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REPAIR OF THE SUMAS RIVER DIKE BREACH, ABBOTSFORD, BC

Brian L. J. Mylleville

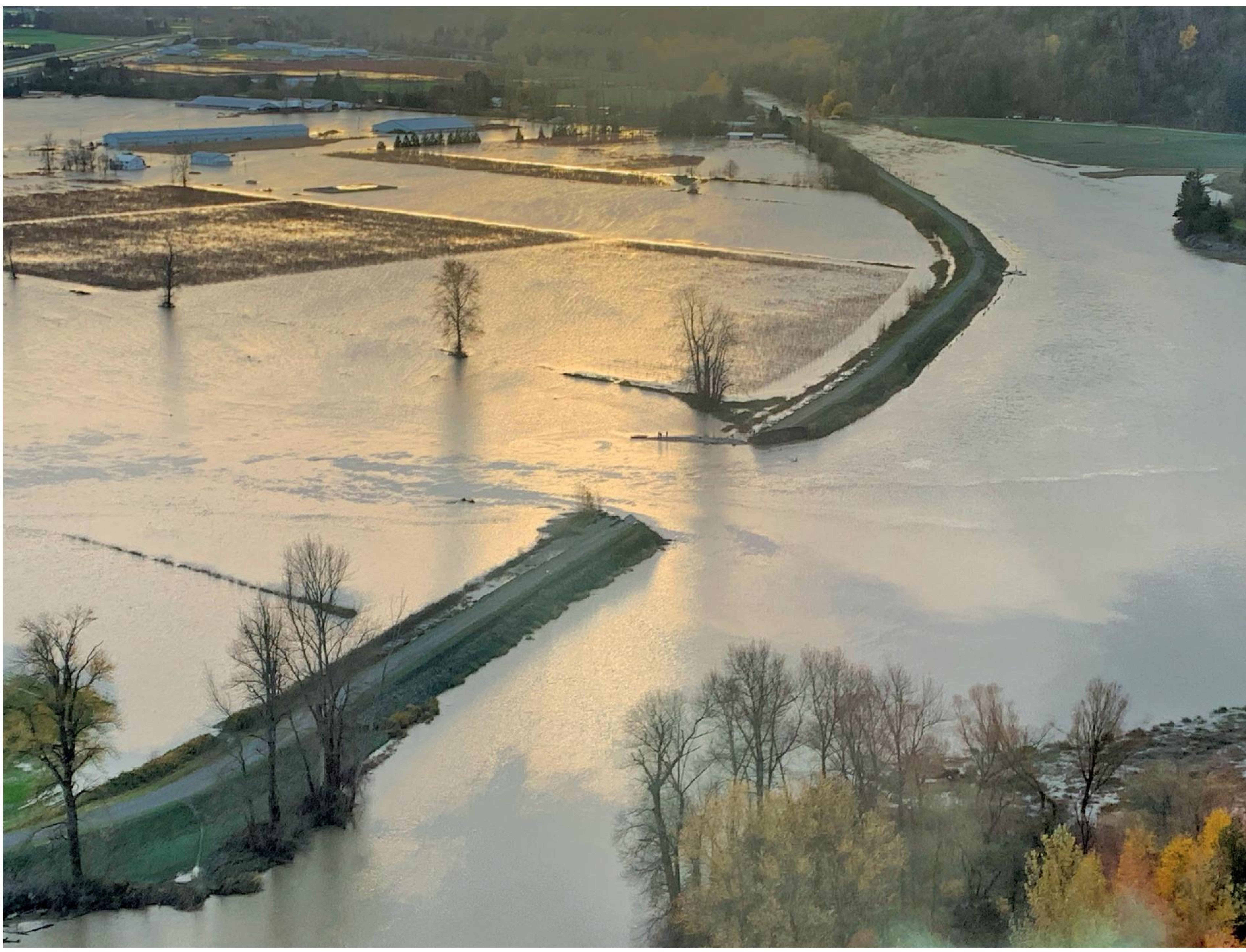

Figure 1. Sumas River Dike breach (water flow from right to left)

INTRODUCTION

On November 16, 2021, during a series of unprecedented atmospheric river events, the Sumas River Dike was breached – resulting in widespread flooding of the Sumas Prairie and closure of the Trans-Canada Highway in Abbotsford, BC. The widespread flooding posed significant challenges for initial emergency response that focused on closing the breach to stop flowing water from the Sumas River entering Sumas Prairie. The approach developed for initial closure of the breach would prove to be crucial to further remedial work that was required to reinstate the breached section as a functioning dike. This article provides a summary of the project, more detailed information can be found in Mylleville et al. (2023) and Mylleville and Whitehead (2024).

THE BREACH

The breach occurred because of floodwaters from the Sumas River overtopping the dike followed by rapid downcutting of the dike structure – allowing floodwaters from the Sumas River to flow into the Sumas Prairie (see Figure 1).

Evidence of significant erosion and downcutting of the landside slopes of the dike

Figure 2. Erosion along the landside slope of the dike near the breach

Figure 3. Initial emergency closure of the breach with coarser crushed rock

could be seen with several sections eroded to near-vertical configuration at the landside crest of the dike slope (see Figure 2).

At the breach, most, if not all, of the dike structure was lost over a length of about 150 m, with a large scour hole eroded well below the land-side toe of the dike and beyond, extending some 150 m into a farm field to the southeast. The bottom of the scour hole was about 3–4 m below the base (bottom) of the existing dike.

CLOSING THE BREACH

Ideally, a dike should have a lower permeability core constructed of silty and/or clayey soils. However, emergency repair work had to be carried out during periods of intense precipitation, working initially under conditions of flowing floodwaters and partially underwater, making it impossible and impractical to use fine-grained soils. To attempt to do so would likely have been disastrous. As such, the temptation might have been to close the breach using coarser material such as crushed rock mixed with some finer material; however, that would most likely have been problematic as well, the reason for which is discussed below.

Figure 4. Constructing the central portion of the breach closure with finer crushed rock

The approach that was adopted for closure of the breach was to construct an initial crossing to stop flow from Sumas River, then continue to widen and build up or raise the closure once the open flowing water was stopped (see Figure 3). The entire closure of the breach was constructed using crushed granular fill of varying sizes, with coarser 600 mm minus crushed rock specified for the outside (initial crossing and along the side slopes) and finer 75 mm minus crushed rock specified within the central portion of the dike. The initial closure was widened to the south and raised using the finer crushed rock to allow for future installation of a low-permeability barrier.

The widening and raising of the breach closure continued using the smaller sized crushed rock (see Figure 4). This material was placed in lifts and compacted using a large vibratory compactor. Specifying the use of finer 75 mm minus crushed rock to construct the central portion of the cross-section for the dike closure was essential to provide some degree of flexibility in terms of considering options to reinstate a low-permeability barrier – without which, the dike would have continued to leak. Coarser crushed rock fill was then placed along the land-side slope of the closure to support the finer fill material within the centre of the closure. The initial emergency closure of the dike breach was completed in late November 2021.

GEOTECHNICAL EXPLORATION

Following completion of the emergency closure of the dike breach, a geotechnical exploration was completed in the Spring of 2022 to check the extent (depth) of the recently placed crushed rock fill zone, the characteristics of the underlying foundation soils, and to confirm the presence or absence of larger rock sizes within the central portion of the repair (constructed of the finer crushed rock) that would present as obstructions to barrier construction. This information was also used to establish the required extent of the low-permeability barrier and to assess suitable options to construct a low-permeability barrier required to mitigate seepage through the breach closure. Twelve test holes were drilled using sonic drilling methods to just over 15 m depth within the central portion of the breach closure, spaced out along the length of the repaired section.

OPTIONS FOR SEEPAGE MITIGATION

Three options for seepage mitigation were considered: (1) reconstruction of the dike section with a low-permeability core, (2) construction of a steel sheet-pile barrier, and (3) construction of a low-permeability core using deep soil mixing.

Reconstruction would require removal of a large portion, if not most, of the repaired section and replacement with new engineered fill including a low-permeability soil core, filter(s), and drainage zones. Reconstruction would likely encounter constructability challenges (e.g., excavation support, dewatering, and the like) associated with earthworks being carried out 4 m or more below the groundwater table and in proximity of the Sumas River.

The steel sheet-pile wall option involves installing a continuous line of interlocking sections of steel sheet-piles along the centre of breach closure to act as a low-permeability barrier to mitigate seepage through the dike fill. However, there could be constructability challenges associated with driving sheet piles through well-compacted 75 mm crushed gravel fill and encountering larger crushed rock sizes while maintaining connection between adjacent sheet piles.

The deep soil mixing option involves mechanically mixing the in-situ soil, in this case the finer 75 mm minus crushed rock fill, with a bentonite/cement slurry mixture to form a low-permeability barrier (core) along the centre of the breach closure. The barrier is constructed by building a series of overlapping rectangular panels along the centreline of the breach closure to form a continuous barrier to mitigate seepage. The primary construction challenge would be associated with encountering larger crushed rock sizes, resulting in cutter teeth breakage and possible cutter head damage.

One of the key considerations in selecting the preferred option to reinstate a low-permeability barrier in the breach closure was that, as much as possible and practical, the preferred option should minimize the need for de-construction.

The option selected for construction of the-low permeability core was Cutter Soil Mixing (CSM), which is one of several proven and locally available methods for deep soil mixing and used successfully in other similar barrier applications (Arnold et al. 2011; Holzman et al. 2019; and others).

DESIGN OF THE CSM BARRIER

Steady-state seepage analyses were carried out to confirm the benefit of a barrier with low permeability (1×10^{-9} m/s) to mitigate seepage flows through the initial breach closure, which was constructed entirely of crushed rock of varying sizes as described previously. The findings of the seepage analysis indicated that for the breach closure without a low-permeability barrier, the estimated seepage through the closure would likely range in the order of between about 5 and 20 litres/min per metre length of dike closure. This analysis considered conditions in the Sumas River that vary from "normal" to flood level. Installing a low-permeability barrier that is 640 mm thick and extends 4 m into the underlying foundations soils reduces seepage by about two orders of magnitude, or to between about 1×10^{-2} and 5×10^{-2} litres/min per metre length of the dike closure. To maintain flexibility in the barrier, an unconfined compressive strength (UCS) of 1 MPa was specified for the constructed barrier.

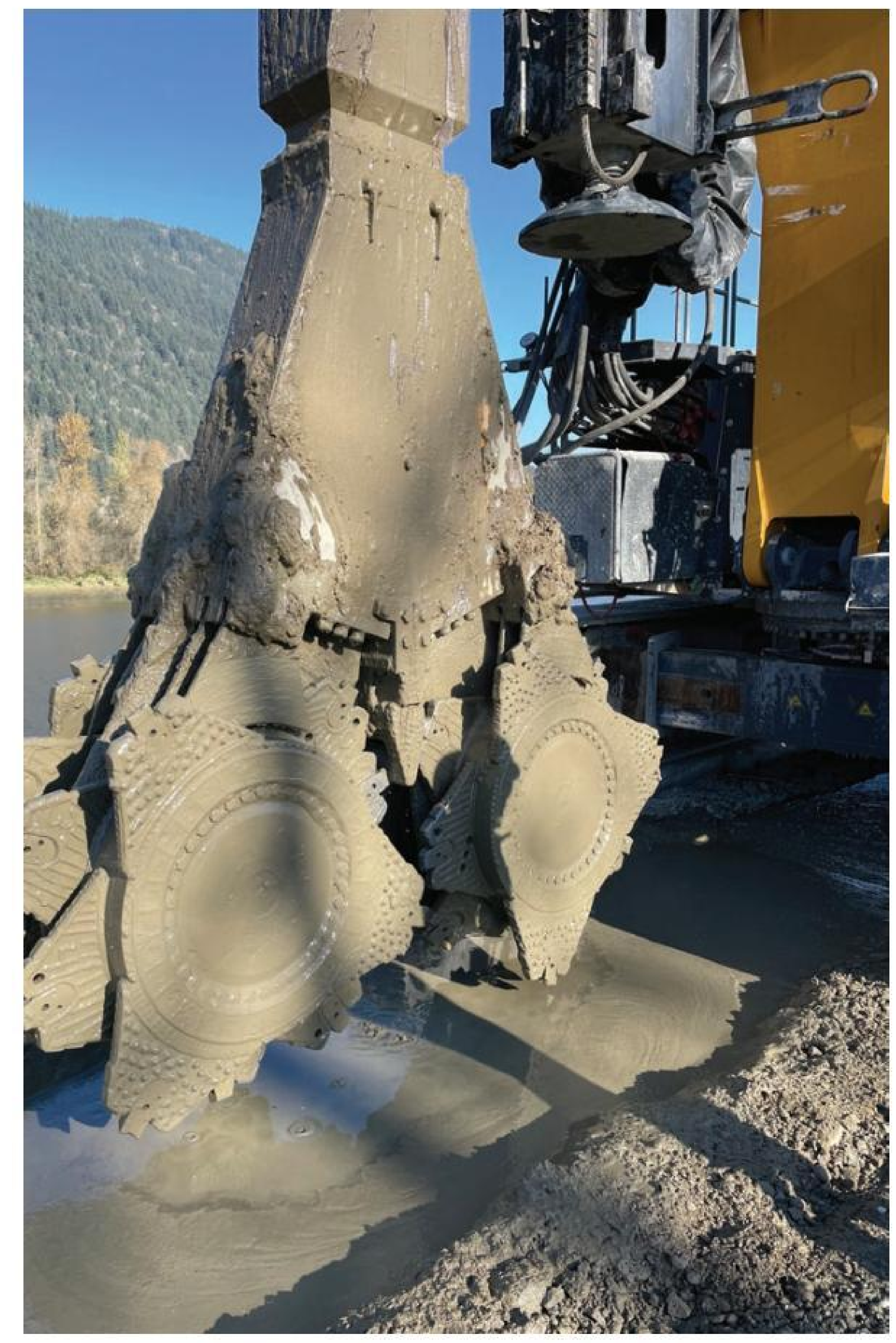

Figure 5. CSM cutting tool being retrieved from the ground following completion of a CSM panel

CONSTRUCTION OF THE CSM BARRIER

The CSM process employs a cutting tool comprising counter-rotating drums fitted with cutting teeth with a configuration that is designed for cutting and mixing in-situ soils with bentonite and Portland cement slurries – to construct rectangular panels 2.8 m long by 640 mm wide extending to the target depth. As the cutting tool advances or cuts its way down into the ground, bentonite slurry is continually added to aid as a cutting fluid and to lower the permeability of the mixed soil-slurry mass. When the cutting tool reaches the target depth, Portland cement slurry (required for strength) is then introduced as the cutting tool is slowly retrieved from the ground. The contractor tailors the bentonite slurry and Portland cement slurry application to achieve the performance requirements set out in the contract specifications. Figure 5 shows the cutting tool being retrieved from the ground following completion of a CSM panel.

Despite best efforts during construction of the initial emergency closure to keep the zone of the central finer crushed rock separate from the outer coarser crushed rock, larger pieces of crushed rock were encountered by the CSM cutting tool, resulting in cutter teeth breakage and construction delay. To alleviate equipment damage and delays, predrilling (with casing) was used to remove larger rock fragments prior to installing the remaining CSM panels.

Figure 6. CSM rig and predrilling equipment on the dike breach closure

Figure 6 shows both the CSM rig (yellow) and pre-drilling equipment (white) on top of the dike breach closure with the water-filled scour hole in the foreground and Sumas River and Sumas Mountain in the background.

A total of 60 CSM panels were required to construct the low-permeability barrier, with depths varying between 5.25 and 12.75 m as measured from the top of dike. Construction of the CSM barrier was completed in December 2022.

CONSTRUCTION CHALLENGES

During the initial stages of the emergency works, heavy precipitation made for difficult working conditions including continued flooding of some crucial access roads. A second series of atmospheric rivers resulted in rising water levels in the Sumas River that threatened continued work at the breach site. Much of Sumas Prairie was flooded, therefore access and haul routes for equipment and materials had to be carefully planned, staged, and coordinated as many of the local roads including stretches of the Trans-Canada Highway were closed.

During the remedial phase of the project, obstructions such as larger pieces of crushed rock posed a challenge to CSM installation, but this was overcome with appropriate predrilling to remove the obstacles.

LESSONS LEARNED

Several lessons were learned from this (hopefully) once-in-a-lifetime experience:

- An experienced and motivated team was crucial to the successful completion of the initial emergency works in a safe and timely manner;
- Foresight in specifying appropriate materials for the initial dike closure (with finer 75 mm minus crushed gravel for the central portion of the closure) proved to be crucial to the successful construction of a low-permeability barrier using CSM technology without the need to deconstruct the initial emergency works; and
- Pre-drilling with casing proved to be a successful approach to removing obstructions (larger crushed rock) within the finer dike fill and contributed to successful construction of the low-permeability barrier.

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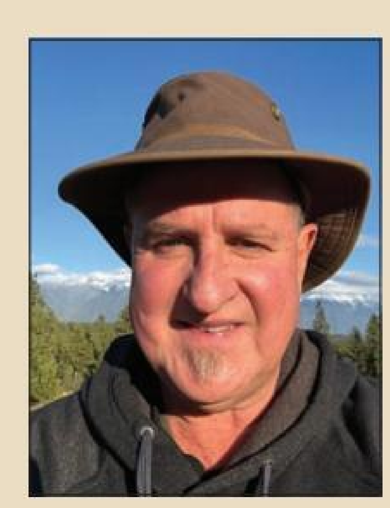

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