Continuous Riverbed Monitoring around Raked Bridge Piles in the Fraser River

Andre Zimmermann, Principal Geomorphologist, Northwest Hydraulic Consultants Ltd., Vancouver, BC, Canada azimmermann@nhcweb.com

Ryan Bradley, Geomorphologist, Northwest Hydraulic Consultants Ltd., Vancouver, BC, Canada rbradley@nhcweb.com

Tim Argast, Geomorphologist, Northwest Hydraulic Consultants Ltd., Vancouver, BC, Canada targast@nhcweb.com

Ashley Dudill, Hydrotechnical Engineer, Northwest Hydraulic Consultants Ltd., Vancouver, BC, Canada adudill@nhcweb.com

Introduction

Northwest Hydraulic Consultants Ltd. (NHC) has worked collaboratively with the British Columbia Ministry of Transportation and Infrastructure to explore the feasibility of installing and operating instrumentation on bridge piers to continuously monitor riverbed elevations. The monitoring furthers our understanding of pier scour in complex locations, and provides a mechanism to quickly alert asset owners of developing problematic pier scour. This paper describes the development and analysis of a Real-time Scour Monitoring System (RSMS) installed on the Middle Arm Bridge, crossing the Fraser River in British Columbia, Canada.

Overview

Middle Arm Bridge, Fraser River

The Fraser River is the largest river on the west coast of Canada, draining ~ 232,000 km^2 of southern British Columbia into the Strait of Georgia. The Fraser River has a snowmelt-dominated flow regime; discharges typically rise in April, peak between May and July, and then recede during the autumn and winter months. Discharges on the lower Fraser River are commonly referenced to the long-term Water Survey of Canada hydrometric station in the town of Hope, which is situated approximately 160 km upstream of the Strait of Georgia, upstream of any tidal influence. The long-term mean flow at Hope is 2,800 m^3/s and the mean annual flood peak from 1990 to 2020 was 8,600 m^3/s. The Middle Arm of the Fraser River is a distributary of the Fraser Delta and carries 5 to 10% of the total river flow.

The Middle Arm Bridge is approximately 7 km upstream of the Strait of Georgia. Consequently, hydraulics at the bridge are governed by both freshwater inflows and tides. Rising and falling tides result in bi-directional flow at the bridge. Further, the tides result in the presence of saline water, which is common in estuarine environments. In addition to the complexity introduced by the tidal influence, the Middle Arm Bridge was selected for the study because of the distinct pier arrangement. Most of the pier piles are raked, meaning they are inclined or battered in a direction other than streamwise. The raked piles are angled at 40° and 130° to the streamwise axis of the pier and inclined at 1H:5V. The raked bearing piles are steel pipes with diameters of

762 mm. Additionally, the central bridge piers have large fenders to prevent damage from vessel impacts. The fenders are floating, so they rise and fall with water level.

Real-time Scour Monitoring System

The Real-time Scour Monitoring System (RSMS) was installed on the fender of a central pier of the Middle Arm Bridge. The RSMS is primarily composed of:

- Two (2) Kongsberg Dual Axis Scanning (DAS) sensors that perform scans of riverbed elevations every 12 hours. One DAS was installed to enable tracking of bed elevations around the upstream-most piles, and another was installed to track around the downstream-most piles.
- A horizontal facing Acoustic Doppler Current Profiler (H-ADCP), which provides continuous measurements of local velocity.
- A conductivity-temperature sensor, which enables sound velocity corrections to the DAS sensor measurements due to the presence of saline water and seasonal changes in temperature.
- Laser distance and pitch and roll sensors, which track the position of the equipment on the moving fender.
- A central control enclosure including power supply and control, datalogger, and a rugged PC.

During the monitoring period, a series of boat-mounted field measurements were collected to calibrate and assess the performance of the RSMS. The field measurements, collected over a variety of hydraulic conditions, included multibeam bathymetric surveys, discharge measurements, and conductivity temperature depth (CTD) casts.

Monitoring Period

RSMS data collection commenced in mid-May 2021, and is currently ongoing. Data presented herein extend to the end of October 2022. Over this ~18-month period, the RSMS documented riverbed elevations around a Middle Arm Bridge pier over two spring snowmelt floods (freshets). Peak daily average flow for the 2021 freshet fell between a 2-year and 5-year return period. Peak daily average flow for the 2022 freshet fell between a 5-year and 10-year return period[1]. Additionally, in November 2021, British Columbia experienced a rare and severe flooding event with a discharge just below the estimated 500-year return period for a peak daily average winter flow[2] (MFLNRORD & NHC, 2014). As sediment transport, erosion and scour processes are often strongly related to extreme flood events, the monitoring period represented a great opportunity to examine scour dynamics at the Middle Arm Bridge.

A discharge record at the RSMS was developed using stage-area and index-velocity relations, enabled by the continuous H-ADCP velocity record and the field measurements undertaken using boat-mounted equipment. Daily averaged flow at the RSMS follows the same pattern observed in the Fraser River record at Hope, BC, with discharge increasing during the freshet from May to July and during the November 2021 flooding event (Figure 1). The instantaneous discharge record illustrates the prevalence of upstream flows at the RSMS due to flood tides,

[1] Return periods referenced to Water Survey of Canada gauge in Hope, BC.
[2] Return period referenced to Water Survey of Canada gauge in Mission, BC.

particularly during the winter when river discharge is low and winter tidal range is high (Figure 1).

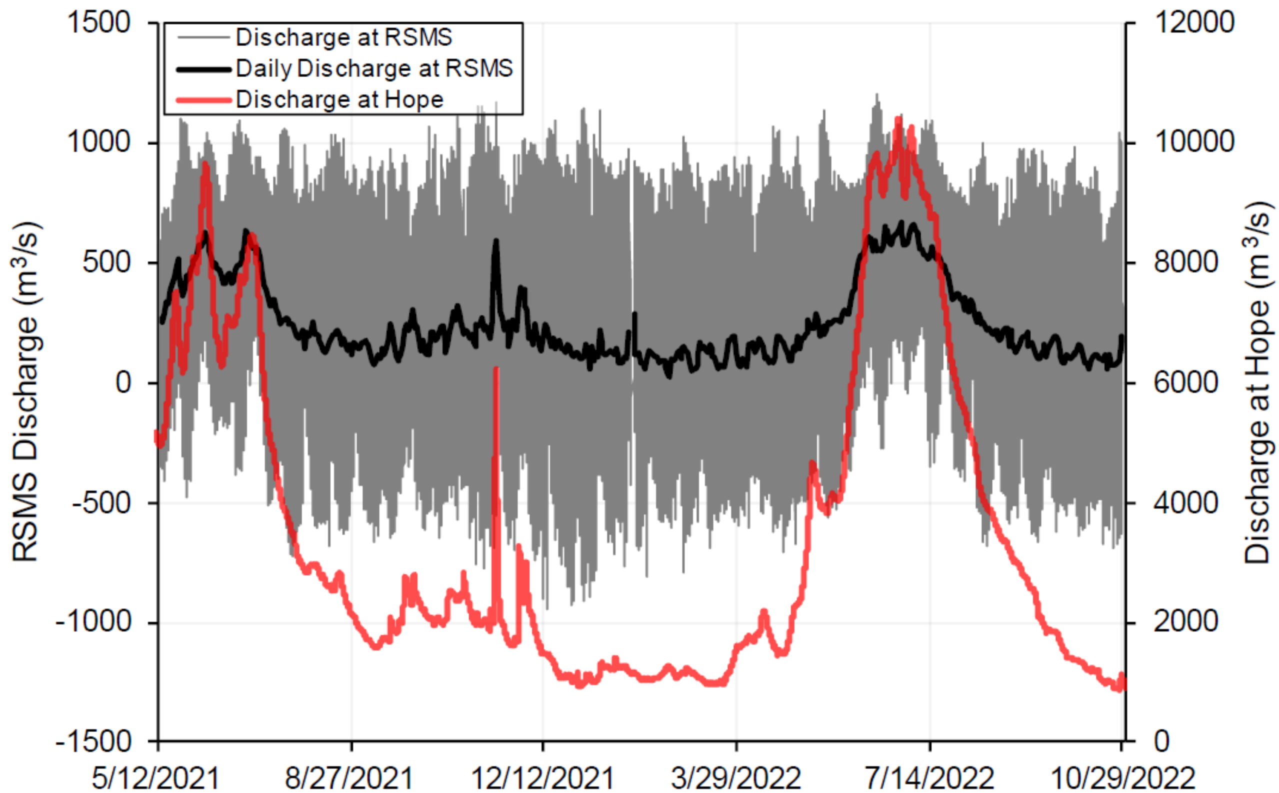

Figure 1. Instantaneous and daily averaged discharge at the RSMS and the Water Survey of Canada gauge in Hope, BC[3]. Negative discharges at the RSMS indicate upstream flow.

Monitoring Outcomes

Riverbed Dynamics

Code was developed and implemented in LabVIEW to run and process the data collected by the RSMS. Through this code, bed elevations could be extracted and averaged within user-defined areas of interest to examine change over time. NHC examined a 4x4 m grid close to the piles, and a 10x10 m grid to examine a more general area around the piles. Figure 2 illustrates the location of these grids, relative to the DAS equipment on the upstream and downstream sides of the pier. Median bed elevations from each grid extracted from the DAS scans are shown in Figure 3.

[3] Note, the RSMS is located approximately ~153 km downstream of Hope, yet the magnitude of discharge is substantially lower at the RSMS than at Hope. At Hope, the Fraser River is a single-thread channel. Between Hope and the RSMS, the Fraser splits into multiple channels. At the RSMS, the Middle Arm carries roughly 5% of the river discharge.

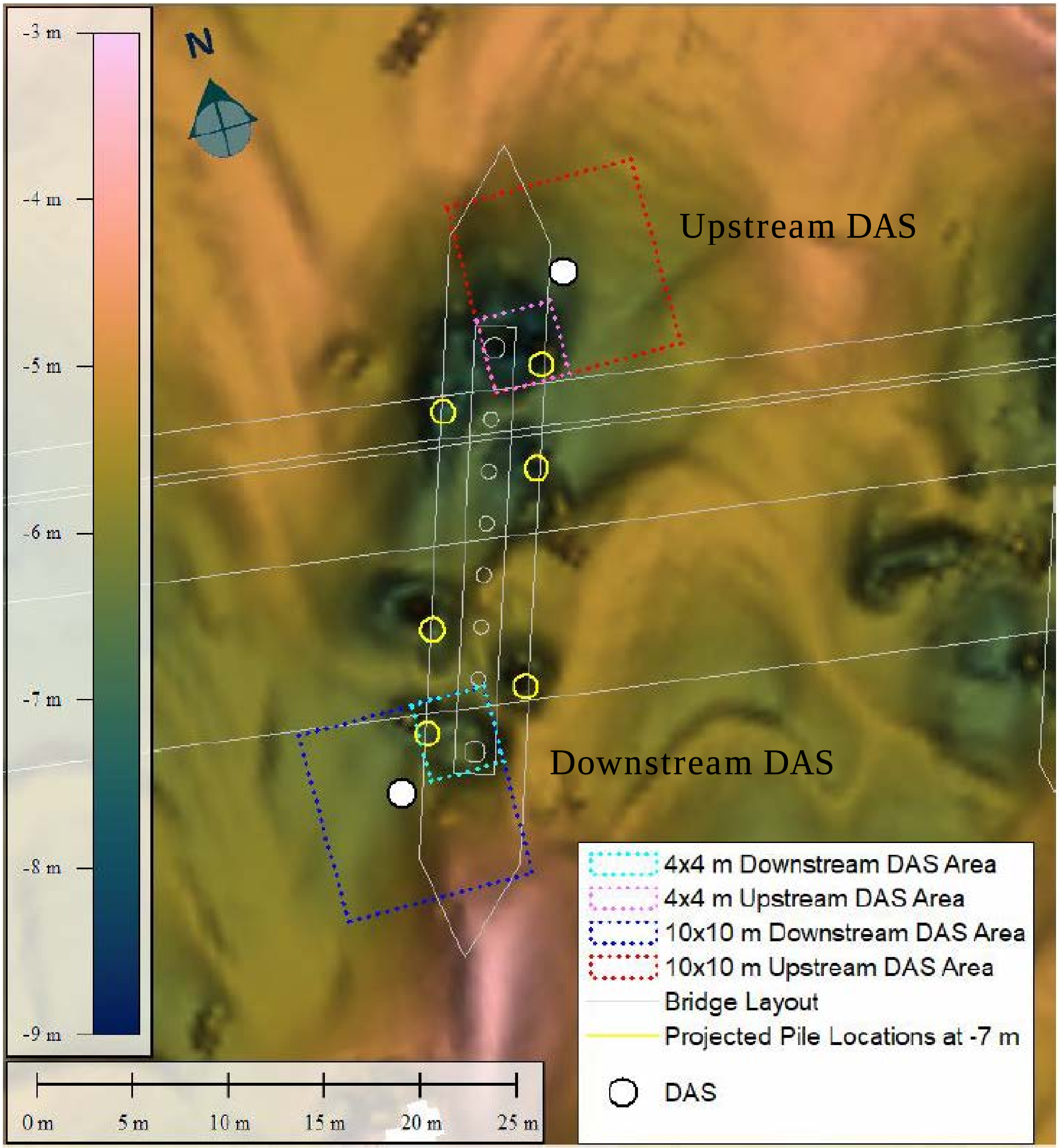

Figure 2. Location of grids used to examine bed elevation changes around the pier through time. Flow reverses at this site, but the landward to seaward direction is from top to bottom. Multibeam bathymetric survey shown in background was collected by NHC in February 2022. Elevations in Canadian Geodetic Vertical Datum of 1928.

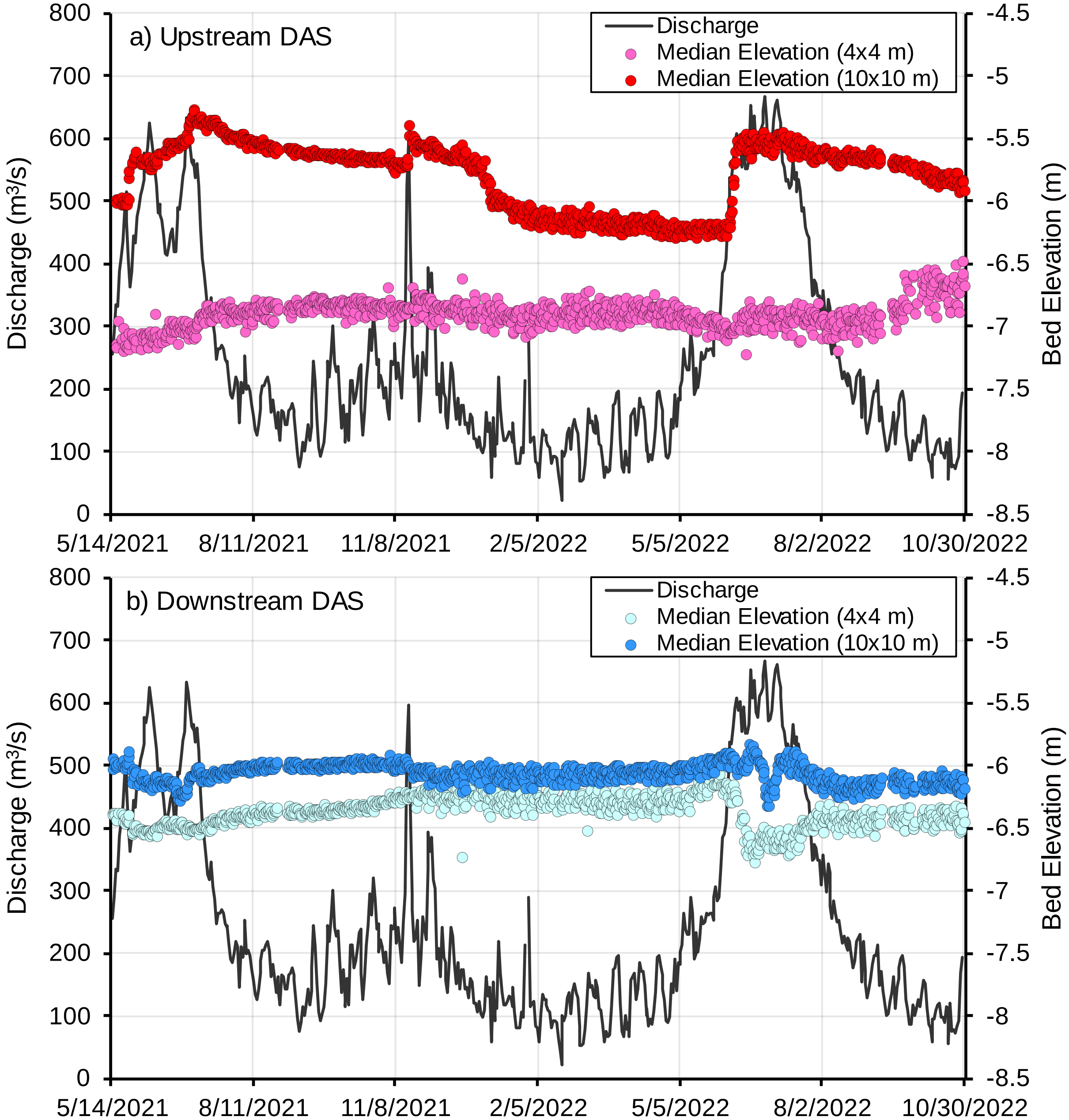

Figure 3. Median bed elevations extracted for each scan from the (a) upstream, and (b) downstream DAS, alongside the daily discharge record for the RSMS.

The measurements to date have revealed the following insights into to the riverbed dynamics :

1. The riverbed next to the piles was generally more stable than expected (Figure 3). It is hypothesized that this relative stability is due to the frequent oscillations in the flow associated with the tidal influence at the study site (Figure 2). The frequent changes in discharges and regular flow reversals, even during floods, may result in insufficient time for scour to develop around the piers in response to extreme conditions.
2. As expected, the riverbed scoured around the downstream piles during freshet 2022 (Figure 3b). Conversely, bed elevations rose by ~0.8 m approaching the upstream pier during freshet 2022 (Figure 3a; 10x10 m grid). Careful investigation of the sonar scans illustrated that the bed elevation increase was due to a migrating dune. As discharges increased during the freshet, the dune migrated downstream and entered the 10x10 m grid. The median bed level increased rapidly as the dune migration appeared to accelerate with the rising discharge. Bed levels local to the upstream piles (Figure 3a; 4x4 m grid) remained relatively stable during to 2022 freshet. As the dune migrated closer to the pier, turbulence appeared to break up the dune, such that the bedform had little effect on bed elevations close to the piles.
3. In September 2022, a log appeared in the upstream DAS scans. The log resulted in a slight increase in bed levels close to the piles (Figure 3a; 4x4 m grid) as it rested against the piles. Upon close investigation of the DAS scans, back-and-forth movement of the log could be observed, presumably due to the oscillating upstream and downstream flows at the site. The back-and-forth movement of the log continues to date. These observations illustrate the usefulness of the RSMS to also track woody debris.

Running a Real-time Scour Monitoring System

While some instrumentation issues arose with the RSMS during the period of operation, the predominant challenges associated with running the system were related to human operation. These challenges were formed of two main aspects:

1. Instrumentation malfunctions required immediate attention, occasionally at inconvenient times. Staff with the skillset and experience required to address instrumentation malfunctions are rare and in high demand. As such, organizational challenges arose, and while rare, some data were lost, due to necessary delays in addressing malfunctions.
2. Interpretation of the collected data was complex and unintuitive. Complexity arose due to the volume of data collected, and the number of variables to consider when interpreting the riverbed dynamics. Further, the sonar scans were unintuitive to interpret by a general audience and untrained engineers and geoscientists. As such, the time demands for training and data interpretation were more substantial than initially anticipated.

Application of the Real-time Scour Monitoring System

The installation of the RSMS on the Middle Arm Bridge provided a unique opportunity to observe the riverbed changes around a bridge pier every twelve (12) hours, for eighteen (18) months. To NHC’s knowledge, this is the first system of its kind installed with DAS sensors on a floating mount that incorporates speed of sound corrections for variability in water salinity and temperature. This study, therefore, marks an exciting milestone in continuous automated riverbed monitoring for both NHC and the British Columbia Ministry of Transportation and Infrastructure (Ministry).

If one was to consider installing an RSMS, similar to that described in this paper, based on our experience we would recommend consideration of the following:

- Ensuring the availability of staff with sufficient experience and technical skills to both maintain the instrumentation and interpret the data. This is particularly relevant if the installation of the instrument is being considered in a remote location.
- Minimal data were lost by the RSMS during the severe flood conditions experienced in November 2021 due to extremely high turbidity. Under the November 2021 flood conditions, NHC also attempted to undertake boat-mounted multibeam surveys; this was generally unsuccessful due to unsafe river conditions. As such, in an emergency flood situation, the RSMS would have provided data about local scour faster than a multibeam survey vessel and crew could have safely launched.
- DAS systems are constrained by 'line of sight' operations and beam spread; data in the shadow of solid objects, therefore, result in lost data. For example, at the Middle Arm, data shadows occurred behind piles and woody debris. This 'line of sight' consideration is critical to consider as solid objects (e.g., pile caps) may inhibit data collection in the area of interest.

As a next step, NHC and the Ministry are considering the application of the RSMS to relatively high-energy environments, on a cobble or gravel-bed river.

References

MFLNRORD & NHC (2014). Simulating the Effects of Sea Level Rise and Climate Change on Fraser River Flood Scenarios. Prepared jointly by Northwest Hydraulic Consultants Ltd. and BC Ministry of Forests, Lands and Natural Resource Operations