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MONITORING OF SCOUR HOLE DEVELOPMENT AT A CONTROL STRUCTURE IN THE ESTUARY OF THE PETITCODIAC RIVER AT MONCTON, NB

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Abstract: In 1968, a control structure became operational as a component of a causeway at Moncton, NB on the estuary of the Petitcodiac River. The control structure with five gates was originally designed to allow water to flow from the land upstream to the estuary downstream. The total clear opening at the control structure is 44.2 m in width and 6.1 m in height. The sill elevation of the control structure is -1.5 m. The structure and the associated approach channels were built on fractured mudstone/siltstone. On April 14, 2010, the gates at the control structure were opened to enhance the passage of fish through the structure. In anticipation of the gate opening, a program involving detailed hydrographic surveys was initiated a few days before the gates were opened. These surveys provided information to assess the development of a scour hole on the upstream side of the structure. In November 2011 surveys were extended to the downstream side of the structure. With all gates opened at the control structure, the estimated peak flow for an average high tide of elevation 6.1 m was about 1500 m^3/s during the flood tide and about 1000 m^3/s during the ebb tide. The 100-year flood flow from the land at the control structure is estimated to be about 1000 m^3/s. With the gates opened the tidal flows usually exceed the magnitude of the 100-year flood flow twice a day. The maximum depth of scour near the control structure was 4.5 m below the sill on the upstream side and 7.3 m below the sill on the downstream side. The paper describes the methods adopted for the surveys and presents the temporal and spatial development of the scour holes.

1 INTRODUCTION

In 1968, a 1000 m causeway was completed across the Petitcodiac River at Moncton, NB. The purpose was to reduce the impact of flooding of the marshlands upstream and to provide another roadway across the estuary.

The control structure was designed to arrest tidal flow upstream of the structure and to allow flow from the land during times that the gates were opened. One of the negative impacts of the construction of the causeway was that it restricted the passage of fish from the estuary to the river upstream even with a fishway built immediately adjacent to the structure. After some trial openings of the gates, considerable input from various non-governmental groups, and assessments of specific hydrotechnical and environmental studies, approval was given to open the gates at the control structure on April 14, 2010.

Background information related to the estuary and proposed modifications to the control structure and the causeway can be found in an EIA study published in 2005 (AMEC Earth & Environmental 2005).

2 DESCRIPTION OF THE SITE FOR THE STUDY

The control structure was built in an excavated area on the Riverview side of the causeway. The excavation was made into partially fractured mudstone/siltstone. The geotechnical properties of the material are not well known. Figure 1 shows aerial views of the control structure during construction in 1966 and at the present time. The fishway is visible in Figure 1b).

a) During construction June 29, 1966

b) With four lane bridge including fishway on December 1, 2015

Figure 1: Aerial view of the control structure on the Petitcodiac River at Moncton, NB

The top of the base of the control structure, also called the sill, was set at an elevation of -1.52 m. There are five gate openings in the structure. Each opening is 8.84 m wide and 6.10 m high and each of the four piers is 3.05 m wide.

The structure was designed for flow from the land only. A concrete apron was constructed on the downstream side of the control structure to control any scour that might take place adjacent to the foundation of the structure. The concrete apron extended 20 m downstream from the base of the piers in the control structure. A concrete lip was constructed at the downstream end of the apron to direct the high velocity flows away from the bed of the channel. The elevation of the top of the lip is -1.7 m. In 1996 an additional two lanes were added to the bridge structure. At that time a horizontal apron with a top elevation of -1.52 m was extended 8.5 m upstream from the bridge deck.
A vertical slot fishway was constructed along the Moncton side of the control structure. Although the fishway did function, it was not considered to be adequate to provide fish passage opportunities for all species and for all life stages of each species.

Originally, one to five gates were opened during periods of high flow from the land to allow water to flow from upstream storage when the water level on the upstream side was higher than the water level on the downstream side of the control structure. Once fish passage issues became significant, some experiments were made to open the gates during flood tides to allow limited fish passage upstream through the control structure. Relatively large quantities of suspended sediment were transported upstream through the control structure during these short periods of inflow from the estuary downstream.

3 INITIAL ESTIMATES OF POTENTIAL LOCAL SCOUR

Since the control structure was protected on its downstream side by a concrete apron, it was thought that the greatest significant erosion would occur just upstream of the control structure when the gates were opened on a continual basis.

The initial estimates of peak flows during a typical tidal cycle for an average high tide of elevation 6.1 m was about 1500 m^3/s during the flood tide and about 1000 m^3/s during the ebb tide (Sawh 1984). For comparison, the estimated 1:100 year flood flow from the land at the site of the control structure was estimated to be about 1000 m^3/s. In rough terms, a typical peak flow on a flood tide is in the order of one and one-half times the 1:100 year flood flow and that would occur two times a day. It is noted that as time passes, the upstream tidal prism will infill and the peak flows from the tidal exchange will decrease.

Based on this simple assessment, it is estimated that the scour on the upstream side of the control structure would develop quite quickly, although no specific estimate of the time was given for an "equilibrium" scour hole to develop. Given this background, it was considered that monitoring should be concentrated in the area immediately upstream of the control structure and it should be commenced as soon as possible and certainly before the gates were opened. Initially there was no plan to monitor the conditions immediately downstream of the control structure.

Based on some methods of estimating local scour hole development found in the literature, it was roughly estimated that the depth of the "equilibrium" scour hole would be in the range of 5 m to 11 m, the lower estimate being for scour in weak rock. Most of the methods for estimating scour hole depths were based on scour in unconsolidated sands.

4 PROGRAM FOR MONITORING LOCAL SCOUR

Surveys were carried out at various cross sections along the entire estuary, since about 1960, that is about eight years before the control structure was in operation in 1968. No detailed monitoring for local scour was carried out at or near the control structure, although some seasonal bed level data were obtained at bridge crossings located about 2 km downstream.

When it was known that the gates would be opened on April 14, 2010 on a long-term basis, plans were made to carry our detailed surveys upstream of the control structure. Echosounding techniques were used along 19 lines spaced 5.0 m apart. The locations of these lines are shown in Figure 2. The surveys were taken as near as possible to the time of high tide. The soundings were performed by Hughes Surveys & Consultants Inc. using a Knudsen 1612 dual frequency sounder. Navigation was performed using HYPACK MAX navigation software and real time differential GPS. All elevations are in metres and are referenced to geodetic datum (CGVD28).

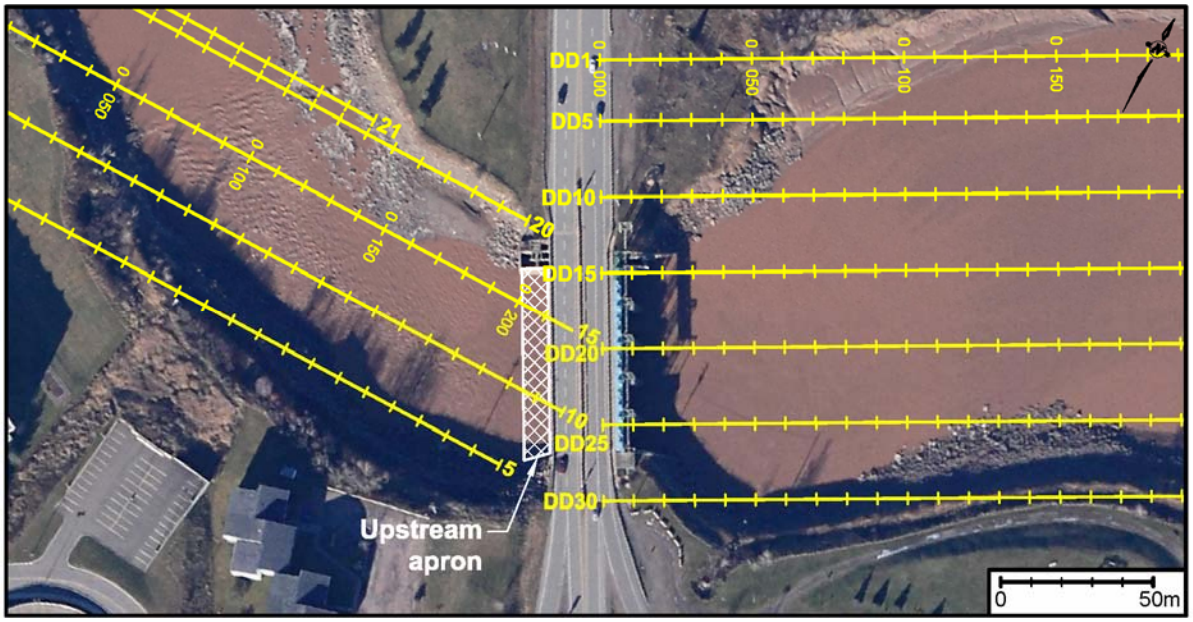


Figure 2: Location of survey lines upstream and downstream of the control structure that were used for the assessment of the development of scour holes in space and time. The outlines of the upstream and downstream aprons are shown with dashed lines

The first survey was completed on April 6, 2010, that is eight days before the gates were opened. The first date on which a survey was performed after the gates were opened was on April 28, 2010, that is 14 days after the gates were opened. A total of 20 surveys were completed from April 6, 2010 to June 27, 2017 (GEMTEC Limited 2017).

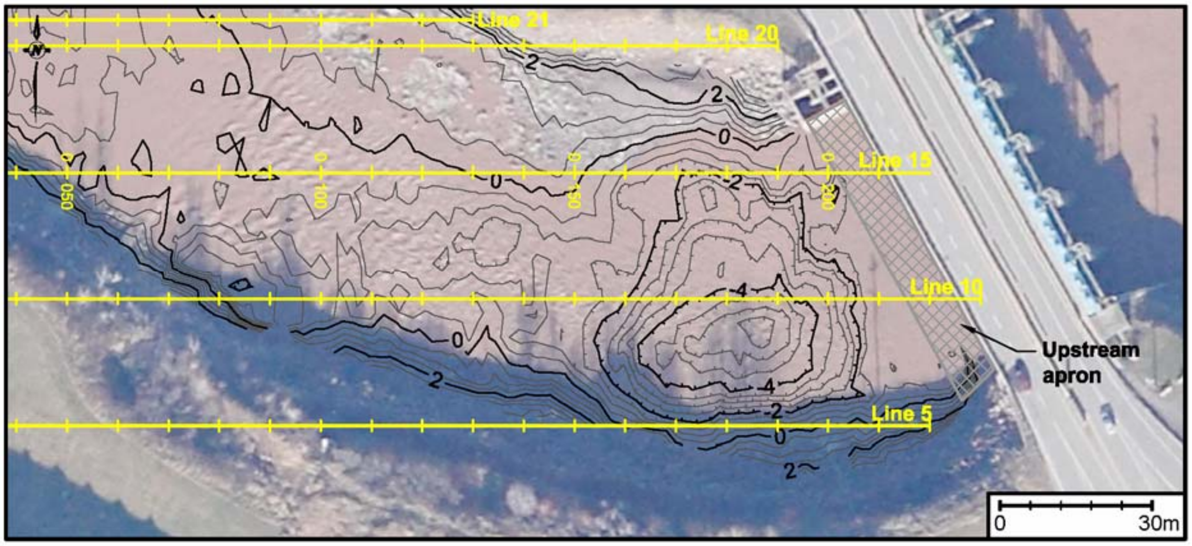
In the late summer of 2010, it was noticed that a mound was penetrating through the water surface downstream of the control structure. It was thought that the mound was most likely the result of material being transported from a scour hole that was developing downstream of the control structure.

As a consequence of this observation, surveys were carried out along 27 lines spaced at 5.0 m apart on the downstream side of the control structure. The locations of these lines are shown on Figure 2. The first survey was on November 30, 2011 and that showed that a scour hole had formed and was 6.4 m below the level of the sill at the control structure. A total of 13 surveys were completed from November 30, 2011 to June 27, 2017.

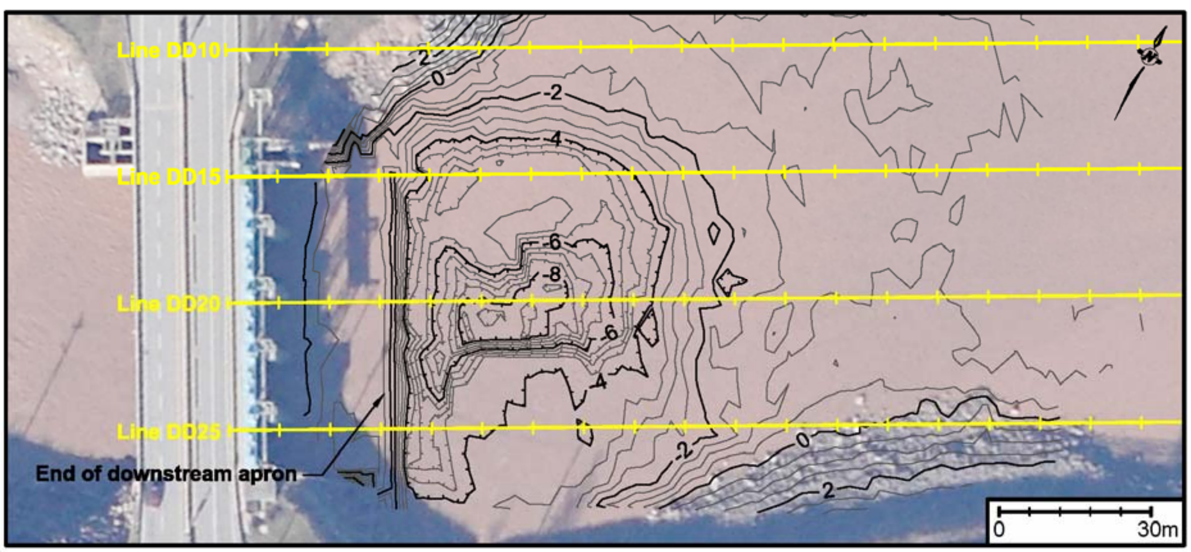
A large amount of data was obtained from these surveys over the seven years from 2010 to 2017. In a few cases, reliable data could not be obtained. In such situations it was assumed that there was a hyper-concentration of sediment in the vertical. However, most of the data were accepted for assessment of local sour for this study. These data were stored in such a manner that they could be readily retrieved for presentation of contours of the bed at a given time, profiles along a given line at a given time, and graphs of elevation at a point through time.

5 CONTOURS UPSTREAM AND DOWNSTREAM OF THE CONTROL STRUCTURE

The data were contoured for each of the surveys to clearly show the features of the scour hole associated with a particular survey date. The contours for the survey of June 27, 2017 are shown in Figure 3 for the scour hole on the upstream side and the downstream side of the control structure. The values shown are the for the local bed elevation in metres.



a) Contours upstream of the control structure on June 27, 2017



b) Contours downstream of the control structure on June 27, 2017

Figure 3: Contours of the bed in the scour hole on the upstream side and the downstream side of the control structure. All elevations are in metres above the geodetic datum (CGVD28)

6 CHANGES UPSTREAM OF THE CONTROL STRUCTURE

This section presents the key results for the echosounding over a distance of about 250 m from the upstream side of the control structure. The area is referred to as the approach channel. The 20 survey lines used for this portion of the study are shown in Figure 2.

The bottom elevations are presented along a line that passes through the deepest local scour over the period April 6, 2010 to June 27, 2017. In addition the elevation of the deepest point in the scour hole over time is presented. It was realized from previous work in the laboratory, that the scour hole should develop quite rapidly after the tidal inflow is allowed to take place. Hence, the frequency of the surveys was weeks apart at the beginning, then months apart and a year apart at the end of the survey program.

6.1 Profiles through the deepest point of the scour hole

Profiles through the location of the deepest scour on Line 10 for various dates are shown in Figure 4a). There were 20 surveys over the period April 6, 2010 to June 27, 2017. The results of eight of these surveys are presented in Figure 4a)

The location of the deepest scour hole in the approach channel was on Line 10. The bottom elevation was -6.00 m on June 27, 2015. The associated depth of local scour below the sill of the control structure was 4.48 m. The bottom of the scour hole was located about 38 m from the upstream edge of the bridge. Once the scour hole was developed it was quite stable in form and in location. The location of the deepest point in the scour hole along Line 10 varied by about 10 m over the observation period.

It is noted that there is a secondary scour hole along Line 10 at a point about 135 m from the upstream edge of the bridge. This local scour has resulted from the presence of a disused pipeline across the approach channel.

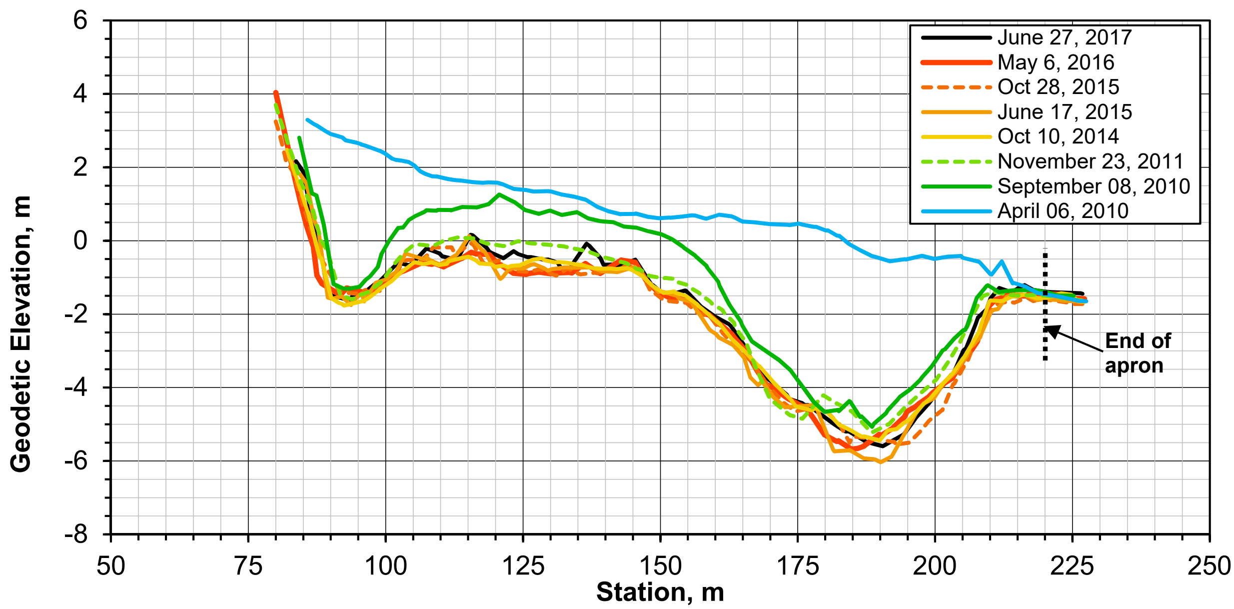
6.2 Variation of depth of scour over time.

There were a total of 20 surveys in the approach channel. The lowest elevation was determined for each survey. The maximum local depth of scour for the period of study occurred on Line 10 on July 15, 2017. That elevation of the bottom of the scour hole on that date was -6.03 m which corresponds to a depth of 4.49 m below the sill of the control structure. The local maximum depth occurred along the other lines at other dates but none exceeded that along Line 10.

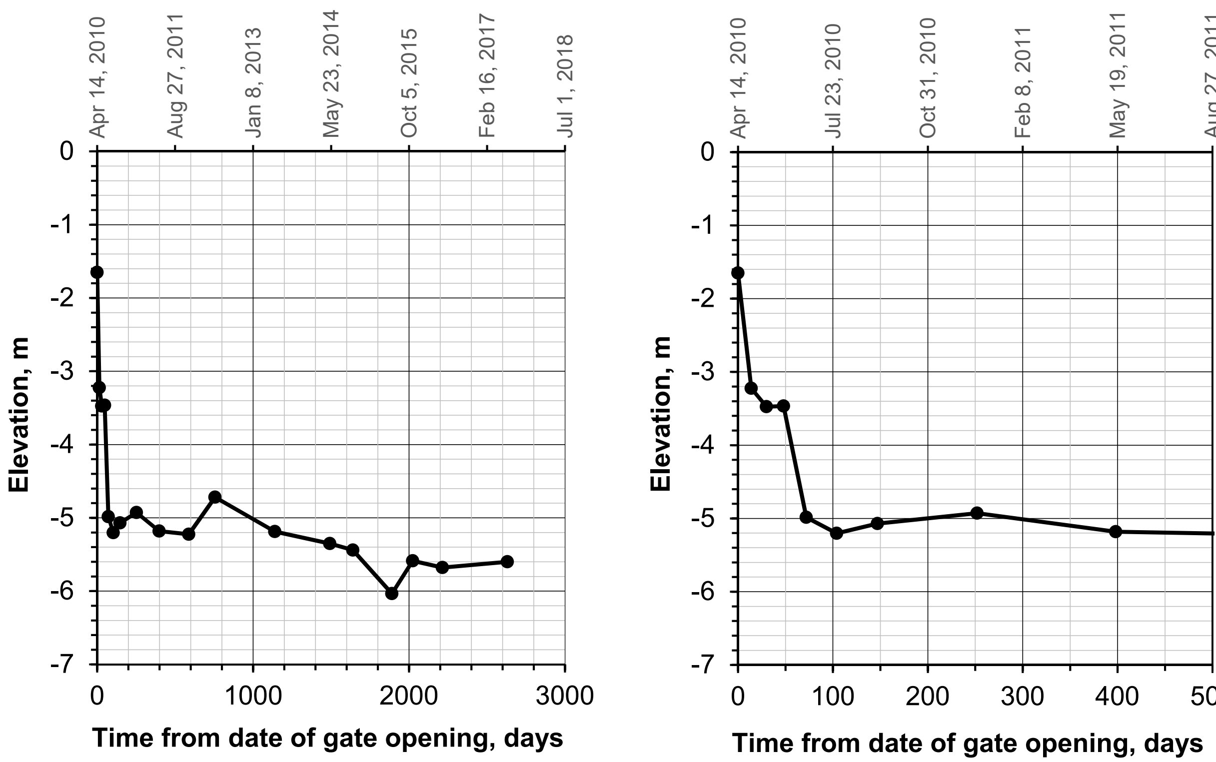
Figure 4b) shows the local maximum depth of scour along Line 10 below the sill elevation of -1.52 m over time. The location of all of the points in Figure 4b) is about 38 m from the upstream edge of the bridge.

On April 6, 2010, eight days after the gates were opened on April 14, 2010, the bed elevation was about +0.50 m at the location of the maximum local depth of scour on June 17, 2017. It is assumed that the scour to the sill at elevation -1.52 m occurred rapidly after the gates were opened, hence, the elevation at time zero was taken to be -1.52 m

Based on the information in Figure 4b), the elevation of the bottom of the scour hole was about -3.48 on May 14, 2010, that is, one month after the gates were opened. The scour hole had reached a depth of about 1.96 m below the sill elevation of -1.52 m which is about 43 percent of the maximum of 4.51 m that occurred on July 17, 2015, about five years after the gates were opened. On July 27, 2010,



a) Profiles through the deepest point along Line 10 for various surveys since the gates were opened on April 14, 2010



b) Variation of bed elevation of the deepest point on Line 10 since the gates were opened on April 14, 2010

Figure 4: Graphs showing profiles of bed elevation along a line through the deepest point and bed elevation at the deepest point upstream of the control structure. The data are from Line 10

about two and a half months after the gates were opened, the depth of the scour hole was 3.68 m or about 82 percent of the maximum of 4.51 m on July 17, 2015, about five years after the gates were opened.

7 CHANGES DOWNSTREAM OF THE CONTROL STRUCTURE

This section presents the main results from the echosounding over a distance of about 300 m downstream of the edge of the concrete apron. The concrete apron has a 1.0 m high vertical lip at the downstream side. The top of the lip is at an elevation of about -1.70 m. The lines for the surveys are shown in Figure 2. Twelve lines, DD14 to DD25 were surveyed on 13 dates from November 30, 2011 to June 27, 2017.

The bottom elevations are presented along a line passing through the deepest local scour over the period November 30, 2011 to June 27, 2017. The first survey was carried out on November 20, 2011 about 20 months after the gates were opened on April 14, 2010. The surveys were started well after the gates were opened because it was considered that a scour hole had already developed because of the flood flows from the land. However, about a year after the gates were opened it was noted that a mound appeared about 100 m downstream from the lip on the apron during periods of low flow from the land.

7.1 Profiles through the deepest point of the scour hole

The location of the deepest scour hole was along Line DD20 at a point about 20 m downstream of the concrete lip on the apron. The maximum depth of scour occurred on June 17, 2015 when the elevation of the lowest point was -8.79 m or 7.27 m below the sill. Figure 5a) shows profiles through the deepest point along Line DD20 on various survey dates.

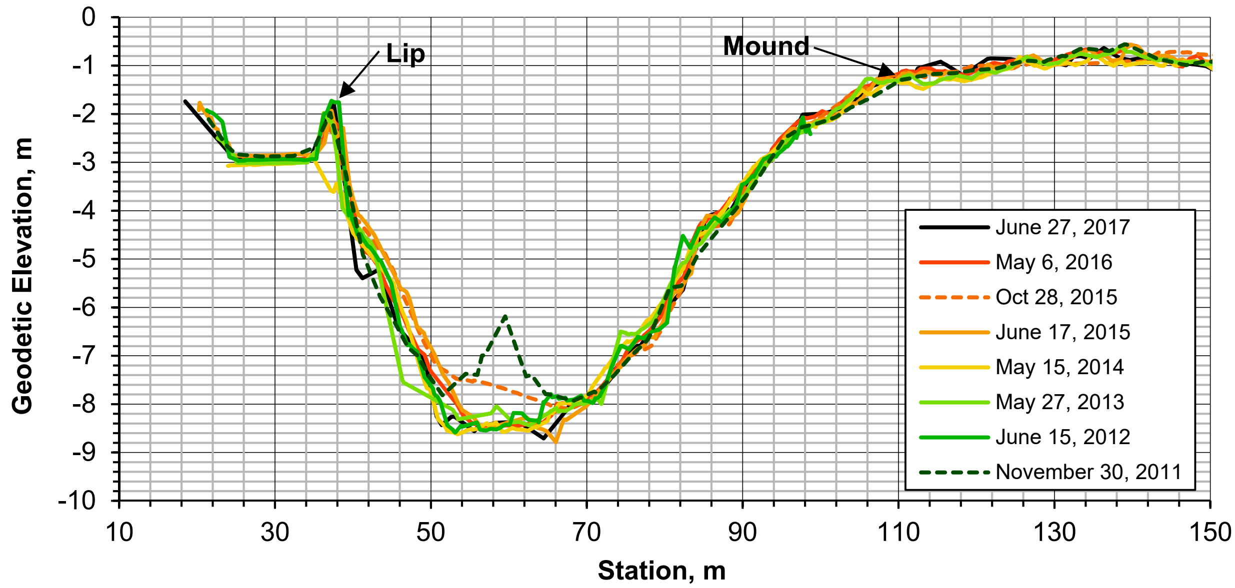
The scour hole was stable from survey to survey after November 30, 2011. No information is available to show the shape of the hole before the gates were opened, but it is assumed that a hole of lesser depth already existed at the time of the gate opening. The top width of scour hole from the top of the lip at elevation -1.70 m is about 65 m.

A mound has developed about 100 m downstream from the lip on the downstream apron. The top of the mound is about 1.0 m above the top of the lip. The length of the mound is about 80 m at the elevation of the top of the lip, that is, at elevation -1.70 m.

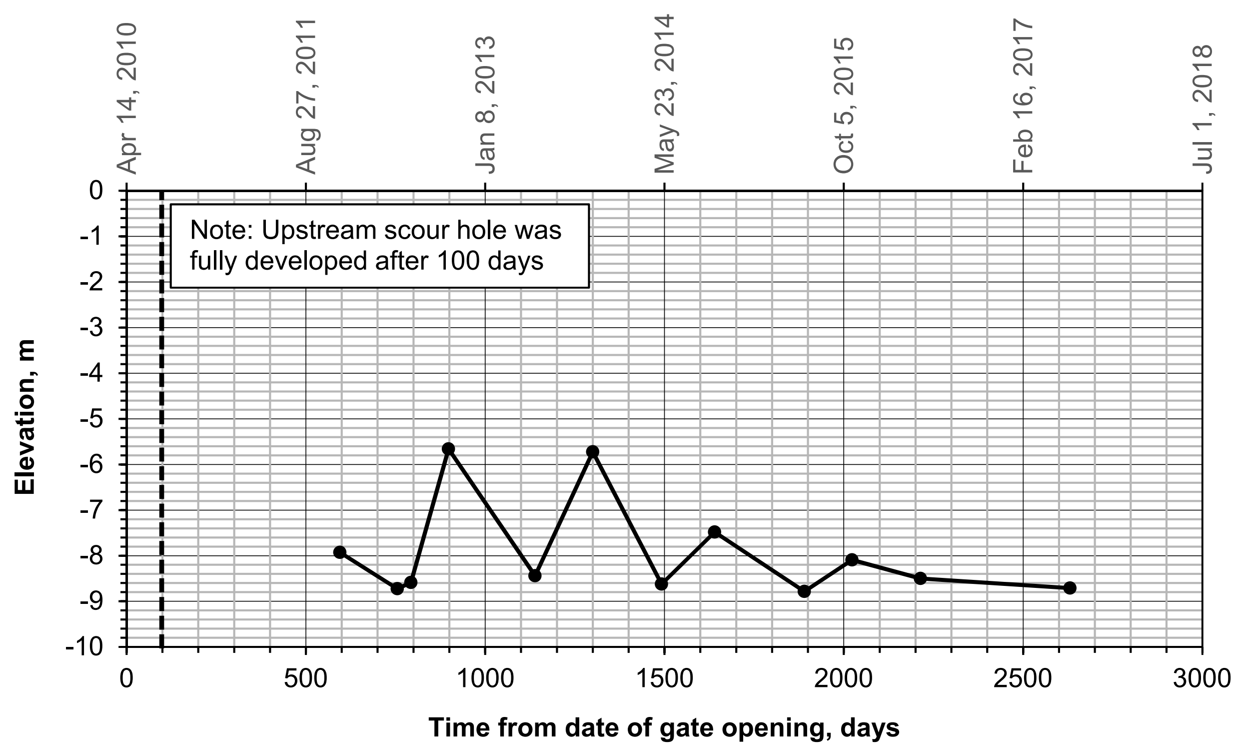
The location of the bottom of the scour hole from Line DD20 is stable than that for any of the other lines immediately downstream of the control structure.

7.2 Variation of depth of scour over time.

There were a total of 13 surveys along Line DD20 that passed though the location of the deepest local scour. These surveys were over the period November 30, 2011 to June 27, 2017. The bottom elevations ranged from -5.660 on September 28, 2012 to -8.786 on June 17, 2015. The highest bed elevation was probably related to low flow from the land and low tidal range. These conditions sometimes contribute to the short term deposition of material on the channel bottom.



a) Profiles through the deepest point along Line DD20 for various surveys since the gates were opened on April 14, 2010



b) Variation of bed elevation of the deepest point on Line DD20 over time since the gates were opened on April 14, 2010

Figure 5: Graphs showing profiles of bed elevation along a line through the deepest point and bed elevation at the deepest point downstream of the control structure. The data are from Line DD20

Figure 5b) shows the elevation of the local maximum depth of scour along Line DD20 over time. Based on the information related to the formation of the scour hole upstream of the control structure, the equilibrium scour hole is expected to develop in about five months. The first survey downstream of the control structure was about 20 months after the gates were opened, so the scour hole should have been fully developed at the time of the first survey on November 30, 2011. The characteristic features of the scour holes along the other survey lines were similar to that along Line DD20.

8 SUMMARY

The detailed bathymetric surveys immediately upstream and downstream of the control structure provided a means of documenting the depth of the scour holes and the rate at which the deepest point in the scour hole developed over time. Based on limited information it is thought that the scour took place in fractured mudstone/sandstone.

Based on the upstream measurements the scour hole developed to a depth of about 3.7 m below the sill in about two and a half months after the gates were opened. The maximum depth was 4.5 m after a period of five years. Based on the upstream measurements, it is considered that the downstream scour hole was fully developed to a depth of 7.3 m below the sill before the detailed surveys were commenced.

The information provided in this paper can serve as a means of assessing methods presented in the literature to estimate scour hole development in such materials.

Acknowledgements

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