APPENDIX III

Groundwater Model Design Basis Memorandum

Appendix III
Groundwater Model Design Basis Memorandum

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III-1 BACKGROUND AND PURPOSE OF STUDY

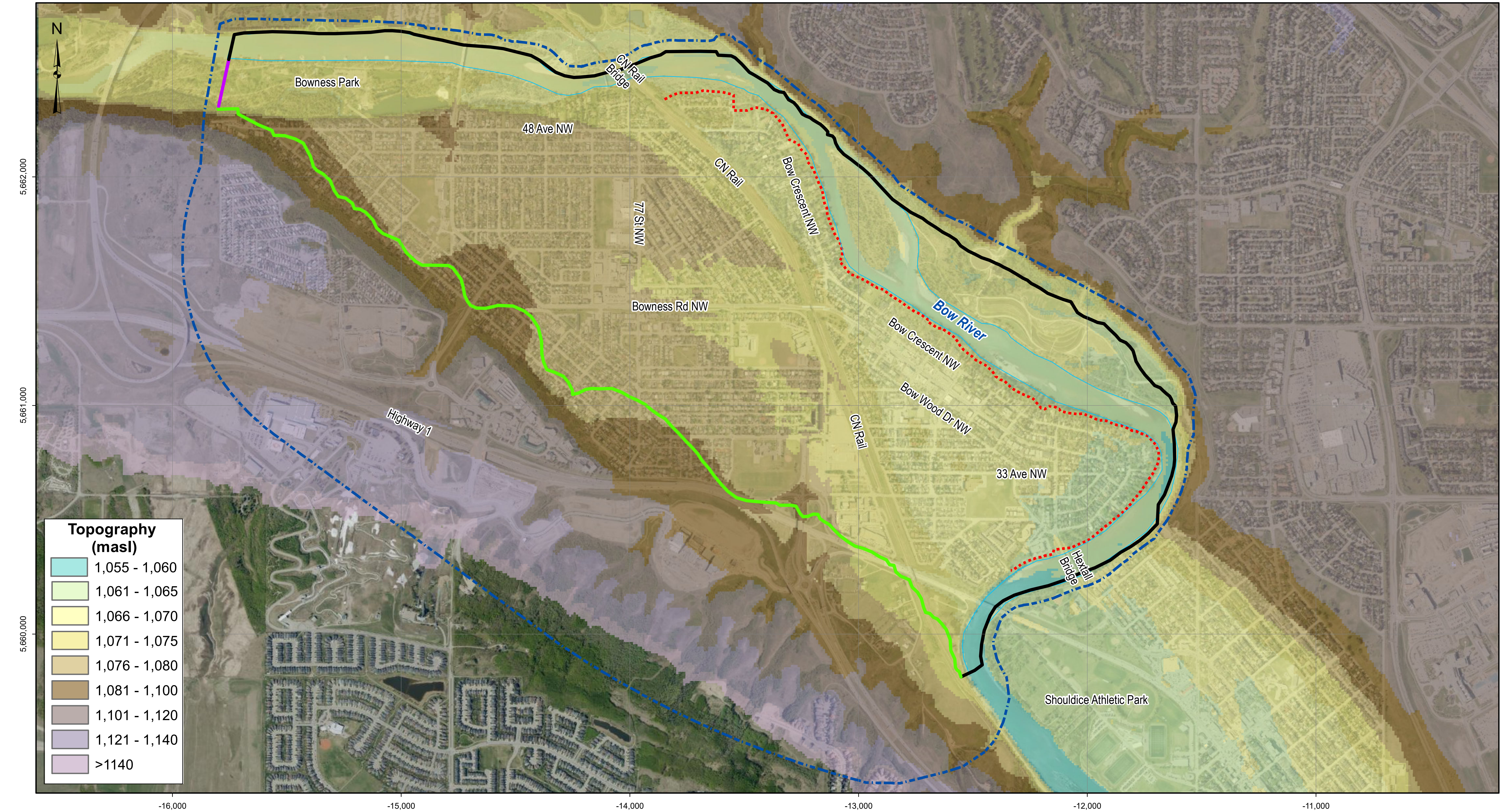
The June 2013 flood in Calgary prompted The City of Calgary (CoC) to conduct a Flood Mitigation Measures Assessment. The Assessment concluded that a combination of watershed-level, community-level, and property-level flood mitigation measures should be pursued to reduce Calgary's flood risk (CoC 2016). The current project, described in the Request for Proposals (RFP) in Appendix II, will investigate three proposed community-level measures, consisting of flood barriers in the communities of Bowness, Sunnyside, and Pearce Estate Park.

Klohn Crippen Berger Ltd. (KCB) has been commissioned by CoC to conduct a hydrogeological study to support the flood barrier investigation within the riverfront community of Bowness. The proposed flood barrier for Bowness would be located along the Bow River, extending from the CP Railway Bridge downstream to Hextall Bridge. The spatial extent of the Project Area was expanded to incorporate all relevant hydrogeological features (Project Area shown in Figure III-1.1) and the greater Bowness community. The purpose of the Bowness hydrogeological study is to:

- Develop and complete a field investigation and monitoring program, to collect site-specific geological and hydrogeological data;
- Develop a physical conceptual model of the geological and shallow groundwater flow system;
- Develop a calibrated three-dimensional (3D) groundwater flow model for the Bowness riverfront community to assess the effect of the proposed flood barrier alignment(s) on the shallow groundwater system;
- Predict the extent, magnitude, and timing of surface flooding due to groundwater level rises associated with specific Bow River flood events and various flood mitigation options; and
- Review potential groundwater mitigation options.

Conceptual flood barrier designs provided in the RFP indicate that the construction of the Bowness flood barrier could potentially affect over 94 private properties, the Bow River Pathway, public open spaces, the Bowness Road Bridge, and the River Valley School.

The key benefits to the community would be the overall reduction in both overland and groundwater-related flooding event frequency.



LEGEND:

- Project Area
- Proposed Flood Barrier
- River Boundary

Model Boundary

- Constant-Head Boundary
- General-Head Boundary
- No-Flow Boundary

0 500 m

NOTES:

1. HORIZONTAL DATUM: NAD 83
2. GRID ZONE: 3TM 114
3. IMAGE SOURCE: CITY OF CALGARY, ArcGIS Map Service. Image Date: May/June 2019.
4: Map scale is 1:16,900 on 11" x 17" paper.

CLIENT: Calgary

Klohn Crippen Berger

PROJECT: BOWNESS FLOOD CONTROL BARRIER

TITLE: BOWNESS PROJECT AREA AND MODEL DOMAIN

SCALE 1:16,900 | PROJECT No. A03330C01 | FIG No. III-1.1

Time: 14:18:47 PM
Date: July 13, 2020

III-2 DESIGN BASIS MEMORADUM

This Design Basis Memorandum (DBM) document represents a 'live' document that will be updated throughout the life of the 3D groundwater modelling study for the Bowness Flood Control Barrier modelling study. This document is intended to reflect any model changes, scope revisions, and updated additional information included in the development of the 3D numerical model.

This is the current version of the DBM, Version 3.0, dated July 08, 2020.

III-3 MODEL DEVELOPMENT AND METHODOLOGY

III-3.1 Design Basis

A 3D numerical groundwater flow model was developed to support the Bowness Flood Control Barrier modelling study based on the 3D geological model (*Leapfrog*™ *Geo*) constructed for the Bowness area, and conceptual hydrogeological model (CHM) compiled for the Quaternary sand and gravel aquifer system (Alluvial Aquifer) in the Bowness community, to assess the impact of the:

- Proposed surface flood barrier design(s) on the shallow groundwater system during normal Bow River flows conditions and significant flood events;
- Potential for groundwater inundation associated with various river flood events, both with and without the surface flood barrier in place; and
- Review various groundwater flood mitigation concept designs (e.g. a groundwater seepage cut-off barrier).

A key design aspect of the proposed flood barrier and potential groundwater cut-off barrier is that the designs do not have an adverse effect on the Bowness community in terms of groundwater-related flooding. There are benefits to mitigating groundwater-related flooding, but also potential ‘damming’ effects and groundwater build-up within the community due to the proposed installation of a groundwater cut-off barrier. Future flood management of the Bow River at the upstream dams operated by TransAlta will affect the river flood response and proposed attenuation of flood flows by TransAlta will be included in the prediction modelling. The river flow magnitude and duration of the groundwater flood event will be the key design aspect of the proposed flood barrier.

III-3.2 Modelling Objectives

III-3.2.1 System Characterization

Compilation of a 3D geology model and hydrogeological characterization of the shallow groundwater system to assist with the development of a robust 3D numerical flow model. The model will serve as a synthesis of the current understanding of the hydrogeological flow system along the Bow River within the Bowness community, including the interaction between the Bow River and the shallow groundwater system.

III-3.2.2 Groundwater Inundation

Simulation of hydraulic heads relative to ground surface and assumed residential basement elevations to estimate potential areas affected by groundwater inundation (i.e., groundwater flooding) during significant Bow River flood events, without the surface flood barrier in place.

III-3.2.3 Flood Barrier Impact Assessment

The flood barrier impact assessment is to include the following details:

- Flood barrier effects on groundwater hydraulic heads, potential for flooding during normal Bow River flow conditions, and significant flood events for differing flood barrier locations and designs; and
- Changes to the magnitude and duration of groundwater seepage flows for selected flood barrier designs.

III-3.2.4 Groundwater Flood Mitigation

The surface flood barrier and various groundwater flood mitigation concept designs will be assessed using a combination of two-dimensional (2D) and 3D modelling under both normal Bow River flow and flood conditions.

III-4 CONCEPTUAL HYDROGEOLOGICAL MODEL

The conceptual hydrogeological model (CHM) details the current understanding of the hydrogeological system within the Bowness Project Area, including the regional understanding of key Hydrostratigraphic Units (HSUs), hydraulic properties, aquifer-aquitard interconnectivity, Bow River - aquifer interaction, groundwater flow regimes, and hydrochemistry. The 3D geological model and conceptual hydrogeological model will form the basis for the development of the 3D groundwater numerical model.

III-5 MODEL SCOPE AND ASSUMPTIONS

III-5.1 Software

III-5.1.1 Groundwater Vistas 7

The 3D finite-difference, groundwater flow and transport modelling software *Groundwater Vistas Version 7* (ESI 2019) (using MODFLOW-based code, including SURFACT) will be used to build the numerical model and analyze the model outputs. The model code was selected because of its ability to incorporate both saturated and unsaturated groundwater flow conditions, broad usage and acceptance in the industry, advanced water balance features, and user-friendly interface. The MODFLOW Unstructured Grid (USG) was another factor in the choice of this code, allowing for greater discretization at a local scale without unduly increasing the number of model cells.

III-5.1.2 ArcGIS 10.4

ESRI's ArcGIS will be used to visualize, assess, and manipulate model surfaces and geological features for input into the groundwater model as ESRI ASCII raster grids and shapefiles. ArcGIS will also be used to visualize and assess model outputs, as well as compile report figures.

III-5.1.3 Leapfrog™ Geo Version 6

The *Leapfrog™ Geo* analysis and visualization program from Seequent Ltd. with the hydrogeology module package was used to create the 3D lithostratigraphic model for input into the 3D groundwater flow model. Leapfrog™ is an industry standard and generally-accepted tool for the construction of geological models. Like most geological and other spatial modelling packages, there are limitations in the application of interpolation techniques, particularly when data are lacking for large areas of the model domain, as is the case at the Bowness Project Area.

III-5.2 Design Parameters

III-5.2.1 Model Domain and Mesh

The model domain is shown on Figure III-1.1 and was defined based on the CHM (key HSU extents/ isopachs, shallow groundwater flow regime, identified hydraulic boundaries, and limits of potential hydraulic effect), potential flood barrier alignment(s), and supported by the compiled 3D (*Leapfrog™ Geo*) geological model. The areal extent of the model domain is approximately 5.2 km^2 and the model boundaries are summarized below:

- North, northeastern and eastern boundary extents follow the Bow River and escarpment;
- Western and southwestern boundaries are defined by the limits of the Alluvial Aquifer which pinches out along the escarpment ridge; and
- Southern boundary extents are set along the southern edge of the Alluvial Aquifer.

The proposed 3D numerical model will be rotated to align with the top of the model at Az 123°, parallel to the linear section of the Bow River and will be separated into the following three mesh density zones:

- High Density Zone – areas along the Bow River boundary extending south from the river to include potential barrier alignments along the river and along Bow Crescent NW (average nodal spacing of 3 m to 6 m);
- Intermediate Density Zone - transition area between the high-density zone and low-density zone (average nodal spacing of 6 m to 12 m); and
- Low Density Zone -extending from the intermediate density zone to the model boundaries along the southern and western edges of the model domain (average nodal spacing of 12 m to 50 m).

III-5.2.2 Current Topography

The top surface of the model will be compiled using the available LIDAR data (CoC 2018) of 0.2 m resolution, illustrated in Figure III-1.1. Key topographic features include:

- Project Area which is generally flat lying with significant elevation changes along the southern side of the model domain (escarpment);
- Ground elevation ranges from 1080 m above sea level (masl) in the west to 1065 masl in the east; and
- The southwestern boundary of the model domain which occurs at the base of an ESE-trending escarpment to the south, with a top elevation of approximately 1235 masl.

III-5.2.3 Boundary Conditions

Proposed boundary conditions are shown on Figure III-1.1 and described further in the sections below.

III-5.2.4 Recharge

Recharge to the shallow groundwater system within the model domain is expected to be controlled by the following sources and mechanisms:

- The Bow River is an important source of local recharge to the Alluvial Aquifer adjacent to the river, especially during and following seasonal (freshet) high flows and flood events;
- Direct precipitation recharge on permeable overburden; and
- Lateral seepage from more permeable surficial deposits and bedrock units along the escarpment areas.

Infiltration of surface runoff along dry gullies may also represent an important recharge pathway; however, the area of the model domain is highly urbanized and this does not appear to be a significant recharge mechanism.

Precipitation Recharge

The mean annual precipitation (MAP) for Calgary is 420 mm, based on data from the Environment Canada weather station at the Calgary International Airport (from years 2000 to 2017). Recharge was allocated in the model based on the following:

- Only consider net recharge (i.e., infiltrated water reaching the groundwater table and evapotranspiration is not be considered as part of the water balance);
- Precipitation recharge is highest during the late spring freshet and results in a time-varying recharge to the Alluvial Aquifer;
- Recharge is higher over outcrops of more permeable sediments. Drill logs were reviewed to assess the presence of permeable alluvial sediments at or near surface. This area (in the vicinity of MW19-04 through MW19-07, MW19-12, and MW19-18) will be assigned a higher

recharge rate, as shown in Table III-5.1.No recharge occurs over the impervious surface area (estimated to cover approximately 40% of the model domain); and

- Based on available groundwater level monitoring and precipitation data for the site, rainfall recharge is expected to have a greater effect on piezometric levels at locations farther from the Bow River. Along the river, piezometric levels are dominated by the river level fluctuations.

Groundwater recharge from precipitation was subdivided based on HSU distributions using the MAP and estimates of average annual groundwater recharge from Barker et al. (2011). Barker et al. (2011) estimated precipitation recharge rates ranging from 51 mm/year to 75 mm/year, which equates to approximately 18% of MAP. Meyboom (1961) estimated an average annual recharge rate of 52 mm for the Elbow River basin.

However, there will be some variability of precipitation recharge rates depending on the permeability of the overburden material. Table III-5.1 below summarizes the MAP recharge rates. These rates will be pro-rated to account for interpreted higher recharge conditions for the 'steady-state' modelling period selected. In this case for the proposed steady-state period of May 5 to 9, 2019, recharge was estimated at an annual rate, based on a review of Bow River hydrographs and interpretation of the baseflow component.

Where an area contains significant impermeable surfaces (e.g., roads, roofs, driveways), the effective recharge was reduced by 50%.

Table III-5.1 Annual Precipitation Recharge Rates per HSU Category

HSU	Recharge Rate (% of MAP)	Mean Annual Groundwater Recharge Rate (mm/year)
Topsoil, Silt and Clay	8.3	35
Topsoil, Silt and Clay – Developed Areas	4.2	17.5
Alluvial Sandy Gravel	16.7	70
Alluvial Sandy Gravel – Developed Areas	8.3	35

Note: MAP - Mean annual precipitation of 419 mm/year.

Within the model domain, only Silty Topsoil/Fill and Alluvial Aquifer were encountered at the surface.

The following information data sources were used:

- Environment Canada weather station data, Calgary International Airport;
- Impervious surface layer for Calgary, provided by CoC (2016); and
- Run-off coefficients estimated from the HEC-RAS model infiltration rating curves (KCB 2019b).

Lateral Seepage Recharge

There have been no significant seepage zones identified in the Project Area during the background data review and hydrogeological conceptualization. Seepage zones are most likely to exist along the escarpment ridges to the south and northeast of the Project Area (outside of the model domain). Lateral seepage to the Alluvial Aquifer from lacustrine sediments and bedrock along the southern margin of the model domain will be simulated using boundary conditions (e.g., elevated hydraulic heads).

Specified Head Boundaries

The southern boundary will be modelled as a Specified Head boundary, using data contoured for the May 5 to 9, 2019 steady-state calibration period (see Section III-5.3.1).

General Head Boundary Conditions (BC) will be applied at the eastern and western ends of the model domain, in order to reduce the potential for a strong, artificial interaction between the Specified Head and River boundaries. The conductance and distance to constant head terms will be reviewed to ensure the boundary handles flux appropriately.

The following boundary conditions may need to be adjusted during the steady-state model calibration:

- Recharge BC – applied to the top active layer;
- Constant Head or General-Head BCs – along the x and y model boundaries to simulate seepage inflows from upgradient HSUs located outside of the model domain;
- Head-dependent Flux BCs using MODFLOW River package – for river levels along the Bow River during normal seasonal flow and flood periods; and
- No-flow BCs – along model base.

III-5.2.5 Bow River Boundary

The groundwater-Bow River interaction will be simulated using the MODFLOW River package – a Head-dependent flux boundary.

The existing 2D HEC-RAS model was used to simulate Bow River stage hydrographs for January to November 2019 along the Bow River at 13 locations adjacent to selected monitoring well locations and four locations upstream of the proposed groundwater cut-off barrier alignment. Three additional river stage hydrographs were simulated for locations within the model domain and upstream of the flood barrier alignment. Ice damming effects are not being considered as the peak period of flooding occurs in June and the river typically is free from ice by May. The potential for elevated river levels due to ice ‘jams’ in Bowness has been greatly reduced with the construction and commissioning of the Bearspaw Dam. The HEC-RAS data were adjusted slightly downstream of MW19-06 to better match observed river levels along this reach within the model boundary.

The river boundary was modelled with an averaged base elevation, as opposed to detailed riverbed topography or thalweg elevation applied across the full width of the river. This data was drawn from river bathymetric cross-sections.

The riverbed material is relatively coarse, and will be assigned a thickness and a relatively high vertical conductivity (K_V) of 1×10^{-4} m/s for the purposes of calculating riverbed conductance.

There are no known significant surface water discharges to the Bow River upstream and within Bowness. Cantafio and Ryan (2014) indicated that stormwater contributions to the baseflow of the Bow River within the Calgary area were relatively small.

The following information sources were used:

- Logger data from two Bow River installations (CN Rail Bridge and Hextall Bridge) provided by CoC from their river monitoring program; and
- KCB HEC-RAS model (KCB 2019b) used for rating-curve analysis and estimation of river stage levels.

III-5.2.6 Hydrostratigraphic Units

Several key geological layers will be incorporated as Hydrostratigraphic Units (HSUs) in the numerical model as defined in the 3D geology model. The following available information was used to develop the geological conceptual model and select the HSUs:

- Desktop review of available geological maps and information for the Calgary area (Meyboom 1961, Moran 1986, Osborn and Rajewicz 1998, and Hamilton et al. 2004);
- August 2018 LIDAR DEM provided by CoC;
- Geological and groundwater information presented in Golder (2016);
- Available geology from boreholes drilled as part of a 2019 field investigation (KCB 2019a) and for selected previous investigations (CH2M 2015a, 2015b, and 2018);
- Available information from site and remediation assessments completed at the Alberta Environment contaminated (GasPlus) site located at 6336 Bowness Road (CH2M 2015a and 2015b);
- Historical borehole lithology available from the Alberta Water Well database and the Environmental Site Assessment Registry (ESAR) database; and
- Bowness geophysical investigation results (Tetra Tech 2020).

The lithostratigraphic units compiled in the 3D geology model were categorized into key HSUs based on their hydrogeological significance. The HSUs and associated hydrogeologic roles are summarized in Table III-5.2 and are listed in stratigraphic order.

Table III-5.2 Model Hydrostratigraphic Units

Hydrostratigraphic Unit (HSU)	Hydrogeological Role	Saturated Thickness (m)
Clayey/Silty Topsoil/Fill	aquitard	unsaturated to 1
Alluvial Sand and Gravel	aquifer	unsaturated to 6
Sandy Lacustrine and Till	aquitard	0 to 14
Sandy and Clayey Lacustrine	aquitard	0 to 11
Clayey Lacustrine	aquitard	0 to 3
Weathered/Jointed Bedrock (Siltstone and Mudstone)	aquifer	fully saturated to 1.5
Competent Bedrock (Siltstone and Mudstone)	aquitard	fully saturated

III-5.2.7 Model Layers

Table III-5.3 below outlines the HSUs and the seven proposed model layers to be included in the model. The sand and gravel layer is discretized into three layers to simulate flow within a relatively thin and irregular unit and allow for model flexibility to assess relatively small scale water level fluctuations (i.e., seasonal changes to Bow River inflows and outflows, and flood prediction simulations). The additional layers may be refined during model development but are originally intended to offer flexibility within the model to calibrate to observation data.

Table III-5.3 Hydrostratigraphic Units and Model Layers

Hydrostratigraphic Unit (HSU)	Model Layer	Comments
Clayey and Silty Topsoil/Fill	1	
Alluvial Sand and Gravel	2 to 4	2 (50% thickness), 3 & 4 (25% thickness each)
Sandy Lacustrine and Till	5	
Sandy and Clayey Lacustrine	5	
Clayey Lacustrine	5	
Weathered/Jointed Bedrock	5 and 6	Assumed 1.5 m weathered layer (based on review of logs) along top of intact bedrock
Intact Bedrock	7	Predominately siltstone and mudstone, minor sandstone.

III-5.2.8 Hydraulic Conductivity and Storage Parameters

The initial bulk hydraulic conductivity values to be assigned to the model HSUs are presented in Table III-5.4 and are derived from the following sources:

- KCB field investigations completed in the 2019 Geotechnical Investigation (KCB 2019a) and unpublished data from KCB 2019 Hydrogeological Investigation;
- Site specific investigation reports from AECOM (2014), CH2M (2015a, 2015b, and 2018), and Golder (2016);
- Site-specific database information available from the ESAR database of historical investigation reports;
- Published literature values where site-specific information is not available; and

- Vertical anisotropy based on a review of the piezometric database, existing geologic bedding, and vertical textural evaluation.

The geometric mean for the reported estimates of hydraulic conductivity are to be used as initial inputs for each HSU in the model.

The Alluvial Aquifer unit varies texturally; key areas near the Bow River may locally consist of gravelly cobbles, some sand and boulders, and trace silt as shown on photographic documentation of the excavations. The high proportion of large particle sizes with a sandy matrix observed at certain locations (see Figure III-5.1), suggests a relatively low porosity and specific yield for this material, since the large particles will have a primary porosity specific yield that is typically very low and the intervening porosity will be filled with finer particles. Analysis of a 50-hour constant-rate pumping test undertaken at well MW19-06D provided a specific yield of 0.24.

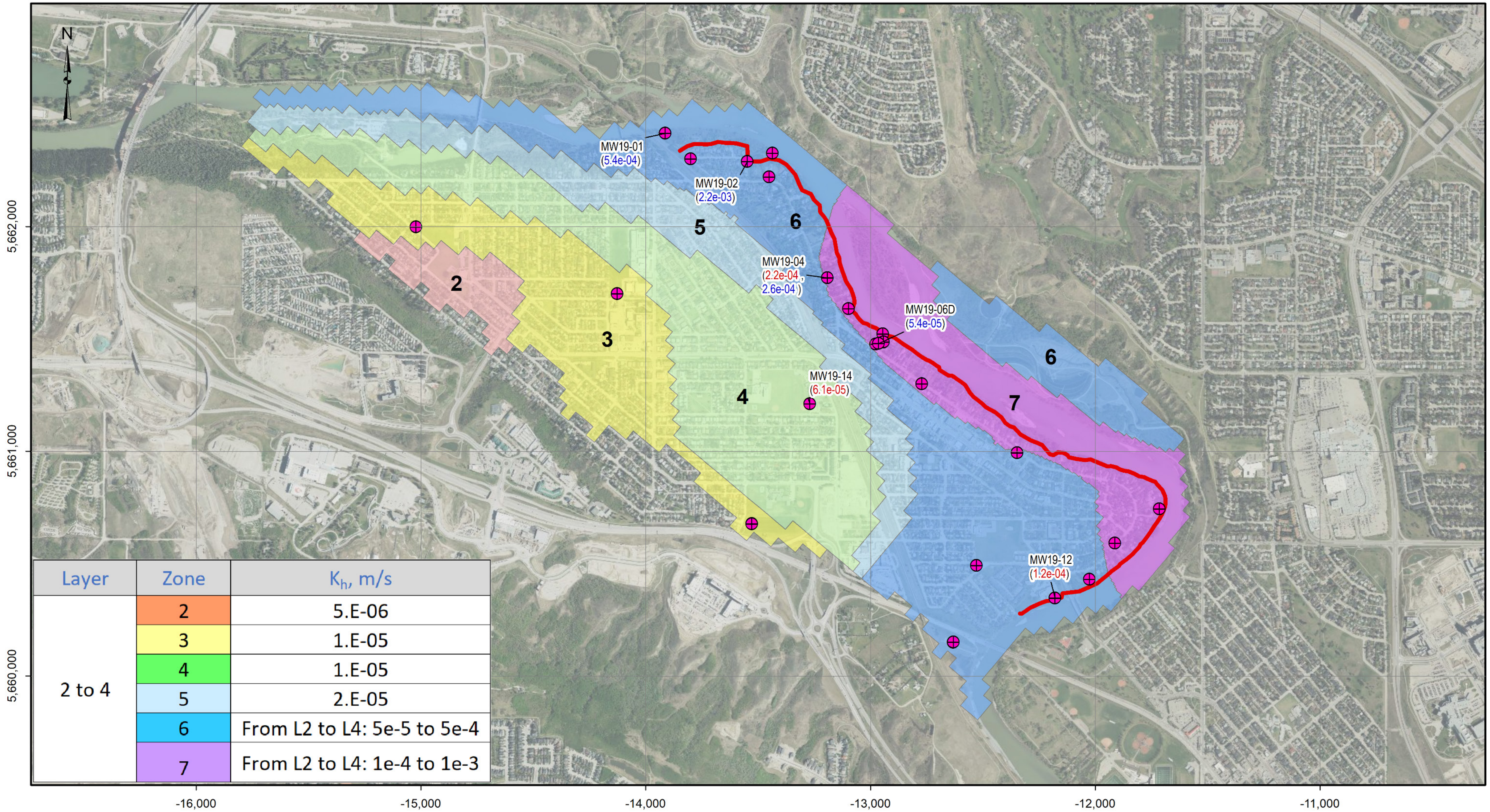
The hydraulic test data for the sand and gravel unit includes approximately 40 tests at eight locations. The spatial plot of available hydraulic conductivity data is provided in Figure III-5.2 and was used as the basis for assigning initial model values. In general, it was interpreted that hydraulic conductivity generally increases towards the river channel, with lowest measured K values observed at MW19-14, MW19-15, and MW19-17. This aquifer permeability zonation appears to be supported by the water table contours and a general sedimentological model for a glaciofluvial system, whereby hydraulic energy is likely to be greatest near the center of the channel.

Published literature value ranges (Freeze and Cherry 1979, Domenico and Mifflin 1965) were used to assume initial hydraulic conductivity and storage values for those layers without site-specific data.

Reported hydraulic conductivities for weathered/jointed bedrock ranged from 4×10^{-8} m/s to 4×10^{-4} m/s and competent bedrock ranged from 1×10^{-10} m/s to 3×10^{-5} m/s. As a result, the bedrock was subdivided into two layers, with a uniform 1.5 m thick weathered/jointed layer assumed (based on review of drill logs), to overly the intact bedrock layer. The siltstone is anticipated to be of low permeability[1], while lenticular sandstone layers typically have a permeability in the range of 1×10^{-5} m/s to 3×10^{-5} m/s (Meyboom 1961). During the 2019 drilling program, sandstone was encountered in two of 21 drill holes that intersected the bedrock. Table III-5.4 below summarizes the initial hydraulic conductivity values assigned to each HSU layer. Figure III-5.2 shows the initial hydraulic conductivity distribution in the Alluvial Aquifer (Layers 2 to 4), based on site testing and review of groundwater contours. Estimated anisotropy values (horizontal hydraulic conductivity [K_H]/vertical hydraulic conductivity [K_V]) were based on review of the geological descriptions and drilling results, as well as data from literature. The more detailed drilling conducted in the vicinity of MW19-06 has shown the potential for local-scale variability in the bedrock topography, and sand and gravel thickness.

[1] Hydraulic conductivity: Very Low: < 1×10^{-9} m/s; Low: 1×10^{-9} m/s to 1×10^{-7} m/s; Moderate: 1×10^{-7} m/s to 1×10^{-5} m/s; High: 1×10^{-5} m/s to 1×10^{-3} m/s; Very High: > 1×10^{-3} m/s

Figure III-5.1 Photograph of Excavation at 6750 Crescent NW showing Alluvial Sand and Gravel Unit



Layer	Zone	K_h, m/s
2 to 4	2	5.E-06
	3	1.E-05
	4	1.E-05
	5	2.E-05
	6	From L2 to L4: 5e-5 to 5e-4
	7	From L2 to L4: 1e-4 to 1e-3

LEGEND:

PROPOSED GROUNDWATER FLOOD BARRIER

June 2019 Wells (Sand and Gravel)
- Slug Test Hydraulic Conductivity (m/s)
- Constant RateTest Hydraulic Conductivity (m/s)

m
0 500

NOTES:
1. HORIZONTAL DATUM: NAD 83
2. GRID ZONE: 3TM 114
3. IMAGE SOURCE: CITY OF CALGARY, ArcGIS Map Service. Image Date: May/June 2019.
4: Map scale is 1:25,000 on A4 paper.
5. Red text represent hydraulic Conductivity (m/s) from 2019 Slug testing
6. Blue text represent hydraulic Conductivity (m/s) from 2019 CRT testing

CLIENT
Calgary

Klohn Crippen Berger

PROJECT
BOWNESS FLOOD CONTROL BARRIER

TITLE
SPATIAL DISTRIBUTION OF HORIZONTAL HYDRAULIC CONDUCTIVITY FOR ALLUVIAL AQUIFER

SCALE 1:25,000
PROJECT No. A03330C01
FIG No. III-5.2

Time: 18:14:51 PM
Date: January 04, 2021
File: \\int.klohn.com\ProjData\ACGY\Alberta\A03330C01 CoC Bowness Flood Control Barrier\400 Drawings\407 Hydrogeology\Report Figures\Model DBM\MXD\Fig 5.2 Hydraulic Conductivity Distribution3_201102.mxd

Table III-5.4 Initial Model Hydraulic Parameters per Hydrostratigraphic Unit

Hydrostratigraphic Unit (HSU)	Saturated Hydraulic Conductivity					Specific Storage [Ss]# (m^{-1})	Specific Yield [Sy]#	Layer Properties
	K_H Tested Range (m/s)	Geometric Mean K_H (m/s)	Arithmetic Mean K_H (m/s)	Initial K_H (m/s)	Anisotropy * [K_H/K_V]			
Clayey Topsoil/Fill	-	-	-	1×10^{-6}	5	1×10^{-5}	0.05	**Model Layer 1**
Silty Topsoil/Fill	-	-	-	1×10^{-6}	5	1×10^{-5}	0.1	
Alluvial Sand and Gravel	1×10^{-7} - 7×10^{-3}	8×10^{-5}	5×10^{-4}	5×10^{-6} - 1×10^{-3}	2	1×10^{-5}	0.05 – 0.20	**Model Layers 2 – 4**
Sandy Lacustrine	2×10^{-7} - 5×10^{-7}	-	3×10^{-7}	1×10^{-6}	5	2×10^{-5}	0.05	**Model Layer 5**
Clayey Lacustrine	n/a	-	-	1×10^{-8}	10	1×10^{-4}	0.03	
Weathered/ Jointed Bedrock (siltstone & mudstone)	4×10^{-8} - 4×10^{-4}	8×10^{-6}	9×10^{-5}	5×10^{-6}	5	1×10^{-5}	0.05	**Model Layer 6** assumes uniform 1.5 m thickness
Intact Bedrock (siltstone & sandstone)	n/a	-	-	5×10^{-7}	10	5×10^{-6}	0.01	**Model Layer 7**

Notes: ^Value intermediate to arithmetic means to be used as initial model parameters.
K_H – Horizontal Hydraulic Conductivity.
K_V – Vertical Hydraulic Conductivity.
n/a -data not available.
* – anisotropy greater than 1 is considered to account for stratification.
# – K_H/K_V, S_Y and S_S values derived from literature for similar materials.

III-5.2.9 Groundwater Levels

Monitoring well construction and groundwater level data was collected from verified sources within the Project Area and from the ongoing Bowness groundwater monitoring program (monitoring data from April 2019 to November 2019). October 2019 groundwater levels were contoured in order to assess the groundwater flow patterns with the Alluvial Aquifer. Historical groundwater level information collected from available databases was used to inform groundwater levels across the model domain, and provide background information on regional gradients and perched groundwater conditions. The October 2019 groundwater level contours for the Alluvial Aquifer are shown in Figure III-5.3.

Sources:

- KCB groundwater monitoring data from wells installed as part of this Project;
- Alberta Water Well Information Database; and
- Available information from ESAR database historical investigation reports.

III-5.2.10 Current and Future Infrastructure

Existing infrastructure includes the following: bridges, buildings (residential and commercial), concrete, pavement surfaces, and roads. These areas will be used to estimate impervious surfaces within the model domain.

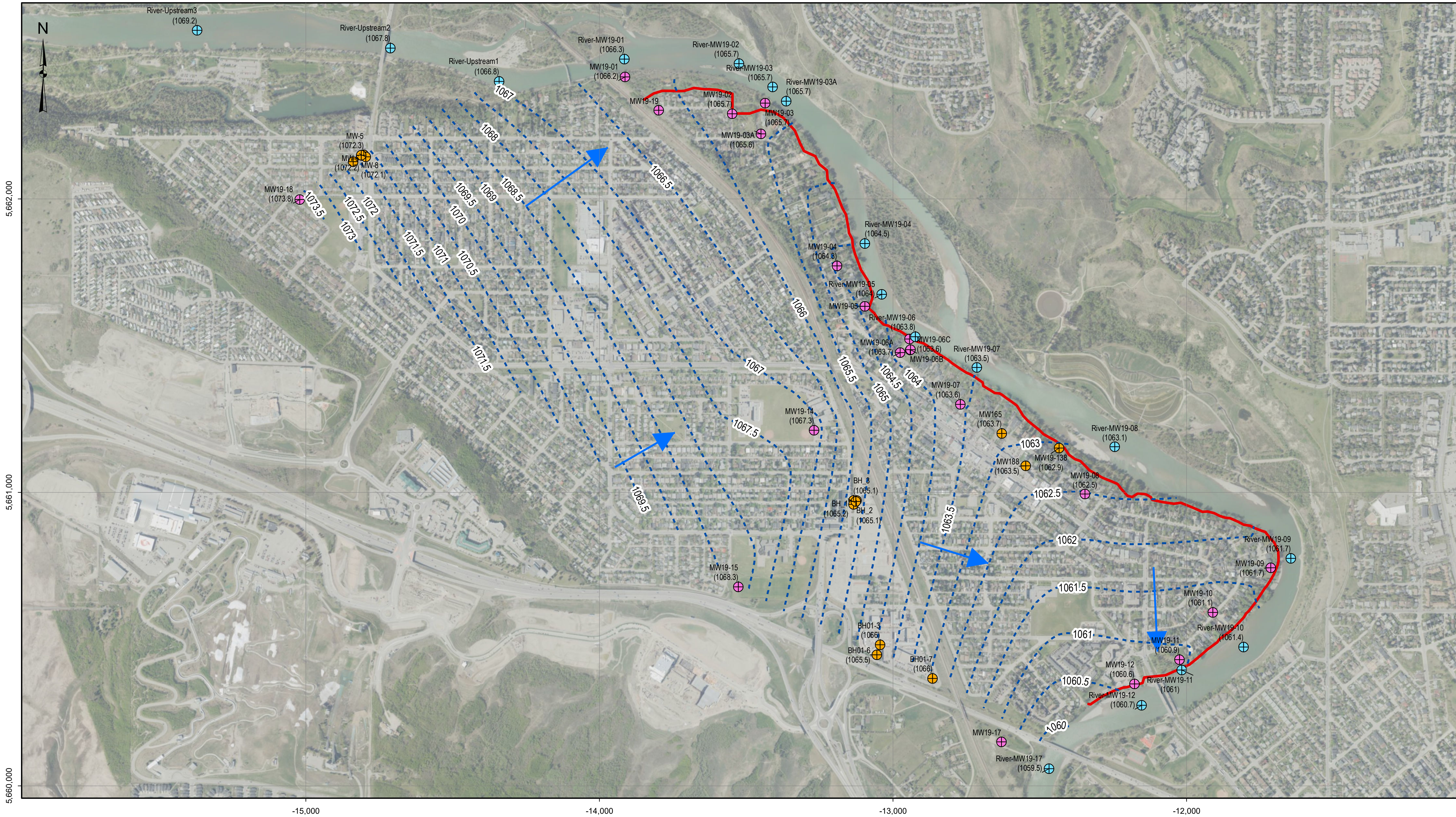
The Flood Control Barrier design and location is to be determined by the Civil Design Team and confirmed by CoC. The proposed Flood Control Barrier will be located along the south side of the Bow Riverbank.

Groundwater mitigation options are to include a cut-off barrier design assessment for a wall extending through the Alluvial Aquifer for the selected barrier lengths.

III-5.3 Calibration

III-5.3.1 Steady-State Calibration

Steady-state (baseline) calibration will be completed using the May 5 to 9, 2019 period, a relatively stable period preceding increases in river stage due to freshet river flows, including groundwater heads and surface water levels simulated by the Bow River HEC-RAS model (KCB 2020). The hydraulic properties of the key HSUs and boundary conditions (recharge zones and seepage flow rates, etc.), and hydraulic conductance, as well as the overall water-balance, will be refined during the calibration process. A combination of manual and automatic calibration methods (i.e., Parameter ESTimation or PEST) may be employed. The results will be analyzed quantitatively and qualitatively by evaluating the data statistics (variance, mean, residuals, and head gradients), matching simulated hydraulic heads with observed heads in monitoring wells, and visual comparison of the simulated to the observed groundwater flow patterns.



LEGEND:

Monitoring Wells:

- Historic Wells (Sand & Gravel)
- HECRAS Bow River
- June 2019 Wells (Sand and Gravel)

- Groundwater Contour (masl) [Interval 0.5m]
- Inferred Groundwater Flow Direction
- Proposed Flood Barrier

0 — 500 m

NOTES:

1. HORIZONTAL DATUM: NAD 83
2. GRID ZONE: 3TM 114
3. IMAGE SOURCE: CITY OF CALGARY, ArcGIS Map Service. Image Date: May/June 2019.
4. Map scale is 1:13,022 on 11" x 17" paper.
5. Water levels from historical wells not considered for contouring.

CLIENT: Calgary

Klohn Crippen Berger

PROJECT: BOWNESS FLOOD CONTROL BARRIER

TITLE: OCTOBER 2019 SAND AND GRAVEL AQUIFER INFERRED GROUNDWATER CONTOURS

SCALE	PROJECT No.	FIG No.
1:13,022	A03330C01	III-5.3

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III-5.3.2 Sensitivity Analysis

A sensitivity analysis will be undertaken on the calibrated steady-state model to investigate the model's sensitivity to HSU hydraulic properties, recharge, and hydraulic conductance of the Bow Riverbed material. At this stage, it is envisaged that the sensitivity analysis will primarily focus on the hydraulic conductivity (K_H and K_V) and specific yield of the Alluvial Aquifer. The following range of multipliers will be used to vary the hydraulic properties of the aquifer and river bed conductance in the model: 0.1, 0.5, 2, and 10. The above proposed parameters for the sensitivity analysis will be reviewed during steady-state calibration of the model and will be finalized in consultation with CoC and the Third-Party Reviewer.

III-5.3.3 Transient Flow Calibration

Transient calibration and/or verification will involve history-matching of measured groundwater levels and river levels for the May 10, 2019 to October 31, 2019 monitoring period. This period may be shortened if model run times are significant.

The calibrated steady-state hydraulic heads will be assigned as starting input values to the transient model. Calibration targets will include:

- Time-variant changes in groundwater levels at monitoring wells within the model domain;
- Comparison of simulated and observed periods of hydraulic interaction (influent and effluent) between the Bow River and adjacent Alluvial Aquifer; and
- Visual assessment of simulated and observed seasonal groundwater flow patterns within the Alluvial Aquifer, i.e., low (October 2019) and high (June 2019) groundwater conditions.

III-5.4 Model Prediction Scenarios

The calibrated transient model results will be applied as the initial conditions for all predictive model runs. Predictive transient modelling will be undertaken to simulate a range of future impacts from the proposed flood barrier on hydraulic heads and groundwater fluxes in the shallow groundwater system. Predictive modelling will include the following scenarios for up to two flood barrier designs:

- Without surface flood barrier:
  - Normal (seasonal) Bow River levels;
  - Estimated 2005 flood levels; and
  - 1:200-year peak discharge with an upstream reservoir and the TransAlta agreement;
- With surface flood barrier:
  - 1:200-year peak discharge with an upstream reservoir and the TransAlta agreement; and
  - Preferred flood barrier with groundwater cut-off barrier (100% cut-off of Alluvial Aquifer) for 1:200-year peak discharge with an upstream reservoir and the TransAlta agreement.;

- 2005 flood levels with a flood control barrier without groundwater mitigation;
- Simulation of preferred flood barrier design and seepage cut-off barrier design (if required) over specific areas that are prone to groundwater flooding based on modelled results.; and
- The predictive scenarios will be agreed between CoC, Third Party Reviewer, and KCB prior to beginning the predictive modelling work.

III-6 MODEL ASSUMPTIONS AND LIMITATIONS

The following summarizes the assumptions and limitations of the model:

- In order to maximize computational efficiency and model stability, without significantly affecting the model function, adjacent geological units with similar hydraulic characteristics will be combined into a single HSU.
- The initial groundwater model build will be based on data collected up to December 2019. Any data received after this date will not be incorporated into the current model. The interpolation technique used in the Leapfrog™ model is not always ideal for stratigraphic correlation in areas without significant data density and requires considerable manual intervention to obtain desired surfaces.
- There may be some difficulty effectively representing the variable geometry (thickness and contact elevations) of the relatively thin sand and gravel unit, and its connection to the Bowness River based on the limited number of borehole logs.
- The model will not explicitly quantify changes to baseflow due to drainage features that may exist within model domain.
- The model will not explicitly consider effects of basements, sumps, dewatering work, or underground infrastructure on the groundwater flow hydraulics, and is hence likely to estimate recharge and conductivity values lower than ‘natural’ conditions.
- The model assumes net rainfall recharge and that there is very limited evapotranspiration of near-surface groundwater.
- The model will not consider alterations in hydraulic conductivity associated with seasonal ground freezing, or compaction due to loading.

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