TECHNICAL MEMORANDUM

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TO Doug Fulford, Director of Flood Recovery
MD of Bighorn

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JURA CREEK DEBRIS FLOOD MITIGATION PROJECT

GROUNDWATER SECTIONS OF DETAILED DESIGN REPORT

1.0 INTRODUCTION

Further to your request for the groundwater sections of Golder's detailed design report for the Jura Creek Debris Flood Mitigation Report, we offer the groundwater related text to be incorporated in the detailed design report. The text is provided in two separate subsections, because the report includes two sections pertaining to groundwater (i.e., existing conditions, and potential impacts of the project on groundwater).

This report should be read with the attached Important Information and Limitation of this Report. The reader's attention is specifically drawn to this information as it is essential that it is followed for the proper use and interpretation of this technical memorandum

2.0 GROUNDWATER TEXT

2.1 Section 4: Existing Conditions, Subsection: Groundwater

There are no available historical investigations into groundwater conditions at the Jura Creek alluvial fan (Jura alluvial fan) but some inferences to groundwater conditions can be gleaned from several geological reports, previous test pitting, the recent excavation for Phase 1 of the Jura Creek debris flood mitigation works and recent drilling to install three groundwater wells. A summary of the available historical information prior to the current detailed design investigations for Jura Creek debris flood mitigation is provided below:

- There are several geological reports that pertain to the Jura Creek alluvial fan, but none of these investigations include measurements of groundwater levels.
- BGC conducted a hydrological investigation of historical debris flood frequencies and their work included field inspections and test pitting. BGC reports that their test pits in Jura Creek were excavated to a depth of 3 to 7 m without encountering groundwater.
- Phase 1 excavation of the Jura Creek channel (deepened by between 1 to 4 m) in 2016 by Golder Associates on behalf of the MD of Bighorn encountered no groundwater during the excavations.

In the absence of detailed groundwater investigations at the Jura Creek alluvial fan, Golder Associates Ltd. (Golder) on behalf of the MD of Bighorn recently installed three groundwater monitoring wells in April 2021, in support of detailed design for Phase 2 construction of the Jura Creek flood mitigation project. Each well was drilled to a depth of between 19.8 to 22.9 m below ground surface (mbgs) with the following observations:

- Sand and gravel soils with variable amounts of fines were generally encountered from ground surface to termination depth.
- Cobbles and boulders were inferred at some depths based on drilling observations and review of recovered sonic core.
- Groundwater was generally between 11.7 to 18.9 mbgs until May 10, 2021 (last download of data prior to this document).

Despite the absence of specific groundwater investigations pertaining to the Jura Creek alluvial fan, it is possible to estimate with a high degree of confidence the groundwater conditions at the Jura alluvial fan based on the known fluvial geomorphology of the Jura alluvial fan, the configuration and material composition of the Jura Creek alluvial fan, the annual inflows to the local groundwater system based on inferences of Jura Creek hydrological investigations, new drilling and groundwater level data, and comparison with the adjacent Exshaw Creek alluvial fan (Exshaw alluvial fan) where groundwater conditions can be characterized based on several drilling investigations, installed monitoring wells and interpretation of the data by McElhanney (2020).

Based on observations of exposed Jura Creek channel banks, the surficial materials of the Jura Creek alluvial fan is composed of silty/sandy gravel and small cobbles ranging in size up to 250 mm diameter with larger size material closer to the apex and smaller size material at the toe of the alluvial fan. Recent groundwater well drilling records by Golder indicates some horizontal stratification. Golder's drilling records indicate larger material sizes with fewer fines further upslope closer to the apex of the alluvial fan. The ground slope has an average value of about 4.9% with deviation up to 0.5% from the average. The alluvial fan covers an area of 1.1 km^2 with an approximate 59 m drop in elevation from the apex at 1,345 masl (meters above sea level) sloping down to the toe of the alluvial fan at the Bow River where the 2-year flood level is 1286.1 masl.

Annual inflows to the groundwater system of the alluvial fan can be estimated based on historic flows in Jura Creek because almost all Jura Creek flows discharge to the groundwater table by infiltration along the length of Jura Creek, except during more extreme flood events. Residents of the Hamlet of Exshaw have reported that flows in Jura Creek infiltrate into the Jura alluvial fan, almost entirely. Flows emanating from the Jura canyon at the apex of the alluvial fan have been observed to diminish as the flow passes along the length of the Jura Creek channel, often reducing to zero flow at or before the highway crossing. Relatively little flow in Jura Creek appears to reach the Bow River via surface flows.

It appears that most of the Jura Creek flow reaches the Bow River via the groundwater system within the Jura alluvial fan. The assessment of Jura Creek flows infiltrating to the groundwater system can also be deduced from the degree of disturbance along the Jura Creek flow path. Prior to the Phase 1 deepening of Jura Creek channel, extensive channelization and reworking of the bed material was evident upstream of the highway but minimal channelization and reworking of bed materials was evident downstream of the highway. In contrast to the disturbed condition upstream of the highway, the Jura Creek flow path downstream of the highway is largely vegetated with large trees and little evidence of recent flowing water.

With most of the local groundwater inflow derived from Jura Creek infiltration, the groundwater table within the Jura Creek alluvial fan is expected to be highest at the apex of the fan, sloping down to the toe of the fan where groundwater levels would be controlled by the level of the Bow River and surrounding floodplain. The depth to bedrock would have a dominant effect on the groundwater level if the bedrock surface (or other relatively impervious material) exceeds the level of the Bow River. In the absence of such controls (bedrock or other less pervious material located above river level), the groundwater table is expected to be locally cone shaped along the axis of the alluvial fan, widening downslope from the apex to the toe. However, the groundwater table would exhibit some mounding beneath the Jura Creek channel as a result of groundwater inflows by infiltration from Jura Creek. With flows in Jura Creek occurring mainly in spring during snowmelt or during infrequent high intensity rainstorms in the summer, the groundwater table in the Jura Creek alluvial fan is expected to fluctuate in response to flows in Jura Creek.

The groundwater table in the Jura alluvial fan is believed to be at a low level relative to the surface of the alluvial fan as a result of the high hydraulic conductivities of the pervious gravel flow medium and deep bedrock conditions. This assessment is consistent with data from the recent groundwater wells drilling program. Bedrock was not encountered at any of the three drill holes despite drill tip elevations of 1287.2 masl, 1276.9 masl and 1301.2 masl (relative to the Bow River 2-year flood level of 1286.1 masl). The groundwater table is expected to be within a few metres of the Bow River level where bedrock is at or below the level of the Bow River. Drill holes JC20-01 and JC20-02 indicate ground water levels within a few metres of the river level (roughly 1289.7 masl and 1285.0 masl respectively). Drill hole JC20-03 indicates a much higher groundwater level of 1301.5 masl indicating the likelihood of higher bedrock or other relatively impervious zone at depth.

Existing groundwater conditions at the Jura Creek alluvial fan can also be inferred based on available groundwater investigations and data from seven existing groundwater monitoring wells that have been installed at the Exshaw alluvial fan by Golder, McElhanney (2020) and others. The Exshaw alluvial fan is a good surrogate for the Jura alluvial fan because of its proximity (they are located adjacent to each other with the canyons at the apex of each alluvial fan separated by only about 2 km). The areal extent of each alluvial fan is similar (1.2 km^2 at Exshaw and 1.1 km^2 at Jura), the overall gradients of the fans are similar (4.9% at Jura and 4.5% at Exshaw), and the height of the apex (level of the apex above the 2-year Bow River flood level) of each alluvial fan are comparable (59 m at Jura and 49 m at Exshaw). Despite its smaller drainage area (less than half of Exshaw Creek drainage area) the Jura alluvial fan is a little larger (higher with slightly more volume) than the Exshaw alluvial fan. This is likely because the Bow River is closer to the apex of the Exshaw alluvial fan so that a greater portion of the Exshaw Creek sediment load reaches the Bow River.

A recent report on groundwater conditions at the Exshaw alluvial fan by McElhaney (2020) presents much of the available hydrogeological data and a good characterization of groundwater conditions at the Exshaw alluvial fan. Pertinent features of the groundwater system at Exshaw alluvial fan are as follows:

- The groundwater table in the Exshaw alluvial fan is situated close to the ground surface near the toe of the alluvial fan but well below ground surface at the apex and at the upstream reaches of Exshaw Creek. Based on the reported hydraulic gradients by McElhanney, the groundwater table could be within 10 m of the Bow River level throughout the Exshaw alluvial fan wherever it is unimpeded by bedrock or other less pervious zones.
- The groundwater table in the Exshaw alluvial fan fluctuates annually with a rising groundwater table in spring beginning in mid-April and peaking in early June. This phenomenon results in occasional flooding of

the residential area during the spring freshet. In 2020, the groundwater table reached a peak on June 4 when three groundwater wells recorded water levels at the ground surface.

- Groundwater hydraulic gradients range from 0.12% to 0.44% radiating outward from the upstream reaches of Exshaw Creek. The highest gradients occur in spring during the freshet when the groundwater table exhibits mounding resulting from Exshaw Creek infiltration. These gradients are far less than the average ground surface slope of the Exshaw alluvial fan (4.5%). Based on this data, it appears that the groundwater table typically exists far below the ground surface of the Exshaw alluvial fan except at the downslope perimeter (toe) of the alluvial fan where the water table is close to the ground surface and sometimes reaches the ground surface during the spring freshet depending on the snowpack and Bow River water levels.
- Calculated hydraulic conductivities based on slug tests range from 6.0×10^{-4} to 5.1×10^{-4} m/s and calculated seepage velocities range from 390 m/year during times of high flow in spring conditions down to 120 m/year in late summer. The McElhanney (2020) report indicates that seepage velocities at other locations may be greater.
- The main environmental factors contributing to groundwater levels are snowmelt, precipitation, snowmelt runoff from the local drainage area (that includes much of the hamlet area as well as the adjacent mountainside on the north side of the hamlet) and the level of the Bow River. A high snowpack (as in 2020) increases inflows to groundwater by infiltration from Exshaw Creek. In 2020, the Alberta River Basins Website reported mountain snowpack was much higher than average (146%). High precipitation onto the Exshaw alluvial fan resulted in increased infiltration and contribution to the local groundwater table. The level of the Bow River may also affect the groundwater table within the Exshaw alluvial fan by reducing the hydraulic gradient during river flood conditions when river levels may exceed the ground surface levels at the toe of the Exshaw alluvial fan.

It is reasonable to expect that the groundwater fluctuations at the Jura alluvial fan will have a similar pattern as measured at Exshaw with the water table rising in early spring, peaking in early June and receding in summer, fall and winter. The recent installation of three groundwater monitoring wells are expected to support this interpretation. Hydraulic gradients are expected to be smaller at the Jura alluvial fan because, with less than half the drainage area, flows and associated infiltration rates are expected to be much smaller at Jura Creek than at Exshaw Creek. The groundwater level at the Jura alluvial fan is expected to be close to the level of the Bow River, similar to Exshaw except where bedrock or other relatively impervious zones impede seepage. Considering the smaller flows of Jura Creek and the higher ground surface elevations of the Jura alluvial fan, it is also reasonable to expect that the groundwater table at the Jura alluvial fan is subject to less groundwater level fluctuation than at the Exshaw alluvial fan.

2.2 Section 10: Potential Impacts of the Proposed Debris Flood Mitigation Measures, Subsection 10.2 Groundwater Impacts, Subsection 10.2.1 Without Mitigation

Golder’s design of the Jura Creek debris flood mitigation project has been questioned because of possible increased infiltration to the local groundwater table in the Jura alluvial fan. Increased infiltration of Jura Creek flows is of concern to some local residents who wonder if higher groundwater levels in the Jura alluvial fan could result in higher groundwater levels in the Exshaw alluvial fan located next to the Jura alluvial fan. The principal concern of residents is that increased infiltration into the Jura alluvial fan would result in higher peak groundwater levels in the Exshaw alluvial fan, thereby affecting basement flooding in residences in the Hamlet of Exshaw, namely the residences at east Exshaw, close to the eastern toe of the Exshaw alluvial fan.

Two potential sources of increased inflows to the groundwater system at the Jura alluvial fan have been postulated by some local residents. One involves increased infiltration along the Jura Creek channel that was deepened in 2016 during Phase 1 of the Jura Creek debris flood mitigation project. It is alleged that the recent excavations deepened the channel by removing a less pervious layer at the surface thereby exposing coarser, more pervious materials at depth, leading to increased infiltration. This mechanism for increased infiltration is based on a false assumption that a less pervious zone at the ground surface was removed by the recent excavations. Golder verifies that the Jura Creek channel was fully disturbed by natural fluvial processes and that no ‘less pervious zone’ existed near the surface, prior to the recent excavations. The description of a near-surface, less pervious zone on the Exshaw alluvial fan might apply to non-channelized areas adjacent to Jura Creek but would not apply to the highly disturbed 40 m to 80 m wide flow path of Jura Creek. Recent excavations for Phase 1 of the Jura Creek debris flood mitigation project were limited to the highly disturbed flow path of Jura Creek and did not encroach on the adjacent treed areas that might contain less pervious materials.

A second mechanism for increased infiltration is the provision of a sediment pond proposed for Phase 2 of the Jura Creek debris flood mitigation project. The proposed sediment pond could result in increased infiltration, not because of the depth of excavation or removal of surficial materials, but because such a sediment pond would provide increased storage along Jura Creek which could attenuate flood flows to prolong infiltration to the groundwater table within the Jura alluvial fan. This mechanism could cause increased infiltration in the Jura alluvial fan but it is highly unlikely that it could result in higher peak groundwater levels in the adjacent Exshaw alluvial fan, leading to increased flooding of basements at existing residences at east Exshaw. This assessment of negligible impacts of the project) is based on the following rationale:

- The presence of the proposed sediment pond along Jura Creek would not necessarily result in increased infiltration. The presence of a sediment pond may actually reduce infiltration depending on the flow sequences and sediment pond levels.
- Any increase in infiltration resulting from the proposed sediment pond is expected to be very small because most of the Jura Creek flow currently infiltrates into the Jura alluvial fan upstream of the highway crossing as discussed above. Therefore, provision of new storage along Jura Creek is expected to have limited potential for increasing the quantity of Jura Creek flows reporting to groundwater.
- The location of the proposed sediment pond relatively close to the Bow River would result in predominant infiltration and groundwater flow pathways directly to the Bow River. The groundwater gradient is believed

to radiate outward from the apex of the alluvial fan toward the toe of the alluvial fan, same as the seepage paths that have been documented at the Exshaw alluvial fan (McElhanney, 2020).

- The residences at east Exshaw are located on the Exshaw alluvial fan, west of a lowland area between the two alluvial fans. From the available topographic maps, it appears that the residences of east Exshaw are situated about 1 to 2 m above the lowest levels of the lowland area. These residences are located on the opposite side of the lowland area, well removed from the main groundwater discharges emanating from the toe of the Jura alluvial fan.

- The groundwater table gradient in the Exshaw alluvial fan (ranging from 0.11% to 0.44% as measured by McElhanney (2020)) is expected to be greater than the groundwater gradient in the Jura alluvial fan as discussed above. Accordingly, discharges and groundwater levels at the lowland area near east Exshaw are expected to be dominated by seepage flows in the Exshaw alluvial fan. Any seepage discharge from the Jura alluvial fan would occur at the toe of the Jura alluvial fan and would not be expected to encroach on the Exshaw alluvial fan.

- There is a large time delay between the infiltration at the proposed sediment pond and flooding at east Exshaw. The time delay is caused by the very slow seepage velocity in the alluvial fan. McElhanney (2020) calculated seepage velocities of 390 m/year to 120 m/year at two monitoring wells on the Exshaw alluvial fan. Accordingly, any impact of increased infiltration caused by the proposed sediment pond would occur long after the peak impact of surface flooding. Any impact of increased infiltration of Jura Creek flows would also occur after the peak groundwater table rise at the toe of the Exshaw alluvial fan that occurs each year as a result of Exshaw Creek infiltration into the Exshaw alluvial fan. The reason for the delayed impact of Jura Creek infiltration is the greater distance from the source of additional groundwater. Accordingly, any impact of altered groundwater conditions in the Jura alluvial fan would not be expected to coincide with peak raises in groundwater levels at the Exshaw alluvial fan.

There are risks of flooding at the lowland area of east Exshaw, but the dominant risks are increased infiltration from Exshaw Creek during years of unusually high snowpack, rainfall and snowmelt runoff from the local drainage area (that includes much of the hamlet area as well as the adjacent mountainside on the north side of the hamlet), and impeded groundwater drainage to the Bow River during floods on the Bow River. The impacts of these sources of flooding are large. In contrast, based on the above rationale, groundwater conditions in the Jura alluvial fan are expected to have negligible impact on the residences of east Exshaw.

2.3 Subsection 10.2.2 With Mitigation

Golder's assessment of the effects of the Jura Creek debris flood mitigation works on groundwater levels at east Exshaw concluded that the effects would be negligible, and that further mitigation is not required. However, further mitigation by a relatively impervious liner or rock drain beneath the sediment pond and through the weir embankment, would provide a further degree of certainty as well as evidence of no increases to infiltration along Jura Creek. A rock drain would allow the sediment pond to empty relatively rapidly after filling during a flood. An empty sediment pond and a functioning rock drain would be a clear indication of no increase in infiltration.

The option of a relatively impervious liner was determined to be more costly both in terms of capital works and operations. Provision of a rock drain was therefore selected by the MD of Bighorn as a reliable, low-cost measure that would require minimal maintenance.

3.0 CLOSURE

This memorandum was prepared and reviewed by the undersigned:

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REFERENCES

McElhanney November 2020. Physical Hydrogeological Assessment.

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