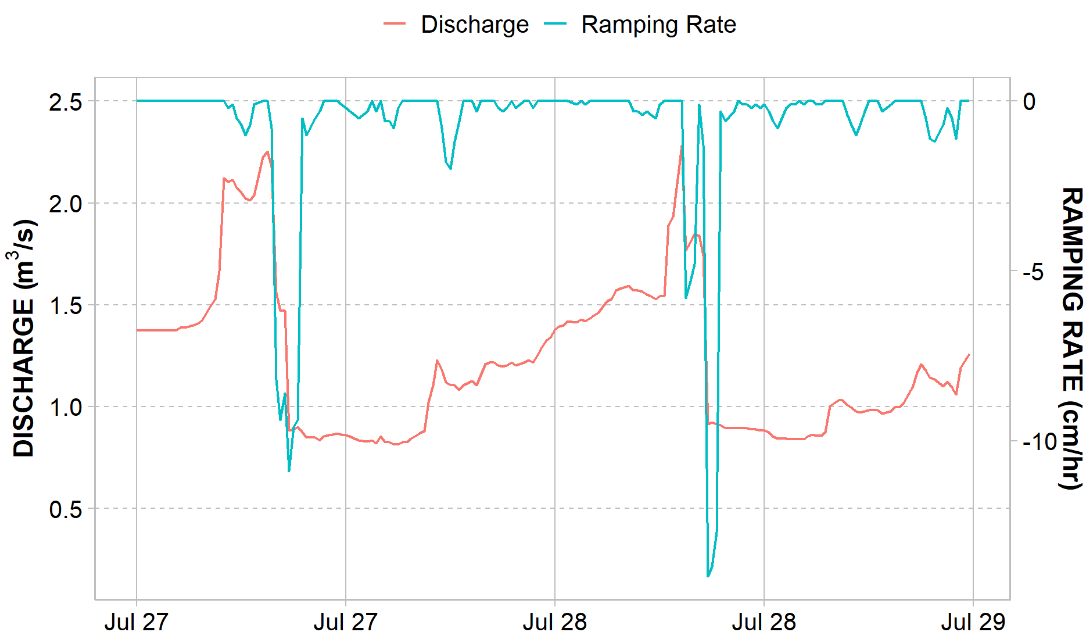


Figure 6. Flow and ramping rate for August 6, 2018 for Measuring Point A.

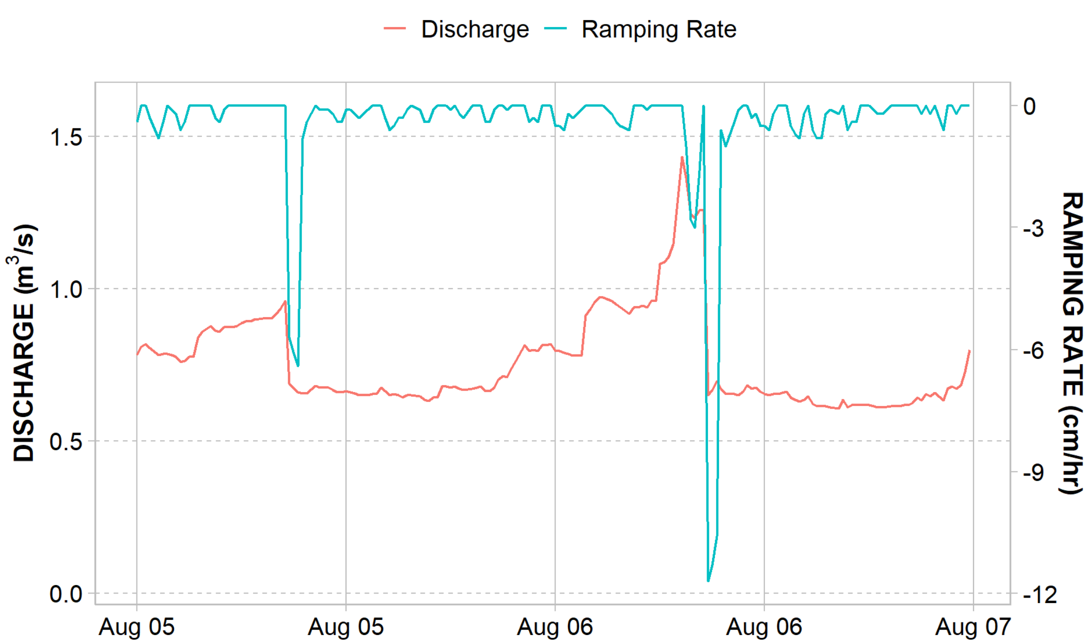


Figure 7. Flow and ramping rate for April 28, 2018 for Measuring Point B.

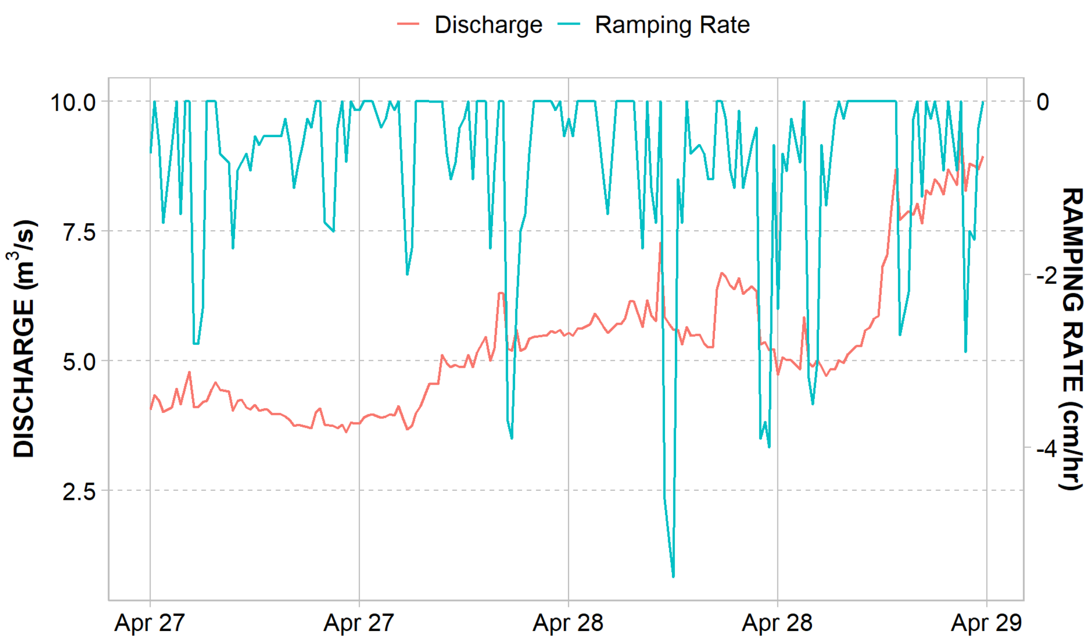


Figure 8. Flow and ramping rate for May 7, 2018 for Measuring Point B.

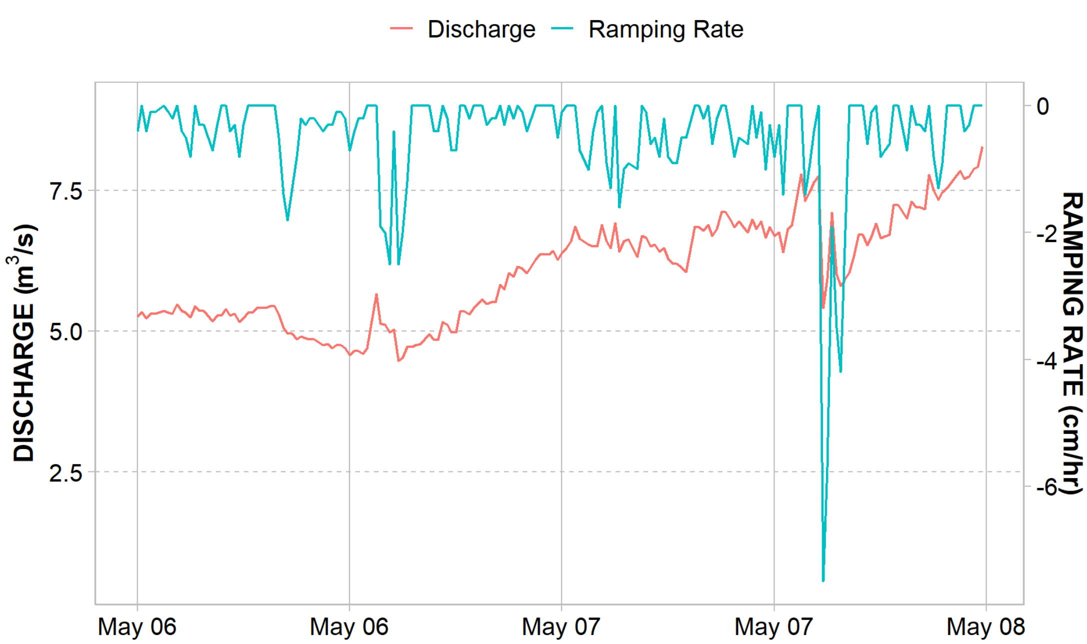


Figure 9. Flow and ramping rate for Potential Exceedance at FRD-SD01 on September 7, 2018.

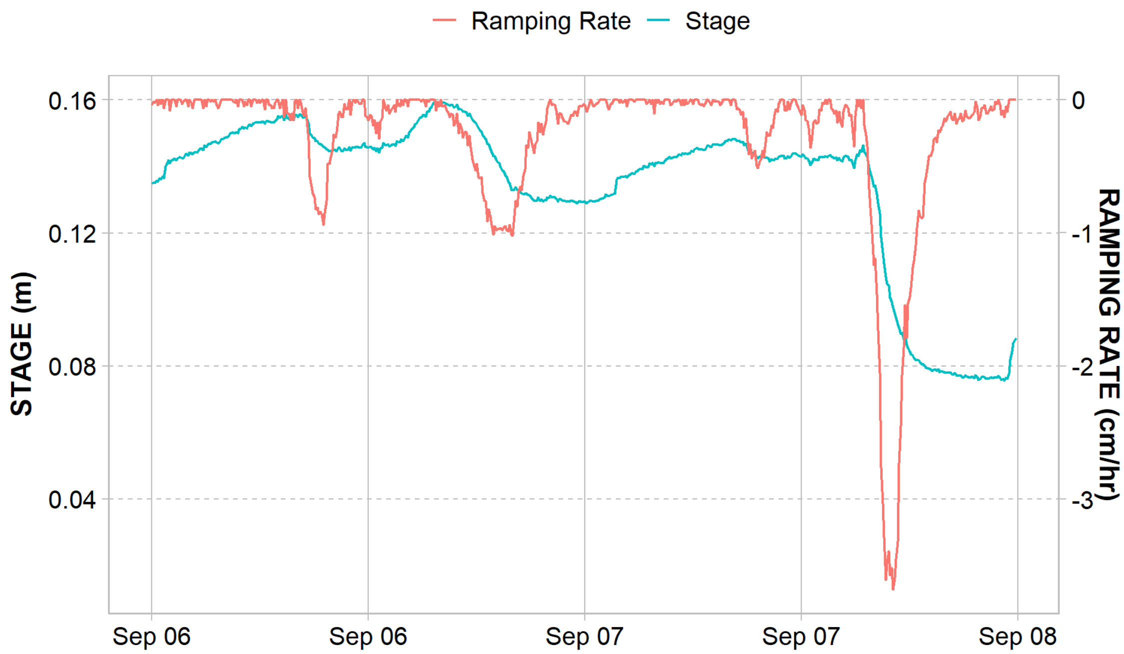


Figure 10. Flow and ramping rate for Potential Exceedance at FRD-SD02 on September 7, 2018.

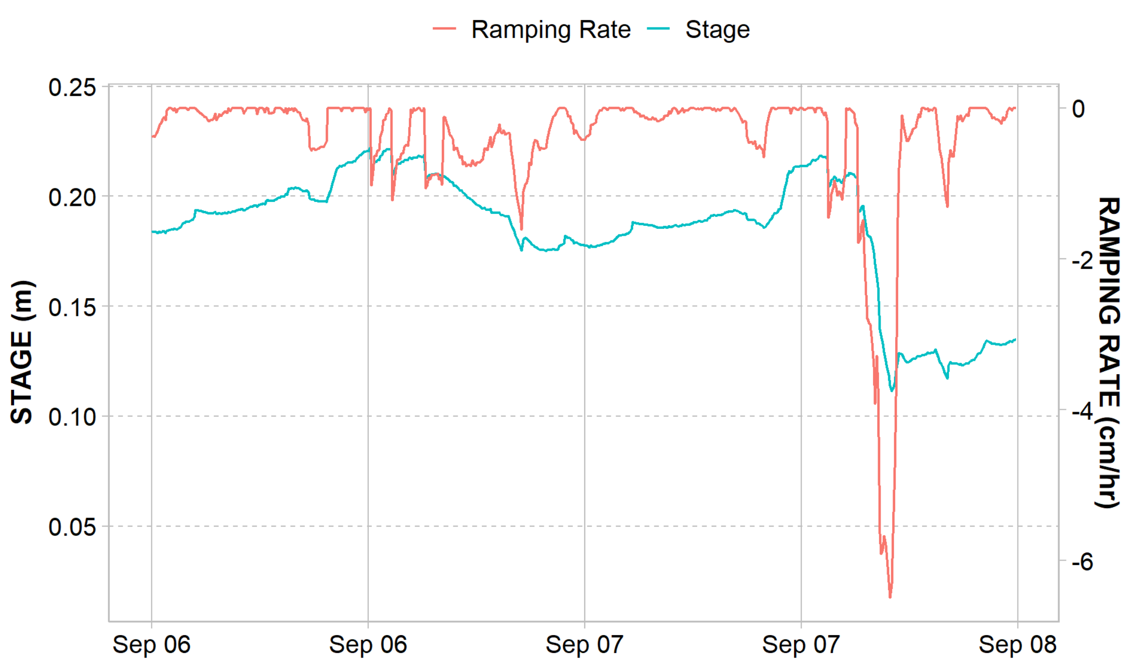


Figure 11. Flow and ramping rate for Potential Exceedance at FRD-SD02 on September 17, 2018.

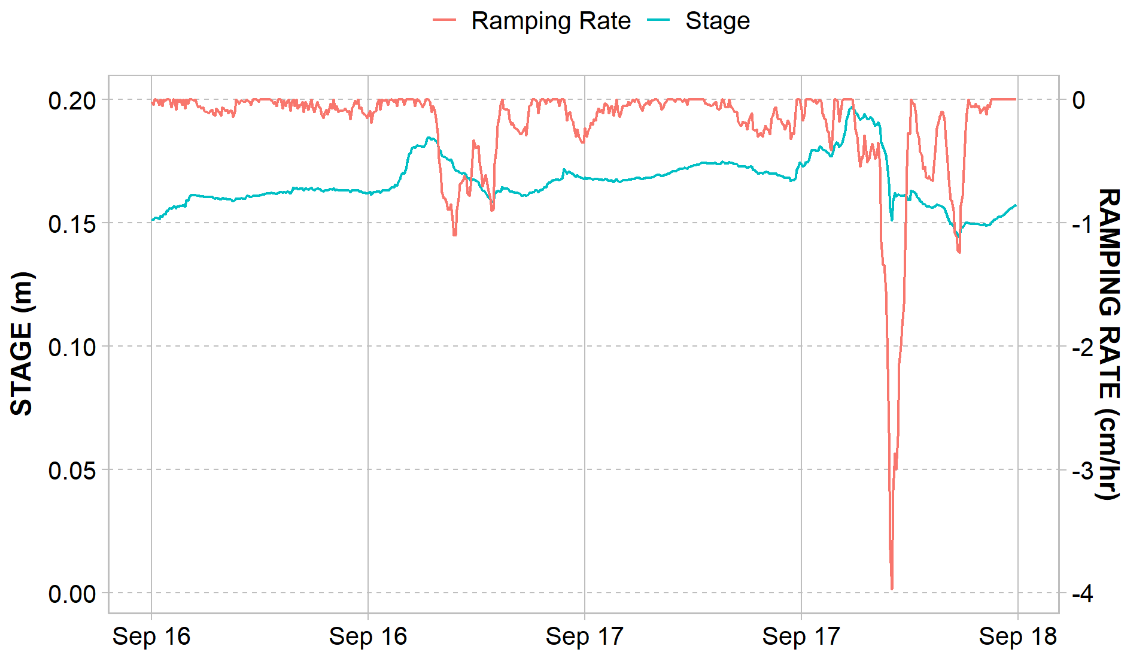


Figure 12. Flow and ramping rate for Potential Exceedance at FRD-SD02 on September 27 and 28, 2018.

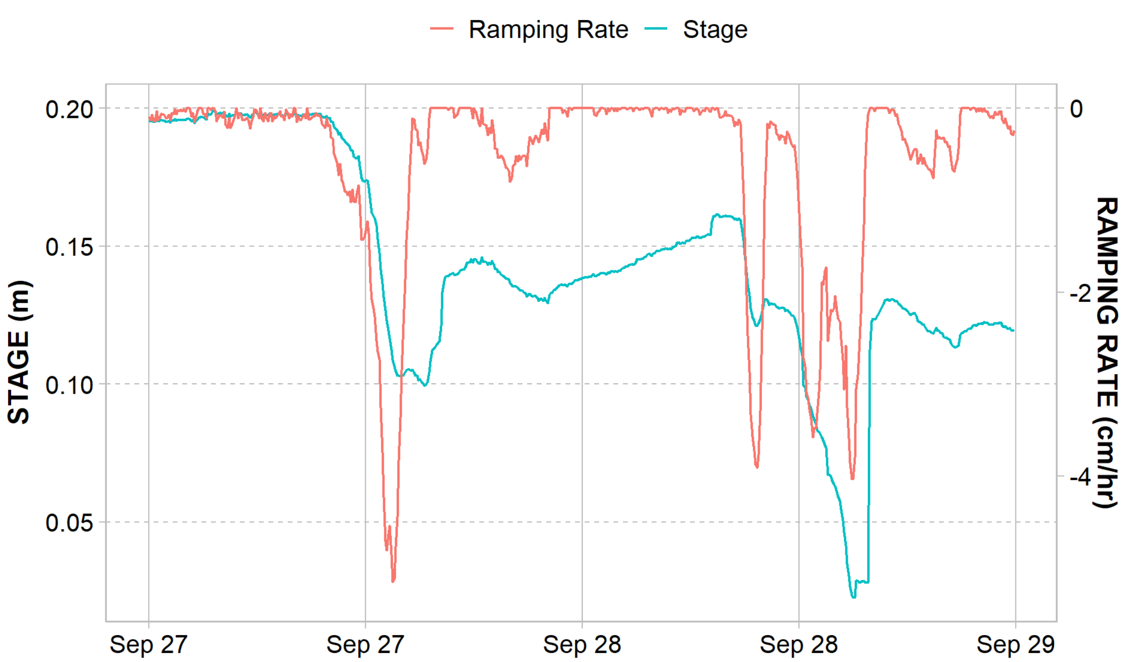


Figure 13. **Flow and ramping rate for Potential Exceedance at FRD-SD02 on October 12, 2018.**

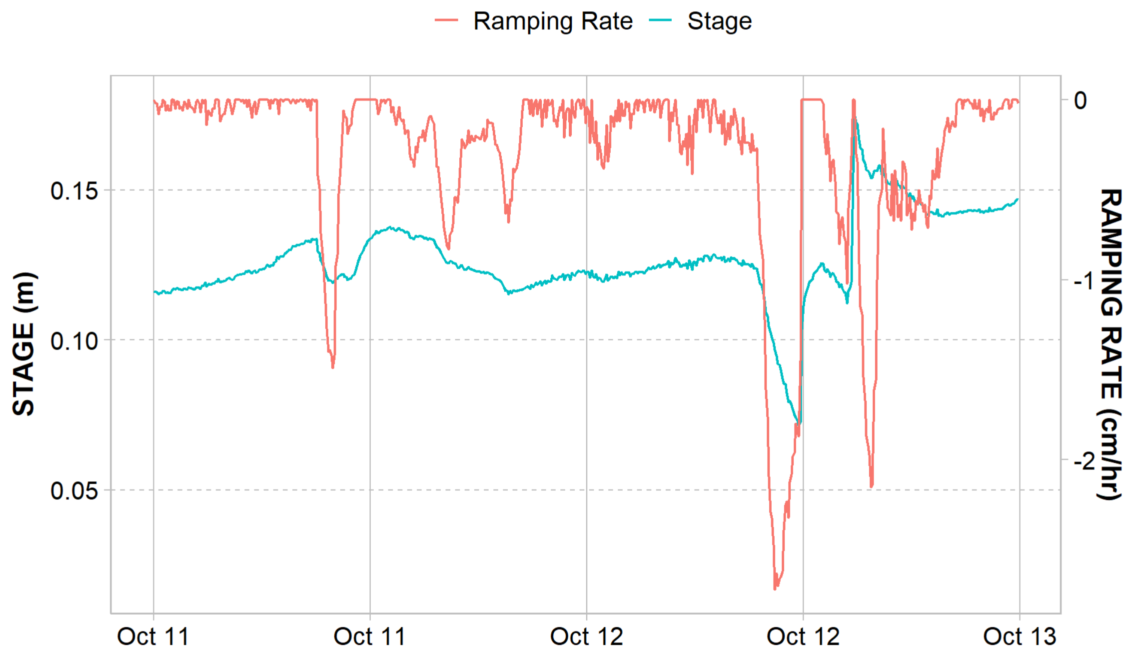


Figure 14. **Flow and ramping rate for Potential Exceedance at FRD-SD02 on October 16, 2018.**

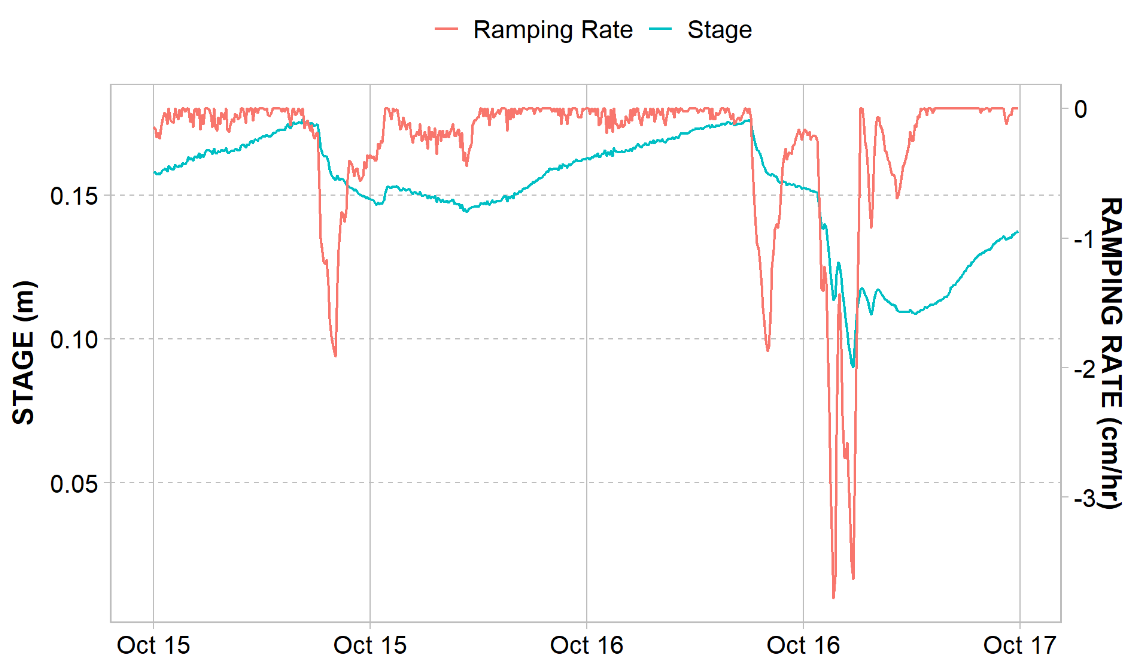


Figure 15. Flow and ramping rate for Potential Exceedance at FRD-SD02 on October 17, 2018.

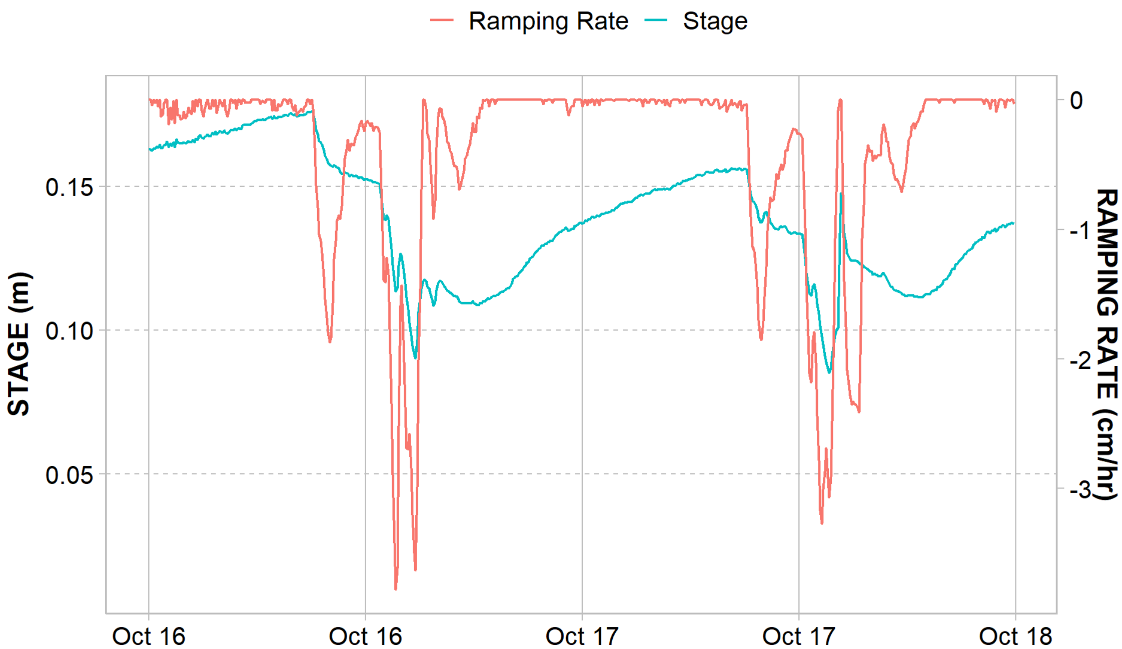


Figure 16. Flow and ramping rate for Potential Exceedance at FRD-SD02 on October 24, 2018.

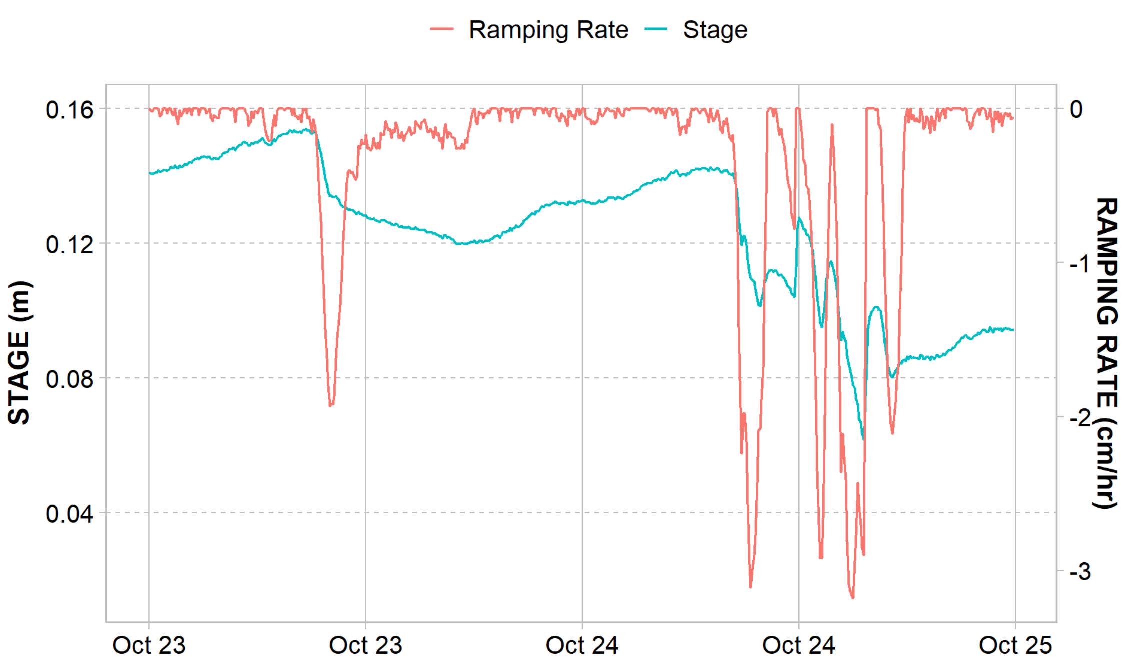


Figure 17. Flow and ramping rate for Potential Exceedance at FRD-LWTR16 on June 18, 2019.

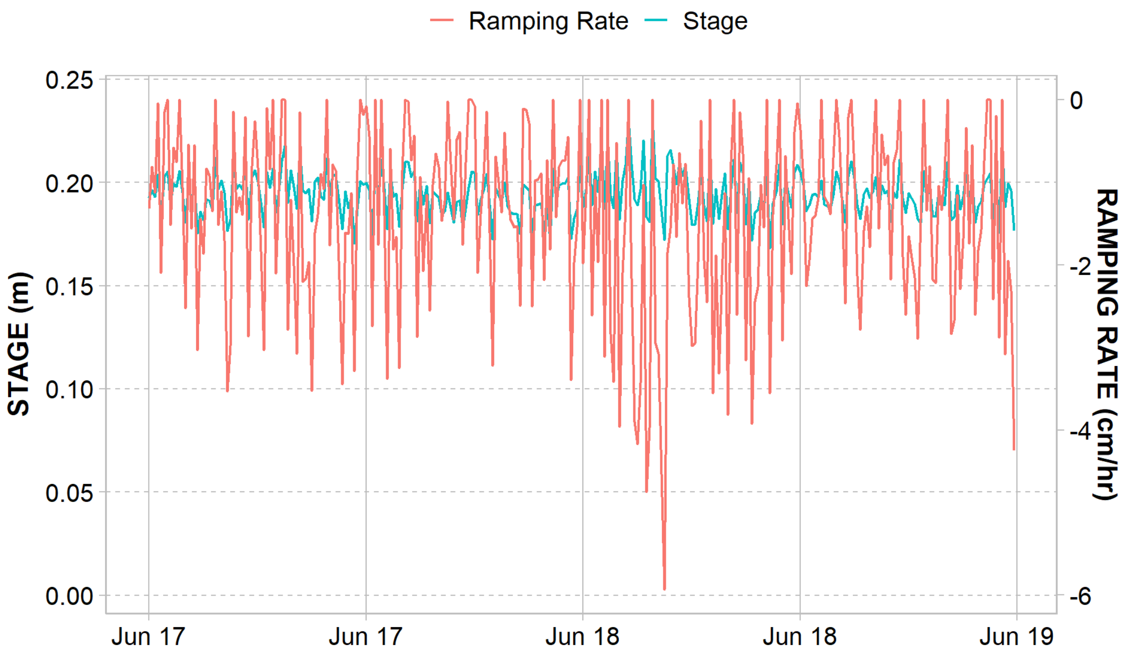


Figure 18. Flow and ramping rate for Potential Exceedance at LCO-DC1 on June 3, 2017.

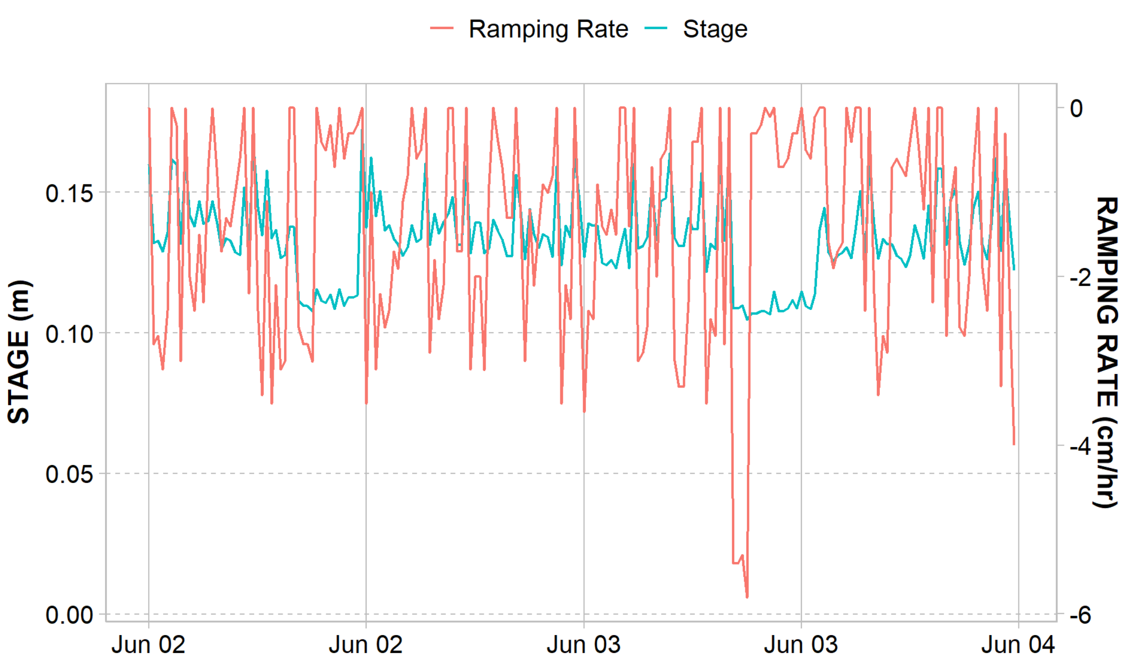


Figure 19. Flow and ramping rate for Potential Exceedances at LCO-DC1 on May 9, 2018.

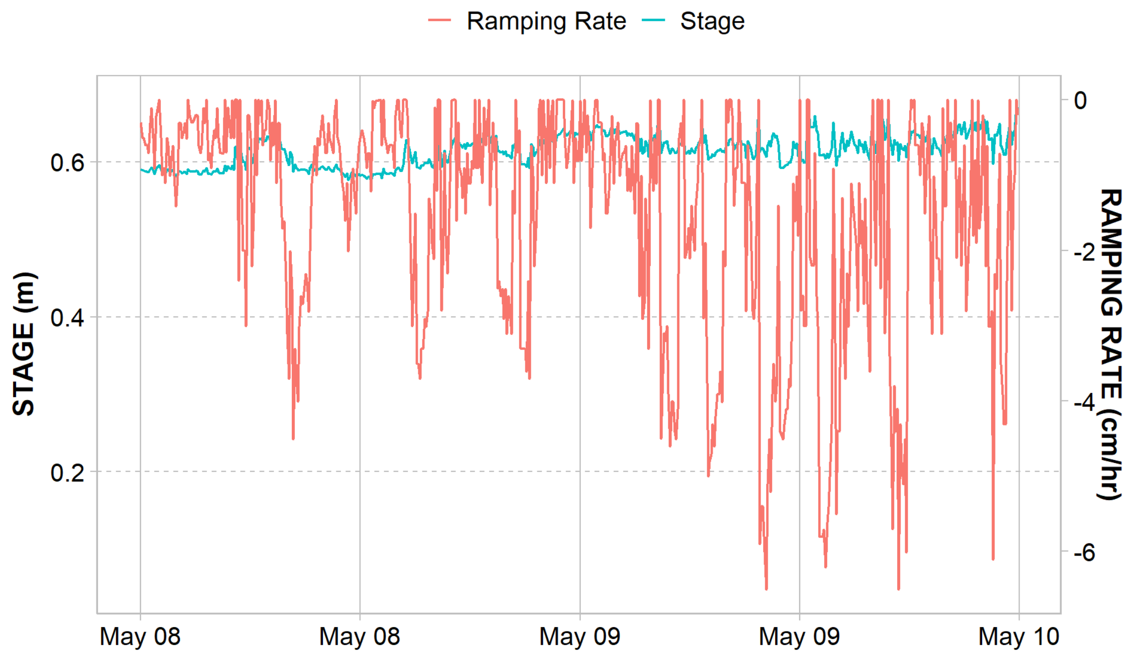


Figure 20. Flow and ramping rate for Potential Exceedance at LCO-DC1 on May 10, 2018.

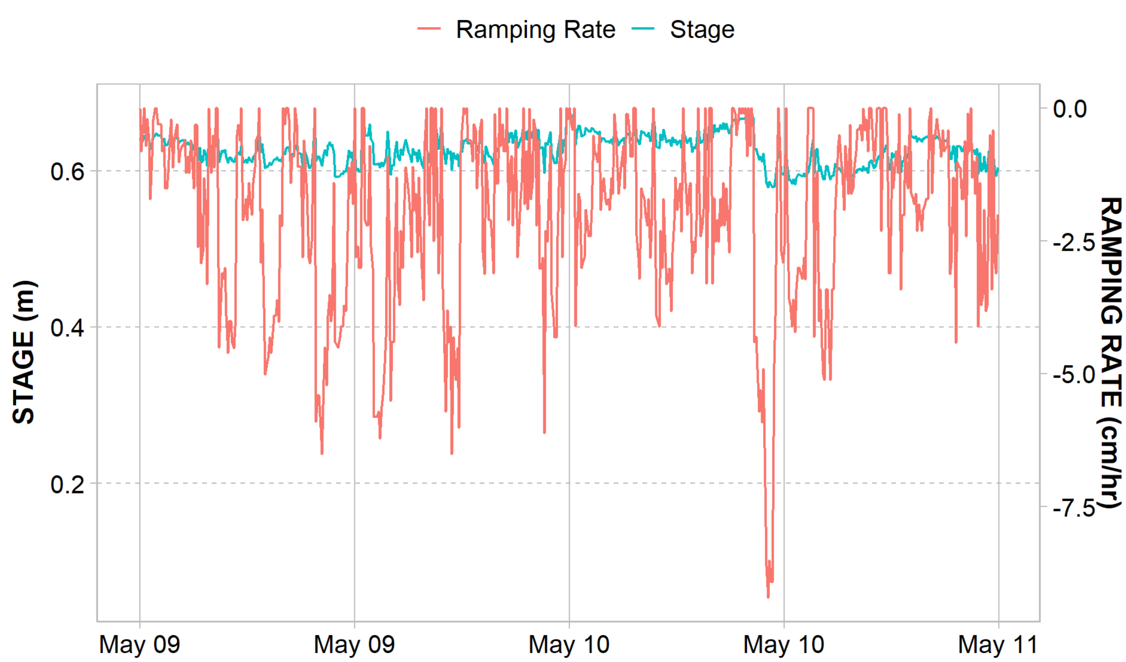


Figure 21. Flow and ramping rate for Potential Exceedance at LCO-DC1 on May 11, 2018.

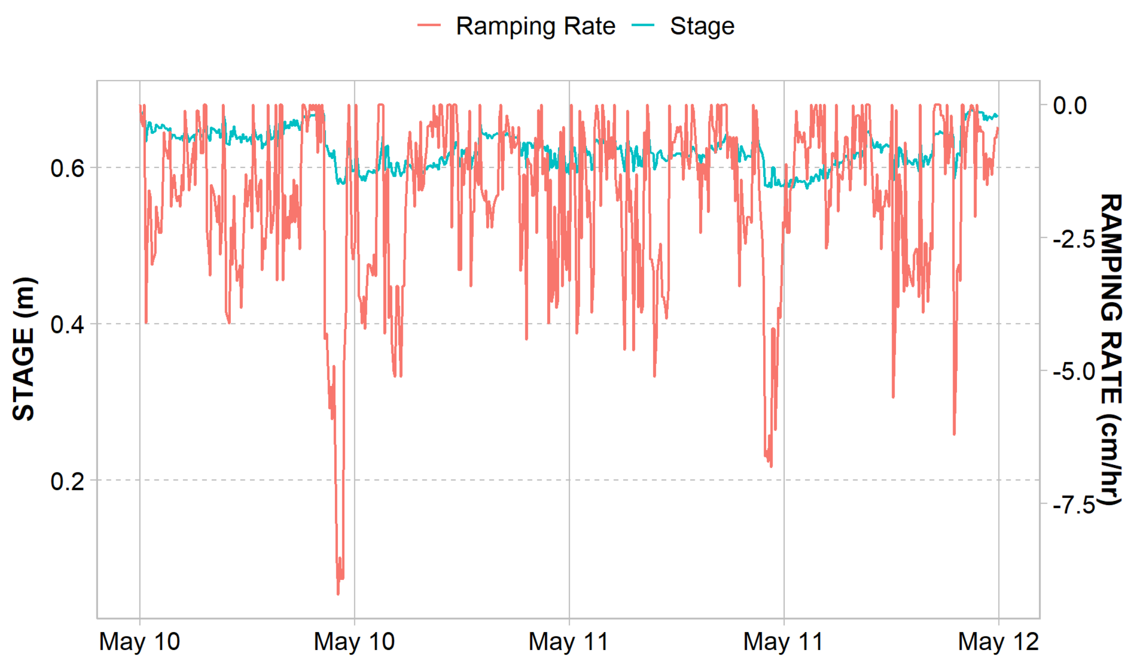


Figure 22. Flow and ramping rate for Potential Exceedances at LCO-DC1 on May 12, 2018.

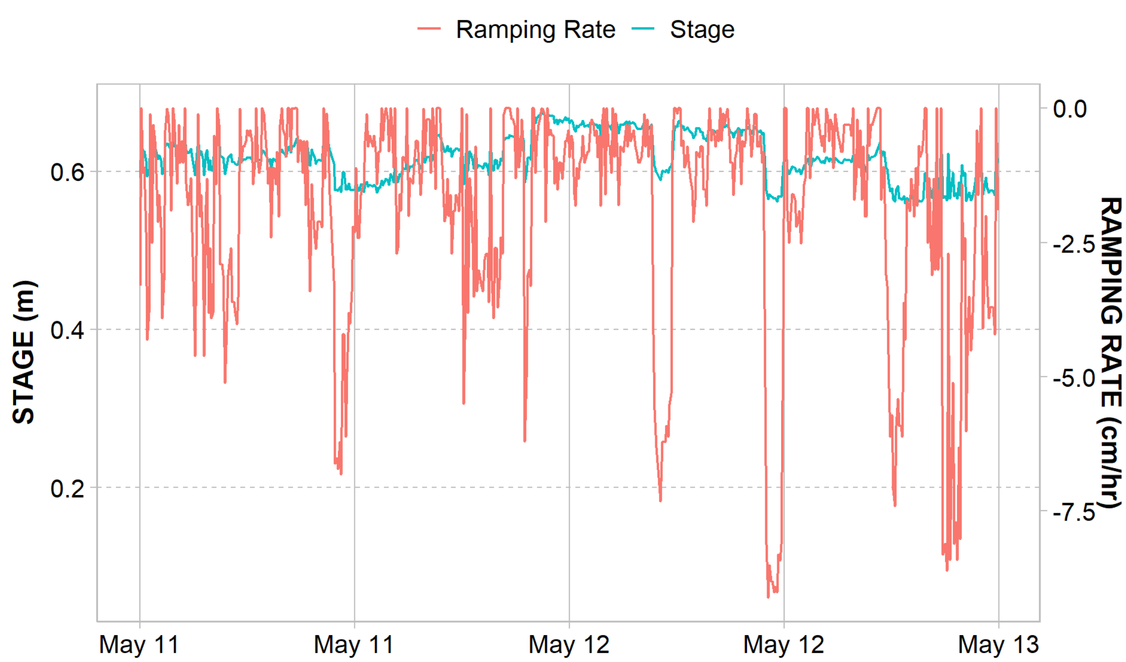


Figure 23. Flow and ramping rate for Potential Exceedances at LCO-DC1 on May 13, 2018.

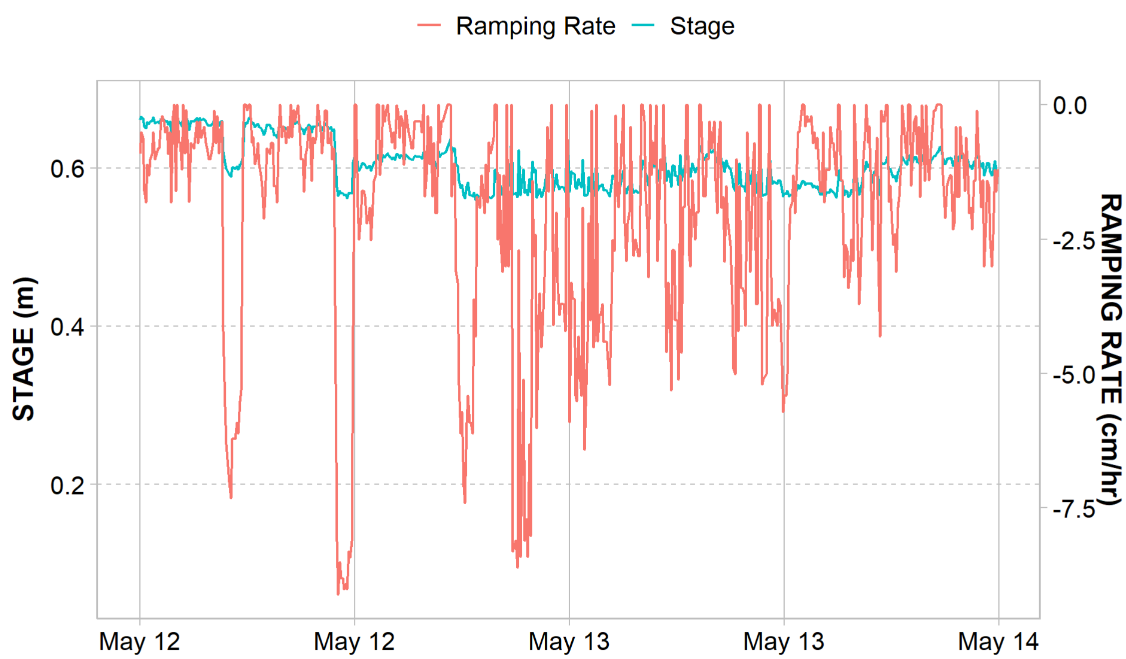


Figure 24. Flow and ramping rate for Potential Exceedance at LCO-DC1 on May 14, 2018.

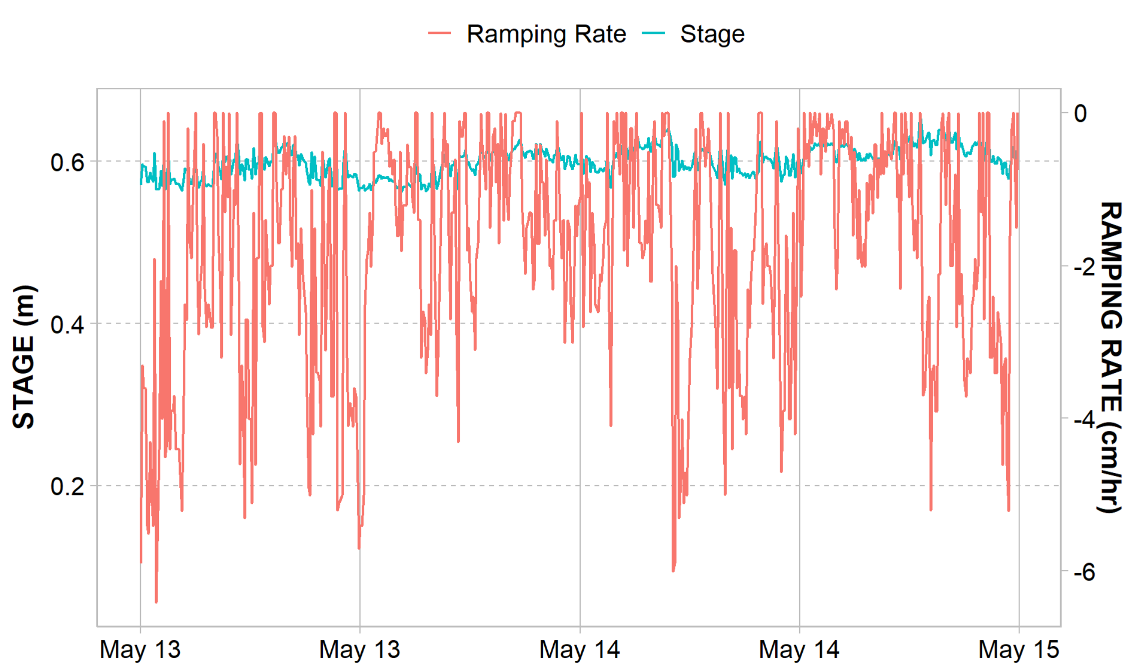


Figure 25. Flow and ramping rate for Potential Exceedance at LCO-DC1 on May 15, 2018.

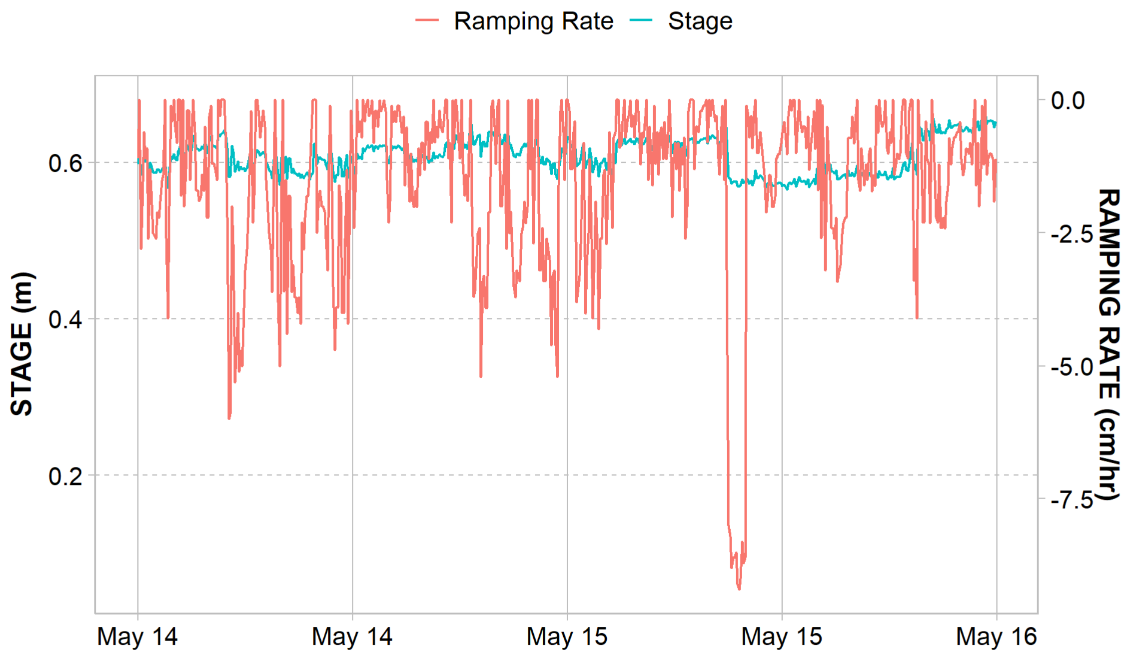


Figure 26. Flow and ramping rate for Potential Exceedance at LCO-DC1 on May 16, 2018.

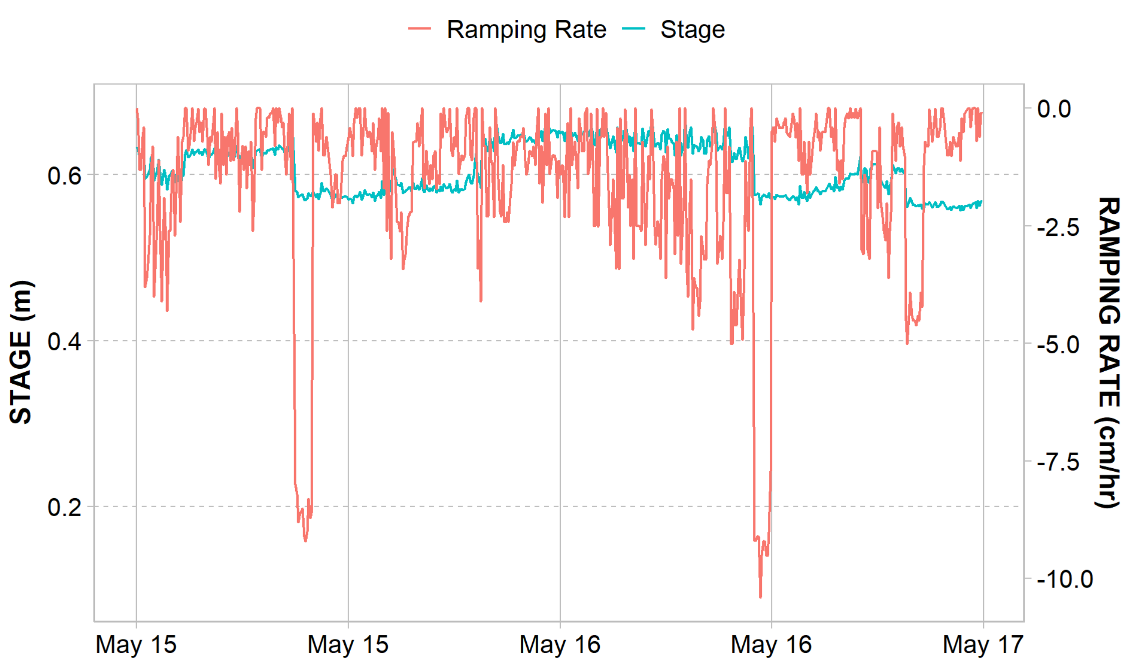


Figure 27. Flow and ramping rate for Potential Exceedances at LCO-DC1 on May 22, 2018.

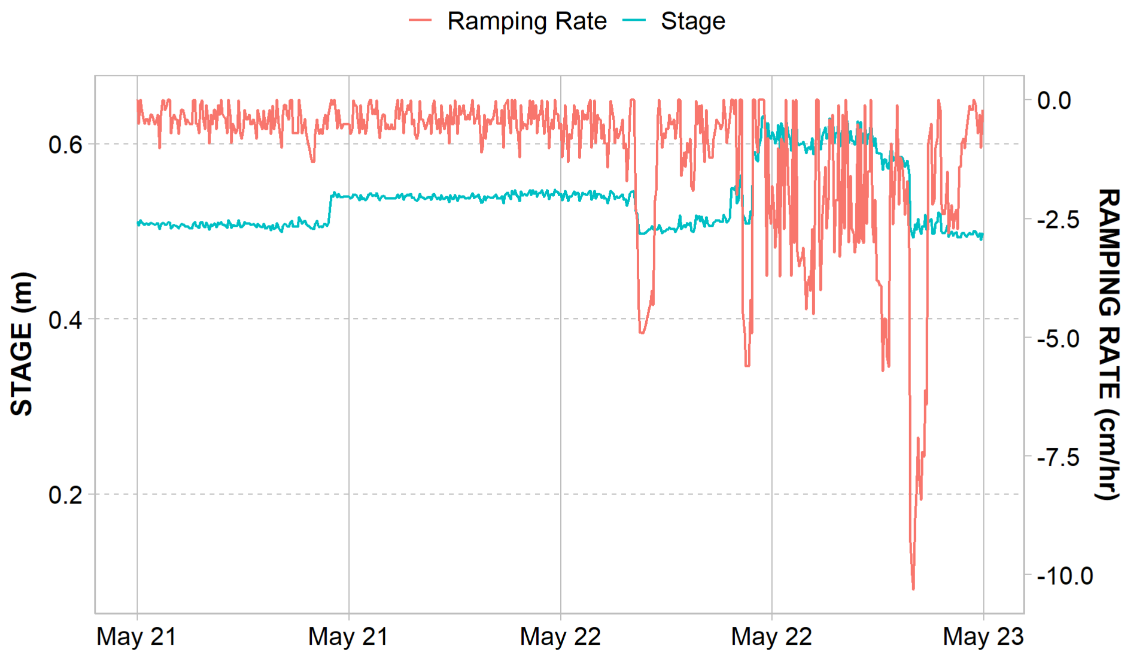


Figure 28. Flow and ramping rate for Potential Exceedance at LCO-DC1 on May 23, 2018.

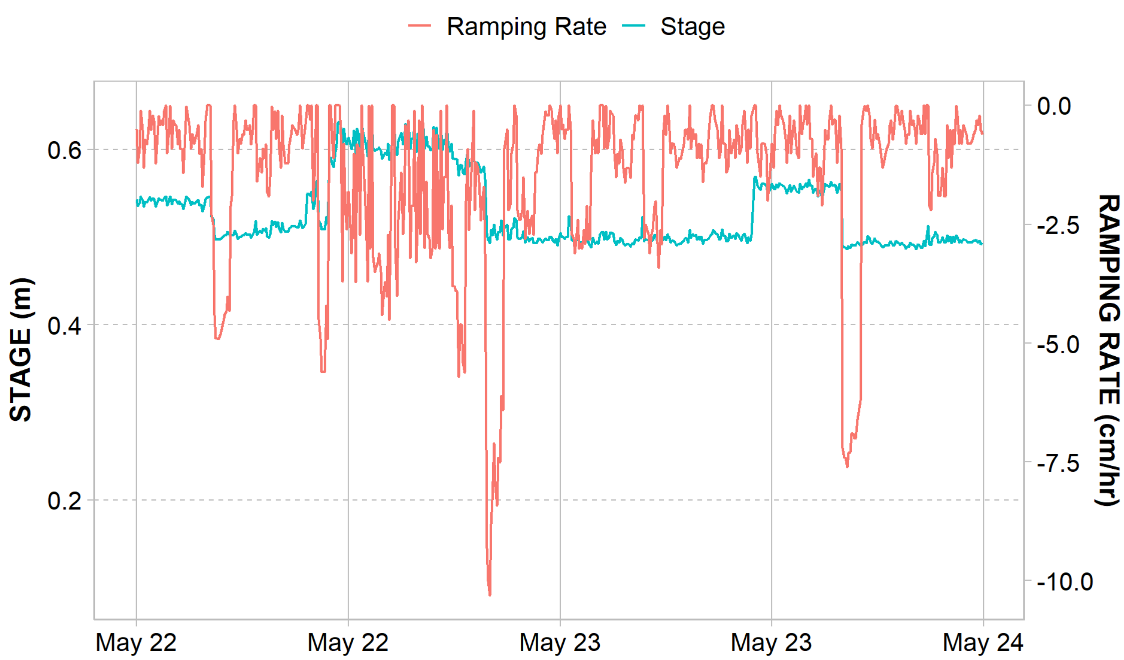


Figure 29. Flow and ramping rate for Potential Exceedance at LCO-DC1 on May 24, 2018.

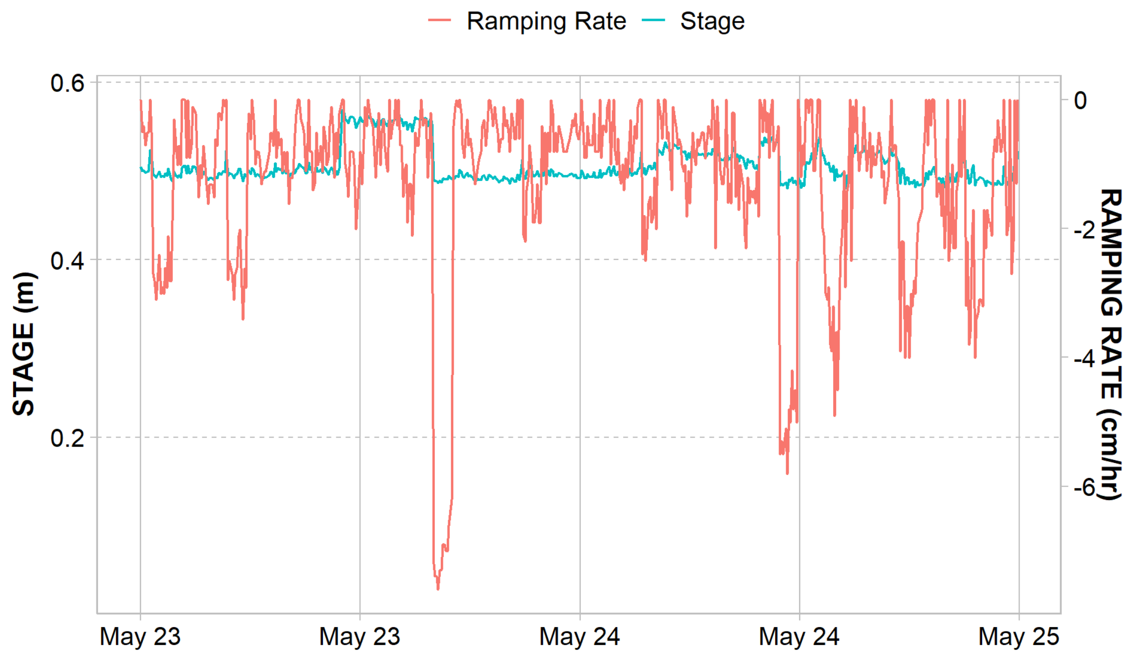


Figure 30. Flow and ramping rate for Potential Exceedance at LCO-DC1 on May 25, 2018.

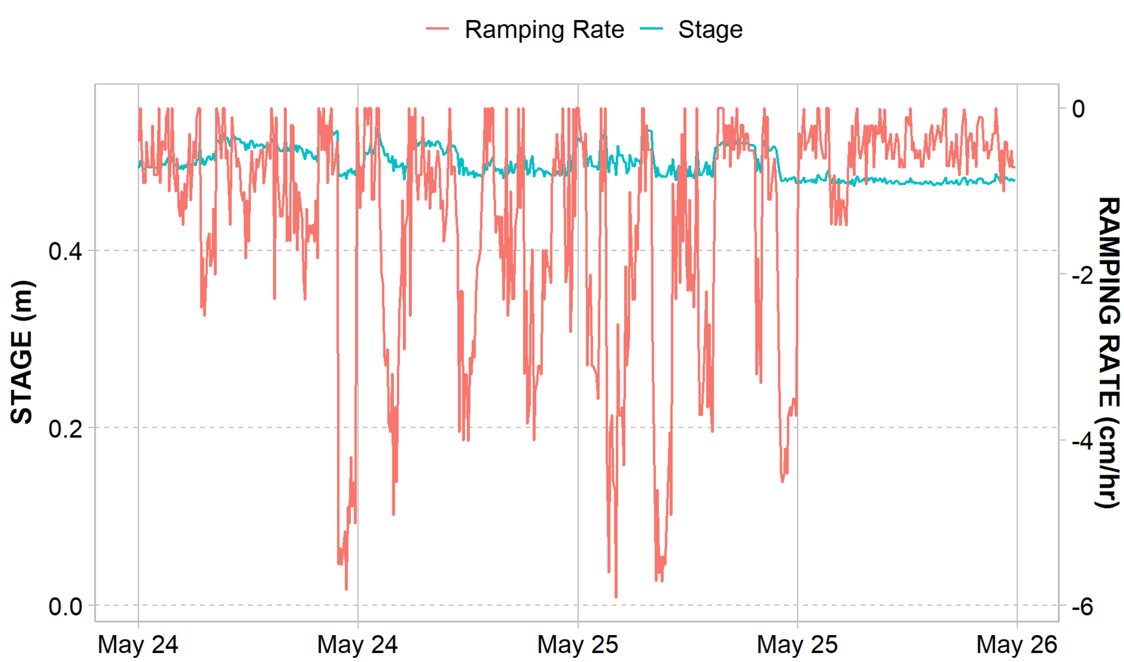


Figure 31. Flow and ramping rate for Potential Exceedance at LCO-DC1 on August 18, 2018.

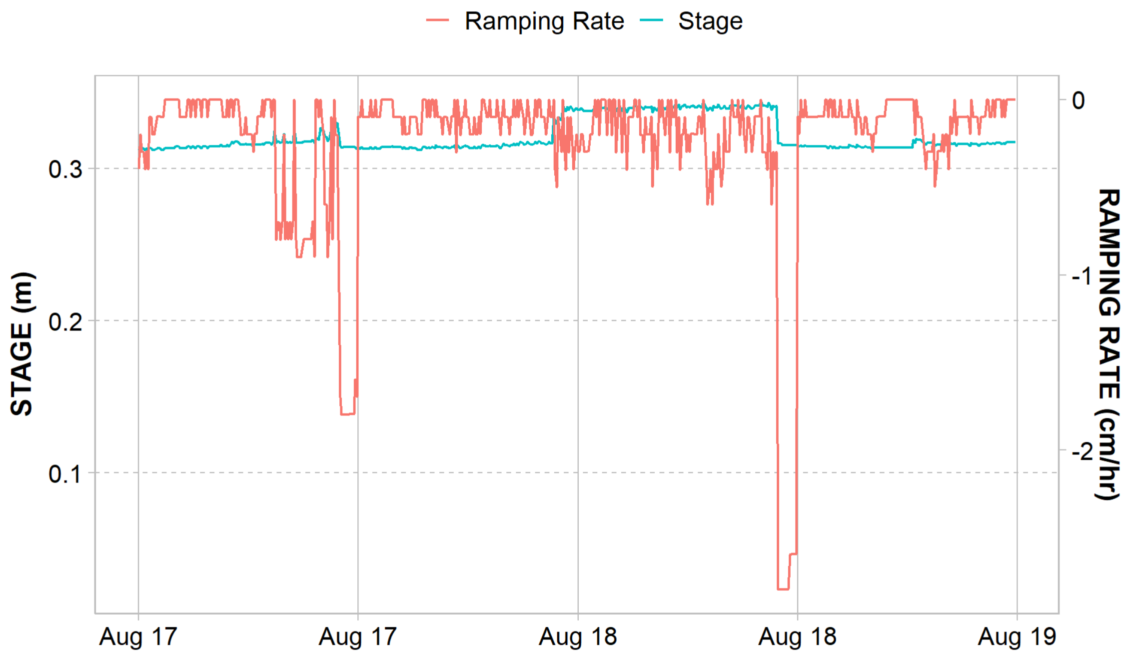


Figure 32. Flow and ramping rate for Potential Exceedance at LCO-DC1 on August 27, 2018.

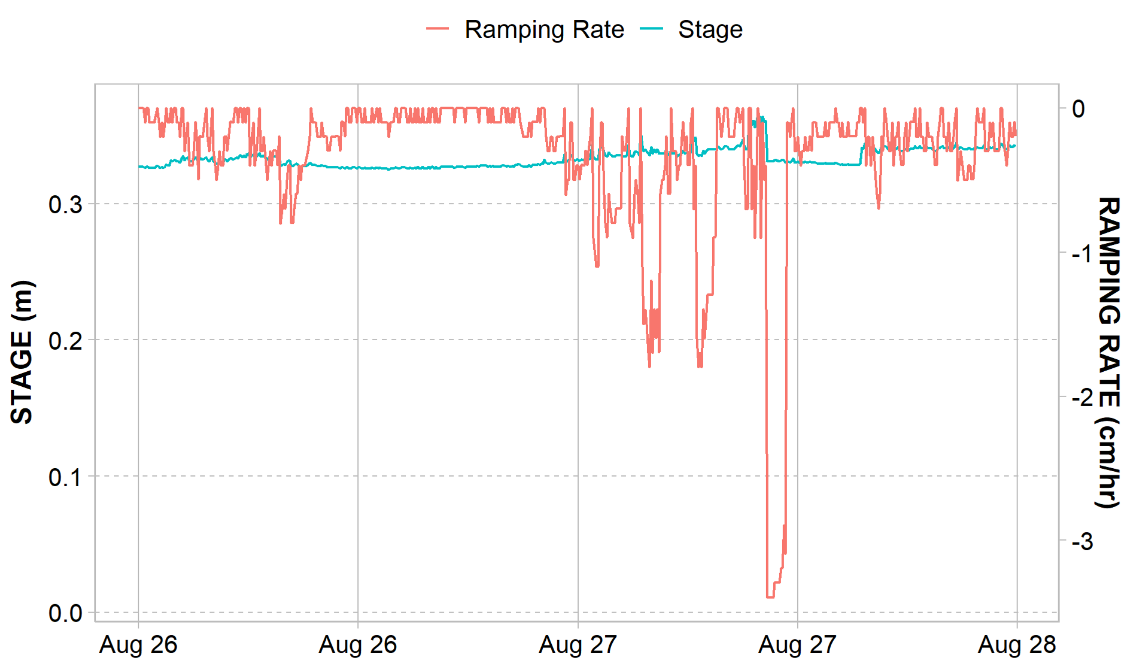


Figure 33. Flow and ramping rate for Potential Exceedances at LCO-DC1 on September 4, 2018.

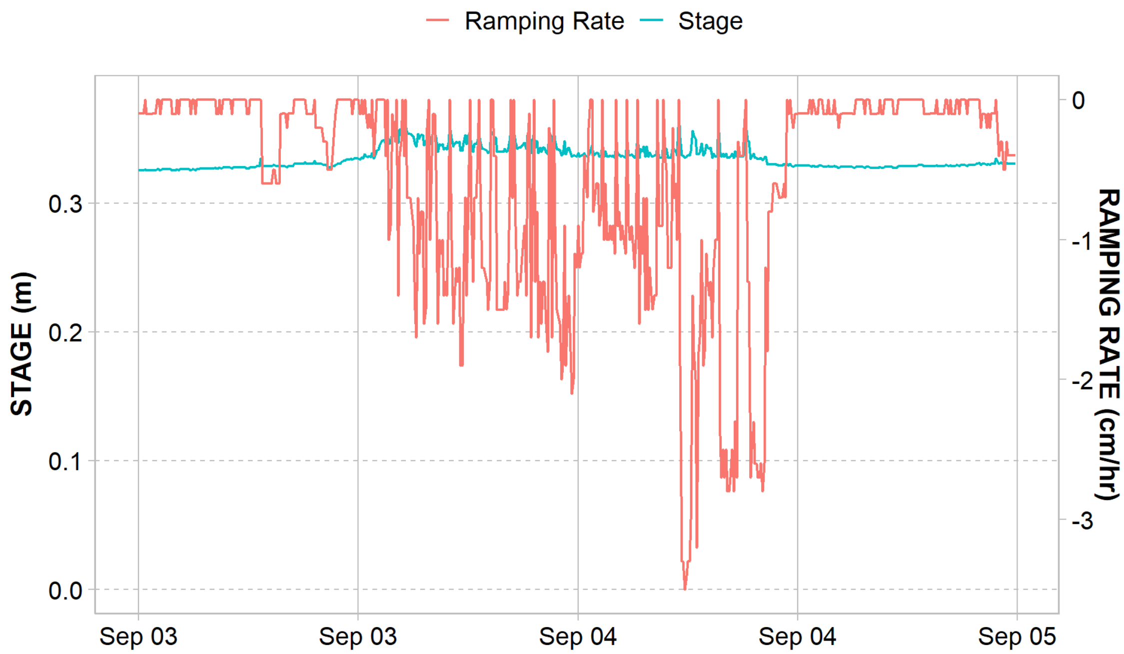


Figure 34. Flow and ramping rate for Potential Exceedance at LCO-DC1 on September 8, 2018.

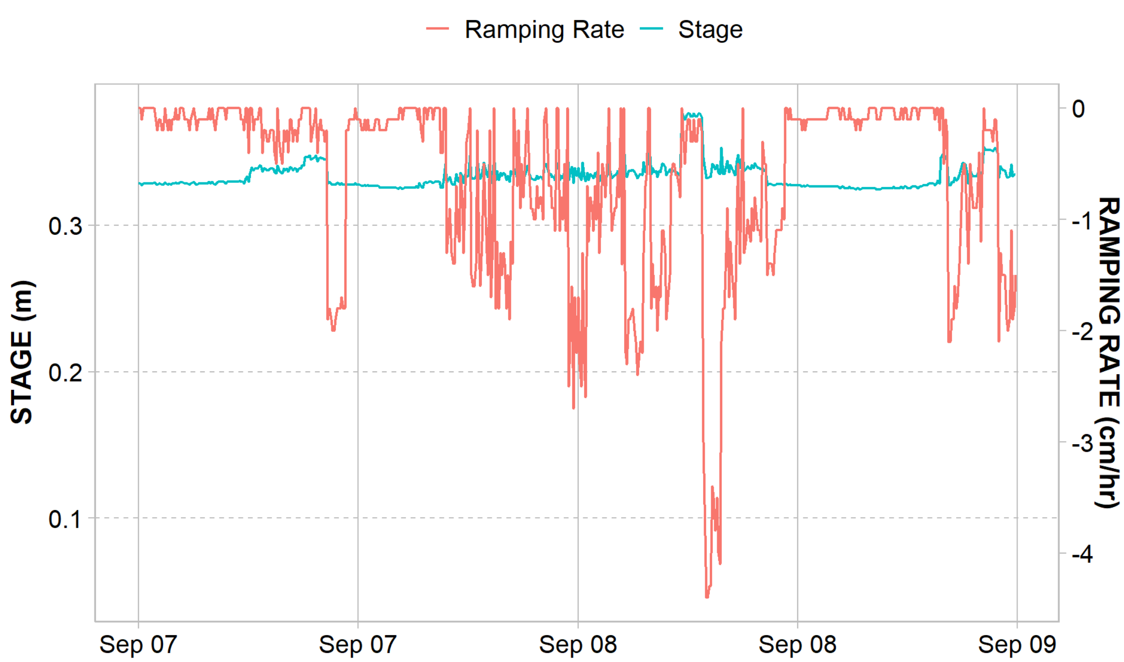


Figure 35. Flow and ramping rate for Potential Exceedances at LCO-DC1 on September 9, 2018.

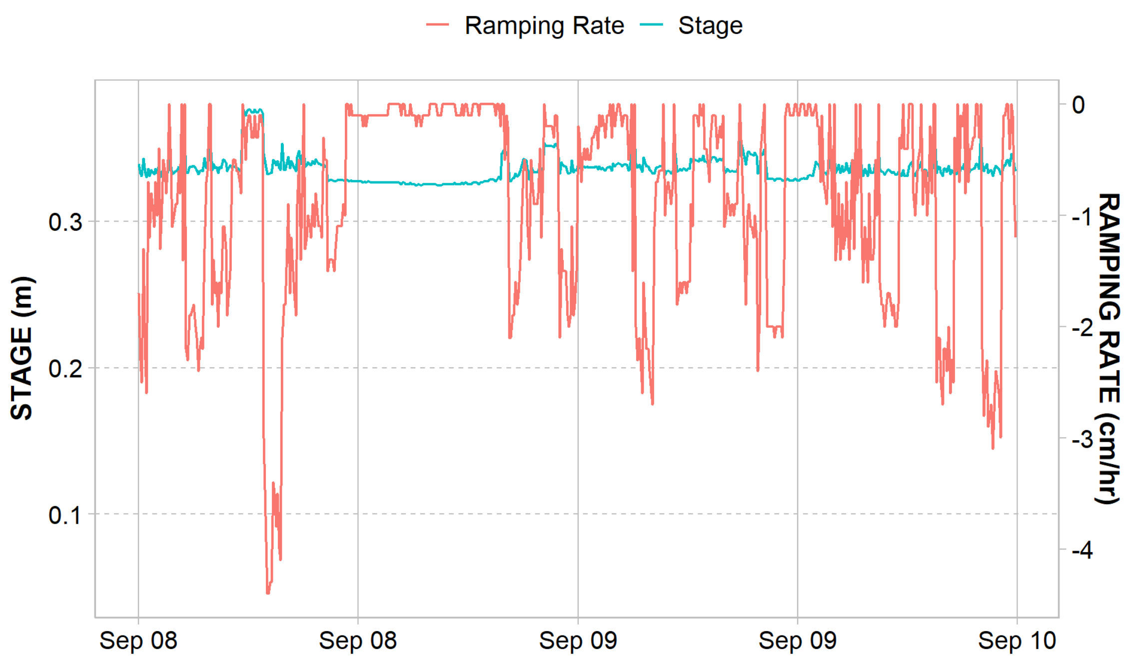


Figure 36. Flow and ramping rate for Potential Exceedance at LCO-DC1 on September 10, 2018.

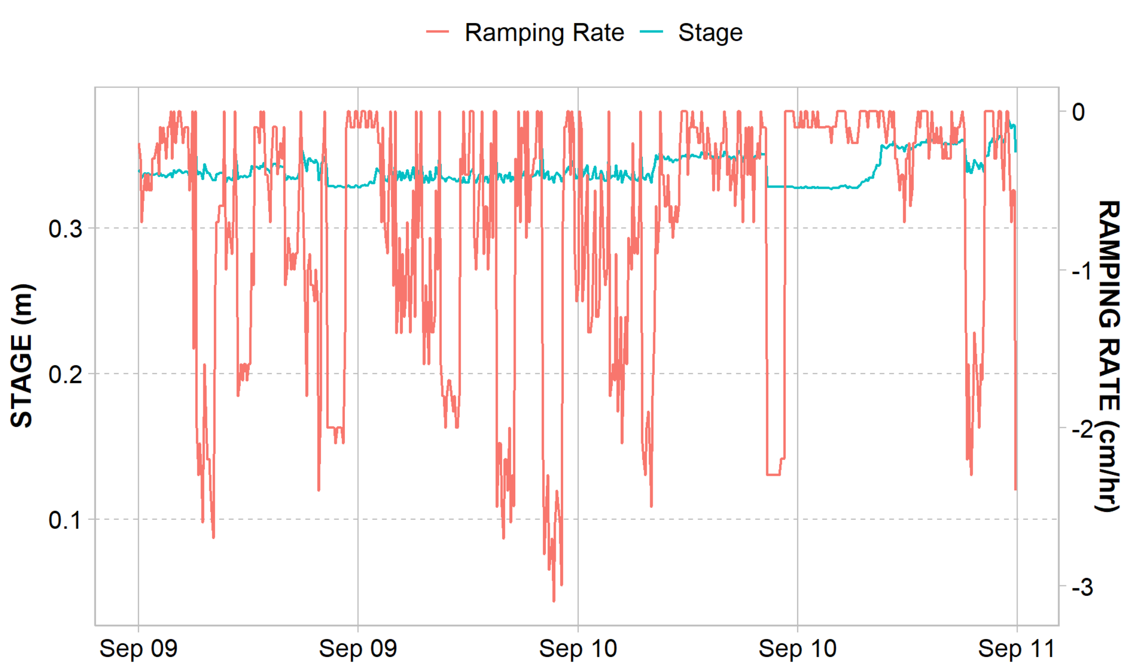


Figure 37. Flow and ramping rate for Potential Exceedances at LCO-DC1 on September 14, 2018.

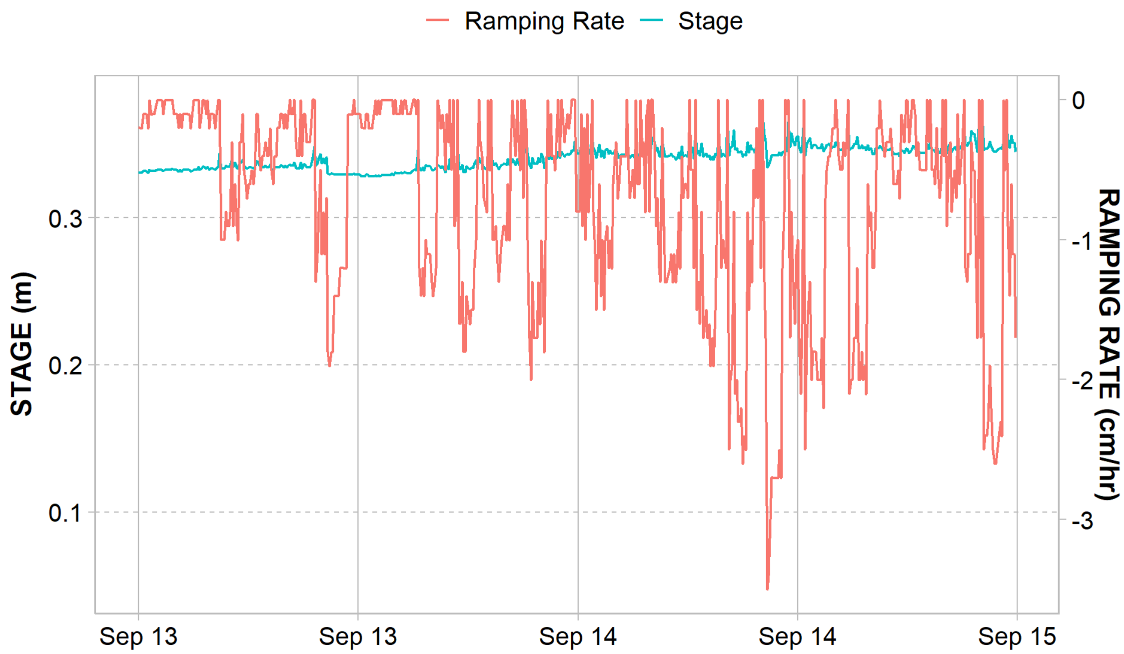


Figure 38. Flow and ramping rate for Potential Exceedances at LCO-DC1 on September 15, 2018.

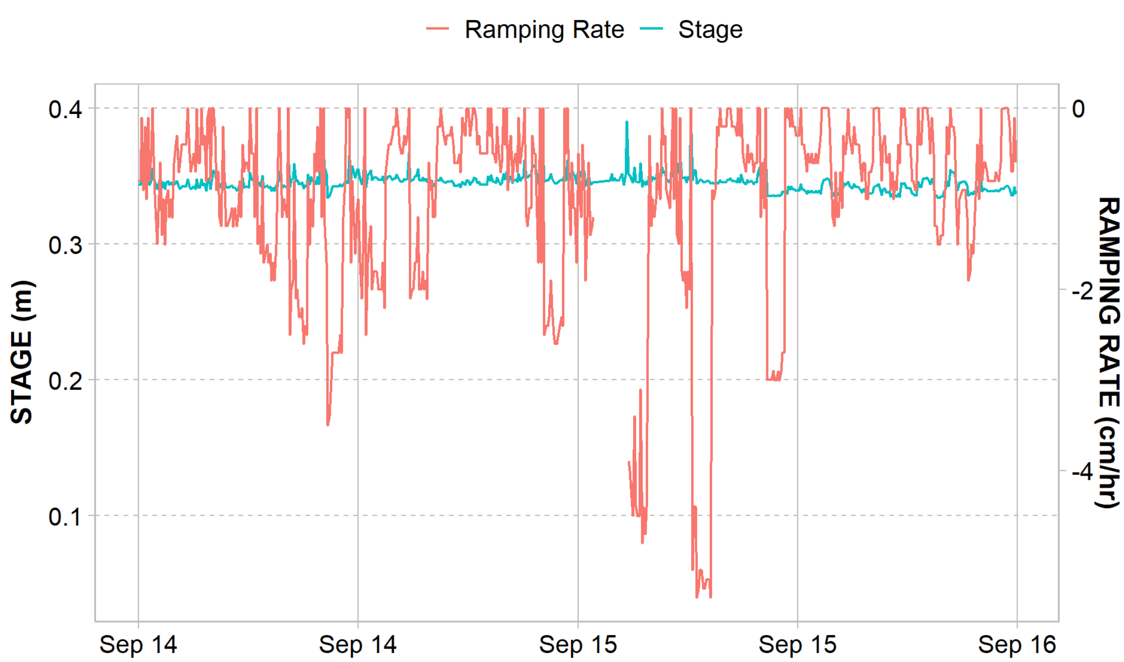


Figure 39. Flow and ramping rate for Potential Exceedances at LCO-DC1 on September 16, 2018.

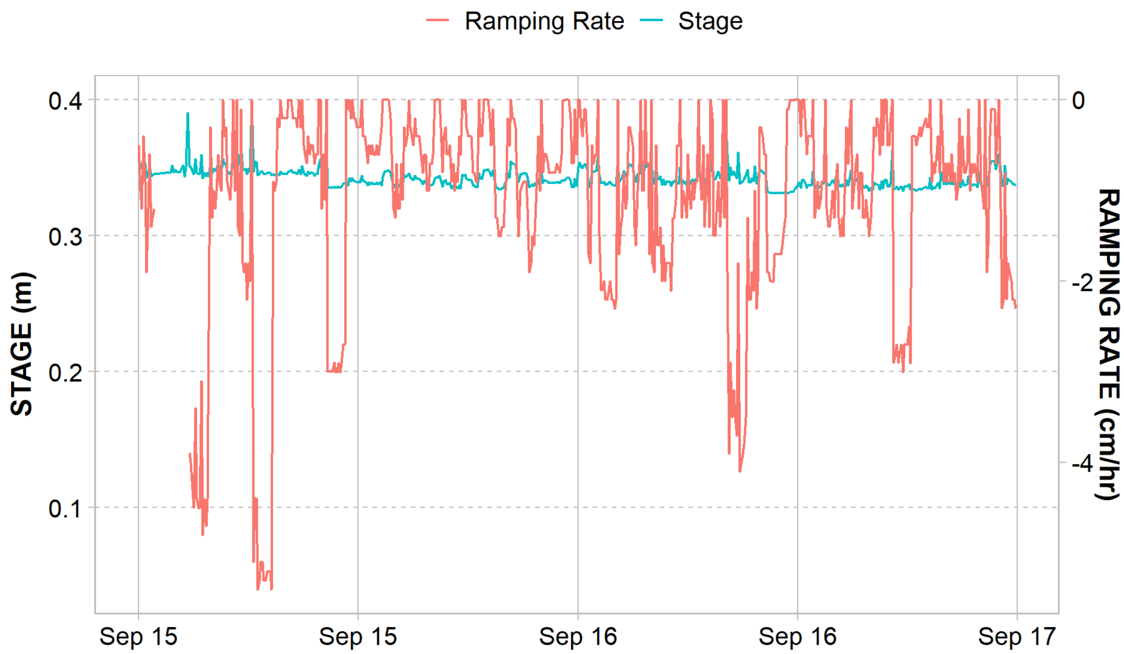


Figure 40. Flow and ramping rate for Potential Exceedances at LCO-DC1 on September 17, 2018.

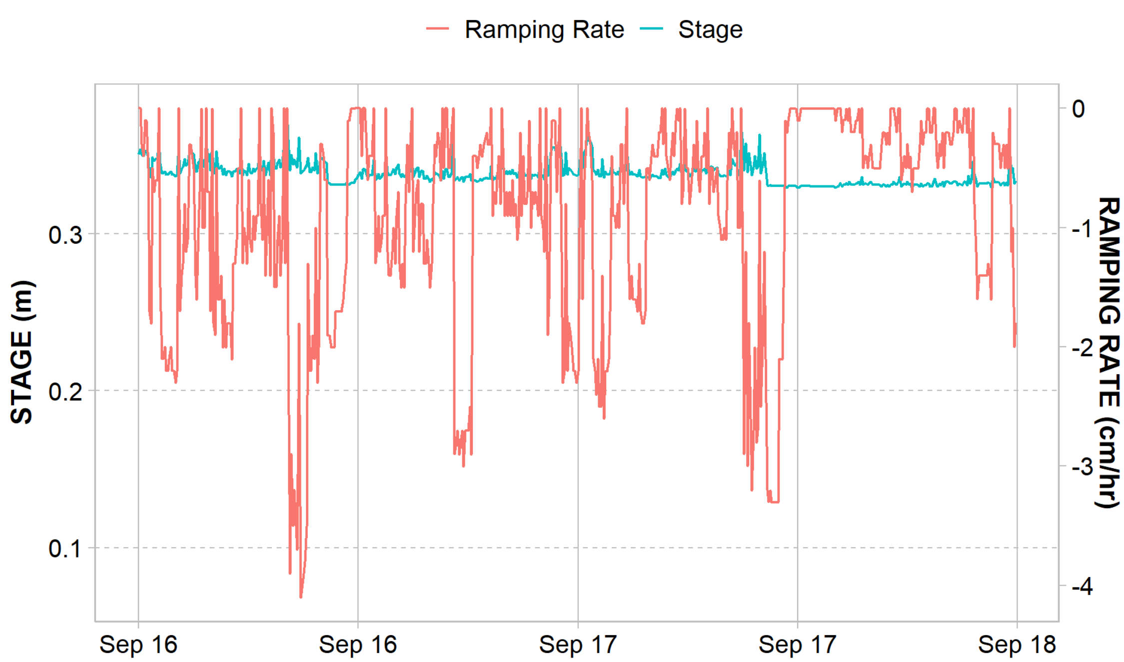


Figure 41. Flow and ramping rate for Potential Exceedance at LCO-DC1 on October 3, 2018.